POTSDAM 2022

Programme Book

12th EARSeL Workshop on Imaging Spectroscopy

22-24 June 2022, Potsdam, Germany

UNIVERSITÄT GREIFSWALD
Wissen lockt. Seit 1456

GFZ
Helmholtz Centre
POTSDAM

EARSeL

Jointly organised by EARSeL and GFZ Potsdam in cooperation with the University of Greifswald

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Welcome

It is with great pleasure that EARSeL and the local organizers at GFZ Potsdam and the University of Greifswald welcome all participants to this 12th EARSeL Imaging Spectroscopy Workshop, originally planned for March 2021! This workshop marks the end of a rather challenging preparation time and we are all even happier to organize this workshop with 200+ people in a face-to-face format.

Over the past years, imaging spectroscopy has gained an increasing relevance in integrated environmental analysis. This development has been driven firstly, by an increase in the availability of airborne imaging spectroscopy data, operational processing chains and robust and accurate analysis methods. Secondly, the recent and upcoming launches of several spaceborne imaging spectrometers hold the prospect of obtaining more accurate, frequent, timely and large-scale information on the environment than ever before. These missions are accompanied by rapid developments at the local scale in Unmanned Aerial Systems and close-range spectroscopy. Lastly, rapid advancements in newer fields such as fluorescence and mid-infrared spectroscopy for environmental applications add to the relevance of Earth Observation by imaging spectroscopy. The workshop series of the EARSeL Special Interest Group on Imaging Spectroscopy has consequently been attracting an increasingly international and interdisciplinary audience and is being recognized as one of the leading conferences on imaging spectroscopy for Earth Observation in Europe and worldwide.

Therefore, we are convinced that a face-to-face event after more than two years of limited personal exchange is urgently needed to bring forward communication and cooperation in our science community. We wish all participants successful and enjoyable days in Potsdam and at the workshop!

Saskia Foerster, Sebastian van der Linden and the Organizing Committee

Scientific Committee

Helge Aasen (ETH Zürich, CH)
Eyal Ben-Dor (Tel Aviv University, IL)
Katja Berger (LMU München, DE)
Véronique Carrère (University of Nantes, FR)
Sabine Chabrillat (GFZ Potsdam, DE)
Fabian Fassnacht (FU Berlin, DE)
Jean-Baptiste Feret (Irstea, FR)
Claudia Giardino (IREA CNR, IT)
Uta Heiden (DLR Oberpfaffenhofen, DE)
Lucie Homolová (CzechGlobe, CZ)
Robert O. Green (NASA JPL, US)
Luis Guanter (Univ. Politècnica de València, ES)
Lammert Kooistra (Wageningen University, NL)
Zbyněk Malenovský (University of Bonn, DE)
Tim Malthus (CSIRO, AU)
Cindy Ong (CSIRO, AU)
Akpona Okujeni (HU Berlin, DE)
Tom Painter (NASA JPL, US)
Uwe Rascher (FZ Jülich, DE)

Organizing Committee

Saskia Foerster (GFZ Potsdam, DE)
Sebastian van der Linden (Univ. of Greifswald, DE)
Mathias Kneubühler (University of Zürich, CH)
Martin Bachmann (DLR Oberpfaffenhofen, DE)
Heide Bierbrauer (EARSeL Secretariat)
Arlena Brosinsky (GFZ Potsdam, DE)
Bernd Bobertz (University of Greifswald, DE)
Jörg Hartleib (University of Greifswald, DE)
Niklas Bohn (GFZ Potsdam, DE)
Robert Milewski (GFZ Potsdam, DE)
Christin Skala (GFZ Potsdam, DE)

Scientific Committee (cont.)

Michael Rast (ISSI Bern, CH)
Michael E. Schaepman (University of Zürich, CH)
Anke Schickling (DLR Space Agency Bonn, DE)
Phil Townsend (University of Wisconsin, US)
Jochem Verrelst (University of Valencia, ES)

Practical Information

POTSDAM 2022

Internet Access

There is Eduroam in all buildings. Use your institutional account to connect with these settings: Network SSID: eduroam; Wireless security: WPA2-Enterprise; Authentication: Protected EAP (PEAP); Inner authentication: EAP-MSCHAPv2; Root certificate: T-TeleSec GlobalRoot Class 2 or system certificates; User name: Your-Login@Your-Institute.de; Password: Your Eduroam password

In all GFZ buildings (Houses H, C4, A42) you may also use the GFZ-Guests-network. Connect to the WIFI "GFZ-Guests". The registration page wlc.gfz-potsdam.de will be opened automatically by most modern devices. 1. Connect to SSID GFZ-Guests; 2. Start your internet browser, it will redirect to the login-site: wlc.gfz-potsdam.de; 3. Fill in username and password for GFZ WIFI exactly as written on your badge

When in the PIK building (A56) the PIK-Guests-network is available. You will find the login information in the lecture room on a notice board.

Posters

Posters will be displayed throughout the workshop, located in the same area as the coffee breaks. Please hang your poster on workshop day 1 on the poster board indicated in the programme. Sticky pads to hang the posters are available at the venue. To give more visibility to the posters, authors are asked to present their poster in short (1-3 min) poster pitches in the associated oral sessions.

Oral Presentations

Oral presentations will usually be of 12 min length plus 3 min for questions and change over to the next speaker. The length of the presentations may vary in some sessions depending on the planned number of presentations. Please check the workshop programme or consult the session chair, if unsure. Please upload your presentation as PPT or PDF file directly to the presentation laptop in the lecture hall well before the session. From 30 min before the session start, there will be technical staff on site to assist with this.

Young Scientist Award

A first and second prize will be awarded both for the best Young Scientists' oral presentations and posters. The candidate talks are given in a dedicated plenary session on 23 June at 15:30. The posters are shortly presented at 15:15 and can be visited before in the morning poster session. The winners are selected during a live voting after the respective presentations using the following QR codes:

Posters

Talks

Tutorials

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Following the successful tradition of past EARSeL Imaging Spectroscopy Workshops, several tutorials are offered on 21 June, the day before the workshop starts. The tutorials are organized at Telegrafenberg premises and can be attended free of charge.

10:00 – 12:00

- **From Box to Flight to Data. UAV demo flight**
  Headwall – Meeting in front of Building H
- **Hyperspectral processing routines for HySpex airborne data**
  Norsk Elektro Optikk AS – PC Pool, Building A42, room: 131
- **Programmatic Access to the Spectral Information System SPECCHIO**
  A. Hueni, RSL, University of Zurich – building C4, room: 2.06
- **Hands-on EnMAP-Box: Imaging Spectroscopy with QGIS**
  A. Rabe, B. Jakimow (HU Berlin) and F. Thiel (University of Greifswald) – Building H, main lecture hall

13:00 – 15:00

- **UAV imaging spectroscopy data processing and analysis**
  Headwall – Building C4, room: 2.06
- **The ENVI Modeler – User-Defined Workflows for Hyperspectral Analysis**
  L3Harris Technologies, Inc – PC Pool, Building A42, room: 131
- **Hands-on EnMAP-Box: Imaging Spectroscopy with QGIS**
  A. Rabe, B. Jakimow (HU Berlin) and F. Thiel (University of Greifswald) – Building H, main lecture hall

15:30 – 17:30

- **Introduction to the EnGeoMAP/EnSoMAP toolboxes**
  R. Milewski and H. Dämpfling, GFZ Potsdam – Building H, main lecture hall

15:30 – 18:00

- **The ARTMO toolbox for analyzing and processing of remote sensing data into biophysical variables**
  J. Verrelst (Uni. Valencia) & J. Vicent (Magellium) - Building C4, room: 2.06

Guided tours Science Park at Telegrafenberg on the Tutorial Day

In addition to the tutorials, there will be guided tours of one hour duration on the Science Park Albert Einstein on Telegrafenberg on 21 June, starting at 12:00 and 15:30. Meeting point for the tours is the Pillar Forum in front of Building H.

Workshop Dinner

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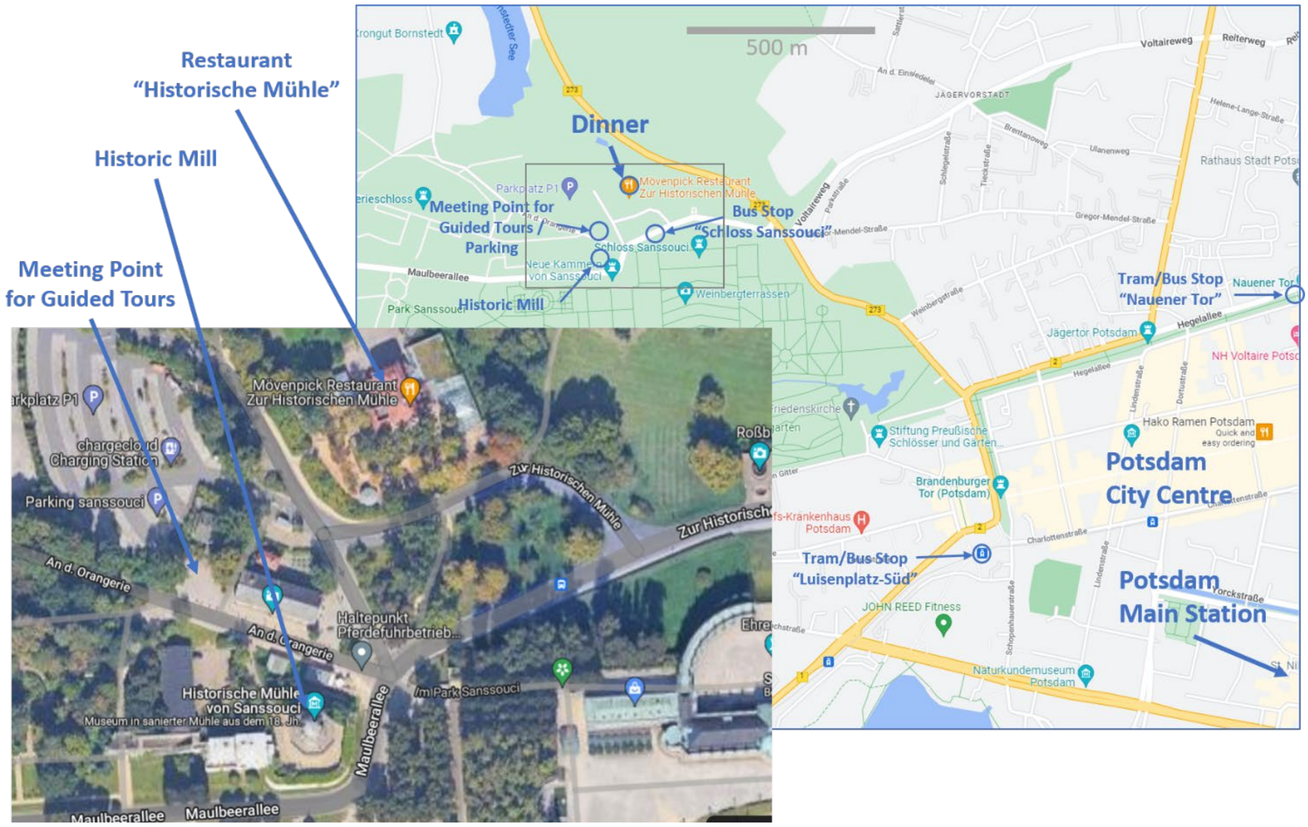
Location: Restaurant Mövenpick „Zur Historischen Mühle" in close vicinity to Sanssouci Palace und the Historic Mill.

Time: Thursday, 23 June, 19:00-22:00.

Social programme: 18:00-19:00, guided outdoor tours in Park Sanssouci and special opening of Historic Mill. Meeting point for tours: 18:00 between visiting centre and car park next to the Historic Mill (see detailed map).

Transport: Free bus transfer from the workshop venue on Telegrafenberg to the location of the guided tours and dinner. Departure of busses outside of the entrance to the Science Park at Telegrafenberg at 17:30. Please note that there will be no organized bus transport provided on the way back. Public transport options to go back to Potsdam main station after dinner: Bus 695 leaving at 21:54 and 22:54 (last bus), Tram/Bus stops in the city centre as indicated in the map (alternative: walking to the city centre 15-20 min, to the main station 30-40 min).



Programme (find all abstracts following page 17)

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Location: Building H</td></tr>
<tr><td>9:30 - 10:00</td><td colspan="3">Welcome: Opening session with welcome notes
Location: Building H
Chair: Saskia Foerster, Sebastian van der Linden
Welcome note GFZ - Harald Schuh, Director Department 1 "Geodesy"
Welcome note EARSeL - Jean-Christophe Schyns, EARSeL President
Welcome note SIG Imaging Spectroscopy – M. Bachmann, M. Kneubühler, SIG Chairmen</td></tr>
<tr><td>10:00 - 10:30</td><td colspan="3">1-1 Keynote: "Multi-sensor synergies for crop stress detection - on the role of imaging spectroscopy" by Katja Berger
Location: Building H (Plenary Hall); Chair: Saskia Foerster</td></tr>
<tr><td>10:30 - 11:00</td><td colspan="3">Coffee 1-1: Coffee break around poster area
Location: Building H (Posters area)</td></tr>
<tr><td>11:00 - 12:30</td><td colspan="3">1-2 Plenary: Updates from spaceborne imaging spectroscopy missions
Location: Building H (Plenary Hall); Chair: Luis Guanter, Michael Rast

The ENMAP Hyperspectral Spaceborne Mission Launched, Sabine Chabrillat, Sebastian Fischer, Karl Segl, Saskia Foerster, Maximilian Brell, Luis Guanter, Anke Schickling, Tobias Storch, Hans-Peter Honold

PRISMA Mission And Beyond: Current Status And Future Plans For The First Italian Hyperspectral Mission, Ettore Lopinto, Luigi Ansalone, Luca Fasano, Francesco Longo, Patrizia Sacco

The spaceborne imaging spectrometer DESIS: Mission Summary and Potential for Scientific Developments, Uta Heiden, Kevin Alonso, Martin Bachmann, Kara Burch, Emiliano Carmona, Daniele Cerra, Daniele Dietrich, Uwe Knodt, David Krutz, Heath Lester, David Marshall, Rupert Müller, Peter Reinartz, Raquel de los Reyes, Mirco Tegler

Progress toward NASA's Surface Biology and Geology Mission, Robert O. Green, David R Thompson, Ralph Basilio, Ian Brosnan, Kerry Cawse-Nicholson, K. Dana Chadwick, Liane Guild, Michelle Gierach, Simon J. Hook, Scott D. Horner, Glynn Hulley, Raymond Kokaly, Charles E. Miller, Kimberley R. Miner, Christine M. Lee, Daniel Limonadi, Jeffrey Luvall, Ryan Pavlick, Benjamin Phillips, Benjamin Poulter, Ann Raiho, Kevin Reath, Stephanie Schollaert Uz, Amit Sen, Shawn Serbin, David Schimel, Philip Townsend, Woody Turner, Kevin Turpie, And the SBG Team

Status And Planning Of The Copernicus Hyperspectral Imaging Mission For The Environment (CHIME), Marco Celesti, Michael Rast, Jennifer Adams, Valentina Boccia, Ferran Gascon, Claudia Isola, Jens Nieke

The FLuorescence EXplorer (FLEX) Mission: Imaging Spectroscopy In Very High Spectral Resolution, Jose Moreno, Roberto Colombo, Alexander Damm, Yves Goulas, Franco Miglietta, Gina Mohammed, Matti Mottus, Peter North, Uwe Rascher, Christiaan van der Tol, Matthias Drusch

NASA Earth Surface Mineral Dust Source Investigation (EMIT) Imaging Spectrometer Performance and Mission Status, Robert Green, David Thompson</td></tr>
<tr><td>12:30 - 13:30</td><td colspan="3">Lunch 1: Lunch break and group photo
Location:</td></tr>
<tr><td>13:30 - 15:00</td><td>1-3a SpecSess VegTraits: Quantifying priority vegetation traits from spaceborne imaging spectroscopy data – Part 1
Location: Building H
Chair: Martin Schlerf
Chair: Jochem Verrelst</td><td>1-3b SpecSess Soils: Hyperspectral remote sensing of soils
Location: A56
Chair: Eyal Ben Dor
Chair: Sabine Chabrillat</td><td>1-3c SpecSess Water: Towards inland and coastal water monitoring using hyperspectral data - Part 1
Location: A45
Chair: Mariana Soppa
Chair: Claudia Giardino</td></tr>
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	Retrieval Of Fluorescence Quantum Efficiency And Quantitative Photosynthetic Traits In The Context Of The FLEX Mission, Shari Van Wittenberghe, Neus Sabater, Ana Belen Pascual, Eatidal Amin, Adrian Moncholi, Carolina Tenjo, Luis Alonso, MaPilar Cendrero Mateo, Jose Moreno Advances in Vegetation Traits Models in the Context of the Hyperspectral CHIME Mission Preparation, Jochem Verrelst, Enrique Portales, Eatidal Amin, Miguel Morata, Pablo Reyes Muñoz, Ana Belen Pascual-Venteo, Jose Luis Garcia, Juan Pablo Rivera, Giulia Tagliabue, Cinzia Panigada, Mirco Boschetti, Gabriele Candiani, Karl Segl, Stephane Guillasso, Katja Berger, Matthias Wocher, Tobias Hank, Claudia Isola Recent Progress And Challenges In The Derivation Of Non-photosynthetic Cropland Biomass From Spaceborne Imaging Spectroscopy Data, Katja Berger, Andrej Halabuk, Tobias Hank, Juan Pablo Rivera-Caicedo, Matthias Wocher, Matej Mojses, Katarina Gerhatova, Giulia Tagliabue, Miguel Morata Dolz, Ana B. Pascual Venteo, Pablo Reyes Munoz, Jochem Verrelst Representativeness of Airborne Imaging Spectroscopy for Global Upscaling for Spaceborne Missions, Philip Townsend, Ryan Pavlick, Morgan Dean, Kyle Kovach, Fabian Schneider Quantifying Crop Residue Cover by Spectroscopy Techniques Exploiting In-situ, Aerial and Simulated Spaceborne Hyperspectral Data for PRISMA Mapping Applications, Monica Pepe, Loredana Pompilio, Gabriele Candiani, Micol Rossini, Cinzia Panigada, Mirco Boschetti	Airborne Imaging Spectroscopy For Assessing Land-Use Effect On Soil Quality In Dryland, Nathan Levi, Arnon Karnieli, Tarin Paz-Kagan Synergies of VNIR-SWIR and LWIR Hyperspectral Remote Sensing Data for Soil Property Mapping in an Agricultural Landscape of Northern Greece, Robert Milewski, Sabine Chabrillat, Theodora Angelopoulou, Maximilian Brell, Nikos Tziolas, Georges Zalidis, Eyal Ben Dor Characterizing Soil Surface Covers Within Ice-free Areas of the Northern Antarctic Peninsula Region Using Reflectance Spectroscopy, Thomas Schmid, Ana Nieto, Marta Pelayo, Sabine Chabrillat, Robert Milewski, Stéphane Guillaso, Jerónimo López-Martínez Multi-Temporal Estimation of Soil Properties from Hyperspectral Prisma and Multispectral Sentinel-2 Data, Nada Mzid, Raffaele Casa, Fabio Castaldi, Massimo Tolomio, Simone Pascucci, Stefano Pignatti Estimation Of Water Infiltration Rate In Mediterranean Soils Using Airborne Hyperspectral Sensors, Nicolas Francos, Nikos Tziolas, Maximilian Brell, Sabine Chabrillat, Nunzio Romano, Paolo Nasta, Yijian Zeng, Brigitta Szabó, Salvatore Manfreda, Giuseppe Ciraolo, János Mészáros, Ruodan Zhuang, Bob Su, Eyal Ben-Dor Quantification and Variability Analysis of Forest Carbon to Nitrogen Ratio in Different Soil Horizons using Spectroscopy: A National-Scale Study, Asa Gholizadeh, Mohammadmehdi Saberioon, Nastaran Pouladi, Eyal Ben-Dor	Lessons Learned and Recent Advances Towards Hyperspectral Aquatic Remote Sensing, Mariana A. Soppa, Leonardo Alvarado, Dieu A. Dinh, Brenner Silva, François Steinmetz, Astrid Bracher Exploring PRISMA Data For Chlorophyll-a Retrieval Through Hyperspectral NDCI, Felipe Nincao Begliomini, Cláudio Clemente Faria Barbosa, Vitor Souza Martins, Evlyn Márcia Leão de Moraes Novo, Daniel Andrade Maciel, Rejane de Souza Paulino, Rogério Flores Júnior, Thainara Munhoz Alexandre de Lima Comparison Of Coincident Hyperspectral Data From Satellite, Airborne And Fieldworks For Retrieving Water Quality Parameters In Lake Trasimeno, Alice Fabbretto, Andrea Pellegrino, Mariano Bresciani, Salvatore Mangano, Monica Pinardi, Nicola Ghirardi, Claudia Giardino, Massimo Cosi, Leandro Chiarantini Using Imaging Spectroscopy to Retrieve Suspended Sediment Properties in a Nearshore Coastal Estuary, Joshua Harringmeyer, Nilotpal Ghosh, Matthew Weiser, David Thompson, Xiaohui Zhu, Cédric Fichot Retrievals of the Main Phytoplankton Groups at Lake Constance Using OLCI and Evaluated with Field Observations, Leonardo M. A. Alvarado, Peter Gege, Svetlana Losa, Iris Dröscher, Mariana Soppa, Hongyan Xi, Astrid Bracher

15:00 - 15:30	Coffee 1-2: Coffee break *Location: Buildings H, A56, A45*		
15:30 - 16:45	1-4a SpecSess VegTraits: Quantifying priority vegetation traits from spaceborne imaging spectroscopy data – Part 2 *Location: Building H* *Chair: Katja Berger* *Chair: Jochem Verrelst* Cutting Out The Middleman: Calibrating And Validating An Ecosystem Model Using Remotely Sensed Surface Reflectance, Alexey N Shiklomanov, Istem Fer, Toni Viskari, Michael Dietze, Shawn Serbin Estimation Of Winter Wheat Yield Using Time Series Of Airborne Hyperspectral Data, Lucie Homolová, Miroslav Pikl, Švik Marian, Růžena Janoutová, Lukáš Slezák, Barbora Veselá, Karel Klem Detecting spatial patterns of change in vegetation condition inside Bavarian Forest National Park using Multi- and Hyperspectral spaceborne datasets, Nivedita P. Kamaraj, Stefanie Holzwarth, Martin Bachmann, Edzer Pebesma, Simon König, Marco Heurich Retrieval of Carbon Content and Biomass from Hyperspectral Imagery over Cultivated Areas, Matthias Wocher, Katja Berger, Jochem Verrelst, Tobias Hank Downscaling of Far-red Solar-induced Fluorescence from Canopy to Leaf Level – A Necessary Step to Derive Physiological Information of Plants from Remote Sensing Data, Bastian Siegmann, Juliane Bendig, Juan Quiros-Vargas, Onno Muller, Sergio Cogliati, Alexander Damm, Uwe Rascher	1-4b SpecSess SoilContamination: Monitoring soil contamination by imaging spectroscopy *Location: A56* *Chair: Rollin Gimenez* *Chair: Sophie Fabre* Determination of Chromium Concentration and Spatial Distribution in a Copper Mine using Reflectance Spectroscopy and Remote Sensing, Vahid Khosravi, Asa Gholizadeh, Mohammadmehdi Saberioon Hyperspectral Analysis of Contaminated Soil Using Ultra High Resolution, Nicolas Venjean Environmental Monitoring of Trace Metal Element Impact on Vegetation: Exploitation of In-situ and Airborne Hyperspectral Data, Luc Béraud, Philippe Déliot, Laurent Poutier, Olivier Berseille, Arnaud Elger, Camille Larue, Thomas Rivière, Sophie Fabre Impact of Spatial Correlation on Classification Accuracy Assessment for Vegetation Mapping in a Former Industrial Site, Rollin Gimenez, Arnaud Elger, Guillaume Lassalle, Anthony Credoz, Dominique Dubucq, Rémy Hédacq, Sophie Fabre	1-4c SpecSess Water: Towards inland and coastal water monitoring using hyperspectral data - Part 2 *Location: A45* *Chair: Mariana Soppa* *Chair: Claudia Giardino* An open-source Hydrolight-based Framework for Fast Inverse Modelling of Hyperspectral Observations from Coastal and Inland Waters, Tadzio Holtrop, Hendrik Jan van der Woerd SWIPE: Spectral Water Inversion Processor and Emulator, Jeremy Alan Kravitz, Liane Guild, Lisl Lain, Steffen Mauceri, Jake Lee, Didier Ramon, François Steinmentz Preparing for CHIME and SBG: Algorithms for Retrieving Snow and Ice Properties in Earth's Mountains, Jeff Dozier, Edward H. Bair, Thomas H. Painter
16:45 - 18:00	Posters Day 1 (List of posters at the end of this programme book) *Location: Building H*		
18:00 - 20:00	Ice Breaker: Gathering with drinks and snacks at the venue *Location: Building H*		

Thursday, 23/June/2022			
8:30 - 9:00	2-1 Keynote: "The future for environmental change research in a global context: added value of spaceborne imaging spectroscopy" by Inge Jonckheere (FAO) *Location: Building H (Plenary Hall); Chair: Martin Herold*		
9:00 - 10:00	2-2 Panel discussion: "Imaging spectroscopy towards 2030" *Location: Building H (Plenary Hall), Chair: Michael Rast* Panelists: Godela Rossner (DLR), Marco Celesti (ESA), Patrick Hostert (HU Berlin, Landsat Science Team), Phil Townsend (UW Madison, SBG AlgoWG), Inge Jonckheere (FAO)		
10:00 - 11:00	Posters Day 2 (List of posters at the end of this programme book) *Location: Building H*		
11:00 - 12:15	2-3 Plenary: New pathways in the analysis and application of (imaging) spectroscopy *Location: Building H (Plenary Hall); Chair: Zbyněk Malenovský, Helge Aasen* Remote Estimation of Sulfur Content in fuel from Quantification of Ship Exhaust Plume, Jean-Philippe Gagnon, Stéphane Boubanga-Tombet Change Detection in Urban Areas from Airborne-based Hyperspectral and Lidar Data. Case Study: Baerum, Norway, Agnieszka Kinga Kuras, Maximilian Brell, Kristian Hovde Liland, Vinith Balasingam, Stian Teien, Bjørn-Eirik Roald, Thomas Thiis, Ingunn Burud Mapping Methane Emissions Around the World with Satellite Imaging Spectroscopy Missions, Luis Guanter, Itziar Irakulis-Loitxate, Javier Roger, Javier Gorroño How Does Photon Recollision Probability Perform In Modeling Forest Reflectance Spectra? - Lessons Learned From An Extensive Field And Airborne Campaign, Aarne Hovi, Miina Rautiainen Coupling Physics and Machine Learning for Improved Atmospheric Correction, Philip G. Brodrick, David R. Thompson, Niklas Bohn, Amy Braverman, Nimrod Carmon, Michael L. Eastwood, Regina Eckert, Jay Fahlen, Robert O. Green, Sarah R. Lundeen, Steffen Mauceri, Winston Olson-Duvall, Charles Sarture, Jouni Susiluoto		
12:15 - 13:15	Lunch 2: Lunch break *Location: Building H*		
13:15 - 14:45	2-4a SpecSess ForestTraits: The potentials and limits of monitoring forest traits with imaging spectroscopy *Location: Building H* *Chair: Michael Foerster* *Chair: Fabian Ewald Fassnacht* Gaussian Processes Regression and PLSR for mapping forest canopy traits from Fenix Airborne Hyperspectral Data, Rui Xie, Roshanak Darvishzadeh, Andrew K. Skidmore, Marco Heurich, Stefanie Holzwarth, Tawanda W. Gara, Ils Reusen Seasonal Changes in Leaf Chlorophyll Content of Floodplain Forest's Tree Species: A Comparison of Spectral, Biochemical and Portable Chlorophyll Meter Measurements, Lucie Červená, Zuzana Lhotáková, Eva Neuwirthová, Petr Lukeš,	2-4b ThemSess SensorsMissions: Concepts, activities and processing developments for missions and sensors *Location: A56* *Chair: Anke Schickling* *Chair: Sebastian Fischer* Identifying Distinct Plastics In Hyperspectral Experimental Lab-, Aircraft-, And Satellite Data Using Machine/Deep Learning Methods Trained With Synthetically Mixed Spectral Data. Shanyu Zhou, Hermann Kaufmann, Niklas Bohn, Theres Kuester, Karl Segl, Mathias Bochow Enmap Data Product Validation – Status, Maximilian Brell, Luis Guanter, Daniel Scheffler, Niklas Bohn, Karl Segl, Mariana Altenburg Soppa, Javier Gorrono, Astrid Bracher, Tobias Hank, Martin	2-4c SpecSess GenericLibs: Unlocking the potential of generic spectral libraries for remote sensing applications *Location: A45* *Chair: Frederik Priem* *Chair: Frank Canters* GENLIB: Developing a Generic Framework for Library-based Mapping of Urban Areas, Frederik Priem, Ben Somers, Frank Canters The Data Concept Behind the Data: From Metadata Models and Labelling Schemes Towards a Generic Spectral Library, Marianne Jilge, Uta Heiden, Frederik Priem, Chaonan Ji, Andreas Hueni, Stefan Arnold, Frank Canters The SPECCHIO Spectral Information System – Status and New Functionalities,

	Lucie Kupková, Jana Albrechtová Hyperspectral Image Analysis of Scots Pine Wood Affected with Decay Fungi Using Partial Least Squares and Library Spectra of Cellulose and Lignin, Arnoud Jochemsen, Gry Alfredsen, Ingunn Burud Detection of Tree Mortality Induced by Bark Beetle During Drought in Recent Years, Vojtěch Bárta, Tomáš Fabiánek, Lumír Dobrovolný, Lucie Homolová UAS-based Experiences of the Temporal, Spectral, and Spatial Accuracy to Detect the Green Attack Phase of Bark Beetle Infestations in the Arnsberger Forest and the Bavarian Forest, Germany, Michael Förster, Alexander Marx, Chunyan Xu, Ahuvit Trumper, Tobias Gränzig, Johannes May, Simon König, Birgit Kleinschmit Prediction of Leaf Area Index Using Hyperspectral Thermal Infrared Imagery over the Mixed Temperate Forest, Elnaz Neinavaz, Roshanak Darvishzadeh, Andrew K. Skidmore	Bachmann, Emiliano Carmona, Tobias Storch, Saskia Foerster, Anke Schickling, Sabine Chabrillat Advances in Imaging Spectrometer Atmospheric Correction With The Open Source ISOFIT Codebase, David R. Thompson, Philip Brodrick, Niklas Bohn, Nimrod Carmon, Kerry Cawse-Nicholson, Adam Chlus, David Connelly, Regina Eckert, Jay Fahlen, Michael J. Garay, Robert O. Green, Evan Greenberg, Michelle Gierach, Olga Kalashnikova, Matthew Lebsock, Benjamin Poulter, Ann Raiho, Mark Richardson, Alexey Shiklomanov, Philip Townsend Final Results Building EnMAP and First Results Operating EnMAP, Tobias Storch, Hans-Peter Honold, Martin Habermeyer, Paul Tucker, Andreas Ohndorf, Katrin Wirth, Sebastian Loew, Steffen Zimmermann, Matthias Betz, Michael Kuchler, Emiliano Carmona, Mathias Schneider, Peter Schwind, Helmut Muehle, Martin Muecke, Simon Baur, Martin Bachmann, Nicole Pinnel, Sabine Chabrillat, Sebastian Fischer PRISMA Signal Dependent Noise Characterization On A Rural Area: The Test Case Of Pignola (South Italy), Maria Francesca Carfora, Raffaele Casa, Nada Mzid, Simone Pascucci, Stefano Pignatti The CEOS CARD4L Conform EnMAP L2A Land Product, Martin Bachmann, Kevin Alonso, Emiliano Carmona, Birgit Gerasch, Martin Habermeyer, Stefanie Holzwarth, Harald Krawczyk, Maximilian Langheinrich, David Marshall, Miguel Pato, Nicole Pinnel, Raquel De Los Reyes, Mathias Schneider, Peter Schwind, Tobias Storch	Andreas Hueni, Bastian Buman, Kimberley Mason Regression-based Unmixing Through Ensemble Learning from Synthetic Training Data Enables the Use of Large Generic Spectral Libraries, Akpona Okujeni, Frederik Priem, Sam Cooper, Sebastian van der Linden, Patrick Hostert Spectral Library Optimization for Fractional Cover Estimation and Classification, Dar Alexander Roberts Rethinking spectral libraries using GIS-workflows, Benjamin Jakimow, Sebastian van der Linden, Andreas Janz, Fabian Thiel, Sam Cooper, Akpona Okujeni, Patrick Hostert

14:45 - 15:15	Coffee 2-2: Coffee Break around poster area *Location: Building H (Posters area)*
15:15 - 15:30	Posters 2d YSA: Presentation of candidate posters for young scientist award and voting *Location: Building H (Plenary Hall), Chair: Sebastian van der Linden* From Spectra to Functional Plant Traits: Aggregating Multiple, Heterogeneous and Sparse Data Sets for a Generalizable Multi-trait Model, Eya Cherif, Teja Kattenborn, Hannes Feilhauer Using Simulated Grassland Communities And Radiative Transfer Models To Test The Spectral Variation Hypothesis, Antonia Dorea Ludwig, Daniel Doktor, Hannes Feilhauer Planting Contexts Affect Urban Tree Species Classification Using Airborne Hyperspectral Imagery, Dengkai Chi, Jingli Yan, Ben Somers Asymmetry of Leaf Internal Structure Affects PLSR Modelling of the Anatomical Traits from VIS-NIR Leaf Level Spectra, Eva Neuwirthova, Zuzana Lhotakova, Lucie Cervena, Jana Albrechtova Hyperspectral Analysis Of The Contaminants On The Surface Of Ganymede, Katherine Villavicencio Valero, Pascal Allemand, Fabien Dubuffet
15:30 - 17:00	2-5 Plenary: Young Scientist Award - presentation of candidate talks and voting *Location: Building H (Plenary Hall), Chair: Sebastian van der Linden* Spatially Constrained Imaging Spectroscopy Retrievals, Regina Eckert, Philip Brodrick, David R Thompson, Steffen Mauceri, Jay Fahlen, Robert O Green, Michael L Eastwood, Mark Helmlinger Comparison of Uncertainties in the Retrieval of Vegetation Traits Using Machine Learning Regression Algorithms, José Luis García Soria, Juan Pablo Rivera Caicedo, Ana B Pascual Venteo, Giulia Tagliabue, Katja Berger, Jochem Verrelst Emulation of hyperspectral imagery from Sentinel-2 images using Regression Neural Networks, Miguel Morata Dolz, Bastian Siegmann, Adrian Pérez-Suay, Juan Pablo Rivera-Caicedo, Jochem Verrelst Modeling Spectral and Directional Soil Reflectance in the Solar Domain (400-2500 nm) as a Function of Moisture Content, Alice Dupiau, Stéphane Jacquemoud, Xavier Briottet, Jason Champion, Sophie Fabre, Françoise Viallefont-Robinet Solar Photovoltaic Module Detection Based On Multi-sources Hyperspectral Data, Chaonan Ji, Martin Bachmann, Andreas Hueni, Susanne Weyand, Julian Zeidler, Annekatrin Metz-Marconcini, Marion Schroedter-Homscheidt, Thomas Esch, Uta Heiden
17:30 - 18:00	Bus transfer from venue to guided tours and dinner
18:00 - 19:00	Guided Tours: Outdoor tours in Park Sanssouci *Required booking during registration. Contact EARSeL Bureau for late booking.*
19:00 - 22:00	Conference Dinner: Joint evening at the Mövenpick restaurant near Schloss Sanssouci *Required booking during registration. Contact EARSeL Bureau for late booking.*

Friday, 24/June/2022		
8:30 - 9:45	3-1a ThemSess Biodiv: Analyzing and mapping biodiversity with imaging spectroscopy data *Location: Building H* *Chair: Lucie Homolová, Uta Heiden* Why The Link Between Spectral Variation And Biodiversity Is Weak, Fabian Ewald Fassnacht, Jana Müllerova, Luisa Conti, Marco Malavasi, Sebastian Schmidtlein	3-1b ThemSess Developments: Recent software and sensors developments, incl. sponsored talks *Location: A56* *Chair: Robert Milewski* *Chair: Véronique Carrère* HYPERNOR; Plans for a Hyperspectral Imager for Microsatellites, Lars Lierstuen, Andrei Fridman, Magnus Breivik, Erlend Leirset, Trond Løke

	Relating Spectral Variance to Taxonomic Diversity: Experimental Evidence from Imaging Spectroscopy over a Tropical Forest, Colette Badourdine, Jean-Baptiste Féret, Grégoire Vincent, Raphaël Pélissier Evaluating Distortion Factors In The Assessment Of Plant Spectral Diversity From Ultra-high Resolution Hyperspectral Imagery, Erika Piaser, Andrea Berton, Michele Caccia, Francesca Gallivanone, Massimo Giannoni, Giovanna Sona, Paolo Villa Mapping Peatland Vegetation Communities on the Rewetted Fens with AVIRIS-NG and PRISMA data, M Arasumani, F Thiel, M Kaiser, S van der Linden Deriving Plant Genetic Diversity From Imaging Spectroscopy Systems, Ewa A. Czyz, Meredith C. Schuman, Andreas Hueni, Cheng Li, Marylaure de La Harpe, Bernhard Schmid, Michael E. Schaepman	Physical Atmospheric Correction of UAS Imaging Spectroscopy Data by DROACOR® in Complex Topography, Daniel Schläpfer, Sara Salehi, Rudolf Richter EUFAR - Current Status and Development, Jan Hanuš Partially Supervised Detection in Hyperspectral Imagery, Daniel C. Heinz, Thomas Bahr, David Streutker, Greg Terrie, Michael Ingram Visual Data Analysis & Exploration Tools In The EnMAP-Box Plugin For QGIS, Andreas Janz, Benjamin Jakimow, Fabian Thiel, Sebastian van der Linden, Patrick Hostert	
9:45 - 10:15	Coffee 3-1: Coffee break *Location: Buildings H, A56, A45*		
10:15 - 11:30	3-2a SpecSess Fluorescence: Measuring and understanding solar-induced fluorescence as an indicator for actual photosynthesis and vegetation function *Location: Building H* *Chair: Uwe Rascher* *Chair: Alexander Damm* Challenges in the Retrieval and Interpretation of Sun-induced Chlorophyll Fluorescence for Its Use in Ecosystem Research, Uwe Rascher, Alexander Damm HyScreen - A Ground-based Imaging Spectrometer System Measuring Solar-induced Fluorescence (SIF), Huaiyue Peng, Juliane Bendig, Kelvin Acebron, M.Pilar Cendrero-Mateo, Kari Kataja, Caspar Kneer, Uwe Rascher A Multi-Layer Perceptron Based Regressor for SIF Retrieval from Hyperspectral Imagery of the Airborne HyPlant Sensor in Topographically Variable Terrain, Jim Loïc Buffat, Hanno Scharr, Uwe Rascher Understanding Solar-induced Chlorophyll Fluorescence of Structurally Diverse Forests	3-2b ThemSess Campaigns: Insights from recent field and airborne campaigns *Location: A56* *Chair: Andreas Hueni* *Chair: Martin Bachmann* CHIME-SBG 2021 Airborne Imaging Spectroscopy Campaign, Andreas Hueni, Michael L. Eastwood, Carmen Meiller, Mike Werfeli, Helena Kuehnle, Marius Voegtli, Robert O. Green, Michael E. Schaepman, Jens Nieke, Jennifer S. Adams, Marco Celesti, Michael Rast Thermal Infrared Airborne Hyperspectral Data for Vegetation Land Cover Classification in a Mixed Temperate Forest, Hillary K. Korir, Elnaz Neinavaz, Andrew K. Skidmore, Roshanak Darvishzadeh Imaging Spectroscopy In Wetland Environments: Early Results From The Delta-X Campaign, David Thompson, John Chapman, Cedric Fichot, Daniel Jensen, Evan Greenberg, Joshua Harringmeyer, Mark Simard Impact of Processing Schemes on Reflectance Differences in	3-2c SpecSess RawMaterialEnergy: Imaging spectroscopy for raw materials and the energy transition *Location: A45* *Chair: Christoph Hecker* *Chair: Martin Schodlok* An Integrated Method for Utilizing Multi- and Hyperspectral Imaging for Raw Material Characterization in an Underground Mine,Feven Desta, Mike Buxton Hyperspectral Imaging For Open Pit Mining Applications, Friederike Koerting, Nicole Koellner, Friederike Kaestner, Helge Daempfling, Christian Mielke, Constantin Hildebrand Alteration Footprints Of A Porphyry Copper Deposit As Revealed By Airborne Imaging Spectroscopic Data, Saeid Asadzadeh, Nicole Koellner, Helge Daempfling, Sabine Chabrillat Exploring Porphyry Copper Tailings With Visible Light To Long Wave Infrared Reflectance Spectroscopy - A Case Ctudy In Erdenet, Mongolia Michael Denk, Yaron Ogen, Cornelia Gläßer

	with Three-dimensional Radiative Transfer Modelling, Zbyněk Malenovský, Růžena Janoutová, Lucie Homolová, Omar Regaieg, Nicolas Lauret, Eric Chavanon, Jordan Guilleux, Jean-Philippe Gastellu-Etchegorry Non-photochemical Quenching From In-situ Spectroradiometer Measurements In Lakes: Implications On Phytoplankton Fluorescence Remote Sensing, Remika Gupana, Alexander Damm, Abolfazl Irani Rahaghi, Camille Minaudo, Daniel Odermatt	the Overlapping Area of Neighbouring Flight Lines of Airborne Imaging Spectroscopy Data, Marius Vögtli, Daniel Schläpfer, Meredith C. Schuman, Michael E. Schaepman, Mathias Kneubühler, Alexander Damm Early results from SHIFT - the SBG HIgh Frequency Time series, Philip G. Brodrick, Kerry Cawse-Nicholson, K. Dana Chadwick, Michelle Gierach, Christine Lee, Charles Miller, Kimberley Miner, Ryan Pavlick, Benjamin Poulter, David Schimel, Alexey Shiklomanov, David R. Thompson, Philip Townsend	Utilizing Lidar Intensity Data to Improve Copper and Molybdenum Prediction Models in a high-wetness environment Yaron Ogen, Michael Denk, Cornelia Glaesser, Holger Eichstaedt
11:40 - 12:00	3-3 Awards ceremony: Note from EARSeL and award ceremony for YSA talk and YSA poster and GreenEARSeL award *Location: Building H (Plenary Hall), Chair: Jean-Christophe Schyns*		
12:00 - 12:30	3-4 Keynote: "Ecological Insights from Imaging Spectroscopy of Foliar Functional Traits" by Phil Townsend *Location: Building H (Plenary Hall), Chair: Mathias Kneubühler*		
12:30 - 13:15	Lunch 3: Lunch break *Location: Building H*		
13:15 - 14:45	3-5 ThemSess CropsGras: Imaging spectroscopy of cropland and grasland *Location: Building H (Plenary Hall); Chair: Akpona Okujeni, Lammert Kooistra* Why and How to Map Leaf-chlorophyll Dynamics from Ultrahigh-resolution UAV Hyperspectral Imagery and Machine Learning?, Yoseline Angel, Matthew McCabe Mapping Of Esca Symptoms On Grapevine Using Hyperspectral And Thermal UAV Data, Miriam Machwitz, Christian Bossung, Melina Käfer, Gilles Rock, Vanessa Hüffer, Daniel Molitor, Doriane Dam, Franz Ronellenfitsch, Mareike Schultz Disease Assessment in Potato Crop Combining Imaging Spectroscopy and Point-cloud Based Features, Marston Franceschini, Lammert Kooistra, Benjamin Brede, Harm Bartholomeus Utilizing UAS-based Imaging Spectroscopy Information to Estimate the Soil Moisture Content at Different Grassland Types in Germany, Veronika Döpper, Michael Förster, Katja Berger, Alby Duarte Rocha, Tobias Gränzig, Birgit Kleinschmit Evaluating the Potential of HySpex and Sentinel-2 for Fractional Cover-based Drought Analyses in Grasslands, Katja Kowalski, Patrick Hostert, Maximilian Brell, Akpona Okujeni Multi-Temporal Imaging Spectroscopy Data Processing Framework For Estimating Biomass In Alpine Grasslands, Nargiz Safaraliyeva, Anna K. Schweiger, Christian Rossi, Andreas Hueni, Michael E. Schaepman, Mathias Kneubuehler, Maria J. Santos		
14:45 - 15:45	Posters Day 3 (List of posters at the end of this programme book) *Location: Building H*		
15:45 - 16:00	Closing: Workshop closing session		

Posters (find all abstracts following page 17)

POTSDAM 2022

Wednesday, 22 June 2022: 16:45 - 18:00

Posters 1a VegTraits: Quantifying priority vegetation traits from spaceborne imaging spectroscopy data

2. Effects Of Sample Size On Regression Models For Biophysical Parameter Retrieval From Spectral Data. Hannes Feilhauer.

Posters 1b Soils: Hyperspectral remote sensing of soils

3. Identifying And Mapping Soils From Remote Sensing Hyperspectral Sensors With fCover. David William Marshall, Martin Bachmann, Eyal Ben-Dor, Martin Habermeyer, Uta Heiden, Daniela Heller Pearlshtien, Stefanie Holzwarth, Thomas Schmid.

4. Development of a Generic Database of Soil Optical and Biochemical Traits. Petr Lukeš, Jan Mišurec, Karel Klem, Jiří Tomíček.

5. Simulation of Spectral Disturbance Effects for the Generation of Landscape-like Soil Spectral Libraries in Support of Current and Upcoming Satellite Missions. Robert Milewski, Sabine Chabrillat, Alice Dupiau, Klara Dvorakova, Theres Küster, Stéphane Jacquemoud, Xavier Briottet, Bas van Wesemae.

6. Potential of Hyperspectral Remote Sensing Data and a Soil Spectral Library for Large Scale SOC Mapping. Kathrin J. Ward, Sabine Chabrillat, Maximilian Brell, Fabio Castaldi, Daniel Spengler, Saskia Foerster.

7. Using Drone-based Hyperspectral Information To Support Mapping Of Soil Organic Carbon And Clay Content By Sentinel-2 Data In Baden-Wuerttemberg. Larissa Torney, Michael Blaschek, Richard Mommertz, Martin Schodlok.

8. Predicting Soil Properties of Mountainous Agricultural Land in the Caucasus Mountains Using Mid-infrared Spectroscopy. Elton Mammadov, Michael Denk, Frank Riedel, Karolina Lewinska, Cornelia Glaesser.

9. Monitoring Biological Degradation Of Historical Stone Using Hyperspectral Imaging. Eva Matoušková1, Kateřina Kovářová, Michal Cihla, Jindřich Hodač.

10. Soil Organic Carbon Modelling Using Open-Access Soil Spectroscopy Libraries And Machine Learning Algorithms. Mohammadmehdi Saberioon, Asa Gholizadeh, Ali Ghaznavi, Sabine Chabrillat, Kathrin Ward.

11. Detecting Soil Organic Carbon In Agricultural Soils Adjacent To Mining Area Of Kajaran, Armenia Using Proximal Sensing Spectroscopy. Garegin Tepanosyan, Gevorg Tepanosyan, Vahagn Muradyan, Yeva Grigoryan, Shushanik Asmaryan, Lilit Sahakyan, Michael Denk, Cornelia Glaesser.

Posters 1c Water: Towards inland and coastal water monitoring using hyperspectral data

12. The Water Quality Prototype To Process PRISMA Products For Inland And Coastal Waters Mapping. Mariano Bresciani, Federica Braga, Maria Lucia Magliozzi, Corrado Avolio, Mario Costantini, Alice Fabbretto, Andrea Pellegrino, Claudia Giardino, Luca Pietranera, Gian Marco Scarpa, Patrizia Sacco, Deodato Tapete, Massimo Zavagli.

14. Optical Characterization of Pollutants in Industrial Waste Waters by Imaging Spectroscopy. Louis Zaugg, Rodolphe Marion, Laure Roupioz, Xavier Briottet, Malik Chami.

15. Contribution of Multispectral S2A and Hyperspectral (PRISMA, EO1) Data for Estimating Turbidity in Coastal Shallow Water. Rim Katlane, David Doxaran, Boubaker Elkilani, Samuel Martin.

16. Data Management Quality Management Framework for the Hyperspectral Radiometry System onboard the RV Celtic Explorer. Catherine Jordan, Caroline Cusack, Adam Leadbetter, Ramona Carr, Jochen Wollschlaeger, Peter Croot.

17. Diffuse Attenuation Of Underwater UV And Short Blue Light Obtained From TROPOMI's High Spectral Resolution. Astrid Bracher, Julia Oelker, Leonardo Alvarado, Svetlana Losa, Hongyan Xi, Mariana Soppa, Ana Brito, Vanda Brotas, Maycira Costa, Luciane Favareto, Mara Gomes, Vishnu P. Suseelan, Andreas Richter.

Posters 1d SoilContamination: Monitoring soil contamination

18. Trace Metal Elements Impact On The Thermal Infrared Spectral Signatures Of Pines. Luc Béraud, Sophie Fabre, Laurent Poutier, Arnaud Elger, Oliver Berseille, Camille Larue, Thomas Rivière.

19. Identification of Potential Toxic Elements (PTE) in Technosols and in the Hyperaccumulator Plant Brassica Juncea with Imaging Spectroscopy. Friederike Kaestner, Magdalena Sut-Lohmann, Mark Grimm, Hannes Feilhauer, Theres Kuester, Thomas Raab.

20. The Use Of Satellite Remote Sensing And Machine Learning Algorithms For Identification, Measurement And Classification Of Mine Waste Sites. Nina Maria Küpper, Jan-Niklas Sander, Lorenz Richter, Justus Freer, Bernd Georg Lottermoser.

Thursday, 23 June 2022: 10:00 - 11:00

Posters 2a: The potentials and limits of monitoring forest traits with imaging spectroscopy

21. Do Norway Spruce Needle Spectra Vary Between Geographic Locations?. Aarne Hovi, Petr Lukeš, Lucie Homolová, Jussi Juola, Miina Rautiainen.

22. Speeding Up The Hyperspectral Reflectance Phenotyping In Scots Pine Seedlings. Zuzana Lhotáková, Jan Stejskal, Jaroslav Čepl, Jiří Chuchlík, Eva Neuwirthová, Jana Albrechová, Milan Lstibůrek.

23. Modelling Thermal Anisotropy and Energy Balance in Forests. Jennifer Susan Adams, Alexander Damm, Kathrin Naegeli.

24. Use Of Laboratory And Image Spectroscopy To Distinguish Ecotypes And Detect Drought Stress In Scots Pine. Filip Raasch, Lucie Kupková, Zuzana Lhotáková, Miroslav Barták, Eva Neuwirthová, Lucie Červená, Jana Albrechtová.

25. Tree Species Classification from AVIRIS-NG Hyperspectral Imagery using Convolutional Neural Networks. Benjamin Zehnder, Mathias Kneubühler, Anna K Schweiger.

26. Investigating the Potential of Thermal Infrared UAS Imagery for Detecting the Health Status of Pine Trees (Pinus Brutia) in Lefka Ori National Park in West Crete, Greece. Azeb Gidey Kahsay, Elnaz Neinavaz, Panagiotis Nyktas.

27. Linking Airborne Hyperspectral AVIRIS Reflectance with Plant Traits Affected by Bark Beetle Infestation. Martin Schlerf, Henning Buddenbaum, Johannes Stoffels, Brian Epie, Zavud Baghirov, Max Gerhards, Christian Bossung, Jan Rommelfanger, Achim Röder, Thomas Udelhoven.

Posters 2b: Unlocking the potential of generic spectral libraries for remote sensing applications

28. Development of a Multitemporal Urban Spectral Library for a Typical Mediterranean City. Dimitris Tsirantonakis, Giannis Latzanakis, Emmanouil Panagiotakis, Konstantinos Politakos, Nektarios Spyridakis, Dimitris Poursanidis, Nektarios Chrysoulakis.

Posters 2c: Concepts, activities and processing developments for missions and sensors

29. EnMAP Observation Planning and Data Access for Scientific Users. Nicole Pinnel, Helmut Mühle, Anett Gidofalvy, Daniele Dietrich, Emiliano Carmona, Peter Schwind, Martin Bachmann, Martin Habermeyer, Tobias Storch, Sabine Chabrillat, Sebastian Fischer.

30. HyperEdu Online Learning Initiative for Imaging Spectroscopy: Concept, Current Status, Lessons Learned and Future Perspectives. Arlena Brosinsky, Saskia Foerster, Charlotte Wilczok, Theres Kuester, Robert Eckardt, Michael Bock.

31. Evaluation of PRISMA Imaging Spectroscopy Mission Data over Different Natural Targets. Roberto Colombo, Caludia Giardino, Beniamino Gioli, Federico Carotenuto, Federica Braga, Mariano Bresciani, Mirco Boschetti, Loredana Pompilio, Monica Pepe, Daniela Meloni, Stefano Pignatti, Giuseppe Satalino, Sergio Cogliati, Giulia Tagliabue, Cinzia Panigada, Roberto Garzonio, Biagio Di Mauro, Simone Pascucci, Patrizia Sacco, Ettore Lopinto, Lorenzo Genesio, Franco Miglietta.

32. Field Intercomparison of Drone-borne Hyperspectral Systems – Towards Reproducibility Of Surface Reflectance Measurements. Magdalena Smigaj, Benjamin Brede, Harm Bartholomeus, Lammert Kooistra.

33. Automatic Bore Sight Angle Determination And Georeferencing For Dual Push Broom Sensors. Andreas Schmidt.

34. Validation of Atmospheric Correction of DESIS L2A Products: comparison of hyperspectral and Sentinel-2-like multispectral sensors. Raquel de los Reyes1, Bringfried Pflug, Jerome Louis, Kevin Alonso, Martin Bachmann1, Emiliano Carmona, Maximilian Langheinrich, Rupert Mueller, Rudolf Richter.

35. Assessing the Land Use / Land Cover Classification Performances of Multispectral and Hyperspectral Data: Landsat and PRISMA Satellite. Buse Tırmanoglu, Aylin Tuzcu Kokal, Nebiye Musaoglu.

36. Eradiate: Modern radiative transfer simulation software for Earth observation. Vincent Leroy, Yvan Nollet, Sebastian Schunke, Nicolas Misk, Yves Govaerts.

37. Validation of Sentinel-2 Atmospheric Correction Using Radiative Transfer Models Emulators. Daria Malik, Jorge Vicent Servera, Juan Pablo Rivera Caicedo, Jochem Verrelst, Luca Martino, Beatrice Berthelot.

38. DESIS And Copernicus Sentinel-2 Surface Reflectance, AOT and WV Products Compared To Measurements On Ground. Bringfried Pflug, Raquel de los Reyes, Rudolf Richter, Maximilian Langheinrich.

39. Overview and Application of the Atmospheric Look-up Table Generator (ALG) tool (v3. 2). Jorge Vicent Servera, Jochem Verrelst, Beatrice Berthelot, Jose Moreno.

40. Status of the IEEE P4001 Working Group forStandardization in Hyperspectral Imaging. Trond Løke, Chris Durell, John R Gilchrist, Torbjørn Skauli.

41. Disentangling Random And Correlated Radiometric Uncertainty Contributors In Sentinel-2 L1C TOA Reflectance Factors. Lukas Valentin Graf, Javier Gorroño, Achim Walter, Helge Aasen.

Posters 2d YSA: Presentation of candidate posters for young scientist award

42. From Spectra to Functional Plant Traits: Aggregating Multiple, Heterogeneous and Sparse Data Sets for a Generalizable Multi-trait Model. Eya Cherif, Teja Kattenborn, Hannes Feilhauer.

43. Using Simulated Grassland Communities And Radiative Transfer Models To Test The Spectral Variation Hypothesis. Antonia Dorea Ludwig, Daniel Doktor, Hannes Feilhauer.

44. Planting Contexts Affect Urban Tree Species Classification Using Airborne Hyperspectral Imagery. Dengkai Chi, Jingli Yan, Ben Somers.

45. Asymmetry of Leaf Internal Structure Affects PLSR Modelling of the Anatomical Traits from VIS-NIR Leaf Level Spectra. Eva Neuwirthova, Zuzana Lhotakova, Lucie Cervena, Jana Albrechtova.

46. Hyperspectral Analysis Of The Contaminants On The Surface Of Ganymede. Katherine Villavicencio Valero, Pascal Allemand, Fabien Dubuffet.

Friday, 24 June 2022: 14:45 - 15:45

Posters 3a: Analyzing and mapping biodiversity with imaging spectroscopy data

47. Mapping Succession Species Using Airborne Hyperspectral Data – Different Reference Preparation Approaches and Their Impact on Classification Accuracy. Aleksandra Radecka, Katarzyna Osińska-Skotak, Hubert Piórkowski.

48. Comparison Of HySpex Airborne Hyperspectral Images With Multi-temporal Sentinel-2 Compositions For Mapping The Dominant High-mountain Plant Communities. Marcin Kluczek, Bogdan Zagajewski, Marlena Kycko.

Posters 3b: Recent software and sensors developments

49. Unsupervised Detection in Hyperspectral Imagery. Daniel C. Heinz, Thomas Bahr, David Streutker, Greg Terrie, Michael Ingram, Nicolai Holzer.

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Posters 3c: Measuring and understanding solar-induced fluorescence as an indicator for actual photosynthesis and vegetation function

50. 3D Forest Reconstruction From Terrestrial Laser Scanning Of Trees For Solar-induced Chlorophyll Fluorescence Sensitivity Analysis. Ruzena Janoutova, Zbynek Malenovsky, Lucie Homolova, Jan Novotny, Barbora Navratilova, Miroslav Pik

51. Winter Wheat Case Study In A Field In Germany On The Suitability Of Optical Remote Sensing Parameters To Track GPP Dynamics From Sub-diurnal To Seasonal Scale. Vera Krieger, Bastian Siegmann, Joe Berry, John Gamon, Juan Quiros, Kelvin Acebron, Laura Junker-Frohn, Marco Celesti, Marius Schmidt, Mirco Migliavacca, Paul Naethe, Ran Wan, Tommaso Julitta, Yelu Zeng, Uwe Rascher

52. Solar-Induced chlorophyll Fluorescence (SIF) and its relation with Soil Moisture (SM) and Gross Primary Productivity (GPP) at European scale during a heat wave. Juan Quiros-Vargas, Bastian Siegmann, Alexander Damm, Cosimo Brogi, Philipp Köhler, Roel Van Hoolst, David Martini, Onno Muller, Uwe Rascher

53. Design For An Active Laser-Induced Fluorescence System On Unmanned Aerial Vehicles. Hasib Mustafa, Harm Bartholomeus, Lammert Kooistra.

Posters 3d: Imaging spectroscopy for raw materials and the energy transition

54. The Influence Of Illumination Elevation Angle On Mineral Classification Of Hyperspectral Images. Tingxuan Jiang, Harald van der Werff, Frank van Ruitenbeek, Mark van der Meijde.

55. Hyperspectral Mapping of Clay Industrial Minerals With AHS Airborne Data. Eduardo García-Meléndez, Montserrat Ferrer-Julià, Mercedes Suárez, Javier García-Rivas, Emilia García-Romero, Elena Colmenero-Hidalgo.

56. The Contribution of Shortwave and Longwave Infrared Imaging Spectroscopy (IRIS) to Mapping Alteration Indicator Minerals in Geothermal Reservoirs. Christoph Hecker, Kartika Palupi Savitri.

57. Airborne Imaging Spectrometry Using AHS Data For The Evaluation Of The Spatial Distribution Of Sulfate Minerals. Eduardo García-Meléndez, Montse Ferrer-Julià, Asun Riaza, Elena Colmenero-Hidalgo, Antonio Espín de Gea, Juncal A. Cruz.

Posters 3e: Imaging spectroscopy of cropland and grassland

58. Application of Hyperspectral Imaging for Estimation of Potassium Content Across Different Plant Species. Anna Siedliska, Piotr Baranowski, Jaromir Krzyszczak, Grażyna Supryn.

59. Crop Identification Using One-Shot Airborne Hyperspectral Images. Beata Hejmanowska, Piotr Kramarczyk.

60. Detection of Grassland Degradation in Azerbaijan by Combining Multi-decadal NDVI Time Series and Fractional Cover Estimates Based on DESIS Data. Sarah Asam, Frederic Schwarzenbacher, David Marshall, Martin Bachmann.

61. Tempo-spatial Dynamics of Multispectral Assessment of Agricultural Field Heterogeneity. Quirina Noëmi Merz, Achim Walter, Helge Aasen.

62. Feature Selection And Classification Of Infected Tubers Using Hyperspectral Images And Compressive Sensing. Janez Lapajne, Matej Knapič, Saša Širca, Barbara Gerič Stare, Nik Susič, Uroš Žibrat

Abstracts

All conference abstracts in the order of
Keynotes,
Oral sessions, and
Poster sessions

KEYNOTE 1

MULTI-SENSOR SYNERGIES FOR CROP STRESS DETECTION - ON THE ROLE OF IMAGING SPECTROSCOPY

Katja Berger[1,2], Jochem Verrelst[2], Miriam Machwitz[3], Martin Schlerf[3] and SENSECO WG3 review paper co-authors[4]

1 Ludwig-Maximilians-Universität München, Department of Geography, Munich, Germany; 2 Image Processing Laboratory (IPL), University of Valencia, Valencia, Spain; 3 Remote Sensing and Natural Resources Modelling Group, Environmental Research and Innovation Department, Luxembourg Institute of Science and Technology (LIST), Belvaux, Luxembourg; 4 COST Action 17134 "Optical synergies for spatiotemporal SENsing of Scalable ECOphysiological traits" (SENSECO)

Abstract

We are facing an unprecedented global transition. About three-quarters of the Earth's terrestrial surface has been altered by humans in the last decades, going along with climate change and an exponential increase in the world's population. Thus, one of the most challenging concerns of today is finding answers to the question "How to feed the world?", as formulated in the 2nd Sustainable Development Goal. By 2050, global food production needs to be expanded by 70% to feed the future population. In this context, remote detection and monitoring of the crop responses to stress, i.e. biotic and abiotic pressures, became relevant for sustainable agriculture. A wide array of sensors operating in the optical domain can be used to detect crop stress at scales from sub-field level to large cultivated regions, but the synergic exploitation of multi-source sensor measurements remains largely unexplored.

This keynote aims to provide an overview of the main sensor technologies for the detection of crop stress in agriculture, identify gaps, elaborate integrative concepts and discuss the crucial role of (near-term) spaceborne imaging spectroscopy missions. Reliable, accurate and near real-time information on stress at crucial time stamps are essential for the future of precision agriculture. We will present integrated views on: (i) biotic and abiotic stress factors, the plant responses to stress, stress phases and severity, and (ii) the affected traits, appropriate spectral domains and corresponding methods for measuring traits remotely. Representative results of a systematic literature analysis will be highlighted, identifying the current status and possible future trends in stress detection and monitoring. Distinct plant responses occurring under short-term, medium-term or severe chronic stress exposure can be captured with hyperspectral remote sensing technologies due to specific light interaction processes, such as absorption and scattering manifested in the reflected radiance, i.e. visible, near-infrared, shortwave infrared, and emitted radiance, i.e. solar-induced fluorescence (SIF) and thermal infrared. Synergistic use of multiple spectral signals from these sensing domains can provide significant advantages over single-source sensor usage, among others for: (i) identifying cause-effect relationships of stress, (ii) analyzing multiple stress responses simultaneously (holistic view), and (iii) determining stress severity. From the analysis of 100 research papers, the following trend can be observed: an increasing usage of satellite data in parallel with a shift in methods from simpler parametric approaches towards more advanced physically-based and hybrid models. However, the majority of reviewed studies compared stress proxies calculated from single-source sensor domains rather than using data in a synergistic way. Specifically, through imaging spectroscopy, the following traits with direct relevance to crop stress detection can be accurately inferred: crop nitrogen and protein contents, photosynthetic pigments, leaf water content, carbon-based constituents and soil organic carbon, all providing insights into crop health status. In particular, SIF observations will provide prospects for early stress detection.

As a future outlook, we recommend combining multiple remote sensing data streams into crop model assimilation schemes to build up Digital Twins of agroecosystems. Upcoming hyperspectral data streams from launched (EnMAP, PRISMA) and planned (CHIME, SBG, FLEX) spaceborne imaging spectroscopy missions will play a crucial role in providing hyperspectral time-series needed to address major challenges for sustainable global agriculture.

KEYNOTE 2

THE FUTURE FOR ENVIRONMENTAL CHANGE RESEARCH IN A GLOBAL CONTEXT: ADDED VALUE OF SPACE BORNE IMAGING SPECTROSCOPY

Inge Jonckheere

FAO Forestry and Climate Group

Abstract

Environmental change has always been a very important research topic to understand our changing planet, but now its importance is more than ever, in the actual climate crisis in which it is clear that we only have a small time window to act in order to reduce the global warming before bringing the temperature to catastrophic heights. Greenhouse gas reporting for the agriculture, forestry and other land use (AFOLU) sector requires land use changes to be characterized to estimate the associated greenhouse gas emissions or absorptions. It is becoming increasingly common to generate the (change) estimates using satellite data. This technique has been widely used in recent years in the generation of activity data- particularly for estimating areas of deforestation and is on its way to be used much more due to the wide variety of very high quality data freely accessible and often freely available. However, implementing countries and agencies have repeatedly highlighted the lack of guidance on how to address certain issues using this data.

In this talk, a possible roadmap is laid out in order to discuss pros and cons of the use of space borne imaging spectroscopy in the environmental change research. A state of the art is given and an outlook done to solutions and options to bridge the knowledge gaps in using space borne imaging spectroscopy for the environmental change research.

KEYNOTE 3

ECOLOGICAL INSIGHTS FROM IMAGING SPECTROSCOPY OF FOLIAR FUNCTIONAL TRAITS

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Abstract

Climate and land use/land cover change have the potential to dramatically alter Earth's terrestrial ecosystems through impacts on biodiversity and vegetation function, with significant long-term ramifications for human populations. The gold-standards for characterizing ecosystem responses to global change include detailed plot-based field studies, manipulative experiments in vegetation types of concern, space-for-time studies, modeling, and especially syntheses drawing on data from multiple studies. However, there are critical gaps in our baseline knowledge of macroecological patterns and understanding of the drivers of patterns observed at regional-to-global-scales. These gaps arise due to fundamental logistical challenges of expense, time and access. Remote sensing has provided the capability to document the status of landscapes and to track changes, but, in many respects, has struggled to provide new insights into the ecological processes that underlie the mapped patterns of ecosystem properties.

In recent years, imaging spectroscopy has emerged as an effective tool for characterizing foliar functional traits, which are widely used as surrogate measures to represent vegetation investment in growth, maintenance and defense. Maps of leaf traits can complement or even replace traditional field sampling, and have been shown to provide a basis for quantifying functional diversity at broad scales, especially because multiple traits are measured concurrently. Imaging spectroscopy thus provides insights into drivers of ecological dynamics at unprecedented spatial scales that would not otherwise be possible from traditional in-situ sampling. For example, imaging spectroscopy reveals differing phenological trajectories in resource allocation among species across landscapes. From this, we can assess ecological niche space use in both space and time to predict likely responses to a changing environment. Imaging spectroscopy derived trait maps also enable testing basic ecological hypotheses at broad scales. Analyses of AVIRIS-Classic imagery covering the duration of the 2011-2017 California drought illustrated trends in vegetation response to the drought, as vegetation exhibited a shift towards traits associated with maintenance and away from photosynthesis and defense. Such patterns were predictable based on ecological theory, but had not been demonstrated at regional scales. Ultimately, emerging continental-scale airborne networks such as NEON in the US and satellite imaging missions such as PRISMA, EnMAP, CHIME and SBG will offer further capabilities to quantify regional-to-global drivers of trait variation related to climate, environment and phylogeny. These will enable further testing of hypothesized drivers of geographic variation and trait tradeoffs, as shown here using foliar phenolics derived from NEON imagery as well as additional analyses linking imaging spectroscopy with flux tower data. Our hope is that emerging regional, continental and global imaging spectroscopy data sets will provide baseline data on macroecological relationships in time to address effects of global change on Earth's ecosystems.

1-2 PLENARY: UPDATES FROM SPACEBORNE IMAGING SPECTROSCOPY MISSIONS

THE ENMAP HYPERSPECTRAL SPACEBORNE MISSION LAUNCHED

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Abstract

The launch of the EnMAP (Environmental Mapping and Analysis Program) satellite is upcoming. On 1st April 2022, this first hyperspectral satellite developed and built in Germany is scheduled to begin its journey into space on board a U.S. Falcon 9 rocket from NASA's Kennedy Space Center in Florida. EnMAP was developed and built by OHB System AG on behalf of the German Space Agency at DLR with funding from the German Federal Ministry of Economic Affairs and Climate Action. The ground segment is being developed and operated by DLR in Oberpfaffenhofen. The GFZ in Potsdam has the scientific lead of the mission.

The EnMAP is a spaceborne hyperspectral satellite mission that will provide a continuous spectrum in 218 spectral bands from 420 nm to 2450 nm, with a mean spectral sampling of 6.5 nm (VNIR) and 10 nm (SWIR). EnMAP aims at monitoring and characterizing the Earth's environment on a global scale. The EnMAP mission (www.enmap.org) will significantly contribute to the availability of highly calibrated space-based imaging spectroscopy products. The main scientific goal of EnMAP is to study environmental changes, investigate ecosystem responses to human activities, and monitor the management of natural resources. By measuring diagnostic parameters that quantify the state and trend of environmental change, the stability of ecosystems, and the sustainability of resource use, the EnMAP mission aims to provide critical information for an improved understanding and management of the Earth System. The satellite is based on a push-broom type concept and will operate in a polar, sun-synchronous, low earth orbit in 653 km height. Crucial for the scientific aims of EnMAP is the 27 days revisit time (nadir), and a short target revisit times requiring an agile satellite pointing up to 30° off-nadir. This allows for revisit times of maximum 4 days with a single satellite that can be used to monitor dynamic events.

After successful flight acceptance review in early 2022, the satellite was released for transport and was transported from OHB's site in Bremen to NASA's Cape Canaveral spaceport in Florida by an Ilyushin Il-76 transport aircraft at the end of February 2022. Currently the subsequent functional tests after transport were successfully completed, and the system is being integrated in the rocket. Furthermore, the operational readiness review of the ground segment was just successfully finalised. After launch, the satellite will undergo a 6 months commissioning before release of the data to the users planned October 2022. In this presentation, we will present an update of the latest developments in EnMAP satellite toward the launch and preparations for the upcoming commissioning and nominal phase, including mission update, calibration and validation plans, data access, science preparation, and if possible first images.

1-2 PLENARY: UPDATES FROM SPACEBORNE IMAGING SPECTROSCOPY MISSIONS

PRISMA MISSION AND BEYOND: CURRENT STATUS AND FUTURE PLANS FOR THE FIRST ITALIAN HYPERSPECTRAL MISSION

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Abstract

PRISMA (PRecursore IperSpettrale della Missione Applicativa) is an Italian EO hyperspectral Mission fully funded by ASI and realized by an Italian industries consortium as a pre-operational and technology demonstrator, with a focus on the space qualification of a PAN/HYP payload and the development and validation of a series of PAN/HYP products. Launched on March 2019, the mission opened the access to users on May 2020, after the completion of the commissioning activities.

In these two years of operations, the PRISMA user community has grown considerably, reaching 1169 users (evaluated at mid Feb 2022). Observing the following graphs which show the distribution of the statistically most representative part of the user population, the Italian user account for the 27% of the population, with another 29% associated with 4 nations (India, USA, Germany, China). The 64% of the users are scientists and most of them are non italian (52%), witnessing the high exploitation of the mission outside the Italian borders. Only the 11% of the users belongs to commercial companies, which is coherent with the actual high scientific interest toward PRISMA, however non Italian commercial users are two times the Italian ones, signaling the expectation of the foreign EO companies in the creation of value added services based on PRISMA data. The institutional users are less than the commercial users (9%) while the remaining mix (non profit organization, spin off / start-up, special & generic users, ASI users) account for the remaining 16%. About the data usage domains, 33 typologies account for the 71% of all usages, with the two most important categories being the Agriculture and the Land use cover (either 7%). The remaining users represent a widely heterogeneous user community.

Various activities are being conducted, in the frame of the cooperation with other space agencies. PRISMA is currently supporting the ESA ACIX and CMIX projects, aimed at the inter-comparison of the various techniques and performance in the atmospheric correction of multispectral/hyperspectral data and cloud masking; respectively. PRISMA is programming acquisitions on the many projects test sites (33+) at each orbital cycle and with a high priority. After two years of scientific usage, ASI is evaluating to enable the commercial exploitation of products continuing to release them free of charge. When approved, the new policy will allow users to exploit the PRISMA data for creation and sell of value-added products and services. The only constraint is that the group shall register in PRISMA system with a main user belonging to an Italian company active in the field of EO. Since the group could include non-Italian companies, the commercial exploitation will not be restricted to Italian people only.

Two main technical improvements are foreseen in the close future of PRISMA. The first will allow to generate the L2x products with the best geolocation accuracy allowed by the system (15m CE90), by building and exploiting a GCPs database covering the entire PRISMA access area (earth regions with a sun zenith angle lower than 75°). The second is related to the development of a PRISMA toolbox capable to ingest and render the PRISMA datacube in quasi realtime, thanks to the usage of the PC graphic card. This tool will also include a Python interface allowing the processing of the datacube with user defined algorithms, hence expanding his native capabilities with new libraries and algorithms. Both these improvements will be ready in Q4-2022.

ASI will continue to support the hyperspectral technology with the PRISMA Second Generation mission characterized by many and substantial improvements in SNR, spatial resolution, revisit time, maximum off-nadir angle, satellite agility as well spatial coverage at Italian, European and worldwide scale. The development of the mission program has started in February 2022 with the Phase A KO and is expected to be launched in 2025.

1-2 PLENARY: UPDATES FROM SPACEBORNE IMAGING SPECTROSCOPY MISSIONS

THE SPACEBORNE IMAGING SPECTROMETER DESIS: MISSION SUMMARY AND POTENTIAL FOR SCIENTIFIC DEVELOPMENTS

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Abstract

The DLR Earth Sensing Imaging Spectrometer (DESIS) is a spaceborne instrument installed and operated on the International Space Station (ISS). The German Aerospace Center (DLR) has developed the instrument and the full pre-processing chain up to L2A, while the US company Teledyne Brown Engineering (TBE) provided the Multi-User System for Earth Sensing (MUSES) platform and the infrastructure for operations and data tasking.

DESIS is equipped with an on-board calibration unit and a rotating pointing mirror (POI). The POI can change the line of sight in the forward/backward direction (independently of the MUSES orientation), allowing the observation of the same area with different pointing angles within an overflight. About four years after the mission's kick-off, the DESIS spectrometer was integrated into MUSES in August 2018, marking the start of the commissioning phase. The DESIS on-orbit functional tests were successful, and the DLR-built processing chain installed at DLR for scientific users and at Amazon Web Service for commercial users started to generate operational L1B, L1C and L2A DESIS products.

In October 2019 the operational phase started the distribution of the data to scientific and commercial users. Since then, the instrument performance has been constantly evaluated. In a continuous monitoring process, the data quality is controlled and, if necessary, the calibration algorithms and tables are adjusted. This is essential for the later data application by scientists. In particular, the monitoring approaches emphasize the need for high and consistent data quality over long time periods. In autumn 2021, the first DESIS user workshop demonstrated the widespread use of DESIS data for topics like water and terrestrial resource monitoring, biodiversity and forest management.

This presentation will give an overview of the DESIS mission, data quality, data access, and provides examples and perspectives on the scientific exploitation of the mission. The contribution for the CHIME mission is presented exemplarily for the CHIME test sites that are constantly observed by DESIS since 2020. DESIS data acquisition opportunities rely on the non-sun-synchronous ISS orbit, resulting in observation and illumination conditions difficult to reproduce. On the other hand, DESIS time series contain images of different day times, sensor incident angles as well as sun zenith angles and thus, can open up new opportunities for the monitoring of Earth system processes that have a daily variability such as photosynthesis. Finally, DESIS multitemporal data stacks can be an essential data base for algorithm and operational processor developments that shall be able to handle massive data amounts. The DESIS data archive is open for such research and developments and thus, is a valuable imaging spectroscopy data source.

1-2 PLENARY: UPDATES FROM SPACEBORNE IMAGING SPECTROSCOPY MISSIONS

PROGRESS TOWARD NASA'S SURFACE BIOLOGY AND GEOLOGY MISSION

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Abstract

Following on the recommendations of the Earth Science Decadal Survey conducted by the National Academies of Science, Engineering and Medicine, the National Aeronautics and Space Administration (NASA) is developing an Earth System Observatory (ESO). ESO is a series of missions that will observe a wide range of phenomena throughout the Earth's interior, surface and atmosphere. The Surface Biology and Geology (SBG) investigation is a component of this observatory. SBG will observe Earth's land, inland waters, and coastal oceans. Its planned architecture includes multiple spacecraft slated for launch in 2027-2028. Its science questions and geophysical variables cross diverse disciplines including geology, ecology in terrestrial and aquatic environments, hydrology, and the cryosphere. SBG will also reveal the links between the different domains to better understand the Earth as a connected system. SBG measurements will benefit diverse societal applications including agriculture, terrestrial and aquatic biodiversity, natural hazards, public health, and management of water and other natural resources. The mission will coordinate its data products, and analyses with other ESO elements, and international missions such as CHIME, TRISHNA, and LSTM, to deliver an integrated Earth System perspective of Earth and its changing climate.

1-2 PLENARY: UPDATES FROM SPACEBORNE IMAGING SPECTROSCOPY MISSIONS

STATUS AND PLANNING OF THE COPERNICUS HYPERSPECTRAL IMAGING MISSION FOR THE ENVIRONMENT (CHIME)

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Abstract

Hyperspectral imaging is a powerful remote sensing technology based on high spectral resolution measurements of light interacting with matter, thus allowing the characterisation and quantification of Earth surface materials. Quantitative variables derived from the observed spectra, e.g. directly through distinct absorption features, are diagnostic for a range of new and improved products in the domain of agriculture, food security, raw materials, soils, biodiversity, environmental degradation and hazards, inland and coastal waters, and forestry. These are relevant to Copernicus Services and various EU policies that are currently not being met or the support to which can be substantially improved, but also to the private downstream sector.

In the second half of the 2020s an evolution in the Copernicus Space Component (CSC) is foreseen to address priority user needs not fulfilled by the existing infrastructure, and/or to reinforce services by monitoring capability in the thematic domains of CO2, ocean, cryosphere, and agriculture/forestry. This evolution will be synergetic with the enhanced continuity of services for the next generation of CSC. Among these new missions, the Copernicus Hyperspectral Imaging Mission for the Environment (CHIME) aims to provide routine hyperspectral observations through the Copernicus Programme in support of EU- and related policies for the management of natural resources, assets and benefits. This unique visible-to-shortwave infrared spectroscopy based observational capability will in particular support new and enhanced services for food security, agriculture and raw materials. This includes sustainable agricultural and biodiversity management, soil properties characterization, sustainable mining practices and environment preservation. The observational requirements of CHIME are driven by the primary application domains i.e. agriculture, soils, food security and raw materials, and are based on state-of-the art technology and results of previous hyperspectral airborne and experimental spaceborne systems. They were drafted by an international group of experts and reflected in the Mission Requirement Document.

For the development of the Space Segment Contract (Phase B2/C/D/E1) Thales Alenia Space (France) as Satellite Prime and OHB (Germany) as Instrument Prime were selected. The contract was signed in November 2020 and the corresponding Kick-Off released the start of Phase B2. The System Requirement Review (SRR) was conducted in July 2021 and the Preliminary Design Review (PDR) is planned for mid-2022, when the CHIME Space Segment will be confirmed. Currently there are two satellites foreseen each of which will embark a HyperSpectral Instrument (HSI). The HSI is a pushbroom-type grating Imaging Spectrometer comprising a single telescope, and three identical spectrometers each covering one-third of the total swath of ~130 km. The three spectrometers each have a single detector covering the entire spectral range from 400 to 2500 nm, delivering high Signal-to-Noise Ratio (SNR), high radiometric accuracy and data uniformity.

CHIME data will be processed and disseminated through the Copernicus core Ground Segment allowing the generation of CHIME core products: L2A (bottom-of-atmosphere surface reflectance in cartographic geometry), L1C (top-of-atmosphere reflectance in cartographic geometry) and L1B (top-of-atmosphere radiance in sensor geometry). Additional higher level prototype products related to key vegetation, soil and raw material properties are also being developed.

In this contribution, the main outcomes of the activities carried out in Phase A/B1 and B2, as well as the planned activities for Phase C/D/E will be presented, covering the scientific support studies, the technical developments and the user community preparatory activities. The ongoing international collaboration towards increasing synergies of current and future imaging spectroscopy missions in space will be reported as well.

1-2 PLENARY: UPDATES FROM SPACEBORNE IMAGING SPECTROSCOPY MISSIONS

THE FLUORESCENCE EXPLORER (FLEX) MISSION: IMAGING SPECTROSCOPY IN VERY HIGH SPECTRAL RESOLUTION

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Abstract

The FLuorescence EXplorer (FLEX) mission was selected in 2015, by the European Space Agency, as the 8th ESA Earth Explorer, to be launched in 2025. The key scientific objective of the mission is the quantitative mapping of actual photosynthetic activity of terrestrial ecosystems, at a global scale and with a spatial resolution adequate to resolve land processes associated to vegetation dynamics. To accomplish such objective, the FLEX satellite carries the Fluorescence Imaging Spectrometer (FLORIS). FLEX will fly in tandem with Copernicus Sentinel-3 (same orbit at 815 km, 27 days repeat cycle). Together with FLORIS, the OLCI and SLSTR instruments on Sentinel-3 provide all the necessary information to retrieve the emitted vegetation fluorescence, including compensation for atmospheric effects and the derivation of the additional biophysical information needed to map the spatial and temporal dynamics of vegetation photosynthesis from such global measurements.

The FLORIS instrument provides images with a 150 km swath and 300 m pixel size. By using two combined imaging spectrometers, FLORIS will measure the radiance between 500 and 780 nm with a spectral sampling of 0.093 nm (HR spectrometer) and 0.6 nm (LR spectrometer), with high spectral resolution of 0.3 nm in particular at the Oxygen-A (755-780 nm) and -B bands (677-697 nm). It will also cover the photochemical reflectance features between 500 and 600 nm, the variable chlorophyll absorption from 600 to 677 nm, and the red-edge from 697 to 755 nm. The specific information provided by the FLORIS instrument includes the full-spectrum of fluorescence emission in the range 650-780 nm, to account for dynamical changes in the shape of fluorescence emission spectrum induced by stress factors, and the spectral variability in surface reflectance in the 500-600 nm spectral range indicative of chemical adaptations in regulated heat dissipation, to estimate the amount of energy dissipated by non-radiative processes.

FLEX will provide validated ready-to-use high-level science products that can be directly used by vegetation dynamical models, climate models and applications. Efforts are put in place to guarantee proper Cal/Val activities and dedicated validation networks. The FLEX Level-2 products are already provided in the same geographical grid as Sentinel-2 products to facilitate multi-mission data exploitation strategies. Usage of common global multi-resolution spatial grids for high-level L3/L4 products maximizes the inter-operability of FLEX products in global data assimilation approaches and multiple applications. Particular efforts are in place to provide each product with realistic and properly estimated uncertainties, and also to propagate the derived uncertainties from the original satellite data until the final high-level products.

Most of the technical issues, spectral and radiometric corrections and retrieval strategies, are common to other imaging spectroscopy missions, but some effects have to be taken more carefully given the very high spectral resolution. Atmospheric corrections and compensation for spectral distortions are specially challenging in the case of FLEX, because the information used in FLEX is just coming from such little spikes in surface apparent reflectance which are taken as noise and spectrally smoothed in other imaging spectroscopy missions.

The legacy of FLEX for imaging spectroscopy will benefit from the lesson learned about characterization of such atmospheric effects and spectral correction methods, but also from the developments of new leaf/canopy radiative transfer models, coupling structural, biochemical and physiological effects, and new techniques for the

retrievals of new vegetation products from such spectral observations. The End-to-End mission simulation tools, and the advances in dedicated Cal/Val activities with robust statistical approaches developed for FLEX, will also be beneficial for future imaging spectroscopy missions.

1-2 PLENARY: UPDATES FROM SPACEBORNE IMAGING SPECTROSCOPY MISSIONS

NASA EARTH SURFACE MINERAL DUST SOURCE INVESTIGATION (EMIT) IMAGING SPECTROMETER PERFORMANCE AND MISSION STATUS

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Abstract

The Earth Surface Mineral Dust Source Investigation (EMIT), uses new observations from an advanced F/1.8 visible to short wavelength infrared (VSWIR) imaging spectrometer planned for launch to the International Space Station (ISS) on a SpaceX rocket in 2022. The EMIT instrument is the latest in a series of more than 30 imaging spectrometers and testbeds developed at JPL beginning with the Airborne Imaging Spectrometer (AIS) that first flew in 1982. Mineral dust emitted into the atmosphere plays an important role in the Earth system impacting direct and indirect radiative forcing, atmospheric chemistry, cryosphere melt, surface hydrology, and the biogeochemistry of ocean and terrestrial ecosystems, as well as being a hazard to human populations. The Earth's dust cycle consists of source, transport, and deposition elements. Updated source knowledge is required today to run state-of-the-art Earth System Models (ESMs) to simulate the dust cycle and understand current and future impacts on the Earth system. Currently, detailed knowledge of the composition of the Earth's mineral dust source regions is uncertain and traced to less than 5000 surface sample mineralogical analyses. The EMIT's specific science objectives are to reduce uncertainty in the direct radiative forcing effect of mineral dust in the Earth system today and assess future changes in the effect under a range of climate scenarios. These objectives are addressed by acquiring the first comprehensive maps of mineral composition in the Earth's arid land regions and using these new observations to initialize ESMs. The development of the EMIT imaging spectrometer instrumentation has been completed successfully despite the severe impacts of the COVID pandemic on space hardware development at many levels. The EMIT Science Data System is complete with the implementation of the full set of algorithms required. These tested algorithms are open source and available to the broader community. These include: calibration to measured radiance, atmospheric correction to surface reflectance, mineral composition determination, aggregation to ESM resolution, and ESM runs to address the science objectives. The spectral, radiometric, spatial, and uniformity performance of the EMIT imaging spectrometer as well as the status and plans for the ground system, in-orbit checkout, and prime science measurement observation phase are reported here. EMIT's measurements, products, and updated models will enable a broad set of additional science investigations and will be freely available from the NASA Land Process Distributed Active Archive Center.

1-3A SPECSESS VEGTRAITS: QUANTIFYING PRIORITY VEGETATION TRAITS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA - PART 1

RETRIEVAL OF FLUORESCENCE QUANTUM EFFICIENCY AND QUANTITATIVE PHOTOSYNTHETIC TRAITS IN THE CONTEXT OF THE FLEX MISSION

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Abstract

Due to emerging high spectral resolution, remote sensing techniques and ongoing developments are focussing on the retrieval of the spectrally resolved vegetation fluorescence spectrum and the smooth top-of-canopy reflectance. These products generate new perspectives towards the retrieval of quantitative information contained by the general light reactions of photosynthesis, and hence, the monitoring of the Earth's carbon balance. Sensor-retrieved vegetation fluorescence (from leaf, tower, airborne or satellite scale) originates from the excited antenna chlorophyll a molecule and has become a new quantitative biophysical vegetation parameter retrievable from space using global imaging techniques. However, to retrieve the actual quantum efficiencies related to the actual photosynthetic performance, all signal distortions must be accounted for, and a high-precision true vegetation reflectance must be resolved. In the context of the preparatory activities for ESA's upcoming Fluorescence Explorer (FLEX) mission, higher-level products are being developed for the physical retrieval of additional parameters that allow the further quantitative interpretation of the spectrally resolved vegetation fluorescence. Hereby, the high spectral resolution reflectance in the 500-780 nm region is used for the further retrieval of essential parameters to interpret the vegetation fluorescence.

Considering a bottom-up spectral fitting approach, the energy which is effectively absorbed by the photosynthetic pigments is retrieved from the reflectance and the incoming solar radiance. These quantities allow the further calculation of the (apparent) fluorescence quantum efficiency (FQE) which is the ratio between the (apparently) emitted fluorescence quanta and the absorbed quanta that trigger the emission. FQE can be used as a first indicator for the photosynthetic efficiency of the vegetation surface and is indicative for the excitation pressure on the Chlorophyll molecules and by assumption the whole photosynthetic antenna system. Despite the relationship tends to be more complex than that due to the activation of non-photochemical quenching mechanisms which changes the qualitative coupling between fluorescence and photosynthesis, the retrieval of FQE serves as the essential step to quantify more precisely the energy eventually used by the carbon reactions. Further, by using a bottom-up approach to characterize and fit the shape of spectral fluorescence emission, additional information can be gained on the energy partitioning mechanisms in the light-harvesting reactions, through the two photosystems, PSI and PSII.

With these advances in the interpretation of the vegetation fluorescence signal, both quantitatively and qualitatively, the actual light use through photosynthesis and vegetation growth with carbon assimilation will be better quantified. Hence, with the retrieval of FQE, combined with additional information on the dynamic regulation of the energy pathways in the light reactions, promising opportunities are presented to improve our understanding of the vegetation dynamics in the global carbon cycle.

1-3A SPECSESS VEGTRAITS: QUANTIFYING PRIORITY VEGETATION TRAITS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA - PART 1

ADVANCES IN VEGETATION TRAITS MODELS IN THE CONTEXT OF THE HYPERSPECTRAL CHIME MISSION PREPARATION

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Abstract

The Copernicus Hyperspectral Imaging Mission for the Environment (CHIME) is in preparation to carry a unique visible to shortwave infrared spectrometer. CHIME will globally provide routine hyperspectral observations to support new and enhanced services for, among others, sustainable agricultural and biodiversity management. The mission shall provide Level 1B, 1C and 2A products, as well as a set of downstream products related to the different environmental applications, such as the quantification of vegetation traits. In this context, this work presents the latest status of developed retrieval models for the operational delivery of vegetation traits products.

As part of the CHIME mission preparation, ESA initiated the development of an end-to-end (E2E) mission performance simulator, which is able to simulate realistically and accurately the complete chain starting from data recording, sensor calibration and data pre-processing to sensor products up to final surface parameter maps. The E2E simulator generates realistic and synthetic CHIME data sets at raw data level in forward mode. It subsequently creates L1B, L1C and L2A products, together with the presented vegetation traits (L2BV). One of the main advantages of the E2E simulator is that any of the generated products can be validated against reference input data given multiple scenarios.

The L2BV module is in charge of the processing of L2A reflectance data into vegetation variables (traits), such as leaf and canopy nitrogen content. Apart from the processing software, the core work involved the development of retrieval models covering the priority vegetation variables. Based on experience within the context of developing retrieval models for the FLEX mission, we present a workflow of building so-called hybrid models. Hybrid models combine elements of machine learning statistics with physically based methods. The same strategy is pursued for all the variables, and boils down to the following steps:

1) To enable training generic hybrid models, a broad spectral database was generated using simulations coming from the SCOPE radiative transfer model (RTM). For the variables not present in SCOPE, alternative leaf RTMs were explored such as PROSPECT-PRO. These RTMs were subsequently coupled with the 4SAIL model for generating top-of-canopy reflectance simulations.

2) Once having the training data sets prepared, Gaussian noise was applied to render the simulated spectra more similar to real (noisy) data. Subsequently, the spectral data was transformed into 20 components using principal component analysis (PCA).

3) For each variable, a Gaussian process regression (GPR) algorithm was trained, validated and refined during the course of the E2E project. For validation, the models were first validated against in situ data collected during different field campaigns. In addition, models were tuned using active learning methods providing representative training data sets. Further, to enable processing of complete heterogeneous images, non-vegetated spectra were included in the training data sets (i.e., bare soil, man-made surfaces, water, etc.).

Following some internal rounds of model development, testing and improving, we present here the v.1.8 vegetation models. This version covers the development of 13 trait retrieval models with band settings according to CHIME E2E L2A spectral configuration. The prototype retrieval models were applied to both hyperspectral airborne (HyPlant) and spaceborne (PRISMA) imagery that were resampled to CHIME band settings and processed through the E2E chain. Among the provided vegetation products, it led to a first space-based canopy nitrogen content map over a heterogeneous landscape. Besides, the retrieval models provide uncertainty information along with the estimates for each trait. We conclude that the obtained CHIME-like L2BV traits maps demonstrate the feasibility to routinely deliver a collection of next-generation vegetation products across the globe.

1-3A SPECSESS VEGTRAITS: QUANTIFYING PRIORITY VEGETATION TRAITS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA - PART 1

RECENT PROGRESS AND CHALLENGES IN THE DERIVATION OF NON-PHOTOSYNTHETIC CROPLAND BIOMASS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA

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Abstract

Non-photosynthetic (NP) biomass has been identified as a priority variable for upcoming spaceborne imaging spectroscopy missions, such as the Environmental Mapping and Analysis Program (EnMAP) or the Hyperspectral Imaging Mission for the Environment (CHIME). Being an essential part of the total organic carbon within the biosphere, the spatiotemporal knowledge of the lignocellulosic plant material helps to understand carbon fluxes, soil carbon loss or drought effects. Nonetheless, in the past, the focus was almost exclusively on the retrieval of NP or crop residue coverage given in percentage. In this work, we surveyed existing studies using hyperspectral data for NP biomass or coverage estimation within agricultural contexts. We identified a gap in the provision of NP biomass information by remote sensing data, caused by missing satellite sensors equipped with the required spectral resolution in the shortwave infrared (SWIR) domain to identify absorption features of non-photosynthetic plant compounds. Based on this, we propose a hybrid strategy for the retrieval of NP cropland biomass from actual and near-term hyperspectral missions. Recently, significant advances have been achieved with the inclusion of the carbon-based constituents (CBC) variable into the leaf optical properties model PROSPECT-PRO. The spectral signal can be upscaled to the canopy through the radiative transfer model 4SAIL, which allows simulating NP biomass by multiplying CBC with leaf area index (LAI). In this way, PROSAIL-PRO generates a database for training machine learning (ML) regression methods to build retrieval models. We selected Gaussian process regression (GPR) algorithms due to their appealing intrinsic property to provide uncertainty information along with estimates, which is outstanding compared to alternative ML methods. In addition, efficient active learning (AL) methods were employed to reduce and optimise the training data set. We further reduced the spectral dimensionality condensing essential information of non-photosynthetic signals by means of principal component analysis (PCA). The resulting NPbiomass-GPR models were successfully validated, among others, against soybean field data with normalised root mean square error (NRMSE) of 13.4% and coefficient of determination (R^2) of 0.85. As a key result, we achieved substantially high accuracy through the implemented Euclidean distance-based diversity (EBD) active learning method. To demonstrate mapping capability, the NPbiomass-GPR model was tested on PRISMA hyperspectral images acquired over agricultural areas in the North of Munich, Germany. Reliable estimates were mainly obtained over senescent croplands as also confirmed by model uncertainties. The main bottleneck of our proposed method is the separation between green and non-green vegetated elements by the applied RTM. Thus, in follow-up research, improvements could be achieved through the separation of green and non-green vegetation types as a first step, followed by applying specifically trained retrieval models. The presented workflow for mapping NP cropland biomass is currently under investigation within the framework of the CHIME mission. Along with other vegetation traits models, the NPbiomass-GPR model could be implemented into CHIME's end-to-end (E2E) mission performance simulator. With the launch of the EnMAP mission in April 2022, we expect an exciting opportunity to further test, improve and optimise the retrieval strategy. The proposed workflow can be a first step towards the quantification of NP cropland biomass as a next-generation product from scientific precursor (EnMAP) or near-term operational spaceborne missions, such as CHIME.

1-3A SPECSESS VEGTRAITS: QUANTIFYING PRIORITY VEGETATION TRAITS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA - PART 1

REPRESENTATIVENESS OF AIRBORNE IMAGING SPECTROSCOPY FOR GLOBAL UPSCALING FOR SPACEBORNE MISSIONS

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Abstract

We are entering an era of unprecedented availability of spaceborne imaging spectroscopy from sampling missions such as EMIT, PRISMA, HISUI and EnMAP and planned global missions CHIME and SBG. Many of these missions have plans to generate vegetation products such as foliar traits (e.g., leaf or canopy chlorophyll, nitrogen, water content and leaf mass per area). These traits vary considerably between and within taxa, driven by a combination of environmental factors (climate, soils), phylogeny, ontogeny, and phenology. Current in-situ sampling networks and available airborne imagery are insufficient for calibration and validation of such vegetation products should they be produced globally and at sub-monthly scales. Here we demonstrate an approach to assess the representativeness of existing spatially and temporally coincident in-situ and image data based on hypothesized environmental drivers of trait distributions. We evaluated the similarity between environmental conditions observed at locations of coincident in-situ and image data and those across North America and the globe based on a principle components analysis of ~20 bioclimatic and edaphic variables on a 4 km grid. Our approach enables a spatial assessment of representativeness of existing data to identify new locations for field sampling and image collection. As well, it facilitates pairwise comparisons of locations to assess the degree of comparative representativeness among locations targeted for further work. We demonstrate the approach using in-situ and imagery data coincidently collected across North America in support of the U.S. National Ecological Observatory Network (NEON), NASA's Arctic Boreal Vulnerability Experiment (ABoVE), and other NASA AVIRIS campaigns.

1-3A SPECSESS VEGTRAITS: QUANTIFYING PRIORITY VEGETATION TRAITS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA - PART 1

QUANTIFYING CROP RESIDUE COVER BY SPECTROSCOPY TECHNIQUES EXPLOITING IN-SITU, AERIAL AND SIMULATED SPACEBORNE HYPERSPECTRAL DATA FOR PRISMA MAPPING APPLICATIONS

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Abstract

PRISMA is the forerunner of a series of hyperspectral spaceborne missions that will empower quantitative satellite remote sensing (RS). Such satellites, by sensing surfaces in narrow and contiguous spectral bands from visible, to near and shortwave infrared intervals (VIS-NIR-SWIR), will ensure a better characterization of Earth surfaces, at a higher level of detail and with increased reliability, in different application frameworks, including RS of vegetation. Among those applications, the studies on Non-photosynthetic vegetation (NPV) and carbon based constituents (CBC) particularly benefit from the availability of hyperspectral reflectance in the SWIR region at wavelengths longer than 1600nm, where they present main diagnostic features. NPV detection and quantification represent a key information in applications regarding conservative agriculture, and, more recently, carbon farming because of its role in water, nutrient and carbon cycling. For this reason, its estimation and mapping represent an important subject for RS studies

Early studies already proved the potential of PRISMA in NPV studies exploiting either hybrid approaches able to train machine leaning regression algorithm (MLRA) on the base of radiative transfer model (RTM) simulations (Berger et al. 2021. Remote Sens., 13(22)), and spectroscopic approaches able to model and characterize with Exponential Gaussian Optimization (EGO) specific absorption features (Pepe et al. 2020. Remote Sens., 12). This second technique is also proposed in this study for the quantification of crop residue cover (CRC) starting from in situ data, used to train a knowledge-based data driven statistical model to be applied on aerial AVIRIS – NG and satellite PRISMA data.

The study exploits an extensive and well documented spectral library consisting of 916 in situ surface reflectance spectra (400 to 2400 nm) and metadata on corresponding agricultural field conditions; this dataset, made available online (Hively, et al. 2021. Remote Sens. 13(18); U.S. Geological Survey Data Release), was analyzed to infer a predictive relationship for the quantification of CRC starting from NBH data. Gaussian surface reflectance without simulated residual atmospheric effects and sensor noise, resampled at 10nm (“gaussian original” dataset), were used for modelling the well-known ligno-cellulose absorption feature at 2100nm by EGO (Pompilio et al. 2009. Icarus, 201). Among the exponential gaussian model parameters the band depth (s) shows a clear and strong regression with CRC values, which is almost linear.

The obtained regression model was initially validated using on ground reflectance spectra collected during a field campaign (June 2021) in the context of the CHIME Mission Requirement Consolidation Study over the Jolanda di Savoia (Italy) farm test site (3800ha with different croplands). Here, ground reflectance spectra, AVIRIS-NG EU airborne and PRISMA data were acquired together with field CRC observations. Next, the regression was also adapted to AVIRIS-NG and PRISMA spectral bands by resampling the original USGS spectra. The obtained models returned approximately the same correlation parameters and comparable RSME values for both sensors, confirming the consistency of the relationship. Later the regression model was applied for CRC mapping to AVIRIS image data (Ground Sampling Distance of 5.5m) and validated against field observations; results on the prediction capabilities seem encouraging. Further analysis will encompass the evaluation of performances obtained by applying the PRISMA-Like model to actual PRISMA data and by performing intercomparison analysis with AVIRIS maps to evaluate the CRC prediction performances at the different levels.

1-3B SPECSESS SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

AIRBORNE IMAGING SPECTROSCOPY FOR ASSESSING LAND-USE EFFECT ON SOIL QUALITY IN DRYLAND

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Abstract

Global population growth has resulted in land-use (LU) changes in many natural ecosystems, causing deterioration in the environmental conditions that affect soil quality. The effect of LU on soil quality is acute in water-limited systems that are characterized by insufficient availability of soil organic resources. Thus, the main objective of this study was to assess the effects of human activities (i.e., land-use as grazing, modern agriculture, and runoff harvesting system) on soil quality using imaging spectroscopy (IS) in the arid regions of Israel. For this, 12 physical, biological, and chemical soil properties were selected and further integrated into the soil quality index (SQI) as a method to assess the significant effects of LU changes in an arid area in southern Israel. A flight campaign of the AisaFENIX hyperspectral airborne sensor was used to develop an IS prediction model for the SQI on a regional scale. The spectral signatures, extracted from the hyperspectral image itself, were well separable among the four LUs using the partial least squares-discriminant analysis (PLS-DA) classification method (OA = 95.31%, Kc = 0.90). The correlation was performed using multivariate support vector machine-regression (SVM-R) models between the spectral data and the measured soil indicators and the overall SQI. The SVM-R models were significantly correlated for several soil properties, including the overall SQI (R2adjVal = 0.87), with the successful prediction of the regional SQI mapping (R2adjPred = 0.78). Seven individual soil properties, including fractional sand and clay, SOM, pH, EC, SAR, and P, were successfully used for developing prediction maps. Applying IS, and statistically integrative methods for comprehensive soil quality assessments enhances the prediction accuracy for monitoring soil health and evaluating degradation processes in arid environments. This study establishes a precise tool for sustainable and efficient land management and could be an example for future potential IS earth-observing space missions for soil quality assessment studies and applications.

1-3B SPECSESS SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

SYNERGIES OF VNIR-SWIR AND LWIR HYPERSPECTRAL REMOTE SENSING DATA FOR SOIL PROPERTY MAPPING IN AN AGRICULTURAL LANDSCAPE OF NORTHERN GREECE

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Abstract

Monitoring the soil status is in great demand for environmental applications and agricultural to adjust practices such as tillage, fertilization, and irrigation. Critical soil properties, such as texture and organic and inorganic carbon content, provides farmers with the information to detect soil vulnerable to soil erosion and land degradation in its early stages in order to locally intervene and to assess soil fertility. Hyperspectral remote sensing has proven to be a powerful method for the quantitative prediction of top-soil properties. However, remote sensing observations of the traditionally used visible-near infrared (VNIR) and shortwave infrared (SWIR) wavelength regions (0.4-2.5 µm) can be limited for the estimation of coarse texture soils due to the lack of distinct spectral characteristics of these properties in the VNIR-SWIR (e.g., sand content, quartz and feldspar mineralogy). Spectral information from the longwave infrared region (LWIR, 8-12 µm) has the potential to improve the determination of these properties, due to the presence of fundamental vibration modes of silicate and carbonate minerals, as well carbon-hydrogen bonds in this spectral range. Given the recent technological advances in high spectral resolution airborne sensors operating in the LWIR range, there is a growing interest in applying this technology in environmental research and soil monitoring.

The main objective of this work is to evaluate the synergies in combining VNIR-SWIR and LWIR hyperspectral data for estimating soil properties, focusing on soil organic matter, texture, and mineralogical composition. As part of an EnMAP GFZ/FU airborne campaign, an extensive aerial survey with the HySpex VNIR-SWIR and Hyper-Cam LWIR cameras mounted on a Cessna aircraft and simultaneous soil sampling took place in September 2019 within the Amyntaio region, in Northern Greece. The region is mainly auricularly used with diverse cultivations of alfalfa, winter wheat, corn and sunflower crops. Soils in the study area have highly variable top soil composition ranging from silicate to carbonate rich mineralogy, loamy to clay texture and to organic carbon rich fields around a lignite mine in the south-east of the area. Topsoil properties are estimated based on the combined VNIR-SWIR-LWIR airborne dataset using different statistical and machine learning methods such as Partial Least Square, Random Forest, Cubist and Support Vector Regression, as well as different spectral pre-treatments for data smoothing and normalisation. First results show significant increase in the model accuracies, specifically for soil organic matter and carbonate content, after including information from LWIR spectral range. A further goal of this study is the simulation and validation of the soil products with recent relevant satellite sensors (e.g., EnMAP, PRISMA, ECOSTRESS), as well as upcoming next generation of hyperspectral optical and thermal multispectral satellite missions (ESA CHIME and LSTM, NASA/JPL SBG) to evaluate their potential for quantitative soil properties mapping on larger scales.

1-3B SPECSESS SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

CHARACTERIZING SOIL SURFACE COVERS WITHIN ICE-FREE AREAS OF THE NORTHERN ANTARCTIC PENINSULA REGION USING REFLECTANCE SPECTROSCOPY

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Abstract

Terrestrial land of ice-free areas in the northern Antarctic Peninsula region represents less than 3% of the total land surface area. As a result of climate change and subsequent warming, the seasonally-exposed terrestrial area of the mentioned region is expected to expand up to three times its current size by 2100. The retreat of permanent ice cover will provide new habitats for flora and fauna to colonize and form bigger extensions by coalescing some areas that are currently isolated due to glaciers and permanent snowfields. It is therefore of great interest and importance to characterize the different soil surface covers to study the evolution of the ice-free areas. For this purpose, reflectance spectroscopy is a powerful technique for the determination and modelling of indicators associated to soil and sediment surfaces that are related to periglacial, glacial and fluvial processes. The advantages of this technique are that measurements are rapid and do not need an exhaustive preparation compared with other conventional methods of soil, sediment and surface analyses. The study area is Fildes Peninsula, located in the southwestern part of King George Island (approx. 62° 11′ S–58° 58′ W), in the South Shetland Islands, Western Antarctica. The peninsula has an extension of approximately 29 km2 and is limited by the Collins Glacier to the NNE. The ice-free area accounts for the most extensive snow-free coastal area in the austral summer on King George Island, most of which is permanently covered by ice.

The objective of this work was: 1) to compile a site specific spectral library for representative terrestrial soil surface covers for Fildes Peninsula on King George Island; and 2) determine indicators of specific surface cover properties and indexes that determine the different stages of development within the ice-free areas and form the basis for monitoring environmental changes. Soil samples were obtained from 25 different locations during the field campaigns of 2013 and 2017, air dried and 2 mm sieved. Chemical and physical soil analysis included pH, electrical conductivity, free iron oxide content, organic matter content, total carbon and nitrogen content, available phosphorous content, cation exchange capacity and mineralogy. Spectral laboratory measurements were obtained for the visible, near-infrared and shortwave infrared (400–2500 nm) range using a spectroradiometer (ASD FieldSpec3). This has resulted in a site-specific spectral library with samples distributed throughout the peninsula representing areas affected by periglacial and glacial processes, including elevated marine platforms, patterned ground areas and glacial deposits. Partial least-squares regression was used to model the different soil properties and reflectance measurements. The models were validated using leave-one-out cross validation and best results were obtained applying reflectance or transformed absorbance data for free iron oxide, clay minerals such as smectites, and total carbon reaching R2 values in the range of 0.72 to 0.8. Further acceptable prediction models were obtained for clay texture, organic matter content and cation exchange capacity with an R2 in the range of 0.6 to 0.7. Using first and second derivatives of absorbance data further improved the significant number of predictors that determine the regression coefficients and with fewer latent vectors the prediction models have a better signal-to-noise ratio. Geomorphological stability and environmental conditions allow a moderate evolution of the surface covers and these parameters are indicators of terrain stability where sediment and soil processes have developed over time and are not affected by degradation processes. In ice-free areas, this is indicative when glacier forefronts are retreating and leave newly exposed areas.

1-3B SPECSESS SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

MULTI-TEMPORAL ESTIMATION OF SOIL PROPERTIES FROM HYPERSPECTRAL PRISMA AND MULTISPECTRAL SENTINEL-2 DATA

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Abstract

An increasing demand for spatio-temporal coverage of soil information drives the rising use of soil imaging spectroscopy. Due to the influence of soil moisture, vegetation cover, and crop residues, the ideal temporal window for bare soil data acquisition in an agricultural domain is limited. This constraint leads to an emerging need for involving multi-temporal satellite remote sensing, to optimize the relationship between soil spectra and soil attributes. In this regard, this work explores the use of multi-temporal PRISMA hyperspectral images to estimate bare soil properties (calcium carbonate, organic carbon, clay, and sand) in comparison with Sentinel-2 data.

To demonstrate the role of the multi-temporal hyperspectral imagery for soil properties mapping, topsoil samples were collected in three experimental areas located at Northern (Jolanda), Central (Maccarese), and Southern (Pignola) Italy. A pixel based multi-temporal approach was developed to select bare soil pixels along a satellite time series of three years (2019 - 2021) for both PRISMA and Sentinel-2 data. Twenty-six cloud-free images (thirteen images over Jolanda, eight images over Maccarese and five images over Pignola) images were processed for both satellite missions. The satellite multi-temporal approach consists of a filtering process for each acquired image, to detect and exclude cloudy pixels, green and dry vegetation, so keeping only bare soil pixels. The remaining pixels were further elaborated to retrieve a single spectral data for each pixel by computing the median reflectance value for each band or selecting the acquisition date as close as possible to dry soil condition. After that, machine learning estimation models were built starting from soil samples collected in the different fields and by using the satellite spectral data obtained by the multi-temporal approach. To reduce the noise of the PRISMA data and enhance the spectral features related to soil properties, the Savitzy–Golay filter (SG) spectral pre-treatment was applied.

The results of the preliminary study over Maccarese and Pignola farms revealed, on one hand, that the multi-temporal approach allows to improve the accuracy of soil properties estimation as compared to a single image approach, and on the other hand, that the high spectral resolution of the hyperspectral sensor permits to get better results than those obtained from the multispectral imager. Indeed, the multi-temporal PRISMA imagery data provided the best Ratio of the Performance to Deviation (RPD) and Ratio of Performance to Inter-Quartile distance (RPIQ) for clay (respectively 2.32 and 2.61), sand (2.63 and 3.11), organic carbon (1.35 and 1.40), and calcium carbonate (3.94 and 2.50) estimation.

This research assesses the ability and usefulness of the hyperspectral sensor PRISMA to predict and map bare soil properties from multi-year imagery in Italian farmlands. We conclude that time-series of hyperspectral remote sensing data can provide valuable information for the mapping and monitoring of soil components as compared to the currently available multispectral imagers.

1-3B SPECSESS SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

ESTIMATION OF WATER INFILTRATION RATE IN MEDITERRANEAN SOILS USING AIRBORNE HYPERSPECTRAL SENSORS

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Abstract

A critical hydrological soil attribute is the water infiltration rate (WIR) to the soil profile due to its effect on the runoff regime, leaching, soil erosion, and water availability for both plants and groundwater.

Whereas the topography is a regional parameter that affects the WIR mainly due to the slope and landscape conditions, the WIR is highly affected by soil moisture, organic matter (OM) content, soil mineralogy, soil texture, and soil sealing. Amongst these factors, the WIR is highly affected by the interface between the atmosphere and the pedosphere that is controlled by the soil seal condition that is evolving from raindrop energy (known as physical crust), from biological substances (known as biogenic crust), and from mineral alteration (known as fire-driven crust). Negative effects (low WIR) are due to hydrophobic organic substances and fine particles of soil minerals that transport to the soil surface. Positive effects (high WIR) are due to stabilization of the soil aggregation processes that increase the water permeability to the soil and are a result of the interaction between cementation agents at the soil (such as OM, soil texture, and minerals).

Assessing the WIR level in advance and under high and wide spatial coverage may help farmers to reduce soil water runoff and soil erosion process by applying wise agrotechnical practices (e.g. no-till). In this study, we first apply a proof-of-concept (POC) activity to demonstrate that the WIR can be estimated via proximal spectral sensing on a pixel-by-pixel basis using airborne hyperspectral data.

This first exercise used unmanned aerial vehicles (UAV) across the VIS-NIR region with a hyperspectral sensor (Cubert). The results showed that the WIR can be mapped in a clayey agriculture field in Southern Italy with very reasonable accuracy (R2=0.76).

The second experiment of this study was to apply a similar methodology on sandy soils exploiting the entire VIS-NIR-SWIR spectral region data acquired from a hyperspectral airborne sensor (Hyspex) in Northern Greece. The WIR maps that were generated from both exercises in several agriculture fields from Italy and Greece were validated on the ground level yielding reasonable results (R2=0.59).

The success to exploit the hyperspectral technology for soil practices as shown in this study goes beyond the traditional soil attributes assessment from reflectance spectroscopy. This study is thus paving the way for more innovative ideas in soil remote sensing practices using spectral information, especially on the field domain.

1-3B SPECSESS SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

QUANTIFICATION AND VARIABILITY ANALYSIS OF FOREST CARBON TO NITROGEN RATIO IN DIFFERENT SOIL HORIZONS USING SPECTROSCOPY: A NATIONAL-SCALE STUDY

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Abstract

Forest soils have large contents of carbon (C) and nitrogen (N), which have significant spatial variability laterally across landscapes and vertically with depth due to decomposition, erosion and leaching. Therefore, the ratio of C to N contents (C:N), which is a crucial indicator of soil quality and health is also different depending on soil horizon. These attributes can cost-effectively and rapidly be estimated using visible–near infrared–shortwave infrared (VNIR–SWIR) spectroscopy; however, the effect of different soil layers, particularly over large scales of highly heterogeneous forest soils, on performance of the technique has rarely been attempted. The current study evaluated the potential of VNIR–SWIR spectroscopy in quantification and variability analysis of C:N in soils collected from different organic and mineral layers of forested sites of the whole Czech Republic. At each site, we collected five samples from the litter (L), fragmented (F) and Humus (H) organic layers, and also from the A1 (depth of 2–10 cm) and A2 (depth of 10–40 cm) mineral layers to provide a total of 2505 soil samples. Support vector machine regression (SVMR) with radial basis kernel was used to train the prediction models of the selected attributes at each individual soil layer and the merged layer (profile). We then further produced the spatial distribution maps of C:N as the target attribute at each soil layer. Results showed that the prediction accuracy based on the profile spectral data was adequate for all attributes. In addition, F was the most accurately predicted layer, regardless of the soil attribute. C:N models and maps in the organic layers performed well although in mineral layers, models were poor and maps were reliable only in areas with low and moderate levels of C:N. On the other hand, the study indicated that VNIR–SWIR spectroscopy could efficiently predict and map organic layers of the forested sites in the Czech Republic but in mineral layers, it didn't differentiate classes of C:N higher than 50.

1-3C SPECSESS WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING HYPERSPECTRAL DATA - PART 1

LESSONS LEARNED AND RECENT ADVANCES TOWARDS HYPERSPECTRAL AQUATIC REMOTE SENSING

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Abstract

Hyperspectral remote sensing shows great potential for investigating aquatic ecosystems. Over the past two decades several hyperspectral spaceborne imagers with applications to coastal and inland waters were successfully launched as Hyperion, the Compact High Resolution Imaging Spectrometer (CHRIS), Hyperspectral Imager for the Coastal Ocean (HICO), PRecursore IperSpettrale della Missione Applicativa (PRISMA) and Deutsches Zentrum fur Luft–und Raumfahrt German Aerospace Center (DLR) Earth Sensing Imaging Spectrometer (DESIS). However, except for HICO, these missions were designed for land applications. Unlike the land surfaces, the water surfaces are dark in most cases, so the signal leaving out the water is only a small fraction of the total signal measured by the sensor. This requires dedicated instruments with enough signal to noise and large dynamic ranges (Dekker et al. 2018, Dierssen et al. 2021). Aquatic ecosystems are also highly dynamic demanding imaging sensors with frequent revisit time and high spatial resolution. These mission requirements for investigating aquatic ecosystems are challenging and can hardly be achieved by a unique mission, reinforcing the need to combine synergistically data provided by the different missions. Looking forward, the remote sensing over coastal and inland waters is developing rapidly and it is entering a new era with the launch of hyperspectral sensors DESIS and PRISMA as well as the upcoming Environmental Mapping and Analysis Program (EnMAP), Plankton AErosol Cloud and ocean Ecosystem (PACE), and Surface Biology and Geology (SBG). In this study, we give an overview on the lessons learned and recent advances towards hyperspectral aquatic remote sensing. We present a brief overview of the past, current and upcoming missions, focusing on knowledge gain on aquatic ecosystems, critical needs for further development (e.g. in situ hyperspectral measurements) and challenges of the scientific community and users (e.g large datasets). Following that lead, we show results on the evaluation of Polymer Atmospheric Correction (Steinmetz et al. 2011) applied to Level 1 data of the DESIS, PRISMA and Sentinel-2 MultiSpectral Instrument (S2-MSI) over coastal and inland waters. We have observed an improvement in the discrimination of water quality parameters in optically complex waters as well as the correct flagging of pixels by Polymer. Polymer Atmospheric Correction can be applied to EnMAP data using the EnMAP-Box and EnMAP processing tool (EnPT).

1-3C SPECSESS WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING HYPERSPECTRAL DATA - PART 1

EXPLORING PRISMA DATA FOR CHLOROPHYLL-A RETRIEVAL THROUGH HYPERSPECTRAL NDCI

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Abstract

The Normalized Difference Chlorophyll Index (NDCI) is one of the most widespread semi-empirical algorithms for monitoring phytoplankton's Chlorophyll-a (chla) concentration through orbital remote sensing data. Originally, the NDCI aimed the bands centered at 665 nm (chla absorption feature) and 708 nm (algae cell scattering peak) from the MERIS sensor. Therefore, this study evaluates other combinations of red and near-infrared (NIR) bands for retrieving chla concentration taking advantage of the PRISMA hyperspectral configuration. Data collected from a highly eutrophic urban reservoir in Brazil was used as a study case. The in situ dataset comprises 129 samples of Remote Sensing Reflectance (Rrs) ranging from 400-900 nm (1 nm resolution), where 118 have Rrs and concomitant chla measures (4.54-906.15 ug/L). Twenty-four radiometric samples were acquired in matchup condition with PRISMA (± 3 hours), 13 of them with chla concentrations between 15.37 and 196.91 ug/L. First, the Rrs were simulated for PRISMA bands using its spectral response function. Then, as the L2D product presented some georeferencing mismatching over the region of interest, the L2C image was georeferenced using ground control points selected over a Sentinel-2/MSI image. The Mean Absolute Error (MAE) and Bias, between the in situ and satellite data, were calculated for the evaluated spectral range (632-877 nm) to assess the atmospherically corrected PRISMA product. The mean angular difference was also estimated using the Spectral Angle Mapper. The assessed image had a MAE of 1.59 (59% of mean error) and a Bias of 1.44 (44% of overestimation tendency). The results indicated a good agreement among the spectral shapes with a mean angular difference of 0.30 radians. To assess NDCI estimation, seven red bands (632-689 nm) and 18 NIR bands (699-877 nm) were selected, resulting in 127 combinations. The correlation between each NDCI, calculated with the Rrs simulated bands, and chla were compared using the Spearman coefficient. The Exponential (Exp) and Quadratic Polynomial (QP) fits were evaluated for the ten top-scored indexes (Spearman from ~0.9) through Monte Carlo Simulation with 10,000 iterations. The dataset was randomly divided into 80% for train and 20% for test using MAE to assess the results for each set. The Exp fits had lower median MAE values than QP for all indexes. The three combinations with better performance in the median MAE (699/689, 709/689, and 699/660) and the original NCDI (709/660) were selected from the Exp results to perform the subsequent evaluations. To NDCI validation, the matchups (N=13) were separated from the rest of the field dataset (N=105) used to calibrate an Exp curve for each of the four selected NDCI arrangements. NDCI calculated from both image and field radiometry were used to derivate chla concentrations from the fitted equations. The results were compared with the measured chla concentration through MAE and Bias. The best accuracy metrics for field radiometry were provided by the 709/689 combination, with a MAE of 1.15 and a Bias of 1.03. The red band at 689 nm contains the chla's fluorescence spectral feature, centered at 685 nm. The sensitivity of the newly derived NDCI to the fluorescence signal might explain the obtained accuracy metrics. However, when the satellite derived reflectance was used, the original NDCI overperformed the 709/689 index. The 709/660 NDCI had a MAE of 1.41 and a Bias of 1.20, whereas the 709/689 metrics were 1.55 and 0.75, respectively. This study demonstrates the potential of using orbital hyperspectral imagery for mapping chla on inland waters.

1-3C SPECSESS WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING HYPERSPECTRAL DATA - PART 1

COMPARISON OF COINCIDENT HYPERSPECTRAL DATA FROM SATELLITE, AIRBORNE AND FIELDWORKS FOR RETRIEVING WATER QUALITY PARAMETERS IN LAKE TRASIMENO

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Abstract

Nowadays, anthropogenic development and increasingly aggressive climate change phenomena are seriously affecting the stability of the world's ecosystems, especially aquatic systems. In this context, there is an increasing use of remote sensing techniques because thanks to the characteristics of satellite acquisitions, such as synoptic view and revisit time, it is possible to monitor the spatio-temporal dynamics of aquatic processes, which are usually highly variable in time and space (e.g., Tyler et al. 2016 Science of the Tot. Env., 572). In particular, the use of hyperspectral remote sensing provides measurements across several discrete narrow bands, forming a contiguous spectrum that allows the detection and identification of improved biophysical properties of the water column and bottom (e.g., Giardino et al. 2019 Surv Geophys, 40). This study focused on the analysis of hyperspectral images of Lake Trasimeno (a turbid shallow lake in central Italy) provided by PRISMA and DESIS sensors in early June 2021. In this period, a rich dataset was available for the comparison, with airborne, satellite and in-situ data characterized by different spectral and spatial resolutions: AVIRIS-NG hyperspectral data, 5 m pixels (acquired on June 4th); PRISMA and DESIS data, 30 m pixels (June 3rd and June 4th respectively); Sentinel-2 (S2) and Sentinel-3 (OLCI) multispectral data, respectively resampled at 10 m and 300 m pixels (June 4th and June 3rd); in-situ hyperspectral data from the WISPStation permanent measurement station and an ad-hoc radiometric and limnological campaign (June 4th). This dataset allowed us to assess the quality of products in terms of Remote sensing reflectance (Rrs) as well as the developing and testing of algorithms for retrieving water quality parameters. To perform the comparison in terms of Rrs, PRISMA and DESIS images were processed by using the atmospheric correction scheme implemented in the ATCOR software; moreover, because a run of AVIRIS-NG was affected by sunglint, empirical methods for its removal were tested. PRISMA and DESIS spectra were comparable to AVIRIS-NG, S2, OLCI and in-situ observations and hence promising and encouraging a synergic use of imaging spectroscopy with the existing multispectral missions. Given the good match of Rrs spectra for the entire data sources and given the availability of in-situ measurements of water quality parameters - as well as radiometric measurements - the next step of the study is the generation of water quality products by testing different algorithms made available by the scientific community such as those based on bio-optical model (e.g., BOMBER, Giardino et al. 2012 Comput. Geosci., 45) having the knowledge of the Specific Inherent Optical Properties (IOPs) of the area of interest. Notably, with hyperspectral data there is the possibility to overcome the problem that band ratio algorithms are generally very sensitive to reflectance variability due to the influences of other water constituents, natural variability of IOPs and errors in atmospheric correction (Sterckx et al. 2007 Marine Geodesy, 30). This is done through the use of adaptive algorithms: the advantage of applying these algorithms to a hyperspectral image is that of not using the value of a single band in the equation, but rather, having different bands available in that spectral range, to search for the real maximum and minimum values by means of an algorithm. Once the water quality maps are generated by PRISMA, DESIS and AVIRIS-NG products, a comparison will be made with both in-situ measurements and products obtained from S2 and OLCI data which are already widely used for aquatic application.

1-3C SPECSESS WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING HYPERSPECTRAL DATA - PART 1

USING IMAGING SPECTROSCOPY TO RETRIEVE SUSPENDED SEDIMENT PROPERTIES IN A NEARSHORE COASTAL ESTUARY

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Abstract

Existing multispectral approaches for analyzing ocean color imagery have long allowed for the estimation of suspended sediment concentration across large areas and at high spatial resolution. In many areas, multispectral approaches and quantification of suspended sediment concentration alone do not fully characterize suspended sediment in the nearshore coastal ocean, as particles from various mineral and algal sources occur across a wide range of sizes, densities, and chemical compositions. These properties influence sedimentation rates, biogeochemical cycling, and the fate of suspended particles in the coastal ocean. Imaging spectroscopy offers the potential to differentiate particle types and infer other characteristics including size distribution in optically complex coastal waters, by resolving subtle spectral shifts in reflectance associated with particle properties. As part of the NASA EVS-3 Delta-X campaign, we collected field measurements simultaneously with airborne imaging spectroscopy. These field measurements included hyperspectral remote-sensing reflectance (Rrs) by an above-water approach, total suspended sediment (TSS) concentration, turbidity, particle absorption spectra (ap, aphi , ad), particle grain size distribution (Sequoia Scientific LISST-200X), and particulate organic carbon concentration (POC) at more than 150 stations across contrasting estuarine waters in the Mississippi River Delta in Louisiana, USA. Contemporaneous in-situ Rrs observations were also used to validate airborne imaging spectroscopy (5 m spatial sampling and 5 nm spectral sampling from 380-2510 nm) from the NASA Airborne Visible-InfraRed Imaging Spectrometer – Next Generation (AVIRIS-NG) and aid in atmospheric correction. Field data were used to develop algorithms for retrieving suspended particle properties, and these algorithms were then applied to AVIRIS-NG imagery to map variability in particle properties between contrasting basins dominated by stable and rapidly eroding coastal marshes and across seasons. New capabilities for retrieving suspended particle properties from imaging spectroscopy are particularly exciting in the context of a new generation of ocean-viewing imagers including the PACE, DESIS, PRISMA, EnMAP, and GLIMR missions, as these sensors are expected to provide unprecedented imagery of nearshore coastal systems, creating opportunities to better quantify sediment and organic carbon fluxes, monitor water quality, and assess the vulnerability of coastal ecosystems.

1-3C SPECSESS WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING

RETRIEVALS OF THE MAIN PHYTOPLANKTON GROUPS AT LAKE CONSTANCE USING OLCI AND EVALUATED WITH FIELD OBSERVATIONS

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Abstract

Phytoplankton plays an important role in the aquatic biogeochemical cycling such as for the formation of organic matter by photosynthetic processes through the fixation of carbon dioxide, and assimilation of macro- and micronutrients depending on their metabolic needs. These processes are common to all phytoplankton, however some phytoplankton groups have specific needs and thus play different functional roles in the biogeochemical cycle, which are used to classify phytoplankton into different phytoplankton functional types (PFTs). Information on the phytoplankton groups can be obtained from satellite observations such as the Ocean and Land Colour Instrument (OLCI) onboard of Sentinel-3. PFTs global ocean abundance can be estimated based on the OC-PFT algorithm (Hirata et al. 2011 and related updates to it) which is based on the assumption that a marker pigment for a specific PFT varies in dependence to the chlorophyll-a concentration. In this study, OC-PFT retrieval has been developed and adapted for estimation of PFT from Lake Constance by using a large collection of in-situ HPLC data set measured since 2000 at the largest German inland water by the regional authority and further analysed to derive PFT using the diagnostic pigment analysis following Vidussi et al. (2001) with adapted coefficients for Lake Constance. The PFT retrieved from OLCI are validated using independent in situ data derived from HPLC pigment measurements from 4 field campaigns performed in 2019 and 2020 at Lake Constance. Concentrations for five phytoplankton groups (diatoms, dinoflagellates, cryptophytes, green algae, and prokaryotes) are retrieved for Lake Constance, being the dominants diatoms and cryptophytes and at lesser degree green algae. In addition, evaluation of synergistic PFT products are presented to enlarge the capabilities of PFT data in inland and coastal waters analytically retrieved from high spectral and high spatial data such as DESIS, EnMAP or PRISMA by synergistic use with OLCI OC-PFT data sets is discussed.

1-4A SPECSESS VEGTRAITS: QUANTIFYING PRIORITY VEGETATION TRAITS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA - PART 2

CUTTING OUT THE MIDDLEMAN: CALIBRATING AND VALIDATING AN ECOSYSTEM MODEL USING REMOTELY SENSED SURFACE REFLECTANCE

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Abstract

Canopy radiative transfer is the primary mechanism by which models relate vegetation composition and state to the surface energy balance, which is important to light- and temperature-sensitive plant processes as well as understanding land–atmosphere feedbacks. In addition, certain parameters (e.g., specific leaf area, SLA) that have an outsized influence on vegetation model behavior can be constrained by observations of shortwave reflectance, thus reducing model predictive uncertainty. Importantly, calibrating against radiative transfer outputs allows models to directly use remote sensing reflectance products without relying on highly derived products (such as MODIS leaf area index) whose assumptions may be incompatible with the target vegetation model and whose uncertainties are usually not well quantified. Here, we created the EDR model by coupling the two-stream representation of canopy radiative transfer in the Ecosystem Demography model version 2 (ED2) with a leaf radiative transfer model (PROSPECT-5) and a simple soil reflectance model to predict full-range, high-spectral-resolution surface reflectance that is dependent on the underlying ED2 model state. We then calibrated this model against estimates of hemispherical reflectance (corrected for directional effects) from the NASA Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and survey data from 54 temperate forest plots in the northeastern United States. The calibration significantly reduced uncertainty in model parameters related to leaf biochemistry and morphology and canopy structure for five plant functional types. Using a single common set of parameters across all sites, the calibrated model was able to accurately reproduce surface reflectance for sites with highly varied forest composition and structure. However, the calibrated model's predictions of leaf area index (LAI) were less robust, capturing only 46 % of the variability in the observations. Comparing the ED2 radiative transfer model with another two-stream soil–leaf–canopy radiative transfer model commonly used in remote sensing studies (PRO4SAIL) illustrated structural errors in the ED2 representation of direct radiation backscatter that resulted in systematic underestimation of reflectance. In addition, we also highlight that, to directly compare with a two-stream radiative transfer model like EDR, we had to perform an additional processing step to convert the directional reflectance estimates of AVIRIS to hemispherical reflectance (also known as “albedo”). In future work, we recommend that vegetation models add the capability to predict directional reflectance, to allow them to more directly assimilate a wide range of airborne and satellite reflectance products. We ultimately conclude that despite these challenges, using dynamic vegetation models to predict surface reflectance is a promising avenue for model calibration and validation using remote sensing data.

1-4A SPECSESS VEGTRAITS: QUANTIFYING PRIORITY VEGETATION TRAITS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA - PART 2

ESTIMATION OF WINTER WHEAT YIELD USING TIME SERIES OF AIRBORNE HYPERSPECTRAL DATA

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Abstract

Wheat (Triticum spp.) is one the most important cereals produced worldwide, as well as in Europe. Accurate and timely assessment of crop yields and its spatial variability within a field can help to optimise fertilisation application and water management. The main objective was to evaluate airborne hyperspectral data from three consecutive growth seasons for prediction of winter wheat yields. We aimed to evaluate different machine learning methods and contribution of acquisition days.

For this study we selected two sites that are part of the Czech Republic long-term crop rotation experiment: Ivanovice (49°18’40’’N, 17°05’45’’E, 225 m.a.s.l) and Lukavec (49°33’23’’N, 14°58’39”E, 620 m.a.s.l). At both sites, the same fertilisation experiment design was applied on winter wheat plots (12 combinations of organic and mineral fertilisation in four replicas, 48 subplots in total). The average yield per subplot varied between 2.25 and 10.01 t/ha. The average yield was 5.4 t/ha in 2019, 7.5 t/ha in 2020 and 7.3 t/ha in 2021. Yields at Ivanovice were generally higher (4.55 – 10.01 t/ha), which is likely due to a lower elevation than at Lukavec (2.25 – 9.10 t/ha).

Airborne hyperspectral data were acquired several times during three consecutive vegetation seasons: 2019 (5 acquisitions for Ivanovice and 3 acquisitions for Lukavec), 2020 (6 acquisitions at both sites) and 2021 (4 acquisitions for Ivanovice and 3 acquisitions for Lukavec) using CASI and SASI spectroradiometers (Itres, Canada) on board Flying Laboratory of Imaging Systems (https://olc.czechglobe.cz/en/flis-2/). For this study we evaluated only the visible and near infrared CASI data with 48 bands between 383 and 1053 nm with the spectral step of 14.25 nm and the spatial resolution was 0.5 m. The images were corrected for radiometric, geometric and atmospheric effects. Average spectral signatures were extracted for each wheat subplot (5 x 5 m) for each image acquisition.

Yields were estimated from the spectral data using machine learning methods available in the ARTMO toolbox. Data were divided into two parts, 70% of the data were used for model training and 30% for validation.

A pooled model, when all acquisitions dates were combined together provided promising results. We tested five machine learning methods, namely canonical correlation forests (CCF), gaussian processes regression (GPR), support vector regression (SVR), least square linear regression (LSLR) and partial least square regression (PLSR). All methods provided similar results reaching $R2 > 0.8$ and $RMSE < 0.67$ t/ha. In the validation process the GPR outperformed other tested methods (R2 = 0.82, RMSE = 0,57 t/ha). A GPR model that combined only the acquisitions from the end of April and beginning of May suggested that wheat yield could be accurately estimated with R2 = 0.89 and RMSE = 0.55. Those promising results from experimental plots, however, should be further verified across the years and other localities from the long-term experiment. Consequently, the best model should be tested at a larger scale in real production conditions of a farm.

1-4A SPECSESS VEGTRAITS: QUANTIFYING PRIORITY VEGETATION TRAITS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA - PART 2

DETECTING SPATIAL PATTERNS OF CHANGE IN VEGETATION CONDITION INSIDE BAVARIAN FOREST NATIONAL PARK USING MULTI- AND HYPERSPECTRAL SPACEBORNE DATASETS

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Abstract

Forests are an integral part of the natural ecosystem and are beneficial to humankind in many ways. Natural disturbances, both biotic (insects and pathogens) as well as abiotic (wildfire, drought, windthrow) are key processes in temperate forest ecosystems. Recent increases in both disturbance severity and frequency have been observed around the globe. Nowadays, numerous forest health monitoring studies implementing remote sensing datasets for assessing biophysical and biochemical properties of vegetation species are widely used. The purpose of this study is to monitor changes in vegetation condition inside the Bavarian Forest National Park (BFNP) which are mostly induced by outbreaks of the European Spruce Bark Beetle. For this purpose, a novel hyperspectral dataset the DLR Earth Sensing Imaging Spectrometer (DESIS) along with Sentinel-2 Multispectral (S2 MSI) time-series are used.

In this study, the DESIS data with a spectral sampling distance of 2.55nm and a measured wavelength ranging from 400-1000nm is compared with S2 MSI datasets having a finer spatial and temporal resolution, in order to evaluate the potential to use both sensors in combination for monitoring the forest condition. This study aims to develop an integrated approach by examining spatial-temporal patterns and spectral properties using Vegetation Indices (VIs) to identify healthy vs stressed vegetation. Computation of several VIs enables to analyze the spatial patterns of change in vegetation happening seasonally inside the BFNP. Detailed analysis on the relationship between the higher spectral resolution of DESIS and S2 data, their different temporal resolution, and the resulting possibilities to use both systems in combination for monitoring forest health are exploited. This work was conducted in the frame of the Data Pool Initiative for the Bohemian Forest Ecosystem.

Since only coniferous forests are affected by the European Spruce Bark Beetle and exhibit less seasonal changes than deciduous forests, only these are considered in the analysis. Seasonal variation in conifers from 2017 to 2021 are estimated for S2 MSI using a vegetation vitality index called Combined Vegetation Index (CVI). In addition, narrow-band indices are estimated for multi-annual DESIS data between 2019 and 2021 to determine a suitable spectral index to identify changes in vegetation conditions. Finally, the results are validated in correspondence with in-situ field observations of deadwood areas.

The results show that mean CVI from the S2 time-series shows subtle changes when observed seasonally and narrow-band VIs from DESIS match with in-situ collected infested areas. Few narrow-band VIs, especially chlorophyll indices focusing on the red-edge range like Modified Chlorophyll Absorption Ratio Index (MCARI), perform well. MCARI and S2 CVI -when checked for accuracy- show an overall accuracy of 81% and 20% when compared to the reference data. The detection rate for the “change class” in MCARI increased from 18% to 70% when applying a buffer of 1 pixel and using a morphological clump operator and for CVI clump class accuracy increased to 86%. The study also concludes that S2 results can be reliable if there are more consistent cloud-free acquisitions available to map vegetation changes seasonally. Also, DESIS provides high-quality spectral input data which is found suitable for mapping inter-annual changes in vegetation condition.

1-4A SPECSESS VEGTRAITS: QUANTIFYING PRIORITY VEGETATION TRAITS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA - PART 2

RETRIEVAL OF CARBON CONTENT AND BIOMASS FROM HYPERSPECTRAL IMAGERY OVER CULTIVATED AREAS

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Abstract

Spaceborne satellite imaging spectroscopy for terrestrial applications constitutes a highly promising data source for diverse agricultural disciplines, requiring the retrieval of essential crop properties. We are approaching a new era of innovative spaceborne imaging spectrometers, being already launched, under design or planned, such as the PRecursore IperSpettrale della Missione Applicativa (PRISMA), Environmental Mapping and Analysis Program (EnMAP) or Copernicus Hyperspectral Imaging Mission for the Environment (CHIME). By means of these unprecedented data streams, we will be able to timely monitor the status and dynamics of cultivated land in high detail, essential among others, for managing agricultural systems. Opposed to multispectral data sources, hyperspectral sensors are capable of resolving subtle absorption features, such as those caused by specific pigments, proteins or carbon. Thus, new opportunities arise for the development of retrieval models for higher-level and priority vegetation products, such as biomass or carbon content. Therefore, in this study, we present a workflow for inferring crop carbon content (Carea), as well as dry (AGBdry) and fresh above-ground biomass (AGBfresh) from spaceborne imaging spectroscopy data. To achieve this, a hybrid workflow was generated, combining radiative transfer modelling (RTM) with machine learning (ML) regression algorithms. Currently, these hybrid methods became popular, as they blend previous retrieval efforts through their unique combination of physical awareness and inductive capabilities of data-drivenness. Being at the forefront of retrieval strategies in the context of future hyperspectral spaceborne missions, we decided to pursue hybrid methods and based our key concept on the following six steps:

(1) coupling the RTMs PROSPECT-PRO and 4SAIL (PROSAIL-PRO) for simulation of a wide range of vegetation states and in particular of canopy carbon and biomass contents (=training data set generation);

(2) reducing spectral dimensionality in form of principal component analysis (PCA) to deal with collinearity;

(3) applying active learning (AL) techniques to optimize and condense the data sets for efficient ML algorithm training;

(4) training of Gaussian process regression (GPR) algorithms and testing of model performance based on a field campaign dataset;

(4) adding bare soil spectra to the training database and retraining of GPR models;

(5) processing of spectrometric imagery;

(6) validating retrieved Carea, AGBdry, and AGBfresh contents based on in situ data.

As the core ML, GPR was used due to its ability to provide analytical estimates of predictive uncertainties together with the variable estimates.

To reduce computational cost, the variance-based pool of regressors (PAL) AL tuning was performed on a PROSAIL database. Training of GPR-PAL models was conducted based on proximal sensing data acquired at the long-term consolidated EnMAP test site Munich North Isar (MNI). Validation of the GPR models over MNI site achieved normalized root mean square errors (NRMSE) of 13.4%, 14.0%, 17.0% and coefficients of determination (R2) of 0.80, 0.77, 0.69 for Carea, AGBdry, and AGBfresh, respectively. An independent evaluation of the GPR-PAL retrieval models was performed using AVIRIS-NG campaigns data (ESA campaign 2021) from the German CHIME test site Irlbach.

Mapping yielded adequate estimations of all three variables both in terms of value distributions and absolute averages. In general, plausible estimates were achieved over vegetated surfaces as suggested by associated GPR-model uncertainties.

We conclude that our workflow presents a promising path towards mapping plant-bound carbon content and above-ground biomass to be evaluated both temporally and spatially with the scientific precursor missions PRISMA and EnMAP. After successful model testing, these products could be included in the catalogue of Level 2B vegetation traits (L2BV) products by the operational CHIME mission.

1-4A SPECSESS VEGTRAITS: QUANTIFYING PRIORITY VEGETATION TRAITS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA - PART 2

DOWNSCALING OF FAR-RED SOLAR-INDUCED FLUORESCENCE FROM CANOPY TO LEAF LEVEL – A NECESSARY STEP TO DERIVE PHYSIOLOGICAL INFORMATION OF PLANTS FROM REMOTE SENSING DATA

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Abstract

Remote sensing of solar-induced chlorophyll fluorescence (SIF) is a powerful approach to monitor plant functioning at different spatial and temporal scales. SIF is the most direct measure of photosynthetic activity at canopy scale, and therefore important for the monitoring of gross primary production (GPP) and the early detection of vegetation stress.

Several confounding factors challenge the physiological interpretation of canopy SIF and thus complicate its association with photosynthesis. Accurate knowledge of these factors is required, including i) absorbed photosynthetically active radiation (APAR), ii) the rate of the complementary non-photochemical quenching (NPQ), iii) scattering and reabsorption of SIF in the canopy, iv) SIF retrieval and atmospheric compensation methods, and v) sensor characteristics and non-uniformities.

Several of these superimposing factors were addressed in recent studies, while a particular understanding of SIF scattering in canopies across vegetation types and time is still insufficiently investigated but essential to disentangle the structural and physiological contributions that determine dynamics in canopy SIF. Scattering of SIF is wavelength-dependent and affected by canopy structure, e.g., leaf area, leaf orientation, and leaf clumping. The concept of SIF escape fraction (fesc) was introduced to describe the scattering of SIF within the canopy and corresponds to the ratio of SIF at canopy level to SIF at leaf level.

This study aims to evaluate different recently introduced approaches such as the near infrared reflectance of vegetation (NIRv) index and its derivatives (e.g., NIRvH), and the fluorescence correction vegetation index (FCVI) and their capacity to determine fesc of far-red SIF for structurally different crops (e.g., sugar beet, winter wheat, maize). We used diurnal airborne data sets from the HyPlant airborne imaging spectrometer recorded in summer 2018 and 2019 and simultaneously analyzed the spatial and temporal dynamics of the linkage between canopy and leaf level far-red SIF.

Our results clearly show that sugar beet characterized by distinct changes in leaf orientation across the day led to variability in fesc, while winter wheat, which has an almost spherical and constant leaf angle distribution, is characterized by temporarily stable fesc in the course of the day. Based on the analysis of the two crops in the observed phenological stages, calculating fesc only once a day for winter wheat and twice or three times a day for sugar beet would have been sufficient to scale far-red SIF from canopy to leaf level. Furthermore, we could determine the influence of canopy structural (e.g., leaf area index (LAI), average leaf inclination angle (ALIA)) and biochemical variables (e.g., chlorophyll content (cab)) as well as the impact of the changing illumination geometry on fesc throughout the day. This was done by scaling SIF from the canopy to the leaf level using the abovementioned indices (FCVI, NIRv) and then applying multiple linear regression to predict SIF at canopy scale from SIF at leaf scale, LAI, ALIA, Cab and sun elevation angle (SZA). The determined importance of the predictor variables illustrate that LAI and ALIA have a significant influence on fesc, which is differently pronounced for different crops. Additionally, SZA severely impacts fesc, especially for row crops such as maize.

Our findings provide important insights that facilitate the future development of methods to scale far-red SIF from canopy to leaf level, yielding improved capabilities to interpret variations in plant photosynthesis in the

spatial and temporal domains. This is especially important for satellites measuring SIF of entire ecosystems, such as the upcoming FLuorescence EXplorer (FLEX) mission of the European Space Agency (ESA).

1-4B SPECSESS SOILCONTAMINATION: MONITORING SOIL CONTAMINATION BY IMAGING SPECTROSCOPY

DETERMINATION OF CHROMIUM CONCENTRATION AND SPATIAL DISTRIBUTION IN A COPPER MINE USING REFLECTANCE SPECTROSCOPY AND REMOTE SENSING

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Abstract

Weathering and oxidation of Sulphide minerals in mine wastes release toxic elements in surrounding environments. Accumulation of these elements in the upper soil horizons and their transfer into the food chain adversely affects crop yield, food quality, and soil microbial groups. Chromium (Cr), as one of the most harmful toxic elements, causes severe health implications. Therefore, continuous environmental monitoring should be conducted to identify and track Cr at the early release stages. The standard chemical analysis methods are expensive, time-consuming, and laborious, requiring sample preparation with harmful acids-containing solutions. As an alternative method, proximal and remote sensing in the range of Visible-Near Infrared-Shortwave Infrared (VNIR-SWIR: 350-2500nm) has been recognized as alternative and efficient non-contact detection methods for monitoring and mapping of various soil toxic elements. The main objective of the current study was the prediction and mapping of Cr in the Sarcheshmeh mine waste dump using images from Hyperion and Sentinel-2A satellites. The capability of Hyperion and Sentinel-2A in Cr prediction and mapping was then compared to the performance of Aster and Landsat 8-OLI satellites, and laboratory reflectance spectroscopy as an accurate practice for toxic elements determination.

One hundred and twenty soil samples were collected from a dumpsite in Sarcheshmeh copper mine, Iran. The samples' mineralogy and Cr concentration were determined and were then subjected to laboratory reflectance spectroscopy in the range of VNIR-SWIR. The raw spectra were pre-processed using Savitzky-Golay First-Derivative (SG-FD) and Second-Derivative (SG-SD) algorithms. The important wavelengths were determined using the Genetic Algorithm (GA) and Partial Least Squares Regression (PLSR) coefficients. Artificial Neural Networks (ANN), Stepwise Multiple Linear Regression (SMLR), and PLSR data mining methods were also applied to the selected spectral variables to assess Cr concentration. The developed models were then applied to the selected bands of Aster, Hyperion, Sentinel-2A, and Landsat 8-OLI satellite images of the area. Afterward, rasters obtained from the best prediction model were segmented using a binary fitness function.

Wavelengths related to Fe-oxide/hydroxides and clay minerals were among the key wavelengths obtained by applying GA and PLSR on the spectra, indicating the internal relations of Fe-oxides and clay minerals with Cr ions in the soil. According to the laboratory reflectance spectroscopy outputs, the highest prediction accuracy was obtained using ANN applied to the SD pre-processed spectra with R2 = 0.91, RMSE = 8.73 mg/kg, and RPD= 2.76. SD-ANN also showed an acceptable performance on mapping the spatial distribution of Cr by the ordinary kriging technique. Using satellite images, SD-SMLR provided the best prediction model with an R2 value of 0.61 for Hyperion. This could be explained by Hyperion's relatively high spatial resolution and continuous coverage in both VNIR and SWIR regions, and its more significant number of similar wavebands with the samples' spectra. This led to the higher visual similarity of the segmented Hyperion image with the Cr distribution map. Using the outcomes of this study, surface reflectance derived from remote sensing data coupled with feature selection and machine learning algorithms can be considered a promising technique for rapid, cost-effective, and eco-friendly assessment of Cr concentration in highly heterogeneous mining areas.

1-4B SPECSESS SOILCONTAMINATION: MONITORING SOIL CONTAMINATION BY IMAGING SPECTROSCOPY

HYPERSPECTRAL ANALYSIS OF CONTAMINATED SOIL USING ULTRA HIGH RESOLUTION

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Abstract

Contamination of soils due to leaks, spills and seepage is a worldwide problem usually diagnosed by costly and time consuming methods. Hyperspectral analysis of soil is a good alternative to identifying contaminates without sample preparation or destruction.

A UV-VIS-NIR portable spectrometer is a good tool for soil analysis by identifying the reflectance absorption features of different quantities of contaminate like the hydrocarbon groups. Hydrocarbon features from oil, gasoline and diesel are common contaminates found in soil. This identification is especially important for ecological groups and agriculture. The type of hydrocarbon can be assessed depending on the shift of the feature. This method can be used in the field and the lab to identify which type of contaminant is present without need to destroy the sample.

Standard resolution spectrometers have been used in the past for soil analysis with a spectral resolution of 3nm in the visible, 8nm in SWIR1 and 6nm in SWIR2. Newer technology has allowed scientists to identify hydrocarbon features with more detail using an Ultra High Resolution field spectrometer with a spectral resolution of 1.5nm, 3nm and 3.8nm.

The samples used in this study were collected and characterized by the Natural Resources and Environment department at University of New Hampshire. Three separate locations were chosen for this study: McLennan Reservation, Black Rock Forest Consortium and the Pittsfield State Forest. A total of 54 samples were used with variety of clay loam, silty loam and silty clay loam was observed in all samples. Before contamination, these samples were used in a study (Anthony, M.A. et al. 2020) for soil warming and nitrogen enrichment. These locations were chosen due to the variance of silty vs clay loam characterizations also used by other scientists studying the affects on soil contaminants (Yazdi, A et al. 2021).

The contaminated samples were prepared by mixing the soils with crude gasoline, diesel and oil in the amounts of 0.012%, 0.032% and 0.052% of dry weight. The most important hydrocarbon features are present at the 1700-1770nm and 2290-2360nm regions. These features are present as a single absorption with standard standard spectral resolution. Throughout the study, it was found that using ultra high resolution provided better quality data in showing the important hydrocarbon features as doublets and triplets compared to standard spectral resolution. Results showed that reflectance percentages decreased as contaminant was introduced. Ultra high resolution made identification of heavy hydrocarbons possible even with low reflectance of contaminated soils. This finding also allowed for discrimination between contaminates due to the spectral shift being more visible and distinct, thus making analysis of soil contamination a quick method.

1-4B SPECSESS SOILCONTAMINATION: MONITORING SOIL CONTAMINATION BY IMAGING SPECTROSCOPY

ENVIRONMENTAL MONITORING OF TRACE METAL ELEMENT IMPACT ON VEGETATION: EXPLOITATION OF IN-SITU AND AIRBORNE HYPERSPECTRAL DATA

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Abstract

Trace metal elements (TMEs), released by specific anthropic activities, can lead to their dissemination in the environment and in particular to persistent pollution in soil. Therefore, detection and quantification of TMEs on geographically large scale is of great interest. The vegetation exposed to TMEs can exhibit a reduction of physiochemical activities (e.g., pigment concentrations), a structural damage at leaf and canopy scales … (Fabre et al., 2020). Such vegetation trait changes impact the spectral signature in the reflective domain [0.4 – 2.5 µm]. Remote sensing techniques, including hyperspectral data, have been widely used to assess these vegetation traits. However, the TME pollution may have a minor impact and be species-dependent according to species sensitivity to particular TMEs and combined to other natural or environmental stressors of greater impact, such as drought, poor soil, quality surface runoff, etc. The specific retrieval of TME effects on vegetation with hyperspectral data is thus challenging and site-specific (Wang et al., 2018).

Pines can be sensitive to TMEs and take them up from the soil with a transfer to the needles. To reduce the environmental stress and to achieve sensitive species inventory, the TME effects on vegetation spectral signature can be studied first at the leaf or canopy scale before being scaled up at airborne or satellite level (Lassalle et al., 2021). The accuracy of prediction may be reduced when upscaling to airborne acquisition, with the increasing influence of background signal, mixed pixels and canopy structure (Rautiainen et al., 2018). Several studies assessed the ability of field spectrometers on naturally grown vegetation to retrieve TME contents (Liu et al., 2011; Tan et al., 2019; Zhou et al., 2018…), including of pine needles (Shin et al., 2019). Few studies use airborne hyperspectral data for such purpose (Lassalle et al., 2021; Tan et al., 2019; Yang et al., 2020).

The objective of this study is to determine and characterize the impact of TMEs on the spectra in the reflective domain [0.4-2.5 µm] for two pine species. The spectra are measured by both in-field spectrometer and an aerial hyperspectral camera. The study focuses on ten TMEs: Cu, As, Ni, Mo, Fe, Mn, Al, Cr, Pb, Zn.

The study area is on a former ore processing site phytostabilized in 2006 along with steel shot spreading in the soil. Pines were selected in this study for several reasons: their use for phytostabilizing the site, their natural development in the surrounding environment, their sensitivity to some TMEs and their size being suitable to the spatial resolution of the airborne hyperspectral camera. The two species studied are Aleppo Pine (Pinus halepensis) and Stone Pine (Pinus pinea). Control areas 1 to 3 km from the site, assumed uncontaminated, have been also surveyed. The needles spectral signatures were acquired (i) with a field spectrometer ASD FieldSpec Pro 3 equipped with a contact probe (February 2021), and (ii) by an aerial hyperspectral acquisition (February 2019) with a spatial resolution of 75 cm and 450 spectral bands in the [0.4 – 2.5 µm] range. A complete dataset including various measurements related to soil and vegetation traits has been created, such as spectral signatures at needle and airborne scales, upper soil layer (0 – 10 cm) TMEs measurement with a portable X-ray fluorescent analyser and foliar pigment concentrations, etc.

We (1) analyse the correlation between reflectance and vegetation index according to vegetation traits and (2) TMEs in soil, (3) use further transformations such as derivatives, Principal Component Analysis, (4) create a cartography of the TMEs of the study site that is then compared to external reference data. The process is applied to both hyperspectral data, with an emphasis on the use of the aerial image (considering atmospheric absorption, spectral resolution, discrepancies of variables correlated…).

1-4B SPECSESS SOILCONTAMINATION: MONITORING SOIL CONTAMINATION BY IMAGING SPECTROSCOPY

IMPACT OF SPATIAL CORRELATION ON CLASSIFICATION ACCURACY ASSESSMENT FOR VEGETATION MAPPING IN A FORMER INDUSTRIAL SITE

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Abstract

Vegetation mapping based on remote sensing could be motivated by a wide range of applications extending from forest management to invasive species monitoring, contamination-induced stress monitoring, or biodiversity assessment. In the context of anthropogenic activities, changes in species composition and spatial distribution are caused by the presence of plant stressors in soils. The mapping of species and genera in such a context is, however, essential for assessing anthropogenic impacts on the soils underlying the vegetation. For this, precise species mapping is necessary.

Hyperspectral imagery has proven its suitability to obtain high-performance genera or species level mapping using supervised classification methods. Their high spectral resolution permits indeed to detect subtle spectral differences linked to biophysical and biochemistry vegetation traits specific to species. Using supervised classification methods, a key step lies within the choice of the reference dataset construction, divided into a training set and an evaluation set. This dataset and assigned classes must be representative of the site under investigation and adapted to the image spatial resolution. This step could be particularly challenging due to accessibility in the field, plant environment properties, heterogeneity at the pixel scale, and background signals that can increase intra-class variance and make the classification more complex. Another source of difficulty lies in the spatial independence of the training and the evaluation sets. Several studies have shown that a high spatial correlation led to biased performance which limits the generalization capabilities of the evaluated method. In the context of anthropogenic activities, the intra-species variance is increased by the heterogeneity of impacts in soil, considerably complicating the dataset construction and division.

The objective of the current study consists in assessing the effects of dataset construction and division on vegetation mapping accuracy assessment in a study area partially impacted by former industrial activities. Half of the study site is an industrial brownfield with various anthropogenic impacts on soils (heavy metals contamination, hydrocarbons contamination, soil reworking …) while the rest of the site is an area with little or no anthropogenic impacts. The total area covered in this study is two square kilometers across which ten plant genera or assemblages of genera, ranging from grass mixtures to individual trees, are identified. Classification is made at the pixel level using machine learning algorithms (Random Forest, Support Vector Machines, Regularized Logistic Regression). The reference dataset is separated into training and evaluation sets in three ways: at the pixel level, at the object level, or at the area level (reference, impacted). In each case, the evaluation is then performed not only with respect to the confusion matrix and its derivatives (Overall Accuracy, Producer's Accuracy, User's Accuracy), but also regarding spatial autocorrelation, assessed using the Moran index, and other underlying causes of misevaluation (plurality of identified species within a genus, spectral differences potentially related to soil composition…).

Results show that the commonly used classification approaches can be biased by exploited reference data and data-splitting procedures. Huge differences, raising up to 23% in terms of overall accuracy, were observed between the different procedures. Recommendations on the choice of reference data and data-splitting are suggested for the studied context.

1-4C SPECSESS WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING HYPERSPECTRAL DATA - PART 2

AN OPEN-SOURCE HYDROLIGHT-BASED FRAMEWORK FOR FAST INVERSE MODELLING OF HYPERSPECTRAL OBSERVATIONS FROM COASTAL AND INLAND WATERS

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Abstract

With increasing environmental pressure on the earth's waterways and coastal areas there is urgency to establish advanced water quality monitoring capabilities to track changes over time. Current and new upcoming hyperspectral orbital sensors will complement already existing multi-spectral mission with additional temporal, spatial and spectral information. However, most of the current data processing is tailored to multispectral sensors and is not easily extensible to hyperspectral platforms. Although ubiquitous, most retrieval models rely on empiricism and only use information contained in a few wavebands for the inversion, critical spectral information could potentially be lost. To help the ocean color community bridge the gap between multi- and hyperspectral platforms, we have developed an open-source and extensible inversion framework that can be readily applied to any ocean color sensor (Holtrop & van der Woerd. 2021. Remote Sensing, 15). The formerly developed HYDROPT algorithm (van der Woerd & Pasterkamp 2008. Remote Sens. Environ., 4) is completely updated with the capability of multi- and hyperspectral retrievals in the 400 – 710 nm range. Our framework is based on HydroLight radiative transfer simulations (Mobley. 1994, Academic Press, San Diego, CA), thereby providing generalizable and physically consist inferences of aquatic optical characteristics. Computation time is greatly reduced by the use of polynomial interpolation of the radiative transfer solutions, while at the same time maintaining high accuracy. Validation results of HYDROPT forward model simulation show accurate reconstruction of spectral reflectance within 1% of the radiative transfer simulations. The determination of water quality indicators for inland and coastal waters, including phytoplankton composition, requires retrieval models that account for bidirectional effects of the remote sensing reflectance and the inherent optical properties (IOPs) of the water column. We show that HYDROPT forward calculations are consistent with radiative transfer simulations across different sensor viewing geometries. Additional features of HYDROPT are the specification of IOP spectral models. We showcase the success of the framework by evaluating the retrievals of up to 5 optical components including 3 phytoplankton size classes, CDOM and non-algal particles. Our large hyperspectral synthetic dataset is used to benchmark the performance of HYDROPT over a large range of optical conditions including water bodies representing inland and coastal waters. We further test the applicability of the framework for phytoplankton size class retrievals in optically complex waters in the Eastern Australian Current. The incorporation of regional specific IOPs allows HYDROPT to directly retrieve the concentration of two phytoplankton size classes from hyperspectral in-situ measurements and coincident multispectral observations from OLCI. A reduction of up to 40% in chlorophyll-a retrieval error is achieved by HYDROPT compared to NASA's operational OC4 model. In addition, uncertainty estimates and goodness-of-fit metrics are simultaneously derived for the inversion. Our results highlight the merit of physics-based retrieval frameworks to increase the accuracy and interpretability of ocean color retrievals. We emphasize the need for on-going research efforts to maintain and improve upon current methodology. The HYDROPT framework is now available as an open-source Python package (https://github.com/tadz-io/hydropt).

1-4C SPECSESS WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING HYPERSPECTRAL DATA - PART 2

SWIPE: SPECTRAL WATER INVERSION PROCESSOR AND EMULATOR

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Abstract

Degradation of Earth's inland water resources due to anthropogenic perturbations and climate anomalies at both local and global scales continues to place human health at substantial risk. There is now a growing necessity to develop pragmatic approaches that allow timely and effective extrapolation of local processes, to spatially resolved global products, and to promote operational and sustainable resource policy management. This presentation will be discussing the progress made developing SWIPE: Spectral Water Inversion Processor and Emulator. SWIPE is a platform for advanced modeling of coastal and inland aquatic habitats. The goal is create a comprehensive and cohesive system to leverage recent advancements in computation and machine learning to develop a synthetic training ground for sensitivity studies and algorithm development. The four principal facets of SWIPE include: 1. Advanced two-layer coated sphere bio-optical modeling and GPU radiative transfer modeling, 2. Big Data involving massive synthetic spectral libraries of optical properties of various global aquatic particles, surface reflectance, and top-of-atmosphere reflectance, all at hyperspectral resolution leveraging high-end computing systems at NASA Ames Research Center, 3. Deep Learning for algorithm development for water quality inversion of concentrations of common biogeophysical variables as well as optics, full uncertainty characterization by water type, and forward emulation, and lastly, 4. Image Processing for application of developed retrieval algorithms for both hyperspectral and multispectral sensors with experimental corrections for global adjacency, noise, sunglint, and benthic reflectance. This presentation will demonstrate the Equivalent Algal Populations (EAP) two-layer coated sphere scattering model which has been used develop spectral libraries of hyperspectral inherent optical properties of roughly 80 species of phytoplankton, covering 15 different classes and nine taxonomic functional types. The EAP model was also used to derive spectral properties of 10 different non-algal particle functional types. Examples of how the SMART-G (Speed-up Monte-carlo Advanced Radiative Transfer using GPU) radiative transfer code is used to model optically complex aquatic signals will be presented and discussed in the context of creating a massive synthetic database which can leverage the full power of next generation machine learning techniques and high end computing for water quality inversion. We will discuss our active investigation in things like appropriate model architectures, dimensionality reduction techniques such as PCA and autoencoders, uncertainty quantification and abstaining, and which variables actually benefit most from hyperspectral information versus multispectral resolution. We are also curious about questions relating to cost/benefit analysis in terms of computation resources, neural network complexity, and data volumes. Answers to these questions will hopefully elaborate on cost efficiency for potential future sensor design considerations.

1-4C SPECSESS WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING HYPERSPECTRAL DATA - PART 2

PREPARING FOR CHIME AND SBG: ALGORITHMS FOR RETRIEVING SNOW AND ICE PROPERTIES IN EARTH'S MOUNTAINS

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Abstract

The U.S. National Academies' 2018 decadal survey for Earth science, Thriving on Our Changing Planet, identifies imaging spectroscopy as a necessary measurement to address a crucial objective for the hydrologic cycle: "Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability." Meeting this objective requires the ability to measure snow albedo and temperature and understand how and why they vary, especially in the world's mountains, which comprise a quarter of the world's land area but contribute at least half of our water resources. Two complimentary spectroscopic missions, CHIME (Copernicus Hyperspectral Imaging Mission for the Environment) from Europe and SBG (Surface Biology and Geology) from the U.S., will address this objective with sensors with spatial resolution of 20 to 30 m, spectral coverage from 400 to 2500 nm at spectral resolution of 10 nm or less. SBG also includes a thermal infrared sensor. Likely launch dates are 2027 or 2028. Together, the two missions shorten the revisit interval and provide resilience and cross-validation.

The history of retrieval of snow properties based on inversion of a radiative transfer equation dates back to 1981 for multispectral sensors, and in 1990 the first papers invoking imaging spectroscopy to study snow appeared. Among questions that arise for these emerging spaceborne missions, this presentation addresses the main technical one: How does sensitivity of imaging spectroscopy retrievals of snow and glacier properties in the mountains vary depending on the snow reflectance model, the solution method for the inversion, and the corrections for atmosphere and terrain?

The forward problem, estimating snow spectral reflectance based on properties of the snowpack, benefits from insightful research and observation stretching back six decades. Similar development for glacier albedo has not happened yet. The inverse problem, using spaceborne remote sensing to retrieve the snow properties that govern albedo, has seen a few convincing results in mountainous regions, with often discontinuous snow, local and long-distance transport and deposition of light absorbing particles, and forests and topography that shelter and obscure the snow. Questions under debate address atmospheric and terrain correction: should they be independent or integrated?

The presentation reviews the state of the practice in solving for snow properties—fractional snow cover, snow grain size and shape, concentration and optical properties of light absorbing particles, liquid water content, and snow water equivalent for shallow snowpacks—accounting for effects of the atmosphere, terrain, and vegetation on the signal measured by a spaceborne spectrometer.

In most snow-dominated environments, net solar radiation drives melt and metamorphism of snow. In modeling these processes, inaccuracy in the estimation of snow albedo constitutes the major source of uncertainty in calculating the snowpack's energy balance. That lack of knowledge propagates to uncertainty in forecasting runoff, analyzing ecohydrological processes, estimating melt rate, and determining when the seasonal snow cover melts to expose darker glacier ice in the ablation zones of glaciers.

2-3 PLENARY: NEW PATHWAYS IN THE ANALYSIS AND APPLICATION OF (IMAGING) SPECTROSCOPY

REMOTE ESTIMATION OF SULFUR CONTENT IN FUEL FROM QUANTIFICATION OF SHIP EXHAUST PLUME

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Abstract

Remote Estimation of Sulfur Content in fuel from Quantification of Ship Exhaust Plume

Sulfur oxide (SOx) from seagoing ships contribute to local air pollution in cities and coastal areas around the world. Sulfur dioxide (SO2) emissions in particular, are a precursor to acid rain and atmospheric particulates leading to ocean acidification which can contribute to negative human health outcomes1. The International Convention for the Prevention of Pollution from Ships (MARPOL) defines limits on the sulfur content in ship fuel oils, since the sulfur is ultimately released into the atmosphere through the ship's exhaust system as sulfur dioxide (SO2). The current approved method to verify compliance to these limits requires direct sampling and analysis of on-board fuel storage tanks by regulatory personnel, a complex, time consuming and costly task. The use of remote hyperspectral imaging data along with signal processing techniques can provide rapid and accurate estimation of sulfur content in fuel oils. This work will describe how the Hyper-Cam, a hyperspectral camera, was used to detect, image and quantify SO2 emissions from several seagoing ships and then retrieve the sulfur content of the fuel.

For the measurements presented in this work, the camera was located on the shore of the Saint-Lawrence river at distances ranging between 500 m to 1.5 km away from the ship's exhaust plume. The instrument field of view was narrowed in order to keep the measurement rate at ~1 sec/datacube. Since the Hyper-Cam is not mounted on a tracking platform, the ship displacement during one acquisition (datacube) causes strong variations in the raw data (interferogram) measurements, also called scene change artifacts. The ship movement across the image must be corrected before applying SO2 quantification algorithms. To this end, a digital image correlation algorithm based on a frequency-domain representation of the data is used. In order to exploit the rich information content of Hyper-Cam datacubes, we developed a suite of gas identification and quantification algorithms suitable for distant ship emissions monitoring. These algorithms are based on previous work related to distant smokestack emissions monitoring. These applications account for turbulences in the exhaust plume induced by unsteady/uneven gas streams and/or fluctuating wind conditions. In order to calculate the amount of sulfur in the fuel, it is necessary to make the following assumptions.

1. Sulfur content in the fuel is converted almost completely to SO2 in the exhaust gas. Combustion of fuel in marine vessels is usually complete and most of the sulfur emitted is in the form of SO2. Therefore, SO2 can be used as a proxy for the sulfur content in the emission plumes.

2. All of the carbon in the fuel is converted to CO2.

3. The average mass fraction of the carbon in the fuel is 0.865 (around 87%).

Based on these assumptions, the percentage of sulfur in the fuel can be calculated using the atomic weights of sulfur and carbon, the concentration of SO2 and CO2 retreived from quantification algorithm, and the fractional composition of carbon in the fuel.

The sulfur content results obtained from the hyperspectral dataset compare very well to the sulfur content in the fuel obtained from bunker delivery notes provided by the ship's owner as well as in situ measurements performed by an approved regulatory organisation. This system offers a distinct advantage over existing, more complex, and time-consuming sulfur monitoring techniques as it does not require direct sampling of the fuel or the ship exhaust emissions.

2-3 PLENARY: NEW PATHWAYS IN THE ANALYSIS AND APPLICATION OF (IMAGING) SPECTROSCOPY

CHANGE DETECTION IN URBAN AREAS FROM AIRBORNE-BASED HYPERSPECTRAL AND LIDAR DATA. CASE STUDY: BAERUM, NORWAY

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Abstract

Urban change detection is an important research subject, especially with regard to climate change and the quality of life in urban areas. Monitoring changes in the vegetation state is essential to control irrigation and the general temperature in the city. Also, constant supervision of buildings regarding their stability and material durability is relevant for safety and material quality studies.

An urban environment consists of a mixture of complex materials and surfaces of low and high vegetation types, non-vegetated pervious surfaces, partially and fully impervious surfaces, including asphalt, concrete, and various roofing systems. These materials and surfaces undergo natural and anthropogenic processes, constantly increasing urban heterogeneity and moving objects. Such a large variety of urban materials also contributes to complex analyses based on nonlinear behaviors, e.g., change detection.

Change detection based on hyperspectral data compares different materials, material conditions, stability, degradation, pollution, alteration, anthropological and atmospheric changes in bi- or multitemporal data. The high amount of spectral features enables the effective detection of changing materials and surface compositions. The use of lidar in change detection focuses mainly on geometrical and 3D structural changes, e.g., single-tree levels in forestry applications or urbanization level monitoring. The synergistic use of hyperspectral and lidar data is outstandingly suitable due to the high spectral and spatial supplementation of these properties. However, it has significant challenges in terms of complexity and acquisition effort.

This study demonstrates the great potential of combining hyperspectral and lidar to detect complex urban change dynamics of objects and qualitative surface properties at different complexity levels, including material, object, and context-based analysis. The developed change detection technique tackles the challenges of high-dimensionality, computational cost, and limited data acquired from one area at different times with key feature extraction and state-of-the-art deep learning techniques for semantic segmentation and classification. The urban changes are based on object classification with contextual representations.

For this study, airborne-based hyperspectral and lidar data were acquired simultaneously on 24 August 2019 and 26 June 2021 under cloud-free conditions over Baerum municipality near Oslo in Norway. The study area represents a complex urban environment with pervious and impervious surfaces. The HySpex VNIR-1800 (400 – 1000 nm) and HySpex SWIR-384 (1000 – 2500 nm) sensors acquired images with a spatial resolution of 0.3 m and 0.7 m, respectively. Lidar data were acquired using Riegl VQ-1560i.

The preprocessed data are used to retrieve the most distinct urban objects and surface properties. An automatic iterative endmember selection based on spectral characteristics is applied to each segment. Additionally, another endmember feature space to lidar data is built to refine segments spatially. All segments are analyzed in terms of intraclass variability and used to select representative spectral and structural endmembers for each complex class for the 2019 and 2021 datasets. The abundance maps from spectral endmembers and lidar features are fed into a deep learning classifier to retrieve desired urban changes in bitemporal data. Training data shall include a high class variety and complexity to optimize the results, e.g., data augmentation. This is intended to help the approach to be more transferable. The results are validated on simulated changes and changes extracted from segment intersections from the two datasets. Change detection analysis has a great

potential to generate a dynamic local database containing complex urban targets. Such a database can help to update maps very precisely and automatically.

2-3 PLENARY: NEW PATHWAYS IN THE ANALYSIS AND APPLICATION OF (IMAGING) SPECTROSCOPY

MAPPING METHANE EMISSIONS AROUND THE WORLD WITH SATELLITE IMAGING SPECTROSCOPY MISSIONS

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Abstract

Methane emissions from fossil fuel production activities typically happen as so-called “point emissions”, namely plumes emitted from small surface elements and containing a relatively large amount of gas. The detection and elimination of these methane emissions have been identified as “low hanging fruits” to reduce the concentration of greenhouse gases in the atmosphere.

Satellites offer a unique capability for global monitoring of methane emissions. The retrieval of methane from space measurements typically relies on spectrally-resolved measurements of solar radiation reflected by the Earth's surface in the shortwave infrared (SWIR) part of the spectrum (~1600–2500 nm). The Sentinel-5P TROPOMI mission allows to monitor methane emissions around the globe at regional scales with a daily resolution, but lacks the spatial resolution needed to pinpoint single point emissions.

Imaging spectrometers, such as PRISMA, EnMAP or the Chinese Advanced Hyperspectral Imagers (AHSI), sample the 2300 nm region with tens of spectral channels and a typical spatial resolution of 30-m, which can be exploited for the detection of point emissions and the attribution to particular emitting elements. PRISMA is currently the only 400–2500 nm imaging spectrometer with potential for high resolution methane mapping currently accessible to the international science community, which will soon change thanks to the advent of EnMAP. On the other hand, the AHSI has shown an outstanding methane retrieval performance because of its enhanced spectral resolution and signal-to-noise ratio in the 2300 nm region.

In this contribution, we will present an overview of the state-of-the-art in methane mapping with satellite imaging spectroscopy missions. This will include the description of methane retrieval and emission flux rate quantification methods, and the presentation of different studies using PRISMA and AHSI data to detect and quantify methane point emissions in several regions of the world, including oil and gas extraction fields in Algeria and Turkmenistan and coal mines in China. Initial results from EnMAP will also be shown if data are already available by the time of the conference.

2-3 PLENARY: NEW PATHWAYS IN THE ANALYSIS AND APPLICATION OF (IMAGING) SPECTROSCOPY

HOW DOES PHOTON RECOLLISION PROBABILITY PERFORM IN MODELING FOREST REFLECTANCE SPECTRA? - LESSONS LEARNED FROM AN EXTENSIVE FIELD AND AIRBORNE CAMPAIGN

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Abstract

Quantitative interpretation of hyperspectral remote sensing data from vegetation relies on models that link together the leaf-level biophysical characteristics, canopy structural parameters, and the observed hyperspectral reflectance signal. Reflectance characteristics of forests, and coniferous forests in particular, are difficult to model due to their complex canopy structure. Photon recollision probability (p) theory is a promising alternative for traditional radiative transfer models. The p-theory incorporates the effect of canopy structure (leaf area index, foliage clumping) into one structural parameter (p) that describes the multiple scattering behavior of the forest canopy. Despite a large number of theoretical studies conducted on the topic, empirical tests of the p-theory are still rare and more evidence on its suitability in modeling reflectance spectra of different forest types is still needed.

This contribution presents results from a recent extensive field and airborne measurement campaign, in which the p-theory and a model derived from it (called PARAS) were tested in a wide range of forests in different biomes in Europe. The study sites were located in Finland, Estonia, and the Czech Republic, with latitudes ranging from 48° to 62° N. Hyperspectral data were collected with airplane-mounted Itres CASI/SASI sensors, and coincident field and lab spectral measurements, as well as measurements of canopy structure, of a total of 50 forest plots were conducted.

We showed that the model based on p-theory can simulate forest reflectance spectra with just a few key input parameters, with wavelength dependent RMSE of 20%, 15%, and 11% on average in coniferous, broadleaved, and mixed forests, respectively. However, it is important that the spectra of the canopy elements (leaves, woody elements) used as model input are accurate and representative for the study species in question. In particular, woody elements contribute to increase the canopy absorption in the near-infrared and ignoring them can cause large overestimation of forest reflectance. Further, the general directional reflectance characteristics of the forest canopy can be captured by the model, but variation from stand to stand is large. In open canopy forests, such as boreal forests, the forest floor has a significant contribution to total forest reflectance and cannot be ignored. Application of the theory in removing the canopy contribution and thus predicting the spectral characteristics of the forest floor is also discussed. Finally, we discuss that the use of terrestrial and airborne laser scanning data can provide input parameters for the model, which can help to further understand their variability in space and time and constrain the model inversion, thus aiding the practical use of the model.

This work advances the research and practical use of the p-theory in mapping forest and other vegetation characteristics from space. The p-theory can be particularly useful in interpreting data from new hyperspectral satellite sensors that can have tens (hundreds) of spectral bands and the efficiency and simplicity of the interpretation model is a benefit.

2-3 PLENARY: NEW PATHWAYS IN THE ANALYSIS AND APPLICATION OF (IMAGING) SPECTROSCOPY

COUPLING PHYSICS AND MACHINE LEARNING FOR IMPROVED ATMOSPHERIC CORRECTION

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Abstract

Inferring surface reflectance from at-sensor radiance is essential for remote imaging spectroscopy of Earth's surface. It is also a computationally expensive stage, relying (in the Optimal Estimation formulation) on complex radiative transfer models and nonlinear optimization. Augmenting or replacing full physics calculations with machine learning in critical steps can lead to significant computational savings - which in turn can unlock the capacity for more sophisticated retrievals. However, extreme care is necessary to preserve the accuracy of the retrieval. Here, we overview several recent advances in the area. We begin by presenting several strategies for the emulation of radiative transfer models, including a hybrid physical and machine learning approach that will be used for the EMIT mission, as well as nonparametric Gaussian process inference (specifically, a Kernel Flows approach) for pure statistical emulation. We evaluate model efficacy by comparing atmospheric coefficients, subsequently retrieved surface reflectances, and by comparing distributions of retrieved surface characteristics. Next, we present a series of recent advances used to speed up atmospheric retrievals, leveraging the oversampling of smooth atmospheric fields by imaging spectrometers. We demonstrate how training suites of local linear emulators at runtime can speed up retrievals by several orders of magnitude. We also show how conditional dependence of adjacent atmospheres can lead to a more uniform solution of the atmospheric field, which can subsequently be utilized in surface retrievals. Together, these advances demonstrate how machine learning is both speeding up and reshaping the nature of joint surface and atmospheric retrievals from imaging spectrometers.

2-4A SPECSESS FORESTTRAITS: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

GAUSSIAN PROCESSES REGRESSION AND PLSR FOR MAPPING FOREST CANOPY TRAITS FROM FENIX AIRBORNE HYPERSPECTRAL DATA

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Abstract

Machine learning algorithms, and specifically kernel-based methods such as Gaussian processes regression (GPR), have been shown to outperform traditional empirical methods for retrieving vegetation traits. GPR is attractive for its property of automatically generating uncertainty estimates for predicted traits. GPR has been increasingly used for the estimation of canopy traits from hyperspectral remote sensing data in agricultural fields and grassland ecosystems. However, to our knowledge, the application of GPR using full-spectrum airborne hyperspectral data in forest ecosystems remains under-explored. Therefore, in this study we evaluated the performance of GPR as a representative of kernel-based machine learning algorithms in estimating two essential forest canopy traits (i.e., LAI and canopy chlorophyll content) using airborne hyperspectral data. The performance of GPR was compared with partial least square regression (PLSR) which is widely used for retrieving vegetation traits in spectroscopic studies. Field measurements of LAI and leaf chlorophyll content were collected in the Bavarian Forest National Park (BFNP) in Germany, concurrent with the acquisition of the Fenix airborne hyperspectral data (400−2500 nm) in July 2017 in the framework of the EUFAR summer school RS4forestEBV. The cross-validated coefficient of determination (R2) and normalised root mean square error (nRMSE) between the field-measured and retrieved traits were used to examine the accuracy of the respective methods. The results indicated that GPR somewhat outperformed PLSR in producing accurate estimations for LAI (GRP nRMSE = 16.7%; PLSR nRMSE = 23.0%) and canopy chlorophyll content (GPR nRMSE = 16.2%; PLSR nRMSE = 22.5%). The uncertainty maps generated by GPR showed that the retrieval uncertainties were generally low across the map, whereas higher uncertainties mainly corresponded with regions with low vegetation cover or under-represented in our field sampling. The capability to generate accurate predictions and associated uncertainty estimates suggest the GPR may be a promising candidate for the retrieval of vegetation traits.

2-4A SPECSESS FORESTTRAITS: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

SEASONAL CHANGES IN LEAF CHLOROPHYLL CONTENT OF FLOODPLAIN FOREST'S TREE SPECIES: A COMPARISON OF SPECTRAL, BIOCHEMICAL AND PORTABLE CHLOROPHYLL METER MEASUREMENTS

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Abstract

The overall condition of a plant or even an entire ecosystem is often assessed by its chlorophyll content. To be able to obtain or validate absolute values of chlorophyll content from remote sensing data, we need reliable ground truth data. Non-destructive measurements using various portable chlorophyll meters are often used as the ground truth data in remote sensing studies. Therefore, we decided to compare these data obtained with two different devices (transmittance-based chlorophyll meter SPAD-502 and fluorescence-based chlorophyll meter CCM-300) with the biochemically assessed chlorophyll content and spectral indices. Our aim was to verify the accuracy of chlorophyll measurements obtained by different non-destructive methods against a laboratory reference, for samples of different tree species and their phenological phases.

The comparison was made on a dataset acquired in The Soutok floodplain forest district located between the rivers Morava and Dyje (48.68° N, 16.94° E) in 2019 (four field campaigns conducted in April, July, September and October) and 2020 (three field campaigns in May, July, October). During each field campaign, sunlit and shaded branches were trimmed with a tree climber from eighteen deciduous trees of six species: Austrian oak, English oak, Narrow-leaved ash, European hornbeam, White poplar and Small-leaved linden. Representative leaves were measured using SPAD-502, CCM-300, ASD FieldSpec4 Standard-Res spectroradiometer (sampling 350 – 2,500 nm spectral domain) coupled with an integrating sphere RTS-3ZC and then taken to the laboratory for spectrophotometric determination of chlorophyll content from dimethylformamide extracts. In the 2019 season, each field campaign was also accompanied by the acquisition of CASI aerial hyperspectral data (450-1000 nm, 0.5 m spatial resolution).

Data from the 2019 season (204 samples of leaf level chlorophyll readings and leaf optical properties) were used to build simple regression models and the best models were validated on the data from the season 2020 (193 samples). First, regressions were performed between biochemically determined chlorophyll content and portable chlorophyll meters – the best fit for SPAD-502 was achieved by polynomial regression (R2 = 0.863) and for CCM-300 by exponential regression (R2 = 0.881). Subsequently, dozens of chlorophyll indices were calculated using integrating sphere's spectra based on previous studies (Croft et al. 2014. Ecol. Complex.; leMaire et al. 2008. Remote Sens. Environ. 10; Main et al. 2011. ISPRS J. Photogramm. Remote Sens. 6; Mišurec et al. 2016. Remote Sens. 2) and linear regressions were performed with chlorophyll content values. The best fit for biochemically determined chlorophyll content was with the MNDVI8 index ((R755-R730)/(R755+R730), R2 = 0.819, RMSE = 6.3 µg/cm2), for the chlorophyll content determined by SPAD with N705 index ((R705-R675)/(R750-R670), R2 = 0.858, RMSE = 4.9 SPAD value) and by CCM-300 with Carter2 index (R710/R760, R2 = 0.854, RMSE = 0.121 CFR value). The index that performed best for all three chlorophyll determination methods was N715 ((R715-R675)/(R750-R670), R2 from 0.797 to 0.845).

The results show that among all three chlorophyll content determination methods, the empirical models with leaf-level spectral indices perform well. Incorporating seasonal data improves the results significantly (the best results for empirical models based on July data only reached R2 of around 0.6 at best). The next step is to apply the models also to seasonal hyperspectral CASI imagery, which will be also presented at the workshop.

2-4A SPECSESS FORESTTRAITS: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

HYPERSPECTRAL IMAGE ANALYSIS OF SCOTS PINE WOOD AFFECTED WITH DECAY FUNGI USING PARTIAL LEAST SQUARES AND LIBRARY SPECTRA OF CELLULOSE AND LIGNIN

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Abstract

Given the right climatic and environmental conditions, wood can get deteriorated by a range of microorganisms, and decay by basidiomycete fungi account for significant volumes of wood in service that need to be replaced.

In this study, a short-wave infrared (SWIR) hyperspectral camera was used to analyze different degradation stages of Scots pine sapwood (Pinus sylvestris L.) specimens inoculated with monocultures of either a brown rot fungus (Rhodonia placenta Fr.) or a white rot fungus (Trametes versicolor L.). Data analysis was performed using Partial Least Squares (PLS) algorithm with the mass loss due to fungal decay as the response variable. Library spectra of the main wood polymers cellulose and lignin are used to explain the PLS loadings and correlation coefficients.

This study shows that the images of a SWIR hyperspectral camera are suitable for predicting wood mass loss due to basidiomycete decay, and suitable for the characterization of the type of fungal decay. Wood decay by basidiomycete fungi leads to a lower density of the wood specimens and shows a lower absorbance in general for the entire wavelength range.

The mass loss is predicted predominantly from the relative decrease in absorbance in the cellulose related wavelength range around 1460-1600 nm. This is true for all models, whether brown rot, white rot, or both fungi. A single PLS component can be sufficient to describe the mass loss to a high degree (90%). Adding a second component improves the cross-validation results and provides information on whether the mass loss was due to brown rot or white rot.

The distinction between brown and white rot fungal decay is mostly based on the bigger lignin peaks at 1680 and 2240 nm, which results from the difference in effect that brown and white rot fungi have on lignin.

The imaging of both front and back sides of the specimens allows for an analysis of how the decay progresses on the specimens in the Petri dishes. The front sides and edges of the specimens have a bigger spectral change than the back sides, suggesting the decay goes faster there.

2-4A SPECSESS FORESTTRAITS: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

DETECTION OF TREE MORTALITY INDUCED BY BARK BEETLE DURING DROUGHT IN RECENT YEARS

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Abstract

The bark beetle Ips Typographus is considered as the most dangerous biotic agent in Eurasia. Its outbreaks have been usually triggered by large-scale windthrow, but ongoing outbreak (2016-2021) in the Central Europe was mostly driven by drought effect. The combination of lack of precipitation and above-average temperature for several years in row cased the loss of tree vigour that made bark beetles easier to overcame the defence mechanism of trees. Thereupon, the mass Norway-spruce trees mortality across the Central Europe was recorded, for instance most severely culminating in 2018 in the Czech Republic. The large-scale bark beetle calamity has shown shortcomings in the search for bark beetle infested trees.

To minimalize the ecological and economical losses and mitigate the further spreading, the early detection of infested trees is necessary. Traditionally, the newly infested trees are identified during field survey. This method reliably identifies the bark beetle-infested trees since early stages of infestation, but is laborious, time-consuming and quite subjective. Its limits have become more clear over the past years, when the forest managers were unable to identify large number of newly infested trees in time. In this context a remote sensing presents an ideal and effective tool for mapping large areas of forest.

Historically, many remote-sensing studies were focused on detection of infested trees in late stages (i.e. red or grey –attack), but only few of them was focused on early detection (i.e. green-attack), where any foliage colour change is not apparent. Also, it is not always clear when the green-attack stage passes into the next red-attack stage or what is the connection between these stages (such as green-, red-, grey-attack) and observations from traditional field survey are. To find out these we performed an experiment combining airborne hyperspectral data with results of field survey.

The experiment took place in the southern part of the Czech Republic in 2020 and was focused on Norway spruce stands in age classes of 30-40 and 90-100 year. During 2020 seven hyperspectral acquisition were performed with one-month gap between each acquisition, the first was acquired in before bark beetle swarming and the last of growing season. At the same time the area of interest was also monitored using field survey on weekly bases. For airborne scanning the Flying Laboratory of Imaging Systems (FLIS), operated by Global Change Research Institute of the Czech Academy of Sciences was used. Airborne hyperspectral data were acquired with a CASI-1500 and SASI-600 spectroradiometers, covering the spectral range 380-2500 nm. We manually selected 75 Norway spruce trees being infested during spring 2020 and the same number of noninfested trees. Using CASI and SASI data we mapped the transition from healthy to green-attack up to red-attack stage. Both groups of trees were analysed by vegetation indices or other classification method (e.g. Random-Forest).

The classification accuracy of all employed methods is increasing in time, from 45-55 % in April 8 up to 96-99% in September 15. We also found that data from visible and near infrared area (CASI) separated groups of infested and noninfested trees later than in combination with short wavelength data (SASI). Where the remote sensing data from CASI detect the infestation 23 after in-situ detection. While data from both sensors was able to identify infested trees 4 day ahead of in-situ detection. Our results showed that the combination of VNIR and SWIR remote sensing has a potential to detect bark beetle infestation since early phases, being compared or may be better that classic field survey. We are also aware, that the classification accuracy depends on segmentation of tree crown, in our experiment the tree crown was selected manually in each acquisition that is hugely time consuming. Therefore, for success implementation is needed to develop automatic segmentation of tree crown.

2-4A SPECSESS FORESTTRAITS: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

UAS-BASED EXPERIENCES OF THE TEMPORAL, SPECTRAL, AND SPATIAL ACCURACY TO DETECT THE GREEN ATTACK PHASE OF BARK BEETLE INFESTATIONS IN THE ARNSBERGER FOREST AND THE BAVARIAN FOREST, GERMANY

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Abstract

Regarding the massive drought-induced forest damages in Central Europe, the research project FirSt 2.0 (Forest damage inventory based on rapid Satellite technologies) is investigating forest vitality with multiple sensors and across scales to derive a continuous forest vitality and forest damage information product over various areas in Germany. The areas are mainly covered by either spruce or beech stands, which are the main tree types in Central Europe and have both been heavily affected by the drought period in 2018/19.

One specific aim of the project is the investigation of the early stages of bark beetle infestations with imaging spectroscopy information. For the understanding of this so-called green attack stage we utilized unmanned aerial systems (UAS) and imaging spectroscopy data in the visible (VIS) to near-infrared (NIR) spectral range. In the vegetation period 2021 (March to September), we acquired data with the Headwall Hyperspec Nano Sensor (271 bands, 399 – 1002 nm, mounted on a DJI Matrice 600Pro +) at nine data-sets over two different spruce-dominated sites in Arnsberger Forest (AF) and Bavarian Forest (BF) with simultaneous bark beetle infestation. At the same time, intensive field surveys of damage evaluation (needle loss), observations of bark beetle development stages, and LAI measurements took place.

The entire spectral range of the hyperspectral datasets is examined and it is attempted to identify the spectral bands and calculated indices that best respond to change in the observed categories. The analysis is implemented through the application of exploratory data analysis. In our analysis we apply the machine learning algorithms Gaussian Process Regression (GPR) and Random Forest Regression (RFR) for the retrieval of the forest vitality indicators LAI, needle loss (NL), and infestation stage (IS). A training data set for each site was created to account for different image acquisition characteristics and the different phenological stages. For the retrieval strategy, relevant bands were selected using the Kernel Ridge Regression (KRR) band selection tool. For both machine learning approaches, we trained a the RFR and GPR algorithms using the selected bands as predictor set and LAI, NL, and IS as target variable. By applying a 10-fold cross-validation the coefficient of correlation (R) and root mean squared error (RMSE) of the corresponding models were derived.

The first preliminary results show a correlation between the external factors and spectral signatures. Especially the red edge wavelengths (700 to 750 nm) tend to shift and increased green visible reflectance (approx. 550 nm) indicate the early infestation stages, while the increase of values at 650 nm show the transition between green attack and red attack phase. The last stage is clearly associated with a decrease in the NIR. Since there are often different infestation stages in neighboring trees, the real potential of distinguishing green from red attack might be due to the limited spatial resolution of satellite-based approaches. Imaging spectroscopy data are especially useful at the blue shift in the first stage of the infestation.

The results show that UAS-derived imaging spectroscopy information on short-term damages of bark beetle infestations in both areas clearly correspond with the field-based observations. Compared to satellite data, the higher spatial and specific temporal resolution of the UAS images is more suited for early detection and local management of damages, while the satellite imagery is able to detect interrelations of different degradations and subsequently damage chains (e.g. from drought-related degradation to insect infestation).

2-4A SPECSESS FORESTTRAITS: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

PREDICTION OF LEAF AREA INDEX USING HYPERSPECTRAL THERMAL INFRARED IMAGERY OVER THE MIXED TEMPERATE FOREST

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Abstract

The leaf area index (LAI)- as one of the most important vegetation biophysical variables, has been retrieved in vegetation canopies using data from different remote sensing platforms. LAI was recently proposed as a remote sensing-enabled essential biodiversity variable. To our knowledge, however, the retrieval of the LAI using hyperspectral thermal infrared (i.e., TIR 8-14 m) data has been addressed only under controlled laboratory conditions and has not yet been accomplished using thermal infrared hyperspectral data acquired from an airborne platform. Therefore, the primary goal of this study is to determine the accuracy of LAI prediction using thermal infrared hyperspectral data acquired from an airborne platform. The field campaign was conducted during July 2017 in the Bavarian Forest National Park in southeast Germany, and biophysical parameters, including LAI, were measured for 36 plots. Concurrently, thermal hyperspectral data were obtained using the Twin Otter aircraft operated by NERC-ARF (i.e., the U.K. Natural Environment Research Council- Airborne Research Facility) and the AISA Owl sensor. LAI was retrieved using an artificial neural network Levenberg-Marquardt algorithm. The results indicated that thermal infrared hyperspectral data could estimate LAI with relatively high accuracy (R= 0.734, RMSE=0.554). The study showed the significance of using an artificial neural network. It proved the possibility of using hyperspectral thermal infrared data to estimate vegetation biophysical properties at the canopy level and over a large forest area.

2-4B THEMSESS SENSORSMISSIONS: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

IDENTIFYING DISTINCT PLASTICS IN HYPERSPECTRAL EXPERIMENTAL LAB-, AIRCRAFT-, AND SATELLITE DATA USING MACHINE/DEEP LEARNING METHODS TRAINED WITH SYNTHETICALLY MIXED SPECTRAL DATA

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Abstract

The growing production and use of plastics are becoming a serious progressive issue and people pay increasing attention to the effects of plastics on ecosystems and human health. The availability of hyperspectral data from space sensors inspired us to study the possibilities to detect and identify different types of plastics in airborne data, Goafen-5 (GF-5) and PRISMA satellite data by means of deep learning and machine learning models trained with spectral signatures. In this context, various in-house and public spectral libraries are used to create a comprehensive database with mixed pixels of different plastic and non-plastic materials. The endmembers of plastic types involved in this study are polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyethylene terephthalate (PET) and polystyrene (PS), covering 95% of the global production. Additionally, some important varieties of industrial plastics types such as acrylonitrile butadiene styrene (ABS), ethylene vinyl acetate (EVA), polyamide (PA), polycarbonate (PC), and polymethyl methacrylate (PMMA) were included in the investigations. Different samples with varying optical properties (color, brightness, transmissivity) have been selected for each plastic type. As non-plastic materials we have chosen spectra of vegetation, rocks, soils and minerals contained in the public US libraries (JPL and USGS). The number of spectra for the training of the deep learning and machine learning models was enlarged by a random linear mixing method and the resulting database was separated into a training and a test group for subsequent multi-label classification. Algorithms selected are a convolutional neural network (CNN), random forest (RF) and support vector machines (SVM). To investigate the transferability to any hyperspectral image data obtained by air-, and spacecraft sensors, we opted for a unification of the spectral response functions (SRF) and the spectral sampling intervals of all data. Validation is accomplished based on the test group of the spectral database and tested by controlled laboratory and aircraft experiments recorded over surfaces with varying background materials. Results are further analyzed for the influence of different noise quantities and abundance levels. The performance of the three models is roughly balanced for the validation of the spectral data with an overall accuracy of 97%, 96%, and 95% for the CNN, RF, and SVM models, respectively. In the controlled lab experiments, various accuracy indicators, such as the recall rates and the comprehensive metrics F1-score, OA, and Kappa suggest the RF classifier as the most robust one, followed by the SVM and CNN models. As for the evaluation of the aircraft data from controlled experiments, the RF further outperforms the other two models, behaving most robustly and reliably against conditions with unknown plastics and unknown background surfaces. Thus, the RF was used to classify the ten types of plastics mentioned above in one GF-5 and two PRISMA satellite recordings of the same area. In comparison of both sensor systems, the RF produced high quality and transferable results for detecting plastic mainly related to greenhouses, sport fields, photovoltaic constructions and industrial sites.

2-4B THEMSESS SENSORSMISSIONS: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

ENMAP DATA PRODUCT VALIDATION - STATUS

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Abstract

After the successful launch of EnMAP (The Environmental Mapping and Analysis Program) in April 2022 and the confirmation of sensor stability by the Ground Segment (GS) at DLR EOC and GSOC, the independent validation activities of GFZ have started and the official EnMAP data products (L1B, L1C, and L2A) will be released and available to the public after commissioning phase. As the commissioning phase continues, the radiometric, spectral, reflectivity, geometric, and general uniformities of the three official EnMAP products will require intensive validation. To meet the requirements of the EnMAP Product Validation Plan (PVP), validation activities must be performed from the end user's perspective and independent of the GS calibration and data quality control activities.

We provide the current status of the data product validation activities, a detailed look at the overall approach, and the specifically developed methods described in the EnMAP PVP. Both in-situ and scene-based validation scenarios are presented which include:

• L1B (radiometrically-corrected and spectrally-characterized radiance data) validation regarding absolute and relative radiometric uncertainty, spatially-coherent artifacts (striping and dead pixel), signal-to-noise ratio (SNR), spectral parameters (e.g., SRF and smile), and spatial parameters (keystone and modulation transfer function).

• L1C (geometrically-corrected L1B data) validations including the geometric performance (absolute and relative spatial mis-registrations), detector co-registration and band-to-band co-registration.

• L2A (atmospherically-corrected L1C data) validation of the reflectance uncertainty as well as aerosol and water vapor contents.

In-situ reference measurements from experienced international partners, from extensive science-oriented field- and airborne campaigns, as well as from selected core sites in Germany and international collaborators will be supplemented by the already established CAL/VAL sites and networks (e.g., CEOS, RadCalNet, AERONET, BOUSSOLE, and HYPERNETS) for the respective validation scenarios. Pseudo invariant calibration sites (PICS), as well as data from other missions (e.g., PRISMA, EMIT, DESIS, Sentinel-2), will be used for stability- and cross-validation scenarios. The availability of valid EnMAP observations at the same time as in situ measurements is increased by also including up to ±15° off-nadir EnMAP observations in the validation. The resulting revisiting time of about 7 days for a given in situ target is an attempt to increase the statistical significance of the validation despite the associated uncertainties introduced by off-nadir observations.

All in-situ and image-based validation scenarios are performed at least once during the commissioning phase. In case of anomalies or special requirements, the validations can also be performed on request from the GS. Results will be compared to mission requirements in semi-automated product validation reports which will be provided to the GS. To track changes in data quality over time, validation tasks will be performed periodically during the nominal mission phase.

2-4B THEMSESS SENSORSMISSIONS: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

ADVANCES IN IMAGING SPECTROMETER ATMOSPHERIC CORRECTION WITH THE OPEN SOURCE ISOFIT CODEBASE

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Abstract

Accurate atmospheric correction is critical for remote imaging spectroscopy of Earth's surface. This presentation describes recent advances in the atmospheric correction used for NASA's Earth Surface Mineral Dust Source (EMIT) mission. The code has been distributed to the community through the open source repository ISOFIT (https://github.com/isofit/isofit). The approach, colloquially termed optimal estimation, frames atmospheric correction formally as a model inversion problem. It uses Bayesian Maximum A Posteriori inference to find the most likely surface and atmospheric state to explain each observation. Advantages include rigorous uncertainty accounting and propagation, and the flexibility to incorporate diverse radiative transfer modeling assumptions. Since the codebase was released in 2018 the approach has been used for over 17 publications with validation at dozens of terrestrial and aquatic field sites. These results include the highest-ever resolution maps of water vapor scaling properties (Thompson et al., AMT 2021; Richardson et al, AMT 2021, 2022). The FIREX-AQ campaign demonstrated accurate mapping of aerosol optical properties over diverse terrain, at aerosol optical depths up to 2.0 (at 550 nm), without reliance on dense dark vegetation assumptions (Brodrick et al., JGR-Atmospheres, 2021). EMIT mission preparatory studies show end-to-end uncertainty propagation for radiance, reflectance, and derived products (Thompson et al., RSE 2020; Connelly et al., RSE 2020; Carmon et al., RSE 2020). Field studies show closed uncertainty budgets, in which uncertainty predictions fully explain discrepancies with in situ observations across aquatic and terrestrial regimes (Thompson et al., RSE 2019a, 2019b). Uncertainty in radiative transfer models and calibration can be quantified using flight data alone, by exploiting the existence of spectrally invariant surfaces (Thompson et al., RSE 2021). Joint retrievals combining VSWIR and thermal infrared spectrometers show improvements in temperature/emissivity separation (Fahlen et al., RSE 2021). We close by describing future planned upgrades, including incorporation of more detailed topographic information and spatial constraints on atmospheric smoothness. In these and other studies, researchers across multiple institutions are leveraging applied statistics and physics to advance the science of atmospheric correction for the next generation of orbital imaging spectrometers.

2-4B THEMSESS SENSORSMISSIONS: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

FINAL RESULTS BUILDING ENMAP AND FIRST RESULTS OPERATING ENMAP

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Abstract

The launch of the spaceborne imaging spectroscopy mission EnMAP (Environmental Mapping and Analysis Program; www.enmap.org) is scheduled for April 2022.

The presentation will primarily focus on the final results building EnMAP with its space and ground segment, as well as on first results operating EnMAP with its Launch and Early Orbit Phase (LEOP) (0.5 months) and Commissioning Phase (CP) (5.5 months). This leads approval of the products expected to be accessible for users in October 2022. The LEOP covers the first contact with satellite after separation, setting up telemetry and telecommand communications, continuous monitoring of health status, checkout and configuration of all platform functions, activation and calibration of sensors and actuators, and acquisition of required orbital parameters. The CP covers the activation of the instrument data storage and all payload functions including the first image acquisition, downlink, and processing. The presentation will, in particular, compare the first in-flight calibrations with the final pre-flight calibrations, focusing first on radiometric, second on spectral, and in parallel on geometric characterizations. The first Earth Observations will also be analyzed.

The spectral range of EnMAP covers 420 nm to 2450 nm based on a prism-based dual-spectrometer with a spectral sampling distance between 4.8 nm and 12.0 nm. A doped Spectralon sphere enables a spectral accuracy of better than 1.0 nm. The target signal-to-noise ratio (SNR) is 500:1 at 495 nm and 150:1 at 2200 nm (at reference radiance level representing 30% surface albedo, 30° Sun zenith angle, ground at sea level, and 40 km visibility with rural atmosphere). Sun calibration measurements with an on-board full-aperture diffuser enable a radiometric accuracy of better than 5%. Additional measurements, e.g. for non-linearity and closed shutter measurements for subtraction of dark signal, complement the calibration. Level 1B products are corrected to Top-of-Atmosphere (TOA) radiances.

Each detector array has 1000 valid pixels in spatial direction and, with a geometric resolution 30 m x 30 m, a swath width (across-track) of 30 km is realized. All data are long-term archived in tiles of 30 km x 30 km. A catalogue based on standardized protocols allows users to search, browse, and access all products. A swath length (along-track) of 5000 km, split to several observations, is reached per day. Level 1C products are orthorectified to a user selected map projection and resampling model. The repeat cycle of 398 revolutions in 27 days combined with an across-track tilt capability of 30° enables a target revisit time of less than 4 days. And each region is viewable under an out-of-nadir angle of at most 5°. The local time of descending node is 11:00 am.

Level 2A products are compensated for atmospheric effects with separate algorithms for land and water applications. For the land case the units are expressed as remote sensing, namely Bottom-of-Atmosphere (BOA), reflectances. For the water case the units are normalized water leaving remote sensing reflectance or subsurface irradiance reflectance based on user selection. At all processing levels per-pixel quality information and rich metadata are appended online. This is complemented by offline quality control, e.g. based on pseudo invariant calibration sites. The independent product validation, e.g. based on already established validation procedures, sites, networks, and products of other missions, is performed by the science segment.

For the routine phase (54 months) all elements are supervised, the satellite is kept in the required orbit, data are acquired and dumped according to the requests, and quantitative imaging spectroscopic measurements substantially improving remote sensing standard products and allowing advantageous user-driven information products are processed and delivered to users.

EnMAP operational activities are planned to be continued until April 2027.

2-4B THEMSESS SENSORSMISSIONS: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

PRISMA SIGNAL DEPENDENT NOISE CHARACTERIZATION ON A RURAL AREA: THE TEST CASE OF PIGNOLA (SOUTH ITALY)

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Abstract

The proposed research aims to evaluate the signal dependency of the noise affecting the PRISMA (Italian Space Agency- ASI) hyperspectral images and their SNR by using the Pignola test site (Italy). This work would like to present a quantitative estimation of the PRISMA L1 products as depicted by using a typical Southern Italian rural area during almost two years of measurements. To this aim, we collected from October 2019 to July 2021 seven PRISMA images.

PRISMA signal, as for other sensors, is affected by two noise components, random noise, and fixed pattern noise like striping. Within this analysis, we assume that fixed pattern noise (i.e., coherent noise) has been already mitigated by the standard L1 procedure. Authors are aware that the data analysis should be applied to L0 data, but such raw data are not accessible for scientists according to the ASI distribution policy.

Under the common hypothesis of additive noise, the PRISMA L1 image intensity X for each pixel in the n PRISMA channels (with n = 234) can be viewed as a superposition of two vectors: the signal vector s = (s1,…, sn) and the random noise vector N(s) = (N1(s1),..., Nn(sn)). Moreover, while the signal is characterized by a significantly strong spectral correlation, the noise vector, comprising both photon and thermal noise, is modeled by a zero-mean Gaussian random noise whose variance in each spectral band depends on the useful signal. Therefore, the noise variance σ_λ^2 in the band λ is modeled as the sum of two contributions, one linearly dependent on the signal through a coefficient γ_(SD,λ) (photon noise coefficient) and the other assumed as signal independent, γ_(SI,λ) (thermal noise coefficient).

The processing applied to the PRISMA imagery acquired on Pignola comprises three steps: (i) estimation of both components of the PRISMA noise in each spectral band, as described by γ_(SD,λ) and γ_(SI,λ); (ii) analysis of its behavior on acquisitions with different spatial, temporal and seasonal characteristics; (iii) test of an assessment procedure for the SNR on PRISMA images characterized by a fragmented land cover such as the Pignola site. The PRISMA noise components as retrieved from the Pignola images were then compared to the ones assessed on the Rail Road Valley (RRV) image pertaining to the RadCalNet network images.

PRISMA noise estimates at step (i) have been obtained through an image-based procedure: first, a multiple linear regression (MLR) within a narrow spectral window was used to separate the useful signal from the noise; then, a constrained maximization of the noise likelihood for each spectral band has allowed retrieving the two noise components, i.e., photon and thermal noise. Their further analysis has confirmed that both coefficients (γ_(SD,λ) and γ_(SI,λ)) appear not to be correlated to targets. Their spectral behavior is comparable to what was observed in the ones retrieved in a more homogeneous test site (i.e., RRV). Moreover, the SNR (in decibel) for each Pignola imagery was derived along with the specific contributions from the two noise components.

The ratio of 〖SNR〗_(Si,λ) / 〖SNR〗_(SD,λ) points out that the retrieval procedure is relatively low affected by the different land covers occurring at Pignola and that PRISMA quality is limited by the γ_(SI,λ) noise component, especially in the SWIR spectral region. As a final remark, the procedure highlighted the presence of a residual coherent pattern noise composed by a horizontal disturbance and a diagonal one affecting images from about line 630. Horizontal FFT of the images detects a disturbance with a frequency of about 0.3-0.4 cycles/pixel on all the analyzed images in the lines from 630 to 800.

The signal-dependent noise characterization of PRISMA imagery needs further work both on a larger data set to set up a robust correction algorithm apt to reduce the noise and the use and comparison of the results on other international calibration sites.

2-4B THEMSESS SENSORSMISSIONS: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

THE CEOS CARD4L CONFORM ENMAP L2A LAND PRODUCT

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Abstract

Within the field of airborne hyperspectral remote sensing, standardization of file formats, quality layers and metadata has already been conducted by European data providers as part of the EUFAR HYQUAPRO project. With the increasing availability of data from spaceborne hyperspectral sensors such as EnMAP, DESIS and PRISMA, and in preparation for the future global hyperspectral mapping missions CHIME and SBG, the provision of well-characterized analysis ready hyperspectral data will be of increasing interest. For this purpose, the CEOS Analysis Ready Data for Land (CARD4L) provides a common baseline for atmospherically corrected data of hyper- and multi-spectral optical sensors.

Within this presentation, we briefly summarize the outcomes of the EUFAR HYQUAPRO initiative and present the design of the EnMAP Level 2A Land product, providing the requirements to generate CARD4L compliant data products, including rich metadata and quality layers. The focus is then set on the necessary pre-processing chain, as well as the resulting challenges for product generation.

For EnMAP, the raw L0 data is archived and then processed by user request to the desired product level using the latest version of the processing chain and calibration information. The L1B Top-of-Atmosphere (TOA) Radiance product includes the radiometric calibration, and the correction of non-linearity, straylight and other sensor-related effects. Defective pixels are interpolated using an advanced approach, which includes a conversion to the smoother reflectance level and back to radiances. The L1B product is also fully spectrally referenced, taking spectral smile in account if needed. The L1C product is fully orthorectified and combines the VNIR and SWIR cubes. This step also includes a co-registration to a Sentinel-2 global master image, and uses the COPERNICUS DEM (GLO-30). Therefore, a high relative geometric consistency between EnMAP and Sentinel-2 data is ensured, which allows for an easy integration in multi-sensorial time-series. For L2A, the EnMAP processing chain offers multiple products which can be selected and ordered by the user. This includes the “land” product (Bottom-Of-Atmosphere (BOA) reflectance), and two “water” products (BOA water leaving reflectance as well as BOA subsurface reflectance). The EnMAP Level 2A land processor is based on PACO (Python-Based Atmospheric Correction), which is a descendant of the well-known ATCOR. Because of this heritage, the advantages and shortcomings are well understood, and the good overall performance is shown in the results of many comparison studies. The water algorithm is based on the Module Inversion Program (MIP).

In order to generate Analysis Ready Data, the L1B product already contains the full set of quality-related metadata and quality layers, as generated by the L1C and L2A processors. The per-pixel quality flags include flags for Land, Water, Cloud, Cloudshadow, Haze, Cirrus, Snow, and also for Saturation, Artefacts, Interpolation and a Per-Pixel Quality Rating. Quality-related parameters are also provided within the XML metadata, such as the percentage of saturated pixels, the scene mean Aerosol Optical Thickness and Water Vapor content, as well as the RMS error of the geolocation based on independent control points.

Based on this operational approach, the user of EnMAP products will be provided with CARD4L compliant analysis ready data, containing rich metadata and quality information, which can easily be integrated in analysis workflows and combined with data from other sensors.

2-4C SPECSESS GENERICLIBS: UNLOCKING THE POTENTIAL OF GENERIC SPECTRAL LIBRARIES FOR REMOTE SENSING APPLICATIONS

GENLIB: DEVELOPING A GENERIC FRAMEWORK FOR LIBRARY-BASED MAPPING OF URBAN AREAS

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Abstract

The establishment of remote sensing big data, that is now increasingly supplemented with imaging spectroscopy, presents interesting opportunities for monitoring of urban areas on a worldwide scale. Yet image processing remains strongly hampered by the limited access to spectral reference data and the tools required to manage this data. The GENLIB research project proposes the concept of a Generic Urban Spectral Library (GUSL) to address these challenges and help streamline urban mapping. A GUSL is defined as a multi-site collection of richly labelled spectral libraries, equipped with the tools needed to query, transform and apply these libraries for various urban mapping applications. It is envisioned to be distributed through an openly accessible data system and grow dynamically with contributions of new spectral libraries from a benefiting user community. As such, the GUSL will become spectrally representative for ever more urban areas.

The main objectives of GENLIB are positing and disseminating the GUSL as a concept, while also proving its feasibility. The presentation will start with an outline of the GUSL framework and its core components. Next, we will describe how an experimental version of the GUSL was produced using earlier published urban spectral libraries and additional libraries produced by our project partners. The third part of the presentation will cover a series of experiments carried out as proof-of-concept of the proposed framework.

To highlight the feasibility of the GUSL and illustrate its workings, the experiments consider 3 common use cases. The first use case handles spectral library production, which remains a challenging task requiring some expert knowledge. Here we emphasize the so far underused potential of image-derived spectral libraries, and we show how the GUSL can facilitate the production of such libraries. The second GUSL use case tackles its application for high-resolution land cover classification. Here we consider varying levels of thematic detail and perform tests with 3 urban hyperspectral datasets, covering different sites. One of these sites, corresponding to the well-known Pavia dataset, is used to investigate GUSL performance in absence of local spectral information on the image being mapped. The third use case addresses the application of the GUSL for medium-resolution subpixel fraction mapping. While urban fraction mapping typically draws on the Vegetation-Impervious-Soil or similar mixing frameworks, we investigate if the GUSL can be leveraged to perform fraction mapping targeting a thematically enhanced mixing framework with 6 generalized material classes: Ceramics-Minerals, Metals, Plastics, Semiconductors, Vegetation and Water. For this purpose, use is made of a simulated hyperspectral EnMAP satellite image of Brussels.

The favorable outcomes of our proof-of-concept experiments indicate that the GUSL can help produce spectral libraries and deliver detailed and accurate maps with limited user input. The mapping remains reasonably accurate even under challenging conditions, e.g., when local spectral information is partially absent. The presented work thus underscores the potential of multi-site spectral library collections for more efficient urban mapping. As such, we show that a GUSL stands to benefit different types of urban remote sensing users. While the scope of this project covers urban environments, with a particular focus on artificial cover types, we note that the GUSL framework can be extended to serve other remote sensing application domains, like forestry, agriculture and soil science.

2-4C SPECSESS GENERICLIBS: UNLOCKING THE POTENTIAL OF GENERIC SPECTRAL LIBRARIES FOR REMOTE SENSING APPLICATIONS

THE DATA CONCEPT BEHIND THE DATA: FROM METADATA MODELS AND LABELLING SCHEMES TOWARDS A GENERIC SPECTRAL LIBRARY

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Abstract

Spectral libraries play a major role in imaging spectroscopy. They are commonly used to store end-member and spectrally pure material spectra, which are primarily used for mapping or unmixing purposes. However, the development of spectral libraries is time consuming and usually sensor and site dependent. Spectral libraries are therefore often developed, used and tailored only for a specific case study and only for one sensor. Multi-sensor and multi-site use of spectral libraries is difficult and requires technical effort for adaptation, transformation, and data harmonization steps. Especially the huge amount of urban material specifications and its spectral variations hamper the setup of a complete spectral library consisting of all available urban material spectra. By a combined use of different urban spectral libraries, besides the improvement of spectral inter- and intra-class variability, missing material spectra could be considered with respect to a multi-sensor/ -site use. Publicly available spectral libraries mostly lack the metadata information that is essential for describing spectra acquisition and sampling background, and can serve to some extent as a measure of quality and reliability of the spectra and the entire library itself.

In the GenLib project, a concept for a generic, multi-site and multi-sensor usable spectral library for image spectra on the urban focus was developed. This presentation will introduce a 1) unified, easy-to-understand hierarchical labeling scheme combined with 2) a comprehensive metadata concept that is 3) implemented in the SPECCHIO spectral information system to promote the setup and usability of a generic urban spectral library (GUSL). The labelling scheme was developed to ensure the translation of individual spectral libraries with their own labelling schemes and their usually varying level of details into the GUSL framework. It is based on a modified version of the EAGLE classification concept by combining land use, land cover, land characteristics and spectral characteristics. The metadata concept consists of 59 mandatory and optional attributes that are intended to specify the spatial context, spectral library information, references, accessibility, calibration, preprocessing steps, and spectra specific information describing library spectra implemented in the GUSL. It was developed on the basis of existing metadata concepts and was subject of an expert survey. The metadata concept and the labelling scheme are implemented in the spectral information system SPECCHIO, which is used for sharing and holding GUSL spectra. It allows easy implementation of spectra as well as their specification with the proposed metadata information to extend the GUSL.

Therefore, the proposed data model represents a first fundamental step towards a generic usable and continuously expandable spectral library for urban areas. The metadata concept and the labelling scheme also build the basis for the necessary adaptation and transformation steps of the GUSL in order to use it entirely or in excerpts for further multi-site and multi-sensor applications.

2-4C SPECSESS GENERICLIBS: UNLOCKING THE POTENTIAL OF GENERIC SPECTRAL LIBRARIES FOR REMOTE SENSING APPLICATIONS

THE SPECCHIO SPECTRAL INFORMATION SYSTEM – STATUS AND NEW FUNCTIONALITIES

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Abstract

The SPECCHIO Spectral Information System (Hueni, A., Chisholm, L., Ong, C., Malthus, T., Wyatt, M., Trim, S., A., Schaepman, M. E. and Thankappan, M. (2020). "The SPECCHIO Spectral Information System." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 13: 5789-5799.) has been under continuous development since 2006 with new functions being added over time. In this presentation, we aim to give an update about the current range of functionality in order to inform existing and prospective new users alike.

SPECCHIO comprises a relational database used as storage facility hosted by a web service, allowing multiple users to upload, edit, share and retrieve spectral data and their metadata, either via graphical user interfaces or via application programmer interfaces (APIs).

SPECCHIO is now used operationally by various research organisations, such as UZH and Geoscience Australia and within a number of research projects like GENLIB. As a use case study, we will present the integration and function of SPECCHIO in the calibration and validation tool for airborne imaging spectroscopy as implemented by UZH and applied in recent international airborne campaigns like Hypersense 2018 and CHIME 2021 (Meiller, C., Kuehnle, H., Werfeli, M. and Hueni, A. (2020). A Calibration and Validation Tool for Data Quality Analysis of Airborne Imaging Spectroscopy Data. IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium.).

SPECCHIO has recently been updated to support the storage of uncertainty data within the framework of the MetEOC3 project. Uncertainty analysis must be considered as one of the next big steps to advance spectroscopy. New probabilistic models will make use of such information to achieve better fits (Thompson, D. R., Natraj, V., Green, R. O., Helmlinger, M. C., Gao, B.-C. and Eastwood, M. L. (2018). "Optimal estimation for imaging spectrometer atmospheric correction." Remote Sensing of Environment 216: 355-373.), considering the fact that all measurements are uncertain. To exemplify the use of the uncertainty support in SPECCHIO we will present a use case that generates an uncertainty tree structure for a typical field spectroscopy measurement data set.

Further changes include, but are not limited to: increased insert, retrieval and deletion speeds for databases with millions of spectra such as generated by the FLOX systems, updated file readers, and encryption of data connections using SHA2 and salting for the more demanding institutes.

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2-4C SPECSESS GENERICLIBS: UNLOCKING THE POTENTIAL OF GENERIC SPECTRAL LIBRARIES FOR REMOTE SENSING APPLICATIONS

REGRESSION-BASED UNMIXING THROUGH ENSEMBLE LEARNING FROM SYNTHETIC TRAINING DATA ENABLES THE USE OF LARGE GENERIC SPECTRAL LIBRARIES

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Abstract

Spaceborne imaging spectroscopy has made significant progress in the past decade. Recent/upcoming scientific (e.g. PRISMA, EnMAP) and candidate operational (e.g. CHIME, SBG) satellite missions will facilitate regional- to global-scale hyperspectral analyses at regular time intervals. This will open up new opportunities for a variety of environmental applications, including a more accurate and detailed quantification of land cover characteristics. To make best use of hyperspectral satellite imagery with large spatial and higher temporal coverage, generalized mapping approaches that can be applied through space and/or time are required. The use of spectral unmixing approaches in combination with generic spectral libraries constitutes a suitable strategy in this regard. Generic spectral libraries comprise comprehensive collections of pure surface reflectance signatures representative of multiple sites and seasons, and thus constitute useful training sources for generalizing mixture models. Utilizing such large spectral databases is not straightforward and many approaches require pruned library subsets prior to unmixing. However, such library subsets, particularly when tailored for specific mapping tasks, can adversely impact the generalization capabilities of mixture models.

To avoid subsetting large spectral databases, we propose regression-based unmixing through ensemble learning from synthetic training data. Based simulated EnMAP data, we demonstrate how regression models can be generalized when trained with randomly generated synthetic training data from generic, multi-site and multi-date spectral libraries, and how the generalized models can be applied across imagery from different regions and seasons. The approach was evaluated both for vegetation class fraction mapping across different ecoregions and seasons as well as for urban mapping across multiple cities. Average Mean Absolute Errors (MAE) over all classes based on generalized models were below 15% for vegetation class mapping and below 13% for urban class fraction mapping, respectively. No loss on map quality was found when compared to site- and date-specific unmixing models, which were trained based on spatially and temporally filtered library subsets. At the same time, site- and date-specific unmixing models showed reduced performances when applied to unknown regions and seasons. These findings indicate the great use of our approach for land cover mapping with generalized unmixing models based on larger generic spectral libraries.

Our study exploited simulated EnMAP data. Due to their similarity in spatial and spectral resolution, we are confident that the approach can be similarly applied to future operational hyperspectral satellite missions, e.g. CHIME or SBG. Given the diversity of natural and anthropogenic surface types, our study encompasses a representative cross-section of many structurally similar ecosystems globally. We therefore conclude that our findings provide a vital stepping stone toward a wall-to-wall quantification of land cover characteristics from global spaceborne imaging spectroscopy missions.

2-4C SPECSESS GENERICLIBS: UNLOCKING THE POTENTIAL OF GENERIC SPECTRAL LIBRARIES FOR REMOTE SENSING APPLICATIONS

SPECTRAL LIBRARY OPTIMIZATION FOR FRACTIONAL COVER ESTIMATION AND CLASSIFICATION

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Abstract

Spectra that capture the diversity and variability of surface materials are needed to estimate fractional cover and classify terrestrial and aquatic environments. These spectra are particularly important to support current and planned spaceborne missions, such as the Hyperspectral Precursor and Application Mission (PRISMA), the Earth Surface and Mineral Dust Source Investigation (EMIT), and Surface Biology and Geology (SBG). Multiple strategies exist for developing spectral libraries, including automated approaches that locate pure spectra (called endmembers) in imagery, and those that construct libraries from reference polygons in imagery, field and laboratory collections or radiative transfer simulations. The former approach tends to produce compact spectral libraries, but often generates spectra that are physically unrealistic or mixed. In contrast, the latter approach tends to generate excessively large libraries that result in considerable confusion between similar materials and result in an excessive number of combinations between endmembers that makes computation of fractional cover infeasible.

In this talk, I will provide an overview of several common “pruning” techniques, designed to optimize spectral libraries by selecting subsets of spectra that maximize between class spectral differences, while capturing variability within a class. I will introduce the concept of hierarchical meta data, which enables researchers to optimize libraries to discriminate materials at different levels of organization ranging from broad classes such as green vegetation, to plant functional types or species. Optimization approaches I will discuss include Count-Based Endmember Selection (COB), Endmember Average RMS (EAR), Mean Average Spectral Angle (MASA) and Iterative Endmember Section (IES). COB optimizes endmembers by identifying spectra within a class that model the highest number of spectra within that class in a spectral library. EAR and MASA select spectra within a class that best fit the class, either by selecting the spectrum within a class that has the lowest Root Mean Squared Error (RMSE) when used to unmix all spectra within that class, or by selecting the spectrum with the smallest mean spectral angle within that class. IES is an iterative approach that initially selects the spectrum within a library that generates the highest kappa coefficient when used to classify all spectra in the library. Endmembers are then added iteratively by selecting additional spectra that, in combination with earlier selections, produce the highest improvement in kappa. I will also discuss synergies with wavelength optimization approaches, such as the Instability Index and Stable Zone Unmixing. Using examples drawn from research in natural vegetation and urban environments, I will discuss the advantages and disadvantages of each approach. I will conclude with a discussion of the challenges we will face as we transition from local case studies to global, multi-seasonal data sets.

2-4C SPECSESS GENERICLIBS: UNLOCKING THE POTENTIAL OF GENERIC SPECTRAL LIBRARIES FOR REMOTE SENSING APPLICATIONS

RETHINKING SPECTRAL LIBRARIES USING GIS-WORKFLOWS

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Abstract

Spectral libraries are frequently used in imaging spectroscopy to collect and describe spectral profiles from field campaigns, laboratory measurements, or air- and spaceborne spectrometers. Describing the spectral characteristics of exemplary materials, surfaces, or land-covers, spectral libraries like the USGS Spectral Library, ECOSTRESS or SPECCHIO are an important reference for further analyses. Spectral profiles in these libraries can be used, e.g., to simulate or classify satellite images, to unmix land cover fractions, or to calibrate biophysical models [1, 2].

As diverse as the creation and use of spectral libraries can be, so are the ways how spectral profiles and their metadata are made available. Libraries and spectra are commonly searched and downloaded manually from webpages, while some providers also offer project specific APIs. Spectral libraries are usually available in different formats (e.g., CSV text files, binary formats or a combination of both). While widely accepted formats (TIFF, Shapefile, …), metadata standards (Dublin Core, FGDC, …), and libraries for reading and writing (GDAL) are common with regard to image processing and geoinformation systems, similar is missing for the handling of spectral libraries.

The EnMAP-Box, a QGIS plugin to visualize and process hyperspectral remote sensing data [3], addresses this problem with a novel approach that realizes spectral libraries based on QGIS vector data workflows. This has various advantages: (i) spectral profiles are linked to geometries, e.g., points or polygons, making the library an integral component of the image analysis workflow. (ii) spectral profiles can define relationships between different measurements and sensor types, e.g., white reference, field measurement and EnMAP pixel profile. (iii) spectral libraries can range from local files to server-based database management systems and offer a maximum flexibility to define required metadata schemes. (iv) the spectral library field types (Integer, Text, Date, …) can be constrained by other data-format specific constraints (not NULL, triggers, foreign-keys, …). This ensures data integrity by design and avoids incorrect inputs. (v) spectral libraries and its metadata can be modified with standard and well-known GIS tools, like the QGIS field calculator.

The EnMAP-Box allows to process spectral libraries with the same processing workflows which are used to analyze raster imagery, e.g., to derive pixel-based land cover fractions or biophysical parameters. This way, processing workflows can be first developed based on spectral library data before they are applied to images. In addition, the EnMAP-Box provides comprehensive tools to import spectral profiles from other spectral library formats, to interactively collect spectral profiles from raster image data, and to visualize spectra dynamically.

Our presentation will explain how the spectral library concept of the EnMAP-Box facilitates the development of generic spectral libraries and discuss its advantages compared to other approaches. We will show how profiles from different sensors can be visualized interactively and be used for subsequent image processing. Finally, we will give an outlook on future EnMAP-Box developments regarding hyperspectral missions like EnMAP.

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2-5 PLENARY: YOUNG SCIENTIST AWARD - PRESENTATION OF CANDIDATE PAPERS AND VOTE

SPATIALLY CONSTRAINED IMAGING SPECTROSCOPY RETRIEVALS

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Abstract

Accurate retrieval of surface reflectance properties in imaging spectroscopy relies upon high-quality recovery of atmospheric parameters. However, the joint retrieval of surface reflectance and atmospheric parameters is an ill-posed problem, with many surface and atmospheric features providing similar spectral signatures that are difficult to disentangle. By constraining the retrieval algorithm through our knowledge of system noise, surface, and atmospheric parameters, this retrieval problem has been made more tractable (Thompson et al., RSE 2018). However, current methods recover the surface reflectance and atmospheric parameters for each spatial pixel independently, which ignores valuable spatial information. In this presentation, we will show how introducing spatial constraints on smooth atmospheric parameters can improve the retrieval of both surface reflectance and atmospheric features in imaging spectroscopy. Atmospheric parameters are expected to vary smoothly across a spatial scene in standard imaging conditions. In order to incorporate this knowledge in our retrieval, we first estimate the atmospheric parameters from a subsampled scene with an uninformed prior constraint on the atmospheric parameters. We then use a Gaussian process regression to estimate the underlying smooth atmospheric field. Using an efficient belief propagation inference method, we estimate the resultant marginal distributions of both the surface and atmospheric properties under the spatially-constrained atmospheric features. We present results from simulated scenes with known atmospheric properties and AVIRIS-NG imagery with collated in-situ measurements to verify the efficacy of introducing spatial constraints for improved surface reflectance and atmospheric retrievals. By introducing spatial constraints into imaging spectroscopy retrievals, we anticipate that we will be able to improve surface and atmospheric retrieval accuracy for a wide variety of surface properties.

2-5 PLENARY: YOUNG SCIENTIST AWARD - PRESENTATION OF CANDIDATE PAPERS AND VOTE

COMPARISON OF UNCERTAINTIES IN THE RETRIEVAL OF VEGETATION TRAITS USING MACHINE LEARNING REGRESSION ALGORITHMS

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Abstract

Hyperspectral imagery allows the retrieval of multiple biochemical and canopy vegetation traits with an unprecedented precision thanks to its rich spectral information, e.g. through trained machine learning algorithms. One of the key questions of retrieval models developed by machine learning algorithms is related to their transferability and robustness when applied to other scenes. In this scenario, a crucial aspect for a retrieval method is its ability to estimate the interval of confidence or uncertainty associated with the predictions. Uncertainty estimates give information about the behavior of the model when applying it to a scene distinct to the ones used for training or validation. Bayesian regression methods, such as Gaussian Processes Regression (GPR), can estimate uncertainties and therefore emerged as an appealing algorithm for retrieval applications. However, the large majority of currently used regression algorithms lack the provision of uncertainties.

In an attempt to introduce uncertainty estimations for multiple regression algorithms, we propose the usage of a bootstrapping-based methodology. This method consists of taking random subsets from the training dataset, and so realizing a set of distinct models. In this approach, the mapping prediction consists of the mean of the predictions of all the models, and the associated uncertainty estimate will be the standard deviation of the models. This type of uncertainty is closely related to the data distribution in the input space.

To demonstrate the validity of this bootstrapping method, we present a comparison of distinct regression algorithms for the retrieval of vegetation traits along with derived uncertainties. We analyzed the following four regression algorithms: (1) GPR, which already calculates an estimation of the uncertainty intrinsically; (2) Partial Least Squares Regression (PLSR), calculating its uncertainty by making use of the bootstrapping methodology; (3) Kernel Ridge Regression (KRR), again using bootstrapping; and (4) Random Forest (RFR), calculating uncertainty using a quantile regression tree. The analysis mainly focused on two aspects: computational cost, as it can be a main factor when used in operational contexts, and the interpretability of the retrieved uncertainties. To train the models, we used both simulated data generated with the radiative transfer models PROSAIL, and real hyperspectral data belonging to CHRIS/PROBA and PRISMA missions together with corresponding in situ data. These datasets were chosen to be able to analyze possible dependencies related to spectral variability. For the comparison of the computational cost we trained the algorithms and reported their training and validation times. In the case of the bootstrapping method, we evaluated their performance by varying the number of models used, as this is one of the key parameters determining the computational cost. For the interpretability comparison, we applied the algorithms to simulated scenes and analyzed the uncertainty behavior according to distinct surface covers.

All analyzed algorithms were developed and implemented in the scientific Automated Radiative Transfer Models Operator (ARTMO), a MATLAB-based software environment. ARTMO allows the users, among others, to generate training databases from diverse RTMs and to train and evaluate a diversity of machine learning methods in its Machine Learning Regression Algorithm (MLRA) toolbox. The bootstrapping method has been implemented in the latest version of the MLRA toolbox (v1.27) as a new module, enabling that any MLRA can provide maps of estimates with associated uncertainties. In conclusion, the new bootstrapping module enables the ARTMO users to evaluate MLRAs on their robustness by giving information about the confidence interval of the trained models.

Provided uncertainties will further support the correct interpretation of retrieved vegetation traits obtained from current and upcoming hyperspectral missions.

2-5 PLENARY: YOUNG SCIENTIST AWARD - PRESENTATION OF CANDIDATE PAPERS AND VOTE

EMULATION OF HYPERSPECTRAL IMAGERY FROM SENTINEL-2 IMAGES USING REGRESSION NEURAL NETWORKS

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Abstract

Imaging spectroscopy provides unprecedented information for the evaluation of the environmental conditions in soil, vegetation, agricultural and forestry areas. The use of imaging spectroscopy sensors and data is growing to maturity with research activities focused on proximal, UAV, airborne and spaceborne hyperspectral observations. However, there are only a few imaging spectroscopy satellites presently in operation, implying that satellite-based hyperspectral data is still scarce. An alternative approach is to emulate synthetic hyperspectral data from multi-spectral satellites, such as Sentinel-2 (S2). The principle of emulation is approximating the input-output relationships by means of a statistical learning model, also referred to as emulator. The core idea is that once the emulator is trained, it allows generating synthetic hyperspectral images consistent with an input multispectral signal, and this at a tremendous gain in processing speed. A synthetic hyperspectral image is an image that is artificially created from a set of spectral data. Emulating a synthetic hyperspectral image from multi-spectral data is challenging because of its one-to-many input-output spectral correspondence. To overcome this, thanks to dimensionality reduction techniques that take advantage of the spectral redundancy and non-linear relationships between the low resolution and high spectral resolution data, the emulator is capable of relating the output hyperspectral patterns that can be consistent with the input spectra. As such, emulators can reconstruct the spectral signature with a much higher spectral level of detail.

To achieve the main objective, we trained an emulator using two coincidentally recorded reflectance subsets. The S2 multi-spectral spaceborne image was used as input for generating the emulator, while a HyPlant airborne hyperspectral image was used as output. The images were recorded on 26th and 27th June 2018, respectively, and were acquired around the city of Jülich in the western part of Germany. The S2 image provides multispectral information in 13 spectral bands covering the range from 430 to 2280 nm. The used image was acquired by the MSI sensor of S2A and provided bottom-of-atmosphere (BOA) reflectance data (L2A). The HyPlant DUAL image provides contiguous spectral information from 402 to 2356 nm with a spectral resolution of 3-10 nm in the VIS/NIR and 10 nm in the SWIR spectral range. We used the BOA reflectance product of nine HyPlant flight lines mosaiced to one image and compared it with the S2 scene.

We evaluated the potential of emulators to generate synthetic hyperspectral reflectance data cubes from the S2 image. The following factors were systematically investigated to evaluate the emulator performance: number of bands, spatial resolution, type of machine learning regression algorithm (MLRA) and sample size of the training data. The highest accuracy was achieved by using a neural network (NN) to develop an emulator based on 100.000 randomly selected training samples. This method proved to be powerful and reliable for the rapid generation of a huge hyperspectral reflectance image covering a large area. In summary, the presented emulator approach offers possibilities for the fast generation of synthetic hyperspectral scenes using only data from multi-spectral images. The validation of emulated data against reference data demonstrated the potential of the technique, obtaining values of R^2 between 0.75 - 0.9 and NRMSE between 2 - 5% in full spectral range. Finally, it must be remarked that emulated imagery does not replace hyperspectral image data recorded by spaceborne sensors. However, they can serve as synthetic test data in the preparation of future imaging spectroscopy missions such as FLEX or CHIME. Furthermore, the emulation technique opens the door to fuse high spatial resolution multi-spectral images with high spectral resolution hyperspectral images.

2-5 PLENARY: YOUNG SCIENTIST AWARD - PRESENTATION OF CANDIDATE PAPERS AND VOTE

MODELING SPECTRAL AND DIRECTIONAL SOIL REFLECTANCE IN THE SOLAR DOMAIN (400-2500 NM) AS A FUNCTION OF MOISTURE CONTENT

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Abstract

Soil moisture content (SMC) plays a key role in the interactions between land surfaces and the atmosphere. Its estimation is therefore essential for applications such as agriculture, hydrology, climate, or defense. Because of the high temporal and spatial variability of soil moisture, field measurements are not well suited for mapping this variable over large areas. Since the 1970s, airborne or satellite remote sensing has emerged as a promising tool for estimating SMC. Different wavelength ranges can be used: solar (0.3-3 µm), thermal infrared (3-12 µm), and microwave (0.5-100 cm). The longer the wavelength, the deeper the water can be probed. In the solar domain, light penetrates very little into the soil because it is quickly absorbed: SMC is estimated over a maximum depth of about one millimeter.

The challenge to quantify soil moisture content is to link the reflectance spectrum to the SMC. MARMIT (Bablet et al. 2018. Remote Sens. Environ.), a two-layer radiative transfer model that depicts a wet soil as a dry soil topped with a thin layer of pure liquid water, can be used for that purpose. This water layer may not fully cover the soil, allowing for dry and wet areas. The reflectance spectrum of wet soil can be expressed as a function of the reflectance spectrum of the corresponding dry soil and two input parameters: the thickness of the water layer and the surface fraction of wet soil. MARMIT predicts SMC with relatively good accuracy but the fit between measured and modeled reflectance spectra is unsatisfactory, especially for high moisture contents in the water absorption bands around 1.4 µm and 1.9 µm. To address this issue, we developed an improved version of MARMIT, called MARMIT-2 (Dupiau et al. 2022. Remote Sens. Environ.), in which soil particles are included in the water layer, adding two new parameters: a fixed one, the complex effective refractive index of soil particles, and a free one, the volume fraction of soil particles. MARMIT-2 has been validated on a database of 225 soil samples whose reflectance spectra have been measured in the laboratory at various moisture contents. The RMSE between the measured and modeled reflectance spectra is on average 0.8% with MARMIT-2 versus 1.8% with MARMIT.

For MARMIT-2 to be operational for remote sensing, it is necessary to study the variation of the reflectance of a wet soil as a function of the spatial resolution: laboratory reflectance measurements are performed on a disk of about 2 cm in diameter at the surface of soil samples, whereas the spatial resolution of an airborne hyperspectral image is of the order of a few meters. In order to understand the effects of surface roughness on spectral and directional reflectance, we studied the BRDF (Bidirectional Reflectance Distribution Function) of wet soil samples both experimentally and numerically. We measured the BRDF of several flat samples of agricultural and desert soils at various moisture levels. Using these measurements coupled to a high-resolution DTM (Digital Terrain Model) cut into micro-facets, we simulated the BRDF of rough wet soils with DART (https://www.cesbio.cnrs.fr/dart/), a ray-tracing software developed at CESBIO. The BRDF of the micro-facets is modeled by non-linear models such as the Hapke model or the RPV (Rahman-Pinty-Verstraete) model. The simulated BRDFs of rough and wet soils will be presented.

2-5 PLENARY: YOUNG SCIENTIST AWARD - PRESENTATION OF CANDIDATE PAPERS AND VOTE

SOLAR PHOTOVOLTAIC MODULE DETECTION BASED ON MULTI-SOURCES HYPERSPECTRAL DATA

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Abstract

Solar photovoltaic is a promising and growing resource for green energy generation. Detecting and monitoring the performance of photovoltaic modules is necessary. The use of remote sensing data has the potential to avoid labor- and time-consuming fieldwork. However, current research on PV detection mostly focuses on airborne and spaceborne color images, which require high spatial resolution i.e., about 30 cm per pixel, and can lead to confusion with the module types due to similar structure (e.g., solar thermals) or color (e.g., dark PV arrays on dark roofs). Hyperspectral images allow the exploitation of the material-specific spectral characteristics of PV modules to identify and separate them from spectrally similar surfaces.

The city of Oldenburg in Germany was selected as the study area because of the presence of various PV installations, including large PV power plants and small PV modules, etc. In order to train a classifier, a set of laboratory measurements of two PV samples and other similar material samples with a goniometer setting of 60 spectra per sample and a large library containing HyMap spectra of 31 urban surface material classes (5627 spectra samples) were implemented. In addition, the airborne HySpex data over the city of Oldenburg were used, which were acquired in July 2018 and pre-processed to a spatial resolution of 1.2 m.

In this study, we defined and developed a combination of spectral indices for PV materials based on laboratory measurements of PV modules and a large urban surface material spectral library, and then applied the spectral indices to airborne HySpex data. The results show that the approach can provide accurate PV area classifications. Specifically, the combination of spectral indices is able to accurately detect PV modules in different arrangements and within different environments, without requiring explicit training samples for each setting, but purely based on their spectral characteristics. The spectral indices derived from robust spectral features can effectively identify PV areas, and a clear advantage of the presented approach is that it works well even in the absence of large amounts of labeled training data. However, for the detection of new types of PV modules (e.g. thin-film PV), the features for new PV materials must be included.

The proposed approach aims at providing an applicable, robust, and transferable method for PV module detection using hyperspectral data by exploring the physical-based robust spectral features of PV modules. The benefits are not limited to detecting the areas and sizes of PV modules, but may also enable the detection of surface dust thickness and defection of PV modules in the near future. Our goal is to create greater awareness of the potential and applicability of airborne and spaceborne imaging spectroscopy data for PV module identification and monitoring. Moreover, this work is intended to enrich the current spectral library for urban surface materials, with particular attention to specific materials such as PV modules, and to make it adaptable and expandable.

3-1A THEMSESS BIODIV: ANALYZING AND MAPPING BIODIVERSITY WITH IMAGING SPECTROSCOPY DATA

WHY THE LINK BETWEEN SPECTRAL VARIATION AND BIODIVERSITY IS WEAK

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Abstract

Mapping and monitoring biodiversity by means of passive optical remote sensing is an important contribution to conserve biodiversity. Various strategies have been suggested to relate remote sensing data with field-measured biodiversity metrics (mostly number of plant species in a given area). Within this context, the spectral variability hypothesis (SVH) has received a lot of attention amongst others probably due to its intriguing simplicity. The SVH states that the higher the spectral variation in a given area is, the higher is its biodiversity. The underlying assumption is that higher spectral variation is caused by a higher variation in habitats or plant communities or species (depending on scale). In this study, we discuss the SVH with respect to several variables that influence the spectral signal observed by remote sensing sensors including for example scale and phenology. Furthermore, we conduct data simulation experiments based on hyperspectral FieldSpec data to demonstrate that the metric used to capture spectral variation has an important influence on the link between plant species counts and spectral variation. Finally, we showcase conceptual flaws in the SVH which relates to the problem that individual habitats or plant communities with very high species richness will severely affect biodiversity metrics but often have a marginal influence on spectral variation. The discussed findings are not only relevant for the SVH but also for most other remote sensing approaches to map and monitor biodiversity.

3-1A THEMSESS BIODIV: ANALYZING AND MAPPING BIODIVERSITY WITH IMAGING SPECTROSCOPY DATA

RELATING SPECTRAL VARIANCE TO TAXONOMIC DIVERSITY: EXPERIMENTAL EVIDENCE FROM IMAGING SPECTROSCOPY OVER A TROPICAL FOREST

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Abstract

Biodiversity conservation is challenged by multiple factors related to global change. Remote sensing is a crucial source of information towards operational biodiversity monitoring systems. Optical sensors are widely used to study vegetation, as canopy reflectance results from interactions between incoming light and key vegetation properties. High spatial resolution imaging spectroscopy has shawn strong potential to estimate plant diversity in various ecosystem types. Spectral diversity metrics are often used as an indicator of various dimensions of plant diversity, including taxonomic, structural and chemical diversity. This hypothesis is scale dependent and a variety of spectral diversity metrics can be derived from remote sensing data, with potentially very different capacity to relate to biodiversity.

Our objective was to identify relevant spectral information to be used for the computation of spectral variance, and for estimating taxonomic diversity from tropical forested ecosystems using high spatial resolution imaging spectroscopy. The link between spectral diversity and taxonomic diversity is usually limited by ground information, which is mainly obtained from a limited number of inventoried field plots. Here, we took advantage of an experimental dataset including spectral information extracted from visible to near infrared imaging spectroscopy acquired over an experimental tropical forest station in French Guiana, encompassing about two thousand individual tree crowns from two hundred species. Each individual tree was carefully delineated based on a combination of very high spatial resolution imagery, airborne LiDAR, plot inventories, and ground validation. We explored the relationship between spectral variance and taxonomic diversity expressed as Shannon index by generating a set of artificially assembled communities covering a broad range of taxonomic diversity. Each individual community included one thousand pixels extracted from one hundred tree crowns, selected from two to one hundred species. We analyzed the correlation between Shannon index and the variance computed from spectral information following various preprocessing steps, including spectral normalization, spectral transformation through principal component analysis (PCA), and feature selection. The feature selection was applied on reflectance, normalized reflectance, and PCA-transformed normalized reflectance. We analyzed total spectral variance, inter/intra specific and inter/intra crown components.

The correlation between total variance of reflectance and Shannon index was weak, while reflectance normalization resulted in substantial increase in correlation. This evidenced the influence of multiple factors extrinsic of species and species traits on spectral variance, such as illumination effects, which were partly removed from the signal after normalization. The application of feature selection resulted in dramatic improvement of the correlation between Shannon index and spectral variance for all types of reflectance. The spectral variance computed from normalized and PCA-transformed normalized reflectance showed strong correlation with Shannon index, while the correlation obtained from raw reflectance showed high variability, ranging from poor to moderate.

Our results evidence the relationship between spectral variance and taxonomic diversity but highlight i) lack of robustness of the spectral diversity metrics computed from unprocessed reflectance, and ii) strong potential of properly preprocessed and selected spectral information acquired at metric spatial resolution to predict taxonomic diversity in tropical ecosystems. The influence of spatial resolution and spectral sampling is now investigated in order to assess the applicability of these results to decametric resolution multispectral satellites (Sentinel-2) and future satellite missions including spaceborne imaging spectroscopy sensors (CHIME, SBG).

3-1A THEMSESS BIODIV: ANALYZING AND MAPPING BIODIVERSITY WITH IMAGING SPECTROSCOPY DATA

EVALUATING DISTORTION FACTORS IN THE ASSESSMENT OF PLANT SPECTRAL DIVERSITY FROM ULTRA-HIGH RESOLUTION HYPERSPECTRAL IMAGERY

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Abstract

The loss of biodiversity and decline in worldwide ecosystems require comprehensive monitoring, especially for vegetation which plays a pivotal role in mitigating global climate change providing an array of vital ecosystem services. Vegetation spectral diversity (i.e. diversity in spectral reflectance derived from remote sensing data) is known as an expression of plant phylogenetic, taxonomic, and functional diversity of plant communities. Assessing vegetation spectral diversity starts with remote sensing techniques that exceed traditional methods - too expensive, date lagged, and time-consuming - and offer a synoptic view with higher temporal resolution.

Limitations of resolutions achievable from multispectral spaceborne sensors have boosted the use of airborne hyperspectral cameras data, acquired with metric spatial resolution, for monitoring vegetation, and applications of image spectroscopy are under development for mapping phenological changes, providing biochemical and structural features, and assessing community diversity and health.

The recent development of lightweight, fully hyperspectral cameras to be integrated on UAV platforms, opened the way to assessing spectral plant diversity at detail scales which were unthinkable till some years ago. The potential of using ultra-high resolution (< 5 cm pixel) hyperspectral imaging in mapping vegetation spectral diversity lays in the massive amount of data on spatial and structural plant community patterns that can be detected during a flight, theoretically providing means for mapping and monitoring individuals across scales - from detecting species composition within a community up to characterizing traits from single leaves. On the other hand, centimetre-scale imagery features spectral/spatial distortion factors, such as fine-scale internal and cast shadows in canopy elements, variable view angles, and illumination conditions, presence of non-photosynthetic vegetation (e.g. flowers, trunks/branches, dead leaves), small gaps in the canopy, which all together contribute to uncertainties towards practical use of spectral data to infer plant diversity features. The main aim of this work is to evaluate some of these uncertainties by taking into account changes in spatial scales and propose approaches for mitigation and correction, with a specific focus on wetland and aquatic plant communities.

For this purpose, ultra-high (3-4 cm nominal pixel size) resolution data acquired from a pushbroom hyperspectral sensor (range 400-1000 nm, 270 spectral bands) carried on board of a UAV platform, were collected during flights carried out over aquatic vegetation communities in summer 2021, covering wetland study sites located in northern and central Italy: Lake Pusiano, Lake Annone, Torbiere del Sebino wetland, Mantua Lakes system, and Lake Massaciuccoli. Across these sites, a total number of 80 vegetation plots were surveyed, 44 on riparian helophyte communities and 36 on emergent/floating hydrophyte communities comprising 29 plant species.

Starting from this dataset, we investigated the influence of some disturbing factors (e.g. illumination conditions from direct sunlight to overcast sky, differences in plant material brightness due to leaf orientation and shadowing), with varying spatial resolution from centimetric to decimetric and metric pixel size. Outputs of such assessment were channeled into a methodological workflow for evaluating the distortions brought on hyperspectral imagery radiometry. The final outcome can contribute to a preliminary framework of ultra-high

hyperspectral image processing for vegetation mapping and monitoring, comprising pre-screening of data immediately after the acquisition, towards filtering and/or mitigating distortions due to isolating spectrally meaningful information on photosynthetic material from which to derive quantitative information (e.g. classification, biochemical and morphological traits), relevant for assessing plant spectral diversity.

3-1A THEMSESS BIODIV: ANALYZING AND MAPPING BIODIVERSITY WITH IMAGING SPECTROSCOPY DATA

MAPPING PEATLAND VEGETATION COMMUNITIES ON THE REWETTED FENS WITH AVIRIS-NG AND PRISMA DATA

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Abstract

Peatlands play a crucial role in climate change mitigation. On the one hand, intact peatlands play an essential role as carbon sinks. On the other hand, peatlands are a substantial source of carbon emissions when drained. In the federal state of Mecklenburg-Western Pomerania of northeastern Germany, 95 per cent of the original peatlands are drained. These are the single most extensive source of carbon emissions in this little industrialised region. Thus, various initiatives have been taken for peatland restoration, e.g. rewetting on fen or coastal peatlands. Before rewetting, most areas were used as cropland or grassland; hence alternative schemes for agricultural usage are needed. Paludiculture is one way to utilise the areas after rewetting, e.g., planting cattail (Typha spp.). Remotely monitoring the success of cattail paludiculture could be possible by regularly estimating the area and the biomass of cattail. However, challenges exist due to the significant spectral variation of a single species itself over the year, the spectral similarity of different peatland species, and the complex spatial patterns with shadowed regions. Thus, imaging space-borne spectroscopy data (PRISMA and EnMAP) with multiple observations during the year seems to be a promising approach for spatial-temporal monitoring of peatland vegetation communities in rewetted sites.

We investigated the possibilities of mapping cattail and common reed within a complex landscape of the Peene river valley in Mecklenburg-Western Pomerania using multitemporal PRISMA scenes and high spectral resolution AVIRIS-NG data. We have downloaded the PRISMA level-2D data, acquired on 19/04/2021, 10/06/2021, and 31/08/2021, consisting of ~ 250 bands at 30 m ground sampling distance. We downloaded the AVIRIS-NG level-2 product, acquired on 30/05/2021, containing 5.4m GSD and 430 spectral bands. We co-registered PRISMA and AVIRIS-NG data with Planetscope images using the Arosics python module. Data on the extent of fens and their possible rewetting status were available through the Global Peatland Database at the Greifswald Mire Centre. Moreover, a field visit was conducted to manually map areas covered by cattail and common reed and other peatland species.

We have classified the AVIRIS-NG data into land cover classes, including urban, water, open soil, cropland, grassland, forest, shrubs, cattail and reed using machine learning algorithms in the EnMAP-Box. The PRISMA data were quantitatively mapped into land cover fractions of respective classes using regression-based unmixing with synthetically mixed training data using the EnMAP-Box. The classification results show that the high spectral information content of the AVIRIS-NG data allows for the identification of pure areas of the wetland vegetation. However, vegetation mixtures with water make the classification more challenging. Similarly, the regression results on the 30m PRISMA data vary significantly in accuracy, relying on the purity of pixels. The use of multiple dates became complicated due to the variation in the water table; therefore, diverse mixtures with peatland vegetation pixels accompanied by water and grassland classes.

Further additional trials will be conducted to improve the accuracy before the presentation. Current results show the significant influence of water and background vegetation on classification and regressions precisions. Furthermore, the complexity introduced by the water table variation may lead to mapping approaches that rather focus on the best date approach, i.e. a moment in phenology where class separability is highest, rather than a multitemporal approach. However, further analyses are needed to check the single vs multi-season approach for peatland species mapping, especially by using more multitemporal space-borne data (e.g. after the launch of the EnMAP and HyspIRI satellites).

3-1A THEMSESS BIODIV: ANALYZING AND MAPPING BIODIVERSITY WITH IMAGING SPECTROSCOPY DATA

DERIVING PLANT GENETIC DIVERSITY FROM IMAGING SPECTROSCOPY SYSTEMS

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Abstract

Remote sensing has demonstrated its potential for wide-scale biodiversity monitoring. It overcomes the spatial limitations of ground-based measurements and allows repeated acquisitions of spectrally resolved data. Among remote sensing approaches, imaging spectroscopy can provide spectrally extensive information, which is indicative of multiple physiological and structural plant traits, and can be associated with genetic identities of plant individuals. Genetic diversity among individuals is a key aspect of biodiversity because it captures the adaptive potential of a plant population in changing environments. Loss of genetic variability can increase the susceptibility of a population to diseases, limits its evolutionary potential and may lead to inbreeding depression. Ground-based monitoring of genetic variation within species is extremely work-intensive, but this limitation might be overcome if a link between spectral and genetic information could be established, allowing remote assessments from above a plant canopy. We combined airborne spectral measurements with ground-based DNA sampling of the tree species Fagus sylvatica L. (common beech) as a model towards establishing links between spectral and genetic diversity over large areas and at regular time-intervals.

We selected 19 sites with well-preserved forests dominated by F. sylvatica and distributed across the species range in Europe. We collected spectral data with a hand-held ASD FieldSpec spectroradiometer from sunlit leaves of ten individual trees at each site (7 at one), with an airborne instrument (AVIRIS-NG, NASA JPL) above ten sites, and from the spaceborne satellites DESIS (The DLR Earth Sensing Imaging Spectrometer, The German Aerospace Center) and PRISMA (Hyperspectral Precursor of the Application Mission, The Italian Space Agency) above each site. The spectral images were acquired in May–July 2021; the leaf-level measurements were obtained in July–September 2020 and in July 2021 together with collection of leaf tissue from which we derived genetic information. Genetic data comprise sequences of nuclear DNA of 187 tree individuals.

Relationships between spectral and genetic signatures are now being analyzed. As a first step, we derive population structure and genetic distances from nuclear microsatellites and associate these with variations among leaf spectra. We investigate to what extent either measure is related to variation in leaf surface micromorphology as a further indicator of plant phenotypic variation. For assessments of genetic variation underpinning spectral and phenotypic variation, we plan on conducting genome-wide association studies with spectra. We plan to conduct the spectral-genetic associations on leaf, canopy and patch levels and discuss potential mismatches induced by technical and biological variations across these levels. Based on this analysis, we will present and discuss the potential of imaging spectroscopy to assess genetic variation within species at large spatial scales.

3-1B THEMSESS DEVELOPMENTS: RECENT SOFTWARE AND SENSORS DEVELOPMENTS, INCL. SPONSORED TALKS

HYPERNOR; PLANS FOR A HYPERSPECTRAL IMAGER FOR MICROSATELLITES

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Abstract

Fast and economical access to space are among the characteristics of small satellites, making remote sensing data available for a broader range of communities. Due to their small size, several micro-satellites can be launched at the same time, and constellations of microsatellites are feasible due to their low cost. The temporal resolution and ground coverage that can be achieved from a constellation of these satellites cannot be matched by a single, large, satellite.

The Ground Sampling Distance (GSD) of existing and planned satellite Hyperspectral Imagers (HSIs) is rarely less than 30 meters in the SWIR range (1000 to 2500 nm) and rarely less than 10 meters in the VNIR range (400 to 1000 nm). Based on interviews with existing customers of Norsk Elektro Optikk (NEO) and what we regard being the general opinion of the participants of the PRISMA workshop (April 2021), we have concluded that the GSD appears as a weak point limiting the usefulness of existing, institutional, instruments. Additionally, these huge instruments require equally large satellite platforms, and in the end the cost will also be huge.

Having high spatial resolution as one of the major goals for the HSI design unavoidably leads to an instrument with a narrow swath. These conflicting design parameters will determine the usefulness of the instrument in different applications. The focus remains on the GSD spec, since an unsatisfactory swath width can be compensated by using a satellite constellation, whereas GSD, once designed, cannot be changed. Also, some of our existing customers explicitly stated that they would rather have smaller GSD – even if this means having narrower swath.

Creating a high-performance HSI that is compatible with a small platform, is a challenge. Achieving useful spatial resolution in combination with acceptable signal-to-noise-ratio (SNR) is particularly difficult. One of the goals of the development in this project is to devise an HSI that surpasses the common limitations introduced by small satellite platforms and, in some respects, provides hyperspectral data that are better than what is currently available for free from larger instruments.

To design a hyperspectral imager for a microsatellite, it was necessary to make compromises between parameters like ground sampling distance (GSD), swath, spectral sampling, and signal to noise ratio (SNR). We have focused on making the GSD as good as possible while keeping the other parameters within an acceptable range.

This will be the first presentation of this project, and as we are early in this development program the presentation will focus on some of the initial decisions that have been taken, the predicted instrument performance and the foreseen roadmap.

The instrument development is funded by the Norwegian Space Agency via ESA's GSTP-6.

3-1B THEMSESS DEVELOPMENTS: RECENT SOFTWARE AND SENSORS DEVELOPMENTS, INCL. SPONSORED TALKS

PHYSICAL ATMOSPHERIC CORRECTION OF UAS IMAGING SPECTROSCOPY DATA BY DROACOR® IN COMPLEX TOPOGRAPHY

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Abstract

Reflectance retrieval from low altitude, UAS based imaging spectroscopy data is often done by normalization to in-situ reference panels. Such methods are a valid approach for a small number of image data takes. However, this approach bears some problems for large scale data acquisitions: The variability of the irradiance due to terrain and adjacency influences can not be easily considered and temporal changes of illumination in the course of long data acquisitions can not be tracked. Furthermore, the whole normalization relies on a singular panel reference which is prone to pollution and is to be positioned within the image scene at a well suited reference position.

The new atmospheric correction software DROACOR® (Schläpfer et al., ISRS Int. Arch, Vol. XLIII-B3-2020) has been developed and further enhanced in view of such complex data acquisitions. It relies on modern laboratory-calibrated imaging spectroscopy instruments and can be operated without reference panels. The model uses the LibRadtran radiative transfer code (Mayer et al. 2019, www.libradtran.org) in combination with digital elevation data and standard image meta data streams for modelling transmittances, direct irradiance and diffuse irradiance including adjacency effects on a per-pixel level in order to solve for the bottom of atmosphere reflectance. The aerosol optical thickness is calculated by an enhanced dark target approach whereas the total water vapor amount is derived by spectral fitting to the modelled spectra. Residual atmospheric influences are reduced by a transmittance-based optimization and subsequent spectral 'polishing' techniques by Savitzky-Golay and derivative filters are applied, while omitting fully absorbing spectral bands.

Subsequently to the BOA reflectance calculation, the terrain influence is corrected using the modified Minnaert semi-empirical correction. Cast shadows can be corrected by quantifying the diffuse irradiance in the shaded areas for optimization of the diffuse irradiance model in fully shaded areas. Finally, a standard BRDF model can be used for reducing the observation geometry based BRDF effects. The combination of theses methods in a streamlined workflow allows to retrieve relatively consistent reflectances even for very complex topography and oblique observation geometries.

The method is evaluated based on a demanding data set acquired in summer 2019 in North-East Greenland over a mountainous area using the NEO Mjolnir VS-620 instrument instrument (NEO 2022, www.hyspex.com). A helicopter-based integrated imaging system was designed for collecting oblique hyperspectral data cubes and simultaneous stereo images to provide low altitude data in steep terrain (Salehi 2019, FEM conference).

Geometric processing is done using an updated PARGE® method (Schläpfer 2020, manual.parge.com), capable of handling such off-nadir acquisitions even if parts of the image are reaching over the horizon line. A DEM generated from collected image sets has been used and a coregistration between VNIR and SWIR detector on the pixel level could be achieved for most areas as long as the observation geometry was better than 80° between observation and surface. True pixel distances and observation angles from the PARGE® mapping are then used as major inputs for the subsequent DROACOR® reflectance retrieval.

The finally achieved reflectance spectra are evaluated against geological reference spectra. The evaluation shows consistent mapping results across the spectrum and in variable terrain. It can be shown that physical radiometric processing now is feasible even for challenging data acquisitions such as in the arctic region.

3-1B THEMSESS DEVELOPMENTS: RECENT SOFTWARE AND SENSOR DEVELOPMENTS, INCL. SPONSORED TALKS

EUFAR - CURRENT STATUS AND DEVELOPMENT

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Abstract

Created in 2000, EUFAR was born out of the necessity to create a central network for the airborne research community in Europe with the principal aim of supporting scientists, by granting them access to research aircraft and instruments otherwise not accessible in their home countries. In essence, EUFAR links scientists with operators of research facilities including airborne imaging spectroscopy facilities.

In 2017, EUFAR was transformed into an AISBL – an international non-profit association under Belgian law. Currently, EUFAR consists of 14 members and 4 partners.

Among the main objectives of the EUFAR AISBL belong to assure some previous EUFAR activities e.g. database of previously acquired datasets as well as portal www.eufar.net and coordination of the existing airborne infrastructures.

Developments for the short term include realization of a metadata database of datasets acquired by all EUFAR members and partners including imaging spectroscopy datasets. Planned is also list of future airborne campaigns, so interested users could join the campaign.

The medium-term EUFAR ambition is creating an integrated Infrastructure supported by Horizon Europe together with the HEMERA consortium and the COST community HARMONIOUS. Our effort aims at defining the frame of a Research Infrastructure (RI) that could act as a single point of contact for all users interested in airborne (manned/remotely piloted)/balloonborne exploratory, mobile, deployable observing systems across all areas of the Earth system - atmosphere, hydrosphere, biosphere, solid Earth, surface.

3-1B THEMSESS DEVELOPMENTS: RECENT SOFTWARE AND SENSORS DEVELOPMENTS, INCL. SPONSORED TALKS

PARTIALLY SUPERVISED DETECTION IN HYPERSPECTRAL IMAGERY

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Abstract

In this presentation we utilize three partially supervised least squares unmixing detection methods referred to here as the UnConstrained Abundance, Nonnegatively Constrained Abundance and Fully Constrained Abundance methods. Their performance is compared against some of the current state-of-the-art detection methods including the Adaptive Cosine/Coherence Estimator, Matched Filter, Spectral Angle Mapper, Constrained Energy Minimization and Mixture Tuned Matched Filter. It can be difficult to characterize the performance of detection algorithms using field data, especially at the subpixel level, due to limited ground truth. Fortunately, the SpecTIR Hyperspectral Airborne Experiment (SHARE) 2012 contains multiple sets of targets for testing detection algorithms with excellent ground truth. Field reflectance spectra collected with a SpectraVista SVC-1024 field spectrometer were used for six target spectral signatures. Four of the six targets tested were placed in a large multiple pixel checkerboard pattern, with each square of the checkerboard containing a subpixel target. Each method is initialized with a single field spectral target signature, and detection performance of each method is separately assessed for each of the six targets. Detailed evaluation of these detection methods on the SHARE 2012 hyperspectral data is provided.

3-1B THEMSESS DEVELOPMENTS: RECENT SOFTWARE AND SENSORS DEVELOPMENTS, INCL. SPONSORED TALKS

VISUAL DATA ANALYSIS & EXPLORATION TOOLS IN THE ENMAP-BOX PLUGIN FOR QGIS

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Abstract

Visual data analysis and exploration of hyperspectral imagery in free and open-source software (FOSS) GIS is getting more attention recently, due to the PRISMA, DESIS, and the upcoming EnMAP missions. In contrast to remote sensing software like ENVI, SNAP and ERDAS Imagine, FOSS GIS software like QGIS was originally not developed with spectral wavelength characteristics in mind. While this drawback may be acceptable for multi-spectral imagery like Landsat and Sentinel-2, it becomes problematic for hyperspectral data management.

The EnMAP-Box is especially designed to bridge the gap between a classic GIS with strong focus on vector data and spatial visualization, and remote sensing software with focus on precise raster data handling. QGIS as a platform is strong in visualization, open for third-party Python extensions and has a big and active developer community. Best conditions for developing new tools in an agile and science-friendly way to bring hyperspectral data analysis and exploration into the GIS world.

The EnMAP-Box provides product import functionality for common multi-spectral and hyperspectral sensors like, Landsat, Sentinel-2, PRISMA, DESIS and EnMAP. By assigning spectral wavelength metadata to imported products, the user is enabled to i) properly visualize spectral profiles, ii) select spectral bands for RGB, gray or pseudocolor visualizations by wavelength, iii) resample spectral images into other target sensors using corresponding point spread functions (PSF), e.g. PRISMA to Sentinel-2, and iv) create over 100 predefined spectral indices.

Another focus of a hyperspectral analysis workflow is the exploration of derived products like spectral indices, biophysical variables retrieved from radiative transfer models, classification maps, class probability maps and fractional abundance maps from spectral unmixing. The EnMAP-Box provides several innovative tools for an interactive exploration of such results.

With the Band Statistics tool, the user is enabled to investigate basic statistics for spectral bands/indices like the minimum, maximum, average, standard deviation and histogram for the whole image or interactively updated statistics for the current map extent. The Classification Statistics tool allows users to investigate class-wise statistics like number of pixels, area percentage and total area assigned to a class. Band and classification statistics, offer to analyze an entire image or interactively defining a map extent, while the user can also turn individual classes on and off.

Visualization of class probability and fractional abundance maps is usually limited to three bands at a time. With the Classification Fraction/Probability Renderer and Statistics tool, the user is enabled to visualize an arbitrary number of class fractions at the same time. Original class colors are averaged and weighted by their class fractions. Pure pixels with 100% fraction in a single class will appear in original class colors, while mixed pixels will appear in mixed class colors. Even though original class fractions and renderer RGB values aren't in a one-to-one correspondence, the human-eye can differentiate pure and mixed regions very well.

In conclusion, we showed that the EnMAP-Box plugin for QGIS greatly enhances one of the most popular FOSS GIS software, by introducing the concept of spectral wavelength characteristics. This enables and motivates classical remote sensing software users of ENVI and SNAP to integrate QGIS into their multi- and hyperspectral analysis workflows, gaining all the benefits of a powerful GIS.

3-2A SPECSESS FLUORESCENCE: MEASURING AND UNDERSTANDING SOLAR-INDUCED FLUORESCENCE AS AN INDICATOR FOR ACTUAL PHOTOSYNTHESIS AND VEGETATION FUNCTION

CHALLENGES IN THE RETRIEVAL AND INTERPRETATION OF SUN-INDUCED CHLOROPHYLL FLUORESCENCE FOR ITS USE IN ECOSYSTEM RESEARCH

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Abstract

Remote sensing of sun-induced chlorophyll fluorescence (SIF) provides complementary information to advance ecosystem research in general and assess subtle ecosystem processes (e.g. gross primary production, transpiration) and vegetation stress in particular. Large progress has been made in the past decade concerning the development of dedicated, high-resolution fluorescence spectrometers applicable in situ, from airplanes and satellites. A diversity of retrieval methods exists and is currently under consolidation, and broad ranging SIF based environmental applications are under development.

This contribution consolidates current insights and identifies open challenges that need to be addressed in future research to make SIF a robust and operational measure for diversified ecosystem research. We focus on retrieval challenges concerning i) the consistency of SIF retrievals across scales, ii) the development of schemes to extract the full SIF emission spectrum, and iii) the consideration of 3D vertical canopy structure. We address the interpretation challenge caused by the dynamic nature of SIF and its sensitivity for physiological, structural and other canopy properties. We outline challenges related to the use of SIF to i) mechanistically assess ecosystem processes, and ii) to detect pre-visual vegetation stress dynamics in time and space. Our contribution will help defining research priorities to further advance the use of SIF for ecosystem research.

3-2A SPECSESS FLUORESCENCE: MEASURING AND UNDERSTANDING SOLAR-INDUCED FLUORESCENCE AS AN INDICATOR FOR ACTUAL PHOTOSYNTHESIS AND VEGETATION FUNCTION

HYSCREEN - A GROUND-BASED IMAGING SPECTROMETER SYSTEM MEASURING SOLAR-INDUCED FLUORESCENCE (SIF)

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Abstract

The retrieval of top-of-canopy (TOC) solar-induced fluorescence (SIF), as well as non-photochemical quenching (NPQ), is crucial to improve the remote estimations of plant photosynthetic capacity. The distortions introduced by the canopy structure and changing illumination conditions make relating the measured TOC SIF to leaf level physiological process difficult. Down-scaling TOC SIF to leaf level is needed and can be improved by characterizing the spatial distribution of SIF as well as the incoming light on a single plant. However, due to the lack of imaging spectrometers with adequate spatial and spectral resolution these two processes have not been well characterized. To close this gap, we have developed a ground-based imaging spectrometer system (HyScreen) with a high spatial resolution that measures SIF from the TOC where SIF signals from the individual leaves can be differentiated. HyScreen consists of two imaging spectrometers: the fluorescence (FLUO) module for SIF retrieval with full width mean at half maximum (FWHM) 0.38 nm, and the visible and near infra-red (VNIR) module with mean FWHM 3.36 nm from which vegetation indices can be calculated. Before using HyScreen to derive leaf level physiological process, it is mandatory to develop a measurement protocol and data processing chain and characterize the performance of the system. HyScreen could be mounted either on a movable scaffolding or a more flexible mobile field platform, and for both scenarios measurement protocols were established. The data processing includes dark current correction, radiometric calibration, and atmospheric correction by the empirical line method which enabled calculating TOC radiance. For SIF retrieval at O2B and O2A, the improved Fraunhofer line discrimination (iFLD) and spectral fitting method (SFM) methods were applied. Normalized difference vegetation index (NDVI), photochemical reflectance index (PRI), and transformed chlorophyll absorption in reflectance index (TCARI) were calculated from VNIR data. In this study, two experiments were designed to evaluate the developed measurement protocol and data processing chain. In the first case study, we compared SIF from simple fluorescent and non-fluorescent targets. In the second case study, we compared six replicates of wild type Arabidopsis plants with two mutants either lacking violaxanthin de-epoxidase or PsbS protein, both resulting in reduced capacity to dissipate excess energy by heat through NPQ. In case study one, sunlit fluorescent targets presented fluorescence emissions levels consistent with previous studies (1.13 to 4.24 and 1.96 to 4.62 mW/m2/nm/sr for O2B and O2A), while non-fluorescent targets presented retrieved SIF close to 0 mW/m2/nm/sr. It was further observed that the sunlit leaf area had higher SIF values than the shaded leaf area. In the second case study, SIF signals from Arabidopsis were generally stronger in the plant center coming from the younger leaves. In addition, leaves facing the sun showed higher SIF signals than leaves with other orientations. In comparison to the wild type, both mutants showed higher SIF, higher PRI indicating less NPQ related to violaxanthin de-epoxidase, and no difference in NDVI and TCARI. Lastly, small biases of SIF were observed across-track when targets with high reflectance, which were likely due to stray light effects at the sensor optics. In conclusion, HyScreen captured SIF distribution on plants with simple structure at a very high spatial resolution, demonstrating its potential to characterize SIF emission from leaves on top of canopy, which will translate in an improvement of the remote estimations of plant photosynthetic capacity.

3-2A SPECSESS FLUORESCENCE: MEASURING AND UNDERSTANDING SOLAR-INDUCED FLUORESCENCE AS AN INDICATOR FOR ACTUAL PHOTOSYNTHESIS AND VEGETATION FUNCTION

A MULTI-LAYER PERCEPTRON BASED REGRESSOR FOR SIF RETRIEVAL FROM HYPERSPECTRAL IMAGERY OF THE AIRBORNE HYPLANT SENSOR IN TOPOGRAPHICALLY VARIABLE TERRAIN

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Abstract

Sun-induced fluorescence (SIF) is an important biophysical parameter linked to gross primary productivity of plants and allows the detection of vegetation stress. The retrieval of SIF from hyperspectral imagery allows to follow spatial patterns and photosynthetic dynamics more closely. It could thus prove an important information for monitoring crop growth in the future.

SIF retrieval from hyperspectral images aims at performing a decomposition of the at-sensor radiance into backscattered solar irradiance and fluorescence. This is an ill-posed inversion problem that can be addressed by making use of the spectral variability of atmospheric transfer functions as well as by specific assumptions about the reflectance and the fluorescence spectrum. In traditional retrieval methods fluorescence and reflectance are estimated in a pixel-wise fashion. The atmospheric transfer functions, however, are estimated over arbitrarily defined windows causing performance decreases in regions where variable atmospheric conditions and complex topography invalidate the assumption of a constant atmospheric influence on at-sensor radiance.

We present a neural network trained with a novel semi-supervised loss function. It integrates physical constraints and principles of the Spectral Fitting Method (SFM) to recover SIF from hyperspectral imagery acquired by the airborne HyPlant sensor. As in SFM the loss evaluates the reconstruction error of a physical forward model. However, differently to SFM this approach is able to fit the atmospheric transfer functions locally. Moreover, our predictor relies on the full HyPlant at-sensor radiance spectrum as well as a general distribution of atmospheric transfer functions, only. Our approach to recover SIF could prove an interesting addition to the well-established SFM as it allows to leverage physically motivated constraint formulations for consistent predictions in topographically variable and spectrally complex regions where SFM is known to be unreliable.

We compare our semi-supervised method's predictions to the SFM on different data sets acquired by the airborne HyPlant sensor. While the absolute SIF prediction accuracy is inferior to SFM on average, we can show that the normalized prediction reproduces well spatial and temporal SIF patterns at increased spatial resolution. Our method achieves a Pearson correlation score of 0.8 and RMSE=0.49 mW/nm/sr/m² with respect to normalized SFM predictions on a multi-acquisition HyPlant data set. Upon direct comparison to SIF ground measurements our approach yields a Pearson correlation score of 0.88 and RMSE=0.75 mW/nm/sr/m².

In regions where assumptions needed for SFM estimation are well fulfilled, our approach does not outperform SFM when validating with available ground measurement data sets. However, it has the advantage of locally adapting to topography, illumination variation and ground surfaces. Thus, as an advantage over SFM our approach can provide physically consistent SIF predictions in topographically variable terrain and over human-made surfaces.

Further development of the method will concentrate on improving the absolute prediction accuracy with respect to ground measurements. Furthermore, large scale validation of the method with simulated HyPlant data is planned to supplement the validation.

3-2A SPECSESS FLUORESCENCE: MEASURING AND UNDERSTANDING SOLAR-INDUCED FLUORESCENCE AS AN INDICATOR FOR ACTUAL PHOTOSYNTHESIS AND VEGETATION FUNCTION

UNDERSTANDING SOLAR-INDUCED CHLOROPHYLL FLUORESCENCE OF STRUCTURALLY DIVERSE FORESTS WITH THREE-DIMENSIONAL RADIATIVE TRANSFER MODELLING

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Abstract

It has been shown that solar-induced chlorophyll fluorescence (SIF) sensed remotely at the top of canopy (TOC) is multi-angularly anisotropic, strongly modulated by canopy structural and optical properties, especially in forest ecosystems. Here, we quantified effects of canopy structural elements on TOC SIF using computer simulations in the discrete anisotropic radiative transfer (DART) model. DART was enabled to simulate three-dimensional (3D) radiative transfer (RT) and radiative budget (RB) of SIF through inclusion of the leaf model FLUSPECT (Malenovský et al. 2021. Remote Sens. Environ., 263). We investigated canopy interactions of SIF fluxes emitted at 686 and 740 nm for stands of three architecturally diverse tree species: Norway spruce (Picea abies), European beech (Fagus sylvatica), and Australian white peppermint (Eucalyptus pulchella). The SIF emissions in DART were set as temporally static, i.e., the fluorescence quantum efficiencies (fqe) of both photosystems (PSI and PSII) were scalar numbers unmodified by any photosynthetic protection or other physiological mechanisms. Consequently, the intensity of leaf SIF emissions was driven only by fqe values in combination with the fraction of absorbed photosynthetically active radiation (fAPAR) influenced by actual forest structure.

The DART 3D representations of forest stands were constructed from terrestrial laser scanning (TLS) point clouds of real trees with a semi-automatic routine (Janoutová et al. 2021. In Silico Plants, 3(2)). The foliage was represented by 3D leaves, created according to real leaf samples/needles arranged in shoots, and distributed throughout tree crowns according to field-measured shoot angles for spruce, planophile leaf angle distribution (LAD) for beech, and erectophile LAD for peppermint. Foliage TLS point clouds were used as attractors for placing leaves, mimicking a genuine leaf clumping at the branch level. The baseline (reference) scenarios were simulated as close as possible to real forest stands, with fixed inputs measured at the Bílý Kříž study site (Czechia) or obtained from literature, and with varying stand LAI: low ~ 4-5, medium ~ 7-8, and high ~ 10-11. To investigate the impact of bark-covered trunks and branches (wood), we also simulated scenarios with their absence.

Our results suggest that the impact of forest wood on TOC SIF can be superior to other tested forest architectural features (i.e., differences in LAI, LAD, and leaf clumping). Removal of wood from simulated scenes increased fAPAR of leaves, and consequently their SIF emissions, by 45-55% for spruce, around 15% for beech, and about 20-25% for peppermint. Wood SIF obstruction effect (i.e., scattering and absorbance), defined as the relative difference in nadir SIF escape factor, was found to be significant and highly variable among tested species for 740 nm SIF (5-45%), but it was much smaller for 686 nm SIF (between -3 and 8%). Analyses of SIF RB in canopy vertical profiles of DART-simulated stands revealed that the majority of the 686 and 740 nm TOC SIF originates in the top half of the relative canopy height of all three species. However, SIF balance for both wavelengths, computed per 10 m thick horizontal layer of canopies as the difference between a total emitted and absorbed SIF, showed quite varying distributions of SIF origins due to different canopy architectures. Spruce canopy produced SIF signals most homogeneously, in accordance with fAPAR vertical profile. SIF vertical profile of upper half of peppermint canopy was occasionally impaired by wood absorptance, driving the 686 and 740 nm SIF balances into negative values. Finally, foliage in the lower half of beech canopy was found to produce quite

significant SIF fluxes at both investigated wavelengths. These results highlight the potential of 3D RT modelling to characterize and eventually reduce the negative confounding impacts of canopy structure and its components (e.g., wood) on TOC SIF observations.

3-2A SPECSESS FLUORESCENCE: MEASURING AND UNDERSTANDING SOLAR-INDUCED FLUORESCENCE AS AN INDICATOR FOR ACTUAL PHOTOSYNTHESIS AND VEGETATION FUNCTION

NON-PHOTOCHEMICAL QUENCHING FROM IN-SITU SPECTRORADIOMETER MEASUREMENTS IN LAKES: IMPLICATIONS ON PHYTOPLANKTON FLUORESCENCE REMOTE SENSING

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Abstract

Sun-induced chlorophyll fluorescence (SIF) emission can be used as a proxy for chlorophyll-a concentration (chl a) and as an indicator of phytoplankton physiological status. However, interpreting SIF is challenging since various factors can cause dynamics in apparent SIF including the targeted phytoplankton physiology, optical properties of the atmosphere and the water body, instrumental effects, and assumptions inherent to retrieval schemes. Due to the complexity of factors that must be accounted for in SIF retrievals, lack of appropriate measurement protocols and few studies on retrieval methods, its exploitation remains limited.

The recent and future availability of hyperspectral satellite sensors could facilitate the retrieval of aquatic SIF since algorithms utilizing contiguous bands can be implemented. An upcoming satellite mission from ESA, the Fluorescence Explorer, designed to measure terrestrial SIF globally, can also potentially be used in aquatic environments. Exploiting data from other satellite sensors and future missions such as PRISMA and PACE, can also contribute significantly to aquatic SIF research.

Retrieved SIF signals are inherently related to the quantum yield of fluorescence (φF), which represents the small fraction of absorbed photons in phytoplankton that is emitted as SIF. Often assumed constant, φF may exhibit a diel cycle related to light stress due to varying contributions of Photochemical Quenching (PQ), associated with photochemistry, and Non-Photochemical Quenching (NPQ), related to increased heat dissipation. Changing PQ and NPQ ratios significantly complicate the interpretation of SIF. The possibility to determine φF could advance mechanistic understanding of quenching processes and SIF emission of the phytoplankton community observed.

Using an autonomous Thetis profiler from the LéXPLORE platform in Lake Geneva, we aim to demonstrate a novel way of estimating φF based on an ensemble of in-situ profiles of Inherent Optical Properties (IOPs) and Apparent Optical Properties (AOPs) taken between October 2018 and August 2021. We exploited the profiler's hyperspectral radiometers to obtain upwelling radiances and downwelling irradiances in the top 50 m of the water column. These AOPs were the main basis of our SIF retrieval, representing natural variations in fluorescence emission under different bio-geophysical conditions. Absorption and backscattering measurements representing the water's IOPs were used in radiative transfer model simulations. The simulations were set to φF=0 to obtain a second set of AOPs without fluorescence contributions. Measured and simulated reflectances outside the fluorescence emission region that satisfy the optical closure analysis were kept in the succeeding steps. By associating the difference between these measured and simulated AOPs, known chl a concentrations, attenuation coefficients and IOPs, we obtained estimates of φF.

We analysed vertical and temporal changes of obtained φF values to determine the conditions at which NPQ occurs. We observed diurnal changes in NPQ occurrence, particularly during clear sky conditions when irradiance changes significantly throughout the day. Our results indicate that φF can be up to 65% lower when NPQ is activated compared to PQ dominated conditions. While available irradiance is a significant contributor to changes in φF, its role is sometimes not easily interpretable because the threshold of radiant flux at which NPQ is activated is not consistent. Other factors such as phytoplankton photo-adaptation and community composition also play significant roles in understanding phytoplankton response to incident light and, therefore, quenching

mechanisms. Our results contribute insight into the nature of SIF and can facilitate activities to assimilating SIF and φF estimates in remote sensing algorithms, which would aid us in monitoring not only phytoplankton biomass but also the eco-physiological state of phytoplankton.

3-2B THEMSESS CAMPAIGNS: INSIGHTS FROM RECENT FIELD AND AIRBORNE CAMPAIGNS

CHIME-SBG 2021 AIRBORNE IMAGING SPECTROSCOPY CAMPAIGN

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Abstract

The Remote Sensing Laboratories (RSL) of the University of Zurich (UZH) carried out a Europe wide airborne hyperspectral imaging campaign in cooperation with NASA/Jet Propulsion Laboratory (JPL) on behalf of the European Space Agency (ESA) and NASA, to provide data to support the upcoming Copernicus Hyperspectral Imaging Mission for the Environment (CHIME) and Surface Biology and Geology (SBG) satellite missions.

The campaign was carried out using NASA/JPL's Airborne Visible / InfraRed Imaging Spectrometer - Next Generation (AVIRIS-NG), operating on an airborne platform, which was stationed in Duebendorf, Switzerland from Mid-May to the beginning of August 2021. Around 30 flights departing from Switzerland have been performed across Europe, ranging from Great Britain to South Italy and from Spain to Germany, to collect data from diverse land cover types (e.g. forests, soils, coastal and fluvial regions). This mission was operated under challenging circumstances, due to the global Covid-19 pandemic, unfavorable weather conditions, especially in May and June and other scientific or flight operational constraints.

Due to the large extent of the campaign a preparation phase of two years was necessary to plan and coordinate the flights with the Principal Investigators (PIs), the air traffic control of the respective countries and field teams that were sent to collect ground reference measurements. One stringent scientific constraint was the coordination of an airborne mission with an overpass of the Italian Space Agency's PRecursore IperSpettrale della Missione Applicativa (PRISMA) satellite. Acquiring image data on the same date with both instruments allows for calibration and validation and serves as well as data sets for CHIME and SBG.

To keep track of the constraints and to evaluate the optimal time window for an acquisition an automated MATLAB tool was designed, resulting in a decision matrix for each target depending on weather, flight operation and overpass conditions for the next five days. Since the operation of a passive optical sensor like AVIRIS-NG depends highly on clear weather conditions, a more detailed weather assessment was performed beyond the decision matrix and the allocated acquisition time was communicated to the PIs.

The collected airborne hyperspectral data sets were processed to level 2 data by NASA/JPL and sent back to RSL for validation purposes. The airborne data were compared with the spectroradiometric in-situ data acquired by the field teams on reflectance basis.

In detail, the validation was performed using the RSL in-house Calibration and Validation Tool (CAL/VAL Tool) which queries the in-house spectral database SPECCHIO to automatically compare the processed airborne with the in-situ data and thereby computes different statistical measures describing the data quality.

The collected data (around 30 days of operation, 80 targets and 400 lines imaged) are made publicly available to reach a larger community via the campaign homepage (https://ares-observatory.ch/esa_chime_mission_2021/).

3-2B THEMSESS CAMPAIGNS: INSIGHTS FROM RECENT FIELD AND AIRBORNE CAMPAIGNS

THERMAL INFRARED AIRBORNE HYPERSPECTRAL DATA FOR VEGETATION LAND COVER CLASSIFICATION IN A MIXED TEMPERATE FOREST

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Abstract

Land cover, which is an essential climate variable and a remote sensing-enabled essential biodiversity variable is important for understanding terrestrial ecosystems functioning. Many studies have investigated forest land cover classification using remote sensing data from the visible, near, and short-wave infrared (VNIR-SWIR, 0.4-2.5 µm) regions. However, to our knowledge, no study has addressed forest land cover classification using thermal infrared (TIR, 8-14 µm) hyperspectral data. In this study, for the first time, we present the preliminary assessment of vegetation classification using TIR hyperspectral data. TIR hyperspectral images (7.5 – 12.5 µm) were acquired by EUFAR aircraft using the AISA Owl sensor in July 2017 in Bavaria Forest National Park, Germany. In addition, fieldwork was conducted in 2017, concurrent to the flight campaign as well as in 2020 and 2021, and vegetation types were recorded in 92 plots. Canopy emissivity spectra were extracted for three vegetation classes namely, coniferous, broadleaves, and mixed classes. The extracted emissivity spectra were further used to classify three vegetation classes by means of a supervised Random Forest classifier. The results confirmed the expected capabilities of hyperspectral TIR data to produce an acceptable land cover map with an overall accuracy of 66%. The study showed that for coniferous class the most important spectral bands for classification were wavelengths 8.9 µm, between 9.7 – 9.9 µm and 10.3 µm. While for broadleaves there were,10.2 µm, 10.8 µm, and between 11.0 – 11.4 µm bands. The findings of this study show the possibility of using airborne hyperspectral TIR data for forest land cover classification. However, further investigation should be done applying other machine learning and deep learning techniques to examine the potential of TIR hyperspectral data for land cover classification.

3-2B THEMSESS CAMPAIGNS: INSIGHTS FROM RECENT FIELD AND AIRBORNE CAMPAIGNS

IMAGING SPECTROSCOPY IN WETLAND ENVIRONMENTS: EARLY RESULTS FROM THE DELTA-X CAMPAIGN

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Abstract

River deltas play critical roles for humanity and the environment. They are key habitats for diverse plant and animal species; they protect coastal communities from winds and erosion; and they serve as efficient sinks for atmospheric carbon. However, many river deltas worldwide are threatened by relative sea level rise. Deltas are dynamic systems, in which vegetation may play an active role in creating and capturing sediment. Traditional "bathtub" models of rising sea levels fail to account for these effects, and do a poor job of predicting historical land loss or gain. To better understand this process, and to inform delta conservation efforts, the National Aeronautics and Space Administration (NASA) selected the Delta-X campaign to perform a field experiment near the mouth of the Mississippi river in 2021. Delta-X deployed field teams for in situ measurements including vegetation and water column properties, soil accretion rates, water levels, and surface reflectance. Simultaneously, aircraft surveyed the experiment area with radar and imaging spectroscopy. The Delta-X team is mapping vegetation properties, elevation and hydrodynamics over wide areas, constructing more sophisticated models of sediment transport, creation, and accretion. This presentation reports on the imaging spectroscopy measurements, which were acquired by NASA's Next Generation Visible Near Infrared Imaging Spectrometer (AVIRIS-NG) over three separate deployments. The imaging spectroscopy products include calibration, atmospheric and BRDF/glint corrections, and maps of vegetation functional type and water column properties. Uniquely, the datasets include imaging before and after the destructive Hurricane Ida event in the summer of 2021, offering an opportunity to evaluate the disruptive effects of such extreme events on wetland ecosystems. The campaign provides insight into the unique challenges and opportunities of performing remote imaging spectroscopy at the land/ocean interface. All data and code are open sourced and available to the broader scientific community.

3-2B THEMSESS CAMPAIGNS: INSIGHTS FROM RECENT FIELD AND AIRBORNE CAMPAIGNS

IMPACT OF PROCESSING SCHEMES ON REFLECTANCE DIFFERENCES IN THE OVERLAPPING AREA OF NEIGHBOURING FLIGHT LINES OF AIRBORNE IMAGING SPECTROSCOPY DATA

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Abstract

Studies have shown that factors such as illumination and observation geometry, an uncertain estimation of the irradiance field, and surface anisotropy, affect the retrieval accuracy of surface reflectance and, subsequently, information products derived from imaging spectroscopy data. These effects become increasingly pronounced with increasing spatial and spectral resolution of acquired data. A range of processing schemes is available to compensate for these factors, including topographic correction methods (e.g., the Modified Minnaert correction) which account for changes of the terrain orientation towards the sun, or BRDF correction approaches (e.g., BREFCOR) which account for reflectance variability due to changing observation angles. We lack a systematic assessment of available approaches for high-resolution imaging spectroscopy data.

This study aims to evaluate the capacity of three well-established processing schemes along a gradient of methodological complexity to compensate reflectance anisotropy effects. We use several datasets acquired with the airborne imaging spectrometer Advanced Prism Experiment (APEX) in July 2016 and July 2019 over a mountainous study site in the Swiss National Park. Resulting neighbouring flight lines have an approximate length of 25 km, a width of 2 km and a lateral overlap of approximately 25% (500 m). The data have a spatial resolution of 2 m and cover a wavelength range of approximately 400 to 2500 nm in 299 contiguous spectral bands. All flight lines were processed to at-sensor apparent reflectance and, within the ATCOR software package, to three different atmospherically corrected products: i) surface reflectance assuming a flat terrain (ATCOR F), ii) surface reflectance considering terrain ruggedness (ATCOR R), and iii) ATCOR R with a subsequent BRDF correction using the BRECFOR method. We calculated pixel-wise reflectance differences in the overlapping area of the neighbouring flight lines for a random sample of observations in different land cover types, allowing us to quantify the capability of the different processing schemes to account for reflectance differences. In addition, we evaluated how well tested processing schemes allow to reduce uncertainties in commonly used spectral indices (i.e., PRI, NDVI, NDWI), and spectral albedo.

Preliminary results suggest that more advanced processing schemes yield smaller reflectance differences in the overlapping area of the neighbouring flight lines and, thus, better compensate for the mentioned effects. This observation also holds for the investigated spectral albedo product. However, due to the subtractive nature of the atmospheric correction, leading to a higher variability, the spectral indices show slightly larger pixel-wise differences in the more advanced processing schemes. Our results indicate that the choice of the processing approach has a significant impact on the outcome of subsequent applications. We also found that the best choice is product-dependent, while even the most advanced processing schemes leave residual differences that currently cannot be corrected. We conclude with recommendations on the choice of processing level for various applications.

3-2B THEMSESS CAMPAIGNS: INSIGHTS FROM RECENT FIELD AND AIRBORNE CAMPAIGNS

EARLY RESULTS FROM SHIFT - THE SBG HIGH FREQUENCY TIME SERIES

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Abstract

Understanding the spatial distribution of vegetation phenology is a fundamental question of ecology, and a key aspect of NASA's upcoming Surface Biology and Geology (SBG) mission. Yet to date, the emphasis in airborne imaging spectroscopy has been to understand spatial distributions and/or annual-level trends. The SHIFT airborne and field campaign was conceived and executed throughout the spring season in terrestrial and aquatic environments in Southern California in order to gather the high frequency data necessary to more fully understand the value of information of repeat spectral acquisitions. Airborne campaigns were conducted approximately weekly over several months, with identical flight plans. Concurrently, a multitude of field teams, including many collaborative efforts, collected spatially and temporally linked samples for algorithm calibration and validation. Terrestrial field measurements included vegetation traits (LMA, Nitrogen, Leaf Water, etc.), fractional cover, gas exchange, and plant water status, while aquatic measurements included kelp data (species, cover, pigment, etc.), water leaving reflectance, and ocean biogeochemistry. Together with the latest processing methods, these data provide a basis to understand our ability to characterize the spatial distribution of phenology in terrestrial and aquatic vegetation, and the opportunity to explore a host of possible algorithms and applications for SBG. In this talk we overview the recently concluded campaign and present an initial outlook of the results.

3-2C SPECSESS RAWMATERIALENERGY: IMAGING SPECTROSCOPY FOR RAW MATERIALS AND THE ENERGY TRANSITION

AN INTEGRATED METHOD FOR UTILIZING MULTI- AND HYPERSPECTRAL IMAGING FOR RAW MATERIAL CHARACTERIZATION IN AN UNDERGROUND MINE

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Abstract

Sensor technologies can play a significant role in geological material characterization for mining applications. This study describes an innovative data-driven methodology that integrates the (Red-Green-Blue) RGB imaging and hyperspectral imaging techniques for enhanced characterization of a polymetallic sulphide deposit. The hyperspectral images were acquired in the visible-near infrared (VNIR) and short-wave infrared (SWIR) regions. A multi-step methodological approach was developed for the integrated analysis of data from the three imaging techniques, and the fusion of the VNIR and SWIR data. The approach commences with data pre-processing, followed by usability assessment of the individual techniques and data fusion, and culminates with data modelling and model validation. The RGB imaging was used to produce mineral maps and define the target domain at the mine face of the underground mine. The output from the RGB imaging-guided the selection of sampling locations. Subsequently, the VNIR and SWIR measurements were performed using the collected drill core and rock chip samples. Minerals such as pyrite (using the reflectance pattern), hematite, goethite and siderites were identified using the VNIR data. The minerals identified using the SWIR data include muscovite, montmorillonite, illite, siderite, quartz, sulphides (with no particular absorption features), and mineral mixtures. The featureless nature of the sulphide minerals was used as a characteristic value to map ore and waste using the SWIR data and spectral angle mapper (SAM) technique. Following the usability assessment of the individual techniques, endmembers weight-based data fusion approach was developed to integrate the VNIR and SWIR data. Data conversion was performed to transfer the hyperspectral image data of each sample into a representative spectrum. The pure endmembers of the VNIR and SWIR image data were extracted using the maximum noise fraction (MNF) transformation and pixel purity index (PPI) algorithms. The representative spectrum of each sample represents the average of pure endmembers multiplied by their weight. The same procedure was followed to generate the VNIR and SWIR representative spectra separately. The usability of the transformed (generalised) data for the discrimination of ore and waste materials was assessed. The extracted features from the VNIR and SWIR data were concatenated to produce a fused data matrix. The VNIR, SWIR and the fused data blocks were used to classify the ore and waste materials at 3% and 7% measured Pb and Zn cut-off grades using a support vector classification (SVC) classifier. Sensor derived measurements were validated using conventional laboratory-based techniques namely inductively coupled plasma mass spectrometry and X-ray diffraction. The obtained results indicate that the individual techniques yielded promising results for the mapping of minerals and the classification of ore and waste materials. However, the integrated analysis of the three techniques allowed a better understanding of the material composition at the study site. The fusion of the VNIR and SWIR spectra improved the classification of ore and waste material in the analysed samples. At 3% cut-off grade, the best-achieved result of the fused VNIR and SWIR data yielded a correct classification rate of 81.6%, whereas the results from the individual VNIR and SWIR data are 58% and 73.7%, respectively. The proposed approach enables a significant reduction in data volume while maintaining the relevant information in the spectra. This has implications for data storage, data processing and visualisation. The approach provides a versatile solution for the fusion of multiple sensor outputs and permits enhanced characterisation of materials in operational mines.

3-2C SPECSESS RAWMATERIALENERGY: IMAGING SPECTROSCOPY FOR RAW MATERIALS AND THE ENERGY TRANSITION

HYPERSPECTRAL IMAGING FOR OPEN PIT MINING APPLICATIONS

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Abstract

Advancing technology developments, increasing world population, and diversification of raw material needs are leading to rapidly increasing global demand for metals and other mining products. In the context of global climate policy, a drastic reduction of CO2 emissions is required. This will lead to a strong increase in mining activities for decarbonization technologies, especially for lithium, nickel, cobalt, manganese, graphite, rare earths, copper, and aluminum. In order to meet the goals of increasing energy transition according to the Paris Agreement and the International Energy Agency (IEA), in one scenario the demand for copper and rare earths will increase by 40%, for nickel and cobalt by 60-70%, and for lithium by almost 90% by 2040. The goal has to be to support mining with technologies that enable safer and more efficient mining, sorting and recycling processes. This is where reflectance spectroscopy comes into play.

The material distribution within a mine can differ in the small scale – dependent on the heterogeneity of the deposit, surface weathering and in different extraction horizons. Hyperspectral imaging offers a spatial detection method of the mining surface and allows for a classification of mineral- and element-distributions to aid an efficient extraction and material-handling. The aim is to implement hyperspectral imaging into open pit and mining workflows sustainably covering a variety of applications. This presentation will give an overview of the different use-cases of hyperspectral data within the mining environment and presents feasibility studies and research around the development of solutions with the HySpex VNIR-SWIR systems.

For industry applications, a study is presented that focuses on an application-based sensor adaptation and a comparison of conventional analysis methods. A spectral mine face monitoring workflow was developed and tested for both an operating and an inactive open pit copper mine in the Republic of Cyprus (Koerting, 2021). Mine-face and UAV scans and analyses of an open pit lithium pegmatite mine in Portugal are presented that are based in the Lights Project (Lightweight Integrated Ground and Airborne Topological Solutions) (Cardoso-Fernandes et al., 2020). Within this project, underground measurements were carried out in the Zinnwald visitor mine, the results of which will also be presented. Hyperspectral microscopic imaging of thin sections for the automated REE mineral detection will be shown (Daempfling et al., in review) as well as hyperspectral UAV analyses from Cuprite Nevada for exploration use-cases and from an operating Copper-Skarn mine in Arizona.

3-2C SPECSESS RAWMATERIALENERGY: IMAGING SPECTROSCOPY FOR RAW MATERIALS AND THE ENERGY TRANSITION

ALTERATION FOOTPRINTS OF A PORPHYRY COPPER DEPOSIT AS REVEALED BY AIRBORNE IMAGING SPECTROSCOPIC DATA

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Abstract

Porphyry copper deposits (PCDs) represent large, relatively low-grade, epigenetic, intrusion-related deposits with vast alteration footprints resulting from convective fluid circulation. Multispectral remote sensing data such as ASTER has been successfully used to explore for such deposits. However, due to a limited number of spectral bands in the VNIR-SWIR range, they fall short of delineating the alteration footprints of PCDs in detail in spatial and mineralogic terms. On the other hand, hyperspectral imaging spectroscopy can provide an effective tool for the systematic mapping of mineralogical footprints of hydrothermal alteration systems, including the PCDs at local to deposit scales. To demonstrate this capability, a portion of the HyMap hyperspectral data collected over the Shadan porphyry Cu-Au-Mo deposit was selected and processed to reveal the mineralogic footprints of the system at approximately five-meter ground sampling distance. This area was covered during a campaign for hyperspectral data collection in 2006 by the Geological Survey of Iran. Shadan is a typical deposit with near-perfect zonation located in the volcanic belts of eastern Iran. Copper (and Gold) mineralization occurs in the monzonitic intrusions as disseminated and stockworks styles. A combination of spectral unmixing techniques and feature extraction methods available in the EnGeoMap toolbox was used to process the atmospherically corrected and geometrically orthorectified HyMap data. The EnGeoMap toolbox is a spectral processing tool for material detection and characterization from hyperspectral imaging data based on automated absorption feature extraction and mineral abundance quantification. The feature extraction methodology uses a variety of spectral parameters for the accurate identification and quantification of mineralogy in geological environments. The wavelength minimum of white micas' absorption feature centered at 2200 nm was tracked using polynomial fitting. In this way, the chemical composition (level of Tschermak substitution) of the mineral was effectively detected and portrayed in image format. The combined spectral processing approach revealed a wide variety of mineral products, including white mica abundance, composition, and crystallinity, kaolinite abundance and crystallinity, ferric oxide content and composition, together with jarosite, chlorite-epidote, amphiboles (tremolite-actinolite), and tourmaline abundance maps. The resulting maps showed that the mineralized parts of the system are characterized by Al-poor (varying between 2187 to 2200 nm), well-crystalline white micas together with high proportions of goethite, jarosite, and tourmaline. The propylitic zonation was discovered to contain both the tremolite-actinolite and the chlorite-epidote minerals as the middle and the outer propylitic zones, respectively. The results of this study were subsequently validated by field observations, sampling, reflectance spectroscopic analysis in the lab (using an ASD FieldSpec-4), and also bulk rock analyses. We also explored the possibility of replicating the same results using simulated EnMap hyperspectral data. This study showed that hyperspectral remote sensing imagery coupled with advanced processing algorithms could be effectively used to delineate the alteration patterns of porphyry copper systems in arid to semi-arid regions of the world and help target the most promising zones for follow-up exploration activities.

3-2C SPECSESS RAWMATERIALENERGY: IMAGING SPECTROSCOPY FOR RAW MATERIALS AND THE ENERGY TRANSITION

EXPLORING PORPHYRY COPPER TAILINGS WITH VISIBLE LIGHT TO LONG WAVE INFRARED REFLECTANCE SPECTROSCOPY - A CASE CTUDY IN ERDENET, MONGOLIA

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Abstract

Tailings are fine-grained residuals from ore processing. Though often considered mine waste, such materials can contain relevant quantities of economically important raw materials. Thus, tailings storage facilities (TSF) are of increasing interest in times of high raw materials demands, volatile markets and the aspiration to use existing secondary deposits. Since TSF can be difficult to access and analysing such materials is time consuming and cost-intensive, new approaches are required to aid the exploration of tailings and to reduce analytical workloads.

In this study, we compared the predictive capability of visible light to shortwave infrared spectra with mid- to longwave infrared spectra for quantifying copper and molybdenum contents in copper tailings. Aside from other chemical parameters, we aimed at sand, silt and clay contents, since Cu is linked to specific particle sizes and properly estimating grain size fractions is important for assessing the raw material potential of tailings.

The samples for this research were collected at the tailings dam of the porphyry copper mine in Erdenet, Mongolia. The TSF cover an area of approximately 7.5 km² and show highly variable micro-morphology, wetness conditions and texture in situ, causing hetereogenous physico-chemical parameters of the deposited tailings. 170 samples were analyzed for their elementary composition using X-ray fluorescence and ICP-OES. Grain size fractions were determined with a HELOS/KR laser diffraction. Spectral laboratory measurements of air dried and homogenized samples were conducted using a Spectral Evolution SR-3500 spectrometer (VNIR/SWIR, 0.35-2.5 µm) and an Agilent 4300 Handheld FTIR for covering the mid and longwave infrared (MWIR/LWIR, 2.5-15 µm). The spectra were corrected for unwanted scattering effects using Multiplicative Scatter Correction (MSC). Statistical models were calibrated using Partial Least Squares Regression (PLSR) and validated using a 20-segment random cross-validation set-up.

We found comparable solid results for predicting Cu based on VNIR/SWIR as well as on MWIR/LWIR data (R^2val = 0.75 and 0.77, respectively). For Mo, the results were moderate for both wavelength ranges (R^2val = 0.47 and 0.51). The grain size fractions clay, silt and sand could be predicted with high accuracies (R^2val = 0.84-0.94), whereas the MWIR/LWIR data provided superior models compared to VNIR/SWIR models. For Al, K, Na, Mg, Mn, S and Si we found promising results (R^2val = 0.68-0.90). Here, models based on MWIR/LWIR spectra provided distinctively better results for Al, K, Na, Mg and Zn. Models using VNIR/SWIR spectra were superior only for S. The modelling performance for Ca, Mn and the medium sand fraction was similar for both spectral ranges, though with minor advantages for the mid and longwave infrared spectra. The combination of the two spectral data sets yielded in slight improvements of model performances for 7 out of 15 parameters.

Our study shows that robust predictions for Cu as well as for relevant grain size fractions in porphyry copper tailings can be achieved using VNIR/SWIR as well as MWIR/LWIR spectral data. The models based on MWIR/LWIR spectra provided models that are more robust for the majority of studied parameters. These results indicate that reflectance spectroscopy is a complementary tool for assessing the raw material potential of porphyry copper tailings. This can aid exploring secondary deposits and support the recovery of valuable materials.

3-2C SPECSESS RAWMATERIALENERGY: IMAGING SPECTROSCOPY FOR RAW MATERIALS AND THE ENERGY TRANSITION

UTILIZING LIDAR INTENSITY DATA TO IMPROVE COPPER AND MOLYBDENUM PREDICTION MODELS IN A HIGH-WETNESS ENVIRONMENT

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Abstract

Accurate prediction of chemical properties via remote sensing is difficult, owing to the significant flaws and uncertainties inherent in the data collecting process. Integrating LiDAR intensity data, on the other hand, may improve the models and result in a more favorable conclusion due to its correlation with moisture content and geochemical parameters. The purpose of this work was to improve the prediction of copper and molybdenum in a wet tailing facility by including LiDAR intensity data into the modelling procedure. The research was conducted over an area of 3 km2 in a tailing settling basin of a porphyry copper deposit at Erdenet, Mongolia. Due to seasonal changes in the discharge of the residue into the basin, the area is characterized by varied micromorphology and a high variability of water content which affect the accessibility to other parts of the tailing. Therefore, the capabilities and advantages of remote sensing can be manifested particularly in these inaccessible areas despite the high-water content. In August 2019, 65 samples were collected from the surface and their copper and molybdenum contents were determined using a Niton XL3t XRF and the water content was determined using ML2x ThetaProbe. The sampling campaign was conducted simultaneously with a hyperspectral scanner HySpex VNIR1600 (160 bands, 400-1000 nm), SWIR320me (256 bands, 1000-2500 nm), and a LiDAR Riegl Q780 data (1064 nm) at 1000 m above ground. Additional copper and molybdenum measurements were made in the laboratory using the ICP-OES method. Statistical models were calibrated using the PLSRegression method in EnMAP-Box 3 plugin in QGIS: i) with the original chemical data, and ii) with normalized chemical data based on normalized intensity data. In order to compensate for the small sample size, each dataset was randomly divided three times for calibration and validation (70%-30%) to build a total of six models for each parameter: three models using the unnormalized data and three models using the normalized data. Subsequently, a comparison between the unnormalized and the normalized models were done using the maximum R2, the mean of the two highest R2, and the mean R2 of each three models. Our results show that the mean R2 values of copper and molybdenum measured in field condition, increased from 0.36 to 0.43 and from 0.23 to 0.35, respectively, and for laboratory data, the mean R2 of copper increased from 0.16 to 0.27. However, the mean R2 molybdenum showed a slight decreased from 0.27 to 0.25. Except from that, all other parameters show an improvement in the maximum R2 (between 0.03 and 0.18) and the mean of the two highest R2 (between 0.06 and 0.15). Thus, our findings indicate that the normalized copper and molybdenum contents provided a greater degree of accuracy on average, than the unnormalized datasets and even though the increase is small, it is significant as it demonstrates the benefits of using intensity data for raw material prediction in a high-wetness environments.

3-5 THEMSESS CROPSGRAS: IMAGING SPECTROSCOPY OF CROPLAND AND GRASLAND

WHY AND HOW TO MAP LEAF-CHLOROPHYLL DYNAMICS FROM ULTRAHIGH-RESOLUTION UAV HYPERSPECTRAL IMAGERY AND MACHINE LEARNING?

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Abstract

Monitoring leaf chlorophyll (Chl) in-situ is a widely used labor-intensive process, limiting representative sampling that allows for detailed Chl mapping at field scales and across time. Unmanned aerial vehicles (UAV) coupled with hyperspectral cameras provide a highly flexible platform for observing agricultural lands, procuring high-resolution spatial, spectral, and temporal data in a timely and useable manner, and overcoming the sampling constraints. A customizable machine learning (ML) workflow was evaluated for the retrieval and mapping of leaf Chl level dynamics across a crop cycle, combining sub-centimeter resolution (7 mm) UAV-hyperspectral imagery (400-1000 nm) with leaf reflectance (350-2500 nm) and SPAD measurements [Angel & McCabe, 2022. Front. Plant Sci. doi: 10.3389/fpls.2022.722442]. The study is performed within a phenotyping experiment designed to monitor wild tomato species across five different development stages (e.g., establishment, development, flowering, fruiting, and pre-harvest). While ML allows for exploring connections between ground-truth and spectrally derived functional traits, there is still much unknown about capturing temporal correlations, selecting relevant predictors, retrieving accurate results under different conditions, and quantifying the uncertainties of the retrievals. We undertake a comprehensive assessment to evaluate the robustness and accuracy of multiple ML models, including: 1) exploring sequential vs. retraining learning; 2) comparing insights gained from using spectral bands vs. pigment-based vegetation indices (VI); 3) an assessment of six widely used regression methods (linear, partial-least-square; PLSR, decision trees, support vector, ensemble trees, and Gaussian process; GPR); and 4) an examination of relevant predictors (e.g., spectral bands vs. VI). The goodness-of-fit (R^2) and accuracy metrics (MAE, RMSE) were determined to assess model performance. A comparative analysis between retrievals and a validation subset informed on the ability of models to capture Chl temporal variability through SPAD levels. The top three models were used to translate the hyperspectral imagery into high-quality multi-temporal SPAD-based chlorophyll maps. Overall, results show that: (a) the retraining strategy improves the ability to model SPAD-based Chl dynamics through time; (b) VI predictors slightly improve the R^2 (e.g., from 0.65 to 0.68 units for random forest and from 0.59 to 0.74 units for GPR) and accuracy (e.g., MAE and RMSE differences of up to 2 SPAD units) in specific algorithms; (c) the PLSR, random forest, and GPR models provided the most accurate fits; and (d) the spectral bands and VI identified as relevant for leaf-Chl retrieving are strongly overlapped. Of note, the methodological and practical considerations on the proposed workflow guide the application of customized ML architectures and learning strategies to ensure accurate and transferable solutions while modeling temporal dynamics by using large volumes of spectral, temporal, and spatial datasets, even under limited in-situ data and in a timely manner.

3-5 THEMSESS CROPSGRAS: IMAGING SPECTROSCOPY OF CROPLAND AND GRASLAND

MAPPING OF ESCA SYMPTOMS ON GRAPEVINE USING HYPERSPECTRAL AND THERMAL UAV DATA

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Abstract

Esca is a grapevine (Vitis vinifera) trunk disease, which was observed for the first time in the 1990ies in vineyards in Luxembourg. Since then, it is spreading tremendously, and no chemical control measures are available. Symptoms appear on single plants without spatial patterns, and they might disappear in the following year. This makes an observation and finally an accounting of affected plants difficult for the grape grower. Objective monitoring is essential to better understand the disease, the appearance, and pattern of symptomatic plants, and the economic impact. The objective of the MonESCA project is the systematic monitoring of Esca symptoms with hyperspectral and thermal UAV (Unmanned Aerial Vehicle) data.

5 classes of symptoms (no, slight, medium, severe leaf symptoms, apoplexy) were defined, and each vine in the field was assessed from the ground. To have precise digital field observations, a single plant inventory was created, and an app was developed to do the field assessments in the vineyard. In parallel, UAV data were acquired for 2 years (2020 and 2021). Sensors were a Headwall Nano Hyperspec, TeAx thermal capture, and a high-resolution RGB camera.

The cultivation of vine in rows, the pruning, and the training system, as well as the symptoms development of Esca, makes accurate pre-processing and the extraction of ROIs (Region Of Interest) essential for the analysis. The separation of vine and background was realized by a combination of a 3D model, which was calculated by using high-resolution RGB data and a spectral mask based on a maximum likelihood classification. Afterwards, the ROIs have been extracted based on half circles around each trunk in the direction of the row and a pixel stratification according to illumination was realized. In detail, the pixels within each ROI have been selected according to their brightness in a NIR channel, to exclude shaded leaves.

The classification of Esca symptoms was afterward realized by a combination of different methods which were combined in a random forest classifier. The input data include (i) narrow-band vegetation indices, (ii) most important band selection, (iii) the image-based CWSI (Crop Water Stress Index) calculated based on the thermal data, and (iv) estimated biochemical characteristics. Latter have been calculated with a hybrid RTM (Radiative Transfer Model) inversion using the toolbox ARTMO. Chlorophyll, carotenoid, anthocyanin, and LAI (Leaf Area Index) have been estimated.

Our five years field observation showed that up to 50% of symptomatic plants have been observed to be un-symptomatic in the following year. This confirms the need of an objective observation. The classification results of the UAV data showed a high classification accuracy of 75-92% (cross-validation). Analysis of the single input parameters showed high relevance of the pigment content (chlorophyll and carotenoid) as well as narrow-band indices which are sensitive to photosynthetic activity (RedEdgeNDVI, PRI-Photochemical Reflectance Index, or CRI-Carotenoid Reflectance Index). Mapping of Esca symptomatic plants was possible based on the implemented classifier and showed an accuracy of 80%.

We conclude that the established method allows for regular monitoring of Esca symptomatic plants. Especially the modeling of leaf pigment content could improve the classification accuracy. Essential for a good classification result is a particularly good pre-processing and high geometric accuracy. In most cases, uncertainties in the

results have been introduced by small uncertainties in the plant location or small errors in the masking of the background.

The operation of a hyperspectral and a thermal sensor is work-intense and further tests with multispectral sensors are foreseen to simplify the application. That would allow for continuous and less expensive monitoring in practice.

3-5 THEMSESS CROPSGRAS: IMAGING SPECTROSCOPY OF CROPLAND AND GRASLAND

DISEASE ASSESSMENT IN POTATO CROP COMBINING IMAGING SPECTROSCOPY AND POINT-CLOUD BASED FEATURES

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Abstract

Plant diseases are a major limiting factor for crop yield and production quality. Methods to assist field scouting are of great interest and proximal or remote sensing with high spatial resolution have increasingly been proposed as possible alternatives for disease incidence detection. Recently, imaging spectroscopy cameras on board of Unmanned Aerial Vehicles (UAV) were tested for disease assessment in potato and combined with multiple machine learning (ML) models resulting in relatively high detection accuracy. Despite that, depending on the pathological agent and host, structural changes can be useful to describe infection progress over time, in particular if coupled with information about plant pigments or physiological state.

In this study, imaging spectroscopy based imagery, LiDAR and point cloud obtained through Structure from Motion algorithm (SfM) applied to high resolution RGB images were evaluated as possible alternatives to detect Blackleg (caused by bacteria of the genera Pectobacterium and Dickeya) in potato. Disease incidence observations and UAV based imaging spectroscopy (Hyperspectral Mapping SYstem – Wageningen University), LiDAR (RIEGL RICOPTER with VUX-1UAV system), and RGB imagery (Panasonic GX1) were acquired over an experimental field (near Tollebeek in the Netherlands) on 21 June 2017 (71 Days After Planting). It was demonstrated that all the different datasets have potential to discriminate healthy from diseased plants using a ML approach adopting Support Vector Machines (SVM). The combination of Vegetation Indices (VIs) derived from the imaging spectroscopy data with structural features from the LiDAR data resulted in the best validation results (Balanced Accuracy = 0.859). Only small improvements were achieved by combining VIs and SfM features (BA = 0.789) in comparison to the use of VIs alone (BA = 0.782). Finally, analysis of false positives and negatives indicated limits to the predictive potential of the different datasets, with diseased and healthy plants eventually presenting opposed structural and spectral characteristics to those expected for their classes. Therefore, multi-source sensing, including additional modalities (e.g., thermal or fluorescence), might be required to further improve detection of pathogens with complex symptoms, such as those affecting roots, tubers and stems.

3-5 THEMSESS CROPSGRAS: IMAGING SPECTROSCOPY OF CROPLAND AND GRASLAND

UTILIZING UAS-BASED IMAGING SPECTROSCOPY INFORMATION TO ESTIMATE THE SOIL MOISTURE CONTENT AT DIFFERENT GRASSLAND TYPES IN GERMANY

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Abstract

Soil Moisture Content (SMC) is a key parameter of soil-plant-atmosphere interactions, controlling plant physiological development and biomass productivity. Global large-scale monitoring of SMC using satellite platforms with spatial resolutions of minimum 100 m exists, but the validation suffers a significant scale gap to common ground measurements.

Therefore, the aim of this study was to derive SMC of heterogeneous grassland sites with unmanned aerial systems (UAS) and imaging spectroscopy data in the visible (VIS) to near-infrared (NIR) spectral range. In the vegetation periods 2019/20, we acquired hyperspectral data with the Headwall Nano Sensor (270 bands, 400 – 1000 nm, mounted on a DJI Matrice 600Pro+) at seven datasets over three different grassland sites managed by grazing (GB), mowing (FE) and irrigation (MAR). One of the sites was prone to significant water stress with SMC values lower than 5 Vol. %. Two of the sites comprise data of more than one day. Additionally, we acquired in-situ SMC measurements of the top soil. To account for the influence of biomass, we collected leaf area index (LAI) measurements for all sites and acquisition times.

In our analysis we applied hybrid and data-driven methods and compared their potentials and limitations for SMC retrieval. The hybrid approach relied on combined usage of machine learning (ML) and the PROSAIL model targeting the soil reflectance factor (psoil). The training data set for the ML algorithm was established using site-specific measurements and common grassland parameters. A training data set for each site was created to account for different image acquisition characteristics and the different soil types. A linear relationship between SMC and psoil was applied to obtain a final SMC product. For the retrieval strategy, relevant bands were selected using the Kernel Ridge Regression (KRR) band selection tool implemented in the ARTMO software environment. The 10,000-sample training data set was optimized and reduced using active learning via the Euclidean distance-based (EBD) diversity method and fast KRR. Finally, a variational heteroscedastic Gaussian process regression (VHGPR) algorithm was trained on the EBD-optimized sample and the established model was applied to the measured spectra. Since the contribution of the soil reflectance to the canopy reflectance decreases with increasing canopy cover, we iteratively searched for site-specific maximum LAI threshold.

For the data-driven approach, we trained a VHGPR algorithm using the selected bands as predictor set and the SMC as target variable. By applying a 10-fold cross-validation the coefficient of correlation (R) and root mean squared error (RMSE) of the corresponding models were derived.

Using the hybrid method, for the site with a mowing regime (FE) a relation of SMC to modeled psoil values could be established (R = 0.69 / RMSE = 16.36 Vol. %). We found a significant but moderate correlation between psoil and SMC on the irrigated side (MAR) (R = 0.45), combined with very small RSME (value range: 5.9 Vol. %). However, the relation is suitable for SMC contents lower than approximately 10 Vol. %. At GB sites, a correlation was absent (R = 0.02). Compared to the hybrid strategy, the model error revealed lower for the ML approach in the case of FE (R = 0.96, RMSE = 8.66 Vol. %) and MAR (R = 0.63, RMSE = 10.52 Vol. %) sites, while for GB again no accurate model could be achieved (R = 0.18, RMSE = 4.18 Vol. %).

We found that the hybrid approach indicates variations in vegetation cover rather than soil-background reflectance. In addition, the SMC retrieval accuracy can be influenced by farming practices, and by a significant

time lag between change in SMC and vegetation response. In conclusion, data-driven ML approaches may be the most suitable method for deriving SMC for diversely managed grassland sites.

EVALUATING THE POTENTIAL OF HYSPEX AND SENTINEL-2 FOR FRACTIONAL COVER-BASED DROUGHT ANALYSES IN GRASSLANDS

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Abstract

Grasslands play a vital role for a range of ecosystem services, including biomass production, biodiversity conservation and carbon sequestration. European grasslands were heavily impacted by extreme droughts in 2018 and 2019. It is therefore of utmost importance to develop measures of grassland vitality that allow for climate change adapted grassland management. Kowalski et al. (2022, Remote Sens. Environ., 268) were recently able to differentiate drought impacts in central European grasslands based on Sentinel-2. Specifically, they developed an approach based on fractional cover estimates of photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV) and soils to quantify drought impacts. However, the authors report remaining uncertainties in accurately differentiating NPV and soil fractions due to subtle spectral differences of both cover types in broadband multispectral data.

It is well known that the contiguous narrowband coverage provided by imaging spectroscopy data better resolves absorption features relevant for more accurate differentiation between NPV (e.g. lignin and cellulose in the SWIR) and soil. As an alternative solution to a rigorous validation based on independent ground truth sample sites, fraction maps of PV, NPV and soil from hyperspectral imagery may serve as a solid and spatially-explicit baseline for both a vicarious validation of fraction estimates from Sentinel-2 data and for quantifying uncertainties related to the reduced spectral information content of multispectral sensors. An in-depth comparative analysis between hyperspectral and multispectral sensors focusing on NPV and soil and their respective spectral separability has to our best knowledge not yet been presented for central European grasslands.

We here used hyperspectral images from the Hyspex airborne campaigns in 2018 (May, September) and 2019 (July) to derive PV, NPV and soil fraction maps for grasslands in Northern Germany. We followed the proposed by Guerschmann et al. (2009, Remote Sens. Environ., 113) to derive an image spectral library from the vertices of the Cellulose Absorption Index (CAI)/Normalized Difference Vegetation Index (NDVI) mixing space. Subsequently, regression-based unmixing with synthetic training data from image spectral libraries was used for fraction mapping based on all Hyspex bands. To obtain comparable fraction cover estimates, we applied the same approach to contemporary Sentinel-2 data. As proposed by Guerschmann et al. (2009), the hyperspectral CAI was replaced by the SWIR2/SWIR1 ratio.

Hyperspectral and multispectral feature spaces show a consistent typology of the grassland mixing space indicating that NPV and soil are separable within feature spaces based on NDVI and either the hyperspectral CAI or the multispectral SWIR ratio. The vicarious validation of Sentinel-2-based estimates with HySpex fractional cover revealed a linear agreement of NPV cover with MAEs of 7.2%, 8.7% and 12.6% and errors in the low and high value ranges. We found similar uncertainties for soil fractions (MAEs: 6.4%, 7.4%, 13.1%) with overestimations most prevalent in low value ranges indicating a slight confusion of NPV and soil from Sentinel-2. Kowalski et al. (2022) report coherent validation results based on sample sites within the same region. Our analyses confirm the suitability of HySpex for a vicarious validation of Sentinel-2-based grassland analyses, further offering to identify areas of uncertainty in a spatially explicit manner, which is impossible with a sample-based validation approach.

Hyperspectral data accordingly provides the best possible basis for estimating NPV and soil cover fractions, thereby facilitating a reliable assessment of vegetation status during drought periods. Future operational hyperspectral missions such as CHIME and SBG, will hence enable improved wall-to-wall time series analyses of grassland drought, which are currently only possible with Sentinel-2 and Landsat.

3-5 THEMSESS CROPSGRAS: IMAGING SPECTROSCOPY OF CROPLAND AND GRASLAND

MULTI-TEMPORAL IMAGING SPECTROSCOPY DATA PROCESSING FRAMEWORK FOR ESTIMATING BIOMASS IN ALPINE GRASSLANDS

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Abstract

Ecosystem monitoring requires high-spectral, spatial, and temporal resolution remote sensing data and analyses to provide reproducible and reliable estimates of change and process. More specifically, biodiversity state changes, as for instance measured by changes in plant functional traits, and our understanding of these changes can lead to a better interpretation of the ecosystem processes on a multi-temporal scale. Nevertheless, few studies have so far benefitted from high temporal resolution imaging spectroscopy data. Acquiring spectral measurements at different times across years, potentially subject to inter-seasonal variations, requires consistent data processing. Imagining spectroscopy (IS) is an emergent technology that holds the promise of meeting the challenges needed for ecosystem monitoring. Therefore, there is a need for a robust multi-temporal imaging spectroscopy data processing chain across years.

This study aims to assess a chain of data processing steps to (i) minimize multi-annual APEX (Airborne Prism Experiment) IS data quality disturbances caused by instrument, (ii) account for acquisition and data processing-related factors, including radiometric, atmospheric, and (iii) geometric compensations in a rugged terrain, high Alpine ecosystem of the Swiss National Park (SNP). Being a protected area without human intervention, the SNP bears the potential to analyse biodiversity dynamics in space and time. Our results show that multi-temporal IS processing requires many pre-processing steps to be well aligned and the effects of instrument, radiometric and atmospheric corrections are relatively well resolved for the SNP. We find that the statistical model predicts well inter-annual aboveground biomass, and this is explained by the number of growing degree days and topographical location of the subalpine grasslands. These preliminary results already show that IS data in the multi-temporal domain enable estimating important parameters to expand our understanding of ecosystem dynamics.

POSTERS 1A VEGTRAITS: QUANTIFYING PRIORITY VEGETATION TRAITS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA

EFFECTS OF SAMPLE SIZE ON REGRESSION MODELS FOR BIOPHYSICAL PARAMETER RETRIEVAL FROM SPECTRAL DATA

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Abstract

Machine learning (ML) regression is a frequently used approach for the retrieval of biophysical vegetation properties from spectral data. ML is often preferred in this context because it is able to cope with the following challenges that impair conventional regression models:

(1) Spectral data are highly inter-correlated. This strong correlation between bands or wavelengths violates the assumption in linear regression that the predictor variables are statistically independent and impairs the interpretation of regression coefficients.

(2) The relation between spectral data and the response variable is non-linear and not well described by linear models.

(3) The relation between individual spectral bands and the response variable is rather weak and many bands are necessary to build an adequate prediction model.

In addition, some ML approaches promise to require only a comparatively small sample size for achieving robust model results. This makes ML suitable for data sets that are asymmetric in terms of having fewer samples than spectral bands. In practice, the sample size for training data in remote sensing studies targeting biophysical variables is most often determined by availability and is frequently limited to n<100. This practice and the promise of ML to require only a few observations for sufficient model training is encountered by reports that these techniques are prone to over-fitting. So far, no systematic analysis of the effects of sample size on ML regression performance in biophysical property retrieval is available. This study hence addresses the question 'How does the training sample size affect the model performance in machine-learning based biophysical trait retrieval?'

For a comprehensive analysis, two common parameters were selected that are physically linked to the spectral signal of vegetation at the leaf and at the canopy level: leaf chlorophyll (LC, two data sets at the leaf and two at the canopy level) and leaf mass per area (LMA, seven and two data sets, respectively). Due to the differences in their spectral absorption features, these two parameters were expected to behave differently in regression analysis.

Three different ML regression techniques were tested for effects of training sample size on their performance: Partial Least Squares regression (PLSR), Random Forest regression (RFR) and Support Vector Machine regression (SVMR). For each data set and regression technique, the target variable was repeatedly modeled with a successively growing training sample size. Trends in the model performances were identified and analyzed.

The results show that the performance of ML regression depends on the sample size of the training data. On both leaf and canopy level, for both LC and LMA, as well as for all three regression techniques, an increase in model performance with a growing sample size was observed. This increase is non-linear and tends to saturate. The saturation in the validation fits emerges for training sample sizes larger than ncal = 100 to ncal = 150. While it may be possible to build a model with an adequate fit and robustness even with a rather small training data set, the risk of a weak performance, over-fitted and thus not transferable model and erratic band importance metrics are increasing considerably.

With increasing availability of Earth observation data, the bottleneck of a spatio-temporal assessment of biochemical and biophysical vegetation properties is shifting towards the acquisition of accurate ground truth

data. Both field sampling campaigns and laboratory analyses are costly in terms of manpower and financial resources. Sampling a sufficient data basis for training and validation of retrieval models may thus not always be possible. Freely accessible data archives such as the ecosysis data base offer hence extremely valuable opportunities for data augmentation.

POSTERS 1A VEGTRAITS: QUANTIFYING PRIORITY VEGETATION TRAITS FROM SPACEBORNE IMAGING SPECTROSCOPY DATA

DECONSTRUCTING PLSR AND OTHER DATA-DRIVEN METHODS FOR FOLIAR TRAIT MAPPING USING IMAGING SPECTROSCOPY AT BROAD SPATIAL SCALES

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Abstract

Recently, considerable attention has been given to a variety of approaches for mapping vegetation foliar traits using hyperspectral imagery, including empirical methods such as partial least-squares regression (PLSR) and gaussian processes regression (GPR), radiative transfer methods, and hybrid approaches. Despite their known limitations, data-driven methods such as PLSR remain the dominant approach for foliar trait mapping, due to their ease of implementation, ready interpretability, and general robustness. In this talk, we use field data and spectroscopic image data from AVIRIS, NEON and HySpex to rigorously assess the limitations of data-driven approaches including PLSR, lasso, elastic net, ridge regression, GPR and other machine learning approaches. We have developed an open-source python package (HyTraits) that enables testing and comparison among different methods, as well as development of ensemble predictions. We investigate the sensitivities of these methods with respect to data stratification and hyperparameter optimization with a large scale Monte Carlo study and illustrate an ensemble approach that enables robust foliar trait estimation across new data sets. These results demonstrate the potential for repeatable, interpretable implementation of data-driven spectroscopic trait models for broad implementation. The approach provides a foundation for users to quantify and address limitations of statistical methods in spectroscopy.

POSTERS 1B SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

USING DRONE-BASED HYPERSPECTRAL INFORMATION TO SUPPORT MAPPING OF SOIL ORGANIC CARBON AND CLAY CONTENT BY SENTINEL-2 DATA IN BADEN-WUERTTEMBERG

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Abstract

Various conventional data sources, for example soil surveys, forest site maps, geological data, and elevation models with derived morphological parameters are source datasets for the soil map of the German federal state Baden-Wuerttemberg (scale approx. 1:50 000). Satellite and airborne sensors provide the opportunity to map soil surface properties as efficient and low cost supplementary data. They offer a sufficient resolution in the temporal, spatial and radiometric domain. This essentially helps to keep soil maps up to date and to support a comprehensive understanding of soil properties.

This work aims at developing a mapping procedure for key soil parameters like organic carbon and clay contents on cropland in Baden-Wuerttemberg with special focus on analyzing spectral soil signatures. Therefore, the soil parameters are derived from their spectral characteristics based on Sentinel-2. Due to free availability and easier access, sources like satellite data are more often implemented into research and application workflows. The Sentinel-2 sensor covers a spectral range between the Visible and the Short Wave Infra-Red with 13 bands. It offers a best-case pixel size of ten meters and a revisit frequency of five days. Thus enabling the detection of soil parameters and their observation in time series.

In addition to multispectral satellite images, hyperspectral data from drone surveys as an additional source of spectral information and scale are examined. The drone survey used a HySpex MJOLNIR VS-620 sensor attached to a drone, which covers a spectral range between 400 and 2500 nm with 490 bands. Two agricultural fields located in the Kraichgau area in Northwest Baden-Wuerttemberg were recorded with the HySpex sensor in September 2021. At the same time in-situ spectra were measured with a portable spectroradiometer (Spectral Evolution PSR+ 3000) and soil samples were collected for lab analysis. The hyperspectral data is mainly used for validation purposes, whereas the soil samples are an integral part of the training dataset.

A broad collection of reference datasets is available for training, comprising, for example, the Land Use/Cover Area frame statistical Survey (LUCAS) and datasets from various projects. In total, the mapping algorithm is trained on a set of more than 800 reference points with measured soil organic carbon and soil clay content. In addition to the NDVI, the new broadband spectral angle index (BAI) is implemented in the preprocessing of the Sentinel-2 images, which is also examined in ESA´s WorldSoil Experts Workshop. Based on the spectral signatures of the parameters at reference points, bare soil pixels of the whole state of Baden-Wurttemberg are modelled regarding their soil organic carbon and clay contents using Random Forest.

This work is embedded in the Copernicus implementation project "BopaBW – near-surface soil parameters Baden-Wuerttemberg", aiming to establish remote sensing data as an additional source to improve official soil maps both in terms of product resolution and quality. Moreover, it can be used as a variable for digital soil mapping projects.

POSTERS 1B SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

PREDICTING SOIL PROPERTIES OF MOUNTAINOUS AGRICULTURAL LAND IN THE CAUCASUS MOUNTAINS USING MID-INFRARED SPECTROSCOPY

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Abstract

Given the importance of mountainous agricultural lands in food security and ecosystem services, the necessity for sustainable soil management and protection thereby requires high spatial and temporal resolution soil information. Since mountainous regions are data-sparse and costly for sampling, a viable alternative technique for the rapid assessment of soil properties is required. The objective of this study was to test the potential of mid-infrared spectroscopy in predicting soil properties of mountainous agricultural sites in the Caucasus Mountains in Azerbaijan.

114 soil samples were collected from the surface horizon (0-20 cm). Samples were air-dried, milled and sieved to < 2mm. The studied physico-chemical parameters were soil organic carbon (SOC), particle sizes (clay, silt, sand), pH, calcium-carbonate (CaCO3), hygroscopic water (HW), macro- and micro-nutrients in Mehlich 3 extractant (available Ca, K, P, Mg, Mn, Fe, Zn, Cu, Pb and Cd). Spectral measurements were undertaken in laboratory condition using a portable Agilent 4300 Handheld FTIR (5000-650 cm-1) for diffuse reflectance measurements in the mid- and longwave infrared. 40 different spectral preprocessing approaches, comprising filtering, normalization and linearization approaches, were applied. We applied partial least squares regression (PLSR) for model calibration and determined the optimal number of PLSR factors via the Akaike Information Criterion. Models were run for all pre-processing techniques using all samples and leave-one-out cross validation. This approach served to rank the effect of the pre-processing methods on prediction accuracy based on RMSE, R2 and RPD.

The 1st derivative was found most optimal for 10 out of 18 soil properties. For other parameters, absorbance, Savitzki-Golay smoothing, continuum removal, multiplicative scatter correction, standard normal variate and squared root of the spectra provided the best modelling results. Models considered optimal were again calibrated and validated with 75% and 25% of the samples, respectively. We found notable differences between the statistics of cross-validation, calibration and validation for several soil properties whereas all soil properties were successfully predicted. The R2 of the validation subset ranged from 0.48 (for HW) to 0.99 (CaCO3) and correspondingly RPD ranged from 1.12 (poor model; 1.0 < RPD < 1.4) to 6.47 (excellent model; RPD > 2.5).

Significant relations were found between all tested soil properties, of which Ca, Cd, Fe, Mg and Pb showed higher correlation with the basic soil properties (CaCO3, pH, clay, sand, SOC), while others (Cu, K, P, Mn and Zn) showed weaker correlations. The noted relationships indicate that the availability of nutrient elements is associated with basic soil properties, mostly CaCO3 and pH. Therefore, the correlation coefficients between nutrient elements and spectral reflectance across the wavelength region showed similar pattern to those of their associated basic soil properties. These relations were also reflected in important wavelengths contributing to the predictions. Furthermore, the inter-correlations e.g., between Ca and Cd, Ca and Pb, Cd and Pb, Fe and Mg show that those elements are similarly bound in the soil matrix. All noted relationships indicate that the prediction of available nutrient elements relies on their indirect bond to clay minerals, iron oxides, carbonates and organic matter.

Our study successfully demonstrated the potential of mid- and longwave infrared spectroscopy to aid the prediction of soil properties in the agricultural lands of the Caucasus Mountains in Azerbaijan. This is of high relevance for assessing and quantifying soil parameters important for cultivation in this mountainous region as well as for monitoring the condition of the soils, which are highly susceptible to erosion.

POSTERS 1B SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

IDENTIFYING AND MAPPING SOILS FROM REMOTE SENSING HYPERSPECTRAL SENSORS WITH FCOVER

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Abstract

Identifying pure soil spectra from spaceborne hyperspectral images is a vital step towards mapping crucial soil surface parameters such as soil organic carbon and soil mineral composition, which are inputs for monitoring soil health on a large scale. However, images of natural environments acquired by spaceborne imaging spectrometers are characterised by a high number of mixed pixels containing soil and vegetation. For accurate soil models, predominantly pure surface cover pixels are needed, requiring a clear strategy to disentangle spectral signals of soil, photosynthetically active vegetation (PV) and non-photosynthetically active vegetation (NPV). Hyperspectral images provide an opportunity to achieve this as features in the short-wave infrared range (such as the ligno-cellulose absorption feature at ~2100 nm and clay absorptions at ~2200 nm) allow NPV and soil to be separated from each other. The availability of hyperspectral data is increasing with the advent of new spaceborne missions (DESIS, PRISMA, HISUI) and the promise of further instruments (EnMAP, CHIME, SBG) to complement observations from airborne sensors (HySpex, AVIRIS-NG).

To find pure soil spectra, a fractional vegetation cover processor called fCover is used to calculate per pixel soil abundances. The first processing step identifies pure spectra (vegetation and soil) from the image using a spatial-spectral endmember extraction method, iterating in blocks across the image to find local endmembers before being distilled into a single global endmember library. Next, a classifier is used to label each endmember as PV, NPV or bare soil. In the last step, using a MESMA approach, each pixel in the original image is treated as a linear combination of one PV spectrum, one NPV spectrum and one soil spectrum from the labelled global endmember library. An additional component for shade is also considered and the results are normalised to one. Hence, the weights on each component correspond to the abundance of each class. The abundance value found for the soil class indicates which pixels in the image represent relatively pure examples of bare soil.

Based on a synthetic study, the pixel abundances for soil can be determined with an RMSE of 5-6% for instruments covering the spectral range 400-2500nm such as HySpex, PRISMA and EnMAP; with real world data, the mean error is in the range 8-15% abundance for all classes. When applying the fCover chain to an instrument like DESIS, which lacks observations in the SWIR range, the RMSE on soil abundance increases to 10% for synthetic data. Nevertheless, this still suggests that hyperspectral instruments with a limited infrared range can still indicate the location of pure soil spectra.

Two case studies are investigated here for the purpose of identifying pure soil pixels. The first covers an area in central Israel with spaceborne data from PRISMA, and the second study uses observations from the airborne system HySpex and the spaceborne system DESIS of Camarena, Spain – a rainfed agricultural area covering about 75 km2 in a semi-arid climate – to explore the possibility of soil mapping. After processing these images with fCover, maps for the abundances, the used endmembers and statistical measures (residuals, RMSE) are found. With appropriate thresholding of the retrieved soil abundances, the purest soil pixels can be identified in the images and compared to field measurements in order to test the validity of the methodology. As a by-product of fCover, the reconstruction of underlying 'pure' soil spectra from pixels with up to 40% vegetation cover can be applied for the retrieval of soil organic carbon.

POSTERS 1B SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

POTENTIAL OF HYPERSPECTRAL REMOTE SENSING DATA AND A SOIL SPECTRAL LIBRARY FOR LARGE SCALE SOC MAPPING

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Abstract

Imaging spectroscopy is a valuable tool to generate spatially accurate topsoil maps and can thereby contribute to soil monitoring and to combat soil degradation. This study aims at assessing the potential of hyperspectral satellite remote sensing in combination with soil spectral libraries for large scale SOC mapping using a two-step approach. We use hyperspectral data based on airborne HySpex and simulated satellite EnMAP platforms. The data was acquired over a test site in north-eastern Germany with the aim to quantify the content of soil organic carbon (SOC). Therefore, we apply an approach consisting of two steps: (i) a local partial least squares regression (PLSR) based on the European LUCAS (land use/cover area frame statistical survey) Soil database to quantify the SOC content of soil samples collected at the study site using their laboratory spectra, and (ii) based on the just calculated SOC contents of the soil samples and the image spectra of the corresponding pixels a remote sensing model is calibrated. To estimate the quality of this approach it is compared with the traditional PLSR approach which uses the soil sample's SOC content measured by wet chemistry and again the image spectra of the corresponding pixel.

In the first step of the two-step approach an individual SOC prediction model is calibrated for each soil sample from the test site based on selected samples from the LUCAS database. Here prediction accuracy is high with R2 = 0.86 and RPD = 2.77. Given the additional uncertainty induced by the first step, results of the second step are below those of the traditional approach but still in a reasonable range. The airborne prediction accuracy of the traditional approach is R2 = 0.78, RPD = 2.19 and of the two-step R2 = 0.67, RPD = 1.79. Applying both approaches to simulated EnMAP imagery leads to an overall decrease in accuracies owing to the reduced spectral and spatial resolution (traditional: R2 = 0.77, RPD = 2.15; two-step: R2 = 0.48, RPD = 1.41). The remote sensing models of the two-step approach calibrated for both sensors are applied to all bare soil pixels of the respective images to produce SOC maps. It can be concluded that the local PLSR approach, which makes use of large scale soil spectral libraries, provides an alternative to the wet chemistry SOC measurements of local soil samples. It shows the potential of hyperspectral satellite remote sensing data for repeated inexpensive SOC mapping given that spectral measurements of a few local samples are available for model calibration.

POSTERS 1B SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

MONITORING BIOLOGICAL DEGRADATION OF HISTORICAL STONE USING HYPERSPECTRAL IMAGING

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Abstract

Stone is one of the most common materials used as a building material in central Europe. Together with wood and brick this material has been used for centuries to construct various objects like houses, walls, bridges and also castles and churches. Historical objects are endangered by degradation procedures coming from physical, chemical and biological weathering agents. These agents do not often act isolated but together and thus amplify their effects on each other. Biological weathering processes contribute to both physical and chemical processes as well. The presence of organisms like algae and lichens on the stone surface is very common. These organisms influence the stone integrity thanks to pressure caused due to root growth and chemically thanks to production of organic compounds. The production of organic compounds also causes the growth of salt crystals in pore space, which consequently causes the pressure action to pore walls. These procedures together violate the surface and make it liable to decay. Cyclic action of weathering processes depending on atmospheric conditions like humidity, insolation, freezing water and extent of organisms plays an important role in the stone degradation process and therefore the study of their dynamics in time is very important. The most sensitive stones to weathering action are sedimentary stones, especially clastic sedimentary stones, which have been historically widely used as a building material thanks to their wide distribution, easy excavation and easy workability. Due to their way of origin, these stones often have relatively high amounts of pores in which the weathering processes take place. They also frequently contain portions of clay minerals, which are able to change their volume thanks to their sorption ability and thus contribute to grain disintegration. In order to prevent historical objects from weathering, restoration cleaning techniques are used. These methods are prepared with respect to the investigated material and are very complex. In order to enhance these methods the weathering process itself should be analyzed in detail as well. For investigation of the year- round process of biodegradation hyperspectral sensor was used. The data were purchased by a hyperspectral camera with 400 to 1000 nm spectral range placed on Pan&Tilt unit and a tripod creating a hyperspectral system specially designed for in-situ measurements. A carefully chosen historical stone was analyzed during time to monitor biological changes on the surface. The object of interest is situated on the right bank of the Vltava river and is in the immediate vicinity of Charles bridge, one of the most famous historical sites in Prague, Czech Republic that is protected as a UNESCO heritage site. The studied stone block is made from medium to coarse grained sandstone which was used on many historical sites in Prague city center. The inspected location is about 2m above average water level and is a part of a 19th century wall under the Křížovnické náměstí that is next to the first bridge vault. This site was chosen due to nearness of water and therefore high overall humidity all year long. It is expected to follow conditions that occur on bridge pillars.

The research is part of the Czech Ministry of Culture project DG20P02OVV021 "Stone surface topography and its application in stone element restoration field" that explores possibilities in stone restorations and also considers new non-invasive methods and their potential in cultural heritage documentation. This contribution demonstrates project preliminary results of the Charles bridge stone.

POSTERS 1B SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

DEVELOPMENT OF A GENERIC DATABASE OF SOIL OPTICAL AND BIOCHEMICAL TRAITS

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Abstract

Soil optical properties are an important source of information for precision agriculture - either for accounting for the reflectance of different soil types in the process of retrieval of crop traits (yield, biochemical and structural traits) or for direct retrieval of soil properties (e.g. soil structural properties, soil chemistry). Due to the high variability of soil reflectance depending on soil type and soil moisture, it is crucial in the case of remote sensing applications over a large area to establish a representative database of soil optical properties and their corresponding structural and biochemical properties for a wide range of soil types and across a gradient of soil moisture. Such local measurements can further contribute to global databases of soil optical properties. Further uscaling of optical soil properties to the level of airborne or satellite RS will allow non-destructive acquisition of soil properties at a given location and time and has the potential for retrospective assessment of soil trends from historical time series of Landsat and Sentinel-2 satellite observations.

The aim of this study is to present a methodology for ground-based collection of optical and biochemical soil properties for a wide range of soil types occurring in the Czech Republic and the development of an algorithm for their interpretation at the level of laboratory spectroscopy data and multispectral sensors OLI (Landsat 8-9) and MSI (Sentinel-2A,B). In the first step, we collected 167 soil samples representing 43 main soil types (17 in simplified classification) for different locations in the Czech Republic. Soil samples were analyzed for the percentage of carbon (%C) and nitrogen (%N), Ca (mg x kg-1), K (mg x kg -1), Mg (mg x k -1), P (mg x kg -1), H+ (mmolchekv/kg) and KVK (mmolchekv/kg) of the dry sample. Subsequently, the samples were measured for their optical properties in the laboratory using an ASD FieldSpec 4 spectroradiometer (350 - 2500 nm, 1 nm sampling) and a turntable to homogenize the measurements. For each sample, a gradient of soil moisture from 0% (dry soil) to maximum saturation (100% moisture) was measured. This yielded 1655 unique spectral measurements (approximately 10 soil moisture gradients for each of 167 soil samples). The spectra were further resampled using the sensor response function OLI and MSI.

Using different statistical approaches (vegetation indices, regression, machine learning methods), we evaluated the potential of the retrieval of soil biochemical parameters for different spectral domains (hyperspectral and multispectral) and different soil moisture conditions. The best results were obtained for %C, %N, Ca, Mg and KVK (r2 > 0.5), other soil parameters were not significant. There were no major differences among spectral scenarios, but the increasing soil moisture decreased the performance of models. Using the ratio of two SWIR channels around 2100 nm and 1600 nm, we were able to obtain information about soil moisture with high accuracy (r2 > 0.9) and such information could be used to further increase the accuracy of the retrieval of soil parameters. The trained models can be used to retrieve soil biochemical parameters from image spectroscopy data as well as to study long-term trends in soil chemistry if applied to bare soil composites constructed from time series of satellite observations.

POSTERS 1B SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

SOIL ORGANIC CARBON MODELLING USING OPEN-ACCESS SOIL SPECTROSCOPY LIBRARIES AND MACHINE LEARNING ALGORITHMS

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Abstract

Soil organic carbon (SOC) is an essential indicator of good soil quality, and it is necessary to monitor and quantify SOC. However, the high cost and time-consuming nature of conventional laboratory analysis restrict the monitoring of SOC at a large scale.

Visible–near-infrared (Vis-NIR) spectroscopy is a recognized technique to monitor and quantify soil attributes in an accurate, rapid, and inexpensive approach. An increasing number of soil spectral libraries (SSLs) on regional, continental and global scales, such as the World SSL, the European land use/cover area frame statistical survey (LUCAS), the Brazilian SSL (BSSL), the African SSL (ICRAF-ISRIC) and the Mediterranean SSL (GEO-CRADLE) brings the tremendous opportunity to develop spectral-based models to assess SOC in large scales.

However, soil properties in SSLs are covertly encoded, and valuable information from the spectral data must be extracted to establish a proxy approach to detect soil parameters. Machine learning algorithms have often been applied to calibrate SOC prediction models from spectra. Nevertheless, with the development of large SSLs, we need to seize the opportunity to use big data analytics for spectral data processing.

The main objective of this study is to apply different machine learning algorithms on good-sized open-access soil spectroscopy libraries to predict SOC and compare the developed model accuracies.

POSTERS 1B SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

SIMULATION OF SPECTRAL DISTURBANCE EFFECTS FOR THE GENERATION OF LANDSCAPE-LIKE SOIL SPECTRAL LIBRARIES IN SUPPORT OF CURRENT AND UPCOMING SATELLITE MISSIONS

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Abstract

Optical remote sensing observations and in particular imaging spectroscopy, have been shown to be powerful techniques for the quantitative determination and modelling of a range of soil properties including topsoil mineralogical composition such clay, iron-oxide or carbonate content, as well as textural composition and soil organic carbon content. Quantitative soil spectroscopy has largely benefited from technological and methodological developments over the past decades and is expected to further increase in attractiveness due to the upcoming increase in high-quality data availability provided by the next generation of orbiting hyperspectral sensors. However, advances are still necessary to fully develop soil products that can support soil monitoring demand on continental and global scale. Currently, efforts are being made to create large scale harmonized soil spectral libraries (SSL) that can be used to develop more robust spectral models that are applicable for larger areas in order to create global maps with less need for local soil sampling and analyses. A major challenge in the exploitation of these SSLs is the difference in laboratory measured soil reflectance spectra acquired under controlled conditions and the remotely sensed soil surface signal. On the remote sensing scale variations in surface conditions can have a strong impact on the quality and accuracy of soil property prediction. Depending on the fragmentation of the landscape, there is likely to be a mixture of soil and vegetation in the satellite sensor’s field of view due to trees, crops or post-harvest crop residue. In addition, the spectral reflectance of soil surface can be heavily affected by residual soil moisture and microtopography such as tillage ridges that produce shaded areas according to illumination and viewing conditions.

In order to assess and potentially reduce the impact of these spectral disturbing effects caused by variations in surface conditions the development of a Spatially Upscaled Soil Spectral Libraries (SUSSL) is proposed in this work. The SUSSL is based on a sub-selection of the European LUCAS soil database, and combines spectral modelling and aggregation/mixing techniques to simulation of realistic scenarios of ‘landscape-like’ cropland reflectance data. Specifically, the results of spectral models such as HySimCar (ray-tracing for soil/vegetation canopy reflectance), MARMIT (soil moisture modelling), and MODTRAN (atmospheric scattering of shaded areas) are combined to simulate the disturbed soil reflectance. The modelled scenarios include soil reflectances affected by (1) the partial presence of photosynthetic active (green) emerging crop within the field-of-view, (2) the partial presence of non-photosynthetic active (dry) crop residues, (3) mixing with photosynthetic active (green) tree canopy reflectance for taking into account mixed pixels at field edges or individual trees in the middle of fields, (4) variable level of soil moisture and (5) variable level of soil shading caused by microtopography. Afterwards, the spectral database is convoluted to the spectral response functions of two current multispectral (Landsat 8 OLI and Sentinel-2 MSI) and two upcoming hyperspectral (EnMAP and CHIME) satellite sensors. In a next step, the SUSSL can be used for the test and validation of different correction, disaggregation and unmixing techniques to assess the capabilities of the retrieval of undisturbed surface reflectance, to which soil prediction models can be applied with increased accuracy. In this contribution, the developed database, including methodological choices and parameter selections for the simulation of the different disturbing effects will be presented. Overall, this effort highlights the potential and limitations of imaging spectroscopy for soil mapping and monitoring, and capabilities and of current and upcoming spaceborne sensors as support for a more informed and sustainable use of our world’s soil resources.

POSTERS 1B SOILS: HYPERSPECTRAL REMOTE SENSING OF SOILS

DETECTING SOIL ORGANIC CARBON IN AGRICULTURAL SOILS ADJACENT TO MINING AREA OF KAJARAN, ARMENIA USING PROXIMAL SENSING SPECTROSCOPY

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Abstract

Soil Organic Carbon (SOC) is a key property of soil quality. Moreover, in comparison with some metals/oids including potentially toxic elements (PTE), which are minute components in soil constitute, SOC, soil moisture and other soil minerals have stronger spectral response and may provide an indirect signature for proximal spectral estimation. However, the role of these soil properties in linking spectral reflectance and specific elements may be site-specific. The aim of this study is to examine the potential of proximal sensing of soils (visible, near-infrared (VIS-NIR) spectroscopy) to monitor SOC in agricultural soils near the mining town of Kajaran (Armenia) situated in a natural biogeochemical province enriched by Mo, Cu and other PTE. To study the relationship between the studied variables Spearman correlation was applied. In addition, a hierarchical cluster combined with the compositional data analysis was applied to reveal the grouping features of the variables. The Partial Least Square Regression (PLSR) was used to reveal the potential of reflectance spectra for elements and SOC quantities estimation. The data was randomly split into training (75%) and testing (25%) sets. To calibrate the model a 10-fold cross-validation (CV) approach was adopted. To achieve the research aim, the content of SOC were estimated via Welkley-Black Method: Colorimetric Method, GLOSOLAN-SOP-02 and corresponding reflectance spectra were collected using Spectral Evolution SR-3500 spectrometer, respectively. The obtained data were included in an existing dataset of chemical elements. The results showed that significant correlation between SOC and spectra was detected in 2051-2059 nm and 2266-2274nm (0.82; 0.84 and ($p<0.05$)). Moreover, significant negative correlation was detected between SOC and Ti, V, K (0.33; 0.35; 0.36 ($p<0.05$), respectively). Positive significant correlation observed between SOC and Zn, Mo (0.62, 0.4 ($p<0.01$)). In addition, SOC was in the same cluster with Zn and Mo whereas Ti, V, K group together in another cluster. The results showed that PLSR models based on VIS-NIR spectra provided acceptable estimation accuracies for SOC. Best estimation accuracy was achieved (R2Test = 0.53, RMSETest = 0.14; R2train = 0.88, RMSEtrain = 0.01; R2(CV) = 0.68, RMSE(CV) = 0.04). At the same time, some metals (i.e. Ti, V, K, Zn, etc) express promising relationship with spectra, as well. Concluding, the results are promising for SOC estimations. However, more research needs to be done in terms of getting indirect spectral signatures for PTEs estimation in agricultural soils near the mining town of Kajaran.

POSTERS 1C WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING HYPERSPECTRAL DATA

DIFFUSE ATTENUATION OF UNDERWATER UV AND SHORT BLUE LIGHT OBTAINED FROM TROPOMI'S HIGH SPECTRAL RESOLUTION

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Abstract

In this study, we exploited high spectrally reoslved Sentinel-5 Precursor's (S5P) sensor TROPOMI's potential to retrieve the diffuse attenuation for three bands reaching from the UV-B to the short blue wavelengths range. As a baseline, previously developed algorithms applied to similar atmospheric satellite sensors such as SCIAMACHY, GOME-2 and OMI were adapted and extended. Opposed to these precursor sensors, TROPOMI enable data acquisition due to a large swath with spatial and temporal resolution nearly as good as obtained from common open ocean color sensors, until today only multispectral. The later sensors do not enable retrievals in the UV spectral region, but are used for intercomparison to the short blue diffuse attenuation retrieved from TROPOMI. In this presentation, we provide detailed insights into the retrieval method, its uncertainty and the application to obtain data in the global ocean in open ocean and coastal regions.

POSTERS 1C WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING HYPERSPECTRAL DATA

THE WATER QUALITY PROTOTYPE TO PROCESS PRISMA PRODUCTS FOR INLAND AND COASTAL WATERS MAPPING

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Abstract

The field of aquatic hyperspectral remote sensing is advancing rapidly, and new products are informing water quality monitoring, as well as the biodiversity of phytoplankton and benthic habitats in shallow waters (Dierssen et al. 2021. Front. Environ. Sci., 9). Accordingly, a range of algorithms has been developed and tested: from those making use of single band, band ratio or band difference positioned at switching wavelengths (hereinafter referred to as “semi-empirical”), where water reflectance is sensitive to variation in water components, to those where water reflectance is used as a reference to be matched against spectra generated with forward bio-optical modelling (hereinafter referred to as “semi-analytical”).

This study presents a prototype developed in Python allowing the processing of PRISMA surface reflectance Level 2D (L2D) products for aquatic ecosystems mapping, which was developed by e-GEOS in the framework of the project “Sviluppo di Prodotti Iperspettrali Prototipali Evoluti” funded by the Italian Space Agency (ASI) (Contract ASI N. 2021-7-I.0). The main objective of the project was the prototyping of a subset of value-added products to be retrieved by means of hyperspectral data processing. The ‘Water Quality’ prototype is a combination of state-of-the-art techniques for the retrieval of optical parameters useful for the characterization of inland and coastal waters. The prototype processor ingests at-surface reflectance products and implements adaptive semi-empirical and semi-analytical methods for parameters retrieval. In particular, an adaptive band ratio algorithm was developed for the retrieval of the concentration of phytoplankton primary photosynthetic pigment (Chlorophyll-a (Chl-a)) and the cyanobacteria accessory pigment (Phycocyanin (PC)). The processor exploits the diagnostic reflectance spectral feature of Chl-a and PC. Chl-a is correlated with both the height and position of the red-edge scattering signal near 700 nm, which shifts towards increasing wavelengths as biomass increases. Thanks to the spectral resolution of the PRISMA sensor, the relative maximum and minimum diagnostic features can be pixel-wise and adaptively identified in the image scene (based on Hestir et al. 2015. Remote Sens. Env., 197; Bresciani et al. 2013. Mar. Freshw. Res., 64). Moreover, the prototype processor also implements a semi-empirical algorithm to retrieve Total Suspended Matter concentration and water turbidity exploiting different wavelengths in the visible or near-infrared range (based on Nechad et al., 2010. Remote Sens. Environ., 156). A bio-optical model inversion (based on Giardino et al. 2012. Comput. Geosci., 45) then allows the retrieval of Chl-a concentration in optically deep oligotrophic waters; in case of shallow waters, the bio-optical model inversion provides bottom substrate fractional coverage (e.g. macrophytes, sand) (based on Brando et al. 2009. Remote Sens. Env., 113). The model parameters for the calibration of both semi-empirical and bio-optical model methods are selected based on a priori-knowledge of the optical properties specific for the case studies investigated in the project.

The Water Quality processor were tested on PRISMA L2D data over some Italian lakes (i.e. Garda, Mantua, Varese and Trasimeno) with waters spanning significant ranges of trophic status and turbidity as well as in transitional and coastal areas (Venice lagoon and northern Adriatic Sea). The preliminary results of the prototype products validation show a good agreement respect to the in-situ data, both for water quality parameters and bottom substrate products. In some of the maps produced, it was possible to highlight some critical issues of the aquatic environments, for example a high blooming of cyanobacteria with high concentration of Chl-a and PC (>100

mg/m3) on 16/10/2021 in Lake Varese, and high TSM concentrations in Lake Trasimeno (>50 g/m3) on 30/11/2020.

POSTERS 1C WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING HYPERSPECTRAL DATA

OPTICAL CHARACTERIZATION OF POLLUTANTS IN INDUSTRIAL WASTE WATERS BY IMAGING SPECTROSCOPY

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Abstract

Water is a natural resource whose management is subject to strong geopolitical, environmental and societal issues. The main water pollution sources are urban sewage, agricultural practices and industrial wastes. Currently, remote sensing observation techniques such as imaging spectroscopy are fairly robust to evaluate water quality in natural environments. Multiple methods exist to extract qualitative and quantitative information from imaging spectroscopy. Among them are band ratioing techniques (Morel and Gentili, 2009.Remote Sens. Environ., Gordon and Morel, 1983. Coast. estuar. stud.), spectral derivative methods (Torrecilla et al., 2011. Remote Sens. Environ., Lubac et al., 2008. J. Geophys. Res.), data coordinate transformations (Catlett and Siegel, 2018. J. Geophys. Res., Smith and Bernard, 2020. Front. Mar. Sci.) or neural network approaches (Paoletti et al., 2019. J. Photogramm. Remote Sens.). However, in the case of polluted waters, methods are generally site specific and often require in situ data. Moreover, most pollutant inherent optical properties (IOPs), namely the absorption and backscattering coefficients, remain largely unknown. This study aims at detecting and characterizing pollutants in industrial ponds using imaging spectroscopy. We therefore seek to retrieve the IOPs of the major pollutants in water using a physically-based approach.

To do so, we propose an inverse method based on the radiative transfer analytical model developed by Lee et al. 1998 (Lee et al., 1998. Appl. Opt.). In the forward mode of this model, the subsurface remote sensing reflectance is calculated using an equation that depends on the optical properties of the water constituents, the water column depth and the bottom reflectance. In natural waters, the total absorption coefficient consists in the sum of the absorption caused by pure water, colored dissolved organic matter and phytoplankton. The total backscattering coefficient consists in the sum of pure water and particulate backscattering coefficients. Such values are provided from literature data. In the case of industrial waters, we have to take into account the IOPs of the pollutants. When dissolved, they mostly influence the absorption coefficient. When in suspension, they mostly influence the backscattering coefficient of the water mass. Lee inversion method (Lee et al., 1999. Appl. Opt.) requires IOPs as input to estimate scalar values (parametrization coefficients of IOPs and bottom reflectance, depth) by minimizing the difference between measured and simulated reflectances. The goal of our inversion method is to estimate, from the remote sensing reflectance, the spectral values of the total absorption and backscattering coefficients as well as the scalar values of the bottom reflectance parameter and the pond depth, leading to an ill-posed problem.

To solve it, we must reduce the number of unknown parameters that need to be retrieved. By taking advantage of the spatial homogeneity of the IOPs of the major pollutant for a given pond, we assume that the total absorption and backscattering coefficients are the same for all the pixels in the pond. Also, phytoplankton concentration is assumed to be weak, as a result of the extreme pH conditions generally encountered in such waters. Moreover, various measurements of bottom reflectance spectra are considered. From this, a multipixel inversion method is used to retrieve the IOPs. The proposed method has been tested on a simulated dataset. A sensitivity study performed using forward radiative transfer calculations showed that the IOPs of a given pollutant might be distinguished from the optical properties of natural constituents. The method will be further applied and validated using real data. Our results will be presented and discussed during the workshop.

POSTERS 1C WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING HYPERSPECTRAL DATA

CONTRIBUTION OF MULTISPECTRAL S2A AND HYPERSPECTRAL (PRISMA, EO1) DATA FOR ESTIMATING TURBIDITY IN COASTAL SHALLOW WATER

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Abstract

Ocean color satellite data offers satisfactory results on the quantification and estimation of the various parameters of water quality, but this remains ineffective and not validated mainly in coastal regions which have considerable areas of very shallow water, where most of water pixels are masked by ocean colors atmospheric corrections. Visible multispectral and hyperspectral remote sensing is an effective technique for estimating water quality and monitoring some of these environmental issues. (Jadidi et al.,2020 , Remote Sensing, issue 12, Zhu et al.,2013 Remote Sensing of Environment, issue 134) The socioeconomic interest of intertidal regions is very important, especially to the extent of pollution, industrial or urban discharges, or in relation to certain depollution actions, or even developments, particularly in estuarine or lagoon environments.

The objective of this research is to detect the effects of the bottom contamination on ocean color satellite data and to extract the water quality parameters. For this research we used Sentinel 2 multispectral imagery (MSI), the Earth Observing 1 EO1 Hyperion and PRecursore IperSpettrale della Missione Applicativa PRISMA in two different areas.

The first one is the lagoon of Bizerte (extreme north of Tunisia) which is subject to several anthropogenic and natural pressures, in particular industrial pollution, discharges of urban wastewater and eutrophication. Bizerte lagoon covers an area of 128 km2 with an average depth of 7 m. The lagoon drains a catchment area of around 380 km2. The second study site is the Kneiss archipelago lie in Skhira bay in the Gulf of Gabes in the southeastern coast of Tunisia at Khaouala village. This archipelago is located about 3.5 km off the continent with an area of about 5850 ha. The entire archipelago is a part of the shallow water that has emerged above the waterline. It belongs to a shallow extended platform cut into by tidal channels that become visible at low tide. The hydrodynamics of this area are influenced by semi-diurnal tides with a maximum amplitude of 2 m.

In our study we used in situ, multispectral and hyperspectral data to map the turbidity in the two selected coastal areas. Sensors used are PRISMA provides hyperspectral images with 239 bands (400–2500 nm) at <12 nm spectral resolution and 30 m spatial resolution, EO1 is a hyperspectral imager capable of resolving 220 spectral bands (from 0.4 to 2.5 micron) with a 30 m ground resolution and S2A data, characterized by a high spatial resolution (20 m, 10 m) and 13 spectral bands. Several field campaigns were carried out in the Bizerte lagoon on May 23, 2021, July 2, 2021 and December 24, 2021 and in the Kneiss Islands on May 27, 2017. The parameters measured are the turbidity and the transparency of the water with a maximum of 2.2 (NTU) and a minimum of 0.5 (NTU) in the Bizerte lagoon and a maximum of 37.8 (NTU) and a minimum of 2.22 (NTU), in the Kneiss islands. The adopted methodology started on the application of a shallow water area mask. Then, extraction of linear statistical relationships between remote sensing reflectance and in situ measured turbidity concentration is done to estimate and map turbidity. Thus, the first result is to create a mask from uncorrelated pixels via 2D scatter plot between 665 nm and 865 nm in order to eliminate the overestimation of water quality concentration parameters due to the effect of the bottom albedo. The second result is to use the Semi-empirical methods to developpe a local turbidity algorithm based on the water reflectance (Rrs) in the 560nm and 490nm bands. In spite of the fineness of the hyperspectral data, we could use only 39 bands among the available 220 bands of EO1 and removed 40 bands to PRISMA bands data because of their bad radiometric quality. Despite this, a correlation coefficient greater than 0.7 between S2A, PRISMA data and in situ data was recorded.

POSTERS 1C WATER: TOWARDS INLAND AND COASTAL WATER MONITORING USING HYPERSPECTRAL DATA

DATA MANAGEMENT QUALITY MANAGEMENT FRAMEWORK FOR THE HYPERSPECTRAL RADIOMETRY SYSTEM ONBOARD THE RV CELTIC EXPLORER

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Abstract

A five sensor above-water hyperspectral radiometry system was installed on the RV Celtic Explorer; Ireland's largest research vessel. Instrumentation set-up included a TriOS RAMSES-ACC hyperspectral cosine irradiance meter for Ed (λ) downwelling solar irradiance and four TriOS RAMSES ARC hyperspectral radiance meters: two for measuring upwelling solar radiance Lsfc (θsfc, ΦSun, λ) and two for measuring sky leaving radiance Lsky (θsky, ΦSun, λ), with the sky and sea surface radiance sensors at zenith angles θ sfc = 45° and θ sky = 135°. The radiometers collect irradiance and radiance measurements automatically at 15-minute intervals with automatic time integration throughout the survey path over a spectral range of 300-950 nm (λ) using the TriOS RAMSES software MSDA_XE. Measurements are autonomous and continuous during daylight hours resulting in over 100,000 files for a three-week scientific cruise. In 2019, 16 research cruises were conducted on the RV Celtic Explorer covering a total of 42,147 nautical miles. These took place over 320 days from January to December. A Data Management Quality Management Framework (DM-QMF) pack was created for the end-to-end hyperspectral data collection and processing system. A series of components document running the system and the overall data management which complies with the International Oceanographic Data and Information Exchange of UNESCO's Intergovernmental Oceanographic Commission (IOC-IODE) standards. Components of the DM-QMF system consist of Standard Operating Procedures (SOPs), process flows, requirements and acceptance criteria, a data management plan, data catalogues and performance evaluations. A case study that uses the hyperspectral radiometer data from two RV Celtic Explorer scientific research cruises (reference CE19009 and CE19010) accompanied with ocean colour satellite data collected in May, June and July, 2019 are presented. Comparisons are made between the RV Celtic Explorer hyperspectral above-water data and Copernicus Marine Environment Monitoring Service (CMEMS) satellite ocean colour data products. Remote Sensing Reflectance bands investigated included 443 nm (dataset-oc-atl-opt-multi_cci-l3-rrs443_1km_daily-rep-v02_1639576520171.nc), 490 nm (dataset-oc-atl-opt-multi_cci-l3-rrs490_1km_daily-rep-v02_1637145966390.nc), 510 nm (dataset-oc-atl-opt-multi_cci-l3-rrs510_1km_daily-rep-v02_1637146408185.nc) and 560 nm (dataset-oc-atl-opt-multi_cci-l3-rrs560_1km_daily-rep-v02_1637146700845.nc). The satellite products available are part of the European space agency Climate Change Initiative (CCI). This is a two-part programme that aims to produce 'climate quality' merged data records from multiple sensors, derived from level 2 data produced by SeaDAS l2gen (SeaWiFS) and Polymer (MODIS, VIIRS, MERIS and OLCI-3A) with the Rrs bias corrected and a spatial resolution of 1km x 1km. Datasets were processed using Mathworks (MATLAB) scripts. Five-step MATLAB scripts were used to process the ship-based hyperspectral data, and a 3x3 pixel MATLAB script was used to process the satellite data centred at the geographic location where above-water measurements were collected on dates during the 2019 cruises. Spearman rank statistical tests showed that each Remote Sensing Reflectance band comparison between the sensors was statistically significant and the strongest relationship ($r_s = 0.68916$, $p = 0.0001$) between the above-water sensors and the satellite data was with the 560 nm band. The objective of this study is to highlight the ship-based above-water radiometry system and the products associated with this data (satellite validation, water quality monitoring, bio-optical modelling and algorithm development). Using the DM-QMF pack, the authors demonstrate how the TriOS RAMSES system works onboard the RV Celtic Explorer, how the radiometry data is processed and compared to satellite-derived measurements using a 2019 case study.

POSTERS 1D SOILCONTAMINATION: MONITORING SOIL CONTAMINATION

IDENTIFICATION OF POTENTIAL TOXIC ELEMENTS (PTE) IN TECHNOSOLS AND IN THE HYPERACCUMULATOR PLANT BRASSICA JUNCEA WITH IMAGING SPECTROSCOPY

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Abstract

Vital, fertile soil is a limited resource and must be considered equal to air and water in its status as a protected good. In Europe, there are around 2.5 million potentially contaminated areas due to natural and anthropogenic activities. One third of these areas have been identified and 15% of them have already been remediated. An efficient approach for remediation is phytoremediation, a cost-effective and ecosystem-friendly method compared to conventional methods.

We showed that hyperaccumulator plants, which have a high tolerance to the accumulation of potentially toxic elements (PTE), are suitable for phytoremediation methods. Imaging spectroscopy allowed us to monitor and optimize the process of accumulation. Our study was conducted in two steps: First we analysed the potential of multivariate procedures using Partial Least Squares Regression (PLSR) and Random Forest Regression (RFR) to predict highly contaminated areas with an inhomogeneous distribution of PTE concentrations. Therefore, we used contaminated soil samples analysed for heavy metal contents. The fully-trained models assisted to monitor PTE contaminated areas during phytoremediation. In a second step, we investigated hyperaccumulator plants and their spectral fingerprints during PTE uptake to detect the highest possible amount of PTE the plant can tolerate.

Soil samples were measured after different preparation steps (“oven-dried”, “sieved”, “ground”, “Loss on Ignition (LOI)”) with a HySpex VNIR-1600 and HySpex SWIR 320m-e hyperspectral sensor under laboratory conditions with an internal measurement protocol. The spectral range of both sensors covers 408 nm to 2500 nm with a spectral sampling interval of 3.7 nm for the VNIR sensor and 6.25 nm for the SWIR sensor. The resulting spectral library was used for the PLSR and RFR analysis. Considering the optimal coefficient of determination (R2), PLSR showed an improving performance and accuracy with increasing preparation steps: R2_Cr: 0.52–0.78; R2_Cu: 0.36–0.73; R2_Ni: 0.19–0.42 and R2_Zn: 0.41–0.74. In comparison, RFR showed a weaker estimation performance, even when using higher sample preparation levels (R2_Cr:0.36–0.62; R2_Cu: 0.17–0.72; R2_Ni: 0.20–0.35 and R2_Zn: 0.26–0.67). The results indicate that PLSR provides a more robust estimation than the user-friendly RFR method. Additionally, the PTE estimation performance in strong heterogeneous soil samples can be improved by pre-treatment of soil samples in the laboratory.

Second, we cultivated Brassica juncea in a greenhouse and applied the plants with different controlled zinc, nickel and copper concentration levels (low, medium, high). Measurements with a HySpex VNIR-SWIR hyperspectral sensor (408-2500 nm) and a point spectrometer PSR+ from Spectral Evolution (350-2500 nm) were conducted in-situ and in the laboratory. A principal component analysis (PCA) was performed on reflectance spectra to identify and visualize spectral changes with increasing PTE uptake. In addition, different indices were calculated, such as Leaf Area Index (LAI) and Red-Edge Inflection Point (REIP) to investigate known vegetation indices and their relationship with PTE concentration in hyperaccumulator plants. First results revealed changes at the chlorophyll feature between 500-600 nm and at the REIP position with increasing PTE concentration. Further spectral features and indices will be investigated to check hyperspectral responses of PTE concentration. With reflectance imaging we are already able to detect differences of the PTE accumulation within the hyperaccumulator plants.

POSTERS 1D SOILCONTAMINATION: MONITORING SOIL CONTAMINATION

THE USE OF SATELLITE REMOTE SENSING AND MACHINE LEARNING ALGORITHMS FOR IDENTIFICATION, MEASUREMENT AND CLASSIFICATION OF MINE WASTE SITES

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Abstract

Readily available mineral raw materials are of crucial importance for the global economy. In the mining sector, vast amounts of solid materials are moved, particularly waste streams from the extraction and processing of mineral deposits. These wastes contain residual concentrations of valuable minerals that cannot be recovered at the time of waste disposal. In general, mine waste is disposed due to economic reasons or the fact that current technologies cannot extract the remaining valuable minerals. Therefore, in view of the increasing demand for mineral resources, mine wastes containing elevated concentrations of valuable elements represent possible sources of secondary raw materials. In order to estimate the economic potential of these discarded materials, it is necessary to conduct site surveys of the waste locations and to acquire additional information on waste properties. Such information is nowadays mostly generated by ground surveys, which are time consuming and costly.

In the AuBeSa project ("Automated identification, measurement and mineralogic classification of mining heaps and tailings ponds via satellite remote sensing"), satellite remote sensing and machine learning (ML) algorithms are used to make data collection from mining waste locations more efficient. The aim is to generate a database with information on the location, mineral content and material volume of existing mining waste sites that will allow better decisions on potential mineral recovery. For this purpose, an artificial intelligence (AI) algorithm is programmed to automatically identify mining waste locations and capture the characteristics of the waste material. Three steps are implemented. First a machine learning model is trained to extract mining tailings and heaps from Sentinel-2 satellite images and classify them automatically. The next step is to estimate the volume of the identified objects using topographic satellite data. Finally, the mining waste is mineralogical and chemical analysed via hyperspectral PRISMA-satellite data.

For a suitable implementation of the ML model, the world is divided into different zones regarding climatic and vegetational properties. Initially, the methodology was applied to arid and semi-arid regions in Chile and Peru due to their simplicity of surface analysis and the availability of ground-truth data. The model is currently extended to other areas of other conditions. Therefore, humid latitudes, as well as mining waste of unknown mineralogical composition will be analysed using the ML model. By extension of the ML model, extensive information on mining waste locations is collected worldwide. The use of remote sensing combined with ML is revolutionising the collection of mining site data. Dependence on field survey as well as time and costs are reduced, and global coverage can be achieved. Overall, the database provides the basis for assessing of the raw material potential of mining waste locations and thus of their potential contribution to meeting raw material needs.

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POSTERS 1D SOILCONTAMINATION: MONITORING SOIL CONTAMINATION

TRACE METAL ELEMENTS IMPACT ON THE THERMAL INFRARED SPECTRAL SIGNATURES OF PINES

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Abstract

In the presence of anthropogenic stressors, vegetation undergoes metabolic disturbances leading, for example, to the alteration of the foliar pigment contents, the modification of the hydric status, and the deterioration of the tissue structure. Studying the spectral characteristics of plants (which are mainly governed by pigments, cellular structure, water content) is useful in rapid diagnosing metal-induced vegetation stress before any stress-related damage occurs (Slonecker, 2010). Current works focus on the exploitation of optical properties of the reflective domain [0.4-2.5 µm] to analyze the impact of pollutants on vegetation (Lassalle, 2019). Few studies focus on the exploitation of the Thermal Infra-Red (TIR, [3-14 µm]) spectral domain for monitoring vegetation health (Fabre, 2011) (Buitrago, 2016). This domain is of interest to investigate vegetation phenomena for which temperature plays a critical role (e.g. evapotranspiration and photosynthesis). The analysis of the contribution of this spectral domain to provide information about the health of vegetation in a chemically contaminated soil context is the central theme of this study.

The objective of this work (in the frame of the VITHE project funded by PNTS-National French Program of Spatial Remote Sensing) is then to assess the contribution of TIR spectral domain to access new indicators in order to improve the analysis of vegetation health in a context of Trace Metal Elements (TMEs) contamination.

The study site is a former ore processing site partially phytostabilized in 2006 to avoid mobility of TMEs in soil, and natural vegetation has grown over the years. Two pine species (Aleppo- Pinus halepensis, stone- Pinus pinea) were selected for this study. These species are mostly naturally established in the environment of the study area, and they also have been introduced during the phytostabilisation process. The control area is located approximately 1 to 3 km from the contaminated area to avoid the potential release of TMEs. Under each pine, the upper soil layer (0 – 10 cm) was sampled and analyzed for granulometry (grain size distribution) and TME concentrations (9 elements).

The spectral signatures of the fresh needles sampled on each pine are measured in-situ using a directional reflectometer (20°)-hemispherical spectro-reflectancemeter SOC400T covering the spectral domain 2.9-13.3 µm with a spectral resolution of 4 cm-1. These spectral measurements are also acquired in laboratory with a Fourier transform infrared instrument, Bruker Equinox 55 spectrometer, covering the spectral domain 3-13 µm with a spectral resolution of 4 cm−1. The comparison of fresh needles measurements achieved in-situ and in laboratory with both instruments demonstrates the robustness of the measurement protocol and the good conservation of the samples. These measurements are completed by laboratory spectral measurements to analyze the behaviour of needle spectral signatures according to the variations in water content which could be impacted by soil pollution and other stressors. To complete this spectral dataset, measurements of needle traits are also carried out in the laboratory (water content, needle dimensions, pigment concentrations analyzed by HPLC- High Pressure Liquid Chromatography, foliar TME concentrations...). The implementation of rigorous measurement protocols and the construction of this database is a step forward because to our knowledge there is no such complete database available to carry out this study.

The database composed of needle spectral signatures and traits is used to:

- verify whether specific wavelengths can be correlated with concentrations of TMEs in soil;

- define the needle trait correlated to the concentrations of TMEs in soil and the corresponding significant wavelengths. The database will be described more thoroughly and information on the interest of exploiting the TIR domain in this study context (defined by species and TMEs) will be provided.

POSTERS 2A: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

SPEEDING UP THE HYPERSPECTRAL REFLECTANCE PHENOTYPING IN SCOTS PINE SEEDLINGS

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Abstract

Hyperspectral VIS-NIR reflectance contains valuable information about foliage biochemical composition, leaf or shoot structure, and water content. These foliar traits are indicators of a plant's physiological status. Therefore, the foliar traits derived from seedlings' hyperspectral reflectance promise to be a powerful tool in tree nurseries to evaluate the quality of the seedlings.

Currently, high-throughput phenotyping has become widely utilized in crop science and forestry. Phenotypical traits (the hyperspectral reflectance in the present study) could be combined to a certain degree with genotyping efforts. This complex information can help the tree breeders to distinguish and select seedlings with desired adaptation potential to local environments. The first goal of the present study is to test a fast, accurate, and non-destructive method for measuring hyperspectral reflectance of 1-2 years old Scots pine seedlings. Next, we used hyperspectral reflectance to distinguish between two Scots pine ecotypes: low-elevation and high-elevation.

Approximately 1200 one-year-old Scots pine seedlings from three different local populations in the Czech Republic comprising lowland and upland ecotype were studied. Reflectance measurement was conducted by the spectroradiometer ASD FieldSpec 4 Hi-Res in two measuring setups. 1) The ASD Plant Probe with a spectrally black background was used. The plant probe has its light source with stable radiation intensity and geometry producing accurate results. However, delicate young foliage may suffer heat and water stress in case of repeated measurements. Moreover, fitting of the seedlings on a black background or a leaf clip hinders the measurements. 2) The bare optical cable was used to measure the seedlings' reflectance from 5 cm above the seedling during several consecutive bright sunny days in September 2021. The major limitation of this setup is its high susceptibility to changes in the ambient light and atmospheric conditions. However, the measurement speed is significantly higher and avoids any intervention with seedlings.

The contact probe measurement was taken as a target quality of the measurement. A Piecewise Direct Standardization algorithm (Wang et al. 1991. Anal. Chem. 23) was used to standardize spectra acquired by optical cable. Subsequently, the contact probe spectra were compared to the merged spectral product. This standardization of spectra measured by the bare optical cable decreased the high reflectance variability in water absorption bands, which are crucial for the evaluation of seedling status. Both spectral datasets (contact probe and optical cable) showed statistically significant differences between lowland and upland Scots pine ecotypes almost within the full range of VIS-NIR spectrum.

We conclude that both approaches of hyperspectral phenotyping are viable for disentangling the phenotypic and potentially genetic variation within young pine seedlings. The next step is to apply the presented approach to the same seedling population treated by water stress and evaluate the ecotype 's stress response based on hyperspectral reflectance. Manual high-throughput hyperspectral phenotyping may be a powerful tool for breeding and selection in forest tree nurseries without access to an automated phenotyping unit.

POSTERS 2A: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

DO NORWAY SPRUCE NEEDLE SPECTRA VARY BETWEEN GEOGRAPHIC LOCATIONS?

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Abstract

Foliage spectra form an important input to physically-based forest reflectance models used in estimating forest biophysical characteristics from optical remote sensing data. While differences in leaf spectra between plant functional types or species have been examined, little is known about geographical variability of coniferous foliage (i.e., needle) spectra within or between biomes. Foliage spectra are usually measured with spectrometers coupled with integrating spheres, which provide a standardized observation geometry, and therefore the measurements should be comparable between measurement campaigns. However, uncertainties exist in spectral measurements of coniferous needles, because the needles are narrow and do not completely fill the sample port of an integrating sphere.

We present an assessment of the geographical variability of Norway spruce needle albedo, reflectance, and transmittance spectra across three study sites at latitudes of 49–62° N in Europe (in Finland, Estonia, and Czechia). We measured the spectra of nine samples of one-year-old and nine of current-year needles per site. The samples were taken from the top of canopy (predominantly sun-exposed needles). An ASD FieldSpec4 spectrometer (wavelength range 350–2500 nm) and an ASD RTS-3ZC integrating sphere were used in the measurements. Importantly, all spectra were measured and processed using exactly the same methodology and parameters, which guarantees reliable conclusions about geographical variability. As a comparison, we also used the same methodology to measure samples of Scots pine needles and the leaves of broadleaved trees from a subset of the study sites.

In summary, small geographical variability in Norway spruce needle spectra was observed, when the between-site variability in our current measurement campaign was compared to variability observed between previous measurement campaigns (employing slightly varying measurement and processing parameters), or to variability between plant functional types (broadleaved vs. coniferous tree species).

Our results indicate that, when acquiring coniferous needle spectral libraries for use in physically-based remote sensing models, it is important to harmonize the measurement protocols. Even small differences in the data acquisition or processing parameters can introduce systematic differences to the needle spectra. Furthermore, sampling the local (within-stand) variability might be more important than maximizing the geographical coverage of the measurements. More generally, geographical variability in the relations between forest reflectance spectra and canopy biophysical characteristics can complicate the re-use of any (physically-based or statistical) interpretation models for remote sensing data. However, our results suggest that variability of needle spectra is not a major factor introducing the geographical variability in the abovementioned relations. Finally, the data from our measurements can be useful in future studies where accurate information on spectral differences between coniferous and broadleaved tree foliage is needed.

POSTERS 2A: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

TREE SPECIES CLASSIFICATION FROM AVIRIS-NG HYPERSPECTRAL IMAGERY USING CONVOLUTIONAL NEURAL NETWORKS

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Abstract

This study focuses on the automatic classification of tree species using a three-dimensional convolutional neural network (CNN) based on field-sampled ground reference data, a LiDAR point cloud and AVIRIS-NG airborne hyperspectral remote sensing imagery with high spatial resolution acquired on 14 June 2021. We created a tree species map for our 10.4 km2 study area which is located in the Jurapark Aargau, a Swiss regional park of national interest. We collected ground reference data for six major tree species present in the study area (Quercus robur, Fagus sylvatica, Fraxinus excelsior, Pinus sylvestris, Tilia platyphyllos, Acer pseudoplatanus, total n = 362). To match the sampled ground reference to the AVIRIS-NG 425 band hyperspectral imagery, we delineated individual tree crowns (ITCs) from a canopy height model (CHM) based on LiDAR point cloud data. After matching the ground reference data to the hyperspectral imagery we split the extracted image patches to training, validation, and testing subsets. The amount of training, validation and testing data was increased by applying image augmentation through rotating, flipping and changing the brightness of the original input data. The classifier is a 3D-CNN trained on the first 32 components of the PCA (principal component analysis) transformed AVIRIS-NG data. Our 3D-CNN uses image patches of 5 × 5 pixels and consists of four hidden three dimensional convolutional layers and two fully connected layers. The latter of which is responsible for the final classification using the softmax activation function. Pixels with a prediction confidence below 70% are not classified as the forested areas within the study area contain more than the six major tree species selected. Our results show that the 3D-CNN classifier outperforms comparable conventional classification methods producing a highly accurate tree species classification map at the resolution of the AVIRIS-NG hyperspectral imagery of 2 m. Applying a simple Random Forest classifier to the same input data yielded an average F-score of 0.73 ranging from 0.62–0.78 depending on species. Similar classification performance is shown by a Support Vector Machine classifier resulting in an average F-score of 0.71 in the range of 0.57–0.77. Our work highlights that CNNs based on imaging spectroscopy data can produce highly accurate high resolution tree species distribution maps based on a relatively small set of training data thanks to the high dimensionality of hyperspectral images and the ability of CNNs to utilize spatial and spectral features of the data. These maps provide valuable input for modelling the distributions of other plant and animal species and ecosystem services. In addition, our work illustrates the importance of direct collaboration with environmental practitioners to ensure user needs are met. This aspect will be evaluated further in future work by assessing how our products are used by environmental practitioners and as input for modelling purposes.

POSTERS 2A: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

MODELLING THERMAL ANISOTROPY AND ENERGY BALANCE IN FORESTS

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Abstract

Thermal Infrared (TIR; 3–14 µm) remote sensing data are a valuable data source for monitoring the water status and stress of continental ecosystems. However, these measurements are often impacted by the effects of directional anisotropy and the hot-spot phenomena. In vegetated areas, anisotropy can impact measurements up to 5°C in forests and 15°C in row structured vegetation such as vineyards (Lagouarde et al; 2014). Available and upcoming thermal satellite missions are often characterised by a wide field of view (FOV), for example the TRISHNA (Thermal infraRed Imaging Satellite for High-resolution Natural resource Assessment) high-resolution TIR mission with a FOV of up to 35° (Lagouarde et al; 2018). Accordingly, understanding and compensating anisotropy effects is critical for generating comparable mission products.

This contribution will review challenges related to directional anisotropy in terms of data analysis and interpretation. We will also outline the set up of experiments to understand, measure and model directional anisotropy and its impact on downstream ecosystem stress products derived from satellite remote sensing such as evapotranspiration. We particularly propose two approaches i) model-based and ii) observation-based techniques over a range of experimental sites. Priority experimental sites have been identified, that are already well characterised in terms of ground measurements and remote sensing data. 3D virtual models and associated field data of these sites have been generated for 3D models such as DART (Discrete Anisotropic Radiative Transfer). We will show preliminary results for the measurements and modelling of anisotropy over complex forested canopies. Finally, we will outline our strategy to assess anisotropy effects on ecosystem stress products such as evapotranspiration through coupling of 3D RTM simulations and energy balance models such as a SPAC (soil-plant-atmosphere continuum) model.

This work is conducted in the context of a wider study to understand thermal measurements from the TRISHNA mission in different ecosystems, particularly over the alpine cryosphere, inland aquatic water systems and arctic tundra vegetation types. Both model-based and observation-based approaches will be explored in each ecosystem.

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POSTERS 2A: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

INVESTIGATING THE POTENTIAL OF THERMAL INFRARED UAS IMAGERY FOR DETECTING THE HEALTH STATUS OF PINE TREES (PINUS BRUTIA) IN LEFKA ORI NATIONAL PARK IN WEST CRETE, GREECE

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Abstract

Natural and anthropogenic stressors such as increasing drought, pests, and diseases exert increasing pressure on the condition of forests. Forest health assessment, mapping and monitoring are crucial for targeted management interventions and conservation. Direct forest health assessment in the field, although accurate, is a labour-intensive approach. Remote sensing (RS) is widely used in forest health assessment to create standardized methods that reduce subjectiveness, extrapolate observations in unvisited, inaccessible areas and reduce labour and costs. Unmanned Aerial Systems (UAS) have gained popularity in many forest-related management activities and research. Stress in trees causes a change in their physiological process, resulting in a temperature rise of the canopy. Thermal infrared (TIR, 7.5 -13.5 µm) remote sensing data can detect such canopy temperature changes. Previous research has confirmed the ability of UAS imagery to detect plants' health status. This study aims to investigate whether UAS-TIR imagery can be used to accurately map the health status of Pine trees (Pinus brutia). The usefulness of UAS acquired thermal data was examined in an open Mediterranean Pine forest in west Crete, Greece. The UAS campaign was conducted between 1 and 2 September 2021 over two sites covering 105.9 hectares. During fieldwork, the defoliation and decolouration of individual trees were recorded, and preliminary analysis was done using 56 observation data. Average canopy temperature was calculated for the delineated crowns and used to classify trees health status. In line with past research in other ecosystems, the present study results indicate a positive but weak correlation between defoliation and canopy temperature (R= 0.38). Further investigation is needed to assess the performance of thermal data in combination with multispectral and hyperspectral imagery.

POSTERS 2A: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

LINKING AIRBORNE HYPERSPECTRAL AVIRIS REFLECTANCE WITH PLANT TRAITS AFFECTED BY BARK BEETLE INFESTATION

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Abstract

Bark beetle (Ips typographus) has recently become an important cause of forest dieback in spruce forest. While monitoring of forest vitality in general is feasible with operational satellite systems such as Sentinel-2, early detection of bark beetle attacks in the so-called green-attack stage (i.e., no visible signs of damage in tree crown) has received limited attention and success in research. This study therefore aims to better understand how plant traits and damage attributes are affecting the leaf and canopy reflectance of affected spruce trees during green- to red-attack stage.

As part of the European wide CHIME campaign organized and funded by ESA, NASA-JPL and RSL Zurich, on 23 July 2021 airborne hyperspectral AVIRIS-NG data were acquired over a site within the National Park Hunsrück Hochwald in Rhineland-Palatinate, Germany. Images were acquired with the aircraft flying at low altitudes and 1 meter pixel resolution for individual tree crown detection and corrected to geo-located above canopy reflectance by NASA-JPL and RSL. In parallel, an intensive ground sampling campaign was conducted jointly by Trier University, LIST, and the NP administration. Along transects across the site area, 32 trees with varying degree of damage (from healthy green tree crowns to first signs of reddish crowns) were identified by experts within the site area and subsequently felled by forest rangers. After the felling, the tree positions were surveyed using a differential GNSS to achieve a sub-meter position accuracy. The positions, attributes and photos were stored in a file geodatabase. A larger number of tree specific attributes were collected: (i) general attributes (tree diameter, tree height, shrub and herb layers), (ii) tree crown attributes (needle color, degree of defoliation), (iii) trunk attributes (eggs, larvae, pupas, juvenile and adult beetles), and (iv) lab measurements of foliage (leaf reflectance, leaf water concentration, leaf nitrogen concentration).

Reflectance spectra were extracted at individual crown level and spectral indices (MSI, PRI) and spectral transformations were correlated with measured attributes. The coupled radiative transfer models PROSPECT5, 4SAIL and optionally FLIM were used to simulate forest reflectance. A hybrid inversion approach was implemented based on simulated forest reflectance and Artificial Neural Networks for retrieval of chlorophyll (Cab) and water content (Cw). Results of the analysis reveal significant correlations of leaf colour observations and leaf N measurements with remotely sensed Cab and pigment-sensitive indices and of leaf water measurements with Cw and water sensitive indices. Thus, the research contributes to a better understanding of how plant traits change during bark beetle green-attack stage and can help to support development of early warning systems.

POSTERS 2A: THE POTENTIALS AND LIMITS OF MONITORING FOREST TRAITS WITH IMAGING SPECTROSCOPY

USE OF LABORATORY AND IMAGE SPECTROSCOPY TO DISTINGUISH ECOTYPES AND DETECT DROUGHT STRESS IN SCOTS PINE

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Abstract

In a time of climate change and increasing risk of drought, it is necessary to look for data and methods that will help identify and select resistant genotypes of forest trees that can withstand drought better than others. Progeny of those genotypes can be prioritised in planting to make the landscape more drought resistant. This study aimed to test whether we can use laboratory and image spectroscopy to distinguish clonal ramets in seed orchards and seedlings of low-elevation and high-elevation Scots pine (Pinus sylvestris) ecotypes and monitor and compare their drought response.

The first aim of this work was to propose a non-destructive method for measuring the spectra of Scots pine seedlings. Measuring setup was designed to minimise noise in the data and to ensure the same conditions for each measurement. The pine seedlings were placed in a black pot on a hever (the same height for different sized seedlings). The distance of the pine tree from the optical cable was 24 cm. With a field of view of the optical cable of 25°, the radius of the circle entering the measurement at this distance from the optical cable was approximately 5.3 cm. The seedlings were illuminated with special ASD lights, which emitted radiation with the same intensity at all wavelengths in the range 350-2500 nm. The distance from the seedling was 50 cm for each light. The angle between the lights was 60°. The rest of the room was completely darkened.

The reflectance values of the pine seedlings measured by ASD FileldSpec 4 Wide-Res spectroradiometer were corrected using photographs of the seedlings, from which the ratio of black background and pine in the field of view of the spectroradiometer's optical cable was calculated. Due to the reduced coefficient of variation at most wavelengths after spectra correction, accurate results and comparison with the literature, the system can be considered suitable for non-destructive measurements of Scots pine seedlings.

The second objective of the work was to determine whether water stress of different intensities can be detected in laboratory spectra of pine seedlings and whether the water stress sensitivity of pine seedlings depends on ecotype. To this end, a greenhouse experiment was conducted. Canopy level reflectance was gained 11times within 3 months (April 22-July 15, 2021). The measurements took place every Thursday between 8 am and 2 pm. Two-years old seedlings of low-elevation and high-elevation ecotypes were treated with three different irrigation regimes (control, moderate drought, and severe drought). Spectra were analysed using analysis of variance (ANOVA), mixed linear model analysis (MLMA), principal component analysis (PCA), training of four classifiers and vegetation indices. After 8 weeks, drought stress was detected in spectral signal of both ecotypes (increase in significantly different bands for analysis of variance, changes in vegetation index values). The mid-infrared region (1,000-2,500 nm) was the most sensitive to needle water content. However, stress spectral response was only evident in the severe drought group.

The third objective of the study was to determine whether it is possible to distinguish different Scots pine ecotypes in image and laboratory spectra. Image spectra were taken by Headwall Nano-Hyperspec® camera from three seed orchards - Doubrava, Holičky (both low-elevation) and Děčín (high-elevation) in the summer of 2020. Analysis of variance, MLMA and four classifiers were used. The accuracy of grouping seedlings according to ecotypes ranged from 87-99% for linear discriminant analysis. Significant differences between ecotypes were also confirmed by ANOVA and MLMA. From the laboratory data (greenhouse experiment), ecotypes were distinguishable despite the high inter-individual variability caused by water stress. It was confirmed that different ecotypes are distinguishable from both laboratory and image spectra of Scots pine.

POSTERS 2B: UNLOCKING THE POTENTIAL OF GENERIC SPECTRAL LIBRARIES FOR REMOTE SENSING APPLICATIONS

DEVELOPMENT OF A MULTITEMPORAL URBAN SPECTRAL LIBRARY FOR A TYPICAL MEDITERRANEAN CITY

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Abstract

The increasing availability of temporally coherent multispectral and hyperspectral data from remote sensing instruments such as satellite platforms and Unmanned Aerial Systems (UAS) opens the way for numerous Earth Observation (EO) applications related to the urban and natural environments. Coupling the above with in-situ observations, such as spectral signatures collected during dedicated field campaigns using spectroradiometers, is critical for providing profound insight of the optical and thermal properties of surface elements, as well as the corresponding earth processes at larger scales. Furthermore, given the high inter- and intra-city material heterogeneity,site-specific spectral signatures are required to accurately charaterize the urban form, and evaluate heat mitigation urban interventions in order to develop efficient urban planning strategies in the face of climate crisis.

However, the availability of spectral libraries is disproportionately limited compared to satellite observations, while few of them represent materials observed under conditions similar to imagine observations from satellites and UAS platforms equipped with multi- and hyperspectral imagine systems. The evolution and the new developments in the EO domain require updated and high quality in situ data. The increasing availability of high resolution multispectral and hyperspectral data such as the PRISMA mission, the hyperspectral sensors on the ISS (DESIS, HICO, HISUI), the new planned missions of EnMAP (DLR), CHIME (ESA), SBG (NASA), along with the miniaturized systems that can be used onboard of UAS systems (i.e., HySpex) require high quality and updated spectral observations in a standardized and well documented approach under the FAIR data principles.

This study presents the first extensive spectral library created with the Spectral Evolution RS-3500 handheld spectroradiometer, which provides spectral information in the Ultraviolet (UV), Visible (VIS), Near-Infrared (NIR) and SWIR (Short-wave infrared) spectrum in the range of 350-2500 nm for the urban materials available for construction material in city of Heraklion, Crete, a typical Mediterranean city. A hierarchic classification scheme has been designed based on the abundance of material and cover that occupy the city. The samples are classified as building materials, which include roofs of various materials (tiles, metal surfaces, concrete, other) and façade samples, ground materials, vegetation and miscellaneous. Additional information about the library metadata refer to a variety of characteristics regarding the nature of the material (e.g., texture etc.) and the conditions during the sampling process (e.g., local time, solar angle etc.).

The spectral signature acquisitions and the library architecture have been designed to assist coupling with satellite observations by ensuring similar acquisition times with satellite overpasses, which are now focused on the Landsat 8/9 and Sentinel 2, as well as UAS acquisitions, both nadir and façade by providing façade samples, which are indispensable for studying the thermal properties of buildings. The next step will be to incorporate the temporal variability of the selected sites for a year-around spectral signature behavior along with the use in analysis of UAS-based hyperspectral data, aiming at a complete mapping of the urban materials of Heraklion, making robust geospatial datasets for use in emissivity corrections of thermal observations, optimum designations of urban planning along with targeted activities for the removal of hazardous materials.

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

DISENTANGLING RANDOM AND CORRELATED RADIOMETRIC UNCERTAINTY CONTRIBUTORS IN SENTINEL-2 L1C TOA REFLECTANCE FACTORS

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Abstract

Any top-of-atmosphere (TOA) reflectance factors are subject to radiometric uncertainty. The uncertainty results from a superposition of random and correlated effects that influence the reflectance factor values to varying degrees. For example, noise in the instrumentation is a source of random uncertainty, i.e., the uncertainty is stochastically independent for each pixel and spectral band. In turn correlated effects - caused, for instance, by the solar diffuser for on-board calibration - show statistical dependencies in the spectral, spatial (across-track) and temporal (along-track) dimensions of TOA scenes. Disen- tangling and quantifying random and correlated radiometric uncertainty con- tributors enables users to evaluate if the TOA data fits their purpose. Equally important, estimates of uncertainty allow propagation of these into higher levels of processing, e.g., bottom-of-atmosphere reflectance factors. While random uncertainty components can usually be compensated for by spectral indexing and other normalisation steps, systematic uncertainties can lead to bias in the resulting higher-level products.

In this contribution we exemplary show how to evaluate these effects for the Sentinel-2 mission, which has been providing multispectral satellite data for for nearly six years. However, the procedure can also be applied similarly to state-of-the-art and upcoming hyperspectral satellite missions such as EnMap,PRISMA or CHIME.

We developed a Monte Carlo framework based on the outputs of the Sentinel- 2 Radiometric Uncertainty Toolbox (S2-RUT). The framework models the effects of a set of 10 random and correlated uncertainty contributors for all spectral bands of Sentinel-2 L1C TOA scenes. Using a sufficiently large number of Monte-Carlo runs (N=1000) we were able to determine overall radiometric uncertainty estimates for a series of S2-TOA scenes over Switzerland. In most cases, the overall radiometric uncertainty did not exceed the desired relative uncertainty threshold of 3% as specified in the Sentinel-2 mission requirements. To further quantify radiometric uncertainty components we selected different targets of approximately 20ha size with relatively homogeneous spectral properties. These targets include green herbaceous vegetation, mixed broad- and needle leave forests as well as deep convective clouds. For each target we extracted

histograms of the random and correlated uncertainty components. Depending on the target and spectral band, characteristic ”uncertainty fingerprints” appear, which can be explained by the underlying pixel level. The fingerprints are considered similarly informative as spectral signatures. They can therefore be used to develop more realistic noise models for radiative transfer model outputs and heteroscedastic Gaussian process regression models.

The uncertainty propagation developed for Sentinel-2 can similarly be applied to hyperspectral sensors. The prerequisite, however, is that the radiometry can be sufficiently characterized and the measurement and calibration process be mathematically described. Moreover, correlations of the individual sources of uncertainty have to be quantified.

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

ENMAP OBSERVATION PLANNING AND DATA ACCESS FOR SCIENTIFIC USERS

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Abstract

EnMAP (Environmental Mapping and Analysis Program; www.enmap.org) is the first German imaging spectroscopy mission, to be launched in April 2022. After its Launch, Early Orbit and Commissioning Phase (6 months), the EnMAP mission will be available to the international user community for the data access and ordering process. EnMAP will be operated by the German Aerospace Center (DLR) covering all aspects relevant to assure successful mission operations. This comprises controlling and commanding the satellite using multi-mission infrastructures as well as observation planning, data reception, hyperspectral data processing including calibration, data archiving, data access and delivery, and providing web-interfaces to the international user community. This presentation will give an overview of EnMAP observation planning and data access concepts and outlines the data ordering workflow in particular for scientific users.

The user can get access to EnMAP data using two different order options: On the one hand the user can submit future order requests through the EnMAP Data Access Portal (EDAP). The EDAP links to a set of functions for registered users that will support the international user community. This portal includes amongst others a Proposal Portal allowing submission of proposals for all scientific users responding to an Announcement of Opportunity (AO) and an Observation Request Portal providing planning support of observation requests and allowing submission of future orders. On the other hand, the already acquired data can be searched, processed and delivered based on catalogue from the archive through the EOWEB® GeoPortal.

Although EnMAP is based on an open data policy and every type of user is in principle entitled to download data and request acquisitions, there will be different user categories to set acquisition priorities. The scientific (Cat-1) orders have higher priority and are requested to submit a proposal, which will undergo a scientific evaluation. The associated results will be presented by an interactive map supporting the establishment of a worldwide user network and guarantee the highest transparency of the proposal process.

In the Observation Request Portal the user is able to submit future order requests by specifying following order parameters, such as the geographic area of interest (AOI) (between 74° North and 74° South), length of the AOI as a multiple of 30 km and up to 1000 km, the specification of the maximum allowable tilt angle of the satellite across the orbit (5° to 30°), the time span in which the acquisition should be performed as well as the option for time series and the number of data takes per months. To ensure acceptable illumination conditions, only images with sun zenith angle lower 60° will be considered.

As for data acquisition EnMAP will be able to collect 5000 km along track and 30 km across track per day. The probability that the order will be included in the mission planning depends on the requirements for the observation as well as the specified priority and quota. Whether a specific data take is scheduled at the end depends on factors such as e.g. available data storage, cloud probabilities (e.g. historical and predicted cloud coverage) and, if requested by the user, sunglint probability (this is relevant for water products only). Users should make a request at least 25 hours before the scheduled recording to ensure the uplink. All data are available no later than 24 hours after collection for further processing into data products. The EnMAP ground segment will provide a range of standardized data products with different levels of processing of Level 1B, Level

1C and Level 2A based on archived Level 0 comprising extensive quicklooks and metadata. Due to required multiple processing options, each product is generated specifically for the order and delivered using FTPS (FTP with SSL) provided by multi-mission facilities.

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

OVERVIEW AND APPLICATION OF THE ATMOSPHERIC LOOK-UP TABLE GENERATOR (ALG) TOOL (V3.2)

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Abstract

Atmospheric radiative transfer models (RTMs) are physically based computer models that simulate the scattering, absorption and emission processes in the entire electromagnetic spectrum. These models offer a powerful tool for researchers to understand the radiative processes occurring in the Earth's atmosphere and are thus widely used in many Earth observation applications, such as: (1) satellite/airborne data processing, (2) satellite mission simulation, (3) meteorology and climatology, and (4) atmospheric chemistry and physics. Through continuous improvements, these models have increased in realism from simple semi-empirical equations towards advanced 3D representations of complex interactions in the atmosphere. With this evolution, atmospheric RTMs have also increased in complexity, requiring a good user knowledge of the model configuration, interfaces and execution. This steep learning curve limits their use by a broader remote sensing community and non-expert users. To overcome this limitation, graphical user interfaces (GUIs) have been developed to facilitate RTM streamlining, offering users a complete access to all functionalities and configuration parameters, and including user support and continuous updates. However, each of these GUIs are customized for their specific RTM; and none can be used to define and run simulations for multiple RTMs in a consistent manner. In addition, they are not designed to generate large look-up tables (LUTs) , which is an important feature due to the high computational burden of the atmospheric RTMs. In practice, users of atmospheric RTMs need to develop their own scripts to create simulated datasets, which are typically (1) limited to a handful input variables and (2) hardly extensible to other RTMs.

In an attempt to facilitate the consistent simulation of databases for a wide range of atmospheric RTMs, we developed the Atmospheric Look-up table Generator (ALG). ALG is a MATLAB-compiled software package that allows generating LUTs based on a suite of atmospheric RTMs. ALG provides consistent and intuitive user interaction for configuring, running and storing RTM data for any spectral configuration in the optical domain. In its current version v3.2, ALG is compatible with the following RTMs: MODTRAN (v5 and v6), libRadtran, 6SV (v2.1), and libRadtran (v2.0.4), ARTDECO (v1.2.0) and SBDART (v2.4). ALG also allows users to easily configure RTM simulations to integrate data from a broad range of meteorological datasets (e.g. ECMWF profiles, AERONET). Furthermore, ALG comes together with a suite of functions (e.g. interpolation, spectral convolution, emulation) allowing to use the generated LUTs in practival Earth observation data processing applications.

In this work, we first give an overview of the implemented features in ALG and the generated LUT data; then we demonstrate the utility of this tool in the context of ESA's FLEX mission. We expect that ALG can be a useful tool to the spectroscopic community, facilitating the usage of atmospheric RTMs in a wide range of applications, particularly for the simulation and processing of hyperspectral satellite/airborne missions.

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

ASSESSING THE LAND USE / LAND COVER CLASSIFICATION PERFORMANCES OF MULTISPECTRAL AND HYPERSPECTRAL DATA: LANDSAT AND PRISMA SATELLITE

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Abstract

Land Use / Land Cover (LU/LC) classification has become a critical application that provides valuable information for ecosystem monitoring and management all around the world with the development of the earth observation satellites. Landsat satellites developed by USGS (United States Geological Survey) and NASA (National Aeronautics and Space Administration) acquire multispectral images, which have been extensively used in several LU/LC mapping studies for many decades. High accuracies were achieved by applying ensemble Random Forest (RF) classification method to Landsat satellite images for the purpose of LU/LC classification (Shih et al., 2021, Geocarto International, DOI: 10.1080/10106049.2021.1923827). However, LU/LC classification in urban areas, which are heterogeneous structures, by using multispectral satellites has some limitations. For that reason, the high spectral resolution is needed to map complex urban objects. Recent advances in satellite sensors enable acquire hyperspectral satellite images that include narrow and contiguous spectral bands in a wide electromagnetic spectrum range. The state-of-the-art PRISMA (Precursore IperSpettrale della Missione Applicativa) satellite sensor of the ASI (Italian Space Agency), can acquire hyperspectral images that include hundreds of spectral bands. PRISMA satellite images were used in various fields of environmental applications such as sustainable agriculture (Pepe et al., 2020, Remote Sensing, 23) and forestry applications (Verrelst et al., 2021, ISPRS Journal of Photogrammetry and Remote Sensing, DOI: 10.1016/j.isprsjprs.2021.06.017). However, there is lack of studies about discriminating complex urban LU/LC classes by using PRISMA satellite images.

The main objective of this study is to carry out comparison of the LU/LC classification performances of free and open access Landsat-8 and PRISMA satellite images that includes 11 and 240 spectral bands, respectively and have 30 m spatial resolution (Cogliati et al., 2021, Remote Sensing of Environment, DOI: 10.1016/j.rse.2021.112499). Landsat-8 and PRISMA satellite images were acquired on 20.07.2021 and 27.07.2021, respectively. As a study area, Küçükçekmece Lake Region (14 km x 20 km), which is located in European side of İstanbul was selected. The study area chosen has a complex structure that includes agricultural areas, industrial or commercial units, roads, airport, coastal lagoon, sea, water bodies, residential areas, forest and barren land. To extract these classes from satellite imageries, RF algorithm, which was widely used in the image classification, was used. Accuracies of the classification results were assessed through metrics (producers' accuracy, users' accuracy, overall accuracy and kappa coefficient) that were derived from confusion matrixes by using ground truth data. And also, McNemar's chi-square test was used to compare the accuracy of two classifiers statistically. Overall accuracies of the preliminary RF classification results obtained from Landsat-8 and PRISMA were calculated as 0.72 and 0.86, kappa coefficient values were calculated as 0.67 and 0.83, respectively. The RF classification results show that the highest accuracy was achieved by using PRISMA image. Thus, hyperspectral images can be preferred to detect different classes in heterogeneous urban areas in order to achieve high accuracy.

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

HYPEREDU ONLINE LEARNING INITIATIVE FOR IMAGING SPECTROSCOPY: CONCEPT, CURRENT STATUS, LESSONS LEARNED AND FUTURE PERSPECTIVES

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Abstract

Imaging spectroscopy data are a valuable source of accurate and quantitative information about terrestrial and aquatic ecosystems of the Earth required in various application fields. While the current availability of imaging spectroscopy data is still limited, it can be expected to substantially increase in the near future with the rising number of imaging spectrometers deployed on airborne and spaceborne platforms. In view of these developments, an increasing interest in hyperspectral data analyses is expected in the next few years. However, these sorts of analyses require extensive training, and educational resources on imaging spectroscopy are still scarce, especially in the online learning system. Therefore, the development of HYPERedu was started in 2019 as part of the EnMAP science program.

HYPERedu is an online learning initiative for hyperspectral remote sensing. On the one hand, it provides online learning resources on principles, methods and applications of imaging spectroscopy at master's level addressing students as well as professionals in research, business, and public institutions. The resources comprise annotated slide collections and hands-on tutorials (based on the EnMAP-Box software) that are continuously extended and increasingly used in training courses as well as university teaching.

On the other hand, within HYPERedu a series of MOOCs is being developed. A first (to our knowledge first ever) MOOC on the basics of imaging spectroscopy titled "Beyond the Visible: Introduction to Hyperspectral Remote Sensing" was successfully launched in November 2021. It teaches the principles of imaging spectroscopy, sensor technologies and data acquisition techniques as well as data sources and software using state-of-the-art eLearning approaches. The course is structured in three thematic lessons and offers plenty of opportunities for activity and interaction such as interactive graphics, quizzes and expert-led hands-on training exercises. It is designed to take about five hours to be completed at one's own pace. After successful completion, participants receive a certificate. Lessons learned during the course from user feedback in the integrated surveys and discussion forum will be evaluated in detail and used to improve the basic MOOC to be offered in a revised version in spring 2022. The insights gained will be further used in the development of shorter follow-up MOOCs from 2022 onwards. These shorter MOOCs will complement the basic MOOC by focusing on specific hyperspectral data application fields such as agriculture, inland and coastal waters, soil and geology and urban environments.

All resources and courses are hosted on the EO College platform (https://eo-college.org/) and are provided free of charge under a CC-BY License, except where noted otherwise. EO College is a learning hub for online courses, open educational resources and discussion forum in the field of Earth Observation and funded by the German EO program of the DLR Space Agency.

Even though HYPERedu was initiated as part of the EnMAP science program, it is regarded as an initiative by and for the entire hyperspectral community: An increasing number of groups are already contributing to the development of HYPERedu and all resources are provided free of charge for use in training courses, university teaching or individual learning to increase the number of users employing hyperspectral data in the future.

This contribution aims to present and discuss the concept, current status, lessons learned and future perspectives of HYPERedu. In addition, participants will be actively asked for feedback and ideas for further development and collaboration in the education initiative, such as in the form of a small survey during the poster session.

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

VALIDATION OF SENTINEL-2 ATMOSPHERIC CORRECTION USING RADIATIVE TRANSFER MODELS EMULATORS

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Abstract

The Copernicus' Sentinel-2 satellite mission aims at providing systematic global acquisitions of high-resolution optical data for applications such as vegetation monitoring, land use, emergency management and security, water quality and climate change (Drusch et al. 2012. Remote Sens. Environ., 120). Such operational mission needs efficient and accurate data processing algorithms to extract the final mission products, i.e. surface bio-/geo-physical parameters. One of the most critical data processing steps is the so-called atmospheric correction, i.e. the compensation of scattering and absorption effects from the measured Top-Of-Atmosphere (TOA) radiance and inversion of surface reflectance. ESA developed and maintains the Sen2Cor processor (Main-Knorn et al. 2017. SPIE: 10427), a collection of physically-based algorithms for processing Sentinel-2 TOA radiance that retrieves atmospheric properties (water vapor and aerosols) and inverts surface reflectance. Sen2Cor atmospheric correction relies on the use of libRadtran, a Radiative Transfer Model (RTM) that models the processes of scattering and absorption of electromagnetic radiation though the Earth's atmosphere. Since the computational cost of libRadtran makes it impractical for routine applications, Sen2Cor overcomes this limitation by interpolating of a set of look-up tables (LUT) of precomputed libRadtran simulations, resampled to the 13 Sentinel-2 spectral channels. However, over a million simulations are still needed to achieve sufficient accuracy, with the consequent impact in data storage and computation time for LUT generation.

In the recent years, the emulation of RTMs have been proposed as an accurate alternative to LUT interpolation (Vicent et al. 2021. TGRS. 60). An emulator is a statistical model that approximates the original deterministic model at a fraction of its running time and thus, in practice, being conceptually the same as LUT interpolation. In this work, we carried out an exhaustive validation of the emulation method applied to the atmospheric correction of Sentinel-2 data. We used Gaussian Process regression as the core of our emulators and principal components analysis to reduce the dimensionality of the RTM spectral data. Our spectrally-resolved emulator was trained with as little as 1000 libRadtran simulations. The emulator method was validated in three test scenarios: (1) using a simulated dataset of libRadtran simulations, (2) against RadCalNet field measurements, and (2) comparison against Sen2Cor for the atmospheric correction of Sentinel-2. In all the test scenarios, the surface reflectance was inverted with relative errors below 2% (absolute errors below 0.01) in the entire spectral range, and in agreement with Sen2Cor results. Our results indicate that emulators can be used for the atmospheric correction of Sentinel-2 data, offer improvements of the current Sen2Cor processor and find wide application in other sensors with similar characteristics. Indeed, with only a small training dataset being required, emulators can be used to add new aerosol models in the Sen2Cor processor. In addition, working with spectrally-resolved emulated data would allow us to better model instrumental effects such a smile. These improvements would be impractical with precomputed LUTs due to the large number of simulations needed.

In this presentation, we will give an insight of the implemented emulation methodology and show our validation test results with Sentinel-2 data. With this, we expect to inform the spectroscopic community about the current advances in machine learning emulation for operational atmospheric correction of satellite data. We envisage that emulators can potentially offer practical solutions for the atmospheric correction to address the challenges of future hyperspectral satellite missions.

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

AUTOMATIC BORE SIGHT ANGLE DETERMINATION AND GEOREFERENCING FOR DUAL PUSH BROOM SENSORS

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Abstract

The HySpex system consists of two separate sensors which gather information in the VNIR and SWIR range of the electromagnetic spectrum. These two sensors come with a slightly differing view angle. Hence, the area captured at a point in time does differ between the sensors which causes respective image shifts between VNIR and SWIR georeferenced image.

This work addresses this mismatch by determining: (1) the boresight angles between the two sensors, aligning the VNIR and SWIR georeferenced image; and (2) the boresight angle between VNIR sensor and INS, aligning the flight lines to each other. The fully automatic computation greatly enhanced the data processing workflow.

The developed software is capable of fully automatic georeferencing of dual sensor (VNIR + SWIR) push broom hyperspectral data.

The processing can be separated into three steps:

1. Georeferencing (irregular interpolation)

2. Tie point generation (image matching)

3. Parameter optimization (numerical optimization)

The georeferencing step is generating the destination images in the destination projection. It takes into account the sensor model (defining the viewing direction of each sensor element), the INS (inertial navigation system) data, the DEM (digital elevation model) and the destination projection (e. g. UTM projection). The interpolation for the destination raster is done using an irregular interpolation scheme that takes into account the n nearest DEM intersection points and samples these according to their distance to the interpolation target point. The distance computation can be euclidean or Mahalanobis distance, to take the Gaussian like integration shape into account.

For generating tie points from the georeferenced image data we split the whole georeferenced flight line image into smaller sub images (500 to 1000 pixels edge length). For finding the tie points within the corresponding sub images we used two image feature detectors, namely AKAZE for edge like features and SIFT for blob like features. Both detectors complement each other so that pretty uniform image coverage is achieved. After further filtering we generate about 400 tie points per km of flight line (200 tie points per 1000 recorded image lines).

The georeferencing model has 5 free parameters that can be optimized: 3 bore sight angles, 1 scale parameter (DEM height) and 1 INS time synchronization parameter. Because of their correlation these parameters are optimized in two separate steps: 1. roll and pitch angle, 2. azimuth, time sync and scale. The numeric optimization is done using the CMAES algorithm (covariance matrix adaptation evolution strategy).

We first optimize the VNIR parameters using the tie points from overlapping flight lines from a cross like pattern: 1 flight line forward, 1 flight line backwards and 1 flight line crossing both with about 90 degrees. This aligns the flight lines to each other.

After the VNIR parameters we optimize the SWIR parameters by the matching VNIR - SWIR tie points. The optimized 5 VNIR and the 5 SWIR parameters are and then used to georeference both sensors into one common data cube.

The resulting RMSE for the VNIR optimized VNIR tie points is about 2.6 m and 0.8 m for the optimized VNIR – SWIR tie points, with a ground sampling distance (GSD) of 0.5 m for VNIR and 2.0 m for SWIR.

Further analysis of the optimized VNIR – VNIR tie point deviations show a strong correlation with the roll and pitch angle (R^2 = 0.5 … 0.7) with unknown origin, this is part of ongoing analysis.

The software is written in C++ and all the heavy workloads are parallelized. The determination of the bore sight angles takes about 5 min and georeferencing an 4 km flight line takes about 3 min on a 8 core machine (mainly disk IO bound).

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

VALIDATION OF ATMOSPHERIC CORRECTION OF DESIS L2A PRODUCTS: COMPARISON OF HYPERSPECTRAL AND SENTINEL-2-LIKE MULTISPECTRAL SENSORS

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Abstract

The "DLR Earth Sensing Imaging Spectrometer" (DESIS) is a VNIR sensor

on-board of the International Space Station (ISS) and it is operational since October 2019.

DESIS acquires images of the Earth at user request with a swath of about 30 km and 235 bands with a Full Width at Half Maximum (FWHM) of 3.5 nm in the spectral range from 400 to 1000 nm.

The DESIS Ground Segment L2A processor corrects the at-sensor received terrestrial reflection of the incident solar radiation for the effects of atmospheric constituents.

The PACO atmospheric correction software is the python-based software of the IDL ATCOR software package. It is implemented in the L2A processor, and it processes ortho-rectified Top-Of-Atmosphere (TOA) radiance scenes and generates the Bottom-Of-Atmosphere (BOA) ground reflectance spectral image cube, along with pixel-classification masks, Aerosol Optical Thickness (AOT at 550 nm) and Water Vapor (WV) maps.

The same atmospheric correction program is used internally at EOC for processing multi-spectral data like Sentinel-2 and Landsat-8. This multi-sensor support was used to compare the atmospheric correction results between multi-spectral and hyperspectral sensors.

In this contribution we summarize the uncertainty of the DESIS L2A products. The uncertainty is determined by validating the DESIS atmospheric parameters (AOT550 and WV) against the AERONET (Aerosol Robotic Network) in-situ measurements. The spectral products (BOA reflectance) are validated against the Radiometric Calibration Network (RadCalNet) in-situ measurements.

The uncertainty values presented here are generally formulated as a function of the in-situ BOA surface reflectance and WV reference values, except for the AOT. Within this study, the lack of scenes with high AOT values allows only to determine a global RMSE for all available AOT data.

These results are complemented and compared with a simulated DESIS-multispectral sensor characterized by the Sentinel-2 spectral response functions and atmospherically corrected by the same software.

The difference in the water vapor estimation by the Atmospheric Pre-corrected Differential Algorithm (APDA) between the two sensors is discussed. The hyperspectral properties of the DESIS sensor allow the estimation of the water vapor by using the 820 nm absorption region and a collection of several bands inside the APDA algorithm while the Sentinel-2 sensor has its water vapor band at 940 nm within APDA.

Lessons learned from this study between multi-spectral and hyperspectral atmospheric correction will be presented.

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

FIELD INTERCOMPARISON OF DRONE-BORNE HYPERSPECTRAL SYSTEMS – TOWARDS REPRODUCIBILITY OF SURFACE REFLECTANCE MEASUREMENTS

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Abstract

Over the last decade Unmanned Aerial Vehicles (UAVs) have become an ubiquitous tool for environmental monitoring, providing a cost-effective alternative for surveys at local scale with applications including habitat monitoring, wildlife conservation, surface deformation monitoring and many others. This is largely due to sensor miniaturisation, which has allowed employment of sensors and multi-sensor arrays that were previously restricted to satellite and airborne platforms. A recent upsurge in the availability of UAV hyperspectral sensing systems is opening new possibilities for detailed spectral characterisation for applications which simultaneously require high spatial level of detail, such as precision agriculture. There is currently a variety of solutions on the market that have different sensing systems (point-based, pushbroom and snapshot) and processing workflows for surface reflectance retrieval (relying on irradiance measurements and/or on ground calibration targets). These, especially when combined with uncertainties resulting from variations in data acquisition designs, raise questions around the comparability of spectral information collected with different systems.

The aim of this study was to conduct an intercomparison of two UAV-borne hyperspectral systems and assess similarity of spectral information they produce, both in terms of absolute surface reflectance values and spectrum shape. For this purpose, we employed the Hyperspectral Mapping System (HYMSY) and the Nano-Hyperspec camera (Headwall Photonics, Boston USA), and followed workflows established by manufacturers. Both sensors utilise lightweight pushbroom spectrometers and sense in the VNIR spectral range (HYMSY: 450-950 nm, Nano-Hyperspec: 400-1000 nm). To facilitate the intercomparison, a number of manmade and natural targets were established in an agricultural field located in Wageningen, the Netherlands. These included supplementary ground targets of known spectral properties, tarmac, bare soil, water feature, and sample crop types. Multiple UAV experimental flights were then conducted with both sensors. The survey was complemented with field spectra of the surfaces collected using an ASD FieldSpec spectrometer. For each target surface, comparisons were made using the retrieved surface reflectance values and derivative reflectance signatures, allowing analysis of differences in the shape of the spectrum. We will present results of this assessment and comment on the interchangeability of obtained spectral information. As such, this study will contribute towards understanding of whether surface reflectance measurements can be easily reproduced using different UAV spectral imaging systems.

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

ERADIATE: MODERN RADIATIVE TRANSFER SIMULATION SOFTWARE FOR EARTH OBSERVATION

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Rayference, Belgium

Abstract

Radiative transfer modelling and simulation is centric to many Earth observation (EO) workflows nowadays. Numerical radiative transfer models (RTM) are used for various tasks such as atmospheric correction, retrieval of physical properties or instrument calibration. All those use cases have different requirements in terms of features and performance, which led to the development of many simulation software packages with varied scope and complexity.

The need for yet another RTM originated from the realisation that instruments onboard modern satellites have become accurate enough so that verifying their radiometric calibration (Level-1 data) often requires simulating their observations with an accuracy better than 3%. Reaching an equivalent accuracy when simulating satellite data notably requires accounting for 3D effects such as surface roundedness or complex geometry (e.g. terrain or vegetation) and accurately simulating the radiative coupling between the surface and the atmosphere.

While all these features are separately available from many specialised libraries or applications, few software packages currently integrate all of them, none of which is free software to our knowledge. The Eradiate radiative transfer model (www.eradiate.eu) is an attempt at addressing this need and was thought as a way to conveniently combine the advances made by all the subcommunities (e.g. atmosphere, land, cryosphere, ocean colour, etc.) contributing to the development of radiative transfer modelling for Earth observation applications. It is also designed as a platform for experimenting with radiative transfer simulation algorithms: integrating new data and algorithms is relatively easy thanks to an architecture inherited from rendering software and modern data processing pipelines.

The development of Eradiate started in 2019 with the goal of producing by 2022 an open-source radiative transfer simulation platform sufficiently accurate for usage in calibration/validation activities. It is written in C++ and Python using the Mitsuba physically based rendering library (Nimier-David et al. 2019, ACM Trans. on Graphics 38), which provides powerful tools to assemble radiative transfer simulations accounting for the aforementioned physical phenomena. Eradiate integrates in current scientific analysis workflows and offers a modern and comprehensive interface suitable for usage in interactive computing environments. Special care is taken to use concepts and vocabulary with which RTM users in EO communities can feel familiar, while relying on programming abstractions inherited from the graphics community. Eradiate ships sourced, tested and traceable algorithms and data. Finally, Eradiate is publicly available under a free software license and is thoroughly documented.

In this presentation, we will see how the Eradiate radiative transfer model can be relevant in the context of land satellite data processing, with a focus on the radiometric calibration of optical imaging passive sensors, including uncertainty propagation when simulating satellite data. We will also review the current development progress and plans for this simulation platform.

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

DESIS AND COPERNICUS SENTINEL-2 SURFACE REFLECTANCE, AOT AND WV PRODUCTS COMPARED TO MEASUREMENTS ON GROUND

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Abstract

The hyperspectral instrument "DLR Earth Sensing Imaging Spectrometer" (DESIS) was developed within a collaboration between the US company Teledyne Brown Engineering (TBE) and the German Aerospace Center (DLR). It is operating onboard of the International Space Station (ISS) since August 2018 and it is in operational phase since October 2019. DESIS provides data in 235 bands in the spectral range from 400 to 1000 nm at 30 m spatial resolution. Copernicus Sentinel-2 is a multispectral optical remote sensing mission providing global data in 13 spectral bands in the spectral range 0.4 – 2.2 µm at different spatial resolution of 10m, 20m and 60m. The mission is a constellation of two polar orbiting satellite units equipped with the same optical imaging sensor MSI (Multi-spectral Instrument). The mission is fully operating since June 2017.

PACO atmospheric correction software is implemented in the DESIS L2A processor providing Bottom-Of-Atmosphere (BOA) ground reflectance spectral image cube together with aerosol optical thickness (AOT) and integrated water vapour (WV) maps. PACO can also be applied to Sentinel-2 data providing equivalent outputs.

This presentation will rely on reference measurements of SR, AOT and WV which had been performed on ground in parallel to Sentinel-2 overpasses in August 2019 and 2020. Microtops photometers are used for measurements of the atmospheric parameters and SR measurements used a hyperspectral SVC spectroradiometer covering the spectral range from 380 nm to 2.5 µm. There are DESIS acquisitions over the same area on the same day. Both DESIS and Sentinel-2 data will be processed with PACO and then compared to the available reference measurements.

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

STATUS OF THE IEEE P4001 WORKING GROUP FORSTANDARDIZATION IN HYPERSPECTRAL IMAGING

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Abstract

Hyperspectral imaging has over the last thirty years developed into a power analytical tool for the determination of chemical and other properties. As a result, there has been strong development in both the design of spectral cameras and in the applications for which they are used. This has led to a diversity in the way fundamental instrument

performances are characterized, reported, and understood. As a result, this makes it difficult to compare instruments for application-specific needs, or for commercial market needs.

In 2018, the IEEE P4001 group was formed to facilitate the development of a standard to unify the use of terminology, spectral camera characterization methods, and the meta-data structures that are needed to represent spectral camera

performance. This talk provides an update on the work to date, and the significant progress made towards the first draft of the standard.

POSTERS 2C: CONCEPTS, ACTIVITIES AND PROCESSING DEVELOPMENTS FOR MISSIONS AND SENSORS

EVALUATION OF PRISMA IMAGING SPECTROSCOPY MISSION DATA OVER DIFFERENT NATURAL TARGETS

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Abstract

PRISMA (PRecursore IperSpettrale della Missione Applicativa) is a demonstrative space imaging spectroscopy mission, deployed by the Italian Space Agency (ASI). The PRISMA satellite mission launched on March 22nd, 2019 is one of the last spaceborne imaging spectroscopy missions for Earth Observation aiming to characterize and monitor environmental and natural resources. The PRISMA satellite comprises a high-spectral resolution VNIR-SWIR imaging spectrometer and a panchromatic camera.

To support the cal/val activities of the PRISMA mission, ASI and the National Research Council (CNR) started in 2019 the PRISCAV project, with the objective to evaluate the quality of the PRISMA images. To this end, PRISCAV created a network of 12 test sites, located in Italy, encompassing different targets from very low to high albedo and characterized by different seasonal dynamics (Inland, Coastal and Sea Water, Forest and Cropland, Snow surfaces).

In this contribution, we present the PRISCAV-related activities, providing key parameters related to the spectral, spatial and radiometric performances of PRISMA data. The performances of PRISMA Level 1 (L1) product Top-Of-Atmosphere radiance and the Bottom-of-Atmosphere Level 2 (L2) Reflectance standard products were analysed using different vicarious and image-based state-of-art methods or by cross-comparing PRISMA data with ground/airborne spectroscopy measurements. The in-situ surface reflectance measurements over different targets were propagated to LTOA using MODTRAN5 and 6SV radiative transfer simulations and compared with satellite observations. Field spectroscopy measurements over selected bright/dark natural surfaces and the extended area sampled by airborne imaging spectroscopy were considered in the study to provide a statistically relevant sample. On some of these sites, simultaneous PRISMA and airborne AVIRIS-NG acquisitions were made coupling remote sensing with in-situ observations to support new mission development and in particular the Copernicus Hyperspectral Imaging Mission for the Environment (CHIME). Therefore, in this contribution we also present data coming from ground/airborne campaigns carried out over the different sites to collect in-situ spectroscopy measurements at different scales simultaneously with PRISMA.

To date, over 250 PRISMA acquisitions were collected over the 12 targets. The comparisons between PRISMA L1 TOA and atmospheric model simulations showed a good agreement. In general for different targets, the VIS spectral region is characterized by a relative difference equal or lower than 5%, with the tendency to slightly decrease toward NIR to values lower than 5%. The relative difference slightly increases in the SWIR to values of around 5-7% and it only exceeds 10% for few SWIR wavelengths at the far limit of the spectrum. The multiscale experimental framework also enabled to perform a comparison between PRISMA and airborne reflectance's over selected targets. Results showed an overall good agreement between the measurements across different targets (+/-5%) and a tendency of PRISMA to slightly underestimate reflectance with respect to AVIRIS; a higher divergence is instead shown at wavelengths higher than 2350 nm where satellite signal drops.

Overall, this study offers a unique quantitative insight about the PRISMA mission performance and data product consistency. Obtained results are in-line with the expectations and mission requirements and indicate that acquired L1 images are suitable for further scientific applications.

POSTERS 2D YSA: PRESENTATION OF CANDIATE POSTERS FOR YOUNG SCIENTIST AWARD

FROM SPECTRA TO FUNCTIONAL PLANT TRAITS: AGGREGATING MULTIPLE, HETEROGENEOUS AND SPARSE DATA SETS FOR A GENERALIZABLE MULTI-TRAIT MODEL

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Abstract

Our understanding of the Earth´s functional biodiversity and its imprint on ecosystem functioning, structure and resilience is still incomplete. Large-scale information on functional ecosystem properties (‘plant traits’) is thus urgently needed to assess functional diversity and better understand biosphere-atmosphere interactions. Hyperspectral remote sensing is a powerful tool to map these biophysical properties. Such data enable repeatable and non-destructive measurements using numerous platforms and sensors and providing information at different spatial and temporal scales over continuous narrow bands. However, we are still lacking efficient and accurate methods to translate hyperspectral reflectance into large scale information on biophysical properties across species, land cover and sensor types. In this regard, Deep Learning (DL) techniques are revolutionizing our capabilities to exploit large data sets given their flexibility and efficiency to detect features and their complex non-linear relationships. Accordingly, it is expected that Convolutional Neural Networks (CNNs) have the potential to provide generalizable predictive models of biophysical properties at the canopy scale from spectroscopy data. On the other hand, the absence of globally representative data sets and the gap between the available reflectance data and the corresponding in-situ measurements have hampered such analyses until now. In recent years, several initiatives (e.g. EcoSIS) have contributed to provide a constantly growing source of data of hyperspectral reflectance and plant trait encompassing different plant types and sensors. Exploring such heterogeneous source of data, we propose an end-to-end workflow that simultaneously infers multiple biophysical properties. As the interrelation of traits and spectral variability largely prevents the transferability of retrieval methods, having a multi-output architecture in conjunction with the use of CNNs may prove advantageous. With this setting, the model would be able not only to learn interesting features from the spectral data but also exploit the internal correlation between multiple traits and hence improves predictions. However, the cured data from the different studies are sparse to fit the global model because of missing values. Therefore, we also propose a self-filling approach, based on the weakly supervised learning paradigm to enrich these data sets. In the present study, we target a broad set of plant properties related to light capture, growth and propagation (e.g pigments, nitrogen), structure and defense (e.g LAI, EWT, LMA) and nutrients (e.g phosphorus). The preliminary results of the predictive model cross a broad range of vegetation types (crops, forest, tundra, grassland) are promising and outcompete the performance of the state-of-the-art machine learning approaches (e.g Partial Least square regress (PLSR)). Compared to the separate PLSR models, our model learned distinguishable and generalized features despite of the high variability in the used data sets. We found that the global multi-output model reached an improvement of prediction (% RMSE) of 5-22 % for the above-mentioned traits. The key contribution of this study is to highlight the potential of weakly supervised approaches together with DL to overcome the scarcity of in-situ measurements and take a step forward in creating efficient predictive models of multiple Earth’s biophysical properties.

POSTERS 2D YSA: PRESENTATION OF CANDIATE POSTERS FOR YOUNG SCIENTIST AWARD

PLANTING CONTEXTS AFFECT URBAN TREE SPECIES CLASSIFICATION USING AIRBORNE HYPERSPECTRAL IMAGERY

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Abstract

Spatially-explicit detailed tree species information is vital in understanding the tree-provided ecosystem services, optimizing urban tree management, and improving urban environments. Airborne hyperspectral and LiDAR data have exhibited promising performance in tree species discrimination in the urban environment. However, the properties of urban trees are shaped by environmental factors (e.g. local climate, soil sealing, and air pollution) and management activities (e.g. pruning and fertilization) differing between planting contexts (e.g. streets and parks), which may lead to distinct intra-species variation and thereby hamper the tree species classification using remote sensing data. In this study, we classified seven broadleaved tree species in the City of Brussels, Belgium using airborne hyperspectral and LiDAR data collected in the summer of 2015. Specifically, we examined how planting contexts affect urban tree species classification. For each

species, the sample numbers of street and park trees were equal, with in total of 702 tree samples. The hyperspectral data had a spatial resolution of 2 m, comprising 285 spectral bands distributed across the 412–2431 nm spectral range. The point density of LiDAR data was 15 points/m2. We manually delineated individual tree crown polygons based on the canopy height model, with a spatial resolution of 0.5 m, derived from LiDAR data. The hyperspectral pixels within each tree crown were extracted and 218 original spectral bands (excluding the atmospheric absorption bands) were retained for further analysis. Crown-level reflectance was calculated by averaging all the within-crown pixels. LiDAR point cloud for each tree was also extracted based on the tree crown polygon. We then calculated 40 LiDAR features describing height, intensity, crown shape and size, or crown porosity and density. We employed linear discriminant analysis (LDA) with different feature sets (i.e. spectral bands, LiDAR features, and their combination) to classify tree species at the individual tree crown level. LDA was conducted to 1) reduce the feature dimensionality (i.e. for each feature set, six (the number of species minus one) discriminant functions which are linear combinations of the original features were created) and 2) classify tree species using the generated discriminant functions. The LDA was carried out on a street tree dataset, park tree dataset, and pooled dataset respectively. We also tested the performance of Random Forest (RF) in classifying the seven tree species in the pooled tree dataset using the combined spectral bands and LiDAR features. A binary variable indicating the planting context was further included in the RF classification. Our results showed that a planting context-specific modeling approach (i.e. street tree models and park tree models) significantly improved the classification accuracies compared to the general models (i.e. using the pooled tree dataset) across all the examined feature sets in LDA. The overall accuracies using spectral bands, LiDAR features, and their combination in LDA were 79.8%, 72.1%, and 84.7% for planting context-specific models and 71.0%, 62.1%, and 78.3% for general models. The overall accuracy of the general RF model using the combined spectral bands and LiDAR features was 57.0% and the addition of the planting context variable only increased the overall accuracy by 0.1%. We concluded that improvements in urban tree species classification may be achieved by the stratification of trees in terms of planting contexts.

POSTERS 2D YSA: PRESENTATION OF CANDIATE POSTERS FOR YOUNG SCIENTIST AWARD

ASYMMETRY OF LEAF INTERNAL STRUCTURE AFFECTS PLSR MODELLING OF THE ANATOMICAL TRAITS FROM VIS-NIR LEAF LEVEL SPECTRA

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Abstract

Plant functional traits can be used to predict ecosystem function responses and provide new insights into global climate change at the ecosystem level (He et al., 2018; Functional Ecology). The most used traits are biophysical and structural including photosynthetic pigment content, water content, leaf mass per area (LMA) and leaf thickness. However, more detailed anatomical traits such as the proportion of palisade parenchyma to spongy parenchyma are often neglected although they affect leaf physiological function and its optical properties.

The factors of ongoing long-term climate change affect leaf structure and function. Higher leaf density, due to a greater number of palisade parenchyma cells, reduces photosynthetic rate due to lower CO2 conductance (Niinemets 2001; Ecology). Higher CO2 conductance and thus higher photosynthetic rate are found in thicker leaves with more chloroplast surface area exposed to the intercellular environment.

Our aim was to construct partial least squares regression (PLSR) models for predicting leaf biophysical traits from its bidirectional reflectance factor (BRF). We hypothesized that the estimation of leaf anatomical properties would differ if the BRF obtained from the adaxial (upper) and abaxial (lower) sides of the leaf serves as model input.

We measured optical and biophysical traits, focusing on a detailed anatomical analysis of ten woody species with dorsoventral leaves (differentiation of palisade and spongy parenchyma). We included common temperate deciduous trees (Acer campestre, A. platanoides, Carpinus betulus, Quercus robur, Tilia euchlora), a red cultivar of shrub Corylus maxima, and evergreen woody plants (Ficus benjamina, F. triangulata, F. lyrata, Rhododendron sp.). Leaves were sampled on three dates (29th April; 16th September; 21st October,) during the 2019 growing season at the Botanical Garden of the Faculty of Science, Charles University, in Prague (Czech Republic). Bidirectional reflectance factor at the leaf level was measured with a spectroradiometer ASD FieldSpec4 wide-res (350-2500 nm) and a contact probe (CP). The leaf biophysical properties we measured were: Photosynthetic pigments (chlorophyll (Chl) and carotenoid (Car) content, anthocyanin (Ant) content, leaf mass per area (LMA), equivalent water thickness (EWT), leaf density (LD), leaf thickness (LT), palisade (PT) and spongy (ST) parenchyma thickness, and adaxial (AD) and abaxial (AB) epidermis thickness. PLSR models using the whole spectral range were constructed using Unscrambler 11 (Aspen Technology Inc.) and a random-cross-validation was conducted.

The model performance was evaluated according to the R2 of its cross-validation. The best PLSR models for individual leaf traits were following: Chl (R2=0.94); Car (R2=0.77); Ant (R2=0.27); LMA (R2=0.72); EWT (R2=0.88); LT (R2=0.80); PT/LT (R2=0.73); ST/LT (R2=0.81); LD (R2=0.63); AD (R2=0.71); AB (R2=0.65). For the biochemical traits Chl, Car content and EWT, the PLSR model performed better for BRF obtained from the adaxial side of the leaf; surprisingly, the estimation for Ant content performed better from BRF based on the abaxial side of the leaf. For the anatomical traits LT, ST/LT ratio, AD, AB, LD the PLSR models performed better if based on abaxial BRF; for the PT/LT ratio, the model was better calibrated from the adaxial BRF and the validation of the models based on adaxial and abaxial BRF sides was the same.

Since leaf anatomy can affect optical properties regardless of pigment content, radiative transfer models (RTMs) incorporating leaf anatomical structure (QSPEC and Dorsiventral Leaf Model (DLM)) should not be neglected. Correct estimation of anatomical properties can help to improve these RTMs. Based on these RTMs, which include both biochemical and anatomical inputs, ecosystem function can be investigated and modelled with greater accuracy.

POSTERS 2D YSA: PRESENTATION OF CANDIATE POSTERS FOR YOUNG SCIENTIST AWARD

HYPERSPECTRAL ANALYSIS OF THE CONTAMINANTS ON THE SURFACE OF GANYMEDE

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Abstract

Ganymede, one of the moons of Jupiter and the largest in the Solar System, presents a surface characterized by a complex tectonic activity. The surface of the satellite is covered by two types of terrains, the dark and the bright ones. The dark terrains are the older one. They are covered by a mixture of ice-silicate minerals that possibly came from a past cryovolcanism associated with an extrusion of material through fissures and fractures. Dark terrains are locally dislocated by wedge-shaped areas of bright terrain. The emplacement of these bright terrains could be related to extensional deformation and extrusion of cryovolcanism in extensional context, similar to terrestrial rifts on Earth. The bright terrains, composed by silicate-free ice, are shaped by linear topographical depressions called grooves. The water lava flooded and down faulted the ancient dark terrain causing a resurfaced and tectonically deformed bright terrain so called chaotic terrains. The density of impact craters is less than in the dark terrain indicating they are younger.

Spectral data from the latest Jovian InfraRed Auroral Mapper (JIRAM) instrument onboard the Juno mission also show the existence of hydrated salty material on bright terrains. The origin of these hydrated salts could be associated with the internal geodynamic activity of Ganymede. The water ice at the surface of bright terrains results from the fusion of the ice shell or from the ocean that exists under this shell. Water lave migrated through the ice shell to the surface along fractures and faults visible in the bright terrain. Some of the hydrated salt minerals detected are $MgSO4$ and $Na2SO4$. Those minerals are detected in chaotic terrains. Water ice detections are concentrated in the polar regions. The JIRAM data and the ground-based spectrums also show evidence of non-water ice material different from hydrated salts. The composition of this material is not clear.

Here we present an analysis of the recent hyperspectral IR data that have been acquired on Ganymede by the Juno mission. The digital spectral data were obtained at the cartography and imaging sciences node of the Planetary Data System (PDS). We used the data from the JIRAM on board of Juno, which spectrometer provides measurements in the region of 2.0 µm to 5.0 µm.

The resolution of these data is good enough to map differentially bright and dark terrains. A general map has been drawn from the spectral dataset. This map has been compared to the map of the repartition of bright and dark terrains. In a second time, the IR spectra have been processed in order to find a possible signal of hydrated salts. A specific study has been realized on the largest impact craters of bright and dark terrains in order to evaluate the differences in ice composition between these two kinds of salts. Finally, it has been performed a geodynamic model of the energy sources like tidal heating within the outer ice shell of Ganymede in order to figure out, if the stress as a product of the dissipation of this energy, could influence the tectonic activity on surface.

The spectral analysis was realized using the Toolkit software. We made the geometry projection of the data using the kernels of the Juno mission which contain all the coordinates and ephemeris of the spacecraft, the planet, and the satellite. We also performed an evaluation of the quality of the data, applying the radiometric and geometric corrections for detecting any absorption bands. Then we performed the estimation of the PO spectrums and the treatment for detecting the physical parameters, obtaining the classification of the spectral profiles. Later, the extracted spectral profiles were compared with spectral libraries to evaluate the nature of element or molecule responsible for the absorption band. The geodynamic numerical model was simulated using the ASPECT mantle convection software.

POSTERS 2D YSA: PRESENTATION OF CANDIATE POSTERS FOR YOUNG SCIENTIST AWARD

USING SIMULATED GRASSLAND COMMUNITIES AND RADIATIVE TRANSFER MODELS TO TEST THE SPECTRAL VARIATION HYPOTHESIS

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Abstract

Increasing land use and climatic change lead to a global decline of biodiversity at alarming rates. To counteract this massive loss, global aims such as the convention of biological diversity's Aichi targets and related conservation programs have been launched. These programs require a detailed monitoring of biodiversity across large areas, which raises high expectation with respect to biodiversity assessments from EO data. One frequently discussed approach is an application of the Spectral Variation Hypothesis (SVH). This approach aims to link the spectral variation of image data (i.e., textures) to environmental heterogeneity as the main driver of species diversity in a given area. According to the SVH, diversity in plant biophysical properties increases with increasing species diversity what in turn drives variations in the spectral signature of the plant communities.

Various studies that exploit these correlations in terrestrial ecosystems come to promising conclusions. However, the causal links between spectral variation and species or biophysical diversity of plant communities remain unclear. Consequently, the SVH has recently become the focus of attention again.

Further research is in particular needed with respect to four limitations of the state of the art.

(1) Non-universal: The majority of previous studies has been restricted to single sensors, vegetation types and seasons.

(2) Non-standardized: Up to date, no common standard on how to measure spectral variation and trait or species diversity has been established. Therefor, it is hard to compare results of different studies.

(3) Non-transferable: So far, the spatio-temporal transferability of the relation between spectral variation and trait or species diversity is unclear.

(4) Non-sensitive: High species richness does not necessarily lead to a high diversity in biophysical properties and vice versa. It is thus unclear if vegetation assessments based on the concept of the SVH are able to capture different types of ecosystems.

To address these research gaps, we developed a combined approach to bring trait data from field measurements together with canopy reflectance simulations for a systematic and in-depth analysis of the relationships underlying the SVH. For this purpose, we parameterized PROSAIL with in-situ trait measurements of biophysical properties from three different grassland types in Germany : a nutrient-poor, a nutrient-rich and a dry grassland area. The biophysical properties of these grasslands were measured in spring, summer and fall in 2021 to capture the seasonal and site specific aspects of the prevailing plant community in the respective areas. Based on vegetation surveys from the field sites, we simulated artificial grassland communities that we can further modulate for our analyses. In combination with our trait data library, we generate season and site specific spectral signatures using PROSAIL.

Based on these simulations, we aim to (1) test the relations between the spectral variation and trait diversity with regard to several aspects, including the influence of individual biophysical properties and spectral features. We investigate (2) the effect of spatial resolution by re-sampling the artificial grassland communities for different pixel sizes. Further, we consider (3) the seasonal development of optical plant traits in our analyses to test the effects of changing biochemical and structural plant components on the reliability and temporal transferability of the SVH. Additionally, we analyze (4) the role of plant communities with different levels of species richness

and biophysical heterogeneity in different combinations to test the sensitivity of the SVH in relation to different ecological contexts. First results will be discussed.

POSTERS 3A: ANALYZING AND MAPPING BIODIVERSITY WITH IMAGING SPECTROSCOPY DATA

COMPARISON OF HYSPEX AIRBORNE HYPERSPECTRAL IMAGES WITH MULTI-TEMPORAL SENTINEL-2 COMPOSITIONS FOR MAPPING THE DOMINANT HIGH-MOUNTAIN PLANT COMMUNITIES

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Abstract

The Tatra Transboundary Biosphere Reserve, being one of the most environmentally valuable areas in Central Europe being the target of many vegetation studies. The use of phytosociology field methods, such as Braun-Blanquette approach is important and valuable, but also time and labour consuming. However, these methods are limited in space to a fixed network of measurement points. Additionally, these methods are affected by the subjectivity of the researcher who identifies plant communities. A solution may be the use of remote sensing techniques that provide objective, large-area and repeatable information about vegetation, enabling the monitoring of plant communities over time.

In our study, we compared multitemporal Sentinel-2 data with HySpex airborne hyperspectral images for Tatra mountains plant communities mapping. As high-mountain areas developed ecosystems adapted to topographic conditions, an important element of the assessment was the impact of particular LIDAR derivatives on the accuracy of classification of individual communities. Also, the effect of the number of training pixels on classification accuracy was tested providing useful information for the design of time- and cost-limited field campaigns in order to determine reliable classification accuracies. The proposed method is based on two machine learning algorithms, Random Forest (RF) and Support Vector Machines (SVM), with radial kernels function. The classification procedures were conducted using the open-source R programming language. The algorithms learning parameters were optimized using the grid search method, where each combination of the parameters is checked from the pool of parameters. The bias of classifications was reduced using an iterative accuracy assessment, which was repeated 100 times. Training and testing datasets were randomly selected in the 50:50 ratio; it was ensured that they were divided according to their belonging to a polygon in order to meet the condition of their independence. Then training of Random Forest and Support Vector Machines classifiers and classification accuracy results were saved for each classification. For the final map production, models with the highest average F1-score for all scenario classes were selected.

Comparing obtained results (overall accuracy: 90%−98%) are quite comparable to those obtained by other authors; as an example, Zhang et al. (2020), who used RF and multitemporal satellite data classified nine classes of mountain vegetation, achieved the following results: deciduous forest 75%-93% (PA); conifer forest types 89%-95% (PA), and subalpine shrubs and meadows 75% (PA).

Mishra et al. (2020) identified 17 classes of mountain vegetation (including eleven forest vegetation communities) based on multitemporal Sentinel-2 and Digital Elevation Model (DEM) using RF with an overall accuracy of 70–87%. The use of DEM improved overall accuracy about 15% of eight forest types in the case of Liu et al. (2018), who used multitemporal Sentinel-2 and Random Forest algorithm.

The results for 13 classes (from rock scree communities, alpine grasslands to montane conifer and deciduous forests) were in the range of 76% to 90% F1-score depending on the dataset. Topographic LiDAR derivatives (DTM, nDSM, aspect and slope maps) have increased the F1-score accuracy of individual HySpex, MNF, Sentinel-2 datasets by 5%-15%. Obtained classification maps based on HySpex data (2 m, 430 bands) had high similarity to maps obtained from multi-temporal Sentinel-2 data (less than 1% for classifications based on 500-1000 pixels).

POSTERS 3A: ANALYZING AND MAPPING BIODIVERSITY WITH IMAGING SPECTROSCOPY DATA

MAPPING SUCCESSION SPECIES USING AIRBORNE HYPERSPECTRAL DATA – DIFFERENT REFERENCE PREPARATION APPROACHES AND THEIR IMPACT ON CLASSIFICATION ACCURACY

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Abstract

The process of secondary succession happening on non-forest Natura 2000 areas in Poland is considered as one of the threats to different types of valuable habitats like meadows, grasslands, fens or heaths. The succession process can be understood as the encroachment of trees and shrubs on the mentioned habitats which results in the decrease of biodiversity and the transformation of natural landscapes. The information about species composing the succession process, next to geometrical characteristics of this vegetation, is important for the decision-makers as the choice of active protection measures depends on it.

A set of different research experiments aimed at distinguishing succession species was made by applying machine learning algorithms to airborne hyperspectral images (1-meter in pixel size, acquired by the HySpex cameras – VNIR-1800 0.5-meter and SWIR-384) and ALS data (acquired by Riegl LMS-Q680i, characterized by a density of 7 points/m2). These algorithms included e.g. pixel-based Random Forest for classification, Recursive Feature Elimination for feature selection, Minimum Noise Fraction for feature extraction and t-SNE for high dimensional data visualization. The experiments were conducted on seven research areas located in Poland, using data acquired in three different time periods within the growing season of 2017.

The research revealed that the approach to reference data preparation is one of the key factors affecting the classification accuracy being achieved. Despite the fact that the spatial resolution of the data used was very high, delineation of the spatial extent of different reference specimens was still very challenging. The succession process at its early stages is mostly formed by small shrubs and trees – 1 or 2 meters in diameter and height. Therefore they may often occur in the data as mixed pixels. Moreover, these trees and shrubs usually do not grow in isolation and are often surrounded by other types of higher vegetation e.g. grass or reed, what makes it difficult to separate one from the another. Finally, different species change their appearance and other characteristics throughout the growing season e.g. their leaves discolor, what changes the level of difficulty connected with delineating them. The presented research compares a few approaches to reference data preparation, from basic buffers to more complex expert methods, by looking at the speed of calculation, statistical accuracy and stability of the final result.

The research was conducted using data acquired by the MGGP Aero Sp. z.o.o. company within the project HabitARS (BIOSTRATEG2/297915/3/ NCBR/2016) The innovative approach supporting monitoring of non-forest Natura 2000 habitats, using remote sensing methods, co-financed by The National Centre for Research and Development.

POSTERS 3B: RECENT SOFTWARE AND SENSORS DEVELOPMENTS

UNSUPERVISED DETECTION IN HYPERSPECTRAL IMAGERY

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Abstract

In this paper, performance of unsupervised detection algorithms are compared. The SpecTIR Hyperspectral Airborne Experiment (SHARE) 2012 contains multiple sets of targets for testing detection algorithms with excellent ground truth. In this paper we utilize a single hyperspectral dataset collected by ProSpecTIR VS during the SHARE 2012. Detailed evaluation of these unsupervised methods at detection of six pure and mixed pixel targets is provided.

Three of the unsupervised (U) methods are least squares spectral unmixing based methods, referred to here as the UnConstrained Abundance (UCA(U)), Nonnegatively Constrained Abundance (NCA(U)), and Fully Constrained Abundance (FCA(U)) methods. The UCA(U) is an unconstrained least squares based method. The NCA(U) method enforces the abundance nonnegativity constraint (ANC), while the FCA(U) enforces both the ANC and abundance sum-to-one constraint (ASC). Unlike the UCA(U) method, which produces a closed-form solution for each endmember set, the NCA(U) and FCA(U) methods do not have analytical solutions since the ANC is formed by a set of p linear inequalities rather than equalities. However, a fast, iterative algorithm was developed in [1] to impose the ANC. Each of these least squares based methods is initialized with a prescribed estimate of the number of endmembers in the scene. To start, the brightest endmember in the scene is selected as the first endmember. We then assume that all pixel vectors in an image scene are pure pixels made up of this endmember with 100% abundance. Since this is generally not true, we find the next endmember that has the largest Least Squares Estimator between itself and the first endmember and select it as the second endmember. This process is continued until the prescribed number of endmembers are detected.

For performance comparison, we use all the unsupervised detection algorithms in ENVI®. The first of these is the Sequential Maximum Angle Convex Cone (SMACC) which uses a convex cone model (also known as Residual Minimization) to identify image endmember spectra [2]. SMACC is implemented in ENVI® as follows [2]: Extreme points are used to determine a convex cone, which defines the first endmember. A constrained oblique projection is then applied to the existing cone to derive the next endmember. The cone is increased to include the new endmember. The process is repeated until the specified number of endmembers are found. The second method is the Pixel Purity Index (PPI). PPI is used to find the most spectrally pure (extreme) pixels in hyperspectral images, which typically correspond to mixing endmembers [2]. It is implemented as follows [2]: PPI is computed by repeatedly projecting n-D scatter plots on a random unit vector. ENVI® records the extreme pixels in each projection and a Pixel Purity Image is created where each pixel value corresponds to the number of times that pixel was recorded as extreme. For completeness, performance of two unsupervised classification methods, ISODATA and K-Means in ENVI® are also evaluated. The ISODATA method in ENVI® [2] starts by calculating class means evenly distributed in the data space, then iteratively clusters the remaining pixels using minimum distance techniques. Each iteration recalculates means and reclassifies pixels with respect to the new means. This process continues until the percentage of pixels that change classes during an iteration is less than the change threshold or the maximum number of iterations is reached. K-Means unsupervised classification is very similar to ISODATA with some different settings [2].

[1] C.-I Chang and D. Heinz, "Constrained Subpixel Target Detection for Remotely Sensed Imagery," IEEE Trans. on Geoscience and Remote Sensing, vol. 38, no. 3, 1144-1159, 2000.

[2] ENVI® Documentation, https://www.l3harrisgeospatial.com/docs

POSTERS 3C: MEASURING AND UNDERSTANDING SOLAR-INDUCED FLUORESCENCE AS AN INDICATOR FOR ACTUAL PHOTOSYNTHESIS AND VEGETATION FUNCTION

SOLAR-INDUCED CHLOROPHYLL FLUORESCENCE (SIF) AND ITS RELATION WITH SOIL MOISTURE (SM) AND GROSS PRIMARY PRODUCTIVITY (GPP) AT EUROPEAN SCALE DURING A HEAT WAVE

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Abstract

Remote sensing of vegetation from satellite platforms have several decades of history, since the launch of satellites like the Sputnik (in the late 50's) and the first Landsat missions (in the 70's). Yet, subsequent advances in the development of imaging spectroscopy methods and instruments have had great impact on the assessment of vegetation functioning. In particular, the retrieval of Solar-Induced chlorophyll Fluorescence (SIF) from satellite spectroscopic data has attracted the attention of the scientific community in recent years. Initially, missions like the Global Ozone Monitoring Experiment 2 (GOME-2) from the European Space Agency (ESA), and the Orbiting Carbon Observatory 2 (OCO-2) from the National Aeronautics and Space Administration (NASA), have been used for the retrieval of SIF at satellite scale. Nevertheless, the subsequent unprecedented combination of spectral resolution, signal-to-noise ratio, and spatial coverage of the TROPOspheric Monitoring Instrument (TROPOMI) motivated novel approaches for global scale SIF assessment; e.g.: the TROPOMI-SIF (Köhler et al., 2018) and the TROPOSIF (Guanter et a., 2021) products. For our analysis we used ~7x3.5 km pixel-1 (at nadir) daily SIF data provided by the TROPOMI-SIF product, which has large potential to advance our knowledge on large scale ecosystem dynamics. The latest is true especially if the satellite-based SIF is integrated with data from other ecosystem variables at similar spatiotemporal resolutions, e.g. satellite-based Soil Moisture (SM) and Gross Primary Productivity (GPP) information. Following such direction, in this study we analyze the relationship that SIF has with the subsurface SM (obtained from the NASA's soil moisture active/passive –SMAP- mission) and the GPP (generated within the ESA's Scientific Exploitation of Operational Missions -SEOM- TerrA-P project) during the European Heat Wave (HW) in 2018, aiming to understand the continental scale response of vegetation to abnormally high temperatures. Therefore, we classified the averaged SM maps from June to early August into eight groups (from ~50 l m-3 to 300 l m-3) and analyzed their relation with the corresponding SIF and GPP information. Moreover, we analyzed the behavior of SIF in each SM class with special attention to HW peaks in the fourth week of June and the third week of July. We found a strong positive SIF-SM relation ($r = 0.91$, $p < 0.01$) and lower SIF, but more heat sensitive SIF patterns across time, in the lower SM classes. Moreover, our results suggest that a positive SIF-GPP relation is uncoupled and even becomes negative during the heat wave (as reported by Martini et al., 2021) in regions with SM below 130 l m-3, but remains positive in areas with higher soil water content. This study provides the first insight of the SIF-GPP relation contextualized in the frame of the soil water content at continental scale; and furthermore motivates future deeper analyses of this three-variate (SIF, SM, and GPP) relation within individual lowest and highest SM regions.

POSTERS 3C: MEASURING AND UNDERSTANDING SOLAR-INDUCED FLUORESCENCE AS AN INDICATOR FOR ACTUAL PHOTOSYNTHESIS AND VEGETATION FUNCTION

3D FOREST RECONSTRUCTION FROM TERRESTRIAL LASER SCANNING OF TREES FOR SOLAR-INDUCED CHLOROPHYLL FLUORESCENCE SENSITIVITY ANALYSIS

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Abstract

This study presents a method for three-dimensional (3D) reconstruction of forest tree species that are required, for instance, for simulations of 3D canopies in radiative transfer models (RTMs). We designed and tested the method on three forest tree species of different architecture: Norway spruce (Picea abies) and European beech (Fagus sylvatica), as representatives of European production forests, and white peppermint (Eucalyptus pulchella), a common forest species of Tasmania. Each species has a very specific and distinct crown structure and foliage distribution (Janoutová et al. 2021. In Silico Plants, 3(2)).

Our algorithm for 3D model construction of a single tree is based on terrestrial laser scanning (TLS) of individual trees and ancillary field measurements of leaf angle distribution (LAD), percentage of current-year and older leaves, and other parameters that could not be derived from TLS data. The algorithm comprises of four steps: (i) segmentation of a TLS tree point cloud separating wooden parts from foliage, (ii) reconstruction of wooden parts (trunks and branches) using TLS point clouds, (iii) biologically genuine distribution of foliage within the tree crown, and (iv) separation of foliage into two age categories (for spruce trees only, Janoutová et al. 2019. Forests, 10(3)). The reconstructed 3D models of the tree species were used to build virtual forest scenes in the Discrete Anisotropic Radiative Transfer (DART) model (Gastellu-Etchegorry et al. 2017. IEEE Journal of Selected Topics in Applied Earth Obs. and Remote Sens. 10(6), Malenovský et al. 2021. Remote Sens. Environ., 263). Subsequently, canopy optical signals, specifically solar-induced chlorophyll fluorescence signal (SIF), were simulated to carry out detailed 3D sensitivity analysis that cannot be performed within field experiments.

For its correct interpretation, the remotely sensed angularly anisotropic SIF (like a top-of-canopy (TOC) SIF signal of the upcoming FLEX satellite mission) must be corrected for its interactions with canopy structures. To investigate the potential impacts of selected forest structural traits and elements, i.e. leaf area index (LAI), LAD, canopy closure (CC) and the presence/absence of wood, we carried out detailed sensitivity analysis in DART. Results showed, for instance, that removal of woody components from clumped erectophile canopies of w. peppermint with CC of 80% and 40% and LAI of 2.5 increased the far-red TOC SIF radiance by 24% and 14%, respectively, while the hemispherical SIF escape ratio (SIF TOC radiance/total SIF emission) increased by 10% and 8%, respectively, and the nadir SIF escape ratio only by 6 and 4%, respectively. Interestingly, the change in CC from 80% to 40% triggered a similar change in far-red SIF hemispherical and nadir escape ratio, i.e., a respective decrease by 8% and 6%. The elimination of woody material in the N. spruce canopy (spherical LAD, LAI = 8.5, CC ~ 80% and single generation of needle leaves) increased the far-red TOC SIF radiance almost twice (90%), whereas the hemispherical and nadir far-red SIF escape ratio increased by 42% and 40%, respectively. The greater change in the far-red TOC SIF radiance over its canopy escape ratio indicates that the effect of wood shadowing is larger than direct scattering and absorption of SIF by woody elements. Our results demonstrate a potentially significant influence of wood and other structural canopy traits that should be considered when interpreting remote sensing SIF observations.

POSTERS 3C: MEASURING AND UNDERSTANDING SOLAR-INDUCED FLUORESCENCE AS AN INDICATOR FOR ACTUAL PHOTOSYNTHESIS AND VEGETATION FUNCTION

WINTER WHEAT CASE STUDY IN A FIELD IN GERMANY ON THE SUITABILITY OF OPTICAL REMOTE SENSING PARAMETERS TO TRACK GPP DYNAMICS FROM SUB-DIURNAL TO SEASONAL SCALE

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Abstract

To accurately monitor and predict the Earth carbon fluxes, a precise characterization of plant photosynthetic efficiency is essential. To get a better understanding which measures can be used for this purpose, we performed a comparison of available optical remote sensing (RS) parameters to track photosynthetic efficiency on seasonal and diurnal scales in a winter wheat field (~70 ha) in Western Germany (50°51''N and 6°26'''E). The site is a class 1 site within the European ICOS infrastructure (www.icos-cp.eu). We used gross primary productivity (GPP) as a measure for Photosynthetic efficiency, modelled by eddy covariance technique from net CO2 exchange measurements. As optical RS parameters, Vegetation indices (VIs) and sun induced fluorescence (SIF) were derived from a fluorescence box. We tested reflectance-based NDVI and EVI, Chlorophyll Carotenoid Index (CCI), proposed as an indicator of changing chlorophyll and carotenoid pigment ratios tracking seasonal changes in photosynthetic activity, Near-infrared reflectance of terrestrial vegetation index (NIRvref= NDVI * reflectance@800nm), proposed as a suitable proxy for global GPP estimates, and radiance-based NIRvrad (NDVI* radiance@800nm), shown in other studies to hold the NIRvrad-GPP relationship under drought conditions. SIF760, SIF687, SIFTOT were retrieved by Spectral Fitting Method (SFM), and to normalize for incoming radiation, divided by incident radiation between 400 and 700 nm (PAR).

We show seasonal patterns with diurnal variations from two measurement campaigns in the 2018 growing season: i) ‘Green canopy’: 18 days in May when the canopy is green and closed while the plants elongate and ears emerge; and ii) ‘Senescence’: 9 days by end of June when the canopy visibly turns from green to brown before harvest. For exemplary analysis two dates (May 9 and June 29) with clear sky conditions were selected for further analyses of diurnal pattern.

In the ‘green canopy’ GPP first increases and then drops again with fluctuations on diurnal and sub-diurnal scale, while VIs remain relatively unchanged. The radiance-flux parameters NIRvrad and SIF, show even more variations than GPP, both on diurnal and sub-diurnal scale, while Normalized SIFTOT shows a tendency to decrease. ‘Senescence’, marked as a steady decrease by GPP, was followed by VIs as a larger seasonal pattern. NIRvrad shows a slight decrease during this period, while varying diurnally. SIF signals are already very low by the beginning of this period and stay low. Diurnal changes in photosynthesis on May 9, marked by GPP with positive diurnal course with peak around noon, are followed most closely by NIRvrad and SIFTOT. On June 29, when GPP decreases over the day, VIs show slight diurnal changes, and NIRvrad shows a diurnal course.

Our results demonstrate, that for the investigated wheat field, each of these metrics offer different and complementary information. Reflectance based VIs are useful to track the greenness on larger temporal scales, while NIRvrad, incorporating PAR, was shown to do generally better following diurnal GPP dynamics. It tracks more closely the absorbed PAR and thus better represents actual photosynthetic efficiency. We found SIF,

although being highly sensitive to physiological-structural interactions, to be the most direct measure of the photosynthetic activity and thus a valuable indicator for the dynamic changes in plant physiology which cannot be replaced by NIRvrad.

Based on our findings, we suggest the joint use of optical RS parameters, reflectance- and radiance-based VIs and SIF, to improve current estimates of GPP from sub-diurnal to seasonal scale. Further work is in progress to include them in a full (LUE) model to describe the observations in GPP as a proxy for carbon fixation and to improve forward models of GPP to provide better estimates of actual vegetation function on ecosystem scale.

POSTERS 3C: MEASURING AND UNDERSTANDING SOLAR-INDUCED FLUORESCENCE AS AN INDICATOR FOR ACTUAL PHOTOSYNTHESIS AND VEGETATION FUNCTION

DESIGN FOR AN ACTIVE LASER-INDUCED FLUORESCENCE SYSTEM ON UNMANNED AERIAL VEHICLES

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Abstract

The EU H2020 I-Seed project aims for sustainable environmental monitoring of topsoil and air above soil environments by employing Unmanned Aerial Vehicles (UAV) to distribute, localize and read-out of the fluorescence signal of the artificial I-seeds. Reaction with relevant environmental parameters and process of bio-degradation will induce a change of fluorescence in the artificial seeds, which will be recorded from an airborne platform with sufficient signal-to-noise ratio to identify the concentration of targeted soil parameters, such as mercury, carbon dioxide, humidity and temperature. Remote sensing based laser-induced fluorescence systems are used in atmospheric and environmental monitoring, where the emitted fluorescence is collected at a working distance of couple of meters to hundreds of meters from the zone of interest. However, technology maturation, miniaturization and cost has always been a major bottleneck for developing mini-UAV based active spectroscopic systems. Here we present the design ideas and results of first lab-scale experiments to realize an active laser-induced fluorescence system on UAV platform. Such a system has potentials to address not only the sustainable environment monitoring and agricultural production, but also the threats in food security, climate change and sustainable resource management.

POSTERS 3D: IMAGING SPECTROSCOPY FOR RAW MATERIALS AND THE ENERGY TRANSITION

THE CONTRIBUTION OF SHORTWAVE AND LONGWAVE INFRARED IMAGING SPECTROSCOPY (IRIS) TO MAPPING ALTERATION INDICATOR MINERALS IN GEOTHERMAL RESERVOIRS

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Abstract

Infrared spectroscopy has been successfully applied for mapping clay alteration in drill samples of high-enthalpy (i.e. volcanic) geothermal reservoirs. Particularly the ‘clay rank’ ranging (with increasing temperature) from smectite, to mixed-layer illite/smectite minerals, to pure illite is useful for mapping the clay cap of a geothermal system and help decide where the actual, exploitable reservoir starts. These clay minerals can be detected and differentiated with off-the-shelf portable infrared spectrometers. Many other useful indicator minerals, however, such as epidote, zeolites, Ca-sulphates and others, are less common and spectrally less active than those clay minerals. This means that in mixed rock spectra their signal may be ‘swamped out’ by those of the clay minerals, and the other indicator minerals may not be detected successfully. In this talk we will look at recent and ongoing research in using imaging spectrometers on geothermal drill cuttings to detect indicator minerals which may occur in small percentages (or in sub-percent levels) in the drill cuttings but have a vital impact on the correct geothermal reservoir interpretation. We will look at the potential of the SWIR IRIS and at the complementarity of LWIR IRIS data to answer some of the questions the SWIR range by itself cannot produce.

POSTERS 3D: IMAGING SPECTROSCOPY FOR RAW MATERIALS AND THE ENERGY TRANSITION

AIRBORNE IMAGING SPECTROMETRY USING AHS DATA FOR THE EVALUATION OF THE SPATIAL DISTRIBUTION OF SULFATE MINERALS

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Abstract

Mining exploration causes a multitude of impacts on the environment, related to the construction of access roads and paths to the areas of interest, the movement of heavy machinery and ground surveys prospection. Remote sensing has been successfully used in mineralogical mapping and should be considered in the mining exploration process in order to reduce the associated environmental impact by selecting key areas in the exploration phase for further prospecting issues in the context of increasing raw materials demands. The use of AHS (Airborne Hyperspectral Scanner) images in the SWIR spectral region working with 31 bands (between 1970 and 2468 nm) is evaluated for mapping the presence of mineral indicators accounting for possible geological resources of economic interest. The study area is located in the Cenozoic Tagus sedimentary basin (Madrid province) in geological units containing clays (smectites), evaporitic (gyspsum, anhydrite) and carbonate rocks (limestones and dolostones). The area is well known for the presence of gypsum and glauberite quarries for sodium sulphate production for detergents, glass industry, etc. The study is based on the spectral response of key minerals such as calcite, gypsum and both Mg and Al-bearing clays and their mixtures in order to map their presence in the landforms surfaces as indicators for possible resources of sulfate minerals in depth. Simultaneous to the AHS flight campaign, a field spectroradiometry survey took place for the characterization of soil surface mineral variability in the visible-near infrared and shortwave infrared (VNIR-SWIR, 350-2500 nm) wavelength interval using an ASD FieldSpec-4 spectroradiometer. Field sampling for laboratory reflectance spectroscopy and X-Ray Diffraction was used in order to link the spectral response (absorption features) with the mineralogical characterization of the samples and to validate the outcome of the surface spectral response and mapping in the image data set. Visual interpretation was carried out through color compositions with image band ratios calculated in order to explore the location of areas with the interest minerals and their mixtures compared to spectral libraries, and to provide further support to the interpretation of the results. The mapping procedure was based on a MNF (Minimum Noise Fraction) transform, identifying endmembers through the Pixel Purity Index (PPI) and n-D Visualizer, in order to apply the MTMF technique (Mixture Tuned Matched Filtering). The results show a complicated mixture pattern between clay, carbonate and sulfate minerals because of the overlapping of some absorption features in certain wavelengths. Nevertheless, gypsum areas were the best differentiated providing detailed location of surface mineral abundances for further exploration. The overall outcomes of this study show that hyperspectral techniques are useful for specific location of areas with sulfate minerals that are not present in the geological formations of conventional maps.

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POSTERS 3D: IMAGING SPECTROSCOPY FOR RAW MATERIALS AND THE ENERGY TRANSITION

HYPERSPECTRAL MAPPING OF CLAY INDUSTRIAL MINERALS WITH AHS AIRBORNE DATA

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Abstract

Clay minerals have a large interest in several fields of Science and Applied Science. On the one hand, clay minerals have a wide range of industrial applications in the manufacture of paper, ceramics, rubber, plastics, paints, glass fibres, pet substrates, etc. and, special absorbent clays (sepiolite, palygorskite and bentonite), are used not only as industrial absorbents, but also in catalysis, cosmetics, pharmaceuticals and animal feed. On the other hand, they play an important role as natural hazards related to expansive soils. Clay minerals are spectrally active, and provide surface compositional information for mineral exploration. For these reasons, Imaging Spectrometry applied to the exploration and mapping of clay minerals is of great interest. The study area is located in the Cenozoic Tagus sedimentary basin in Central Spain, an area particularly interesting because it is one of the richest in Mg-rich clays worldwide, mainly sepiolite and Mg-smectite. This area conforms a gentle sloping terrain with an almost complete absence of outcrops, being difficult to delimit clear boundaries between different units through conventional mapping methods. The main objective of this work is to map different mineralogical associations with clay minerals through the analysis and interpretation of AHS (Airborne Hyperspectral Scanner) images in the spectral range between 2000 and 2500 nm (31 bands). The methodological procedure included: a) ratio image analysis for an initial exploration based on the diagnostic mineral absorption features; b) identification of image reference endmembers to use in the SAM (Spectral Angle Mapper) supervised classification algorithm. The endmember selection was based on the geological knowledge of the area, taking into account the image ratio analysis, common spectral libraries, and critical analysis of purest image pixels using MNF transform and PPI images. Simultaneous to the airborne campaign acquisition, field campaigns took place including field spectroradiometry for the characterization of soil surface mineral variability and sampling for laboratory spectral and X-Ray Diffraction (XRD) analysis in different lithological units. Both reflectance measurements for field and laboratory covered the visible-near infrared and shortwave infrared (VNIR-SWIR, 350-2500 nm) using an ASD FieldSpec spectroradiometer. The compositional characteristics of the samples reflect different components, among them Mg-smectites, Al-bearing clays, gypsum and carbonate minerals. The mapping results show precise indications of the presence of the interests minerals such as sepiolite deposits located in arkosic facies, showing sometimes contents of palygorskite, while smectites are more concentrated in mudflat facies, in the so-called “Green Clays Unit”, comprising both green and pink levels of saponitic and stevensitic clays. The mapping results, validated with XRD, field-work, and coincidence with previous descriptions of large mapping units, represent a clear improvement of the official published geological map and a key for further mining prospecting of these clayey raw materials in areas not previously studied.

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POSTERS 3D: IMAGING SPECTROSCOPY FOR RAW MATERIALS AND THE ENERGY TRANSITION

THE INFLUENCE OF ILLUMINATION ELEVATION ANGLE ON MINERAL CLASSIFICATION OF HYPERSPECTRAL IMAGES

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Abstract

Hyperspectral studies of vegetation and water surfaces often have a multi-temporal component, and therefore involve an analysis of the effect of illumination elevation angle (an angle between the horizontal plane and illumination rays) and azimuth angle (a horizontal angle between the north and illumination rays). This seems a lot less a point of concern when an invariant and flat surface cover is mapped, such as soil and rock outcrop. However, there is always a time-dependency as the outdoors measuring environment does change.

In this paper, we present a systematic analysis of changing illumination elevation on mineral spectra to measure how it affects mineral classification. We used a lab-acquired dataset and evaluated the effect on spectral features and classification results.

First, we measured seven mineral samples in a lab using an Analytical Spectral Device (ASD) FieldSpec 3 under 9 illumination elevation angles (IEA): from 85° to 5° measure each sample per 10°. We used pure loose mineral samples: vivianite, gypsum, malachite, borax, calcite, kaolinite, and montmorillonite. We optimized and calibrated the ASD before measurements that succeed every time we lower the IEA. After the measurement, we corrected spectral offsets in the reflectance spectra caused by transitions between different detectors. Subsequently, we created a dataset consisting of spectra of the pure mineral and mixed spectra, because pure mineral spectra rarely exist in real-world data. The mixed spectra were created by using spectra of each of the seven minerals once as the main component and the spectra of the other six minerals were equally distributed in the mixture. There are four fractions for the main component t: 95%, 85%, 75%, and 50%. Second, on two features of each mineral, we analyzed two spectral feature parameters: center wavelength position and absorption depth. Third, we classified the dataset using three classifiers: SAM (spectral angle mapper), ED (Euclidean distance), and ESDT (expert system decision tree). We selected the three classifiers from two working principles. Color-based classifiers (SAM & ESDT) label unknown spectra based on their feature positions. On the other hand, the brightness-based classifier (ED) labels unknown spectra based on comparing reflectance.

Results show that the decreasing IEA progressively affects both feature center and depth. The center position of pure spectra shifts within 0-10 nm. For mixed spectra, the shifts extent to 0-30 nm, and a lesser main component causes a bigger shift. Two exceptions are the 50% fraction calcite and borax whose features are merged by the OH feature, which causes a shift up to 40-160 nm. The feature depth is 1.5-4 times deeper from shallowest to deepest. The feature depth is stable or slowly increases before an IEA of around 65° (depending on minerals), but after 65° a distinct decrease can be observed. This is because the spectral brightness fast increases after 65°, which is a result as the white reference presenting more specular reflection under a low IEA. Classification results show that, in terms of accuracy, color-based classifiers (SAM & ESDT) outperform the ED which depends on brightness. For pure spectra, the IEA affects the ED results only when lower than 15°, and has no effects on the SAM and ESDT. However, for the mixed spectra, a significant influence can be observed for all three classifiers since the purity of 75%.

We conclude that, when lowering the IEA, the spectral brightness gradually increases, while the shift of feature position is mainly a result of the spectral mixture. We therefore suggest that the color-based classifiers are more resistant to varying IEAs than the brightness-involved ones.

POSTERS 3E: IMAGING SPECTROSCOPY OF CROPLAND AND GRASLAND

CROP IDENTIFICATION USING ONE-SHOT AIRBORNE HYPERSPECTRAL IMAGES

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Abstract

The aim of the research was to analyze the possibility of using airborne hyperspectral images in crop control in areas with predominantly small plots with fragmented structure.

The research is conducted within the IDUB AGH project.

Motivation of the work.

Under the agricultural direct payment control system (IACS), the area of a crop is measured and the type of crop is determined. The information from the control measurement is compared with the data declared by the farmer. A discrepancy may result in penalties being charged to the farmer. Recently, there is a modification in the control approach. Instead of on-the spot check, a remote sensing method based on Sentinel-1 and Sentinel-2 images is proposed. Some tests have been performed in 2019-2020 in Poland. The possibility of confirming the declaration at the level of 79% was obtained even based on a single S-2 registration made 4 weeks before harvest (Hejmanowska et. al 2021, Remote Sens. 2021). Obviously, higher accuracy can be obtained from multi-temporal images and precise information on agrotechnical treatments from dense time series.

In southern Poland, the area of more than 60% of agricultural plots is below 0.5 ha, which makes it difficult and sometimes impossible to use Sentinel images. In addition to spatial resolution, recognition of individual plants not only crop type is also a problem. Therefore, a study was conducted using hyperspectral aerial photographs.

Date

Hyperspectral data were acquired on 5 July 2021 for the 5x4km area of Kolbuszowa municipality in southern Poland. The registration was performed at an altitude of 867 - 882 m. The HySpex VS-725 hyperspectral set was used to acquire hyperspectral data. The set consists of two SWIR-384 scanners and one VNIR-1800 scanner. 16 series were recorded. Radiometric, geometric PARGE, atmospheric ATCOR4 correction was performed using the MODTRAN physical model. The hyperspectral mosaic made from the processed hyperspectral images has a spatial resolution of 0.5 m, consists of 430 spectral channels and is registered in the UTM 34N coordinate system (EPSG:32634).

In addition to the remote sensing data, a field inspection was performed to identify the crop type. Information on 69 agricultural plots was acquired by positioning the location using handheld GPS. 10 classes were defined: winter wheat, rye, wheat-rye, barley, oats, potatoes, beets, corn, meadow, and bare soil.

Methods

Hyperspectral images and in-situ measurement points were integrated in QGIS 3.22.0. Reference polygons were created based on the points from the field inspection. Then, using the training set, random forest (RF) classification (estimator = RandomForestClassifier n_estimators=100, oob_score=True), cross-validation with 3-folds was performed in EnMAP software (as QGIS plug-in).

Results

RF classification overall accuracy (OA) was 74.95%, mean value of user accuracy (UA) was 69.22%, and mean value of producer accuracy (PA) was 73.54%.

The UA values above 70% were obtained for almost all crops except the bare soils. Similarly, PA for most crops except potatoes and rye.

Discussion

A similar study can be found in (Meng et. al 2021 Computers and Electronics in Agriculture, Vol. 186), which deals with crop mapping using one-shot hyperspectral satellite imagery. In the cited study, only two crop types were analyzed: winter wheat and rapeseed. OA was calculated as (tp+tn)/(tp+tn+fp+fn). Thus understood, the classification accuracy of a single hyperspectral registration by RF method was OA = 89,96%, for comparison of time series classification S2: channels and NDVI 89.44% (6 registration dates).

OA is traditionally calculated in remote sensing as: sum tp for classes/(tp+tn+fp+fn).

In our study, a one-shot hyperspectral registration yielded an RF accuracy OA of 74.95%.

For comparison, in our past study cited above, we obtained classification accuracy of 3 Sentinel-2 registrations of 80.80% and of a single image of 78.58%.

POSTERS 3E: IMAGING SPECTROSCOPY OF CROPLAND AND GRASLAND

TEMPO-SPATIAL DYNAMICS OF MULTISPECTRAL ASSESSMENT OF AGRICULTURAL FIELD HETEROGENEITY

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Abstract

Agricultural fields are seldom completely homogeneous. Soil, slope, and previous management decisions can influence the conditions under which a current crop grows and determine its nutritional needs. However, in current farming situations in Switzerland, the fields are largely treated as a homogeneous entity. Fertilizers are spread mostly subjectively, according to the knowledge of the field manager, even though it is crucial that the right amount of fertilizer is applied at the right time and in the right place, both for ecological and economic reasons. This prevents over-fertilization of the field, fertilizer run-off, and saves fertilizer. Precision farming tools like e.g. variable rate technology (VRT) take the field heterogeneity into account and can help to apply fertilizer according to the actual need of the plants. VRT can be based on field imagery as input for fertilizer calculation - this imagery can be obtained with hand or tractor mounted sensors, UAVs or satellites; mostly these techniques rely on multispectral data. However, VRT in combination with sensors is very expensive. The profitability of VRT systems varies depending on the cost of sensor technology which is used and the attributes of the respective field. UAV-based field imagery is available at a very high spatial resolution of a few centimetres, but the costs for the flight missions are considerably high. Satellite-based data comes at little or no cost at all, however, the spatial resolution is much lower, this can cause errors especially in small scale fields. It is unclear, which spatial resolution is needed to capture the in-field variability reliably in small scale fields. It is also unclear, which temporal resolution or which bands provide the greatest benefit in heterogeneity mapping. It is further estimated that the use of VRT and sensors only pays off once a certain threshold of overall heterogeneity in the field is reached. In general, data on field heterogeneity is scare, especially in the context of spatio-temporal changes throughout the vegetation season. In order to investigate this, a fixed-wing UAV (WingtraOne) was regularly flown over a small rural area in Switzerland at relevant times of the vegetation period over 2.5 consecutive years. Fixed-wing UAVs manage to cover 50 to 100 ha in one flight and are thus ideal for these studies. The study area included a diverse set of crops, ranging from winter wheat, canola, maize, sugar beet, sunflower to grassland and vegetables. Soil maps and field book data of the respective farm managers complemented the data set. The drone was equipped with different cameras: a high-resolution RGB camera (Sony RX1RII, 42 megapixels) and 3 different multi-spectral cameras (Red-Edge M, Red-Edge MX and Altum, all by Mica Sense). All multispectral cameras captured data in at least 5 bands of the RGB and near infrared spectrum (Altum also collected thermal data). The multispectral data was radiometric calibrated using the inbuilt down-welling light sensor and external calibration panels. The cameras offered a spatial resolution of 0.7 to 1.2 cm (RGB) and 6 to 8 cm (multispectral). The multispectral data was used to calculate vegetation indices that are associated with crop health and vigour, such as the NDVI or NDRE. These indices served as a basis for the overall in-field heterogeneity investigation. In this contribution, first results of this study on spatio-temporal dynamics of field heterogeneity are introduced aiming to identify relevant times in the growing season, relevant ground sampling distances, and also relevant bands or vegetation indices to assess the field heterogeneity in small scale fields.

POSTERS 3E: IMAGING SPECTROSCOPY OF CROPLAND AND GRASLAND

APPLICATION OF HYPERSPECTRAL IMAGING FOR ESTIMATION OF POTASSIUM CONTENT ACROSS DIFFERENT PLANT SPECIES

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Abstract

Potassium (K) is one of the most essential components of plant organic matter, which play an important role in many metabolic processes that affect crop quality. The plant requirements for K are higher than other macro nutrient after nitrogen therefore it is necessary to supply this element in the form of chemical fertilizers. However, excessive consumption of fertilizers might lead to severe food poisoning. If nutritional deficiencies are detected early, it can help farmers to design better fertigation practices before the problem becomes unsolvable. Therefore, monitoring of potassium content in plants and soil as well as efficient application of mineral nutrients are crucial for ensuring crop yield and for minimizing the negative environmental impact of fertilization. Traditional techniques to estimate potassium content in plant are based on leaf sampling and foliar analysis. However, these methods are destructive, time-consuming and expensive. Therefore, it is necessary to consider efficient alternatives. Recently, hyperspectral imaging has shown to be a promising non-destructive tool for determination of nutrient content in plant leaves (Singh and Budihal. 2021, J. Intell. Comput. Appl.). This method allow to obtain information on the relationships between plants and electromagnetic energy in narrow bands of the electromagnetic spectrum.

The proposed approach uses leaf spectral data in the region of 400 - 2500 to predict the amount of potassium level in plant leaves across different plant species. A study was carried out on two species of crops: celery (Apium graveolens L., cv. Neon) and sugar beet (Beta vulgaris L., cv. Tapir) fertilized with four different doses of potassium (33%, 67%, 100% and 133% of the recommended potassium dose). Leaf images were captured by a VNIR and SWIR hyperspectral cameras, and potassium content was measured by laboratory ordinary destructive methods. Twelve wavelengths were selected using correlation-based feature selection as the most appropriate for determination of potassium content in plant leaves. Subsequently, models were established using four algorithms: k-nearest neighbours, support vector regression, random forest and linear regression. Model performance was evaluated by adjusted correlation coefficients - R2 and root mean square error. All studied models indicated the high efficiency with estimation of potassium content. The best results were achieved by Random Forest algorithm with R2 = 0.807, RMSE= 6.611 and with R2 = 0.797, RMSE= 5.880 for celery and sugar beet plants, respectively.

Results obtained in this study demonstrate that hyperspectral imaging could be utilized for developing a decision-making tool for farmers to allow a real-time foliar nutrient assessment leading to control fertilizer inputs in farm.

POSTERS 3E: IMAGING SPECTROSCOPY OF CROPLAND AND GRASLAND

FEATURE SELECTION AND CLASSIFICATION OF INFECTED TUBERS USING HYPERSPECTRAL IMAGES AND COMPRESSIVE SENSING

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Abstract

Plant diseases are among the principal causes of considerable economic losses in food production. These losses are expected to increase, due to proliferation of invasive species, be it pests or vectors of diseases. Therefore, various new technologies, tools and techniques are continually tested, aiming to mitigate problems caused by plant diseases. Root-knot nematodes (Meloidogyne spp.) are among the most destructive plant pests, and can rapidly infest entire fields, e.g. by seeding material, such as potato tubers, where latent infections have been confirmed.

In recent years, hyperspectral imaging (HSI) has become an attractive tool for early detection of diseases. It's a non-invasive method, and doesn't necessarily require destructive sampling. HSI sensors capture reflected light of each pixel in the visible to short-wave infrared spectrum (400 – 2500 nm), and divide it into several spectral bands with narrow bandwidth (up to approximately 10 nm). A typical hyperspectral sensor has more than 20 bands in just the visible part of the spectrum (400 – 750 nm). Investigation of these bands gives us essential insights into the characteristics and properties of the analysed object. Furthermore, for certain applications e.g. classification problems, only a limited number of the spectral bands are needed, since the entire spectrum has high redundancy and using raw spectra can reduce classification accuracy. This is especially true when analysed objects exhibit similar spectral responses in the same parts of the electromagnetic spectrum. Consequently, for a specific application, HSI could be used to develop a more cost-effective multispectral system, focused on only the most relevant spectral bands for any given application, and provide similar information compared to more advanced systems, which can acquire numerous spectral bands.

In this study, we used compressive sensing (CS) for efficient selection of the most relevant spectral bands and tested how the decision affected classification metrics. Specifically, relevant features were extracted using Sparse Sensor Placement Optimization for Classification (SSPOC) algorithm, which transforms the original feature space into a low-dimensional one. It exploits the most informative features for a task, using the L1 minimization procedure. In addition, we also used Extreme gradient boosting (XGBoost) as a second dimensionality reduction method, and compared the results. The core classification algorithm, for which the spectral wavelengths were optimized, was Linear Discriminant Analysis (LDA). We tested the efficacy of our approach on a binary classification problem, a hyperspectral data set comprising 60 reflectance signatures of healthy and potato tubers infected with the root-knot nematode Meloidigyne luci. A 4:1 stratified split was performed to divide data into train and test datasets, respectively. The results indicate an exceptionally adequate decision for the selection of hyperspectral bands. LDA achieved 75% classification accuracy on test data set using only one, the most prominent wavelength, and 100% accuracy using two. In contrast, LDA performed worse on wavelengths selected by XGBoost. It achieved 60% classification accuracy using one, 83% using two, and 100% using three among the most prominent wavelengths ordered by Gini importance. In this paper, we showed that the sparsity-promoting technique SSPOC works well with the selection of the most essential features of hyperspectral signatures, for plant disease detection. Furthermore, we presented an interesting application of why the selection of wavelengths may be used in the agriculture domain. To the author's best knowledge, the SSPOC algorithm was never used for this particular purpose. We hope that our research will promote sparsity techniques to see more related articles in the future.

POSTERS 3E: IMAGING SPECTROSCOPY OF CROPLAND AND GRASLAND

DETECTION OF GRASSLAND DEGRADATION IN AZERBAIJAN BY COMBINING MULTI-DECADAL NDVI TIME SERIES AND FRACTIONAL COVER ESTIMATES BASED ON DESIS DATA

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Abstract

Degradation is one of the most pressing global environmental problems and is projected to worsen due to climate change and land use pressure. Grassland ecosystems used for pasturing are especially prone to degradation. In the Caucasus region, livestock farming is an important part of the agricultural sector and subsistence farming is commonplace, hence threats to pastures can significantly impact livelihoods. The grassland areas of Azerbaijan are under heavy anthropogenic pressure, leading to vegetation cover loss and erosion, especially on community pasture land.

Degradation is generally assessed in remote sensing by quantifying changes in vegetation indices (VIs). This is a challenging task, as information from long time series is needed to detect trends, and frequent observations are needed to distinguish degradation from phenological variability. For such time series, only multispectral data is available. However, especially in regions where vegetation is sparse, information on the fractions of ground cover such as photoactive vegetation (PV), non-photoactive vegetation (NPV) or soil is important, as soil reflectance affects VIs. Hyperspectral data are particularly valuable in this regard as they have the spectral resolution required to distinguish soil, vital and degraded vegetation. In this study we therefore investigate the potential of combining multispectral time series with hyperspectral data.

In a first step, a nationwide land cover map is generated. During two field campaigns in August and October 2018, 296 plots in grassland, cropland and shrubland were visited, for which land cover, coverage and erosion intensity were recorded. In addition, samples of urban areas, soil, water and forests were collected from Google Earth Engine (GEE) imagery. 70 spectral-temporal metrics of the Sentinel-2 imagery of 2018 were used as input features together with the field data in a random forest classifier. Land cover is modeled with an overall accuracy of 83 % (Asam et al. 2019, ESA LPS).

A Normalized Difference Vegetation Index (NDVI) time series is used to identify grassland degradation on a national scale. Acquisitions from the Landsat Missions (TM, ETM+, OLI; 1984-2020) are harmonized and each image is masked using fmask on the GEE platform. For each year, median NDVI of the grassland areas are generated and trends are calculated using the Sen's slope and the Mann-Kendall test.

For 2019 – 2021, 9 DESIS acquisitions are available with cloud coverage < 25% and recorded with sun angle < 40°, covering parts of the western lowlands and Lesser Caucasus of Azerbaijan. For each scene, fractional cover was calculated using the “fCover” processor. It derives pure material signatures using the Spatial-Spectral Endmember Extraction (Rogge et al. 2012, JSTARS, 5(1)), which are then classified into the classes PV, NPV and soil, using a pre-trained random forest. fCovers are then calculated using a Multiple Endmember Spectral Mixture Analysis (Bachmann et al. 2009, 6th EARSeL-SIG-IS) with each pixel treated as a linear combination of each spectral class. Originally developed for hyperspectral sensors covering the full VNIR-SWIR range, this method was successfully applied also to VNIR-only DESIS data (Marshall et al., 2021, 1st DESIS User Workshop).

First results indicate that 5.4 % of Azerbaijan’s grasslands show a significant ($p < 0.05$) negative NDVI trend, pointing to potential degradation hotspots. PV could be derived from DESIS with a mean absolute error of 8,94 %. Next, areas showing a degradation trend are intersected with PV and NPV fractions and analyzed regarding their statistical relationship. First results show that pixels with a high PV coverage are less degraded. In addition, effects of topography and degradation time scales will be analyzed. Using this approach, a country-wide multi-

decadal assessment of vegetation changes can be enhanced by adding canopy structure information from hyperspectral DESIS data.