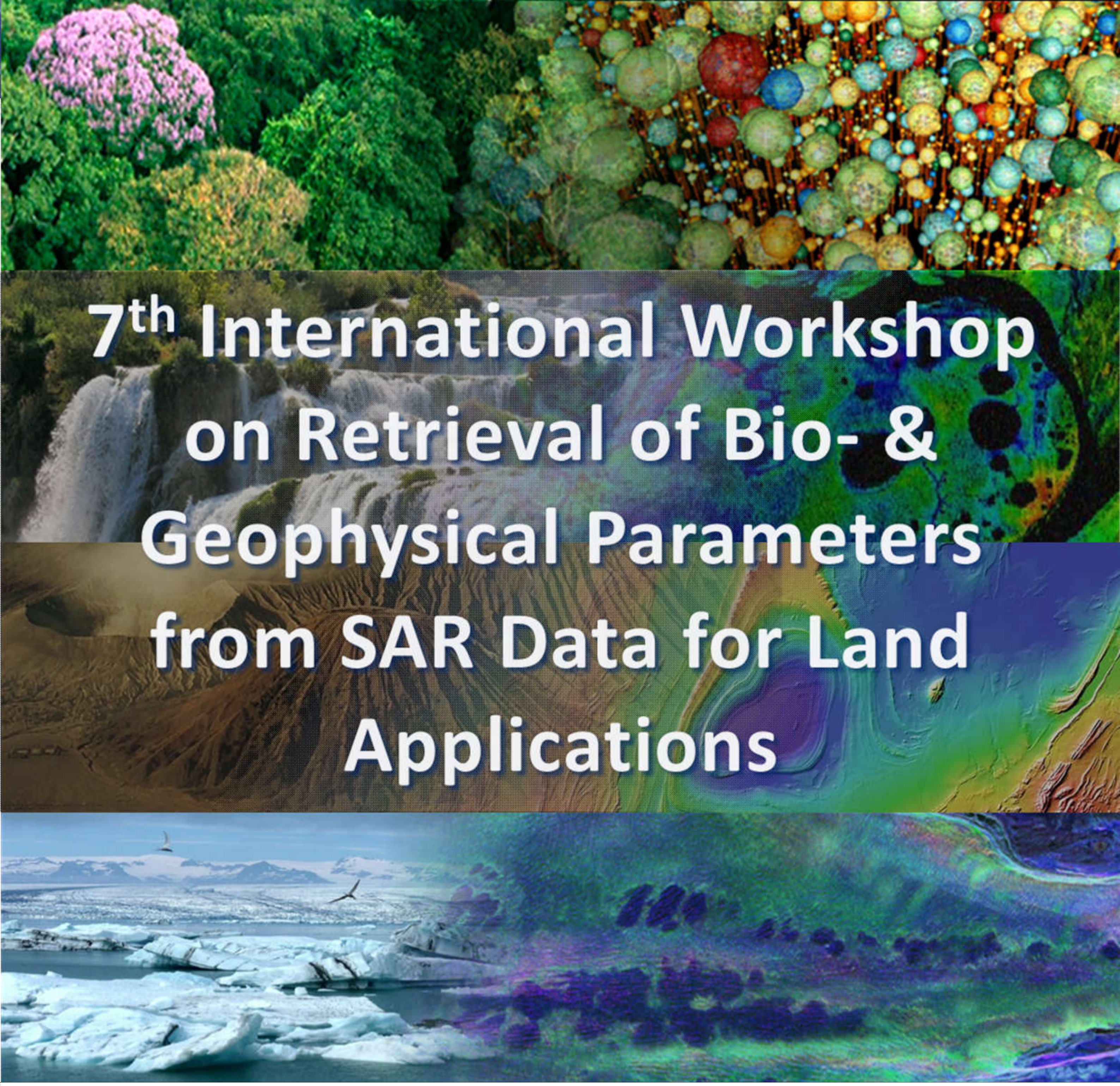


# 7th International Workshop on Retrieval of Bio- & Geophysical Parameters from SAR Data for Land Applications

## FINAL PROGRAM

November 12 – 15, 2018
DLR-Oberpfaffenhofen
Münchner Str. 20, 82234 Weßling

esa

DLR

## Welcome to the BioGeoSAR-18 Workshop

The German Aerospace Center (DLR), European Space Agency (ESA) and the Science Committee warmly welcome you to the Bio-GeoSAR-18 workshop. It is the 7th meeting since the late 1990s, with a goal of providing a vibrant and dynamic forum for discovery and discussion of the latest research in SAR remote sensing and geomatics for the extraction of bio- & geophysical parameters.

Based on the numerous abstract submissions we organized an compelling program of presentations and tutorials around the five main themes: (1) Ice and Snow, (2) Soil and hydrology, (3) Forestry, (4) Agriculture, (5) Land-use and classification. In order to trigger the discussion at the workshop and to provide some guidance to authors, the following seed questions have been prepared:

- ➔ For the development of new and/or the improvement of existing products based on bio-/geo-physical parameters retrieved from SAR data:
  - What is the impact of multi-temporal acquisitions? What temporal resolutions (i.e. revisit times) are required?
  - What is the importance of combining measurements at different frequencies? What is the added value of simultaneous multi-frequency acquisitions?
  - How important are repeat-pass interferometric observables?
  - How critical are quad- / dual-polarimetric measurements?
- ➔ What are the SAR applications that have an unquestionable added value with respect to other non-SAR techniques? Which new applications are suitable for commercialisation?
- ➔ What is the importance of Ku- and Ka-band SAR measurements for the development/improvement of applications? Which applications have the potential to profit the most?
- ➔ What are potential new bio- and geophysical products that can be derived from either tomographic SAR measurements or through exploiting multi-static SAR geometries?
- ➔ What applications would mostly profit from a combined use of space-borne optical remote sensing data with SAR data? What is the complementary nature of such a combination?
- ➔ To what extent are new machine learning algorithms able to complement EM modelling and inversion practices?

TABLE OF CONTENT

Welcome .................................................. 2
Quick View .............................................. 3
General Information ................................ 4
How to reach DLR .................................... 5
Program .................................................. 7
Tutorial Abstracts .................................. 14
Ice & Snow Abstracts ............................. 18
Soil & Hydrology Abstracts ..................... 27
Forest Abstracts ..................................... 35
Agriculture Abstracts ............................. 53
General Land Use Abstracts.................... 60

**BioGeoSAR-18 organizing committee**

Björn Rommen, ESA-ESTEC
Konstantinos Papathanassiou, DLR-HR
Sandra Reigber, DLR-HR

| | am | | | | | | | | | pm | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 08:30 | 09:00 | 09:30 | 10:00 | 10:30 | 11:00 | 11:30 | 12:00 | 12:30 | 13:00 | 13:30 | 14:00 | 14:30 | 15:00 | 15:30 | 16:00 | 16:30 | 17:00 | 17:30 | 18:00 | 18:30 | 19:00 |
| Monday, 12th Nov. | | | | | Regis-tration | The role of remote sensing products in hydrologic modelling | | | Lunch Break | | | Assimilation of SAR data for land applications | | | Coffee Break | Linking remote sensing and vegetation modelling | | | | | | |
| Tuesday, 13th Nov. | Welcome | Snow and Ice | | Coffee Break | Snow and Ice | | | | Discussion | Lunch Break | | Soil & Hydrology | | Coffee Break | Soil & Hydrology | | | Discussion | Break | Future Perspectives of SAR Systems and Missions | | |
| Wednesday, 14th Nov. | Forest Session I | | | Coffee Break | Forest Session I | | | | Lunch Break | | | Forest Session II | | | Coffee Break | Forest Session II | | Discussion | | Dinner | | |
| Thuersday, 15th Nov. | Agriculture | | | Coffee Break | Agriculture | Discussion | General Land Use | | Lunch Break | | General Land Use | | | Discussion & Coffee Break | Review & Closing Discussion | | | | | | | |

| | |
|---|---|
| Tutorials | |
| Oral Talks | |
| Round Table Discussions | |
| Dinner (for registered participants only) | |

**General workshop information**

The BioGeoSAR workshop will take place November, 13-15 from 8.30 am to 6.00 pm in building 112 at the DLR site in Oberpaffenhofen, Germany.

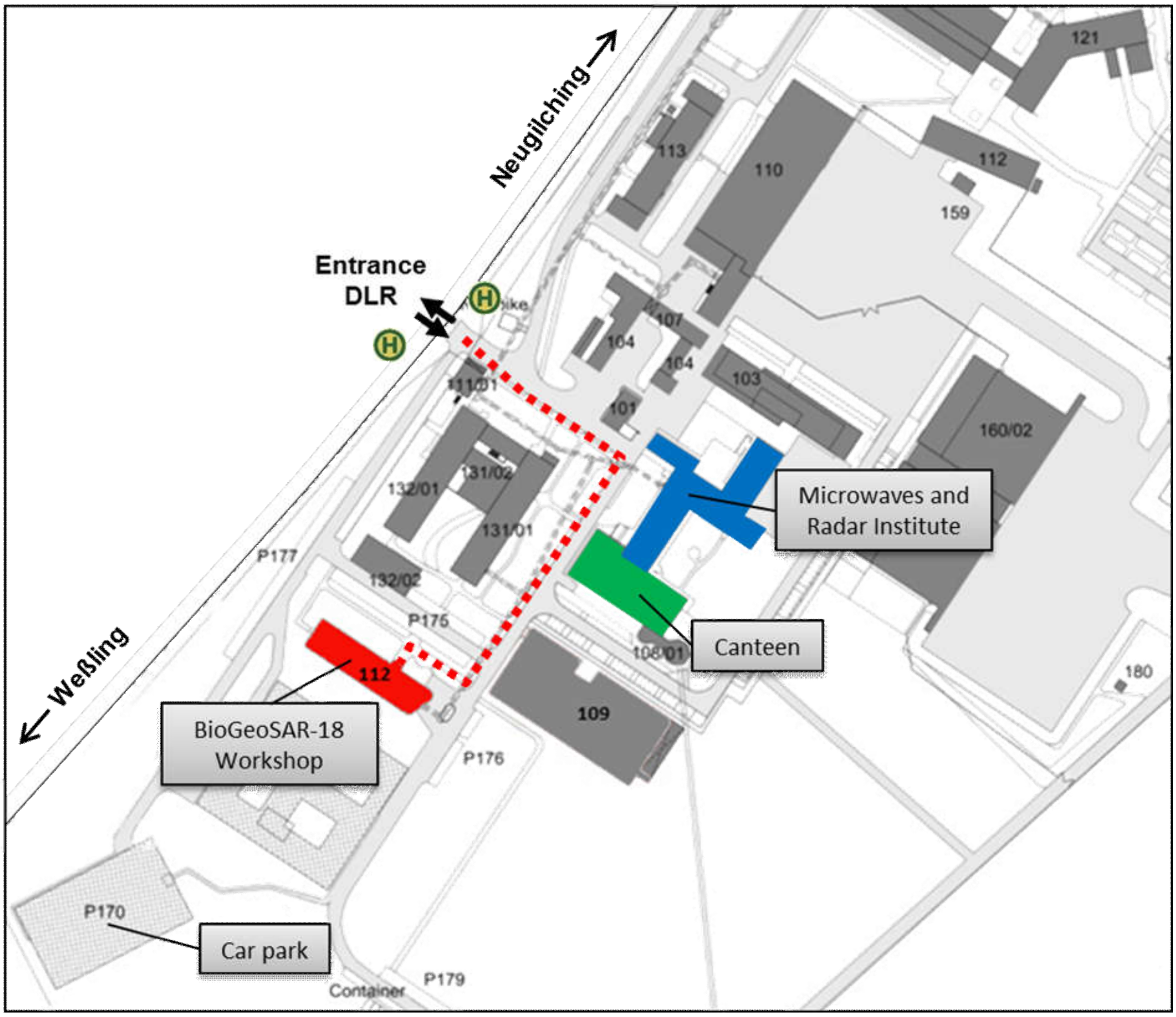
Lunch is not provided by the organizers and can be taken in the cafeteria in building 102.
On Wednesday evening you will have the opportunity to participate in our welcome dinner. The restaurant easily accessible by public transportation. If you would like to attend the dinner, please contact Sandra Reigber (sandra.reigber@dlr.de) for registration, no later than October 26.

**Tutorial courses**

Most of the tutorial courses will be held Monday, November12. The first tutorial starts at 9.30 am (see agenda) also in building 112 . On Tuesday evening Gerhard Krieger will give a tutorial about...

**Registration at the DLR site**

Upon arrival at the DLR site you will have to registered at the entrance gate. Please bring a valid identity with you. You will receive your guest card which you must carry during your stay on the premises of DLR. You will find your conference badges at the entrance of the workshop in building 112, 3rd floor.



**Possible connections to DLR in Oberpfaffenhofen (OP) by public transport** (approx. arrival time 8:15)

*Munich Central Station to DLR-OP. [Single-Ticket: Einzelfahrt Erwachsene (2 Zonen) -> 5:80 €]*

*1.*

| Time | | Departure | Arrival | Direction |
|---|---|---|---|---|
| **7:05** | | S8 Central station (tunnel, platform 2) | Neugilching (platform 2) | Herrsching |
| 7:38 | | Neugilching (platform 2) | Neugilching (bus stop) | |
| 7:44 | | MVV 947 Neugilching | Oberpfaffenhofen, DLR | Weßling (S) |
| **7:52** | | Oberpfaffenhofen, DLR | | |

*2.*

| | | | | |
|---|---|---|---|---|
| **7:25** | | S8 Central station (tunnel, platform 2) | Weßling (platform 2) | Herrsching |
| 8:01 | | Weßling (platform 2) | Weßling (bus stop) | |
| 8:10 | | ExpressBus X910 | Oberpfaffenhofen, DLR | Klinikum Großhadern |
| **8:15** | | Oberpfaffenhofen, DLR | | |

*Munich, Pasing to DLR-OP. [Single-Ticket: Einzelfahrt Erwachsene (2 Zonen) -> 5:80 €]*

*1.*

| | | | | |
|---|---|---|---|---|
| **7:17** | | S8 Pasing (platform 7/8) | Neugilching (platform 2) | Herrsching |
| 7:38 | | Neugilching (platform 2) | Neugilching (bus stop) | |
| 7:44 | | MVV 947 Neugilching | Oberpfaffenhofen, DLR | Weßling (S) |
| **7:52** | | Oberpfaffenhofen, DLR | | |

*2.*

| | | | | |
|---|---|---|---|---|
| **7:37** | | S8 Pasing (platform 7/8) | Weßling (platform 2) | Herrsching |
| 8:01 | | Weßling (platform 2) | Weßling (bus stop) | |
| 8:10 | | ExpressBus X910 | Oberpfaffenhofen, DLR | Klinikum Großhadern |
| **8:15** | | Oberpfaffenhofen, DLR | | |

*Herrsching to DLR-OP [Single-Ticket: Einzelfahrt Erwachsene (2 Zonen) -> 5:80 €]*

*1.*

| | | | | |
|---|---|---|---|---|
| **7:25** | | S8 Herrsching (platform 1/2) | Weßling (platform 2) | Flughafen München |
| 7:36 | | Weßling (platform 2) | Weßling (bus stop) | |
| 7:40 | | ExpressBus X910 | Oberpfaffenhofen, DLR | Klinikum Großhadern |
| **7:45** | | Oberpfaffenhofen, DLR | | |

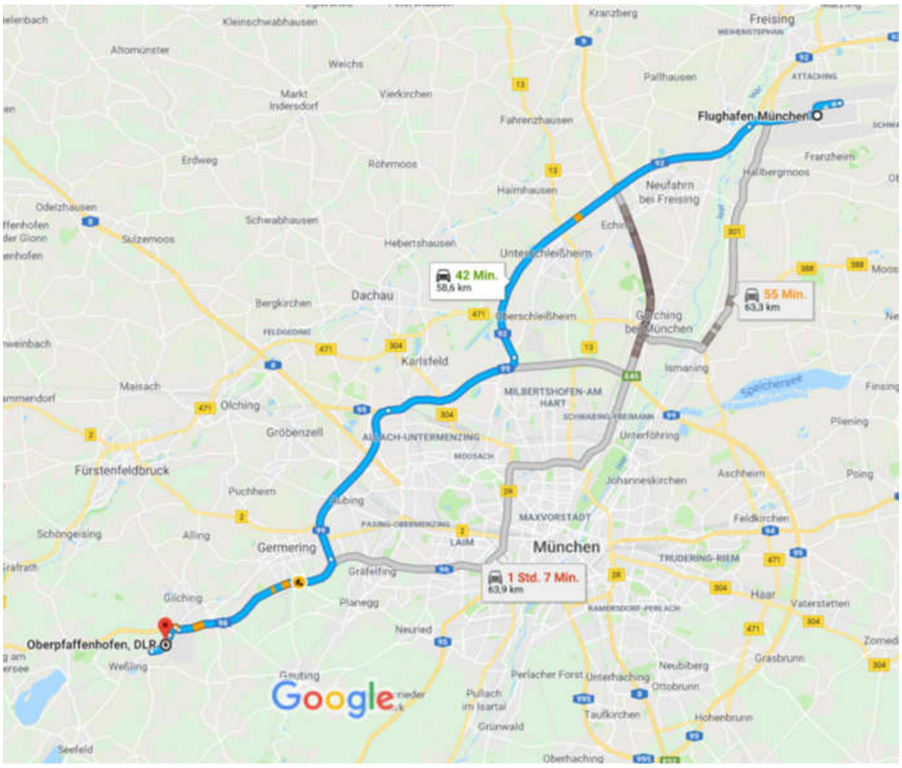
*2.*

| | | | | |
|---|---|---|---|---|
| **7:45** | | S8 Pasing (platform 7/8) | Weßling (platform 2) | Herrsching |
| 7:56 | | Weßling (platform 2) | Weßling (bus stop) | |
| 8:10 | | ExpressBus X910 | Oberpfaffenhofen, DLR | Klinikum Großhadern |
| **8:15** | | Oberpfaffenhofen, DLR | | |

If you need more information about your journey, tickets etc., please have a look at https://efa.mvv-muenchen.de/ or use the Android App Öffi which you can download in the google playstore.

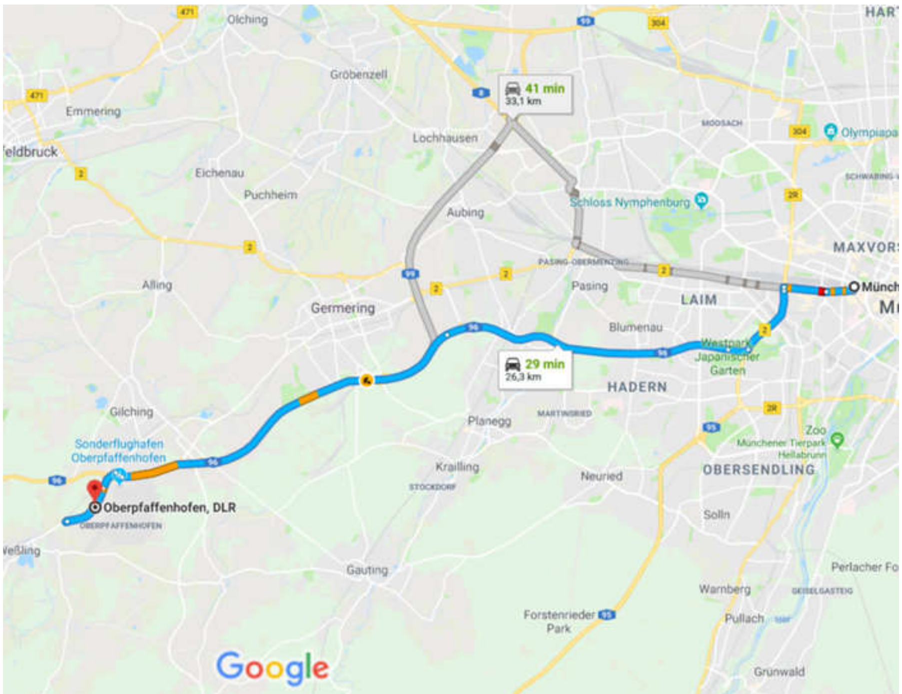
If you arrive by car, please register at the gate of the DLR campus and park your car in the multi-storey car park (see map on the page general information)

**How to reach DLR from Munich Airport by car**




- Munich International Airport Nordallee
- Continue to Freising
- Follow A92, A99 and A96 direction Lindau
- Take exit 32-Oberpfaffenhofen from A96
- Turn left onto Landsberger Str. until DLR campus (2nd traffic light)
- Destination will be on the left site

**How to reach DLR from Munich Central Station by car**




- Get on A96 from Landsberger Str. and B2/B2R10 min
- Follow A96 to exit Ober-pfaffenhofen
- Take exit 32-Oberpfaffenhofen from A96
- Turn left onto Landsberger Str. until DLR campus (2nd traffic light)
- Destination will be on the left site

**Monday November 12th, 2018**

| | |
|---|---|
| **Tutorials** | |
| 10:30 | **Registration** |
| 11:00 | **Tutorial I: The role of remote sensing products in hydrologic modelling**<br>*Luis Samaniego – Centre for Environmental Research UFZ* |
| **12:30** | **Lunch Break** |
| 14:00 | **Tutorial II: Assimilation of SAR data for land applications**<br>*Susan Steele-Dunne – Technical University Delft* |
| **15:30** | **Coffee Break** |
| 16:00 | **Tutorial III: Linking remote sensing and vegetation modelling**<br>*Andreas Huth – Centre for Environmental Research UFZ* |

**Tuesday November 13th, 2018**

| | |
|---|---|
| 08:30 | **Welcome to the BioGeoSAR-18 Workshop** |
| **09:00 – 13:00** | **Snow & Ice Session** |
| 09:00 | **TanDEM-X and TerraSAR-X for the mass balance of the Patagonian calving glaciers**<br>***Dana Floricioiu**, Wael Abdel Jaber, Erling Johnson – German Aerospace Center; Helmut Rott – ENVEO IT* |
| 09:20 | **Surface elevation change of outlet glaciers in NE Greenland from TanDEM-X and Cryosat-2** |
| 09:40 | **X-Band SAR Signal Penetration and Interferometric Bias in Antarctic Snow**<br>*Helmut Rott, Stefan Scheiblauer – ENVEO IT; **Dana Floricioiu**, Lukas Krieger, Paola Rizzoli – German Aerospace Center; Jan* |
| 10:00 | **Wet snow depth from TanDEM-X single pass InSAR DEM Differencing**<br>***Silvan Leinss** – ETH Zurich; Oleg Antropov – Aalto University; Juho Vehviläinen, Juha Lemmetyinen – Finnish Meteorological* |
| **10:20** | **Coffee Break** |
| 10:50 | **Advancements in Snow Cover Monitoring Based on Synergy of Sentinel-1 SAR and Sentinel-3 SLSTR Data**<br>***Thomas Nagler**, Helmut Rott, Joanna Ossowska, Gabriele Schwaizer – ENVEO IT GmbH; David Small – University of Zurich; Eirik Malnes – NORUT; Kari Luojus, Sari Metsaemaeki – Finnish Meteorological Institute; Simon Pinnock – ESA Climate Office* |
| 11:10 | **snow: modeling vs. field measurements: chances and challenge**<br>***Silvan Leinss** – ETH Zurich* |
| 11:30 | **Analysis of Multi-Frequency Polarimetric SAR Data Across Different Ice Zones of Greenland**<br>***Giuseppe Parrella**, Konstantinos Papathanassiou – German Aerospace Center; Irena Hajnsek – ETH Zurich / German Aerospace Center* |
| 11:50 | **Time series of high-res vertical snow profiles obtained from tomographic profiling using SnowScat**<br>***Othmar Frey** – Gamma Remote Sensing / ETH Zurich; Charles Werner, Rafael Caduff, Andreas Wiesmann – GAMMA Remote* |
| 12:10 | **Recent Advances Towards Glacier Subsurface Information Retrieval by Means of Tomographic SAR Techniques**<br>***Georg Fischer**, Konstantinos Papathanassiou – German Aerospace Center; Irena Hajnsek – German Aerospace Center/ETH Zurich* |
| 12:30 | **Discussion** |
| **13:00** | **Lunch Break** |

**Tuesday November 13th, 2018**

| | |
|---|---|
| **14:00 – 17:40** | **Soil & Hydrology Session** |
| 14:00 | **Surface Moisture and Vegetation Cover Analysis for Drought Monitoring in the southern Kruger National Park using Sentinel-1, Sentinel-2 and Landsat-8**<br>***Marcel Urban***, *Christian Berger – Friedrich-Schiller-University Jena; Tami E. Mudau – Council for Scientifc and Industrial Research; Kai Heckel, John Truckenbrodt, Victor Onyango Odipo – Friedrich-Schiller-University Jena; Izak P.J. Smit – Scientifc Services, South African National Parks; Christiane Schmullius - Friedrich-Schiller-University Jena* |
| 14:20 | **Hyper-temporal Water Body Dynamics Mapping using Sentinel-1 Time Series Clustering**<br>*John Truckenbrodt, Victor Onyango Odipo, Jan Bongard, Stefan Werner, Marcel Urban,* ***Mikhail Urbazaev****, Christiane Schmullius – Friedrich-Schiller-University Jena; Kathrin Weise - Jena-Optronik GmbH* |
| 14:40 | **Validation activity of a Sentinel-1 Soil Moisture product**<br>***Francesco Mattia***, *Anna Balenzano, Giuseppe Satalino, Francesco Lovergine – CNR-IREA; Jian Peng – LMU University & Oxford University; Urs Wegmuller, Oliver Cartus – Gamma Remote Sensing; Malcolm Davidson - ESA-ESTEC* |
| 15:00 | **SenThIS – A project for generating information from Copernicus Sentinel satellite data for the administration of the Free State of Thuringia: The application case soil moisture.**<br>***Carsten Pathe***, *Max Tobaschus, Martyna Stelmaszczuk-Górska – Earth Observation Services GmbH; Christiane Schmullius – Friedrich-Schiller University Jena; Peter Krause, Sandra Naue – Turingian State Agency of Environment and Geology* |
| **15:20** | **Coffee Break** |
| 15:50 | **Soil moisture retrieval over Europe based on a fusion of Sentinel-1 and SMAP data implemented in the Google Earth Engine platform**<br>***Jan Musial*** *– Institute of Geodesy and Cartography* |
| 16:10 | **Performance analysis of different SAR radiative transfer models for soil moisture estimation over the a test site in south Germany**<br>***Thomas Weiß***, *Thomas Ramsauer, Philip Mahrzahn – Ludwig-Maximilians-Universität München* |
| 16:30 | **Use of SAR-derived surface soil moisture to initialize the WRF model: effect on the forecast of two extreme weather events occurred in the Mediterranean region**<br>***Luca Pulvirenti***, *Martina Lagasio, Antonio Parodi, Lorenzo Campo – CIMA Research Foundation; Nazzareno Pierdicca – Sapenza University of Rome; Björn Rommen – ESA-ESTEC* |
| 16:50 | **Water status inversion from SAR closure phases**<br>***Francesco de Zan***, *Giorgio Gomba – German Aerospace Center* |
| 17:10 | **Discussion** |
| **17:40** | **Break** |
| 18:10 | **Tutorial IV: Future Perspectives of SAR Systems and Missions**<br>***Gerhard Krieger*** *– German Aerospace Center* |

**Wednesday November 14th, 2018**

| | |
|---|---|
| **08:30 – 12:30** | **Forest Session I** |
| 08:30 | **Experiences on biomass retrieval with spaceborne SAR backscatter at C- and L-band in Swedish forest**<br>***Maurizio Santoro****, Oliver Cartus – GAMMA Remote Sensing; Johan Fransson – Swedish University of Agricultural Sciences* |
| 08:50 | **Exploiting multi-temporal and multi-frequency radar backscatter for above-ground biomass estimation in boreal and tropical forest**<br>***Oliver Cartus****, Maurizio Santoro, Urs Wegmuller - GAMMA Remote Sensing; Björn Rommen – ESA-ESTEC* |
| 09:10 | **Forest Mapping exploiting Sentinel-1 interferometric time-series**<br>***Francescopaolo Sica****, Andrea Pulella, Paola Rizolli – German Aerospace Center* |
| 09:30 | **Potential of Sentinel-1 time series for deforestation and forest degradation mapping in temperate and tropical forests**<br>***Mikhail Urbazaev****, Felix Cremer, Christiane Schmullius, Christian Thiel – Friedrich-Schiller-University Jena* |
| 09:50 | **Biomass with InSAR**<br>***Svein Solberg*** *– Norwegian Institute of Bioeconomy Research* |
| **10:10** | **Coffee Break** |
| 10:40 | **A Case for Polarimetric Phase: Dielectric Constant in Volume Scattering**<br>***Shane Cloude*** *– AEL Consultants* |
| 11:00 | **A Machine Learning Approach to PolInSAR and LiDAR Data Fusion for Improved Tropical Forest Canopy Height Estimation Using NASA AfriSAR Campaign Data**<br>***Maryam Pourshamsi*** *– University of Leicester; Mariano Garcia – University of Alcala; Marco Lavalle – Jet Propulsion Laboratory; Heiko Balzter – Centre for Landscape and Climate Research* |
| 11:20 | **Retrieval of Forest biophysical parameters using L-band airborne multi-baseline UAVSAR datasets**<br>***Shubham Awasthi****, Kamal Jain – Indian Institute of Technology Roorkee* |
| 11:40 | **TropiScat-2: A multifrequency tower-based scatterometer experiment at P,L,C bands for a better characterization of temporal effects impacting tropical forests backscatter**<br>***Salma El Idrissi Essebtey*** *– ONERA/CESBIO; Ludovic Villard - CESBIO; Thierry Koleck - CNES; Pierre Borderies - ONERA; Thuy le Toan - CESBIO* |
| 12:00 | **Insights on temporal decorrelation from the AfriScat campaign: implications for the BIOMASS mission and beyond**<br>***Ludovic Villard*** *– CESBIO; Alia Hamadi – ONERA/CESBIO; Pierre Borderies – ONERA; Salma El Idrissi Essebtey – ONERA/CESBIO; Thierry Koleck – CNES; Thuy le Toan – CESBIO* |
| **12:30** | **Lunch Break** |

**Wednesday November 14th, 2018**

| | |
|---|---|
| **14:00 – 18:00** | **Forest Session II** |
| 14:00 | **Forest remote sensing in Sweden**<br>***Henrik Persson**, Johan Fransson – Swedish University of Agricultural Sciences* |
| 14:20 | **Retrieval of terrain topography in tropical forest by P-Band SAR Tomography**<br>*Mauro Mariotti d´Alessandro, **Stefano Tebaldini** – Politecnico di Milano* |
| 14:40 | **TomoSAR Focusing Through Statistical Regularization: A Way to Ease the Characterization of the Forest Structure**<br>***Gustavo D. Martín del Campo Becerra**, Andreas Reigber, Matteo Nannini – German Aerospace Center* |
| 15:00 | **P-Band Interferometry and Tomography for tropical forest parameters retrieval: lessons learned from BIOMASS preparatory studies**<br>***Stefano Tebaldini**, Mauro Mariotti d´Alessandro– Politecnico di Milano* |
| 15:20 | **Towards a Physical Interpretation of SAR Tomography for Forest Structure Estimation**<br>***Victor Cazcarra-Bes**, Matteo Pardini, Konstantinos Papathanassiou - German Aerospace Center* |
| **15:40** | **Coffee Break** |
| 16:10 | **An assessment of the contribution of multiple frequencies to the observation of 3-D forest structure by means of multi-baseline SAR data**<br>***Matteo Pardini**, Victor Cazcarra-Bes, Konstantinos Papathanassiou – German Aerospace Center* |
| 16:30 | **Ground and Volume Scattering Decomposition: The Pol-InSAR Perspective**<br>***Konstantinos Papathanassiou**, Matteo Pardini – German Aerospace Center* |
| 16:50 | **Understanding the link between Lidar and SAR measurements towards enhanced forest structure products: The model-based and the structure-based frameworks**<br>*Matteo Pardini – German Aerospace Center; John Armston – University of Queensland; Wenlu Qi – University of Maryland; Seung Kuk – NASA/GSFC; **Changhyun Choi**, Victor Cazcarra-Bes, Maria Tello Alonso, Konstantinos Papathanassiou – German Aerospace Center; Ralph Dubayah – University of Maryland; Lola Fatoyinbo - NASA/GSFC* |
| 17:10 | **Discussion** |
| **18:00** | **Dinner** |

**Thursday November 15th, 2018**

| 08:30 – 11:50 | Agriculture Session |
|---|---|
| 08:30 | **Identification of Soil Tillage Change by Temporal Series of Sentinel-1 & Sentinel-2**<br>***Giuseppe Satalino*** *– CNR-IREA; Francesco Mattia – CNR/ISSIA; Anna Balenzano, Francesco Lovergine – CNR-IREA; Michele Rinaldi, Angelo De Santis, Salvatore A. Colecchia – CREA-CI* |
| 08:50 | **Synergistic use of Sentinel-1 and Sentinel-2 data for the retrieval of bio- and geophysical parameters using a data assimilation approach**<br>***Philip Marzahn*** *– Ludwig-Maximilians-Universität Munich; Thomas Kaminski, Michael Vossbeck – The InversionLab; Tristan Quaife, Ewan Pinnington – University of Reading; Joris Timmermans – University College London; Björn Rommen, Claudia Isola – ESA-ESTEC* |
| 09:10 | **Using Sentinel-1 in Agricultural Applications - A case study in the Netherlands**<br>**Susan Steele-Dunne** – TU-Delft |
| 09:30 | **Potential of Sentinel-1 time-series for crop monitoring and disturbance mapping in Thuringia**<br>***Linara Arslanova****, Nesrin Salepci, Marcel Urban, Felix Cremer – Friedrich-Schiller-University Jena; Carsten Pathe – Earth Observation Services GmbH; Larissa Torney, Christiane Schmullius – Friedrich-Schiller-University Jena* |
| 09:50 | **Separating Ground and Volume Scattering in Agricultural Crops using MB Polarimetric Interferometric SAR Data**<br>***Hannah Joerg****, Matteo Pardini, Alberto Alonso-Gonzales, Konstantinos Papathanassiou – German Aerospace Center; Irena Hajnsek - German Aerospace Center/ETH Zurich* |
| **10:10** | **Coffee Break** |
| 10:40 | **Automated time-series analysis integrating optical and SAR based biophysical indices for agricultural applications**<br>*Neha Pankaj Hunka,* ***Jana Slacikova****, Lubos Kucera – GISAT s.r.o.* |
| 11:00 | **Evaluation of the double-bounce contribution in the retrieval of biophysical parameters of vegetation using Pol-InSAR with TanDEM-X bistatic data**<br>***Noelia Romero-Puig****, Juan M. Lopez-Sanchez, J. David Ballester-Berman – University of Alicante* |
| 11:20 | **Discussion** |

**Thursday November 15th, 2018**

| | |
|---|---|
| **11:50 – 15:40** | **General Land Use Session** |
| 11:50 | **Advanced Sentinel-1 Analysis Ready Data for the Ghana Open Data Cube and Environmental Monitoring**<br>***Jörg Haarpaintner*** *– Norut-Northern Research Institute; Brian Killough – NASA-CEOS; Stella Ofori-Ampofo, Edward O. Boamah – CERSGIS* |
| 12:10 | **Demonstrations of Wide-area Radar Backscatter Time Series Applications**<br>***David Small****, Christoph Rohner - University of Zurich; Nuno Miranda – ESA-ESRIN; Stephen Howell – Environment and Climate Change Canada; Marius Rüetschi, Lars Waser – Swiss Federal Institute for Forest, Snow and Landscape Research WSL* |
| **12:30** | **Lunch Break** |
| 13:30 | **Use of L-band polarimetric data to classify flooded areas beneath vegetation**<br>***Nazzareno Pierdicca*** *– Sapienza University of Rome; Luca Pulvirenti, Giorgio Boni, Giuseppe Squicciarino – CIMA Research Foundation; Marco Chini – Luxembourg Institute of Science and Technology* |
| 13:50 | **SInCohMap: Land Cover Classification and Vegetation Mapping based on Sentinel-1 Multi-Temporal Interferometric Coherence**<br>*Fernando Vicente-Guijalba - Dares Technology; Alexander Jakob – Eurac Research; Juan Manuel Lopez-Sanchez – University of Alicante;* ***Carlos López-Martínez*** *– Luxembourg Institute of Science and Technology); Dariusz Ziółkowski – IGIK; Claudia Notarnicola – Eurac Research; Javier Duro – Dares Technology; Ruth Sonnenschein – Eurac Research; Agata Hoscilo, Katarzyna Dąbrowska, Zbigniew Bochenek – IGIK; Jordi J. Mallorqui – Universitat Poltecnica de Catalunya; Erik Pottier – Universite de Rennes 1; Marco Lavalle – JPL; Marcus Engdahl – ESA-ESRIN* |
| 14:10 | **Land observations with L-band bistatic systems**<br>***Leila Guerriero*** *– University of Rome Tor Vergata;* ***Nazzareno Pierdicca*** *– Sapienza University of Rome; Marco Brogioni – IFAC-CNR; Davide Comite, Fabio Fascetti – Sapienza University; Nicolas Floury – ESA-ESTEC* |
| 14:30 | **Improved multi satellite retrieval by combining SAR with Optical observations - The MULTIPLY framework**<br>***Joris Timmermans****, Peter van Bodegom – Leiden University; Philip Marzahn, Thomas Weiss, Thomas Ramsauer – Ludwig-Maximilians-Universität Munich; Jose Gomez Dans, Feng Yin - University College London; Tonio Fincke – brockmann consulting; Nicola Pounder, Gerardo Lopes Saldana – Assimila* |
| 14:50 | **Multi-temporal approach for the detection of temporary flooded vegetation based on Sentinel-1 data**<br>***Viktoriya Tsyganskaya*** *– Ludwig-Maximilians-Universität Munich; Sandro Martinis – German Aerospace Center; Philip Marzahn - Ludwig-Maximilians-Universität Munich* |
| **15:10** | **Coffee Break & Discussion** |
| 15:40 | **Review of the BioGeoSAR workshop** |

# Modeling Dominant Hydrological Land Surface Processes with the Mesoscale Hydrologic Model

Luis Samaniego

*Centre for Environmental Research (UFZ)*

## Abstract

In this talk, I will introduce the audience to the Mesoscale Hydrologic Model (www.ufz.de/mhm), its main characteristics, and provide potential practical applications. Special emphasis will be given to the interaction and dependence of the model with remotely sensed products either as a source of input data or as means for the verification of simulated model states.

The Mesoscale Hydrologic Model (www.ufz.de/mhm) is a spatially explicit distributed hydrologic model that uses grid cells as a primary hydrologic unit, and accounts for the following processes: canopy interception, snow accumulation and melting, soil moisture dynamics, infiltration and surface runoff, evapotranspiration, subsurface storage and discharge generation, deep percolation and baseflow, as well as, flood routing. mHM is driven by hourly or daily meteorological forcings (e.g., at least precipitation, temperature), and it utilizes observable basin physical characteristics (e.g., soil textural, land cover, LAI, and geological properties) to infer the spatial variability of the required parameters.

Interested readers may refer to Samaniego et al. WRR 2010; Samaniego et al. HESS 2017; Rakovec et al. JHM 2016; Rakovec et al. WRR 2016; Zink et al. WRR 2018 (among others) for further information.

# Assimilation of SAR data for land applications

Susan Steele-Dunne
*University Delft*

**Abstract**

Data assimilation has evolved from its roots in oceanic and meteorological sciences to become a popular, and increasingly accessible tool in the earth sciences. In the past 20 years, ensemble and particle techniques have been widely used to constrain modeled estimates of soil moisture, snow water equivalent, LAI in a wide range of applications.

This tutorial will start with an overview of the different assimilation techniques and some examples in which data from across the EM spectrum have been assimilated to constrain land surface states and parameters.

We will discuss the key components of a data assimilation framework, and identify the challenges associated with each of them in the context of SAR assimilation. We will address the following questions: (1) What is the current state of the art in terms of the assimilation of SAR data in key applications of social and economic benefit? (2) What role could data assimilation play in accelerating the operational use of SAR data in these key applications? (3) What is the added value of using assimilation as a tool to integrate SAR and other EO data?

# Linking remote sensing and vegetation modelling

Andreas Huth[1,2,3], Edna Rödig[1], Rico Fischer[1], Franziska Taubert[1], Nikolai Knapp[1]

*[1] Centre for Environmental Research (UFZ), [2] German Centre for Integrative Biodiversity Research,*

*[3] University of Osnabrück*

**Abstract**

The presentation will cover several examples how remote sensing measurements can be combined with vegetation models. Aim is to show the benefit of linking remote sensing and ecological models. Such methods allow to derive import additional vegetation attributes (e.g. forest productivity, carbon balance) which are difficult to quantify from remote sensing measurements alone.

Precise descriptions of forest productivity, biomass, and structure are essential for the role of forests in the global carbon balance. We developed an approach to simulate carbon dynamics of around 410 billion individual trees within 7.8 Mio km² of Amazon rainforest. We integrated remote sensing observations on forest height (here from Lidar) in order to detect different forest states and structures caused by small-scale to large-scale natural and anthropogenic disturbances. Under current conditions, we identified the Amazon rainforest as a carbon sink, gaining 0.56 Gt C per year. This carbon sink is driven by an estimated mean gross primary production (GPP) of 25.1 tC /(ha a), and a mean woody aboveground net primary production (wANPP) of 4. 1 tC /(ha a). We found that forest structure has a substantial impact on productivity and biomass. It is an essential factor that should be taken into account when estimating current carbon budgets for forests.

Other topics will be horizontal, vertical forest structure and forest fragmentation and how this information on this can be derived from remote sensing.

# Future Perspectives of SAR Systems and Missions

Gerhard Krieger

*German Aerospace Center (DLR)*

**Abstract**

Coming soon

# TanDEM-X and TerraSAR-X for the mass balance of the Patagonian calving glaciers

Dana Floricioiu[1], Wael Abdel Jaber[1], Erling Johnson[1], Helmut Rott[2]

*[1] German Aerospace Center; [2] ENVEO IT*

## Abstract

Glaciers are responding rapidly to climate change and are likely to be the second largest contributor to sea level rise over the 21st century. However there are large uncertainties in the mass balance estimation in particular for calving glaciers, the main contributors to ice loss in certain climatic sensitive areas. In order to understand and develop realistic scenarios for glacier depletion, spatial detailed information on the surface elevation change is needed. In addition, an estimation of the individual components of the glacier mass balance contributes to a better comprehension of thinning or thickening.

In the present work we are using multitemporal bistatic TanDEM-X datasets acquired over the South Patagonia Icefield to provide time series of ice surface elevation. We are focusing on several of the major outlet glaciers to complement the information on ice thickness change over entire basins with the ice loss due to calving at the terminus in the same period of 1 to 4 years. The calving flux can be estimated from frontal retreat and terminus velocity derived from TerraSAR-X repeat pass acquisitions as well as bathymetry data at the front. The ice elevation changes from TanDEM-X integrated over the glacier surface can be converted into mass change in the time interval between the DEM data acquisitions. The comparison of the total mass change and mass loss due to calving gives insights into how realistic the surface mass balance values resulted from modelling are.

# Surface elevation change of outlet glaciers in NE Greenland from TanDEM-X and Cryosat-2

Lukas Krieger[1], Undine Strößenreuther[2], Dana Floricioiu[1]

*[1] German Aerospace Center, [2] TU Dresden*

**Abstract**

The geodetic mass balance is a method to describe the development of glaciers or ice sheets without the need for modelling of precipitation and melting. The measurement is based on changes in surface elevation that occur over the entire area attributed to a single glacier or sector of an ice sheet. Most recent geodetic mass balance measurements on ice sheets have been performed with laser and radar altimeters. These sensors offer the advantage of a coarse, but complete coverage over the vast regions of ice sheets with a high number of repeating acquisitions. However, space-borne altimeters have a worse performance in areas with steeper slopes at the margins of the ice sheet than over the flat interior.

The TanDEM-X mission (TDM) provides a different possibility to obtain temporally spaced elevation measurements. With the twin satellite constellation we are able to generate DEMs for a region of interest from bistatic InSAR acquisitions. Due to the swath width of approx. 30 km there are only a limited number of scenes available for each location. Especially for the flat ice sheet interior, the acquisitions from 2010/2011 and 2011/2012 are too close in time to capture surface elevation change (SEC) within the accuracy of the instrument. However, during the effort to create a global high resolution DEM with TDM, additional coverages of the margin of the Greenland Ice Sheet have been acquired in 2013/2014.

We combine the SEC measured with the SIRAL instrument on the Cryosat-2 (CS-2) radar altimeter together with DEM differencing of InSAR DEMs from TanDEM-X in the time period of winter 2010/11 to winter 2013/2014. The sensors complement each other in the way that TDM measurements are used at regions of interest at the margin of the Northeast Greenland Ice Sheet. The SAR mode of CS-2 is utilised for the remaining area. This ensures high resolution maps of SEC where dynamic processes are expected on the glacier termini. At the same time, a complete coverage of entire drainage basins or sectors can be achieved. Additionally, the signal penetration at the dry snow zone of the ice sheet interior is kept minimal by using retracking procedures during the CS-2 processing.

To identify the area over which SEC is integrated to calculate volume change, a method has been developed to generate individual drainage basins for outlet glaciers. This approach employs a modified watershed algorithm, that uses the TDM global DEM as source of slope information and takes ice surface flow directions into account for areas moving faster than 20 m/a.

# X-Band SAR Signal Penetration and Interferometric Bias in Antarctic Snow

Helmut Rott[1], Stefan Scheiblauer[1], Dana Floricioiu[2], Lukas Krieger[2], Paola Rizzoli[2], Jan Wuite[1], Thomas Nagler[1]

*[1] ENVEO IT, [2] German Aerospace Center*

**Abstract**

Digital elevation models, derived from single-pass interferometric SAR (SP-InSAR) data, are a main source for mapping surface elevation and its temporal change over ice sheets and glaciers. SPInSAR data are not affected by temporal decorrelation and variations in atmospheric delay, but effects of signal penetration have to be taken into account. The apparent surface for uncorrected InSAR elevation data refers to the position of the scattering phase centre in the snow and ice volume. Main factors determining the phase centre depth are the position and strength of scattering sources and the losses due to absorption and scattering. The absorption losses can be estimated from dielectric properties which depend on snow density and temperature. The scattering sources and losses can be highly variable, depending on snow microstructure and stratification. We report results of a field study and radar signal propagation modelling in order to assess the factors governing signal penetration and to evaluate the related bias in surface elevation. We performed field measurements on snow structure and stratigraphy on Union Glacier in the Ellsworth Mountains, West Antarctica. The study area comprises ice-free surfaces, bare ice (blue ice), and cold snow and firn with a variety of structural features. Differences in exposure to wind are a main factor for local variations in the accumulation rate and in structural properties of the snow/firn volume. The satellite data base comprises X-band SAR data of the TanDEM-X mission, including amplitude images, SP-InSAR coherence images, across-track interferograms and DEMs, acquired between 2013 and 2017. Several repeat-pass lidar tracks of the ICESat mission crossed the area between 2002 and 2009. These data show very little temporal change of surface elevation so that the ICESat topography can be used as reference. Precise vertical co-registration of the TDM DEMs and ICESat elevation is performed over targets for which the volume scattering contribution is negligible, including bare ground and the blue ice field. In order to assess the impact of snow structure and stratification on signal penetration we performed backscatter modelling for the different field sites using a multi-layer dense media radiative transfer (DMRT) model with the Quasi-Crystalline Approximation (QCA). This shows the dominating backscatter contribution coming from the top 2 m to 3 m and large variations with depth depending on snow metamorphic state. The inversion of this model provides a good estimate of penetration depth. We tested also the feasibility for inverting TanDEM-X backscatter and coherence data with single layer radar propagation models. The single layer approach provides a reasonable estimate of penetration depth and InSAR elevation bias, but shows a trend for overestimating the total span. Tis can be explained by the typical stratification of the snow/firn medium which accounts for enhanced backscatter contributions of the top snow layers. Even so, backscatter and coherence signals can be used as indicator for detecting changes in penetration. In case of temporally stable signals penetration corrections are not required for deriving glacier surface elevation change (SEC) from SP-InSAR repeat DEMs. This is confirmed by the good agreement of multi-year SEC products from coincident airborne lidar and TanDEM data over Antarctic Peninsula glaciers.

# Wet snow depth from TanDEM-X single pass InSAR DEM Differencing

Silvan Leinss[1], Oleg Antropov[2], Juho Vehviläinen[3], Juha Lemmetyinen[3], Irena Hajnsek[1,4]
Jaan Praks[1]

*[1] ETH Zurich, [2] Aalto University, [3] Finnish Meteorological Institute, [4] German Aerospace Center*

## Abstract

Single pass radar interferometry (sp-InSAR) is a well-established technique for generation of digital elevation models (DEM). Differencing two DEMs acquired at different times can reveal topographic changes. However snow depth estimation by DEM differencing is still an ongoing topic in radar research: in contrast to snow free surfaces, the snow surface elevation is difficult to detect either because of microwave penetration into dry snow or because of the weak backscatter return from wet snow which significantly decorrelates the interferometric signal. In this study we demonstrate first results of wet snow depth estimation by differencing sp-InSAR DEMs acquired by the TanDEM-X satellite mission. The results show, in contrast to dry snow, a clear sensitivity to wet snow. However, additionally to a high vertical sensitivity of a few ten centimeters a very low noise-equivalent-sigma-zero (NESZ) is crucial for successful snow depth estimation.

# Advancements in Snow Cover Monitoring Based on Synergy of Sentinel-1 SAR and Sentinel-3 SLSTR Data

Thomas Nagler[1], Helmut Rott[1], Joanna Ossowska[1], Gabriele Schwaizer[1], David Small[2], Eirik Malnes[3], Kari Luojus[4], Sari Metsaemaeki[4]; Simon Pinnock[5]

*[1] ENVEO IT, [2] University of Zurich, [3] NORUT, [4] Finnish Meteorological Institute, [5] ESA Climate Office*

## Abstract

The synergistic use of data from different satellites of the Sentinel series offers excellent capabilities for generating advanced products on parameters of the global climate system and environment. A key parameter for climate monitoring, hydrology and water management is the seasonal snow cover. In the frame of the ESA project SEOM S1-4-SCI Snow, led by ENVEO, we developed, implemented and tested a novel approach for mapping the total extent and melting areas of the seasonal snow cover by synergistically exploiting Sentinel-1 SAR and Sentinel-3 SLSTR data and applying this on the Pan-European domain.

Data of the Copernicus Sentinel-1 mission, operating over land surfaces in Interferometric Wide Swath (IW) mode at co- and cross-polarizations, are used for mapping the extent of snowmelt areas applying change detection algorithms. In order to select an optimum procedure for retrieval of snowmelt area, we conducted round-robin experiments for various algorithms over different snow environments, including high mountain areas in the Alps and in Scandinavia, as well as lowland areas in Central Europe covered by grassland, agricultural plots, and forests. In mountain areas the tests show good agreement between snow extent products during the melting period derived from SAR data and from Sentinel-2 and Landsat-8 data. In lowlands, ambiguities may arise from temporal changes in backscatter related to soil moisture and agricultural activities. Dense forest cover is a major obstacle for snow detection by SAR because the surface is masked by the canopy layer. Therefore, areas with dense forest cover are masked out. Based on the results of the round-robin tests, we selected for the retrieval of snowmelt area a change-detection algorithm using dualpolarized backscatter data of S1 IW acquisitions over land. The algorithm applies multi-channel speckle filtering and data fusion procedures for exploiting VV- and VH-polarized multi-temporal ratio images. The binary SAR snowmelt extent product at 100 m grid size is combined with the Sentinel-3 SLSTR snow product in order to obtain combined maps of total snow area and melting snow. Complementary to the melt snow extent from SAR, the optical satellite images provide information on snow extent irrespective of melting state, but are impaired by cloud cover. For generating a fractional snow extent product from Sentinel-3 SLSTR data, we apply multi-spectral algorithms for cloud screening, the discrimination of snow free and snow covered regions, and the retrieval of fractional snow area extent. In order to fill gaps in the snow extent time sequence due to cloud cover, we apply a data assimilation procedure using a snow pack model driven by numerical meteorological data from ECMWF, simulating daily changes in the snow extent. We present the results of round robin experiments on SAR wet snow algorithms and their performance in different environments, and show time series of synergistic snow products using SAR and optical satellite data over the Pan-European domain.

# Snow: modeling vs. field measurements: chances and challenge

Sivlan Leinss[1]
[1] *ETH Zurich*

**Abstract**

Snow is a transient state of water which can store significant amounts of water on the earth surface. The extreme albedo affects the earth's radiation balances and the water content is important for hydrological applications. Therefore, many different remote sensing methods focus on snow parameter retrieval. However, such parameter retrieval often requires significant modeling expertise, knowledge of snow physics and precise field validation data. Tis talk will focus on the complexity of snow modeling. I will talk over numerous pitfalls which can occur while modeling - not only—snow.

I will present how meteorological information, polarimetric radar data and micro-computertomographic data can be combined to develop a model which can predict the structural anisotropy of snow - layer by layer with cm resolution. The model extends the snow modeling software SNOWPACK developed by WSL-Institute for Snow and Avalanche Research SLF.

# Analysis of Multi-Frequency Polarimetric SAR Data Across Different Ice Zones of Greenland

Giuseppe Parrella[1], Konstantinos Papathanassiou[1], Irena Hajnsek[1,2]

[1] German Aerospace Center, [2] ETH Zurich

**Abstract**

Multi-frequency SAR measurements provide more exhaustive information of a given scattering scenario, compared to the single-frequency case, due to the sensitivity of longer and shorter wavelengths to scatterers of different size. In combination with polarimetry, they potentially allow to retrieve geometric and dielectric properties of scatterers at different size scales. For snow and ice scenarios, this means that it should be possible to study snow and ice microstructure at high frequencies (e.g. X-band) while for larger features, like ice lenses and subsurface layers, lower frequencies (L-band) should be preferred. In addition, the penetration depth of microwaves increases with increasing wavelength, making higher frequencies more sensitive to surface and shallow subsurface layer, and lower frequencies more suitable to sense features located deeper (down to some tens of meters).

Due to the complexity of the scattering scenario, the exploitation of PolSAR data still plays a secondary role in the retrieval of snow and ice properties. Most of the previous works focused on the analysis and modeling of the amplitude (or intensity) of the backscattered signal at different polarizations. Recent studies have shown that also the coherent nature of the polarimetric signature is essential. For instance, it has been shown that polarimetric phase differences between the HH and VV channels can reveal details of the microstructure of snow and firn layers 1,[2].

In this study, a multi-frequency analysis of polarimetric signatures over the different ice zones of the Greenland ice sheet is carried out. The objective is to assess the potential of polarimetric SAR to identify ice zones by means of different scattering mechanisms related to their peculiar surface and subsurface features. A set of descriptors is employed to extract and interpret the polarimetric information from the data, which includes backscattering coefficients, the scattering entropy, the mean alpha angle, polarimetric ratios and phase differences. The study is based on a multi-frequency (L-, C- and X- band) airborne Pol-SAR dataset acquired in May 2015, during the ARCTIC15 campaign, over a 200km long (and 5 km wide) transect in West Greenland.

[1] Leinss S., Parrella G. and Hajnsek I.: Snow height determination by polarimetric phase differences in X-band SAR data, JSTARS, vol. 7, no. 9, pp. 3794-3810, 2014.

[2] Parrella G., Hajnsek I. and Papathanassiou K.: On the interpretation of polarimetric phase differences in SAR data over land ice, GRSL, vol. 13, no. 2, pp. 192-196, 2016.

# Time series of high-res vertical snow profiles obtained from tomographic profiling using SnowScat

Othmar Frey[1,2], Charles Werner[3], Rafael Caduff[3], Andreas Wiesmann[3]
[1] Gamma Remote Sensing, [2] ETH Zurich, [3] GAMMA Remote Sensing

**Abstract**

One of the recommendations resulting from previous radar-based earth observation mission concepts for snow parameter retrieval is that high-resolution imagery of the vertical structure of snow is required to gain further insight into the complex electromagnetic interaction within snow packs.

As part of the ESA SnowLab campaign the SnowScat device, a terrestrial stepped-frequency continuous-wave (SFCW) scatterometer, which supports fully-polarimetric measurements within a frequency band from 9.2 to 17.8 GHz, was operated in tomographic profiling mode to obtain time series of high-resolution vertical snow profiles. (See also the attached collage of images, which, on the left, shows the SnowScat device deployed in tomographic mode.).

In this tomographic profiling mode, the SnowScat device is subsequently displaced in elevation direction to obtain a high resolution not only in range direction but also along elevation. This yields two-dimensional vertical profiles of the snowpack, which means that observables such as radar backscatter, co-polar phase difference, interferometric phase and coherence can be distinguished also along the vertical dimension.

In winter 2014/2015, a first test campaign at a test site hosted by the WSL Institute for Snow and Avalanche Research (SLF), in Davos, Switzerland was carried out yielding a successful proof of concept of the enhanced hardware, the tomographic measurement, and a basic processing concept. First comparisons of tomographic profiles with in-situ snow profiles indicated that melt-freeze crusts/ice layers present within the snowpack could be identified.

As a follow-up to this proof of concept the ESA SnowLab project has been set up to provide an experimental framework to investigate the interaction of microwaves with a snowpack under the varying conditions throughout an entire alpine snow season. One aspect within this 3-year project was to acquire and process time series of tomographic profiles - as well as regular SnowScat measurements - at dedicated test sites in the Swiss Alps. During these campaigns, up to three tomographic profiles were acquired per day.

Using this data set it could be shown that various phenomena can be investigated based on this time series of tomographic profiles, such as using 1) the variation of radar backscatter to locate melt-freeze crusts/horizontal layers within the snow pack, 2) using the co-polar (HH-VV) phase difference to characterize potential anisotropy or changes in anisotropy, and 3) using differential (temporal) coherence between tomographic profiles along the time series to measure changes in the propagation delay, spatially resolved in the 2-D vertical profile.

In this talk, we will give a summary and outlook of three years of daily time-series of tomographic measurements of snow obtained within the ESA Snowlab campaign at two different locations in the Swiss Alps.

(1) the measurement and imaging concept of SnowScat in tomographic mode is presented, (2) examples of acquired data products obtained within the ESA SnowLab campaign in the Swiss Alps during three snow seasons are shown, and (3) approaches to retrieve snow parameters as well as comparisons with in-situ snow measurements are discussed.

# Recent Advances Towards Glacier Subsurface Information Retrieval by Means of Tomographic SAR Techniques

Georg Fischer[1], Konstantinos Papathanassiou[1], Irena Hajnsek[1,2]

*[1] German Aerospace Center, [2] ETH Zurich*

**Abstract**

Microwave penetration into dry snow, firn and ice bodies leads to the fact that the backscattered signals received by SAR sensors depend on the characteristics of the subsurface of glaciers and ice sheets. Tis provides a potential link between SAR measurements and geophysical information, e.g. density, firn thickness, stratigraphy, accumulation rate, and melt-refreeze features.

While SAR polarimetry can provide information about the characteristics of the scatterers in the subsurface of glaciers, interferometric (InSAR) and tomographic techniques are mandatory to provide depth information. It was shown in previous (Pol-)InSAR studies that the InSAR coherence is affected by different subsurface characteristics and the estimation of the signal penetration was attempted by means of interferometric models under the assumption of a constant signal extinction with depth 1[2]. An approach to estimate accumulation rates with more physically based snow scattering models was shown in [3] with the drawback of relying on a priori information and assumptions about e.g. grain size and interface roughness. In recent studies multi-baseline data was exploited for SAR tomography and the imaging of subsurface features in both alpine glaciers [4] and the Greenland ice sheet [5] was demonstrated. Tis revealed that the subsurface of glaciers and ice sheets has a far more complex backscattering structure than what can be described by constant extinction models.

This contribution will give an overview on current InSAR modelling and its limitations and show research towards an improved model representation of the complexity of subsurface backscattering. Based on experimental airborne data acquired with DLR's F-SAR sensor in Greenland, the influence of subsurface layers on InSAR coherence is demonstrated. Furthermore, SAR tomography is employed to investigate the vertical backscattering structure in the firn of the percolation zone of Greenland. This is utilized to find more flexible parameterizations of the vertical structure functions for InSAR modelling. These analyses are conducted at different polarizations and frequencies. The tomographic data indicates that e.g. X- and L-band signals are sensitive to complementary features in the subsurface of glaciers, due to their different penetration depths and scattering behavior. Therefore, there is great potential in multi-frequency approaches, but generally it is desirable to acquire data at longer wavelengths, e.g. L-band, to gain access to deeper parts of the subsurface. The presented tomographic experiment indicates that the co-polarization channels (HH, VV) are more sensitive to layered structures in the firn, which fits to the expected rough surface scattering mechanism at ice layers or interfaces, and that cross polarization channels (HV) are more sensitive to volume scattering from ice inclusions and firn grains. This shows that the combination of co- and crosspol data is crucial.

Despite the potential of glacier subsurface information retrieval by means of interferometric SAR data, the links to quantitative geophysical parameters, which are of value to the glaciological community, are not established yet.

[1] E. W. Hoen and H. Zebker, "Penetration depths inferred from interferometric volume decorrelation observed over the Greenland ice sheet," IEEE Trans. Geosci. Remote Sens., vol. 38, no. 6, pp. 2572–2583, Nov. 2000.

[2] J.J. Sharma, I. Hajnsek, and K.P. Papathanassiou, "Estimation of glacier ice extinction using long-wavelength airborne Pol-InSAR," IEEE Trans. Geosci. Remote Sens., vol. 51, no. 6, pp. 3715-3732, Jun. 2013.

[3] S. Oveisgharan and H. Zebker, "Estimating snow accumulation from InSAR correlation observations," IEEE Trans. Geosci. Remote Sens., vol. 45, no. 1, pp. 10–20, Jan. 2007.

[4] S. Tebaldini, T. Nagler, H. Rot, and A. Heilig, "Imaging the Internal Structure of an Alpine Glacier via L-Band Airborne SAR Tomography," IEEE Transactions on Geoscience and Remote Sensing, vol. 54, no. 12, pp. 7197–7209, Dec. 2016.

[5] F. Banda, J. Dall, and S. Tebaldini, "Single and Multipolarimetric P-Band SAR Tomography of Subsurface Ice Structure," IEEE Transactions on Geoscience and Remote Sensing, vol. 54, no. 5, pp.

# Surface Moisture and Vegetation Cover Analysis for Drought Monitoring in the southern Kruger National Park using Sentinel-1, Sentinel-2 and Landsat-8

Marcel Urban[1], Christian Berger[1], Tami E. Mudau[2], Kai Heckel[1], John Truckenbrodt[1], Victor Onyango Odipo[1], Izak P.J. Smit[3], Christiane Schmullius[1]

*[1] Friedrich-Schiller-University Jena, [2] Council for Scientifc and Industrial Research,*
*[3] Scientifc Services, South African National Parks*

## Abstract

During the southern summer season of 2015 and 2016, South Africa experienced one of the most severe meteorological droughts since the start of climate recording due to an exceptionally strong El Niño event. To investigate spatio-temporal dynamics of surface moisture and vegetation structure, data from ESA's Copernicus Sentinel-1/-2 and NASA's Landsat-8 for the period between March 2015 and November 2017 were utilized. In combination, these radar and optical satellite systems provide promising data with high spatial and temporal resolution. Sentinel-1 C-band data was exploited to derive surface moisture based on a hyper-temporal VV-polarized radar backscatter change detection approach, describing dynamics between dry and wet seasons. Vegetation information from a TLS (Terrestrial Laser Scanner) derived Canopy Height Model (CHM) as well as the Normalized Difference Vegetation Index (NDVI) from Sentinel-2 and Landsat-8 were utilized to analyze vegetation structure types and dynamics with respect to the surface moisture index (SurfMI). Our results indicate that our combined radar-optical approach allows for a separation and retrieval of surface moisture conditions suitable for drought monitoring. Moreover, we conclude that it is crucial for the development of a drought monitoring system for savanna ecosystems to integrate land cover and vegetation information for analyzing surface moisture dynamics derived from Earth observation time series.

# Hyper-temporal Water Body Dynamics Mapping using Sentinel-1 Time Series Clustering

John Truckenbrodt[1], Victor Onyango Odipo[1], Jan Bongard[1], Stefan Werner[1], Marcel Urban[1], Christiane Schmullius[1], Kathrin Weise[2]

*[1] Friedrich-Schiller-University Jena, [2] Jena-Optronik GmbH*

**Abstract**

This study aims at providing water body dynamics maps at highest temporal resolution for better wetland characterization from space and as such is a mapping component of H-2020 project Satellite-based Wetland Observation Service (SWOS) (Grant No 642088). By depending on freely available data and demanding a high acquisition frequency across a large number of test sites from the North of Sweden to Central Africa, the Sentinel-1 SAR mission was chosen as the primary source of satellite images. Data from this mission acquired in Ground Range Detected (GRD) Interferometric Wide Swath (IW) mode VV polarization was selected as suited best for the mapping task due to storage volume (as compared to SLC data) and acquisition frequency (as compared to VH and HH polarization).

While SAR offers great possibilities for mapping water bodies from space, due to its insensitivity to clouds and independence from sunlight, difficulties arise from varying sea states. A roughened sea surface, returning more radiation to the sensor than a smooth surface, might be indistinguishable from land in the image. This effect of reduced contrast between land and water is particularly prominent in images from short wavelength SAR systems like X-Band and C-Band. Thus, common thresholding approaches like Otsu and Kittler-Illingworth, which assume a bimodal distribution of gray values in the image for distinguishing between dark water pixels and brighter land pixels, are likely to be inaccurate. However, by incorporating e.g. interferometric and polarimetric techniques in combination with change detection approaches, a high accuracy for flood detection can be achieved regardless of wavelength. Yet, many of these methodologies are impossible to use on large spatial scales and high temporal frequency due to data scarcity and/or cost.

The choice of data, a single polarization C-Band VV setup, is not the most favorable for per-image water mapping due to the explained sensitivity to sea state, precluding land-water thresholding as described above for a large number of acquisitions. Thus, it was decided to perform the classification purely in the temporal domain making use not only of image intensity but also its variability over time. In this context a bright pixel resulting from high sea state can be seen as an outlier in an otherwise series of dark backscatter pixel acquisitions and thus be discarded from being classified as land unless it is succeeded by other bright pixels indicating a change from water to land. This combination of pixel value and time series neighbor relationships is transformed into a synthetic data space and subsequently clustered using a simple K-means approach for all pixels. After restoring the original time series with the clustering result a classification of land and water is achieved for each pixel in time.

Though being clustered/classified completely independent from each other, the pixels from the same acquisition form a low-noise and accurate classification map even at highest sea states. This approach has proven highly successful under different conditions in the observed wetlands while being conceptually simple and completely automated.

# Validation activity of a Sentinel-1 Soil Moisture product

Francesco Mattia[1], Anna Balenzano[1], Giuseppe Satalino[1], Francesco Lovergine[1], Jian Peng[2,3], Urs Wegmuller[4], Oliver Cartus[4], Malcolm Davidson[5]

*[1] CNR-IREA, [2] Ludwig-Maximilians-Universität Munich, [3] Oxford University, [4] Gamma Remote Sensing, [5] ESA-ESTEC*

**Abstract**

Soil moisture (SM) content is an essential climate variable that is operationally delivered at low resolution (e.g. 36-9 km) by earth observation missions, such as ESA/SMOS, NASA/SMAP and EUMETSAT/ASCAT. However numerous land applications would benefit from the availability of soil moisture maps at higher resolution. For this reason, there is a large research effort to develop soil moisture products at higher resolution using, for instance, data acquired by the new ESA's Sentinel missions.

The objective of this study is to present the validation status of a pre-operational soil moisture product derived from Sentinel-1 at 1 km resolution and at large scale. The product is developed within the context of an ESA SEOM study (seom.esa.int/page_project034.php).

The paper will present: i) a comparison of S-1 SM estimates against in situ observations collected over various cal/val sites located in USA, Canada, Australia and Europe and ii) a cross comparison between S-1, SMAP, SMOS and ASCAT SM estimates retrieved over a large area of the Mediterranean basin. In addition, a strategy to derive SM fields at higher resolution, e.g., ~0.1 km, will be discussed and examples provided.

# SenThIS – A project for generating information from Copernicus Sentinel satellite data for the administration of the Free State of Thuringia: The application case soil moisture.

Carsten Pathe[1], Max Tobaschus[1], Martyna Stelmaszczuk-Górska[1], Christiane Schmullius[2], Peter Krause[3], Sandra Naue[3]

*[1] Earth Observation Services GmbH, [2] Friedrich-Schiller University Jena,*
*[3] Turingian State Agency of Environment and Geology*

**Abstract**

For the first time, the Copernicus Programme of the European Union provides access to valuable satellite Earth Observation data and dedicated services for the interested public free of charge. The satellites Sentinel-1 and 2 offer extensive sets of microwave and optical data at least until the year 2030. This guaranteed long-term availability enables the development of value-added information products for the public administration.

The project SenThiS (Sentinels for Thuringian Information Systems) has been funded by the German Federal Ministry of Transport and Digital Infrastructure (funding codes 50EW1512 and 50EW1513). It links two state authorities of the Free State of Thuringia, Germany, the Thuringian State Agency of Environment and Geology and the Thuringian Forest Administration (institution under public law) with two SMEs, the Earth Observation Services GmbH and Feiffer consult. These project partners were investigating the information potential of Sentine-1 and 2 for the two state authorities for different use cases.

One of these use cases is soil moisture, being an important variable in the hydrologic cycle. It controls the partitioning of precipitation into infiltration and surface-runoff and are an essential component of precipitation-runoff models used for flood forecasting.

The SAR sensor of Sentinel-1 is operating at C-band in the microwave region of the electromagnetic spectrum. A multitude of publications proofed the sensitivity of SAR data for soil moisture. One approach for extracting surface soil moisture related information from SAR data is the use of change-detection models. Here it is assumed that the environmental factors controlling radar backscatter are acting on different temporal scales. Short-term changes in the range of hours to a few days are addressed to soil moisture changes. If a sufficient number of SAR data sets is available, a change detection model can be developed to describe the temporal evolution of the SAR data on a pixel-by-pixel basis. Over time, a minimum and maximum radar backscatter level can be estimated, which are related to wilting level and field capacity. Once these two levels are known, each radar backscatter measurement can be scaled between these values to yield a relative surface soil moisture value. To mask out areas for which a soil moisture retrieval is not meaningful (e.g. forests, settlements, water surfaces), a land cover map has been produced from optical Sentinel-2 data. The surface soil moisture data, generated by the Earth Observation Services GmbH, are then transferred to the Thuringian State Agency of Environment and Geology, where they have been used to feed a precipitation-runoff model. Overall, a good agreement with modelled data has been found. Nevertheless, there are environmental phenomena like dew have been found to be problematic for soil moisture retrieval.

In conclusion, it can be stated that surface soil moisture information can be extracted from Sentinel-1 SAR data and are of great value for hydrologic modelling.

# Soil moisture retrieval over Europe based on a fusion of Sentinel-1 and SMAP data implemented in the Google Earth Engine platform

Jan Musial

*Institute of Geodesy and Cartography*

**Abstract**

Climate change and frequent episodes of severe drought urge to monitor soil moisture changes at global scale. To answer this demand the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) launched two satellite missions: Soil Moisture and Ocean Salinity (SMOS), and Soil Moisture Active Passive (SMAP); consisting of radiometers acquiring data in L-band (1.2-1.4 GHz). Spatial resolution of these passive radiometers (SMAP active radar failed on 07.07.2015) is around 35–50 km which is suitable for global soil moisture studies but not for local hydrological modeling, regional climate models (RCMs), precision farming, land slide monitoring, etc. In this respect Synthetic Aperture Radars (SARs), featuring several meters resolution of a pixel, match the requirements of regional scale applications. This opportunity has been explored by the ESA within projects devoted to soil moisture retrieval from Sentinel-1 SAR C-band (5.4 GHz) imagery (projects: "Biebrza Sentinel-1 Supersite": ESA EXPRO no. 4000112578/14/NL/MP), and "Exploit-S-1": ESA/AO/1-8306/15/I-NB).

This study present one of the soil moisture retrieval algorithms developed within the aforementioned projects that utilize NASA-USDA SMAP Global Soil Moisture product to derive linear relationship between soil moisture and Sentinel-1 sigma nought VV backscatter coefficient, separately for every SMAP pixel, for every month (to ensure quasi-stable surface roughness conditions), and for every relative satellite track (to ensure constant incidence angle). This is performed exclusively for pixels marked as agriculture by the CORINE Land Cover classification featuring low (< -15 dB) VH backscatter to eliminate volume scattering occurring in dense canopy. Further, the derived linear regression coefficients are interpolated by means of the ordinary kriging method to match spatial resolution of the final product. Then, Sentinel-1 imagery, screened for non-agriculture and volume scattering pixels, is upscaled to 500-1000 m to reduce the speckle noise. Ultimately, computed sigma nought backscatter at VV polarization is convolved with the regression coefficients. Derived Sentinel-1 soil moisture product together with the SMAP product are validated against in-situ soil moisture measurements distributed by the International Soil Moisture Network (ISMN). Estimated accuracy (see Figure) of the products across TERENO soil moisture network (Germany) reveals moderate agreement with ground data ($R2=0.58$ for SMAP product and $R2=0.47$ for Sentinel-1 product).

Numerical implementation of the described method has been performed within the Google Earth engine platform, that merges extensive satellite data archive with sophisticated programming environment. This allows for dissemination of the presented algorithm, embedded in an intuitive graphical user interface (GUI), among wide end-user community.

# Performance analysis of different SAR radiative transfer models for soil moisture estimation over the a test site in south Germany

Thomas Weiß, Thomas Ramsauer, Philip Mahrzahn
*Ludwig-Maximilians-Universität Munich*

## Abstract

Soil moisture plays an important role in land surface processes such as water and energy fluxes. To derive soil moisture in high spatial and temporal resolution SAR remote sensing technologies has proven to be very suitable. Over the last decades different retrieval approaches, from empirical (Water Cloud Model) over semi-empirical (Oh et al., Dubois et al.) to more physical based (Integral Equation Method) radiative transfer (RT) models, have been proposed. In the past all these RT-models have been widely used on different test-sites and studies. Nevertheless, a clear validation site and tool for the comparison of different models among themselves and in different model combinations for the different backscatter contribution of soil and vegetation is missing. The Copernicus Sentinel missions and especially the Sentinel 1A and 1B satellites offer new opportunities in terms of spatial and temporal resolution to analyze and validate the outputs of the different radiative transfer models.

This study presents a comparative analysis of different RT-model combinations for soil moisture retrieval over agricultural fields. The tested RT-models consist of vegetation and a soil scattering component. Therefore, soil models with different complexity for estimating the soil scattering contribution (Oh et al., Dubois et al., Integral Equation Method) are coupled with vegetation models which are calculating the vegetation scattering contribution (Water Cloud Model, Single Scattering Radiative Transfer) of the total radar backscatter. The RT-models are driven with in-situ data on field basis which has been acquired at the Munich-North-Isar (MNI) test-site located in the south of Germany. The retrieved backscatter is compared to available Sentinel 1 time series. In addition, an outlook on how these models can be used in a variable land-data-assimilation scheme is given.

# Use of SAR-derived surface soil moisture to initialize the WRF model: effect on the forecast of two extreme weather events occurred in the Mediterranean region

Luca Pulvirenti[1], Martina Lagasio[1], Antonio Parodi[1], Lorenzo Campo[1], Nazzareno Pierdicca[2], Björn Rommen[3]

*[1] CIMA Research Foundation, [2] Sapenza University of Rome, [3] ESA-ESTEC*

## Abstract

Despite the technological and scientific advances in recent decades, it is still a challenge to accurately forecast the onset and/or the spatio-temporal evolution of high impact weather events (HIWE), especially in complex topography coastal areas (present, for instance, in the Mediterranean Region). Nowadays, the skill of numerical weather prediction (NWP) models has improved thanks to the increasing model resolution from cloud-permitting (5 km) to cloud-resolving (1 km) grid spacing. However, challenges in predictive abilities with respect to HIWE derive from the poor knowledge of the initial state of both atmosphere and surface at small scales. Satellite data can be of great importance in this context, because forecast uncertainties can be significantly reduced by ingesting into models, operated at cloud-resolving grid spacing, high-resolution EO observational data. Hence, a challenging application of SAR could be the continuous and automatic generation of soil moisture (SM) maps used to routinely initialize high resolution NWP models. Sentinel-1 products in the Interferometric Wide swath mode are very effective for this purpose, allowing for a frequent and regular update (3-6 days considering both ascending and descending orbits) of soil moisture maps.

The STEAM (SaTellite Earth observation for Atmospheric Modelling) project, funded by ESA, aims at investigating new areas of synergy between high-resolution numerical atmosphere models and data from spaceborne remote sensing sensors, with focus on Copernicus Sentinels satellites. An example of synergy is just the Use of Sentinel-1-derived surface soil moisture to initialize a NWP model. In the framework of the STEAM project a number of experiments were carried out considering two HIWEs occurred in Italy, namely the floods that hit Livorno (Tuscany, Central Italy) on September 9, 2017 (casing nine casualties) and Silvi Marina (Abruzzo, Central Italy) on November

15, 2017. As numerical model, the Weather Research and Forecasting (WRF) one was chosen because it is well-established in the high resolution limit, has different physics parameterizations and enables the use of various data assimilation techniques. The soil moisture retrieval from Sentinel-1 was accomplished by applying a multi-temporal retrieval algorithm to time series of Ground Range detected Interferometric Wide Swath Sentinel-1 products. To perform the initialization experiments, the consistency between the original soil moisture data included in the land surface model (LSM) implemented into WRF (the rapid update cycle model) and those retrieved from Sentinel-1 must be taken into account. On the one hand, the soil moisture data are related to different soil depths. In fact, while the LSM included in WRF has six layers, the SAR derived SM is relative to approximately the first 5 cm of soil. On the other hand, the SAR derived maps have gaps in urban, forested, or densely vegetated areas, so that a direct insertion of SAR derived data to replace the LSM ones in the upped layer would generate strong inhomogeneities. Hence, the calculation of the difference between the retrieved SM values and the original (model) ones in the upper layer was firstly carried out. Then, this difference was spatially interpolated and, finally, the map of interpolated difference was added to the original (model) one. Obviously, in areas where gaps are not present, this procedure has no effect and the retrieved data are maintained. Successively, LSM derived vertical profile of SM was corrected through a linear interpolation of the difference between the S1-derived surface SM and the model one. The difference was assumed as equal to 0 m^3/m^3 at the deepest level. The major outcomes of the initialization experiments will be shown at the conference.

# Water status inversion from SAR closure phases

Francesco de Zan, Giorgio Gomba

*German Aerospace Center*

## Abstract

SAR interferometric closure phases signal consists in a kind of inconsistency in triplets of interferograms. Closure phases have been shown to carry information about the propagation in semitransparent media, typically the moisture status in soils and forests. Simple physical models can explain the phenomenon.

Recently, we have developed an inversion algorithm based on closure phases to retrieve the moisture variations from time series of interferometric SAR images. The crucial part in this algorithm is the solution of an ambiguity in model space, for which we propose the use of interferometric coherence or backscatter changes. Once this ambiguity has been solved correctly, the model inversion follows very easily. The results correlate with a number of well-established remote sensing products (e.g. scatterometers) and large scale models (like ECMWF).

Our real data experiments are mostly based on L-band data (ALOS-2). The closure phase and inverted moisture signal appear to be unexpectedly clean over some forested areas, which may allow applications like water status monitoring of forests and wildfire prediction.

Many issues remain open about the use of moisture products derived from closure phases: Is integration with backscatter-based techniques possible? If so, at which level of processing? How do we explain and exploit differences in polarization? To what extent it is possible to make use of C-band and higher frequencies data? Which spatial resolution is ultimately attainable?

At the workshop we will present inversion examples and validation data. We will also present first attempts with C-band Sentinel-1 data over especially coherent areas. The attached figure displays a closure phase map over a desert area after an unusual rain event.

# Experiences on biomass retrieval with spaceborne SAR backscatter at C- and L-band in Swedish forest

Maurizio Santoro[1], Oliver Cartus[1], Johan Fransson[2]

[1] *GAMMA Remote Sensing,* [2] *Swedish University of Agricultural Sciences*

**Abstract**

Sweden covers approximately 450,000 km2, almost 60% consisting of forests. More than 95% of the forests are intensively managed, thus representing a major source of income besides being a substantial carbon sink. Forest resources in Sweden have been quantified since 1923 with on ground surveys at inventory plots. Currently, the national forest inventory (NFI) consists of field plots that are being visited with a 5-years cycle and a number of field plots that are visited once. In total, 12,000 inventory plots are surveyed yearly. The forest field inventory allows for a broad assessment of forest resources; to capture the spatial distribution of these resources, the use of remote sensing has been fostered in Sweden already in the early days. In particular, spaceborne remote sensing was acknowledged to achieve detailed and complete coverage of the whole country in a reasonable amount of time and at reasonable costs compared to on ground surveys. Since 2000, optical imagery has been used to generate country-wide estimates of forest variables on a 5-years basis. A non-parametric approach is used to combine plot data from the national forest inventory and optical bands to estimate a number of forest variables, including stem volume and above-ground biomass. Besides the indirect relationship between optical reflectances and biomass, the mapping reflects the necessity of stitching estimates from images acquired under different viewing geometries and atmospheric conditions resulting in seams and unnatural biomass spatial distributions. More recently, elevation information from laser waveforms and SAR interferometric phase at X-band has been used together with NFI inventory data to generate two country-wide datasets of biomass estimates. In order to achieve full coverage, several years of acquisitions and detailed planning of the acquisitions were necessary, which translates in high costs of operation. Because of its relatively weak sensitivity to biomass and, until recently, sparse availability, the SAR backscatter from spaceborne missions has not been used as widely. Nonetheless, there is an increasing attention paid by space agencies to achieve full and repeated coverage with spaceborne SAR missions and there is evidence that the estimation of biomass based on SAR backscatter appears reasonable when based on multi-temporal observations. In this paper, we present a number of datasets with biomass estimates for Sweden based on Envisat ASAR and Sentinel-1 (C-band), ALOS PALSAR and ALOS-2 PALSAR-2 (L-band). Each biomass dataset is accompanied by per-pixel estimates of the standard error. All datasets share the same retrieval framework, namely the BIOMASAR algorithm, and the same strategy for validation based on the forest inventory plots of the NFI. Here, we discuss the impact of amount and specifications of the SAR data on the retrieval, the impact of the modelling framework on the retrieval, the validity of the SAR-based estimates and, finally, the usefulness and the limitations of the datasets in a user's context.

# Exploiting multi-temporal and multi-frequency radar backscatter for above-ground biomass estimation in boreal and tropical forest

Oliver Cartus[1], Maurizio Santoro[1], Urs Wegmuller[1], Björn Rommen[2]

*[1] GAMMA Remote Sensing, [2] ESA-ESTEC*

**Abstract**

Approaches exploiting the complementary information on forest above-ground biomass contained in multi-frequency radar backscatter, considering the variability in the sensitivity of backscatter to biomass dependent on the imaging conditions, have hardly been explored. Based on a set of 225 air- and spaceborne backscatter images acquired at X-, C -, L-, and P-band by TerraSAR-X/Tandem-X, Sentinel-1, Radarsat-2, ERS-2, ALOS PALSAR, ALOS-2, FSAR, and SETHI for BioSAR and AfriSAR campaign sites in Sweden and Gabon, we analyzed i) the sensitivity of backscatter at different frequencies to above-ground biomass under varying environmental conditions, ii) the performance of a biomass retrieval using different frequencies separately or combined, and iii) the role of forest structure on the backscatter to biomass relationship. A semi-empirical modeling framework was implemented for retrieving biomass from X-, C-, and L-band backscatter; empirical models were used for P-band.

The results suggest that i) P-band is most sensitive to above-ground biomass under all imaging conditions in the tropics and the boreal zone, ii) C- and L-band backscatter, provided multi-temporal observations are available, may achieve comparable accuracies as (few) P-band observations up to biomass levels of 150 to 200 t/ha, and iii) the benefit of combining P-band with higher frequency backscatter is limited. With respect to the role of the imaging conditions, we find that i) wet season conditions are associated with reduced sensitivity to biomass at all frequencies in the tropics, ii) frozen conditions maximize the sensitivity to biomass at high frequencies in the boreal zone, unfrozen dry conditions maximize the sensitivity at L- band. For the test sites in Sweden, we also find that forest structural differences associated with different forest management affect the backscatter to biomass relationship and lead to biased biomass estimates when not considered in the modeling.

The results of this study reemphasize that P-band is a critical frequency for mapping biomass, in particular in the tropics. Nonetheless, multi-temporal C- and L-band may provide almost equivalent information in biomass ranges below 200 t/ha. Implications of the results with respect to large scale mapping applications will be discussed in the context of ongoing global mapping efforts (ESA GlobBiomass, CCI Biomass).

# Forest Mapping exploiting Sentinel-1 interferometric time-series

Francescopaolo Sica, Andrea Pulella, Paola Rizolli

*German Aerospace Center*

## Abstract

Remote sensing represents a powerful tool for an effective monitoring at a global scale of vegetated areas [1-3]. In particular, given the daylight independence and the capability to penetrate clouds, space-borne synthetic aperture radar (SAR) systems represent a unique solution for the mapping and monitoring of forests.

Sentinel-1, with its large coverage and short revisit-time, is a breakthrough technology, ideal for the generation of a constantly updated forest coverage map product and for the rapid monitoring of large-scale areas, aiming at detecting ongoing deforestation activities and forest disturbance. Even though the detected SAR backscatter already provides useful information on forest coverage and structure, the use of SAR interferometry adds valuable and reliable information to the classification method [4-5]. In this work, we investigate the evolution in time of the interferometric coherence for different land cover types and exploit its potentials for classification purposes.

In particular, the exponential decorrelation model presented in [6] is used to model the temporal evolution of Sentinel-1 stacks. The model parameters, experimentally retrieved from the data, show a highly informative content and can be used as input observables for the derivation of an ad-hoc classification algorithm based on machine learning.

In the final paper we will present the preliminary results for mapping forested areas over the Amazon rainforest by exploiting Sentinel-1 interferometric time-series. The test site is located in the Rondonia state, Brazil, where constantly deforestation takes place and an up-to-date mapping is therefore highly recommended. Moreover, we will assess advantages and drawbacks of using Sentinel-1 repeat-pass interferometry for classification purposes. Finally, we will address the potential of combining this approach with high-resolution forest/non-forest maps from bistatic TanDEM-X data for an effective monitoring of on-going deforestation [7].

[1] M.C. Hansen, P.V. Potapov, R. Moore, M. Hancher, S.A. Turubanova, A. Tyukavina, D. Thau, S.V. Stehamn, S.J. Goetz, T.R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C.O. Justice, and J.R.G. Townshend: High-resolution global maps of 21st century forest coverage change. Science, vol. 342, pp. 850-853, 2013.

[2] R.O. Dubayah and J. B. Drake: Lidar Remote Sensing for Forestry. Journal of Forestry, vol. 98, no. 6, pp. 44-46, Jun. 2000.

[3] Schmullius, C., Thiel, C., Pathe, C., Herold, M. and Avitabile, V.: DUE GlobBiomass-Estimates of Biomass on a Global Scale.

[4] Hagberg, J. O., Ulander, L. M., and Askne, J. : Repeat-pass SAR interferometry over forested terrain. IEEE Transactions on Geoscience and Remote Sensing, 33(2), 331-340, 1995.

[5] J. I. H. Askne, P. B. G. Dammert, L. M. H. Ulander, and G. Smith: C-Band Repeat-Pass Interferometric SAR Observations of the Forest. IEEE Trans. On Geoscience and Remote Sensing, vol. 35, n. 1, pp. 25-35, Jan. 1997.

[6] F. Rocca. Modeling interferogram stacks. IEEE Trans. On Geoscience and Remote Sensing, vol. 45, n. 10, pp. 3289-3299, Oct. 2007.

[7] M. Martone, F. Sica, C. Gonzalez, J.-L. Bueso-Bello1, P. Valdo, and P. Rizzoli: High-Resolution Forest Mapping from TanDEM-X Interferometric Data Exploiting Nonlocal Filtering, Remote Sensing MDPI, under review.

# Potential of Sentinel-1 time series for deforestation and forest degradation mapping in temperate and tropical forests

Mikhail Urbazaev, Felix Cremer, Christiane Schmullius, Christian Thiel

*Friedrich-Schiller-University Jena*

**Abstract**

In this study we investigated the potential of dense synthetic aperture radar (SAR) time series collected by the ESA's Sentinel-1 satellites to detect deforestation and forest degradation areas. Since SAR data are affected by speckle, it is crucial to filter speckle before the time series analysis. Accordingly, we explored the potential of empirical mode decomposition (EMD), a data-driven approach to decompose the temporal signal into components of different frequencies. Based on the assumption that the high frequency components are corresponding to speckle, these effects can be isolated and removed. Since the EMD approach operates in the time domain only, it fully preserves the geometric resolution, which is required to detect small scale changes (e.g., forest degradation). We assessed the speckle filtering performance of the EMD approach. The results over forested areas showed similar statistics compared to the multi-temporal Quegan speckle filter in terms of speckle suppression (based on Equivalent Number of Looks) and an improved edge preservation. In the next step, we analyzed EMD-filtered Sentinel-1 data for detection of deforestation and forest degradation areas. For this, we first selected forested, deforested and degraded areas based on visual interpretation of multi-temporal very high resolution (1 m) optical imagery over temperate and tropical forests of Mexico. Further, we plotted EMD-filtered Sentinel-1 time series for the three reference classes and were able to determine the time frame of deforestation and forest degradation. The initial analyses showed promising results regarding the separation of forest and forest-change classes with EMD-filtered Sentinel-1 data in contrast to original SAR backscatter images. Furthermore, we present preliminary deforestation maps for study sites in Mexico and South Africa based on Bayesian probability approach and EMD-filtered Sentinel-1 time series backscatter.

This study is supported by DLR in the Sentinel4REDD project (FKZ:50EE1540) to develop new remote sensing based methods using Sentinel-1 and Sentinel-2 data to support UNFCC (United Nations Framework Convention on Climate Change) REDD+ MRV (Measurement, Reporting and Verification) Systems.

# Biomass with InSAR

Svein Solberg

*Norwegian Institute of Bioeconomy Research*

**Abstract**

Biomass can be mapped and monitored with interferometric SAR (synthetic aperture radar), where the main clue is based on having a vertical dimension of the forest canopy. While biomass mapping with InSAR requires access to a high-quality DTM, biomass changes can be estimated based on height changes over time. The idea is to demonstrate the ability to derive forest height changes and AGB changes for the period 2000 – 2012 from the combination of the TanDEM-X WorldDEM and the SRTM DEMs, including providing estimates of the accuracy of these change estimates, and an evaluation of the strengths and weaknesses of this approach as a supplement to other technologies. The study areas have sizes of 100 000 km2 or more, and are located in Tanzania, Ethiopia, Uganda, Colombia and Russia, and as well a data set in Norway. The data sets covering these areas are provided from DLR and Airbus Defense and Space, and they are currently available. We will (i) derive height change data. There are two main issues in this, i.e. a correction for striping errors and height biases in the SRTM data, and correction for differences in canopy penetration between X- and C-band. This will provide the geography of height changes within each study area. Secondly, we will (ii), fit models of AGB as a function of interferometric SAR (InSAR) height based on available field inventory plots, and use these models to convert height changes to AGB changes. This work is meant to serve as a large-scale demonstrator, which if successful, can be up-scaled to a near-global coverage as a later step.

# A Case for Polarimetric Phase: Dielectric Constant in Volume Scattering

Shane R. Cloude,

*AEL Consultants*

## Abstract

In most approaches to polarimetric decomposition theory, volume scattering carries no phase information. In the simplest such model, the random dipole cloud, the 3x3 polarimetric coherency matrix is given in trace normalised form as T3 = diag(0.5,0.25,0.25). Even in more adaptable models like the Yamaguchi decomposition, where T3 is no longer diagonal, volume scattering still has a real matrix representation.

In this paper we question these assumptions by using an EM model of radar volume scattering as a cloud of small ellipsoidal particles of complex dielectric constant $\varepsilon_r$. We show that for all non-spherical particle shapes (both oblate and prolate) in reflection symmetric orientation distributions, complex dielectric constant leads to non-zero phase of the $t_{12}$ element (called the Pauli phase in polarimetry) [1]. Importantly, this phase can also be estimated using compact polarimetry [2].

Further, we show that this phase is independent of the functional form of the particle orientation distribution (which effects only the coherence) and is only weakly dependent on particle shape. In this way we suggest that, contrary to accepted wisdom, we can retrieve estimates of the dielectric constant of particles in a volume from measurement of polarimetric phase. We also consider phase errors due to the presence of sub-canopy surface scattering and use it to generate a predictive model for the phase observed in polarimetric SAR imagery. This model is shown in equation 1, where $\mu$ is the surface-to-volume ratio and $\phi$ the observed Pauli phase. Note that even if $\mu = 0$ we obtain a non-zero phase in volume scattering.

$$\tan\phi = \frac{\sin\phi_v}{\cos\phi_v - \mu}$$

$$\varepsilon_r = \varepsilon' - i\varepsilon'' \rightarrow \begin{cases} \tan\phi_v = \dfrac{5\varepsilon''}{|\varepsilon_r|^2 + 3\varepsilon' - 4} & \text{prolate} \\ \tan\phi_v = \dfrac{-5\varepsilon''}{-3|\varepsilon_r|^2 + \varepsilon' + 2} & \text{oblate} \end{cases}$$

We further show that phase retrieval allows estimation of $\varepsilon_r$ only around circles in the complex dielectric plane. We validate this model using L-band quadpol and compact data from the ALOS-2 satellite [2]. We conclude by arguing that polarimetric phase offers a unique window on dielectric constant in volume scattering applications and its measurement, preferably through full quadpol modes or at least using compact pol, should be considered in future sensors.

[1] S. R. Cloude, “Zap functions: Phase Information in Quad and Compact Polarimetry”, Proc. 2017 Earth Observation Summit, Montreal, Canada, June 2017

[2] S.R. Cloude, H. Chen, D G Goodenough, D Hill, “Phase Calibration for Compact Polarimetry: An ALOS-2 Case Study in Victoria, B.C.”. Proc. of CEOS SAR Calval Workshop, JPL Pasadena, November 2017

# A Machine Learning Approach to PolInSAR and LiDAR Data Fusion for Improved Tropical Forest Canopy Height Estimation Using NASA AfriSAR Campaign Data

Maryam Pourshamsi[1], Mariano Garcia[2], Marco Lavalle[3], Heiko Balzter[4]

*[1] University of Leicester, [2] University of Alcala, [3] Jet Propulsion Laboratory,*
*[4]Centre for Landscape and Climate Research*

**Abstract**

This paper investigates the benefits of integrating multi-baseline polarimetric interferometric SAR (PolInSAR) data with LiDAR measurements using a machine learning approach in order to obtain improved forest canopy height estimates. Multiple interferometric baselines are required to ensure consistent height retrieval performance across a broad range of tree heights. Previous studies have proposed multi-baseline merging strategies using metrics extracted from PolInSAR measurements. Here, we introduce the multi-baseline merging using a Support Vector Machine trained by sparse LiDAR samples. The novelty of this method lies in the new way of combining the two datasets. Its advantage is that it does not require a complete LiDAR coverage, but only sparse LiDAR samples distributed over the PolInSAR image. LiDAR samples are not used to obtain the best height among a set of height stacks, but rather to train the retrieval algorithm in selecting the best height using the variables derived through PolInSAR processing. This enables a more accurate height estimation for a wider scene covered by the SAR with only partial LiDAR coverage. We test our approach on NASA AfriSAR data acquired over tropical forests by the L-band UAVSAR and the LVIS LiDAR instruments. The estimated height from this approach has a higher accuracy ($r2=0.81$, RMSE = 7.1 m) than previously introduced multi-baselines merging approach ($r2=0.67$, RMSE = 9.2 m). This method is beneficial to future spaceborne missions such as GEDI and BIOMASS, which will provide a wealth of near-contemporaneous LiDAR samples and PolInSAR measurements for mapping forest structure at global scale.

# Retrieval of Forest biophysical parameters using L-band airborne multi-baseline UAVSAR datasets

Shubham Awasthi, Kamal Jain

*Indian Institute of Technology Roorkee*

**Abstract**

Forests are one of the important part of ecosystem. They play a crucial role in the carbon cycle. A significant amount of the carbon is stored in the form of the forest biomass. These forest cover areas and their stored carbon stock are affected by various natural and anthropogenic factors. In the recent years, due to the various factors such as forest fires, climate change, and forests encroachments there has been a continuous depletion in the forest cover. Hence, in this present scenario regular monitoring of the forest areas is an urgent need. This study focuses on the utilization of PolInSAR and SAR Tomography technique for the forest biophysical parameters retrieval. UAVSAR datasets of AfriSAR mission operating in L-band (1.5 GHz) frequency region with the azimuth resolution of 1.5m* 12m. The used datasets were acquired on the date 15 June 2015 for the Rabi forest area of Gabon in Africa. Using these datasets the coherence optimization was done and the effect of the spatial baseline and interferometric wave number (Kz) was analyzed on the forest estimation. The three-stage inversion technique was implemented for this PolInSAR based height inversion. The appropriate baseline estimation for the correct forest height estimation was done. Also, the SAR Tomography based forest height parameter retrieval was also implemented. The aperture synthesis in the radar cross range direction was able to resolve the forest heights in the vertical direction. The Beamforming and Capon based spectral estimation technique was used for tomographic implementation. The phase calibration was done to remove the interferometric errors. The comparative analysis of the PolInSAR band SAR Tomography based retrieved forest heights was done. The mean forest height retrieved using this technique was 31m. The DSM of the forest area was generated using airborne Land, Vegetation, and Ice Sensor (LVIS) based airborne LIDAR point cloud datasets which was used for the forest height validation. High accuracy was achieved using SAR Tomography technique estimation. The Capon based technique was giving highest accuracy in the height estimation.

# TropiScat-2: A multifrequency tower-based scatterometer experiment at P,L,C bands for a better characterization of temporal effects impacting tropical forests backscatter

Salma El Idrissi Essebtey[1,2], Ludovic Villard[2], Thierry Koleck[3], Pierre Borderies[1], Thuy le Toan[2]

*[1] ONERA, [2] CESBIO, [3] CNES*

**Abstract**

Following the TropiScat and AfriScat experiments that took place in French Guiana and Ghana respectively between 2011 and 2017 in the framework of the preparation phase of BIOMASS mission, a new campaign TropiScat-2 has been set up since March 2018. This campaign, located in the experimental site of Paracou in French Guiana, has three major interrelated objectives: First, to extend the time series provided from previous TropiScat and AfriScat missions, mainly aiming at characterizing P-band temporal decorrelation, a key element for BIOMASS mission acquisition scenarios. Second, to investigate the possible synergies between BIOMASS and other sensors, such as SENTINEL1 that provides C-band data acquired with a short revisit time. Finally, to deepen our understanding of the underlying physics, based on electromagnetic models requiring a detailed characterization of the environment, both in regard to the 3D geometry of the scatterers and their water content (dielectric constants).

This new campaign started by a feasibility study that allowed us to select different types of C-band antennas which were tested in March 2018 according to several configurations by adjusting the acquisition time and studying the coherence and intensity variability over many days. Preliminary results demonstrated an important effect of environmental conditions on the evolution of intensity and coherence. In particular, differences between day and night coherences were highlighted and explained by the convective motion of forest scatterers. Indeed, daytime coherence values obtained from repeat-acquisitions were already low after few seconds onwards, while we were able to obtain high coherence values (>0.6) up to several hours during night.

In addition to its multi-frequency features, this campaign is enriched with extensive in-situ measurements dedicated to the scene geometry by means of TLS (terrestrial laser scanning) acquisitions in addition to vegetation water content and soil moisture collected with new sensors. Future results from longer time series are expected to contribute to a cross-quantitative analysis among these in-situ measurements and multi-frequency data, while these preliminary results already provide a very interesting database for the development of future innovative C-band configurations.

# Insights on temporal decorrelation from the AfriScat campaign: implications for the BIOMASS mission and beyond

Ludovic Villard[1]; Alia Hamadi[1,2], Pierre Borderies[2], Salma El Idrissi Essebtey[1,2], Thierry Koleck[3], Thuy le Toan[1]

*[1] CESBIO, [2] ONERA, [3] CNES*

## Abstract

Following the TropiScat campaign initiated during the early stages of the Biomass mission preparation activities, the AfriScat campaign has been also supported by ESA in order to consolidate the previous findings, considering two independent cases of dense tropical forests in French Guiana and Ghana respectively. Among these findings, the characteristics of the temporal decorrelation patterns at P-band are not only a key topic for the design of Biomass repeat passes, but also contribute to a better understanding of the backscatter temporal changes in relation to environmental conditions.

In this paper, we will first focus on a statistical analysis dedicated to assess the expected temporal decorrelation according to various mission scenarios, including the Biomass tomographic and PolInSAR phases. Consistently with TropiScat results, we show that seasonal effects strongly impact the coherence decrease as a function of temporal baseline, with a constant decrease during the dry season while the rainy season is characterized by a drop during the first days before reaching a plateau which eventually provides after about 30 days higher coherences than for the dry season. In order to better understand these results and their extension to ground and volume layers separated by tomography processing, a quantitative analysis has been performed using EM simulations based on the MIPERS model, from which several hypothesis can be tested. Among them, the possible effects of wind motion, vegetation growth, leaf flushing, vegetation water content and soil moisture variations have been tested, given a parametrization based on ranges derived from additional in situ measurements that could be acquired during experiments dedicated to diurnal cycles, on top of the 3D tree architecture derived from TLS data.

Finally, this study is extended with L-band results, which are not only interesting for the design of future L-band SAR missions but also to strengthen the simulations results with additional observables and the same input parametrization. Further results dedicated to prospects of synergies between P and L-bands observations will be also introduced in the frame of the upcoming Biomass and NiSAR missions.

# Forest remote sensing in Sweden

Henrik Persson, Johan Fransson

*Swedish University of Agricultural Sciences*

**Abstract**

Swedish forestry has used remote sensing (RS) data for decades to support and optimize their management. Satellite images were used for manually observing forest extents or support planning of field visits. The introduction of airborne laser scanning (ALS) data has revolutionized the information content by providing 3D data much appreciated by the industry. In addition to local ALS acquisitions financed by forest companies, the Swedish National Land Survey (Lantmäteriet) has been mapping Sweden with ALS between 2009 and 2016, to collect a complete coverage that the Swedish Forest Agency with support of the Swedish University of Agricultural Sciences (SLU) has used to generate national maps of several forest variables, including biomass, stem volume, tree height and basal area. Inventory plots from the Swedish National Forest Inventory (NFI) were used to link the RS data to the interesting variables, and the resulting maps have been made freely available. The entire Swedish forest sector has quickly adapted to this new situation and field visits are already much sparser and the ones carried out are more of the manner "ensuring the RS estimations look reasonable". The RMSE for biomass is of the magnitude 20-22% at the stand level, and the industry is quite satisfied but is also aiming for improved accuracy. They have also realized the rapid outdating of the ALS based maps, and it has been agreed on a national program that continuously will provide updated free ALS data on a 7 year repeat period. However, changes happening in-between these acquisitions, e.g., natural disasters and other changes, remain unidentified.

In 2017, we published a corresponding national map of biomass, generated on a similar manner as the ALS ones, but based on TanDEM-X data. The accuracy was about 21-25% at the stand level, and would hence probably comprise a sufficient substitute for the time in-between maps from ALS are available. It is, nevertheless, not the only possible substitute, and for example the national aerial photography mapping program also provides national data with a 2-5 year cycle. Hence, in order to provide additional value, satellite radar based solutions can (currently) mainly compete with its superior temporal coverage. Moreover, radar based products that can provide sufficient accuracy are using interferometry as processing technique and require a bi-static configuration with suitable baselines for the interferometer. Also, the influence of weather conditions can be severe, and must be further researched in order to possibly establish a near real-time forest monitoring system. Hence, the high requirements might limit the actual future use of this solution, if no synergistic advantages can be found with other applications.

In this presentation we discuss some results from ALS and TanDEM-X radar data sources in relation to expressed requirements from the industry. Moreover, the role of C-band data (such as Sentinel-1) in a future solution is touched upon.

# Retrieval of terrain topography in tropical forest by P-Band SAR Tomography

Mauro Mariotti d´Alessandro, Stefano Tebaldini

*Politecnico di Milano*

**Abstract**

The increasing request for accurate maps of ground elevation in many fields of human activity strongly pushed forward this research field. Commercial uses include infrastructure administration, regional planning and risk management; scientific uses range from subsidence analysis to vegetation characterization. Tropical forests represent the most challenging environments for this kind of task: trees can reach up to 50m and the vegetation is dense and heterogeneous. LiDAR systems rely on the few echoes that are not intercepted by leaves or branches and reach the ground. SAR systems working at frequencies lower than 1GHz collect returns coming from the upper crown down to the ground level, however the echoes associated with different elevations get mixed at the receiver as they fall in the same resolution cell. According to the InSAR principles, the exploitation of a couple of SAR images gives access to the interferometric coherence whose phase is linearly dependent on the elevation of the scattering target. However, this elevation is associated with the phase center of the target; for a forest the phase center is a point placed somewhere between ground level and tree top depending on scene geometry and wave extinction. As opposed to InSAR, TomoSAR allows to focus the signal in the 3D space by jointly exploiting several interferometric SAR images. By doing so, SAR tomography provides an estimation of the whole vertical profile of the target, thus pinpointing the ground location. The aim of this talk is to provide a careful evaluation of the capabilities of P-Band tomographic data in the retrieval of terrain topography in tropical forests. The analysis is carried out based on experimental data acquired in the frame of the ESA campaign AfriSAR, flown in 2015 in equatorial Africa. Results demonstrate that tomography can be used to produce high quality digital models of the terrain below a tropical forests, to within an accuracy comparable to that of high-resolution Lidar systems.

# TomoSAR Focusing Through Statistical Regularization: A Way to Ease the Characterization of the Forest Structure

Gustavo D. Martín del Campo Becerra, Andreas Reigber, Matteo Nannini

*German Aerospace Center*

## Abstract

The mapping of the global forest structure by means of synthetic aperture radar (SAR) tomography (TomoSAR) [1] – [4] is an important motivated issue for the upcoming Tandem-L and BIOMASS space missions. In recent works [5], it has been demonstrated that the forest structure can be characterized from the vegetation layers that compose it, reflected as local maxima in the tomographic profiles. For each pixel of the already focused TomoSAR data, the horizontal and vertical structure measurements are recovered from the peaks of the corresponding reflectivity profiles. The presence or absence of multiple maxima in certain zones, within the illuminated forested scene, has a direct influence (meaning) in the retrieval of the forest structure measurements [5], by instance, it could represent a forest with an undisturbed growth or a forest after a fire event. Such characterization of the forest structure entails several challenges on the retrieval of the needed tomographic slices, specifically: (i) the number of baselines is constrained to the revisit time that avoids temporal decorrelation issues; (ii) enhanced resolution is expected, since the forest structure is characterized from the multiple maxima present in the vertical profiles; (iii) suppression of artifacts and ambiguity levels reduction is desired to avoid false detections.

The TomoSAR problem at hand is conventionally treated as an ill-conditioned non-linear inverse problem [2] – [4], and is commonly tackled within the direction-of-arrival (DOA) estimation framework. The DOA-inspired non-parametric techniques, as the celebrated matched spatial filter (MSF) and minimum variance distortionless response (MVDR) beamformers [2] – [4], are well suited to cope with distributed targets, since these techniques recover an estimate of the continuous power spectrum pattern (PSP); nonetheless, the achievable resolution highly depends on the span of the tomographic aperture. Alternatively, super-resolved parametric approaches, as multiple signal classification (MUSIC) [3], have the main drawback related to the white noise model assumption that guaranties the separation of the signal and noise sub-spaces. On the other hand, taking advantage of the sparse representations of the cross-range profiles in the wavelet domain, super-resolved compressed sensing (CS) based approaches [6], [7], are also employed to solve the TomoSAR inverse problem. However, CS-based techniques often imply a considerable computational burden, due to their iterative nature and due to the non-availability of adapted efficient convex optimization algorithms.

To overcome such drawbacks and as an alternative to the aforementioned commonly performed TomoSAR-adapted focusing techniques, we suggest to apply instead statistical regularization approaches, in the context of the statistical decision-making theory. In the statistical regularization methodology, the inference is made in terms of probabilistic statements, where the Bayes minimum risk (BMR) estimation strategy plays a key role [8], [9]. Therefore, we first present the Bayes strategy, which makes use of probabilistic models to quantify the uncertainty of the unknowns. Later on, the addressed BMR methodology is extended to the maximum-likelihood (ML) approach, by imposing no constrain on linearity and by assuming no a priori knowledge about the statistical distribution of the desired PSP, to be retrieved. To guarantee well-conditioned solutions (in the Hadamard sense) of the TomoSAR nonlinear inverse problem, the derived ML-based technique is implemented in a closed fixed-point iterative manner, yielding what we define as the MARIA (ML-inspired Adaptive Robust Iterative Approach) technique [9].

The MARIA technique presents particular advantages in comparison to the previously discussed TomoSAR-adapted focusing methods: (i) it provides resolution-enhanced tomographic profiles with a reduced (limited) number of baselines, performing suppression of artifacts and reduction of the ambiguity levels; (ii) allows the separation of multiple scattering contributions within each resolution cell, retrieving an accurate location of the corresponding arbitrarily close phase-centers; (iii) as a non-parametric technique, it does not require any a priory knowledge about the number

of backscattering sources that constitute the illuminated area; (iv) it incurs less computation time in comparison to the other CS-based competing methods. The latter mentioned properties of MARIA facilitate the characterization of the forest structure, to be recovered from the 3D distribution of peaks of the reconstructed reflectivity profiles [5].

[1] A. Reigber and A. Moreira, “First demonstration of airborne SAR tomography using multibaseline L-band data”, IEEE Trans. Geosc. Remote Sens., vol. 38, no. 5, pp. 2142–2152, Sep. 2000.

[2] F. Gini, F. Lombardini and M. Montanari, “Layover solution in multibaseline SAR interferometry”, IEEE Trans. Aerosp. Electron. Syst., vol. 38, no.4, pp. 1344-1356, Oct. 2002.

[3] M. Nannini, R. Scheiber, and A. Moreira, “Estimation of the minimum number of tracks for SAR tomography”, IEEE Trans. Geosc. Remote Sens., vol. 47, no. 2, pp. 531-543, Jan. 2009.

[4] M. Nannini, R. Scheiber, R. Horn, and A. Moreira, “First 3-D reconstructions of targets hidden beneath foliage by means of polarimetric SAR tomography”, IEEE Geoscience and Remote Sensing Letters, vol. 9, no.1, pp. 60-64, Jan. 2012.

[5] V. Cazcarra-Bes, M. Tello-Alonso, R. Fischer, M. Heym and K. Papathanassiou, “Monitoring of Forest Structure Dynamics by Means of L-Band SAR Tomography. Remote Sensing, vol. 9, no.12, pp. 1229–1250, Nov. 2017.

[6] E. Aguilera, M. Nannini and A. Reigber, “A Data-Adaptive Compressed Sensing Approach to Polarimetric SAR Tomography of Forested Areas”, IEEE Geoscience and Remote Sensing Letters, vol. 10, no.3, pp. 543–547, Sept. 2012.

[7] E. Aguilera, M. Nannini and A. Reigber, “Wavelet-Based Compressed Sensing for SAR Tomography of Forested Areas”, IEEE Trans. Geosc. Remote Sens., vol. 51, no.12, pp. 5283–5295, Dec.2013.

[8] Y. V. Shkvarko, “Unifying regularization and Bayesian estimation methods for enhanced imaging with remotely sensed data—Part I and Part II”, IEEE Trans. Geosc. Remote Sens., vol. 42, no.5, pp. 923–940, May 2004.

[9] G. D. Martín del Campo, M. Nannini, and A. Reigber, “Towards Feature Enhanced SAR Tomography: A Maximum-Likelihood Inspired Approach”, IEEE Geoscience and Remote Sensing Letters, pp. 1–5, August 2018.

# P-Band Interferometry and Tomography for tropical forest parameters retrieval: lessons learned from BIOMASS preparatory studies

Stefano Tebaldini, Mauro Mariotti d´Alessandro

*Politecnico di Milano*

**Abstract**

Synthetic Aperture Radar (SAR) Tomography (TomoSAR) is an emerging technology to image the 3D structure of the illuminated media. TomoSAR exploits the key feature of microwaves to penetrate into vegetation, snow, and ice, hence providing the possibility to see features that are hidden to optical and hyper-spectral systems. The research on the use of P-Band waves, in particular, has been largely propelled since 2007 in experimental studies supporting the future spaceborne Mission BIOMASS, to be launched in 2022 with the aim of mapping forest Above Ground Biomass (AGB) accurately and globally. The results obtained in the frame of these studies demonstrated that TomoSAR can be used for accurate retrieval of geophysical variables such as forest height and terrain topography, and, especially in the case of dense tropical forests, to provide a more direct link to AGB. In this talk, we analyze the causes behind the link between tomographic intensities and forest AGB, trying to single out the roles of forest structure, rejection of ground contributions, and wave extinction. The analysis is carried out by studying the correlation with respect to forest AGB of several forest parameters, including forest height, extinction, and ground and volume backscattered intensities, as derived by using multi-pass tomographic data and single-baseline interferometric data. Results indicate that tomography brings information about AGB in tropical forests by virtue of its ability to single out the returns from different layers within the vegetation while rejecting ground scattering. Interestingly, this study indicates that that total volume backscatter is simply not the right parameter to consider for AGB retrieval, and points out the role of forest height and wave extinction. On the base of these findings, an interferometric approach is proposed to enhance the correlation between Radar intensity and AGB by or notching out ground scattering while preserving scattering from the main canopy layers.

# Towards a Physical Interpretation of SAR Tomography for Forest Structure Estimation

Victor Cazcarra-Bes, Matteo Pardini, Konstantinos Papathanassiou
*German Aerospace Center*

**Abstract**

Synthetic Aperture Radar (SAR) has been used for multiple forest applications like forest cover or biomass estimation. More advances techniques like Polarimetric SAR interferometry (Pol-InSAR) further increases the potential of radar as remote sensing tool for forest applications. Pol-InSAR is able to combine different polarizations of the electromagnetic wave with interferometric techniques to determine vertical structure information of the forest 1. However, the results are limited to forest height [2] or the estimation of vertical structure with limited accuracy [3]. In this context, SAR tomography (TomoSAR) aims to get a more accurate estimation of the vertical structure of the forest by combining multiple SAR acquisitions over the same area [4]. Whit the condition of using a frequency low enough to penetrate and interact with the forest, the result of TomoSAR provides a three dimensional (3-D) image of the forest until the ground, represented by the backscattering of the elements contained in the forest. This 3-D capability makes TomoSAR a powerful tool to be taken it into account for the characterization of forests.

The direct result from TomoSAR is the 3-D radar reflectivity and has not a straightforward ecological meaning that can be directly used for the forestry community. Further interpretation and processing of the results need to be done to extract forest information. This interpretation is challenging, the TomoSAR result depends on the configuration of the system (e.g. frequency, polarisation or the number and distribution of acquisitions), the dielectric properties of the scene (e.g. moisture content) or the algorithm used to get the 3-D backscattering of the forest. Therefore it is not easy to extract forest information from the radar signal and this topic is still under investigation [5].

In this presentation, we discuss how we can relate TomoSAR results with physical 3-D forest structure, i.e. the arrangement of trees in the 3-D space, by means of the local maxima obtained from the vertical radar reflectivity profiles. More in detail, two indices to define the forest structure will be presented, one for the horizontal structure, which represents the canopy density in the upper part of the forest and another one for the vertical structure, which reflects the distribution of trees in the vertical direction [6].In order to evaluate this concept, three tomographic SAR datasets (in 2008, 2012 and 2016) over a managed temperate forest in the south of Germany together with Lidar and ground measurements are available. The results will show on a first step how we can differentiate different forest structure types and then how we can use the horizontal and vertical indices to monitor changes on the structure of the forest over time [7].

[1] A. Moreira, P. Prats-Iraola, M. Younis, G. Krieger, I. Hajnsek and K. P. Papathanassiou, “A tutorial on synthetic aperture radar,” in IEEE Geoscience and Remote Sensing Magazine, vol. 1, no. 1, pp. 6-43, March 2013.

[2] K. P. Papathanassiou and S. R. Cloude, “Single-baseline polarimetric SAR interferometry,” in IEEE Transactions on Geoscience and Remote Sensing, vol. 39, no. 11, pp. 2352-2363, Nov. 2001.

[3] S. Cloude, “Polarization Coherence Tomography,” Radio Science, vol. 41, RS4017, Sep. 2006.

[4] A. Reigber, A. Moreira, “First demonstration of airborne SAR tomography using multibaseline L-band data,” IEEE Trans. Geosci. Remote Sens. 2000, 38, 2142–4152,

[5] O. Frey, E. Meier, “Analyzing Tomographic SAR Data of a Forest With Respect to Frequency, Polarization, and Focusing Technique,” IEEE Trans. on Geosc. and Remote Sensing, vol. 49, No. 10, 2011.

6] M. Tello, V. Cazcarra-Bes, M. Pardini and K. Papathanassiou, “Forest Structure Characterization From SAR Tomography at L-Band,” in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. doi: 10.1109/JSTARS.2018.2859050

[7] V. Cazcarra-Bes, M. Tello-Alonso, R. Fischer, M. Heym, and K. Papathanassiou, “Monitoring of Forest Structure Dynamics by Means of L-Band SAR Tomography,” Remote Sensing, vol. 9, no. 12, p. 1229, Nov. 2017.

# An assessment of the contribution of multiple frequencies to the observation of 3-D forest structure by means of multi-baseline SAR data

Matteo Pardini, Victor Cazcarra-Bes, Konstantinos Papathanassiou

*German Aerospace Center*

**Abstract**

The availability of multiple Synthetic Aperture radar (SAR) acquisitions separated by different spatial baselines allows to form an imaging aperture in the elevation direction and therefore to estimate a vertical profile of the backscattered power (or reflectivity). This kind of profile depends on the radar frequency and polarization, the acquisition geometry, the 3-D distribution of the scatterers in space, and their dielectric properties. In particular, different frequencies provide imaging sensitivity to different physical forest structure components. Lower frequencies (P- and L -band) penetrate through and interact with vegetation elements from the canopy top down to the ground, and they have been demonstrated to be able to fully characterize 3-D structure and to distinguish between different structure types. The sensitivity to smaller vegetation elements, which are still relevant from an ecological point of view, increases with increasing frequencies (S-, C-, X-band), but at the same time the penetration is reduced. However, recent experiments for instance with TanDEM-X data have demonstrated that the limited penetration capability becomes actually an advantage for instance for characterizing structural canopy heterogeneity in the horizontal direction.

The characterization of the information content of the different frequencies in terms of physical structure is in a very early stage of development, and becomes of particular relevance to future planned and under study SAR missions, e.g. BIOMASS (ESA), NISAR (NASA), Tandem-L (DLR). Thus, the characterization of synergies and complementarities among observations at different frequencies is crucial not only for a unified generation of biophysical products, but also for the definition of observation strategies. In this work, vertical reflectivity profiles estimated at different frequencies (from P- up to X-band) are compared, and a first assessment of the contribution of each of them in distinguishing different forest structure types is carried out. For this, structure indices derived from the radar reflectivity profiles are compared against each other as well as against plot-derived indices. Experimental results will be presented, obtained by processing real airborne (DLR F-SAR platform) acquired over temperate and tropical forests.

# Understanding the link between Lidar and SAR measurements towards enhanced forest structure products: The model-based and the structure-based frameworks

Matteo Pardini[1], John Armston[2], Wenlu Qi[3], Seung Kuk[4], Changhyun Choi[1], Victor Cazcarra-Bes[1], Maria Tello Alonso[1], Konstantinos Papathanassiou[1], Ralph Dubayah[3], Lola Fatoyinbo[4]

*[1] German Aerospace Center, [2] University of Queensland, [3] University of Maryland, [4] NASA/GSFC*

## Abstract

Active remote sensing techniques based on LIght Detection And Ranging (lidar) and Synthetic Aperture Radar (SAR) can provide high resolution three-dimensional (3-D) information about forest volumes. Full waveform lidars transmit a pulse and record the continuous distribution of the laser energy (i.e., the full waveform) returned to the sensor after being reflected by the vegetation elements within the illuminated footprint. On the other hand, SAR acquisitions in tomographic or interferometric modes allow the reconstruction of the (vertical) profiles of the backscattered power (i.e., radar reflectivity) and / or the estimation of a parameterization of them. Both lidar waveforms and SAR reflectivity profiles and interferometric coherences depend on the 3-D distribution of the vegetation elements, and their potential to contribute uniquely to the observation and quantitative characterization of forest structure has been recognized in several experiments.

Therefore, the optimization of observation strategies and combination algorithms for the generation of unified and enhanced forest structure products for future space borne missions has become a crucial issue. With this in mind, two frameworks have been proposed in which synergies and complementarities between lidar and SAR measurements are being investigated:

1) In the model-based framework, lidar waveforms (and derived parameters) are used to initialize polarimetric-interferometric (Pol-InSAR) backscattering models. The applicability of this framework has been investigated mostly for forest height estimation and proved its effectiveness for instance in those cases in which the Pol-InSAR observation space is too small to allow a balanced model inversion and / or the SAR wavelength does not allow penetration until the ground. However, this framework may reach its limit when it comes to SAR reflectivity profiles. Depending on the SAR frequency, look angle and resolution, differences in propagation make lidar and SAR pulses interact differently with the physical vegetation elements, and the parameterization of the SAR models provided by lidar waveforms can lose significance.

2) The structure-based framework, which is in a very early stage of development, consists in establishing a correspondence between lidar waveforms and SAR profiles by means of their capability in reflecting physical 3-D forest structure. This can be accomplished for instance by defining two complementary structure indices expressing heterogeneity in the horizontal and in the vertical direction with the aim to reflect the behavior of analogous indices based on ground inventory single-tree measurements. The main challenge here is the definition of appropriate structure indices from remote sensing observables that can express physical structure characteristics, remembering that current and future space borne lidar and SAR implementations do not possess spatial resolution capabilities to allow to extract information down to the single trees.

The purpose of this work is to discuss the link between lidar and SAR measurements as characterized by the model-based and the structure-based frameworks. Experimental results obtained by processing data collected in recent airborne campaigns will be presented, with particular reference to the NASA's Global Ecosystem Dynamics Investigation (GEDI) full waveform lidar mission. Indeed, towards enhanced products, GEDI is expected to use data of present and future space borne synthetic aperture radar (SAR) missions for instance to fill the gaps in its coverage, increase its product resolution, and gain from different ways to calibrate and estimate biomass. In this frame, the possibility of fusing GEDI waveforms and TanDEM-X single-pass X-band interferometric (In-SAR) coherences is currently being investigated.

# Identification of Soil Tillage Change by Temporal Series of Sentinel-1 & Sentinel-2

Giuseppe Satalino[1], Francesco Mattia[2], Anna Balenzano[1], Francesco Lovergine[1], Michele Rinaldi[3], Angelo De Santis[3], Salvatore A. Colecchia[3]

*[1] CNR-IREA, [2] CNR-ISSIA, CREA-CI[3]*

**Abstract**

There is a convincing evidence that tillage operations have negative effects on soil, water and organic matter conservation (e.g., Foley, Nature 2011). Particularly in semi-arid regions, they produce an increase of soil erosion and evaporation that may reduce crop production (Aboudrare et al., Agricultural Water Management, 2006). For these reasons, the Food and Agricultural organization (FAO) of the United Nations promotes the Conservative Agriculture, i.e. the maintenance of a permanent soil cover with a minimum soil disturbance (i.e. no tillage). Indeed, Conservative Agriculture is expected to contribute to preserve soil water and nutrient availability in agricultural areas and maintain a sustained crop production (“Strategic work of FAO”, 2017).

Earth observation (EO) can be a cost effective tool to monitor soil tillage practices, which are characterized by a sparse occurrence in space and in time (Hadria et al., Agricultural Water Management, 2009).

The objective of this study is to describe a new technique, based on dense time series of Copernicus Sentinel-1 (S-1) and Sentinel-2 (S-2) data, aimed to identify tillage changes at regional/continental scale and at approximately 100 m resolution.

The technique applies to bare or scarcely vegetated fields identified by setting a threshold to time series of S-2 NDVI data. In order to identify tillage changes, the proposed approach implements a multi-scale change detection that is applied to S-1 VH data. Cross polarized components are exploited due to their high sensitivity to changes of surface roughness and, at the same time, relative insensitivity to anisotropic component of surface roughness (e.g., Wegmuller et al., Remote Sensing of Environment, 2011).

The detection of temporal VH changes is performed at two spatial scales, i.e. 0.1 km (high) and 5.0 km (medium). This is to discriminate between changes that take place only at field scale and, therefore, are likely due to tillage changes and those that take place both a field and medium scale and, therefore, are very likely due to large scale phenomena, such as precipitation events.

A proof of concept of the proposed methodology has been carried out at farm scale using in situ observations and S-1 and SPOT5-Take5 data, acquired over the agricultural Apulian Tavoliere JE-CAM site (southern Italy) in 2015. Subsequently, a large validation effort involving various sites in Europe and using S-1 and S-2 data has been undertaken in the context of the H2020 Sensagri project. In this paper, ground data collected in 2017 and 2018 over the Apulian Tavoliere site and including information on the tillage status of more than 600 fields has been analysed. First results on data acquired in 2017 indicate that the methodology can identify the tilled/no-tilled classes with an overall accuracy of 83%.

# Synergistic use of Sentinel-1 and Sentinel-2 data for the retrieval of bio- and geophysical parameters using a data assimilation approach

Philip Marzahn[1], Thomas Kaminski[2], Michael Vossbeck[2], Tristan Quaife[3], Ewan Pinnington[3], Joris Timmermans[4], Björn Rommen[5], Claudia Isola[5]

*[1] Ludwig-Maximilians-Universität Munich, [2] The InversionLab, [3] University of Reading,*
*[4] University College London, [5] ESA-ESTEC*

**Abstract**

In recent years monitoring of earth system dynamics by means of remote sensing satellites has begun to play an important role in the provisioning of spatial distributed input or validation data for earth system and or land surface models. With the different global initiatives such as the essential climate variables (ECV) defined by the World Meteorological Organization (WMO) or the European Space Agency Climate Change Initiative (ESA-CCI), global monitoring programs by means of satellite data are envisaged. Currently, several ECVs are provided by means of unique retrieval schemes which are based on either using optical or microwave data streams such as for the retrieval of LAI, FAPAR or soil moisture. Consequently they tend to show discontinuities or data gaps in the optical domain due to clouds or do not use the combined information content of all available frequency domains (e.g. VIS, NIR, SWIR, TIR, microwave) in a joint retrieval.

In this presentation, we present first results of a joint retrieval of land surface parameters over agricultural landscapes such as LAI, FAPAR, vegetation height and soil moisture by means of a weak constraint variational data assimilation approach. Here we invert two physically consistent radiative transfer models in the microwave and optical domain using Sentinel-1 and Sentinel-2 data respectively and employing prior information about the land surface provided by the Joint UK Land Environment Simulator (JULES). In addition we include a prior term which takes expectations of the temporal evolution of the land surface state into account. Outputs are generated in terms of target variables such as LAI and soil moisture as well as their associated uncertainties.

Results are validated against field measurements over the Munich-North-Isar site, Germany. It will be shown that the retrieval of bio- and geophysical parameters from remote sensing data greatly benefit from a joint retrieval from optical and microwave data especially in terms of uncertainty reduction and by providing a consistent retrieval of the spatiotemporal dynamics of land surface variables such as e.g. LAI and soil moisture.

# Using Sentinel-1 in Agricultural Applications - A case study in the Netherlands

Susan Steele-Dunne

*TU-Delft*

**Abstract**

In this study, we monitored a full growing season of five key crop types across the Flevopolder in the Netherlands. Crop height and growth stage were monitored weekly in a total of 25 parcels of maize, potato, sugar beet maize and English rye grass. Hydrometeorological data were collected throughout the season. Here, these results are used to interpret time series of Sentinel-1 data processed for the province of Flevoland. Results demonstrate that Sentinel-1 data follow the phenological stages and can be used to identify key moments in crop development.

# Potential of Sentinel-1 time-series for crop monitoring and disturbance mapping in Thuringia

Linara Arslanova[1], Nesrin Salepci[1], Marcel Urban[1], Felix Cremer[1], Carsten Pathe[2], Larissa Torney[1], Christiane Schmullius[1]

*[1] Friedrich-Schiller-University Jena, [2] Earth Observation Services GmbH*

**Abstract**

Crop assessment and monitoring with optical sensor imagery is limited by cloud cover and therefore high acquisition gaps. In contrast, radar images are not influenced by weather conditions thus offer dense time series. In April 2014 and 2016, the European Space Agency launched the new synthetic aperture radar (SAR) satellites Sentinel-1A and Sentinel-1B. Their sensors feature an enhanced radiometric and spatial resolution as well as a fundamentally improved temporal coverage compared with previous (C-band) SAR satellites.

In this study, 105 Sentinel-1A/B co- and cross-polarized (VH/VV) scenes acquired over Thuringia were analysed to retrieve parameters for wheat monitoring (summer/winter barley) and detection of disturbances inside the fields. Additional information, such as meteorological data (rainfall, temperature) and yield information have been integrated into this project.

The radar vegetation index (RVI) was investigated as an alternative to the normalized difference vegetation index (NDVI) to estimate phenological stages of the crops. The RVI has shown very similar trends compared to NDVI.

We used in situ yield information to assess the possibilities to delineate the differences between high and low yield patterns in the Sentinel-1 time series data. We have examined that the direct use of the co- and cross-polarized SAR data has a higher distinguishability between high and low yield than the RVI.

# Separating Ground and Volume Scattering in Agricultural Crops using MB Polarimetric Interferometric SAR Data

Hannah Joerg[1], Matteo Pardini[1], Alberto Alonso-Gonzales[1], Konstantinos Papathanassiou[1], Irena Hajnsek[1,2]

*[1] German Aerospace Center, [2] ETH Zurich*

**Abstract**

Electromagnetic scattering mechanisms in agricultural scenarios, i.e. in dependency of dielectric and geometric soil and plant parameters, are highly complex. Towards an inversion of such parameters from multi-parametric SAR measurements, it is therefore of interest to separate the scattering mechanisms occurring on the ground, i.e. surface (soil) and dihedral (soil-trunk interactions) scattering, from the volume scattering in the vegetation layer above. In this respect, the observation space provided by polarimetric SAR measurements is limited. Therefore, model-based decomposition techniques commonly assume that either surface or dihedral scattering can be neglected. Additionally, it is not necessarily given, that the scattering mechanisms associated to the ground (surface or dihedral) are actually located at the ground height.

By utilizing one or multiple spatial baselines, the variation of the interferometric coherence with polarization allows separating scattering mechanisms along height and a two-layer model – ground plus vegetation – can be employed for ground and volume separation. [1,2]. Knowing the interferometric coherences associated to ground and volume scattering then enables to estimate the ground and volume polarimetric covariance matrices [2,3]. It can be assumed that the ground height is a priori known, e.g. from an external digital terrain model, thus fixing the interferometric ground coherence. However, the estimation of the interferometric volume coherence is intrinsically ambiguous and is subject to regularization constraints, independently of the number of available baselines [3,4,5]. As a direct consequence, also the estimation of the polarimetric ground and volume covariance matrices is ambiguous and this clearly impacts their physical interpretation and any parameter inversion attempt.

This work intends to give an overview of the aforementioned problematic using airborne SAR data acquired by DLR's F-SAR in the frame of the CROPEX 2014 campaign. Polarimetric, multibaseline SAR data at X-, C- and L-band are available as well as simultaneously collected in-situ measurements of soil and plant parameters on eight different dates between May and August [5]. This unique data set allows investigating the impact of different regularization constraints on the ground and volume scattering separation as a function of frequency and number of baselines on one hand and crop type and phenological stage on the other hand.

[1] S. R. Cloude, and K. P. Papathanassiou, "Three-Stage Inversion Process for Polarimetric SAR Interferometry", Proc. Inst. Elect. Eng. - Radar, Sonar Navig., vol 150, no. 11, pp. 2352-2363, Jun. 2003.

[2] S. Tebaldini, "Algebraic Synthesis of Forest Scenarios from Multibaseline PolInSAR Data", IEEE Trans. Geosci. Remote Sens., vol. 47, no. 12, pp. 4132-4142, Dec. 2009

[3] M. Pardini, and K. Papathanassiou, "On the Estimation of Ground and Volume Polarimetric Covariances in Forest Scenarios with SAR Tomography," IEEE Geosci. Remote Sens. Lett., vol. 14, no. 10, pp. 1860-1864, Oct. 2017.

[4] A. Alonso-Gonzalez, and K. P. Papathanassiou, "Multibaseline Two Layer Model PolInSAR Ground and Volume Separation," Proc. of EUSAR 2018, vol. 12, Aachen, Germany, 2018.

[5] H. Joerg, M. Pardini, I. Hajnsek, and K. P. Papathanassiou, "3-D Scattering Characterization of Agricultural Crops at C-Band Using SAR Tomography", IEEE Trans. Geosci. Remote Sens., vol. 56, no. 7, pp. 3976-3989, 2018.

# Automated time-series analysis integrating optical and SAR based biophysical indices for agricultural applications

Neha Pankaj Hunka, Jana Slacikova, Lubos Kucera

*GISAT s.r.o.*

**Abstract**

The Sentinel constellation of Earth Observation (EO) satellites provides unique and new possibilities to monitor European agricultural landscapes. The vast database of images acquired at a high temporal frequency of every 5 to 6 days can now enable identifying changes in land use management or intensity, specific cropping practices and land use dynamics, and harvests of various crop types multiple times in a single season. Most agricultural practices often manifest as very subtle changes in vegetation cover occurring over a short period of time in one season. Only frequent satellite-based monitoring provides sufficient data sources to monitor such subtleties efficiently and accurately. Dense time-series analysis of satellite imagery carry the advantage of being able to capture both highly dynamic and gradual or long-term change processes, compared to traditional multi-temporal image classifications alone.

The presented approach uses Sentinel time-series of pre-processed optical and SAR based biophysical indices (NDVI, SAR backscatter, SAR coherence) on agricultural parcel level. These time-series are interpreted, individually, to their expected trajectory in response to the agricultural practices to be monitored. Separated workflows for analysis of time-series of each biophysical indicator are constructed, so as to reflect different situations in availability of input data (e.g. optical data is likely to be relatively less dense time-series compared to SAR data). The time-series of all indices are tested to identify three transition periods in each agricultural parcel, including (i) onset of vegetation growth, (ii) a period where the maximum vegetation canopy is present and (iii) the onset of senescence or sudden occurrence of loss of vegetation. The last period is expected to be detected as a “break” in the time-series, whose occurrence is interpreted as either the presence (indicating undisturbed vegetation) or the absence (indicating harvest, clearance or disturbance) of vegetation at a given date. Such “breaks” could occur more than once a year, often indicating the repeated clearance or disturbances on the parcel in a single agricultural season. Using the trends in the biophysical indicators a set of conditions derived from the different biophysical indicators are established.

Various statistical analyses, regression analyses, trend analyses, and decision-tree thresholds for each conditions, and different logical combinations of the conditions, are tailored to best capture the agricultural practice (e.g. the harvest, mowing, presence/absence of catch crops) for the area of interest. In the case of ambiguous parcels with contrasting time-series, such individual conditions also allow for expert judgement to be called upon for specific observations of vegetation changes.

The above described method is based on the approach that has been developed by Gisat company within the DROMAS (Agricultural Crop Monitoring and Assessment driven by Satellites) project co-funded by ESA. The project aims at development of innovative tools for continuous monitoring of crop vegetation at parcel level. The first implementation has been done for grassland monitoring with the goal to detect grassland mowing & grazing events. The pilot testing and semi-operational automated production within the demonstration phase of the project have shown very promising performance providing high quality results comparing to other common classification or change detection approaches.

The further development and tailoring of this approach has been done internally and this method was selected for application within the Sen4CAP (Sentinels for Common Agriculture Policy) project funded by ESA. After the thorough benchmarking and prototyping activities done on selected sites in six European countries this method is being implemented as an operational tool for monitoring of agricultural practices. In particular the developed procedures aim at the identification of crop harvesting and compliancy assessment for farmer declarations of fallow lands or the growing of catch-crops and nitrogen fixing crops.

# Evaluation of the double-bounce contribution in the retrieval of bio-physical parameters of vegetation using Pol-InSAR with TanDEM-X bistatic data

Noelia Romero-Puig, Juan M. Lopez-Sanchez, J. David Ballester-Berman

*University of Alicante*

**Abstract**

The retrieval of biophysical parameters of vegetation (forest and agriculture) using Polarimetric SAR Interferometry (PolInSAR) [1, 2] is carried out through the inversion of a physical model of the scene. The most extended approach for this purpose is based on the Random Volume over Ground (RVoG) model [3, 4, 2], a simplified electromagnetic model that relates the physical variables of vegetation and the observables in PolInSAR data.

With the TanDEM-X sensor [5], PolInSAR data are gathered in single-pass mode thanks to its bistatic configuration, i.e. one satellite transmits and both of them receive, resulting in one monostatic image and one bistatic image. A consequence of this bistatic acquisition is the presence of a double-bounce contribution at the ground that affects the interferometric coherence with a decorrelation factor [3]. The double-bounce term has been mostly ignored in the estimation of forest height with PolInSAR TanDEM-X data [6, 7, 8, 9], or just taken into account in the inversion of the RVoG model over rice fields [10].

In this work, a detailed analysis of the influence of the double-bounce decorrelation term in the estimation of scene parameters, i.e. ground topography, vegetation height, extinction coefficient, etc., is carried out with simulations. Real data acquired over rice fields during the science phase of the TanDEM-X mission are also exploited. Results show the limitations of the current procedures on the inversion of the different parameters. For instance, the error in height when ignoring the double-bounce term becomes noticeable for incidence angles shallower than 30 degrees and large products of vertical wavenumber and vegetation height. The resulting vegetation height estimates have been normalised, i.e. expressed as k v , so that the results can be extrapolated to other scenarios, e.g. forests.

[1] S. R. Cloude and K. P. Papathanassiou, "Polarimetric SAR interferometry," IEEE Trans. Geosci. Remote Sensing, vol. 36, pp. 1551–1565, Sept. 1998.

[2] K. P. Papathanassiou and S. R. Cloude, "Single baseline polarimetric SAR interferometry," IEEE Trans. Geosci. Remote Sensing, vol. 39, pp. 2352–2363, Nov. 2001.

[3] R. N. Treuhaft, S. N. Madsen, M. Moghaddam, and J. J. van Zyl, "Vegetation characteristics and underlying topography from interferometric radar," Radio Science, vol. 31, pp. 1449–1485, Nov. 1996.

[4] R. N. Treuhaft and P. R. Siqueira, "Vertical structure of vegetated land surfaces from interferometric and polarimetric data," Radio Science, vol. 35, pp. 141–177, 2000.

[5] G. Krieger et al., "TanDEM-X: A satellite formation for high-resolution SAR interferometry," IEEE Trans. Geosci. Remote Sensing, vol. 45, pp. 3317–3341, Nov. 2007.

[6] F. Kugler et al., "TanDEM-X Pol-InSAR performance for forest height estimation," IEEE Trans. Geosci. Remote Sensing, vol. 52, pp. 6404–6422, Oct. 2014.

[7] F. Kugler et al., "Forest height estimation by means of Pol-InSAR data inversion: The role of the vertical wavenumber," IEEE Trans. Geosci. Remote Sensing, vol. 53, pp. 5294–5311, Oct 2015.

[8] S. K. Lee and T. E. Fatoyinbo, "TanDEM-X Pol-InSAR inversion for mangrove canopy height estimation," IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens., vol. 8, no. 7, pp. 3608–3618, 2015.

[9] S. Abdullahi, F. Kugler, and H. Pretzsch, "Prediction of stem volume in complex temperate forest stands using TanDEM-X SAR data," Remote Sensing of Environment, vol. 174, pp. 197–211, Mar. 2016.

[10] J. M. Lopez-Sanchez et al., "Retrieval of vegetation height in rice fields using polarimetric SAR interferometry with TanDEM-X data," Remote Sensing of Environment, vol. 192, pp. 30–44, Apr. 2017.

# Advanced Sentinel-1 Analysis Ready Data for the Ghana Open Data Cube and Environmental Monitoring

Jörg Haarpaintner[1], Brian Killough[2], Stella Ofori-Ampofo[3], Edward O. Boamah[3]

*[1] Norut-Northern Research Institute, [2] NASA-CEOS, [3] CERSGIS*

**Abstract**

The Africa Regional Data Cube (ARDC) is a new tool that aims to provide the latest earth observation and satellite technology to African countries, currently focusing on Kenya, Senegal, Sierra Leone, Ghana, and Tanzania, to address the sustainable development goals like food security as well as issues related to agriculture, deforestation, water access, etc. The open data cube (ODC) was developed by the Committee on Earth Observation Satellites (CEOS) in partnership with the Group on Earth Observations, Amazon Web Services, Strathmore University in Kenya, Office of the Deputy President - Kenya, and the Global Partnership for Sustainable Development Data.

Recent efforts have been undertaken to also include synthetic aperture radar (SAR) data and specifically Sentinel-1 CSAR in the form of “easy to use” analysis ready data (ARD) sets with the intention to make SAR data accessible to a broader community and explore more its potential for environmental monitoring in Africa.

As a first country case, the full Sentinel-1 interferometric wide swath mode level-1 GRD (ground range detected) data over Ghana has been processed into higher level ARD covering the period March 2015 to the present. The ARD consist in a time series of dual-polarization (VV and VH) monthly-averaged slope-corrected gamma naught ($\gamma 0$) backscatter mosaics. Additionally, first order yearly statistical parameters are also extracted during the processing.

In this study, we will present the full set of ARD time series over Ghana that will be made available through the ARDC and show how they can be used by local stakeholders for environment monitoring. We will specifically focus on the monitoring of “galamsey”, which is illegal small-scale gold mining and a main threat to the environment in Ghana.

The 3.5 year time series show clearly the resultant large scale environmental damage of forest loss resulting from the illegal mining. The results confirm earlier studies from 2017 done with optical Sentinel-2 data that have been validated with ground truth observation. The recent Sentinel-1 mosaics are also compared to historic observation based on L-band SAR from ALOS PALSAR from 2007/2008, showing the extent over a whole decade. Furthermore, we investigate the potential to use such Sentinel-1 ARD for near-real time detection of new areas of mining activities in the future. Other environment applications of Sentinel-1 ARD will also be discussed.

# Demonstrations of Wide-area Radar Backscatter Time Series Applications

David Small[1], Christoph Rohner[1], Nuno Miranda[2], Stephen Howell[3],
Marius Rüetschi[4], Lars Waser[4]

*[1] University of Zurich, [2] ESA-ESRIN, [3] Environment and Climate Change Canada,
[4] Swiss Federal Institute for Forest, Snow and Landscape Research WSL*

## Abstract

The effects of variable terrain within a SAR image often dominate the backscatter signature, as the phenomenon of radar foreshortening is much stronger than radiometric distortions seen in aerial photography or satellite images obtained with optical instruments. Radiometric terrain correction (RTC) makes use of a digital elevation model (DEM) to simulate the radar imaging geometry and correct for the modeled effects on radar backscatter. RTC backscatter products are therefore simpler to interpret across time, esp. in the presence of variable viewing geometries, beam-modes, or even sensors.

We combine multiple level 1 RTC products, by employing the image simulations originally put to use for the terrain corrections a second time, to enable the generation of multi-track wide-area backscatter composite images. The image simulations are "local imaged area" estimates in radar geometry. The reciprocal of the "local imaged area" is the local resolution. By weighing contributions to the composite by the local resolution, the observations made with the best geometry (i.e. down a mountain's non-shadowed back slope) are given the highest weights. All observations made within a set date range are processed to RTC level and then combined with local resolution weighting into a single composite backscatter map. The process is then repeated over a series of sliding time-windows. The resulting seamless composites enable change detection over wide areas, unrestricted by swath-size.

Using Sentinel-1 data, we demonstrate application of the technique over multiple regions, from the Alps to the Arctic, at medium resolution (400m), and at full sensor resolution (20m). We illustrate multi-sensor integration with C-band composites generated by combining Radarsat-2 and Sentinel-1 data. We demonstrate wide-area wet snow mapping, sea ice melt-onset detection, and forest-type mapping, all using wide-area backscatter composites as their basis. We conclude with an outlook to upcoming possibilities given combination of Sentinel-1 with Radarsat-Constellation-Mission data.

# Use of L-band polarimetric data to classify flooded areas beneath vegetation

Nazzareno Pierdicca[1], Luca Pulvirenti[2], Giorgio Boni[2], Giuseppe Squicciarino[2], Marco Chini[3]

*[1] Sapienza University of Rome, [2] CIMA Research Foundation, [3] Luxembourg Institute of Science and Technology*

**Abstract**

Among the problems related to the use of SAR data for target classification purposes, the discrimination of floodwater beneath vegetation still represents a challenge. Double-bounce backscattering is the key process to detect flooded vegetation. When ground is covered by a smooth and very reflective water surface, the intensity of the double-bounce effect involving the surface and vertical structures such as stems, shrubs, or trunks is increased, if the penetration into the canopy is sufficient. This increase can make the backscatter from flooded vegetation significantly higher than that from non-flooded vegetation, so that the former may appear brighter in a SAR image. However, flooded vegetation does not always have a clear radar signature that can be easily detected using SAR intensity (i.e., the backscattering coefficient) because several unknowns (e.g., plant water content, structure and geometry) influence the radar response from this target.

Considering that radar polarimetry is potentially able to discriminate the double-bounce among different scattering mechanisms, it can be worthwhile to investigate the potential of quad-pol SAR data for the classification of flooded areas beneath vegetation. L-band can represent the optimal band from this point of view, thanks to the capability of L-band radiation to penetrate the canopy. In this study, three ALOS-2 fully polarimetric images of rice fields are analyzed to investigate the added value of L-band polarimetry in detecting the increase of the intensity of the double bounce effect due to the presence of floodwater beneath vegetation. The fields are located in the Vercelli district (Northern Italy) and are periodically flooded and drained in sequence. The images were acquired in spring/summer 2015 (namely May 19th, June 16th and July 14th). The images (fine beam quad products) were multi-looked, geocoded, and calibrated. Polarimetric features were extracted taking advantage of the freely available POLSARpro software developed by the European Space Agency. First, the coherence and covariance matrices were derived. Then, the Freeman decomposition, that models the covariance matrix as the contribution of three scattering mechanisms, namely volume scattering, double-bounce scattering, and surface scattering, was used. Finally, the unsupervised Wishart classifier available through POLSARpro, was applied to classify the polarimetric images.

The classification results obtained by using L-band polarimetric data were compared to those obtained by using also C-band Radarsat polarimetric data, as well as single pol COSMO-SkyMed data. In addition, optical Landsat data were used as benchmark. The major outcomes of the classification results will be presented at the conference

# SInCohMap: Land Cover Classification and Vegetation Mapping based on Sentinel-1 Multi-Temporal Interferometric Coherence

Fernando Vicente-Guijalba[1], Alexander Jakob[2], Juan Manuel Lopez-Sanchez[3], Carlos López-Martínez[4], Dariusz Ziółkowski[5], Claudia Notarnicola[2], Javier Duro[1], Ruth Sonnenschein[2], Agata Hoscilo[5], Katarzyna Dąbrowska[5], Zbigniew Bochenek[5], Jordi J. Mallorqui[6], Erik Pottier[7], Marco Lavalle[8], Marcus Engdahl[9]

*[1] Dares Technology, [2] Eurac Research, [3] University of Alicante, [4] Luxembourg Institute of Science and Technology, [5] IGIK, [6] Universitat Poltecnica de Catalunya, [7] Universite de Rennes 1, [8] JPL, [9] ESA-ESRIN*

**Abstract**

The Sentinel-1 (S-1) mission defines a whole new playground where to explore the limits and potentialities of diverse technologies to generate updated and precise land-cover maps all around the globe. The availability of frequent and global data favors the emergence of alternative approaches to the mapping scene where mostly the optical, but also the radiometric, data have established their predominance.

In this regard, the ESA SEOM SInCohMap project is aimed to develop, analyse and validate novel methodologies for land cover and vegetation mapping by using time series of S-1 data and by exploiting the temporal evolution of the interferometric coherence. Since the Sentinel-1 constellation is operational, we are now in the fortunate position of having 6-day observation repeat intervals and hence can compute interferometric measures on this time scale. Additionally, S-1 data is available in two different polarizations, increasing the possible feature space that can be derived. Further, the project aims at quantifying the impact and possible benefit of using Sentinel-1 InSAR (Interferometric Synthetic Aperture Radar) data relative to traditional land cover and vegetation mapping using optical data (especially Sentinel-2) and traditional intensity-based SAR (Synthetic Aperture Radar) approaches. In general, interferometric coherence is affected by a combination of terms derived from the system, the observation geometry or the observed scene. In previous studies, this parameter has proven to be a good feature for deriving the particular land cover on ground.

Within the framework of the project, a Round Robin consultation has been devised with the objective of performing a valuable comparison between classification strategies. A pre-processed dataset consisting in two-year InSAR data covering three study areas (Spain, Italy and Poland) with a wide variety of land-covers and vegetation has been offered to external and internal participants of the project consortium. The main goal of this consultation was to evaluate classical and state-of-the-art classification strategies to assess the full potentiality of the interferometric data focused in the generation of land-cover and mapping information. Along with an overview and status of the project, in this paper the specifics about the consultation process and the final results of the Round Robin consultation will be presented and discussed.

# Land observations with L-band bistatic systems

Leila Guerriero[1], Nazzareno Pierdicca[2], Marco Brogioni[3], Davide Comite[2], Fabio Fascetti[2], Nicolas Floury[4]

*[1] University of Rome Tor Vergata, [2] Sapienza University of Rome, [3] IFAC-CNR, [4] ESA-ESTEC*

## Abstract

Bistatic Radar for Earth Observation has been recently proposed for interferometric and urban applications, addressing bistatic geometry with relatively small spatial baselines, i.e., quasi monostatic configurations. In this work, we explore the scattering behaviour of land surfaces for arbitrary bistatic configuration, that is for any observing direction of the passive element, even out of the incidence plane and with large baselines. This study is based on electromagnetic model simulations with two main objectives: i) providing a characterization of the target scattering coefficient to support the technical design of a bistatic imaging system at L-band, ii) understanding its potential to infer bio-geophysical parameters, namely soil moisture and vegetation biomass, eventually in combination with conventional monostatic data.

The electromagnetic models adopted in this work for bare soil incoherent scattering are the Advanced Integral Equation Model (AIEM) and the Small Slope Approximation up to the second order (SSA2) [Johnson and Ouellette, 2013]. As far as vegetated targets are concerned, we have considered the Tor Vergata (TOV) model [Guerriero et al., 2013], which is a radiative transfer model with a discrete approach for vegetation elements. As for the coherent scattering from the rough soil surface, which is important when looking at the specular direction, we have adopted a revised version of the model in [Fung and Eom, 1983].

The performance analysis has been carried out by means of the Cramer Rao Lower Bound (CRLB), starting from the sensitivities predicted by the models to the different target parameters. Here it has been considered for the retrieval of soil moisture of both bare and vegetated soil, considering the effect of unknown roughness variations, and for that of biomass of a vegetated surface, considering the unknown variation of soil moisture. Possible limitations can be related to the noise equivalent sigma naught (NE 0), i.e. the lowest measurable 0 due to system noise. The retrieval capability can be affected when the signal is below the noise floor, a condition that can be achieved in particular configurations. The results of this study show that the most effective configuration for the passive system is at an azimuth angle close to 90° with respect to the incidence plane, and at VV polarization. This is mainly because at HH polarization the signal is lower and the saturation due to the noise floor is more likely reached.

The availability of a bistatic measurement at VV polarization at about 90° azimuth angle improves also the accuracy of the SMC estimation in vegetated surfaces, with respect to monostatic measurements.

The CRLB tool has been used also to detect the azimuth anisotropy of the surfaces. A theoretical study has demonstrated a significant improvement in the retrieval of wind speed when active and passive systems flow on the same orbital plane, provided that the AT baseline is long enough. Finally, L-band bistatic synthetic images with different land covers have been generated with the addition of the speckle noise. A retrieval exercise has been carried out using monostatic or multistatic images, i.e, simultaneous monostatic and bistatic acquisitions, to show the potential of a multistatic approach, although in a simulated scenario.

# Improved multi satellite retrieval by combining SAR with Optical observations - The MULTIPLY framework

Joris Timmermans[1], Peter van Bodegom[1], Philip Marzahn[2], Thomas Weiss[2], Thomas Ramsauer[2], Jose Gomez Dans[3], Feng Yin[3], Tonio Fincke[4], Nicola Pounder[5], Gerardo Lopes Saldana[5]

*[1] Leiden University, [2] Ludwig-Maximilians-Universität Munich, [3] University College London, [4] brockmann consulting, [5] Assimila*

**Abstract**

Human society increasingly depends on information derived from Earth Observation (EO) data. In particular, there is an growing demand for information facilitating agriculture, forestry, soil moisture and hydrology. To this purpose the number of space-borne satellites is projected to increase dramatically over the next years, in the form of ESA/NASA scientific missions but also small cube-sat constellations. This increase in available satellite observations also provides enormous challenges in terms of retrieving actual information from this big data. The general trend currently is to create individual land surface products for each satellite mission. In that regard, a range of individual products are created using a single-sensor approach for similar land surface parameters. Such single-sensor approaches do not take into account synergies between different sensors. Additionally the diversity of single-sensor processing chains cause an inconsistency between the different produced land surface products. In order to facilitate actual usage of earth observation data, a novel multi-sensor framework (together with a new mindset) needs to be created that circumvents these limitations.

Currently, there is no consistent framework to integrate observations from different sensors in order to obtain the best possible estimate of the land surface state, as it is hard to account for the different characteristics of different sensors and to coordinate the data streams. MULTIPLY proposes a solution to this challenge. Specifically: MULTIPLY aims to:

1) Combine data from SAR observations flexibly with optical remote sensing data using compatible radiative transfer models.

2) Design a data assimilation platform incorporating as many information sources (observational, prior, multi-temporal) to optimally retrieve satellite information that are gap-free.

3) Deliver a set of internally consistent data products at different resolutions (coarse and high) with quantified uncertainties.

4) Explore potential applications that demand consistent land surface products, such as agriculture, forestry and soil moisture.

Within this presentation the operational MULTIPLY data assimilation framework will be discussed in detail. The presentation will specifically focus on a) the coupling of the different SAR observations together with optical observations in order to jointly and consistently retrieve soil parameters as well as vegetation traits and b) elaborate on the results of the fieldwork validation efforts.

# Multi-temporal approach for the detection of temporary flooded vegetation based on Sentinel-1 data

Viktoriya Tsyganskaya[1], Sandro Martinis[2], Philip Marzahn[1]
*[1] Ludwig-Maximilians-Universität Munich, [2] German Aerospace Center*

**Abstract**

Flood events can have devastating consequences on society, economy and ecosystems worldwide. Precise information about the flood extent in the affected areas is therefore an essential foundation for local relief workers, decision-makers from crisis management authorities or insurance companies. Besides the open water, flooded vegetation areas are essential for a detection of the entire flood extent. Synthetic Aperture Radar (SAR) is particularly suitable for mapping large-scale inundations, as this tool allows recording of the affected area regardless of illumination or weather conditions. Continuous monitoring of the Earth's surface is achieved by the Sentinel-1 satellite constellation, which provides C-band SAR time series data that can be used to detect changes over time. Based on this SAR time series data and auxiliary information about land cover and topography, a multi-temporal approach was developed for the extraction of flood extent with a focus on temporary flooded vegetation (TFV).

The method is tested on a three case studies in Namibia, Greece and China, all characterized by a large flood event. Due to the strong dependence of the backscatter values on the different TFV types and other environmental conditions it is revealed that for the individual study areas different time series feature, which are based on different polarisations and their combinations, have been identified as reliable for the classification. It is demonstrated that the SAR time series approach enables the extraction of flood-related classes and the derivation of the entire flood extent by supplementing temporary open water by TFV areas. A quantitative evaluation of the generated inundation maps for the individual case studies shows that all study areas have obtained an overall accuracy between 75.0% and 87.3% for pixel- and object-based classification.