PROGRAM BOOK

14th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment

April 11-14, 2016, Espoo, Finland

Editors: Martti Hallikainen, Jaan Praks, Jaakko Seppänen





SCIENCE + TECHNOLOGY CONFERENCE PROCEEDINGS

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MICRORAD 2016

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Aalto University School of Electrical Engineering Department of Radio Science and Engineering

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WELCOME TO MICRORAD 2016 IN ESPOO!

On behalf of the Local Organizing Committee and the Steering Committee, we are very pleased to welcome you to the 14th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment, MicroRad 2016, in Espoo, Finland. MicroRad meetings have been held usually every 2 years since their inception in Rome in 1983. All previous meetings were organized alternately in Italy and the United States, but the MicroRad Steering Committee invited us in 2013 to organize the next European meeting. We are honored to organize MicroRad 2016 on Aalto University Campus in Espoo, a neighboring city of Helsinki, the Capital of Finland.

MicroRad is a unique gathering where the microwave radiometry community has an opportunity to present new designs, research results, technological advances and unique innovations in the field of passive microwave remote sensing. The meeting will cover radiometry applications and fields such as soil moisture and state, terrestrial snow, sea ice, ocean salinity and dynamics, atmosphere sounding, precipitation, instrument calibration, experimental campaigns, current and future missions, remote sensing using small satellites, theory and electromagnetic modeling, radio frequency interference issues, and new technologies.

The MicroRad 2016 Call for Papers generated a response of 174 abstracts. Following the tradition of MicroRad, we will have a single track of oral sessions along with interactive sessions during the week. The papers were peer reviewed and organized into 16 oral sessions with 78 papers and 13 interactive sessions with 69 papers. We organized the technical topics over the week so that attendees will find topics directly related to their research spread over the entire meeting. The poster sessions are scheduled within two hour interactive sessions placed between the afternoon oral sessions on Tuesday and Wednesday of the conference. Additionally, the coffee breaks and lunches will be held in the immediate vicinity of the posters allowing for extended informal discussions.

As a new feature in the technical program, we have three invited presentations covering new technologies and applications. An invited presentation will be the first talk on Monday, Tuesday, and Wednesday. A technical tour to Aalto University will take place on Friday morning after the conference.

The social program consists of an Opening Reception on Monday, a Reception sponsored by the City of Espoo on Tuesday, and the Conference Dinner on Wednesday. These events will provide additional opportunities to catch up with colleagues.

We hope you will find the depth and diversity of the MicroRad 2016 technical program representative of the current state of the art. Passive microwave radiometry has since the launch of the ESA SMOS satellite in 2009 entered a very interesting period together with the subsequent launches of Aquarius in 2011 and SMAP in 2015, with L-band radiometers being used for monitoring the Earth's land and ocean areas. This is reflected in the conference program. Other new fields include the development of small satellites and nanosatellites for remote sensing. We have organized the sessions based on technical and scientific topics rather than based on the used instruments.

Authors are encouraged to submit full papers to the proceedings via the MicroRad 2016 website. The deadline for submitting a proceedings paper is May 5, 2016. In addition to the conference proceedings that will be available after the conference, there will be a Special Issue of the IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (JSTARS) for MicroRad 2016. The JSTARS Special Issue is open to all contributions in the field of microwave radiometry, with primary interest in MicroRad topics. The submission deadline is July 1, 2016.

We express our gratitude to all members of the MicroRad 2016 Local Organizing Committee, the Permanent Steering Committee and session co-chairs for their assistance in the planning and execution of MicroRad. We gratefully acknowledge the support and cooperation of the IEEE Geoscience and Remote Sensing Society (GRSS), Aalto University, URSI Commission F, and the Center for Microwave Remote Sensing (CeTeM). We thank Conference Management Services for excellent co-operation.

We would also like to recognize the efforts of the reviewers appearing below and thank them for their contributions to MicroRad 2016. Their reviews, scoring and insightful comments provided a strong basis for organization of this meeting. We hope you enjoy your visit to Espoo and your participation in MicroRad 2016!

We wish you an enjoyable and productive MicroRad 2016 in Espoo, Finland!

Sincerely, Martti Hallikainen General Chair, MicroRad 2016

Jaan Praks Technical Chair, MicroRad 2016

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TRANSPORTATION

FROM/TO HELSINKI INTERNATIONAL AIRPORT

The Helsinki-Vantaa International Airport is the main gateway to Helsinki and the rest of Finland. You can travel from the airport to Helsinki by Airport City Bus, train, taxi, or Yellow Line shuttle. If you stay in Espoo, probably the best way is to take a taxi directly to your hotel. Also car rental is available at the airport. The website for Helsinki Airport services is

http://www.finavia.fi/en/helsinki-airport/

AIRPORT CITY BUS

Finnair City Bus provides service between the Airport and the central railway station in Helsinki with departures approximately every 20 minutes. The website for checking the time table and route is

https://media.finnair.com/files/pdf/FINNAIR_CITY_BUS_TIMETABLE.pdf

AIRPORT TRAIN

Helsinki Airport is connected to the national railway network. Trains take passengers from the airport to Helsinki city center in about 30 minutes and depart approximately every 15 minutes, depending on weekday and time of day. More information is available at

https://www.hsl.fi/en/ringrailline

AIRPORT TAXI

Taxi service is available at the airport. For somewhat cheaper service, you can use taxi shuttle to and from the airport. Taxis and Yellow Line shuttles accept major credit cards. Information on Yellow Line is available at

http://www.airporttaxi.fi/index_airporttaxi_en.html

AIRPORT CAR RENTAL

Several car rental companies operate at the airport. For more information see http://www.finavia.fi/en/helsinki-airport/services/parking-and-traffic/

PUBLIC TRANSPORTATION IN GREATER HELSINKI AREA

Public transportation serves well the whole Helsinki region and is recommended for all your transportation needs while staying in Espoo/Helsinki. The easiest way to navigate in the public transportation network is to use Journey Planner

http://www.reittiopas.fi/en/

which gives timetables, stop lists, and route maps online. The following links at the MicroRad 2016 website (http://www.microrad2016.org) provide information on transportation between the airport, Helsinki Bus Terminal, and Aalto University's Otaniemi campus:

Airport to Aalto University http://www.reittiopas.fi/en/?from_in=airport&to_in=otakaari%201

Airport - Helsinki Bus Terminal (Kamppi) http://www.reittiopas.fi/en/?from_in=airport&to_in=kamppi

Helsinki Bus Terminal (Kamppi) – Aalto University http://www.reittiopas.fi/en/?from_in=kamppi&to_in=otakaari%201

Aalto University - Helsinki Bus Terminal (Kamppi) http://www.reittiopas.fi/en/?from_in=otakaari%201&to_in=kamppi

The Journey Planner can be used also on your smartphone by using for example Andropas app for Android or OnTimely-Helsinki for iPhone. Both apps can be downloaded and used for free, but data charges may apply according to your data plan.

TAXI IN HELSINKI AND ESPOO

You can order a taxi anywhere in Helsinki area by calling +358 1000 700. Taxis are also available next to the entrance of the Dipoli Congress Centre (no. 19 on Campus map). Taxis accept major credit cards.

How to Get from Helsinki to Conference Venue

The conference venue is located in Otaniemi, on Aalto University campus, 9 km west from Helsinki city center. The campus area is well connected with Helsinki city center and airport with public transport. If you are staying in Original Sokos Hotel Presidentti in downtown Helsinki, you can walk to the nearby Helsinki Bus Terminal and take bus no. 102 or 103 (these are faster), or 102T or 103T to Otaniemi.

There is massive building construction work in progress near the Conference venue, preventing buses from entering the western part of Otakaari Street. The temporary bus route for bus 102 is shown below. The bus stop close to the Conference venue (also for bus 103) is near the roundabout as shown on the map below. Follow signs from the bus stop to the MicroRad venue.

Parking on Campus is not recommended due to the ongoing construction work. Parking slots are limited and most parking areas require a permit.





Aalto University Otaniemi Campus: 1 MicroRad 2016 venue, 4 School of Electrical Engineering, 15 Aalto University Library and bus stop, 20 Shopping Centre (including a grocery store, pharmacy, and kiosk), below 42 Radisson Blu Hotel Espoo. Symbol T near no. 19 is for a taxi station.

CONFERENCE VENUE

ORAL SESSIONS

The venue is the Aalto University main building (no. 1 on Campus Map). Oral sessions are held on Level 2 in Lecture Hall B. Presenters should upload their presentation onto the conference computer at the desk outside Hall B. Presentations before lunch should be loaded prior to the first session of the day. Presentations after lunch can be loaded in the morning or during the lunch break.

POSTER SESSIONS

The poster sessions will take place on Level 2 outside Hall B. Authors are requested to attend their poster during the official Poster Session time. Posters can also be viewed informally during the coffee breaks. Authors in the Tuesday session are asked to hang their posters by Monday afternoon and remove them by Wednesday morning. Authors in the Wednesday session are asked to hang them by lunch time on Wednesday and remove them by Thursday afternoon. Material for mounting the posters will be available at the registration desk.

Following the tradition of MicroRad, the best posters will receive a prize. A specific committee is responsible for the evaluation.

LUNCHES AND COFFEE BREAKS

Lunches and coffee during breaks are included in the conference registration. All lunches and coffee breaks will take place on Level 2 outside Hall B. A cafeteria is located on Level 1.

ADDITIONAL INFORMATION

The following functions are located on Level 1: Guarded wardrobe for MicroRad attendees (free of charge), cafeteria, and entrances to washrooms located on Level -1.

WI-FI NETWORK

The **aalto open** network is an unencrypted wireless network available for everyone. WLAN devices, such as smart phones and tablets, connect usually automatically to **aalto open**, because it is fully open without any authorization. Also the **eduroam** network can be used at campus area.

SPECIAL EVENTS

APRIL 11: OPENING RECEPTION

An opening reception will be held on Level 2 outside Hall B directly after the last oral session of the day. The event will feature snacks along with wine and other beverages. The opening reception is open to all registered for MicroRad.

APRIL 12: ESPOO CITY RECEPTION

The City of Espoo sponsors a reception at the Tapiola Cultural Center about three kilometers from the conference venue. Buses for the reception will leave in front of the conference building main entrance. Mr. Harri Tanska, Director of Espoo City Public Works, will welcome attendees at the reception. The event will feature snacks along with wine, beer and soft drinks. After the reception bus transportation is provided to Radisson Blu Hotel Espoo and Original Sokos Hotel Presidentti in Helsinki.

APRIL 13: CONFERENCE BANQUET

The MicroRad banquet will be held in Restaurant Sipuli (address: Kanavaranta 7, 00160 Helsinki), which is a restored red brick warehouse, located next to the Uspenski Cathedral. Dinner tickects (80 Euro) can be bought until Monday afternoon, April 11. The Golden Florin Award will be presented at the banquet. Bus transportation from conference venue to Restaurant Sipuli will be available. After the Banquet bus transportation will be available to Original Sokos Hotel Presidentti in Helsinki and Radisson Blu Hotel Espoo.

APRIL 15: TOUR TO AALTO UNIVERSITY

The Aalto tour will take place on Friday, April 15, starting at 9:00 am and is open to those that have registered for it. You should plan to arrive at the School of Electrical Engineering (no. 4 on Campus map) by 8:45 am. The tour starts with a visit to the Remote Sensing and Nanosatellite facilities in the EE Building and proceeds then to selected laboratories on Campus. Cameras are permitted on the tour, which will end by 12:00 noon.

PROCEEDINGS PAPERS

Authors are encouraged to submit full-length manuscripts for the MicroRad 2016 proceedings by May 5, 2016. Only papers submitted, registered and presented at the conference will be included in the proceedings. These full-length articles will be reviewed by the technical committee and published in the IEEE Xplore as part of the conference proceedings. Manuscripts should be submitted electronically on the MicroRad 2016 website. Submissions must be between a minimum of 2 pages and maximum of 6 pages long. Templates for formatting can be found on the MicroRad 2016 website.

SCHEDULE OVERVIEW

Monday, April 11

07:00 - 08:00	Registration	Outside Hall B
08:00 - 08:20	Opening Remarks	Lecture Hall B
08:20 - 08:50	Simon Yueh: SMAP Mission and Science Recovery Status	Lecture Hall B
08:50 - 10:10	M1: Oceans	Lecture Hall B
10:10 - 10:40	Coffee Break	Outside Hall B
10:40 - 12:20	M2: Satellite Missions	Lecture Hall B
12:20 - 13:20	Lunch	Outside Hall B
13:20 - 15:00	M3: Sea Ice	Lecture Hall B
15:00 - 15:30	Coffee Break	Outside Hall B
15:30 - 17:30	M4: Snow	Lecture Hall B
17:30 - 19:30	Opening Reception	Outside Hall B

Tuesday, April 12

08:00 - 08:30	Ville Kangas: Current and Future Microwave Radiometers at ESA	Lecture Hall B
08:30 - 09:50	T1: Soil Moisture	Lecture Hall B
09:50 - 10:20	Coffee Break	Outside Hall B
10:20 - 12:00	T2: Instruments and Techniques	Lecture Hall B
12:00 - 13:00	Lunch	Outside Hall B
13:00 - 14:40	T3: Small Satellite Instruments and Missions	Lecture Hall B
14:40 - 16:00	TP: Atmosphere Sounding and Global Change	Outside Hall B
14:40 - 16:00	TP: Clouds and Precipitation	Outside Hall B
14:40 - 16:00	TP: Current and Future Missions	Outside Hall B
14:40 - 16:00	TP: Experimental Campaigns	Outside Hall B
14:40 - 16:00	TP: Instruments and Techniques	Outside Hall B
14:40 - 16:00	TP: Ocean and Ice	Outside Hall B
14:40 - 16:00	TP: Small Satellite and UAV Instruments and Missions	Outside Hall B
16:00 - 18:00	T4: Precipitation	Lecture Hall B
18:30 - 20:00	Espoo City Reception	Espoo Cultural Center

Wednesday, April 13

08:00 - 08:30	Jiancheng Shi: Monitoring Vegetation with Microwave Radiometers	Lecture Hall B
08:30 - 09:50	W1: Vegetation	Lecture Hall B
09:50 - 10:20	Coffee Break	Outside Hall B
10:20 - 12:00	W2: Instrument Technology	Lecture Hall B
12:00 - 13:00	Lunch	Outside Hall B
13:00 - 14:40	W3: Atmosphere Sounding	Lecture Hall B
14:40 - 16:00	WP: Passive/Active Instruments and Techniques	Outside Hall B
14:40 - 16:00	WP: RFI and Spectrum Management	Outside Hall B
14:40 - 16:00	WP: Sensor Calibration	Outside Hall B
14:40 - 16:00	WP: Snow and Antarctica	Outside Hall B
14:40 - 16:00	WP: Soil Moisture and Vegetation I	Outside Hall B
14:40 - 16:00	WP: Soil Moisture and Vegetation II	Outside Hall B
16:00 - 17:40	W4: Sensor Calibration	Lecture Hall B
19:00 - 22:30	Banquet	Restaurant Sipuli

Thursday, April 14

08:00 - 09:40	H1: Soil and Hydrology	Lecture Hall B
09:40 - 10:10	Coffee Break	Outside Hall B
10:10 - 11:50	H2: RFI and Spectrum Management	Lecture Hall B
11:50 - 12:50	Lunch	Outside Hall B
12:50 - 14:30	H3: Snowfall Retrieval and Atmospheric Modeling	Lecture Hall B
14:30 - 15:00	Coffee Break	Outside Hall B
15:00 - 16:20	H4: Theory and EM Models	Lecture Hall B
16:20 - 16:40	MicroRad 2018 Venue and Organizer	Lecture Hall B
16:40 - 16:50	Closing Remarks	Lecture Hall B

Friday, April 15

09:00 - 12:00 Technical Tour to Aalto UniversityMeet at School of Electrical Engineering (no. 4 on Campus map)

Monday, April 11	SMAP Mission and Science Recovery Status	08:20 - 08:50
Invited Presentation	Simon Yueh, NASA Jet Propulsion Laboratory	Lecture Hall B

Monday, April 11	Oceans	08:50 - 10:10
Lecture Session		Lecture Hall B

Session Co-Chairs: David Le Vine, NASA Goddard Space Flight Center; Simon Yueh, NASA Jet Propulsion Laboratory

Paper 1 OCEAN PRODUCTS FROM THE SMAP RADIOMETER: SURFACE SALINITY AND WIND SPEEDS

08:50 Thomas Meissner, Frank Wentz, Remote Sensing Systems, United States; David LeVine, Emmanuel Dinnat, Goddard Space Flight Center, United States; Gary Lagerloef, Earth and Space Research, United States

With the demise of Aquarius the ability of the SMAP sensor to measure ocean salinity has gained importance. Our presentation discusses the adaption of the Aquarius salinity retrieval algorithm to SMAP. It includes corrections for signals from the rough ocean surface, the atmosphere and ionosphere, cold space, galaxy, sun, moon as well as sidelobe and cross polarization effects from the SMAP antenna.

Our presentation will also address several important differences between the Aquarius and SMAP sensors that impact the ocean salinity retrieval algorithm and its performance:

1. The full 360-deg look of SMAP makes it possible to take observations from the forward and backward looking direction basically at the same instance of time. This two-look capability strongly aids the salinity retrievals. It is possible to observe some of the spurious contamination sources such as the reflected galaxy or Faraday rotation in the Earth's ionosphere from different directions.

2. The spatial resolution of a SMAP radiometer measurement is about 40 km compared with 100 km for Aquarius. This higher resolution is associated with a higher noise for SMAP. Performing weekly or monthly time averaging is essential to reduce the noise in order to still achieve the accuracy goal of 0.2 psu. The 1000 km wide swath and 360-deg scan make this possible.

3. Due to the demise of the SMAP radar, SMAP does not provide valuable L-band scatterometer wind speeds at the same location and time as the radiometer observation as Aquarius did. Therefore the SMAP salinity retrieval algorithm needs to use wind speeds from WindSat and SSMIS for correcting the surface roughness effect.

4. The emissivity of the Aquarius antenna was negligible, whereas the SMAP antenna is slightly emissive and its emissivity is estimated to be about 1%. This causes significant spurious biases in the SMAP salinity data that correlate with the physical temperature of the antenna, which depends on solar heating. It is therefore necessary to develop a correction for this emissivity signal.

5. SMAP has better RFI detection and filter capability than Aquarius. We expect that this will result in improved salinity retrievals in the North Atlantic along the North American and European Coast and in the Eastern Pacific near the China and Japan.

Finally, we will address the capability to measure ocean surface wind speed with the SMAP radiometer. As it has been demonstrated with Aquarius and SMOS the L-band passive ocean surface emission exhibits very good sensitivity to surface wind speeds up to at least 35 m/s and it is very little affected by precipitation. This allows the retrieval of ocean surface winds, in particular in storms and even under rainy conditions.

Paper 2 THE APPLICATIONS OF SMAP DATA TO RETRIEVAL OF OCEAN SURFACE WIND AND SALINITY

09:10 Simon Yueh, Alexander Fore, Wenqing Tang, Hayashi Akiko, NASA Jet Propulsion Laboratory, CalTech, United States

NASA's Soil Moisture Active Passive (SMAP) mission, the first Earth Science Decadal Survey mission, was launched January 31, 2015 to provide high-resolution, frequent-revisit global mapping of soil moisture. SMAP included two L-band (\sim 1 GHz) instruments, a polarimetric radiometer and a multi-polarization synthetic aperture radar. (The radar ceased operation on July 7, 2015). The radiometer has been operating with excellent performance using a single 6-m rotating mesh antenna to produce a fixed incidence angle conical scan at 40° across a 1000-km swath and a 2-3 day global revisit.

We have analyzed the available SMAP data acquired over ocean surfaces. The collocated data analysis with NCEP wind, Reynolds sea surface temperature, and HYCOM's sea surface salinity indicated an excellent agreement of the SMAP data with the Aquarius radiometer and radar model functions on ocean surface wind effects. The SMAP ocean surface wind retrieval algorithm was developed at the Jet Propulsion Laboratory by leveraging the QuikSCAT and Aquarius algorithms to account for the two-look geometry (fore and aft looks from the conical scan) and dual-polarization observations. The retrieval algorithm has been applied to more than five months of SMAP data. The retrieved ocean surface wind speed from SMAP's data is in excellent agreement with the European Center for Medium-Range Weather Forecast (ECMWF) with RMS difference of about 1.2 ms-1. We have also compared the SMAP wind speed with the best track analysis of several category 4 and 5 Pacific hurricanes and typhoons in 2015, including Jimena, Nangka, Ignacio, Dolphin, Noul, and Chan_Hom. The maximum wind speed observed by SMAP was in general agreement with the best track analysis. Our results indicate that the L-band remote sensing data will be useful for severe ocean weather monitoring. This corroborates the findings from the SMOS data published in the literature.

We have also applied the SMAP data for sea surface salinity retrieval. The spatial patterns of the SMAP SSS agree well with climatological distributions, but exhibit several unique spatial and temporal features. The temporal evolutions of freshwater plumes from several major rivers, such as the Amazon, Niger, Congo, Ganges, Salween, and Mississippi, are all consistent with the timing of rainy and dry seasons, indicated in the SMAP's soil moisture products.

Paper 3 FEASIBILITY OF ESTIMATING OCEAN SURFACE WINDS UNDER PRECIPITATION WITH GPM GMI AND DPR

09:30 Stephen (Joe) Munchak, NASA Goddard Space Flight Center, United States; William Olson, University of Maryland, Baltimore County, United States; Mircea Grecu, Morgan State University, United States; Robert Meneghini, NASA Goddard Space Flight Center, United States

The Global Precipitation Measurement Mission's Microwave Imager (GMI) and dual-frequency Precipitation Radar (DPR) are designed to be sensitive to precipitation, and thus cover the frequency range from 10-183 GHz (GMI) and Ku/Ka band (DPR). The lower range of GMI frequencies and surface backscatter of DPR are also sensitive to roughening of the ocean surface by wind, and thus a framework to simultaneously retrieve the winds and precipitation column has been developed.

First, a geophysical model function (GMF) for KuPR and KaPR surface backscatter cross-section is derived by referencing well-calibrated GMI-retrieved ocean winds under clear-sky conditions. Then, the GMF is built from coincident DPR observations of the surface backscatter cross-section. This GMF is then used in an ensemblebased precipitation retrieval algorithm, where the surface wind is perturbed in the initial ensemble generation along with properties of the precipitation profile. Next, the ensemble is filtered by calculating the sample covariances between simulated observations and properties of the precipitation profile and surface.

In light and moderate rain (< 10 mm/hr), the sample covariances between lower-frequency (10-18 GHz) brightness temperatures and Ku-band backscatter with wind are substantial, allowing the retrieval to improve upon the initial state. Ka-band backscatter and higher-frequency brightness temperatures, which are more sensitive to precipitation, allow for some separation of the precipitation and wind impact on observations. Comparisons to buoy data result in a wind root-mean-square error of 3.7 m/s using Ku+6MI observations, and 3.2 m/s when using Ku+Ka+6MI observations. The effects of wind direction and precipitation-induced surface roughness will also be discussed.

Paper 4 IMPACT OF ATMOSPHERIC BOUNDARY LAYER STABILITY ON OCEAN EMISSIVITY AT L-BAND: UNDERSTANDING 09:50 REGIONAL AND SEASONAL SALINITY BIASES IN AQUARIUS DATA

Shannon Brown, Sidharth Misra, NASA Jet Propulsion Laboratory, CalTech, United States

The correction for wind-driven rough surface emission is one of the largest corrections that are required for satellite based sea surface salinity (SSS) retrieval. Missions such as SMOS, Aquarius and SMAP use models that describe the excess emission as a function of wind speed to remove this signal from the data in order to accurately estimate the sea water dielectric and hence SSS. Several studies have shown boundary layer stability is a key factor in air-sea interaction, including wave and foam formation and that wind speed alone may not be sufficient to describe the excess emission of the ocean. Analysis of Aquarius salinity biases with respect to in situ probes (ARGO) and an ocean model (HYCOM) have revealed systematic biases in the northern and southern high latitudes that are a half-year out of phase which each other, indicating a probable shortcoming in the physics of one of the correction models. These biases have been shown to be related to atmospheric boundary layer stability by correlating the biases with respect to air-sea temperature difference, a measure of boundary layer stability. The boundary layer is unstable when the atmosphere is colder than the ocean surface and stable when the air is warmer than the surface. There is a strong seasonal and regional degendence of girsea temperature difference, with winter months at high-latitudes having on-average unstable conditions and summer months having on-average stable conditions. Microwave sea surface excess emissivity has been shown to have a significant dependence on air-sea temperature difference at C-band and higher, with sensitivities upward of -0.4 K/C reported at Cband. The main reason is thought to be the influence of boundary layer stability on foam-formation. Monghan and O'Muircheartaigh (1986) show that foam fraction increases by about 10% per dearee of air-sea temperature difference at a fixed wind speed and Salisbury et al. (2013), show a decrease in foam fraction for warm SSTs (> 15C). In this paper, we will describe a new ocean surface roughness geophysical model function derived from Aquarius data which explicitly accounts for atmospheric boundary layer stability. It is shown that the residual SSS retrieval error reaches 0.07 psu/delta-C if this correction is not accounted for. We will show an improvement of the Aquarius salinity retrievals after the correction is applied and the reduction of the regional and seasonal salinity differences that are observed in the Version 4 product. This correction will be implemented in the end-of-mission Version 5 data product.

Monday, April 11	Satellite Missions	10:40 - 12:20
Lecture Session		Lecture Hall B

Session Co-Chairs: Elena Lobl, University of Alabama in Huntsville; Mariano Kornberg, LSE Space GmbH

Paper 1 STATUS OF AQUARIUS AND THE SALINITY RETRIEVAL

10.40

David Le Vine, NASA Goddard Space Flight Center, United States; Emmanuel Dinnat, Chapman University, United States; Thomas Meissner, Frank Wentz, Remote Sensing Systems, United States; Gary Lagerloef, Earth and Space Research, United States

Aquarius is a radiometer/scatterometer combination specifically designed for remote sensing of sea surface salinity. The instrument was lost on June 7, 2015 when a power failure on the satellite resulted in loss of control of the observatory. This paper will report the plans for the mission and data processing and the status of the validation of the SSS data against Argo measurements.

Aquarius functioned well from the time it was turned on August 25, 2011 until the observatory was lost in June, 2015, providing almost 4 years of data on the global sea surface salinity field. This included a short look at the inter-annual variability. A plan for terminating the mission has recently been approved that includes a final reprocessing of the Aquarius data (version 5.0) to be completed late in 2016 or early 2017 followed by an official end of the mission in June, 2017.

Just before the observatory failure in June, Aquarius released Version 4.0 of the salinity retrieval. This version included several changes to improve the retrieval. The most significant are an update of the corrections for land and ice in the radiometer FOV and inclusion of the SST bias into the geophysical model function for emissivity. In addition, an error estimate is now provided for the retrieval, the RFI algorithm has been tuned to have equal false alarms rates over ocean and land, and density has been added as a product in the level 2 file. Version 4.0 retrievals meet the requirement of 0.2 psu in most areas of the ocean, although high latitudes still present problems. Matchups with Argo will be presented to illustrate the overall performance of V4.0 and also the remaining dependence on latitude.

Work is currently under way on a final version of the retrieval, V5.0, which will be produced before the mission is closed by June 2017. This will include several issues that have been the subject of research by the project including an instrument-dependent correction for gain and drift, update of the full-range calibration (i.e. land, ocean and sky), effect of rain, optimum choice of ancillary values of SST, improved model for land emission (consistency with SMAP), performance at high latitudes, and improvements in the RFI detection algorithm. After the mission ends, the Aquarius data and documentation will remain available to the public for other applications and future reprocessing. There is hope that SMAP will help continue the legacy of SSS measurements.

Paper 2 SMOS MISSION AFTER 6 YEARS IN SPACE: WHERE ARE WE?

11:00 Yann H. Kerr, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Susanne Mecklenburg, Steven Delwart, ESA-ESRIN, Italy; Jacqueline Boutin, Paolo Ferrazzoli, LOCEAN, France; Jordi Font, Institute of Marine Sciences, CSIC, Spain; Ali Mahmoodi, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Nicolas Reul, IFREMER, France; Philippe Richaume, Arnaud Mialon, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Amen Al Yaari, INRA ISPA, France; Simone Bircher, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Jean-Pierre Wigneron, INRA ISPA, France

The SMOS (Soil Moisture and Ocean Salinity) satellite was successfully launched in November 2009. This ESA led mission for Earth Observation is dedicated to provide soil moisture over continental surface (with an accuracy goal of 0.04 m3/m3) vegetation water content over land and ocean salinity. These geophysical features are important as they control the energy balance between the surface and the atmosphere. Their knowledge at a global scale is of interest for climatic and weather researches in particular in improving models forecasts.

The SMOS instrument measures the passive microwave emission of the Earth surface at a frequency of 1,4 GHz (L-band). The instrument is an interferometer and provides brightness temperatures with an average resolution of 40 km, at several angles and dual polarizations. Data are acquired at two times in a day at 6 am and 18 pm (local time) and insure a complete coverage of the Earth surface in 3 days with a sampling of 15 km. The main products of the mission are of course Soil Moisture and Sea Surface salinity, but also vegetation opacity (directly related to water content) of vegetation covers including forests, surface dielectric constant for level two but also brightness temperatures at the surface, strong winds, root zone soil moisture and RFI (radio frequency interferences) maps. From Level 2 SMOS data several groups have started making new products several of them being either operational or on the verge of being such. We will show some of them or refer to related presentations. They include freeze defreeze (FMI), thin sea ice (Klimat Center Hamburg), near real time brightness temperatures and soon soil moisture (ECMWF), root zone soil moisture and drought indices (USDA and CESBIO). We are also working on more elaborate products such as water fractions, flood risk indices, improved precipitation with use of assimilated SMOS data, etc. The focus in this presentation will be given to the latter new science products.

The purpose of this communication is to present the mission results after almost 6 years in orbit and a major re-processing as well as some outstanding results already obtained. A special attention will be devoted to level 2 products and to the retrieval quality improvements from version 3 (at launch) to the current version 620.

Paper 3 MICROWAVE RADIOMETERS OF METOP SECOND GENERATION

11:20 Ville Kangas, Salvatore D'Addio, Ulf Klein, Marc Loiselet, Graeme Mason, European Space Agency, Netherlands

Since 2006, the European contribution to operational meteorological observations from polar orbit has been provided by the Meteorological Operational (MetOp) satellites, which is the space segment of the EUMETSAT Polar System (EPS). As part of the next generation EUMETSAT Polar System (EPS-SG), the MetOp Second Generation (MetOp-SG) satellites will provide continuity and enhancement of these observations in the 2020 – 2040 timeframe. The MetOp-SG will consists of two series of satellites ("Satellite A" and "Satellite B"), with three satellites of each series.

The payload complement of MetOp-SG includes three microwave radiometers, namely Microwave Sounder (MWS), Microwave Imager (MWI) and Ice Cloud Imager (ICI). This payload complement provides a unique suite of high performance, operational microwave radiometers covering very wide frequency range never seen before. In total MWS, MWI and ICI provide 63 channels ranging from 18.7 GHz up to 664 GHz.

The radiometer suppliers were selected by ESA in 2013. MWS is built by Airbus Defence and Space (UK), MWI is built by Compagnia Generale per lo Spazio (IT) and ICI is built by Airbus Defence and Space (E). The major work performed in Phase B, since the selection of the instrument primes has been performing the instrument preliminary design and the selection of subsystem suppliers through competitive tendering process. All radiometers have selected critical suppliers during Phase B and suppliers were kicked-off during 2015. Specifically receivers, mechanisms and antenna/optics are in schedule critical path of the radiometers. In addition to hardware development, instrument performance modelling and data processing has been improved and developed.

The development of the radiometers is on-going and the Preliminary Design Review (PDR) took place in 2015 and all radiometers have moved to Phase C/D of the programme. Critical Design Review (CDR) is planned in spring 2017 for MWS (Satellite-A) and in 2018 for MWI and ICI (Satellite B).

The performance, lifetime and reliability requirements of MetOp-SG radiometers are much more demanding than those of MetOp. In addition, ICI type on instrument has no predecessor in space which required specific development approach especially in receivers. Therefore in preparation of this ESA has run a large technology pre-development programme aimed for MetOp-SG needs.

For receivers, ESA concentrated on key technologies, Mixers, low noise amplifiers and detectors. For mixers, the development approach aimed at two goals, first to develop high performance mixer working up to 664 GHz, and second to passivate all mixer circuitry so that they would survive up to 15 years on-ground storage followed by 7.5 years of operation in-orbit. For LNAs, the goal was to develop very low noise figure to achieve the radiometers challenging NEDT. LNAs have been developed to cover frequencies from 50 GHz up to 250 GHz. For detectors the aim was to provide state-of-the-art sensitivity detectors up to 89GHz. Developed detector has the best performance at 89 GHz known to authors.

For mechanisms, MWI and ICI are demanding 7.5 years lifetime at 45 RPM. This poses a large reliability challenge and therefore complete life-testing is planned. For the MWS, for the first time in history all channels are working through single antenna. Therefore the quasi-optics network (QON) must be able to split frequencies to receivers from 23 GHz up to 230 GHz. For MWS and MWI lowest frequencies, radio frequency interference (RFI) can be an issue. Therefore additional filtering has been added and MWI lowest channel includes RFI processor using Kurtosis to remove RFI.

This paper provides on overview of all three radiometers on-board MetOp-SG, including technology developments undertaken by ESA over the past years. Also data processing and products overview will be given for each instrument.

Paper 4 TRMM, GPM AND BEYOND: GLOBAL PRECIPITATION MEASUREMENTS FOR SCIENCE AND SOCIETY

11:40 Gail Skofronick-Jackson, Scott Braun, George Huffman, NASA Goddard Space Flight Center, United States; Christopher Kidd, University of Maryland, United States

The Global Precipitation Measurement (GPM) mission is an international network of satellites that provide next-generation global observations of rain and snow. The GPM concept centers on the deployment of a GPM Core Observatory satellite, a joint NASA/JAXA partnership, carrying an advanced radar and radiometer system to measure precipitation from space and serve as a reference standard to unify precipitation measurements from a constellation of research and operational satellites. The GPM Core Observatory launched on February 27th, 2014 at 1:37pm EST from Tanegashima Space Center, Japan. GPM has a unique role in providing datasets for science and societal applications related to the Earth's water cycle at both regional and global scales and over long time periods if one includes the 17-year record of precipitation from the Tropical Rainfall Measuring Mission (TRMM) along with the expected 10 years from GPM.

GPM is a mission with both scientific and application goals and as such has both high quality research data products and near real time (NRT) data products. The NRT products are released 1-4 hours after data collection and are important for operational users and weather related disaster applications. The research products are

used for scientific research and climatology and weather/climate models. It is expected that the product most in demand will be GPM's IMERG that, by using IR data, provides near-global precipitation rates at 30 minute by 0.1 o by 0.1 o grid box. IMERG's best-case data release latency is 4 hours. IMERG's instantaneous precipitation rates can be summed for accumulation maps of rain and snow.

NASA's CloudSat, TRMM (Tropical Rainfall Measuring Mission) and GPM (Global Precipitation Measurement) along with other satellite missions (e.g., EarthCare, AURA, AQUA and more) have brought much understanding to the science of clouds and precipitation. Thus, teams at NASA Goddard and NASA Jet Propulsion Laboratory, along with university scientists, are in the process of defining concepts for science and measurement requirements for a cloud and precipitation processes mission to be proposed as part of NASA's Earth Science Decadal Survey. Indeed, the great challenge confronting adaptation to climate change is the issue of predicting how the planet's water cycle will change on all scales, and understanding the implications of such changes for global and regional water availability and security. Understanding the latter and the development of adaptation strategies to address impacts heavily depends on better projections of changes in precipitation. This in turn requires a clearer evaluation and improvement of cloud-to-precipitation processes represented in models. Projected climate change using present-day climate models is extremely sensitive to assumptions about these processes. Therefore it is essential to develop the right observational strategy to measure parameters central to the formation of precipitation from both warm and cold cloud processes. We are proposing a future mission concept that provides joint observations of cloud and precipitation.

The successes of TRMM and current state of GPM will be presented along with the underlying science motivation for a new cloud and precipitation mission.

Paper 5 MICROWAVE SCANNER SOUNDER MTVZA-GY ON NEW RUSSIAN METEOROLOGICAL SATELLITE METEOR-M N 2: 12:00 MODELING, CALIBRATION AND MEASUREMENTS

Leonid Mitnik, Vladimir Kuleshov, Maia Mitnik, VI. Il'ichev Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences, Russian Federation; A. M. Streltsov, Grigory Cherniavsky, Igor Cherny, Scientific-Technological Center "Kosmonit", JSC "Russian Space Systems, Russian Federation

The Meteor-M N 2 spacecraft with microwave radiometer MTVZA-GY has been launched on July 8, 2014 on sun-synchronous orbit at an altitude of 830 km. MTVZA-GY is a 29 channel microwave imager/sounder for remote sensing of the ocean and land surface parameters as well as for measuring total atmospheric water vapor content, total cloud liquid water content, air temperature and humidity profiles. MTVZA GY operates at frequencies of 10.6, 18.7; 23.8; 31.5; 36.5; 42.0; 48.0 and 91.65 GHz with vertical (V) and horizontal (H) polarization. 52.80. 53.30. 53.8. 54.64 and 55.63 GHz with V polarization. 56.87 - 57.71 GHz (10 channels at low-frequency slope of strong molecular oxygen absorption band) and 186.31 - 190.31 GHz (6 channels in neighborhood of a strong water vapor absorption line centered at 183.31 GHz) with H-polarization. The total-power radiometer configuration is employed. The channels of 10-48 GHz are the direct amplification radiometers. The channels of 52-57 GHz, 91 GHz and 183 GHz are built as superheterodyne receivers using balanced mixers. The antenna system of MTVZA-GY consists of an offset parabolic reflector of dimension 65 cm, illuminated by four feed-horns antenna. The MTVZA GY scanning platform period is 2.5 s during which the sub-satellite point travels 16 km. A swath width is 1500 km. The viewing angle is 53.3 deg. and the incidence angle with respect to the Earth surface - 65 deg. The sampling rate is 16 x 16 km for all microwave channels. To provide required sensitivity the size of imagery pixel differs depending on channels frequency V. Fluctuation sensitivity of radiometric channels at antenna temperature of 300 K is 0.3-0.6 K / pixel for the scanner channels and 0.4-1.7 K / pixel for the sounder channels. A special test experiment was conducted to measure antenna pattern when orientation of spacecraft was changed and antenna beam crossed limb of the Earth. On board and vicarious calibration were used to transfer radiometer counts into the briahtness temperatures TB(v). On board MTVZA-GY calibration consists of the hot reference absorber and small mirror which reflects the cold cosmic backaround radiation of 2.7 K into the feed-horns. External calibration was also applied. The cloudless areas in the open ocean with low wind speed and the sea surface temperature from -1.8 to 10°C were selected as a cold reference. The brightness temperatures TB(v) in these regions were computed by numerical integration of microwave radiative transfer equation using radiosonde-derived or model vertical profiles of atmospheric pressure, temperature and humidity. The tropical Amazon rain forest was used as hot reference target. Long-term stability of MTVZA-GY channels was studied by analysis of data acquired over the Eastern Antarctica plateau during one year. MTVZA-GY data were compared with air temperature of automatic weather stations, with TB(v) computed with reanalysis-derived profiles of meteorological parameters over test area and with GCOM AMSR2 measurements taken at the identical frequency channels. Examples of the MTVZA-GY data obtained over the globe and over the intense marine weather systems are presented and discussed. This work was partly supported by the FEB RAS Research project 15-1-1-009 O and by the Japan Aerospace Exploration Agency Project F12.

Monday, April 11	Sea Ice	13:20 - 15:00
Lecture Session		Lecture Hall B

Session Co-Chairs: Georg Heygster, University of Bremen; Paolo de Matthaeis, NASA Goddard Space Flight Center

Paper 1 SEA ICE THICKNESS RETRIEVAL AT L-BAND: COMPARISON BETWEEN RESULTS FROM AQUARIUS AND SMAP DATA

13:20 Paolo de Matthaeis, NASA Goddard Space Flight Center, United States

Passive microwave measurements from the Soil Moisture Ocean Salinity (SMOS) mission, operating in the L-band at a frequency of 1.41 GHz, have been used to retrieve sea ice thickness with promising results [1], and a daily data product is now available from the Integrated Climate Data Center of the University of Hamburg [2]. The purpose of this work is to apply a similar technique to measurements from two other L-band passive instruments, Aquarius and SMAP.

Aquarius is a NASA sensor flown aboard the Argentinean SACD spacecraft and also operating at L-band [3]. The instrument was designed for the main goal to measure sea surface salinity with a spatial resolution of 150 km, and it is composed by three radiometers, operating at the same frequency as SMOS, and one scatterometer. The Soil Moisture Active Passive (SMAP) is a NASA mission developed with the overall objective to monitor global soil moisture with unprecedented resolution, sensitivity, area coverage, and revisit time [4]. It includes a conically-scanning passive radiometer operating at the same L-band frequency as SMOS and Aquarius, and an L-band (1.22 to 1.30 GHz) radar. The SMAP radiometer measures brightness temperatures at a constant incidence angle and spatial resolution of 40 km, while the radar has a spatial resolution of 3km.

Aquarius and SMAP brightness temperature data are used to estimate sea ice thickness in the polar regions. The method is based on the inversion of a radiative transfer model for ice-covered sea. This model predicts the emission from ice-covered sea and is similar to the one used by the SMOS group. The sea ice thickness values retrieved from Aquarius and SMAP measurements using this technique are compared with the SMOS data products and also with estimates from Cryosat 2 radar altimeter [5]. Since Aquarius ceased operation due to component failure on at the beginning of June 2015, while the SMAP radiometer began operating at the end of March 2015, data from April 2015 are used in the comparison. Results obtained using Aquarius and SMAP data are consistent with the SMOS sea ice thickness product. how a consistent behavior, but they have higher uncertainties due to both possible ancillary input inaccuracy and the less refined approach compared to

the SMOS sea ice thickness algorithm. The effect on the sea ice thickness retrieval of the differences in operating principles, geometry and other system parameters between the instruments is discussed. Uncertainties due to the limited knowledge can also play an important role. The presence of melt ponds or snow over sea ice is also considered.

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Paper 2 A REFERENCE DATASET TO EVALUATE SEA ICE CONCENTRATION ALGORITHMS

13:40 Rasmus Tonboe, Leif Toudal Pedersen, Gorm Dybkjær, Jacob Høyer, Danish Meteorological Institute, Denmark; Marko Mäkynen, Finnish Meteorological Institute, Finland; Stefan Kern, University of Hamburg, Germany; Thomas Lavergne, Met Norway, Norway; Natalia Ivanova, NERSC, Norway; Georg Heygster, University of Bremen, Germany; Roberto Saldo, Technical University of Denmark, Denmark

The European Space Agency's (ESA) climate change initiative (CCI) sea ice project has established a round robin data package (RRDP) for sea ice concentration (SIC) algorithm inter-comparison and evaluation. The dataset is openly available. It contains an extensive collection of collocated microwave radiometer data and other geophysical parameters with relevance for computing and understanding variability of the microwave radiometer SIC over open water and 100% sea ice. It covers the Northern and Southern hemispheres, thin ice, first-year ice, multiyear ice and all seasons including summer melt.

The open water data (SIC=0%) are collected in selected regions outside but relatively close to the ice edge in the Atlantic and the Pacific on both hemispheres. High resolution sea ice drift fields derived from consecutive and overlapping SAR scenes have been used to identify regions of sea ice convergence. During winter these regions are assumed to have \approx 100% sea ice cover (either due to the convergence or due to refreezing of eventual remaining openings). Similarly to the open water data all ice data have been resampled to coarse resolution. A thin ice dataset has been established using ENVISAT ASAR data to identify areas of near 100% ice concentration, and SMOS to quantify the ice thickness, and a Summer dataset with melt-pond fractions has been derived from MODIS data.

The database consists of TB data measured by:

AMSR-E, SMMR and SSMI microwave radiometers,

• Simulated data; using a radiative transfer model for snow and ice; using modified Wentz radiative transfer models for the atmosphere and the open ocean. The simulated data contain in addition to the brightness temperatures at SMMR, SSM/I and AMSR channels also geophysical parameters snow depth, physical temperature and atmospheric parameters

- SMOS brightness temperatures
- NWP data from ERA Interim
- ASCAT backscatter at 40 degree incidence angle

This study is part of a Sea Ice Concentration algorithm evaluation of the European Space Agency (ESA) Climate Change Initiative (CCI) project. The project is developing capacity to construct a sea ice climate record from satellite data including sea ice thickness from radar altimetry (ERS 1-2, ENVISAT and eventually Cryosat 2 and Sentinel - 3) and sea ice concentration.

This presentation focus entirely on the SIC estimate sensitivity to geophysical noise over ice and open water including the influence of the atmosphere and the implications for climate applications. In particular, we wish to identify the role and impact of individual noise sources over open water and on snow covered sea ice including summer melt.

Paper 3 COHERENCE EFFECTS FROM SNOW COVER ON THE EMISSION OF SEA ICE AT LOW MICROWAVE FREQUENCIES – 14:00 COMBINING MODELS AND OBSERVATIONS

Marcus Huntemann, Alfred Wegener Institut, Helmholtz-Zentrum für Polar- und Meeresforschung, Germany; Georg Heygster, Malte Gerken, University of Bremen, Germany

Several L-band passive microwave sensors have been launched in recent years to observe ocean salinity and soil moisture. As a secondary data usage, retrieval methods for sea ice thickness are being developed, mainly based on empirical relations. For a quantitative understanding of the radiation emitted by sea ice, microwave emission models are needed. With the complexity of the sea ice structure and the highly variable weather condition under which sea ice forms, its permittivity can only be modeled with a high uncertainty. Additionally, sea ice usually has a snow layer on top which modifies both electromagnetic and thermal properties, the latter by its low thermal conductivity which increases the ice temperature. However, the permittivity of snow is better understoad than that of sea ice. It typically takes intermediate values between those of ice and air. The dielectric loss is lower compared to that of sea ice and is practically zero for dry snow. With decreasing difference in permittivity at the two media boundaries, the transmissivity through the interfaces is increasing as described by the Fresnel equations. Hence, for the two-boundary system of ice to snow and snow to air, the transmissivity increases compared to the single boundary system of ice to air. Moreover, with the snow layer as low-loss medium, multiple reflections at the layer interfaces can cause interference effects for the penetrating radiation. Thus, a homogeneous snow cover leads to coherent oscillations as a function of snow depth.

For sea ice thickness and snow depth observations from NASA's Operation Ice Bridge, distributions are fitted within footprint sizes of 50 km, a typical resolution for satellite based L-band sensors. These thickness distributions serve as input to a coherent radiative transfer model to simulate the microwave emission. We compare the results to an incoherent model and observations from the Soil Moisture and Ocean Salinity (SMOS) satellite. For narrow snow depth distributions, the coherence effects induced by the snow cover cause differences up to 10 K in horizontally polarized brightness temperatures while the effect on vertically polarized brightness. temperatures is negligible. Using snow depth to parameterize snow depth distributions, we quantify the influence of snow depth on L-band brightness temperatures over sea ice for the comparison to SMOS observations. It turns out that the influence of coherence effects under realistic snow thickness distributions can reach the order of the thermal insulation by the snow.

Paper 4 VALIDATION OF THE EUMETSAT OSI SAF NEAR 50 GHZ SEA ICE EMISSIVITY PRODUCT

14:20 Rasmus Tonboe, Leif Toudal Pedersen, Gorm Dybkjær, Jacob Høyer, Luis Flores Vargas, Danish Meteorological Institute, Denmark; Markku Similä, Marko Mäkynen, Finnish Meteorological Institute, Finland; Georg Heygster, University of Bremen, Germany

In order to assimilate atmospheric temperature sounding data from the Microwave Sounding Unit (MSU) and Special Sensor Microwave Imager/ Sounder (SSMIS) in numerical weather prediction models over the Arctic and Southern Oceans, a first guess on sea ice surface emissivity is required.

An operational sea ice microwave emission model at 50 GHz was developed under EUMETSAT's Ocean and Sea Ice Satellite Application Facility (OSISAF) programme. The corresponding emissivity product and model coefficients are available via ftp and EumetCAST for operational use. The model is based on correlations between the surface brightness temperatures at 18 and 36 GHz and at 50 GHz. The model coefficients are estimated using simulated data from a combined sea ice thermodynamic and emission model. Continuous validation and monitoring of the sea ice emissivity is challenging because the snow and ice micro-physical parameters affecting the emissivity are not measured on large scale and they are a stretch target even for process models at present. The micro-physical parameters include snow depth, snow layering and density, snow grain size, snow wetness/brine content and ice salinity, temperature and porosity. However, a methodology for monitoring and comparison has been developed which is in many ways similar to how the emissivity product is used in numerical weather prediction models.

Here, the simulated emissivity from the OSISAF model is compared to the emissivity derived using SSMIS brightness temperatures at 50.3 and at 52.8 GHz. The measured brightness temperature at near 50 GHz is a combination of contributions from the sea ice and the atmosphere. Therefore, we use a radiative transfer model describing the atmospheric and surface atmospheric interaction together with an optimal estimation scheme for minimization and meteorological input including the atmospheric water vapour the air temperature, and the cloud liquid water. The implementation of the optimal estimation system is presented including system constraints and potential future applications.

Paper 5 L-BAND RADIOMETRY FOR THICKNESS OF THIN SEA ICE

14:40 Catalin Patilea, Marcus Huntemann, Georg Heygster, University of Bremen, Germany

Thickness of Arctic and Antarctic sea ice belongs to the parameters most urgently required for climate modelling, but is difficult to observe regularly area-wide. The interferometric altimeter CryoSat-2 allows climatological observation of sea ice thickness larger than 1m. However, for thinner ice the uncertainty increases. Therefore, methods to retrieve thickness of thin sea ice are being developed based on L band satellite observations such as SMOS (Soil Moisture and Ocean Salinity) and SMAP(Soil Moisture Active and Passive). The SMOS instrument MIRAS (Microwave Imaging Radiometer with Aperture Synthesis) creates brightness temperature maps in units of so-called snapshots, i.e., images where each pixel is seen under a different angle, and the overlapping, consecutive snapshots show the same pixel under many angles. For SMOS, two algorithms for thickness of thin sea ice have been developed, one using the intensity and low incicence angles from 0° to 40°, and one using intensity and polarization difference at higher incidence angles between 40° and 50°. Both methods have been validated, yied similar results and are being used to produce daily thickness maps of thin sea ice.

SMAP is an L band radiometer scanning conically with 40° opening angle. In order to compare brightness temperatures from both sensors and to transfer the high incidence angle retrieval algorithm from SMOS to SMAP, a comparison of the brightness temperatures from both sensors at 40° is performed. For SMOS, these are obtained as values of a fit of all observations during one day within one SMOS grid cell (DGG) to an analytic function of incidence angle.

Having thus determined the SMOS brightness temperatures at 40° incidence angle, they

will be compared to those of SMAP in polar regions. Moreover, the SMOS thin ice retrieval procedure is translated to SMAP and results will be compared.

Although sources for RFI (Radio Frequency Interference) are generally confined to a small area on ground, their influence is frequently spread over large areas of the involved SMOS snapshot during the Furier-transform like image reconstruction process. Therefore, even RFI sources on land may contaminate large areas of SMOS brightness temperatures over ocean. In order to eliminate these cases, currently the complete snapshot is discarded if one or more DGGs are recognized to be RFI affected. In contrast, the RFI influences in SMAP radiances are expected to be restricted to the area near the RFI source. Therefore we expect SMAP brightness temperatures and ice thickness retrievals to be less affected by RFI.

Another means of comparison of SMOS and SMAP will be comparing the differences between brightness temperatures from ascending and descending half orbits, respectively. For SMOS data verson 5.05 distributed until recently, these differences tend to show signals around 20 K at edges of brightness temperatures like coastlines and sea ice edges, with sign and magnitude depending on the orientation. We presume this effect was also caused by the SMOS image reconstruction process. In the SMOS data version 6.2 the effect is largely reduced with values around 4 K.

Monday, April 11	Snow	15:30 - 17:30
Lecture Session		Lecture Hall B

Session Co-Chairs: Edward Kim, NASA Goddard Space Flight Center; Martti Hallikainen, Aalto University

Paper 1 SNOW ON LAKE ICE: OVERVIEW OF A MULTIYEAR AIRBORNE RADIOMETER DATA COLLECTION PROGRAM AND 15:30 RELATED MODELING EFFORTS

Martti Hallikainen, Aalto University, Finland; Juha Lemmetyinen, Finnish Meteorological Institute, Finland; Matti Vaaja, Jaakko Seppänen, Jaan Praks, Aalto University, Finland

Space-borne microwave radiometry is presently used in several countries to map characteristics of terrestrial snow cover. Especially in northern areas mixed pixels tend to decrease accuracy of obtained SWE information: both forests and lakes affect the sensitivity of brightness temperature to dry snow. Forests mask microwave emission from snow and underlying ground. The emission characteristics of the snow/lake ice/water system may result in brightness temperatures that are higher than those for adjacent land areas. Additionally, accumulation of water on top of ice strongly affects brightness temperatures especially at lower microwave frequencies. The effect of lakes to the satellite-derived brightness temperatures should be accounted for in order to obtain adequate accuracy in SWE retrieval. Detailed investigation of the brightness temperature behavior of snow on lake ice can be only done with airborne radiometers, due to the modest spatial resolution of space-borne radiometers.

We have recently completed a multiyear airborne data collection program concerning the brightness temperature behavior of snow on lake ice. We conducted airborne radiometer measurements over two lakes in southern Finland starting in 2004 and, with a more intense schedule, during 2011-2014. The test site includes two lakes and, additionally, a forested area and an open, mostly agricultural area next to the lakes. This arrangement allows us to compare the behavior of the brightness temperature of snow on lake ice with that of snow on terrain. The main instrument was our HUTRAD system, which operates at five frequencies between 6.8 and 36.5 GHz and provides both vertically and horizontally polarized data at an incidence angle of 50 degrees off nadir. All antenna beam-widths are between 3 and 5 degrees. Additional data were collected with our HUT-2D interferometric imaging radiometer, which operates at 1.4 GHz and covers an incidence angle range of up to ±25 degrees with a swath of 95 % of the flight altitude. The radiometers were accommodated onboard our Skyvan research aircraft. Relevant in-situ data were collected simultaneously with airborne measurements.

A variety of snow conditions including dry snow/ice, occasional water on top of ice, moist snow surface, and the melting season was encountered. In order to study the effect of diurnal temperature variations during the melting season we also collected data both in the morning (dry refrozen snow) and afternoon (moist topmost snow layer).

This presentation provides an overview of the airborne measurements, in situ data, and experimental results. Our data indicate that the brightness temperature mainly depends on snow grain size at higher frequencies. At lower frequencies presence of water on top of ice may cause the brightness temperature to vary substantially from that for dry conditions. We also compare experimental data for various snow/ice conditions with simulations performed with the HUT Snow Emission Model, using observed in situ data as input values.

Paper 2 EVALUATION OF THREE L-BAND SNOW-COVERED EMISSION MODELS USING GROUND-BASED RADIOMETRIC 15:50 MEASUREMENT IN THE CANADIAN PRAIRIES ENVIRONMENT

Alexandre Roy, Alain Royer, Université de Sherbrooke, Canada; Chris Derksen, Peter Toose, Environment Canada, Canada; Marion Leduc-Leballeur, Laurent Bergeron, Ghislain Picard, Laboratoire de glaciologie et de Géophysique de l'environnement, France; Juha Lemmetyinen, Finnish meteorological institue, Finland; Aaron Berg, Tracy Rowlandson, Matthew Williamson, University of Guelph, Canada; Alexandre Langlois, Université de Sherbrooke, Canada

In subarctic regions, the physical state of the soil (freeze versus thaw) affects the surface energy and water budgets, therefore, it is a key parameter in climate models. Although, the Aquarius and SMOS observations show a clear seasonal signal in the L-band polarization ratio (PR = TBV-TBH/TBV+TBH) that is well correlated with air and soil temperature-derived F/T information (Roy et al., 2015), the low spatial resolution of spaceborne observations (~45 km) make it difficult to isolate potential contributions to the F/T signal from landscape components including soil, snow, and vegetation properties. For example, Lemmetyinen et al. (2015) shows the potential of L-Band to retrieve information on snow density demonstrating the utility of the application of L-Band snow-covered emission models. In this study we examine the use of several LSEMs to understand the different contributions (soil, snow, layers) to the signal for inversion to obtain significant variables. An L-band radiometer measurement campaign was conducted in Saskatchewan, Canada during the 2014-2015 fall, winter, and spring to implement/validate three emission models: L-Band microwave Emission of the Biosphere coupled with Microwave Emission Model of Layered Snowpack(LMEB-MEMLS, Shwank et al., 2015), the Dense Media Radiative theory – Multi Layer (DMRT-ML) and Wave approach for low-frequency microwave emission in snow (WALOMIS).

The Environment Canada L-band radiometer measures 512 narrow bands between 1375 to 1575 MHz which allows improved RFI mitigation compared to a single broadband measurement. The ground-based radiometer was operated in two configurations. First, temporally continuous measurements were conducted through the winter over an agricultural bare soil site, with a comprehensive set of snow and soil observations within the approximately 2 x 2 m footprint. By slightly shifting the radiometer position, measurements were also made at 2 adjacent sites: - an undisturbed site; - over a footprint that was kept snow free; - and a site with artificially deep and compacted snow. Secondly, once a month, the radiometer was moved to record measurements of frozen ground at six sites within the in-situ soil monitoring network in the Kenaston/Brightwater Creek watershed (centered on 51.41N -106.46W). Furthermore, several snow removal experiments were conducted, where measurements were first made over undisturbed footprints, and repeated after manual snow removal to quantify the effect of snow on the signal at L-band.

The database was used to decouple the effect of soil and snow and to parameterize both aspects in the models. The results show that the has a non-negligible effect on TB at L-Band, but that the omission of coherence in the emission model leads to overestimation of TB for DMRT-ML and Schwank et al. (2015) models. WALOMIS is then implemented for seasonal snow to evaluate the impact of snow layering and coherence effect on TB. The results are compared and discussed.

Paper 3 L-BAND RADIOMETRY APPLIED FOR RETRIEVAL OF SNOW DENSITY AND GROUND PERMITTIVITY

16:10 Juha Lemmetyinen, Finnish Meteorological Institute, Finland; Mike Schwank, GAMMA Remote Sensing Research and Consulting AG, Switzerland; Kimmo Rautiainen, Anna Kontu, Tiina Parkkinen, Finnish Meteorological Institute, Finland; Christian Mätzler, Andreas Wiesmann, Urs Wegmüller, GAMMA Remote Sensing Research and Consulting AG, Switzerland; Chris Derksen, Peter Toose, Environment Canada, Canada; Alexandre Roy, Université de Sherbrooke, Canada; Jouni Pulliainen, Finnish Meteorological Institute, Finland

Theoretical studies have indicated the feasibility of L-band (1 – 2 GHz) to provide information on the density of dry snow cover and ground permittivity under snow cover conditions [1,2]. Conventionally considered as having minimal effect on microwave radiation at L-band, dry snow nevertheless affects observed microwave signatures through changes in impedance matching and refraction angle at the soil interface. A discernible effect in emitted microwave radiation is achieved with changing snow conditions. Using a dual parameter retrieval scheme, this allows simultaneous retrieval of density of the snow layer in contact with the ground, as well as the effective permittivity of the ground layer, from dual polarization L-band observations. Such information has, in turn, the potential to support e.g. retrievals of Snow Water Equivalent from other sensors [3].

We present results of a recent study supporting the theoretical findings, using experimental data from tower-based instruments over several winter seasons in Finland [4] and Canada. Snow excavation experiments demonstrate the capability of a simplified emission model to estimate the effect of snow cover on emitted L-band brightness temperature. Retrievals covering entire winter periods over predominantly mineral soil sites indicate that both snow density and the effective ground permittivity can be retrieved from the L-band observations; following theoretical predictions, the retrieved snow density is correlated with snow densities measured at lower layers of the snowpack. Over complex terrain such as a wetland site, the retrieval may occasionally produce erroneous results, indicating a need to further develop the applied emission model for different soil and vegetation regimes.

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[4] J. Lemmetyinen et al. Snow density and ground permittivity retrieved from L-Band radiometry: application to experimental data. Remote Sens. Environ. (submitted June 2015)

Paper 4 MODELING L-BAND BRIGHTNESS TEMPERATURE IN CONNECTION WITH SNOW SURFACE PROPERTIES VARIATIONS AT DOME C, ANTARCTICA.

Marion Leduc-Leballeur, Ghislain Picard, LGGE (CNRS, Univ. Grenoble Alpes), France; Giovanni Macelloni, Marco Brogioni, Institute of Applied Physics "Nello Carrara" – National Council of Research, Italy; Laurent Arnaud, LGGE (CNRS, Univ. Grenoble Alpes), France; Arnaud Mialon, CESBIO (CNES, CNRS, IRD, UPS), France; Yann H. Kerr, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France

During the last few years, several studies have highlighted the sensitivity of L-band observations to snow-covered areas. In Antarctica, a very good knowledge of the sensitivity is essential to develop applications and contribute to a better understanding of the ice sheet, a key element of the climate system. Moreover, Antarctica has been identified as a potential satellite calibration target.

L-band radiometers measurements collected over the Dome C area demonstrated that the brightness temperature is relatively stable at vertical polarisation (standard deviation lower than 1 K at annual scale), while is more variable at horizontal polarisation. From November 2014 to March 2015, a significant event has been observed from both the DOMEX ground campaign and the SMOS satellite. The brightness temperature at horizontal polarisation shows a continuous increase followed by a sharp decrease (about 5 K at 42 degrees of incidence angle) within a few days. No such variations have been observed at vertical polarisation, which suggests that this event could be due to near surface changes. Here we use atmospheric and snow in situ measurements to investigate these variations. When the decrease in brightness temperature of horizontal polarisation occurred, a corresponding increase in snow surface density from 150 kg m-3 to 300 kg m-3 was measured. This could be related to a storm passing on Dome C, which may have compacted light snow or removed it from the surface uncovering old denser snow layers.

Electromagnetic models (DMRT-ML, WALOMIS) have been used to reproduce this decrease in L-band brightness temperature at horizontal polarisation. For that, in situ measurements have provided snow temperature and density profiles, as well as snow surface density. Simulations of time-series from January to June 2015 are performed changing only the density of the top snow layer. First results show a good agreement between modelled and measured brightness temperatures and confirm the major role of the surface density. However, when snow surface density is low (about less than 200 kg m-3), the model skills are still unsatisfying, suggesting that more investigations are needed to understand and improve the simulations.

Paper 5 EVALUATION OF TB RESPONSE TO SNOWPACK BY MULTIPLE MICROWAVE RADIATIVE TRANSFER MODELS

16:50 Dohyuk Kang, NASA Goddard Space Flight Center, United States; Shurun Tan, University of Michigan, Ann Arbor, United States; Edward Kim, NASA Goddard Space Flight Center, United States

A radiative transfer model (RTM) to calculate a snow brightness temperature (Tb) is a critical element to invert it to a terrestrial snow resolved by microwave remote sensing observations. The RTM simulates the Tb based on a layered snow by solving a set of microwave radiative transfer formulas. Even with the same snow physical inputs provided, currently existing RTMs such as Microwave Emission Model of Layered Snowpacks (MEMLS), Dense Media Radiative Transfer (DMRT-Tsang), and Helsinki University of Technology (HUT) models produce different Tb responses. To backwardly retrieve snow physical properties from the simulated Tb, the differences from the RTMs are to be quantitatively explained. To this end, this study evaluates the sources of perturbations in the RTMs, and locates the equations where the variations are made. Investigations are conducted by providing the same but gradual changes in the snow physical inputs such as a snow grain size, and a snow density to the 3 different RTMs. Adapted from conventional channels used in the microwave remote sensing, the frequencies used are consistent with the Advanced Microwave Scanning Radiometer-E (AMSR-E) at 6.9, 10.7, 18.7, 23.8, 36.5, and 89.0 GHz. Furthermore, the 3 RTMs are simultaneously driven by the same snow physics model with the meteorological forcing datasets and are validated by the snow samplings from the CLPX (Cold Land Processes Field Experiment) 2002-2003, and NoSREx (Nordic Snow Radar Experiment) 2009-2010. The analyses of Tb simulations are also used to retrieve the snow physical properties, and are compared with the in situ measurements in accordance with the 2 field sites.

Paper 6 ASSESSMENT OF SATELLITE-BASED SWE RETRIEVAL APPROACHES FOR NORTHERN HEMISPHERE

17:10 Kari Luojus, Jouni Pulliainen, Juval Cohen, Jaakko Ikonen, Matias Takala, Juha Lemmetyinen, Tuomo Smolander, Finnish Meteorological Institute, Finland; Chris Derksen, Environment Canada, Canada

Reliable information on snow cover across the Northern Hemisphere and Arctic and sub-Arctic regions is needed for climate monitoring, for understanding the Arctic climate system, and for the evaluation of the role of snow cover and its feedback in climate models. In addition to being of significant interest for climatological investigations, reliable information on snow cover is of high value for the purpose of hydrological forecasting and numerical weather prediction. Terrestrial snow covers up to 50 million km2 of the Northern Hemisphere in winter and is characterized by high spatial and temporal variability. Therefore satellite observations provide the only means for timely and complete observations of the global snow cover.

While multiple independent passive microwave derived SWE products are available, their full potential has not been realized because of poorly constrained error budgets due to the challenges related to the physical processes underpinning the SWE retrievals, and the extensive snow covered regions of the world without adequate surface observations for algorithm validation. The purpose of the ESA funded SnowPEx project is to obtain a quantitative understanding of the uncertainty in remotely sensed SWE products through an internationally coordinated and consistent evaluation exercise.

The currently available Northern Hemisphere wide satellite-based SWE datasets have been acquired and the preliminary intercomparison of the different products have been performed. The inter-comparison has been carried out for the 1) GlobSnow SWE [1], 2) the NASA Standard SWE [2], 3) NASA prototype and 4) NSIDCSSM/I [3] SWE products. The intercomparison has been carried out by using ground-based snow course observations as the reference. The evaluations have been carried out using Finnish Snow Course data, available for 1979-2014, covering Finland and distributed snow transect data collected from the former Soviet Union and Russia covering the period 1979-2012. The reference dataset contains snow path measurements carried out within 517 different snow path locations, ranging from 35° to 85° northern latitude and 14° to 179° of eastern longitude. The detailed results will be presented at the conference.

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Tuesday, April 12	Soil Moisture	08:30 - 09:50
Lecture Session		Lecture Hall B

Session Co-Chairs: Yann Kerr, CESBIO; Paolo Pampaloni, CNR-IFAC

08:30

Paper 1 VALIDATION OF SMAP RADIOMETER-BASED SOIL MOISTURE PRODUCT USING CORE VALIDATION SITES

Andreas Colliander, NASA Jet Propulsion Laboratory, CalTech, United States; Thomas Jackson, USDA ARS Hydrology and Remote Sensing Laboratory, United States; Steven Chan, Narendra Das, Seungbum Kim, Scott Dunbar, NASA Jet Propulsion Laboratory, CalTech, United States; Rajat Bindlish, USDA ARS Hydrology and Remote Sensing Laboratory, United States; Aaron Berg, Tracy Rowlandson, University of Guelph, United States; Todd Caldwell, University of Texas at Austin, United States; Michael H. Cosh, USDA Agricultural Research Service, United States; Hala Allassar, Kuwait University, Kuwait; Ernesto Lopez-Baeza, University of Valencia, Spain; Jose Martínez-Fernández, Ángel González-Zamora, University of Salamanca, Spain; Heather McNaim, Anna Pacheco, Agriculture and Agri-Food Canada, Canada; Mahta Moghaddam, University of Southern California, University of Salamanca, Spain; Heather McNaim, Anna Pacheco, Agriculture and Agri-Food Canada, Canada; Mahta Moghaddam, University of Southern California, University of Salamanca, Spain; Heather McNaim, Anna Pacheco, Agriculture and Agri-Food Canada, Canada; Mahta Moghaddam, University of Southern California, University of Salamanca, Research Center Juelich, Germany; Claudia Notarnicola, Georg Niedrist, EURAC, Italy; Thierry Pellarin, University of Grenoble, France; Jouni Pulliainen, Kimmo Rautiainen, Finnish Meteorological Institute, Finland; Judith Ramos, Universidad Nacional Autónoma de México, Mexico; Mark Seyfried, USDA ARS Northwest Watershed Research Center, United States; Zhongbo Su, Yijian Zeng, Rogier van der Velde, University of Fwente, Netherlands; Marouane Temimi, NOAA CREST, United States; Marc Thibeault, Comisión Nacional de Actividades Espaciales (CONAE), Argentina; Wouter Dorigo, Mariette Vreugdenhil, Vienna University of Technology, Austria; Jeffrey P. Walker, Monash University, Australia; Dara Entekhabi, Massachusetts Institute of Technology, United States; En Njoku, Simon Yueh, NASA Jet Propulsion Laboratory, CalTech, United States

NASA's Soil Moisture Active Passive (SMAP) Mission was launched in January 2015. The objective of the mission is global mapping of soil moisture and landscape freeze/thaw state. SMAP data product suite includes a soil moisture product based on the measurements of its L-band radiometer. The radiometer employs a rotating 6-meter mesh reflector antenna to achieve spatial resolution of 40 km and revisit time of 2-3 days. The primary validation reference of the data products is comparison to ground-based measurements. Well characterized sites with calibrated in situ measurements are being used to determine the quality of the data products; these sites are designated as core validation sites. The mission success criteria will be evaluated with respect to these core site comparisons. Also remote sensing and model-based products will be used as additional resources to expand the spatial and temporal scope of the evaluation. In an effort to ensure the geographic distribution and diversity of conditions of the core validation sites, SMAP has partnered with investigators across the globe. The suitability of the various sites for validation of the SMAP soil moisture products has been assessed while considering several factors. The main factors are the calibration of the sensors within a site and determination of a spatial scaling function of the sensor measurements up to the SMAP resolution scales. The mission has been able to utilize the core site measurements since the launch of the satellite because the infrastructure for data transmission and processing was established well before the launch. In this presentation we will show the current performance of the radiometer-based soil moisture product and discuss the status of the validation process.

Paper 2 FIRST APPLICATION OF REGRESSION ANALYSIS TO RETRIEVE SOIL MOISTURE FROM SMAP BRIGHTNESS 08:50 TEMPERATURE OBSERVATIONS CONSISTENT WITH SMOS SOIL MOISTURE

Amen Al-Yaari, Jean-Pierre Wigneron, INRA, France; Yann H. Kerr, Nemesio Rodriguez-Fernandez, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Peggy E. O'Neill, NASA Goddard Space Flight Center, United States; Thomas Jackson, USDA ARS Hydrology and Remote Sensing Laboratory, United States; Gabrielle De Lannoy, NASA Goddard Space Flight Center (GESTAR), United States; Ahmad Al Bitar, Arnaud Mialon, Philippe Richaume, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Simon Yueh, NASA, United States

Two dedicated soil moisture (SM) spaceborne missions, ESA's Soil Moisture and Ocean Salinity (SMOS) and NASA's Soil Moisture Active Passive (SMAP) satellites, were launched in 2009 and 2015, respectively. Both satellites have been providing microwave brightness temperature (TB) observations and SM retrievals at L-band since then (Entekhabi et al., 2010; Kerr et al., 2012). A recent study (Al-Yaari et al., submitted) demonstrated the efficiency of physically-based multiple-linear regression equations (Wigneron et al., 2004) to retrieve SM from AMSR-E TB observations. The regression equations were derived analytically from the radiative transfer model (τ - ω model) (Mo et al., 1982; Wigneron et al., 1995). The purpose of that initial study was to extend the SMOS SM product into the past i.e., 2003-2009, using AMSR-E TB observations. The current study follows the same strategy to retrieve SM from SMAP TB observations and SM level 3 (SMOSL3 as a training data), over the global scale. Regression coefficients were calibrated using SMOS horizontal and vertical TB observations during the 31/03-08/09/2015 period (referred here to as SMAP-reg). The SM data set obtained from SMAP TB using the regression equations has been compared to the SMAP SM dataset computed with the single channel algorithm and both exhibit the same temporal dynamics. For instance, figure 1 shows the (Pearson) correlation coefficient (R) between SMAP-reg and SMAP-reg SM product, with comparison to the SMAP original SM, against the global MERRA-Land SM simulations and in situ measurements will be presented. The main interest in the SMAP-reg SM product, with comparison to the SMAP original SM, against the global MERRA-Land SM simulations and in situ measurements will be presented. The main interest in the SMAP-reg SM product is that it is fully consistent with the SMOS Level 3 SM product. One of the key remaining tasks is to ensure the consistent relative calibration between SMAP-TB.

Paper 3 FORWARD MODEL CALIBRATION FOR PASSIVE SOIL MOISTURE RETRIEVAL USING SATELLITE OVERPASS 09:10 ACCUMULATION OF OBSERVATIONS

Steven Chan, Eni Njoku, NASA Jet Propulsion Laboratory, CalTech, United States; Rajat Bindlish, USDA ARS Hydrology and Remote Sensing Laboratory, United States; Peggy E. O'Neill, NASA Goddard Space Flight Center, United States; Thomas Jackson, USDA ARS Hydrology and Remote Sensing Laboratory, United States

The Soil Moisture Active Passive (SMAP) mission is an L-band mission launched in January 2015. The SMAP instruments consist of a radar (active) and a radiometer (passive) that acquire complementary information to provide global mapping of soil moisture and freeze/thaw state every 2-3 days with unprecedented accuracy and coverage. This improvement in hydrosphere state measurement is expected to advance our understanding of the processes that link the terrestrial water, energy and carbon cycles, improve our capability in flood prediction and drought monitoring, and enhance our skills in weather and climate forecasts.

Since September 2015 the SMAP Level-2 and Level-3 Passive Soil Moisture products (SPL2SMP and SPL3SMP, respectively) have attained a preliminary (beta) science performance level and been released to the public for evaluation from the NASA Distributed Active Archive Center (DAAC) at the National Snow and Ice Data Center (NSIDC). The release is expected to accelerate future product improvement in data accuracy and usability through feedback from the research and application communities.

At present the SMAP passive soil moisture products contain soil moisture retrieval fields produced by several algorithms. Common to these algorithms is the same underlying forward model commonly known as the tau-omega model. This model takes radiometer observations and external ancillary data as inputs and converts them into soil moisture retrieval. Differences in soil moisture retrieval among algorithms arise due to differences in input observations, ancillary data, and model assumptions unique to each algorithm. To obtain accurate retrieval, the inversion process of these algorithms requires a set of model coefficients that should be calibrated a priori. Traditionally, these calibrated coefficients were derived from past field experiments of limited diversity in time spans, land cover heterogeneity, and spatial scales. Although these coefficients resulted in accurate retrieval in some selected areas at fine spatial scales, they could incur significant retrieval uncertainty when applied globally in large-scale regions where the land surface conditions had not been considered in past field experiments.

In this presentation, a novel approach to optimally determining these model coefficients is proposed and evaluated. In this approach, the forward model is subject to its own behavior constrained in time and space when observations from successive satellite overpasses are considered. Once enough observations become available at a given observed location, the unknown quantities – geophysical parameters and model coefficients – of the forward model can be solved iteratively using standard nonlinear optimization methods. The mechanism of this approach will be illustrated using the Level 1 brightness temperature observations acquired by the SMAP radiometer to date, along with the ancillary data that go into the operational processing of the products. The corresponding retrieval of model coefficients and geophysical parameters will be presented, followed by their comparison with proxies and in situ data as available. The implications of this study on the outlook of improvement and development of the SMAP passive soil moisture products will also be discussed.

Paper 4 EXPLOITING THE AMSR2 POTENTIAL FOR HYDROLOGICAL APPLICATIONS IN HETEROGENEOUS LANDSCAPES 09:30 THROUGH ARTIFICIAL NEURAL NETWORKS.

Emanuele Santi, Simonetta Paloscia, Simone Pettinato, Institute of Applied Physics - National Research Council (IFAC - CNR), Italy; Luca Brocca, Luca Ciabatta, Christian Massari, IRPI - CNR, Italy

In this paper, the soil moisture content (SMC) estimated from the Advanced Microwave Scanning Radiometer 2 (AMSR2) on board the GCOM-W satellite was compared with the outputs of a hydrological model. The comparison was performed over the Umbria region in central Italy, by considering all the available overpasses of AMSR2, since July 2012. The aim of this work was to exploit the potential of AMSR2 for hydrological applications on a regional scale and in heterogeneous environments. The complex orography of the Italian landscape and the large variety of surface covers at sub-pixel resolution sets indeed severe constraints to the use of spaceborne microwave radiometers for such applications. In this work, the ANN based "HydroAlgo" algorithm [1], originally developed for AMSR-E, was adapted and re-trained for working with AMSR2 data. The disaggregation technique implemented in HydroAlgo [2], devoted to the improvement of ground resolution, made this algorithm particularly suitable for the application to such heterogeneous environments. The hydrological model used for generating the reference SMC was the soil water balance model (SWBM) [3], a well assessed model that was found to perform very good in the reproduction of observed soil moisture data in the study area.

The comparison between HydroAlgo and SWBM SMC provided encouraging results in terms of R, with median values higher than 0.8, and RMSE, lower than 0.05 m³/m³, pointing out however slight differences in the retrieval if using ascending or descending overpasses. This discrepancy can be attributed to the two training processes that were carried out in order to set up two different ANN, for processing independently the data collected in ascending and descending orbits respectively.

Hydroalgo followed quite well the SMC variations, with a few overestimation of the very dry and a few overestimation of the very wet surface conditions, which can be attributed to the scarce sensitivity of microwave emission to extremely low and extremely high SMC.

Moreover, HydroAlgo was found able to reproduce satisfactorily the short-term SMC variability, from the analysis on SMC anomalies; consistently better than the results obtained in previous studies with AMSR-E data.

The SMC generated by Hydroalgo was then considered as input for generating a rainfall product through the SM2RAIN algorithm [4], which is able to simulate the daily rainfall data (mm/day) at 1-degree spatial resolution, obtaining encouraging results.

These results confirmed the potential of AMSR2 for the SMC monitoring of soil moisture at a local scale and in heterogeneous landscapes, evidencing the capabilities of the ANN based inversion algorithms for such kind of applications.

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Tuesday, April 12	Instruments and Techniques	10:20 - 12:00
ecture Session		Lecture Hall B

Session Co-Chairs: Shannon Brown, NASA Jet Propulsion Laboratory; Francesc Torres, Universitat Politècnica de Catalunya

Paper 1 BRIGHTNESS TEMPERATURE SPATIAL CORRELATIONS IN SMOS ANTENNA

10:20 Justino Martinez, Antonio Turiel, Verónica González-Gambau, Estrella Olmedo, Institute of Marine Sciences, CSIC, Spain

The European Space Agency mission Soil Moisture and Ocean Salinity (SMOS) is devoted to provide soil moisture and sea surface salinity. SMOS uses an L band 2-D aperture synthesis interferometric radiometer to obtain

polarimetric brightness temperature images.

The instrument measures the cross-correlations of all pairs of receivers to derive the visibility function. The vector of visibilities is linearly related to brightness temperatures TB by means of a reconstruction matrix [1]. This fact, together with an image reconstruction under aliasing conditions can induce spurious spatial correlations in the antenna among TB. The uncorrelation assumption is a key point in the SSS and SM retrieval

processes, therefore the knowledge of spatial correlation at antenna level of measured brightness temperatures is the first step to delucidate the goodnes of uncorrelation assumption and, if necessary, to propose ways to diminish its impact. In this work we will focus our efforts into get a clear response to the first question: Are there significant spatial correlations in the measured TB?. Having this question in mind we have computed correlations using differences between consecutive snapshots of the same polarization. The use of differences between snapshots, and not the snapshots themselves, allows us to avoid external sources of correlations (geophysical conditions, presence of the reflected Sun...) This work shows that non-negligible correlations are induced independently from the type of scenes present in the SMOS field of view (land, ocean or deep sky).

The precise origin of these correlations is unknown, but seems to be caused by the adquisition and processing procedure. A way that we propose to diminish the impact of these correlations involves the description of the SMOS response to a point source: the Point Spread Function (PSF). The computation of SMOS PSF can be addressed assuming that the radiometric error is unbiased. In this case a punctual source located at a given point can be synthetized from the measures averaging all the snapshots multiplied by the sign of the measured TB difference at the point under study. This procedure allows us to compute the PSF matrix without any model assumption. Nevertheless the PSF's coming from operational data (2791 non-redundant baselines) lead to a ill-conditioned matrix and inversion is not reliable using the operational 128x128 antenna samples. Fortunately,

we have strong indications that to consider PSF matrix as a convolution kernel is a good approximation. Then, the convolution kernel is constructed by averaging all PSF avoiding the inversion problem by working in the frequency domain.

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Paper 2 MITIGATION OF CROSS-POLAR ANTENNA PATTERN ERRORS IN SMOS: SIMPLIFIED APPROACH

10:40 Israel Durán, Universitat Politècnica de Catalunya, Spain; Lin Wu, Key Laboratory of Microwave Remote Sensing, Chinese Academy of Sciences, China; Francesc Torres, Ignasi Corbella, Nuria Duffo, Universitat Politècnica de Catalunya, Spain; Manuel Martín-Neira, European Space Agency, Netherlands

SMOS is the acronym for the Soil Moisture and Ocean Salinity mission by the European Space Agency (ESA) [1]. Its single payload, the Microwave Imaging Radiometer using Aperture Synthesis (MIRAS), was successfully launched in November 2009 to provide a continuous flow of fully polarimetric brightness temperature images. Along these years of operation, SMOS calibration and imaging algorithms have undergone a continuous evolution to further improve the accuracy of the retrieved geophysical parameters. These improvements are particularly useful in Ocean Salinity (OS) applications where accuracy and stability requirements are very demanding and spatial and temporal averaging is required to achieve SMOS mission objectives.

In the first versions of the L1OP processor (SMOS Level 1 Operational Processor) one of the major sources of systematic spatial error (spatial bias) on retrieved polarimetric brightness temperatures was related to the impact of antenna cross-polar antenna patterns. That is, the G-matrix used in the image reconstruction procedure was taking into account exclusively the co-polar antenna patterns. The new version of the L1OP processor (v620 released in May 2015) mitigates this error to a large extend, especially on Stokes 3 and Stokes 4 parameters, by introducing the full-pol G-matrix, an image reconstruction procedure that takes into account the cross-polar antenna patterns [2][3].

Although the full-pol G-matrix image reconstruction approach has significantly improved SMOS radiometric error performance, it also resulted in a significant increase on computational time and memory requirements. However, the recent work presented in [4] showed that a few cross-polar terms in the full-pol G-matrix are responsible for the bulk of the spatial error. Within this context, the work to be presented at Microrad'16 is devoted to show the performance of a simplified image reconstruction procedure that exclusively takes into account these most significant cross-polar antenna pattern terms. This simplified approach has yielded a significant reduction of computational effort at a minimum cost on radiometric performance.

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Paper 3 SMOS SALINITY RETRIEVALS ENHANCEMENT IN COASTAL AREAS BY JOINT APPLICATION OF NODAL SAMPLING AND CORRECTED CORRELATOR EFFICIENCY

Verónica González-Gambau, Institute of Marine Sciences, CSIC, Spain; Estrella Olmedo, Antonio Turiel, Justino Martínez, Barcelona Expert Center, Spain; Israel Durán, Universitat Politècnica de Catalunya, Spain

Abrupt changes in the ESA's Soil Moisture and Ocean Salinity (SMOS) brightness temperatures, such as those produced by land/sea/ice transitions and Radio-Frequency Interference (RFI) sources, produce artificial rippling patterns (the so-called Gibbs-like contamination) that propagate through the SMOS reconstructed image. The nodal sampling, a novel image reconstruction technique, is focused on the reduction of this kind of contamination by sampling the signal at the points where the perturbation vanishes (the so-called nodal points), so the distortion of the geophysical signal is minimum [1]. The nodal sampling algorithm encompasses three steps: (i) the spatial oversampling of the brightness temperature (TB) image (since the better definition of the oscillating structures leads to a more accurate determination of the nodal points), (ii) the nodal grid determination and (iii) the reconstruction of a corrected TB image at the original spatial sampling.

Comprehensive assessments of the performance of this image reconstruction technique have been performed over the ocean. Results show that the application of nodal sampling reduces ripples and sidelobes in the reconstructed images, with the new brightness temperatures in better agreement with the theoretically modeled ones. Validation of the SSS (Sea Surface Salinity) retrievals against near-surface Argo salinity observations has shown that this technique leads to a significant

quality enhancement of the SSS in open ocean with respect to those retrievals obtained by using the current SMOS image reconstruction strategy. However, in coastal areas, enhancements by the application of nodal sampling could be masked [2] since besides RFI contamination, systematic biases are also present due to land-sea contamination (an increase in oceans' brightness temperature near land masses).

Recently, a study about the origin of this land-sea contamination (LSC) has shown that correlator efficiency errors are the main driver of this contamination and a simple correction scheme has been proposed to mitigate it [3]. The aim of the present work is twofold: (i) the assessment, for the first time, of the quality of LSC-corrected SSS global maps and (ii) the assessment of the nodal sampling capabilities to provide valid salinity retrievals not only in open ocean, but also in strongly RFI-contaminated coastal areas once the LSC-correction has been applied (prior to the image reconstruction by nodal sampling). Our results show a significant improvement of the retrieved SSS quality when nodal sampling is applied, especially close to the coast.

[1] V. González-Gambau, A. Turiel, J. Martinez, E. Olmedo, and I. Corbella, "A novel reconstruction algorithm for the improvement of SMOS brightness temperatures," in Microwave Radiometry and Remote Sensing of the Environment (MicroRad), 2014 13th Specialist Meeting on , vol., no., pp.124-127, 24-27 March 2014, doi: 10.1109/MicroRad.2014.6878922.

[2] V. González-Gambau, E. Olmedo, A. Turiel, J. Martínez, J. Ballabrera, M. Portabella, and M. Piles, "Enhancing SMOS brightness temperatures over the ocean using the nodal sampling image reconstruction technique," Remote Sensing of Environment, August 2015, in review.

[3] I. Corbella, I. Durán, L. Wu, F. Torres, N. Duffo, A. Khazaal, M. Martin-Neira, "Impact of Correlator Efficiency Errors on SMOS Land-Sea Contamination," in Geoscience and Remote Sensing Letters, IEEE, vol. 12, no.9, pp. 1813-1817, Sept. 2015, doi: 10.1109/LGRS.2015.2428653.

Paper 4 ANALYSIS OF RADIOMETER RESOLUTION ENHANCEMENT TECHNIQUES AND THEIR IMPACT ON SMAP RADIOMETER 11:20 ONLY SOIL MOISTURE PRODUCT

Sidharth Misra, Shannon Brown, NASA Jet Propulsion Laboratory, CalTech, United States

Radiometer resolution enhancement techniques have been studied by the remote sensing community for many decades. These enhancement algorithms have been different versions of the optimum sampling algorithm originally proposed by [Poe, G., 1990] derived from the Backus-Gilbert theory [Backus, G. and Gilbert, F., 1969]. The enhancement algorithms are based off de-convolution methods applied in different domains.

In the following presentation, we will present a new method of resolution enhancement for space-borne microwave radiometer products. The enhancement algorithm can be broken down into three main portions: (1) Re-sampling and Re-gridding, (2) Enhancement Inversion and (3) De-noising. The first part of the algorithm converts a non-uniformly sampled integrated brightness temperature (Tb) into a uniform high-resolution grid. This grid still reports data at a low resolution integrated by the antenna pattern made spatially uniform with respect to azimuthal direction. We perform our image enhancement in the spatial spectral domain by balancing three different criterions – high spatial frequencies attenuated by the re-gridded antenna pattern function, noise-floor of the radiometer measurement, relative level of the spectral properties of the antenna pattern with respect to noise. Enhancement is achieved by increasing the gain of high spatial frequency elements. The final step involves applying denoising algorithms to the enhanced image. A blind inversion for resolution enhancement can increase radiometer noise levels to unrealistic values, denoising algorithms have to be applied at various stages of the algorithm to get realistic enhanced images. We will present various algorithms applied and their impact on the radiometer calibration.

The second portion of the talk will concentrate on algorithm performance. The algorithm performance itself is an optimal function between the noise floor of the radiometer, the attenuation of the antenna pattern and anomalies added by the denoising algorithm. We will quantify the algorithm based on those parameters. We will also study other metrics, such as the spatial correlations of the residual errors introduced during the enhancement process.

The final portion of the talk will discuss algorithm validation efforts. The SMAP mission measured an active-passive product at a high-resolution of 10km for the first two and a half months of the mission when the radar was still operational. Aggregating the 3km resolution SMAP radar data and disaggregating the 40km radiometer data to 10km created this active/passive soil moisture product. We will apply our algorithms to the low-resolution radiometer-only product and compare it with high resolution active-passive products to analyze and validate the effectiveness of the algorithm. We will also discuss further work based on the initial results obtained.

Paper 5 MULTISPECTRAL SUPER-RESOLUTION OF TROPICAL CYCLONE IMAGERY USING SPARSITY-BASED APPROACHES

11:40 Igor Yanovsky, Bjorn Lambrigtsen, NASA Jet Propulsion Laboratory, CalTech, United States

An aperture synthesis system produces ringing at sharp edges and other transitions in the observed field. In this paper, we have developed an efficient multispectral deconvolution method, based on Split Bregman total variation minimization technique, and showed it to reduce image ringing, blurring, and distortion, while sharpening the image and preserving information content. We also present a multispectral multiframe super-resolution method that is robust to image noise and noise in the point spread function and leads to additional improvements in spatial resolution. The methodologies are based on current research in sparse optimization and compressed sensing, which lead to unprecedented efficiencies for solving image reconstruction problems.

Physically deforming phenomena, such as hurricanes and tropical storms, will soon be continuously captured using geostationary microwave sensors. These sensors are designed to penetrate through thick clouds to see the structure of a storm. The images collected are valuable for evaluating the storm's internal processes and its strength.

The Geostationary Synthetic Thinned Aperture Radiometer (GeoSTAR) is a microwave spectrometer aperture synthesis system that will be used to capture hurricane imagery. A characteristic of an aperture synthesis system is that the point spread function (PSF) is a 2-dimensional sinc-like function, showing positive and negative excursions, that produces ringing at sharp edges and other transitions in the observed field. The conventional approach to suppressing such sidelobes is to apply linear apodization, which has the undesirable side effect of degrading spatial resolution.

Compressed sensing efficiently reconstructs a signal from a very few measurements by exploiting its sparsity. For sparse signals, it requires much fewer linear measurements than required by the Nyquist-Shannon sampling theory. One of the early applications of compressed sensing and sparsity based reconstruction is image reconstruction. For example, total variation (TV) based image restoration reconstructs images from noisy signals by exploiting the sparsity of edges.

In order to reduce image ringing while sharpening the image and preserving information content, we formally solve the deconvolution inverse problem for singlechannel images. Since the convolution problem in the presence of noise is highly ill-posed, regularization is applied to achieve stability while preserving a priori properties of the solution. In this paper, we generalize an efficient total variation-based Split Bregman deconvolution method to efficiently reconstruct multispectral imagery. Session Co-Chairs: Martin Suess, European Space Agency; Jaan Praks, Aalto University

Paper 1 PRE-LAUNCH SENSOR CHARACTERIZATION AND PERFORMANCE OF THE COMPACT OCEAN WIND VECTOR 13:00 RADIOMETER SYSTEM

Shannon Brown, Paolo Focardi, Amarit Kitiyakara, Frank Maiwald, Oliver Montes, Sharmila Padmanabhan, Richard Redick, Damon Russell, Lance Milligan, NASA Jet Propulsion Laboratory, CalTech, United States

The Compact Ocean Wind Vector Radiometer (COWVR) is a new-generation low-cost conically imaging microwave radiometer system developed by the Jet Propulsion Laboratory for a United States Air Force spaceborne technology demonstration mission planned for launch in 2017. The radiometer operates at 18.7, 23.8 and 33.9 GHz and is fully polarimetric in each band. The fully-polarimetric observations enable retrieval of ocean surface wind vector, as well as other key environmental parameters such as precipitable water vapor, cloud liquid water, precipitation rate and sea ice. Its compact size is well suited for implementation on an ESPA-class satellite, enabling low launch costs as a secondary payload. COWVR is a novel design that uses Electronic Polarization Basis Rotation (EPBR) to eliminate a complex and costly spin mechanism and reduce spun mass along with compact MMIC polarimetric receivers to reduce the overall sensor cost and complexity. The mission objective is to demonstrate the sensor performance on-orbit relative to WindSat to inform future DoD microwave sensor design. The sensor development was completed in September 2015, meeting all of its performance requirements. This paper describes the overall pre-launch calibration approach which has been tailored to the unique aspects of the new sensor design. Two critical aspects of the pre-launch campaign were demonstrating the end-to-end antenna temperature calibration performance after EPBR correction and the modeling and measurement of the antenna pattern as a function of antenna azimuth angle. We will describe the test methodology and results which form the basis for the pre-launch performance estimate.

Additionally, we will discuss the unique processing techniques required for this system, including Electronic Polarization Basis Rotation to transfer the polarimetric measurements from the instrument frame (non-rotating fixed feed) to the Earth frame and describe how this actually improves the sensor on-orbit calibration compared to the more traditional sensor design approach. Finally, we will describe several concepts for low-cost sensors that build on the novel COWVR architecture. The COWVR technology demonstration mission is focused on wind vector retrieval and therefore only required frequencies between 19-35 GHz. The design is scalable to a broader frequency range to cover more environmental data records, such as sea surface temperature, soil moisture and atmospheric temperature and moisture sounding. We will describe several designs including small ESPA class systems for moderate resolution operation at frequencies above 19 GHz and larger aperture systems for operation at 6 GHz and above. We will discuss sensor designs that cover frequencies between 6-183 GHz.

Paper 2 A QUEST FOR MINIATURE, INTEGRATED, LOW POWER, AND COMMERCIALLY VIABLE RADIOMETERS.

13:20 Marian Klein, Colton Dunlap, Boulder Environmental Sciences and Technology, United States; Reno K. Y. Choi, Korea Meteorological Administration, Republic of Korea

The design of a miniature, integrated and low power consuming radiometer can significantly widen the applications where passive microwave remote sensors could benefit environmental observations. The lack of the data from the atmosphere and especially the boundary layer and the need for more observations of the thermodynamic state of the atmosphere is acknowledged by meteorologists, see for example (Archer, et al. 2014) and (National Research Council 2009). In addition, radiometry is recognized as one of the most mature, reliable, and least expensive technologies for thermodynamic profiling, (Hardesty and Hoff 2012). Despite all of the above, ground based radiometers are still not widely accepted and used for operational weather observations.

This lack of wider acceptance of ground based radiometers into the operational observations is partially caused by the relative immaturity of the technology. Reliance on cryogenic calibrations, requirement of thermal stabilization of the radiometer receiver components, problematic observations during precipitation events, and a requirement for a very knowledgeable operator to maintain and calibrate these radiometers makes them very expensive instruments. The most significant problem for a radiometer operator is not being able to determine when a radiometer requires calibration. Currently, a common way to check if a radiometer is properly calibrated is to use a cryogenic target, which is not a trivial task and it removes the radiometer from its operation.

Besides ground based measurements, other applications require compact and low power radiometers. These applications include operations on an Unmanned Aerial Vehicle (UAV), in remote locations outside of a power grid (such a buoy in the middle of the ocean), or on a CubeSat. In addition, extending any instrument's operational capabilities, in terms of its bandwidth and number of channels, is easier with a small and compact receivers. Such instruments are sometimes referred to as hyperspectral radiometers, (Blackwell, et al. 2010) (Harris 2005). In any application, customers for radiometry are expecting instruments that are reliable and provide well calibrated data while operating in all atmospheric conditions - in extreme weather conditions on the ground, at the edge of the atmosphere in stratosphere, or in space.

BEST has developed a compact, integrated radiometer, the Profiling Radiometer for Atmospheric and Cloud Observation (PRACO). Based on experience with the development of PRACO, we are designing and building radiometers for the Korea Meteorological Administration CHAISR, (Choi, et al. 2015).

A microwave radiometer capable of operating on a high altitude UAV platform, has to overcome several technological challenges, such as:

• It must be robust and operate reliably in extreme environments, such as temperature, humidity and pressure variations during a flight, and it must be able to cope with mechanical vibrations during the flight and while landing

- It must reliably operate within a wide temperature range without any significant power consumption for thermal stabilization
- It should be able to observe during most atmospheric conditions, within clouds, and during misty, rainy, or even during freezing precipitation conditions

• In-flight calibration without external targets is preferable, since targets add a lot of weight to an instrument and consume a significant amount of power for their temperature control

Application of cryogenic gases for calibration, even during preflight on the ground, is impractical in most field deployments, thus it should be avoided

• A radiometer should be able to operate independently of the aircraft, i.e., it should have its own measurement of in situ environmental parameters, such as temperature, pressure, humidity, instrument location (via Global Positioning System) and its attitude (via inertial measurement system).

We will present our progress in the development of integrated radiometers for PRACO and CHAISR.

Paper 3 THE CUBESAT RADIOMETER RADIO FREQUENCY INTERFERENCE TECHNOLOGY VALIDATION (CUBERRT) MISSION

13:40 Joel Johnson, Chi-Chih Chen, The Ohio State University, United States; Sidharth Misra, Shannon Brown, Jonathon Kocz, Robert Jarnot, NASA Jet Propulsion Laboratory, CalTech, United States; Damon Bradley, Priscilla Mohammed, Jared Lucey, Jeffrey Piepmeier, NASA Goddard Space Flight Center, United States

Recent passive microwave measurements below 40 GHz have shown an increase in the amount of man-made interference, corrupting geophysical retrievals in a variety of crucial science products, including soil moisture, atmospheric water vapor, sea surface temperature, sea surface winds, and many others. Spectrum for commercial use is becoming increasingly crowded, accelerating demand to open the bands reserved for passive microwave Earth observation and radio astronomy applications to general use. Due to current shared spectrum allocations, microwave radiometers must co-exist with terrestrial RFI sources. As these sources expand over larger areas and occupy additional spectrum, it will be increasingly difficult to perform radiometry without an RFI filtering capability. Co-existence in some cases should be possible provided that a subsystem for filtering of RFI is included in future systems. Successful RFI filtering will not only open the possibility of microwave radiometry in an RFI intensive environment, but may also allow future systems to operate opportunistically over a larger bandwidth resulting in lower measurement noise.

Initial progress in RFI filtering technologies for microwave radiometry has been achieved in the SMAP mission, which is currently operating in space a digital subsystem for this purpose in a 24 MHz bandwidth centered in the protected 1413 MHz band. RFI subsystems for higher frequency microwave radiometry over the range 6-40 GHz however require a larger bandwidth, so that the capabilities of RFI filtering backends in terms of bandwidth, processing power, and onboard operation must also increase. To demonstrate such technologies for future radiometer missions, the CubeSat Radiometer Radio Frequency Interference Technology Validation (CubeRRT) mission has been proposed and selected under NASA's In-space Validation of Earth Science Technologies (INVEST) program.

The enabling CubeRRT technology is a digital Field-Programmable Gate Array-based spectrometer with a bandwidth of 1 GHz that is capable of implementing advanced RFI filtering algorithms such as the kurtosis and cross-frequency methods in real time on board the spacecraft. Though the technology can be demonstrated for any frequency band from 1 to 40GHz, CubeRRT will integrate this backend with a wideband radiometer operating over a 1 GHz bandwidth tunable from 6-40 GHz to demonstrate RFI detection and filtering in important microwave radiometry bands. Along with a wideband dual-helical antenna, the CubeRRT payload will be integrated into a 6U CubeSat for deployment from the International Space Station. Although the spatial resolution to be achieved by CubeRRT will be coarse (~120-300 km, due to the limited antenna size possible), the goal of demonstrating observation, and filtering of RFI should be achievable in this configuration.

The CubeRRT project schedule plans for completion of the satellite by late 2017 with availability for launch beginning 2018. CubeRRT will act as an immediate risk reduction of new technologies that are necessary for future Earth science missions and directly relevant for future microwave Earth science missions such as SCLP, GMI follow on, SMAP follow on, and others.

Paper 4 CUBESAT SCALE RECEIVERS FOR CHARACTERIZATION OF ICE IN CLOUDS

14:00 Pekka Kangaslahti, Erich Schlecht, NASA Jet Propulsion Laboratory, CalTech, United States; Steven Reising, Colorado State University, United States; William Deal, Alex Zamora, Kevin Leong, Northrop Grumman Corporation, United States; Xavier Bosch-Lluis, Mehmet Ogut, Colorado State University, United States; Jonathan Jiang, NASA Jet Propulsion Laboratory, CalTech, United States

Global measurements of water vapor and cloud ice in the upper troposphere at varying local times is highly desired, because it will enable more accurate cloud and moisture simulations in global climate models. This goal can be aided by the recently demonstrated scaling of InP MMIC amplifiers to 1 THz, which will impact upper troposphere radiometry by transitioning to modern semiconductor technology, with significant reductions in the size and power of the receivers.

To this end, we are developing receivers for 230 GHz, 310 GHz and 670 GHz window channels; as well as for 183 GHz and 380 GHz water vapor sounding and for 118 GHz temperature sounding. These miniature receivers will fit in the focal plane of a CubeSat optical system using three feedhorns. The 670 GHz channel will have its own feedhorn and a cascade of InP HEMT MMIC amplifiers followed by a band-definition bandpass filter and a Schottky diode detector. The 230, 310 and 380 GHz receivers will share a common feedhorn and InP HEMT MMIC amplifiers to amplify and detect the 230 and 310 GHz channels with a detector as well as to downconvert the 380 GHz sounding channel with an InP HEMT MMIC second harmonic mixer. These receivers will be supplemented by an updated version of the previously demonstrated 118/183 GHz sounder using the latest generation of MMICs.

Paper 5 TEMPORAL EXPERIMENT FOR STORMS AND TROPICAL SYSTEMS TECHNOLOGY DEMONSTRATION (TEMPEST-D): RISK REDUCTION FOR CONSTELLATIONS OF 6U-CLASS NANOSATELLITES

Todd Gaier, NASA Jet Propulsion Laboratory, CalTech, United States; Steven Reising, Christian Kummerow, V Chandrasekar, Colorado State University, United States; Sharmila Padmanabhan, Boon Lim, Shannon Brown, NASA Jet Propulsion Laboratory, CalTech, United States; Christopher Ruf, University of Michigan, United States; Sue van den Heever, Colorado State University, United States; Tristan L'Ecuyer, University of Wisconsin, United States; Zhengzhao Johnny Luo, City University of New York, United States; Stephen (Joe) Munchak, NASA Goddard Space Flight Center, United States; Ziad Haddad, NASA Jet Propulsion Laboratory, CalTech, United States; Sid-Ahmed Boukabara, NOAA NESDIS STAR, United States

The Temporal Experiment for Storms and Tropical Systems Technology Demonstration (TEMPEST-D) will demonstrate technology required to enable a constellation of 6U-Class nanosatellites to directly observe the time evolution of clouds and study the conditions that control the transition of clouds to precipitation using hightemporal resolution observations. TEMPEST-D millimeter-wave radiometers in the 90-GHz to 183-GHz frequency range will penetrate into the cloud to observe key changes as the cloud begins to precipitate or ice accumulates inside the storm. The evolution of ice formation in clouds is important for climate prediction since it largely drives Earth's radiation budget.

TEMPEST-D provides observations at five millimeter-wave frequencies from 90 to 183 GHz using a single compact instrument that is well suited for the 6U-Class architecture and fits well within the capabilities of NASA's CubeSat Launch Initiative (CSLI), for which TEMPEST-D was approved in February 2015. TEMPEST-D will demonstrate that millimeter-wave radiometer measurements from 6U-Class nanosatellites can be precisely geolocated and remain calibrated with respect to other orbiting millimeter-wave radiometers with similar frequencies.

The full TEMPEST mission involves the deployment of 5-10 identical 6U-Class satellites in the same orbital plane with 5-10 minute spacing at roughly 400 km altitude and 50°-65° inclination. A baseline one-year mission is expected to capture 3 million observations of precipitation, including 100,000 deep convective events. The full TEMPEST mission improves understanding of cloud processes and helps to constrain one of the largest sources of uncertainty in climate models. TEMPEST is designed to provide critical information on the time evolution of cloud and precipitation microphysics, yielding a first-order understanding of the behavior of assumptions in current cloud-model parameterizations in diverse climate regimes. Session Co-Chairs: Ville Kangas, ESA/ESTEC; Leonid Mitnik, POI DVO RAS

Paper 1 SMOS PAYLOAD STATUS AFTER SIX YEARS IN ORBIT: OPERATIONAL AND THERMAL PERFORMANCE, CALIBRATION STRATEGY AND RFI MANAGEMENT

Mariano Kornberg, ESA, ESTEC, European Space Research and Technology Centre, Netherlands; Jorge Fauste, ESA, ESAC, European Space Astronomy Centre, Spain; Manuel Martín-Neira, ESA, ESTEC, European Space Research and Technology Centre, Netherlands; Roger Oliva, ESA, ESAC, European Space Astronomy Centre, Spain; Elena Daganzo-Eusebio, Elena Checa, ESA, European Space Research and Technology Centre, Netherlands

The SMOS satellite was launched on 2nd November 2009 from the Plesetsk Cosmodrome in northern Russia. With an initial mission duration of three years, the SMOS satellite is now in its extension period owing to its optimal technical status and scientific accomplishments and thanks to funding made available through the ESA Earth Observation Envelope Programme. The SMOS platform is based on the PROTEUS platform developed by CNES/ASPI and built by Thales Alenia Space. The SMOS Payload is a single instrument, the Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) that was built by EADS CASA Espacio. MIRAS is a passive microwave 2D-interferometric radiometer working in the L-Band (the MIRAS bandwidth is 1404 – 1423 MHz). The MIRAS antenna aperture is synthesized from 69 antenna elements arranged in a Y-shaped configuration. This paper will address the status of the SMOS payload from four different perspectives, as it is summarized in what follows.

(1) Management of anomaly issues and its impact on availability time: Several anomalies took place in the SMOS payload but none of them making a risk for the mission or for a degradation of its scientific products. Although some anomalies are recurrent, taking place over high radiation zones, some strategies have been implemented to diminish or even suppress their impact on unavailability time. An overview of the main problems and the techniques to deal with them will be presented in this paper.

(2) MIRAS Thermal performance and validity of scientific data: To ensure the proper operation of the SMOS Payload, specific thermal requirements were set for the receivers of the 69 antennas in order to guarantee the validity of the scientific data. In particular, the target temperature of the receivers is 22°C with a maximum spatial gradient of 6°C among all of them and a maximum orbital excursion of 4°C. To achieve this goal, the SMOS payload required the implementation of a dedicated Thermal Control Subsystem which is based on a passive design supported by heaters. We will present in this paper an overview of the performance of the MIRAS Thermal Control Subsystem with emphasis on how it continues to ensure quality data under different external environmental conditions.

(3) Calibration strategies and their impact on data quality: The calibration strategy was set following the Commissioning Phase of the satellite, which ended in May 2010, and has only suffered few modifications since then. The instrument is calibrated using internal loads and the galaxy as main references. Calibration using the galaxy as reference is performed when the satellite is turned around to point to the cold sky. Some of the modifications to the calibration strategy have led to a significant improvement in the overall stability of the data. The most important one was the introduction of a methodology to estimate in-orbit the antenna losses using the galactic observations.

(4) Improvement of the global Radio Frequency Interference (RFI) scenario as a result of ESA RFI management approach and its impact on data availability and quality: Since launch, RFI has impacted SMOS data products particularly over Europe, Asia and the Middle-East. The RFI situation has been continuously monitored worldwide with special efforts in the detection and geo-location of the interference sources. ESA has reported regularly the RFI cases to the relevant administrations asking them to initiate investigations and take due actions to switch-off or at least to mitigate its impact. The overall RFI scenario has improved considerably with approximately 500 RFI sources (60%) having either reduced or cancelled their emissions in the 1400-1427 MHz passive band. In this paper we will show the positive impact in SMOS data products of the RFI reduction worldwide.

Paper 2 ANTENNA PATTERN DIFFERENCES IMPACT IN MIRAS RECONSTRUCTION ERROR

Raúl Díez-García, Manuel Martín-Neira, European Space Agency, Spain

After 6 years in orbit, the European Space Agency (ESA) Soil Moisture and Ocean Salinity mission (SMOS) continues to provide high-quality, global maps of soil moisture and ocean surface salinity. Its payload MIRAS (Microwave Imaging Radiometer with Aperture Synthesis) is an L-band interferometric radiometer which achieves unprecedented resolution. It was successfully launched in November 2009 under the European Space Agency Earth Explorers program, and has since been acquiring high resolution images whose accuracy, precision and stability have been steadily improved

The present work analyses in detail the observed reconstruction error in SMOS brightness temperature images, and its relationship with the antenna pattern differences between receivers. Such reconstruction error is defined as the time-averaged spatial ripple that remains after an image reconstruction process, assuming perfect knowledge of the instrument and no calibration errors. The noise error is therefore completely independent of the radiometric noise or the presence of modelling errors, being then solely related with the reconstruction process. Antenna pattern differences, up to 5% of the nominal peak value, have an strong impact in the observed reconstruction error. Moreover, this impact is more significant when the spacing between element is above the Nyquist alias-free threshold, as is the case in SMOS.

In this paper the behaviour of the reconstruction error is parameterized in terms of antenna differences and element spacing. All simulations have been performed with the best possible model of the instrument and full polarimetric mode. Although the analysis here is done for MIRAS antennas, it is intended to provide a guidance for future interferometry radiometry missions.

Paper 3 FARADAY ROTATION WITH THE SMAP RADIOMETER

David Le Vine, NASA Goddard Space Flight Center, United States; Saji Abraham, Wyle Information Systems, United States

Faraday rotation is an issue that needs to be considered in the retrieval of ocean salinity and soil moisture at L-band where these measurements are made. As a result, each of the recent L-band missions in space, SMOS, Aquarius and SMAP, have included measurement of the third Stokes parameter to provide an in situ estimates of Faraday rotation. Aquarius demonstrated that the ratio of the third and second Stokes parameter [Yueh, 2000] could be used successfully to measure the local Faraday rotation over oceans [Le Vine et al, 2013]. The SMAP geometry (conical scanning) and the need to operate over both ocean (for retrieval of salinity) and over land (for retrieval of soil moisture) complicates the retrieval. The conical scan results in a rapid change of the viewing angle with respect to the local Earth magnetic field and issues such as vegetation canopy and inhomogeneity of the scene are potential sources of error for SMAP. In this manuscript comparison is presented of the rotation angle retrieved from the SMAP radiometer and the theoretical value predicted using the TEC (total electron content) from the International GNSS Service [IGS 2015] and the local magnetic field. A correction to the antenna pattern to correct for cross-polarization coupling is applied and improves the retrieval. In general, the global patterns and mean value along track agrees reasonably well with the theory. Over the ocean, the values of retrieved angle at individual points around the scan also compare reasonably well with theory. However, over land, the retrieval is very noisy. Over dense vegetation the retrieval can become unstable in the presence of noise and large errors are often observed over scenes that include large changes in the brightness temperature such as land-water boundaries.

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IGS 2015: http://www.igs.org

S.Yueh, "Estimates of Faraday Rotation with Passive Microwave Polarimetry for Microwave Remote Sensing of Earth Surfaces", IEEE Trans. Geosci. and Remote Sens., vol. 38, no. 5, pp 2434-2438, 2000.

Paper 4 THE ICE CLOUD IMAGER PRELIMINARY DESIGN AND PERFORMANCE

Marc Bergadà, Raquel González, Jaione Martínez, Miguel Ángel Palacios, Massimo Labriola, David Marote, Ana Andrés, José Luis García, Daniel Sánchez-Pascuala, EADS CASA Espacio, SL, Spain

The Ice Cloud Imager (ICI) instrument for Metop-SG, being developed by EADS CASA Espacio SL for ESA and EUMETSAT, has reached the preliminary design phase at system level. At this phase, most of the sub-system contractors have been selected, the specifications as well as the interfaces with the satellite have been consolidated and the most critical elements are being supported by prototyping activities to mitigate development risks.

ICI is a scanning sub-millimeterwave imaging radiometer acquiring noise-like signals from the Earth through the atmosphere at frequencies ranging from 183 GHz to 664 GHz, including 2 window and 9 sounding (absorption-line) channels. Its main objective is determining ice cloud properties to improve the current weather prediction models. All frequency channels produce pixels of around 15 Km average size, with an incidence angle of some 53° at the Earth surface, and receive linear vertical polarization; the 2 window channels receive horizontal polarization as well. This is the first instrument of its kind to use such frequency range for Earth observation from space and will help to fill the current gap regarding the measurement of ice cloud profiles and various precipitation parameters that cannot be obtained using existing instruments.

Five instrument models will be manufactured: a Structural and Thermal Model (STM), an Engineering Model (EM), and three flight models; of them, one Protoflight (PFM) and two recurrent models (FM2 and FM3). The three flight models will be launched in 7-year steps to guarantee the continuity of this operational mission.

The most critical design issues affect both the instrument performance and its reliability. The first one includes antenna pattern modelisation, radiometric calibration, thermal control, alignment and spectral shape. Regarding the second, ICI reliability is driven by the sub-millimeterwave technology of the receivers and the fact that the instrument has to be kept rotating during 7.5 years of mission lifetime at 45 rpm. In addition, a long-term storage period on-ground before launch has to be foreseen for the recurrent models, thus imposing also some design constraints.

This paper presents the current design status, making special emphasis to the performance-driven aspects.

Paper 5 PRE-LAUNCH PERFORMANCE OF THE ADVANCED TECHNOLOGY MICROWAVE SOUNDER (ATMS) ON THE JOINT POLAR SATELLITE SYSTEM-1 SATELLITE (JPSS-1)

Edward Kim, NASA, United States; Vince Leslie, Massachusetts Institute of Technology, Lincoln Lab, United States; Joseph Lyu, IMSG@NASA/GESTAR, United States; Lisa McCormick, Fibertek, United States; Craig Smith, SGT, United States; Kent Anderson, NGES, United States

The Advanced Technology Microwave Sounder (ATMS) is the newest generation of microwave sounder in the international fleet of polar-orbiting weather satellites, replacing the Advanced Microwave Sounding Unit (AMSU) which first entered service in 1998. The first ATMS was launched aboard the Suomi NPP (S-NPP) satellite in late 2011. The second ATMS is manifested on the Joint Polar Satellite System-1 Satellite (JPSS-1). ATMS provides 22 channels of temperature and humidity sounding observations over a frequency range from 23 to 183 GHz. These microwave soundings provide the highest impact data ingested by operational Numerical Weather Prediction (NWP) models, and are the most critical of the polar-orbiting satellite observations, particularly because microwave sensing can penetrate clouds.

This paper will present performance characterizations from pre-launch calibration measurements of the JPSS-1 ATMS conducted by the instrument vendor, Northrop Grumman Electronic Systems of Azusa, California. The measurements were conducted in a thermal vacuum chamber with blackbody targets simulating cold space, ambient, and a variable Earth scene. They represent the best opportunity for calibration characterization of the instrument since the environment can be carefully controlled.

We will present characterizations of the sensitivity (NEDT), accuracy, nonlinearity, noise spectral characteristics, gain stability, repeatability, and inter-channel correlation. An estimate of expected "striping" will be presented, and a discussion of reflector emissivity effects will also be provided. Comparisons will be made with the S-NPP flight unit. Finally, we will describe planned on-orbit characterizations—such as pitch and roll maneuvers—that will further improve both the measurement quality and the understanding of various error contributions.

Paper 6 MICROWAVE IMAGER INSTRUMENT FOR METOP SECOND GENERATION: DESIGN AND VERIFICATION

Tito Lupi, Fabio Tominetti, Marco Grilli, Walter Di Nicolantonio, CGS S.p.A Compagnia Generale per lo Spazio, Italy; Carine Bredin, Christian Tabart, Franck Bayle, Airbus Defence and Space SAS, France; Enrico Vetrano, Elena De Viti, Lorenzo Scialino, Alfredo Catalani, Space Engineering S.p.A., Italy; Salvatore D'Addio, European Space Agency, Netherlands

The payload complement of MetOp-SG satellites includes three microwave radiometers, namely MicroWave Sounder, MicroWave Imager and Ice Cloud Imager. This payload complement will provide high quality measurements covering a very wide frequency range from 18.7 GHz up to 664 GHz.

The main objective of the MicroWave Imager (MWI) is to provide cloud and precipitation observations as well as water vapour and temperature gross profiles.

The MWI is a conical scanning total-power microwave radiometer, providing calibrated and geolocated measurements in 26 channels ranging from 18.7 GHz up to 183.31 GHz, offering dual polarisation measurements up to 89 GHz.

The instrument is composed of one rotating part and one fixed part. The rotating part includes the main antenna reflector, the feed assembly and the receivers electronics. The front-end receivers are assembled as close as possible to the feeds for loss minimization, and a LNA is implemented in front of each receiver to fulfil the stringent sensitivity requirement. Depending on specific channel requirements and technical constraints, direct detection or heterodyne configuration are used. Noise diodes are introduced as additional calibration points at low frequency.

The rotating part is completed by two electronic units: the Front End Electronics furnishing the power supply to the receivers and the Command and Data Processing Unit managing all the rotating part, including data acquisition, thermal control, and implementing the interface with the fixed part. It integrates also a high speed digital processor for the detection and mitigation of interferences.

The fixed part contains the passive hot calibration target, the reflector for the cold-sky view for cold calibration and the electronics for the instrument control and interface with the platform. A scan mechanism provides continuous rotation at a constant speed of 45 rpm.

The footprints are ranging from 10 km to 50 km depending on frequency, with an along-track consecutive overlap of 20% minimum.

The effective azimuth range for the Earth scene observation is +/-65 degrees. Two additional sectors of about 30 degrees each along the scan are dedicated to calibrations by measurement of cold sky view and hot target.

To achieve very good radiometric accuracy and stability, the MWI is designed with sunshields to minimize sun-intrusion. Sunshields consist of a main tubular structure embracing all the rotating part with the exception of the openings for the earth view and cold-sky view, plus a baffle and a racetrack protecting the hot calibration target from sunlight.

For MWI development, an end-to-end simulator is implemented to support the verification of the required challenging performances. It is composed of two main software modules representing the on-board (Instrument Data Simulator – IDS) and the on-ground (Ground Processor Prototype – GPP) data processing functionalities. The IDS acts as forward model processing from the top of atmosphere radiance (or brightness temperatures) to level 0 (engineering measurements) data. Then, performing the calibration, the radiometric correction, and the geolocation of the level 0 data, the GPP module produces level 1B products. Within the whole chain, biases and random error contributions are introduced and different processing algorithms are tested. The performances are analysed and characterized comparing the level 1B output with the brightness temperature (input to IDS) convolved with the antenna pattern.

The GPP is also significantly exploited to verify the on-ground performance (e.g. radiometric gain, accuracy, linearity, and noise figure) of the EM and PFM models. Furthermore, during the satellite in-orbit verification phase, the GPP is employed to demonstrate the overall radiometric and geometric performances and for crossvalidation with the operational MWI ground processor.

The present paper will provide a description of the MWI instrument, covering in particular, the design, expected performance and verification activities.

Paper 7 REQUIREMENTS FOR A ROBUST PRECIPITATION CONSTELLATION

George Huffman, NASA Goddard Space Flight Center, United States; Ralph Ferraro, National Oceanic and Atmospheric Administration, United States; Christopher Kidd, University of Maryland, United States; Vincenzo Levizzani, CNR-Institute of Atmospheric Sciences and Climate, Italy; F. Joseph Turk, NASA Jet Propulsion Laboratory, CalTech, United States

Over the last 15 years the constellation of satellites carrying passive microwave (PMW) sensors has grown to a mature collection of almost a dozen satellites at any given time. Increasingly, a broad range of science and user communities have come to depend on the quasi-global precipitation analyses from High Resolution Precipitation Products (HRPP) that intercalibrate and merge these individual PMW precipitation data streams. Current HRPPs include Climate Prediction Center Morphing (CMORPH), Global Satellite Mapping of Precipitation (GSMaP), Integrated Multi-satellite Retrievals for the Global Precipitation Measurement (GPM) mission (IMERG), and Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA). At present, the constellation of precipitation-relevant conical and cross-track scanning multi-channel PMW instruments depends on many satellites past their design life and in continued operation by the responsible agencies.

The Group on Earth Observations (GEO) Water Strategy and subsequent discussions in Coordinating Group for Meteorological Satellites (CGMS) and Committee on Earth Observing Systems (CEOS) have raised the issue of how a robust future precipitation constellation should be constructed. This talk will discuss this issue of robustness by examining how retrievals are impacted by sensor resolution and channel diversity, the observation interval, and the use of a quasi-operational satellite precipitation radar for calibration. Specifically: 1) Sensor footprints larger than about 10-20 km start to introduce significant amounts of non-linearity in the retrievals, the so-called beam-filling problem. 2) Channel diversity has been shown to be necessary for covering the range of precipitation rates and types (liquid vs. solid). For example, the current inability to use the lower-frequency microwave channels (37 GHz and below) over land reduces the skill of retrievals compared to oceans, where these channels are already useful. As well, diverse polarization at a given frequency is also important. 3) An observation interval less than three hours for every time around the day barely accommodates the observed e-folding decorrelation times for cloud-scale precipitating systems. Sufficient sampling would be facilitated by coordinated satellite orbits. 4) The precipitation radars on the precessing TRMM and GPM Core Observatory satellites have demonstrated the utility of routine calibration for precipitation estimates across all the PMW sensors (and in the case of GPM this is done for most of the Earth's climate zones). Such considerations are critical to the discussion on how to shift to a new, more diverse generation of precipitation-relevant sensors while preserving the characteristics that provide (and support continued innovation of) quality PMW retrievals and value-added products such as HRPP that many users find attractive.

Tuesday, April 12	Experimental Campaigns	14:40 - 16:00
Poster Session		Outside Hall B

Session Co-Chairs: Leena Leppänen, Finnish Meteorological Institute; Robert Stachnik, NASA Jet Propulsion Laboratory

Paper 1 PERFORMANCE OF THE CONICAL SCANNING MILLIMETER-WAVE IMAGING RADIOMETER (COSMIR) DURING THE GPM OLYMPEX CAMPAIGN

Rachael Kroodsma, University of Maryland ESSIC / NASA Goddard Space Flight Center, United States; Matthew Fritts, Mathew Schwaller, Caitlyn Cooke, Lawrence Hilliard, Jared Lucey, NASA Goddard Space Flight Center, United States

The Conical Scanning Millimeter-wave Imaging Radiometer (CoSMIR) is flying onboard the NASA DC-8 aircraft as part of the Global Precipitation Measurement (GPM) Olympic Mountains Experiment (OLYMPEX). OLYMPEX is a ground validation campaign for GPM focusing on measuring rain and snow over mountainous regions. OLYMPEX utilizes a variety of ground and airborne instruments to help validate precipitation retrieval algorithms for GPM. CoSMIR provides important measurements in the campaign since it is a radiometer with similar channels to the GPM Microwave Imager (GMI) near 89 GHz, 165 GHz, and 183 GHz. Using measurements from CoSMIR along with the other airborne instruments and ground observations will aid in understanding how these specific frequencies interact with rain and snow, leading to improvements in the GPM radiometer precipitation algorithms. A unique feature of CoSMIR that makes it suitable for GPM validation is its ability to obtain measurements in both conical and cross-track modes. The GPM constellation consists of both conical and cross-track radiometers so CoSMIR can be used to validate retrieval algorithms for both types of radiometers.

CoSMIR was last flown in the GPM IPHEX ground validation campaign in May-June 2014. Since then, there have been many improvements made to CoSMIR which greatly enhance its performance and will improve the quality of data collected during OLYMPEX. One improvement is with the motion control system. Prior to flying in OLYMPEX, CoSMIR was tested in a thermal chamber and during testing an anomaly in the motion control was detected. This anomaly caused an error in the pointing direction of CoSMIR but was detected with sufficient time to correct prior to OLYMPEX. Data taken during the chamber test also gives greater insight into the absolute calibration of CoSMIR and helps to identify any anomalies present in the scan such as edge of scan obstruction.

This presentation will describe the performance of CoSMIR and show results from the OLYMPEX campaign. Comparisons will be made between CoSMIR data, other airborne instrument measurements, and ground surface precipitation measurements to show how well they agree. CoSMIR measurements will also be compared with GMI observations for those cases when the GPM Core spacecraft makes an overpass with the DC-8 flight path.

Paper 2 MICROWAVE RADIOMETRIC CHARACTERIZATION OF DEEP SPACE KA-BAND CHANNEL FROM NUMERICAL MODELS AND EXPERIMENTAL GROUND DATA

Marianna Biscarini, Mario Montopoli, La Sapienza University of Rome, Italy; Domenico Cimini, CNR-IMAA, Potenza, Italy; Luca Milani, Frank Silvio Marzano, La Sapienza University of Rome, Italy; Klaide De Sanctis, HIMET, Italy; Saverio Di Fabio, CETEMPS, University of L'Aquila, Italy; Maria Montagna, Mattia Mercolino, Marco Lanucara, ESA/ ESOC, Germany

The increasing demand for high data rate services of space exploration missions lead to the designation of the downlink Ka frequency band (31.8 - 32.3 GHz) as the standard for deep space telecommunications. This paved the way to a new era of deep space exploration programs, with respect to the more conventional X frequency band (~ 8.4 GHz). This choice is supported by two main reasons: i) a 16x factor improvement in the power strength (due to the squared-frequency law increase of antenna directivity of the downlink beam for the same antenna effective area) going from X-band to Ka-band; ii) a 50x factor in allocated bandwidth for deep space communications (500 MHz at Ka-band, 10 MHz at X-band), leading to an increase of the actual transmitted data per unit of time (throughput) when using Ka-band. However, the main drawback when using Ka-band is due to the weather effects (rain precipitation above all), which cause much larger fluctuations on Ka-band than on X-band. The traditional method of increasing the transmitted power (power margins) to compensate these fluctuations is wasteful of energy for deep space Ka-band. Therefore, a different operations concept is needed for Ka-band links.

In this context, the aim of this work is to investigate weather effects on the propagation of Ka-band signals in a typical deep-space transmission link in order to prompt transmission data-rate adaptation strategies based on the knowledge of the link channel conditions from the present to future instants.

To achieve the aforementioned goal, we make use of a weather forecast model (WFM), a radio propagation model (RPM) and a downlink budget model (DBM) set up in the area of Cebreros, Spain where an European Space Agency ground station for deep space communication is located.

WFM, RPM and DBM are bound together to forecast weather scenarios. The WFM provides the atmospheric state (i.e. pressure, humidity temperature, rain, etc.). The RPM exploit the atmospheric state to derive the expected channel state and its effects on the propagating signal (i.e. path attenuation, brightness temperature). Finally, the DBM converts these effects into expected transferred data volume (i.e. probability of correct transmission and data loss).

More in details, the adopted WFM is the Mesoscale Model (MM5), whereas the RPM is a physically-based radio propagation model which makes use of a radiative transfer solver based on the Eddington approximation as well as accurate scattering module. The general idea for a future practical use in deep space communications is to exploit WFM, RPM and DBM to provide predictions of transmission channel scenarios to allow data rate adaptive strategies.

The validation of the proposed modelling chain, based on simulation of the atmospheric related parameters, is performed against co-located ground-based microwave radiometer (MWR) observations. A multichannel MWR, working in the 22-58 GHz band is operating in Cebreros, providing reference measurements of Ka-band brightness temperature and path attenuation and estimates of the columnar integrated water vapour and liquid water contents. These quantities are of uppermost interest for assessing the precision and accuracy of the outputs of the WFM and RPM. A period of several months is considered as validation test, thus covering the seasonal variability of selected target area.

The presentation gives an overview of the main results, highlighting the improvement achieved with respect to more conventional transmission strategies, and indicating the accuracy interval of the forecasts in terms of transferred data throughput.

Paper 3 SODANKYLÄ RADIOMETER EXPERIMENT SORAX

Leena Leppänen, Anna Kontu, Juha Lemmetyinen, Jouni Pulliainen, Finnish Meteorological Institute, Finland

Snow and soil frost are vital components of the water cycle, as well as being critically important for meteorological and climatological studies. Remote sensing of cryosphere is significant for global daily observations. Microwave instruments are used for snow water equivalent (SWE) and soil frost observations. Radiometer is a passive instrument which measures microwave emission (brightness temperature) originated from soil and snow. Scatterometer receives backscattering of transmitted microwave radiation from the snowpack. Inversions of snow and soil properties are made from observations with interpretation algorithms.

Ground-based instruments are used for satellite instrument development and validation, and for interpretation algorithm development. Those actions need also extent reference observations of snow and soil. For that purpose, one of the largest platforms locates in Arctic Research Centre of Finnish Meteorological Institute (FMI-ARC) in Sodankylä, Finland. The research station is experienced in remote sensing of cryosphere by extent measurements of natural snowpack and soil properties, data processing, and operational satellite data receiving.

Sodankylä Radiometer Experiment (SORAX) started in 2015 at FMI-ARC. SORAX includes hourly measurements of microwave emission with three tower-based radiometers using 1.4, 10.6, 18.7, 21, 36.5, 89 and 150 GHz frequencies, and both vertical and horizontal polarization. The radiometers are based on the same tower, so that observation area is closely the same. Measurements of backscattering will be made with a 1-9 GHz tower-based scatterometer from spring 2016. Close by is also made reference measurements, such as manual snow pit measurements, and automatic snow depth, soil temperature, SWE and meteorological measurements. Good quality reference measurements are important for successful utilize of SORAX data. All observations are made from low vegetation soil and natural snowpack in a forest opening. Preliminary results from the first measurement season 2015-2016 of SORAX will be presented in MicroRad 2016.

SORAX microwave measurements are made since 2015 in FMI-ARC, which hosts various soil and snow measurements for remote sensing related purposes. SORAX tower-based radiometer configuration is unique and very efficient for development and validation of satellite instrumentation and interpretation algorithms. Aim of the experiment is to collect long and extent dataset of soil and snow microwave observations from one location.

Paper 4 ON THE COMPARISON BETWEEN AIRBORNE L-BAND BRIGHTNESS TEMPERATURE AND GNSS-REFLECTIVITY: A CASE STUDY IN AUSTRALIA

Alberto Alonso Arrayo, Adriano Camps Carmona, Universitat Politècnica de Catalunya, Spain; Alessandra Monerris, Christoph Rüdiger, Jeffrey P. Walker, Ying Gao, Monash University, Australia; Jorge Querol Borras, Hyuk Park, Daniel Pascual, Raul Onrubia, Universitat Politècnica de Catalunya, Spain

The measurement of soil moisture is a trending topic and its importance is increasing day by day as it is one of the key parameters in the Global Water Cycle, and thus one of the main drivers of the Earth's climate. The potential of L-band microwave radiometry for soil moisture estimation has been widely assessed over the last decades, but little is known about the applicability of the novel Global Navigation Satellite Systems (GNSS)-Reflectometry (GNSS-R) for land surface parameters estimation. Both techniques are passive, and have similar operating frequencies: 1.4 GHz and 1.575 GHz for L-Band microwave radiometry and GNSS-R, respectively, whereas microwave radiometry has coarser spatial resolution than GNSS-R.

This work compares both techniques using the data collected during three flights conducted in the Austral Spring of 2013 in the context of the GNSS-R Experiments over Land in Australia (GELO2). The Polarimetric L-Band Microwave Radiometer (PLMR) was flown together with the LARGO (Light Airborne Reflectometer for GNSS-R Observations) GNSS-R scatterometer. The flight route started at Tyabb airport, VIC, south-east of Melbourne, and finished at Narrandera airport, NSW, with low altitude airborne observations (150 m) and in-situ ground sampling over the main focus area: the Yanco experimental site, NSW. This site is a semi-arid agricultural and grazing area which has been intensively monitored since 2001 (http://www.oznet.org.au), and has been the core site for a series of CalVal experiments for the ESA Soil Moisture and Ocean Salinity (SMOS), and the NASA Soil Moisture Active Passive (SMAP) missions. Different surface soil moisture conditions were observed across the Yanco site during each of the three flights, with soil moisture ranging from 0.15 m3/m3 in average during the first experiment, to 0.08 m3/m3 in the second one, and 0.3 m3/m3 in the third one (note that 28 mm rainfall had been registered in the area before the last experiment).

Results indicate that the correlation between GNSS-R and brightness temperature (TB) is larger for higher incidence angles (> 30 deg), with values ranging from 0.88 to 0.72. This occurs because the coherent scattering is the main mechanism for those incidence angles, as the surface "seems" to be smoother. On the other hand, for incidence angles lower than 30 degrees, the correlation between the radiometer and the GNSS-R decreases, ranging from 0.71 to 0.55. This occurs because the scattering mechanism in those situations is a mixture between the coherent and the incoherent components, as the surface seems rougher. Linking models between TB at linear polarization and GNSS-R reflectivity will be presented also at the conference, including the use of the first Stokes parameter and the Microwave Polarization Difference Index (MDPI). The large correlation found between L-band microwave radiometry and GNSS-R indicates that both techniques could be combined to improve the spatial resolution of microwave radiometry measurements and their derived soil moisture products.

Paper 5 APPLICATION OF HIGH-RESOLUTION DIGITAL SPECTROMETERS TO EARTH ATMOSPHERIC SCIENCE: RECENT RESULTS FROM JPL AIRBORNE SCANNING AND BALLOON-BORNE MICROWAVE LIMB SOUNDERS

Robert Stachnik, Nathaniel Livesey, Paul Stek, Robert Jarnot, Ryan Monroe, NASA Jet Propulsion Laboratory, CalTech, United States

The JPL Submillimeter-wave Limb Sounder (SLS) is a balloon-borne 650 GHz SIS receiver to study the photochemistry of ozone and related trace gasses, e.g. ClO, HO2, HCl, N2O, BrO, in the Earth's stratosphere and upper troposphere. The Airborne Scanning Microwave Limb Sounder (A-SMLS) is a 240 GHz receiver using a side-band separating SIS mixer. The A-SMLS antenna scans in elevation and azimuth measuring gas profiles across a 300 km wide horizontal swath for the study of atmospheric dynamics and gas transport in, for example, mesoscale convective events. SLS and A-SMLS use digital polyphase spectrometers (3 GHz bandwidth 8192 channels) implemented on UC Berkeley Casper project ROACH-1 hardware. Spectra, retrievals and photochemical modelling from the high altitude balloon flight of the SLS instrument from Ft. Sumner, New Mexico in September 2014 are presented. A-SMLS results are shown from high altitude flight onboard the NASA ER-2 across the southwestern U.S. in July 2015.

Paper 6 ISMAR - AN AIRBORNE TEST PLATFORM TO DEMONSTRATE RECEIVER (OR OTHER) TECHNOLOGY LATEST DEVELOPMENTS AND A DESCRIPTION OF THE PLATFORM

Ian Rule, Met Office, United Kingdom

I. BRIEF HISTORY

ISMAR, the International SubMillimetre Airborne Radiometer, is an aircraft mounted remote sensing instrument, owned by the Met Office. The initial case for ISMAR was based on the need to make retrievals of cloud ice water path, and hence the submillimetre frequencies noted below, which are sensitive to ice, were chosen for ISMAR. The design concept, driven by the Met Office with significant input by Rutherford Appleton Laboratory, was for a platform with accommodation for an array of receivers in an easily removable mount, known as the 'Plug', coupled with a flexible data acquisition system which allows for relatively easy changes to the receiver channels. This instrument has now been flown on the FAAM BAe-146 aircraft (http://www.faam.ac.uk/) with 118GHz (not an ice sensitive channel), 243GHz V&H, 325GHz, 448GHz and 664GHz V&H and 424GHz receivers.

II. LATEST DEVELOPMENTS

• Two receivers at 874GHz, funded by ESA, one with horizontal polarisation and the other with vertical, are almost finished manufacture by Omnisys of Gothenburg in Sweden. These will be integrated into the existing receiver array in 2016 or 2017.

• To cope with the additional heat generated by these receivers, the front end cover box will be redesigned to provide larger accommodation and controlled ventilation.

• A stretched polypropylene film window has been utilised to exclude external airflow from the heated calibration target, greatly improving the thermal stability and with no adverse radiometric effects.

• Omnisys have been funded to design and build a single feedhorn, dual polarisation receiver which they would like to test fly on ISMAR. It is hoped to integrate this 424GHz receiver into the instrument by 2018.

• A small infra-red camera has been built into a new mount facing the scan mirror, principally to see how the surface temperature of the onboard calibration targets varies in flight, but other applications can be envisaged.

III. AIRBORNE TESTBED FOR RECEIVER TECHNOLOGY

The modular design of ISMAR comprises an enclosure and easily removable mount (Plug) for receivers, which is adjacent to a scan mirror or antenna; a separate enclosure on which receiver specific electronics are mounted on easily fitted and removed individual plates; a data acquisition and real time computing system located adjacent to the receiver electronics section, but in its own shielded box; two separate power supplies sections – one for receiver and electronics only and the other for other requirements; two onboard thermal calibration targets viewed by the scan mirror, one heated, the other ambient; the motor drive box located away from the other components to minimise electronic noise coupling; and finally the scan motor and heated mirror, mounted in a double skinned drum to reduce airflow around the calibration targets and Plug viewing apertures (or lenses as in the current Plug). The instrument is flown in a blister mounted on the outside of the FAAM BAe146 research aircraft where the receivers can directly view a range of nadir and zenith angles.

This poster will describe the space and interfaces available for new technology, to be fitted and test flown in a very cost effective manner, and will also inform of the latest developments to the instrument.

Paper 7 COMPLEX EXPERIMENT OF TERRESTRIAL MICROWAVE RADIOMETRIC SYSTEM DATA VALIDATION FOR ATMOSPHERIC MEASUREMENT

Eugene Miller, Eugene Kadygrov, Evgeny Ganshin, Central Aerological Observatory, Russian Federation; Gennadiy Ilyin, Institute of Applied Astronomy, Russian Federation; Arkadiy Troitskty, Alexander Knyazev, Central Aerological Observatory, Russian Federation

The most important air condition characteristics are temperature profile, integrated water vapor and integrated liquid content. Over the last years terrestrial devices based on microwave radiometry method are of a more extensive use to determine this characteristics. Commercially affordable microwave profilers produced in several countries (USA, Germany, Russia) has been launched. In 2014-2015 integral comparisons of this devices were held at Central Aerological Observatory. The comparisons were made using following devices: the multichannel microwave complexes for the measurement of troposphere temperature profiles, integrated water vapor and liquid water content in atmosphere RPG-HARPRO G4 (Germany), «Microradkom» (Russia), single-channel scanning microwave profiler MTP-5 for the measurement of atmospheric boundary level (ABL) temperature profiles, dual-channel microwave complex WVR-2 (Russia) for the measurement of integrated water vapor and liquid water content in atmosphere. Besides the data of the nearest (100m) radiosounding aerological station (station Nº27612, Moscow, due to the WMO classification) and also GPS receivers data of integrated water vapor content were used. There were two parts in the experiment. The first one was the direct comparison between radiometric data Q, radiosounding data and navigation system GPS of Zelenograd station. The direct comparison took place in April-May 2015 in Dolgoprudniy, CAO. The radiometric and radiosounding data mean difference of Q was 0.05 g/Cm2. The second part was temperature profiles of radiometric complexes and radiosouning data comparison. The root-mean-square error (RMSE) of profile T(h) in the height range 0+1.2 km was (0.2+1.2)° C and the accurancy in the height 4+8 km ~ (2.5+3.5)° C in accordance with the meteorological conditions. The experiment was partly completed with the help of the Russian Foundation for Basic Research (grant 14-05-0038).

Tuesday, April 12	Atmosphere Sounding and Global Change	14:40 - 16:00
Poster Session		Outside Hall B

Session Co-Chairs: Boon Lim, NASA Jet Propulsion Laboratory; Terhikki Manninen, Finnish Meteorological Institute

Paper 1 ASSESSMENT OF A NEW MTP-RETRIEVAL BASED ON TIKHONOV TYPE REGULARIZATION

Mareike Kenntner, Jian Xu, Andreas Fix, Franz Schreier, Thomas Trautmann, Matthias Jirousek, Markus Rapp, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany

Airborne Microwave temperature profilers (MTP) are used all over the world to study atmospheric processes. They measure thermal emission at the 50-60GHz oxygen lines from which temperature profiles along the flight path of the aircraft can be derived.

So far, vertical temperature profiles recorded during research flights have been derived using a statistical retrieval method. This retrieval relies on radio soundings from the time and region of the respective research campaign as a priori data. This method leads to reliable vertical temperature profiles, which have proven to be useful in various studies. However, since the radiosonde measurements are part of the retrieval input, the dataset produced by this retrieval method is not independent from other measurements, which complicates the validation process.

A new retrieval algorithm, TIRAMISU (Temperature Inversion Algorithm for Microwave Sounding), has been developed. It is based on Tikhonov type regularization. This retrieval algorithm uses the line-by-line radiative transfer model GARLIC (Generic Atmospheric Radiation Line-by-line Infrared Code). The new method provides the opportunity to derive temperature profiles independently from other temperature data as a priori input.

In this study, first results of the processing of MTP data using the TIRAMISU algorithm, and a comparison to the results of processing MTP data with the statistical approach as well as NWP-model data will be presented.

The two retrieval methods will be applied to data from research flights performed during the ML CIRRUS campaign aboard the German research aircraft HALO in spring 2014 over Western Europe.

The resulting temperature profiles of the two different approaches will be compared for different meteorological conditions and flight patterns.

Paper 2 A FUNDAMENTAL CLIMATE DATA RECORD OF SSM/I & SSMIS BRIGHTNESS TEMPERATURES

Karsten Fennig, Marc Schröder, Axel Andersson, Deutscher Wetterdienst, Germany

The satellite based HOAPS (Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data; http://www.hoaps.org/) climatology provides climate data records of precipitation, evaporation and the resulting freshwater flux over the global ice-free ocean between 1987 and 2008. The latest version of HOAPS has been released by CM SAF and is available from the CM SAFs web user interface (http://wwi.cmsaf.eu/).

The HOAPS climate data records are primarily based on passive microwave measurements from the SSM/I (Special Sensor Microwave/Imager) sensor family. In order to derive reliable long term trend estimates of the global water and energy cycle parameters it is strictly necessary to carefully correct for all known problems and deficiencies of the SSM/I radiometers as well as to inter-calibrate and homogenise the different instruments. Moreover, all applied corrections need to be clearly documented to provide a complete calibration traceability for a Fundamental Climate Data Record (FCDR). Following these recommendations, CM SAF released in 2013 a FCDR of SSM/I brightness temperatures (DOI:10.5676/EUM_SAF_CM/FCDR_SSMI/V001), freely available from the web user interface (http://wui.cmsaf. eu/). This FCDR has already been used in the ESA CCI Sea ice project and will also be used in the upcoming reanalysis ERA5.

In order to further extend the HOAPS dataset in time, the SSM/I successor instrument SSMIS (Special Sensor Microwave Imager Sounder) has to be used from 2009 onwards. CM SAF has now reprocessed the SSMIS sensors onboard F16, F17, and F18 to the same standards as the SSM/I data record for the time period 2006 - 2013. (D01:10.5676/EUM_SAF_CM/FCDR_MWI/V002). Amongst others, known instrument issues like sunlight intrusions, moonlight intrusions, and reflector emissivity have been accounted for and the brightness temperatures have been inter-calibrated to the SSM/I instrument series to allow a seamless continuation of existing TCDRs.

This presentation will focus on the main calibration issues identified for the SSMIS instruments and compares the different inter-calibration procedures implemented to homogenise the time series of all SSMIS instruments. A validation of the brightness temperatures is a challenging task as there are no ground-truth reference measurements available for the microwave band. Hence, the homogeneity of the FCDR is evaluated by an analysis of the relative biases between the different instruments before and after the intercalibration offsets are applied. Finally, two different FCDRs, the CM SAF FCDR and an FCDR from Colorado State University are compared to identify strengths and weaknesses of the intercalibration approaches.

Paper 3 ALBEDO AND SEA ICE CONCENTRATION, EXTENT AND BRIGHTNESS TEMPERATURE CUMULATIVE ANOMALIES OF THE ARCTIC

Terhikki Manninen, Aku Riihelä, Kati Anttila, Emmihenna Jääskeläinen, Finnish Meteorological Institute, Finland

The Arctic sea ice concentration and albedo have been shown to have markedly decreasing trends during the last decades. The decrease of the albedo is not only due to the decrease of the sea ice concentration, but also due to a shift from a multiyear to seasonal ice cover. Focusing solely on the decreasing sea ice concentration does not provide the full picture, as the lengthening melt season and increasing boundary-layer air temperatures also contribute to the albedo decrease by changing the characteristics of the surface layer of the remaining ice cover.

In this study cumulative anomalies of the sea ice albedo and concentration variation in the Arctic marginal seas are analyzed using detrended data. Here the period of interest is the whole illuminated part of the year, i.e. spring and summer in order to integrate the whole radiation effect in one. The albedo data set used is the CLARA-A1-SAL (1982-2009) produced by CM SAF, which is one of the Satellite Applications Facilities of EUMETSAT (www.cmsaf.eu). The mean sea ice concentration and extent are provided by NSIDC. They are based on SMMR, SSM/I, SSMIS brightness temperature retrievals. Also the actual brightness temperature values are studied. In addition, reanalysis data of NCEP-DOE R2 is used for temperature, precipitation rate and total cloud cover. When the trend is removed from the data, possible dominant oscillations of the sea ice albedo and concentration will manifest.

The cumulative anomalies of the detrended surface albedo and sea ice concentration in the Arctic marginal seas have a wave structure with a period of about 20 years. The cumulative albedo and concentration anomalies are in phase in Baffin Bay and Greenland Sea, whereas in Arctic Siberian Seas and Barents Sea the sea ice concentration cumulative anomaly has a slightly longer period than the albedo. The detrended albedo and sea ice concentration of the Inner Arctic Ocean did not manifest any marked periodic behaviour until early 1990's. After that the characteristics are highly oscillating.

The coefficient of determination for the linear relationship between the albedo and sea ice extent cumulative anomalies is highest for Beaufort sea (R2=0.83), Arctic Siberian seas (R2=0.81), Eastern Arctic Ocean (R2=0.77), Baffin Bay (R2=0.77) and Greenland Sea (R2=0.75), whereas for the whole Arctic Ocean it is very low (R2=0.26). Interestingly, in the Central Arctic Ocean tha sea ice extent anomaly correlated with that of Beaufort Sea, whereas the cumulative albedo anomaly is more dominated by the Eastern Arctic Ocean and thus correlated with that of the Arctic Siberian Seas.

For the surface albedo anomaly of the Arctic Siberian Seas the highest correlation (R2=0.77) with the anomaly of the mean temperature of the top 10 cm of land during the same time period (the illuminated half year) was found was found for Siberia north of 60°N. Almost as high was the correlation with the Arctic Siberian Seas surface albedo anomaly and the land surface layer temperature of America north of 60°N (R2=0.71). The relationship of the anomalies of the surface albedo and the mean air temperature at 2 m was altogether weak, the only significant correlation being that of the Northern America air temperature and the surface albedo of the Arctic Siberian Seas (R2=0.69), the link to the Northern Siberia air temperature anomaly being only vague (R2=0.54). The anomaly of the total cloud cover of Northern Siberia was also linked to the surface albedo anomaly of the Arctic Siberian Seas (R2=0.76) and less strongly to the surface albedo of Barents Sea (R2=0.64).

Paper 4 ON THE AMOUNT OF INFORMATION CONTENT IN DOWN-LOOKING MICROWAVE RADIOMETERS FOR ATMOSPHERIC SENSING

Jose Maria Gual, Adriano Camps, Universitat Politecnica de Catalunya-Barcelona Tech, Spain

This study analyzes the amount of information contained in microwave radiometry of the atmosphere, with special emphasis in the downlooking configuration of the microwave radiometers used in conjunction to radar altimeters.

Using the Rosenkranz [1] model and a radiative transfer equation, a total of 304 frequencies are computed from 5 GHz to 200 GHz for three different reference atmospheres corresponding to tropical, temperate, and polar climates, and assuming water (emissivity \sim 0.5) or land/ice (emissivity \sim 1) at surface level.

Following an approach similar to [2] the number of degrees of freedom (DoF) is then computed according to Rodgers formulation [3] as a measure of the amount of information contained in these measurements for different noise levels (radiometric sensitivities).

The frequencies conveying non-redundant information are then selected as potential candidate frequencies for upcoming spaceborne water vapor radiometers, although no retrievals are attempted at this stage.

Results will be presented at the conference.

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[3] C. D. Rodgers, Inverse Methods for Atmospheric Sounding: Theory and Practice. Singapore: World Scientific, 2000

Paper 5 OBSERVATIONS OF GRAVITY WAVES USING THE NCAR MICROWAVE TEMPERATURE PROFILER

Julie Haggerty, Kelly Schick, National Center for Atmospheric Research, United States; Boon Lim, NASA Jet Propulsion Laboratory, CalTech, United States

A newly-designed Microwave Temperature Profiler (MTP) was developed at JPL for the NSF-NCAR Gulfstream-V (GV). MTP is a scanning microwave radiometer that measures thermal emission at spectral lines in the 50-60 GHz oxygen complex. MTP scans from near-zenith to near-nadir angles, measuring brightness temperatures forward, above, and below the aircraft at 17 s intervals. A statistical retrieval method derives vertical temperature profiles from the measurements, using radiosonde profiles in the vicinity of the aircraft as a priori information. Data products from MTP include atmospheric temperature profiles above and below the aircraft, as well as estimates of tropopause height, cold-point, and thermal lapse rate. Since 2008 this MTP has been deployed in numerous field experiments for a variety of scientific applications.

The Deep Propagating Gravity Wave Experiment over New Zealand (DEEPWAVE) investigated the dynamics of gravity waves, including generation mechanisms and propagation of gravity waves from the troposphere to the stratosphere. As part of the airborne payload on the NSF-NCAR GV, MTP provided the vertical temperature structure associated with gravity waves in the Upper Troposphere and Lower Stratosphere (UTLS). Examples of mountain wave activity, tropopause folds, and waves associated with convective activity and the polar jet stream are evident in the MTP-derived temperature fields. Retrieval procedures and applications for this data set will be discussed at the conference.

Paper 6 THE SYSTEM OF GROUND-BASED GEOPHYSICAL INSTRUMENTS AND SATELLITE MONITORING DATA AS TOOL FOR CHARACTERIZATION OF THE EARTH SURFACE MOTIONS AND THEIR INTERRELATION WITH DISTURBANCES IN OCEAN-ATMOSPHERE SYSTEM AND NEAR-EARTH ELECTROMAGNETIC ENVIRONMENT

Mstislav Dubrov, Sergey Golovachev, Kotel'nikov Institute of Radioengineering and Electronics of RAS, Russian Federation; Victor Volkov, Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences, Russian Federation; Alexander Milshin, Alexander Golovachev, Kotel'nikov Institute of Radioengineering and Electronics of RAS, Russian Federation

To estimate the risks of the powerful natural disasters interactions, impacts in the Earth environment such as earthquakes and tropical cyclones at the level of hurricane (typhoon) it is necessary to recognize maximally the Earth surface motions and their interrelation with the disturbances in the ocean-atmosphere system and near-Earth electromagnetic environment.

Earth observations by means of space-born and ground-based tools of radiophysical / geophysical monitoring provide the new methods and data systems available the important information about interrelation of mentioned processes to be revealed.

Although the long-range forerunners of strong earthquakes were preliminary described decades ago (Nersesov and Latynina, 1992) the first reliable observational results have been obtained owing to our ground-based data and satellite data comparisons.

The phenomenon explanation: powerful hurricanes may influence on the earthquake triggering, together with the evidence that hurricane transition features may be influenced by the solid Earth activity.

Moreover, the powerful events in ocean-atmosphere system having large horizontal scale are necessary to interact not only with the Earth surface, but also with higher layers of the thermosphere and near-Earth environment.

In this paper, we present the results of comparison of geophysical fields variations and seismic activity of the Earth.

The interaction between tropical cyclonic activity in the World Ocean, and seismic processes in the solid Earth can be resulted in appearing or increase in amplitude of the strainmeter measured wide-band oscillations disturbed by hurricanes which impact on the ocean bottom and provoke powerful earthquakes through the triggering effect.

The spatial / temporal tracks of powerful tropical hurricanes are coupled with place and time of earthquakes occurrence.

The examples of geophysical disturbances having near-Earth environment origin are presented and discussed too.

The comet C/2011 L4 (PanSTARRS) transit on March 2013 has been recorded by spatially distributed and in this period synchronously operating ground-based instruments.

We used the system of wide-band geophysical laser strainmeters, pendulum gravimeters, and tiltmeters in our observations. Data from four measuring sites in the East Europe were presented and analyzed.

The distance between separate instruments varies from a few hundred kilometers within local site installations, and up to thousands kilometers for a different remote sites and observatories.

The datasets of geostationary satellites GOES13 and GOES15 of Space Weather Prediction Center (NOAA USA, 1998-2015) and another satellite data have been used in complementation to the ground-based instrument recordings.

Earthquakes and hurricanes records during the recent strong earthquakes (Nepal, 25.04.2015, and Chile, 16.09.2015) were presented and analyzed.

The Investigation of the observed phenomena and the attempt to reveal the detailed interaction mechanisms of objects in the atmosphere, lithosphere, and other adjacent geospheres would give a chance to acquire more accurate information, knowledge concerning the regularity and origins of such natural disasters as earthquakes and hurricanes.

The extra precise ground-based laser interferometer and gravity-inertial techniques being supplemented by satellite observational systems can be considered as promising methods for the earthquake, hurricane and another powerful processes in the Earth environment to be monitored and predicted.

References:

Nersesov I.L., Latynina L.A., 1992, Tectonophysics v. 202, No. 2-4, pp. 221-225

Session Co-Chairs: Sante Laviola, CNR-ISAC; Sarah Ringerud, NASA Goddard Space Flight Center

Paper 1 SATELLITE RADIOMETRY OF VOLCANIC PLUMES: MICROWAVE AND INFRARED SENSOR SYNERGY FOR A CHILEAN CASE STUDY

Frank Silvio Marzano, La Sapienza University of Rome, Italy; Domenico Cimini, CNR, Italy; Montopoli Mario, Mereu Luigi, La Sapienza University of Rome, Italy; Kylling Arve, NILU, Norway; Stefano Corradini, Merucci Luca, INGV, Italy

[INTRO]. Volcanic ejections divide into gas and solid emissions. The latter are characterized by mineral fragments with size from micrometres to several centimetres, generally referred as tephra. Both emissions represent one of the most impacting sources of natural pollution as well as a natural hazard for nearby communities. In this context, the prediction of time-space dispersion of volcanic emissions is crucial for better defining the solar-Earth energy budget as well as ensuring enhanced safety standard for commercial flights. However, there is still a lack of knowledge in the initialization of the volcanic transport and dispersion models (VTDM), a fact which tends to prevent accurate predictions. Geophysical parameters characterising the volcanic emission at the source (called source parameters), are of predominant interest for the initialization of VTDM. Source parameters of main interest would be the top altitude of the volcanic plume, strictly related to the flux of the mass ejected at the emission source and the distribution of volcanic mass concentration along the vertical column.

[GOAL]. The goal of this work is to show how LEO-based satellite microwave (MW) radiometric measurements in the 50-183 GHz spectral range can complement satellite thermal-infrared (TIR) measurements at 10.8 and 11.9 micron in the detection of volcanic solid emissions in the area close to the volcanic fissure.

[OBSERVATIONS AND CASE STUDY]. The recent Calbuco volcanic eruption in Chile is considered as case study. On the morning of April 23, 2015 the Calbuco started to erupt and its tephra column rose to heights approximately within 17- 18 km. As a consequence, the local authorities evacuated about 4000 people living nearby and some flight cancellations took place. The Calbuco plume was observed by the cross-track scanning Visible Infrared Imaging Radiometer (VIIRS) and the Advanced Technology Microwave Sounder (ATMS), both of them embarked on the LEO Suomi National Polar-orbiting Partnership (NPP) platform. This allowed acquiring unprecedented coincident images of the Calbuco eruption in the infrared (0.746 – 12.013 microns) and microwave (23.8 – 183.31 GHz) spectrum with a nadir footprint of 750 m and from 15.8 km to 74.8 km, respectively.

[BEYOND THE STATE OF THE ART]. Indeed, thermal infrared (TIR) observations are the most used to detect emitted tephra particles. This is due to the fact that the fine tephra absorbs more radiation than water and ice at 10.8 microns while the reverse is true at 11.9 micron. Thus the difference (DT) between 10.8 and 11.9 micron brightness temperatures is taken as a proxy of the presence of ash when DT, whereas its negative strength depends from the cloud optical thickness and particle mean size. However, when the absorption is particularly high, as near the volcano vent during eruption, both TIR channels tend to saturate and thus the difference becomes insensitive (DT equal to about zero in the proximity of the volcano vent.

[EXPECTED RESULTS AND NEW ASPECTS]. Conversely, microwave observations hardly saturate and thus show a clear differential signature corresponding to volcanic tephra close to the volcano. On the other hand, the low resolution of MW observations, their poor sensitivity to finest tephra particles and their dependence to background emissions (e.g., surface, water vapor), makes MW observations much less sensitive to distal diluted ash cloud than TIR.

In this presentation, VIIRS and ATMS images during the recent Calbuco eruption are discussed to demonstrate experimentally the complementarity of microwave and TIR satellite observations for volcanic ash monitoring. This work, with the support of numerical modelling and other available satellite data, shall pave the way for a robust development of satellite microwave retrievals of volcanic source parameters for aiding the quality of VTDM outputs by improving their near-source parameter initialization.

Paper 2 THE COMMUNITY ACTIVE SENSOR MODULE (CASM): AN EXTENSION OF MIIDAPS FOR ACTIVE MICROWAVE SENSORS

Benjamin Johnson, Atmospheric and Environmental Research Inc., United States; Sid-Ahmed Boukabara, National Oceanic and Atmospheric Administration, United States; Kevin Garrett, Riverside Technology Inc., United States; Jean-Luc Moncet, Atmospheric and Environmental Research Inc., United States

The Multi-Instrument Inversion and Data Assimilation pre-Processing System (MiiDAPS) is a uniform Quality Control (QC) and pre-processing system, used as a tool to pre-process space-based microwave and IR sensor data before they are assimilated into the Community Gridpoint Statistical Interpolation (GSI) system. This tool optimizes the QC filtering and spatial thinning of the ingested data, and provides an estimate of the dynamic surface emissivity. It also provides simultaneous estimates of sounding profiles obtained from passive sensors in cloudy/precipitating conditions – situations where the data is currently rejected in GSI. The goal of MiiDAPS is to increase number and types of satellite observations assimilated, including those traditionally difficult to assimilate. This is accomplished through optimized filtering, improved assimilation of surface sensitive channels, and extending into to cloudy/precipitating scene radiance assimilation – an area that is neglected in operational data assimilation.

The present work describes an ongoing effort at NOAA/JCSDA to extend the capability of MiiDAPS to pre-process active microwave sensor observations. MiiDAPS depends critically on the Community Radiative Transfer Model (CRTM) to act as a forward operator for simulating observable quantities (passive and active), however, the present version of CRTM (and consequently MiiDAPS) does not provide the capability to simulate the active microwave sensor response to all-weather all-surface environments.

The Community Active Sensor Module (CASM), described here, extends MiiDAPS ability to forward model and retrieve microwave scattering and extinction and surface scattering properties needed for observations obtained from microwave-based active sensors. Via MiiDAPS, CASM facilitates the accurate assimilation of all-weather active sensor observations, such as observed by the Global Precipitation Measurement mission (GPM) Dual-frequency Precipitation Radar (DPR), and the ISS-RAPIDSCAT scatterometer. This presentation will cover the development of CASM, and will highlight the new capabilities that MiiDAPS provides with respect to ingesting and processing satellite-based radar reflectivities and surface reflectivities in this 1DVAR system.

For this presentation, selected case studies for light, medium and heavy precipitation (with and without rainfall) are obtained from coincident ground radar + GPM radar observations, and are used to assess the retrieval capabilities of MiiDAPS. The primary focus is on vertical profiles of retrieved hydrometeor physical properties, with discussion of the impact of the physical properties of land and ocean surfaces. Jacobians of radar reflectivity and two-way path-integrated attenuation (as an indirection function of specific humidity and temperature) are also presented to explore the vertical structure of the sensitivity of the forward operator to variations in temperature and humidity – the two parameters of interest for current data assimilation systems.

Paper 3 PERFORMANCE OF A NOVEL RPG 94 GHZ FMCW DOPPLER CLOUD RADAR

Thomas Rose, Martin Philipp, Harald Czekala, Radiometer Physics GmbH, Germany

RPG has developed a unique 94 GHz (W-band) Doppler cloud radar. Its high sensitivity to cloud liquid makes it a well suited instrument for cloud observations in research projects as well as in operational now-casting networks.

The instrument operation is based on FMCW technology (Frequency Modulated Continuous Wave), which implies a low transmitter power (compared to pulsed radars), a 100% integration duty cycle, low power consumption, lower cost and high flexibility in the selection of radar parameters as range resolution, Doppler velocity resolution and maximum range. The radar software determines all moments as radar reflectivity, Doppler velocity, spectral width, skewness and kurtosis as well as cloud properties derived from these moments.

The maximum transmitter power of approximately 2 W is automatically adjusted internally to increase the radar's dynamic range by 16 dB (auto power-levelling), avoiding receiver saturation in the case of high reflectivity in the proximity of the radar antennas. This way a total dynamic range of 80 dB (-60 dBZe to +20 dBZe) can be achieved. The transmitter's center frequency is user adjustable within the range of 93 GHz to 95 GHz. We achieve sensitivities of -60 dBZe at 500 m height and -40 dBZe at 5 km height. We use a variety of combined chirp programs to achieve best performance over the whole atmosphere. The chirp settings can be reconfigured to user needs very easily.

The RPG FMCW cloud radar has a built-in passive radiometric channel centered at 89 GHz (3 GHz bandwidth) which is using the same antenna and same Low-Noise-Amplifier (LNA) as the radar receiver. The instrument implements a neural network LWP (integrated liquid water path) retrieval, using the passive channel brightness temperature and the surface sensor readings of the radar's integrated weather station as input parameters. Retrievals tests have shown that even a single channel at the 89 GHz window without additional water vapor line channels can yield reliable LWP estimates when the radar's weather station data (relative humidity, temperature, pressure at the location of the radar) are used as additional inputs. The 89 GHz single channel within the radar is well suited to supply the LWP information needed in synergetic retrievals and serves a consistency parameter in the radar's data evaluation processing.

Another unique feature is the included rain mitigation system, comprising two super blowers with an air flow of 2000 m3/h each and an optional air heater system (dry air flow during fog conditions). The system is effectively protecting the antenna radomes from rain, dew, snow, and icing. This protection is essential for the passive 89 GHz channel measurements as well as for the radar itself due to its high operating frequency.

The RPG radar also includes a high end internal calibration system with a receiver Dicke switch and a thermal control system keeping the receiver and transmitter components thermally stable within +/-200 mK. The calibration system continuously monitors the transmitter power and therefore guarantees a long term stability of the radar's absolute accuracy.

Future extension to full scanning capabilities (elevation and azimuth) are planned as well as dual-polarization options (STAR mode: two polarizations in Tx, two polarizations Rx). The radar will be integrated with RPG's standard passive temperature and humidity profilers providing synergetic products, e.g. to identify supercooled water or to determine cloud base height.

Tuesday, April 12	Ocean and Ice	14:40 - 16:00
Poster Session		Outside Hall B

Session Co-Chairs: Rasmus Tonboe, Danish Meteorological Institute; Stephen Munchak, NASA Goddard Space Flight Center

Paper 1 COMPARISON OF SEA SURFACE SALINITY RETRIEVED FROM SPACEBORNE RADIOMETRIC OBSERVATIONS AND MEASURED IN SITU

Emmanuel Dinnat, NASA Goddard Space Flight Center / Chapman University, United States; David Le Vine, NASA Goddard Space Flight Center, United States; Thomas Meissner, Remote Sensing Systems, United States; Jacqueline Boutin, Nicolas Martin, Locean IPSL UPMC, France

During the last few years, two satellite missions shared the scientific objective of mapping the global Sea Surface Salinity (SSS), yet their observations showed significant differences. Both the Soil Moisture and Ocean Salinity (SMOS) and the Aquarius/SACD missions use L-band (1.4 GHz) radiometers to measure emission from the sea surface and retrieve SSS. SMOS observations started in 2010 and are still ongoing. Aquarius has been acquiring data from August 2011 to June 2015 when the mission ended due to spacecraft failure. Despite the unfortunate loss of Aquarius, there are 3 years and 9 months of concurrent SSS retrievals between both instruments available to be analyzed. In 2015, a new L-band radiometer started observing the ocean as part of the Soil Moisture Active Passive mission (SMAP). SMAP overlapped with Aquarius during 2 months and is still ongoing.

Significant differences in SSS retrieved by both SMOS and Aquarius have been reported in the past, with SMOS SSS being generally lower than Aquarius SSS, except for very cold waters where SMOS SSS is the highest overall. Differences were mostly between -1 psu and +1 psu (psu, practical salinity unit), with a significant regional and latitudinal dependence. In 2015, improved data products have been released for both instruments. Our presentation will report comparisons between SSS retrieved by SMOS and Aquarius, and comparisons between satellite SSS and in situ measurements. We will discuss the impact of the latest changes in the SMOS and Aquarius processing on the retrieved SSS and the differences between both instruments. The impact of differences in the retrieval algorithms (e.g. dielectric constant, ancillary sea surface temperature, surface roughness model, Faraday rotation) on the differences in SSS will be analyzed. If the maturity of the SSS retrieval algorithm for SMAP permits, we will also report first comparisons of SMAP SSS with other satellite SSS and in situ data.

Paper 2 SIGNATURES OF ACTIVE AND RESIDUAL WHITECAPS IN BRIGHTNESS TEMPERATURE TIME SERIES IDENTIFIED USING INFRARED IMAGERY

Magdalena D. Anguelova, David J. Dowgiallo, Justin P. Bobak, Charlotte M. Snow, Henry Potter, Geoffrey B. Smith, Naval Research Laboratory, United States

Whitecaps formed by waves breaking and air entrainment are dynamic features on the ocean surface which evolve quickly and thus have markedly different properties in different lifetime stages. Active whitecaps accompany the turbulent mixing in the moment of wave breaking. In contrast, residual whitecaps are almost motionless foam patches left behind the breaking wave. The relative contributions of active and residual whitecaps to air-sea interaction processes differ. Therefore, to properly parameterize modifications of momentum, heat, and mass transfers across the air-sea interface in presence of breaking waves, it is desirable to separately quantify the fraction of the ocean surface covered by active and residual whitecaps. Because active and residual whitecaps in photographic and radiometric observations exhibit small, subtle changes of image intensity and foam emissivity, respectively, their separation is highly uncertain. Infrared (IR) imagery at 3-5 micrometers provides clear separation of the whitecap lifetime stages because active and residual whitecaps are represented with opposite signatures, i.e., bright and dark pixels. We describe observations from multi-instrumental field campaign on R/P FLIP and data analysis that demonstrates the use of the specific IR signature of whitecaps for identification of active and residual whitecap stages in radiometric measurements.

Simultaneous capture of 24 breaking events in both IR imagery and microwave brightness temperature TB allows unambiguous identification of whitecap signature in TB time series. Within the uncertainty of the IR time stamp, the peaks of the active whitecaps in IR images correspond to pairs of peaks in TB at horizontal and vertical (H and V) polarizations in 70% of the cases. The TBV peak precedes the TBH peak in 90% of the cases with an average value of 0.36 + -0.32 s. In all cases, TBH and TBV vary in-phase during the active whitecap stage and are out-of-phase during the residual whitecap stage. These variation patterns are explained by TB response to warmer water and radiation depolarization by sea foam during the active lifetime stage, and different responses of TBH and TBV to wave steepness during the residual lifetime stage. A methodology to distinguish the signature of active and residual whitecaps in radiometric time series without a priori IR information has been developed. The degree of polarization P = (TBH + TBV)/(TBH - TBV) is a suitable quantity to capture breaking events as prominent spikes in P time series. The utility of spikes in time series of P has been verified with identification of breaking events in the corresponding IR and video images. Stringent requirement for detection of active whitecap is observation of peaks in the TBH peak, while the zero-crossing of dP determine the peak and timing of active whitecaps is ous the first derivative of P. The maximum of dP pin-points the TBH peak, while the zero-crossing of dP determine the P peak. The transition from active to residual whitecaps in brightness temperature TB time series is suitable for individual whitecaps in brightness temperature TB time series is suitable for individual whitecaps in brightness temperature TB time series is suitable for individual whitecaps in brightness temperature TB time series is suitable for shorts, low-flying airplanes or unmanned systems. More IR-TB data and statistical analysis are required to make this

Paper 3 IMPROVING MULTIYEAR ICE CONCENTRATION ESTIMATES WITH ICE DRIFT

Yufang Ye, University of Bremen, Germany; Mohammed Shokr, Environment Canada, Canada; Georg Heygster, Gunnar Spreen, University of Bremen, Germany

Arctic sea ice cover is a sensitive climate indicator. Due to the warming climate, it has decreased by over 4% per decade in the past three decades. Moreover, multiyear ice (MYI), ice which survives at least one summer, is declining at a much higher rate (i.e., 10-15% per decade). Traditionally the majority of the Arctic Ocean was covered by multiyear ice. It was replaced by thinner, first-year ice (FYI), which today is the dominant ice type. The loss of thick multiyear ice leads to persistent decrease of the Arctic sea ice volume, which has consequences for the Arctic and global climate system. For example, for a thinner ice cover the heat and mass exchange between ocean and atmosphere increases and the release of additional freshwater alters the ocean stratification.

Several methods exist to retrieve total sea ice concentration from satellite microwave remote sensing observations. However, the discrimination of ice types poses more difficulties. For example, ice deformation, snow wetness and metamorphism can cause significant changes in microwave brightness temperature and backscatter, leading to misidentification of FYI as being MYI. This study introduces a correction scheme to correct the MYI concentrations under these conditions. The correction utilizes ice drift records to constrain the MYI changes within a plausible area contour. In addition snow melting events are identified. Thereby over-estimated MYI concentrations are identified and replaces with those of the previous days. The correction is applied to MYI concentration results from the Environment Canada's Ice Concentration Extractor (ECICE) using an input of combined QuikSCAT and AMSR-E data, acquired over the Arctic in a series of winter months (October - May) from 2002 to 2009. The correction reduces the estimated MYI area in Arctic by over 0.5×10^6 km^2 on average. The MYI area removed by the correction is increasing through the winter months and reaches the maximum at the end of May. The largest corrections stem from regions of the Arctic peripheral seas, where MYI concentrations are over-estimated due to the response of snow-covered FYI to warm temperatures or sea ice deformation. MYI concentration maps after the correction agree well with the visual interpretation from RADARSAT-1 images in the aforementioned regions. After the correction, the total MYI area always stays equal or smaller than the September sea ice minimum area of the summer before. And the MYI area is slowly decreasing during winter, which is expected as MYI gets continuously exported out of the Arctic Basin. Before the correction the MYI area for some years was artificially increasing throughout the winter. The correction is important in the operational applications where knowledge of ice conditions is crucial on small and meso scale and fo

Paper 4 INTEGRATED RETRIEVAL OF SURFACE AND ATMOSPHERIC PARAMETERS OVER ARCTIC SEA ICE

Raul Cristian Scarlat, Georg Heygster, Institute of Environmental Physics, University of Bremen, Germany; Leif Toudal Pedersen, Danish Meteorological Institute, Denmark

Optimal estimation inverse methods have been used for decades in atmospheric sounding and sea surface temperature retrieval. Here we present improvements on the method presented in Melsheimer, Heygster and Pedersen (2008). The forward model of the method is based on Wentz and Meissner (2002) which, in our version uses as input bulk parameters for the atmosphere, SST and wind speed for the ocean and ice concentration and multi-year ice fraction for ice. The model uses empirically determined sea ice surface emissivities from Matthew(2009), in order to simulate satellite observed brightness temperatures in ice covered areas. As a starting point, the method uses reanalysis data for the atmospheric parameters and NASA Team retrieval for sea ice parameters. The parameters are then iterated until they best match the observed brightness temperatures from a passive microwave radiometer such as AMSR-E, typically reached within 10-15 iterations.

A number of modifications is made to the original method regarding the first guess data and the covariance matrix that constrains the seven parameters. A larger focus is on retrieving atmospheric parameters over partially and totally sea ice covered regions where coverage by other observation methods is low. We have implemented a new covariance matrix for the atmospheric and surface parameters in order to constrain the method better. To this end a distinct set of covariances had to be determined from collocated measurements of sea ice concentration and water vapor. This provides the method with an extra condition that needs to be fulfilled for the retrieved water vapor load and sea ice concentration. A different set of covariances is derived from datasets of atmospheric measurements over open water. This constrains the water vapor, cloud liquid water and wind speed retrievals over open water. After implementing the new covariance matrix and testing the retrieval against the AMSR-E ocean product from Remote Sensing Systems (RSS), the RMSD for sea surface temperatures improves from 7.4K to 3.7K with a sign change in bias from 0.4K to -0.3K. Cloud liquid water RMSD has decreased as well from 1.18kg/m2 to 0.13kg/m2. The atmospheric water vapor retrieval is affected differently depending on surface type. Over sea ice regions the RMSD tested against the retrieval from Melsheimer and Heygster (2008) has decreased from 8.2kg/m2 to 5.9kg/m2 while the bias decreased from 1.76kg/m2 to 1.23kg/m2. Over open water areas both the absolute bias and RMSD increased from 0.85kg/m2 to -2.57kg/m2 and from 5.5kg/m2 to 11kg/m2 respectively when compared to the RSS product. The comparison was done over the summer season in 2006 and we are still investigating wether the retrieval is performing worse over open ocean areas in summer or if the reference dataset is not optimal as a benchmark for this case.

In order to increase the sensitivity towards atmospheric influences in the radiometer signal we tried including the two AMSR-E 89GHz channels in the retrieval. This has had an impact on the water vapor retrieval. Over open water there is little change with a decrease in bias from 1.1kg/m2 to -0.1kg/m2 and an increase in RMSD from 10.5kg/m2 to 11.2kg/m2. Over sea ice the extra channels contribute to higher RMSD of 8.2kg/m2 from 5.4kg/m2 but also yield a higher correlation of 0.4
from 0.2 against the collocated reference dataset. The bias has increased as well to 1.76kg/m2 from 0.57kg/m2. These results are expected because scattering effects that might contribute to the atmospheric signal are not included in the forward model calculations. The improvement in correlation stems from a better sensitivity to low values of water vapor which are more common in the central, ice covered Arctic.

Tuesday, April 12	Instruments and Techniques	14:40 - 16:00
Poster Session		Outside Hall B

Session Co-Chairs: Lin Wu, National Space Center, CAS; Verónica González-Gambau, Institut de Ciències del Mar

Paper 1 MORPHOLOGICAL TOOLS FOR SPATIAL AND MULTISCALE ANALYSIS OF PASSIVE MICROWAVE REMOTE SENSING DATA

Sébastien Lefèvre, Université Bretagne Sud, France; Erchan Aptoula, Okan University, Turkey

Earth Observation benefits from a wide range of satellite sensors. Among the available imaging modalities, microwave radiometry is particularly useful for various applications, e.g., soil moisture, ocean salinity, or sea ice cover. Such applications have gathered numerous works aiming to provide automatic measurements from analysis of remote sensing data. However, most of these image processing / data analysis techniques do not rely on any spatial information, similarly to the early years of optical / hyperspectral remote sensing. After more than a decade of research, it has been observed that spatial information can very significantly improve the accuracy of land use / land cover maps. The object-based image analysis (OBIA) paradigm, computation of multiscale features, spatial regularization of classification maps are among the various techniques that have shown great success for remote sensing of the environment. Surprisingly, such advances have not impacted the field of passive microwave remote sensing yet. Meanwhile, the launch of new missions, e.g., ESA SMOS (2009), NASA/JAXA GMP (2014), or NASA SMAP (2015), brings new data that call for the development of new efficient and accurate image processing algorithms.

In this context, the goal of this paper is to propose a few insights on how spatial information can benefit to (passive) microwave remote sensing. To do so, we focus on mathematical morphology, a nonlinear image analysis framework equipped with rigorous mathematical foundations and efficient tools for exploiting spatial information. We thus provide some illustrative examples where morphological operators can improve the processing and analysis of microwave radiometric information. First, OBIA paradigm is explored through a region-based representation and classification of SMOS images. Second, characterization power of multiscale attribute profiles is assessed on SMAP data. Finally, morphological processing of multivariate information is demonstrated on microwave multispectral images such as the ones provided by NASA Aqua or JAXA GCOM-W missions. We believe these various experiments will convince the microwave radiometry community to rely on advanced spatial / multiscale image processing solutions for more accurate and more efficient analysis of remote sensing data. Such tools had great influence on multispectral/hyperspectral remote sensing in the past, and are expected to hava a similar impact in the microwave field in the future, with the launch of upcoming missions with improved spatial resolution, e.g. SMOS-NEXT.

Paper 2 ANTENNA ARRAY DESIGN FOR THE NEW GIMS DEMONSTRATOR

Cheng Zhang, Hao Liu, Key Laboratory of Microwave Remote Sensing, Chinese Academy of Sciences, China; Ji Wu, National Space Science Center, Chinese Academy of Science, China

The concept of Geostationary Interferometric Microwave Sounder (GIMS) is proposed for China's future geostationary Earth orbit meteorological satellite (FY-4). GIMS employs a 50-56GHz synthetic aperture radiometer with a rotating circular shaped array. A ground-based proof-of-concept demonstrator has been developed, which successfully demonstrate some working principles especially the rotation scanning imaging. Now in the next round, a new full scale demonstrator with larger antenna array and more antenna elements is under developing. The new GIMS demonstrator is aiming to solve the main technical problems before coming to a real mission and being designed as close as possible to the future space version.

The antenna array design is the first thing for the GIMS demonstrator development. Array design is critical because it relates to the system complexity and also has strong influence on the system performance. The antenna array used in synthetic aperture radiometer is a correlating array, which is different to the traditional adding phased array, so the array optimization is focused on getting a good uv sampling grid other than pursuing the lowest side-lobe level (SLL) of the point spread function (PSF). In actual case, the merits of good uniform u-v sampling distribution and low SLL may conflict to each other. When one minimizes the SLL, it generally leads to an uneven u-v sampling distribution with many sampling gaps. It is compulsory for the GIMS array to have a complete u-v sampling coverage, because the iterative algorithms like the Clean method used in radio astronomy to deal with the sparse u-v sampling is not valid, so incomplete sampling with holes implies unmeasured Fourier components which will lead to unremovable artifacts in the reconstructed image.

Therefore, in this work, the array placement optimization for GIMs demonstrator is focused on the u-v distribution. Furthermore, the rotation array obtains a concentric polar grid, where the angular sampling points are equal-spaced with an interval being equal to the travel distance during one integration time; while the radial sampling interval is determined by the distribution of the antenna baselines length, which is commonly uneven-spaced. The array optimization is then focused on the radial sampling points' distribution.

The array design starts from the main required parameters of the array. Since the spatial resolution is out most demanding compared to the radiometric resolution and time resolution for the Geo earth observation, the array design should meet the spatial resolution requirement at first. The relationships between the array complexity and the achieved radiometric resolution with some basic window functions are also analyzed. The radiometric resolutions with the antenna element number are computed under the conditions of meeting the required spatial resolution and temporal resolution which are $\Delta s=50$ km, Timag=5 minutes for the GIMS demonstrator.

The global optimization algorithm of deferential evolution (DE) is used for the new array optimization in this work. In brief words, the objectives of array optimization is to obtain an array having no gap, more smooth, more redundant baseline distribution, as well as conforming to the physical constrains. The final array optimization results of the GIMS array in diameter of 3.7m with 70 antenna elements are present, which can provide good reference for future GIMS array design.

Paper 3 TEMPORAL RESOLUTION ENHANCEMENT OF IMAGE SEQUENCES CAPTURING EVOLVING WEATHER PHENOMENA laor Yanovsky, Bjorn Lambrigtsen, NASA Jet Propulsion Laboratory, CalTech, United States

Temporal resolution enhancement is important in the studies of physically evolving phenomena, such as hurricanes and tropical storms. Such weather phenomena will soon be continuously captured using geostationary microwave sensors. These sensors are designed to penetrate through thick clouds to see the structure of a storm. The images collected are valuable for evaluating the storm's internal processes and its strength. Temporal resolution specifies the revisiting frequency of a satellite sensor for a specific location, or equivalently, refers to how often an area can be imaged by a sensor. In other words, temporal resolution defines the time interval between consecutive captured frames. It also relates to the duration of time for acquisition of a single frame of a dynamic process.

There is often a tradeoff between temporal resolution of a measurement and its spatial resolution. Acquiring a high spatial resolution image requires more time, which inadvertently affects temporal resolution of a sequence. On the other hand, spatial resolution is affected if images are acquired quickly. Both spatial resolution and temporal resolution enhancements are challenging inverse problems.

In our studies, we consider the Geostationary Synthetic Thinned Aperture Radiometer (GeoSTAR), which is a microwave spectrometer aperture synthesis system that will be used to capture hurricane imagery and other evolving weather phenomena. A characteristic of an aperture synthesis system is that the point spread function (PSF) is a 2-dimensional sinclike function, showing positive and negative excursions, that produces ringing at sharp edges and other transitions in the observed field. The conventional approach to suppressing such sidelobes is to apply linear apodization, which has the undesirable side effect of degrading spatial resolution.

We use sparsity-based approaches to first enhance spatial resolution of image sequence. In order to reduce image ringing while sharpening the image and preserving information content, we formally solve the deconvolution inverse problem for single-channel images. Since the convolution problem is highly ill-posed, regularization is applied to achieve stability while preserving a priori properties of the solution. We formulated the restoration problem within the variational framework, using the total variation regularization. Total variation (TV) of an image measures the sum of the absolute values of its gradient and increases in the presence of the ringing artifact caused by sidelobes. By minimizing the TV, we showed that the process reduces not only the ringing within the image, but also significantly reduces the brightness temperature errors in the overall image. These processes were rendered efficiently by employing methodologies based on current research in sparse optimization and compressed sensing.

We next describe the methodology to enhance temporal resolution of image sequences capturing evolving weather phenomena. Given a pair of spatially resolved frames, we solve an image registration problem in order to find an unknown intermediate frame. An important observation, which stimulated the development of intensity-based nonlinear image registration algorithms, was the connection of the image data with a physically deforming system. Physical continuum models consider the deforming image to be embedded in a deformable medium, which can be either an elastic material or a viscous fluid. We use the viscous fluid registration in order to temporally resolve multiframe sequence of images.

Paper 4 GEOSTAR-III FINAL INTEGRATION AND PRELIMINARY TESTS

Isaac Ramos-Perez, Todd Gaier, Alan Tanner, Pekka Kangaslahti, Bjorn Lambrigtsen, NASA Jet Propulsion Laboratory, CalTech, United States

The Geostationary Synthetic Thinned Array Radiometer (GeoSTAR) demonstrator was developed under NASA's Instrument Incubator Program (IIP) to measure humidity and temperature from Geostationary Earth Orbit (GEO). The instrument allows continuous observations of nearly a complete hemisphere of the Earth, essential for the observation of hurricanes and rapidly evolving atmospheric phenomena [1]. The instrument comprises 144 horn antennas each followed by a heterodyne Monolithic Microwave Integrated Circuit (MMIC) receiver, distributed across nine manifolds. The receivers receive a LO signal through the manifolds. Each receiver has two IF outputs (I and Q) whose signals are amplified and passed to a correlation subsystem. The digitalizer/correlator subsystem, which was the result of an intensive technology development effort, is based upon a custom ASIC circuit using 65 nm CMOS technology. The ASIC, representing the final technological hurdle in the implementation of NASA's PATH mission [2], processes 64x64 IF inputs digitized at 2-bits resolution at 1 GSPS (500MHz bandwidth), and digitally crosscorrelates all pairs, while consuming a mere 1.5 W of power. The subsystem uses 3 ASIC circuit boards and FPGAs to process and read out the multiplied signals. After component testing, the instrument was quickly integrated and evaluated for performance. We first tested the phase stability over time, and determined the overall phase calibration of the array. We then performed observations of the sun as it passed through the array field of view. Additional imaging tests were performed on a variety of thermal sources and the results will be discussed.

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Paper 5 IMPROVEMENTS IN ATMOSPHERIC WATER VAPOR CONTENT RETRIEVALS OVER OPEN OCEANS FROM SATELLITE PASSIVE MICROWAVE RADIOMETERS

Elizaveta Zabolotskikh, Russian State Hydrometeorological University, Russian Federation; Bertrand Chapron, IFREMER, France

Long-term observations of water vapor - one of the major greenhouse gases - in the Arctic atmosphere over the open sea water is provided by satellite passive microwave instruments. Both atmospheric total water vapor content (WVC) and total cloud liquid water content (CLW) have been successfully retrieved from satellite microwave sensors, such as Scanning Multichannel Microwave Radiometer (SMMR) on board the Nimbus 7, Special Sensor Microwave/Imager (SSM/1) and Special Sensor Microwave Imager and Sounder (SSMIS) on board the DMSP series satellites, WindSat radiometer, Microwave Instrument onboard the Tropical Rain Measurement Mission (TRMM) satellite (TMI) and a series Advanced Microwave Sounding Radiometers (AMSR, AMSR-E and AMSR2). Many algorithms for WVC and CLW retrievals from microwave radiometer data have been developed. Still all of them always had larger errors under significantly changing environmental conditions.

In this study we show the potential in the improvement of the accuracies of the WVC retrievals from satellite borne passive microwave radiometers.

High accuracy retrieval algorithm is developed for WVC retrieval from Advanced Microwave Sounding Radiometer 2 (AMSR2) measurements over open ocean areas. The algorithm is based on physical modeling of the brightness temperature (BT) of the upwelling radiation of the atmosphere – ocean system. The brightness temperature inversion is carried out with Neural Networks (NNs), trained on an ensemble of BTs, calculated using the data set of the atmospheric and oceanic parameters, governing passive microwave radiation of the atmosphere – ocean system. The improvement in the WVC retrieval is associated with the usage of the new ocean emissivity empirical model and exclusion of vertically polarized BT from the NNs inputs. The new model was incorporated into BT geophysical model and a new set of NNs coefficients was obtained for WVC algorithm. Though the results of the numerical experiment demonstrate higher retrieval accuracy for the old version of the NN model, real-valued validation with Global Positioning System WVC shows better performance of the new NN model with excluded vertically polarized measurements from NN inputs. The advantages of the new algorithm are the most remarkable under conditions of high winds. This is especially important in the studies of extreme weather events such as Polar Lows, Extratropical and Tropical Cyclones associated with high winds. Examples of WVC retrievals under extreme events are given.

Tuesday, April 12	Small Satellite and UAV Instruments and Missions	14:40 - 16:00
Poster Session		Outside Hall B

Session Co-Chairs: Antti Kestilä, Aalto University; Pekka Kangaslahti, NASA Jet Propulsion Laboratory

Paper 1 ANALYSIS AND DESIGN OF A SOC SIGE MM-WAVE DETECTOR FOR SPACEBORNE OBSERVATION OF SOLAR FLARES

Luca Aluigi, Domenico Zito, Tyndall National Institute, Ireland

This paper addresses the analysis of a Silicon-Germanium (SiGe) millimeter-wave (mm-wave) detector to be employed as the key building block of a Ka-Band (26-40 GHz) system-on-chip (SoC) radiometer for spaceborne observation of solar flares.

Mm-wave radiometers are commonly employed in radio-astronomic experiments and are implemented through hybrid technologies [1], thereby resulting bulky, heavy and expensive. Space agencies have manifested a considerable interest in developing miniaturized instruments compliant with constraints imposed by micro- and nano-satellites [2].

Mm-wave imagers are the most sensitive systems currently available to observe the highest energy electrons accelerated in solar flares [3]. Observations of solar flares at mm-waves are needed in order to obtain the peak- and high-frequency slope of radio spectra and are also exploited to study Sun's Coronal Mass Ejections [4].

Measurements of Sun emissions at mm-waves and in particular at Ka-band are only available from ground-based instruments [5]. The list of flares detected at mmwaves from the ground is sensibly reduced because the observations are limited by the tropospheric transmissivity random fluctuations, which lead to solar flux errors up to 200 sfu at Ka-Band [6].

In order to improve quantitatively the study of the Sun at mm-waves, instruments with higher detection probability are needed. This can be obtained by moving the radiometric sensor above the tropospheric layer, e.g. in the ionosphere, and having a Heliosynchronous LEO orbit, i.e. 24 hour time-on-target. In a previous work we showed that, exploiting the SoC integration of the radiometer, the error can be reduced down to 0.05 sfu at Ka-Band [7].

This paper presents a comparative analysis aimed at identifying the most suitable detector circuit topology in the frequency band of interest. We considered a commercial SiGe-BiCMOS 0.13µm technology by IHP-Microelectronics, currently under space evaluations. We compared the following detector topologies: Common-Emitter (CE), Common-Collector (CC), Common-Base (CB), Darlington and Cascode. The analysis compared the five architectures in terms of Responsivity (R) and Noise Equivalent Power (NEP).

The results show that the CE topology is the most suitable topology in the Ka-band. In detail, it exhibits a Responsivity of about 480 kV/W and NEP of about 150 fW/V Hz. Moreover, the analyses show very good agreement between theory and simulations, so providing a good rationale basis for an accurate design methodology.

Last, the system analysis and design of the SoC radiometer incorporating the CE detector topology is carried out. The results show that the targeted resolution of 0.7 K (1 sfu) can be achieved with reasonable integration time (below 50 ms) also in the cases of insertion losses of the antenna switch.

Finally, the results of this study, extendable also in other frequency bands, are very encouraging and provide a good basis for further developments both for 1-, and 2-D observations when combined in focal plane arrays of SoC radiometers.

This work is supported by the European Commission through the FP7-PEOPLE-2013-IEF project FLARES under Grant 625907.

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Paper 2 TROPOSPHERIC WATER VAPOR AND CLOUD ICE (TWICE) MILLIMETER- AND SUB-MILLIMETER WAVE RADIOMETER INSTRUMENT FOR 6U-CLASS NANOSATELLITES

Steven Reising, Colorado State University, United States; Pekka Kangaslahti, Erich Schlecht, NASA Jet Propulsion Laboratory, CalTech, United States; Xavier Bosch-Lluis, Mehmet Ogut, Colorado State University, United States; Sharmila Padmanabhan, Richard Cofield, Nacer Chahat, Shannon Brown, Jonathan Jiang, NASA Jet Propulsion Laboratory, CalTech, United States; William Deal, Alex Zamora, Kevin Leong, Sean Shih, Gerry Mei, Northrop Grumman Corporation, United States

Measurements of water vapor and cloud ice in the upper troposphere/lower stratosphere (UTLS) at a variety of local times are critically needed to provide information not currently available from microwave sensors in sun-synchronous orbits. Such global measurements would enable increased accuracy of cloud ice and humidity parameters that are critically linked in global circulation models, improving climate predictions as well as knowledge of their uncertainty. In addition, this capability would address the need for measurements of cloud ice particle size distribution and water vapor profiles in both clean and polluted environments. Complementary measurements of aerosol pollution would allow investigation of its effects on cloud properties and climate. This is particularly important since the uncertainty in the aerosol effect on climate is at least four times as great as the uncertainty in greenhouse gas effects.

To address this unmet need, a collaborative team involving Colorado State University, Caltech Jet Propulsion Laboratory and Northrop Grumman Corporation is developing and fabricating the Tropospheric Water and Cloud ICE (TWICE) radiometer instrument. TWICE is being designed to meet size, mass, power consumption and downlink data rate requirements for deployment aboard a 6U-Class nanosatellite. TWICE is advancing the state of the art of spaceborne millimeter-wave/ submillimeter-wave radiometers by transitioning from Schottky mixer-based front ends to MMIC low-noise amplifier front ends, substantially reducing the radiometer's mass, volume and power consumption. Based on 25-nm InP HEMT MMIC technology, JPL and Northrop Grumman have completed and are testing new designs for low-noise amplifiers and related front-end components, including LO chains and mixers for spectrometer channels. The TWICE instrument will provide 16 radiometer channels, including window frequencies near 240, 310 and 670 GHz to provide information on ice particle size distribution and to determine total ice water content. In addition, four sounding channels near each of three absorption lines from 118 GHz to 380 GHz will provide temperature and water vapor sounding during nearly all weather conditions, particularly useful in the upper troposphere/lower stratosphere in the presence of ice clouds.

Paper 3 NARROWBAND SUPERHETERODYNE HF RADIO RECEIVER SYSTEM FOR A NANOSATELLITE

Jakke Mäkelä, University of Jyväskylä, Finland; Esa Kallio, Juuso Mantere, Petri Koskimaa, Antti Kestilä, Tuomas Tikka, Jari Hänninen, Juha Mallat, Jaan Praks, Aalto University, Finland

A radio instrument is being designed for the Finland 100 nanosatellite, which will be launched into low Earth orbit (LEO) in 2017 to celebrate the centennial of Finnish independence in 1917. The mission has equal parts of a scientific, pedagogical, and historical focus. For the RF instrument, we have chosen a rather unique approach: we wished to design an instrument whose operating principles can be understood by any high school student, and which also would have been understandable to scientists back in 1917.

Therefore, we are implementing a narrowband (maximum 10 kHz bandwidth) superheterodyne radio receiver with a quick sweeping capability. In effect, the instrument is a normal AM radio. The basic superheterodyne architecture was invented as early as World War I; however, we will add programmability and signal-processing capabilities that were not available before the start of this century.

The instrument will operate near the HF spectrum (approximately 0.1-10 MHz). This frequency range has been studied by very few satellites, since measurements tend to be marred by very high levels of manmade interference, whose propagation is highly dependent on ionospheric characteristics.

Our design philosophy is partly optimized for this situation: a 10 kHz bandwidth is used in AM radio broadcasting, and we should be able to identify and isolate at least such transmissions. Since the transmission characteristics of AM stations are known, we can establish propagation characteristics at least roughly by tracking the transmissions for longer time periods.

We are aiming for a full-spectrum sweep time of at most 1-2 minutes. The instrument would then have a spatial resolution of about 1000 km. This is sufficient to identify large-scale regions of space such as the auroral oval. We will study methods that could allow a better spatial resolution by for example sampling frequencies randomly, thus reducing the effective sweep time.

Using this frequency range has the major advantage that it allows us to use ferrite-core coil antennas, which combine high sensitivity with very small physical size and very low cost. Furthermore, unlike whip antennas, the ferrites require no moving parts when deployed. They are thus almost uniquely suited to a nanosatellite environment. Yet, it seems that no spaceborne mission so far has used such antennas. The Finland 100 mission will thus provide a feasibility study for this technology.

Paper 4 DEVELOPMENT OF COMPACT HIGH ALTITUDE IMAGER AND SOUNDING RADIOMETER (CHAISR)

Reno K. Y. Choi, National Institute of Meteorological Sciences, Republic of Korea; Seunghyun Min, Satrec Initiative Co., Ltd, Republic of Korea; Marian Klein, Boulder Environmental Sciences and Technology, United States; B. J. Sohn, H. S. Jang, Seoul National University, Republic of Korea; Jong-Chul Ha, Young-Jun Cho, Ki-Hun Kim, Eunha Im, National Institute of Meteorological Sciences, Republic of Korea

Joint Civilian-Military Committee, under Advisory Council on Science and Technology, Korea, has approved a technology demonstration project for building a lightweight, HALE UAV (High-Altitude, Long Endurance; Unmanned Aerial Vehicle). HALE UAV aims to operate at lower stratosphere, i.e. altitude of 16 ~ 20 km, where air becomes thin preventing operation of fossil fuel engines. Atmospheric science community has been interested in its potential scientific and operational value as an observation platform.

As a civilian stakeholder in the project, NIMS (National Institute of Meteorological Sciences, Korea) is developing a payload for meteorological measurements, the Compact High Altitude Imager and Sounding Radiometer (CHAISR). CHAISR consists of three microwave radiometers (MWR) with 16 channel, and medium resolution cameras operating in a visible and infrared spectrum. One of the technological challenges for CHAISR is to accommodate those instruments within <4 kg of weight and >50 W of power consumption. Statistical analysis shows CHAISR will experience temperature between -75 and 43°C, pressure as low as 50 hPa at operational altitude, and even 100% humidity through clouds. Such operational environment require passive thermal control of the payload to keep electronic subsystems from overheating on the ground and warm enough at the operational altitude with minimal power available. Safety considerations and contingency plans, such as payload power management and thermal control, are taken place flawless operation with minimal user input.

Three radiometers acquire brightness temperature at frequency ranges 18.325~22.425, 36.7~40.8, 49.3~57.29 GHz. In order to provide temperature and humidity profiles along the flight line the radiometers operate in a cross track mode. In addition to saving power, weight management for radiometers is one of the crucial elements. Estimated total weight of all radiometer hardware, from the antennas to data acquisition system, is less than 1.1 kg and a maximum allowable power consumption is 13 W. In such condition, conventional blackbody target for onboard calibration is not feasible. Radiometers rely on two internal calibration points and a targets of opportunity for their calibration. The flight in the lower stratosphere and zenith sky view provide an excellent cold calibration target with almost constant temperature.

Spatial distributions of clouds from visible and thermal cameras are used as initial input data for radiometers' retrieval process, indicating presence and estimated height of clouds for each acquisition. Medium spatial resolution of image has spatial resolution of 50~100 m for cloud cover.

In situ sensors within the CHAISR acquire realtime ambient temperature, humidity and pressure. The observations from radiometers and optical cameras, all atmospheric measurements available from CHAISR will contribute to updates of the aviation weather information for the HALE UAV with hourly 36-hour forecast from KMA (Korea Meteorological Administration). CHAISR not only provides meteorological observations, but it will also be used as the most accurate realtime weather information for the safety of its own operations [1].

First flights of the CHAISR onboard of the HALE UAV are expected to be summer 2017. The aircraft is envisioned to operate for a few weeks of period, and realtime downlink will transmit the observation data to ground segment. With ground speed of around 100 km/h, CHAISR will enable to track typhoons, improved observations of weather fronts and seasonal conditions such as monsoon rains.

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Session Co-Chairs: Ed Westwater, University of Colorado; Chris Kidd, University of Maryland / NASA

Paper 1 COMBINED ACTIVE-PASSIVE PRECIPITATION RETRIEVALS FROM GPM GMI AND DPR

16:00 Stephen (Joe) Munchak, NASA Goddard Space Flight Center, United States; Mircea Grecu, Morgan State University, United States; William Olson, University of Maryland, Baltimore County, United States

The Global Precipitation Measurement Satellite carries two instruments that are designed to sense falling rain and snow, the GPM Microwave Imager (GMI) and Dualfrequency Precipitation Radar (DPR). The data from both of these instruments are used as input to the GPM Combined Radar-Radiometer Algorithm. The basis of this algorithm is an ensemble filtering approach which begins with an ensemble of precipitation profile solutions that are consistent with the observed Ku-band reflectivity profile. These solutions are then updated (filtered) to match the observed Ka-band reflectivity profile and GMI radiances using the ensemble covariances to guide the updates.

Critical to the success of the filtering approach is a forward model capable of simulating precipitation-affected radiances from 10-183 GHz and Ku and Ka-band reflectivities affected by multiple scattering. In addition to the details of the precipitation particle size distribution, the ensemble also needs to adequately represent the unknown variability in non-precipitation parameters (e.g., cloud water, water vapor, surface properties) which have some influence on the measurements. Depending on the observations available for input and their sensitivity to precipitation, these assumptions may significantly influence the output.

This presentation will provide an overview of the broad climatology derived from the first two years of GPM combined radar-radiometer retrievals and algorithm sensitivities to input observations and a priori assumptions. Ongoing work to better represent nonspherical ice particle scattering at frequencies above 89 GHz and surface properties will also be discussed.

Paper 2 STUDYING CLOUD-TO-PRECIPITATION PROCESSES BY USING SYNERGETIC MULTI-FREQUENCY RADAR, MICROWAVE RADIOMETER AND LIDAR OBSERVATIONS DURING BAECC

Dmitri Moisseev, University of Helsinki, Finland; Annakaisa von Lerber, Finnish Meteorological Institute, Finland; Davide Ori, University of Bologna, Italy

Retrievals of snow microphysics from microwave remote sensing observations rely on a number of assumptions about microphysical properties of snow, i.e. shape and mass of snowflakes, and about their connection to scattering properties of ice particles. Validation of these assumptions is a challenging task and often is limited by the lack of coinciding microwave and snow microphysics measurements and associated retrievals. During Biogenic Aerosol Effect of Clouds and Climate, where ARM mobile facility was deployed in Finland, a dedicated intensive observation period focusing exactly on these research questions was carried out. Three radars operating at X, Ka and W -bands, profiling microwave radiometers and lidars were deployed at the University of Helsinki measurement station in Hyytiälä. At the same site a comprehensive suit of precipitation ground instruments was placed. To minimize wind effects on snow measurements a dual fence (DFIR) was build.

To link microwave properties of falling snow to snow microphysics retrievals of physical properties of snowflakes, namely mass-dimensional relations, terminal velocity- diameter and shapes and fall velocity were carried out. To insure that the retrievals are meaningful different methods utilizing different sets of instruments were applied for the retrievals. For example, mass-dimensional relations were retrieved using two different instruments, NASA Particle Image Package and 2D-video disdrometer, by utilizing Böhms method. At the same time these retrievals are validated by comparing measured X-band radar reflectivity and precipitation liquid equivalent accumulation to ones calculated from observed particle size distributions and retrieved m-D. A number of other cross checks was applied to insure consistence of different retrievals.

Paper 3 PRECIPITATION RETRIEVALS FROM PASSIVE MICROWAVE CROSS-TRACK SOUNDING INSTRUMENTS

16:40 Christopher Kidd, University of Maryland, United States; Sarah Ringerud, USRA, United States; Gail Skofronick-Jackson, George Huffman, NASA Goddard Space Flight Center, United States

Passive microwave cross-track sounding instruments form a vital component of the Global Precipitation Measurement mission (GPM) constellation of international partner satellites. The GPM Core Observatory, launched on 27 February 2014, with the GPM Microwave Imager (GMI) and the Dual-frequency Precipitation Radar (DPR) allow the atmospheric profiles of hydrometeors to be generated through the direct comparison of passive and active observations. Once these profiles are established for the Core Observatory they can be expanded to the other eleven constellation partner satellites with both the conically-scanning sensors and the crosstrack sensors. Precipitation retrievals are then generated through the common framework of the Goddard-PROFiling (GPROF) scheme.

This study focuses upon the development of the latest version of the GPROF for the cross-track sounding instruments that currently contribute six out of the twelve passive microwave radiometers used routinely for precipitation retrievals. The latest version, GPROF2014v2, is designed to exploit the precipitation measurements obtained by the GPM DPR. The vertical reflectivity profiles provided by the DPR are combined with the GMI passive microwave observations to generate hydrometeor profiles; these are adjusted to ensure the best agreement between the DPR and GMI measurements. Since the sounding instruments do not necessarily have the same frequencies to those of the GMI, the hydrometeor profiles are used to simulate the observed brightness temperatures of the sounding instruments at their respective frequencies, earth incidence angles and resolutions. As a consistency check, these simulated Tbs are then compared with actual observations where both the GMI/DPR and sounder observations occur; a total of 9.6 million matchups are available during the first year of GPM data between the DPR and Microwave Humidity Sounder (MHS) instruments. The hydrometeor profiles are then used to populate the a priori database of the GPROF retrieval scheme. Results of the new version of the technique are presented for case studies over the United States and Europe. Longer-term comparisons of mapped precipitation are presented for the different satellite sensors; these reveal subtle differences that relate to fundamental differences in the observational capabilities and characteristics of the different sensors.

Paper 4 A PROTOTYPE PRECIPITATION RETRIEVAL ALGORITHM OVER LAND USING MICROWAVE OBSERVATIONS STRATIFIED 17:00 BY SURFACE CONDITION AND PRECIPITATION VERTICAL STRUCTURE

Nai-Yu Wang, Yalei You, University of Maryland, United States; Ralph Ferraro, National Oceanic and Atmospheric Administration, United States

Introduction:

Precipitation plays a key role in the earth's climate system, particularly in the aspect of its water and energy balance. Satellite microwave (MW) observations of precipitation provide a viable mean to achieve global measurement of precipitation with sufficient sampling density and accuracy. However, accurate precipitation information over land from satellite MW is a challenging problem. The highly dynamic and variable microwave land surface emissivity is the main limiting factor in

using the direct relationships between the rain and snow falling on the surface and the emission and scattering signals from the atmosphere hydrometeors. Instead, MW algorithms rely on indirect relationships between the surface precipitation and the scattering signals from ice hydrometeors aloft the precipiting clouds. This paper reports advances in satellite precipitation algorithms from MW observations.

Method:

The Goddard Profiling Algorithm (GPROF) algorithm for the Global Precipitation Measurement (GPM) is built around the Bayesian formulation (Evans et al., 1995; Kummerow et al., 1996). GPROF uses the likelihood function and the prior probability distribution function (PDF) to calculate the expected value of precipitation rate, given the observed brightness temperatures (TB). It is particularly convenient to draw samples from a prior PDF from a predefined database of observations or models. GPROF algorithm does not search all database entries but only the subset thought to correspond to the actual observation. The GPM GPROF VI database focuses on stratification by surface emissivity class, land surface temperature (TS) and total precipitable water (TPW). However, there is much uncertainty as to what is the optimal information needed to subset the database for different conditions. To this end, we conduct a database stratification study of using 4-year of National Mosaic and Multi-Sensor Quantitative Precipitation Estimation (NMQ), Special Sensor Microwave Imager/Sounder (SSMIS), and reanalysis data from Modern-Era Retrospective Analysis for Research and Applications (MERRA).

Results:

Our database study (You et al., 2015) shows that environmental factors such as surface elevation, relative humidity, and storm vertical structure and height, and ice thickness can help in stratifying a single large database to smaller and more homogeneous subsets, in which the surface condition and precipitation vertical profiles are similar. It is found that the probability of detection (POD) increases about 8% and 12% by using stratified databases for rainfall and snowfall detection, respectively. In addition, by considering the relative humidity at lower troposphere and the vertical velocity at 700 hPa in the precipitation detection process, the POD for snowfall detection is further increased by 20.4% from 56.0% to 76.4%.

Discussion and Conclusions:

The database study demonstrates that stratifying the a priori database with surface conditions (such as surface type, surface temperature, and land elevation) and storm vertical structure (such as ice layer thickness) outperforms a single database in the Bayesian precipitation algorithm.

Paper 5 HIGH-FREQUENCY PREDICTION OF RAIN ATTENUATION FROM GROUND-BASED MICROWAVE RADIOMETRIC 17:20 MEASUREMENTS THROUGH A SUN-TRACKING TECHNIQUE

Vinia Mattioli, EUMETSAT, Germany; Frank Silvio Marzano, La Sapienza University of Rome, Italy; Ada Vittoria Bosisio, Politecnico di Milano, Italy; George A. Brost, Kevin M. Magde, USAF AFMC AFRL/RITE, United States

Ground-based microwave radiometers are affected by a significant unaccuracy when estimating rain path attenuation using fixed values or clear-air estimate of mean radiative temperature. Model-based approaches have been proposed in the recent literature to overcome this problem (Mattioli et al., 2013). Indeed, a Sun-beacon approach can be used to perform radiometric measurements of path attenuation during rainy events, based on the principle adopted to detect the solar radiation through a radio telescope. The basic idea consists in utilizing the Sun as a source of radiation: the atmospheric emission is measured pointing alternately toward-the-Sun and off-the-Sun, with and without the Sun contribution in the main lobe according to a beam switching strategy. By properly choosing the switching time interval and taking into account the main lobe aperture, we can infer the atmospheric attenuation in all-weather condition along the observed path through indirect evaluation of the difference between the two measurements (Brost et al., 2014; Hogg and Chu, 1976). Observations toward-the-Sun and off-the-Sun aul off-the-Sun at the effective antenna temperature of the Sun at the different frequencies; ii) during rain events, they allowed to compute the path attenuation due to the rainfall.

In this work the Sun-tracking technique is thoroughly examined and applied to microwave radiometric measurements at Ka, V and W band. The available dataset consists of measurements collected by a ground-based radiometer (named AFRL-MWR) during May 2015 (24 days) and June 2015 (29 days) in Rome, NY (43.2°N, 75.4°W). Measurements have been collected at elevation angle between 15° and 70°, with a scan step of 0.1° in both elevation and azimuth. AFRL-MWR has four channels with receivers at 23.8, 31.4, 72.5 and 82.5 GHz. The antenna profile is approximately Gaussian with a half-power beamwidth decreasing with the frequency and equal to 3.4, 2.97, 1.47, and 1.30°, respectively. The AFRL-MWR is a slightly modified version of the standard dual-channel water-vapor and cloud-liquid microwave radiometers, characterized by an elevation scan resolution of 0.1° and a Sun-switching operation mode. The AFRL-MWR measurements, collected in the Sun-tracking experiments during rain events, have recorded path attenuation events greater than 20 dB at different elevation angles, Two different techniques (based on elevation-scanning and surface meteorological data, respectively) are proposed and compared to estimate the equivalent brightness temperature of the Sun disk at Ka, V and W band from measured solar antenna temperature. Comparison of measured path attenuations in all weather condition with those obtained from physically-based parametric prediction models are illustrated. Error budget analyses, examining the predicted performance characteristics in terms of errors with respect to antenna pattern and Sun brightness temperature uncertainties, are also discussed.

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Mattioli V., F. S. Marzano, N. Pierdicca, C. Capsoni, A. Martellucci, "Sky-Noise Temperature Modelling and Prediction for Deep Space Applications from X Band To W Band" IEEE Trans. of Antennas and Propagation, Volume: 61, Issue: 7 Page(s): 3859 – 3868, 2013

Paper 6 COMPARISON OF WATER VAPOR AND CLOUD MACROPHYSICAL PROPERTIES DERIVED FROM SATELLITE SENSORS 17:40 AND FROM AIRBORNE REMOTE SENSING INSTRUMENTS ON HALO

Emiliano Orlandi, Mario Mech, Sabrina Schnitt, University of Cologne, Germany; André Ehrlich, University of Leipzig, Germany; Frank Werner, Joint Center for Earth Systems Technology, United States; Sara Dal Gesso, Roel Neggers, Susanne Crewell, University of Cologne, Germany

The representation of clouds is one of the largest sources of uncertainty in climate and weather model predictions. On a global scale, atmospheric water vapor and cloud macrophysical properties like size distribution and liquid water path (LWP) can be observed with the help of satellites, which, however, miss small-scale features due to the coarse spatial resolution. Measurements with a finer resolution can be performed on airborne remote sensing platforms, such as the novel German High Altitude and LOng (HALO) range research aircraft. Within the NARVAL (Next- generation Aircraft Remote sensing for VALidation studies) campaign, HALO was equipped

Wednesday, April 13	Monitoring Vegetation with Microwave Radiometers	08:00 - 08:30
Invited Presentation	Jiancheng Shi, Institute of Remote Sensing and Digital Earth	Lecture Hall B

with a remote sensing suite consisting of a 26 channel passive microwave radiometer (22183 GHz), cloud radar (36 GHz), water vapor lidar, spectrometer and drop sondes. The first part of the campaign (NARVAL-South in December 2013) investigated cumulus clouds in the trade wind region, while the second part (NARVAL-North in January 2014) focused on post frontal convection over the Northern Atlantic.

Within this presentation, the integrated water vapor and the LWP derived from the aircraft measurements collected during the NARVAL-South campaign will be compared to those obtained from satelite observations. The amount of missed LWP, due to the coarser resolution of the satellite observations, is investigated. Furthermore, due to the high spatial resolution of the HAMP microwave radiometer (<1km), combined LWP and cloud size horizontal distribution are derived to give guidelines for the development of parameterization for atmospheric models.

Wednesday, April 13	Vegetation	08:30 - 09:50
Lecture Session		Lecture Hall B

Session Co-Chairs: Roger Lang, George Washington University; Jiancheng Shi, Institute of Remote Sensing and Digital Earth

Paper 1 L-BAND EFFECTIVE SCATTERING ALBEDO INVERSION FROM VEGETATION OVER A GROWTH CYCLE

08:30 Mehmet Kurum, Roger H. Lang, Leila Farhadi, George Washington University, United States; Peggy E. O'Neill, Alicia T. Joseph, NASA Goddard Space Flight Center, United States; Michael H. Cosh, USDA Agricultural Research Service, United States

In radiometric remote sensing of soil moisture through vegetation canopies, a zero-order radiative transfer approach, called the tau-omega model, is largely utilized in the hydrology community. The model has several advantages such as simplicity (very few parameters), ease of inversion and implementation, and extensive validation over many types of vegetation. The model links terrain geophysical variables to the observed brightness temperature through microwave reflectivity and two vegetation parameters, the optical depth and the single-scattering albedo.

The vegetation parameter "omega" (also known as single scattering albedo) is normally considered to have a small constant value for a given frequency, incident angle, and polarization in microwave inversion algorithms. This assumption may be true for short and stationary vegetated terrain at L-band. However, considering that satellites in orbit collect microwave data all over the globe, one could expect that the large fraction of data in land is acquired over vegetation that can be spatially and temporally variant. Agricultural crops particularly change substantially from planting to harvest. It is thus expected that the constant albedo approach may not be appropriate over many types of vegetation. In addition, the small albedo assumption is not fully consistent with theory and ground observations for moderate and dense vegetation.

We have recently introduced a new "effective scattering albedo" concept that generalizes some of the restrictions imposed by the original tau-omega model. This new parameter explicitly incorporates complex scattering processes inside the vegetation canopy, and also at the vegetation-soil interface into the generalized tau-omega model. Since the new parameter involves multiple surface scattering and ground-vegetation interactions, the parameter depends on the ground conditions, unlike the restrictive single scattering albedo. Our previous investigations also indicated that the constant albedo may introduce a significant error in soil moisture values retrieved using the tau-omega over temporally varying vegetated terrains unless its dynamic nature is taken into account.

In this study, we apply the "effective scattering albedo" concept to microwave data recently collected by NASA's Combined Radar/Radiometer system (a ground-based simulator for NASA's Soil Moisture Active Passive (SMAP) mission) over corn and soybean fields for entire growing season in 2012. Ground truth data associated with vegetation and ground conditions were also acquired to verify microwave models under a controlled experimental setup. We invert the effective scattering albedo from the measured brightness temperature by utilizing knowledge of the transmissivity of the vegetation and reflectivity of the ground that are calculated from ground truth measurements. The main focus of the study is to investigate relationships between the effective scattering albedo and dynamic scene conditions such as growth stage of the vegetation and soil moisture.

Paper 2 AN OPERATIONAL ALGORITHM FOR RETRIEVING THE VEGETATION WATER CONTENT FROM AMSR2 08:50 MULTIFREQUENCY ACQUISITIONS.

Emanuele Santi, Simonetta Paloscia, Paolo Pampaloni, Simone Pettinato, Institute of Applied Physics - National Research Council (IFAC - CNR), Italy; Mieko Seki, Keiji Sekiya, Remote Sensing Technology Center of Japan (RESTEC), Japan; Takashi Maeda, Misako Kachi, Japan Aerospace Exploration Agency (JAXA), Japan

In this work, an algorithm for the retrieval of Vegetation Water Content (VWC) from AMSR2 data is presented. The algorithm is based on Artificial Neural Networks (ANN), which have been demonstrated to be a good compromise between retrieval accuracy and computational cost with respect to other statistical or numerical approaches [1]. The ANN implemented for this purpose are feedforward multilayer perceptron type, trained with the back propagation (BP) learning rule. The algorithms has been developed for generating output maps of VWC at global scale with enhanced spatial resolution, thanks to the SFIM disaggregation technique [2] which allowed obtaining a VWC product at 0.1° x 0.1° spatial resolution.

The retrieval algorithm was based on the well-demonstrated sensitivity of the polarization difference, expressed as the Polarization Index, at various frequencies to VWC. While microwave emission at a given frequency increases or decreases when vegetation grows, depending on the plant geometry, PI decreases as the biomass increases, resulting rather independent on crop type [3].

The algorithm is based on the previous implementation for AMSR-E [4], which makes synergistic use of PI at X and Ku bands. In this updated implementation for AMSR2, the PI at C band has been also added to the algorithm inputs.

Considering the difficulties in obtaining "ground truth" data of VWC for validating the algorithm on large or global scale, the validation was carried out referring to VWC values derived from NDVI thanks to the relationship established by [5]. Although this relationship was initially developed for corn and soybean vegetation, it can be considered valid for other types of vegetation too.

The validation was carried out on a wide test area in Africa, extending from the Sahara desert to the Equatorial forest and including a very high variability of vegetation types and landscapes. The "reference" VWC was derived from NDVI data obtained from http://free.vgt. vito.be/home.php, resulting from 10 days of SPOT4 acquisitions on the African continent. These data were resampled on the AMSR2 grid and compared with the corresponding AMSR2 acquisitions, in both ascending and descending orbits, for a time series covering whole seasonal cycle.

A further validation has been carried out using direct WWC measurements on the JAXA validation site in the Yanco river basin, Australia. This test site is located in a vast plain where site-to-pixel representation issues are mitigated.

In both cases, the validation returned encouraging results, with a RMSE error on the VWC retrieval < 1 Kg/m2.

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Paper 3 ACTIVE/PASSIVE REMOTE SENSING OF VEGETATION: THEORETICAL AND EXPERIMENTAL RESULTS

09:10 Leila Guerriero, Paolo Ferrazzoli, Cristina Vittucci, Matteo Aurizzi, Alessio Mattioni, Tor Vergata University of Rome, Italy

In the last decades, researches based on passive and active systems were mostly conducted separately. More recently, a joint use of the two techniques were investigated with the objective of exploiting both the good properties of SAR in terms of high resolution and the good sensitivity of radiometric observations to soil moisture. Signatures collected by Aquarius instrument mounted on the SACD satellite, although dedicated to ocean applications, are also used to investigate a joint use of active and passive L band observations over land, particularly in large homogeneous areas (Piles et al., TGRS, pp. 4700-4711, 2015). Moreover, L band SAR systems that are in orbit, such as ALOS, or planned, such as SAOCOM, can be exploited jointly with spaceborne L band radiometers. In this framework, several works focus on the estimation of the slope β of a linear relation between emissivity and backscattering coefficient, for different land covers and soil/vegetation parameters.

In the past years, some works demonstrated that the emissivity e and the backscattering coefficient σ° of land surfaces are affected in different ways by soil and vegetation variables (Ferrazzoli et al., TGRS, pp. 772-778, 1989; Ferrazzoli and Guerriero, Proc. Microrad 2011). In particular, for several vegetation kinds and for an angle higher than about 30°, an increase of soil roughness or vegetation biomass produces an increase of both the emissivity and the backscattering coefficient, while an increase of soil moisture produces opposite effects on the two variables. A physical interpretation of this result is based on the relationships between backscattering coefficient, emissivity, and bistatic scattering coefficient. The present paper exploits this theoretical formulation to simulate backscattering coefficient and emissivity of bare soils, growing corn crops and broadleaf forests under various values of soil moisture. The advantage of this approach is that a unique physical formulation is adopted to compute the backscattering coefficient and the emissivity of the observed medium, through its bistatic scattering coefficient.

The theoretical results are compared with experimental data collected by various systems over different kind of surface cover. First, we have included data from the Soil Moisture Active and Passive Experiment (SMAPEx), collected during eight flights in September 2011 over the Gillenbah forests in New South Wales (Australia), in the framework of SMAPEx-3 campaign (www.smapex.monash.edu.au). Then, data from the 1999 Southern Great Plains (SGP99), Soil Moisture Experiment 2002 (SMEX02) and Cloud and Land Surface Interaction Campaign (CLASIC) campaigns over agricultural crops in the United States have been considered (Colliander et al., RSE, pp.309-322, 2012). Finally, we have included data globally collected by Aquarius in a 3-day interval of time, from July 1 to July 3, 2012. Near simultaneous values of soil moisture and vegetation optical depth retrieved by Soil Moisture and Ocean Salinity (SMOS) radiometric mission (Level 3) are used to interpret the Aquarius results.

Experimental data from both airborne and satellite acquisitions confirm the theoretical simulations.

Finally, the model is also used to predict the different sensitivities of active and passive instruments to soil moisture variations for different land covers, as well as the coefficient β of a linear relationship between emissivity and backscattering coefficient.

Paper 4 COMBINED ACTIVE AND PASSIVE MICROWAVE REMOTE SENSING OF VEGETATED SURFACES

09:30 Huanting Huang, Tien-Hao Liao, Leung Tsang, University of Michigan, Ann Arbor, United States; Eni Njoku, Andreas Colliander, Simon Yueh, NASA Jet Propulsion Laboratory, CalTech, United States; Thomas Jackson, USDA ARS Hydrology and Remote Sensing Laboratory, United States

Passive microwave models are usually based on the omega-tau model which is a zeroth-order radiative transfer solution, with h-Q formulation for the roughness effects. The parameters b, ω , h and Q are introduced empirically and not physically based. Recently, we use the distorted Born approximation for an active model which has the three scattering terms of volume scattering, double bounce, and rough surface scattering. The rough surface scattering is calculated by numerical solutions of Maxwell's equations in 3D simulations (NMM3D). The model was used to calculate the W and HH backscatter at L-band for grass, wheat and canola fields. The active model has been validated with the Soil Moisture Active Passive Validation Experiment 2012 (SMAPVEX12) data. This paper uses a consistent active and passive microwave remote sensing model for vegetated surfaces. The active model is extended to calculate bistatic scattering and an integration of the bistatic scattering over the hemispherical solid angle is used to compute emissivity in the passive remote sensing, where the same physical parameters for characterizing the vegetation as well as soil are used. The vegetation canopy is modeled as a layer of uniformly distributed dielectric cylinders and disks representing stalks and leaves, respectively. The distorted Born approximation is derived from Foldy-Lax equation with first-order iteration using the half-space Green's function and T-matrix. The bistatic scattering amplitude from stalks needed in the computations of the volume and double bounce scatterings is calculated using the infinite cylinder approximation. ICA) while the generalized Rayleigh-Gans approximation is used for leaves. The coherent reflectivity in the double bounce term is determined by NMM3D. The attenuation through the vegetation layer is accounted for by the imaginary part of the effective propagation constant calculated using Foldy's approximation. Data-cubes are then generated for both active and passive. From the active and passive data-cubes, t

backscatter is also derived for various rough surface and vegetation conditions. The data-cubes are useful for retrievals of detailed soil and vegetation characteristics such as soil moisture. The model results are validated by airborne Passive Active L-band Sensor (PALS) data and Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) data taken during the SMAPVEX12 field campaign. The combined active and passive model is used for L-band. We also study the use of the combined model with active at C-band and passive at L-band.

Wednesday, April 13	Instrument Technology	10:20 - 12:00
Lecture Session		Lecture Hall B

Session Co-Chairs: Manuel Martin-Neira, ESA/ESTEC; Alan Tanner, NASA Jet Propulsion Laboratory

Paper 1 SYSTEM INTEGRATION AND PERFORMANCE ANALYSIS OF A DUAL FREQUENCY DEMONSTRATOR FOR FPIR

10:20 Lin Wu, Key Laboratory of Microwave Remote Sensing, Chinese Academy of Sciences, China; Jingye Yan, Ji Wu, National Space Science Center, Chinese Academy of Science, China

Since one main geophysical source of error in the retrieval of Sea Surface Salinity (SSS) from L-band is the impact of the surface roughness and foam [1], a radiometer which can measure SSS and roughness at the same time is expected. Full Polarization Interferometric Radiometer (FPIR) is a one-dimensional full polarization interferometric radiometer for the SSS. It is composed of two frequency channels. L band is the primary detection channel for the SSS, which is sensitive to the SSS. X band is a secondary detection channel which is sensitive to the roughness and precipitation but not the salinity and atmosphere [2]. Also, compared with two-dimensional interferometric radiometer, FPIR has the advantages of light weight, low power and relatively simple electronics.

FPIR demonstrator consists of 6 antenna elements in each detection frequency. In L-band, small scale element antenna is designed. Each of the element antennas is a combination of 12 patches in a linear array. Length of the element antenna is around 1.5m, thus allowing an airborne test in the near future. Beam width of the L-band antenna of the demonstrator is 10 degree. In X-band, full scale element antenna is designed. Beam width of the X-band antenna is 2.5 degree, which is consistent with the L-band full scale antenna. A dedicated squint angle of 29 degree apart from the normal antenna plane is allocated in order to produce similar pixel resolution and incident angles across the swath. An additional element antenna for external calibration is inversely installed in the antenna plane, which will look at the cold sky when observation antennas observe the Earth surface. Unprecedented calibration system is designed, which allows each receiver to be switched to cold sky, common noise, Matched load or Earth observation, sequentially. Based on this new calibration system, a new calibration procedure has been implemented in this instrument to highly improve the instrument performance.

Before the integration, key parameters of the system, including the antenna patterns, receiver bandwidth, receiver gain, power splitter, amplitude and phase balance between channels and the digital correlator performance are accurately measured. Each individual component has shown a good performance.

After the integration, the first image has been produced. Retrieved image shows that the demonstrator is functioning well. Salinity retrieval experiments are scheduled using water pool and aircraft, which will show the performance of the SSS measurement. Remarkably, the SSS retrieval model will be improved by the pool experiment, which will lay a solid foundation for the future space applications.

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Paper 2 GEOSTAR SYSTEM DESIGN AND DEVELOPMENT UPDATE

10:40 Alan Tanner, Todd Gaier, Bjorn Lambrigtsen, Pekka Kangaslahti, Isaac Ramos-Perez, NASA Jet Propulsion Laboratory, CalTech, United States; Michael Flynn, Zhengya Zhang, David Austerberry, Chris Ruf, Darren McKague, University of Michigan, United States

The Geostationary Synthetic Thinned Array Radiometer (GeoSTAR) development efforts at JPL and the University of Michigan has now produce a third functional demonstrator instrument- GeoSTAR-III. This instrument represents over 12 years of focused technology developments to produce a viable microwave imaging system suitable for observations of the Earth's atmosphere from geostationary orbit. Key technologies which have been matured include a massively parallel, integrated, 1 G-sample/second 2-bit digitizer-correlator capable of digitizing and cross correlating fully 128 analog IF signals with just 1.5 Watts power consumption; and miniature millimeter-wave low noise receivers with less than 30 milliwatts consumption per receiver and less than 500 K noise figure at 183 GHz.

This talk will review how the system design requirements were developed for GeoSTAR, and how the GEOSTAR-III instrument now performs relative to these requirements. The basic sensitivity is of course paramount in this discussion, and has been the driver in terms of noise performance and correlator architecture and speed. Phase stability is also a driver, and test data will be presented which demonstrate how the intrinsic stability of the system has obviated the need for any on-board phase reference. Fault tolerance; power consumption; and performance versus thermal stability will also be discussed and demonstrated using the new system. These will all be discussed in the context of the overall calibration of GeoSTAR.

Paper 3 FOURIER CORRELATION IMAGING FOR PASSIVE EARTH REMOTE SENSING: A PROPOSAL FOR SMOS-NEXT

11:00 Younes Monijd, Bernard Rougé, Yann H. Kerr, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Daniel Braun, Institut für theoretische Physik, Universität Tübingen, Germany

Aperture synthesis is an interferometric technique in which the signals received by pairs of small antennas are processed in a way to synthesize a single large antenna [1]. This concept has been adapted from radioastronomy to Earth remote sensing. Thanks to this technique, limitations on antenna size in microwave passive remote sensing through satellites have been overcome [2].

A new concept based on a passive spatio-temporal interferometry has been proposed as the newest generation of the well-known SMOS mission successfully operating since November 2, 2009 [3]. The aim of the proposed concept is an enhancement of the currently achieved geometric resolution to meet the stringent user's requirements in local scale hydrological applications where sub-kilometric resolutions are needed [4]. This interferometric concept is based on the idea of integrating the displacement of the observer (satellite's antenna), and hence the time variable, in the calculation of the correlation, or visibility, function, which yields the creation of virtual baselines between the positions of antennas at different instants, in addition to the physical ones formed between the instantaneous antennas' spatial positions. Unfortunately, the additional information due to the virtual baseline is exactly cancelled by the Doppler shift [5]. But we show that when combining the multi-time correlations in the aforementioned spatio-temporal interferometric system by a Fourier correlation imaging procedure, consisting in cross-correlating the Fourier components at different frequencies of the fluctuating electric fields received by a pair of antennas, the 2D position dependent brightness temperature on the surface of the Earth can be reconstructed. The analytical derivation of the correlation function gives rise to a relationship linking the measured correlations to the position-dependent brightness temperatures by means of a highly oscillatory integral (HOI) kernel. The HOI kernel leads to the remarkable property that a correlation still exists between the signals at slightly different frequencies observed by two different antennas. While existing systems had, until now, only considered the 1D information contained in the correlation at the same frequency, the two-frequency correlation function bears 2D information. Based on this, one is capable, in principle, of reconstructing 2D brightness temperatures starting from a simple 1D geometry, i.e. two antennas arranged perpendicular to the direction of flight.

We test this method of Fourier Correlation Imaging by reconstructing the image of a single point-like source. Based on this, we arrive, at a first estimation, to a spatial resolution of the order of one km.

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Paper 4 A COMPACT 142-GHZ-RADIOMETER FOR CONTINUOUS MIDDLE-ATMOSPHERIC WIND MEASUREMENTS

11:20 Jonas Hagen, Axel Murk, Niklaus Kämpfer, University of Bern, Switzerland

The Wind Radiometer for Campaigns (WIRA-C) is a new, very compact microwave remote-sensing instrument which has been developed at the Institute of Applied Physics in Bern.

It is heavily inspired by the WIRA instrument, that has been delivering wind profiles since 2010 with great success.

Just like its predecessor, the new WIRA-C observes the ozone emission line at 142 GHz and the Doppler shift induced by wind is used to retrieve horizontal wind speeds.

The pressure broadening effect allows the retrieval of wind profiles for the middle atmosphere from approximately 30 to 70 km altitude.

The frontend of WIRA-C contains a temperature-stabilized heterodyne single-sideband receiver.

It is built around a low noise amplifier operating at a frequency of 142 GHz and has a system noise temperature of only 510 K.

A Universal Software Radio Peripheral (USRP) is used as a FFT spectrometer with a bandwidth of 120 MHz and a spectral resolution of 14.6 kHz.

The receiver is calibrated with the tipping-curve method and an internal ambient temperature load.

The new instrument has been developed specifically as a campaign instrument and the mechanical design is held compact.

Optics, frontend and backend are integrated into a single housing with the dimensions 0.6 × 0.75 × 0.5 m and the whole instrument is thus easy to transport and set up on a tripod.

The independent azimuth and elevation drives allow the observation of the four cardinal directions as used for differential wind measurements.

WIRA-C is undergoing a validation campaign in Bern, Switzerland with the WIRA instrument.

The two instruments will then participate in the ARISE2 project and deliver wind profiles for the middle atmosphere from polar and tropic latitudes.

We report on the concept and design of the novel wind radiometer and about results obtained during winter 2015/16 at Bern.

Paper 5 AIRBORNE OBSERVATIONS WITH THE ISMAR SUB-MILLIMETER RADIOMETER

11:40 Stuart Fox, Met Office, United Kingdom; Patrick Eriksson, Chalmers University of Technology, Sweden; Chawn Harlow, Clare Lee, Met Office, United Kingdom

ISMAR (International SubMillimeter Airborne Radiometer) is a passive millimeter and sub-millimeter wave radiometer designed for remote sensing of cloud ice. It has been developed as a satellite demonstrator for ICI (Ice Cloud Imager) and contains a number of heterodyne receivers operating at frequencies between 118 and 664 GHz. Submillimeter frequencies are sensitive to scattering by cloud ice particles, and using a range of frequencies enables the retrieval of cloud ice mass, as well as additional cloud properties such as effective particle size and altitude.

During winter 2014/15 ISMAR flew on the STICCS and COSMICS campaigns with the FAAM BAe-146 atmospheric research aircraft based in Prestwick, Scotland and Keflavik, Iceland. A variety of conditions were observed including clear skies, thin cirrus and frontal precipitation. Additional remote sensing and in-situ measurements were collected during the campaigns to characterise the atmospheric column and cloud properties for comparison with the ISMAR measurements.

We present an initial analysis of results from the airborne campaigns for both clear and cloudy conditions. We show that there is a good agreement between the ISMAR measurements and simulated brightness temepratures using the ARTS radiative transfer model in clear sky cases, and that clouds introduce detectable brightness temperature depressions at submillimeter frequencies. Initial Bayesian retrievals of cloud ice water path based on a database derived from CloudSat profiles are also shown, with promising results. Session Co-Chairs: Steven Reising, Colorado State University; Frank Marzano, Sapienza University of Rome

Paper 1 THE NWP CONTRIBUTION FROM THE MICROWAVE SOUNDER ON METOP SECOND GENERATION

13:00 George Tennant, David Hurd, Airbus Defence and Space Ltd, United Kingdom; Ville Kangas, European Space Agency, Netherlands

Observations from microwave sounding instruments have played a key role in operational numerical weather prediction (NWP) and climate research for the last 35 years and will continue to do so for the foreseeable future. Building on a heritage of cross-track sounding radiometers including MSU, AMSU-A/-B, MHS and ATMS, the Microwave Sounder (MWS) will serve weather and climate applications from launch in 2021, until at least 2042.

MWS is a total power radiometer that has been selected by ESA as part of the MetOp-SG programme, with Airbus Defence and Space Ltd, chosen as the instrument prime contractor. MWS measures the brightness temperature at various altitudes and delivers calibrated and geo-located atmospheric temperature and water-vapour sounding data, in all weather and illumination conditions. MWS is thus an essential instrument for the provision of operational meteorology, offering significant improvements in measurement performance over MetOp First Generation and indeed all microwave sounders currently operating on meteorological satellites.

The primary purpose of the MWS, in the context of operational NWP, is to provide observational constraints on the initial conditions for NWP forecast models through the process of data assimilation. Data from current microwave radiometers provide a large fraction of the total benefit realised from all satellite observations for weather forecasting. Within NWP systems the MWS measurements will be assimilated directly as brightness temperatures. The high, and improving, accuracy of NWP systems in representing global temperature and humidity fields drives stringent performance specifications for MWS – in terms of stability, bias characteristics and noise performance of Level 1 products.

NWP applications have shown the value of, and need for, careful pre-launch characterisation of sounding radiometers and calibration of the resulting Level 1 products to provide accurate brightness temperature data. For MWS, calibration is based on the two-point method, utilising a cold space view and a warm target view, provided by an on-board black body target. However the basic method is supplemented by corrections applied in the ground processing for receiver non-linearity, scan-bias, and radiometric contamination, in particular from the antenna side-lobes in both the earth and cold space views and from the spacecraft. The calibration relies on the instrument characterisation data base, which is constructed using on-ground instrument measurements from radiometric calibration and antenna pattern characterisation campaigns.

MWS measures the total power, atmospheric brightness temperature in 24 channels over the spectral range from 23.8 - 229 GHz. Footprints are ranging from 40 km at the lowest frequency to 17 km at the highest frequencies. A fixed, parabolic sub-reflector is used to fold the signal into a quasi-optic network (QON). The QON separates the incoming radiation signal into seven separate frequency bands by the use of dichroics, polarisers and mirrors. The signals are then captured by RF feed horns, which are then coupled to 8 receiver front-end modules, specific for the different channels. The eighth receiver provides full redundancy for the temperature sounding channels (50 GHz - 58 GHz).

In addition to performance, MWS also provides a robust design as required for an operational instrument. MWS includes an input filtering at the two lowest channels to provide protection against radio frequency interference. The Instrument also has a high level of autonomy, with sophisticated FDIR, in-order to maintain system availability. Instrument reliability is currently estimated to be > 0.94.

This paper will present the MWS instrument key design features, predicted performance, development status of associated key technology developments, both at equipment and instrument level, and the current status of equipment procurement and instrument MAIT, including MWS calibration plan. MWS data processing to level 1b will also be presented.

Paper 2 SYNERGY OF MICROWAVE RADIOMETRY AND LIDAR FOR HIGH VERTICAL TEMPERATURE AND WATER VAPOR 13:20 PROFILING

Maria Barrera Verdejo, Emiliano Orlandi, Susanne Crewell, Ulrich Löhnert, University of Cologne, Germany; Paolo Di Girolamo, Università degli Studi della Basilicata, Italy; Martin Wirth, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany

Atmospheric humidity and temperature are important variables to describe any meteorological event. Highly resolved, accurate and continuous measurements of these parameters are required to better understand atmospheric processes. Unfortunately, remote sensing instruments available nowadays are not able to provide sufficient spatial resolution to describe short time scale processes. In order to overcome the specific limitation of a given sensor, instrument synergies are gaining importance in the last years. Here, we present the synergy of a Microwave Radiometer (MWR) and lidar systems.

The retrieval algorithm that combines these two instruments is an innovative scheme, based on an Optimal Estimation Method (OEM). It allows a complete error description of the retrieved profiles. The method is designed for clear sky periods and simple cloudy scenarios.

Firstly, the OEM has been applied to the two months dataset of HOPE, a field campaign in Jülich, Germany. In addition to a ground-based multi-frequency MWR, a Raman lidar (RL) provides information on water vapor and although limited temperature profiles. Different experiments are performed to evidence the improvements of the synergy. We demonstrate that, when applying the combined retrieval to the HOPE period, the absolute humidity error is reduced by 60% and 38% on average, with respect to the retrieval using only-MWR data or only-RL, respectively. Further, we show that the joint use of temperature and humidity measurements provides improved relative humidity estimates, which is especially useful to study cloud formation in the vicinity of cloud edges. In general, the benefits of the sensor combination are especially strong in regions where Raman Lidar data is not available (i.e. overlap region, poor signal to noise ratio), whereas if both instruments are available, RL dominates the retrieval.

In addition to the ground-based application during HOPE, the algorithm is used with aircraft-based measurements. High Altitude and Long-range research aircraft (HALO) data, collected over the Tropical Atlantic by a 26-channel microwave radiometer and the Water Vapor Differential Absorption LIDAR (WALES) are analyzed and we present preliminary results. The talk will discuss the differences between ground-based and airborne geometries and the extension of the algorithm to cloudy cases.

Paper 3 WET-PATH DELAY AND INTEGRATED WATER VAPOR RETRIEVALS FROM THE HIGH-FREQUENCY AIRBORNE 13:40 MICROWAVE AND MILLIMETER-WAVE RADIOMETER (HAMMR) MEASUREMENTS DURING THE 2014 WEST COAST FLIGHT CAMPAIGN

Xavier Bosch-Lluis, Steven Reising, Colorado State University, United States; Pekka Kangaslahti, Alan Tanner, Shannon Brown, Sharmila Padmanabhan, NASA Jet Propulsion Laboratory, CalTech, United States; Thaddeus Johnson, Victoria Hadel, Karen Ng, Colorado State University, United States

In May 2014, NASA and CNES administrators signed a bilateral agreement to move from feasibility studies to implementation of the Surface Water and Ocean Topography (SWOT) mission, now planned for launch in late 2020. An important science objective of SWOT is to transition satellite altimetry from the open ocean into the coastal zone and over inland water. In addition, Jason-3 is planned for launch in 2016. Past and current precision ocean altimeters operating for the past 23 years, including the Jason series, have nadir-viewing, co-located low-frequency 18-34 GHz microwave radiometers to correct the radar signal for wet-tropospheric path delay. Since surface footprints are substantial at these frequencies, the accuracy of wet path delay retrievals is significantly degraded within approximately 30-40 km of the world's coastlines, and retrievals are not provided over land. To improve this capability, high-frequency millimeter-wave window channels in the 90-180 GHz band may be added to achieve finer spatial resolution for a fixed reflector size. These higher-frequency channels are expected to provide retrievals of wet-tropospheric delay in coastal areas and to enhance the potential for over-land retrievals.

To address these needs, Colorado State University (CSU) and NASA/Caltech Jet Propulsion Laboratory (JPL) have designed, fabricated and demonstrated the Highfrequency Airborne Microwave and Millimeter-wave Radiometer (HAMMR) to enable increased spatial resolution of wet-tropospheric path delay correction for highresolution ocean surface altimeter missions. HAMMR is a cross-track scanning airborne radiometer with 25 channels combining low-frequency microwave channels similar to Jason-2/3 at 18.7, 23.8 and 34.0 GHz at both vertical and horizontal polarizations with high-frequency, wide-band millimeter-wave window channels at 90, 130 and 168 GHz, as well as eight temperature and water vapor sounding channels near each of 118 GHz and 183 GHz, respectively. The new HAMMR instrument (1) provides calibration and validation support for the SWOT, Jason-3 and Jason-CS missions, complementary to JPL's AirSWOT radar, (2) assesses wet-tropospheric path delay variability on 1-km and smaller spatial scales, and (3) provides high-frequency millimeter-wave radiometers with direct detection and internal calibration that can be integrated into future space missions, including nanosatellite constellations.

HAMMR was deployed on a Twin Otter aircraft over nearly the entire U.S. West coast during the West Coast Flight Campaign (WCFC) from November 4 to 17, 2014. During the WCFC, the HAMMR instrument flew on the Twin Otter on 11 of the 14 days to collect more than 53.5 hours of data under diverse atmospheric conditions, including clear sky, scattered and dense clouds, as well as surface types, including coastal ocean areas, inland water and land. Five flight days out of 11 were devoted to traversing nearly the entire U.S. West coast from Camarillo, CA, to the Canadian border. Furthermore, during the WCFC, HAMMR performed radiometric measurements over inland water bodies, in particular the San Joaquin River Delta in CA and the Strait of Juan de Fuca (leading to Puget Sound) in WA. Finally, two flight days were devoted to overflights of Lake Tahoe, CA/NV, and Mono Lake, CA. These flights were performed at the same time as the AirSWOT radar overflew the same two lakes.

Antenna temperatures measured by HAMMR during the WCFC were radiometrically calibrated using multiple techniques and geolocated accurately. Wet-path delay was retrieved using the microwave channels with better than 1-mm height precision and 150-m horizontal resolution. These results will be compared to those obtained using the millimeter-wave window channels with improved horizontal resolution. Furthermore, atmospheric temperature and humidity profiles will be retrieved using the millimeter-wave sounder channels. Integrated water vapor obtained from these profiles will be compared to the wet-path delay obtained from the microwave channels. Quality control has been performed for the entire data set to determine the performance of the instrument over the 11-day WCFC campaign.

Paper 4 APPLICATION OF MICROWAVE TEMPERATURE PROFILERS DATA FOR URBAN ATMOSPHERIC BOUNDARY LAYER 14:00 PROCESSES STUDY AND FORECASTING

Evgeny Kadygrov, Central Aerological Observatory, Russian Federation; Iren Kuztetsova, Hydrometeorological Center of Russia, Russian Federation; Evgeny Miller, Central Aerological Observatory, Russian Federation; Nataly Brusova, Yydrometeorological Center of Russia, Russian Federation

Monitoring of temperature profiles in Atmospheric Boundary Layer (ABL) is required for many meteorological and ecological applications. The ABL plays an important role in the interaction between the atmosphere and the Earth surface. Temperature stratifications of the ABL determines a number of important physical processes such as high concentration of antropogenic air pollution, vertical structure of urban heat island (UHI) over the megacity, radio-wave propagation, dissipation of fog and stratus. It is also important in the forecasting of the distribution and dispersion of gases emitted from low-level sourses into the free atmosphere, short-term local meteorological forecasting, forecasting of alaze, fog and others dangerous meteorological conditions, Traditional in-situ sensors (radiosondes) and satellite remotesensing instruments are not capable of providing continuous measurements of ABL temperature profiles. In Russia for ABL temperature profile monitoring we used microwave temperature profilers MTP-5. More than 20 profilers are in operation at the meteorological stations in the biggest Russian cities at the moment. The MTP-5 instrument is commercially available an anaular -scanning , self-calibrating single-channel microwave radiometer with the central frequency 56.6 GHz, a sensitivity of 0.07 K at 1 s integration time and 3 dB beamwidth of 2.5 0. The angular scanning system has the sharper height resolution in the lower 400 m in contrast with multichannel instruments. The duration of temperature measurement cycle is about 120 s in the completely automatic mode, altitude range is 0-1000 m, the typical mean deviation of MTP-5 instrument is 0.3-0.4 K under adiabatic conditions and 0.8-1.2 K under inversion conditions. MTP-5 meteorological protection system permits measurements practically in all weather conditions without manual operation even during snow and rain. The scientific objectivity of our study was to determine on the basis of the 15-years data set (2000-2015) from three MTP-5 profilers installed in the city center and suburb of Moscow megacity the possible application of this information in meteorology and ecology. As a fact this data were used for : determination of ABL thermal stratification type, monitoring of temperature inversion type and parameters, determination of temperature gradient and mixing layer height, passage of atmospheric fronts, identifications of icing thermal conditions, evaluation of potential influence of urban air circulation on pollution dissipation. Special software made visualizations of this information for the users. Vertical distribution of UHI above Moscow city were also investigated. Spatial distribution of UHI parameters was changing from winter to summer. At winter maximum altitude of UHI was indicated at 100-150 m above surface level and in summer it was 300-500 m. In the central part of the city UHI was accompanied by atmospheric thermal instability in all seasons, vertical temperature aradient at the level 0-100 m was more than 0.980 C/100 m and reiteration of the thermal stability was 1-2 % at the surface level. The MTP-5 data were used in system of early warning and prediction systems for urban air guality and in numerical modeling. In general it was confirmed that surface-based scanning microwave radiometers are very useful instruments for urban ABL study. More details about the methodology and main results will be presented at the conference.

Paper 5 THE MICROWAVE TEMPERATURE HUMIDITY PROFILER AIRBORNE INSTRUMENT

14:20 Boon Lim, Richard Denning, William Read, Alan Tanner, NASA Jet Propulsion Laboratory, CalTech, United States

The Jet Propulsion Laboratory (JPL) is developing a next generation sensor, the Microwave Temperature Humidity Profiler (MTHP) for use on airborne platforms. The instrument will have channels that measure the 60 GHz oxygen band and 183 GHz water vapor band. Scanning the field of view ahead of the aircraft flight path, the instrument will allow for atmospheric retrievals above and below the aircraft, to generate vertical profiles.

The millimeter wave microwave receivers utilize low noise amplifiers made on the 35 nm indium phosphide (InP) High Electron Mobility Transistors (HEMTs) process that offer low noise figures (<4 dB). Continuous calibration is performed with a novel rotating drum, through an aperture matched to the measurement frequencies, with two external targets – one at ambient and another heated to 55oC. The instrument will perform a scan of the vertical distribution of the atmosphere and calibration targets every ~ 1.5 seconds. The signal backend is currently configured for up to 4 channels per frequency band, though only three are required for the retrievals.

The forward model is based on that used for the Aura Microwave Limb Sounder (MLS) with modifications for the aircraft field of view. Parameter retrieval is an optimal estimation combining apriori knowledge with measurement information. Retrieval extent above and below the aircraft are determined by the flight altitude but simulations show that ±4 km is possible (< 20% error) for water vapor. Temperature profiles can be retrieved to a larger extent >±6 km.

First light with the MTHP will be in November/December 2015 on the Northrup Grumman GII aircraft.

Wednesday, April 13	Passive/Active Instruments and Techniques	14:40 - 16:00
Poster Session		Outside Hall B

Session Co-Chairs: Pablo Saavedra Garfias, University of Bonn; Magdalena Anguelova, Naval Research Laboratory

Paper 1 REFLECTIVITY AND EMISSIVITY OF SEA FOAM AT L-BAND

Magdalena D. Anguelova, Derek Burrage, Michael H. Bettenhausen, Naval Research Laboratory, United States

The ubiquitous use of the Global Positioning System (GPS) for navigation of platforms ranging from spacecraft to personal vehicles is well known. GPS operates within the electromagnetic spectrum at L-band frequencies of 1-2 GHz. Because these low microwave frequencies penetrate clouds and light to moderate rain, GPS signals can be reliably used to detect the specular reflection and diffuse scattering from, respectively, flat and rough earth surfaces. This makes the GPS signals useful for geophysical measurements in virtually all weather conditions. Aircraft and satellite-borne L-band (GPS) reflectometers have been shown to successfully sense surface wind speeds. The measuring principle of L-band reflectometry is based on sensing changes in ocean surface reflectivity, due to changes of the ocean surface roughness, as the wind speed increases. The use of GPS, together with other Global Navigation Satellite-borne receivers. With its all weather capability and high temporal resolution, GPS reflectometry has the potential to provide wind speed data in hurricane conditions, i.e., in high winds and under heavy precipitation.

The new Cyclone Global Navigation Satellite System (CYGNSS) project aims to use GPS reflectometry to retrieve hurricane wind speeds and help improve the skill of tropical storm and hurricane intensity forecasts. However, wave breaking under high winds produces sea foam (whitecaps) and sea spray, which complicate processes acting at the air-sea interface. Whitecaps and sea spray have high emissivity at L-band and will thus reduce the ocean reflectivity needed for wind speed retrieval. A combination of L-band reflectometry and L-band radiometry can thus help to better understand and model the physical mechanisms governing the L-band sensor responses to storm-roughened sea surfaces. We use a radiative transfer model formulated in terms of foam thickness and void fraction to evaluate both the reflectivity, for layers with varying thicknesses and void fractions. The reflected GPS signal sensitivity to wind speed variations in the presence of foam, and any tendency for this sensitivity to saturate in high winds, are assessed using the radiative transfer model.

Paper 2 ESTIMATION OF MELTING LAYER MULTI-WAVELENGTH ATTENUATION BY COMBINED POLARIMETRIC PASSIVE AND ACTIVE SENSORS

Pablo Saavedra, University of Bonn, Germany; Alessandra Battaglia, University of Leicester, United Kingdom; Alexander Ryzhkov, University of Oklahoma / NOAA, United States; Clemens Simmer, University of Bonn, Germany

Melting layer is the main mechanism responsible for the conversion of precipitation into liquid precipitation during stratiform rain. Its mixed phase nature makes difficult to estimate the related attenuation and therefore modelers need to assume a certain composition of water-ice electromagnetic properties in order to assess radar related parameters.

The present contribution attempts to estimated the attenuation in the melting layer by combining observation of independent active and passive sensors. In one side, dual polarimetric weather radars which are optimal tools to estimate attenuation for the rain layer by taking advantage of the methods developed specially for Quantitative Precipitation Estimation (QPE) applications. On the other hand, it is exploited the capabilities of the multi-frequency dual-pol radiometer ADMIRARI to simultaneously retrieve water vapor, rain and cloud parameters during precipitating events, e.g. the slant path integrated water vapor, rain and cloud water content independently.

Since the radiometer gives an estimation of the path integrated attenuation (PIA) for the whole observed slant column i.e. rain, melting and ice phase, the melting layer is isolated by subtracting the rain component estimated independently from the radar and the cloud component from the radiometer. This at the three ADMIRARI frequencies bands (X, K and Ka-band).

The present work makes emphasis on the strong dependency on the feasibility of the radar polarimetric methods to estimate the rain layer. Extreme cases will be put into consideration e.g. light rain which produces practically negligible polarization signature and thunderstorms which tend to saturate the passive sensor.

Paper 3 SCANNING L-BAND ACTIVE PASSIVE (SLAP)—INSTRUMENT CHARACTERIZATION DURING RECENT CAMPAIGNS

Edward Kim, NASA, United States; Albert Wu, Eugenia De Marco, NASA, ASRC, United States; Cornelis du Toit, NASA, AS&D, United States; Victor Marrero-Fontanez, Mark Wong, Lynn Miles, NASA, United States

Scanning L-band Active Passive (SLAP) was conceived as an airborne simulator for NASA's Soil Moisture Active Passive (SMAP) mission and was built by NASA's Goddard Space Flight Center.

As with other such airborne instruments, SLAP can be used for algorithm refinement work, post-launch calibration/validation activities, as well as other applications that rely on L-band sensing.

SLAP's principal features are

a) a new thin aerodynamic antenna to permit simple accommodation on multiple aircraft (SLAP currently flies on a King Air),

b) a real-aperture radar at 1.26 GHz and a radiometer at 1.4 GHz,

c) a dual-frequency dual-polarized antenna enabling quad-pol radar and 4-Stokes radiometer operation with the same antenna at the SMAP incidence angle of 40 degrees,

d) conical scanning via a rotating antenna to simulate the conical scanning of SMAP,

e) use of identical or nearly-identical RF front end parts as the SMAP radiometer, for high-fidelity simulation of SMAP performance,

f) a digital backend that exactly mimics the SMAP digital backend, including RFI processing code.

A brief overview of the design of SLAP will be presented, and then a detailed characterization of the radiometer and radar will be given, with example images from both, based on data collected during recent campaigns. The characterizations will include sensitivity, accuracy, noise spectrum, and stability, as well as performance evaluations of the antenna and the digital backend. Examples of radio frequency interference (RFI) analysis will be shown utilizing the capability of the SLAP digital backend to slice in time and frequency, as well as in the statistical domain.

Paper 4 POTENTIAL OF MICROWAVE IMAGER COMBINED ACTIVE/PASSIVE FOR THE RETRIEVAL OF SEA SURFACE SALINITY: A NEW MISSION CONCEPT

Xiaobin Yin, Hao Liu, Risheng Yun, Lin Wu, Xingou Xu, Di Zhu, Key Laboratory of Microwave Remote Sensing, Chinese Academy of Sciences, China

The L-band has been chosen for the sea surface salinity (SSS) remote sensing because it features a sensitivity of sea surface radiometric measurements to changes in salinity that is significantly larger than at higher frequencies and it is protected against human-made emissions. However, even at this frequency, SSS remote sensing is very challenging because the sensitivity of brightness temperature (TB) to SSS remains low: in the range of 0.35 K \bullet pss-1 to 0.8 K \bullet pss-1 for the vertical polarization and 0.2 K \bullet pss-1 to 0.6 K \bullet pss-1 for the horizontal polarization. The main geophysical sources of error in the retrieval of SSS from L-band TB comes from the uncertainty of the ocean surface emissivity related to the surface roughness and sea surface temperature (SST).

A 1-D interferometric system at 1.4GHz, 6.9GHz, 18.7 GHz and 23.8GHz combined with a scatterometer at 1.2GGHz, called microwave imager combined active/ passive, has been proposed to retrieve SSS and to reduce geophysical errors due to the surface roughness and SST. The microwave imager combined active/passive will be the pricinpal payload onboard the Ocean Salinity Satellite of State Oceanic Administration of China.

The retrievals are based on the non-linear iterative convergence method. The first guess geophysical inputs, i.e. SSS, SST, wind speed (WS), vapor (V) and cloud liquid (L) are adjusted in order to minimize a "cost function". The sensitivity of active/passive microwave observations to SSS, SST and wind is analyzed and the stability requirement of the instruments is estimated, with the objective of designing an optimized satellite instrument, dedicated to an "all-weather" estimation of the SSS with high accuracy.

Paper 5 TOWARDS A RADAR/RADIOMETER MODE ON THE DUAL-FREQUENCY, DUAL-POLARIZED, DOPPLER RADAR (D3R) SYSTEM

Manuel Vega, NASA Goddard Space Flight Center / Colorado State University, United States; V. Chandrasekar, Colorado State University, United States

The dual-frequency, dual-polarized, Doppler radar (D3R) system was developed in support of the ground validation segment of the Global Precipitation Measurement (GPM) mission [1]. Although its main purpose is to provide active, Ku/Ka-band, dual-polarized measurements of precipitation, the design presents an opportunity to study its operation in an active/passive mode. The opportunity arises from use of a solid-state transmitters employing a multi-frequency waveform and receiving system. Typically, a sequence of three pulses separated in frequency is transmitted to achieve its radar sensitivity and minimum range. However, one of the three pulses can be disabled with a tolerable decrease in sensitivity and its receive channel can be repurposed to support passive measurements.

The work to be presented focuses on the characterization of the passive channel operating simultaneously with two active as a step towards the provision of brightness temperatures along with the other radar derived products. The study consists on the analysis of the antenna performance, receiver architecture, transfer function and achievable radiometric resolution, calibration method and preliminary observation analysis. The antenna analysis consists in the development of high-resolution models in order to estimate their beam efficiency. The receivers are heterodyne and employ noise injection to track gain fluctuations along with temperature measurements throughout its front-end components to compensate for temperature variations. Sub-banding and detection are performed in the digital domain. The receiver spectral transfer function and sampling have been characterized to estimate the equivalent number of independent samples and achievable radiometric resolution. Given the measurements are performed simultaneously with the radar, it is possible that under some circumstances (e.g. strong convective storms in near range, ground backscatter, etc.) the sub-channel isolation may not be enough to suppress contamination within the passive band. Consequently, kurtosis is computed and used on the detection of self-induced radio frequency interference (RFI). Finally, calibration is achieved through regular tip curve scans during clear sky conditions.

[1] M.A. Vega, V. Chandrasekar, J. Carswell, R.M. Beauchamp, M.R. Schwaller, and C. Nguyen, "Salient Features of the Dual-frequency, Dual-polarized, Doppler, Radar for Remote Sensing of Precipitation," Rad. Sci., 49, 2014.

Paper 6 A NEURAL NETWORK APPROACH FOR DETERMINING RADIOMETER OBSERVATIONS FROM RADAR AND VICE VERSA FOR THE GPM MISSION

Srinivasa Ramanujam Kannan, Indian Institute of Technology Bhubaneswar, India; Chandrasekar V, Colorado State University, United States

Global Precipitation Measurement (GPM)'s Dual Frequency Precipitation Radar (DPR) is one of the rain measuring instrument on board the GPM satellite that senses rainfall in Ku and Ka band frequencies. The Ku PR is an upgraded version of Tropical Rainfall Measurement Mission (TRMM) Precipitation Radar (PR), a highly successful unit flown from recently ended TRMM mission. With the addition of Ka PR in GPM, the DPR is expected to improve detection of light rainfall and snow measurements in high latitude regions using the differential attenuation between the two frequencies On board the same GPM core satellite is the GPM's Microwave Imager (GMI), a passive microwave radiometer, sensing the same rain scene at five different frequencies, two polarizations each. Unlike radar, radiometer detects integrated microwave signal that emerges from the earth surface after passing through vertical rainfall structure which interacts with the radiation signal through emission, absorption and/or scattering. Even though both the rain measuring instruments are on board the same satellite and are meant for measuring vertical rainfall structure, the active – passive combination of rainfall measurement from these instruments are fundamentally different. Hence, it is interesting to explore and find whether prediction of passive observations through active sensor measurement and vice versa is possible. In the present study, a neural network approach based on back propagation and radial basis function is made by using GPM DPR observation as input, while the network is trained against collocated GMI observations. Different network architectures are trained for land / ocean database and the results will be presented.

Wednesday, April 13	Sensor Calibration	14:40 - 16:00
Poster Session		Outside Hall B

Session Co-Chairs: David Draper, Ball Aerospace & Technologies Corp; Janne Lahtinen, Harp Technologies Ltd

Paper 1 CRYOGENIC DESIGN AND UNCERTAINTY ANALYSIS OF THE NIST MICROWAVE BLACKBODY

Derek Houtz, David Walker, Dazhen Gu, National Institute of Standards and Technology, United States

Radiometer calibration fundamentally relies on characterization of the source. The absolute accuracy of any such calibration depends on how precisely the source can be traced to fundamental units, typically brightness-temperature units of Kelvins. NIST is developing a microwave calibration source or 'blackbody' to be used as a national standard for transference of the microwave brightness-temperature scale. Accurate knowledge of electromagnetic emissivity and physical temperature, as well as maintaining temporal and spatial stability and uniformity of these quantities are the critical design requirements. Operating in the frequency range from 18 to 220 GHz and at temperatures from 80 K to 330 K, the standard will allow calibration of a broad range of radiometric systems. The electromagnetic design has been heavily studied and discussed previously, but practical considerations about the thermal performance have been a topic of concern and discussion recently.

Designing a single system to cover broad frequency and temperature ranges both in a thermal-vacuum chamber and in a laboratory ambient environment while maintaining unprecedented temperature stability has been a challenging task. We discuss liquid nitrogen heat exchanger design, cryogenic compatibility of microwave absorbing materials, and choice of a conductive working fluid that allows stabilization at temperatures between 180 K and 330 K. The unique conical geometry of the blackbody allows for thermal uniformity improvements over the widely used pyramidal array-type sources.

Previous experience has shown that common commercial iron-doped epoxy microwave absorbers may experience cracking and separation on larger geometries when cooled to liquid nitrogen temperatures. We have measured complex permittivity and permeability of two iron-doped epoxy species and various carbonyl concentrations suspended in a matrix of a different type of epoxy, at frequencies up to 40 GHz using the waveguide TRL method. These data are used as inputs to electromagnetic models simulating the blackbody performance. We present the performance difference and design changes resulting from the use of the new carbonyl loaded absorber in place of the previously-planned iron-doped epoxy.

A rigorous uncertainty analysis is followed for the electromagnetic simulations, and we predict an overall uncertainty in the total brightness temperature of the calibration source as a function of frequency. A NIST-produced software package known as the Microwave Uncertainty Framework is leveraged to extract uncertainty values for the measured S-parameter data for the material property characterization. These data are then propagated through to uncertainty in material data, target emissivity, and finally combined with physical temperature simulations in a Monte Carlo process to obtain brightness temperature uncertainty of the NIST blackbody design.

The NIST microwave blackbody aims to standardize radiometer calibration in the future and provide a primary absolute reference for brightness temperature. A traceability standard for space-borne microwave instruments will increase consistency and improve weather forecasts and long-term climate record accuracy.

Paper 2 STABILITY ANALYSIS OF THE SWI 530-625 GHZ RECEIVER CHAIN FOR THE JUPITER MISSION JUICE

Karl Jacob, Axel Murk, Hyunjoo Kim, University of Bern, IAP, Switzerland; Jan Stake, Vladimir Drakinskiy, Chalmers University of Technology, Sweden; Anders Emrich, Peter Sobis, Omnisys Instruments, Sweden; Alain Maestrini, Jeanne Treuttel, Ferhat Tamazouzt, LERMA Observatoire de Paris, France; Martin Philipp, Bertrand Thomas, Radiometer Physics GmbH, Germany; Paul Hartogh, Max Planck Institute for Solar System Research, Germany

We report on stability aspects of the 600GHz channel of the Submillimetre Wave Instrument (SWI) which is being developed for the Jupiter Icy Moons Explorer mission (JUICE) of the European Space Agency (ESA). SWI is a passive radiometer/spectrometer instrument, consisting of two orthogonally polarized heterodyne receivers which are independently tunable over a frequency range from 530GHz to 625GHz. Its scientific objectives are the mapping of the chemical composition, temperatures and winds in the stratosphere of Jupiter and the exosphere of its Galilean moons Callisto, Europa and Ganymede. It will also investigate the thermo-physical and dielectric properties of the surface and the subsurface of these icy moons and correlate them with atmospheric and geological features.

The SWI 600GHz receivers consist of a sub-harmonic mixer and a low-noise amplifier (LNA) developed by Omnisys Instruments and based on GaAs Schottky membrane diodes and cryogenic InP HEMT MMIC technology from Chalmers University of Technology. The LNA is directly integrated in the mixer block and optimized for cryogenic temperature operation. These components will be passively cooled to about 150K in order to improve their sensitivity. The tunable Local Oscillator (LO) chain starts with an E-Band tripler and a power amplifier into E-Band, followed by a high power 130 to 160GHz frequency doubler, which have been developed by Radiometer Physics GmbH. The last multiplication stage is a frequency doubler developed at LERMA, Observatoire de Paris, which provides between 4mW and 12mW output power the range from 260 to 320GHz.

The SWI instrument will be calibrated with intermittent views to cold space and an internal conical calibration target. In addition it is planned to use frequency switching calibration for narrow band spectroscopic features. We will present first Allan Variance tests under stable temperature conditions, as well as the temperature dependent gain variations of the receivers. The calculated Allan Variances allow the evaluation of the best range of integration time. Since the SWI instrument calibration procedure is repeated in time intervals of about 30 min the temperature caused drifts in the measurements are one of the main limitations of the measurement precision. Furthermore we will show the thermal time constants which determine the minimum warm-up times that have to pass until a stable operation is reached when turning the receivers on and when the LO frequency is switched.

Paper 3 STATUS OF PRECIPITATION MEASUREMENT MISSION RADIOMETER INTERCALIBRATION

Darren McKague, University of Michigan, United States; Wesley Berg, Colorado State University, United States; Linwood Jones, University of Central Florida, United States; Thomas Wilheit, Texas A&M University, United States

NASA's Precipitation Measurement Missions (PMM) seek to characterize precipitation on a global scale. Goals include the characterization of all phases of precipitation, improving the accuracy and dynamic range for precipitation products, improved understanding of the link between precipitation and climate, and insights into storm structure as well as large-scale atmospheric processes. In order to accomplish these goals, a constellation of radiometers is required to achieve global coverage with relatively high temporal resolution (of order 3 hours). To maximize coverage and measure all phases of precipitation, radiometers with mm-wave channels, which are more sensitive to scattering from frozen hydrometeors than microwave channels, are included (e.g., GMI, MHS, SAPHIR, AMSUB). To extend the record to longer time scales for climate study, data from previous instruments, including in particular those from the Tropical Rainfall Measurement Mission (TRMM), are also included.

The PMM Intercalibration Working Group (XCal) investigates issues impacting the calibration of individual microwave radiometers and uses multiple methods to quantify the differences after accounting for variations in frequency, view angle, etc. For a given sensor, the team investigates the consistency and stability of the calibration and adjusts it when a definitive root cause can be found and a reliable correction can be developed. To account for any residual differences in the calibration between sensors, offsets are specified as a function of brightness temperature and are used to shift the measurements of the constellation to a common reference before deriving precipitation products.

This presentation will describe the foundation for the XCal intercalibration process and will show the latest calibration and intercalibration results for the PMM constellation. The Global Precipitation Mission (GPM) Microwave Imager (GMI) is the current XCal reference satellite to which other satellites are intercalibrated. GMI, which launched in March 2014, is a stable radiometer with a detailed pre and post-launch characterization that provides a strong link between on-orbit calibration and well understood calibration targets. Intercalibration offsets between GMI and the rest of the constellation are typically in the 0.5-1.5 K range, but can in some cases be as large as 4 K. XCal developed updates to the calibration of TRMM TMI and GPM GMI will also be discussed.

Paper 4 GEOLOCATION RESULTS FOR THE SMAP PASSIVE INSTRUMENT

Giovanni de Amici, Goddard Space Flight Center, United States; Jeffrey Piepmeier, NASA Goddard Space Flight Center, United States; Jinzheng Peng, Morgan state university, United States; Priscilla Mohammed, NASA Goddard Space Flight Center, United States

We present an assessment of the accuracy of the geolocation of the SMAP (Soil Moisture Active and Passive) passive instrument, based on the first year of on-orbit operation.

The SMAP radiometer has an effective footprint of 39-by-47 km (HPBW) and a geolocation requirement of 4 km. The accuracy of the geolocation is determined from analysis of the temperature (both antenna and brightness) recorded by the radiometer, and correlation of any temperature change against geophysical features with high radiometric contrast (coastlines).

The analysis technique is not dissimilar from the one employed by heritage microwave instruments (e.g., SSMIS, WindSat), but the full-circular scan of the SMAP antenna allows the detection of coastline crossings which lay at any angle respect to the satellite ground track, thereby removing any bias potentially hidden in the choice of test areas and allowing the collection of statistically-significant numbers of samples (crossings) for each area of interest.

We conducted our analysis on regions which exhibit smooth uniform coastlines. Some of these regions had been exploited by heritage instruments (the eastern coast of Madagascar, the southern coast of Australia), some are newly analyzed here (the southern coast of West Africa, the coast of Angola, the western coast of Australia) and produce results of comparable quality. We also analyzed irregular coastlines like those of western Europe and obtained results consistent with the geolocation accuracy of more favourable landforms. Areas with large RFI (typically large seaside cities or military installations) were found to affect the geolocation results; fortunately those areas are self-evident in the antenna temperature data and missing (excised by the RFI filters) from the brightness temperature data.

Since the quantitative part of the analysis relays upon a fit to the (noisy) data, the presence of islands or inlets or large rivers/lakes near the ocean/landmass boundary produces spurious results. The performance of the algorithm was tested against noise-free simulated data and the parameters that define the fitting function were optimized. When noisy real data were used, the geolocation uncertainty changed only marginally (less than 20%) suggesting that the contributions to the overall pointing accuracy depends approximately in equal parts on the algorithm and on the instrument pointing.

There is no difference in the results obtained from the antenna and the brightness temperature data, confirming that the RFI filters applied to the data do not bias the perceived pointing of the instrument. We find that there is no consistent, repeatable bias in the geolocation of the footprints.

The pointing (knowledge and uncertainty) of the SMAP radiometer meets the mission requirements with good margin.

Paper 5 CALIBRATING GROUND-BASED MICROWAVE RADIOMETERS: ACCURACY AND REPETITION FREQUENCY

Nils Küchler, University of Cologne, Germany; David D. Turner, NOAA National Severe Storms Laboratory, United States; Ulrich Löhnert, Susanne Crewell, University of Cologne, Germany

Data of multi-frequency, ground-based microwave radiometers (MWR) has manifold applications in atmospheric research and has the potential to be assimilated into numerical weather prediction models. To provide reliable measurements, accurate calibrations are necessary. The calibration accuracy of MWRs has been discussed for several decades; however, the uncertainty estimates that have been given were based on comparisons to relative standards and therefore the absolute accuracy of MWR calibrations has not yet been assessed.

The Microwave Radiometer Calibration Experiment (MiRaCalE) was conducted to determine the accuracies and repetition frequencies two ``hot''.``cold'' calibration techniques for a fourth generation Humidity and Temperature Profiler (HATPRO) measuring between 20 and 60 GHz: (i) ``Liquid Nitrogen Calibrations'' (LN2cal) and (ii) ``Tipping Curve Calibrations'' (TCC). New quality thresholds for both calibration types were introduced and tested. It was shown that spectral inconsistent calibrations on the one hand affect multi-frequency retrievals of integrated water vapor and on the other hand can be used to determine biased calibrations. The calibration frequency depends on which system parameter is updated and on the receiver technology.

For the first time, the accuracy of TCCs was determined using a third absolute reference with a temperature of 77 K. It was found that TCCs are accurate within 0.5 K. After assessing the accuracy of TCC, the quality of LN2cals could be obtained by comparing both techniques. TCCs and LN2cals were found to agree within 0.5 K. Furthermore, these results indicate that the radiometric scene temperature of liquid nitrogen cooled blackbodies is accurate within the found uncertainties of 0.5 K, which is a significant reduction of the uncertainty estimates that have been assumed for the HATPRO.

Paper 6 ADVANTAGES OF CALIBRATION ATTITUDE MANEUVERS FOR SPACEBORNE MICROWAVE RADIOMETER MISSIONS

Spencer Farrar, Linwood Jones, University of Central Florida, United States; David Draper, Ball Aerospace & Technologies Corp., United States

Earth observing satellite microwave radiometers have been in use since the 1960's providing geoscientists invaluable insight into the complex interaction of the atmosphere, ocean and land in the climate of our planet. Such key instruments must be vetted of any calibration issues so as to provide the utmost accurate and stabilized dataset for scientific analysis. There are many post-launch calibration methods currently in use, but most require multiple ancillary data sets and a lengthy duration of on-orbit brightness temperature observations to obtain conclusive results. One on-orbit calibration method that can provide accurate & early results is the Calibration Attitude Maneuver (CAM). CAMs, which encompass Deep Space Calibration (DSC) and a recent use of the Second Stokes (SS) analysis, can provide early and much needed insight on the performance of the instrument. This paper describes the benefits of using DSC maneuver as well as a simplified use of the SS analysis method for satellite radiometric calibration.

There have been a handful of instruments that performed DSCMs over the years. Specifically, the first spaceborne radiometer to benefit from a DSCM was the Tropical Rainfall Measurement Mission (TRMM) Microwave Imager (TMI) in 1998. Also in October 16, 2002, during the Moderate Resolution Imaging Spectroradiometer (MODIS) lunar calibration maneuver, the Aqua spacecraft performed approximately a 20° roll which caused the angle between the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) main reflector boresight and tangent to the earth to be \sim 3°. Further, in 2003 the WindSat instrument on the Coriolis satellite performed a set of maneuvers over a 15 month period whereby the forward and aft-scanning beams viewed space. Not until March 2012 did another DSCM occur for the calibration of the Aquarius instrument. Finally, and the most recent, the Global Precipitation Measurement (GPM) Microwave Imager (GMI) performed a CAM during On-orbit checkout on May 2014. Of these maneuvers, only for the WindSat, Aquarius, and GMI instruments were there calibration plans set in place before launch to perform these maneuvers for microwave radiometer calibration purposes.

This paper will describe the CAM procedures and associated analysis procedures to derive certain calibration information. As an example, results will be presented for TMI and GMI using such CAMs. Finally, we will discuss the advantages of such maneuvers to be part of the on-orbit checkout and Cal/Val activities for any mission that wishes to obtain an early assessment of many calibration issues.

Paper 7 CALIBRATION OF THE ULTRA-WIDEBAND SOFTWARE DEFINED MICROWAVE RADIOMETER (UWBRAD) FOR ICE SHEET THERMOMETRY

Mark Andrews, Joel Johnson, Hongkun Li, Mustafa Aksoy, Kenneth Jezek, The Ohio State University, United States; Marco Brogioni, Giovanni Macelloni, "Nello Carrara" Institute of Applied Physics, Italy

The Ultra-wideband Software Defined Microwave Radiometer (UWBRAD) is currently being developed under the support of the NASA Instrument Incubator Program to provide measurements of ice sheet thermal emission over the frequency range 0.5-2 GHz. These measurements are being explored for their use in remotely sensing the internal temperature properties of the Greenland and Antarctic ice sheets.

UWBRAD is a "pseudo-correlation" radiometer design that includes a common 0.5-2 GHz front end used to create twelve 100 MHz channels with center frequencies ranging from 540 MHz to 1980 MHz. Each channel is fully digitized and processed in real time for identification and mitigation of radio frequency interference. The "pseudo-correlation" design of the RF front end was selected instead of a traditional Dicke switched design in order to eliminate the need for wideband isolator components. However, calibration of a "pseudo-correlation" design requires consideration of the multiple paths internal to the radiometer through which signals travel. The UWBRAD team is exploring multiple calibration methods for the system, identifying their relative advantages and challenges, and choosing the optimal calibration procedure for the UWBRAD instrument.

The complete 12 channel UWBRAD system is currently being constructed. A 4 channel test system (center frequencies 540, 900, 1380, and 1740 MHz) was completed in August 2015, and is to be deployed Nov-Dec 2015 on a tower at Concordia Base, Antarctica as part of IFAC-CNR's DOMEX program. Results from calibration experiments with the four channel system will be described in the presentation, as well as analyses of calibration processes for pseudo-correlation radiometers and the implications of these results for future UWBRAD measurements. Experiment results acquired in Antarctica will also be presented.

Paper 8 L-BAND RADIOMETERS INTER CALIBRATION OVER NATURAL TARGETS

François Cabot, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Eric Anterrieu, IRAP, France; Yann H. Kerr, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France

Since the launch of the SMOS mission in 2009, two other satellites carrying L-band radiometers joined it on orbit. Aquarius was launched in June 2011 and SMAP in January 2015. Unfortunately, Aquarius ceased operation later that year. All 3 instruments have been operating simultaneously between April and June 2015. Although this golden age of L-band on orbit radiometery was short lived, it allowed for sound comparison of the performances of these 3 radiometers. Moreover, its untimely termination emphasizes the need for reliable inter calibration to build long term consistent archives of brightness temperature and higher level products.

Still, since all these instruments do not share the same technology and even principle of acquisitions, direct comparison and synergistic use of their measurements is not straightforward.

The objective of this paper is to demonstrate a set of methods to make them inter-comparable, down to a common reference. Instead of a ground reference, we use here SMOS as a transfer radiometer.

This method can be applied over different types of surfaces: i) making use of a stable target to assess the consistency and stability of both data sets. This is done over the area surrounding Dome Concordia in Antarctica. After careful selection and filtering, statistics of the comparison are retrieved along with long term trends in both data sets. ii) Once every so often, satellites overpass the same area within a very short time period. Due to different orbit inclinations these alignments occur essentially along the equator, but over different surfaces, giving access to wide dynamic range in brightness temperature. iii) At last, all radiometers are aimed at the deep sky for calibration purposes. But despite this use of a common reference, it can be shown that the retrieved brightness temperature exhibit some differences, traceable to the differences in calibration strategies and acquisition principles.

This presentation will briefly describe the already established methods, along with a full record of results over the lifetimes of SMOS, SMAP and Aquarius. A more general conclusion on common use of these data sets will also be given.

Session Co-Chairs: Rajat Bindlish, UDSA ARS HRSL; Kimmo Rautiainen, Finnish Meteorological Institute

Paper 1 GLOBAL SURFACE EFFECTS ESTIMATED BY THE L-BAND SMOS SATELLITE

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The Soil Moisture and Ocean Salinity (SMOS) mission is the first satellite dedicated to providing global surface soil moisture (SM). SMOS operates at L-band (1.4 GHz) and at this frequency, the signal depends on soil moisture and vegetation optical depth but it is also significantly affected by surface effects and in particular by the soil roughness. However, when dense vegetation is present, the L-band signal is poorly sensitive to the soil effects. First, by using multiple regressions between soil moisture (SM) and brightness temperature (TB) at different incidence angles and polarizations. SMOS sensitivity to the soil effects are evaluated. A global-scale map of SMOS sensitivity to the soil effects is computed and shows that for 87\% of the land surfaces, the SMOS observations are sensitive to the soil effects, while a very low sensitivity to the soil effects was estimated over \sim 13% of the land surfaces. For instance, over broadleaf evergreen forest (essentially the Amazon and Congo forest), SMOS is sensitive to the soil effects for only half of the pixels considered. In a second step, in L-MEB (L-band Microwave Emission of the Biosphere), the forward emission model of the SMOS algorithm, the vegetation and roughness effects were combined in only one parameter referred to as TR in this study. By inverting L-MEB, SM and TR were retrieved at global scale from the SMOS Level 3 (L3) TB observations during 2011. Assuming a linear relationship between TR and LAI obtained by the MODIS data, the effects of roughness and vegetation were decoupled and a global map of soil roughness effects (Hr) was estimated. It was found that the spatial pattern of the Hr values can be associated to the main vegetation types. Higher values of roughness (Hr=0.37-0.41) were obtained for forests (broadleaf evergreen, deciduous and mixed coniferous) while the lower values (Hr=0.15-0.17) were obtained for deserts, shrubs and bare soil. Intermediate values (Hr=0.15-0.20) were obtained over grasslands, tundra and cultivations Over vegetation biomes composed by forests and wooded grasslands, Hr values are mainly correlated to the vegetation density (R ~ 0.55). For deserts, shrubs and bare soil, the Hr values were mainly correlated to the topography slopes (R ~ 0.53). The alobal maps presented in this study, could lead to improved retrievals of soil moisture and vegetation optical depth for present, such as SMOS and the Soil Moisture Active Passive (SMAP), and future microwave remote sensing missions .

Paper 2 ADAPTATION OF THE SMOS SOIL MOISTURE RETRIEVAL ALGORITHM FOR ORGANIC-RICH SOILS AND ITS VALIDATION OVER VARIOUS NORTHERN SITES

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From the passive L-band microwave radiometer onboard the Soil Moisture and Ocean Salinity (SMOS) space mission global surface soil moisture data is retrieved every 3 days. Thus far, the empirical L-band Microwave Emission of the Biosphere (LMEB) radiative transfer model applied in the SMOS soil moisture retrieval algorithm is exclusively calibrated over test sites in dry and temperate climate zones and the included dielectric mixing model relating soil moisture to permittivity accounts only for mineral soils. However, soil moisture monitoring over the higher northern latitudes is crucial since these regions are especially sensitive to climate change and a considerable feedback is expected due to carbon liberated from thawing ground of these extremely organic soils. Due to differing structural characteristics and thus varying bound water fractions, the permittivity of organic material is lower than the one of most mineral soils at a given water content. This assumption was verified by means of measurements in organic and mineral substrates from various sites in Denmark. Finland, Scotland and Siberia, For this purpose, conventional soil moisture sensors were used as well as weak perturbation and waveguide techniques in order to infer effective soil permittivity at the microwave L-band (1-2 GHz). Based on these data, a generic L-band soil moisture – permittivity relation for organic soils was derived and validated with dielectric mixing model runs as well as literature data. Furthermore, the derived function was tested in the L-MEB model. Results showed that modeled data agreed with measurements from a tower-based passive L-band microwave radiometer observing organic-rich soil over a 2 months period in a highly controlled set-up. The generic «organic» empirical model was then implemented in the SMOS Prototype Algorithm to retrieve soil moisture over a site in Northern Finland. The validation with in situ soil moisture observations calibrated for organic soils showed a distinct improvement in the agreement between the satellite and ground datasets when using the «organic» instead of the operational SMOS processor version. This analysis is to be continued in more detail and the validation effort needs to be expanded over as many regions with abundant soil organic matter content as possible. Appropriate in situ observations are currently available from various sites in Alaska, Canada, and the Netherlands. In this communication, first the derivation of the generic L-band «organic» soil moisture-permittivity model will be presented. Focus will then be on the comparison of «organic» SMOS soil moisture retrievals with corresponding operational SMOS products as well as in situ observations over all available sites.

Paper 3 L TO X BAND RADIOMETER MEASUREMENTS OF FOREST COVERED SOILS OVER AURAJOKI CATCHMENT AREA

Jaakko Seppänen, Matti Vaaja, Jaan Praks, Martti Hallikainen, Aalto University, Finland

Radiometry at 1.4 GHz is a prominent technology for detecting soil surface moisture, employed currently in two satellite missions, Soil Moisture and Ocean Salinity (SMOS) of European Space Agency (ESA)[1] and Soil Moisture Active and Passive (SMAP) of National Aeronautics and Space Administration (NASA) [2]. 1.4 GHz radiometer is capable of detecting changes in soil moisture under moderate vegetation canopies, making it more favorable compared to higher frequencies which do not penetrate vegetation as well.

Accuracy of retrieved soil moisture is usually lower in areas where several land cover types exist within a radiometer pixel (mixed pixel problem). Moreover, for forested areas, complex interactions in the vegetation pose a major challenge for emission models and soil moisture retrieval [3]. This is a major concern in boreal region, where vegetation cover dominates landscapes. Current

algorithms try to overcome the problem using leaf area index (LAI) to describe the canopy [4]. While LAI is a good measure for total biomass for grasses and crops, it is recognized, that at L-band the contribution of a forest canopy is mainly due branches

and secondarily stems, while leaves are mostly transparent [5]. Therefore a method to account for branch water content and orientation could improve the forest emission models and enable more accurate moisture retrieval from forested areas.

In this study we concentrate on assessing the influence of different vegetation covers and soil types to total emission. We have measured a forest area with two instruments: The interferometric radiometer HUT2D [6] and multi-frequency radiometer system HUTRAD. HUT2D is a 1.4 GHz airborne interferometric radiometer, designed for use in soil moisture and ocean salinity research. HUTRAD is a multi-frequency radiometer system operating at 6.8, 10.7, 18.7, 24, 36 and 94 GHz [7]. Both instruments have been designed and built in Aalto University (then Helsinki University of Technology). They can be operated simultaneuously aboard the Short Skyvan research aircraft and have been previously used in this manner for multi-frequency measurements of lake ice [7].

In this paper three frequency bands are considered, namely 1.4 GHz, 6.8 GHz and 10.7 GHz. In our results all three frequencies showed responsiveness to soil moisture, but at higher frequencies even moderate vegetation cover appeared opaque, completely covering the soil. X-band shows least reponse to changes in biomass, while at L-band the soil moisture affects measurements even under a forest canopy, and measured brightness temperature is corresponds to combined effect of canopy and soil. At C-band and X-bands measured brightness temperature shows different response to forest canopy at at H- and V-polarizations. We suggest that these differences may be related to canopy structure, encouraging further research of combining L-band radiometry to higher frequency data.

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Paper 4 SOIL MOISTURE IN FRENCH ALPINE VALLEY USING L-BAND RADIOMETER

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Since the beginning of SMOS (Soil Moisture and Ocean Salinity) activities, field campaigns have been of great importance to calibrate the model and validate the SMOS derived soil moisture.

Many sites have been equipped with soil moisture probes and even with L-Band radiometer like Smosrex in France, Vas in the Valencia region, Jülich in Germany, Sodankyla in Finland. In these cases, the L-band radiometers have been placed on structures about 10 meters above ground level, observing a unique surface, i.e. one type of vegetation cover, whereas the SMOS instrument characterized by a radiometric resolution of ~40km is observing a mix of different landscapes.

Keeping this issue in mind, a new experimental site is proposed here with the main objective to observe complex scenes (similar to SMOS instrument) and to test and improve SMOS soil moisture retrieval. The LEWIS (L-Band radiometer for Estimating Water in Soil) radiometer has been placed by a cliff in St Hilaire du Touvet, in the French Alps near Grenoble since May 2014. Its position allows us to monitor a flat valley 800 meters below. With a beamwidth of 13.6°, the observed areas are about 300-500 meters wide. The instrument - equipped with 2 motors - moves in two directions (azimuth and elevation) monitoring continuously various targets composed with agricultural fields, forest and the Montfort marshes.

In addition, soil moisture and temperatures probes (theta probes and Cosmos) are placed in 3 locations in the valley, and a pyrometer is installed with the radiometer to measure the skin temperature of the observed scenes.

The aim of this communication is to present its setting and the first results of a long continuous time series of soil moisture and L-band brightness temperatures.

Paper 5 VEGETATION OPTICAL DEPTH AND SCATTERING ALBEDO RETRIEVAL USING TIME SERIES OF DUAL-POLARIZED L-BAND RADIOMETER OBSERVATIONS

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Passive microwave measurements have the potential to estimate vegetation optical depth (VOD), an indicator of aboveground vegetation water content. They are also sensitive to the vegetation scattering albedo and soil moisture. In this work, we propose a novel algorithm to retrieve VOD and soil moisture from timeseries of dualpolarized L-band radiometric observations along with time-invariant scattering albedo. The method takes advantage of the relatively slow temporal dynamics of early morning vegetation water content and combines a number of consecutive observations to estimate a single VOD. It is termed the multi-temporal dual channel algorithm (MT-DCA). The soil dielectric constant (directly related to soil moisture) of each observation is also retrieved simultaneously. Additionally, the method retrieves a constant albedo, thereby providing for the first time information on global single-scattering albedo variations. The algorithm is tested using three years of L-band passive observations from the NASA Aquarius sensor. The global VOD distribution follows expected gradients of climate and canopy biomass conditions. Its seasonal dynamics follow expected behavior based on precipitation and land cover. The retrieved VOD is closely related to coincident cross-polarized backscatter coefficients. The VOD and dielectric retrievals from MT-DCA are also compared to those obtained from implementing the commonly used Land Parameter Retrieval Model (LPRM) algorithm and shown to have less high-frequency noise. There is almost as much variation in MT-DCA retrieved albedo between pixels of a given land cover class than between land cover classes, suggesting the common approach of assigning albedo based on land cover class may not capture its spatial variability. Globally, albedo appears to be primarily sensitive to woody biomass. The proposed algorithm allows for a more accurate accounting of the effects of vegetation on radiometric soil moisture retrievals, and generates new observations of L-band VOD and effective single-scattering albedo. These new datasets are complementary to existing remotely sensed vegetation measurements such as fluorescence and optical-infrared indices.

Paper 6 SMOS OPTICAL THICKNESS CHANGES IN RESPONSE TO THE GROWTH AND DEVELOPMENT OF CROPS, CROP MANAGEMENT, AND WEATHER

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The SMOS retrieval algorithm uses observed L-band brightness temperature to produce estimates of both soil moisture and τ , the optical thickness of the land surface. It has been shown that τ is directly proportional to the water column density of vegetation. However, it has been difficult to explain the magnitude and temporal variation of SMOS τ . For example, Jackson et al. (2012) examined τ in the Little Washita watershed, an area of mainly rangeland in the state of Oklahoma, and found no seasonal pattern. SMOS τ is expected to mirror the growth and senescence of vegetation, especially in agricultural regions. Wigneron et al. (2012) investigated SMOS τ in Spain at the Valencia Anchor Station, a site consisting of mostly vineyards, orchards, shrubs, and scattered pine trees, and found higher values in the winter than in the summer. Schlenz et al. (2012) evaluated SMOS τ in an agricultural area in southern Germany. They found τ to be highly variable and to not exhibit a clear seasonal pattern. In addition the average value of τ was higher than expected and correlated with SMOS retrieved soil moisture. Bircher et al. (2013) examined SMOS τ in an agricultural watershed in western Denmark and found it to be noisy and too high on average. The expected seasonal trend of increasing τ during the summer season was faint. Recently Lawrence et al. (2014) studied the behavior of SMOS τ in argricultural regions of the U.S. Midwest and found that MODIS NDVI, EVI, and NDWI reached saturation points during the growing season (values plateaued and did not increase further) but τ did not.

We have found that when the noise in the SMOS τ product is removed, τ in the U.S. Corn Belt has a distinct shape that mirrors the growth and development of crops. Corn (maize) is the dominant crop of this region and also contributes the most to growing season changes in τ . We have also found that corn reaches its maximum water column density at approximately 1000 °C day (base 10 °C) growing degree days after planting, during its third reproductive stage of development. Since τ is directly proportional to water column density, we used this finding, along with United States Department of Agriculture crop progress reports, to explain the timing of the peak in τ and its variation over a four-year period for five SMOS pixels in the state of Iowa. In addition, we hypothesized that the magnitude of the change in SMOS τ over the growing season would be related to the amount of accumulated solar radiation, but found this not to be the case. On the other hand, the magnitude of the change in τ over the growing season was smallest for the year in which the most precipitation fell. This could be due to the fact that the SMOS τ product is actually a function of both vegetation and soil surface roughness (Patton and Hornbuckle, 2013), and soil surface roughness may have been reduced the most during this wet year. To fully explain the magnitude of SMOS τ in the Corn Belt, it will be necessary to use agro-ecosystem models that account for all of the relevant biophysical processes that could effect the growth and development of crops and changes in soil surface roughness.

Wednesday, April 13	RFI and Spectrum Management	14:40 - 16:00
Poster Session		Outside Hall B

Session Co-Chairs: Priscilla Mohammed, NASA Goddard Space Flight Center; Jorge Querol, Universitat Politècnica de Catalunya

Paper 1 PERFORMANCE ANALYSIS OF A HARDWARE IMPLEMENTED COMPLEX SIGNAL KURTOSIS RADIO-FREQUENCY INTERFERENCE DETECTOR

Adam Schoenwald, Damon Bradley, Priscilla Mohammed, Jeffrey Piepmeier, Mark Wong, NASA Goddard Space Flight Center, United States

Radio-frequency interference (RFI) is a known problem for passive remote sensing as evidenced in the L-band radiometers SMOS, Aquarius and more recently, SMAP [1, 2]. Various algorithms have been developed and implemented on SMAP to improve science measurements. This was achieved by the use of a digital microwave radiometer [2]. RFI mitigation becomes more challenging for microwave radiometers operating at higher frequencies in shared allocations. At higher frequencies larger bandwidths are also desirable for lower measurement noise further adding to processing challenges. This work focuses on finding improved RFI mitigation techniques that will be effective at additional frequencies and at higher bandwidths.

To aid the development and testing of applicable detection and mitigation techniques, a wide-band RFI algorithm testing environment has been developed using the Reconfigurable Open Architecture Computing Hardware System (ROACH) built by the Collaboration for Astronomy Signal Processing and Electronics Research (CASPER) Group. The testing environment also consists of various test equipment used to reproduce typical signals that a radiometer may see including those with and without RFI. The testing environment permits quick evaluations of RFI mitigation algorithms as well as show that they are implementable in hardware.

The algorithm implemented is a complex signal kurtosis detector which was modeled and simulated. The complex signal kurtosis detector showed improved performance over the real kurtosis detector under certain conditions [3]. The real kurtosis is implemented on SMAP at 24 MHz bandwidth. The complex signal kurtosis algorithm was then implemented in hardware at 200 MHz bandwidth using the ROACH. In this work, performance of the complex signal kurtosis and the real signal kurtosis are compared. Performance evaluations and comparisons in both simulation as well as experimental hardware implementations were done with the use of receiver operating characteristic (ROC) curves. The complex kurtosis algorithm has the potential to reduce data rate due to onboard processing in addition to improving RFI detection performance.

References:

[1] R. Oliva, E. Daganzo, Y. H. Kerr, S. Mecklenburg, S. Nieto, P. Richaume, and C. Gruhier, "SMOS RFI scenario: Status and actions taken to improve the RFI environment in the 1400-1427 MHz passive band," IEEE Trans. Geosci. Remote Sens., vol. 50, no. 5, pp. 1427–1440, May 2012.

[2] J. R. Piepmeier, J. T. Johnson, P. N. Mohammed, D. Bradley, C. Ruf, M. Aksoy, R. Garcia, D. Hudson, L. Miles, and M. Wong, "Radio-Frequency Interference Mitigation for the Soil Moisture Active Passive Microwave Radiometer," IEEE Trans. Geosci. Remote Sens., vol. 42, no. 1, pp. 761-775, Jan. 2014. [3] Bradley, D.; Morris, J.M.; Adali, T.; Johnson, J.T.; Aksoy, M., "On the detection of RFI using the complex signal kurtosis in microwave radiometry," in Microwave Radiometry and Remote Sensing of the Environment (MicroRad), 2014 13th Specialist Meeting on , vol., no., pp.33-38, 24-27 March 2014.

Paper 2 CORRUPTION OF THE TRMM MICROWAVE IMAGER COLD SKY MIRROR DUE TO RFI

Spencer Farrar, Linwood Jones, University of Central Florida, United States

The Tropical Rainfall Measuring Mission (TRMM) has far exceeded its three year mission providing invaluable Earth observations for over 17 years. Over its lifetime TRMM has performed multiple calibration attitude maneuvers (CAMs) to vent any possible issues for the onboard instruments. Specifically, the TRMM Microwave Imager (TMI) utilized these maneuvers and it wasn't until the July 2014 CAMs whereby the reconstruction of the radiometric transfer function revealed that there were anomalies in the cold sky mirror (CSM) view during nominal operation (Earth Observing Mode). After further investigation into these anomalies it became apparent that these occurrences existed over specific areas of the Earth and orientation of the TRMM spacecraft. This paper describes how this anomaly was realized, the speculated cause and justification, how it has changed over a large portion of the mission, and how to correct for it for TMI's final processing (Archive/Legacy of the NASA TMI 1B11 brightness temperature data product).

On July 22, 2014 TRMM performed 3 DSCMs at a Yaw of 0°. These maneuvers were for the sole purpose of calibrating TMI years after the 1998 maneuvers, i.e., to provide insight on whether there was any degradation of the instrument over the years. Within a week of the maneuvers the radiometric reconstruction methods were used so to reconstruct radiometric antenna temperature (TA) since the radiometric transfer function was invalid due to the CSM view intersecting the Earth during the CAM. During validation of the reconstruction method which compared the reconstructed TA to the TMI calibrated TA during TRMM's nominal mode (Earth Observing Mode) it became apparent that during certain portions of the orbit the residuals between the two TAs were curiously higher than expected. After further investigation it was determined that the disagreement was due to the sudden jumps and variation in the cold sky counts. The effects of these jumps on the calibration transfer function is an additive bias only in the cold sky counts and since the CSR is viewing the Cosmic Microwave Background, an unpolarized homogenous scene, which at 19.35 is 2.73 K, there should be very low variation for all CSM view angles.

A simple threshold on the standard deviation (sd) of the CSM counts for each scan over a large portion of the mission was implemented so to flag these occurrence and determine the duration of these effects. After geolocating TRMM's sub satellite point for every sd threshold met a pattern over the Earth became apparent, i.e., intensity of the sd had a maximum and would trail off the maximum in all directions. This is indicative of a geostationary satellite illuminating the Earth and in conjunction of the fact that the cold sky beam illuminates the geostationary belt for a certain pass and yaw maneuver infers that RFI from geostationary satellites is the cause. In fact, only for certain frequencies and locations of the Earth are these thresholds exceeded and repeated.

This paper describes how RFI from Geostationary satellites has influenced the TMI calibration and how it has changed over the mission. A correction for this anomaly has been developed by the Central Florida Remote Sensing Lab (CFRSL) and delivered to the NASA Precipitation Processing System for TMI's final processing (Archive/ Legacy of the NASA TMI 1B11 brightness temperature data product).

Paper 3 NANOSATELLITE BASED RADIO FREQUENCY INTERFERENCE MAPPING

Jaan Praks, Jaakko Seppänen, Martti Hallikainen, Aalto University, Finland; Janne Lahtinen, Harp Technologies Ltd, Finland

The available radio frequency spectrum is a natural resource which is exploited more intensively in the future. Microwave spectrum utilization will increase which brings unwanted sources also to protected frequency areas which makes utilization the spectrum for passive microwave remote sensing more difficult. Currently our knowledge on spectrum usage or interference on global level has large gaps which makes microwave Earth Observation mission planning more challenging. In order to avoid potentially very costly mistakes, the global spectrum usage should be mapped in order to take possible Radio Frequency Interference into account in early planning phase of microwave missions. For this, the global RFI statistics and preferably global maps are required.

In this study we have evaluated the feasibility of popular CubeSat platform for measuring RFI at most used Earth Observation frequencies. A CubeSat can provide a cost-effective platform for quick development of short precursor or technology demonstration missions in LEO orbit. However, the size limitations of the platform restricts the applicable frequency range, radiometric accuracy and spatial resolution. In this work we present trade-off calculations to identify the limiting constraints and frequency ranges where RFI can cause problems for future missions and point to the possible technological solutions such as advances in antenna technology and attitude control of the satellite. We also provide a cost estimates for required single satellite or swarm missions.

Wednesday, April 13	Soil Moisture and Vegetation II	14:40 - 16:00
Poster Session		Outside Hall B

Session Co-Chairs: Jaakko Seppänen, Aalto University; Simone Bircher, CESBIO

Paper 1 VEGETATION OPACITY RETRIEVALS USING SMAP OBSERVATIONS

Rajat Bindlish, USDA ARS Hydrology and Remote Sensing Laboratory, United States; Steven Chan, NASA Jet Propulsion Laboratory, CalTech, United States; Thomas Jackson, USDA ARS Hydrology and Remote Sensing Laboratory, United States; Eni Njoku, NASA Jet Propulsion Laboratory, CalTech, United States; Peggy E. O'Neill, NASA Goddard Space Flight Center, United States; Andreas Colliander, NASA Jet Propulsion Laboratory, CalTech, United States

The Soil Moisture Active Passive (SMAP) mission was launched on Jan 31, 2015. SMAP includes a polarimetric L-band radiometer with a resolution of ~40 km. The objectives of the SMAP (Soil Moisture Active Passive) mission include global measurements of soil moisture with global coverage every 2-3 days.

The SMAP Level 2 radiometer soil moisture (L2SMP) product uses brightness temperature observations along with a number of ancillary data variables to retrieve surface soil moisture. Several algorithms are being considered for the SMAP radiometer-only soil moisture retrieval. These algorithms differ in their inputs and ancillary data variables used in the retrieval process. The single channel algorithms (V- or H-pol) use ancillary data to correct for the effect of vegetation in estimating soil moisture. The multi-channel algorithms use the horizontal and vertical polarization observations to solve for soil moisture and vegetation opacity. All of these algorithms are based on the same zero-order radiative transfer model (commonly known as the tau-omega model).

This presentation will focus on the vegetation opacity used in (single channel)/retrieved (multi-channel) during the generation of the SMAP L2SMP soil moisture product. Differences in input (or estimated) vegetation opacity will result in significant differences in soil moisture retrievals from different algorithms. Underestimation of vegetation opacity will result in underestimation of soil moisture and vice versa. Differences between estimated and climatological optical depth will be investigated. The vegetation opacity retrievals over core validation sites will be evaluated using MODIS VIS/IR and phenological observations at the in situ locations. The global patterns of the vegetation opacity retrievals will be assessed using real-time MODIS observations and SMOS optical depth retrievals. This work will help in the development of the SMAP L2SMP product.

Paper 2 SMOS LEVEL 3 SOIL MOISTURE DATABASE

Arnaud Mialon, Ahmad Al Bitar, François Cabot, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Stéphane Tarot, IFREMER, France; Thierry Pellarin, LTHE, France; Philippe Richaume, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Olivier Vandermarcq, CNES, France; Jean-Pierre Wigneron, INRA, France; Yann H. Kerr, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France

SMOS has been delivering data since January 2010. Three ground segments have been developed among which the CATDS (Centre Aval de Traitements des Données SMOS) by the French space agency CNES [2]. This ground segment is providing the users with level 3 data that are a bit different from ESA level 1 and level 2 as these products : i) are temporally aggregated as daily, during 3-day and 10-day time window and monthly averages ii) are projected on the EASE Grid version 2 iii) using the netcdf format iv) are derived using a modified algorithm taking advantage of 3 consecutive SMOS overpasses [4] v) brightness temperatures are averaged by bin of incidence angles in the Earth reference frame, i.e. H and V polarizations.

Since the beginning of the mission the algorithm to derive the SMOS data has evolved due to improvements of the models and also due to better quality SMOS brightness temperatures. A reprocessing campaign has been done in fall 2015 to deliver the entire time series (2010-spring 2015) using the latest versions of the processors and with a more accurate brightness temperatures (improved bias reconstruction).

The data are available on line (http://www.catds.fr/sipad/startPage.do) through the SIPAD (Système d'Information, de Préservation et d'Accès aux Données) which is a user-friendly dissemination service that allows the users to download their own products according to their criteria (as area of interest, period of time, subset of fields...).

The aim of this communication is then to present the last updates and version of the products delivered by the CATDS that is the Version 3. Derived soil moisture values are validated by comparing to SMOS level 2 and in situ measurements acquired at various climate conditions.

Paper 3 A MICROWAVE SCINTILLOMETER TO ENABLE SIMULTANEOUS OBSERVATIONS OF PATH-INTEGRATED SENSIBLE AND LATENT HEAT FLUXES

Gerrit Maschwitz, Martin Philipp, Thomas Rose, Radiometer Physics GmbH, Germany

Vertical heat fluxes within the atmospheric surface layer are dominated by a diffusive turbulent flow, which is induced by wind friction and radiative heating/cooling. The turbulent fluxes transport energy in form of temperature - corresponding to the sensible heat flux H and in form of humidity - corresponding to the latent heat flux (or evapotranspiration) LvE.

The use of scintillometry to observe heat fluxes is a well-established technique. Optical scintillometers, operating in the infrared, are commercially available for many years now. When observing at optical wave lengths, the scintillation signal is dominated by temperature fluctuations along the path. These fluctuations can be related to the sensible heat flux. H. However, a second observation frequency in the microwave spectral region is needed to measure both, the sensible and the latent heat fluxes. The theoretical concept of dual-wavelength scintillometry had been introduced in the 1980's. Different microwave scintillometers were built since then, but the state of the microwave technique was not reliable enough.

Therefore, Radiometer Physics GmbH (RPG) - in co-operation with the Wageningen University - has developed a microwave scintillometer. The instrument is a transmit / receive system operating at 160.8 GHz. The RPG-MWSC-160 has been optimized in terms of size, weight and power consumption to provide high flexibility in the field. Combined with a small beam of 0.4° (HPBW), long measurement paths of up to 10 km are covered. The microwave scintillometer is operated in combination with an optical Large Aperture Scintillometer (LAS). The microwave receiver unit reads the analogue signal from the connected LAS. Both scintillation signals are synchronously recorded and digitized at a sampling rate of 1 kHz. Synchronous recording is essential, because not only the signal variances at each wave length are calculated: The covariance between the two signals gives a third measurement variable, which allows for an independent calculation of sensible and latent heat fluxes - without additional assumptions on the correlation between the two signals.

The combined system yields sensible- and latent heat flux observations at a kilometer-scale. Extending the observations to the evapotranspiration LvE opens a field of applications including the management of irrigation and water resources, forest fire warning systems, as well as providing ground-truth turbulent fluxes for meteorological and hydrological models. The authors will give an introduction on the technical design of the microwave scintillometer and will present heat flux observations derived from a combined optical/microwave scintillometer system.

Paper 4 EVALUATION OF MODELED HIGH RESOLUTION SOIL MOISTURE VIRTUAL BRIGHTNESS TEMPERATURES COMPARED TO SPACE-BORNE OBSERVATIONS

Pablo Saavedra, Clemens Simmer, Bern Schalge, University of Bonn, Germany

A multidisciplinary research unit has been established in order to develop and improve data assimilation schemes for coupled subsurface-land surface-atmosphere systems (SLASs), namely the coupled suit of models TerrSysMP comprised by ParFlow-CLM-COSMO framework. The framework aims to test how different kinds of observations and networks of observations can improve system state estimations and depictions with a focus on inter-compartmental fluxes of mater and heat energy. To that goal a simulated virtual reality (VR) catchment is being developed by the research unit as a tool to test data assimilation schemes for coupled SLAS models. The virtual reality becomes a convenient tool since it overcome the problem of data scarcity for the different components as subsurface, soil and atmosphere.

The first version of the VR couples the COSMO atmospheric model an the Community Land Model (CLM) to generate virtual observations such as satellite measurements, radar observations and meteorological station data. Currently VR simulations for the Neckar catchment located at south-west Germany, named domain 4 (D4), is available with 1.1km resolution and for the period from 2007 to 2013.

The present contribution is focused on satellite observations of the microwave emission of soil moisture at L-band, mainly concentrated on missions like SMOS and SMAP.

Using the Community Microwave Emission Model (CMEM) as a forward operator, a first set of virtual passive microwave observations (VO) from the virtual reality D4 domain is generated. Different satellite observations (a like SMOS and SMAP) are simulated taking into account features as antenna pattern, revisit times, and angular viewing geometry. The virtual observations are statistically evaluated with available real observations to assess systematic differences between TerrSysMP model and reality. Deficiencies in the forward operator over specific areas as well as down-scaling effects will be discussed in order to evaluate future data assimilation schemes.

Paper 5 AN ASSESSMENT OF SMOS VERSION 6.20 PRODUCTS COMPARED TO ASCAT, ERA-INTERIM LAND AND ISMN SOIL MOISTURE DATA USING THE QUADRUPLE COLLOCATION (QC) TECHNIQUE

Fabio Fascetti, Nazzareno Pierdicca, La Sapienza University of Rome, Italy; Luca Pulvirenti, CIMA Research Foundation, Italy; Raffaele Crapolicchio, Serco SpA, Italy; Joaquin Muñoz-Sabater, ECMWF, United Kingdom

A comparison study has been performed between two remotely sensed surface soil moisture datasets: one from the L-band Soil Moisture and Ocean Salinity (SMOS) radiometer (available through an ESA Category 1 project) and one from the C-band Advanced Scatterometer ASCAT onboard METOP (available through the EUMETSAT H-SAF project). The satellite retrievals have been compared to the modeled ERA-Interim Land soil moisture datasets and to the ground measurements of moisture gauges, belonging to the International Soil Moisture Network (ISMN).

The data acquired during years from 2010 to 2012 have been considered. The SMOS-derived soil moisture content (SMC), produced by the processors (new version 6.20), will be used. As for ASCAT-derived SMC, since each data represents a soil moisture relative index between 0 and 100% (i.e., driest and wettest conditions), the ASCAT retrievals have been converted into volumetric soil moisture by specific strategies to obtain a reasonable comparison. The datasets have been collocated in time in order to minimize the temporal mismatch, while the nearest neighbor has been used for the space collocation; the in-situ probe has been up-scaled to the satellite resolution through averaging of the station measurements within the satellite field of view.

Then, the retrievals have been compared using the Quadruple Collocation (QC) technique [1]. Such method is useful to evaluate unambiguous estimates of the error standard deviation of four systems in a same reference scale. As QC require a constant mean of the considered quantity (i.e., stationarity), the mean spatial pattern was estimated by averaging the SMC maps over time and removed. On the other side, two approaches was adopted for the seasonal variability of the soil moisture. The first one considers it as a temporal drift to be removed (i.e., looking just at the anomalies of soil moisture), while the second approach assumes the seasonal variability as part of the random variability which is retained in the data. The latter assumption can be done since the period of analysis covers almost three years of data.

Then, assuming uncorrelated noise with zero mean, the QC technique was implemented and the noise variances of the products will be estimated. In order to also point out the difference due to the processor version, the results will be also compared with those already obtained considering for the same analysis the SMOS data produced by the processor version 5.51 [1]. In this latter work, ERA-Interim Land showed the lower error standard deviation in the overall dynamic range or anomalies analysis, while the in-situ data, up-scaled at the satellite resolution, did not present a very good performances, which remained stable for both the cases. Such effect can be addressed to the fact that the we did not consider single soil moisture probes, but we evaluated the capability of a point wise measurement to reproduce the average soil moisture within an area equal to the field of view of the satellite sensors. Nevertheless, ground probes remain the only reliable source of point measurements. As for the satellite products, SMOS presented a better behavior when the whole variability of the soil moisture has been considered, but ASCAT performed better in looking the temporal anomalies.

[1] Pierdicca, N., Fascetti, F., Pulvirenti, L., Crapolicchio, R., Munoz-Sabater, J., Quadruple Collocation Analysis for Soil Moisture Product Assessment, 2015, IEEE Geoscience and Remote Sensing Letters, vol. 12, issue 8, pp.1595-1599, doi:10.1109/LGRS.2015.2414654.

Wednesday, April 13	Snow and Antarctica	14:40 - 16:00
Poster Session		Outside Hall B

Session Co-Chairs: Alain Royer, University of Sherbrooke; Anna Kontu, Finnish Meteorological Institute

Paper 1 DIURNAL VARIATION OF BRIGHTNESS TEMPERATURE OF TERRESTRIAL SNOW DURING SNOWMELT

Martti Hallikainen, Aalto University, Finland; Juha Lemmetyinen, Finnish Meteorological Institute, Finland

Space-borne microwave remote sensing has been widely demonstrated to provide information about the terrestrial snow cover and it is used in several countries to monitor characteristics of seasonal dry snow cover: snow extent, water equivalent, depth and, additionally, snowmelt. This information is useful for hydrological applications including hydropower production and water supplies for communities and agriculture, and for studies of climate change. Microwave radiometry provides information on dry snow due to volume scattering of microwave emission in snow: the brightness temperature decreases with increasing snow water equivalent and grain size. For wet snow, absorption dominates over scattering and obtaining any information in addition to snow wetness is not easy. Especially during the snowmelt period, both dry and wet snow layers may be present in the snowpack resulting in large variations in the brightness temperature, thus complicating retrieval of snow parameters from radiometer data.

We compared theoretical 37 GHz brightness temperatures (incidence angle 50 degrees off nadir) to experimental time series data obtained over a 24-hr period in an extensive ground-based experiment in Southern Finland. During the 24-hr monitoring effort, the snowpack included (top layer mentioned first) dry/wet snow, wet/ dry/wet snow, dry/wet/dry/wet snow, and, again, dry/wet snow, with each layer thickness varying considerably with time.

In our simulations we used detailed information collected during the experiment including water equivalent, depth, temperature, layering, and surface roughness and grain size (photographs) of the snow layers. Snow samples were taken from various depths in the snowpack and measured using free-space transmission systems operating at 12 GHz, 35 GHz and, occasionally, 18 GHz. These results were further transformed into extinction coefficients (dry snow) and wetness values (wet snow).

The HUT snow emission model was recently adapted for multiple layers and it was used in our simulations. Comparison of simulated vs. experimental results shows that the HUT model is capable of simulating with reasonable accuracy the basic behavior of the experimental 37-GHz brightness temperatures under varying snow wetness conditions vs. time. However, observed extinction and wetness values of the snow layers had to be slightly modified in order to obtain satisfactory agreement. This is very likely due to, in addition to possible inaccuracies in ground truth, sensitivity of the model to these parameters.

Paper 2 MODELING SMOS SPATIAL VARIATION IN THE EAST ANTARCTIC PLATEAU

Giovanni Macelloni, Institute of Applied Physics - National Research Council (IFAC - CNR), Italy; Marion Leduc-Leballeur, LGGE, France; Marco Brogioni, Institute of Applied Physics - National Research Council (IFAC - CNR), Italy; Catherine Ritz, Ghislain Picard, LGGE, France

The SMOS brightness temperature collected on the East Antarctic Plateau revealed spatial signatures at L-band that have never been observed with higher frequencies passive microwave sensors, opening a new field of research. In particular in the inner part of the East Antarctic Plateau, which shows lowest TB values with respect to the coast area, and a very small multi-annual variation (i.e. < 2 K) over a large region (from 73°S to 83°S), it is clearly possible to distinguish some TB spatial features. Some of them are well-known and related to geo-glaciological structures, e.g. area of Vostok Lake, while other are not yet fully explained. In order to understand and explain these results we use here electromagnetic models, both coherent and incoherent, which have been recently tested over the area of Dome-C

where ground data and glaciological information of the ice sheet are available. Indeed, because of the much larger penetration depth, modeling the microwave ice sheet emission requires to take into account not only snow conditions at the surface but also to include glaciological information. Even if the penetration depth of the L-band is not well known due to the uncertainty on the ice permittivity's imaginary part, it is likely of the order of several hundreds of meters which means that the temperature of the ice over nearly 1 kilometer influences the emission. Over such a depth, the temperature is related to both the surface conditions and the ice sheet thickness and a few other glaciological variables. The comparison between simulated and real SMOS data has been performed at V polarization at an incidence angle close to the Brewster one where reflection at the interfaces vanishes in order to limit the influences of surface or sub-surface effects. Moreover the analysis is carried out along three distinct transects on the Antarctic Plateau selected in order to cover, one hand, a large enough range to observe TB variations in response to a significant variability of some glaciological parameters (i.e. temperature profile which in turn depends on ice thickness, surface temperature, etc.) and, on the other hand, small enough to allow considering as constant other glaciological parameters which need to be derived from ground measurements collected in few sites (i.e. density profile, geothermal heat flux, etc.,). Obtained results show that the electromagnetic models are able to explain the TB spatial variations and confirms that the variation of SMOS along the transects (of about 4 K) appears to be related to variations of the temperature profile due to the spatial variation of the ice thickness and surface temperature but not in a unique way. Moreover the models are unable to predict correctly the absolute value Tb. Detailed analysis points out that the main limiting factor in simulating SMOS data relies in the un

Paper 3 DEPLOYMENT OF THE UWBRAD RADIOMETER AT DOME C: FIRST RESULTS OF THE ANTARCTIC CAMPAIGN

Giovanni Macelloni, Marco Brogioni, Institute of Applied Physics - National Research Council (IFAC - CNR), Italy; Joel Johnson, Kenneth C. Jezek, Mark Andrews, Hongkun Li, Mustafa Aksoy, Domenic Belgiovane, Chi Chih Chen, The Ohio State University, United States

The Ultra-Wideband Software-Defined Radiometer (UWBRAD) has been developed under the support of the NASA Instrument Incubator Program (IIP) to provide measurements of ice sheet thermal emission in 12 frequency channels over the range 0.5-2 GHz for the purpose of remotely sensing internal ice sheet temperature information. The instrument and the retrieval approaches will be fully tested during an airborne campaign planned in Greenland for Spring 2016. In order to ground test the instrument concept and retrieval approach, a prototype version of the radiometer having four channels at 540, 900, 1380, and 1740 MHz has been developed. This UWBRAD prototype is being deployed in a pilot experiment at Dome-C in the East Antarctic Plateau (where the Italian-French Concordia base is located) in Austral summer 2015-2016. The instrument is being deployed on the Dome-C observation tower at a height of ≈ 12 m, and will collect data on a pristine area of ice sheet at incident angles of 30 and 45 deg. Clear sky observations are also planned for calibration purposes. The data collected by the prototype will also be compared to L-band (1413 MHz) brightness temperatures measured by the RADOMEX system operating from the same tower; the RADOMEX system has been operated from the tower in multiple measurements since December 2013 for calibrating and validating SMOS data.

The principal aims of the experiment are: testing of the instrument in a real environment, achieving an assessment of the utility of multi-frequency brightness temperatures, verifying multi-frequency forward models by using in-situ measurements of ice-sheet parameters as model inputs, and validating internal ice sheet temperature retrievals. For these purposes, Dome C is a highly suitable test site for UWBRAD due to the availability of in-situ data including one of the few complete temperature profiles (i.e. from the surface down to 3200 m) of Antarctica (the borehole of the EPICA project.) The presence of RADOMEX also provides valuable TB reference measurements.

The results of the campaign, which will provide the first Tb measurements collected at these frequencies in Antarctica, along a discussion of the performance of the retrieval algorithms and the potential implications for the airborne deployment of UWBRAD in Greenland (planned for Spring 2016) will be presented at the conference.

Paper 4 USING SNOWPACK WITH HUT SNOW EMISSION MODEL IN BRIGHTNESS TEMPERATURE SIMULATIONS OF SNOW COVER

Anna Kontu, Juha Lemmetyinen, Juho Vehviläinen, Leena Leppänen, Jouni Pulliainen, Finnish Meteorological Institute, Finland

HUT snow emission model [1] is widely used in simulation of brightness temperature of snow-covered ground. Typically in situ measurements of snow, either manual or automatic, are used as input. We studied whether snow profiles from a physical snow model, such as SNOWPACK [2], can be used with HUT snow emission model, and whether they can be used as a priori snow information in retrieval of SWE from microwave radiometer observations. We studied the problem by 1) simulating snowpack evolution from meteorological input data with SNOWPACK; 2) validating SNOWPACK snow profiles with manual and automatic field measurements; 3) using SNOWPACK snow profiles in brightness temperature simulations with HUT snow emission models; and 4) used SNOWPACK snow profiles as a priori snow data in SWE retrieval from tower-based microwave radiometer observations.

We used an extensive data set from Sodankylä, Finland, measured during four consecutive winters 2009-2013 at Finnish Meteorological Institute's Arctic Research Centre. Microwave radiometers (18.7 GHz V-pol and 36.5 GHz V-pol), automatic air, snow and soil temperature, SWE, snow depth, and soil dielectricity measurements, and manual profiles of snow temperature, grain size, specific surface area (SSA), density, and SWE were all collected within 20 m of each other in a boreal forest opening of about 80 m in diameter. In addition meteorological data and shortwave radiation measurements from a weather station at a distance of 500 m were used. Manual snow measurements were applied to validate SNOWPACK output, automatic reference measurements were used as input to both SNOWPACK and HUT snow emission model, and microwave radiometer observations were used to validate brightness temperature simulations and in retrieval of SWE.

Our results show that the ability of SNOWPACK to accurately model snow depended on the year. Mean agreements scores between SNOWPACK profiles and manual measurements were 0.65-0.80 for density, 0.71-0.83 for temperature, 0.87-0.91 for classical grain size E, and 0.74-0.75 for optical grain size DD. Bias and RMS error of brightness temperature simulations and SWE retrievals depended on accuracy of snow parameter simulation. Three different sets of a priori snow parameters were studied in SWE retrieval: 1) fixed density, temperature and grain size, 2) 1-layer aggregates of SNOWPACK profiles of temperature, density and DD, and 3) 1-layer aggregates of SNOWPACK profiles of temperature, density and E. SNOWPACK as such simulated total SWE better than any retrieval from microwave radiometer observations (RMS error 16-32 mm, depending on year). In those years that SNOWPACK was able to simulate temperature, grain size and density well, SWE retrieval using SNOWPACK temperature, density and DD was the most accurate retrieval with RMS error of 23-41 mm and bias from -7 to -4 mm. It is not yet clear, why SNOWPACK succeeded in simulating snow parameters only in certain years. However, our results show that SNOWPACK can be used with HUT snow emission model, e.g. to fill in gaps in in situ measurements or to provide parameters that were not measured.

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[1] Pulliainen, J.T., Grandell, J., & Hallikainen, M.T. (1999). HUT snow emission model and its applicability to snow water equivalent retrieval. IEEE Transactions on Geoscience and Remote Sensing, 37(3), 1378-1390 [2] Bartelt, P. & Lehning, M. (2002). A physical SNOWPACK model for the Swiss avalanche warning, Part I. Numerical model. Cold Regions Science and Technology, 35, 126-145

Paper 5 SATELLITE-BASED SNOW WATER EQUIVALENT ESTIMATION AND CLIMATOLOGY ANALYSIS OVER CENTER ASIA AND XINJIANG PROVINCE, CHINA

Yubao Qiu, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, China

The Central Asia, and adjacent areas, such as, Russia, western China, and its southern neighboring countries are highly continental climate, within the central region of Eurasia continent, its water resource are mainly from the precipitation and supplies from mountain glacier melting. Snow precipitation is an important water resource that balances the water redistribution through the atmosphere transportation. Through the snow depth observations, the snow precipitation accumulation can be estimated statistically by the in situ and remote sensing. Geographically, the seasonal snow water at winter covers most of the northern Center Asia, especially, Kazakhstan, and the Xinjiang Province, China. Over the last decades, global warming and its combined temperature and water vapor changing came into being a large influence to the snow water distribution.

Aiming to the understanding on the Snow Water Equivalent (SWE) distribution and its climatology in the last decades, we conduct a research on the estimation of Snow Water Equivalent (SWE) from satellite-based passive microwave observations, with the support and validation from the sparsely distributed in situ snow measurements over the Center Asia, and Xinjiang, China. An empirical algorithm was developed with monthly coefficients which considered the changing snow attributions in the winter time, the algorithm prototype is,

Snow Depth (cm) = (monthly changed coefficient) * (Tb17-Tb37) + Interception

The in situ measurement in Xinjiang province was employed to validate the algorithm monthly, the validation result showed that it achieved a 37.21% Mean Relative Error (MRE), about 40% validation sites achieve 20% MRE, when compared with the traditional algorithm (Chang'92, and NASA operational algorithm), the new updated algorithm has an improvement there.

The long time series of satellite observations are used for a climatology analysis, there are the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) sensor on NASA's Aqua satellite (2002~2011) and Microwave Radiometer Imager (MWRI) on Fengyun-3 satellite (2011~now), which tells the snow water available spatially in a broad area on a high time resolution.

The winter SWE reveals an obvious seasonal trend of SWE time series distribution. The SWE increased from November through December, and reach the peak value at February, then it begins the spring melting season from March. Most of the snow cover pixels concentrate at two SWE value scopes, one is below 40mm and another is between 80 to 120mm. The lower SWE places are mainly on the Center Asia lowland plain area, and the margin area of desert of Tarim basin, while the relative higher SWE distribute over the Northern Kazakhstan and Mountain areas, it shows a clear spatial variable distribution from south to north.

From the validation and analysis, the retrieved SWE products shows it's feasibility over Center Asia and Xinjiang, China. A further analysis is undergoing from multi and consecutive satellite measurements.

Wednesday, April 13	Sensor Calibration	16:00 - 17:40
Lecture Session		Lecture Hall B

Session Co-Chairs: Ignasi Corbella, Universitat Politècnica de Catalunya; Andreas Colliander, NASA Jet Propulsion Laboratory

Paper 1 GLOBAL PRECIPITATION MEASUREMENT (GPM) MICROWAVE IMAGER (GMI) ON-ORBIT CALIBRATION

16:00 David Draper, David Newell, Ball Aerospace & Technologies Corp., United States; Frank Wentz, Remote Sensing Systems, United States

The Global Precipitation Measurement (GPM) Microwave Imager (GMI) was launched aboard the GPM Core Observatory in February 2014. Flying in a 65 degree inclination orbit, the GMI is the calibration standard for radiometer precipitation measurements made by the GPM constellation instruments. The GMI on-orbit calibration has been performed with the help of several on-orbit maneuvers that afford the capability to provide on-orbit absolute calibration of the radiometer with unprecedented accuracy.

The GMI employs a unique dual calibration system. As other scanning microwave imagers, the GMI provides primary calibration uses a hot load blackbody and cold sky views. The GMI also employs a secondary calibration system with noise sources on the lower frequency channels, providing four calibration points rather than two. The dual calibration provides a method of performing backup calibration during the on-orbit maneuvers in the cases where the cold sky view is corrupted with contamination from the Earth.

This paper presents an overview of the on-going efforts to provide high-quality on-orbit absolute calibration of the GMI using the data taken from the maneuvers. Three specific types of maneuvers have been performed: 1) a deep space maneuver where the spacecraft is pitched 55 degrees from nominal geodetic pointing as measure cold space through the main antenna beam; 2) an inertial hold where the spacecraft is effectively pitched from 0 to 360 degrees relative to the earth geoid through which the antenna pattern backlobe can be characterized; 3) a nadir-viewing pitch maneuver where the spacecraft is pitched to point the center of the swath directly toward nadir in order to verify inter-channel calibration of the v-pol and h-pol channels.

Using the on-orbit calibration maneuvers, a number of calibration parameters have been derived including a correction to earth magnetic field susceptibility, onorbit along-scan biases, antenna pattern spillover correction, and overall biases in the main beam view. The initial version of on-orbit calibration is currently used in the Goddard Space Flight Center (GSFC) Precipitation Processing System (PPS). Further enhancements to the calibration have been made by Ball Aerospace and Technologies Corporation and Remote Sensing Systems. An error analysis is presented of the techniques. For the initial version of the on-orbit calibration, the absolute error is within 1K. With the additional enhancements, the absolute accuracy is better than 0.5K.

Paper 2 SMAP L-BAND MICROWAVE RADIOMETER CALIBRATION

16:20 Jinzheng Peng, NASA Goddard Space Flight Center / Universities Space Research Association, United States; Jeffrey Piepmeier, Derek Hudson, David Le Vine, NASA Goddard Space Flight Center, United States; Edward Kim, Giovanni i DeAmic, Priscilla Mohammed, NASA Goddard Space Flight Center, United States; Edward Kim, Giovanni i DeAmic, Priscilla Mohammed, NASA Goddard Space Flight Center, United States

1. INTRODUCTION

The L-band microwave radiometer is the passive portion of the Soil Moisture Active Passive (SMAP) instrument which goal is to measure the global soil moisture and freeze/thaw from space. The radiometer measures all four Stokes antenna temperatures, and the Level 1B Brightness Temperature (L1B_TB) calibration algorithm converts radiometer counts to the Earth's surface brightness temperature [2] with overall radiometer error requirement of 1.3 K to measure soil moisture with <0.04 volumetric fraction uncertainty.

2. APPROACH

The radiometer was calibrated on the ground before launch to produce calibration coefficients for the L1B_TB calibration algorithm. These coefficients are being refined after launch. The goal is to create a consistent calibration over the dynamic range from cold sky to warm land. Validation shows that the current ocean TB has uncertainty <1.25 K.

2.1 Pre-Launch Calibration

Pre-launch calibration of the radiometer hardware was carried out through multiple tests with methods similar to those used on the TOPEX microwave radiometer [3]. The main results of the calibration testing are values and temperature coefficients of the internal noise source and reference load. The room temperature values of the noise source and reference load offset were determined using a liquid nitrogen and ambient target at the input to the feed network. The 3rd and 4th Stokes channels were calibrated with polarimetric grid involved. Validation testing using an additional target heated above ambient indicates the calibration has uncertainty <0.4 K.

2.2. Post-Launch Calibration

SMAP uses Cold Sky (CS) and global ocean as its primary external references to refine pre-launch coefficients and the APC matrix. The CS calibration maneuvers are nominally performed monthly with an ocean background to minimize the backlobe uncertainty on predicted antenna temperatures, while a special CS calibration maneuver was performed with the spacecraft flying over a transition from ocean to Amazonian rain forest to provide information to refine the APC matrix. The global ocean using the L-band GMF model [4] is used to characterize the nature of any potential drifts in the calibration together with the CS and Antarctica. In addition, it also serves to aid in adjusting corrections for extra-terrestrial error sources (i.e., sun, moon and galaxy).

3. CONCLUSIONS

Post launch calibration activities are in progress. Current validation shows that the ocean TB has <1.25 K uncertainty. A beta-release of calibrated radiometer data has been released and the level 1 data release is scheduled in November, 2015. We plan to present the state of the calibration, results of the activities, and remaining uncertainties.

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Paper 3 IMPACT OF AMPLITUDE CALIBRATION ERRORS ON SMOS GLOBAL IMAGES

16:40 Israel Durán, Ignasi Corbella, Francesc Torres, Nuria Duffo, Universitat Politècnica de Catalunya, Spain; Roger Oliva, Manuel Martín-Neira, European Space Agency, Spain

SMOS is the acronym for the Soil Moisture and Ocean Salinity mission by the European Space Agency (ESA) [1]. Its single payload, the Microwave Imaging Radiometer using Aperture Synthesis (MIRAS), was successfully launched in November 2009 to provide a continuous flow of fully polarimetric brightness temperature images. Along these years of operation, SMOS calibration and imaging algorithms have undergone a continuous evolution to further improve the accuracy of the retrieved geophysical parameters. These improvements are particularly useful in Ocean Salinity (OS) applications where accuracy and stability requirements are very demanding and spatial and temporal averaging is required to achieve SMOS mission objectives.

One artifact still present in SMOS images that has a significant effect on ocean salinity products is the so-called land-sea contamination (LSC) effect. It consists of an increased radiometric error in SMOS retrievals for ocean regions in the range of several hundreds of kilometers from the coast. This problem has been recently identified as caused by an inconsistency between the amplitude errors that affect the zero baseline (antenna temperature) and the set of correlation visibilities [2]. This contribution will address the recent research on this topic that includes an assessment on LSC mitigation approaches, the impact of different amplitude errors on LSC and validation scenarios. Finally, validation of the correction procedure shows how independent and complementary amplitude calibration routines, such as the so-called NIR and all-LICEF modes, together with image synthesis autoconsistency properties provides a very robust SMOS performance.

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Paper 4 VICARIOUS CALIBRATION FOR MICROWAVE RADIOMETER HIGH FREQUENCY CHANNELS

17:00 Rachael Kroodsma, University of Maryland ESSIC / NASA Goddard Space Flight Center, United States

Spaceborne microwave radiometers with high frequency channels (150 – 183 GHz) are important for retrieving many geophysical parameters such as atmospheric water vapor profiles. In order to obtain accurate retrievals from the brightness temperature (TB) measurements, the radiometers must be properly calibrated. Many methods have been developed to calibrate the radiometers while on-orbit using the observed TBs. Current methods typically utilize comparisons from radiative transfer models, radio occultation from GPS, or radiosondes to calibrate the radiometers. There has also been extensive work done with inter-calibrating radiometers with these channels to generate fundamental climate data records. This presentation will describe a new method to calibrate high frequency channels and show its ability to detect calibration issues with radiometers as well as its effectiveness as an inter-calibration algorithm.

The new calibration method presented here is loosely based on the vicarious cold calibration (VCC) algorithm, which has been in use for several years to derive a cold calibration reference for radiometers with frequencies from 6 to 90 GHz. VCC finds a cold reference point for these channels over the ocean, using the stable cold ocean surface as a calibration target. The high frequencies between 150 and 183 GHz will only see the surface in extremely dry conditions and the channels closest to the 183.31 GHz water vapor line will not see the surface at all. Therefore, the theory of vicarious cold calibration breaks down at these channels and cannot be used to derive a calibration reference. To derive a vicarious calibration algorithm for the high frequency range, a different calibration target other than the ocean surface needs to be found. VCC makes use of TB histograms to calculate the calibration point, using the cold end of the TB histograms which is associated with TBs from the ocean surface. The high frequency channels do not have a stable cold end of the TB histogram, instead, the warm end of the TB histograms is found to be very stable. Unlike the lower frequencies, the warm end of the TB histograms for high frequency channels does not contain TBs from highly variable scenes, such as raining scenes. At these frequencies, any rain or ice results in scattering, causing the TBs to decrease. Therefore the TBs at the warm end of the histogram for 150 – 183 GHz are the result of absorption only. It is found that the warm end of the TB histogram for 150 – 183 GHz is associated with a stable Earth target that exists not at the surface but in the atmospheric profile. A theoretical analysis of this will be presented.

This presentation uses the new high frequency calibration method to identify and correct calibration issues with current radiometers and derive inter-calibration offsets. One calibration issue that will be presented is with the Special Sensor Microwave Imager Sounder (SSMIS). The method is able to detect an issue with SSMIS due to solar heating of the reflector which introduces an error of several Kelvins if not accounted for. The new calibration method is also validated by using it to inter-calibrate two radiometers and showing that it gives comparable results to published inter-calibration techniques.

Paper 5 FULLY POLARIMETRIC RADIOMETER CALIBRATION: DETERMINING RETARDATION PLATE'S PHASE SHIFT

17:20 Janne Lahtinen, Harp Technologies Ltd, Finland; Martti Hallikainen, Aalto University, Finland

Whereas conventional microwave remote sensing radiometers measure vertical and horizontal brightness temperature signals (T_v and T_h), polarimetric radiometry yields two additional Stokes parameters. These third and fourth Stokes parameters (T_3 and T_4) represent the linearly polarized and circularly polarized components of the signal, respectively.

As shown, e.g., by the WindSat radiometer on-board the U.S. Coriolis satellite, polarimetric radiometry is useful in determining maritime wind vectors, e.g., for tropical cyclone forecasting. In addition, new data can be retrieved on certain other geophysical targets, such as snow and ice and agricultural areas. Finally, polarimetric signals are useful in detecting artificial RFI. Polarimetric satellite missions are currently under development, e.g., in China.

External fully polarimetric calibration standards are complex devices and therefore, unpractical for space use. However, the use of such external targets is very much warranted, e.g., for accurate determination of residual uncertainties on-ground prior to satellite launch or when very high fidelity is needed in ground-based or airborne measurements. An external tri-polarimetric calibration target can be constructed using two blackbody loads and a wire grid polarizer. This way, T_v, T_h, and T_3 reference noise levels are generated. In order to generate also reference T_4 (for fully polarimetric calibration), an additional phase retardation plate is needed. In practise, the retardation plate transforms a part of T_3 into T_4. The polarimetric calibration is based upon generation of a set of linearly independent brightness temperature vectors and their accurate determination a priori. For this purpose, it is seminal to know the phase shift of the retardation plate very accurately. But analytical calculations and electromagnetic simulations have uncertainties and transmission measurements are difficult due to reflections and standing waves.

In this paper, a novel method to accurately determine the phase shift of a retardation plate is introduced. The method applies the very radiometer that is under calibration. The only requirement is that the polarimetric calibration sequence has to include calibrations with and without the phase retardation plate. The method is based on the determination of the radiometer's calibration coefficients for the T_3 channel without the retardation plate (so-called "tri-polarimetric calibration"). When performing the calibration with the retardation plate (fully polarimetric calibration), the calibration coefficients of the T_3 channel shall remain the same. This is achieved if the assumed phase shift value of the retardation plate is correct when calculating the calibration coefficients. Here, we use an iteration algorithm to determine the correct phase shift value. In addition, the small skew angle of the plate (with respect to the polarization basis of the antenna) is retrieved in the process.

The phase shift of the retardation plate of the Aalto University's 36.5 GHz Fully Polarimetric Calibration Standard (FPCS) has been determined in a series of calibrations. The repeatability of the determined phase shift is very good, better than 0.1 deg (std). The reliability of the retrieved phase shift value can be estimated from radiometer measurement data that has been collected from airborne circle flights over sea waves: when calibrated (using the FPCS), no harmonic variation can be detected in T_4 (as it should be), although a clear variation is present in T_3. This indicates negligible polarization mixing between T_3 and T_4 and thus, correct estimate for the phase shift of the retardation plate when calculating the calibration coefficients. In addition, the mean value of the T_3 and T_4 signals, respectively, is 0.3 K and 0.7 K in the worst case over a full circle over sea waves, suggesting that the calibration biases are small in general (theoretically, the mean value should be zero).

Session Co-Chairs: Simonetta Paloscia, CNR-IFAC; Dara Entekhabi, Massachusetts Institute of Technology

Paper 1 SMOS AND HYDROLOGY

08:00 Yann H. Kerr, Ahmad Al Bitar, Simone Bircher, Nemesio Rodriguez-Fernandez, Beatriz Molero, Marie Parrens, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Delphine Leroux, Thierry Pellarin, LTHE, France; Jean-Pierre Wigneron, INRA ISPA, France; Susanne Mecklenburg, ESA-ESRIN, Italy

SMOS, a L Band radiometer using aperture synthesis to achieve a good spatial resolution, was successfully launched on November 2, 2009. It was developed and made under the leadership of the European Space Agency (ESA) as an Earth Explorer Opportunity mission. It is a joint program with the Centre National d'Etudes Spatiales (CNES) in France and the Centro para el Desarrollo Teccnologico Industrial (CDTI) in Spain. SMOS carries a single payload, an L band 2D interferometric, radiometer in the 1400-1427 MHz protected band. This wavelength penetrates well through the vegetation and the atmosphere is almost transparent enabling to infer both soil moisture and vegetation water content. SMOS achieves an unprecedented spatial resolution of 50 km at L-band maximum (43 km on average) with multi angular-dual polarized (or fully polarized) brightness temperatures over the globe and with a revisit time smaller than 3 days. SMOS has been now acquiring data for 5.5 years. The data quality exceeds what was expected, showing very good sensitivity and stability. The data is unfortunately impaired by man-made emission in the protected band, leading to degraded measurements in several areas including parts of Europe and of China. However, many different international teams are now addressing data use in various fields including hydrology. We have now acquired data over a number of significant "extreme events" such as droughts and floods giving useful information of potential applications. We are now working on the coupling with other models and or disaggregation to address soil moisture distribution over watersheds. We are also concentrating efforts on water budget and regional impacts. Assimilation of SMOS data into hydrological modelling showed positive impact in terms of stream flow and soil moisture estimation. With the development of a near real time soil moisture product using neural network approach, a wealth of new applications is bound to occur. From all those studies, it is now possible to express the "lessons learned"

Paper 2 DEVELOPMENT OF A WEAKLY CONSTRAINED LAND SURFACE DATA ASSIMILATION SYSTEM AND ITS APPLICATION 08:20 FOR LONG TERM TERRESTRIAL WATER CYCLE SIMULATION

Hui Lu, Tsinghua University, China; Jianchen Shi, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, China

ACCURATE estimation of water, energy and momentum fluxes between the land surface and the atmospheric boundary layer at regional and global scale is essential in land-atmosphere interaction study. Nowadays, land data assimilation system has been a powerful tool to optimally combine the advantages of microwave remote sensing and land surface model together and then improve the accuracy of land surface fluxes and status estimation. In this study, we developed a land data assimilation system, in which the weak constraint of water conservation is considered. Microwave radiance is directly assimilated into the land surface model through the adopting of a microwave radiative transfer model (RTM), in which the microwave emission ranged from L-band to Ku-band are well simulated. The RTM is consist of a Dobson model for soil dielectric constant estimation, the Advanced Integration Emission Method (AIEM) model for considering the surface roughness effect, the Microwave Emission Model of Layered Snowpacks (MEMLS) for calculating snow contribution (when it exists), and a tau-omega model for vegetation effect. The data assimilation system adopts a variational assimilation scheme and uses Shuffled Complex Evolution method to minimize the cost function.

In general, the water budget is unbalanced after the update of an LDAS. The water balance residual at each assimilating step may be accumulated and consequently break the water conservation in the model. In order to obtain a long term land surface data set simulated by LDAS, A weak constraint a weak constraint is imposed, which accounts for uncertainty in the water budget. Sensitivity test which considering the impacts of assimilation frequency and length of assimilation window are conducted. The results show that for soil moisture assimilation 48 hours window with 2 times assimilation could control the accumulated residual into the acceptable region.

With this weakly constrained data assimilation system, we will conduct long term running to generate a land surface reanalysis data set by assimilating brightness observation from SSM/1, AMSR-E and AMSR2. More results will be presented and analyzed during the conference.

Paper 3 COVARIATIONS OF BACKSCATTER AND BRIGHTNESS TEMPERATURE: COMPARISON OF OBSERVED L-BAND AND L-08:40 AND C-BAND PAIRS

Narendra Das, NASA Jet Propulsion Laboratory, CalTech, United States; Dara Entekhabi, Massachusetts Institute of Technology, United States; Seungburn Kim, Simon Yueh, NASA Jet Propulsion Laboratory, CalTech, United States

In low frequency microwave remote sensing of soil moisture, passive measurements have the advantage of sensitivity and the algorithms have long-standing heritage. Active remote sensing however has the advantage of resolution but the effects of scattering from vegetation and surface roughness remain as challenges. Combining the two types of measurements has emerged as the path forward and it formed the basis for the NASA Soil Moisture Active Passive (SMAP) mission. The SMAP mission collected eleven weeks of global active passive data until the failure of its radar instrument in July 2015. In this presentation we show the covariations of the active and passive L-band measurements and analyze the role of vegetation density on the covariation strength. Currently there are C-band synthetic aperture radar systems that collect high resolution backscatter measurements across large swaths of land. Sentinel-1A data are one example that will be augmented soon with the launch of Sentinel-1B. The Sentinel-1A satellite from European Space Agency (ESA) provides C-band SAR measurement in Interferometric Wide Swath (IWS) mode that has potential to be merged with the SMAP L-band brightness temperature observations to create a new multi-satellite high resolution (~1 to ~3 km) active-passive soil moisture product. Therefore, this approach warrants study of covariation between the observed C-band backscatter and L-band brightness temperature from satellite platforms. The study presented here shows covariation of C-band dual-pol (v and hv) SAR measurements and the SMAP L-band dual-pol (v- and h-pol) radiometer observations over different landcovers from distinct parts of the world. The sensitivity of covariation with respect to different incident angles of the Sentinel IWS acquisition and various level of vegetation cover will be analyzed, and subsequently compared with the modeled covariance and the 2.5 months of L-band radar data from the SMAP mission. The derived parameter from this study will also be applied to the existing SMA

Paper 4 GLOBAL DETECTION OF SOIL FREEZING AND THAWING 09:00 Kimmo Rautiainen. Juha Lemmetvinen. Finnish Meteoroloaical Institute. Finland:

Kimmo Rautiainen, Juha Lemmetyinen, Finnish Meteorological Institute, Finland; Chris Schwank, GAMMA Remote Sensing Research and Consulting AG, Switzerland; Jaakko Ikonen, Finnish Meteorological Institute, Finland; Chris Derksen, Environment Canada, Canada; Alexandre Roy, Université de Sherbrooke, Canada; Matthias Drusch, European Space Agency, ESRIN, Italy; Jouni Pulliainen, Finnish Meteorological Institute, Finland

Information on soil freezing and thawing is important for hydrological, biogeochemical, and climatological applications. Soil freezing has an effect on surface energy balance, surface and subsurface water flow, and exchange rates of carbon with the atmosphere. Soil freezing also has an effect on important biogeochemical processes (photosynthesis and microbial activity).

Finnish Meteorological Institute (FMI) has been developing in close co-operation with Gamma Remote Sensing methods for detecting soil freezing and thawing on a global scale using satellite based microwave radiometer observations. The work has been carried out within the frame of several ESA studies: STSE SMOS+ Innovation and STSE Pathfinder programs and under nationally funded SMOS Calibration and Validation Activities in Northern Areas (NORA) program. The soil freeze/thaw detection methods are based on using SMOS (Soil Moisture Ocean Salinity) satellite passive L-band microwave data. In the most simplistic form, only SMOS brightness temperature (TB) data is used to retrieve alobal soil state maps for the Northern Hemisphere. Soil permittivity decreases at L-band due to soil freezing, which results in higher TB values for frozen soil than for thawed soils. This forms the basis of the soil state monitoring algorithm. Threshold values for frozen and thawed states are first defined for SMOS TB observations; the soil is then categorized to "frozen", "partially frozen" or "thawed" state by comparing the current observation to these threshold values. Naturally, the threshold values are highly dependent on the composition of: land class, soil type, open water fraction, annual physical temperature variation, etc within each pixel. To standardize the method and to enable automatic threshold detection, SMOS TB values are normalized to relative values, which reach a maximum value of 100 in winter and minimum value of 0 in summer. The summer minimum and winter maximum values are experimentally determined from SMOS data for each pixel. Auxiliary data is used to define the seasonal variation in each pixel. The end of the summer period is estimated using WMO synoptic air temperature data interpolated over the Northern Hemisphere. The end of winter period is estimated using snow masks derived from the ESA DUE GlobSnow product. With auxiliary data clearly erroneous soil state detections can be automatically corrected. Currently the method is being validated against in situ data acquired from different environmental conditions and geographic regions. The objective is to provide a global operational soil freeze/thaw product, which is to be updated on a daily bases. The algorithm is easily adjusted to NASA SMAP (Soil Moisture Active Passive) satellite data. Results and comparisons with SMAP data for early winter 2015-2016 will be provided.

Soil state information can be used as input information for various global models and thus may be of great interest to climate change and carbon cycle studies.

Paper 5 MULTI-SCALE L-BAND BRIGHTNESS TEMPERATURE ANALYSIS FOR SOIL FREEZING AND THAWING PROCESS STUDY

09:20 Alexandre Roy, Alain Royer, Université de Sherbrooke, Canada; Chris Derksen, Peter Toose, Environment Canada; Canada; Ludovic Brucker, NASA Goddard Space Flight Center, United States; Arnaud Mialon, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Alexandre Langlois, Université de Sherbrooke, Canada; Yann H. Kerr, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France

Snow and frozen ground play a crucial role in climatological and hydrological processes, and are key factors in modulating energy, water, and carbon budgets. L-band space-borne missions such as Soil Moisture Active Passive (SMAP), Soil Moisture and Ocean Salinity (SMOS), and Aquarius have the potential to provide enhanced information on the surface freeze/thaw (F/T) state over northern regions. It is a key parameter for studies of terrestrial hydroclimatology and ecosystem processes.

In this presentation, we first present an analysis over Canadian sites of the L-band brightness temperature (TB) variations from SMOS, Aquarius and first SMAP data in order to characterize the freeze/thaw (FT) soil state, including in winter when a dry snow cover exists. The analysis shows that because of the strong permittivity difference between ice and water, the signal at L-band is very sensitive to the F/T state. However for forested sites it was shown that the signal change is more subtle during transitional periods, suggesting that the boreal F/T signal is more ambiguously influenced by the vertical soil-vegetation continuum and its developmental stages following vegetation phenology. Despite the strong sensitivity of the L-Band passive microwave signal to soil F/T, the intensity can vary because of spatially varying contributions from vegetation, soil, lake and snow, and their physical properties. Hence, a second analysis was conducted at local scale from surface-based L-band radiometer measurements in Saskatchewan, Canada during the 2014-2015 fall, winter, and spring. This dataset was used to analyse the effects of frozen soil and snow. The results show that the snow has a non-negligible effect on TB at L-Band.

This study brings important information for the development and improvement of F/T algorithm from SMAP and SMOS observations. The work confirms that spaceborn L-Band data can also leads to retrieve other important cryospheric variables such as snow density (Lemmetyinen et al., 2015).

Thursday, April 14	RFI and Spectrum Management	10:10 - 11:50
Lecture Session		Lecture Hall B

Session Co-Chairs: Niels Skou, Technical University of Denmark; Sidharth Misra, NASA Jet Propulsion Laboratory

Paper 1 SMOS AND RFI - CURRENT STATUS

10:10 Yann H. Kerr, Philippe Richaume, Eric Anterrieu, François Cabot, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Yan Soldo, NASA, United States; Arnaud Mialon, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Roger Oliva, European Space Agency, Italy; Manuel Martín-Neira, ESA-ESTEC, Netherlands; Elena Daganzo-Eusebio, ESA, European Space Research and Technology Centre, Netherlands; Susanne Mecklenburg, ESA-ESRIN, Italy

The SMOS mission was launched in November 2009 and allows measuring the surface soil moisture over continental land, covering the entire surface in 3 days. The multi-angular algorithm also enables to estimate the vegetation opacity which is directly related to the water content of the canopy.

However, the SMOS radiometer operates within the Earth Exploration Satellite Service passive band at 1400-1427 MHz. Since its launch in November 2009, SMOS images have been strongly impacted by Radio Frequency Interference (RFI). So far approximately 500 RFI sources distributed worldwide have been detected. Some of the strongest RFI sources might mask other weaker RFI underneath, hence it is expected the total number of RFI detected may increase as strong ones are progressively located and switched off. Most RFIs are located in Asia and Europe, which together hold approximately 80% of the active sources and more than 90% of the strongest interference. The areas affected by RFI may experience either an underestimation in the retrieval values of soil moisture and ocean salinity or data loss, with the associated detrimental impact in the scientific return. ESA and the teams participating in SMOS mission have put in place different strategies to alleviate this RF interference situation with significant successes in Europe.

We will present some detection and localisation approaches together with specific examples of detection in complex environments.

The Aquarius and SMAP missions results in terms of RFI detection will be compared to that of SMOS

Paper 2 SOIL MOISTURE ACTIVE PASSIVE (SMAP) MICROWAVE RADIOMETER RADIO-FREQUENCY INTERFERENCE (RFI) 10:30 MITIGATION: ON-ORBIT RESULTS

Priscilla Mohammed, Jeffrey Piepmeier, NASA Goddard Space Flight Center, United States; Joel Johnson, Alexandra Bringer, Mustafa Aksoy, The Ohio State University, United States

The Soil Moisture Active Passive (SMAP) mission, which was launched launch January 31, 2015, will make global L-band observations of Earth from space [1]. Although SMAP's radiometer passband lies within the passive frequency allocation, both unauthorized in-band transmitters as well as out-of-band emissions from transmitters operating at frequencies adjacent to this allocated spectrum have been documented as sources of radio-frequency interference (RFI) to the L-band radiometers on SMOS and Aquarius [2, 3]. Low level RFI (0.1-10 Kelvin) is especially problematic as it can be mistaken for natural variability and if left unmitigated can corrupt radiometer measurements leading to flawed retrievals. SMAP has an aggressive approach to RFI mitigation using an advanced digital microwave radiometer to provide time and frequency measurements as well as a comprehensive ground processing algorithm [3].

The radiometer instrument architecture provides science data with time-frequency diversity enabling the use of multiple RFI detection methods which occur in the ground processing software. The detection methods include pulse detection referred to as time domain detection, cross frequency detection, kurtosis detection as well as polarimetric detection using the third and fourth Stokes parameters. All detection algorithms are "double sided" and each algorithm has threshold parameters to control the false alarm rate. The maximum probability of detect (MAXPD) algorithm incorporates the results of all the detection algorithms by logically OR-ing all the RFI output flags to produce a single MAXPD flag array which is then used to remove corrupted pixels in each footprint. The flagged data are excluded from the average of good time-frequency samples to produce RFI free footprints.

SMAP radiometer data has been processed and the L1B_TB data products have been analyzed to observe brightness temperatures and their RFI properties. Peak hold plots reveal strong RFI events over much of Asia and Europe. Results indicate that the RFI detection and filtering algorithms are working successfully to remove RFI. The presentation will review the SMAP RFI detection and mitigation procedure and discuss early orbit RFI measurements from the SMAP radiometer as well as algorithm refinements to produce the final release of the L1B_TB data. Assessments of global RFI properties and source types will also be provided.

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Paper 3 PERFORMANCE OF A PROCESSOR FOR ON-BOARD RFI DETECTION AND MITIGATION IN METOP-SG RADIOMETERS 10:50 Niels Skou. Steen S. Kristensen. Technical University of Denmark: Arhiana Kovanen. Janne Lahtinen. Hara Technologies Ltd. Finland

Presently, the MetOp-SG operational satellites are being developed, and it has been decided that the Ku band of the MWI (microwave imager) radiometer must include methods for RFI detection and mitigation. The present paper briefly describes the design of a suitable digital processor breadboard, and discusses tests and performance of the unit.

Baseline RFI detection algorithms are: anomalous amplitude, kurtosis, and frequency domain detection. In addition spectral kurtosis is an option being considered in the development. Detection and mitigation must be carried out on-board in order to avoid excessive data downlink rate.

Traditional radiometers integrate the detected signals over a time comparable to the dwell time per footprint to create one pixel. This results in a low downlink rate. The present system will use temporal sub-sampling as well as spectral sub-bands. Dividing radiometer samples in frequency and time of course increases data rate accordingly, but implementing on-board the RFI detection and mitigation followed by suitable integration, results in a cleaned pixel and the original rather low downlink rate.

Advanced RFI detection algorithms require analogue-to-digital conversion and subsequent digital processing at a high data rate due to the wide bandwidth of radiometer signals. This is feasible using available space qualified ADCs (analogue-to-digital converters) and FPGAs (Field Programmable Gate Arrays). Key system parameters are: 2 inputs, for H and V polarization, centered at 1375 MHz, 200 MHz -3 dB bandwidth, 500 MHz sampling frequency, temporal sub-sampling in the 0.1 – 1.3 ms range, and 10 spectral sub-bands.

The RFI processing is implemented in VHDL. The ADC input modules receive the signals from the converters, estimates the DCoffset of the ADC signals and correct this so that subsequent signals are zero-mean Gaussian distributed if no RFI is present. The first processing step is the filter bank module generating 10 spectral subbands. The second step is squaring each spectral sub-band, followed by a second squaring, so that the accumulation in the third step in the processing calculates both second and fourth order central moments of all spectral sub-bands. The fourth step consists of RFI detection using kurtosis and anomalous amplitude detection in each sub-band before mitigation is performed in the fifth step. In addition to this baseline, spectral kurtosis is optionally calculated and used in the detection procedure.

After detection and mitigation the uncontaminated time-frequency sub-samples are accumulated to generate the output samples.

The breadboard is designed considering space-qualified components but is built using equivalent non-qualified components providing the same functionality. Key components are the EV10AS180 ADCs (10 bit, 1.5 GSps) and the Xilinx Virtex-5 FPGA. The size of the system including housing is 150 x 220 x 25 mm with a total weight of 1050 g. The total power consumption is 11.5W.

The RFI processor is presently being tested using an existing Ku band polarimetric radiometer system. The radiometer views a stable target in the form of a waveguide load connected to the input via a directional coupler. Simulated RFI signals from a suitable test generator are fed into the system through the coupler. The test signals are:

- Continuous RFI signal with varying power, bandwidth varying from 1KHz to full BW
- Pulsed RFI signal with constant PRF and varying power

- Pulsed RFI signal with varying PRF and constant power
- Pulsed RFI signal with varying PRF and varying power

During the tests it is shown that the processor on the pixel level can detect and mitigate typical RFI down to the sub-Kelvin level. This will be elaborated in the final paper.

Paper 4 EVALUATION AND COMPARISON OF RFI DETECTION ALGORITHMS

11:10 Janne Lahtinen, Josu Uusitalo, Teemu Ruokokoski, Harp Technologies Ltd, Finland; Jukka Ruoskanen, Finnish Defence Research Agency, Finland

Anthropogenic Radio Frequency Interference (RFI) is an ever-increasing problem in remote sensing microwave radiometry. Satellite data have shown that a significant amount of RFI is present in L, C, X, and even at Ku bands at many locations around the world. In addition, the RFI problem is getting worse. Therefore, including a RFI detection and mitigation system has been set as requirement for many future radiometers, for example European MetOp Second Generation mission's Microwave Imager (MWI) instrument, 18.7 GHz channels (MWI-1). For optimum performance, the system should detect and mitigate RFI in sub-Kelvin range in brightness temperature.

There are several different methods to detect and mitigate RFI, e.g., anomalous amplitude detection, kurtosis method, polarimetric method, frequency domain detection, spectral kurtosis, and their combinations. It is possible to implement these methods, for example, in an FPGA-based signal processing module, connected to the radiometer, to detect (and mitigate) the RFI in real-time.

There is a variety of potential RFI sources, varying in their frequency, application, waveform, and power. For example, there are RFI signals directly at the radiometer band (illegally or due to shared frequency allocation), spurious signals and harmonics from lower frequency bands, or strong signals close to the radiometer band but not properly rejected by the filters of the radiometer receiver. Radars for defence and air and sea traffic control and various communication systems are potential RFI sources. The waveforms of these emitters can vary significantly, including single frequency Continuous Wave (CW) signals, pulsed signals, and different spread-spectrum signals, for example.

This paper studies and compares the effectiveness of conventional kurtosis, spectral kurtosis, polarimetric method, and frequency sub-banding for detecting continuous wave, pulsed single frequency, and spread spectrum signals. The study has been made in view of the MWI-1 channels of the MetOp-SG mission. To retrieve the results, both simulated waveforms in Matlab environment and measured signals of real signal sources have been used.

Complete set of results will be presented in the final paper. Preliminary results for two sample waveforms (continuous wave and 10% duty cycle pulsed signal) have been presented in Table 1. The following parameters have been assumed: bandwidth (-3 dB) 200 MHz, 8 frequency sub-bands in conventional kurtosis and polarimetry (i.e., bandwidth of each sub-band is 25 MHz), 127 frequency sub-bands in spectral kurtosis, 500 MHz sampling speed, 6.6 ms integration time, 99% probability of detection, and False Alarm Rate (FAR) of 1e-2.

These preliminary results show that different algorithms have complementary characteristics in detecting RFI. While polarimetric detection methods shows the best performance for CW type of signals, the performance of conventional kurtosis and spectral kurtosis methods improves as the duty cycles become lower. Also, the performance of the spectral kurtosis is better than that of the conventional kurtosis in both cases. However, the performance of conventional kurtosis becomes superior as duty cycles become <10%. But all in all, it can be concluded that sub-Kelvin detection capability is a non-trivial task in MetOp-SG context.

Table 1. Simulated detection thresholds for the three studied detection methods detecting CW and pulsed (10 %) RFI.

CW

Kurtosis Spectral kurtosis Polarimetry

5.9 K 2.2 K 0.6 K

Pulsed (10 % Duty Cycle)

Kurtosis Spectral kurtosis Polarimetry

1.9 K 0.7 K 0.6 K

Paper 5 COMPARISON OF TIME-FREQUENCY RFI MITIGATION TECHNIQUES IN MICROWAVE RADIOMETRY

11:30 Jorge Querol Borras, Raul Onrubia, Daniel Pascual, Huyk Park, Adriano Camps, UPCBarcelonaTech, Spain

The number of Radio-Frequency Interference (RFI) occurrences detected over the years is an undoubtedly sign that this phenomenon is nowadays an increasing problem, and presumably, it will grow in the future due to the proliferation of a large variety of wireless technologies around the world. RFI has become a serious threat for passive microwave remote sensing instruments, even though they operate in "protected" frequency bands. In particular, passive microwave radiometers have to deal with very low power signals located in between other frequency bands of an overcrowded spectrum. Consequently, several RFI detection and mitigation algorithms are under development in order to solve, or at least mitigate as much as possible, the problem of RFI in passive remote sensing instruments.

Time-frequency mitigation techniques have been studied over the last years. Common examples of them are pulse blanking [Guner et al. 2007], notch filtering [Borio et al. 2014], wavelet denoising [Forte et al. 2013, Camps and Tarongi 2009], etc. However, a comparison of their mitigation performance in front of a given RFI, have not been evaluated exhaustively. This work aims at presenting a quantitative assessment of several time-frequency RFI mitigation techniques in terms of percentage of lost signal, and residual bias induced in the measurements after the mitigation process, depending on the nature and the RFI signal power.

The assessment is performed taking into account five different RFI mitigation approaches, from lower to higher implementation complexity they are: Pulse Blanking (PB), Frequency Blanking (FB), Spectrogram Blanking (SB), Wavelet Denoising (WD), and Multiresolution Fourier Transform (MFT). Moreover, a threshold value will be calculated following the Binary Hypothesis criterion [Kay 1993]; a previously chosen probability of false alarm will led to a certain probability of detection. This will determine whether a sample is more likely to be RFI-contaminated if its amplitude is higher than the threshold value, or RFI-clean if it is lower than it.

A preliminary evaluation of the mitigation performance shows that pulsed RFI can be almost completely mitigated using PB, sinusoidal RFI from 5 to 25 dB with FB, and chirp RFI more than 20 dB using the MFT technique. The MFT method uses several multi-scale spectrograms working in parallel [Wen et al. 2007], so the input signal is projected with several basis including the ones used in the PB, FB, and SB techniques. Therefore pulsed, sinusoidal as well as chirp RFI signals can be detected with similar performance (or even better for the chirp case) compared to simpler techniques. Further simulations, and results will be presented at the conference as well as the corresponding discussion about the best mitigation technique (or a combination of them) regarding to performance and complexity of its implementation.

Thursday, April 14	Snowfall Retrieval and Atmospheric Modeling	12:50 - 14:30
Lecture Session		Lecture Hall B

Session Co-Chairs: Gail Skofronick-Jackson, NASA Goddard Space Flight Center; Dmitri Moisseev, University of Helsinki

Paper 1 GLOBAL PRECIPITATION MEASUREMENT (GPM) MICROWAVE IMAGER FALLING SNOW RETRIEVAL ALGORITHM 12:50 PERFORMANCE

Gail Skofronick-Jackson, Stephen (Joe) Munchak, NASA Goddard Space Flight Center, United States; Sarah Ringerud, NASA Goddard Space Flight Center, NPP, United States

Retrievals of falling snow from space represent an important data set for understanding the Earth's atmospheric, hydrological, and energy cycles. While satellite-based remote sensing provides global coverage of falling snow events, the science is relatively new and retrievals are still undergoing development with challenges and uncertainties remaining. This work reports on the development and post-launch testing of retrieval algorithms for the NASA-JAXA Global Precipitation Measurement (GPM) mission Core Observatory satellite launched in February 2014. In particular, we will report on GPM Microwave Imager (GMI) radiometer instrument algorithm performance with respect to falling snow detection and estimation.

GMI retrievals are based on a Bayesian framework. The at-launch a priori Bayesian database was generated using proxy satellite data merged with surface measurements (instead of models). Now two years after launch, the Bayesian database is being replaced with the more realistic observational data from the GPM spacecraft radar retrievals and GMI data. It is expected that the reprocessed retrievals using the observational database algorithm will be much more accurate for falling snow retrievals because that database will take full advantage of the 166 and 183 GHz snow-sensitive channels.

We will evaluate the algorithm that was released to the public in July 2014 as well as the revised version released in early 2016. The early algorithm has already shown that it can detect and estimate falling snow. Performance factors to be investigated include the ability to detect falling snow at various rates, causes of errors, and performance for various surface types. Information learned from pre-launch field campaign data will be presented and if available post-launch field campaign data and results from a Nov 2015-Jan 2016 field campaign in the Olympic Mountains in Washington State USA will be included. A major source of post-launch ground validation data is ground-based radar composites. We will report on the analysis of our falling snow validation completed by the time of the MicroRad conference including the first two northern hemisphere winter seasons as measured by GPM. Finally, if available and if time exists, we'll report on the GPM Dual-frequency Precipitation Radar (DPR) estimates of falling snow.

Paper 2 CAN WE RETRIEVE MIXING-LAYER HEIGHT DIRECTLY FROM THE BRIGHTNESS TEMPERATURE MEASUREMENTS?

13:10 Umar Saeed, Universitat Politècnica de Catalunya (UPC), Spain; Ulrich Löhnert, University of Cologne, Germany; Thijs Heus, Cleveland State University, United States; Roel Neggers, University of Cologne, Germany; Francesc Rocadenbosch, Universitat Politècnica de Catalunya (UPC), Spain; Susanne Crewell, University of Cologne, Germany

Mixing-layer height (MLH) is an important parameter for a range of applications including weather forecasting, air-quality and chemical-dispersion models, aviation, and meteorology. While there are several instruments and methods for MLH estimation, temperature-derived MLH is physically consistent and closely linked to the true thermodynamic state of the atmosphere.

Ground-based microwave radiometer (MWR) provides continuous monitoring of the atmospheric boundary-layer by measuring the brightness temperature at several frequencies and elevation angles. However, measurements at several channels are correlated and, therefore, the Degree-of-Freedom (DOF) of the data becomes quite low (approx. 4 for typical boundary-layer profiling configurations) [1]. As a result, MWR-derived physical temperature profiles have coarse vertical resolution and MLH estimates from them suffer from high uncertainties.

In this work, we aim to retrieve MLH directly from brightness measurements without the need to perform a temperature retrieval first. As a further proof of concept, the retrieved MLH is compared with the MLH obtained from the inverted potential temperature by using the "truth" brightness temperatures, hence allowing to study the impact of retrieval errors on the MLH estimates. Towards this end, the algorithm compares "truth" brightness temperatures to algorithm-generated ones by using a least-squares error-decision criterion. The "truth" brightness temperatures, which emulate the real atmosphere, are generated by using the Dutch Atmospheric Large Eddy Simulation (DALES) model [2,3] as a test-bed. LES-generated vertical profiles of the atmospheric temperature, pressure, and water-vapor are first input to a forward model, thus, simulating brightness temperatures.

Algorithm-generated brightness temperatures are obtained from a "state vector" (i.e., the unknown to be solved) parameterizing model temperature along with known pressure and humidity profiles followed by a forward model. The key parameter of the "state vector" is the MLH. The parameterization of the input temperature profile effectively allows to reduce the degrees of freedom of the retrieval problem. The algorithm converges under a least-squares-error criterion that minimizes the error function between the LES-simulated and the algorithm-generated brightness temperatures.

Since the MLH is the key component of the state-vector being solved, the proposed algorithm does not need to carry out the classic two-step procedure in which: (i) physical temperature profiles are inverted from brightness temperatures and, (ii) the MLH is estimated from the retrieved temperature profiles (parcel method). As a result, the proposed algorithm is free from brightness-to-physical temperature retrieval errors associated to classic MLH-estimation methods relying on step (i). The proposed approach is expected to provide MLH estimates with better accuracy and low uncertainty. Finally, real measurements from a Humidity and Temperature Profiler (HATPRO) MWR collected during the HD(CP)2 Observational Prototype Experiment (HOPE) campaign at Jülich, Germany is used to test the proposed method. Doppler wind lidar along with radiosonde (whenever available) data is used as a reference or truth.

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Paper 3 TOWARD IMPROVING THE REPRESENTATION AND RADIATIVE TRANSFER SIMULATION OF ICE HYDROMETEORS IN 13:30 THE GPM CONSTELLATION RETRIEVAL SCHEME

Sarah Ringerud, NASA/ORAU, United States

The Global Precipitation Measurement Mission (GPM) offers the opportunity for a greatly increased understanding of global rainfall and the hydrologic cycle. By employing a constellation of radiometers, coverage and sampling are greatly increased (Hou et al. 2014), while the core satellite acts as a standard, enabling consistent retrievals across constellation members. The combination of GPM core active and passive microwave sensors are used, following techniques developed using the predecessor Tropical Rainfall Measuring Mission (TRMM) satellite, to construct observationally constrained databases of precipitation profiles for use in constellation member retrieval algorithms. The method uses a conservative approach that begins with the operational GPM combined radar-radiometer retrieval algorithm and adjusts its solution while maintaining a match to observed radar reflectivities and radiometer brightness temperature (Tb) in all GMI frequencies. Adjustments include adding a graupel species for convective pixels, cloud ice for improved agreement in the high frequency channels, and drizzle below the sensitivity of the radar. Resulting profiles include surface characterization, atmospheric information, and hydrometeor profiles, radiometers to be utilized in a Bayesian retrieval scheme. Early results indicate good agreement and high correlations of 0.9 and greater between database simulated and observed GPM Tbs, particularly at the lower microwave frequencies.

The method described here, successfully implemented previously for TRMM, includes new challenges moving into the GPM era. Extension to higher latitudes as compared to TRMM requires forward modeling and retrieval over cold and frozen surfaces along with modeling and retrieval of snowfall. The addition of cross-track radiometers such as MHS and SAPHIR as important members of the GPM constellation requires accurate representation of ice hydrometeors for precipitation detection and retrieval, particularly at higher microwave frequencies. The current database includes only two ice species, snow and graupel, of constant density, represented in the forward radiative transfer as "fluffy spheres". By replacing the current scheme with more complex, non-spherical particles, the forward modeling component of the retrieval is able to more accurately match the observed brightness temperatures, particularly in the higher frequency channels, improving the final retrieval. This approach involves new challenges, particularly in partitioning the ice species. Results will be presented in the context of the benefit to the final GPM constellation precipitation retrievals.

Paper 4 PROTOTYPE METHODS FOR HAIL DETECTION BASED ON PASSIVE MICROWAVE HIGH FREQUENCIES

13:50 Sante Laviola, CNR-ISAC, Italy; Jim Beauchamp, ESSIGUniversity of Maryland, United States; Ralph Ferraro, National Oceanic and Atmospheric Administration, United States; Vincenzo Levizzani, CNR-ISAC, Italy

During previous decades, relationships between many geophysical variables and the radiometric measurements in the microwave bands were translated into several satellite-based algorithms. Recently, several studies have revealed the high correlation between the occurrence of hail and the microwave brightness temperature depression in convective clouds. In this work, we propose two independent prototype methods for the detection of hail on the basis of the AMSU-B/MHS brightness temperature variation.

The first method was developed through the use of collocated satellite and surface hail reports over the continental US for a 10-year period (2000-2009). Compared with the surface observations, the algorithm detects approximately nearly 40% of hail occurrences. Simple threshold algorithms are then used to generate a hail climatology based on all available AMSU observations during 2000-2011 and stratified in several ways, including total hail occurrence on a daily (diurnal cycle), monthly, and total annual basis.

The second hail detection algorithm is an improvement of the preexistent MicroWave Cloud Classification (MWCC) method, which exploits the properties of the water vapor channels on board the AMSU-B/MHS to classify the cloud type (stratiform/convection) by estimating the cloud top altitude. Using the results of the MWCC, deep convections were correlated with selected hailstorm events over Europe, South America and the US. The 10-year AMSU-B/MHS observations used for the first method were also employed to refine the algorithm criteria. The hail detector of the MWCC is based on a probabilistic model, which calculates the probability associated with each pixel by following the growth law of the hailstones.

The validation results over the US have demonstrated the high correlation between the two methods and the surface hail reports showing a remarkable agreement in terms of POD and FAR. Furthermore, other pilot sites in South America and Europe have been selected to evaluate the algorithm performances on the global scale for a promising support to the nowcasting systems and limited area modelling.

Paper 5 FORWARD MODELING OF AN ATMOSPHERIC SCENARIO: PATH CHARACTERIZATION IN TERMS OF SCATTERING 14:10 INTENSITY

Ada Vittoria Bosisio, CNR, Italy; Maria P. Cadeddu, Argonne National Laboratory, United States; Ermanno Fionda, Fondazione Ugo Bordoni, Italy; Piero Ciotti, Università degli Studi dell'Aquila, Italy

The increasing demand of high data rates and mobility applications pushes the development of systems and networks forward higher radio frequency such as Ka-band (about 30 GHz) and above (>70 GHz). This is the case of the 5G Wireless Communication systems that foresee large accessibility and real-time reliable connections. The key idea of designing the 5G system architecture is to separate outdoor and indoor scenarios devoting lower frequencies to radio links and relays and privileging the higher bands for indoor users to avoid path loss and penetration due to walls, furniture and so on. Also, the mobile network could be integrated with satellite links.

In this framework it is mandatory to guarantee a high availability and signal quality of the network traffic flowing through the outdoor base stations. In addition, propagation impairments become quite severe as the frequency increases. Specifically, the presence of clouds and rain along the path may corrupt the microwave connection dramatically.

Here, the authors present a forward model, that uses the radiative transfer code ARTS 2.0 [1], that aims at relating the observed brightness temperature values (Tb's) at 23.834, 30.0 and 89 GHz to a scattering indicator or a macro descriptor of the atmospheric status. Simulated Tb's, generated with ARTS on the basis of radio sonde profiles, will be compared with the measured ones. A clear-sky scenario is used as reference to define a scatter-free path. Then, according to the quantity of liquid water in clouds and, if any, the intensity of light rain precipitation, a scattering index is defined. The effect of a scattering atmosphere will be evaluated through comparison of the computed brightness temperatures against scatter-free Tb's.

Initially, in synthetic computations, Decker model will be used to describe the clouds [2]. A database of simulated scenario will be use to assess the relationship between the computed brightness temperature and the scattering index associated to the atmospheric state in the modeling.

The inverse problem will be the derivation of the scattering index describing the atmospheric state from measured brightness temperatures.

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Thursday, April 14	Theory and EM Models	15:00 - 16:20
Lecture Session		Lecture Hall B

Session Co-Chairs: Leung Tsang, University of Michigan; Mike Schwank, Swiss Federal Research Institute WSL

Paper 1 A PARTIAL COHERENT MODEL OF LAYERED MEDIA WITH RANDOM PERMITTIVITIES AND ROUGHNESS FOR POLAR ICE 15:00 SHEET EMISSION IN UWBRAD

Leung Tsang, Shurun Tan, Tianlin Wang, University of Michigan, United States; Joel Johnson, Ken Jezek, The Ohio State University, United States

The snow/ ice accumulation and deposition patterns lead to rapid density fluctuations near the surface of the polar ice sheet that gradually decay with depth. The density fluctuations form layers with thickness on the order of centimeters to decimeters that fall in the coherent range of the UWBRAD frequencies of $0.5^{2.0}$ GHz. The UWBRAD is used to measure brightness temperatures over ice sheets. We note that the phase fluctuations due to fluctuating permittivity is the main cause of coherent wave decay in the layered medium.

Two approaches were previously used: the coherent approach and the incoherent approach. In the coherent approach, the wave is considered to be coherent as waves propagate through the whole body of ice sheet which can have a total thickness of kilometers. The layered medium problem is solved multiple times using different density profiles and the results are then averaged over different realizations to yield final brightness temperatures. In the incoherent approach, one ignores the coherent wave interactions between adjacent/ nearby layers, and use reflectivities of intensities to cascade intensities among layers. The neglect of coherence, even for layer thicknesses of a few centimeters, is a weak assumption at L band.

Recently, we developed a partial coherent approach. In the partial coherent approach, we first investigate the loss of coherence due to scattering by random fluctuations of permittivities. We calculate the coherent decay by a) using a simple analytic model, and b) numerical solutions of Maxwell equations. The two approaches have good agreement . In the analytic model, we assume weak permittivity contrast so that we safely ignore multiple reflections. By modeling the density profile as a Gaussian random process described by a Gaussian correlation function, we apply statistical average to the transmitted wave and obtain an analytical expression for the coherent wave with the magnitude of decay calculated. . Results shows that the coherent transmissivity can decay to less than 20% within less than 10 meters near the surface of the ice sheet at L band. Numerical results show that the coherent waves will extend for distance of about 10 meters to 50 meters depending on the frequency and the magnitude of permittivity fluctuations

In the partial coherent model, we next divide the near surface part of the ice sheet into blocks according to the decay of coherent waves. Wave interactions are considered to be coherent within the same block but incoherent across blocks. In this partially coherent approach, the intensities are cascaded among blocks subject to block boundary conditions. We also take as a special case of the topmost air/ snow interface where abrupt permittivity change occurs. The results of the partially coherent approach are shown to be in agreement with the fully coherent approach but with improved computational efficiency.

The roughness interfaces in the intermediate layer cause angular spreading of the incoherent propagating wave and cause polarization coupling. A 2nd order small perturbation method (SPM2) is developed to compute the bistatic wave scattering and transmission for multiple layered rough interfaces. The coherent wave interaction within the block is simulated using SPM2 including hundreds of layers. The results of SPM2 is further averaged using the Bayes rule of conditional probability to account for changing layer configurations due to density fluctuations

Paper 2 POTENTIAL OF THE TWO-STREAM EMISSION MODEL FOR LAND SURFACE RETRIEVALS USING PASSIVE L-BAND 15:20 OBSERVATIONS

Mike Schwank, Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Switzerland; Christian Mätzler, Andreas Wiesmann, Urs Wegmüller, GAMMA Remote Sensing Research and Consulting AG, Switzerland; Jouni Pulliainen, Juha Lemmetyinen, Kimmo Rautiainen, Finnish Meteorological Institute, Finland; Chris Derksen, Peter Toose, Environment Canada, Canada; Matthias Drusch, European Space Agency, Netherlands; Philippe Richaume, Yann H. Kerr, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France

The optimal exploitation of passive L-band data measured by e.g. SMOS and SMAP is of high interest for scientists using novel data products. Likewise, for the microwave radiometer community, the full exploitation of available L-Band data is of high priority, because this impacts the benefit-cost ratio of a mission, and hence can be a driving force for follow-up missions based on comparable measurement concepts. Beyond the global provision of soil moisture defined as one of the SMOS main objectives, the use of passive L-band data to estimate land-surface states of the cryosphere has become increasingly relevant. Likewise, the retrieval of forest-state parameters based on L-band radiometry has gained increased attention, recently. The two-stream emission model, already developed in the early nineties, is seen as a model that is simple, but at the same time accurate enough over a large optical-depth range for the use in a retrieval algorithm to achieve global estimates of surface states of the cryosphere and of forests. The goal of this presentation is to outline the potential of the two-stream approach in the context of two-parameter retrievals of snow-density and ground permittivity, as well as its potential to improve retrievals of forest optical depth based on multi-angular L-band brightness temperatures as available globally from SMOS. To begin with, the zero-order Tau-Omega emission model (so far the standard for SMOS retrievals) differs from the higher order two-stream model. Subsequently, we show a number of retrieval examples based on ground-based L-band measurements and employing inversion of the respective emission model based on the two-stream gaproach. Finally, very preliminary examples of corresponding retrievals using SMOS data are shown.

Paper 3 GPU-BASED SIMULATIONS OF COMPLEX VISIBILITIES IN SYNTHETIC APERTURE IMAGING RADIOMETRY.

15:40 Eric Anterrieu, IRAP, Université de Toulouse & CNRS, France; François Cabot, CESBIO, Université de Toulouse, CNRS, CNES & IRD, France; Yann H. Kerr, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France

The idea of aperture synthesis is to obtain high-resolution images with the aid of the computer by combining passive interferometric measurements, known as complex visibilities, corresponding to spatial frequencies associated to pairs of receiving antennae. The concept of imaging interferometry by aperture synthesis has been initially developed for radio astronomy some decades ago and it has been recently used for remote sensing of the Earth surface in the microwaves range.

In conventional interferometry, the radio signals received by pairs of spatially separated antennae observing in the same direction are sampled and directly transmitted via coaxial cables, or fiber-optic links, to a correlator unit which produces the interference fringes in real time. In such arrays, the antennae are physically connected to the correlator and the complex visibilities are obtained in real time.

For unconnected arrays, the signals received by the antennae are sampled, recorded alongside with an accurate time base, and then stored on magnetic tapes or on hard disks for deferred time analysis. At that later time, at the location of the correlator unit, the data are synchronized, played back together and combined just as if they were coming in real time from the antennae.

This contribution is concerned with the simulation of the electromagnetic wave emitted by a spatially incoherent source and collected by antennae, as well as with the numerical correlation of the corresponding radio signals.

According to the VAN-CITTERT ZERNIKE theorem, direct simulation of the complex visibilities provided by pairs of antennae observing the same scene is straightforward, whatever the correlation is performed in real time or in deferred time. However this approach rests on assumptions that do not allow studying the role and the impact of some important parameters like quantization and sampling rate of the signals collected by the antennae, integration time and clock errors at correlator level. Moreover, none of the effects that may alter the propagation from the source to the array can be taken into account.

The approach presented here aims at simulating the electromagnetic wave emitted by an extended source and captured by the antennae. The source is assumed to behave like a black body in thermal equilibrium. It can be thought of as being made up of many point sources which are supposed to be responsible for the radiation by acting independently of one another. The electromagnetic wave emanating from the extended source is therefore a linear superposition of random waves. The random wave emitted by each point source is numerically generated with the aid of a white noise filtered with a FIR filter so that its power spectral density takes on the shape of the PLANCK distribution over a wide range of frequencies, at the temperature of the point source. The electromagnetic wave is transported to the antennae where the voltage patterns are taken into account and the corresponding radio signals are then sent to the correlator unit for being cross-correlated.

Numerical comparisons conducted in the L-band around 1.415 GHz confirm that, in an ideal situation, the two approaches lead to the same complex visibilities. However, only the second one can properly account for effects which may affect the propagation of the signal between emission at source level and capture at antenna level, as well as the cross-correlation at correlator level. Nevertheless, the drawback of this approach is the amount of calculations which makes necessary the use of a massive parallel architecture like that found in GPU.

Paper 4 GENERALIZATION OF THE VAN CITTERT-ZERNIKE THEOREM: OBSERVERS MOVING WITH RESPECT TO SOURCES

16:00 Younes Monjid, Bernard Rougé, Yann H. Kerr, Centre d'Etudes Spatiales de la Biosphère (CESBIO), France; Daniel Braun, Institut für theoretische Physik, Universität Tübingen, Germany

Aperture synthesis is an interferometric technique in which the signals received by pairs of small antennas are processed in a way to synthesize a single large antenna [1]. This concept has been adapted from radioastronomy to Earth remote sensing. Thanks to this technique, limitations on antenna size in microwave passive remote sensing through satellites have been overcome [2].

The correlation function obtained by cross-correlating the signals received by the antennas of an interferometric system using aperture synthesis is linked to the brightness temperature of the Earth's surface through a Fourier relationship. This is known as the Van Cittert-Zernike theorem [3]. Its standard formulation is derived by cross correlating the electric fields measured at the same time by different antennas, and does not take into account the relative motion of the observer with respect to the sources of the electro-magnetic fields at the surface of the Earth. Taking into account the relative motion of the satellite could yield additional information which, when combined with a classical spatial aperture synthesis, could be employed for a spatio-temporal aperture synthesis. If successful, this might open a way to even larger spatial resolution, meeting the demands of modern hydrological applications where sub kilometric resolutions are needed [4].

In a recent detailed study of this idea, we generalized the Van Cittert-Zernike theorem to the case of observers moving with respect to the sources and to the correlation of fields measured at times that differ by the travel time of the observer along a virtual baseline [5]. The derivation is based on first principles, starting with the wave propagation in the Earth reference frame of electro magnetic fields arising from incoherent current sources, and Lorentz transforming the fields into the reference frame of the satellite. Our study leads to the remarkable conclusion that the additional phase due to the observer motion is exactly cancelled by the linear Doppler effect. Thus, while preventing a simple spatio-temporal aperture synthesis, our results justify the neglect of the Doppler effect in existing imaging systems based on the standard form of the theorem [6].

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