ABSTRACT BOOKLET of the

4th Satellite Soil Moisture Validation and Application Workshop and the CCI Soil Moisture User Workshop

18 - 20 September 2017, Vienna, Austria

EDITORS: WOUTER DORIGO AND WOLFGANG WAGNER

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The **4th Satellite Soil Moisture Validation and Application Workshop** and the **CCI Soil Moisture User Workshop** are taking place at Vienna University of Technology (TU Wien) from 18 to 20 September 2017, locally organized by TU Wien's Department of Geodesy and Geoinformation.

The purpose of the **Satellite Soil Moisture and Application Workshop** is to discuss and reconcile recent methodological advances in the development, validation and application of global satellite soil moisture data. The workshop series is unique by bringing together satellite soil moisture users and developers to focus on both the derivation and exploration of soil moisture data from passive or active microwave satellite missions (SMAP, SMOS, ASCAT, AMRS-2, Sentinel-1, and other legacy missions). Following research questions will be addressed during this workshop:

- What is the quality of the current satellite products and what can we expect in the near future?
- What is information content at Level 1 and how to exploit the availability of multiple satellites?
- Who is using satellite soil moisture data and for what purpose?
- What are the best practices in validating soil moisture products?
- What are the main limitations of satellite soil moisture data from a user's perspective?
- What is the future of satellite-based soil moisture remote sensing?

The workshop follows up workshops held at the European Space Agency in Frascati (Italy, in 2013), at the Royal Netherlands Academy of Arts and Sciences in Amsterdam (Netherlands, in 2014) and at the Millenium Broadway Hotel in New York (USA, in 2016). The report from the 3rd workshop was published in the GEWEX News November 2016.

The **CCI Soil Moisture User Workshop** is similar in scope but particularly invites users of the CCI Soil Moisture products.Users from any relevant application area are invited to present their experiences with the data and provide ideas for future product improvements. The CCI Soil Moisture User Workshop is an event organized within the framework of ESA's Climate Change Initiative (CCI) Soil Moisture project.

Edited by Wouter Dorigo and Wolfgang Wagner.
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Think before you print!

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Sequential assimilation of satellite-derived vegetation and soil moisture products using SURFEX_v8.0: LDAS-Monde assessment over the Euro-Mediterranean area

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In this study, a global Land Data Assimilation system (LDAS-Monde) is tested over Europe and the Mediterranean basin to increase monitoring accuracy for land surface variables.
The resulting LDAS is able to ingest information from satellite-derived surface Soil Moisture (SM) and Leaf Area Index (LAI) observations to constrain the ISBA land surface model (Interactions Between Soil, Biosphere, and Atmosphere) coupled with the CNRM (Centre National de Recherches Météorologiques) version of the Total Runoff Integrating Pathways (ISBA-CTRIP) continental hydrological system. It makes use of the CO2-responsive version of ISBA which models leaf-scale physiological processes. Transfer of water and heat in the soil rely on the multilayer diffusion scheme. Surface SM and LAI observations are assimilated using a simplified extended Kalman filter (SEKF), which uses finite differences in the observation operator Jacobians to relate the observations to the model control variables. The latter include LAI and seven layers of soil (from 1 cm to 100 cm depth). A sensitivity test of the Jacobians over 2000-2012 exhibits effects related to both depth and season. It also suggests that observations of both LAI and surface SM have an impact on the different control variables. From the assimilation of surface SM, the LDAS is more effective in modifying soil-moisture from the top layers of soil as model sensitivity to surface SM decreases with depth and has almost no impact from 60 cm downwards. From the assimilation of LAI, a strong impact on LAI is found. The LAI assimilation impact is more pronounced in SM layers that contain the highest fraction of roots (from 10 cm to 60 cm). The assimilation is more efficient in summer and autumn than in winter and spring. Assimilation impact shows that the LDAS works well constraining the model to the observations and that stronger corrections are applied to LAI than to SM. The assimilation impact's evaluation is successfully carried out using (i) agricultural statistics over France, (ii) river discharge observations, (iii) satellite-derived estimates of land evapotranspiration from the Global Land Evaporation Amsterdam Model (GLEAM) project and (iv) spatially gridded observations based estimates of up-scaled gross primary production and evapotranspiration from the FLUXNET network. Comparisons with those four datasets highlight neutral to highly positive improvement.

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The Impact of soil moisture temporal and spatial variability on passive satellite microwave observations over the Desert of Kuwait

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In this paper we analyze the spatial and temporal variations of soil moisture over the desert area of Kuwait and their impact on different passive microwave observations from SMAP, SMOS, and AMSR2. An intensive field campaigns were conducted to collect gravimetric samples for every 3 km over the entire 36km x 36km SMAP satellite test site in the desert of Kuwait.
The 156 samples covering 10 soil types collected on the 20th of February 2016 had an average of 0.039 m3 m-3 in soil moisture with standard deviation of 0.015 m3 m-3. On the 19 of March 2016, the soil moisture average for 166 samples (covering the 13 soil types) was 0.046 m3 m-3 with standard deviation of 0.017 m3 m-3. The analysis of these samples with different soil classes and topography showed exceptional homogeneity over the SMAP grid test. A simulated brightness temperatures using the gravimetric soil moisture values were compared with the satellite brightness temperatures from SMAP, SMOS, AMSR2 at different frequencies. The results and analysis of this comparison are discussed in this paper.

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Integrating SMOS and SMAP observations

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Soil Moisture Active Passive (SMAP) mission and the ESA Soil Moisture and Ocean Salinity (SMOS) missions provide brightness temperature and soil moisture estimates every 2-3 days. SMAP brightness temperature observations were compared with SMOS observations at 40o incidence angle. The brightness temperatures from the two missions are not consistent and have a bias of about 2.7K over land with respect to each other. SMAP and SMOS missions use different retrieval algorithms and ancillary datasets that result in further inconsistencies between the soil moisture products. The reprocessed constant-angle SMOS brightness temperatures were used in the SMAP soil moisture retrieval algorithm to develop a consistent multi-satellite product.
The integrated product will have an increased global revisit frequency (1 day) and period of record that would be unattainable by either one of the satellites alone. Results from the development and validation of the integrated product will be presented.

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Towards creating a ESA CCI soil moisture root-zone product

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The European Space Agency Climate Change Initiative (ESA CCI) is dedicated to essential climate variables (ECVs) data production; it currently comprises fourteen projects with soil moisture being one of these. The ESA CCI for soil moisture was initiated in 2012 for a period of six years, the objective for this period is to produce the most complete and consistent global soil moisture data record based on both active and passive sensors.

The ESA CCI soil moisture product v03.2 consists of three surface soil moisture datasets: The "Active Product" and the "Passive Product" were created by fusing scatterometer and radiometer soil moisture products, respectively; the "Combined Product" is a blended product based on the former two datasets.

The ESA CCI soil moisture product is the most comprehensive satellite product, giving superior spatial coverage over stand alone satellites, the new ESA CCI soil moisture product v03.2 is in this work assimilated into the SURFEX land surface model using the ensemble Kalman Filter and a diffusion scheme for the soil physics. For certain conditions data assimilation (DA) allows for an optimal combination of model and observation data, and it is possibly the method with the biggest potential for creating a root-zone product. Several studies have shown that information from the observational layer is transferred further down to the root-zone layers and increases the correlation with in situ data.

We evaluate the resulting level 4 product using data assimilation (DA) consistency tests, in situ data and the independent SMAP level 4 dataset. The potential for creating a ~30 year long time-series of root-zone soil moisture using DA and the ESA CCI product is also discussed.

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Assessment of irrigation water from satellite soil moisture data: is it feasible?

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Nowadays, irrigated agriculture accounts for about 70 percent of water withdrawn worldwide from lakes, rivers and aquifers, thus being perhaps the greatest human intervention in the hydrological cycle. In the last 40 years, global agricultural production has more than doubled and even though irrigated lands account of only 17 percent of total croplands, they produce 40 percent of food worldwide. Therefore, the knowledge of the distribution and the extent of irrigated areas and the amount of water used by irrigation is essential. Notwithstanding its importance, to obtain high-quality information about the actual irrigated areas worldwide is nontrivial and the problem is much more pronounced in terms of the quantification of the water actually used for irrigation.

Satellite soil moisture data can be highly useful in this context and the use of this information for irrigation detection and quantification is the object of an ongoing project funded by European Space Agency (ESA) named WACMOS-Irrigation. Specifically, the algorithm SM2RAIN (Brocca et al., 2014) is exploited for the quantification of irrigation water amount from satellite soil moisture data by using different products: ESA CCI SM (ESA Climate Change Initiative Soil Moisture), SMOS (Soil Moisture Ocean Salinity), SMAP (Soil Moisture Active and Passive), ASCAT (Advanced SCATterometer) and AMSR2 (Advanced Microwave Scanning Radiometer 2).

First results in terms of irrigation detection were already produced in US highlighting that satellite soil moisture data are able to detect large scale irrigated areas in Nebraska and California (Brocca et al., 2017), and potentially provide information on irrigation water amount. More advanced results were obtained in Iran where satellite soil moisture data from AMSR2 were found able to reproduce the ground observed temporal evolution of irrigation in the period 2013-2015.

As the amount of water used for irrigation is largely unknown on a global scale, the capability of satellite soil moisture data to estimate irrigation might have a tremendous impact in future applications. At the conference, the updated results in different regions worldwide (Spain, India, Eastern China), and by using different satellite soil moisture products, will be shown.

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Inter-Calibration of low frequency britghtness temprerature measurements for a long-term uniform soild moisture record

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Soil moisture is a key parameter to determine water availability; it connects the terrestrial water, energy and carbon cycles, and acts as a climate indicator. The 2007 Decadal Survey reinforced the necessity of monitoring soil moisture by recommending a dedicated soil moisture mission. While many sensors capable of soil moisture sensing at different frequencies have been launched over the years, each of them pursues the goal of successfully retrieving soil moisture based on their own calibration and validation metrics. Fundamentally, the interest lies in a consistent long-term soil moisture record which ultimately requires spanning multiple satellite platforms; we therefore need a method to produce a consistent data record across sensors. Soil moisture was named an Essential Climate Variable (ECV) in 2010 by the Global Climate Observing System, emphasizing the need for a long-term soil moisture product.

This study focuses on four satellites that are capable of soil moisture retrieval via brightness temperature observations: JAXA's Advanced Microwave Scanning Radiometer-EOS (AMSR-E) launched in May 2002 on the NASA Aqua satellite (it stopped nominal data acquisition in October 2011), ESA's Soil Moisture and Ocean Salinity (SMOS) mission launched in November 2009, JAXA's Advanced Microwave Scanning Radiometer 2 (AMSR2) onboard the GCOM-W satellite launched in May 2012, and NASA's Soil Moisture Active Passive (SMAP) mission launched in January 2015. The approach is threefold: (a) inter-calibration of the L-, C- and X-band brightness temperatures of AMSR-E, SMOS, AMSR2 and SMAP. This is achieved using a multi-frequency ocean brightness temperature model. The temporal overlaps of SMOS with AMSR-E, and SMAP and SMOS with AMSR2 are utilized to ensure the consistency of the brightness temperature records. (b) A uniformly designed soil moisture retrieval algorithm is applied to the satellite measurements to retrieve consistent soil moisture. In-situ soil moisture data are used as the ground truth to parameterize and test the performance of the soil moisture retrieval algorithm. Finally, (c) the different sensing depths of the different frequencies are compensated using a model. This enables the provision of soil moisture at a uniform depth. This work enables a consistent global soil moisture data record spanning from 2002 to present.

The investigation started in 2016; we will present preliminary results of the effort so far.
The focus will be on brightness temperature inter-calibration and soil moisture algorithm parameterization across frequencies.

The research described in this paper is supported by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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Towards cross-cutting land ECV consistency assessment through data assimilation

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Meteo-France has implemented cross-cutting quality monitoring chains in the Copernicus Global Land service (http://land.copernicus.eu/global/) for near-real-time land products (soil moisture, LST, LAI, FAPAR, surface albedo). These chains are derived from a global Land Data Assimilation System (LDAS-Monde) based on the SURFEX open-source modeling platform.
The latter is also used in the CNRM-ARPEGE climate model. The LDAS-Monde chains are operated over France, and over the Euro-Mediterranean area and are used to assess the quality and the consistency of land ECV products on a yearly basis. This is now the only LDAS chain able to sequentially assimilate vegetation products, jointly with soil moisture products.
Since the assimilation of LAI impacts the soil moisture analysis, and vice versa, the consistency between these products can be assessed. The resulting analyses should be closer to all ECVs (including FAPAR, albedo, LST). This can be considered as a consistency criterion. The DA statistics (e.g. pdf of residuals, innovations) and increment time series provide additional information. Case studies over France and over the Euro-Mediterranean areas are shown for the period covered by ASCAT (2007 to 2016). First results of LDAS-Monde operated at a global scale are shown.

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Exploiting ASCAT-derived Soil Moisture Products for improving Flash Floods Forecast in Mediterranean Catchments via Data Assimilation

Luca Cenci (1), Paola Laiolo, Simone Gabellani, Lorenzo Campo, Francesco Silvestro, Fabio Delogu, Giorgio Boni, Roberto Rudari, Luca Pulvirenti, Giuseppe Squicciarino and Nazzareno Pierdicca

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The exploitation of soil moisture (SM) - data assimilation (DA) techniques in hydrological modelling can reduce the uncertainty of streamflow simulations. In small catchments, such as those characterizing the North-West Mediterranean area, flash floods forecast can thus be improved by adopting such approaches. Given the small sizes these basins, it is interesting evaluating - in such areas - the performances of SM-DA systems based on observations retrieved by using coarse spatial resolution instruments (e.g. scatterometers).

In this work it was assessed the effect of the assimilation of three different ASCAT-derived soil moisture products (i.e., H07, H08 and H14) within a hydrological model (Continuum) currently used in Italy for Civil Protection activities, both at national and at regional level. Three selected Italian catchments, representative of the typical Mediterranean small basins prone to flash floods, were chosen as test sites. During the SM-DA experiments, different Nudging-based techniques were used. The purpose was to evaluate also the potentialities of simple assimilation approaches, computationally efficient, thus suitable for operational applications. Results were evaluated by comparing observed discharge data against the modelled one. The analyses were executed during a two years period (2012 - 2014).

Findings showed that the assimilation of ASCAT-derived SM products with simple DA algorithms can improve flash floods forecasts in Mediterranean catchments. In such areas, the impact of the assimilation was found to depend on the permanent catchment characteristics (e.g., topography, land cover, distance from the sea). Finally, it was shown that although H08 and H14 are added-value products with respect to H07, they may not necessarily perform better.

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Development and Algorithm Updates of the SMAP Resolution-Enhanced Passive Soil Moisture Product

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The NASA Soil Moisture Active Passive (SMAP) is a mission designed to provide frequent and high resolution global mapping of soil moisture and freeze/thaw state through the synergy of a radar (active) and a radiometer (passive) operating at L-band frequencies (~1.4 GHz). Since the beginning of routine science operation in March 2015, the SMAP radiometer has been operating nominally, returning L-band brightness temperature data that enable global mapping of soil moisture estimate at a 36 km spatial scale every 2–3 days. Since the validated release of the standard 36 km SMAP passive soil moisture product (L2_SM_P), the team has been evaluating options to further enhance the product. One emerging option is the enhancement of resolution of the product based on the fact that the SMAP radiometer oversamples in the across-track direction. These oversampled observations provide an opportunity to enhance the resolution of the radiometer observations through the Backus-Gilbert interpolation. The resulting resolution-enhanced brightness temperature observations (L1C_TB_E) are then used with high-resolution ancillary data to produce a new passive soil moisture product (L2_SM_P_E) with enhanced resolution. The resulting L2_SM_P_E is a global soil moisture product posted on a 9 km Earth-fixed grid whose retrieval uncertainty has been shown to be less than 0.040 m3/m3 based on comparison with an annual record of in situ soil moisture measurements collected at core validation sites. As of December 2016, L1C_TB_E and L2_SM_P_E have been available from the National Snow and Ice Data Center (NSIDC) for public evaluation.

In this presentation, the development of the SMAP resolution-enhanced passive soil moisture product will be discussed. Examples of this enhanced product will be given at regional and global scales to illustrate the additional spatial details not apparent in the standard passive soil moisture product. In addition, temporal variability in terms of transient and seasonal patterns of L2_SM_P_E will be examined alongside available in situ soil moisture measurements collected at core validation sites and sparse networks, providing a quantitative way to evaluate the performance of L2_SM_P_E at the different spatial scales. Future plans of algorithm refinements and their preliminary results will also be given.

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Long-term ESA CCI soil moisture derived rainfall product through SM2RAIN

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Accurate and long-term rainfall estimates are the main input for several applications, spanning from crop modeling to climatic analysis. Raingauges are the main source of data, but they provide only punctual measurement and they are characterized by a non-homogenous coverage. Satellite-based rainfall products can provide valuable and reliable rainfall information but the indirect nature of measurement and the biases related to their estimates can limit their use. The exploitation of soil moisture observations for rainfall estimation can represent an important and new source of information for an accurate rainfall estimation, due to the strong relationship between rainfall and soil moisture.

In this study, a new long-term rainfall dataset, obtained from satellite soil moisture observation, is presented. The ESA Climate Change Initiative (CCI) soil moisture products during the period 1998-2015 are used for rainfall estimation via SM2RAIN, in order to generate a 18-year long, daily rainfall product with a spatial resolution of 0.25° on a global scale. The dataset is generated by integrating rainfall estimates obtained from the Active and Passive SM datasets. The quality of the new CCI-derived rainfall product is assessed by comparing the simulated rainfall estimates with state-of-art rainfall products on a global scale (Global Precipitation Climatology Centre Full Data Daily, GPCC-FDD, Tropical Rainfall Measurement Mission Multi-satellite Precipitation Analysis, TMPA 3B42RT, Climate Prediction Center Morphing technique, CMORPH, ERA-Interim and Multi-Source Weighted-Ensemble Precipitation, MSWEP). The assessment has been carried out both on a global and on a local scale, considering 7 areas worldwide, to test the capabilities of the dataset to correctly identify rainfall events under different climate and precipitation regimes. The new soil moisture-derived rainfall dataset provided very good results in terms of correlation coefficient (median $R>0.56$), RMSE (median RMSE<10.34 mm) and BIAS (median BIAS<-14.44%) during the analysis period. Moreover, the new rainfall dataset has been used to force a rainfall-runoff model to test the reliability of such information for hydrological applications over 15 basins within the Mediterranean area. The results showed good performance highlighting the usefulness of obtaining rainfall information from soil moisture observations.

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Impact of Excluding Precipitation Events from Soil Moisture Validation

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Precipitation events create vertically uneven distribution of soil moisture in the top layer of soil. After a precipitation event it will take time for the soil to reach a relative equilibrium again, which will depend upon the characteristics of both the precipitations and the local conditions. An assumption of the common soil moisture retrieval algorithms is that soil moisture is homogeneous in the first few centimeters of the soil. Moreover, many in situ sensors used for soil moisture validation measure the average soil moisture in the surface soil but sometimes this measurement does not include the first couple of centimeters as the probes are installed horizontally at 5 cm depth. Hence, for comparison purposes both the algorithm assumption and the representativeness of the in situ measurement are compromised during and after the rain event. The SMAP product contains a flag for rainfall events which is based on modeled precipitation but currently it captures only a fraction of the actual rainfall occurring during over-passes.

In this investigation the impact of using observed precipitation as a quality flag in soil moisture retrieval was examined. The two metrics of importance are the potential improvement in retrieval performance and the loss of retrievals. The analysis uses the Soil Moisture Active Passive (SMAP) Level 2 enhanced soil moisture product based on the passive microwave radiometer (L2SMPE). Validation included 10 core validation sites (CVS) that had both a dense network of soil moisture sensors and precipitation gauges. The screening of the measurements was done with a variable size time window. The length of the window was defined from the end of each precipitation event so that all measurements during and after the rain event were removed.

The results showed that the mean unbiased root mean square error (ubRMSE) of the in situ comparisons improved with increasing time window size. With a 36-hour window the improvement reached 20% (reducing ubRMSE from 0.034 m3/m3 to 0.027 m3/m3), but at the same time about third of the data was lost.

However, with the increasing window size the mean bias increased about 40% (from -0.018 m3/m3 to -0.027 m3/m3). As the SMAP soil moisture product typically overestimates soil moisture during and right after the rain events, removing these points may reveal the correct magnitude of the underlying underestimation of soil moisture. These results will be accounted for in future development and validation of the SMAP soil moisture algorithm.

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Ongoing research at the Marena Oklahoma In Situ Sensor Testbed (MOISST)

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A testbed for comparing in situ soil moisture sensors was initiated by USDA and Oklahoma State University in2010 in cooperation with the NASA Soil Moisture Active Passive mission.
This testbed was sited in Marena, Oklahoma on the Oklahoma State University Range Research Station. The testbed consists of four base stations, each consisting of different soil moisture sensors installed in profiles to compare their performance. Multiple stations enabled replication of the measurements, while also support the investigation of larger spatial distributions of soil moisture. These include stations from the COSMOS network, GPS Reflectometry Network, Climate Reference Network, and active and passive Distributed Temperature Systems. For the first deployment of sensors, calibration and scaling analysis was performed and most sensors are able to perform with an error less than 0.04 m3/m3, when compared to a gravimetric sample, but site specific calibration is necessary for most of the sensors. Additional sensors have been deployed recently as technologies have been developed and sensors have been replaced.

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Correcting Systematic Land Surface Modeling Error Using Remotely-Sensed Soil Moisture

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Within the past fifteen years, great strides have been made in the development and application of land data assimilation systems designed to filter errors within prognostic land surface model predictions. However, such approaches suffer from a fundamental limitation in that they only address random sources of error (e.g. stochastic uncertainty in model forcing data sets) and offer little or no remedy for systematic errors arising from fundamental process-level deficiencies at the center of these models. This talk will highlight recent efforts to address this shortcoming and exploit remotely-sensed soil moisture data set to identify systematic errors impacting land surface model output. In particular, SMAP, SMOS, ASCAT and AMSR-E remotely-sensed surface soil moisture data sets will be used to evaluate the degree to which existing land surface model adequately capture the relationship between surface soil moisture and both evapotranspiration and storm-scale surface runoff. Surface runoff results, in particular, highlight what appears to be a fundamental (and pervasive) tendency for land surface models to underestimate the impact of pre-storm soil moisture conditions on storm-scale runoff efficiency.
This systematic error may be responsible for squandering an important source of hydrologic predictability in existing stream flow forecasting systems. The presentation will highlight the unique ability of remotely-sensed soil moisture data sets to identify these systematic errors and discuss strategies for broadening the application of remotely-sensed soil moisture beyond data assimilation-based approaches.

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Leveraging Long-term, Remotely-Sensed Soil Moisture Datasets for Optimal Averaging of Ensemble Land Surface Model Predictions

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It is commonly recognized that averaging across on ensemble of land surface model predictions provides an estimate which is (generally) superior to any single member of the ensemble in isolation. However, optimal averaging across a model ensemble requires knowledge of both the error variance for each model as well as the error covariance between various model pairs. Such covariance is typically found in land surface model ensembles due to the models' common reliance on particular meteorological forcing data sets.
This talk will outline a new statistical approach to derive the full error covariance matrix (i.e. both error variance and error covariance information) for surface soil moisture predictions obtained from an ensemble of land surface models based on comparisons with the ESA CCI long-term soil moisture data set. The approach will be demonstrated using ensemble model predictions over the United States obtained from the NLDAS-2 project and special attention will be paid to the impact of temporal sensor variations within the CCI soil moisture data set. Results will demonstrate that this technique represents an important new application for the CCI data set and a valuable pathway towards the generation of long-term, retrospective land surface data sets which optimally combine both remotely-sensed and model-based information.

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High-Resolution Enhanced Product based on SMAP Active-Passive Approach using Sentinel 1A and 1B SAR Data

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SMAP project is working on a new and enhanced high-resolution (3km and 1km) soil moisture product. This product will combine SMAP radiometer data and Sentinel-1A and -1B data, and it will use the heritage SMAP active-passive approach. However, modifications in the SMAP active-passive algorithm are done to accommodate the Sentinel-1A and -1B C-band SAR data. Tests of the SMAP and Sentinel active-passive algorithm has been conducted and results show great promise for the high-resolution soil moisture data. The beta version of this product will be released to the public in end of May 2017. This high-resolution (1 km and 3 km) soil moisture product will be useful for agriculture, flooding, watershed and rangeland management, and ecological and hydrological applications. Specific examples of interest will be shown from the proposed product for the above mention geophysical applications.

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RSMN: 4 Years of In-Situ & Satellite Soil Moisture Observations in Romania

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Almost 4 years ago, with funding from the Romanian Space Agency, project ASSIMO's ambitious goal was to jumpstart satellite soil moisture activities in Romania. With more than 13 million hectares of agricultural land, there was a strong incentive to explore the potential of satellite soil moisture products.

Beside its recognized role in the climate system as one of the Essential Climate Variables (ECV), soil moisture information is essential for crop monitoring and agricultural yields forecasting but it can equally improve the accuracy of flood prediction or contribute to better weather forecast.

A continuous soil moisture & temperature measurement network (RSMN) has been built out of 20 evenly distributed 5TM probes deployed at weather station locations to which a fleet of 25 mobile soil moisture stations has been added - to both increase RSMN density and serve in data collection campaigns over smaller areas. SMOS and SMAP satellite products have been compared against the collected measurements, to help evaluate the satellite soil moisture products suitable for practical applications. Data has been shared with ISMN from the early days.

At project completion, the Romanian Weather Service decided to further support RSMN and to fund its operation and the development of satellite soil moisture products for its own use and that of its industrial customers.

This presentation shows the results obtained during the last 4 years, the RSMN configuration and talks about future plans.

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ESA CCI Soil Moisture - from science to operations

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Climate Data Records of soil moisture are fundamental for improving our understanding of long-term dynamics in the coupled water, energy, and carbon cycles over land. In respond to this need, the European Space Agency (ESA) released in 2012 - as part of its Climate Change Initiative (CCI) program - the first multi-decadal, global satellite-observed soil moisture (SM) dataset. ESA CCI SM combines various single-sensor soil moisture products from active and passive microwave sensors into three harmonised products: a merged ACTIVE, a merged PASSIVE, and a COMBINED active+passive product.

In our presentation, we first give an overview of the latest ESA CCI SM developments and its product and error characteristics. Recently, the ESA CCI SM product saw a large number of enhancements, e.g., with respect to the merging methodology, the inter-calibration of sensors, and the characterisation of errors. Besides, due to the inclusion of recently launched sensors like the Soil Moisture Ocean Salinity (SMOS) mission, the Advanced Microwave Scanning Radiometer 2 (AMSR2) and the Advanced Scatterometer (ASCAT) onboard the MetOp-B satellite, the latest product release now covers the period 1978-present. We show that the product quality has increased since its first release but that for certain surface conditions (e.g., dense vegetation, organic soils) uncertainties are still substantial.

Second, we show what modifications are required to transfer ESA CCI SM into the operational processing chain of the Copernicus Climate Change Service (C3S) for Soil Moisture. From July 2017, C3S is expected to deliver an update of the three multi-satellite products every 10 days. We conclude this presentation by identifying gaps and threats in the existing ESA CCI SM and C3S Climate Data Records and potential ways to overcome these.

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On the evaluation of remotely sensed soil moisture - What are (the) errors?

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Addressing the needs of the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration & Validation (WGCV), a joint team of scientists involved in satellite soil moisture Cal/Val activities from different groups all over the world has initiated the writing of a white paper which shall serve as guideline for such Cal/Val activities.

This paper consists of three parts: (i) An educational part that provides the background knowledge about the challenges of evaluating coarse-resolution data sets (relating to the provision of a precise definition of “error”, the various aspects of data quality, and spatio-temporal representativeness), (ii) a comprehensive review of available evaluation methods and metrics, and (iii) the definition of standardized protocols based on state-of-the-art knowledge and the product users’ needs.

Here we will present the progress that has been made since the last Satellite Soil Moisture Validation and Application Workshop.

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Interannual variability of the satellite observed and WRF modeled soil moisture in connection with dust events

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Dust aerosols affect human life, ecosystems, and the climate. It is important to extend the historical dust records, to better understand their temporal changes, and to use such information to help improve the daily dust forecasting skill as well as the projection of future dust activity under the changing climate. In this study, we develop dust records from the Moderate Resolution Imaging Spectroradiometer (MODIS) deep blue aerosol product, as well as dynamic dust source areas based on the satellite land cover and vegetation index products for the past decade. The temporal changes of the dust events are discussed in relation to the dynamics of land surface (soil moisture and vegetation) and atmospheric weather conditions (e.g., winds). We first explore the relationships between the dynamic dust source areas and dust activity in Arizona, USA with the ESA Climate Change Initiative (CCI) soil moisture product v03.2, for the period of 2005-2015. This analysis extends what's been shown in Huang et al. (2015) using an earlier version of the CCI product for the 2005-2013 period. We then relate the interannual variability of dust events in multiple regions (East Asia, Africa, Western US) in the Northern Hemisphere with the NASA Soil Moisture Active Passive (SMAP) soil moisture product and Weather Research and Forecasting (WRF) modeled weather fields, for 2015 and 2016. The variability of identified dust events is shown related to observed or/and simulated weather patterns and surface conditions, suggesting a potential for use of satellite soil moisture and other products to help interpret and predict dust activity. Although multiple WRF simulations show qualitatively consistent soil moisture interannual variability to SMAP, we demonstrate that a number of factors affect the detailed model performance.

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Dense groundwater networks as an unexplored validation tool for satellite soil moisture

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Two recently developed soil moisture datasets as derived from the Land Parameter Retrieval Model (LPRM) are compared to a dense groundwater network in the Netherlands. The first product was based on C-band satellite observations from the Japanese Advanced Microwave Scanning Radiometer (AMSR2) and the other from the L-band NASA Soil Moisture Active Passive (SMAP) mission. This study revealed that a dense groundwater network of approximately 4000 stations, that was so far never explored, seemed to be an excellent validation tool for satellite soil moisture products over the Dutch lowlands. Strikingly, high correlations were found between the satellite soil moisture products and groundwater observations. Both the AMSR2 and SMAP surface soil moisture products perform well over the Netherlands. The L-band SMAP product has a better skill than the C-band AMSR2 product (R(SMAP)= 0.74 versus R(AMSR2)= 0.62 for the median of all groundwater observations).
Shallow groundwater levels give the best results and a substantial degradation in correlation when the average groundwater level drops below 150 cm below the surface. The promising results of this study could set the base for additional hydrological research and we believe that further research on the relationship between satellite soil moisture and groundwater levels could potentially lead to a better understanding of the hydrological processes in the unsaturated zone.

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The SMOS soil moisture validation and initercomparison approach and results

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The Soil Moisture and Ocean Salinity mission has been collecting data for over 7 years. Several other mission did so and in particular the Soil Moisture Active and Passive for now more than 2 years. SMOS produces as well root zone soil moisture and vegetation opacity and all these products have to be validated. We will present the approach taken both for sparse and dense networks.For surface Soil Moisture, SMOS and SMAP data sets have been reprocessed and intercompared, showing a very strong correlation where data were deemed good for both sensors. This opens the path to two main features:

1) Producing merge data sets to ensure a better global coverage (SMOS over forested areas, SMAP over RFI affected areas for instance)

2) having a higher temporal revisit where both perform as ther do not even require scaling.

We will present the inter-comparison at Brightness temperature level for SMOS and SMAP as well as in terms of soil moisture for several sensors and depict how we could establish an improved data set by merging the SMOS and SMAP sensors. We also produce a SMAP like SMOS product which will be compared to other sensors.

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How well the effects of vegetation and roughness were corrected for soil moisture retrieval using L-band radar data?

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In retrieving soil moisture using radar data, the effects of vegetation scattering/absorption, and scattering from rough soil surface are often major contaminants. These effects need to be rigorously corrected for before accurate soil moisture retrieval. We developed physical models for L-band scattering and absorption at 40deg incidence angle to perform soil moisture retrieval using the Soil Moisture Active Passive (SMAP) synthetic aperture radar (SAR) data. These models were inverted to retrieve soil moisture using the 3-month SMAP SAR data and also the airborne UAVSAR data acquired during the SMAP validation experiment of 2012.
The soil moisture retrievals have an accuracy of 0.052 m3/m3 ubRMSE, -0.015 m3/m3 bias, and a correlation of 0.50, as compared to in-situ measurements.

The successful retrieval offers an opportunity to evaluate how well the effects of vegetation and surface roughness were performed. The evaluation was conducted in two ways. The first was to examine if the scattering mechanism is realistic, which is a pre-requisite of the correction of the vegetation effect. The SMAP retrieval shows that surface scattering was strongest for grass and soybean fields and the early stage of wheat fields; double bounce contribution began to dominate for late-stage of wheat, savanna, and woody savanna. These findings are in agreement with the expectation. The similar analysis will be performed for the UAVSAR retrievals.

Secondly, the retrieved rms height and vegetation correction were examined. At the 14 core validation sites of SMAP, all the retrievals of surface roughness were between 0cm and 5cm. There is a general trend towards rougher surfaces in croplands. Half of the crop lands had rms height greater than 3cm. In comparison, roughness estimates of the pasture lands did not exceed 3cm, as the pasture lands are expected to be smoother than croplands. Two natural surfaces (savanna and shrub) report 3cm and 0.5cm, respectively.

The vegetation effects were estimated by revising the input ancillary information of vegetation water content (VWC) through a scaling factor. The ancillary VWC in Australia is the climatology, which justifies the revision (our approach is to estimate one scaling factor).

Apart from Yanco sites, the adjustment factor was mostly close to 1 regardless of the vegetation type. The retrievals over Yanco sites worked best when the VWC were reduced to ~20% of the climatology. For the SMAP retrieval, however, the in situ observations do not provide the truth values of rms height and vegetation because the pixel size (3km) is too large to characterize these. The similar analysis for UAVSAR retrievals will be presented, where the in situ truths are available.

These results indicate that the forward model is sufficiently reliable to allow the estimates of soil moisture, soil surface roughness, and vegetation water content in many sites tested.

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Optimizing bias correction in SMAP soil moisture assimilation

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Statistical techniques permit the retrieval of soil moisture estimates in a model climatology while retaining the spatial and temporal signatures of the satellite observations. As a consequence, they can be used to reduce the need for localized bias correction techniques typically implemented in data assimilation (DA) systems that tend to remove some of the independent information provided by satellite observations. Here, we use a statistical neural network (NN) algorithm to retrieve SMAP surface soil moisture estimates in the climatology of the NASA Catchment land surface model. Assimilating these estimates without additional bias correction is found to significantly reduce the model error and increase the temporal correlation against SMAP Cal/Val in situ observations over the contiguous United States.
A comparison with assimilation experiments using traditional bias correction techniques shows that the NN approach better retains the independent information provided by the SMAP observations and thus leads to larger model skill improvements during the assimilation. A comparison with the SMAP Level 4 product shows that the NN approach is able to provide comparable skill improvements and thus represents a viable assimilation approach.

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Improving the accuracy of GPM rainfall estimates over the Tibetan Plateau using SMAP soil moisture product

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Rainfall is one of the essential inputs of agricultural, hydrological and land surface models. Satellite remote sensing is able to provide regional and global rainfall estimates. However, there is still room to improve the accuracy of satellite rainfall products in areas where no/less rain gauges available, such as the Tibetan Plateau. In this study, the satellite rainfall product provided by the state-of-art Global Precipitation Mission (GPM) is further improved by using the soil moisture retrieval provided by the Soil Moisture Active Passive (SMAP) mission over Tibetan Plateau. In situ rainfall observations obtained from Ministry of Water Resource, which are not used in the calibration of satellite rainfall products, are used as validation data.

The results demonstrate that the rainfall estimation skills of GPM are significantly improved when SMAP soil moisture data was used. In term of rainfall event detection, the false alarm ratio decreased from 0.4 to 0.3, while the frequency of hit increased from 0.6 to 0.7. For rainfall amount estimation, new product reduced 20~30% root mean square errors and increased the correlation coefficient from 0.3 to 0.7. The results of this study demonstrate the high potential to combine SMAP and GPM for better water cycle study.

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Mapping surface heat fluxes by assimilating SMAP soil moisture and GOES land surface temperature data

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Surface heat fluxes (i.e., sensible and latent heat fluxes) are impossible to measure directly from space as they have no traceable footprints, and the in-situ observations are costly and difficult. It has been demonstrated that surface heat fluxes can be estimated with two variables on clear-sky conditions: 1. a neutral bulk heat transfer coefficient (CHN), and 2. an evaporative fraction (EF). CHN scales the sum of surface heat fluxes, and EF governs the energy partitioning. Previously, in-situ soil moisture and land surface temperature (LST) data have been assimilated to estimate CHN and EF, and this study extends the research by assimilating SMAP soil moisture and GOES LST data over a large area.

The typical revisit time for SMAP is about 2-3 days, while GOES provides LST observations every hour. To overcome this gap, a hybrid particle assimilation strategy is adopted. SMAP soil moisture data are assimilated for each SMAP grid (~36km) using the particle filter (PF) when available, and GOES LST data are assimilated using a newly-developed particle batch smoother (PBS) for each GOES pixel (~5km). A simple heat and water transfer model is constructed and run at 30-min time step. Validation against in-situ flux stations show that flux estimates are greatly improved at both daily and 30-min time step. As the data for model forcing and data assimilation are provided by remote sensing or reanalysis products to minimize the dependence on ground measurements, this methodology can be easily applied in other regions.

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Spatial and temporal variability of soil moisture: 6 years survey of SMOS data and in-situ soil moisture measurements in Poland

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Measurements of soil moisture on a large scale provide important information about soil water content, its spatial distribution and temporal variations. Large scale is mainly domain of satellite measurements, but without "ground truth" validation in local scale (in-situ measurements) they are incomplete for many applications. The comparison of remote sensing data and point in-situ measurements is also a challenge and the opportunity for development of new methods. Moreover, the considered medium ("ground"), that is in fact a mixture of air, plants and soil, is site-specific, heterogeneous and thus problematic, difficult to simplify and modelling. Nonetheless, if properly validated and described, the long-term, large-scale dependencies will help in better understanding of the natural water cycle in the environment and the phenomenon that is commonly called "climate change".

The aim of our research was to find long-term temporal dependencies of surface soil moisture, with focus on Central and Eastern Europe. First, for validation purposes, the soil moisture measurements from SMOS (Soil Moisture and Ocean Salinity) satellite and 9 agrometeorological stations installed in Eastern Poland were compared using classical statistics and other methods. Several methods to SMOS data spatial and temporal analyses were tested in order to find the most effective approach. The analyses revealed that autocorrelation ranges of soil moisture measured in-situ via stations are longer or similar than soil moisture obtained from SMOS. That may be caused by landcover and soil diversities inside every single SMOS pixel. The observed larger variability of SMOS data may be explained by the fact that it is more sensitive to the surface soil moisture, in contrast to a more stable, deeper soil layer measured by in-situ sensors. The temporal analyses have revealed clear downward trend in soil moisture, both for ground and satellite data. The SMOS time-series is too short to draw definitive conclusions about the link between this trend and climate change, but that seems to be justified when looking at the historical in-situ data.

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New opportunities faor integrating global precipitation products based on Triple Collocation Analysis

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State-of-the-art satellite-based rainfall estimates (SBRE) have great potential value for a wide range of applications but are subjected to different sources of error that can limit their utility (Ebert et al. 2007). With the aim of increasing the accuracy of SBRE, the Global Precipitation Measurement Mission (GPM) has implemented an integration of various precipitation-relevant satellite PMW and IR observations intercalibrated against the GPM Combined Core Instrument product through the Integrated Multi-satellitE Retrievals for GPM (IMERG) algorithm. Thanks to the advanced sensor technology on board of the GPM core and improved retrieval schemes, this new product provides much higher quality rainfall estimates than TRMM-era products (He et al. 2016).

Despite this advancement, satellite based estimates still suffer from many issues that are inherent in the type of measurement (Xu et al. 2017). Hence, recent studies (Beck et al. 2017) have demonstrated that integrating rainfall from multiple sources (i.e., soil moisture based, reanalysis and ground based) allows to compensate for the limitations associated to each product and to produce a better quality rainfall estimate. However, an optimal integration must consider the relative accuracy of each source when assigning weights to each product.

The accuracy of the SRBE is normally assessed by a direct comparison with ground-based rainfall observations (e.g., radar and rain gauges) assuming they have a negligible error. However, the physical characteristics of precipitation, particularly at finer spatial and temporal resolutions, necessitate frequent, systematic and sufficiently dense validation measurements – requirements that are often not met within data-scarce regions of Africa, Asia and South America. Recently, Massari et al. (2017) demonstrated that Triple Collocation (TC) can be a valid alternative to rank the relative performance of SRBE provided that the simultaneous availability of three products with mutually-uncorrelated errors are utilized in the analysis.

In this study, TC is used first to characterize the relative performance of the rainfall estimates derived from the two state-of-the art SBRE (the NOAA Climate Prediction Center morphing, CMORPH and the TRMM Multi-satellite Precipitation Analysis TMPA 3B42RT) and two soil moisture-based derived rainfall products obtained via SM2RAIN (Brocca et al., 2014) via inversion of the Advanced SCATterometer (ASCAT) and the Soil Moisture Ocean Salinity mission (SMOS) soil moisture data. Based on the performance obtained with TC, the products are then merged into single rainfall products combining the satellite- and the soil moisture-based estimates via a simplified Kalman scheme.

The methodology is tested at ten diverse sites characterized by different climatic conditions and extensive ground-based precipitation datasets derived from gauge networks during the period 2010-2015.

Results convey the relatively higher accuracy of the integrated products with an improvement of the correlation and a reduction of the error and the bias, thus demonstrating the potentiality of TC to provide a basis for an optimal product integration of rainfall from different sources.

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High resolution Soil moisture content from Sentinel-1 data

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Earth observation (EO) of soil moisture (SM) content at high spatial resolution (e.g. below 1.0 km) and regional or continental scale can enable significant improvements in, e.g.,: i) the understanding of land-atmosphere interactions [Loew et al., 2013, Seneviratne et al., 2013; Taylor et al., 2011; Rieck et al., 2014, Schneider et al., 2014]; ii) the new generation of global climate models, such as the German ICOsahedral Non-hydrostatic (ICON) model [Zängl et al., 2014; Dipankar et al., 2015], which allows for regional nesting and simulations at the 1 km scale and below; iii) the watershed management, runoff prediction or estimation of evapotranspiration [Lathauwer et al., 2011; Brocca et al., 2012; Massari et al., 2015, Zhang et al., 2011] over relatively small (e.g. below 5.0 103 km2) hydrological watersheds; iiii) agriculture applications for which EO SM information has rarely been used until to date [Ge et al., 2011]; iiiii) the validation of downscaling applications of coarse resolution operational SM products (e.g. SMOS, ASCAT, SMAP) by providing an effective methodology to bridge the gap between point scale ground measurements and low resolution EO SM estimates.

The large contrast existing between the dielectric constant of wet and dry soils renders spaceborne SAR sensors the most appropriate systems to monitor SM at high spatial resolution and at scales ranging from the local to the regional and continental. However, despite the numerous methods developed to retrieve SM from the SAR data streams collected in the course of the numerous past space missions, none of them has bridged the gap from a research to an operational product.

The two most important obstacles hampering this transition have so far been the lack of robustness of high resolution SAR-based SM retrieval algorithms and the limitations of past spaceborne SAR systems in particular in terms of frequency of observations, consistency of imaging modes and polarisation diversity. In this respect, the C-band Sentinel-1 (S-1) European Radar Observatory opens new perspectives to SAR derived SM products as, for the first time ever, they may attract a real interest in a wide user community and stimulate a synergistic interaction with SM products at low resolution.

Indeed, S-1 is the only operating SAR mission with monitoring capabilities, frequent revisit and large geographical coverage that will provide data continuity over the next decades.

To demonstrate the use of S-1 to support systematic SM product generation at high resolution and at regional/continental scale, the Scientific Exploitation of Operational Missions (SEOM) program of the European Space Agency (ESA) has recently funded the research project "Exploitation of S-1 for Surface Soil Moisture Retrieval at High Resolution", Exploit-S-1 (https://exploit-s-1.ba.issia.cnr.it).

The objective of this paper is to present the objectives and the status of the Exploit-S-1 project together with initial results obtained over some instrumented sites.

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ESA's Soil Moisture and Ocean Salinity Mission – Status and mission performance over land

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The Soil Moisture and Ocean Salinity (SMOS) mission, launched in November 2009, is the European Space Agency's (ESA) second Earth Explorer Opportunity mission. Significant progress has been made over the course of the now more than 7-years life time of the SMOS mission in improving the ESA provided Level 1 brightness temperatures and Level 2 soil moisture and sea surface salinity data products. The paper will provide an overview on the mission status and a performance assessment of - in particular - SMOS core data products over land, including i) an overview and performance assessment of newly developed SMOS data products, namely soil moisture in Near Real-Time (NRT), ii) give an outlook on future data products currently in preparation (e.g. vegetation optical depth for agricultural applications, freeze/thaw), iii) summarise the potential use of SMOS data for operational applications, e.g. Numerical Weather Prediction (NWP), hydrological forecasting, drought monitoring and fire risk assessment, either currently available or planned for the near future, and iv) the use of SMOS data for the creation of long-term series of soil moisture observations.

The paper will also summarise the current and future land product validation activities. This will include results from the ground based L-Band radiometers, ELBARA, currently operating at the Valencia Anchor station, Sodankyla and on the Tibetan Plateau sites. An overview on the activities at the Antarctica DOME C station will be given, being used as a cross-calibration site for SMOS, SMAP and Aquarius derived brightness temperatures. ECMWF provides continuous performance monitoring of SMOS observations globally over land and ocean as well as over targeted measurement sites.

Finally, an overview will be given on evolving user requirements based on feedback from the user community and potential routes for L-Band continuity.

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The Compounding Effects of Sub-Surface Features in Soil Moisture Retrievals with Radar

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Soil moisture derived from radar backscatter is beginning to enter in-service operation. Simplistically, the retrieval relies upon an increase in backscatter with increased dielectric contrast at the air/soil interface, and which is controlled solely by moisture variations. The dual dependency of the backscatter on surface roughness is referenced as the major confounding consideration in deriving absolute values. However, here, we report on investigations into the additional confusing effects of sub-surface returns. In particular, we look at the presence of rock in a soil, either as a distinct bedrock layer or mixed throughout the volume.

The measurements were all carried out within an indoor radar laboratory on a 4m (l) x 1m (w) x 0.5m (h) trough of sand. A roof-mounted, linear scanner placed centrally down the length of the trough captured vertical profiles of backscatter through the sand using the tomographic profiling (TP) technique. The polarimetric C-band measurements used a 4-8GHz bandwidth to provide high spatial resolution, allowing us to separate the various returns from within a soil column that we normally see overlain in radar imagery. Experiments primarily consisted of adding known amounts of water and carrying out repeat TP imaging as the sand dried. Thus, presented with vertical backscatter profiles we could track the individual amplitude and phase responses of different features to the varying moisture conditions.

The full data set is still being collected, and will be presented at the Workshop. However, the data already show significant distortions of expected moisture-backscatter relations when strong sub-surface returns are present. In particular – brightly reflecting, shallow-buried rock features could dominate backscatter in very dry conditions. In some circumstances, the addition of moisture caused a reduction in the total backscatter. For these cases, the modest increase in backscatter from the wetter sand surface did not compensate for the increased attenuation of the sub-surface signal. These sub-surface distortions were associated with low-moisture regimes. At higher moistures (>10%), the backscatter was dominated by the sand surface return.

However, a multitude of effects were observed and the temporal backscatter behaviours depended subtly on the exact experimental set-up. The presentation will detail the dependence of the results upon the soil surface roughness, sub-surface feature characteristics, imaging geometry, and polarisation.

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A drought event composite analysis using satellite remote-sensing based soil moisture

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Drought is a globally relevant hazard which can lead to severe economical, agricultural and societal damages. While various studies have investigated the relationship between droughts and different climate and ecosystem variables, they are often not global or they do not make use of direct soil moisture observations. Here we use satellite derived soil moisture observations from the Climate Change Initiative of the European Space Agency to quantify the relation between soil moisture drought and various climate and ecosystem variables (temperature, precipitation, evapotranspiration and vegetation) during the peak of the growing season. Furthermore, we follow the temporal evolution of the buildup and recovery surrounding the drought peak.

We find that in many regions longer-term precipitation deficits are the driving factors of large negative soil moisture anomalies. At the peak of the dry period large anomalies are found for precipitation, evapotranspiration, and temperature, while vegetation indices often show a delayed response. This delay is likely related to the limited information contained in the remotely sensed soil moisture signal on the deeper root zone, thus underestimating the available soil moisture for plants. Anomalies over grasslands are generally larger than over forests, likely linked to the ability of trees to better access water at deeper depths, and to save water during dry conditions. An analysis of ERA-Interim/Land soil moisture shows that deeper soil layers exhibit a lesser anomaly, indicating that soil moisture is still available at these deeper depths. Our results illustrate the relevance of remote-sensing based soil moisture as a new independent observation for studying land-vegetation-atmosphere dynamics at the global scale.

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Integration of SAR multi-frequency and optical data for the retrieval of soil moisture and vegetation water content

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Soil moisture content (SMC) and vegetation water content (VWC) are key indicators for quantifying and monitoring important natural processes. The backscattering intensities derived from SAR measurements can be associated to both of these parameters. However, their retrieval is a complex topic. The SAR measurements are influenced by several properties of the observed area, like vegetation structure, surface roughness, VWC, and SMC.

The aim of this work was to develop an algorithm that integrates multi-frequency SAR data and optical data to estimate SMC and VWC in vegetated areas - currently, the retrieval of VWC, from satellite data, is mainly related to the Normalized Difference Water Index (NDWI), which is affected by the classical limitations of optical data. The algorithm relies on a Support Vector Regression (SVR) retrieval approach. A first SVR model is applied to compute SMC, using optical bands (in the visible and in the near-infrared spectrum), optical indices (Normalized Difference Vegetation Index (NDVI), and NDWI), and SAR backscattering intensities, with different frequencies and polarizations, as input. The derived SMC is used to compute and to simulate base soil backscattering by using a physical based model (such as IEM, Oh-model). Bare soil values are compared with original backscattering coefficients in order to isolate the contribution of vegetation. A second SVR model has been trained to model VWC, using the following input parameters: different optical bands, NDVI and NDWI, backscattering at C and L band with polarization HH, VV, HV, and VH, and the simulated bare soil backscattering for C and L band with polarization HH and VV.

The algorithm has been developed using the SMEX02 experiment data-set that has been chosen because, along with sensor observations, extensive ground truth measurements were acquired.

For the preliminary results, comparison with ground data (SMC and VWC) shows encouraging results. For SMC estimates, we get R=0.89 with a RMSE of 0.04 cm3/cm3, while for the VWC R=0.83 and RMSE of 0.48 Kg/m2.

A further test has already been planned for this algorithm, in fact it will be used with COSMO-SkyMed, ALOS-2, Sentinel-1 and Sentinel-2 data to estimate soil moisture and vegetation water content in a test site located in Mazia valley (Trentino Alto-Adige, Italy), where ground stations are available together with measurements from several field campaigns (Greifeneder et al.,2014).

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A review of spatial downscaling of satellite remotely-sensed soil moisture

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Satellite remote sensing technology has been widely used to estimate surface soil moisture. Numerous efforts have been devoted to develop global soil moisture products. However, these global soil moisture products, normally retrieved from microwave remote sensing data, are typically not suitable for regional hydrological and agricultural applications such as irrigation management and flood predictions, due to their coarse spatial resolution.
Therefore, various downscaling methods have been proposed to improve the coarse resolution soil moisture products. The purpose of this paper is to review existing methods for downscaling satellite remotely-sensed soil moisture. These methods are assessed and compared in terms of their advantages and limitations. This review also provides the accuracy level of these methods based on published validation studies. In the final part, problems and future trends associated with these methods are analyzed.

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Sentinel-1 Surface Soil Moisture: Comparison against an optimized Metop ASCAT soil moisture product and in-situ data in Lower Austria

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Soil moisture plays an important role in the water cycle since it has major effects on runoff, subsurface flow, infiltration and evapotranspiration. Agricultural productivity is greatly influenced by changes in soil moisture, which makes the monitoring of this variable so important. Since 2010, soil moisture is considered an Essential Climate Variable (ECV) [1]. In the last years, a large number of satellites have been launched which are used to provide surface soil moisture (SSM) data at different spatial and temporal scales. We will present the results of a comparison between 1 km Sentinel-1 SSM and 12.5 km ASCAT SSM, and in-situ soil moisture over Petzenkirchen, Austria.

Backscatter measurements from the Advanced Scatterometers (ASCAT) onboard Metop-A and Metop-B can be used to retrieve surface soil moisture information. ASCAT provides backscatter observations with a spatial resolution of 25 km. The TU Wien microwave remote sensing research group produces an operational SSM product on a fixed-Earth grid with a regular sampling of 12.5 km [2], [3]. A temporal revisit rate of 6 - 36 hours can be achieved depending on latitude. The operational soil moisture product, generated in the framework of the EUMESAT H SAF project, is based on global model parameters accounting for vegetation. For this study, the retrieval of SSM from ASCAT will be done using a set of optimized model parameters to get the best possible dataset for an area covering Petzenkirchen, Lower Austria. There, a permanent soil moisture network is installed in an agricultural catchment which is used for the validation of the optimized ASCAT product.

Since the launch of the Sentinel-1A satellite in 2014, SSM can be retrieved at a spatial resolution of 1 km at an unprecedented radiometric accuracy level. The retrieval algorithm is currently developed and tested at the TU Wien microwave remote sensing research group [4]. Depending on the spatial coverage of the available Sentinel-1 data, promising results are already achieved over most parts of Europe.

There are however challenges concerning the reflection of vegetation dynamics in the signal, as well as uncertainties due to small individual features that dominate the satellite footprint and thus obscure the observed signal.

By comparing the Sentinel-1 SSM time series to the optimized Metop ASCAT SSM product, and to in-situ data in the Petzenkirchen area, a first assessment of the strengths and weaknesses of this current SSM product is made.

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Assessing the potential of using a soil moisture climatology based on L-band passive microwave observations for the ESA CCI Soil Moisture

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During the last decade, the interest in the protected microwave L-band or "water frequency channel" and technological advances in instrumentation and space technology have resulted in the two first space missions specifically dedicated to measuring soil moisture: the ESA SMOS (Kerr et al., 2010) and the NASA SMAP (Entekhabi et al., 2010). Also, microwave satellite sensors operating at C and X-bands with long technological heritage (e.g. ASCAT, AMSR2) that were initially devoted to atmospheric and/or oceanic sensing have also been proved suitable for SM retrieval. Therefore, they can complement recent L-band missions and allow for a multi-decadal soil moisture observational data record partially covering the last 37 years.
The ESA's soil moisture Climate Change Initiative (CCI) is one of the first initiatives to merge the different microwave products available into a single soil moisture climate data record (http://www.esa-soilmoisture-cci.org/). Despite some limitations, the ESA CCI SM product is nowadays the most complete and consistent long-term soil moisture data record available (Dorigo et al., 2015).

One of the key steps in building a multi-decadal soil moisture data record is that, since different products display different ranges of soil moisture values, data have to be harmonized first using a common climatology. In its current version, the ESA CCI SM product uses the climatology provided by the Global Land Data Assimilation System (GLDAS-1-Noah) as a reference to scale the individual products. However, the impact of using a modeled climatology in absolute retrievals remains unclear, and the climate community has repeatedly stressed the need of a purely satellite-based soil moisture record to serve as a reference for verifying land surface model performance and trends.

Here, we investigate whether soil moisture retrievals based on L-band passive microwave observations could replace the model as the reference in an enhanced ESA CCI SM product based solely on observational data sets.

We hypothesize that the use of a L-band climatology as a reference to harmonize the active and passive soil moisture data sets conforming the CCI SM product will improve retrievals by providing a closer representation of the dominant features of temporal variability in soil moisture. To evaluate this hypothesis, we focus on the skills and differences found between soil moisture data products from satellite observations (SMOS, AMSR2, ASCAT), and two state-of-the-art reanalysis (GLDAS-1-Noah, MERRA2) over different catchments, where in-situ measurements are available. Although modeled, satellite and in-situ observed soil moisture products capture processes occurring at different spatial scales and their comparison is therefore challenging, they should generally agree in terms of temporal dynamics (e.g. trend) and have a similar response to rainfall if the rainfall was equally distributed (Rebel et al., 2012).
We characterized the persistence or "memory" of the different soil moisture products in terms of temporal autocorrelation and found that the temporal response of the uppermost-modeled soil moisture layers to hydrological processes is generally different from the one shown by in-situ and satellite observations, which show a much closer characteristic curve. The impact of using a model- or an observation-based reference in the ESA CCI in terms of retrieved soil moisture dynamics has been quantified. Particular attention has been given to irrigated areas, which are naturally captured by the satellite instruments but not included in the models. Results will be provided at the workshop.

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Homogeneity testing of the global ESA CCI multi-satellite soil moisture climate data record

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ESA's Climate Change Initiative (CCI) creates a global, long-term data record by merging multiple available earth observation products with the goal to provide a product for climate studies, trend analysis, and risk assessments. The blending of soil moisture time series derived from different active and passive remote sensing

instruments with varying sensor characteristics, such as microwave frequency, signal polarization or radiometric accuracy, leads to inhomogeneities in the merged long-term data series, counteracting the committed goal of creating a consistent, homogeneous data product.
To detect the spatio-temporal extent of contiguous periods without inhomogeneties as well as subsequently minimizing their negative impact on the data records, different relative break detection tests (namely Fligner-Killeen test of homogeneity of variances and Wilcoxon rank-sums test) are implemented and tested on the active, passive and combined global ESA CCI SM data set. Inhomogeneities are detected by comparing the data to ground-based reference measurements from the International Soil Moisture network and model based reference time series from MERRA2. Break detection is performed over the ESA CCI SM data time frame of 38 years (from 1978 to 2015), on a global quarter-degree grid and with regard to beforehand known times of possible breaks in the data set due alterations in the combination of observation systems used in the data blending process. This study describes the purpose of testing a multi-satellite soil moisture data product for inhomogeneities and explains observed variations in the spatial and temporal patterns of inhomogeneities in the tested products.
Besides we proposes methodologies for measuring and reducing the impact of inhomogeneities on trends derived from the ESA CCI SM data set and suggest the use of inhomogeneity-corrected data for future trend studies.

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WMO Soil Moisture Demonstration Project (SMDP) Status, Plan and Potential Applications

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Soil moisture is a key variable of the climate system. Soil moisture data are critical for monitoring, assessing and modeling the impact of drought on agriculture, hydrology, and renewable energy. Soil moisture is an important parameter in climate and weather forecasting. It is also involved in many feedback mechanisms at the local, regional and global scales, playing a major role in climate change projections. There is an urgent need to integrate satellite information with in-situ soil moisture measurements to strengthen integrated and participatory early warning systems for weather and climate risks for sustainable agriculture, water resource management and other sectors of society. There is also a critical requirement to develop standards and guidelines for global soil moisture measurements, in support of the International Soil Moisture Network (ISMN), coordinated by the Global Energy and Water Exchanges Project (GEWEX) in cooperation with the Group of Earth Observation (GEO) and the Committee on Earth Observation Satellites (CEOS). The ISMN is an international cooperation to establish and maintain a global in-situ soil moisture database for validating and improving global satellite observations and land surface models. The key to an effective soil moisture observation program is the integration of in-situ stations collecting verifiable and calibrated point data observations with remotely-sensed data observations at various scales. An integrated soil moisture network has the potential to significantly improve the understanding of how the global water cycle impacts extreme events, short-term weather forecasts and long-term climate change projections. George Mason University (GMU) Global Environment and Natural Resources Institute (GENRI) with international partners has undertaken a pilot project initiative, the Soil Moisture Demonstration Project (SMDP), supported by WMO. The SMDP is an integrated soil moisture observation and monitoring system for operational drought management applications. The SMDP provides valuable support for calibration and validation of satellite observed soil moisture products, as well as the development of standards and guidelines for the ISMN. The SMDP has established soil moisture benchmark observation stations in strategic areas of South Africa. Calibration and validation studies have also been conducted in the United States, China, and Brazil. The SMDP project can provide valuable support to the mission and objectives of the IDMP. The SMDP can effectively enhance the quality of an integrated and systematic observation system for drought monitoring and management. It can also strengthen advisory and early warning capabilities, and, can provide value-added information to demand-driven resource delivery systems.

The WMO SMDP status, plan and potential applications will be discussed in this presentation.

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Uncertainty assessment of space-borne passive soil moisture retrievals

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The uncertainty associated with passive soil moisture retrieval is hard to quantify, and known to be underlain by various, diverse, and complex causes. Factors affecting space-borne retrieved soil moisture estimation include: (i) the optimization or inversion method applied to the radiative transfer model (RTM), such as e.g. the Single Channel Algorithm (SCA), or the Land Parameter Retrieval Model (LPRM), (ii) the selection of the observed brightness temperatures (Tbs), e.g. polarization and incidence angle, (iii) the definition of the cost function and the impact of prior information in it, and (iv) the RTM parameterization (e.g. parameterizations officially used by the SMOS L2 and SMAP L2 retrieval products, ECMWF-based SMOS assimilation product, SMAP L4 assimilation product, and perturbations from those configurations). This study aims at disentangling the relative importance of the above-mentioned sources of uncertainty, by carrying out soil moisture retrieval experiments, using SMOS Tb observations in different settings, of which some are mentioned above. The ensemble uncertainties are evaluated at 11 reference Cal/Val sites, over a time period of more than 5 years.
These experimental retrievals were inter-compared, and further confronted with in situ soil moisture measurements and operational SMOS L2 retrievals, using commonly used skill metrics to quantify the temporal uncertainty in the retrievals.

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Version 3 of at the SMAP Level 4 Soil Moisture Product

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The NASA Soil Moisture Active Passive (SMAP) Level 4 Soil Moisture (L4_SM) product provides 3-hourly, 9-km resolution, global estimates of surface (0-5 cm) and root zone (0-100 cm) soil moisture as well as related land surface states and fluxes from 31 March 2015 to present with a latency of ~2.5 days. The ensemble-based L4_SM algorithm is a variant of the Goddard Earth Observing System version 5 (GEOS-5) land data assimilation system and ingests SMAP L-band (1.4 GHz) Level 1 brightness temperature observations into the Catchment land surface model. The soil moisture analysis is non-local (spatially distributed), performs downscaling from the ~36-km resolution of the observations to that of the model, and respects the relative uncertainties of the modeled and observed brightness temperatures. Prior to assimilation, a climatological rescaling is applied to the assimilated brightness temperatures using a 6 year record of SMOS observations. A new feature in Version 3 of the L4_SM data product is the use of 2 years of SMAP observations for rescaling where SMOS observations are not available because of radio frequency interference, which expands the impact of SMAP observations on the L4_SM estimates into large regions of northern Africa and Asia. This presentation investigates the performance and data assimilation diagnostics of the Version 3 L4_SM data product. The L4_SM soil moisture estimates meet the 0.04 m3/m3 (unbiased) RMSE requirement.
We further demonstrate that there is little bias in the soil moisture analysis. Finally, we illustrate where the assimilation system overestimates or underestimates the actual errors in the system.

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Evaluation of 14 years of SMOS and SMOS-like soil moisture against the ESA CCI dataset

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In the framework of an ESA project to investigate different ways to introduce SMOS into ESA's soil moisture (SM) Climate Change Initiative, a new dataset has been constructed using neural networks to link ASMR-E brightness temperatures to the SMOS level 3 SM dataset.

First evaluations of this new soil moisture dataset have been presented by Rodriguez-Fernandez et al. (2016, Remote Sensing) and van der Schalie et al. (2017, submitted to Journal of Climate). In this contribution, we will discuss the evaluation of this dataset in comparison to the ESA CCI SM dataset in terms of climatic trends and SM predictability as a function of different ocean-atmosphere oscillation indexes.

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Prediction of satellite soil moisture sub-grid variability based on soil texture information

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Downscaling of coarse resolution satellite soil moisture products is essential for a variety of applications, as for example for high resolution hydrological modelling. Therefore, recently a number of downscaling techniques for global satellite soil moisture products was developed based on different kinds of auxiliary information. However, the heterogeneity of soil texture is rarely included in downscaling approaches, although it is one of the main sources of soil moisture variability.

In this study, we use high resolution maps of basic soil properties like soil texture and bulk density to estimate the sub-grid variability of SMOS, SMAP and ASCAT soil moisture products at global scale. For predicting the soil moisture standard deviation as a function of mean soil moisture on the basis of soil texture information, we apply a closed-form expression, which relies on the stochastic analysis of 1D unsaturated gravitational flow in an infinitely long vertical profile based on the Mualem-van Genuchten model and first-order Taylor expansions.
This results in a look-up table with the ability to predict the soil moisture standard deviation for the individual SMOS, SMAP, or ASCAT pixel values of low resolution soil moisture.

The results of this approach were subsequently analyzed on global scale, discussing the spatial patterns of the relationship of standard deviation over mean soil moisture for specific mean soil moisture values, as well as for the SMAP mean soil moisture for the year 2016. Furthermore we compare the results to in situ data for specific pixels over Germany and US and generated a high resolution soil moisture data set for SMAP by implementing soil texture information.

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Surface soil moisture spatio-temporal dynamics in southeastern South America observed by SMOS and modeled by ORCHIDEE

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Understanding surface soil moisture (SSM) spatio-temporal dynamics is essential for various research fields, among them climate and its interaction with the land surface. SSM dynamics is mainly driven by precipitation but also by evapotranspiration, infiltration and drainage to deeper layers. Soil types, land cover and vegetation characteristics have significant influence on the last mentioned three drivers.

Soil moisture can significantly affect the atmospheric variability through changes in the partition between latent and sensible energy fluxes on time scales ranging from diurnal to seasonal, in particular over transition regions between wet and dry climates. Several studies that employed climate models and Land Surface Models (LSMs) (Sörensson and Menéndez, 2011; Ruscica et al., 2015; Spennemann and Saulo, 2015; Ruscica et al., 2016) and more recently satellite products (Salvia et al., 2016, Spennemann et al., 2017, submitted) distinguish southeastern South America (SESA) as a hotspot of land-atmosphere interaction during austral summer.

Regarding the behavior of SSM satellite derived products in the area, a recent work by Grings et al. (2015) over the Pampas Plains in SESA shows characteristic soil moisture patterns that follow the standardized precipitation index under extreme wet and dry conditions using the GLDAS Noah-LSM, ASCAT and SMOS satellite products, and in-situ measurements from the soil moisture network established by CONAE's Space Center in Argentina.

The aim of this work is to achieve a deeper understanding of SSM dynamics over the SESA hotspot area during austral summer. The ORCHIDEE LSM (http://labex.ipsl.fr/orchidee/) and the more recent version of SMOS satellite product (v.620) are chosen for this study. ORCHIDEE provides a high vertical resolution of the soil surface, making it suitable for comparison with remote sensing products. For example, ORCHIDEE represents the 35 upper mm with 4 layers, compared to other frequently used LSMs as Noah that represents the 100 upper mm with 1 layer. SMOS v.620 includes a new parameterization for forested areas that reduces uncertainties as well as improvements in L1 and data quality filtering (https://earth.esa.int/documents/10174/1854503/SMOS_L2SMv620_release_note).

The SSM dynamics is explored using 3-hourly data from ORCHIDEE and the SMOS L2 soil moisture product, which provides total coverage over the area every 1-2 days. The spatial resolution of both datasets is 25 km. Temporal e-folding decay of SSM during non-rainy days after a marked precipitation event is explored through composites for both datasets for the summers between2010 and 2014. Results are analyzed in terms of soil and land cover characteristics, sampling frequency and precipitation uncertainties. A specific measurement of SSM dynamics (Mc Coll et al., 2017) is also calculated for a more complete description of the SSM behavior in the area.

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Cross-comparison of independent high-resolution soil moisture products across an agricultural landscape in south-eastern Australia

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Large scale farming operations in Australia have a significant interest in a better understanding of the spatial distribution of soil moisture across their farms, which are often in the order of thou-sands of hectares. While many operate individual soil moisture monitoring stations, a thorough knowledge of the soil moisture patterns across the landscape would provide the potential to fur-ther optimize farming operations. Many soil moisture data products are available to the farmers, however, most not at the resolution required for such applications. In the past, the only solution was to use high-resolution hydrological models to simulate soil moisture conditions. Recently, two new farm-scale soil moisture products are being produced and their performance is being as-sessed: One of them is derived from measurements collected during surveys with a Cosmic Ray Probe (CRP) rover system, and the other one is derived from the Sentinel-1 satellite data.

In this study, model-, CRP-, and satellite-derived soil moisture products are compared tem-porally (model/static CRP/S-1) and spatially (model/CRP rover/S-1) across a dry-land cropping region in south-east Australia. This serves both as a basis to assess the potential of the CRP roving system to be used a ground-reference for future satellite product validation campaigns, as well as a cross-comparison of the three products themselves.

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Combining SMAP and SENTINEL-1 data into a prototype ann algorithm for soil moisture monitoring

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A prototype algorithm based on Artificial Neural Network for estimating the soil moisture content (SMC) from active and passive microwave data is presented here. The algorithm is aimed at overcoming the SMAP radar failure by integrating microwave data from SMAP and Sentinel-1 (S-1), in order to obtain a SMC product at comparable resolution (10 Km) and improved accuracy with respect to the “SMAP Enhanced L2 Radiometer Half-Orbit 9 km EASE-Grid Soil Moisture”, available at NSIDC. A disaggregation technique based on the Smoothing filter based intensity modulation (SFIM – Santi 2010) applied to the SMAP radiometric acquisitions at original resolution (36 Km) allows combining SMAP and S-1 data. Disaggregated microwave data have been combined into the ANN algorithm, which was able to exploit the synergy between active and passive acquisitions. Following the strategy proposed in (Santi et al. 2014), the algorithm training has been carried out by combining experimental data and forward E.M. models simulations. The algorithm has been validated using one year of SMAP and Sentinel-1 co-located acquisitions, collected on agricultural areas in central and northern Italy. Spatially distributed SMC values generated by the well-established Soil Water Balance hydrological model (Brocca et al.) have been considered as a reference for the validation. The synergy of SMAP and S-1 allowed increasing the correlation between estimated and reference SMC on the selected areas from R=0.68 of the NSIDC product up to R=0.87, with a corresponding decrease of the error from RMSE=0.04 m3/m3 to RMSE=0.024 m3/m3.

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ESA CCI Soil moisture: Recent improvements of the soil moisture retrievals from passive microwave sensors

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The soil moisture observations from passive microwave sensors used in ESA CCI Soil Moisture are derived using the Land Parameter Retrieval Model (LPRM, Owe et al., 2008). Several recent algorithmic improvements on the parameterization of LPRM (e.g. Van der Schalie et al., 2017), temperature input (Parinussa et al., 2016) and filtering of radio frequency interference (De Nijs et al., 2015) were not yet applicable to the complete record due to differences in sensor characteristics and data availability. These steps have been revisited and adjusted for application to multiple historical satellite missions (e.g AMSR-E, SMMR, TRMM and WindSat) and now introduced into the latest reprocessing.
In addition, progress has been made towards the integration of L-band based soil moisture retrievals into the long term CCI soil moisture record by adding SMAP and SMOS observations. The results of the improvements are presented including a concise overview of the planned future developments of the ESA CCI soil moisture products.

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Metop ASCAT vegetation parameters estimated from morning and evening orbit overpass and their impact on estimated soil moisture

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The goal of this study was to quantify the difference in slope and curvature determined from ascending and descending Metop ASCAT passes and to examine the impact of diurnal variations on the estimated soil moisture. The relationship between backscatter and incidence angle varies with vegetation phenology during the year. In the TU Wien change detection approach, it is assumed that there are incidence angles **θ**dry and **θ**wet, at which the backscattering coefficient **σ**0 is stable despite seasonal changes in above ground vegetation biomass for wet and dry conditions. Importantly, vegetation phenology influences **σ**0 on a seasonal scale. Local short-term fluctuations are suppressed at the scale of the scatterometer measurements.

The incidence angle behavior of **σ**0 is determined by making use of the fact that the scatterometer provides instantaneous measurements at multiple incidence angles. The incidence angle dependency is described by a second order polynomial determined by the slope and the curvature[1]. The slope (**σ**') and the curvature (**σ**") show a distinct annual cycle, determined by vegetation growth and decay. In the operational Metop ASCAT soil moisture product, it is assumed that the vegetation state is the same for a given day every year, i.e. there is no interannual variability in the vegetation correction at the moment. Backscatter data from all years are combined to determine the slope and curvature values for each day of the year. First results from a study to estimate the slope and curvature values for each year suggest that there is a correlation between the estimated slope and the seasonal vegetation dynamics [2]. In particular, results reveal that interannual variability in the slope parameter is significant and this is expected to have a significant impact on soil moisture retrieval.

In this study, we found that the parameters describing vegetation (slope and curvature) can differ between the ascending and descending overpasses due to variations in vegetation moisture content and geometry. The magnitude of these differences and their impact on the normalized backscatter and estimated soil moisture were quantified using the Metop ASCAT backscatter time series. Results will be presented from a case study in the grasslands of central USA.

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From METOP ASCAT to METOP-SG SCA: Science Needs over Land

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The next-generation C-band scatterometer (called SCA) will be flown on a series of three METOP Second Generation (SG) B-unit satellites that are dedicated to microwave and sub-millimetre-wave imaging, scatterometry and radio occultation. The first METOP-SG B satellite is planned for launch in 2022. The SCA instrument will improve upon the technical measurement capabilities of the METOP Advanced Scatterometer (ASCAT) in three important ways: (i) addition of cross-polarization (VH) and horizontal co-polarization (HH), (ii) improved spatial resolution of 25 km, and (iii) 20% greater spatial coverage than ASCAT. In particular, the new polarization channels hold much promise for improved product generation over land because the three different polarizations show different sensitivities to vegetation and soil surface scattering.
Thus it can be expected that SCA will allow to better disentangling the effects of vegetation water content, vegetation structure, and soil moisture on the backscatter measurements, leading to improved retrievals of soil moisture and vegetation variables (such as the vegetation optical depth). In preparation for the SCA mission, the SCA Science Advisory Group, with the support by EUMETSAT and ESA, has developed a Science Plan which has recently been published (Stoffelen et al. 2017). In this presentation I will review the SCA Science Plan, highlighting currently unresolved science question for ASCAT and suggestions of how to benefit from the Sentinel-1 SAR mission in order to prepare in particular for the new polarization channels (VH and HH) on SCA.

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Soil moisture estimation from L-band active and passive microwave observations acquired by Aquarius over the Tibetan Plateau

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Forward simulations by the Tor Vergata discrete electromagnetic model (hereafter, TV-DEM) are used as a Look-Up-Table to deduce soil moisture from L-band Aquarius active and passive observations across the Tibetan Plateau. Look-Up-Tables (LUTs) are constructed for bare and vegetated areas identified as Leaf Area Index (LAI) > 0.3 m2 m-2 and LAI > 0.3 m2 m-2. In the case of vegetation the LUT is based on simulations with varying soil moisture and LAI, and for the bare soil case only soil moisture is variable, while for the other TV-DEM parameter pre-calibrated values are adopted. Soil moisture is then retrieved by searching for the minimum squared difference between t the brightness temperature and backscatter coefficient observed by Aquarius and the simulations included in the LUT.

The soil moisture retrievals are assessment at footprint scale using in-situ measurements collected at three regional scale network spread across the Tibetan Plateau whereby unbiased root mean squared differences (UB-RMSDs) varying from 0.018 to 0.047 m3 m-3 and R2's from 0.447 to 0.494 (-) are found. This performance is slightly better than the passive-only Aquarius products and a great improvement over the Metop-A Advanced SCATterometer (ASCAT) soil moisture L2 product provided by European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and soil moisture of global atmospheric reanalysis (ERA-Interim) generated by European Center for Medium range Weather Forecasting (ECMWF). At Plateau-scale, all four soil moisture products capture the seasonal trend, whereby the dynamic range during the monsoon captured by the ECMWF product is smallest. Further, the precipitation gradient, increasing from west to east as confirmed by Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) product, is well reflected within the spatial soil moisture distributions present within the TV-DEM and readily available Aquarius products, but less pronounced in the ASCAT and ECMWF products.

This study demonstrates that synergetic use of L-band active and passive observations for soil moisture retrieval using a LUT created with a physically-based discrete electromagnetic model provides robust results in terms of error statistics (e.g. bias, R2 and UB-RMSD) and can generate realistic spatial soil moisture patterns at Plateau-scale.

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Inter-comparison of Operational Global Soil Moisture Products from Satellite Remote Sensing

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Global soil moisture product derived from satellite has been readily available in recent years, with several missions measuring soil moisture implemented, including the Advanced Scatterometer (ASCAT), the Soil Moisture and Ocean Salinity (SMOS), the Advanced Microwave Scanning Radiometer 2 (AMSR2), the Soil Moisture Active/Passive (SMAP) and China's meteorological satellite, Fengyun-3C (FY3C). Investigating the performance of each of these soil moisture products is essential for many applications.

However, due to the differences in the spatial resolution, disparity in spatial scales with in situ measurements, and measurement uncertainties, validation of satellite data with in situ observations is faced big challenges. In this paper, a comprehensive evaluation of different operational soil moisture products (ASCAT, SMOS, AMSR2, SMAP and FY3C) is carried out against in situ measurements at global scale over 2-years period from 2015 to 2016. The in-situ soil moisture measurements are collected from about 30 dense networks across the world, located in China (6 networks), United States (7 networks), Australia (2 networks), Europe (9 networks) and Canada (3 networks). The dense network has multiple soil moisture measurement locations within the sensor footprint, which can better represent area average soil moisture conditions. Moreover, an up-scaling strategy, based on Voronoi diagram, is employed to guarantee an accurate estimate of the grid average soil moisture. To narrow the spatial resolution gap among different soil moisture product, all the soil moisture product are re-gridded to the SMAP 36 km EASE grid.

A set of metrics to evaluate different satellite products is calculated, including the mean difference (MD), the root mean squared difference (RMSD), the unbiased root mean square error (ubRMSE) and the correlation coefficient (R). The five soil moisture products are then inter-compared with each other to highlight their advantages and shortcomings. The reasons for the differences and similarities between the products are identified for better understanding and further improvements of the algorithms.

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SMOS-IC: an alternative SMOS soil moisture and vegetation optical depth product

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Since its launch, end of 2009, the Soil Moisture and Ocean Salinity (SMOS) mission monitors two key variables over the land surfaces: surface soil moisture (SM) and vegetation optical depth (VOD), an index related to the vegetation water content and biomass, based on multi-angular brightness temperature (TB) measurements at L-band. Currently, the SM and VOD products are computed from the operational SMOS ESA Level 2 (L2) and Level 3 (L3) SMOS algorithms which attempt to account for complex physical processes in the signal modelling. For instance, in L2 & L3, footprint heterogeneity is taken into account by computing the land surface emission at 4 km resolution and convoluting it by the antenna patterns at each incidence angle.
Furthermore, ancillary data such as ECMWF SM and ECOCLIMAP LAI are used to better constrain the retrievals. The high complexity allows adding more physics into the algorithm, but it may also introduce more noise and uncertainties associated with the use of ancillary data and with the assumptions made when attempting to consider detailed physical processes at very large spatial scales (SMOS footprint ~40 km x 40 km). In this study, we present an alternative SMOS product, namely SMOS-INRA-CESBIO (SMOS-IC), based on a simplified retrieval algorithm that attempts to minimize the dependence on the ancillary data. The independency of data sets (in situ, modelled or remotely-sensed) is an important pre-requisite if we wish to implement unbiased and fair validation steps and develop robust application activities. As for L2 and L3, SMOS-IC is based on the L-MEB model inversion as proposed in Wigneron et al. (2000, 2007). SMOS-IC does not correct for the effects of the complex SMOS viewing angle geometry, the antenna patterns and the footprint heterogeneity and it is independent of ECMWF SM and LAI data. Currently, the ancillary information in SMOS-IC is limited to physiographic parameters (soil texture, vegetation class) and ECMWF-based temperature estimates. The simplicity of the SMOS-IC algorithm facilitates very fast retrievals (~ 2 days for computing a global IC data set over 6 years using 12 threads on a multi-core desktop processor) and expedites the calibration of soil and vegetation model parameters. Despite the algorithm simplicity, the SMOS-IC SM and VOD products have generally been found to be better correlated to in situ and modelled data sets of soil moisture and vegetation indices (NDVI) than the SMOS L3 products (Fernandez –Moran et al., 2016, 2017ab, submitted). This communication presents SMOS-IC, product inter-comparisons (SMOS-L3, SMOS-IC, SMAP) and first applications.

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Diagnosing agricultural drought from 1980 to 2010 with the ESA CCI soil moisture data

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Drought is one of the main climatic extremes affecting maize production. Recent statistical analyses highlighted the ability of the classical and up-to-date meteorological indicators to estimate drought at the global level.

However, their performances vary dramatically depending on the region because of reasons that are largely unknown. Consequently, the quality of yield data adopted in such estimates is sometimes unfairly blamed. In this study, we show the superiority of the European Space Agency Climate Change Initiative (ESA CCI) soil moisture data set in diagnosing agricultural drought in some of the most important maize producing countries.

Moreover, we use a bias corrected reanalysis adopted in the Agricultural Model Intercomparison and Improvement Project (AgMIP) — together with the remotely sensed data — in order to shed light on the underpinning processes determining the spatial differences of the ESA CCI skill in estimating maize yield losses compared to the meteorological drought estimators.

Posters

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Effects of the mesoscale circulation on soil moisture over Kuwait

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Feedbacks between soil moisture and mesoscale circulation are important for understanding soil moisture variability in the desert regions in summertime. The wind mesoscale circulation over Kuwait plays an important role to changes in soil moisture in the desert.
This paper presents three summer common atmospheric dynamics over kuwait linking wind circulation to soil moisture, based on SMAP satellite, land surface soil moisture observation, and reanalysis atmospheric models. The results show that strong pressure gradient will lead into strong northerly wind over Kuwait, which are favored on the downwind side of dry surfaces, The weak synoptic force over Kuwait in summer will lead into inland easterly gulf light humid winds, consistent with forcing by a mesoscale circulation. Overall, By demonstrating the significance of wind circulations in driving the soil moisture, the study shows that soil moisture increase during summertime is a likely caused by mesoscale circulation feedback seen in recent SMAP remote sensing studies over the region.

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1km Soil Moisture from Sentinel-1 and ASCAT: Evolutions Activities within the Copernicus Global Land Services.

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Earth observation and more specifically, spaceborne radar remote sensing, have made much progress towards retrieving Soil Moisture (SM) at different scales. The use of coarse-scale measurements from active or passive microwave sensors for SM retrieval is well established and in operational use. The Copernicus Global Land Service (CGLS) provides daily global SM data, retrieved from Metop-ASCAT scatterometer measurements at 0.1° spatial sampling. The Sentinel-1 satellite mission, launched in 2014 and deploying Synthetic Aperture Radars (SAR), delivers high-resolution radar imagery at the scale of 20 meters. Those observations from Sentinel-1 can be used for upgrading the SM portfolio of the CGLS.

The CGLS provides a large number of harmonised and co-formatted data products on energy, water and vegetation variables in Near-Real-Time (NRT). In addition to the already operational 0.1° Metop-ASCAT Soil Water Index Version3 (SWIV3), two new products are currently in evolution to pre-operational: 1) Surface Soil Moisture (SSM) from Sentinel-1 SAR data and 2) a SWI product based on data fusion of ASCAT and Sentinel-1 observations, called SCATSAR-SWI. Both products deliver SM data at 1km sampling and feature SM dynamics with much higher detail, allowing the analysis of local hydrological patterns, such as effects from terrain or convectional rains, and thus meet the requirements of many users.

The 1km Sentinel-1 SSM gives in percent the relative soil moisture saturation of the upmost 5 cm, every 2-4 days over Europe, and every 3-12 days globally. The algorithm processes the SAR observations at the initial 20m scale, at which a per-pixel signal analysis drives the algorithm parameter retrieval. Subsequent resampling of pre-processed SAR data to 1km ensures 1) the muting of artefacts stemming from the complex radar interactions at the 20m scale, and 2) the substantial reduction of data volume.

The 1km SCATSAR-SWI gives in percent the relative water content in eight soil layers of the upmost metre, with a daily timestamp. Through combination of both, the high temporal resolution of ASCAT-SSM and the high spatial resolution of Sentinel-1- SSM, it is the first pre-operational dataset that allows resolving SM dynamics with a daily frequency and a 1km sampling.

This presentation gives an overview on the hydrological variables of the CGLS and discusses in detail the new Sentinel-1 SSM and SCATSAR-SWI products, which are currently being processed over Europe.

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The Implementation and Evaluation of a Particle Filter for Assimilation of Soil Moisture Observations

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Better knowledge of the state of the land surface is important for understanding regional and global water and energy cycles. The land surface is highly heterogeneous and the dynamics are often nonlinear.

To monitor the land surface and get a better grip on the water and energy cycle we use i) land surface models ii) remote sensing data or a combination of both through data assimilation (DA).

The different (DA) methods used in land surface data assimilation are, to mention some: i) the simplified extended Kalman filter (SEKF) operational at ECMWF ii) the SEKF in the Land Surface Data Assimilation-Monde (LDAS-Monde) Météo-France, iii) the ensemble Kalman Filter (EnKF) in CaLDAS, and iv) the EnKF SMAP L4 data assimilation product. The SEKF and EnKF both assume Gaussian error distributions and that the forward operator is behaving linear in the assimilation window.

The above assumptions are not always true, in this we work we therefore implement and evaluate the Particle Filter (PF) which represents the underlying pdf of a system. The PF is compared to the EnKF which parameterize the underlying pdf of a system by correcting the different ensemble members according to the model and observational error.

The PF is supposed to be optimal for almost every model while the EnKF becomes suboptimal if i) the linearity

assumption of the state or observations fails and ii) the distribution of errors are non-Gaussian.

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Soil moisture estimation from SMAP polarimetric radar data with aquarius derived regression coefficients

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Electromagnetic scattering from vegetated areas is known to be sensitive to bare surface roughness, dielectric constant of the scattering surface, vegetation geometry, and terrain topography. Most state of the art retrieval algorithms utilize sophisticated electromagnetic models to estimate soil moisture from polarimetric radar data. These models need to be informed by ancillary data, which constrains their applicability and accuracy. Alternatively, simpler empirical approaches reduce the number of unknowns and hence the dependence on ancillary data by simplifying the relationship between volumetric soil moisture and radar backscatter. In this work, we expand an approach by Kim and van Zyl (Kim and van Zyl, 2009), one of the optional SMAP radar soil moisture algorithms, to enable global soil moisture retrievals with the help of minimal ancillary data. The estimated soil moisture is compared with the SMAP Level 2 radiometer-only soil moisture product posted at 36 km.

A linear model is used to relate radar backscatter to volumetric soil moisture with two polarization dependent coefficients (Ulaby et al., 1978). This relationship has been shown to capture the relationship between radar backscatter and volumetric soil moisture at different frequencies, incidence angles, and spatial scales (Kim and van Zyl, 2009; Ulaby et al., 1978; Burgin and van Zyl, 2016). A time-series retrieval approach was developed using extensive field data and was shown to perform well for bare and vegetated surfaces over specific sites (Kim and van Zyl, 2009). We use 2.5 years of Aquarius L-band radar and radiometer derived soil moisture data to determine weekly co- and cross-polarized coefficients on a global scale. The Aquarius L3 Gridded 1-deg weekly soil moisture is re-gridded from its 100 km native Aquarius resolution and posted on a 36 km Earth-fixed grid to match the SMAP Level 2 radiometer-only soil moisture product. The daily Aquarius radar data is incidence angle corrected to 40 degrees based on land cover type, averaged from ascending and descending overpasses, posted on the same 36 km grid, and used as weekly averages to match the Aquarius soil moisture data set.
We assume that radar backscatter over vegetated scenes changes mainly due to variations in the volumetric soil moisture over short time scales.

Therefore, a three-month moving window can be applied to retrieve global maps of weekly coefficients. This procedure assumes that the radiometer derived soil moisture can be used as a de-facto ground truth. The 3 km SMAP radar data are averaged to 36 km and the coefficients are used to estimate soil moisture from the 2.5 months of available SMAP radar backscatter data (April 13, 2015-July 7, 2015). The estimated soil moisture is compared with the SMAP Level 2 radiometer-only soil moisture product. Detailed analysis and results will be shown at the talk.

The research described in this paper is supported by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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Integrating SAR and optical data for producing high spatial resolution soil moisture maps. An indirect validation of the product via data assimilation techniques

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It is well know that the integration of synthetic aperture radar (SAR) and optical data can improve the capabilities of soil moisture (SM) monitoring from space. To this aim, the synergy between Sentinel 1 (S1) and optical (e.g., Sentinel 2, Landsat 8, MODIS) data was exploited to produce a satellite-derived SM product at high spatial resolution (hundreds on meters) and moderate temporal resolution (6-12 days). The active microwave sensor was used for estimating the surface SM values. During the retrieval process, the passive optical data were used to correct the effect of the vegetation on the radar backscattering signal.

The purpose of this work was to present an indirect validation of the aforementioned SM product by means of data assimilation (DA) techniques. To this aim, the S1-derived SM maps were assimilated within a continuous, distributed, physically based hydrological model (Continuum) in a catchment located in the North-West Italy. The Nudging was used as assimilation algorithm. Before the assimilation, satellite-derived SM maps were pre-processed in order to estimate the root zone SM (variable modelled by Continuum) and to remove/reduce the systematic error with respect to the model state (i.e., bias). After the assimilation, results were evaluated by analyzing the impact of the assimilation on the discharge predictions produced by the model, thus performing an indirect validation (i.e., hydrovalidation) of the product. Importantly, findings were used to evaluate the effectiveness of the hydrovalidation via DA techniques as validation strategy.

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Comparison of European Space Agency's (ESA) soil moisture and NDVI trends in monthly scale (Case study: Iran)

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Soil moisture is an important variable in evaporation and plant transpiration processes and is the limiting factor for Photosynthesis. Therefore, it can be used for irrigation scheduling and crop yield forecasting.

Despite the importance of soil moisture, land surface soil moisture observations are not enough for climatological and hydrological analysis, mainly du to the high cost and spatial insufficient coverage. In such condition, determination of soil moisture by remote sensing can be a good alternative for filling the gaps of land surface measurement. Therefore, one of the best data source for soil moisture is remote sensing technique. In this research, we present the trend analyses of 35 years (1979-2013) monthly remote sensing soil moisture time series based on European Space Agency's (ESA) combined soil moisture data with 25km resolution over Iran (40 t0 65 E, 25- 45 N). We depict regions, which have become wetter or drier over 35 years based on long-term trend. We also compare soil moisture with two different sources of the normalized difference vegetation index (NDVI) trends to find out how does soil moister changing effect on vegetation.

Two sets of NDVI used for comparing are GIMMS NDVI (growth seasonal) derived from NOAA AVHRR data and MODIS gridded NDVI dataset (monthly). We use modified Man-Kendall method to do trend analyses. According to the results, almost all the months have negative soil moisture trend and it is harmonic with NDVI trend in some cases.

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Soil Moisture influence in Desert Locust development

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Water identification and monitoring is crucial in areas with extreme climate conditions. Some countries in the Middle East and Northern Africa face an extra threat, insect plagues. Desert locust swarms cause devastation and major agricultural crisis in areas where local economy itself is weak and human misery high. The aim of this study is to identify breeding areas in a certain region of Mauritania during years 2011 and 2012 and predict outbreaks.
Remote sensing information on land surface parameters is used to enhance prediction capabilities; soil moisture data "SMOS-MODIS L4 SM (product from Barcelona Expert Center-BEC)" is essential in this study, since water scarcity is known to be a parameter highly influencing the presence of desert locust. Land Surface Temperature (Terra-Modis) and NDVI (Terra-Modis) are also included as ancillary information. A statistical data analysis was applied and initial results reveal a correlation of outbreaks with soil moisture conditions.

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ISMN based validation of Sentinel-1 soil moisture estimations

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The soil moisture content (SMC) is one important parameter for the understanding of different hydrological and ecological processes – it can be related to run-off, flooding, evaporation, or droughts. Satellite remote sensing, RADARs and Radiometers in particular, has proven to be a useful source of information for the spatially continuous measurement of this parameter.
The currently available SMC products (e.g. from ASCAT, SMOS, or SMAP) all have rather coarse spatial resolutions, in the order of approximately 10-50 km. With Sentinel-1, open access SAR data are now available since the end of 2014, which create the opportunity for the satellite based measurement of SMC, at a high spatial resolution of up to 20 m. This study presents the methods and a set of tools for the Sentinel-1 based estimation of SMC. The validation is based on in-situ time-series from the ISMN station network (Dorigo et al., 2011).

The basic idea for the applied method was inspired by the ERS Scatterometer change detection approach, introduced by (Wagner et al., 1999a; b) – three main parameters (surface roughness, vegetation, and soil moisture) are causing changes in the backscatter time-series, all of which are occurring at different temporal scales. Now with Sentinel-1, the knowledge of the backscatter history (of any given point in space) and the backscatter behavior at different polarizations can be used to separate these three contributors and estimate the SMC. Machine learning (Support-Vector-Regression – SVR) is used to construct a model that allows the solution of this estimation problem. SVR is a technique that was already successfully used for the retrieval of SMC (Pasolli et al., 2015) with RADARSAT-2. For the work presented here, the model training and tuning is based on upscaled Sentinel-1 time series and SMAP L4 modelled surface SMC (Reichle et al., 2016), as reference.

Applying the here presented new approach, it is possible to retrieve the SMC from Sentinel-1, without the requirement of ancillary data. The estimations were compared to measurements from 56 stations of the ISMN, in Europe, giving promising results: the overall Pearson correlation coefficient (R), between true and estimated SMC, is 0.57 and the station-wise bias corrected average error is 0.07 m3/m-3. The analysis of the accuracies for individual stations showed large discrepancies. R values are ranging between 0.85, in the best case, and 0, in the worst case.

Similarly, errors vary between 0.01 m3/m-3 and 0.15 m3/m-3. Further analysis is currently carried out to get a better understanding of the conditions that allow a precise retrieval of SMC.

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Remote Sensing of Soil Moisture in a Forested Peat Wetland in Virginia and North Carolina, USA

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Remotely sensing soil moisture in a high biomass environment is challenging. For this purpose, we used C-band synthetic aperture radar (SAR) data combined with multispectral satellite data and in situ ground verification to map soil moisture as it changes over time in our study area, the Great Dismal Swamp National Wildlife Refuse and Dismal Swamp State Park (GDS), which is mainly forested wetland. This study used soil moisture samples taken over the course of two years, along with precipitation records and satellite imagery, to remotely map soil moisture and inundation in the study area, despite high biomass. Radar backscatter is responsive to vegetation height, structure, density, surface roughness, and dielectric constant of the soil.
Taking these other variables into account allows for detection of changes in soil moisture. Radar also has the advantage of being able to penetrate clouds, and especially longer wavelength radar can retain some signal from soil moisture despite scattering from trees and leaves in areas where other methods cannot penetrate. The biophysical variables will be modeled to determine how the different properties influence radar backscatter for this site with emphasis on soil moisture and inundation. This study demonstrates that active radar remote sensing can be used to map soil moisture even in difficult areas. In the future, longer wavelength radar missions would offer a great advantage in forested areas where soil moisture is important, including the study site and other peat wetlands that store a disproportionately high volume of organic material and carbon, many of which are at risk of disturbance and draining.

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Recent Developments of the International Soil Moisture Network

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The International Soil Moisture Network (ISMN; http://ismn.geo.tuwien.ac.at/), which has been funded by the European Space Agency (ESA) and hosted by the Vienna University of Technology (TU Wien) since 2010, acts as a global data repository for in situ soil moisture measurements. Primarily intended to provide reference data for calibration and validation of satellite-based soil moisture products, nowadays the ISMN reaches a wide spectrum of data users and has become the world's largest database of in situ soil moisture data.
Since its beginning, the ISMN evolved very quickly and the number of contributing networks is growing continuously. Currently, 56 networks including 2249 sites are included in the ISMN database.

In this presentation we show the latest developments of the ISMN. Besides the inclusion of several new networks in data sparse regions (e.g. Canada, China), the ISMN now contains additional metadata information, e.g. on soil texture, land cover and climate classes, originating from ground observations as well as from modeled datasets. In addition, a user forum has been implemented to facilitate the communication between users, data providers and the ISMN team.

All soil moisture observations integrated in the ISMN have to run through a series of sophisticated quality control checks which flag them for their reliability (Dorigo et al., 2013). In our presentation, we show the latest updates of the ISMN quality control algorithms, which have an improved skill in flagging spurious observations, e.g. for outliers. Based on the new procedures we make a global assessment of the data quality issues.

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The contribution of Citizens' Observatories to validation of satellite-retrieved soil moisture product

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The GROW Observatory (GROW) will create a sustainable citizen platform and community to generate, share and utilise information on land, soil and water resources at a resolution hitherto not previously considered.

The European Space Agency's Sentinel-1 is the first mission capable of providing high-resolution soil moisture information, but a proper validation of Sentinel data remains a challenge given the scarcity of available in situ reference measurements. Establishment of a dense network of in situ measurement can bridge the gap in spatial resolution between in situ and satellite-based soil moisture measurements enabling validation between ground and remotely measured soil moisture observations. The potential exists to answer scientific questions including the validity of satellite data, the impact of climate change on land management thus supporting the needs of growers and integrating citizen and scientific research to be more directly applicable and relevant.

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Evaluating Soil Moisture from Space in Central Minnesota combining SMAP-SMOS Satellites and Land Surface Model

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Soil moisture is an important aspect of climate, and a key parameter for Hydrological process but, due to its characteristics, it is difficult to be determined on a large scale. Fortunately, space development has enabled the creation of artifacts that can indirectly measure soil moisture using remote sensors; however, the low temporal and spatial resolution difficult make difficult to obtain useful values. The Soil Moisture Active Passive (SMAP) satellite is specifically designed for soil moisture monitoring, and was launched on January 31, 2015, while Soil Moisture and Ocean Salinity, or SMOS, is a European satellite launched on November 2, 2009. In this paper, we carried out a evaluation of the SMAP and SMOS measurements, combining them with a land surface model called Community, where the land surface is represented by 5 primary sub-grid land cover types (glacier, lake, wetland, urban, vegetated) in each grid cell.
The vegetated portion of a grid cell is further divided into patches of plant functional types, each with its own leaf and stem area index and canopy height. Each subgrid land cover type is a separate column for energy and water calculations. We will evaluate the merging satellite soil moisture retrievals and model simulations for a blended consistent soil moisture product against data gathered from in situ measurements for Central Minnesota.

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An Evaluation of SMAP Soil Moisture Products over Cold and Arid Regions Using Distributed Observation Network Data

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The Soil Moisture Active Passive (SMAP) mission was designed to provide global mapping of soil moisture (SM) on nested 3, 9, and 36 km earth grids measured by L-band passive and active microwave sensors. The validation of SMAP SM products is crucial for the application of the products and improvement of the retrieval algorithm. This abstract presents an evaluation of SMAP radiometer product (SMAP_P), radar product (SMAP_A) and combined product (SMAP_AP) by using distributed ground observations networks in different landscapes in Heihe River Basin of northwestern China. The standard error metrics of SMAP products and relative error are applied to measure the products performances.

The results show that the SMAP SM products exhibit consistently spatial-temporal variation with the ground measurements and typical precipitation events. Three products show various performances associating to product (e.g., active, passive and combined), surface coverage (e.g., bare, vegetated) and climatic region (e.g., cold, arid) types. Relatively, the SMAP_P shows the best performance while the SMAP_A performs worst. Best performances are observed over bare soils but with overestimation and largest relative error, and unsatisfactory accuracies are observed over cold region and woody vegetated surfaces with underestimation. Vegetation effect and freezing-thawing cycle may be the major factors for the unsatisfied performance. Efforts on resolving the influence of these factors are expected to improve the accuracy and to promote the application of SMAP SM products over these regions. The evaluation provides an understanding of SMAP SM products over cold and arid regions, and suggestions for the further refinement of the SMAP SM retrieval algorithms.

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The study of the observation operator of simplified extended Kalman filter in the SL-AV global medium-range weather forecast model

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An accurate description of soil state is very important for numerical weather prediction models. In the absence of a near-real-time global network for providing soil moisture information, screen-level and satellite data is used by current operational soil moisture systems. We implement a Simplified Extended Kalman Filter (SEKF) in the SL-AV global medium-range weather forecast model with (ISBA land-surface scheme) for this purpose. This approach allows to combine easily heterogeneous sources of soil moisture data easily using observation operator. It projects the model state into the observation space. In this paper, we investigate assimilation of in situ screen-level temperature and relative humidity observations for initialization of deep soil moisture field.

One of the SEKF fundamental assumptions of the SEKF is the linearity of the observation operator. This linearization of the observation operator is computed within finite differences, by using small amount of soil moisture as individual perturbations of the model state vector.

The amplitude of the initial perturbation has a straightforward impact on the validity of the linear hypothesis of the observation operator and consequently on the accuracy of model weather forecasts. Influence of different sizes of perturbation on estimate of linearization and screen- level model forecasts is studied performed. Optimal order of magnitude for the perturbation is found for best approximation of the observation operator in the SL-AV model.

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Global soil moisture monitoring with Sentinel-1: required data processing and analysis capabilities

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Satellite observations have been proven to be useful for monitoring of water resources in large spatial scales with short intervals. Several satellites have been launched in recent years with advance sensors onboard, from multispectral to active and passive microwave instruments, solely for monitoring the Earth's surface and environment. The technological advances in spaceborn sensors and data acquisitions capabilities have also been in step with increasing of computing capacities. However, by emerging the new generation of spaceborn high-resolution imaging sensors, processing of such unprecedented big data becomes challenging and needs sophisticated up-taking facilities in terms of hardware and software.

Sentinel-1 (S-1), the first of the European Sentinel satellite-series, is a Synthetic Aperture Radar (SAR) mission, which is designed for monitoring of ocean and land. A constellation of two satellites (S-1A&B) deliver high resolution, day-and-night radar imagery at all weather conditions. The C-band microwaves can penetrate through clouds, rain, and dust with no or negligible attenuation as the long wavelengths are not involved in atmospheric scattering.
Sensitivity of backscatter measured by S-1 SAR instrument to soil water content provides a great opportunity for monitoring of soil moisture dynamics at global scale. The S-1 constellation has a nominal global coverage of landmass in 6 days (12 days with single satellite, 1-3 days over Europe and Canada) acquiring images in high spatial resolution (5, 20, and 88m) in the Interferometric Wide swath mode (IW). The S-1 exploitation capacity can potentially reach to 2 Terabytes of data per day in full operational mode. The S-1 data volume is varying depending on different mission observation scenarios but according to the recently received S-1 A&B data, the monthly expected data-volume over land masses for Level-1 IW Ground Range Detected (GRD) high resolution (20m) product is about 16 TB (above 500 GB daily). The total amount of S1 data is expected to reach to Peta-byte scale during the satellite life period (nominally 7 years).

In this study we present the SAR Geophysical Retrieval Toolbox (SGRT) developed by the Vienna University of Technology (TUWien), its capabilities and optimizations in terms of algorithm and processing software together with the experimental results of the S-1 big data processing for geophysical parameters retrieval including soil moisture. The analysis was carried out at the Earth Observation Data Center (EODC) for Water Resources Monitoring, which utilize the processing capabilities of Vienna Scientific Cluster (VSC-3) via fast InfiniBand connections.

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An intercomparison of soil moisture derived from SMAP and SMOS over eight sites in the Northeast Brazil

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Northeastern Brazil (NEB) is known for being exposed to major drought events, notably in its semiarid portion (the Sertão region), where often droughts generate massive losses of agricultural production. Soil moisture is the main variable to monitor agricultural drought. The amount of available soil moisture is a critical factor for crop growth. Currently active and passive microwave sensors are the best technologies for retrieving soil moisture from space. The Soil Moisture and Ocean Salinity (SMOS) launched in early November 2009 by European Space Agency (ESA), and the Soil Moisture Active Passive (SMAP) launched in January 2015 by National Aeronautics and Space Administration (NASA) are among the satellites most widely used for soil moisture retrieval. Despite the great potential of both, very few works have been published using soil moisture derived from the SMOS and SMAP data at Northeast Brazil (NEB). In this study, an intercomparison of soil moisture derived from SMAP L3 at 36 km and SMOS L3 at 25 km is carried out by using retrieval soil moisture data over eight sites located within four main biomes of the NEB (i.e., Amazônia, Mata Atlântica, Cerrado, and Caatinga). Comparisons are made at 10-day scale, over the time-span of January 2015 to January 2017.
The correlation coefficient (R), the Root Mean Squared Deviation (RMSD), and the bias are used as metrics. Moreover, rainfall estimates derived from CHIRPS v2 and the Normalized Difference Vegetation Index (NDVI) derived from S10 Proba-V are employed to explore the linear association between the SMOS/SMAP-derived soil moisture and the rainfall and vegetation state.

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FCOVER to measure impact of dry rainy seasons in Northern Central America

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In 2016 I presented in Arlo, Belgium statistics about " Use of NDVI Indicators to identify drought areas in Guatemala and Northern Central america". (Link: http://events.ulg.ac.be/copernicus-gl-workshop/programme/) I took 2016 to start analysis.

Now, to have a more clear idea of the impact of El Nino in Northern Central America, I used FCOVER and took statistics from 2010 to 2016. I have measures for South of Mexico, Mayan Biosphere, Guatemala, Honduras and El Salvador. For sample purposes for this summary I am presenting two charts to show FCOVER indexes and its variation for months and years.

Chart One shows the entire region from South of Mexico to Northern Nicaragua. Chart Two shows the eastern part of Guatemala. One of the most affected regions due to lower rainfall. On this region the summer is from November to April. Rainy season is from May to October.Both charts show that the vegetable activity using the FCOVER indicator is having a regular cycle of down to upper indexes. They have coincidences with dry and wet seasons. Link to Chart Two: http://www.qestad.info/fps/dispchartregion.jsp?%20fecha_despliegue_in=2016-10-05&fecha_despliegue_final=2016-10-05&tipo=6&latitud01=14.41&latitud02=15.30&longitud01=-90.58&longitud02=-88.60

A quick conclusion is that even with low indexes of rainfalls reported by the local population, the vegetable activity is having an almost normal life cycle. Another conclusion could be a high density of soil moisture and subterranean water reservoirs. I am doing the same study for California, USA to have an idea of the FCOVER/Vegetable activity life cycle.

To see how the droughts in California has affected the green life. Initial results can be read here: http://www.qestad.info/fps/dispdatagt.jsp Another indicator that I am working on is the water vapor over the Pacific Ocean off coast Northern Central

America. The purpose is to see how the water temperature is affected by El Nino. On both studies I am taking years from 2010 to 2017.

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Validation of the SMOS-BEC products in different networks

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Soil Moisture is considered an Essential Climate Variable because controls interactions between Land surface and atmosphere and changes in soil moisture affect the energy and water cycles. Nevertheless, very few measurements of soil moisture could be acquired until technology has been prepared for developing L-Band radiometers to be launched in a satellite mission. In order to have periodically measurements of soil moisture two missions have already been launched. One in November 2009 by the European Space Agency (ESA) launched the SMOS satellite, which is devoted to measure Soil Moisture and Ocean Salinity at 30-50 km spatial resolution and a global coverage every three days at the Equator. The second is the SMAP (Soil Moisture Active and Passive) launched in January 2015 by NASA (Hubert et al., 2008; O'Neill et al., 2011).
The SMOS Barcelona Expert Centre (http://cp34-bec.cmima.csic.es/), provides different Soil Moisture products. L3 Soil Moisture product provides maps on a 25km grid and the L4 soil moisture is a high resolution soil moisture map (1km). L4 product is obtained applying a downscaling algorithm based on the triangle concept and developed at BEC. It merges soil moisture (40km), NDVI (1km) and Land Surface Temperature (1km) and obtains SM maps at 1km. NDVI and LST are obtained from MODIS. Nevertheless, as visible and IR images are affected by cloud, no LST data is available for areas covered by clouds. Consequently, SMOS-BEC provides the cloud free L4 product, using LST from ERA-Interim (Piles et al., 2014).

The work presented aims to validating the soil moisture L3 (25 km) and L4 (1 km) products of SMOS-BEC in 3 sites located in distinct regions: REMEDHUS (Spain), SMOSMANIA (France) and CEMADEN (Brazil). The REMEDHUS (Red de Estaciones de MEDición de la Humedad del Suelo) is a CAL/VAL site for SMOS and SMAP and consequently it has been used for soil moisture validation products due to the characteristics and homogeneity of the area. It is located in the semi-arid region of the central Duero Basin (Zamora of Spain), which covers an area over 1300 km2. It has 22 soil moisture stations. SMOSMANIA in southwestern France is located in a portion of the automatic ground station network of Meteo-France. The CEMADEN (Centro Nacional de

Monitoramento e Alertas de Desastres Naturais) network is located at the Brazilian Semiarid region. The Brazilian semiarid region covers an area of 969.589.4 km² and comprises 1.135 municipalities in nine states of Brazil. It includes a wide variety of agricultural systems with different soil types, topography and rainfall. CEMADEN network was installed on 2015 and consequently, data are available from then.

In this study, SOMS-BEC L3 and cloud-free L4 product have been compared with in-situ measurements. When results for SMOS ascending passes are analyzed it is observed that L4 product obtains better correlations (values above 0.5) and RMSE of 0.03 m3.m-3 for the 3 networks. For descending passes, differences were smaller between L3 and L4 products. On the other hand, it is important highlighted that SMOS-BEC L4 product shows drier soil moisture conditions than L3 product. Finally, in most ground based stations L4 and L3 products are similar, but, as it was predicted, L4 products is always closer to the ground truth.

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Detecting Soil Moisture by Combining MODIS/Landsat and In-situ Measurements Over Cropland of Iowa State, USA

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Since 2010, a plateau scale soil moisture and soil temperature (SMST) observatory is established on the Tibetan Plateau for quantifying uncertainties in coarse resolution satellite products of SMST. The observatory consists of three regional networks across the Tibetan Plateau and provides reliable measurements of mean and variance in SMST of representative areas comparable in size to coarse satellite footprints. In the Twente region in the Netherlands an identical SMST network is also in operation. Data collected at these networks have been used for the validation and quantification of uncertainties in SCAT/ASCAT, AMSR-E, SMOS, SMAP soil moisture retrievals as well as validation of ECMWF model analyses of SMST.

Over the Tibet-Obs Maqu Network, the ELBARAIII radiometer had been installed since Dec. 2015; furthermore, in Aug. 2017, a scatterometer were set up in the field. The reliable measurements of Tb and backscattering, together with the SMST measurement, Tibet-obs network will support strongly the Cal/Val of SMOS/SMAP baseline science data products, as well as soil moisture products alike ESA CCI Soil Moisture.

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Detecting Soil Moisture by Combining MODIS/Landsat and In-situ Measurements Over Cropland of Iowa State, USA

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Soil moisture is a key factor influencing hydrological and agricultural processes, and, the magnitude, severity and duration of drought. Reliable soil moisture data are essential for drought and flood early warning, irrigation scheduling, and crop yield forecasting. In-situ observations of soil moisture are limited to discrete measurements at sparsely distributed locations, which provide valuable ground-truth point measurements but may not represent the spatial variations. Microwave remote sensing provides the capability for spatial soil moisture estimation.

A number of soil moisture data products from passive microwave remote sensing missions are available for global and regional applications. However, these soil moisture products from microwave remote sensing usually have low spatial resolution at tens of kilometers, which are not adequate for regional and local agricultural applications. The thermal inertia method is a potential soil moisture retrieval method using remote sensing measurements with moderate to high spatial resolutions, such as Terra/Aqua MODIS and Landsat TM/ETM/TIRS. The objective of this study is to investigate the estimation of daily soil moisture with the thermal inertia method at high spatial resolution through data fusion. The Spatial and Temporal Adaptive Reflectance Fusion Model (STARFM) was applied to enhance the temporal resolution of Landsat7/8's Land Surface Temperature (LST) by fusing the MODIS LST data first. MODIS LST products was used to calibrate the fused LST data. Then, the thermal inertia method was used to retrieve surface soil moisture from the fused daily LST data at 30m spatial resolution.

Although the thermal infrared channels of Landsat 7/8 are close to MODIS TIR channels, there are differences among spectral response functions. For consistency of data from different sensors, it's still necessary to check and remove the inter-sensor biases before data fusion.

The Atmospheric Infrared Sounder (AIRS) high spectral TIR measurements over the study area and time period were convolved with the spectral response functions of selected Landsat 7/8 and MODIS channels to determine inter-sensor bias and generate consistent Landsat 7/8 and MODIS data for data fusion to obtain daily LST at 30m resolution. Field experiments were conducted in an agricultural area in Iowa, USA (Lat: 42oN- 430N, Lon: 930W- 94oW), from May to August, 2016.

Two thirds of the in situ measurements were used to combined with daily LST data in order to build a soil moisture monitoring model. The other one third of the in-situ measurements was used to perform the necessary validation and calibration procedures for the model. Long-term soil moisture values can be retrieved through this model using fused remote sensing LST data, soil moisture data from non-temporary sensors at the same place was used for further calibration and validation of the model.

The accuracy of the retrieved soil moisture was evaluated with in situ observations of surface soil moisture at 0-5cm depth. Analysis of soil moisture data at 30m resolution over the study area shows details of spatial variation and temporal change, and demonstrated good potential for agricultural applications at local scale.

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Estimating irrigated cropland from satellite and model soil moisture data over the contiguous US

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Agricultural irrigation plays a key role in ensuring global food security. It greatly alters the hydrological cycle and has a proven impact on the climate system through evaporative cooling. Currently, irrigation is mainly quantified by national agricultural statistics, which only scarcely include spatial information and are inherently problematic due to their heterogeneous quality. The digital Global Map of Irrigated Areas (GMIA) has been the first effort to quantify irrigation at a global scale by merging these statistics with remote sensing data. Furthermore, the MODIS-Irrigated Agriculture Dataset (MIrAD-US) was created, which provides an increased spatial resolution but is limited to the United States.

This study tries to meet the increasing needs for independent and consistent information on the extent of irrigated areas. We confront both active and passive satellite soil moisture time series with various reanalysis datasets. We follow the assumption, that neither the structure nor the forcing of the modeled data account for artificial water supply, while the remote sensing observations do. Spatial irrigation patterns are derived from temporal slope differences between the modeled and remotely sensed soil moisture climatology during the irrigation season.

Results show that a combination of ASCAT and ERA-Interim/Land soil moisture exhibits systematic differences over major irrigation hotspots in the United States. In contrast, passive data such as AMSR-E and AMSR2 show weak agreements, plausibly due to a higher vegetation dependency of the soil moisture signal. Open questions remain, as a strong signal in the midwestern region of the Corn Belt is observed, which is generally outlined as an area dominated by rainfed agriculture. We conclude that the key innovation of this approach is the high temporal resolution, which allows for examination of interannual and intra-annual irrigation dynamics.

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Upscaling of ground measured surface soil moisture using Sentinel and Landsat data

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In order to represent surface soil moisture (SSM) content in detail and at fine spatial resolution, the upscaling of point-based SSM ground measurements by combing different high resolution satellite remote sensors with SSM ground measurements has emerged currently. This study investigates the potential of Synthetic Aperture Radar (SAR) (Sentinel-1) and optical/thermal infrared (Landsat 8, Sentinel-2) images for upscaling of SSM ground measurements. Sentinel-1 data are corrected in terms of atmospheric, geometric and radiometric corrections, and are calculated as backscattering coefficients. Following, the optical images and thermal images are corrected. In addition, the land surface brightness temperature (LST) and reflectance (LSR) are calculated using corrected optical/thermal data. Furthermore, various indices (NDVI, EVI, NMDI, PDI, MPDI, and TVDI) are calculated from the LST and LSR. The basic principle of indices-based methods is that these indices are sensitive to SSM. Ground measured SSM data are collected from a gauge network established in Tibetan Plateau, China, 2015~2016.
Sophisticated algorithms based on multiple linear regression (MLR), support vector regression (SVR) and deep neural network (DNN) based regression establish SSM model using indices, and backscattering coefficients or the LSR bands, LST bands, and backscattering coefficients as independent variables, respectively. Results highlight the potential of SAR and optical/thermal satellite images to accurately upscale the ground measured SSM in support of water resources management.