Adding value to soil moisture information for climate studies

A proposal to ISSI for an "International Team"

W.A. Lahoz *et al.*

Abstract. This proposal is for an "International Team" to bring together various efforts associated with the Soil Moisture ESA CCI. These include: (i) compilation and evaluation of a soil moisture climatology from various satellite datasets; (ii) modelling studies to understand the hydrological cycle and inform developments in climate modelling; and (iii) data assimilation to add value and evaluate soil moisture information from observations and models. The International Team will bring together people associated with the Soil Moisture ESA CCI and with activities with related essential climate variables (ECVs) such as biomass, land cover and ocean colour, to spend 3 1-week periods at ISSI-Bern to discuss the state-of-the-art in hydrological cycle studies and write peer-reviewed papers. Papers are envisaged on one or more of: (i) production and evaluation of a soil moisture climatology; (ii) connections between terrestrial/oceanic ECVs and the hydrological cycle; (iii) role of terrestrial/oceanic ECVs in climate change; and (iv) production and evaluation of soil moisture analyses using data assimilation. Expected outputs are integration of efforts in the terrestrial/oceanic ECV community and peer-reviewed papers; these outputs will add value to soil moisture information for climate studies.

1. Scientific rationale

1.1 Background. The amount of water stored in the unsaturated soil zone is generally referred to as soil moisture. It is one of the key geophysical variables for understanding the Earth's hydrological cycle. It is classed as an essential climate variable (ECV) of the Global Climate Observing System, GCOS (GCOS-107, 2006). Soil moisture determines the partitioning of incoming water into infiltration and run-off. It directly affects plant growth and other organic processes connecting the water cycle to the carbon cycle. Run-off and base flow from the soil profile determine river flows and flooding, connecting hydrology with hydraulics. Soil moisture also has significant impact on the partitioning of water and heat fluxes (latent and sensible heat), connecting the hydrological cycle with the energy cycle. Together, soil moisture, temperature and their impacts on the water, energy and carbon cycle (Fig. 1) play a major role in climate change projections (IPCC, 2007; Seneviratne *et al.*, 2010).

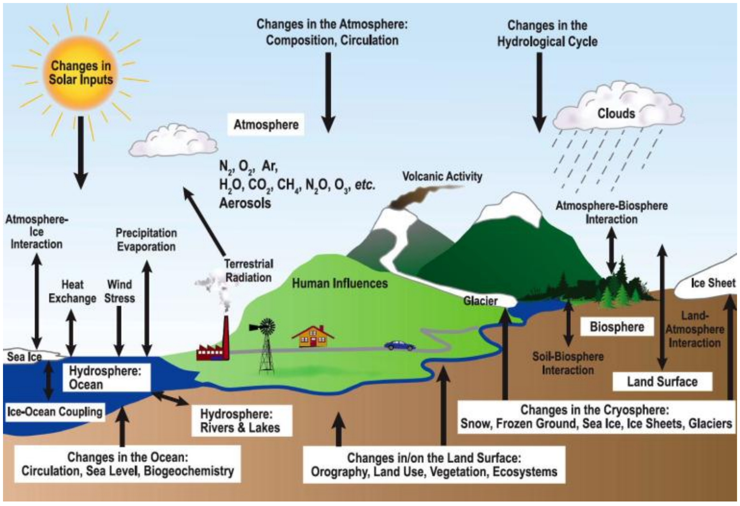


Figure 1 (left). Global climate system. Figure from *IPCC* (2007).

Quantifying the land state and fluxes and understanding land-atmosphere couplings allows a better representation of hydrological processes in climate models and helps reduce uncertainties in future climate scenarios, in particular regarding changes in climate variability and extreme events, and ecosystem/agricultural impacts (Seneviratne *et al.*, 2010). This understanding is also key for improving weather forecasting capabilities, e.g., prediction of convective precipitation (Sherwood, 1999). Key areas that will benefit from satellite soil moisture measurements include (see Lahoz and De Lannoy, 2013): (i) meteorology - improved weather forecast models; (ii) climate - improved climatologies and climate models to study the Earth's climate system; (iii) risk management – improved maps of flooding risk, fire risk, famine risk and drought risk; (iv) agriculture – improved estimates of agricultural production; and (v) hydrology – improved modelling of water resources.

To obtain information about the hydrological cycle, including soil moisture, we have two sources of information (Lahoz and De Lannoy, 2013): (i) observations, from satellite and in situ platforms; and (ii) models representing our understanding, typically land surface models (LSMs) and climate models. Data assimilation (DA), combining observational and model information and their errors in an objective way, is also used (Lahoz and De Lannoy, 2013). Data assimilation adds value to observations by filling in their spatio-temporal gaps, and adds value to models by constraining them with the observations.

Several satellite sensors and missions contribute to our current understanding of the hydrological cycle. These satellite-based observations of soil moisture are made using passive and active microwave instruments. Depending on observed wavelengths, orbit altitude and design details, there are large differences in horizontal, vertical and temporal resolution in the observations. Horizontal resolution ranges from 1-10s m to 10s km; temporal resolution is about one observation every 2–3 days, depending on location on Earth. These instruments typically penetrate the first few mm to cm of the soil: a few mm for X-band (8–12 GHz, e.g., AMSR-E - Njoku and Chan, 2006); ~1 cm for C-band (4–8 GHz, e.g., AMSR-E; ASCAT - Bartalis *et al.*, 2007); and ~5 cm for L-band (1–2 GHz, e.g., SMOS - Kerr *et al.*, 2010)[1]. A conceptual problem is to estimate soil moisture in the root zone (1 m) at a finer spatial resolution. For this, observational information needs to be transferred from the surface layer to the root zone and downscaled from the coarse scale to finer scales, typically using a LSM and/or land DA.

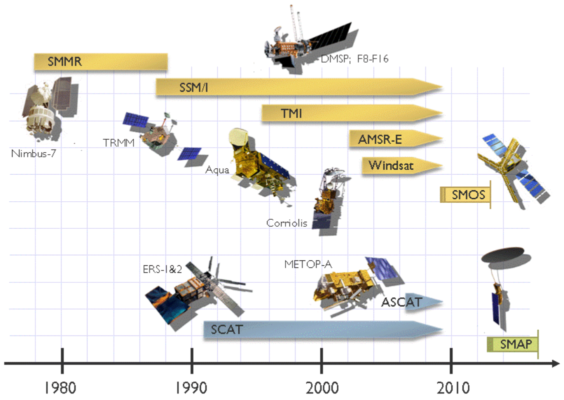
The land component in climate models is typically represented in LSMs. Main state variables of LSMs include soil water content and temperature, snow and vegetation. Examples of widely used LSMs, including their typical elements (schemes for soil moisture, snow, rainfall–run-off, routing/hydraulic processes), are provided in Lahoz and De Lannoy (2013).

Land surface DA considers ground-based in situ data and satellite data (Lahoz and De Lannoy, 2013). Often, satellite land surface data are assimilated and the process validated against in situ measurements or surface variables like surface fluxes. Assimilated satellite observations include retrievals of vegetation characteristics and dynamics (e.g., vegetation cover fraction; LAI - leaf area index; fAPAR - fraction of Absorbed Photosynthetically Active Radiation; NPP – net primary production), land surface temperature, soil moisture, snow water equivalent, and snow cover area. Parameter estimation is also performed.

To address the need to compile soil moisture information to study the Earth's Climate System, ESA set up the Soil Moisture ESA CCI, Climate Change Initiative (www.esa-soilmoisture-cci.org/). Its main objective is to produce the most complete and most consistent global soil moisture data record based on active/passive microwave sensors. It focuses on C-band scatterometers (on ERS-1/2, METOP) and multi-frequency radiometers (SMMR, SSM/I, TMI, AMSR-E, Windsat)[2] as these sensors are characterized by high suitability for soil moisture retrieval and long technological heritage (Fig. 2). Other microwave sensors suitable for soil moisture retrieval, including SMOS, Synthetic Aperture Radars (SARs) and radar altimeters, are not considered in the first phase due to their recentness and/or unfavourable spatio-temporal coverage. Nevertheless, the soil moisture ECV production

[1] Advanced Microwave Sounding Radiometer for EOS, AMSR-E; Advanced SCATterometer, ASCAT; Soil Moisture Ocean Salinity, SMOS

[2] European Research Satellite, ERS; Scanning Multichannel Microwave Radiometer, SMMR; Special Sensor Microwave Imager, SSM/I; TRMM Microwave Imager, TMI



system will be set up in such a way as to allow integration of all these sensors in the next phase(s) of the CCI.

Figure 2 (left). Active/passive microwave sensors used for generation of ECV soil moisture data sets. SMOS and Soil Moisture Active Passive (SMAP) missions will not be considered in Phase 1, but are included in this diagram to highlight potential inclusions in ECV production in the next CCI phase. Figure from ESA CCI soil moisture website.

Another ESA CCI that concerns the hydrological cycle is land cover (www.esa-landcover-cci.org/). ESA has selected the BIOMASS mission, measuring biomass, as the 7th Earth Explorer Mission[3]. Understanding links between soil moisture, land cover, and NPP (associated with biomass), will help improve understanding of the role of the hydrological cycle on Earth's climate system. Ocean colour (covered in an ESA CCI; www.esa-oceancolour-cci.org/) shares technical problems with soil moisture regarding data assimilation (non-linearity, non-Gaussian errors), so comparison of methodologies will improve analysed soil moisture and ocean colour datasets, with benefit to the climate studies community.

In situ soil moisture data from the ISMN (International Soil Moisture Network; ismn.geo.tuwien.ac.at/) will be used to evaluate soil moisture data products produced by the Soil Moisture ESA CCI. Output from LSMs and land surface DA activities will also be used to evaluate and add value to the Soil Moisture ESA CCI products.

1.2 Questions to be addressed by this proposal. To get most value from soil moisture observations provided by the ESA CCI, this proposal addresses the following key questions:

***Question 1*. What is required to construct a soil moisture climatology fit for climate studies?** Addressed by studying characteristics (spatio-temporal variability; errors) of long-term soil moisture climatology built from various satellite datasets in Soil Moisture ESA CCI.

***Question 2*. How do changes in the hydrological cycle impact the Earth's climate system?** Addressed by studying role of various ECVs (soil moisture, land cover, biomass, ocean colour) on Earth's climate system, and connections between these ECVs. This will be done, e.g., by studying the results from hypothesis testing modelling studies.

***Question 3*. How can we add value to soil moisture information from satellite observations?** Done using LSMs to understand the hydrological cycle; combining satellite observations of various ECVs (e.g., soil moisture, land cover, biomass); and studying datasets of ECVs such as soil moisture and ocean colour produced by data assimilation.

***Question 4*. How to compare quantitatively soil moisture retrieved from satellite with observed and modelled soil moisture?** Addressed by evaluating and quantifying, including errors, comparisons between observational, model and assimilated soil moisture datasets.

2. Timeliness

The proposed "International Team" will provide a strong example of the multi-disciplinary nature of the work undertaken in the Soil Moisture ESA CCI. This involves:

[3] www.esa.int/For_Media/Press_Releases/ESA_s_next_Earth_Explorer_satellite

- Multi-decadal satellite observations and climatologies of soil moisture;
- In situ observations to evaluate soil moisture observations from satellites;
- Data analysis methods to assess spatio-temporal trends and errors in multi-decadal soil moisture observations and climatologies;
- Hypothesis testing experiments with LSMs to understand the hydrological cycle;
- Hypothesis testing/scenario experiments with climate models to understand the role of the hydrological cycle in the Earth's climate system, including its future evolution;
- DA methods to combine observational and model soil moisture information (and from other ECVs), and provide value-added products.

All participants cover these areas and will be brought together by the International Team. The Team will be relevant to ISSI's focus on Earth Observation (EO), and help deliver results expected from the Soil Moisture ESA CCI. Results will be of great interest to all actors in the EO community, including:

- ***Space agencies:*** Results will provide information on the quality of satellite soil moisture data, and will help guide plans for future EO missions;
- ***Weather agencies:*** Results will help guide the implementation of algorithms to assimilate land surface parameters;
- ***EO data users:*** Results will provide information on the quality of EO data (e.g., terrestrial/oceanic ECVs), and will guide scientific use of this EO data;
- ***Instrument teams:*** Results will provide information on instrument errors for various satellite platforms, and will help guide efforts to remedy shortcomings;
- ***Climate modellers, hydrological modellers:*** Results will provide information to help develop and improve climate models and hydrological models, and will help guide efforts to remedy model shortcomings;
- ***Data assimilators:*** Results will provide information on land DA techniques, and will help guide efforts to improve them;
- ***Public:*** Results will help improve weather forecasting and climate models.

3. Objectives of the project

- **Objective 1** – Evaluate soil moisture climatologies produced under the ESA CCI;
- **Objective 2** – Understand the role of the hydrological cycle on the Climate System;
- **Objective 3** – Add value to soil moisture information from the ESA CCI;
- **Objective 4** – Write peer-reviewed papers addressing objectives 1-3.

4. Role of ISSI

ISSI and the International Team will be very important to activities in the Soil Moisture ESA CCI. First, it will allow partners in the proposal to hold three week-long meetings in a focused environment, something that partners do not have funds to do. Second, the Team will provide a focused platform to discuss Soil Moisture ESA CCI activities. Third, the Team will provide a focused environment for developing and strengthening collaborations between terrestrial/oceanic ESA CCIs, and disseminating results via publications in the peer-reviewed literature. Results will also be disseminated at community-wide workshops, meetings and conferences on EO and the Climate System. The experience of successful International Teams led by the proposer, shows the benefits of ISSI to the scientific community.

ISSI qualifies as a preferred implementation site for the following reasons:
Location: ISSI is centrally located in Europe;
Facilities: ISSI has excellent facilities for presenting and interpreting results;
Set-up: The focused nature of the ISSI "International Team" provides an ideal environment for bringing together the actors in a multi-disciplinary exercise. The low administrative burden associated with ISSI means that more time can be dedicated to scientific activities;
Financial support: ISSI funds allow partners to do something they are not funded to do.

5. Expected output from the proposal

- "International Team". The membership will include leading experts in the various disciplinary areas contributing to the outcomes of the Soil Moisture ESA CCI;
- Reports and peer-reviewed papers.

6. Schedule Dates relative to the first meeting date (Month 0; M0 – planned October 2014).

- Preparation: M-2 → M0 (all participants);
- Meetings: 3 meetings for 1 week each, Monday-Friday (M0, M6, M12);
- Disseminating results at international workshops: M2 onwards;
- Writing reports/papers: M2 → M12 and later. Experience of previous Teams suggests that submission of first peer-reviewed papers would occur from M12 onwards;
- Report to ISSI: M12.

7. Workshop participation

The proposal invitation list (12 members, plus one soil moisture ESA CCI liaison to cover links between the team and the ESA CCI) for the "International Team" is as follows:

- ***Team:*** William Lahoz - Leader (NILU, Norway); Richard de Jeu (VU-Amsterdam, The Netherlands); Wouter Dorigo, Wolfgang Wagner (TU-Wien, Austria); Sonia Seneviratne (ETH, Switzerland); Brian Barrett (U. Cork, Ireland); Shaun Quegan (U. Sheffield, UK); Laurent Bertino (NERSC, Norway); Philippe Ciais, Robert Vautard, Catherine Ottlé (LSCE, France); Jan Verbesselt (U. Wageningen, The Netherlands);
- ***ESA CCI soil moisture liaison:*** Eva Haas (GeoVille, Austria)

Areas covered by participants:

- ***Soil moisture data (satellite, in situ, climatologies):*** Barrett, de Jeu, Dorigo, Wagner;
- ***Time series analysis:*** Verbesselt;
- ***Climate modelling:*** Seneviratne, Vautard;
- ***Data assimilation:*** Bertino, Ciais, Lahoz, Ottlé;
- ***Soil Moisture ESA CCI:*** Barrett, de Jeu, Dorigo, Haas, Lahoz, Seneviratne, Wagner;
- ***Other ECVs:*** Bertino (ocean colour); Quegan (biomass); Verbesselt (land cover);
- ***ESA EE-7:*** Quegan (BIOMASS mission);
- ***Land surface models:*** Lahoz, Ottlé, Quegan;
- ***Biogeochemical cycles:*** Ciais.

8. Facilities required

One meeting room for a maximum of 15 participants: overhead projector; facilities for powerpoint presentations; small room for breakout meetings (c. 5 people); wireless network; internet connections; 2-3 PCs for those people who do not bring a lap-top; coffee machine.

9. Financial requirements

- Team leader: travel expenses from Norway to Bern (1 return trip).
- "International Team" meeting: accommodation and living expenses for up to 13 participants (including Team leader).

10. External financial support. Partners have funds to support their travel to Bern.

References

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Appendix 1: "International Team" addresses - details

Name	Email	Address
William Lahoz	wal@nilu.no	Norwegian Institute for Air Research (NILU) Instituttveien 18, PO Box 100 Kjeller, 2027, Norway Tel: +47-63898257 Fax: +47-63898050
Richard de Jeu	r.a.m.de.jeu@vu.nl	VU University Amsterdam Faculty of Earth and Life Sciences Earth and Climate Cluster De Boelelaan 1085 1081 HV Amsterdam The Netherlands Tel: +31 20 5987287
Wouter Dorigo	Wouter.Dorigo@geo.tuwien.ac.at	Remote Sensing Research Group Department of Geodesy and Geo-information (GEO) Vienna University of Technology (TU Wien) Gusshausstrasse 27-29, 1040 Vienna, Austria Tel: +43-(0)1-58801-12243 Fax: +43-(0)1-58801-12299
Wolfgang Wagner	wolfgang.wagner@geo.tuwien.ac.at	Vienna University of Technology (TU Wien) Gußhausstr. 25-29 / E120 (CB0321), Wien, 1040 Tel: +43 (1) 58801 - 12225 Fax: +43 (1) 58801 - 122 99
Sonia Seneviratne	sonia.seneviratne@env.ethz.ch	Institute for Atmospheric and Climate Science CHN N11, Universitätstrasse 16, 8092 Zurich, Switzerland Phone: +41 44 632 80 76 Fax: +41 44 633 10 58
Brian Barrett	bbarrett@ucc.ie	University College Cork (UCC) School of Geography & Archaeology Cork Rep. of Ireland Tel: +353 (0) 21 490 2391
Shaun Quegan	S.Quegan@shef.ac.uk	Centre for Terrestrial Carbon Dynamics (CTCD) University of Sheffield Hicks Building Hounsfield Road Sheffield S3 7RH, UK Tel: +44-(0)114 222 3778 Fax: +44-(0)114 222 3809
Laurent Bertino	laurent.bertino@nersc.no	Mohn-Sverdrup Center / NERSC Thormoehlensgt. 47 N-5006 Bergen, Norway Mob: +47 93 45 62 15
Philippe Ciais	philippe.ciais@lsce.ipsl.fr	IPSL - LSCE CEA CNRS UVSQ Centre d'Etudes Orme des Merisiers 91191 Gif sur Yvette, France Tel: +33 1 69 08 95 06
Robert Vautard	robert.vautard@lsce.ipsl.fr	IPSL - LSCE CEA CNRS UVSQ Centre d'Etudes Orme des Merisiers 91191 Gif sur Yvette, France

		Tel: +33 1 69 08 26 40 Fax: +33 1 69 08 77 16
Catherine Ottlé	catherine.ottle@lsce.ipsl.fr	LSCE/IPSL/CEA-CNRS-UVSQ, Centre d'Etudes de Saclay, Orme des Merisiers 91191 Gif-sur-Yvette, France Tel: +33 1 69 08 62 68 Fax: +33 1 69 08 77 16
Jan Verbesselt	jan.verbesselt@wur.nl	Centre for Geo-information, Wageningen University, Wageningen, The Netherlands. Tel: + 31 317 48 52 68 Fax: + 31 317 41 90 00
Eva Haas	haas@geoville.com	EO & GIS Operations GeoVille Information Systems GmbH Sparkassenplatz 2 6020 Innsbruck, Austria Tel: +43 (0)512 562021-12 Fax: +43 (0)512 562021-22