# 34 YEARS OF REMOTELY SENSED SOIL MOISTURE: WHAT CLIMATE SIGNALS DO WE (NOT) SEE?

*Wouter Dorigo[1], Clement Albergel[2], Alexander Loew[3], Tobias Stacke[3], Alexander Gruber[1], Wolfgang Wagner[1], Robert Parinussa[4], Richard de Jeu[4], Luca Brocca[5], Bernhard Bauer-Marschallinger[1],Daniel Chung[1], Christoph Paulik[1]*

[1]Department of Geodesy and Geoinformation, Vienna University of Technology, Vienna, Austria

[2]European Centre for Medium-Range Weather Forecasts (ECMWF), Reading, United Kingdom

[3] Max-Planck-Institute for Meteorology, KlimaCampus, Hamburg, Germany

[4]Earth and Climate Cluster, Faculty of Earth and Life Sciences, VU University Amsterdam, the Netherlands

[5]Research Institute for Geo-Hydrological Protection, National Research Council, Perugia, Italy

## ABSTRACT

Within the Climate Change Initiative of the European Space Agency a multi-satellite soil moisture product covering the period 1979-2010 was released. In this study we first assess its quality by comparing it with soil moisture from ground-based stations and several land surface model estimates. Secondly, the dynamics in the dataset were assessed using trend analysis and comparisons with ancillary data sets of precipitation and vegetation. Significant changes over time were found that largely correspond to changes in precipitation and vegetation vigorousness. However, the influence of changing observation density and data set quality over time need to be better understood for a more precise interpretation of the observed trends.

***Index Terms—*** Soil Moisture, Essential Climate Variable, Climate Data Record, Climate Change

## 1. INTRODUCTION

Soil moisture is one of the main controllers of the exchange of water, energy, and carbon between the land surface and the atmosphere. Thus, dynamics in soil moisture are expected to strongly correlate with short-term and long-term variations of several hydrological and biological variables. During the last few years, various products from past and present satellite microwave missions have become publicly available. However, none of the single missions covers a period long enough to study climate dynamics in a robust manner. To bridge this gap, within the Climate Change Initiative of the European Space Agency a harmonized soil moisture product was released which combines six of the freely available products from active and passive satellite sensors for the period 1979 to present [1, 2]. The harmonized product, referred to as ECV_SM, constitutes the first purely observation-based soil moisture dataset that is long enough to study systematic changes over time [3]. The scope of this study is twofold: first we provide a thorough quality assessment of the multi-satellite dataset using ground-based observations and model data. This is necessary to see whether the signals encountered in the dataset are true signals or related to artifacts. Second, we study the soil moisture dynamics contained within the dataset and confront them with the dynamics encountered in other biogeophysical variables.

## 2. ECV_SM VALIDATION

First, we assessed the quality of ECV_SM using over 600 in-situ data sets from almost 30 networks worldwide taken from the International Soil Moisture Network [4]. The performance was assessed using conventional error metrics like Spearman correlation and unbiased root mean square difference and the recently introduced triple collocation technique. In general a good agreement was found between the in-situ sites and ECV_SM although results over densely vegetated areas and areas of complex topography lagged behind those encountered for semi-arid areas [5, 6]. Results for the Pearson correlation statistics per network are found in coeff

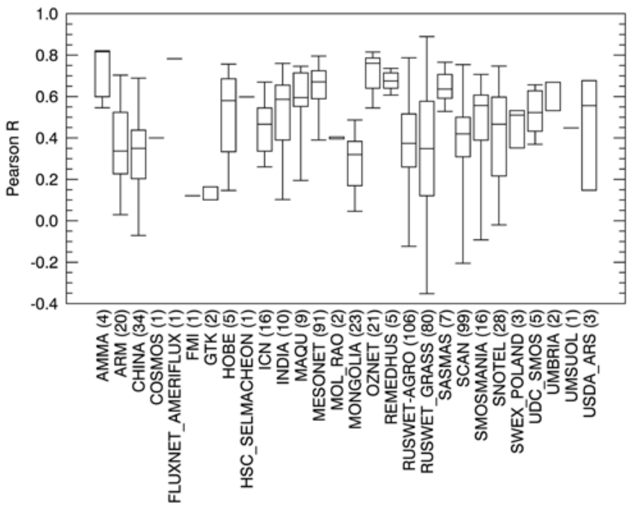


**Figure 1. Pearson correlation coefficient of ECV_SM against in-situ observations, summarized per network. Presented are the median, the interquartile range (as indicated by the box), and the minimum and maximum values (whiskers).**

Due to the heterogeneity of the in-situ datasets in space and time it is difficult to draw any firm conclusions about the global performance of ECV_SM and its evolution over the observation period. Therefore, we compared ECV_SM with various land surface models including ERA-Interim, ERA-Land, an updated version of the ERA-Interim land surface model, and JSBACH [7, 8]. Generally, we found a good agreement between ECV_SM and model data sets, except for the high latitudes where soil moisture retrieval from microwave observations is hampered by frozen soil conditions and snow cover. Nevertheless, the correspondence with ECV_SM varied between models, which is likely to be related to the different forcing data sets used in the models. Besides, the comparison with models allowed us to identify the influence of the different input microwave sensors to the overall product quality. A general increase in accuracy is observed over time. One of the major limitations identified by Loew et al. [8] is the dependency of ECV_SM on the climatology of GLDAS-Noah land surface model soil moisture. Therefore the value of ECV_SM as an independent dataset is limited when assessing absolute values or statistics based on percentile distributions.

## 3. ANALYSING SOIL MOISTURE DYNAMICS

Trends within ECV_SM were calculated for the period 1988-2010 applying the Mann-Kendall test to seasonally averaged soil moisture values (Figure 1)[3]. 26.6% of the area covered by the dataset showed significant trends (p=0.05). Of these, 73.2% were negative and 26.8% positive. Subtle drying trends were found in the Southern US, central South America, central Eurasia, northern Africa and the Middle East, Mongolia and northeast China, northern Siberia, and Western Australia. The strongest wetting trends were found in southern Africa and the subarctic region. Intra-annual analysis revealed that most trends are not uniform among seasons. The most prominent trend patterns in remotely sensed surface soil moisture were also found in GLDAS-Noah, ERA Interim, ERA-Land, MERRA-Land modeled surface soil moisture and GPCP precipitation data, lending confidence to the obtained results, although some care should be taken in interpreting the results in areas that were identified as problematic in the previous section. The relationship with trends in GIMMS Normalized Difference Vegetation Index data seem to be more complex as land cover plays a crucial role in this respect, with crops reacting more directly to changes in available water than bushes and trees. Currently, several evaluations are on the way, which try to explain the major variations in soil moisture by fluctuations in the major climate modes (ocean circulation patterns)[9].

## 4. CONCLUSIONS AND OUTLOOK

The multi-mission ECV_SM soil moisture dataset presented in this contribution offers great potential for studying the dynamics of soil moisture over a period of more than 30 years. It provides an independent source of information with respect to the modeled datasets commonly used for this task. If the single-sensor datasets are combined in an appropriate way, the merged product may profit of the strengths of the individual sources while limiting their weaknesses. For this reason, future efforts will focus on further improving the ECV_SM, e.g. by incorporating additional sensors, enhancing their intercalibration, and filling gaps in the existing product. Improvements of the merging algorithm should eventually lead to a product that is totally independent of any ancillary soil moisture dataset. Ongoing cross-comparisons with additional observation-based data sets will further strengthen our knowledge about the processes behind the observed dynamics and trends.

## 5. ACKNOWLEDGEMENTS

The authors acknowledge the support from the European Space Agency (ESA) through the Climate Change Initiative (CCI) soil moisture project.

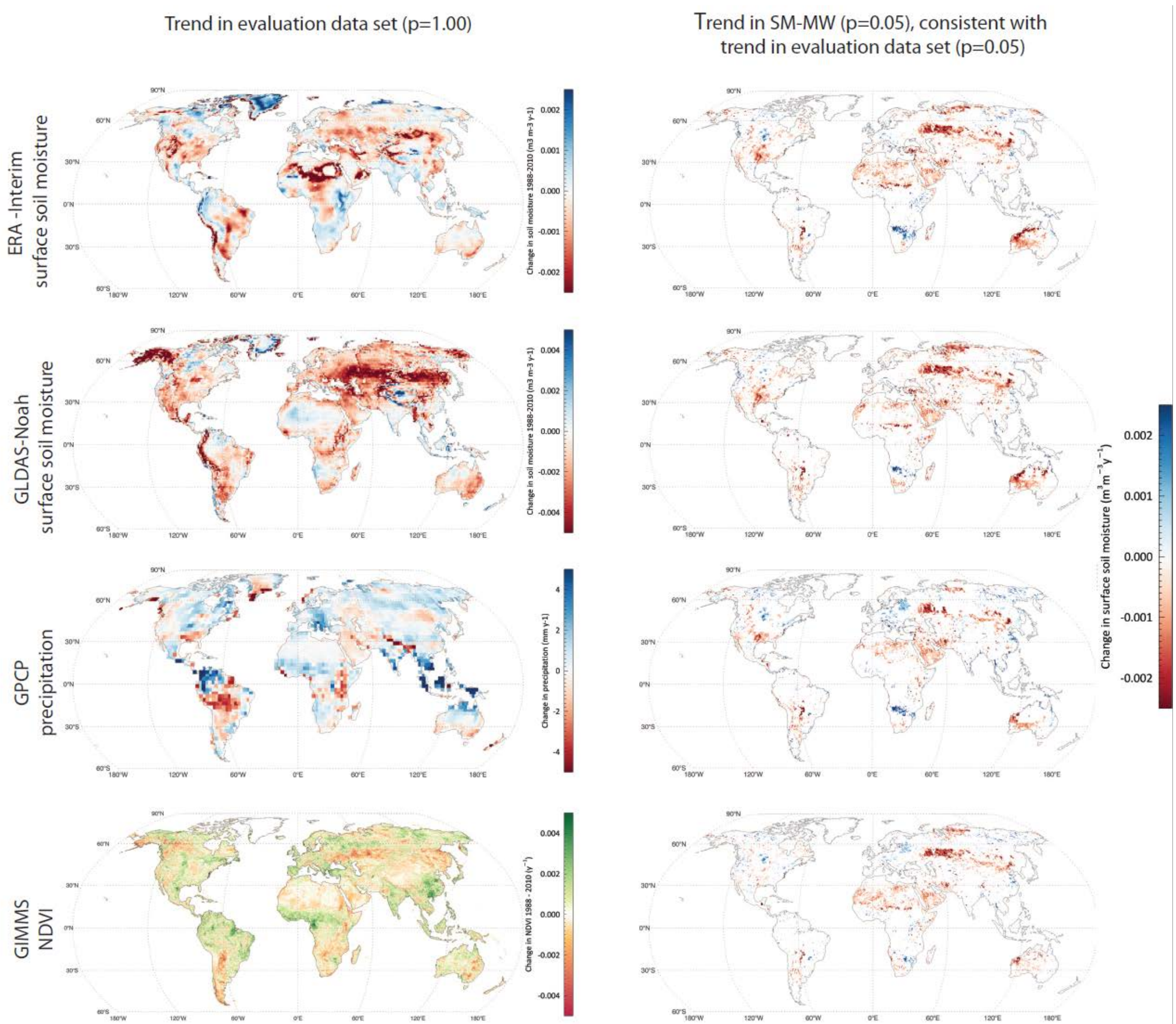


**Figure 2. Change in ECV_SM ($m^3m^{-3}y^{-1}$) over the period 1988-2010. Reprinted from [3], copyright 2012, with permission from AGU.**

## 6. REFERENCES

[1] Y. Y. Liu, W. A. Dorigo, R. M. Parinussa, R. A. M. De Jeu, W. Wagner, M. F. McCabe, J. P. Evans, and A. I. J. M. Van Dijk, "Trend-preserving blending of passive and active microwave soil moisture retrievals," *Remote Sensing of Environment,* vol. 123, pp. 280-297, 2012.

[2] Y. Y. Liu, R. M. Parinussa, W. A. Dorigo, R. A. M. De Jeu, W. Wagner, A. I. J. M. Van Dijk, M. F. McCabe, and J. P. Evans, "Developing an improved soil moisture dataset by blending passive and active microwave satellite-based retrievals," *Hydrology and Earth System Sciences,* vol. 15, pp. 425-436, 2011.

[3] W. Dorigo, R. De Jeu, D. Chung, R. Parinussa, Y. Liu, W. Wagner, and D. Fernandez-Prieto, "Evaluating global trends (1988-2010) in homogenized remotely sensed surface soil moisture," *Geophysical Research Letters,* vol. 39, p. L18405, 2012.

[4] W. A. Dorigo, W. Wagner, R. Hohensinn, S. Hahn, C. Paulik, A. Xaver, A. Gruber, M. Drusch, S. Mecklenburg, P. van Oevelen, A. Robock, and T. Jackson, "The International Soil Moisture Network: a data hosting facility for global in situ soil moisture measurements," *Hydrology and Earth System Sciences,* vol. 15, pp. 1675-1698, 2011.

[5] W. A. Dorigo, A. Gruber, R. A. M. De Jeu, W. Wagner, T. Stacke, A. Loew, C. Albergel, L. Brocca, D. Chung, R. M. Parinussa, and R. Kidd, "Evaluation of the ESA CCI soil

moisture product using ground-based observations," *Remote Sensing of Environment,* In revision.
[6] C. Albergel, W. Dorigo, R. Reichle, G. Balsamo, P. d. Rosnay, J. Muñoz-Sabater, L. Isaksen, R. Reichle, R. d. Jeu, and W. Wagner, "Skill and global trend analysis of soil moisture from reanalyses and microwave remote sensing," *Journal of Hydrometeorology,* vol. in press, 2013.
[7] C. Albergel, W. Dorigo, G. Balsamo, J. Muñoz-Sabater, P. de Rosnay, L. Isaksen, L. Brocca, R. de Jeu, and W. Wagner, "Monitoring multi-decadal satellite earth observation of soil moisture products through land surface reanalyses," *Remote Sensing of Environment,* in review.
[8] A. Loew, T. Stacke, W. Dorigo, R. de Jeu, and S. Hagemann, "Potential and limitations of multidecadal satellite soil moisture observations for climate model evaluation studies," *Hydrology and Earth System Sciences,* vol. in review, 2013.
[9] B. Bauer-Marschallinger, W. Dorigo, W. Wagner, and A. van Dijk, "How ENSO, IOD and SAM Drive Soil Moisture Variations in Australia - Analyzing 32 Years of Remotely Sensed Data," *Journal of Climate,* In revision.