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Evaluation of satellite soil moisture products over Norway using ground-based observations

A. Griesfeller[a], W.A. Lahoz[a,*], R.A.M.de Jeu[b], W. Dorigo[c], L.E. Haugen[d], T.M. Svendby[a], W. Wagner[c]

[a] Norwegian Institute for Air Research (NILU), Postboks 100, 2027 Kjeller, Norway
[b] Department of Earth Sciences, Faculty of Earth and Life Sciences, VU University Amsterdam, Amsterdam, The Netherlands
[c] Department of Geodesy and Geo-Information, Vienna University of Technology, Vienna, Austria
[d] Norwegian Water Resources and Energy Directorate (NVE), Oslo, Norway

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ABSTRACT

In this study we evaluate satellite soil moisture products from the advanced SCATterometer (ASCAT) and the Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) over Norway using ground-based observations from the Norwegian water resources and energy directorate. The ASCAT data are produced using the change detection approach of Wagner et al. (1999), and the AMSR-E data are produced using the VUA-NASA algorithm (Owe et al., 2001, 2008). Although satellite and ground-based soil moisture data for Norway have been available for several years, hitherto, such an evaluation has not been performed. This is partly because satellite measurements of soil moisture over Norway are complicated owing to the presence of snow, ice, water bodies, orography, rocks, and a very high coastline-to-area ratio. This work extends the European areas over which satellite soil moisture is validated to the Nordic regions. Owing to the challenging conditions for soil moisture measurements over Norway, the work described in this paper provides a stringent test of the capabilities of satellite sensors to measure soil moisture remotely. We show that the satellite and in situ data agree well, with averaged correlation (R) values of 0.72 and 0.68 for ASCAT descending and ascending data vs in situ data, and 0.64 and 0.52 for AMSR-E descending and ascending data vs in situ data for the summer/autumn season (1 June–15 October), over a period of 3 years (2009–2011). This level of agreement indicates that, generally, the ASCAT and AMSR-E soil moisture products over Norway have high quality, and would be useful for various applications, including land surface monitoring, weather forecasting, hydrological modelling, and climate studies. The increasing emphasis on coupled approaches to study the earth system, including the interactions between the land surface and the atmosphere, will benefit from the availability of validated and improved soil moisture satellite datasets, including those over the Nordic regions.

1. Introduction

Soil moisture plays an important role in land-atmosphere interactions (Seneviratne et al., 2010). It is classified as an essential climate variable (ECV) since 2010. By directly affecting plant growth and other organic processes it connects the water cycle to the carbon cycle. As soil moisture has a significant impact on the partitioning of water and heat fluxes (latent and sensible heat), it connects the hydrological cycle with the energy cycle (see, e.g., Lahoz and De Lannoy, 2014). Evaporation, through which soil moisture is a source of water for the atmosphere, is an important energy flux (Trenberth et al., 2009), and is connected to the surface skin and soil temperature. By returning 60% of the whole land precipitation back to the atmosphere (e.g., Oki and Kanae, 2006), it is also important for the continental water cycle. Soil moisture, temperature and their impacts on the water, energy and carbon cycles play a major role in climate-change projections (Seneviratne et al., 2010; IPCC, 2013). The state of the land surface, for example identified by the amount of soil moisture, has an impact on the land-atmosphere fluxes of CH_4 (e.g., Blodau, 2002; Tagesson et al., 2012) and of N_2O (e.g., Bouwman, 1998; Thompson et al., 2014), both of which are important greenhouse gases.

The use of observations from satellites has become a powerful tool to enhance our understanding of the role of soil moisture in the

* Corresponding author at: Norwegian Institute for Air Research (NILU), Postboks 100, 2027 Kjeller, Norway. Tel.: +47 63898257.
E-mail address: wal@nilu.no (W.A. Lahoz).

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hydrological cycle in a number of areas, e.g., land-atmosphere processes (Miralles et al., 2012; Taylor et al., 2012); weather and runoff forecasts (Brocca et al., 2010; Bisselink et al., 2011); landslides (Brocca et al., 2012b); and rainfall products (Chen et al., 2012). Since 2000 several satellite missions measuring soil moisture have been launched: e.g., the Advanced Microwave Sounding Radiometer for EOS (AMSR-E) (Njoku and Chan, 2006), the advanced SCATterometer (ASCAT) (Bartalis et al., 2007b), and the Soil Moisture Ocean Salinity (SMOS) (Kerr et al., 2010). The AMSR-2 mission (Imaoka et al., 2012) is continuing the soil moisture measurements from AMSR-E, which failed in late 2011. These missions include either passive or active microwave measurement techniques. More recently, the Soil Moisture Active Passive (SMAP) mission (Entekhabi et al., 2014) was launched on 30 January 2015.

Satellite observations provide information on soil moisture spatio-temporal variability, which is key to understanding processes linking the land surface and the atmosphere, and their impact on, e.g., climate change. This is a key motivation behind the setting up by the European Space Agency (ESA) of the climate change initiative (CCI) project for soil moisture (http://www.esa-soilmoisture-cci.org/). The objective of the soil moisture ESA CCI is to produce the most complete and most consistent global soil moisture data record based on active and passive microwave sensors from satellite platforms. Within this ESA CCI effort, there has been a first attempt to produce a multi-satellite product of surface soil moisture with global coverage at 25 km resolution and a daily time stamp for the period 1979–2010 (Liu et al., 2011, 2012).

For northern high latitudes, the vegetation in its terrestrial ecosystems is interactively controlled by temperature, soil moisture, light and availability of nutrients during the growing season (Barichivich et al., 2014, and references therein). Whereas temperature is the main climate constraint on plant growth in the cooler northern regions, in the southern boreal regions soil moisture becomes more important. The rapid warming at northern latitude regions in recent decades has resulted in a lengthening of the growing season, greater photosynthetic activity and enhanced carbon sequestration by the ecosystem. These changes are likely to intensify summer droughts, tree mortality and wildfires. A key concern is the release of carbon-bearing compounds (CH_4 and CO_2) from soil thawing at high northern latitudes associated with rapid warming of these regions, and which has been identified as a potential major climate change feedback (Hodgkins et al., 2014). These changes make it important to have information on the land surface (particularly, soil moisture and temperature) at high northern latitude regions. In particular, the availability of soil moisture measurements from several satellite platforms provides an opportunity to address issues associated with the effects of climate change at high northern latitudes, e.g., assessing multi-decadal links between increasing temperatures, snow cover, soil moisture variability and vegetation dynamics (see Barichivich et al., 2014, and references therein).

The remote measurements of soil moisture from satellite platforms require evaluation. This is commonly done using ground-based measurements of soil moisture that are independent from the satellite measurements. Several ground-based soil moisture datasets are used to evaluate satellite soil moisture data. A comprehensive data base of in situ soil moisture networks is found in the ISMN (International Soil Moisture Network) website, http://ismn.geo.tuwien.ac.at/ (Dorigo et al., 2011, 2013).

Evaluation of satellite soil moisture data using in situ networks assesses the spatial and temporal correlations between the satellite and in situ datasets. Other metrics such as bias and root mean square difference (RMSD) are also used. Examples include the evaluation of data from ASCAT soil water index (SWI; see Section 3.2 for a discussion of SWI) using data from the SMOSMANIA in situ network (Albergel et al., 2009), the evaluation of ASCAT SWI using data from various in situ networks in the ISMN (Paulik et al., 2014), and the evaluation of ASCAT SWI and AMSR-E SWI using different in situ networks in Italy, France, Spain, and Luxembourg (Brocca et al., 2011). Data from the ISMN is being used to evaluate the satellite-derived soil moisture products from the ESA CCI for soil moisture (see, e.g., Dorigo et al., 2014).

Although evaluation of soil moisture satellite data has been done over many locations over the globe, to our knowledge this has not been done over Norway. This is because measurements of soil moisture are generally difficult or not possible over snow, ice, water bodies, orography and rocks, all present in Norway (see the discussion in Kerr et al., 2010). Most evaluation studies of soil moisture satellite data in Europe have been done at central and southern European latitudes for different climate regimes to those found in Norway. Soil moisture studies in northern regions outside Europe include Canada (e.g., Champagne et al., 2010). Similar to this study, where we use data from June until mid-October, to avoid periods with frozen ground or snow covered ground, Champagne et al. (2010) used only the period from May until October. Al-Yaari et al. (2014) evaluate soil moisture satellite data against land data assimilation estimates at the European Centre for Medium-Range Weather Forecasts (ECMWF) for biomes over the world. They find the northern high latitudes have the worst performance in terms of correlation (R), RMSD, and biases. The results of Al-Yaari et al. (2014) (see, e.g., their Fig. 6) indicate the need to evaluate soil moisture satellite data at northern high latitudes, including the Nordic regions.

Although to our knowledge satellite soil moisture data have not been evaluated hitherto over Norway, the performance of simulated soil moisture over Norway, in particular its spatio-temporal distribution, has been evaluated (Kristiansen et al., 2012). Tests of the sensitivity of screen-level (2 m) temperature forecasts to initial conditions in soil moisture and temperature indicate the importance of an accurate representation of the soil moisture field for numerical weather prediction (NWP) forecasts. This provides a further reason for evaluation of satellite soil moisture over Norway.

In this paper we start to remedy the lack of comprehensive evaluation of remotely sensed soil moisture over northern regions, particularly over Europe, and present results of the evaluation of soil moisture data from ASCAT and AMSR-E over Norway using in situ data from the NVE (Norges vassdrags- og energidirektorat, the Norwegian water resources and energy directorate; http://www.nve.no/en/). This extends the European areas over which satellite soil moisture data are evaluated.

This paper is structured as follows. In Section 2 we describe the main soil moisture datasets used in this paper, namely ASCAT soil moisture data (produced using the change detection approach of Wagner et al., 1999) and AMSR-E soil moisture data (produced using the VUA-NASA algorithm described in Owe et al., 2001, 2008) and NVE in situ soil moisture data. The data treatment needed owing to the different spatio-temporal resolutions of the satellite and in situ soil moisture data is shown in Section 3, followed by results and discussion in Section 4, and conclusions in Section 5.

2. Data

2.1. The advanced SCATterometer: ASCAT

The Advanced SCATterometer (ASCAT), an active real aperture radar backscatter instrument, was launched in October 2006 onboard EUMETSAT's MetOp-A satellite. The MetOp-A is in a sun-synchronous orbit, crossing the Equator at the local times of 09:30 (descending orbit) and 21:30 (ascending orbit). In this study, data from both the descending and ascending orbits are used – this follows the approach in Brocca et al. (2011) and, by increasing the