# The use of Earth observation satellites for soil moisture monitoring

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Soil moisture strongly influences the exchange of water and energy between the land surface and the atmosphere and is thus a key variable of the climate system. While many of its effects on the climate system, such as the role of soil moisture deficits in the occurrence of heatwaves, are reasonably well understood, progress in the scientific understanding of soil moisture–climate interaction has so far been hampered by the lack of soil moisture observations. Fortunately, this situation has improved significantly in the last few years thanks to the increasing availability of in situ (for example, through the International Soil Moisture Network – see www.ipf.tuwien.ac.at/insitu/) and satellite-based soil moisture observations.

## MICROWAVE REMOTE-SENSING OF SOIL MOISTURE

Many Earth observation satellites carry microwave sensors that measure the emission or the reflection of microwave radiation by the Earth's surface. The signal received by these microwave sensors is sensitive to the amount of water contained in the first few centimetres of the soil because, at microwave frequencies, the water molecules contained in the soil rotate as they try to align themselves with the alternating electric field of the microwaves. This rotation not only leads to a minuscule heating of the soil (an effect that is exploited at much higher energy levels in microwave ovens) but also causes scattering of the microwave radiation. Therefore, active microwave instruments (radars) that illuminate a wet soil generally receive a higher backscattered signal than when illuminating a dry soil. For the same reason, wet soil surfaces transmit less natural microwave radiation emanating from deeper soil layers than dry soils, which implies that the natural radiation received by passive microwave instruments (radiometers) decreases with increasing surface soil moisture content.

Despite the strong relationship between soil moisture and microwave observations, it has been quite difficult to develop operational Earth observation capabilities. Technologically, one of the challenges has been to build sensors that are capable of measuring the low energy of microwave signals with good radiometric accuracy. Another challenge has been to push the sensor wavelength to longer wavelengths in order to maximize the sensitivity to soil moisture, but without negative repercussions on the spatial resolution and coverage. Scientifically, the task has been to develop algorithms that single out the soil moisture signal from a host of other parameters affecting the microwave observations, such as the vegetation cover or the roughness of the soil surface. While many scientific questions are still only partially answered, the retrieval algorithms have matured up to a point where global-scale processing has become feasible.

## A VIRTUAL CONSTELLATION OF SOIL MOISTURE SATELLITES

So far only one Earth observation satellite has been built and launched for the primary purpose of measuring soil moisture over land, namely the Soil Moisture and Ocean Salinity (SMOS) satellite launched by the European Space Agency (ESA) in November 2009. The next dedicated soil moisture satellite will be the Soil Moisture Active-Passive (SMAP) mission that is foreseen to be launched by the National Aeronautics and Space Administration (NASA) in the 2014–2015 time frame. But these two dedicated explorative missions are not alone; there is a fleet of other satellites with microwave remote-sensing instruments on board. These instruments have been built for other purposes, for example, for sea-ice or ocean wind monitoring, but they can nonetheless also be used for measuring soil moisture. As a result, there are now several satellites in orbit which, taken together, provide several soil moisture measurements per day for each point of the Earth's land surface. One may thus think of these satellites as a virtual constellation providing day-round global-scale soil moisture observations.

Unfortunately, it is still quite difficult to directly compare soil moisture data derived from the different satellites. This is because the characteristics of the various sensors and scientific algorithms may differ significantly. Also, there are as yet no internationally agreed standards. Nonetheless, the situation improves significantly when systematic differences between the different satellite datasets are removed. Then it becomes apparent that most satellite-derived soil moisture products depict soil moisture trends in space and time quite well. This has also opened up the opportunity to merge soil moisture data from active and passive microwave instruments to create a long-term soil moisture record, as has been done within the framework of ESA's Climate Change Initiative (see www.esa-soilmoisture-cci.org/).

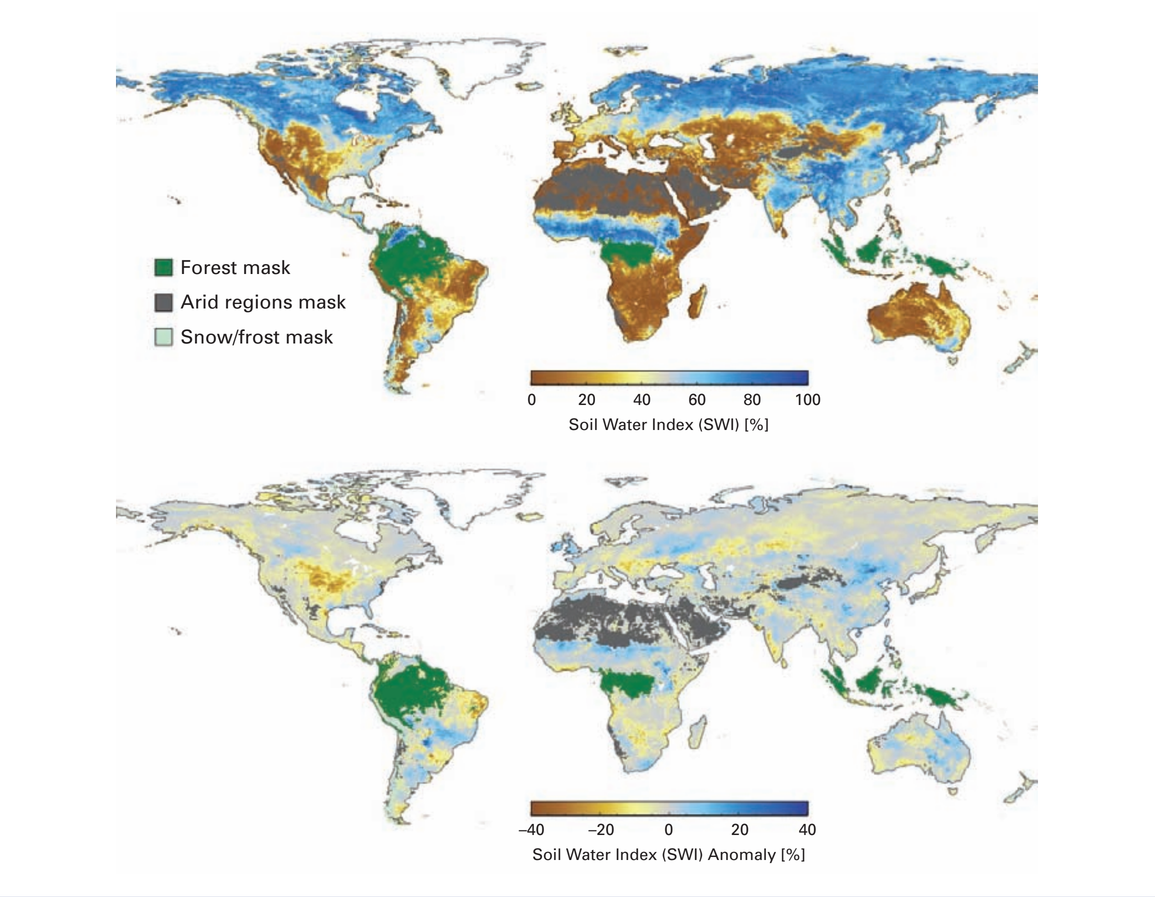
## METOP ASCAT SOIL MOISTURE

Until a few years ago satellite soil moisture products had only been available off-line with a data latency of, at best, a few days. This changed with the Advanced Scatterometer (ASCAT), which is an active microwave sensor that has been flown on a series of Meteorological Operational (METOP) satellites since late 2006. ASCAT soil moisture data are processed and disseminated fully operationally in two stages:

- The European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) generates 25-km ASCAT surface soil moisture data in near-real time within the framework of its Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF). These data are given in the original swath geometry of the instrument, representing only the thin (< 2 cm) topsoil layer accessible to the microwaves.

- By filtering the ASCAT surface soil moisture time series with an exponential filter, the so-called ASCAT Soil Water Index (SWI) is derived, which is an estimate of the moisture content in the soil profile down to a depth of about 0.5 m. Daily ASCAT SWI data are available on a regular global grid through the global land monitoring service of the European Copernicus (formerly GMES) programme.

Both the ASCAT surface soil moisture and SWI data products are freely accessible and can be used by operational and scientific users alike to study weather- and climate-related soil moisture patterns.




Absolute soil moisture (top) and soil moisture anomalies (bottom) for the period July–September 2012 derived from the ASCAT flown on board of the METOP satellites. SWI is an estimate of the relative moisture content in the 0.5-m soil layer derived solely from the satellite observations. Areas where ASCAT cannot provide reliable soil moisture estimates are masked. The SWI anomaly image (baseline period is 2007–2011) shows areas of unusual dryness or wetness, depicting, for example, the severe drought conditions in central North America, north-eastern Brazil, south-eastern Europe, and the unusually wet conditions in Western Africa, which lead to large-scale flooding in the area.