THE HYDROS AND SMOS SATELLITES: GLOBAL SOIL MOISTURE MAPPING

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Abstract: Within the next five years two satellites will be launched that are designed specifically to map and monitor global soil moisture. Each of these is an exploratory mission and a step toward an operational satellite. Each satellite uses highly innovative but different technologies. The first of these will be the European Space Agency Soil Moisture Ocean Salinity (SMOS) mission scheduled for 2007. SMOS will use synthetic aperture radiometry to achieve a moderate spatial resolution. If successful this technology can be extended to even higher spatial resolutions. The second satellite is the Hydrosphere State Mission (Hydros), which is part of the National Aeronautics and Space Administration (NASA) Earth System Science Pathfinder Program (ESSP). The objective of the mission is to provide global measurements of the earth's soil moisture at 10-km resolution with two- to three-days revisit and land-surface freeze/thaw conditions at 3-km resolution with one- to two-days revisit.

INTRODUCTION

Hydrological, weather, and climate modeling can be improved through observation of the current status of soil moisture. Better predictions from these models will lead to improved forecasts of floods and other phenomena. Soil moisture products are now feasible using a new generation of microwave remote sensing satellites. The quality of these products will continue to improve as new sensors are launched over this decade. Within the next five years two satellites will be launched that are designed specifically to map and monitor global soil moisture. Each of these is an exploratory mission designed to contribute to future an operational satellites. The two satellites use highly innovative but different technologies. The first of these will be the European Space Agency Soil Moisture Ocean Salinity (SMOS) mission scheduled for 2007. SMOS will use synthetic aperture radiometry to achieve a moderate spatial resolution. If successful this technology can be extended to even higher spatial resolutions. The second satellite is the Hydrosphere State Mission (Hydros), which is part of the National Aeronautics and Space Administration (NASA) Earth System Science Pathfinder Program (ESSP). The mission includes combined radar/radiometer data products that will use the synergy of the two sensors to deliver enhanced-quality 10-km resolution soil moisture estimates. These new satellites will be described along with reviews of current missions and some basic principles of microwave remote sensing.

BASIC PRINCIPLES OF MICROWAVE REMOTE SENSING OF SURFACE SOIL MOISTURE

Microwave remote sensing provides a direct measurement of the surface soil moisture for a range of vegetation cover conditions. Two basic approaches are used, passive and active. In passive methods, the natural thermal emission of the land surface (or brightness temperature) is measured at microwave frequencies using very sensitive detectors. In active methods or radar, a microwave pulse is sent and received. The power of the received signal is compared to that which was sent to determine the backscattering coefficient.

Microwave sensors operating at very low microwave frequencies (< 6 GHz) provide the best soil moisture information. At low frequencies, attenuation and scattering problems associated with the atmosphere and vegetation are less significant, the instruments respond to a deeper soil layer, and have a higher sensitivity to soil water content.

Most research and applications involving passive microwave remote sensing of soil moisture have emphasized low frequencies (L band). In this range, it is possible to develop soil moisture retrievals based on a single H polarization observation (Jackson 1993). This approach relies on providing ancillary data on temperature, vegetation, land cover, and soils. Other algorithm approaches are described in Njoku et al. (2000). Spatial resolution has been an issue with passive systems (>50 km). However, as will be described, there are solutions being explored that could extend this to 10 km this decade.

Estimating soil water content from radar backscatter is easier when the soil is bare. When there is a vegetation cover, establishing soil water under the canopy is much more difficult and requires unraveling the contribution of the soil itself from that of vegetation. The most common approach to estimating soil moisture from backscatter has been linear regression (Satalino et al. 2002). This of course does not result in a robust retrieval algorithm. More theoretical approaches have limited applicability and are difficult to implement. A more promising technique involves semi-empirical models. These involve multiple polarization observations and restrictions on the range of applicability. Algorithms incorporating this approach for bare soils are presented in Dubois et al. (1995).

A key issue in comparing passive and active microwave methods from satellites is the tradeoff between the high spatial resolution of synthetic aperture radar (SAR) methods and the robust retrieval and frequent temporal coverage provided by passive methods.

CURRENT PASSIVE MICROWAVE SATELLITE OBSERVING SYSTEMS AND PRODUCTS

Currently, all passive microwave sensors on satellite platforms operate at high frequencies (> 6 GHz) (see Table 1). A brief description of some of the current sensor systems follows.

Special Satellite Microwave/Imager: Of particular note, due to the longevity of its data record, is the Special Satellite Microwave/Imager (SSM/I) package on the Defense Meteorological Satellite Platforms. These satellites have been in operation since 1987 and provide high frequencies and two polarizations. Interpreting data from the SSM/I to extract surface information requires accounting for atmospheric effects on the measurement (Drusch et al. 2001). When one considers the atmospheric correction, the significance of vegetation attenuation, and the shallow contributing depth of soil for these high frequencies, it becomes apparent that the data are of limited value for estimating soil water content. Spatial resolution of the SSM/I is very coarse (see Table 1).

There have been few attempts at generating standard land surface products using SSM/I data. NOAA (Basist et al. 1998) uses SSM/I data to produce an experimental data product called the Soil Wetness Index (SWI). This index is intended to provide information on significantly wet soil conditions (areal extent of flooding), which can be more reliably detected than variations at lower levels of soil moisture. A few studies have attempted to extract actual soil moisture from SSM/I data (Jackson 1997, Vinnikov et al. 1999, Owe et al. 1992).

Table 1. Passive Microwave Satellite Systems

Satellite	Period of Coverage	Frequency (GHz)	Polarization	Spatial Resolution (km)	Repeat Frequency (days)
SSM/I	1987 - present	19.4, 22.2, 37.0, 85.5	H and V	70 to 5 km	1-2
TMI	1998 - present	10.7, 19.4, 21.3, 37, 85.5	H and V	60 to 6 km	1
AMSR (Aqua)	2002 - present	6.9, 10.7, 18.7, 23.8, 36.5, 89.0	H and V	75 to 7 km	2-3
AMSR (ADEOS-II)	2002 - 2002	6.9, 10.7, 18.7, 23.8, 36.5, 89.0	H and V	70 to 6 km	2-3
Windsat	2003 -present	6.8, 10.7, 18.7, 23.8, 37	H and V (U in some channels)	50 to 10 km	2-3
SMOS	(2007)	1.4	H and V	50 km	2-3
Hydros	(2010)	1.4	H and V (passive) HH, VV (active)	3 to 40 km	2-3

Tropical Rainfall Measurement Mission Microwave Imager: Another current option is the Tropical Rainfall Measurement Mission (TRMM) Microwave Imager (TMI). It is a five-channel, dual-polarized, and passive microwave radiometer. The lowest TMI frequency is 10 GHz, about half that of the SSM/I. The TMI has a higher spatial resolution (see Table 1) as compared to the SSM/I. TRMM only provides coverage of the tropics, which includes latitudes between 38^{o}N and 38^{o}S for the TMI instrument. However, a unique capability of the TMI is its ability to collect data daily, and in many cases more often, within certain latitude ranges. Jackson and Hsu (2001) and Wen et al. (2003) demonstrated the potential of using these data to retrieve soil moisture. Bindlish et al. (2003) have developed and validated a five-year data set for the Southern U.S. based upon the TMI data.

Advanced Microwave Scanning Radiometer: Several multifrequency passive microwave satellite systems were launched in 2002 and 2003. As opposed to the previously available systems these offered a lower frequency channel operating at C band, which was anticipated to provide a more robust soil moisture measurement. These satellites were the NASA Aqua, Japanese ADEOS-II, and the U.S. interagency Coriolis satellite. The ADEOS-II satellite stopped operations in October of 2003 and will not be discussed here. A component of Aqua is the Advanced Microwave Scanning Radiometer (AMSR) described in Table 1. It was found that over land, in particular the U.S., that there was significant radio frequency interference (RFI)

As opposed to previous passive microwave satellite missions, the Aqua project includes soil moisture as a product. The algorithm originally planned for use has had to undergo modification since it was designed to use the C band channels, which were found to be contaminated with RFI (Njoku et al. 2003). All Aqua AMSR products are available at http://nsidc.org/data/amsre/.

The Coriolis satellite includes the Windsat instrument, which is a multifrequency passive microwave radiometer system. It is similar to AMSR with some differences in frequencies and more polarization options. It is a prototype of one component of the next generation of operational polar orbiting satellites that the U.S. will be implementing at the end of this decade.

NEXT GENERATION PASSIVE MICROWAVE SATELLITE OBSERVING SYSTEMS AND PRODUCTS

Programs are underway to develop and implement space-based systems with a 1.4 GHz channel that would provide improved global soil moisture information. Toward that goal the European Space Agency (ESA) is developing a sensor system called the Soil Moisture Ocean Salinity (SMOS) mission and NASA has initiated a mission called Hydros.

SMOS: SMOS is due to launch in 2007 (See Figure 1). It will use a low frequency (21 cm wavelength) radiometer with multiple look angles in order to derive surface (0 – 5 cm) soil moisture and vegetation water content (Kerr et al. 2001). Instruments operating at such low frequencies are well-suited for measuring soil moisture since signal transmissivity through vegetation and the sensing depth both increase with increasing wavelength.

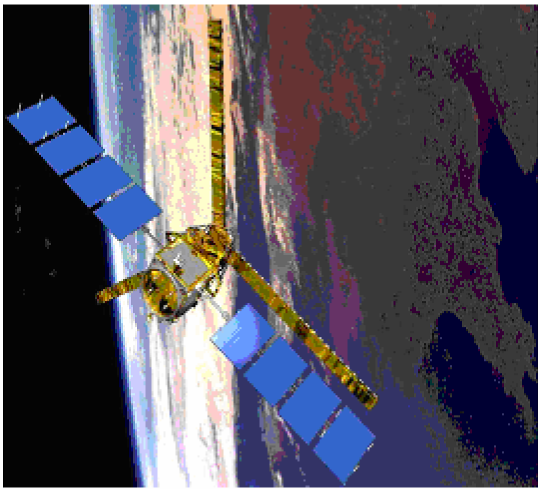

Figure 1. The Soil Moisture Ocean Salinity (SMOS) satellite concept.

The two concepts critical to SMOS are its antenna technology and the use of multi-angular observations in soil moisture retrieval. SMOS employs an interferometric radiometer, which by way of a number of small receivers will measure the phase difference of incident radiation. This is also called two dimensional synthetic aperture radiometry It can achieve what a very large antenna would, but with a much smaller mass and size. The technique is based on the cross-correlation of observations from all possible combinations of receiver pairs. A two dimensional image is taken every 1.2 seconds. As the satellite moves along its orbital path each pixel is observed under all possible viewing angles. These multiple angles are used in radiative transfer equations to retrieve soil moisture (Wigneron et al. 2000). SMOS will provide a 40 km global soil moisture product every 2-3 days.

Hydros: NASA's Hydros mission (see Figure 2) will also make low frequency passive microwave measurements but in addition it will include an active radar system near the same frequency band. Both high-resolution soil moisture and its freeze/thaw state can be detected with the combined active and passive sensors.

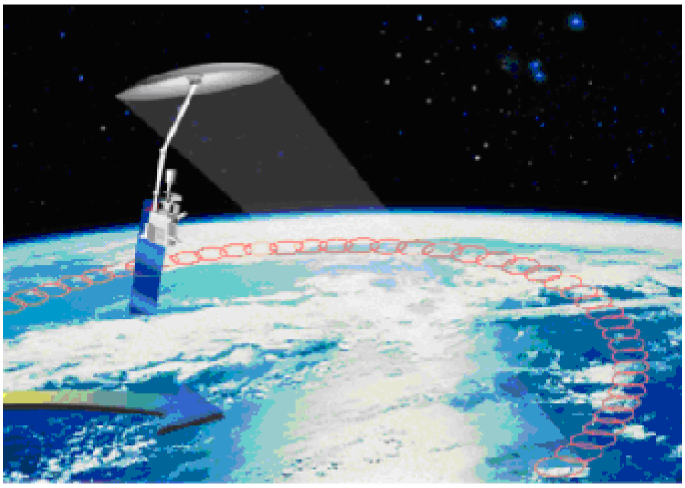

Figure 2. The Hydros satellite concept.

The Hydros antenna will utilize a new approach to achieve a large diameter with low mass and launch dimensions. This involves lightweight wire mesh that can be folded much like an umbrella or accordion for launch. With a 6 m antenna, Hydros will be able to provide a 40 km passive microwave observation and soil moisture product using the multiple polarization 1.4 GHz data and proven retrieval algorithms (Entekhabi et al. 2004).

In addition to the passive microwave instrument, Hydros will have a radar that will share the same antenna. This instrument will be capable of providing a 3 km soil moisture product withpossibly limited accuracy. However, the real role of this sensor is to serve as a disagreggation and data fusion tool that would be combined with the coarser resolution passive product. It is anticipated that a highly reliable 10 km soil moisture product will result from this integration. A 10 km soil moisture product would open the doors to a much wider range of applications and the demonstration of the approach could lead to even higher resolutions in the future. Hydros is scheduled for 2010.

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