Retrieving Soil Moisture from Spaceborne Passive Microwave Data

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Abstract – Soil moisture products will be generated from data acquired by the Advanced Microwave Scanning Radiometer (AMSR-E) on the Aqua satellite. The AMSR instrument, built in Japan, will also be launched on the ADEOS-II satellite. The AMSR-E level 2 and 3 data processing will be performed at the NASA Marshall Space Flight Center (MSFC), and the products will be archived for public distribution at the National Snow and Ice Data Center (NSIDC). The soil moisture products will be generated at a spatial resolution of approximately 56 km and will include associated estimates of vegetation water content and surface temperature at the same spatial resolution. The products will be generated on an earth-fixed grid with a nominal grid spacing of 25 km. Gridded brightness temperatures will be included in the archived level 3 product to facilitate algorithm updates and intercomparisons during the post-launch validation.

INTRODUCTION

A primary goal of land surface investigations using spaceborne remote sensing is to obtain accurate estimates of soil moisture m_e, vegetation water content w_e, and surface temperature T_e on a global, repetitive basis. These quantities play key roles in determining the fluxes of water and energy between the land surface and atmosphere. Such estimates are of use in improving understanding of large-scale land-surface hydrologic processes, monitoring land-surface hydrologic conditions and climate anomalies (floods and droughts), and initializing and validating climate and weather-prediction models. The Advanced Microwave Scanning Radiometer (AMSR) is a new spaceborne sensor, developed by the Japanese National Space Development Agency (NASDA), that has potential for providing useful information on m_e, w_e, and T_e on a routine basis.

The AMSR is a multichannel conically-scanning instrument, with frequencies ranging from 6.9 to 89 GHz and an antenna diameter of 2 m. It is scheduled for launch on the ADEOS-II satellite in late 2001. A copy of the AMSR instrument, AMSR-E, was procured by NASA for launch on the Aqua satellite in December 2000. AMSR-E has a smaller antenna (1.6 m) and will orbit at a lower altitude and different equator crossing time than AMSR (705 km, 1:30 pm vs. 803 km, 10:30 am). The key characteristics of AMSR-E are summarized in Table 1. The 3-dB spatial resolutions shown (IFOVs) are averages of the elliptical footprint dimensions. At the 6.9 to 23.8 GHz frequencies the integration times provide significant oversampling relative to the spatial resolutions. More details on the instrument design, calibration, and operation are available at the AMSR-E website http://wwwghcc.msfc.nasa.gov/AMSR.

Table 1: AMSR-E Characteristics

Freq (GHz)	6.9	10.7	18.7	23.8	36.5	89.0
Bandwidth (MHz)	350	100	200	400	1000	3000
Sensitivity (K)	0.3	0.6	0.6	0.6	0.6	1.1
IFOV (km)	56	38	21	24	12	5.4
Sample spacing (km)	10	10	10	10	10	5
Integration time (ms)	2.6	2.6	2.6	2.6	2.6	1.3
Beam efficiency (%)	95.3	95.0	96.3	96.4	95.3	96.0
Antenna diameter (m)	1.6					
Scan period (s)	1.5					
Ant. offset angle (deg)	47.4					
Earth-inc. angle (deg)	54.8					
Orbit type	Sun-synch., 98.2° incl., 705 km alt., 1:30 pm equator crossing					
Swath width (km)	1445					

The AMSR-E Science Team is charged with developing the algorithms and processing software for the AMSR-E 'standard' products. A set of standard products has been specified by the AMSR-E Team and approved by the EOS Project Science Office. The standard products will be generated at the NASA Marshall Space Flight Center (MSFC) Science Investigator Processing System (SIPS) in Huntsville, AL, and will be archived and distributed by the National Snow and Ice Data Center (NSIDC) in Boulder, CO. The products include resampled 'matched-spatial-resolution' brightness temperatures (level 2A) and ocean, atmosphere, cryosphere, and land geophysical products at level 2 and level 3. The level 2 products are organized by swath while the level 3 products are organized as global or hemispherical grid maps, with daily or longer time-compositing. Descriptions of the products and planned validation activities are provided in the Algorithm Theoretical Basis Documents (ATBDs) and the AMSR-E Science Data Validation Plan, available at the AMSR-E web site.

PRODUCT DESCRIPTION

Primary interest in retrieving land geophysical parameters using AMSR data has focused on retrieval of soil moisture. This is because low-frequency passive microwave sensors are uniquely suited to soil moisture measurement, while surface temperature and vegetation characteristics can also be determined by visible and infrared sensors, such as MODIS and AIRS on Aqua. The accuracy of the retrieved AMSR soil moisture will be limited, however, by vegetation cover since, even at the lowest AMSR frequency of 6.9 GHz, vegetation significantly attenuates microwave emission from the soil surface. Retrievals will not be possible where significant fractions of snow cover, frozen ground, precipitation, open water, or mountainous terrain occur within the footprint. The soil moisture retrieval algorithm currently implemented at the SIPS uses iterative minimum-variance estimation to retrieve simultaneously m_e, w_e, and T_e. As specified in the forward radiative transfer model on which the inversion algorithm is based [1], the retrieved geophysical parameters are defined as: m_e (surface soil moisture, g-cm^{-3})—the soil moisture in the top few millimeters of soil, averaged over the retrieval footprint; w_e (vegetation water content, kg-m^{-2})—the water content in the vertical column of vegetation above the soil, averaged over the retrieval footprint; T_e (land-surface temperature, K)—the microwave radiating temperature of the surface, averaged over the retrieval footprint. The subscripts denote that these are averaged or 'effective' parameters.

For processing convenience, and to facilitate registration with ancillary data sets used by the soil moisture retrieval algorithm, the algorithm operates on brightness temperatures (T_Bs) registered to an earth-fixed grid, i.e. the input level 2A T_Bs are gridded prior to retrieval of geophysical parameters. The gridded T_Bs are output as part of the level 3 standard product along with m_e, w_e, and T_e. The geophysical parameters are retrieved at the spatial resolution of the 6.9 GHz footprint (56 km) since this is the AMSR frequency most sensitive to soil moisture in the presence of vegetation. Table 2 summarizes the retrieved parameters. The expected accuracies and grid definition are discussed in the next section. The level 3 mapped products are composited separately for ascending and descending passes to facilitate study of diurnal temperature effects.

RETRIEVAL ALGORITHM

The retrieval procedure consists of five sequential steps: T_B quality control, gridding, surface classification, geophysical retrieval, and HDF-EOS output. Simple checks are applied to the input T_Bs to screen bad data and possible RFI. The T_Bs are then gridded to an earth-fixed grid using simple binning. A program switch can be selected to implement 2-D interpolation instead of binning if necessary. The projection used for gridding is the 25-km EASE-grid global, cylindrical, equal-area projection, true at 30°N & S. This projection was developed by the NSIDC and has been applied to previous SSM/I data sets. A description of the projection, and the equations used to transform between grid indices and latitude–longitude, is available at the web site, http://www-nsidc.colorado.edu/NASA/GUIDE/EASE. An advantage of this projection is that each grid cell has equal area, although the aspect ratio varies with latitude.

Table 2: AMSR-E Soil moisture algorithm products

Parameter (level)	Expected accuracy‡	Spatial resolution	Grid spacing†	Granularity*
Soil moisture (L2)	0.06 g-cm^{-3}	56 km	~25 km	Half-orbit
Vegetation water content (L2)	0.15 kg-m^{-2}	56 km	~25 km	Half-orbit
Surface temperature (L2)	2.5 K	56 km	~25 km	Half-orbit
Brightness temperatures (L3)	0.3–0.6 K	12, 56 km		1 day
Soil moisture (L3)	0.06 g-cm^{-3}	56 km	~25 km	1 day
Vegetation water content (L3)	0.15 kg-m^{-2}	56 km	~25 km	1 day
Surface temperature (L3)	2.5 K	56 km	~25 km	1 day

‡ Soil moisture accuracy limited to regions with $w_e < \sim 1.5$ kg-m^{-2}
† EASE-grid
* Separate ascending and descending

A surface classification step is applied mainly for the purpose of identifying points at which either no retrieval is done or a retrieval is done but flagged to indicate questionable data. Such points include ocean and large (permanent) water bodies, snow and ice, frozen ground, mountainous terrain, precipitation, and dense vegetation. The starting point for these classifications is a set of ancillary databases, including databases of percent water, topography, and land surface cover obtained from the Global Ecosystems Database [2], and surface classification algorithms available in the published literature [3], [4]. These are combined into a single procedure to produce a surface type flag that will be included as part of the output product. This classification will require validation also, and is intended as a guide to the soil moisture data quality rather than a research product.

The geophysical retrieval step can be summarized briefly as follows. At each sample point screened as suitable for retrieval, the algorithm is initialized with a-priori values $\mathbf{x}_0$ of the geophysical variables $\mathbf{x} = \{m_e, w_e, T_e\}$. These values are adjusted iteratively by an optimization routine until the the sum of the squared differences between computed and observed brightness temperatures in the AMSR channels are minimized. Usually, no more than four to six iterations are required for satisfactory convergence. The forward radiative transfer model used in computing the brightness temperatures is described in [1]. The algorithm can be run using various combinations of the 6.9, 10.7, and 18.7 GHz V and H channels (six channels total). The input level 2A brightness temperatures are processed in an earlier step such that the 10.7 and 18.7 GHz channels are spatially resampled to the same resolution as the 6.9 GHz channels. The algorithm can also be run keeping the a-priori value of T_e fixed, with m_e and w_e as variables to be estimated. This option may be useful if good ancillary surface air temperature is available as a surrogate for T_e. Finally, an option is being implemented to insert alternate algorithms into the processing stream, such as algorithms using linear regression or brightness temperature indices, so that flexibility can be maintained in selecting the optimum post-launch algorithm for long-term processing.

The accuracy estimates in Table 2 were obtained by simulation as described in [1]. The six-channel algorithm was used, and brightness temperature noise of 0.5 K in each channel was assumed. The errors have been multiplied by a factor of two as a rough estimate of the additional effects of model uncertainty. The retrieval accuracies are for the expected ranges of m_e and T_e, but with $w_e < 1.5$ kg-m^{-2}. The retrieval errors for m_e and w_e can be expected to increase significantly as a function of increasing vegetation due to attenuation by the vegetation canopy. The estimates in Table 2 are intended as guides to the expected accuracy of the AMSR products and as objectives for the data validation.

VALIDATION

The AMSR-E validation activities are intended to provide accuracy estimates or confidence limits on the standard products made available through the NSIDC public archive. For land surface studies, validation experiments and resources will focus on soil moisture since this is the primary parameter of interest. Validation of the vegetation water content and surface temperature will be done mainly by comparison with similar MODIS and AIRS products. The following aspects contribute to the challenge of validating the soil moisture product:

(1) The sensor footprints (~56 km) will, in general, contain mixtures of different surface types. Characterizing the actual soil moisture over large areas will require an intensive network of in situ sensors and gravimetric sampling.
(2) The retrieved parameters represent averages over the vertical microwave sampling depth. This depth varies with frequency and the amount of moisture in the soil and/or vegetation. In situ sampling is difficult in the less than 1-cm soil surface layer typically observed by the AMSR channels.
(3) The retrieval errors for m_e and w_e increase with vegetation cover. Development of more reliable w_e-NDVI relationships are needed to make use of optical/IR data for large-area biomass estimates.

The main sources of soil moisture validation data will be in situ sampling and underflights by airborne microwave sensors, conducted in a series of intensive field experiments. These experiments may be of short duration (~1 month) due to limited resources, but will be carried out periodically over the AMSR-E mission lifetime. Several validation sites are needed for diversity in vegetation, climate, and topography. Sites being considered include the Southern Great Plains, Iowa, Arizona, and Georgia (U.S.), and sites in Thailand, Tibet, and Mongolia (Asia). These sites are being investigated jointly with the ADEOS-II AMSR validation.

The validation sites need to be large enough to contain about 3 x 3 AMSR footprints (~200 x 200 km) or larger. Airborne microwave sensor data will be used to scale from the in-situ to satellite footprint scale and to evaluate heterogeneity. The spatial and temporal soil moisture dynamics will be studied at these sites over a 1-month period, as well as effects of vegetation, temperature, soil texture, and topography. Required measurements will include in-situ soil moisture sampling (gravimetric and probe), soil bulk density, soil texture, surface roughness, biomass, and soil temperature (IR and probe). The suite of L and C band airborne microwave sensors available include the PSR-C, Step-C, ACMR, ESTAR, and PALS (in the U.S), and AMR (in Asia). A first experiment of this type was conducted in July 1999 in the Southern Great Plains (SGP99) [5], [6].

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