Explanation

Global Scale Analysis of Soil Moisture and Vegetation Biomass by Using AMSR-E Data

Simonetta PALOSCIA* and Emanuele SANTI*

Abstract

An analysis on the capabilities of microwave radiometers in estimating soil moisture, snow cover and vegetation biomass was carried out on a global scale by using AMSR-E (Advanced Microwave Scanning Radiometer for EOS) data. The temporal trends of brightness temperature together with some microwave indexes, namely combinations of polarizations and frequencies, were taken into account over some test areas. In case of the estimate of soil moisture, the use of these indexes makes it possible eliminating deserts, dense vegetation and snow areas, as well as correcting for the effect of light vegetation. Afterwards, the inversion to retrieve soil moisture is performed by means of an Artificial Neural Network (ANN). Lastly, a technique based on a multi-sensor image fusion technique for enhancing the C-band spatial resolution is described here.

Keywords : Global analysis, AMSR-E, soil moisture maps, snow maps

1. Introduction

The Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E) is a sensor which was successfully exploited for global and regional investigations on the Earth's surface parameters, such as soil moisture, vegetation biomass and snow cover. Indeed, theoretical studies and field experiments, conducted to study microwave emission from land, have revealed a significant sensitivity of brightness temperature to certain features of soil[1)2)], snow[3)4)], and vegetation[5)~7)], which are of great interest in hydrology, meteorology, climatology and agriculture.

Global monitoring of soil moisture with microwave radiometry requests some knowledge on land cover to separate those areas where the measurement can be problematic or impossible due to the high attenuation of dense vegetation and wet snow, and to correct for the effects light vegetation where the measurement is likely. The use of appropriate combinations of frequencies and polarizations can significantly improve the potential of single frequency/polarization in separating bare soil from vegetation and snow.

The objective of this work was to characterize land surfaces and estimate soil moisture on a global scale by using multi-frequency multi-temporal observations from AMSR-E. The brightness temperatures, along with the polarization and the frequency indexes, were related to land features, obtained from ground information and cartography, and their temporal evolution. These parameters were used in an algorithm to retrieve soil moisture in different climatic regions of the world. Moreover a simple method for improving the ground resolution at C-band was developed by using a technique based on a multi-sensor image fusion.

2. The Experimental Data

The analysis was carried out using data from June 2002 to June 2003. In order to minimize the effects due to surface temperature variations, data collected in the early morning (descending orbits of AMSR-E) were separated from those collected in the afternoon (ascending orbits of AMSR-E). All groups of data were averaged over a four- day period. The multi-frequency brightness temperatures, Tb, have been extracted from AMSR-E data obtained in HDF format by the Japan Aerospace Exploration Agency (JAXA) or the National Snow and Ice Data Center (NSIDC), and a preliminary separation between land and ocean pixels is performed. In general, it is convenient to reduce the effects of surface temperature variations by normalizing the microwave brightness temperature by using the infrared brightness temperature. If this measurement is not available, as in this case, the physical temperature of surface can be approximated by the ratio of the vertical polarization component of brightness temperature at 37 GHz (Tb37) by using the following experimental relationship :

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* CNR-IFAC, Via Madonna del Piano, 10–50019 Firenze (Italy)

$$Ts = 0.75 \times TbV37 - 186 \quad (1)$$

Indeed, emission at this frequency is only slightly affected by soil moisture variations, and is strongly correlated to surface temperature.

The atmospheric contribution to the measured brightness temperature, which may have important effects especially at the higher frequencies, was taken into account by developing a correction procedure for cloud free conditions, based on a combination of radiative transfer theory[8)], direct measurements and empirical estimates. The selection of cloud free pixels for the considered test sites was carried out by means of Meteosat IR1 images (http://infomet.am.ub.es/infomet/arxiu/meteosat/). A further check for the presence of precipitation was performed using the standard algorithms suggested in the SSM/I User's Guide and in the scientific literature[9) 10)].

The analysis was based on the following remote sensing parameters :

- The Brightness temperature (Tb) for horizontal (Tbh) and vertical (Tbv) polarization ;
- The Polarization Index (PI = 2(Tbv-Tbh)/(Tbv + Tbh)) ;
- The Frequency Index (FI = (Tb (low frequency V) − Tb (high frequency V) + Tb (low frequency H) − Tb (high frequency H))/2).

3. Multi-Temporal Analysis

3.1 Sensitivity to vegetation and snow cover

Indeed, experimental data collected on agricultural crops and model simulations have pointed out a good sensitivity of the Polarization Index (PI) at 10 GHz to vegetation biomass (PWC) according to the following equation, shown along with its determination coefficient (R^2)[11)] :

$$PI(10) = -7.26 Ln(PWC) + 15.8 \quad (R^2 = 0.76) \quad (2)$$

This trend has been confirmed on a global scale by comparing maps obtained in summer and winter. It has been generally observed that PI is high on smooth dry soil (maximum on deserts) and decreases on vegetation-covered areas being minimum on dense forests[12) 13)]. The marked shift of PI toward low values from January to July in temperate areas corresponds to development of vegetation in summer. On the contrary, the situation remains almost the same on deserts, which contribute the highest values of PI[14)].

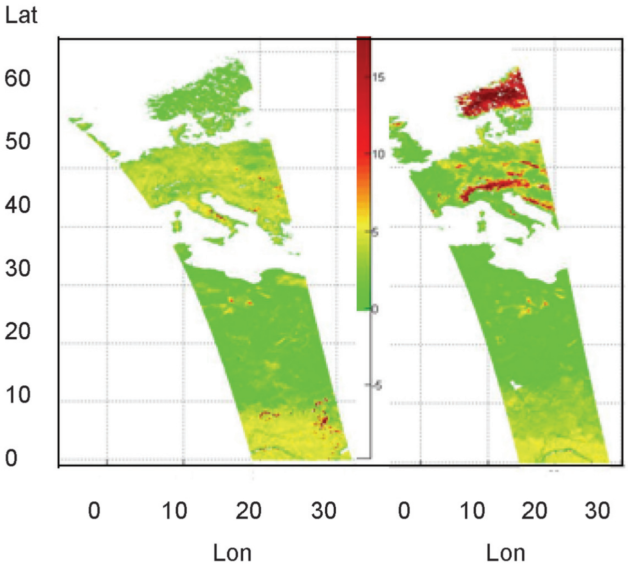

Fig. 1 The Frequency Index (FI19-37) measured in summer (left) and winter (right). Red zones correspond to very high values of FI and therefore to snow-covered areas.

On the other hand, the Frequency Index (FI) obtained from the difference between signals at 19 (or 10) and 37 GHz was found to be a good indicator of snow and has been related to the snow depth (SD) by the following logarithmic equation :

$$FI(19-37) = 15.3 Ln(SD) + 4.37 \quad (R^2 = 0, 78) \quad (3)$$

The potential of this parameter in detecting snow-covered areas is demonstrated by Fig. 1, which represents the same portions of Europe and Africa in winter and summer. Here, snow is indicated by dark red areas and it is clearly evident in Scandinavian and in the Alps (North Italy, Austria, and Switzerland).

The sensitivity of multi frequency brightness temperature and derived parameters to land surface features was further investigated by means of multi-temporal data collected on two sites with different surface and climatic conditions[12)].

The characteristics of the test sites taken into consideration for this study are summarized below :

- The Tundra in Northern Norway is an area without high vegetation (trees) and characterized by the presence of snow in fall-winter and short vegetation in late spring-summer ;
- The Gobi desert, a mid-latitude, sandy/stony desert, with a moderate development of vegetation in summer and some snow in winter.

All land features and meteorological characteristics were derived from cartography, Ecoclimap database, (http://www.cnrm.meteo.fr/gmme/PROJETS/ECOCLIMAP/page_ecoclimap.htm), and from meteorological stations located close to the sites. A very useful tool for obtaining meteorological histories for all the selected areas was the "weather underground" web site (www.wunderground.com), whose large archive provided the meteorological data from past years. Additional ground measurements of snow depth for the

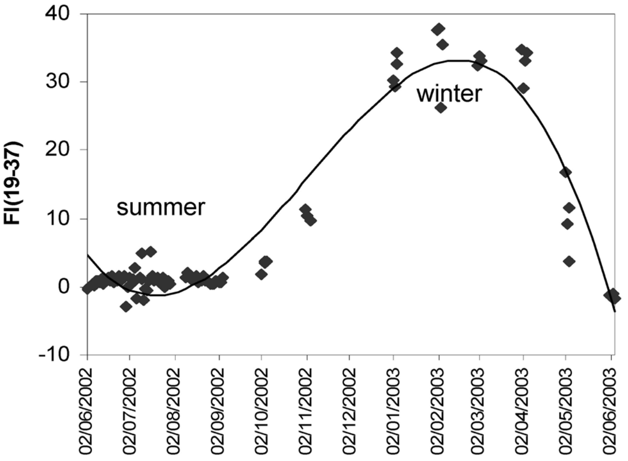

Fig. 2 The variation of Frequency Index (19–37) as a function of time on Tundra. The presence of snow in winter is very well pointed out.

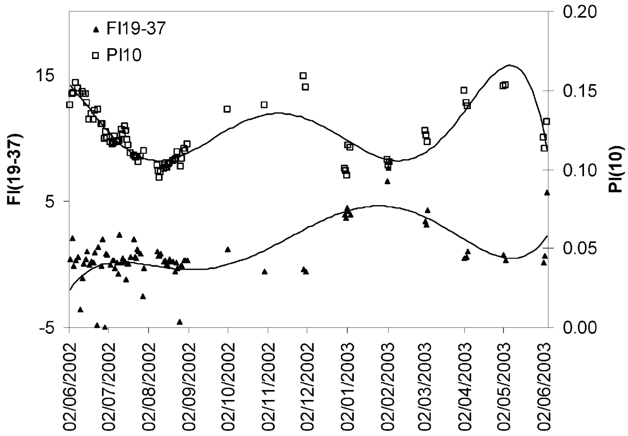

Fig. 3 The variation of Polarization Index at 10 GHz and of Frequency Indexes (19–37) represented as a function of time on the Gobi desert.

Tundra test site were derived from the Russian Weather Server (http://meteo.infospace.ru). As a first step, ground information was used for evaluating the homogeneity of the areas and separating land types and soil characteristics. The size of the studied sites was a compromise between the number of measurements necessary for a statistical analysis and the attempt of maintaining the homogeneity of the site. Usually, the areas included over 100 brightness temperature measurements. The standard deviation of the collected brightness was less than 5 K at the highest frequency.

The temporal trends of Frequency Index (19–37) and PI (10) measured along one year on the two sites are shown in Figs. 2 and 3. The sensitivity of FI to snow cover is well pointed out on Tundra, where FI(19–37) shows a marked increase in winter as shown in Fig. 2. Fig. 3 represents a comparison of the seasonal trends of PI at 10 GHz and FI (19–37) on Gobi desert. PI detects a moderate presence of light vegetation in desert during summer, whereas FI(19–37) is almost insensitive to vegetation, but clearly recognizes the presence of snow in winter.

3.2 The Retrieval of soil moisture

Although the lowest frequency channel of the AMSR-E is not optimal for estimating soil moisture, various field experiments pointed out that C-band emission is sensitive to soil moisture variations, although to a less extent than L-Band. In case of presence of dense vegetation or snow cover, the measurement of soil moisture is not possible. Thus, to generate soil moisture maps on a global scale, first it is necessary to detect and remove these areas. In this case, the areas of dense vegetation were identified by a PI $(10) < 0.01$, and those covered by snow by $\mathrm{FI} > 10$. Also deserts, identified by PI $(10) > 0.1$, were excluded, while the correction for the effects of light vegetation were performed by estimating the attenuation by means of polarization index at 10 GHz. The algorithm was developed according to a simplified approach based on a simplified radiative transfer model, (the ω-τ model), where vegetation was assumed to be a uniform absorbing and scattering layer over the soil surface6) 15) 16). To invert the model and retrieve the value of soil moisture from AMSR-E measurements, an Artificial Neural Network (ANN) algorithm was used. The ANN selected was a feed-forward multi-layer perceptron (MLP), with three hidden layers of neurons (5, 10 and 5) between the input and output and was trained with an extended dataset generated by the omega-tau modele.g. 6), and using the back-propagation learning rule17) 18).

The test of the algorithm was carried out by using a consistent set of ground measurements collected on a test site in Iowa during the SMEX02 and made available by the Goddard Earth Science (GES) of Data and Information Service Center (DISC) (Distributed Active Archive Center-DAAC). SMEX02 was carried out in 2002 on a small watershed (Walnut Creek) well instrumented for in-situ sampling of hydrologic parameters19). The result of validation is shown in Fig. 4, which shows the retrieved SMCe versus measured SMCm value of soil moisture. The regression equation and the determination coefficient are :

$$\mathrm{SMCe} = 0.98 \quad \mathrm{SMCm} + 1.2 \quad R^2 = 0.48 \qquad (4)$$

It should be noted that the relatively low value of the determination coefficient is due, at least in part, to the small dimensions of the test site compared with the AMSR-E footprint.

An example of global maps of soil moisture obtained with this algorithm is represented in Fig. 5, which shows part of Europe and Africa at two dates in winter and summer. The maps show a marked increase of moisture from summer to winter and reasonable variations of this parameter according

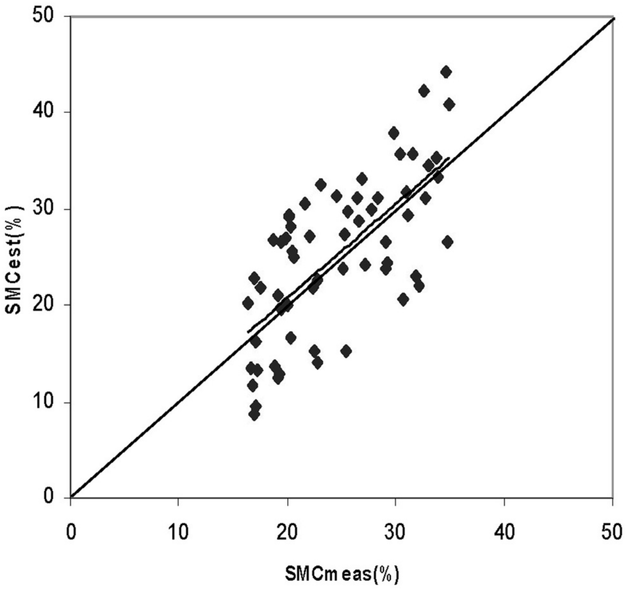

Fig. 4 Retrieved versus measured soil moisture (data from SMEX 02)

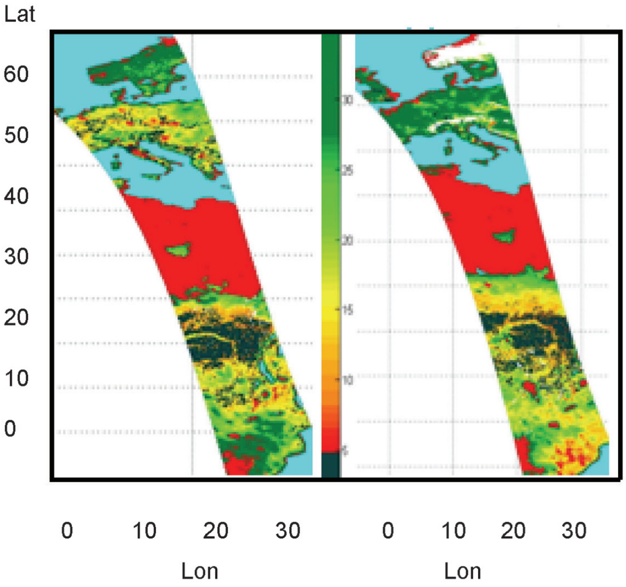

Fig. 5 Maps of soil moisture obtained in summer (left) and winter (right) with the algorithm described in the text (brown dark and white areas represent dense vegetation and snow cover, respectively).

to the geographical areas and the climatic and meteorological conditions.

4. Improvement of the AMSR-E Spatial Resolution at C-Band

One of the problems of the AMSR-E sensor is the coarse spatial resolution in the low-frequency range, which hampers a detailed analysis of the surface, especially in variegated landscape territories. The AMSR-E active scene measurements are recorded at equal intervals of about 10 km along the scan, which means a nominal spatial resolution, except the 89 GHz channel, of about 10×10 km, corresponding to the sampling rate of the sensor. However, the instantaneous field-of-view (IFOV) of each channel antenna is larger than the nominal spatial resolution, especially at C-band, which has an IFOV is, in fact, of about 40×70 km.

A technique for enhancing the C-band spatial resolution was proposed and described here and then tested on the Victoria Lake area, in Africa. The method was derived from the smoothing filter-based intensity modulation technique (SFIM), which is based on a multi-sensor image fusion technique that is usually applied to enhance the Landsat Thematic Mapper resolution by using sensors at higher resolution, such as the SPOT Panchromatic[20]. The fusion results are independent of the spectral properties of the high-resolution image, and should, therefore, preserve the information contained in the original low-resolution image. Although the used technique is not new, this is the first time that it is applied to microwave data. In this case, one of the main advantages brought by this method is the use of data from the same sensor for improving the ground resolution of microwave channels. The proposed algorithm is aimed at increasing the resolution up to values close to the sampling area (i.e., 10×10 km), by means of the higher resolution Ka-band channel, which is first degraded to the resolution of the C-band one by using a two-dimensional low pass filter. This image is then used for modulating the original C-band data, by applying the SFIM processing equation :

$$\mathrm{Tb}_{\mathrm{CHres}}=\mathrm{Tb}_{\mathrm{Kaorig}}/\mathrm{Tb}_{\mathrm{KaLres}}*\mathrm{Tb}_{\mathrm{Corig.}} \qquad (5)$$

where TbC and TbKa are the brightness temperatures (in K) at C and Ka bands, *orig* indicates the original AMSR data, and *Hres, Lres* are the data at enhanced and degraded resolutions, respectively.

As a case study, the algorithm was tested on the AMSR-E sensor acquisitions collected over the area of Victoria Lake, in Africa, which is characterized by open waters surrounded by homogeneous and dense vegetation. The area was selected, as usual, by means of the Ecoclimap database. The spatial resolution improvement appears clearly from the figure 6a) and 6b), which represent a comparison between the original C-band image (ascending orbit of March 3, 2003) and the algorithm output : the output image is evidently sharpened, and the lake appears close to its real shape derived from cartography, shown as a comparison in fig. 6c)[21].

5. Summary

Multi-temporal data from the AMSR-E have shown a

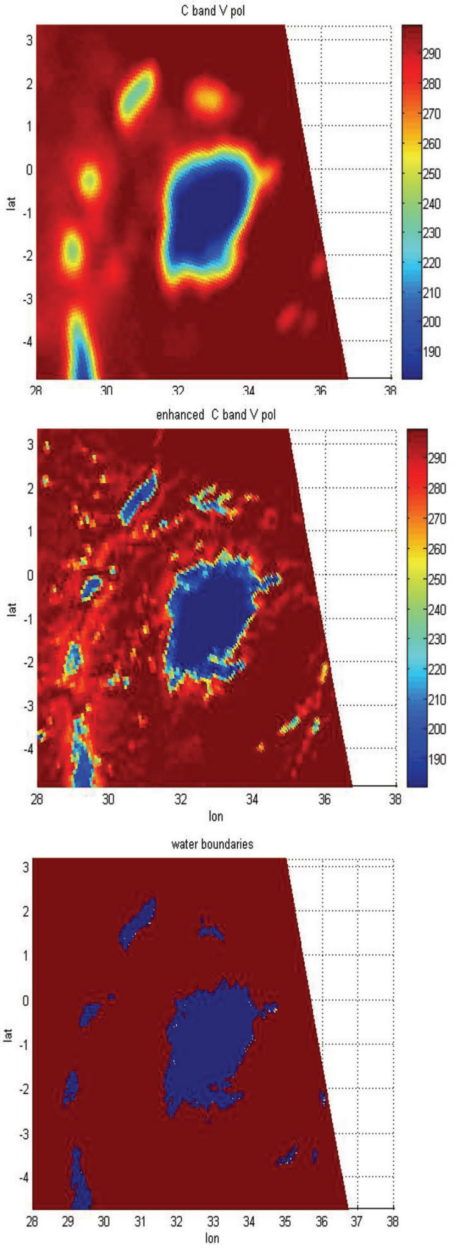

Fig. 6 top : original C-band (V pol.) image of Victoria Lake ; middle : C-band image at enhanced resolution ; bottom : the Victoria Lake from cartography

significant ability in monitoring land surface features in the limits of the spatial resolution offered by this sensor. PI at X-band was confirmed to be the best suitable index for detecting the growth of vegetation biomass, even on a global scale. FI at 19 and 37 GHz is instead more sensitive to snow cover. By using these parameters, a selection on a global scale of the areas where the assessment of soil moisture is feasible can be made. The soil moisture was estimated by using a model based on the radiative transfer theory (ω-τ), which estimates soil moisture from the brightness temperature at C-band by correcting for vegetation effects with the PI at X-band. The model was inverted by using an Artificial Neural Network based algorithm and was validated on the agricultural area of SMEX02. The global maps of soil moisture generated from this method were found to be in reasonable agreement with climatic conditions of the areas and the season of measurements.

Moreover, a simple method for enhancing the ground spatial resolution at C-band was proposed and tested successfully on the Victoria Lake area.

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● Simonetta Paloscia

Simonetta Paloscia has been with IFAC-CNR (Institute of Applied Physics) of the National Research Council (C.N.R.) since 1987. Her research currently concerns with the study of microwave emission and scattering of soil (both bare and snow-covered) and vegetation. In particular she investigates the estimate of hydrological parameters from microwave remote sensing systems.

She participated in various microwave remote sensing campaigns and was principal investigator and co-investigator of many several international projects (ESA, EC, NASA, JAXA). Since 1996 she is Principal Investigators in a Science Team of JAXA (Japan Aerospace Exploration Agency), within the framework of the ADEOS-Ⅱ project, for the use of AMSR-E data in algorithms for measuring soil moisture and vegetation biomass from satellites.

She is author and co-author of more than 60 works published on international journals and books, of more than 80 papers published on proceedings of international meetings.

E-mail : S.Paloscia@ifac.cnr.it

● Emanuele Santi

Emanuele Santi received his degree in Electronic Engineering in 1997, from the University of Florence, and his PhD in Earth's Remote Sensing Techniques from the University of Basilicata in 2005. Since 1998 he works with the Microwave Remote Sensing Group at Institute of Applied Physics of the National Research Council (IFAC-CNR). His research concerns the study of microwave emission and scattering from sea and land surfaces and their relationships with soil, snow and vegetation parameters, using data from passive and active sensors operating from ground based platforms, aircraft and satellite. Main topic of his research activity is the development and validation of models and inversion algorithms for estimating the geophysical parameter of soil, sea, snow and vegetation (i.e soil moisture and roughness, vegetation biomass, liquid water content, snow water equivalent and wind speed over sea).

E-mail : E.Santi@ifac.cnr.it