RETRIEVAL OF SOIL MOISTURE DATA AT GLOBAL SCALES WITH AMSR-E

Simonetta Paloscia, Giovanni Macelloni, Paolo Pampaloni, Emanuele Santi

CNR-IFAC, via Panciatichi 64 – 50127 Firenze (Italy) – E-mail: S.Paloscia@ifac.cnr.it

Abstract – An algorithm for the estimate of the soil moisture content on a global scale from dual-frequency (C- and X-bands) microwave data of the Advanced Microwave Scanning Radiometer (AMSR-E) is presented in this paper. The algorithm is based on the brightness temperature at C-band and uses the Polarization Index at X-band to correct for vegetation effects. The retrieval is obtained by inverting a simplified Radiative Transfer model by using the Nelder-Mead iterative minimization method. The algorithm was validated with microwave data collected on two sites, located in Italy and in Iowa (US), during the MASMEx02 (Microwave Alpine Soil Moisture Experiment) and the SMEX02 (Soil Moisture Experiment) experiments, respectively.

INTRODUCTION

The sensitivity of low frequency microwave emission to the soil moisture is well known and is currently object of several experiments and theoretical studies [1-3]. However, the retrieval of soil moisture from brightness temperature measurements is still challenging, especially in case of global analysis, due to the high number of soil parameters, such as surface roughness, soil composition, vegetation type and density, able to influence the measured emission. Despite these problems, several models, able to reproduce microwave emission of soil and vegetation and to estimate soil moisture content, have been developed and tested in the last years [4,5].

L-band, which is the most suitable frequency for this type of measurements, is not yet available from existing satellite sensors, although the launch of a synthetic aperture L-band radiometer (SMOS) is forthcoming, and another spatial program combining L-band active and passive systems (Hydros) is in progress [6,7]. At higher frequencies, vegetation and surface roughness effects reduce the sensitivity to moisture, although, at C-band a certain ability in measuring moisture has been demonstrated. Research efforts, thus, have been focused on the analysis of C-band data, which are now available from the Advanced Microwave Scanning Radiometer (AMSR-E) onboard the AQUA satellite [8].

This paper describes a method to retrieve soil moisture on a global scale from C and X band channels from AMSR-E. The algorithm is based on a simplified version of the Radiative Transfer Theory, it uses the C-band brightness temperature for computing the soil reflectivity and then soil moisture, and the X-band polarization index for taking into account the vegetation effects. The algorithm, which was tested and subsequently inverted by using the Nelder-Mead method, was validated on data collected on two areas in Italy and US, during the MASMEx02 and the SMEX02 experiments in the Italian Alps and in Iowa, respectively. In spite of some problems due to the coarse ground resolution and to the Radio-frequency interferences, especially in the Iowa test area, the results are rather encouraging and the algorithm was able to reproduce the soil moisture measured on ground.

THE EXPERIMENTAL RESULTS

The Advanced Microwave Scanning Radiometer (AMSR-E) is a dual polarized microwave radiometer with frequency channels at 6.9, 10.6, 18.7, 23.8, 36.5 and 89 GHz. The instrument, developed for NASA by JAXA, was launched in May 2002 on NASA's Aqua satellite to provide observations of several geophysical parameters of interest in hydrology, ecology and climate [9]. Experimental data from the AMSR-E at C and X bands used in this study were collected in 2002 during two experiments carried out in Italy and in Iowa (US). The Microwave Alpine Soil Moisture Experiment (MASMEx 2002) took place in Italy on the alpine test site Cordevole from May 19 to July 6, 2002, with the purpose of investigating the sensitivity of microwave radiometric measurements to soil moisture in an alpine environment. In this case, multi-frequency microwave data were also collected by using ground-based microwave radiometers at L-C- and Ka-bands [10]. AMSR-E data were gathered over an area centered on a plateau at the top of Mount Cherz a few thousands of square meters wide, where ground measurements were carried out. The IFOV of AMSR-E at 6.9 GHz is 75 Km x 43 Km. The area surrounding the plateau is rather homogeneous, mainly covered by lawns characterized by rather uniform soil moisture. Moreover, it should be noted that a part of the test area is covered by forests, rocks and some urbanization, i.e. targets which do not change very much over time and therefore do not significantly affect the temporal behavior of emission. However, the C-band resolution was enhanced by using a simple procedure of "data fusion", generally applied to visible images and described in [11]. In this case, the AMSR-E Ka brightness temperature (i.e. 36.5 GHz) was taken into account for resampling the 6.8 GHz. The Ka-band sensor is, in fact, characterized by an appreciably higher resolution (the IFOV is of about 14 x 8 km^2). During this experiment, the characteristics of soil changed appreciably between April and the end of June, changing from a very moist soil covered with dead vegetation to a less moist soil covered by a fairly thick layer of Alpine grass.

The Soil Moisture Experiment (SMEX02) in Iowa was conducted on the small watershed of Walnut Creek during summer 2002, and aimed at developing soil moisture and vegetation retrieval algorithms and validating airborne and space-borne remotely sensed soil moisture and vegetation measurements over a range of spatial scales. The land cover type for the watershed region is primarily agricultural with corn and soybeans being the major crops [12,13]. The Goddard Earth Science (GES) of Data and Information Service Center (DISC) (Distributed Active Archive Center-DAAC) provided the dataset of SMEX 2002, where, along with AMSR-E data averaged on the area, a consistent set of ground measurements (soil temperature, soil moisture content, rainfalls, etc.) was made available (http://nsidc.org/data/daac.html) [14]. It should be noted that a significant quantity of C-band data in this experiment was affected by man made radio interference. This fact was not new, since several scientists had already observed it over the central part of the United States [15, 16].

The sensitivity of microwave emission at the lower frequencies to SMC was confirmed in the analysis of both data sets. By directly comparing the brightness temperatures at C-bands in H polarization and the ground measured soil moisture, results were comparable to those obtained in the past with other data collected on agricultural fields by means of airborne and ground-based sensors [5,8].

THE RETRIEVAL OF SOIL MOISTURE

The algorithm for estimating soil moisture from AMSR-E data is based on the assumptions that Tb at C band is sensitive to soil moisture content and that the Polarization Index (PI=(Tbv-Tbh)/0.5 * (Tbv+Tbh)) at X band is able to describe the evolution of vegetation cover, as already demonstrated in previous research [17].

The algorithm was developed according to a simplified approach based on the Radiative Transfer Theory (the so-called ω-τ, model), assuming vegetation to be a uniform absorbing and scattering layer over the soil surface [18,19]. The optical depth is related to the Leaf Area Index (LAI) through the polarization index at X-band [18], according to the following expressions: $\tau = \ln [(PI_X(0)/PI_X]$, where PI_X is the Polarization index of vegetation covered soils, and $PI_X(0)$ is the Polarization index of bare soil (usually between 0.05 and 0.07). Since the soil surface under a vegetation canopy can be assumed to be rather smooth, especially at C-band, the contribution of roughness to the emission was not considered.

Nelder-Mead method

To invert the equation and retrieve soil moisture from AMSR-E measurements, an iterative procedure was used, based on the Nelder-Mead method. Nelder–Mead is a direct search method of optimization commonly used in non-linear regression programs and is quite simple to compute [20]. The method was applied to the SMC retrieval as follows: for each H and V polarization Tb value, the corresponding theoretical "true" brightness was calculated using the Radiative Transfer Equation based on initial estimates of the model inputs, such as dielectric constant of soil, ε, surface temperature, albedo and optical depth. Reflectivity was computed from the ε values by means of the Fresnel equations. Once the initial vector has been defined, the algorithm has been varied iteratively for all the model inputs using the Nelder Mead minimization until the minimum of the difference function between measured and computed values of brightness temperatures at C-band, in H and V polarizations, has been reached. The input vector corresponding to the function minimum has been assumed "optimum" and, from the obtained ε value, the corresponding SMC has been calculated by the inversion of the Dobson et al. model [21].

The results of the inversion obtained from the AMSR-E data collected on Cordevole is shown in the diagram of Fig.1. The equation and the determination coefficient R^2 in this case were: SMCest= 0.56 SMCmeas + 14.8, with R^2 = 0.87, and Standard Error of Estimate (SEE) = 0.7. It can be noted that the algorithm performance is satisfactory, although there is a clear overestimation of lower values of SMC. The results showed that the model, which was preliminarily tested on agricultural areas [8] covered by crops such as wheat, corn, and alfalfa, also worked fairly well in this case of spontaneous vegetation.

In the case of SMEX, we considered AMSR-E data collected on the first four days of each month (June, July, and August 2002) separated by ascending and descending orbits. As already said, in this case some data were contaminated by radio-frequency interferences (RFI), and the only possibility of using this data to test the algorithm was to disregard all data with a normalized temperature Tn higher than 0.99. Figure 2 shows the result of the inversion. The computed regression equation was: SMCest = 1.0 SMCmeas – 1.1, with R^2 = 0.64 and SEE = 5.2.

SUMMARY

An algorithm for estimating soil moisture content of vegetated areas, based on the Omega-Tau model and inverted by using the Nelder-Mead iteration method, was validated on two areas, in Italy and the US, by using both AMSR-E and ground based microwave data. The first test was carried out on the Cordevole watershed in the Italian Alps by using both satellite and ground based sensors. The second test was performed on an AMSR-E data set collected on the Washita watershed in Iowa, during the SMEX02 experiment. It has been shown that the results achieved in a mountainous region covered with natural vegetation were comparable to those obtained on agricultural fields. However, satisfactory results have been obtained from data collected in the agricultural region of Iowa, in which five classes of SMC were separated, although the data set of SMEX02 was hampered by a significant presence of interferences.

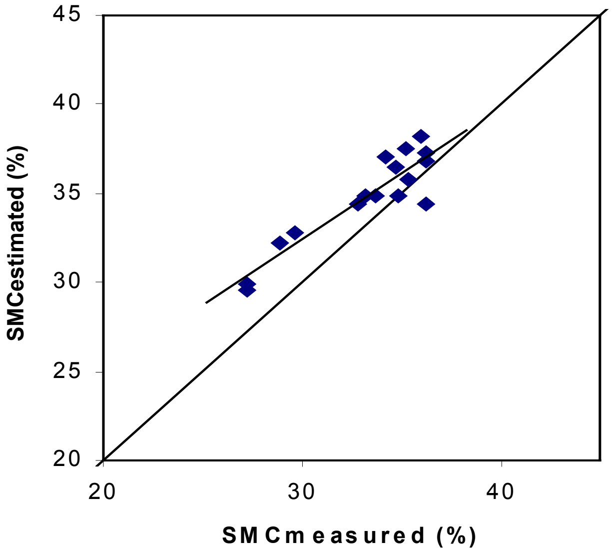

Fig. 1 - Comparison between the SMC estimated by the algorithm, using AMSR-E data, and the SMC measured on ground, during the MASMEx experiment in 2002.

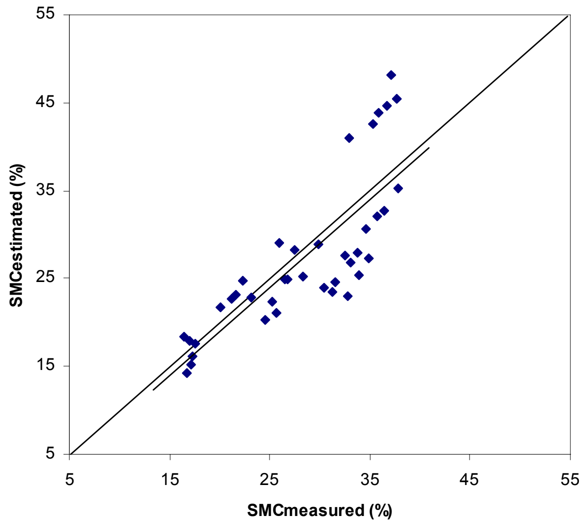

Fig. 2 - SMC computed from AMSR-E data collected during SMEX02 in Iowa was compared with the SMC measured on ground for the available data set, after removing data affected by RFI.

ACKNOWLEDGMENTS
The authors wish to Dr. Tom Jackson for his very useful comments on this research work. They also thank the JAXA and U.S. AMSR-E data processing teams for providing the data used in this paper. This work was partially supported by JAXA (contract A2ARF003), by the Italian Space Agency (ASI) and the CNR-GNDCI.

REFERENCES

[1] Jackson T.J., Schmugge T.J., “Passive microwave remote sensing system for soil moisture: some supporting research”, IEEE Transactions on Geoscience and Remote Sensing, 2: 225 – 235, 1989

[2] Jackson T.J., Le Vine D.M., Griffis A.J., Goodrich D.C., Schmugge T.J., Swift C.T., O'Neill P.E., "Soil moisture and rainfall estimation over a semiarid environment with the ESTAR microwave radiometer", IEEE Transactions on Geoscience and Remote Sensing, 31, 4 , pp. 836 – 841, 1993
[3] Wang J.R., Shiue J.C., Schmugge T.J., Engman E.T., "The L-band PBMR measurements of surface soil moisture in FIFE", IEEE Transactions on Geoscience and Remote Sensing, 28, 5, pp.906 – 914, 1990
[4] T. J. Jackson, A. J. Gasiewski, A. Oldak, M. Klein, E. G. Njoku, A. Yevgrafov, S. Christiani, and R. Bindlish, "Soil moisture retrieval using the C-band polarimetric scanning radiometer during the Southern Great Plains 1999 Experiment," *IEEE Trans. Geosci. Remote Sensing*, pp. 2151–2161, Oct., 2002.
[5] Paloscia S., G. Macelloni, E. Santi, and Toshio Koike, "A Multifrequency Algorithm for the Retrieval of Soil Moisture on a Large Scale using Microwave Data from SMMR and SSM/I Satellites", *IEEE Trans.on Geosci. and Remote Sensing*, vol. 39, 8, pp. 1655-1661, 2001
[6] Entekhabi D., Njoku E.G., Houser P., Spencer M., Doiron T., Kim Y., Smith J., Girard R., Belair S., Crow W., Jackson T.J., Kerr Y.H., Kimball J.S., Koster R., McDonald K.C., O'Neill P.E., Pultz T., Running S.W., Shi J., Wood E., vanZyl J., "The Hydrosphere State (Hydros) Satellite Mission: An Earth System Pathfinder for Global Mapping of Soil Moisture and Land Freeze/Thaw", *IEEE Transactions on Geoscience and Remote Sensing*, 42, 10: 2184 – 2195, 2004
[7] Kerr Y.H., Waldteufel P., Wigneron J.-P., Martinuzzi J., Font J., Berger M., "Soil moisture retrieval from space: the Soil Moisture and Ocean Salinity (SMOS) mission", *IEEE Transactions on Geoscience and Remote Sensing*, 39, 8: 1729-1735, 2001
[8] Jackson T.J., O'Neill P.E, "Attenuation of soil microwave emission by corn and soybeans at 1.4 and 5 GHz" *IEEE Transactions on Geoscience and Remote Sensing*, 28, 5, pp. 978 – 980, 1990
[9] T. Kawanishi, T. Sezai, Y. Ito, K. Imaoka, T. Takeshima, Y. Ishido, A.Shibata, M. Miura, H. Inahata, and R. W. Spencer, "The Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E), NASDA's contribution to the EOS for global energy and water cycle studies," *IEEE Trans. Geosci. Remote Sensing*, vol. 41, pp. 184–194, 2003.
[10] Pampaloni P., Macelloni G., Paloscia S., Tedesco M., Ranzi R., Tomirotti M., Cagnati A., Crepaz A., 2003, "The Microwave Alpine Snow Melting Experiment (MASMEx 2002): a contribution to the ENVISNOW project", *Proceedings IEEE International Geoscience and Remote Sensing Symposium 2003,* IGARSS '03., Vol. 2 , pp.848 – 850, July 2003
[11] Zhijun Wang, Ziou D., C.Armenakis, Deren Li, Qingquan Li, "A comparative analysis of image fusion methods", *IEEE Trans. Geosci. Remote Sensing*, vol. 43, pp. 1391 – 1402, 2005.
[12] Jackson T.J., Bindlish R., Klein M., Gasiewski A.J., Njoku E.G., "Soil moisture retrieval and AMSR-E validation using an airborne microwave radiometer in SMEX02", *Proceedings of IEEE International Geoscience and Remote Sensing Symposium 2003*, IGARSS '03., Vol.1, pp.401 – 403, 21-25, 2003
[13] J.Bolten, U.Narayan, L. Guijarro, V. Lakshmi, "Passive-Active Microwave Remote Sensing of Soil Moisture at Both L and C Bands: A Comparison of Two Field Experiments", *Rivista Italiana di Telerilevamento (Italian Journal of Remote Sensing)*, n.30/31, pp. 65-86, 2004
[14] NSIDC. Equal-Area Scalable Earth Grid (EASE Grid). National Snow and Ice Data Center (NSIDC). [Online]. Available: http://nsidc.org/data/ease/index.html
[15] E. Njoku, T. Chan, W. Crosson, A. Limaye, "Evaluation of the AMSR-E Data Calibration over Land", *Rivista Italiana di Telerilevamento - Italian Journal of Remote Sensing*, 30/31, pp. 15-33, 2004
[16] Li Li, Njoku E.G., Im E., Chang P.S., Germain K.St., "A preliminary survey of radio-frequency interference over the U.S. in Aqua AMSR-E data" IEEE Transactions on Geoscience and Remote Sensing, 42, 2, pp. 380 – 390, 2004
[17] Paloscia S., P. Pampaloni, "Microwave Polarization Index for Monitoring Vegetation Growth", *IEEE Trans. on Geoscience and Remote Sensing*, 26, 5, pp. 617-621, 1988
[18] Mo T. B., J. Choudhury, T.J. Schmugge, J.R. Wang, and T.J. Jackson, "A model for microwave emission from vegetation covered fields", *J. Geophys. Res*., n. 87, pp. 11229-11237, 1982
[19] S. Paloscia, E. Santi, "A semi-empirical algorithm for estimating soil moisture from dual-frequency microwave AMSR data", *Proc. Int. Geosci. Remote Sensing Symp.* (IGARSS 2003), Toulouse, France, vol.I, pp.677-679, 2003
[20] Nelder J. A. and Mead R., "A Simplex Method for Function Minimization", *Comput. J.*, 7, pp. 308-313, 1965
[21] Dobson M.C, F.T Ulaby, M. Hallikainen, and M. El Rayes, "Microwave Dielectric Behaviour of Wet Soil – part II: 4 Component Dielectric Mixing Models", *IEEE Transaction on Geoscience and Remote Sensing*, 23, pp. 35-46, 1985.