TEMPORAL EVOLUTION OF SOIL MOISTURE MAPS OF AREAS AT RISK OF FLOODS DERIVED FROM ENVISAT/ASAR IMAGES THROUGH ARTIFICIAL NEURAL NETWORKS

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Abstract
In this paper, a technique that is able to retrieve soil moisture maps in areas at risk of flood from ENVISAT/ASAR images, based on a Neural Network approach, was tested. Some experimental trials were carried out in 2003 and 2004 in the agricultural area of the Scrivia watershed in northern Italy, simultaneously to the ASAR passes. This area is susceptible to flooding and has a dense hydrometric network. The potential of SAR images for land classification was confirmed from the analysis of an RGB image composition at HH and HV polarizations, from where information on five surface classes was obtained (urban areas, free water, forests, rough and smooth bare soils). The performances of an inversion algorithm based on Artificial Neural Networks (ANN) for the retrieval of several levels of soil moisture from backscattering data were tested. The results obtained were compared with ground data. This showed a satisfactory agreement and enabled us to generate multi-temporal maps with 4-6 levels of soil moisture.

Key words: artificial neural networks, backscattering coefficient, ENVISAT/ASAR image, soil moisture map

INTRODUCTION
The possibility of estimating soil parameters from SAR (Synthetic Aperture Radar) data is extremely attractive, owing to the high sensitivity to moisture content of the observed surfaces and the independence of day light condition and meteorology. The research activities carried out world wide in the past have demonstrated that sensors operating in the low spectrum (P to L band) are able to measure the moisture of a soil layer, the depth of which depends on soil characteristics and moisture profile. The retrieval of soil moisture at higher frequencies, such as C-band, is nevertheless still challenging, since the effects of soil surface roughness and vegetation cover on the backscattering coefficient is high, and needs the use of correcting procedures (Dubois et al. 1995; Benallegue et al. 1995; Macelloni et al., 1999)

The actual capabilities of ENVISAT/ASAR images in retrieving soil moisture maps have been verified on a flat agricultural area of the Scrivia watershed, near the confluence with the Po River. The site selected for the experiment is a portion of a flat alluvial plain located close to Alessandria, in north-west Italy. Several ASAR images were collected in 2003 and 2004, along with ground measurements of soil moisture content, surface roughness and vegetation parameters these are shown in Table 1. Most images were acquired in HH polarization, which is more sensitive to the soil moisture than VV polarization.

Table 1. List of ENVISAT/ASAR Images collected on the Scrivia area.

<table>
<thead>
<tr>
<th>Test site</th>
<th>Dates</th>
</tr>
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<tbody>
<tr>
<td>Scrivia</td>
<td>December 8, 2002</td>
</tr>
<tr>
<td></td>
<td>July 6, 2003</td>
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<tr>
<td></td>
<td>August 29, 2003</td>
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<td>November 7, 2003</td>
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<td></td>
<td>April 30, 2004</td>
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<td></td>
<td>June 4, 2004</td>
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<td></td>
<td>November 26, 2004</td>
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</tbody>
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After a preliminary analysis of the ASAR images, in order to confirm the capabilities of SAR data in land classification, the performances of an inversion algorithm based on Artificial Neural Network (ANN) for the retrieval of soil moisture was tested. The ANN used was a feed-forward neural network having some hidden layers of neurons between the input and the output, trained by using the back-propagation (BP) learning rule.

The obtained results, compared with ground data, showed a satisfactory agreement and enabled us to generate pixel per pixel maps with four to six levels of soil moisture of the test site from the ASAR images.

**EXPERIMENTAL RESULTS**

Simultaneously to the ENVISAT/ASAR passes, ground measurements of soil and vegetation parameters were carried out in a “training area” on some selected fields, chosen for their dimensions and homogeneity. Soil moisture content (SMC) was measured by means of a Time Domain Reflectometry (TDR) probe and gravimetric samples, collected as a reference calibration of TDR; surface roughness measurements were carried out by means of a needle profilometer; some vegetation parameters (plant height, density, leaf number, fresh biomass) were collected too. Crops present in the areas were: wheat, fodder crops, alfalfa, corn, sugar beet.

A preliminary analysis of the potentials of ASAR data for land classification was carried out by using Red Green (RG) composite techniques. As an example, Figure 1 shows an ENVISAT/ASAR RG composite image collected in November, 2004 in Alessandria area, in HH (Red) and HV (Green) polarizations. From the figure, a land classification is feasible: black zones point out the presence of free water (rivers, lakes), light yellow pixels correspond to urban areas, green to forest or dense vegetation (mainly present, in fact, along the rivers), brown to bare, smooth fields, and red to bare, rough fields (Paloscia et al., 2005).

![Figure 1](image.png)

**Figure 1** ENVISAT/ASAR composite R (Red) G (Green) image in APP (HH, HV polarization) acquired in November 2004 on Alessandria area. R = HH polarization, G = HV polarization. Colors correspond to different surface types: yellow = urban areas; black = water bodies; red = rough bare soils; brown = smooth bare soils; green = dense vegetation, forests.
In order to compare the backscattering coefficient ($\sigma^o$) at C-band with data collected on ground, ASAR data have been geocoded with a regional map of the site (scale 1:10,000), so that the areas, where the ground measurements were carried out, were selected with the pixel precision.

The sensitivity of $\sigma^o$ in HH polarization to the SMC is confirmed in Figure 2, where a multi-temporal composition of the SAR images collected in November 2003 (Red), April 2004 (Green) and June 2004 (Blue) is described. In the image the rivers and the structure of agricultural fields are clearly visible. Since the backscattering increases with soil moisture, the dominant colour is green, correspondent to the wettest situation in April (heavy and persistent rainfalls). However, some fields in the northern part of the area (red in the image) show a marked low value of backscattering. Indeed, in April the soil was over-saturated with the formation of a film of water, which caused a scattering mainly forward. Thus, in the composite image total backscattering from these fields is dominated by the measurements of November (Red). The enlargement on the right of the image represents the portion of the area with the fields (marked by white polygons) where ground measurements were carried out.

Figure 2. Composition of multi-temporal SAR backscattering images (C-band, HH pol., $\theta=23^\circ$) collected on November 2003 (Red), April 2004 (Green), and June 2004 (Blue). The great river on the left image is the Po river. The average dimensions of the whole area are about 30 km x 10 km.

A direct correlation between $\sigma^o$, in HH polarization and $23^\circ$ incidence angle ($\theta$), and SMC is shown in the diagram of Figure 3, where a clear correlation between these two parameters can be noted. Data were collected in the Alessandria area in November 2003 (lower cluster), where most fields were bare soils, and June 2004 (upper cluster), where fields where densely vegetated. The spread of data is due both to the surface roughness of bare soils, most of them were in fact ploughed, and to the different sampling between TDR and radar. TDR integrates over a soil layer of several centimetres, whereas the radar was supposed to investigate a soil surface layer of a few centimetres only. The result is in any case comparable to those obtained in the past with similar data sets. The regression equation is $\sigma^o=0.57\text{SMC} – 20.80$, with a determination coefficient, $R^2 = 0.84$. 
SOIL MOISTURE RETRIEVAL

An algorithm based on the Artificial Neural Network (ANN) technique was developed and applied to the retrieval of soil parameters from ASAR data. The ANN used is a feed-forward multi-layer perceptron (MLP), with some hidden layers of neurons between the input and output. In MLPs successive layers of neurons are fully interconnected, with trainable connection weights controlling the strength of the connections. The input to a neuron in a given layer is the sum of all its incoming connection weights, each one multiplied by the output of the connected neuron from the preceding layer. The trainable offset value associated with the neuron is added to the sum, and the result is fed into the activation function of the neuron. The latter is most commonly chosen as a non-linear sigmoid function, which is also the shape we used in the present work. MLP ANNs can be trained to represent arbitrary input-output relations (Hornik et al., 1989; Linden et al., 1989).

During the training phase, training patterns are sequentially presented to the network and the interconnecting weights of each neuron are adjusted according to a learning algorithm. The trained ANN can be considered as a type of non-linear least mean square interpolation formula for the discrete set of data points in the training set. The algorithm chosen for the training phase was the back-propagation (BP) learning rule, an iterative gradient descent algorithm designed to minimize the mean square error between the desired target vectors and the actual output vectors. After several tests, a configuration with two hidden layers of 10 perceptrons each was chosen as the optimal one. The used ANN was trained by using backscattering coefficients as input and SMC expected values as output. The used ANN was a feed-forward neural network having some hidden layers of neurons between the input and output, trained by using the back-propagation (BP) learning rule.

The algorithm of ANN was tested in the Scrivia area by using ENVISAT/ASAR data collected on 7 November 2003. In this case the available backscattering dataset was subdivided into two parts: the first portion was used to generate a training set and the second one to test the ANN performances (Hornik et al., 1989). The comparison between the retrieved and the measured SMC on the test fields is shown in Figure 4. In spite of some underestimation at high values of SMC, the algorithm seems to be able to reproduce fairly well the values of soil moisture.
Figure 4  SMC% estimated by using the ANN algorithm as a function of the SMC% measured on ground. Data refer to the ENVISAT/ASAR image collected on Alessandria area on November 7, 2003.

After this test carried out on the selected fields for which ground measurements were available, the algorithm was validated over the whole test area of Alessandria by using the ENVISAT ASAR images collected on April 30, and June 4, 2004. The images were in HH polarization and at $\theta = 23^\circ$. The weather was rainy in April and sunny and dry in June. At each date soil moisture was rather uniform on the area and its average values decreased from April (SMC> 30-35%) to June (SMC=10%).

Figure 5 shows the pixel per pixel soil moisture maps retrieved from the Artificial Neural Network method. The maps were masked for the areas covered by dense vegetation (magenta), rivers and lakes (blue) and urban areas (black). Although the soil moisture measurements were not available for the whole area, the maps are generally representative of the different soil conditions: Figure 5a shows a very high soil moisture conditions, over 30%, due to the heavy rainfalls of the weeks before and during the satellite pass, which corresponded to the measured average values. Figure 5b shows the low soil moisture situation typical of the summer season.
CONCLUSIONS

The analysis of SAR data collected on the Scrivia area confirmed a rather good sensitivity of C-band radar backscattering coefficient both to the surface characteristics and to soil moisture content. In this paper the actual capabilities of ENVISAT/ASAR images in estimating soil moisture content in flat area have been tested. An inversion algorithm based on Artificial Neural Networks (ANN) in retrieving several levels of soil moisture from backscattering data was tested and successfully compared to ground measurements in the test-site. This technique made it possible to estimate 5-6 levels of SMC.

ACKNOWLEDGMENTS

This work was partially supported by the EC project FloodMan (EVK1-2001-00237), the Italian Space Agency (ASI), and the ESA ENVISAT program.

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