Retrieval of Soil Moisture content using PALSAR data

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Abstract

This study reports on the use of PALSAR data to retrieve soil moisture content over agricultural areas. An algorithm transforming temporal series of PALSAR data into soil moisture content by using a constrained minimization technique, integrating *a priori* information on soil parameters, is presented. The algorithm applies to winter wheat and has been assessed on simulated and experimental data acquired during the 2006 and 2007 growing seasons over two agricultural sites, namely Demmin (Northern Germany) and Foggia (Southern Italy). Preliminary results indicate the feasibility of retrieving volumetric soil moisture content with an accuracy of 5%.

Keywords: Soil moisture, PALSAR, retrieval, hydrology.

1. INTRODUCTION

The monitoring of spatial and temporal distribution of soil moisture content, at the watershed and regional scale, is of major importance for land applications such as hydrology, agriculture and meteorology. The science requirement for the accuracy of the superficial volumetric soil moisture content is usually set to 4%-5%, allowing the identification of 4-5 moisture classes.

Although SAR systems have the potential to meet the science requirements for monitoring the superficial soil moisture at high spatial resolution, to date their use has been generally limited and no operational algorithm is yet available. An important part of the limitations to monitor superficial soil moisture is due to the disturbing effect of surface roughness and vegetation layer modulating the radar sensitivity to the soil moisture content thus rendering intricate the retrieval problem. For relatively simple SAR configurations (e.g. single frequency, one/two polarizations, one incidence angle), there generally exist many combinations of surface parameters mapping the same SAR observable, then the retrieved “optimal” solution (i.e. most probable or *minimum* rms error) may be characterized by poor accuracy. This problem may be tackled by introducing *a priori* information about the surface parameters [1] and using multi-temporal SAR data [2].

The objective of this paper is to describe an algorithm for the retrieval of superficial soil moisture content underlying winter wheat from multi-temporal PALSAR data. The higher penetration of L-band SAR signal into the canopy, with respect to shorter wavelengths such as C- or X-bands, is expected to highly improve the SAR capability to monitor soil moisture content.

Due to the difficulty of gathering frequent PALSAR acquisitions in Europe, a reduced number of PALSAR images have been analyzed to date. They have been acquired in 2006 and 2007 over two sites: one in Germany and one in Italy. In the next section the two experimental data sets will be shortly described. Then the retrieval algorithm and its performances will be illustrated using simulated and experimental data.

2. EXPERIMENTAL DATA

2.1. AGRISAR 2006 campaign

The first data set has been collected during the AGRISAR 2006 campaign, carried out from April to August 2006 over the Demmin site, in the Mecklenburg-Western Pomerania (Northern Germany) [3]. The campaign was funded by the European Space Agency (ESA), coordinated by the Deutsches Zentrum für Luft- und Raumfahrt (DLR) and included the participation of 14 European Institutions. The principal objective of the campaign was to assess the impact of the future Sentinel-1 and –2 missions for land applications and to provide a well documented database to investigate the bio-physical parameter retrieval.

Fig. 1 shows a land use map of the Gormin farm located on the Demmin site. The main cultivated crops are winter wheat, winter rape, winter barley, maize, sugar beet. During the campaign, X-, C- and L- band SAR data were acquired by the airborne ESAR system roughly every week. Coincidently, *in situ* measurements of soil moisture content and vegetation biomass were collected over selected fields in the area. In addition to ESAR acquisitions, two PALSAR images were acquired over the Demmin site during the AGRISAR campaign (see Table 1).

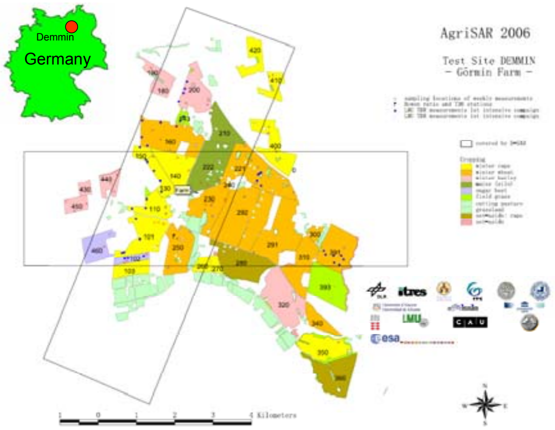


Fig. 1. Land use map of the Gormin farm on the Demmin site (Northern Germany).

Table 1. PALSAR data over the Demmin site

Date	SAR system	Incidence	Track
11/06/06	PALSAR-FBS (HH)	41.5°	637
27/07/06	PALSAR-FBS (HH)	41.5°	637

2.2. AQUATER 2005-2008 campaign

The second data set has been gathered in the framework of a three-year project (i.e. AQUATER, 2005-2008) funded by the Italian Ministry of Agriculture, Food and Forest Policies [4]. The study area lies in the Capitanata plain, the second largest plain in Italy (about 4000 km^2). It is located close to the town of Foggia (41° 33' N, 15° 30' E, 76 m a.s.l.), in the Puglia region (Southern Italy). The climate is typical semi-arid with temperatures which may fall below 0 °C in winter and rise above 40 °C in summer. Annual rainfall (avg. 550 mm/year) is unevenly distributed throughout the year, being mostly concentrated during the winter months. The soil texture of this area is predominantly clay.
In 2006 and 2007, a large number of ASAR and MERIS images and 7 SPOT images were acquired over the area. No PALSAR data were acquired during the 2006 growing season, whereas 3 images, at fine resolution, were acquired in 2007 (see Table 2).

Table 2. PAL SAR over the Foggia site

Date	SAR system	Incidence	Track
02/04/07	PALSAR-PLR (quad. Pol.)	21.5°	630
18/05/07	PALSAR-PLR (quad. Pol.)	21.5°	630
11/08/07	PALSAR-FBD (HH & HV)	34.3°	635

Fig. 2 illustrates an updated land use map of the study area obtained by a supervised classification of three SPOT-5 images acquired in 2006. The principal crop cultivated in the area is durum wheat (48% of the total cultivated area). Other important seasonal crops are tomato and sugar beet.

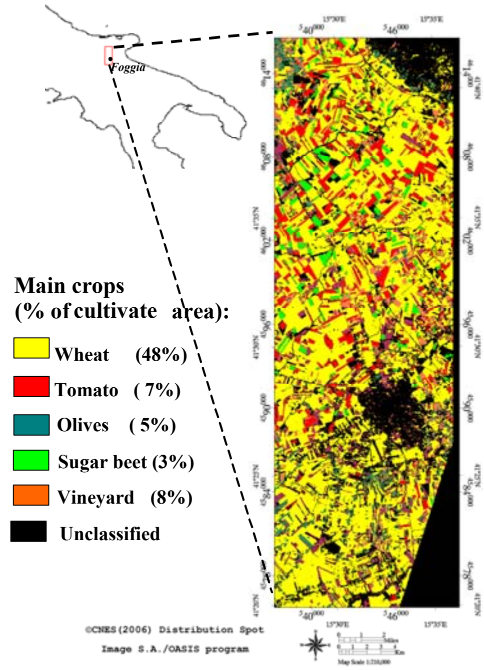


Fig. 2. Land use map of the Foggia site in the Capitanata plain (Puglia region, Southern Italy).

Quantitative measurements of agronomic and structural parameters (e.g. soil moisture content, fresh and dry biomass, LAI, phenological stages, etc.) have been collected, roughly every two weeks from April to August 2006 and 2007, over 12 fields cultivated with wheat, tomato and sugar beet. For a larger number of fields qualitative information has been collected (e.g. land-use, phenological stage, pictures etc). Ancillary data on the site, in terms of digital elevation model, soil texture maps, evapotranspiration, meteorological data etc. are also available.

3. RETRIEVAL ALGORITHM

The proposed algorithm transforms a temporal series of L-band SAR data, acquired at HH polarization and low-medium incidence angles, into soil moisture values. The algorithm is expected to be able to estimate soil moisture content of bare and wheat vegetated fields during the entire phenological cycle. In [2], it is shown that at L-band, HH polarization and low-medium incidence angles, there is a negligible sensitivity of backscatter to the wheat biomass. On the contrary, the most important contribution to HH backscatter comes from the soil and its moisture variations. As a consequence, the adopted approach disregards the presence of vegetation and inverts the IEM surface scattering model by using a constrained optimization technique. The technique integrates *a priori* information on soil parameters to obtain robust and accurate estimates of soil moisture content [2].
The use of multitemporal images is beneficial for the accuracy of the retrieved soil moisture content under the

condition that the surface roughness remains almost constant during the acquisition time (*T)* of the entire time series. For instance, for a temporal series of *N* images, disregarding the presence of vegetation, the number of surface parameters to be estimated is *N+2* (*N* soil moisture values and *2* surface roughness parameters, namely the vertical (*s)* and horizontal roughness (*l*). For *N* equals to *1* there is the worst ratio (i.e. 1/3) between independent measurements and parameters to be estimated (highly inaccurate retrieval). Whereas for *N* large the ratio tends to 1 (highly accurate retrieval). In practice, there is a trade off between the *maximum* possible number *N* of multi-temporal images and the time span *T* of the total acquisitions. For the PALSAR sensor, the most probable configuration is *N* equals to 2 and *T* equals to 46 days.
To investigate the feasibility of retrieving soil moisture content by using a time series of 2 L-band HH polarized SAR images a simulation experiment will be carried out in the next session.

3.1. Simulated experiment

Three conditions of soil surfaces, representing three subsequent dates, were simulated. While the surface roughness was assumed constant for all the three dates, soil moisture content was significantly changed from the first to the second and to the third date. Table 3 reports the values of surface parameters employed in the simulations.

Table 3. Simulated surface parameters

Mean parameters	1st date	2nd date	3rd date
$\langle s \rangle$ *(cm)*	*1.25*	*1.25*	*1.25*
$\langle l \rangle$ *(cm)*	*15.*	*15.*	*15.*
$\Re\left(\varepsilon^r\right)^{(*)}$	*6*	*11*	*17*

(*) Real part of the relative dielectric constant of the soil.

The simulated *a priori* information to be used in the retrieval algorithm was obtained by perturbing the mean parameters reported in Table 3. The perturbation consisted of adding a Gaussian noise with zero mean and a std equals to 20% of total variability of the selected parameter (e.g. for the volumetric soil moisture content this means a std approximately equals to 10%). The simulated data set of σ_0 values at L-band, HH polarization and 23° incidence was obtained by means of the IEM model, run with the input values reported in Table 3. Measurements errors were also simulated by superposing a Gaussian noise with zero mean and 1.0 dB std on the IEM simulations.
Finally, the retrieval algorithm was applied to the simulated data set. Referring to Table 3, two couples of SAR images were simulated (i.e. N=2). The first one included the 1st and 2nd dates, whereas the second one included the 2nd and 3rd dates. Fig. 3 shows the scatter plot obtained for the volumetric soil moisture content. The error is approximately 5%, the correlation is 0.9 and the bias is

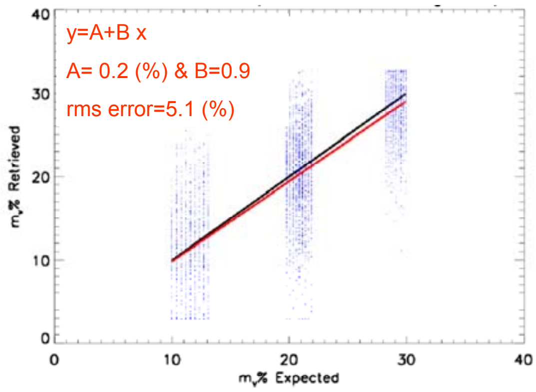


Figure 3. Simulated results. Scatter plot of retrieved vs expected soil moisture values.

negligible. These encouraging simulated results indicate that it is feasible to retrieve soil moisture content over bare and wheat fields by using two PALSAR images at HH polarization and low incidence angles. In the next section the algorithm will be applied to the available experimental data.

3.2. Demmin and Foggia data

The developed algorithm has been applied to the two couples of HH PALSAR data acquired over the Demmin site (i.e. June 13 & July 26, 2006) and over the Foggia site (i.e. April 2 & May 18, 2007). This means to consider *N* equals to 2 and a time span *T* of 46 days. In Fig. 4 and Fig. 5 the soil moisture maps retrieved over wheat fields of the Demmin and Foggia sites, respectively, are shown.

In both cases, *a priori* information concerning soil moisture content was obtained from *in situ* measurements on selected fields, whereas a constant value of 1.5 cm was adopted for the *s* parameter. No *a priori* information on correlation length *l* is used. This is because: 1) it is extremely difficult to provide reliable values of *l* unless accurate *in situ* measurements had been carried out;

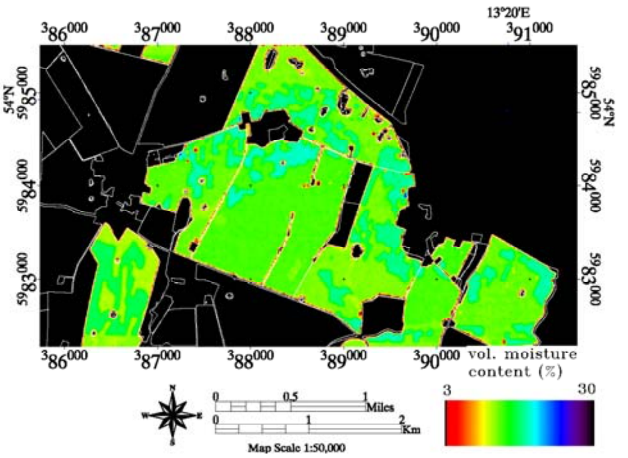
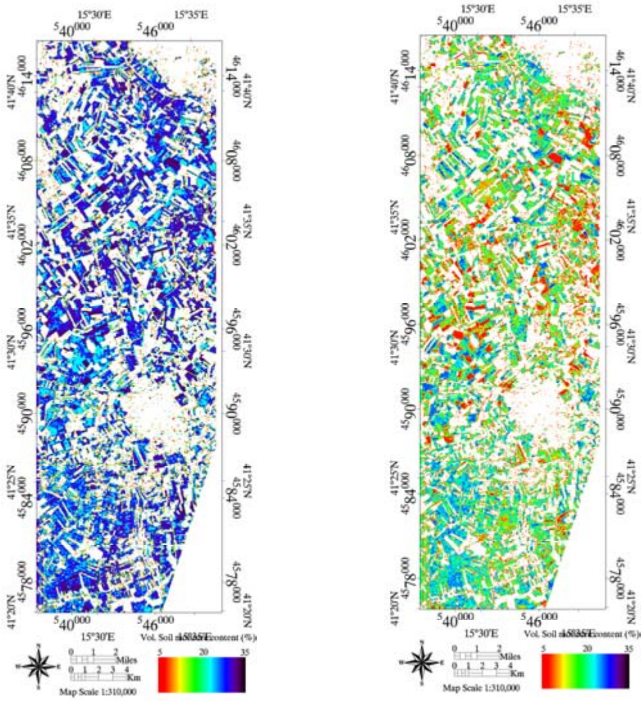


Figure 4. Soil moisture map retrieved from PALSAR data over the Demmin site. The map refers to June 13, 2006.



(a) (b)

Figure 5. Soil moisture maps retrieved from PALSAR data over the Foggia site. The maps on the left (a) and on the right (b) refer to April 2- and May 18, 2007, respectively.

2) in the inversion procedure, the use of *l* as a free parameter may allow to better match the observed SAR data with the IEM model.
It is worth mentioning that other potential sources of *a priori* information on soil moisture content, which deserve to be investigated, may be: networks of TDR ground stations continuously measuring soil moisture values; hydrologic model predictions or else spaceborne microwave radiometers providing soil moisture estimates at coarse scale.

The analysis of maps in Fig. 4 and Fig. 5 is still in progress, however, preliminary results indicate an rms error of 5% between measured and retrieved volumetric soil moisture values on both sites.

4. CONCLUSIONS

A methodology to retrieve superficial soil moisture content underlying wheat fields, based on multi-temporal PALSAR data at HH polarization and *a priori* information has been presented. The algorithm uses a constrained minimization technique to invert a surface scattering model, namely IEM, thus disregarding the effect of wheat canopy on HH backscatter. The performances of the retrieval algorithm were assessed on the AGRISAR and AQUATER data sets employing as *a priori* information the *in situ* measurements. Results indicate that by using temporal series of 2 subsequent PALSAR images it is feasible to retrieve soil moisture content with an accuracy of approximately 5%.

Future work will be dedicated to further assess the robustness of the algorithm versus errors on the *a priori* information and other sources of errors. Moreover, the possibility of extending the methodology to other crops will be investigated.

Acknowledgement

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References

[1] F. Mattia, G. Satalino, L. Dente and G. Pasquariello, "Using *a priori* information to improve soil moisture retrieval from SAR APS data in semi-arid regions", *IEEE Trans. Geosci. Remote Sensing*, vol. 44, no 4, pp 900-912, April 2006.

[2] F. Mattia, et al., "Exploiting L-band SAR Data for the Improvement of Surface Process Modelling", *Proceedings of the 5th International Symposium on Retrieval of Bio- and Geophysical Parameters from SAR Data for Land Applications*, Bari, Italy, September 25-28, 2007.

[3] Final Report "AgriSAR Optical and Radar Campaign", *ESA Contract 19974/06/I/LG*, 2007.

[4] M. Rinaldi et al.,, AQUATER Project: The Measurement Campaign in Capitanata Plain of Soil-Plant-Atmosphere Continuum, *Proceedings of the 5th International Symposium on Retrieval of Bio- and Geophysical Parameters from SAR Data for Land Applications*, Bari, Italy, September 25-28, 2007.