SOIL MOISTURE MAPS FROM TIME SERIES OF PALSAR-1 SCANSAR DATA OVER AUSTRALIA

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ABSTRACT

This paper investigates the use of quasi-dense time-series of L-band SAR images for retrieving soil moisture (m_v) maps at a spatial resolution below 1km^2. 23 WB1 PALSAR-1 products, acquired from 2008 to 2009 with an average revisit time of 11 days, have been used to retrieve m_v maps over an agricultural area, in Southern Australia, hydrologically monitored with a network of ground stations continuously measuring m_v profiles. The retrieval approach is based on the SMOSAR algorithm inverting temporal changes of radar backscatter. Results indicate an rms error of approximately 6.0% v/v.

***Index Terms*—** SAR, PALSAR, L-band, Soil Moisture retrieval

1. INTRODUCTION

Operational Earth Observation (EO) m_v products, derived from radiometers and scatterometers at low spatial resolution (e.g. 25 km^2), are already accessible [1-2] and improved products are expected from the SMAP mission in the near future [3]. However, products at higher spatial resolution (e.g. below 1 km) are still lacking, although they would be highly beneficial for a large number of land applications. The spaceborne systems most suited to monitor m_v at moderate spatial resolutions (i.e. below 1 km) are Synthetic Aperture Radars (SARs) and, for these systems, the near-future scenario is quite promising as by the end of 2013 it is expected to be launched: i) the first of two Sentinel-1 (S-1) satellites, constituting the European Radar Observatory constellation developed by European Space Agency (ESA), ii) the first of the two SAOCOM 1 satellites developed by the Argentina's CONAE, and iii) the Advanced Land Observing Satellite-2 (ALOS-2) developed by the Japanese Space Agency (JAXA). These missions are all characterized by improved observational capabilities with respect to most previous SAR systems, therefore an important progress in the monitoring of land parameters at moderate spatial and temporal resolution is expected. For instance, the shorter revisit time of the forthcoming SAR systems (e.g. 6-14 days) will allow to systematically test the application of m_v retrieval methods based on backscatter temporal changes. The rationale of this method is that temporal changes of surface roughness, canopy structure and vegetation biomass take place at longer temporal scales than m_v changes (excluding cultivation practices). Therefore, dense or quasi-dense multi-temporal acquisitions are expected to be able to track changes in m_v only. An algorithm based on such an approach has been recently developed [4] and, with a view to the forthcoming ALOS-2 mission, its performance over a quasi-dense time series of PALSAR-1 ScanSAR images acquired from 2008 to 2009 over the Yanco agricultural site (Southern Australia), has been investigated in this study.

In the next section, the data set is briefly described, then the retrieval algorithm and the obtained results are presented and discussed.

2. GROUND AND SAR DATA

The Yanco study area is a flat semi-arid agricultural and grazing area of approximately 60 x 60 km, located in the broad western plains of the Murrumbidgee catchment (Fig. 1), monitored for soil moisture remote sensing purposes since 2001 [5].

The principal summer crops are rice, maize and soybeans, while winter crops include wheat, barley, oats and canola. The Yanco area is hydrologically monitored by the OzNet soil moisture monitoring network consisting of 13 soil moisture profile stations installed in a grid-based pattern (see Fig. 1) to continuously monitor precipitation, soil moisture and soil temperature at various depths over the root zone. As an example, Fig. 2 shows the temporal behaviour of m_v and daily rainfall measured in 2008 by the Y7 station, which is located in the centre of the study area (see Fig. 1). Data show that the m_v level is generally low (i.e. below 10% v/v) throughout all the year with the exceptions of short periods after precipitations events, during which the m_v level can reach 20% v/v.

The analysed time series of PALSAR-1 data consists of 23 ScanSAR images acquired over the study area from March 2008 to May 2009. The PALSAR-1 images were acquired at HH polarization and at incidence angles ranging from approximately 19° to 34°, they were all acquired along descending paths and the products were WB1 lev. 1.5, with a pixel spacing of 100m and number of looks of 8. The average temporal resolution of the time series is approximately 11 days. Table I shows the 23 images, which have been subdivided into three groups of quasi-dense images. Only in one case a time gap of 23 days has been included in order to extend the initial series from late March to late May 2008, which is the austral autumn when winter crops are usually sown. The most numerous group of analysed images is the second one, consisting of 12 images acquired from early October 2008 to mid-January 2009, i.e. during the austral spring and summer time. All the images have been calibrated, coregistered, and spatially and temporally filtered.

The m_v ground measurements, used for the validation of the retrieval algorithm, were acquired at the same time of the PALSAR-1 acquisitions by the 13 ground stations. However, due to some data unavailability, the number of observation selected is 272 and its histogram is shown in Fig. 3. The average of the m_v observations is 9.8 % v/v, while the m_v peak is at 5% v/v, and approximately 10% of the total points have values lower than 3% v/v, indicating very dry soil conditions.

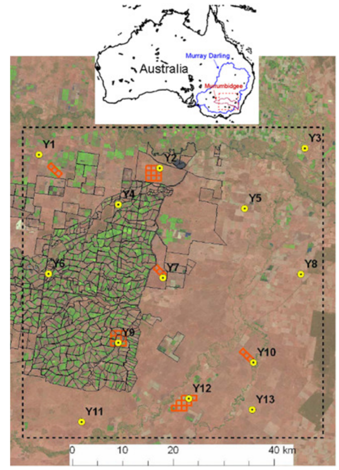

Fig. 1: Yanco study area (Murrumbidgee catchment, Southern Australia). The field boundaries of the Coleambally Irrigation Area and the 13 soil moisture stations are shown.

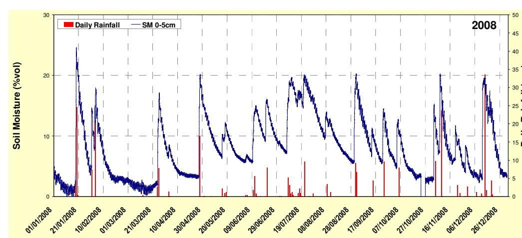

Fig. 2: Temporal behaviour of m_v and daily precipitation measured by the Y7 station in 2008.

3. SOIL MOISTURE RETRIEVAL ALGORITHM

The SMOSAR algorithm [4] transforms quasi-dense time series of N-PALSAR-1 WB1 images at HH polarization into N-m_v maps. The rationale of the method relies on the fact that over agricultural surfaces cultivated with cereals-like crops or over grazing areas the volume scattering contribution at L-band can be disregarded, and therefore the total backscatter can be approximated by the attenuated soil scattering contribution only (i.e. $\sigma_0 \approx \tau^2 \sigma_0^s$, where σ_0^s is the soil surface contribution, and τ^2 is the two-way vegetation attenuation). Then, adopting the *alpha approximation* [6], the backscatter ratio between each two subsequent and temporally close acquisitions (so that any change of roughness, vegetation biomass and canopy structure between the two acquisitions can be disregarded) can be approximated by the ratio between the correspondent Fresnel α_{HH} reflection coefficients, which depend on dielectric constants and incidence angles only. As a result, a time series of N-σ_0 values produces an underdetermined linear system of N-1 equations in N- α_{HH} unknowns. The estimate of the time series of N-m_v values at pixel scale is obtained by solving the linear system subject to linear constraints, which are expressed as an interval of lower and upper bounds for the system unknowns (i.e. α_{min}, α_{max}). Once the α_{pp} coefficient for each date is retrieved, the relative dielectric constant can be derived and then, m_v can be estimated by using the Hallikainen empirical model.

4. RESULTS

A landcover of the study area referring to 2010 has been preliminary applied to all the analysed SAR images in order to mask areas characterized by volume scattering. Then the SMOSAR algorithm has been independently run over the three groups of images identified in Tab I. Each run included *N*=4 subsequent images and then slid over the image group by shifting of one image each time up to the last. This processing produces more than 1-m_v map for the same date, therefore those maps referring to the same date have been averaged to get a single map for each date. A box car filter over a window of 5x5 pixels has then been applied and the spatial resolution of the retrieved m_v maps is below 1km. Fig. 4 shows the scatter plot between the retrieved and observed m_v values. The total rms error is approximately 5.7% v/v and the correlation coefficient R is 0.59. This rather low R value is likely due to the limited dynamics of m_v values, which in the 75% of cases range from 3% v/v to 15% v/v. Moreover, the lowest retrieved m_v value is approximately 3% v/v and this is due to a cut off imposed on the lower bound of the inverse of the Hallikainen empirical model.

Fig. 5 illustrates the rms error between retrieved and observed m_v values at each of 13 measurement stations reported in Fig. 1. The highest rms error (i.e. ≈ 8 %v/v) is found at the station Y9, while the lowest one (i.e. ≈ 3 %v/v) at station Y3. These two stations are approximately 50 km away from one another and are located in a land cropping (Y9) and in a grassland (Y3) area. In Fig. 6, the temporal behaviour of the retrieved and observed m_v values recorded at station Y3 and Y9 are shown. It is worth mentioning that the temporal behavior of the observed (top 5cm) m_v values is quite different between the two stations, probably reflecting the different precipitation patterns over the area. The worse SMOSAR performance observed at station Y9 with respect to that at station Y3 is likely related to the land use characteristics of the area surrounding the two stations. Indeed, as the spatial resolution of the retrieved m_v maps is approximately 1km, the quite heterogeneous landuse of the land cropping area surrounding the station Y9 may affect the m_v retrieval accuracy, whereas the fairly homogeneous grass land area around station Y3 has probably a smaller impact on the m_v retrieval accuracy.

Finally, Fig. 7 shows the PALSAR-1 derived m_v-map on November 29th, 2008. The map average value is ≈15% v/v, however, a distinct elongated strip (stretching over an area of approximately 10x60 km^2), corresponding to a drier area (i.e. average m_v ≈8% v/v), is evident on the bottom part of the image. This drier pattern likely reflects the spatial distribution of daily precipitation in the area. Indeed, the average precipitation observed on November 29th, 2008, by the Y6, Y9, Y10, Y12 and Y13 stations (group-1, located on the dry area), is 2 mm, whereas the average precipitation measured by the rest of the stations (group-2) is 9 mm, ranging from 4mm to 16mm. On the same day, the group-1 of stations measured an average m_v of 8.4% v/v, whereas the group-2 measured an average m_v of 17.0% v/v. These m_v values can be compared with those retrieved from the SAR data around the same stations, which are 12.5% v/v (group-1) and 17.1% v/v (group-2). This example demonstrates the potential of SAR retrieved m_v maps to resolve m_v patterns over the Yanco area.

TABLE I
The three PALSAR-1 WB1 temporal-groups of analysed images. Δ(DoY) is the difference between DoY(t) – DoY(t-1)

DATE	DoY	Δ(DoY)	Track	Pol	Prod
27/03/2008	87	-	18	HH	WB1
13/04/2008	104	17	19	HH	WB1
16/05/2008	127	23	15	HH	WB1
23/05/2008	144	17	16	HH	WB1
29/05/2008	150	6	19	HH	WB1
09/10/2008	283	-	16	HH	WB1
14/10/2008	288	5	19	HH	WB1
26/10/2008	300	12	17	HH	WB1
31/10/2008	305	5	20	HH	WB1
12/11/2008	317	12	18	HH	WB1
24/11/2008	329	12	16	HH	WB1
29/11/2008	334	5	19	HH	WB1
16/12/2008	351	17	20	HH	WB1
22/12/2008	357	6	15	HH	WB1
28/12/2008	363	6	18	HH	WB1
09/01/2009	9	12	16	HH	WB1
14/01/2009	14	5	19	HH	WB1
13/03/2009	72	-	17	HH	WB1
25/03/2009	84	12	15	HH	WB1
11/04/2009	101	17	16	HH	WB1
16/04/2009	106	5	19	HH	WB1
28/04/2009	118	12	17	HH	WB1
15/05/2009	135	17	18	HH	WB1

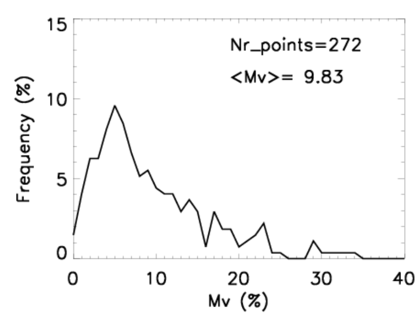

Fig. 3: Histogram of m_v values observed during the PALSAR-1 acquisitions.

5. CONCLUSIONS

A quasi-dense time series of 23 PALSAR-1 ScanSAR images, acquired from 2008 to 2009, over the Yanco agricultural area (Southern Australia) has been used to retrieve m_v maps at approximately 1km resolution. The SMOSAR retrieval algorithm [4], inverting temporal

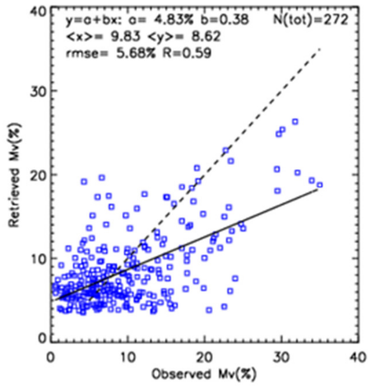

Fig. 4: Scatterplot between retrieved and observed m_v values over the Yanco site.

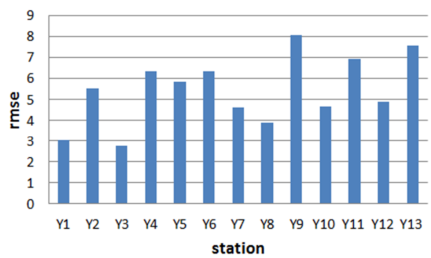

Fig. 5: rms error (v/v) obtained over the 13 measurement stations.

changes of radar backscatter, has been exploited and its performance has been tested against m_v ground data recorded by a network of 13 continuous stations located in the Yanco area. The analysis of the retrieved m_v confirms a good sensitivity of L-band data to soil moisture changes and indicates a retrieval accuracy of approximately 6.0% v/v, evaluated over more than 270 observations. The retrieved m_v-maps also demonstrate the potential of L-band SAR data to resolve m_v spatial patterns reflecting the precipitation distribution over agricultural areas.

6. ACKNOWLEDGEMENT

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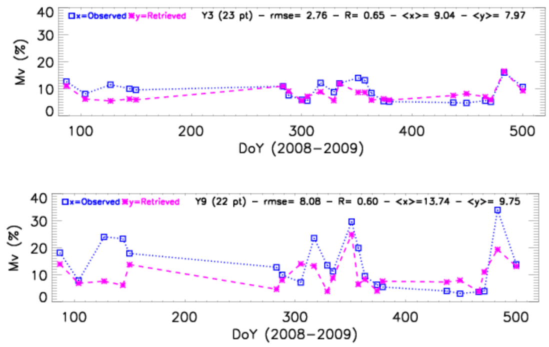

Fig. 6: Temporal behaviour of retrieved and observed (stations Y3 and Y9) m_v values.

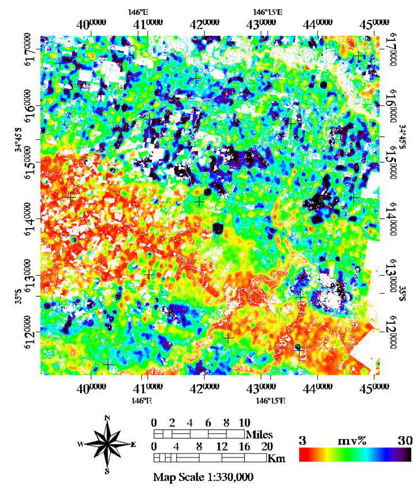

Fig. 7: m_v map retrieved from PALSAR-1 data acquired on November 29th, 2008.

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