COSMO-SKYMED MULTI-TEMPORAL DATA FOR LANDCOVER CLASSIFICATION AND SOIL MOISTURE RETRIEVAL OVER AN AGRICULTURAL SITE IN SOUTHERN AUSTRALIA

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ABSTRACT

This paper uses a time-series of COSMO-SkyMed SAR images for land cover classification and soil moisture retrieval over an agricultural area located in Southern Australia. The SAR products analyzed are 11 StripMap Ping Pong images, at HH and HV polarizations, acquired at 21° incidence angle and with a revisiting time of either 8 or 16 days. The classification accuracy has been assessed as a function of the polarization and the number of images analyzed. Results confirm that the temporal information is crucial to improve the classification results. An overall accuracy of approximately 82% was achieved for 10 classes. Moreover, soil moisture (m_v) maps over bare or sparsely vegetated areas have been retrieved by means of the SMOSAR-X ("Soil MOisture retrieval from multi-temporal SAR data") algorithm, developed in view of the forthcoming Sentinel-1 data and then adapted to X-band SAR data. The SMOSAR-X algorithm is shown to produce m_v maps with an rmse of 6.6% v/v.

Index Terms— SAR, COSMO-SkyMed, X-band, Multitemporal Classification, Soil Moisture retrieval

1. INTRODUCTION

Monitoring of the spatial and temporal variability of land surface parameters is a crucial task for improving a number of land applications, such as crop yield forecast or water management. Several studies have demonstrated the potential of SAR observations for land cover and land use classification as well as emphasizing the role of multi-temporal data in order to achieve good classification accuracies (e.g. [1]). Although X-band SAR data have not been thoroughly investigated (for instance the SIR-C/X-SAR system aboard the Space Shuttle provided data over short periods), they hold a good potential for discriminating various crops [e.g. 2]. For this reason, the launch of new X-band missions, such as the COSMO-SkyMed (CSK) and TERRASAR-X, which can acquire polarimetric data within a short revisiting time (e.g. ranging from 1 to 16 days), provide valuable opportunities to assess the contribution of X-band SAR observations for applications in agriculture and hydrology. The short revisiting time of CSK data is also suitable to test the performance of soil moisture (m_v) retrieval algorithms based on the inversion of temporal changes of radar backscatter. This is the objective of the SMOSAR ("Soil MOisture retrieval from multi-temporal SAR data") algorithm [3, 4], developed in view of the forthcoming ESA Sentinel-1 mission, and subsequently adapted to X- band data (i.e. SMOSAR-X). The main difference between SMOSAR at C- and X-band is that the latter can retrieve m_v over bare or sparsely vegetated soils only, whereas the former can work over a broader range of surfaces. The land cover classification and m_v retrieval tasks are deeply linked in SMOSAR-X since ancillary information on land cover maps are required to mask the densely vegetated areas over which the X-band SAR signal shows poor sensitivity to m_v.

The objective of this study is to investigate the use of multi-temporal co- and cross-polarized CSK data for land cover and land use classification and for m_v retrieval over agricultural sites. The study area is the Yanco site, located in Southern Australia and the ground data used for this study were collected in the framework of the 2nd Soil Moisture Active Passive Experiment (SMAPEx-2) [5].

2. EXPERIMENTAL DATA

The SAR and ground data used in this paper were collected in the Yanco study area, which is a 38km by 36km area located in the western flat plains of the Murrumbidgee

(South of Australia). The area is a semi-arid agricultural and grazing area that has been hydrologically monitored by the OzNet m_v network since 2001 [6]. The network initially consisted of 13 m_v stations to which 24 additional semi-permanent monitoring stations were added in 2009-2010 in a grid-based pattern. Each station records precipitation, m_v and soil temperature at various depths. The study area has been serving as a calibration site for various Earth Observation missions [7, 8]. Intensive ground sampling campaigns were carried out during the 2010-2011 Soil Moisture Active Passive Experiments (SMAPEx-1, -2 and -3 [5]) collecting near-surface (0-5cm) soil moisture and land use information over six experimental farms.

The CSK data acquired and analyzed over the site from early November 2010 to mid-February 2011 (see Table I) include 11 StripMap Ping-Pong images at HH and HV polarization (swath of ~30km x ~30km and pixel resolution of ~20m) at approximately 21° incidence angle. The SAR data have been calibrated, co-registered, and temporally and spatially filtered.

The classification maps obtained from CSK images were validated by using *in situ* visual land use observations collected during SMAPEx-2, collecting near-surface (0-5cm) soil moisture and land use information over six experimental farms. These observations were organized as Regions Of Interest (ROI), i.e. spatial polygons each classified according to one of 10 land use classes, namely: 1-wheat, 2-barley, 3-maize, 4-cotton, 5-rice, 6-grass&pasture, 7-fallow, 8-bare, 9-forest and 10-openwoodland. The CSK-derived m_v maps were validated using the measurements recorded by the Oznet permament and semi-permanent stations coincident with the SAR acquisitions. Out of the total 37 stations, 17 fell inside the swath of the CSK images and 2 of them did not record data in coincidence with the SAR acquisitions. As a result, 15 stations could be potentially exploited for the validation. However, 6 of them had to be masked out of the SAR images because they were located on either maize, rice or cotton fields, over which the SMOSAR-X code is not reliable. As a result, 9 stations, namely Y7, Y9, YA1, YA3, YA5, YA4e, YA7b, YA7e and YA9, were used for the SMOSAR-X assessment. For all the stations but one, the m_v values were recorded at 0-5cm depth. In one case, the observed values were measured at a depth of 0-30cm.

3. CLASSIFICATION AND SOIL MOISTURE RETRIEVAL ALGORITHMS

The Maximum Likelihood (ML) algorithm for multivariate Gaussian distributed data was adopted for this classification study as a robust method to minimize the classification errors (the ML requirement of Gaussian distributed data is satisfied after speckle filtering). The analysis focuses on investigating the classification accuracy as a function of the number of images considered and their

TABLE I
Acquisition dates of StripMap Ping-Pong COSMO-SkyMed images at HH and HV polarization.

Image nr.	Date
1	2010 11 02
2	2010 11 10
3	2010 11 18
4	2010 11 26
5	2010 12 12
6	2010 12 28
7	2011 01 05
8	2011 01 21
9	2011 01 29
10	2011 02 06
11	2011 02 14

polarization. The accuracy was estimated by comparing pixel by pixel the classified map with the land use class contained in the surface database polygons, which were split in a training and a testing data set.

The m_v retrieval was performed using the SMOSAR-X algorithm to convert the time series of *N* CSK images into *N*-time series of m_v maps. The algorithm inverts temporal changes of radar backscatter, under the hypothesis that over short periods the backscatter change is related to m_v changes only [9].

4. CLASSIFICATION AND SOIL MOISTURE MAPS DERIVED FROM SAR DATA

A total of 24 classification experiments were carried out by combining (i) an increasing number of CSK images (going from 1 to 8, as labelled in Table I) and (ii) single- (i.e. either HH or HV) or dual- (i.e. HH and HV) polarized configuration. The last three images, acquired in the final part of the growing season, during which the crop phenology does not significantly change and then the corresponding radar signatures remain fairly stable, were not used because they do not add information to the time series. The overall accuracy (OA) of the classification for each experiment was computed for the training and test data, which consists of approximately 90,000 and 60,000 points, respectively. As expected, the OA computed for the training data was higher than that computed for test data (in average, the difference was 4%). For the test data, Fig. 1 shows the OA as a function of the number of images classified and of their polarization. Results show that the OA increased with the number of images used in the classification algorithm. In addition, the use of dual-polarized data provided more accurate classification than single polarized data. However, for the first date, the HV channel provides slightly (1% difference) better results than HH and HV. When comparing the OA obtained by classifying independently the co- and cross-polarized channel, it was found that the cross-polarized channels provided more accurate classification

Fig. 1. OA% for test data of multi-temporal classification of HH (green), HV (red), and HH&HV (blue) CSK data as a function of the number of images (from 1 to 8).

than the co-polarized one. Summarizing, OA values ranged from 55% (only 1 co-polarized image) to 82.5% (8 dual-polarized images). Fig. 2 shows the classification map of the Yanco site derived from the entire time series of 8 dual-polarized CSK images. As can be seen, pasture is by far the most dominant class covering 55.4% of the entire area, whereas the percentage of cereals (including wheat, barley and oats) cultivated area is 10.4%. The other crops cover smaller areas.

The land use map produced was then used as ancillary information in the SMOSAR-X algorithm, which was applied to the time series of the last 4-images in Table 1. This is because in this period (i.e. from January 21st to February 14th) a significant part of the site is either bare (e.g. harvested cereals) or covered by generally very dry grass (e.g. pasture fields). Therefore the classes not masked out of the SAR images prior to m_v retrieval are bare, wheat and fallow. An example of the m_v maps produced by SMOSAR-X is shown in Fig. 3. The first one (left panel) refers to January 29th, while the second (right panel) to February 6th, i.e. the day after the strong precipitation event reported in Fig. 4, which shows the precipitation events recorded by 5 ground stations. The change of m_v level between the two dates is evident in Fig. 3. A quantitative assessment of the SMOSAR-X derived maps was carried out based on the measurements recorded simultaneously to the 4 SAR acquisitions by the 9 selected ground stations. In total, 32 m_v observations were available as for two dates two stations did not record the data.

The scatter plot in Fig. 5 reports the comparison between retrieved and observed m_v values. The parameters of a linear fit as well as the coefficient of determination, R^2=0.69, are also reported. The total rms error is 6.6% v/v, however, eliminating two outliers, highlighted in red in Fig. 5, the rmse drops to 5.7% v/v. This result is in good agreement with what was found by using SMOSAR-X over the Foggia site (Italy) [10].

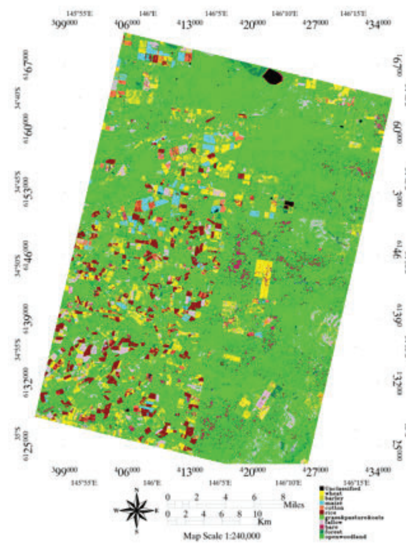

Fig. 2. Classification map of the Yanco site derived from 8 multi-temporal CSK Strip Map dual polarized images.

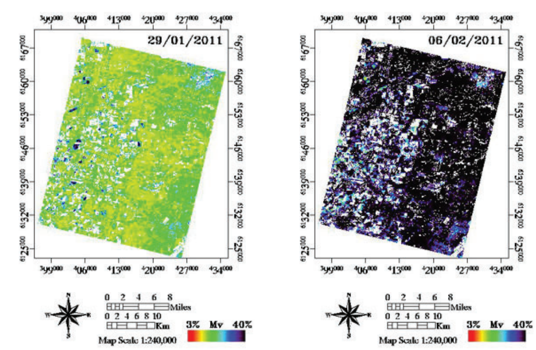

Fig. 3: Soil moisture maps derived by CSK HH images acquired over Yanco on 29/01/2011 (left panel) and 06/02/2011 (right panel).

5. CONCLUSIONS

A time series of CSK SAR images has been used to investigate the potential of X-band SAR data for land cover classification and m_v retrieval. To that end 11 CSK SAR images, acquired at StripMap Ping Pong mode from early November 2010 to mid-February 2011 over the Yanco agricultural area (Southern Australia), were used. The Yanco site has been intensively surveyed during the SMAPEx-2 campaign, when near-surface (0-5cm) m_v and land use information over six experimental farms were collected. A supervised Maximum Likelihood (ML) algorithm was adopted for deriving the land cover map of the area. The influence of using an increasing number of images and

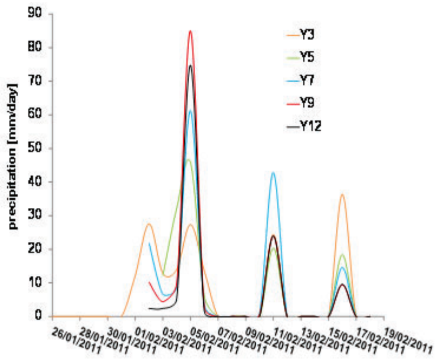

Fig. 4. Precipitation events recoded by the ground stations Y3, Y5, Y7, Y9 and Y12 over the Yanco site between late January and mid February 2011.

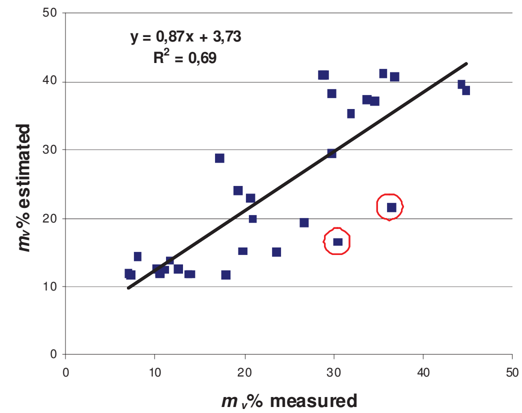

Fig. 5: Scatter plot of the measured and retrieved $\boldsymbol{m_v}$ over the Yanco study area.

single or dual polarization was investigated. Results indicated that double polarization (i.e. HH & HV) images provided more accurate classification than the single polarization, either HH or HV, achieving an OA of 82.5% by using 8 images for the classification of 10 classes. However, when only a single channel classification was considered, HV usually performed better than HH (OA of 73% and 69%, respectively, by using 8 images).

The classification map was then used to select, on the SAR images, the bare or sparsely vegetated areas over which the SMOSAR-X algorithm was run to retrieve a time-series of m_v maps. The analysis of the retrieved values confirms a good sensitivity of X-band data to m_v changes and points to a retrieval accuracy of 6.6% v/v, evaluated over 32 observations.

Future work will be dedicated to further assess the SMOSAR-X performance by extending the analysis to longer time series of CSK data acquired over the Yanco area from late July to October 2011 during the SMAPEx-3 campaign.

6. ACKNOWLEDGEMENT

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