COSMO-SkyMed® imagery for crops characterization

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Abstract. This paper shows some preliminary results on the exploitation of COSMO-SkyMed® (CSK®) data for the characterization of agricultural fields. In particular, we analyze the impact of the planting row direction on the radar backscattering response. We considered two different crop types, namely carrots and potatoes, and we grouped them in two subsets, the first including fields with row direction roughly perpendicular to the Synthetic Aperture Radar (SAR) Look Direction (LD) and the second including fields with row direction parallel to the SAR LD. A multi-temporal analysis of the CSK® backscattering coefficients for this two different sensor-target acquisition geometries, at three different incidence angles and at VV, HH, VH polarization are presented. Moreover, the influence of the row direction on the retrieval of the Normalized Difference Vegetation Index (NDVI) was investigated. The preliminary results show that CSK® at VH polarization is sensitive to crop biomass independently of the sensor incidence angle and rows direction of the crops fields. On the contrary, the backscattering coefficients at HH and VV polarization are sensitive only when the sensor incidence angle is parallel to crops rows.

Keywords. COSMO-SkyMed, SAR, X-Band, Potatoes, Carrots, Vegetation, Agriculture, NDVI, LAI, planting row direction.

1. Introduction

The characterization of crop type and parameters through remotely sensed data is gaining more and more attention in the agricultural practice, for instance in water resource management, crop type identification and crop intensity.

Operative monitoring is mostly based on high spatial resolution (5-30 m pixel size) and on passive sensors operating in the optical domain. Using red and near-infrared observations, the Normalized Difference Vegetation Index (NDVI) has been widely used due to its strong relationship with Leaf Area Index (LAI) and Crop Biomass (CB).

These indices can be strongly influenced by cloud cover and weather condition. For this reasons sensors operating in the microwave spectrum have been exploited for their capability of acquiring during day and night and in all the weather conditions.

The interest of the scientific community to understand the scattering mechanisms in agricultural fields at different polarizations, along with numerous campaign for the collection of ground truth data and the development of scattering models, has allowed to better characterize the phenomenon. Focusing on the X-band, several studies have been carried out in order to investigate the capability of SAR sensors to correctly identify different vegetation types and biomass parameters [1]. © EARSeL and University of Warsaw, 2014, ISBN 978-83-63245-65-8, DOI: 10.12760/03-2014-17, Zagajewski B., Kycko M., Reuter R. (eds.)
or to monitor the crop phenological behavior (e.g. sugarcane) and to predict the harvest time [2] or to investigate the influence of the crop biomass and soil moisture on the X-band backscatter [3].

Studies investigating the influence of crop rows geometry on radar response are scarce [4], [5], [6], [7]. Moreover, few analyses have been carried out using X-band over potatoes fields [9] and none over carrots [8]. Within this context, to better characterize the scattering mechanism of different agricultural fields, the main research questions addressed in this paper are:

1. How does COSMO-SkyMed® respond to different crop types and crop phenological stages?
2. Which is the best combination of incidence angles and polarizations for biomass estimation of different crop types?
3. More in detail, is the direction of the field rows a parameter to take into account for the crop biomass estimation?

The objective of this work is to provide some explanations to the above stated questions, investigating two different crop species: carrot and potato.

2. Study Area and Data Used

2.1. Test Site description

The test site is situated in the "Marchfeld Region" in Lower Austria (Lat. 48.20°N, long. 16.72°E). About 65,000 ha of the area in Marchfeld are used for agricultural production (Figure 1). The main crops are vegetables (11%), sugar beet (10%) and potato (7%). The region is characterized by a semi-arid climate with an average annual precipitation of 500-550 mm that can drop to 300 mm making it the driest region of Austria. Precipitation during the growing season (April-September) is around 200-440 mm.

![Marchfeld Area](image)

Figure 1: Marchfeld Area, one of the major crop production areas of Lower Austria with more than 40,000 ha of irrigated land.
2.2. COSMO-SkyMed® image data set

Twenty-three COSMO-SkyMed® (X-band - 9.65 GHz) images, level 1-D GTC (i.e. Geo-Coded and Terrain Corrected) have been acquired and used for this analysis.

The data set is composed of:

1) A time series of 11 Stripmap PingPong (i.e. dual polarization VV-VH) images acquired at around 23° incidence angle (CSK® beam “PP-0B” Near range 21.85° far range 24.90°), 6 in right ascending (RA) (acquisition time: 04:30 a.m.) and 5 right descending (RD) (acquisition time: 5:05 p.m.) acquisition geometry. This acquisition mode has a ground spatial resolution of around 15 m. The series starts on the 23rd July and ends on the 31st August.

2) A time series of 8 Stripmap PingPong (i.e. dual pol. VV-VH) images acquired at 32° incidence angle (CSK® beam “PP-05” Near range 31.5° Far range 34.01°) in right ascending geometry (acquisition time: 04:20 a.m.). The time series starts on the 22nd June and ends on the 25th August.

3) A time series of 4 Stripmap Himage (single pol. HH) images, acquired at 40° looking angle (CSK® beam “4-9” Near range 38.3° Far range 41.5°), in right descending geometry (acquisition time: 5:05 p.m.). The series starts on the 13th July and ends on the 30th August.

Precipitation events were acquired on 15-min basis from rain gauges located in the study area. A detailed analysis was done to evaluate the cumulative precipitation before the scheduled SAR acquisition. The acquisition plan along with the precipitation events is presented in Figure 2.

![Figure 2: Analyzed CSK® time series over Marchfeld area (bottom) and precipitation measurement (top). The red “X” symbol indicates that the images have been excluded due to precipitation events that have affected the CSK® acquisition](image)

SAR data acquired up to 24 hours after any precipitation event have been excluded from this analysis. The final analyzed dataset is then composed of 19 scenes.

2.3. **NDVI maps**

NDVI was calculated using a time series of 8 multispectral images acquired from DEIMOS-1 (seven images) and Landsat-8 (one image) satellites.

The DEIMOS-1 records surface reflectance in the green, red and near-infrared parts of the electromagnetic spectrum with a ground resolution of 22 m. The Landsat-8 acquires in 9 spectral bands with a ground resolution of 30 m.

Both dataset were orthorectified and atmospherically corrected by using ATCOR-2 [10]. After the radiometric and atmospheric calibration, the NDVI value was calculated for each image.

2.4. **Land Use Maps**

A supervised image classification for the most relevant crops in the region was achieved with the machine learning Random Forest (RF) algorithm. The input data to the classification consisted of multi-temporal Leaf Area Index (LAI) maps derived from multi-spectral satellite acquisitions. The classification scheme included the main crop types present in the region with eight crop specific classes for summer crops, one class for winter crops (including wheat and barley) and an additional class including “other crops”. The latest was necessary to include crops with a limited number of reference points. The result is a land use map with 10 different classes.

3. **Methods**

3.1. **Data pre-processing**

From the land use map, ten carrots and ten potatoes fields have been selected based on their size (larger than 30 pixels) and digitalized considering an inner buffer of 1 pixel.

COSMO-SkyMed® images were calibrated following the procedure described by the data distributor e-geos [11].

The CSK® calibrated images and the NDVI maps from Landsat-8 and DEIMOS-1 were stacked and the pixel values were extracted according to the field boundaries. Finally, the mean backscatter ($\sigma_0$) values and the mean NDVI values over the identified fields were computed.

The NDVI and CSK® acquisition data were not coincident. For this reasons, in order to compare the backscattering coefficients with the NDVI values, these latter were extrapolated by using a linear function between two contiguous NDVI acquisitions at each of the CSK® passing time.

3.2. **Data sub-setting**

Considering the traditional agricultural practices and after visually checking past Google Maps images, it was assumed that the crops rows direction were aligned with the major axes of the fields. The azimuth difference between the SAR LD and the field major axes has been analyzed to select the fields that are approximately parallel or perpendicular to the SAR looking direction. The azimuth angle differences between 75°-105° and 255°-285° have been considered “parallel” and the values between 345°-15° and 165°-195° have been considered “perpendicular” to the SAR LD (Figure 3).
Figure 3: Range of angles in parallel (Grey) and perpendicular (blue) configurations

The correlation matrix of the NDVI temporal signature of all fields of the same plant species was analyzed to select fields with similar growing patterns. Only those fields with the same rows direction and high values of NDVI correlation were further analyzed. The results of this selection are shown in Table 1.

**Table 1** Resume of the field involved in the parallel (∥) or perpendicular (┴) analysis respect at the look direction of SAR sensor and NDVI phenological phase.

<table>
<thead>
<tr>
<th></th>
<th>Himage 40° RD</th>
<th>PingPong 23° RA</th>
<th>PingPong 23° RD</th>
<th>PingPong 33° RA</th>
</tr>
</thead>
<tbody>
<tr>
<td>∥ Carrot</td>
<td>ID1-ID7</td>
<td>ID1-ID7</td>
<td>ID1-ID7</td>
<td>ID1-ID7</td>
</tr>
<tr>
<td>Carrot</td>
<td>ID2, ID6, ID8</td>
<td>ID2, ID6, ID8</td>
<td>ID2, ID6, ID8</td>
<td></td>
</tr>
<tr>
<td>⊥ Potato</td>
<td>ID86-ID103</td>
<td>ID86-ID103</td>
<td></td>
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</tbody>
</table>

The geographical dislocation of the selected carrot and potato fields along with the CSK® azimuth orbit directions is sketched in Figure 4.

Figure 4: Selected carrot (orange) and potato (cyan) fields. The white arrows are the SAR look directions of the different CSK® orbits (blue arrows)
4. Results

4.1. Temporal analysis for the carrot fields – the perpendicular configuration case

Figure 5 shows the precipitation events, the NDVI and backscatter temporal signatures. The NDVI temporal trend varies from 0.2 to 0.9 and leads us to suppose that we are observing the phase between leaf development and the complete expansion of the roots [12]. The HH and VV polarizations show different behaviors in each of the three fields. In the VH polarization, instead, a similar increasing trend is shown in the fields ID2, and ID6, while the ID 8 shows a horizontal trend. This different behavior is probably due to the horizontal profile reached by the NDVI in field ID8 earlier compared to the other fields. In the ID2 field, the NDVI starts at the value of -0.35 and ends at the value of -0.9, the backscattering consequently grows from the value of -24.7 dB to -17.2 dB. In the ID6, the NDVI start at -0.25 and end at the value -0.8 the backscattering have a range from -28.6 dB to -18.2 dB. The ID8 starts at -0.35 and reaches the value -0.9 faster than ID2 and ID6, the backscatter response has a range from -19.3 dB to -18.8 dB.

![Figure 5: NDVI_{mean} and σ_{0,mean} (dB) vs. DOY for carrots fields (ID 2, ID6 and ID8)](image)

4.2. Temporal analysis for the carrot fields – the parallel configuration case

As shown in Figure 6, the NDVI temporal trend for both ID1 and ID7 shows a similar temporal shape as the perpendicular case but the lower value grows from 0.2 to 0.5. So we are not observing the initial phase of leaf development, but the leaves have already started growing.

The HH and VV polarizations, acquired at 40°, 23° and 33° of incidence angle, show a similar temporal trend in both fields. The same happens for VH polarization acquired at 23° and 33° of in-
occurrence angle: the shape of temporal profile is very similar in the two fields. The VV and VH polarizations instead have similar pattern for both incidence angle.

**Figure 6**: NDVI_{mean} and $\sigma_{\text{mean}}$ (dB) vs. DOY for carrots fields (ID1 and ID7)

### 4.2.1. Carrot Backscatter vs NDVI

The comparison between the backscattering $\sigma_0$ (dB) and the NDVI for both parallel and perpendicular configurations is shown in Figure 7. The first column shows the perpendicular geometry. As we can see, the VV and HH polarizations do not show any correlation between $\sigma_0$ (dB) and NDVI. In fact, the correlation coefficient is equal to 0.03 for HH and 0.11 for VV polarizations. The VH polarization, instead, shows good correlation with the NDVI ($r = 0.87$).

The relation between $\sigma_0$ (dB) and NDVI values in the parallel geometry, shows a good correlation in all acquisitions (second and third column of Figure 7).

For the polarizations VV and VH the correlation value grows when passing from 23° to 33° of incidence angle. The HH polarization, acquired at 40° of incidence angle, shows the highest correlation (0.94) value between $\sigma_0$ (dB) and NDVI.

4.3. Potato analysis

Potato fields are identified with the ID 86 and ID 103 (Figure 4) and have row directions that are perpendicular to SAR LD.

NDVI and $\sigma_0$ (dB) temporal trends for polarizations VV, VH and HH have been investigated for each field (Figure 8).

The NDVI temporal trends show for both fields decreasing values of NDVI (from 0.9 to 0.6-0.7) during the acquisition period (day of the year – DOY 194-243). We are observing the period between high leaf cover and the beginning of senescence. It is during the senescence phase that the tubers reach the maximum mass [13]. What we can see in figure 8 is that for HH, VV, VH the $\sigma_0$ (dB) temporal trend shows a horizontal profile, and this is independent of the incident angle. HH polarization is acquired at 40° of incidence angle, instead VV and VH at 23°.

A previous study on backscattering characterization at X-band for potatoes has been conducted by Bouman et al [9]. This study showed that when the vegetation cover reaches the 80%, the backscattering temporal signature converges to a similar flat trend at incidence angles between 20° and 40°.

VV and HH polarizations show similar trends and similar backscattering value range despite the different incidence angles (40° for HH and 23° for VV) and different spatial resolutions (3 m for HH and 15 m for VV). The VH backscatter follows the similar pattern of VV polarization but, as expected, with lower $\sigma_0$ (dB) values.
Figure 8: NDVI_{mean} and \(\sigma_{0,\text{mean}}\) (dB) vs. DOY for potato fields (ID86 and ID103)

5. Conclusions

In this paper, a characterization of two crop species was carried out by using a multi-temporal series of CSK\textsuperscript{®} and NDVI data. Based on our research questions, we can conclude that:

1- As we have seen, the two different crop species respond differently to X-Band SAR signal. In particular: the backscattering of carrot correlates well with NDVI for a wide range of NDVI values. On the contrary, the \(\sigma_{0}\) (dB) of potato fields is not sensitive to NDVI for NDVI values greater than 0.7.

2- The best combination of incidence angles and polarizations for NDVI estimation was analyzed for carrots only. VH polarization is high sensitive to NDVI independently of inclination angle and rows direction. HH and VV polarization seem to be sensitive to NDVI only when the SAR LD is parallel to crop rows. In this latter case, higher incidence angles seem to be preferable to lower ones.

3- Results show that the row direction has an influence on the SAR response. As expected, we found that SAR looking parallel to crop rows is better correlated to NDVI compared to perpendicular observations. This is probably due to the effect of roughness. In case of SAR looking parallel to row direction the roughness effect is minimized thus enhancing the correlation with NDVI. The opposite happens in the SAR looking perpendicular to row direction.

Further experiments will be carried out to improve our knowledge on the response in parallel and perpendicular configuration for potato and carrot species including also other crop types. The high revisit time offered by CSK\textsuperscript{®} is a crucial characteristic of the system for such study. The analysis will be extended to the entire growing season and a multi-polarized and multi-angular dataset will be the key for an extensive investigation.

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References


