# Mountain crop monitoring with multitemporal Sentinel-1 and Sentinel-2 imagery

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***Abstract*—An analysis of radar signal sensitivity to crop and soil conditions was conducted using a time series of Sentinel-1 C-band dual-polarized (VH-VV) SAR images acquired from October 2014 to September 2016 for different crops (meadows, pasture, orchard, vineyards) located in mountain areas. Together with Sentinel-1 images, corresponding Sentinel-2 images and ground measurements were exploited. Preliminary results showed that the cross-polarized VH backscattering coefficients were useful for monitoring crop phenology. In particularly for meadows the VH signal is well correlated with NDVI derived from both Sentinel-2 images and from ground observations.**

***Keywords—Sentinel-1; Sentinel-2; crops; time series; phenology; mountain areas***

## I. Introduction

Satellite imagery plays a unique and important role in monitoring crop and soil conditions for farm management [1]. In the past years, most studies of satellite imagery for crop monitoring have focused on the use of optical imagery exploiting the reflectance of visible and NIR radiation and the emittance of thermal IR radiation to map canopy characteristics over large areas [2]. Clouds and their shadows compromise significantly data in the optical domain, causing inaccuracy of atmospheric correction and bias in vegetation indexes.

Microwave wavelengths have some important advantages over optical remote sensing for agricultural applications being able to pass through the atmosphere and clouds with negligible attenuation. This allows frequent repeat measurements over the short and dynamic growing season of crops. The Sentinel-1A and -1B satellites with a revisiting time of six days offer an unprecedented opportunity to monitor crops.

On the other side, the radar signal can be of difficult interpretation as the total radar backscatter is a complex sum of the backscatter from vegetation and soil, where the radar beam can penetrate both the canopy and soil to a difficult-to-determine depth, making it complicated to determine if the signal is dominated by the crop or soil conditions. Reliable ground measurements of crop growth stage and daily irrigation and precipitation (and/or soil moisture) throughout the growing season are therefore important to understand the influence of these factors. Additionally, in order to understand the SAR signal behavior in correspondence to crops, dense time series are necessary. Some studies have already shown the capability to detect with SAR time series both crop phenology and parameters [3]. Relevant results were also found related to the use of different polarizations. The different attenuation of $\sigma_{VV}$ and $\sigma_{HH}$ is useful for discriminating crops, while the cross-polarized channel with a higher dynamic can improve the crop separability. Also for crop stage and parameters, the cross-polarized channel reports a higher contrast between high and low productivities [4, 5]. The trends in radar backscatter measured on different dates can be correlated with soil moisture content since the effects of spatial roughness variations are smoothed [6]. To reduce these factors, Balenzano et al. [7] reported that a ratio of backscatter measured on two close successive dates might be a simple and effective way to decouple the effect of vegetation and surface roughness from the effect of soil moisture changes when volumetric scattering by the crop canopy is not dominant.

In this context, this work analyzes time series of the Sentinel-1 (S1) and Sentinel-2 (S2) sensors to understand their variability in relationship to different crop types. The main aim of this work is twofold: i) a better understanding of the multitemporal SAR signal in relation to different crop and soil conditions; ii) the capability to distinguish different types of crops by using multitemporal SAR images.

## II. Study Area and Datasets

### A. Study areas

The study area is the South Tyrol region located in Northern Italy. South Tyrol has an area of 7,400 km$^2$ and a total population of 511,750 inhabitants (31.12.2011). South Tyrol is located in the center of the Alps with steep elevation gradients stretching from 190 – 3890 m a.s.l. and is characterized by the typical sensitivities and dynamics of mountain regions. Typical crops of this area are meadows, orchards and vineyards. Moreover, around 44% or 3228 km$^2$ of South Tyrol are covered by forest. Figure 1 shows the area of study as an RGB composition of S1 images.

### B. Datasets

The analyzed data sets are composed of 59 S1 images from October 2014 to September 2016. The data belongs to track 168 which covers the region almost entirely. The 78 S2 images span from June 2015 to November 2016 and cover the tile 32TPS. Together with satellites images, ground data were available for meadows and pasture areas. Most of the stations are equipped

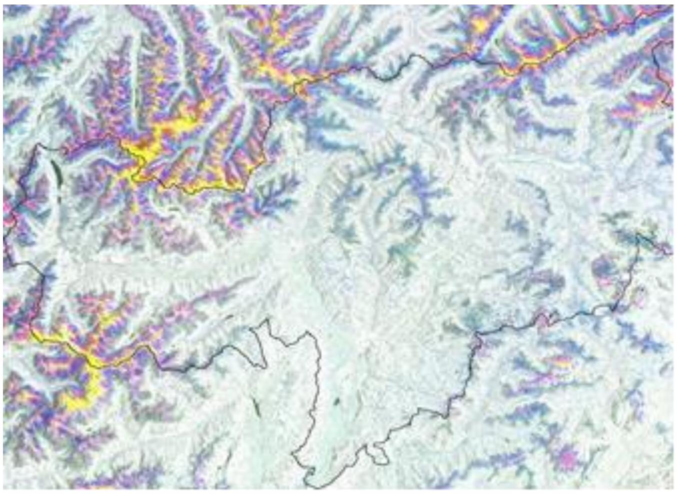

Fig.1 South Tyrol area overlaid on RBG image composition from S1-VH channel (R: 05-03-2016, G: 05-15-2016, B: 07-14-2016).

with sensors to provide information on soil water content (SWC), soil temperature (ST), and NDVI. The data are acquired since 2015 with a time step of 15 min. SWC is available at different depths from 2 to 20 cm.

## III. METHODOLOGY

### *A. Preprocessing of S1 and S2 images*

The S1 data preprocessing encompasses a number of standard steps in order to derive geocoded intensity images starting from the ground range detected (GRD) data. These operations were performed using the tools provided by SNAP (Sentinel Application Platform**)** and custom algorithms developed in Python. Beside the standard operations a spatial and temporal speckle filter was used [5]. The S2 images were preprocessed using the Sen2Cor processor (v.2.3) without cirrus or topographic correction. All non-vegetated areas where masked using the CORINE 2012 land cover information.

### *B. Processing of data for time series analysis*

In this preliminary analysis, S1 backscattering coefficients in VV and VH polarization were extracted over different crops and land-cover. A stack of images have been created and considering a most recent land-cover map of the area (LISS2013), several regions of interest (around 10 for each land cover type) have been extracted for the following land cover classes: meadows, pasture, orchard, vineyard, and forest. Forest has been also considered for sake of comparison with the crops. The size of each area of interest was selected as a compromise between homogeneity of the area and the number of pixels.

S1 backscattering coefficients time series were compared with NDVI extracted from S2 data and with available ground data. In the case of comparison with point data, the area of interest were extracted close to the station and considering homogeneous areas.

Both S1 and S2 data were masked to eliminate layover/ shadow zones and to reduce the contamination due to cloud presence based on the Sen2Cor scene classification, respectively.

### *C. Scattering models*

To understand the impact of the different parameters (soil and vegetation) on the SAR signal, some scattering simulations were carried out. The total scattering from vegetated soils was simulated by using the Water Cloud Model (WCM) [9]:

$$\sigma^0_{pq,tot} = \frac{A\cos(\theta)}{2bNDVI}\left(1-\exp\left(-2bNDVIsec(\theta)\right)\right) + \sigma^0_{pq,b}\exp\left(-2bNDVIsec(\theta)\right)$$

where the dependence on the vegetation is expressed through *NDVI* as a proxy of vegetation water content; $\theta$ is the local incidence angle, $\sigma^0_{pq,b}$ is the scattering from bare soil that for the VH polarization was simulated with the Oh model [10]. *A* and *b* are parameters for crop type and were fitted against ground data.

## IV. PRELIMINARY RESULTS

Trends in VH and VV were analyzed for the different land-cover classes. The highest $\sigma_o$ values in both polarizations were associated with the period in which the crop green biomass generally reaches its maximum. The highest dynamics is associated to meadows, which in this area are strongly managed in terms of fertilization, irrigation, and mowing. The signature of meadows varies between -16dB and -12dB and from -22dB and -17dB for VV and VH polarization respectively (fig.2 and 3). This trend is clearly distinguishable from natural grassland and from the other classes. Natural grassland exhibits higher values in spring due to the higher amounts of precipitation, while the values decrease in summer due to the scarcity of water which was particularly strong in 2015. The trends belonging to vineyards, orchards and forest show similar seasonal trends to meadows and with a higher level of the signal ranging from -12dB to -8 dB and from -17dB to -14dB for VV and VH polarization respectively (fig.2 and 3).

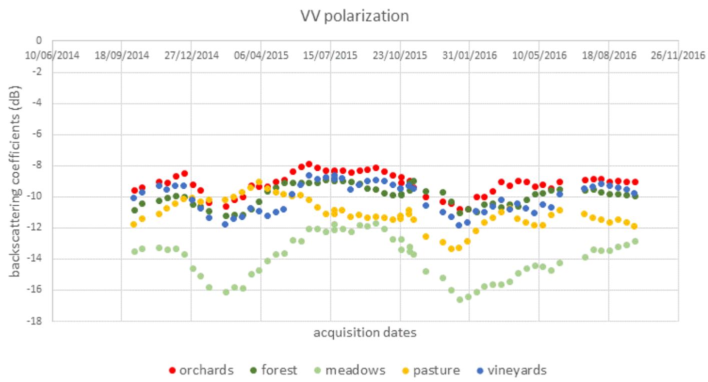


Fig. 2 Trends for S1 VV polarization for different crop types over the areas of interest.

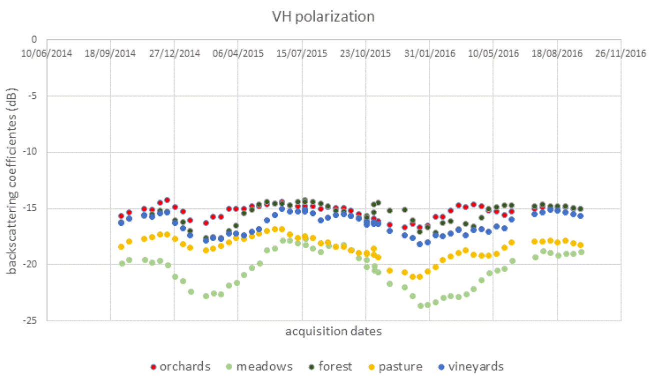


Fig.3. Trends for S1 VH polarization for different crop types over the areas of interest.

Another interesting feature in all different land cover types is the strong positive correlation ($R^2$ from .64 to .92) found between VV and VH polarization for C-band as also reported in other works [11]. This indicates that at C-band both polarization are strongly dominated by vegetation characteristics and may have a limited sensitivity to soil characteristics. Considering the relationship with S2 NDVI, the strongest correlation was found with the meadows where an increase of NDVI is related to an increase of VH channel ($R^2$=.52). This is typically found in other agriculture areas [12].

The relationship between NDVI and backscattering coefficients was compared for some meadow areas with NDVI measured on the ground. This is particularly of interest in order to understand the variability related to the mowing of the grassland and how this can be related to the variability of the SAR signal. For one of the stations, the comparison is shown in fig. 4. The different measurements follow similar dynamics and VH signal decreasing related to mowing is well related to the decrease in the NDVI signals in the time interval between 13 and 20 July 2015. The discrepancy in the dates can be ascribed to several factors. The SAR acquisition time is around 12 days in 2015, so the mowing event can be missed. Moreover, the VH signal represents an area, which may have inside fields with different mowing time. S2 NDVI follows well the ground measurements even though the data present a high variability which may be also ascribed to some remaining cloud contamination.

Considering the relationship with ground measurements, VH signal is well related to NDVI with $R^2$=.81. For this station, measurements of soil water content (SWC) were also available. The VH values show a smooth dependence on SWC with $R^2$=.48 (fig. 5).

For these data, the simulations with the WCM model were carried out considering as input data, SWC and NDVI from ground measurements. The results are shown in fig.6, when the model simulations well capture the variability measured in the VH channel. The RMSE between measured and simulated data is 1.45 dB.

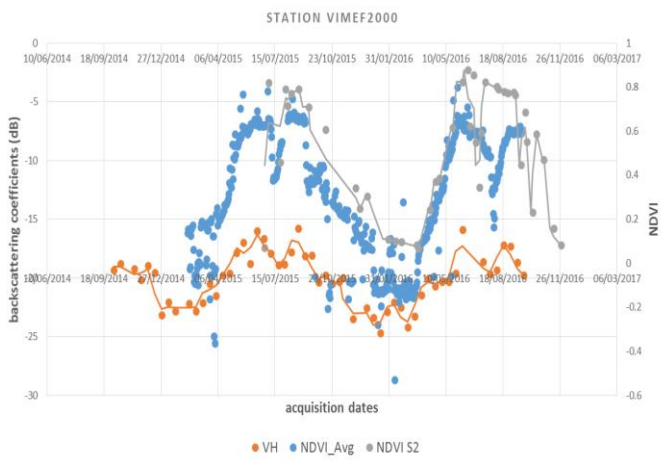


Fig.4 Trends for S1 VH polarization, NDVI from S2 and measured at the ground at station Vimef2000 located in a meadow area at 2000 m altitude.

## V. Conclusions

The multi-temporal SAR signal evaluated in this study enable a detection of phenological dynamics in different land cover types as well as the distinction of different grassland type (pastures and meadows).

S1 backscattering values are also well correlated with S2 data and ground observations. The backscatter model simulations indicate a high sensitivity of the S1 sensor to plant and partially soil conditions.

In the final paper, the analysis will be extended to other areas where ground data are available. Moreover, a case study centered on the Po valley will be exploited in order to address other types of crops.

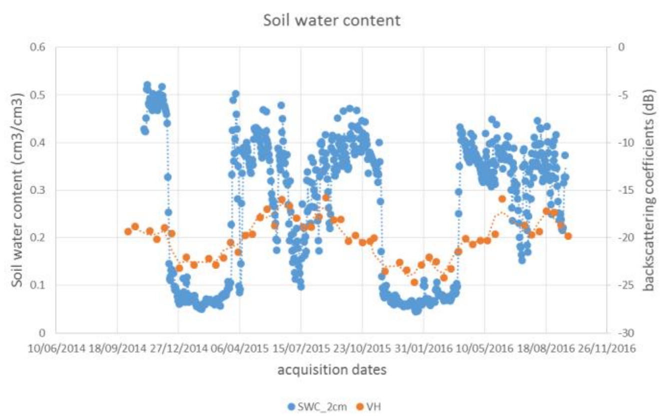


Fig.5 Trends for S1 VH polarization, and SWC derived for the station Vimef2000 located in a meadow area at 2000 m altitude.

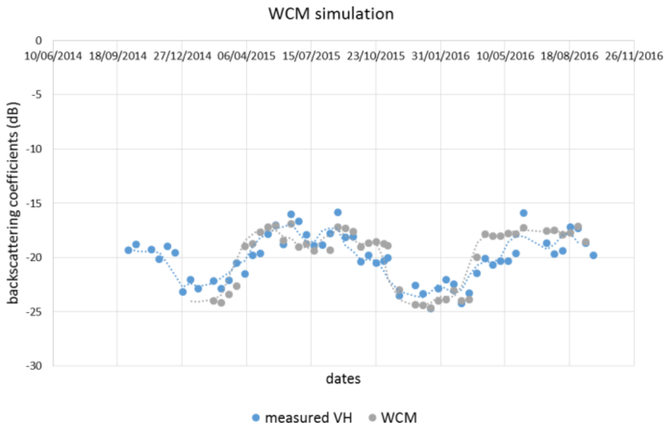


Fig. 6 Comparison between simulated and measured trends for VH polarization for the station Vimef2000 located in meadow area at 2000 m altitude .

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