HydroCosmo: The Monitoring of Hydrological Parameters on Agricultural Areas by using Cosmo-SkyMed Images

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Abstract
In this paper, the results of an experiment carried out for exploiting the capabilities of X-band Cosmo-SkyMed data in the monitoring of soil and vegetation characteristics are summarized. SAR data have been collected in two agricultural areas in Italy and compared with ground truth measurements of soil and vegetation parameters.

A rather good sensitivity to vegetation features, biomass and the moisture of bare or slightly vegetated soils has been confirmed. On bare surfaces the effect of surface roughness was significant, as expected, due to the high observation frequency. Model simulations have also been performed for better explaining the backscattering response to soil moisture at this frequency.

The different backscattering response according to vegetation types, which has already been observed at C-band, has been confirmed at X-band, too. The absorption due to thin vertical stems was observed on wheat crops, whereas sunflower showed a prevalent scattering behavior due to the large circular leaves.

Keywords: COSMO-SkyMed (CSK), backscattering at X-band, vegetation biomass, soil moisture, plant water content.

Introduction
Experimental and theoretical investigations carried out worldwide by many scientists have shown that microwave backscattering from land surfaces is sensitive to soil and vegetation features [e.g. Ulaby et al., 1986; Ferrazzoli et al., 1992; Wickel and Jackson, 2001].

The availability of a considerable amount of Synthetic Aperture Radar (SAR) data, obtained in recent years from airborne and space-borne systems, has stimulated significant research for interpreting data and investigating their potential in various environmental studies. In particular, the research on microwave remote sensing focused on soil moisture retrieval, forest and crop biomass estimation, and ice and snow pack parameter investigation [e.g.
Kasischke et al., 2009; Balenzano et al., 2011; Paloscia et al., 2013; Pettinato et al., 2013a].

Soil moisture and its temporal and spatial variations are influential parameters in both climatic and hydrologic models. The measurement of soil moisture content (SMC) is one of the most important targets of remote sensing, and significant amount of experimental and theoretical studies have been carried out since the late 1970s. Soil dielectric constant at microwave frequencies exhibits a strong dependence on the soil’s moisture content. At L-band, for example, the real part of the dielectric constant ranges from 3 for dry soil to about 25 for saturated soil. This variation can result in a change on the order of 10 dB in the magnitude of the radar backscatter coefficient [Oh et al., 1992] and of 100 K in the magnitude of the brightness temperature [Ulaby et al., 1986]. An important component required in the soil moisture inverse problem is the knowledge of the relationship between the soil dielectric constant to its moisture content. Accurate empirical models and measurements for soil dielectric constant are given in [Dobson et al., 1985; Peplinsky et al., 1995].

The large amount of SAR data collected in different times made it possible to evaluate the potential of multi-temporal analysis in timing critical phases of the crop growth cycle and in separating broad-leaf crops from cereals (small leaf). The radar response to biomass of these two types of crops showed that for crops characterized by small plant constituents such as wheat (narrow-leaf crops), the backscattering coefficient ($\sigma^o$) decreased as the biomass increased, whereas the trend was quite the opposite in plants with bigger leaves and stems such as sunflowers (broad-leaf crops) [Paloscia et al., 1999; Macelloni et al., 2001]. Model simulations confirmed the trends of the experimental data and made it possible to evaluate the contribution of single plant constituents to total backscattering [Yueh et al., 1992]. In “broad leaf” crops, $\sigma^o$ from stalks dominated at L-band, whilst, at C-band, leaves made a significant contribution to scattering and attenuated the contribution of stems. In “narrow leaf” crops, the contributions of leaves and stalks were comparable and close to total backscattering. The analysis of the contributions of each scattering mechanism showed that, in general, double scattering was the most important contribution for stalks, direct scattering prevailed for leaves, and soil contribution was appreciable even for well-developed crops [Stiles and Sarabandi, 1996].

The dielectric characteristics of vegetation material are, in fact, strongly influenced by moisture content over a wide range of the microwave spectrum. In addition, geometrical features of plant constituents affect scattering in a different manner, according to frequency and polarization.

Previous research has pointed out that for each land parameter, there is an appropriate combination of frequencies, polarizations, and incidence angles most suitable for obtaining its best retrieval. In particular, vegetation biomass is better identified at a high incidence angle and HV polarization, whereas soil moisture is well retrieved at HH polarization and at steeper incidence angles [e.g. Bentamy et al., 1994; Zribi et al., 2007; Van Doninck et al., 2012]. On the other hand, most applications require estimates of the global parameters that are useful for agricultural yield prediction and management, such as leaf area index and plant water content. Thus, several studies have been addressed to establishing direct relations (theoretical and experimental) between remote sensing measurements and the above-mentioned global parameters that characterize vegetation growth [e.g. Ulaby et al.,}
1986; Ferrazzoli et al., 1994, 1997; Wickel and Jackson, 2001; Mattia et al., 2003]. So far, most research in this field has been focused on the use of L- and C-band satellite SAR put in orbit by the international and national space agencies (European Space Agency, ESA, Japanese Aerospace Exploration Agency, JAXA, and National Aeronautics and Space Administration, NASA). With the advent of the recent TerraSAR-X and COSMO-SkyMed (CSK) missions much interest has been addressed in evaluating the potential of X-band in the various land applications [Baghdadi et al., 2004; Paris-Anguela et al., 2008].

A significant project, supported by the Italian Space Agency (ASI), for exploiting the capabilities of X-band SAR of the CSK mission in monitoring soil moisture, vegetation biomass and snow cover parameters was carried out in Italy. The project was named “HydroCosmo” and its objective was the development and validation of advanced algorithms for the retrieval of land hydrological parameters (namely, soil moisture and surface roughness, vegetation cover and biomass of forests and crops, snow cover area and wetness) from X-band CSK data.

In this paper, we will be describing the results obtained analyzing CSK data collected on two agricultural areas: one in the North-West (Scrivia watershed) and one close to Florence (Sesto). On both sites the performances of X-band data have been compared with ground data gathered with conventional methods, almost simultaneously to satellite passes. A sensitivity analysis of X-band backscattering to soil moisture and vegetation biomass was carried out by using the available CSK images. Experimental data have also been compared with model simulations obtained with the Advanced Integral Equation Model (AIEM) [Fung, 1994; Wu and Chen, 2004] and with a discrete element radiative transfer model [Macelloni et al., 2001; Santi et al., 2012].

The Cosmo-SkyMed (CSK) mission

COSMO/SkyMed (CONstellation of small Satellites for Mediterranean basin Observation, CSK) is a project of the Italian Space Agency (ASI) and Italian Ministry of Defense (MoD), and it is conceived as a Dual-Use (Civilian and Defence) end-to-end Earth Observation System aimed to establish a global service supplying provision of data, products and services compliant with well-established international standards and relevant to a wide range of applications, such as Risk Management, Scientific and Commercial Applications and Defence/Intelligence Applications [Covello et al., 2009].

The system consists of a constellation of four Low Earth Orbit (LEO) mid-sized satellites, each equipped with a multimode high-resolution SAR operating at X-band orbiting in a sun-synchronous orbit at ~620km height over the Earth surface. The System has the capability to change attitude in order to acquire images at both right and left side of the satellite ground track and it will deliver information in several operational modes. With that launch of the last satellite in the last autumn, all the four radars are now in orbit to observe the Earth surface in single or double polarization and in a quite large range of incident angles. Indeed, the nominal range 25°~50° can be extended to 20°~59.5° with left & right side looking capability. Due to these features the system has a multiple imaging chance to the same area in a very short time. Thus, there is a possibility of estimating land surface parameters by multi-angle observations. Apart from the contributions made in the preparation of these missions, the microwave remote sensing community has been deeply involved in improving the knowledge in the
field by analyzing experimental data collected from satellite, airborne and ground based sensors, and is engaged in developing more advanced forward models and inversion algorithms. Within the frame of this mission, ASI supported the HydroCosmo-1720 project for the development of advanced methods for the retrieval of land hydrological parameters from SAR images.

**The experimental results**  
The experiments planned for this study were carried out on two agricultural sites:  
1. The Scrivia watershed is an agricultural area close to Alessandria, in northern Italy (central coordinates: 45° N°- 8.50 E). It is a flat alluvial plain measuring about 300 Km² and situated close to the confluence of the Scrivia and Po rivers. This area is characterized by large, homogeneous agricultural fields of wheat, alfalfa, corn, and potatoes;  
2. The “Sesto” site is a relatively small area (about 1000 ha) close to Florence, which includes a few large fields of sorghum, sunflower, colza and wheat (central coordinates: 43.81 N, 11.20 E).

CSK images were collected on “Scrivia” in 2010 at different dates, during the vegetation cycle. The CSK images selected on these two areas are listed in Table 1 and 2, along with the agricultural field conditions. Intensive observations starting from the sowing have been planned on “Sesto” site during the winter-summer 2011. In all cases, satellite observations have been supported by accurate ground truth measurements of soil and vegetation carried out with conventional methods as close as possible to satellite overpasses.

![Table 1 - Description of agricultural field conditions during the experimental campaigns on Scrivia and corresponding CSK SAR images acquired on the area. PP= Pingpong images.](image)

| Dates of the Exp. Campaigns | COSMO-SkyMed | Incidence angle (θ, deg) | Crop conditions |
|-----------------------------|--------------|-------------------------|-----------------|
|                             |              |                         | Wheat | Corn |
| **09/04/2010**              | 11/04/2010   | 23.42                   | Stem elongation, flag leaf blade all visible | Bare soil |
|                             | PP HH/HV     |                         |       |      |
| **12/05/2010**              | 12/05/2010   | 23.42                   | Start of flowering | Germination, cotyledons emerge through soil surface |
|                             | PP HH/HV     |                         |       |      |
| **23/07/2010**              | 19/07/2010   | 38.82                   | Stubbles | Fruit development, nearly all kernels have reached final size |
|                             | PP HH/HV     |                         |       |      |
| **27/09/2010**              | 28/09/2010   | 38.82                   | Ploughed soil | Senescence, Stubbles or ploughed soils |
Table 2 - Description of agricultural field conditions during the experimental campaigns on Sesto and corresponding CSK SAR images acquired on the area (only campaigns carried out at the same time of CSK images are reported). HMG=Himage, PP= PingPong images.

| Dates of the Exp. Campaigns | COSMO-SkyMed | Incidence angle (θ, deg) | Crop conditions |
|-----------------------------|--------------|--------------------------|-----------------|
|                             |              |                          | Wheat | Colza | Sunflower |
| 18/02/2011 + 22/02/2011 + 25/02/2011 | 14/02/2011 HMG HH | 26.55 | End of the leaf development and starting of the first tiller | First side shoot visible | Bare soil |
|                             | 15/02/2011 PP VV/VH | 34.97 | | | Bare soil |
|                             | 15/02/2011 HMG VV | 37.02 | | | Bare soil |
| 11/03/2011 + 15/3/2011 | 18/03/2011 HMG HH | 26.55 | Leaf development or tillering | Inflorescence, first flower petals visible; flowers still closed | Bare soil |
| 01/04/2011 + 08/04/2011 | 04/04/2011 PP VV/VH | 34.8 | Tillering, 3 tillers detectable | Full flowering | Bare soil |
| 21/04/2011 | 19/04/2011 HMG HH | 26.55 | Stem elongation, flag leaf blade all visible | End of flowering or beginning of the fruiting phase | Bare soil |
| 03/05/2011 + 07/05/2011 | 07/05/2011 HMG HH | 34.8 | Middle of heading: half of inflorescence emerged | Fruiting, nearly all pods have reached final size | Bare soil |
| 30/05/2011 | 02/06/2011 HMG HH | 26.55 | Ear development, late milk | Senescence | Bare soil |
| 16/06/2011 | 16/06/2011 HMG HH | 34.8 | Senescence | Senescence | Sprouting, cotyledons completely unfolded |
| 04/07/2011 | 05/07/2011 HMG HH | 26.55 | Stubbles | Stubbles | Stem elongation |
| 02/08/2011 | 04/08/2011 HMG HH | 34.8 | Stubbles / Ploughed | Stubbles | Fruiting, seeds on outer edge of the inflorescence are grey and have reached final size |
| 10/08/2011 | 09/08/2011 HMG VV | 34.8 | Ploughed | Stubbles | Fruiting, seeds on outer edge of the inflorescence are grey and have reached final size |
| 27/09/2011 | 27/09/2011 HMG HH | 34.8 | Ploughed | Ploughed | Ripening |
| 02/09/2011 | 03/09/2011 HMG HH | 34.8 | Ploughed | Ploughed | Ploughed |
| 20/09/2011 | 19/09/2011 HMG HH | 34.8 | Ploughed | Ploughed | Stubbles |
| 27/09/2011 | 27/09/2011 HMG HH | 34.8 | Ploughed | Ploughed | Stubbles |
Concerning vegetation, the following quantities were measured: plant density, stem diameter, number and dimensions of leaves, plant height, plant fresh and dry weight, and plant water content (PWC, in kg/m²). On soils, measurements of moisture (SMC, in %), using Time Domain Reflectometry (TDR) probes, and of surface roughness, by using a needle profilometer, were carried out. At least three-four samples of soil and vegetation per field, according to their dimensions, have usually been gathered, in order to have a representative sampling of the field conditions. These measurements were carried out on a limited number of fields: 37 on Scrivia and 24 on Sesto areas.

Vegetation conditions in the two areas during the observation periods can be summarized as follows: Scrivia - in April, corn was not still sprouted and the soils were bare and rather smooth, whereas wheat was already well-developed, and soil moisture was generally high (SMC>30%); in July, wheat plants were harvested and the soil was stubble-covered, corn was instead well-developed, and SMC<20%; in September, wheat fields were already ploughed (and therefore with high surface roughness), and corn fields were covered by senescent vegetation. The remaining fields were stubbles-covered or ploughed soils. Sesto – in April, wheat was well-developed as well as colza in flowering stage; sunflower was just sprouted, and SMC generally high (SMC>30%); in May, wheat plants had ears and colza was ripening; in July, sunflower fields were flowering, wheat plants were ripe and dry, SMC was low (<20%); in September, fields were generally bare or stubble covered and sunflower was drying. In Table 1 and 2 a synopsis of the vegetation conditions at the time of various CSK overpasses is shown for both sites.

Although the same image configuration was desirable, it was not possible to obtain a series of CSK images with the same orbital parameters (i.e. polarization and incidence angles) due to user conflicts.

**Sensitivity to soil moisture (SMC)**

Several experiments carried out worldwide have demonstrated that C-band backscattering, $\sigma^o$, at HH polarization has a quite good sensitivity to SMC of bare and slightly vegetated soils. At VV polarization the sensitivity is lower, especially on vegetated fields [Paloscia et al., 2008, 2013].

The analysis of the sensitivity of X-band $\sigma^o$ to SMC measured on bare soils characterized by different surface roughness led to the diagram of Figure 1, where data at two different angles (23-26° and 38°) have been identified. Data have been collected on bare soils of both Scrivia and Sesto areas. The obtained regression lines between $\sigma^o$ in HH polarization and SMC are the following:

- $\sigma^o_{HH} = 0.22\text{SMC} - 14.99$ (with $R^2 = 0.70$) at 38° incidence angle;
- $\sigma^o_{HH} = 0.35\text{SMC} - 21.39$ (with $R^2 = 0.42$) at 23-26° incidence angle.

The general regression for the whole dataset (represented by the dashed line in the figure) led, on the other hand, to the following equation:

- $\sigma^o_{HH} = 0.15\text{SMC} - 14.66$ (with $R^2 = 0.5$).

The p-value associated to the latter correlation is <0.05, which means that the correlation is valid, in spite of the rather low number of points. Since data have been collected in two different CSK image modes (i.e. Himage and PingPong), the $\sigma^o_{HH}$ values have been corrected according to the specific differences found between these two modes [Pettinato et al., 2013b]. It can be noted that the two clusters are rather close and both show appreciable
determination coefficients, although with different SMC ranges due to the season of acquisition. Points corresponding to highest SMC are also those characterized by higher surface roughness. In general, data at steeper incidence angles showed a higher sensitivity to SMC, in terms of slope; although this can also be due to the presence of fields with higher surface roughness.

The sensitivity of X-band backscattering in HH polarization to SMC was interpreted by using the Advanced Integral Equation Models (AIEM) [Fung, 1994] and, successively, [Wu and Chen, 2004] on two groups of bare fields characterized by different surface roughness situated on the Scrivia watershed. The results are shown in Figures 2a and b, where measured $\sigma_0$, as a function of SMC, was compared with model simulations. Figure 2a refers to rather smooth bare fields, with Height Standard Deviation (HStD) between 1.4 and 1.7 cm, and Correlation Length (Lc) between 5 and 6 cm, whereas Figure 2b refers to rougher bare soils, characterized by HStD randomly varying between 2.0 and 2.5 cm, and Lc between 6 and 8 cm. The SMC range is different for the two diagrams since data have been acquired in two seasons: spring when fields are usually smoother with generally higher SMC, and summer when fields are usually rougher and SMC is lower.

For each value of SMC, simulations include results obtained by randomly varying the HStD and Lc in the range of values of experimental data and typical of agricultural fields.
Figure 2 - Measured (blue) and simulated (red) X-Band backscattering values at HH pol., $\theta=23^\circ$, as a function of SMC. Simulations include values of surface parameters randomly varying for each value of SMC: a) $HStD= 1.4-1.7$ cm, and $Lc= 5-6$ cm; b) $HStD= 2.0-2.5$ cm, and $Lc= 6-8$ cm.

The sensitivity of measured backscattering to SMC resulted in 0.09 dB/% SMC for the smoother surfaces and 0.12 dB/% SMC for the rougher surfaces. It should be noted that the ranges of SMC of the two surface types are different and that the lower sensitivity for the smoother surfaces can be explained by a saturation trend of backscattering as SMC increases.

**Sensitivity to vegetation**

In previous studies [Paloscia et al., 1999; Macelloni et al., 2001], we have shown that the relation between $\sigma^o$ at C-band and the plant biomass, represented by both leaf area index (LAI, in $m^2/m^2$) or plant water content (PWC, in kg/m$^2$), is influenced by the geometry of plants. In particular, for crops characterized by small plant constituents (narrow-leaf crops), $\sigma^o$ at VV polarization decreases as the biomass increases, whereas the trend is the opposite in plants with bigger leaves and stems (broad-leaf crops). The first type of behavior is
typical of media in which absorption represents the dominant effect, whereas scattering is prevailing with respect to the second crop category. At HH polarization, instead, this trend is much less pronounced [Macelloni et al., 2001] and the effect of soil moisture can be important, even under a vegetated canopy.

These behaviours were confirmed from the analysis of CSK data, as it can be observed in the diagram of Figure 3, which shows the backscattering of CSK, collected at HH and VV polarizations over all the wheat fields of the Scrivia and Sesto sites, in 2010, 2011, and 2012, as a function of the PWC, in kg/m². We can observe a general decreasing trend of backscattering as the plants grow, as already observed at C-band in other experiments, and which is a typical behaviour of narrow-leaf crops at these relatively high frequencies.

The obtained regression equations are the following:

- \( \sigma_{HH}^\circ = -1.58 \ln(\text{PWC}) - 10.63 \) (R\(^2\)=0.6) at HH polarization;
- \( \sigma_{VV}^\circ = -5.65 \text{PWC} - 12.15 \) at VV polarization.

![Figure 3 - \( \sigma^\circ \) at HH pol. (red points) and VV pol (blue points) as a function of PWC of wheat fields in both Scrivia and Sesto areas.](image)

The p-value was computed for the correlation between \( \sigma^\circ \) and PWC in HH polarization only and is <0.05. At VV polarization, due to the very scarce number of images available, \( R^2 \) and p-value were not computed. Unfortunately, we obtained CSK images at VV polarization just in the first growth phase of wheat crops and therefore the decreasing trend was not confirmed at higher values of biomass for the presented data. Further investigations, carried out on a test site in Tunisia, on wheat fields well-developed confirmed instead this trend by using TerraSAR-X data too [Fontanelli et al., 2013].

An analogous behavior was observed on colza, which, at the beginning of its growth, is a plant with characteristics significantly different from those of wheat. However, at the flowering stage, it develops a high vertical stem, similar to the stem of the wheat and
therefore with an absorbing effect on the backscattering. Colza showed consequently a sharp decreasing trend of $\sigma^o$ as a function of PWC at HH polarization, as it has been shown in Fig. 4a; whereas at HV polarization, the observed trend is somewhat increasing, with a sensitivity of about 1 dB/kg m$^{-2}$ (Fig. 4b). The presence of a vertical and branched stem in the ripening phase causes this increasing of the scattering in cross polarization. A high scattering response in HV polarization for colza, in fact, has already been observed at C-band during the SIR-C/X-SAR experiment [Baronti et al., 1995; Macelloni et al., 1999]. In the case of HV polarization, however, there is a gap in the data between 0.5 and 3.0 kg/m$^2$, due to the absence of a continuous series of images in the same polarization. It should be noted that the two diagrams refer to different images (see Tab. 2) and therefore the number of observed field is not the same. The obtained correlation lines are the following:

- $\sigma^o_{\text{HH}} = -1.56\text{PWC} - 3.75 \quad (R^2=0.79)$;
- $\sigma^o_{\text{HV}} = 0.83\text{PWC} - 2.9 \quad (R^2=0.56)$.

![Figure 4](image-url)

**Figure 4** – (a) X-band HH backscattering coefficient as a function of PWC (kg/m$^2$) of colza in Sesto area in 2011. The regression line is: $\sigma^o_{\text{HH}} = -1.56\text{PWC} - 3.75 \quad (R^2=0.79)$; (b) X-band HV backscattering coefficient as a function of PWC (kg/m$^2$) of colza in Sesto area in 2011. The regression line is: $\sigma^o_{\text{HV}} = 0.83x - 21.9 \quad (R^2=0.56)$. 


The p-values computed for the correlation between $\sigma^o$ and PWC in both HH and HV polarizations are $<0.05$.

As for corn, an appreciable correlation between the available backscattering data and fresh biomass was found mainly at HV polarization. Indeed, in this case the contribution of soil is smoothed by the higher amount of vegetation biomass, and the sensitivity of X band HV backscattering coefficient to PWC was found to be similar to the one of colza and about 1 dB/kg m$^{-2}$ (Fig. 5). It should be noted that the relatively high spread of data at biomass=0 kg m$^{-2}$ is due to the different SMC values caused by the irrigations after the sowing. The regression line is in this case:

- Corn: $\sigma^o_{HV} = 0.84PWC - 26.46$ ($R^2=0.43$).

![Figure 5 - X-band HV backscattering coefficient as a function of PWC (kg/m$^2$) of corn in Scrivia area in 2010 (PingPong images). The regression line is: $\sigma^o_{HV} = 0.84PWC - 26.46$ ($R^2=0.43$).](image)

Also in this case the p-value was found $<0.05$.

The last crop observed during these experiments was sunflower, which is a plant characterized by thick stems and large circular leaves. The temporal trend of $\sigma^o$ in HH polarization clearly follows the crop growth, as shown in the diagram of Figure 6a. During this period, the PWC increase from 0 to 9 kg/m$^2$ and then decreases again in the senescence phase. The effect of scattering due to the development of the large leaves is evident. In the diagram the trend was approximated by using a polynomial regression line. The direct comparison between $\sigma^o$ in HH polarization and PWC is shown in Figure 6b, where the clearly increasing trend of $\sigma^o$ vs. PWC is marked, with a high determination coefficient ($R^2=0.79$). The regression lines obtained from these two relationships are the following:

- $\sigma^o_{HH} = -3E-05t^3 + 0.017t^2 - 2.9t + 147.84$ ($R^2=0.94$);
- $\sigma^o_{HH} = 0.67PWC - 11.21$ ($R^2=0.76$).
Summary and Conclusions
The potential of X-band backscattering from the CSK mission in monitoring soil moisture and vegetation biomass has been investigated by correlating SAR data to ground measurements. The experiments were carried out on four test areas in Italy: Scrivia, Tuscany-Sesto, Cordevole and the Tuscany-Forests. Here several CSK images have been collected and compared with ground truth data.

The results have shown an appreciable sensitivity to moisture of bare soil in HH polarization (0.1 dB/%SMC), provided the soil is not very rough, i.e. with surface roughness ≤1/1.5 cm. Different agricultural crops were observed (wheat, colza, corn, and sunflower). The sensitivity to crop biomass was found to be relevant especially for crop characterized by large, circular leaves (sunflower) or thin vertical stems (wheat).

Unfortunately, the investigation on the sensitivity to biomass of wheat was hampered by a limited availability of data at VV polarization, since only two images were collected on the site. Indeed, due to the characteristics of this crop, dominated by thin cylindrical stems, the extinction coefficient is significant at VV pol. and rather small at HH, causing a not negligible contribution from soil even at X-band. A similar trend was found for colza at HH polarization, which due to the presence of the flower, has an analogous absorption effect on the backscattering coefficient. Nevertheless, at HV polarization, the trend is slightly increasing as well as for corn.

Although more experimental data would be necessary for drawing definitive conclusions, the results obtained during this experiment were encouraging and confirmed the capability of X-band to monitor soil and vegetation parameters with sensitivity acceptable for most applications of Earth Observation. In fact, the observed sensitivities are about 0.1 dB/% of SMC, 3-4 dB/kg m² of PWC of wheat and 1 dB/kg m² of sunflower, which are values in the order of the requirements of the spatial agencies for satellite products. The p-value computed for the correlations between $\sigma^0_{HH}$ and SMC, and $\sigma^0$ and PWC was found to be

The p-value computed for the correlation between $\sigma^0$ and PWC in HH polarization is also in this case <0.05.
lower than 0.05.

Acknowledgments
This work was partially supported by Italian Space Agency (ASI) through the ASI Agreement I/045/09/0 for the CSK-HydroCosmo project 1720, and by the CTOTUS project, which was co-funded by Regione Toscana within the framework of the “Programma Operativo Regionale - obiettivo Competitività Regionale e Occupazione” - POR-CReO FESR 2007-2013.

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