On the Incoherent COSMO-SkyMed PingPong Mode to Distinguish Among Sea, Vegetated and Urban Scenarios

Lucio Mascolo\textsuperscript{1}, Ferdinando Nunziata\textsuperscript{2}, Alessandro Fanti\textsuperscript{1}, Giuseppe Mazzarella\textsuperscript{1}, Maurizio Migliaccio\textsuperscript{2}

\textsuperscript{1}Università degli Studi di Cagliari, Dipartimento di Ingegneria Elettrica ed Elettronica
\textsuperscript{2}Università di Napoli “Parthenope”, Dipartimento di Ingegneria

\section*{ABSTRACT}
In this study the sensitivity of COSMO-SkyMed (CSK) dual-polarization HH/VV Synthetic Aperture Radar (SAR) data with respect to sea, vegetated and urban areas is investigated. The capabilities of single and dual-pol features derived from such data in distinguishing among the three scenarios are evaluated.

\section*{1. INTRODUCTION}
COSMO-SkyMed (CSK) is the largest Italian investment in Space Systems for Earth Observation (EO) commissioned and funded by Italian Space Agency (ASI) and Italian Ministry of Defense. The system consists of a constellation of four Low Earth Orbit mid-sized satellites, each equipped with a multi-mode Synthetic Aperture Radar (SAR) operating at X-band. Such a SAR constellation ensures a dense spatial coverage and a revisit time lower than 12 hours [1]. Therefore, the CSK constellation is of great relevance for several EO applications, including the monitoring of land areas.

In the recent years CSK data have been exploited for surface types discrimination and vegetation observation. In [2] the correlation between CSK Level 1A Single Look Complex Slant (SCS) incoherent dual-polarization PingPong mode HH/VV SAR data is used to effectively discriminate land from sea for coastline extraction purposes. In [3] the use of CSK interferometric SAR (InSAR) data acquired in HH/HV PingPong mode is proposed to carry out a supervised land cover classification. A crop classification based on the exploiting of multitemporal CSK dual-polarization PinPong mode data is carried out in [4].

This study is aimed at analyzing the capabilities of CSK dual-polarization HH/VV PingPong mode SAR data in discriminating among sea, urban and vegetated areas. In particular, the sensitivity of different features with respect to these three types of scenarios is investigated. Such features are: the complex correlation between the co-polarized channels, the correlation between the HH and VV amplitudes, the HH and the VV intensities and the co-polarization ratio. Experiments are undertaken on actual CSK SCS SAR data collected in different geographical areas (Gulf of Naples, South Holland) and under different incidence angles (AOIs).

\section*{2. THE INCOHERENT CSK PINGPONG MODE AND DUAL-POLARIZATION FEATURES}
CSK Stripmap PingPong mode is implemented by alternating a pair of transmitting/receiving polarizations across bursts by means of an antenna steering [1]. The two co-registered polarimetric channels, that can be selected among (HH, VV), (HH, HV) and (VV, VH), are acquired at slightly different times separated by the time interval $r$. $r$ is an increasing function of the incidence angle and its values range between 0.10 s and 0.25 s. Therefore, the phase link between the two polarimetric acquisition is not preserved and hence the CSK PingPong mode is an incoherent dual-polarization mode.

The dual-polarization features derived from CSK PingPong mode SAR data to assess their sensitivity with respect to sea, vegetated and urban areas are: 1) the amplitude of the correlation between the co-polarized channels $r$

$$r(\tau) = \left\langle |S_{hh}(\tau)|S_{vv}^*(\tau + \tau) \right\rangle,$$  

(1)

2) the correlation between the modulus of co-polarized channels $r_m$

$$r_m = \left\langle |S_{hh}|S_{vv}^* \right\rangle$$  

(2)

and 3) the polarization ratio $r_{HV}$

$$r_{HV} = \left\langle \frac{S_{hv}^*}{|S_{hv}|} \right\rangle.$$  

(3)

In (1)-(3) $S_{hh}$ and $S_{vv}$ are the complex scattering amplitudes for the HH and the VV channel, respectively, $\langle \cdot \rangle$ means the ensemble average and $*$ denotes the complex conjugate.
3. EXPERIMENTS

In this section, two experiments undertaken on X-band level 1A SCS HH/VV CSK PingPong mode SAR data are presented. To get information about the land cover type, a CORINE land cover map (CLC) at 100×100 m² pixel size [5] that covers most of the European continent is used. Moreover, wind information collected by scatterometer data are also available.

For each SAR scene the single-polarization features, i.e. the HH and the VV intensity, and the dual-polarization features \( r \) (1), \( r_m \) (2) and \( r_{HV} \) (3) are evaluated using a \( 7 \times 7 \) average moving window. Then each feature is geocoded (UTM coordinates).

The first experiment (Exp.1) is relevant to the SAR scene collected over the Gulf of Naples on June 12, 2011 at 18:02. In this case the mean AOI is \(-54^\circ\) and the wind speed is \( \sim 8 \) m/s. Only a subset of the whole SAR scene is considered and is represented in geographical coordinates in Fig.1(a).

This includes urban environments (Naples and surrounding cities), vegetated areas and sea. The \( r \), \( r_m \) and \( r_{HV} \), features, together with the HH and VV channel intensities are shown as false color images in Fig.1(b)-(f), where dB scale is used. By roughly comparing the Google Earth image of Fig.1(a) with the features images we note that, in all the cases but the \( r_{HV} \) image, sea surface can be distinguished from land and signals of well-distinguishable levels result from vegetated and urban environments. The \( r_{HV} \) image is very noisy and does not allow a straightforward land/sea discrimination.

To analyze the capability of the features in discriminating among the sea, urban and vegetated scenario a simple k-means clustering algorithm is applied to the features outputs. The number of classes in which each feature output is partitioned is equal to 3: “Sea”, “Vegetation” and “Urban”. \( r_{HV} \) is not considered in the classification due to its poor performance. In order to assess the accuracy of the clustering for each feature, the ground truth information provided by the CLC map is used as input for the computation of the confusion matrix. This requires a preprocessing of the CLC map that consists in selecting the area of interest (i.e. the area imaged by CSK) from the whole map, projecting the resulting map into the geocoded SAR grid and then reducing it to three classes. The CLC map relevant to the Gulf of Naples, and the output of the k-means clustering for each feature are not shown to save space. However, the Overall Accuracy (OA) is 77.97\%, 78.74 \%, 78.10\% and 75.68\% for \( r \), \( r_m \), the HH intensity and the VV intensity, respectively. \( r_m \) performs best, \( r \) and the HH intensity provide very similar performances while the VV intensity provides the poorest performance.

The second experiment (Exp.2) concerns the SAR scene collected over the South Holland on October 23, 2010 at \( 04:27 \) with a mean AOI around \( 45^\circ \). In this case the scene calls for high wind conditions since the wind speed is around \( 15 \) m/s. A subset of the whole SAR image is considered and it is shown in geographical coordinates in Fig.2(a). \( r \), \( r_m \), \( r_{HV} \), and the HH and VV channels intensity are shown in Fig.2(b)-(f), respectively. It can be noted that all the features, but \( r_{HV} \), show a non-negligible variability over land areas. Also in this experiment, 3 classes are used when the k-means clustering algorithm is applied to the features. In this case, the OA is 50.96\%, 53.05\%, 51.07\% and 50.72\% for \( r \), \( r_m \), the HH intensity and the VV intensity, respectively. The overall decrease of the OA for all the features with respect to the previous experiment is a direct consequence of the high wind conditions, since the high sea state conditions induced lead to misclassifications over the sea areas. However, the best performance is provided by \( r_m \).

4. CONCLUSIONS

In this study, the capabilities of single and dual-polarization features derived from CSK HH/VV PingPong mode SAR data in discriminating among sea, vegetated and urban scenarios are investigated.

Experiments undertaken on actual SAR data collected in different geographical areas and under different AOIs demonstrate that, although all the features call for a different sensitivity with respect the three scenarios, the co-polarized ratio provides the worst performance. Moreover, the land/sea discrimination is not a trivial task since sea state conditions significantly affect the discrimination.

5. ACKNOWLEDGMENT

COSMO-SkyMed SAR data used in this study are provided by Italian Space Agency (ASI) under the project 1221. All the COSMO-SkyMed products are owned by ASI (all rights reserved, 2010/2011).

6. REFERENCES


Figure 1. Subset of the CSK SAR scene relevant to Exp.1: (a) Google Earth image, (b) $r$, (c) $r_m$, (d) $r_{HV}$, (e) HH intensity and (f) VV intensity.

Figure 2. Subset of the CSK SAR scene relevant to Exp.2: (a) Google Earth image, (b) $r$, (c) $r_m$, (d) $r_{HV}$, (e) HH intensity and (f) VV intensity.