CALIBRATED POLARIMETRIC SAR DATA FOR SHIP DETECTION

R. Touzi
Canada Centre for Remote Sensing
588 Booth Street, Ottawa
Ontario, Canada K1A OY7

Abstract— **The polarization information is investigated for ship detection using calibrated polarimetric Convair-580 SAR data. It is shown that at operational satellite SAR incidence angles (lower than 60°), there is a significant improvement of ship-sea contrast when the full polarimetric information is used instead of the information provided by the scalar one channel polarization (HH, VV, or HV).**

I. Introduction

Ship detection by synthetic aperture radar (SAR) has become a topic of considerable interest since the upsurge in the commercial market for this type of information. The importance of the transmitting-receiving antenna polarizations on ship detectability is now well recognized. Better ship-sea contrast is obtained with HH whereas VV provides more information on the sea conditions [8]. Radiometric information provided by one classical polarization channel (HH, VV, or HV) is not generally sufficient for effective ship detection, and detection methods which are generally based on a thresholding decision over the sea clutter K distribution are also limited. These methods might lead to some identification of ships provided that the ship radar cross section is relatively well distinguished from the random realization of the K distributed sea clutter.

In this study, the potential of polarimetric SARs for characterization of target scattering mechanisms is investigated for ship-sea discrimination. Polarimetric data were collected over a scene with several ships in Nova Scotia (Canada) with the Department of the Environment airborne Convair-580 SAR [2]. During the flight, reference point targets were deployed to calibrate the four measured linear polarizations (HH, VV, HV, and VH), as explained in Section II. In Section III, the polarimetric signatures of sea and ships are analyzed, and a new tool named "the polarization entropy" is investigated for ship detection within the 45°-70° incidence angle range of the illuminated scene. Ship-sea contrast is calculated for the various ships, and used to compare the performance of the new tool to the ones obtained with the classical linear polarizations.

II. Calibration of the polarimeric Convair-580 SAR

In order to exploit the fully polarimetric capability of the Convair-580 SAR, pure HH, VV, HV, and VH have to be retrieved from the distorted measurements (H and V polarizations are not pure at the transmission and reception). In contrast to most of the existing polarimeters, the Convair-580 SAR polarimeter uses two receiving configurations as a function of the transmitting polarization H or V [3]. A general polarimetric model which includes systems whose receiving configuration is independent of the transmitted polarization (one configuration), as well as systems with two distinct receiving configurations according to the commanded transmitted polarization (H or V), was introduced in [6]. This model was the basis for the development in [6] of a general calibration method which is suitable to most of all the existing systems. The method was adapted in [3] to C-band SAR system which is equipped with highly isolated (better than 50 dB) polarizations switches. As the H and V antennas are highly isolated (35 dB) and their phase centers are co-located (at least for incidence angles of ±20° from the boresight angle), the system can be calibrated using a corner reflector and a recirculating 45-45 Polarimetric Active Radar Calibrator (PARC) placed at the same incidence angle [6], [3]. The antenna high isolation, and the knowledge of the H and V antenna gain patterns (with accuracy of ± 1dB within ±20° from the boresight angle [7]) permit to extend the calibration in range for incidence angles of ±20° from the boresight angle [6], [3].

The stability of the system calibration parameters was studied for various flights in [5]. The objective was to assess whether is it possible to calibrate one set of data using the calibration parameters of a previous flight. Tests run on various data sets lead to the conclusion that that the Convair-580 SAR system is quite stable in short time [5]. The pass to pass relative and absolute radiometric errors obtained for various passes are within 0.5 dB, and the relative phase errors recorded are within 5 degrees. Therefore, the calibration constant derived from the pass on the site of calibration, can be used to calibrate other passes performed in the same day (i.e. which are apart of the same flight). However, the same tests carried in [5] proved that the system is not stable in long-term (from one flight to another). This is mainly due to the fact that the like and the cross-polarizations are fed to two different receivers [3]. System unstability might be corrected for collecting block noise measurements of the 2 receivers at the end of each pass [3]. Block noise measurements are then used during data calibration, and tests were run on various data sets. An offset of 3 dB in radiometry and 25° in phase between the like and cross-polarization was noted using data sets collected one week apart [5]. The radiometric offset might be due to the fact that noise measurements do not include an amplifier device which is used at the input of the cross-polarized receiver to amplify the cross-polarized signal (generally much weaker than the co-polarized signal). The offset in phase is due to the fact that the block noise measurements do not provide information on the phase shifts between the two separate receivers. The 2 receivers complex offset can be measured using a reference point target with non null cross-polarized return. Consequently, the system can only be calibrated provided that reference point targets are deployed during each flight (the system is stable during the same flight for various passes). It is worth noting that according to the tests completed in [5], each separate receiver remains quite stable in radiometry and phase (relative complex offset HH-VV and HV-VH is stable). The offsets recorded for the receiver 1 (between the 2 like-polarized components), and the receiver 2 (between the 2 cross-polarized components) remain within 0.5 dB in radiometry and 5 degrees in phase even with data sets collected 2 years apart [5]. Such stability might support an another option: a measurement of the relative complex offset between the two receivers with the transmission off at the end of each pass should permit the relative calibration between the two receivers, and as such correct for long-term system unstability. The receivers complex offset measurements might be performed using a continuous waveform (CW) which is injected into the two receivers. The CW signal does not have to go through the antennas as they are quite stable according to the stability tests above concerning each separate receiver [3], [5]. Such alternative looks more attractive than the PARC method which remains very sensitive to the accuracy of point target deployment.

III. Analysis of ship-sea contrast using the Convair-580 polarimetric SAR data

A. *Calibration budget error of the scene under study*

For the scene under study , the pointing angle was of 58°, and reference point targets were deployed at about 60°. The scene was calibrated across the range 46° to 70°. For incidence angles within ±20° from the boresight angle, the accuracy is within 1 to 2 dB in radiometry and within 5° in phase [5]. At the presence of system mis-focussing, such accuracy can only be preserved if the complex integration method (CIM) which was introduced in [4], is used for point target phase measurement. This method which was shown to be more robust to system mis-focussing than the conventional peak method [4], permit in certain cases to correct for phase errors of more than 20° which occurred on the phase of point target peak intensity.

B. *Potential of the classical linear polarizations (HH, VV, and HV) for ship detection*

Figure 1 present the ship-sea contrast calculated for the various ships on the scene (Figure 2) at the three linear polarizations. As can be noted, HV gives the best contrast at low incidence angles. At grazing incidence angles (higher than 60°), HH which minimizes the sea return gives the best results. VV gives the lowest contrast for all the range of incidence angles considered.

C. *Analysis of the ocean and ship polarization signatures*

The co-polarized signatures were analyzed across the scene incidence angle range 46°-70°. The results obtained are consistent with the ones obtained in [9]. At the considered incidence angles, the Bragg scattering mechanism dominates, and the co-polarized signatures exhibit a saddle point at horizontal polarization, and a maximum at vertical polarization which becomes more pronounced with increasing incidence angle. At 45°, the cross-polarized signature still remains the Rican signatures obtained at lower incidence angle.

The co-polarized signatures obtained for the ships have more complex shapes than the ones of the sea. At high incidence angles, ships cross-polarized signature exhibit a minimum at HV. This explain the poor performances of the HV polarization at this range of incidence angles (cf. Figure 1) even though the sea cross-polarized signature presents a minimum at HV.

D. *Polarization entropy for ship detection*

The analysis of ship and ocean polarization signature leads to the conclusion that the ship-sea contrast is not optimum if only one pair of transmitting-receiving antenna polarizations are used. Several algorithms have been developed for contrast enhancement (see for example [1]). In this study, a new tool named "the polarization entropy" is investigated for ship detection. It is defined as the polarization information content which might be an effective tool to characterize target nonstationarity. The higher the polarization entropy is, the larger are signal variations with transmitting-receiving polarizations. Figure 3 shows the polarization entropy of the image under study. For low incidence angles up to 60 degrees, the Braggs ocean mechanism has a lower entropy compared to the ship's polarization entropy. The ships which can hardly be seen in the HH polarization (Figure 2) are now well enhanced. The polarization entropy permits a significant improvement of ship-sea contrast as quantified in Figure 1. At incidence angles higher than 60°, the ocean backscattering mechanisms become as heterogeneous as the ones on ships, and the polarization entropy can no longer discriminate ship from ocean. This should not limit the application of the method as most satellite SARs generally operate at incidence angles lower than 60°.

IV. Conclusion

The polarization entropy looks to be very promising for ship detection at incidence angles lower than 60°. These results should promote the use of fully polarimetric data. The launch in the near future of Radarsat 2 which will have this unique capability would certainly make polarimetric data more accessible. Such potential can only be well exploited provided that Radarsat 2 polarimetric modes will be well calibrated. In the future, other campaigns will be performed with the Convair-580 to validate this method at lower incidence angles (20° to 40°), for different ships at various orientations, and at different wind conditions.

Acknowledgments

The author would like to thank Dr. C. Livingstone from DREO, R.K. Hawkins, and P. Vachon from CCRS for helpful discussions. DREO is thanked for having financed a part of this study, and having provided the Convair-580 SAR data. The support of Environment Canada which operates the system is also acknowledged.

References

[1] W.M. Boerner, M. Walther, and A.C. Segal. Development of the polarimetric contrast enhancement optimization procedure and its application to sea surface scatter in POL-SAR image analysis. In *Proc. of IGARSS'93, Tokyo, Japan, August 18-21*, 1993.

[2] R.K. Hawkins, P. Vachon, J. Cranton, and K. Murnaghan. Scene descriptions for CV-580 SAR acquisitions St Magaret's Bay area. In *Report CCRS-TN-1998-021*, 1998.

[3] C. E. Livingstone, A. L. Gray, R. K. Hawkins, P. W. Vachon, T. I. Lukowski, and M. LaLonde. The CCRS airborne SAR systems: Radar for remote sensing research. *Can. J. Rem. Sens.*, 21(4):468–491, 1995.

[4] R. Touzi. Extraction of point target response characteristics from complex SAR data. *IEEE Trans. Geoscience Rem. Sens.*, 30(6):1158–1161, 1992.

[5] R. Touzi. Calibration and analysis of convair-580 polarimetric sar data for forest target characterization. Technical report, Final Report provided to the Defense Research Establishment of Ottawa (DREO) under the CCRS/DREO agreement FY97/98-98/99, June 1999.

[6] R. Touzi, C. E. Livingstone, J. R. C. Lafontaine, and T. I. Lukowski. Consideration of antenna gain and phase patterns for calibration of polarimetric SAR data. *IEEE Trans. Geoscience Rem. Sens.*, 31(6):1132–1145, 1993.

[7] L.M.H. Ulander, R.H. Hawkins, C.E. Livingstone, and T.I. Lukowski. Absolute radiometric calibration of the CCRS SAR. *IEEE Trans. Geoscience Rem. Sens.*, 29(6):922–933, 1991.

[8] P. W. Vachon, J. W. M. Campbell, C. Bjerkelund, F. W. Dobson, and M. T. Rey. Ship detection by the RADARSAT SAR: Validation of detection model predictions. *Can. J. Rem. Sens.*, 23(1):48–59, March 1997.

[9] J.J. Van Zyl, H.A. Zebker, and C. Elachi. Imaging radar polarization signatures: theory and observation. *Radio Science*, 22:529–543, 1987.

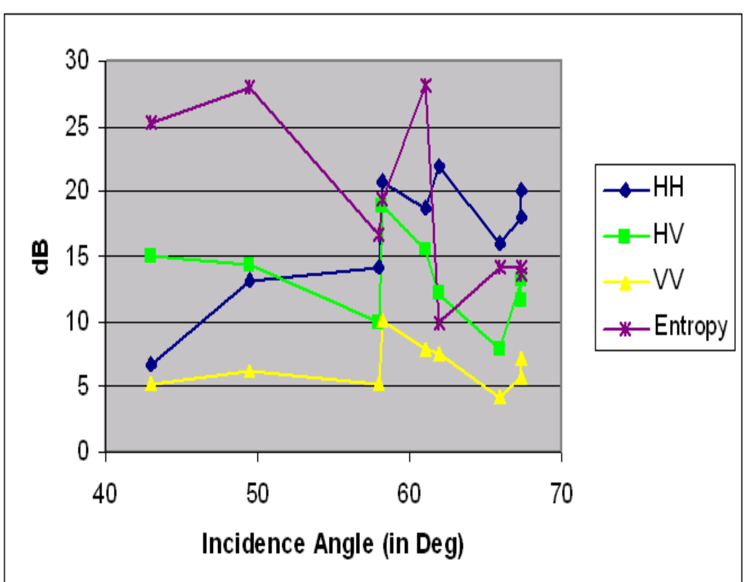

Fig. 1. *Ship-sea contrast as a function of the incidence angle*

Fig. 2. *HH image (46°-70°)*

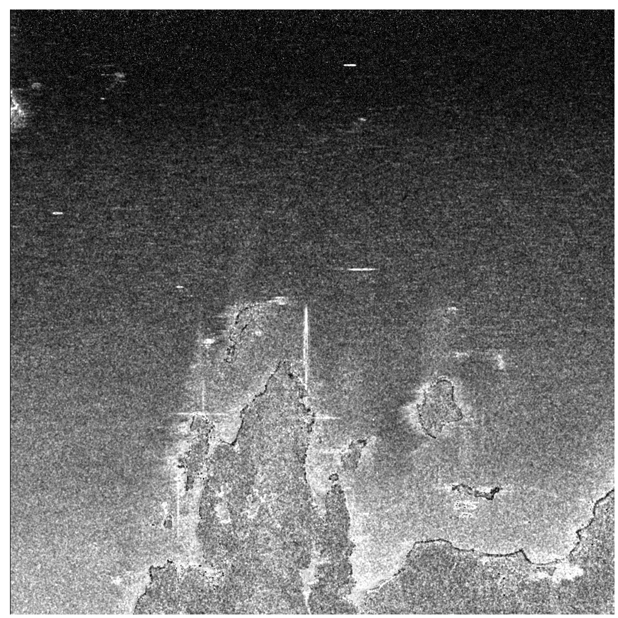

Fig. 3. *Polarization entropy image*