# Polarimetric analysis of iceberg and sea ice radar backscattering mechanisms for iceberg detection


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## Introduction

Multi-polarization synthetic aperture radar (SAR) systems are in particular useful for identification and separation of different scattering mechanisms and their sources in a medium (Oliver & Quegan, 1998, p. 319). The Canadian RADARSAT-2 (RS-2) carries a fully-polarimetric SAR system which measures intensities at VV, HH, HV and VH-polarizations as well as phase differences between the differently polarized channels (http://www.asc-csa.gc.ca/eng/satellites/radarsat2/).

With the aid of different polarimetric parameters such as co- and cross-polarization ratio or entropy, the dominant backscattering processes for icebergs and sea ice and their potential for iceberg detection are investigated. We used three RS-2 Fine Quad Pol SAR images in the southern Weddell Sea region north of Berkner Island, one recorded on 11 September 2011 and two on 18 September 2011 (Figure 1).

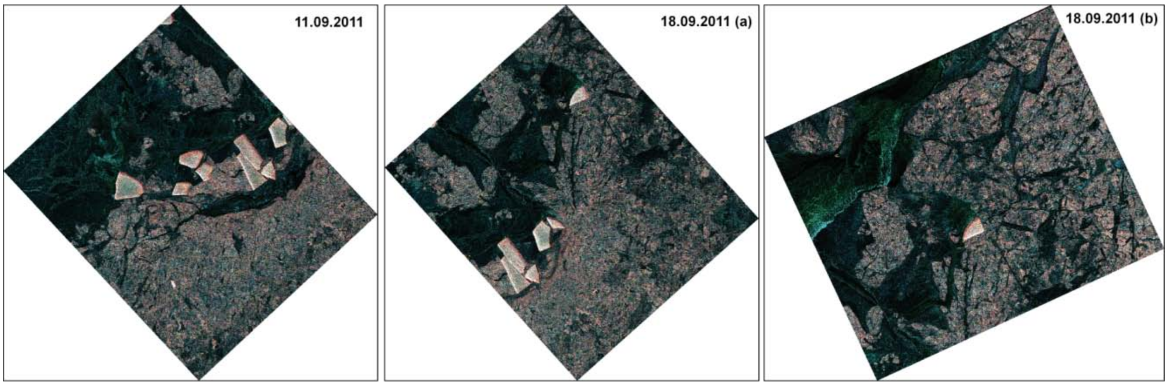


**Figure 1 RGB-colored RS-2 images of the southern Weddell Sea region ($R = \sigma_{HV}$, $G = \sigma_{VV}$, $B = \sigma_{HH}$). Image credits: Canadian Space Agency (CSA).**

For the polarimetric analysis, we defined regions of interest (ROIs) covering the completely visible area of the icebergs and rectangular ROIs on three different sea ice regimes (C1 – rough first-year sea ice (bright), C2 – smooth thin sea ice (dark), and C3 – (probably frost-flower covered) new sea ice (greenish)). The number of ROIs is presented in Table 1.

**Table 1 Number of ROIs.**

| Date | Iceberg | C1 | C2 | C3 |
|---|---|---|---|---|
| **11.09.2011** | 9 | 37 | 30 | -- |
| **18.09.2011 (a)** | 6 | 38 | 15 | -- |
| **18.09.2011 (b)** | 1 | 37 | 26 | 13 |

For each ROI, different polarimetric parameters were computed. The polarization ratios ($\sigma_{VV}/\sigma_{HH}$, $\sigma_{HV}/\sigma_{HH}$ and $\sigma_{VH}/\sigma_{VV}$) are determined using the mean backscattering coefficients at linear scale. Besides the polarization ratios, the co-polarized correlation coefficient ($\rho_{HHVV}$), the co-polarized phase difference ($\phi_{HHVV}$), the entropy (H), the anisotropy (A) and the alpha angle ($\alpha$) were computed (Table 2).

**Table 2 Mean backscattering coefficients of each polarization and the polarimetric parameter.**

| | $\sigma_{HH}$ [dB] | $\sigma_{HV}$ [dB] | $\sigma_{VH}$ [dB] | $\sigma_{VV}$ [dB] | $\sigma_{VV}/\sigma_{HH}$ | $\sigma_{HV}/\sigma_{HH}$ | $\sigma_{VH}/\sigma_{VV}$ | $\phi_{HHVV}$ | $\rho_{HHVV}$ | **H** | **A** | **α** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **11.09.2011** | | | | | | | | | | | | |
| **IB** | -5.87 | -14.46 | -13.95 | -6.43 | -0.56 | -8.03 | -6.99 | 58.12 | 0.52 | 0.55 | 0.47 | 43.01 |
| **C1** | -10.05 | -20.96 | -20.48 | -10.64 | -0.56 | -9.80 | -8.73 | 11.66 | 0.75 | 0.41 | 0.44 | 24.84 |
| **C2** | -15.69 | -31.30 | -30.82 | -16.05 | -0.41 | -15.67 | -14.75 | 6.97 | 0.87 | 0.23 | 0.52 | 13.47 |
| **18.09.2011 (a)** | | | | | | | | | | | | |
| **IB** | -5.21 | -13.44 | -13.49 | -5.29 | -0.03 | -7.55 | -7.58 | 55.30 | 0.52 | 0.54 | 0.47 | 42.10 |
| **C1** | -10.80 | -21.40 | -21.45 | -10.83 | -0.03 | -9.27 | -9.30 | 11.47 | 0.76 | 0.40 | 0.44 | 24.17 |
| **C2** | -16.69 | -31.61 | -31.62 | -16.55 | 0.10 | -15.05 | -15.24 | 7.29 | 0.86 | 0.24 | 0.53 | 14.10 |
| **18.09.2011 (b)** | | | | | | | | | | | | |
| **IB** | -5.65 | -12.48 | -12.58 | -5.64 | -0.06 | -7.28 | -7.28 | 35.90 | 0.59 | 0.51 | 0.43 | 36.73 |
| **C1** | -10.82 | -21.73 | -21.80 | -10.84 | -0.002 | -9.37 | -9.44 | 11.02 | 0.78 | 0.38 | 0.45 | 23.32 |
| **C2** | -17.67 | -31.44 | -31.54 | -16.98 | 0.67 | -14.07 | -14.82 | 7.91 | 0.85 | 0.26 | 0.52 | 16.10 |
| **C3** | -13.87 | -31.87 | -31.97 | -12.34 | 1.31 | -19.46 | -20.92 | 6.10 | 0.93 | 0.14 | 0.52 | 10.83 |

In general, the co-polarization ratio indicates whether the surface is smooth ($\sigma_{VV}/\sigma_{HH} > 0$), rough ($\sigma_{VV}/\sigma_{HH} \approx 0$) or other scattering mechanisms are important ($\sigma_{VV}/\sigma_{HH} < 0$) (Campbell et al., 1993). In many cases, the co-polarization ratios listed in Table 2 (in dB) are close to zero, so a rough surface can be assumed. The ratios from September 11 show a difference of about -0.5 dB between VV- and HH-polarized channels for icebergs and sea ice, which may be due to calibration inaccuracies. Class C3 reveals larger positive co-polarization ratios. According to Campbell et al. (1993) this is typical for scattering from smooth surfaces.

Large depolarization ratios in combination with low correlation coefficients are typical for a considerable contribution of multiple scattering to the received signal (Campbell et al., 1993). The depolarization ratios of icebergs and rough first-year ice are significantly larger than for the smooth sea ice classes C2 and C3. Looking at the mean correlation coefficients in Table 2, the lowest coefficients were found for icebergs. On this basis, it can be concluded that multiple-scattering effects from the surface and from the ice volume cannot be neglected in the case of icebergs.

The small phase differences for the sea ice classes are an indicator for dominant surface scattering. If the phase difference is significantly larger than zero, volume scattering becomes more important.

The results presented in Figure 2 show, that a separation of icebergs from their background is possible using co-polarized correlation coefficients and phase differences.

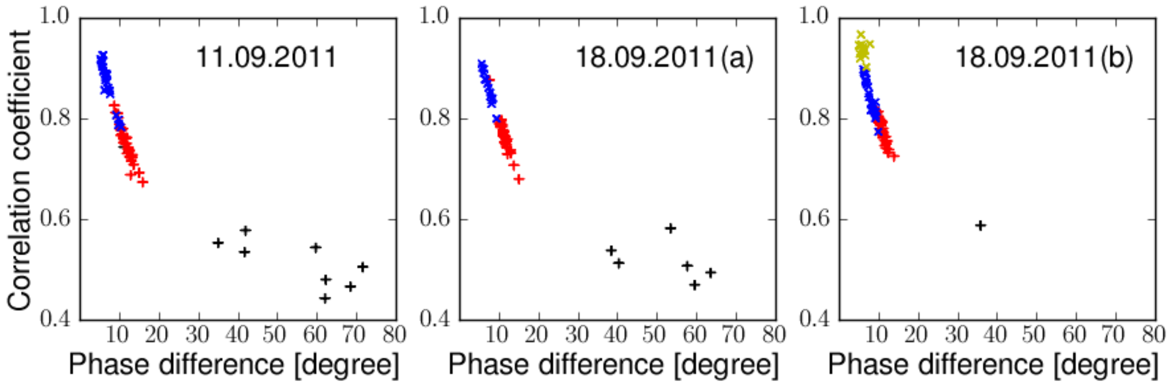


**Figure 2 Mean correlation coefficients over the mean phase differences (degree). Icebergs=black plus, class1=red plus, class2=blue cross and class3=yellow cross**

The polarimetric parameters entropy H, anisotropy A and angle $\alpha$ are related to the coherency matrix which combines the signals of the differently polarize channels VV, HH, HV, and VH. These parameters provide information about the scattering mechanisms of the observed targets (Cloude & Pottier, 1997). The mean entropy describes the degree of randomness of the scattering process, the alpha-angle is used to separate different surface and volume scattering mechanisms and the anisotropy indicates the relative importance of secondary scattering effects. The anisotropy is useful for discrimination of scattering processes for which the entropy is > 0.7. Because, we did not observe such high entropy values, we restricted our analysis to the two-dimensional H-α-space (Figure 3 – for detailed description see Cloude & Pottier, 1997).

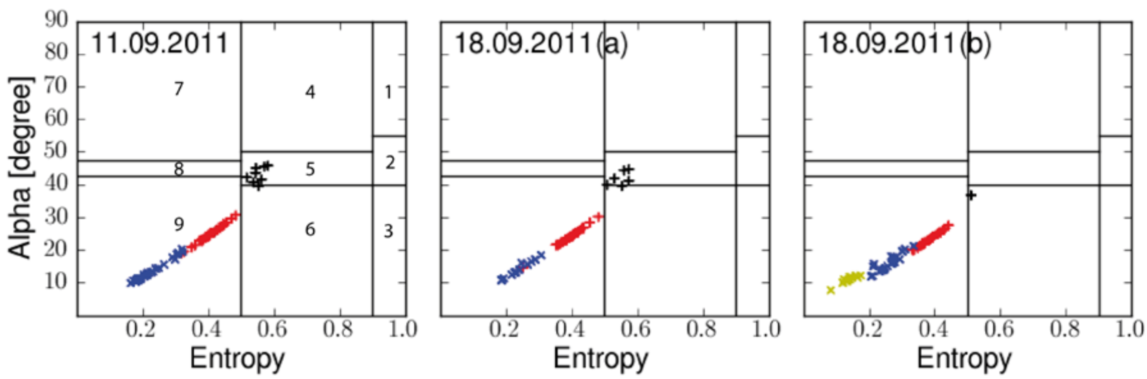


**Figure 1 H-α plot for the three dates. Icebergs=black plus, class1=red plus, class2=blue cross and class3=yellow cross. The numbers in the first plot representing the zones taken from Cloude & Pottier (1997).**

In the H-α-space there is a clear separation between sea ice and icebergs. The sea ice classes are dominated by surface scattering (zones nine - Cloude & Pottier, 1997). Icebergs are dominated by dipole-scattering (zone five).

The presented results show that iceberg detection gains from using polarimetric SAR data. Icebergs can be separated from a background of sea ice on the basis of the co-polarized phase difference and correlation coefficient or in the entropy-alpha plane.

## REFERENCES


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