Iceberg detection using the three modes of SIRAL on Cryosat

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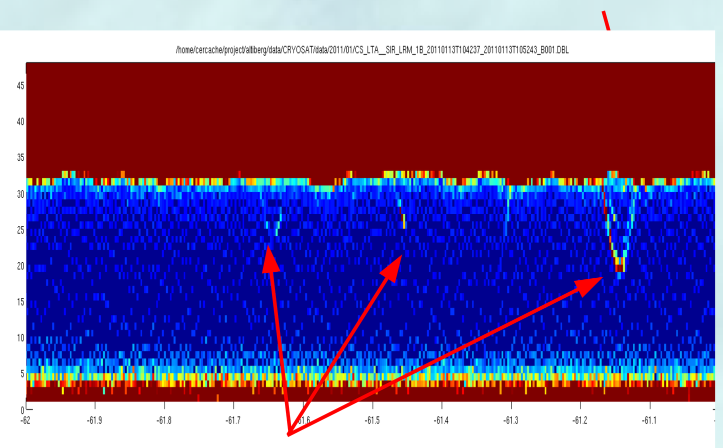
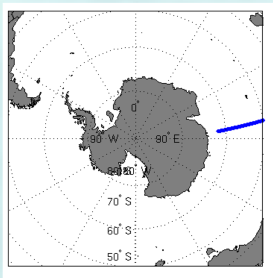
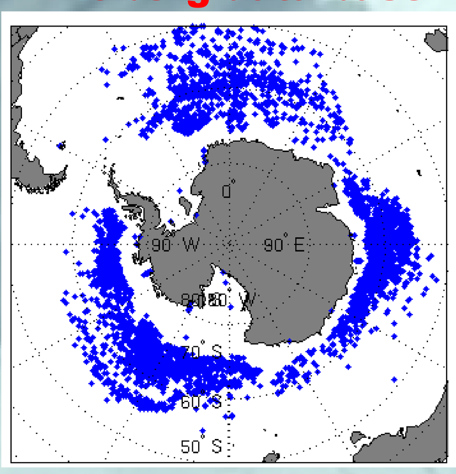
Cryosat is the first ESA satellite mission dedicated to the study of the Cryosphere. Its primary goal is to monitor the thickness of land ice and sea ice and help explain the connection between the melting of the polar ice and the rise in sea levels and how this is contributing to climate change. The main instrument is the SAR/Interferometric Radar Altimeter SIRAL-2
It operates in three modes:
-Low-resolution mode (LRM) like a conventional altimeter, on land ice or sea which are composed of few rough surfaces,
-SAR mode (Delay Doppler Altimetry) operating a high resolution measurement on sea ice,
-SAR interferometer (SARIn) mode operating on rough surfaces like on the sea ice/land limit. Delay Doppler Altimetry (DDA) (Raney, 1998), offers improved altimetric precision and better along-track resolution than pulse limited altimeters. D.D. altimeters have a high pulse repetition frequency to ensure pulse-to-pulse coherence, leading to an along-track resolution about 300 meters, improved signal-to-noise ratio and enhanced altimeter ranging performance.

LRM or Pseudo LRM detection





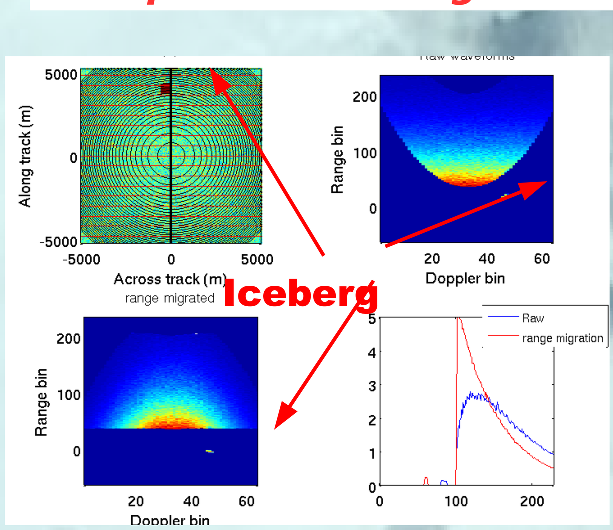
Altiberg data base



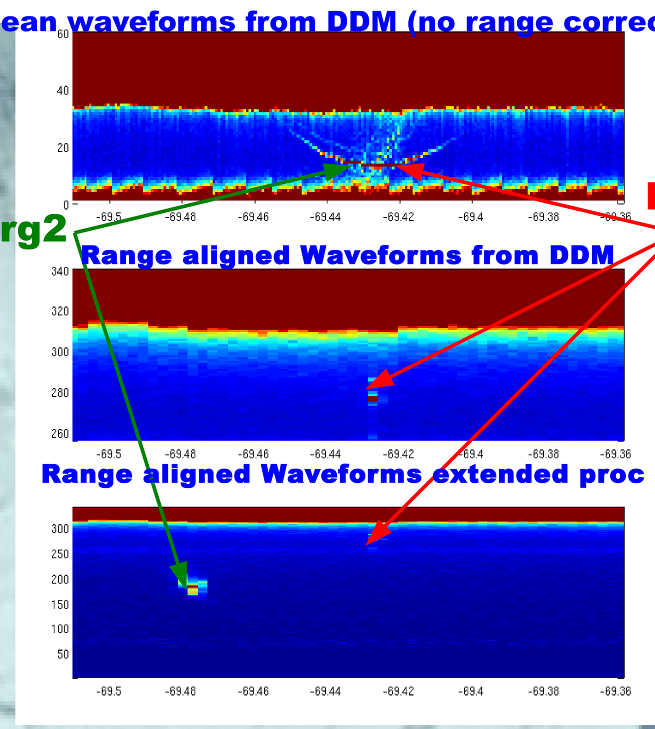
The signature of an iceberg within the altimeter waveform was first described by Tournadre et al (2008). Any target emerging from the sea surface has a detectable signature in the noise part of the waveforms if its range lies within the analysis window and if its backscatter is high enough to come out of the noise. Within the waveform space the signature is a parabola whose characteristics are defined by the orbital and sensor parameters.
For the LRM mode these signatures are easily detected?.This example shows the along-track signature of two icebergs.

Delay Doppler altimetrry

Theoretical Delay Doppler maps over iceberg



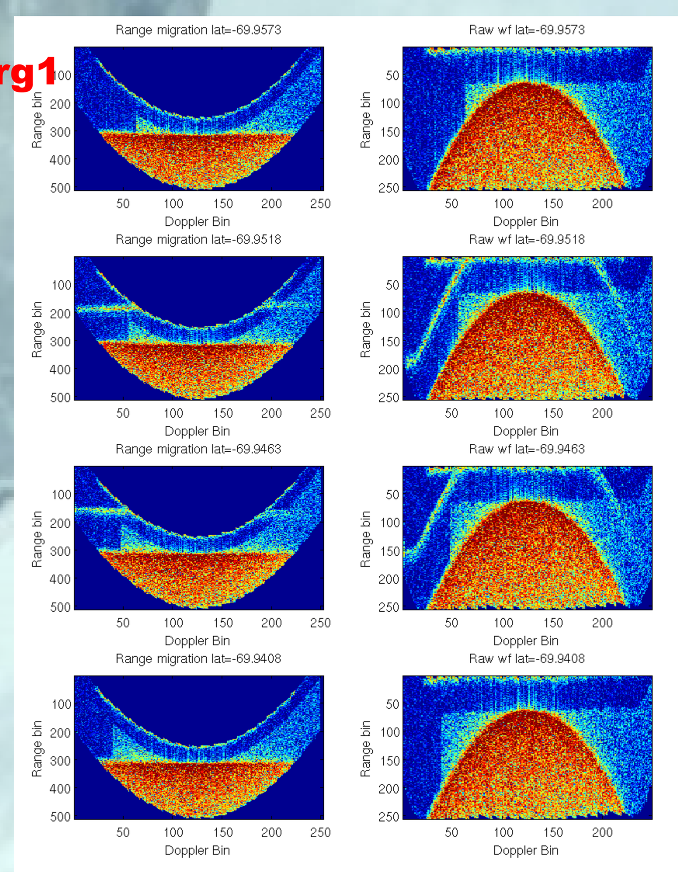
Analytical model of altimeter waveforms of DDM over icebergs
DDM: raw waveforms . Range corrected (aligned) The mis-alignment in range between the DDM beams is corrected.
The mean waveforms from DDM (similar to classical altimetry LRM waveforms) and aligned DDM show the shift of the position of the iceberg signature



Iceberg1: located far enough from nadir. Signature entirely visible within the waveform noise part. In pseudo LRM space the parabola represents the change of iceberg range during the satellite overpass. In range aligned waveform space, the signature is a single bright spot.
Iceberg2: closer to the satellite track and/or higher freeboard. In pseudo LRM space only a portion of the parabola lies within the analysis window. Using the SARVATORE extended radar receiving window size and FFT zero padding (thus 512 range bin waveform) the signature of this icebergs clearly appears in the waveform space (bright spot). The use of such processing more than triple the effective swath of detection of iceberg using DDA

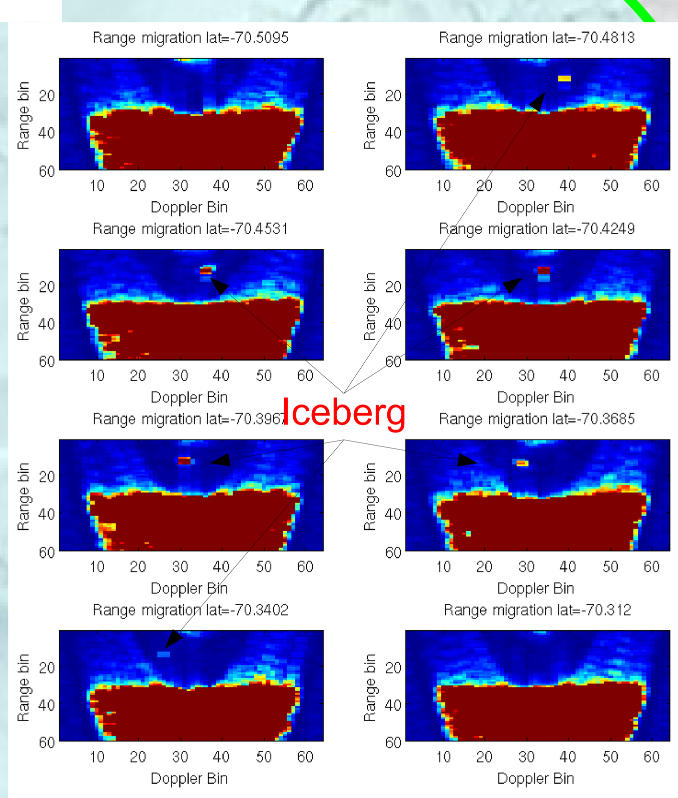
DDA iceberg signature

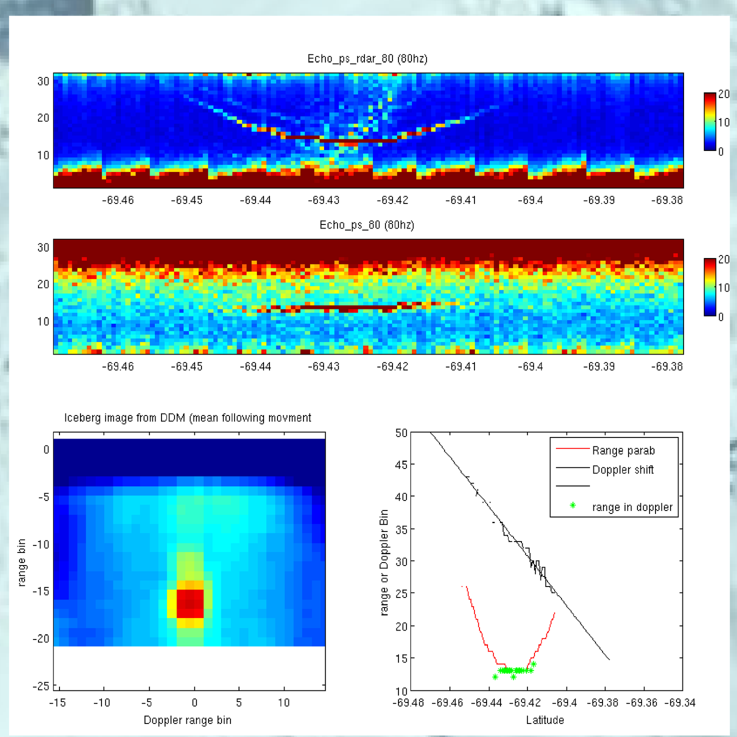
DDM of iceberg 2



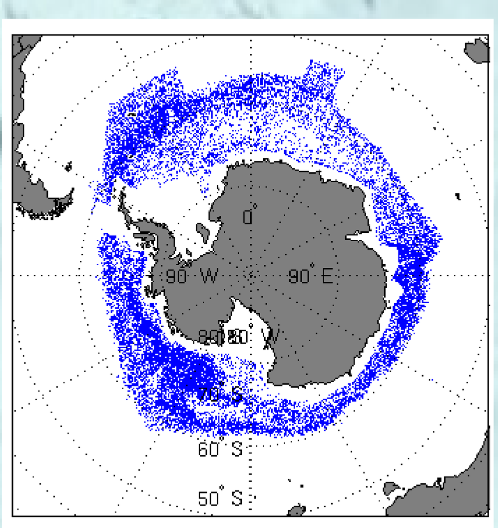
DDA Iceberg signature

The range aligned DDM maps over the iceberg shows the change of Doppler bin during the satellite overpass. For each DDM the position (range and doppler) of maximum backscatter within the waveform noise part is determined. The mean backscatter over the icebergs is computed by summing the DDM translated using the apparent iceberg displacement. This mean field gives a picture of the icebergs and a direct estimate of the iceberg area.



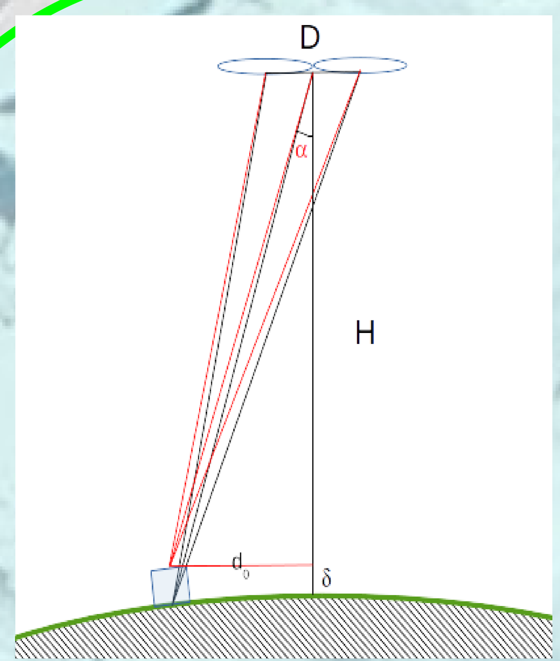


For pseudo no range alignment waveforms: detection of parabola within the noise part of the waveform space using convolution.
For pseudo LRM range aligned waveforms : signature = "**Brigth spot**". The detection is based on image filtering an unsharp contrast enhancement filter.
The range position from the parabola and the bright spot detection shows the complementarity of the two methods. The Doppler position from the DDM analysis is in perfect agreement with theory.
The map of backscatter from the average following the apparent displacement of the iceberg gives an estimate of the iceberg's area. Here the area is about 0.5-1 km².



An algorithm of detection based on bright spot detection has been used to process the DDA Cryosat archive. More than 30000 icebergs detected from 2010 to 2014. The data will be included in the Altiberg data base.

SARin mode



Interferometry on icebergs
The phase difference θ between the 2 antennas

$$\theta = \frac{2\pi D}{\lambda}\sin(\alpha) \qquad \alpha = \frac{\theta\lambda}{2\pi D}$$

Where α : incidence angle, D baseline, λ radar wavelength. Distance d_0 from nadir

$$d_0 = H\alpha$$

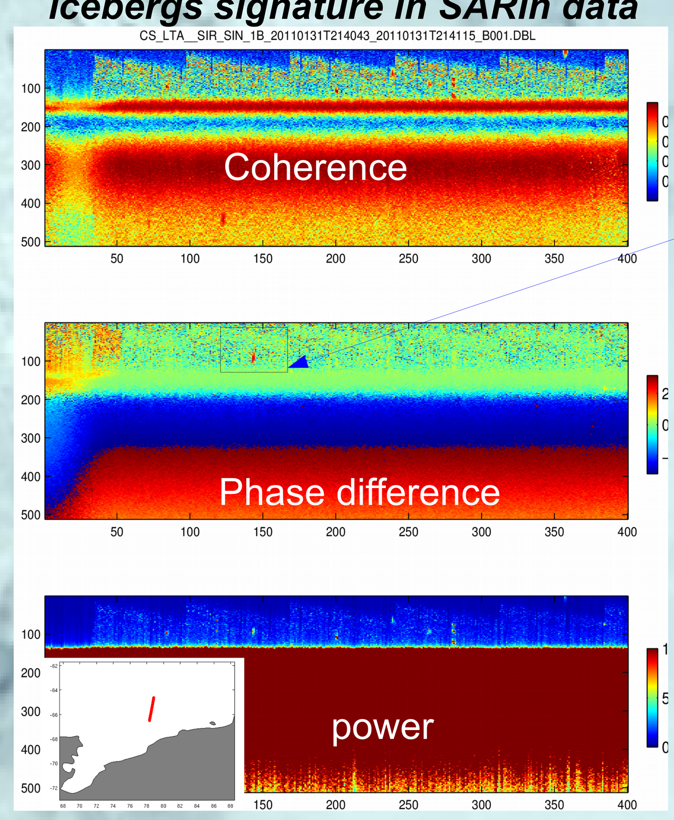
The range t_0 of the iceberg is given by

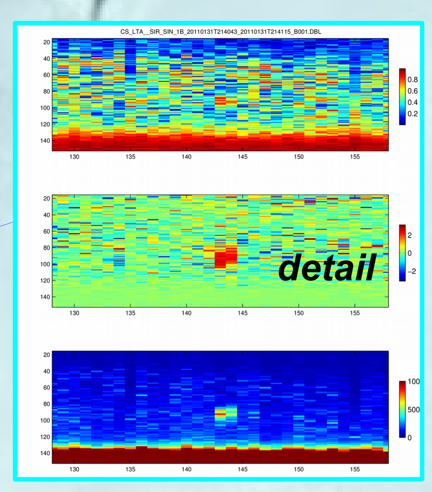
$$\frac{ct_0}{2} = -\delta + \frac{d_0^2}{2H''}$$

Where δ: height (freeboard), H'' extended satellite altitude; This

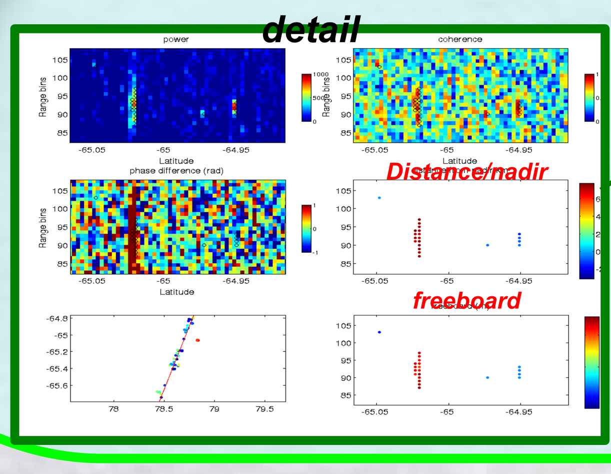
$$\delta = \frac{d_0^2}{2H''} - \frac{ct_0}{2}$$

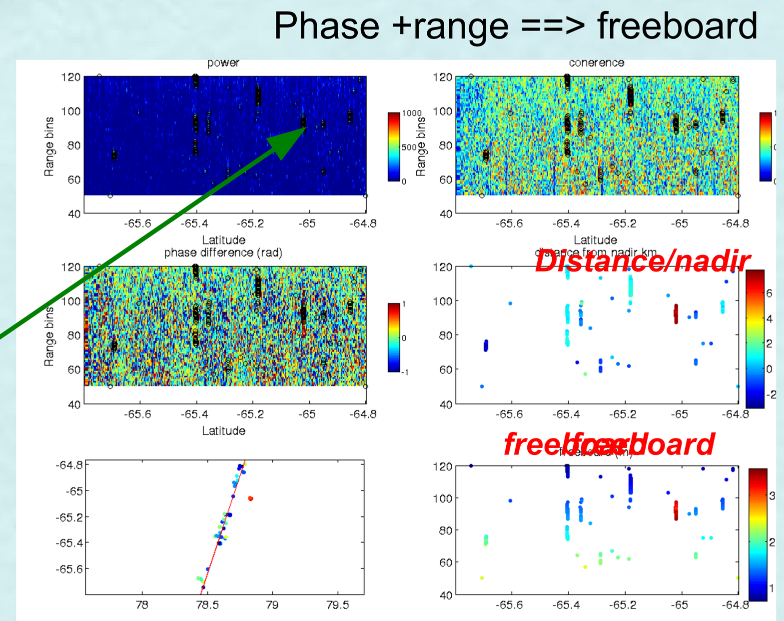
icebergs signature in SARin data





Iceberg: target emerging from sea surface, echo in the noise part where the power received by the 2 antennas is incoherent. The phase difference and coherence have a zero mean. Over an iceberg the returns are coherent and the phase difference depends on the distance from nadir.
Detection: bright spot in power and coherence >0.8.
Phase difference==> incidence angle.
Phase +range ==> freeboard





CONCLUSION & PERSPECTIVE

The three modes of operation of cryosat allows the detection of icebergs. For LRM and pseudo LRM (without range correction) the method is identical to the one used for classical altimeters.
For SAR data, the method of detection is based on the detection of bright spots within the waveforms noise part. Delay Doppler Altimetry provides Delay Doppler Maps that contains a wealth of information. The DDM gives a picture of the icebergs backscatter at high resolution. Using the position in range and Doppler of the iceberg it is possible to average the backscatter following the displacement and thus to reduce the noise level. This method provides a base to calibrate the model relating distance from nadir and area to range and backscatter.
In SARin mode icebergs have a detectable signature in power, coherence and phase difference. Indeed, the surface of icebergs gives a coherent signal in the noise part where the noise is normally incoherent. The detection is first made by bright spots detection and a threshold of coherence. The phase difference gives the distance from nadir and thus the freeboard using the rtelation betwse'en range, freeboard and distance from nadir. The three modes of Cryosat will be included in the Altiberg data base in the near future.

Raney, R.K., "The delay/Doppler radar altimeter," Geoscience and Remote Sensing, IEEE Transactions on , vol.36, no.5, pp.1578,1588, Sep 1998 doi: 10.1109/36.718861
Tournadre, J.; Whitmer, K. & Girard-Ardhuin, F. Iceberg detection in open water by altimeter waveform analysis J. Geophys. Res., 2008, {113}, C08040.