CRYOSAT LRM PROCESSING OVER ANTARCTICA

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ABSTRACT

Like for all past ESA missions (ERS1&2, ENVISAT) the CryoSat2 altimeter Low Resolution Mode (LRM) is used over a large part of the Antarctica ice sheet. In this work we analyze the products delivered by the Cryosat Processing Prototype (CPP) chain implemented by CNES [1].

The main part of the paper is devoted to the analysis of a spatially structured, pattern observed in the crossovers data. We argue that this pattern is caused by a phenomenon that has been already observed in the ERS and ENVISAT data and was previously documented [2], [3], [4].

However, the differences between the Cryosat2 and ENVISAT orbits provide new insights for the analysis which could prove useful in the future for revisiting this phenomenon and improve the processing of the historical data.

1. INTRODUCTION

The motivation for the work described here was to continue a study initiated by F.Boy and presented at the CryoSat meeting in February 2011 [1].

Strange patterns were rapidly detected in the Low Resolution Mode (LRM) data generated by the CNES Cryosat Processing Prototype (CPP) chain using cross-overs analysis. Fig.1 shows the differences at cross-overs for both the retrieved ground height and backscatter. Their amplitude are significant: over +/- 1 meter for the heights and +/- 2 dB for the backscatter.

In the meantime, people in charge of the Precise Orbit Determination (POD) were asked if this behaviour could be caused by an error in the orbit determination. So, we slightly change the focus of our analysis in order to specifically investigate this point.

2. ELIMINATION OF POTENTIAL CAUSES

As Fig.1 shows, the height differences at cross-overs have a direct counterpart in the backscatter. This fact shows us that an error in the POD cannot be the origin of these patterns (if we believed that the POD could be in error by more than 1 meter, which is not possible given the orbit accuracy).

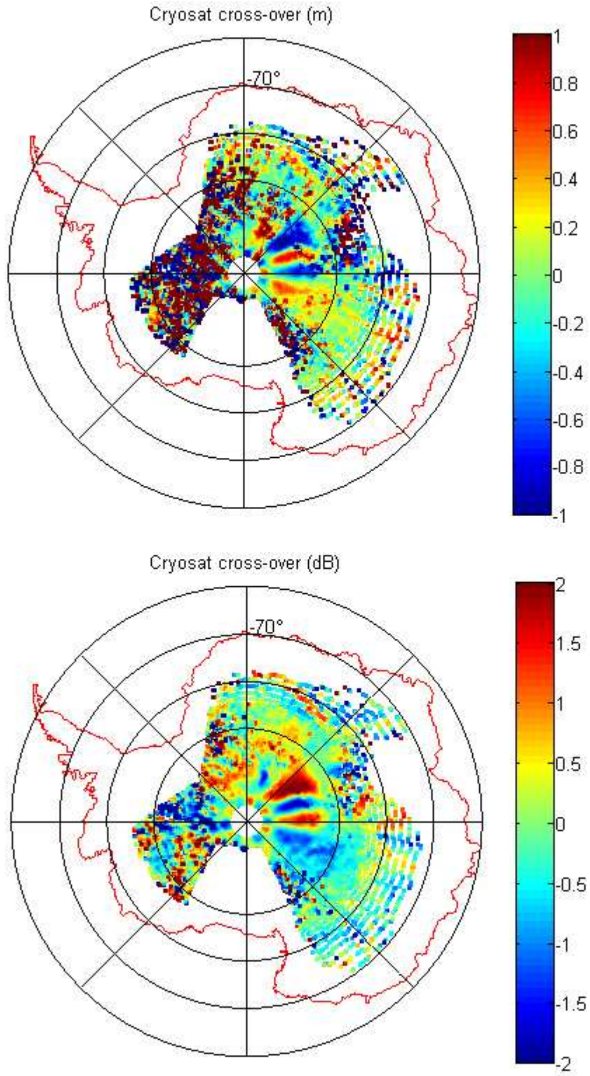

Figure 1. Pattern seen in cross-overs analysis of data produced by the CNES CPP chain

In addition, we note on Fig.1 the strong anti-correlation between height and backscatter differences: when the height difference is maximum and positive, the backscatter difference is minimum and negative and vice-versa.

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An error in the CPP processing is also excluded as we see from Fig.2 taken from the Cryosat Performance Monitoring pages [5] that the pattern in the differences at cross-overs is also seen in the official ESA products.

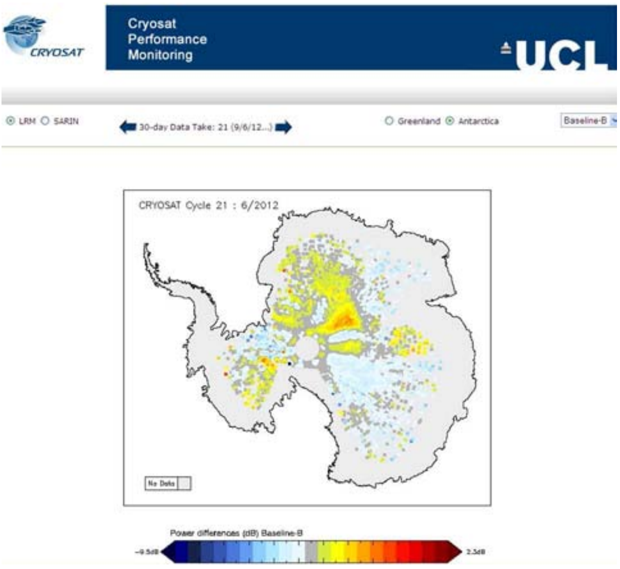


Figure 2. Same effect seen in CryoSat Cal/Val pages

The same reasoning as above excludes an error in the cross-over processing. So we now focus our attention on two of the large homogeneous regions apparent on Fig1. with extreme differences of opposite signs (Fig.3).

3. ANALYSIS OVER TWO LARGE REGIONS

We choose two tracks crossing these regions and analyse the Cryosat measurements along these tracks.

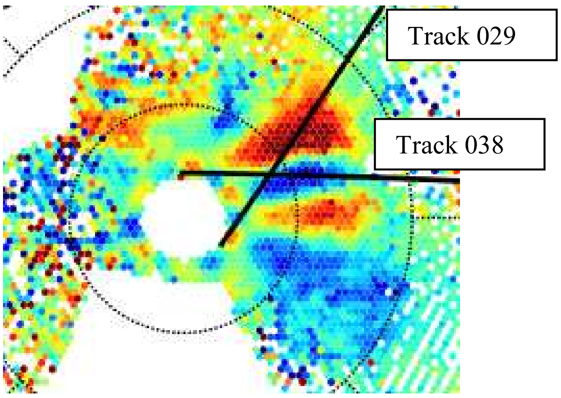


Figure 3. Analysis along the tracks 038 and 029 of subcycle 30 (May 2012, CPP numbering)

Fig 4. shows the along track measurements (ice1 backscatter) for tracks 29 and 38 and the crossing tracks superposed over the MODIS Mosaic Of Antarctica (MOA) at resolution 750 meters [6].

First of all, we note that the cross-over differences are well seen in the along-track data. Even if some topography induced along-track variations are present, we can see very clearly the different behaviour between ascending and descending tracks.

Second, we notice that the terrain overflown by the satellite is very different for track 29 (undulations and dunes) and track 38 (more uniform terrain).

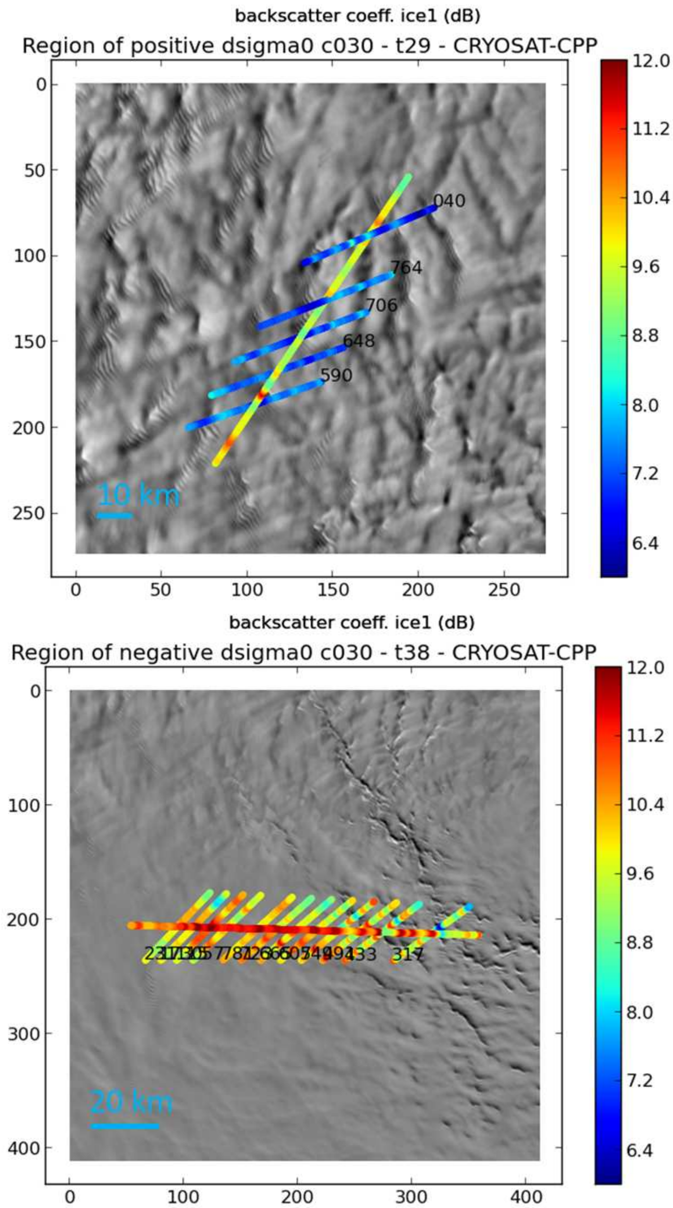


Figure 4. Analysis along the tracks 038 and 029 of subcycle 30 (May 2012, CPP numbering)

Fig.5 shows the waveforms closest to the cross-over point intersection of tracks 029 and 040. As we want to compare the waveforms from these two tracks, three of them from each track are drawn in order to verify that the difference is not caused by along-track variability.

We see on this figure that the shape of the waveforms depends on the track from which it is extracted. The difference is mainly seen around the "peak": the shape is "rounder" for the waveforms on t040 than for the others.

This modification of the shape of the waveforms is likely due to a difference in the ratio of surface and volume backscatter for the ascending and descending tracks.

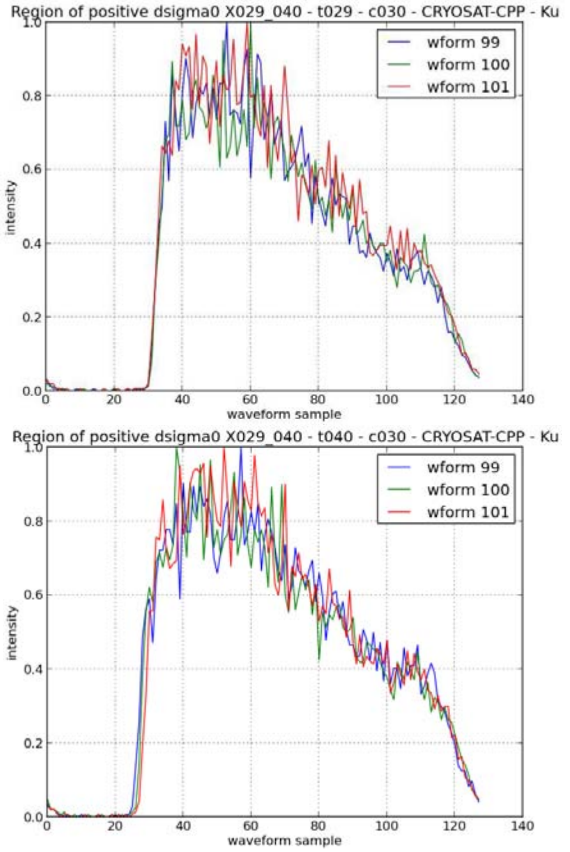


Figure 5. Waveforms extracted around the cross-over t029 x t040 (3 for each track)

Indeed, it is well known that penetration of radar waves in the snow is lower for Ka band than for Ku. This is illustrated by Figure 6 which compares the CryoSat2 waveforms in Ku band (Fig. 6a) with the AltiKa ones in Ka band (Fig. 6b) measured on the same period over the Vostok subglacial lake which is a very flat area.

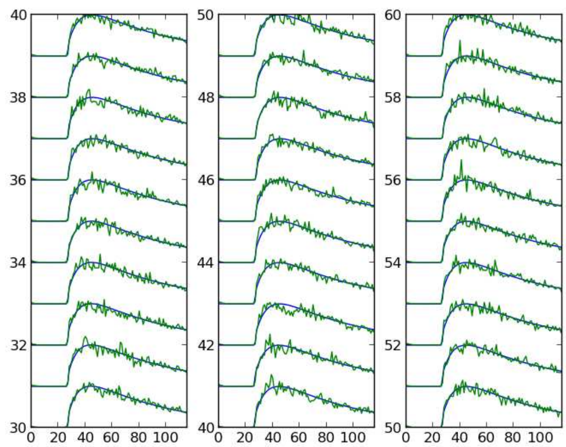


Figure 6a. CryoSat2 waveforms (Ku band) over Vostok

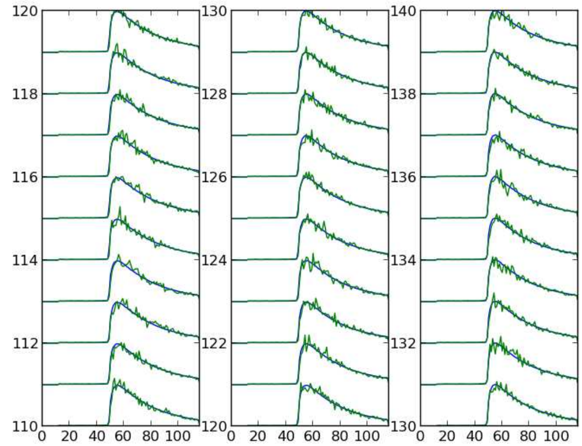


Figure 6b. AltiKa waveforms (Ka band) over Vostok

Two main differences are seen between the waveforms in Fig. 6a and Fig. 6b. First, the leading edge of the Ka band waveforms is steeper, especially just before reaching the maximum. This effect is due to the lesser penetration of the Ka band waves into the snowpack.

Second, the trailing edge for the AltiKa waveforms has a larger (negative) slope than the CryoSat2 ones. In addition they also show a strong curvature of the trailing edge. These two effects are due to the antenna beam which is a lot narrower for AltiKa than for CryoSat.

4. AN ALREADY KNOWN EFFECT

In section 3 we saw that the differences at cross-overs observed on the retrieved height and backscatter is also seen in the shape of the waveforms and then that the cause for these observations is really in the raw measurements of the altimeter.

However, the observation below the figure 1, stating that the height differences are anti-correlated with the backscatter, shows us this already because this is an effect that has been seen in the ENVISAT measurements ([2], [3], [4], and Fig.7).

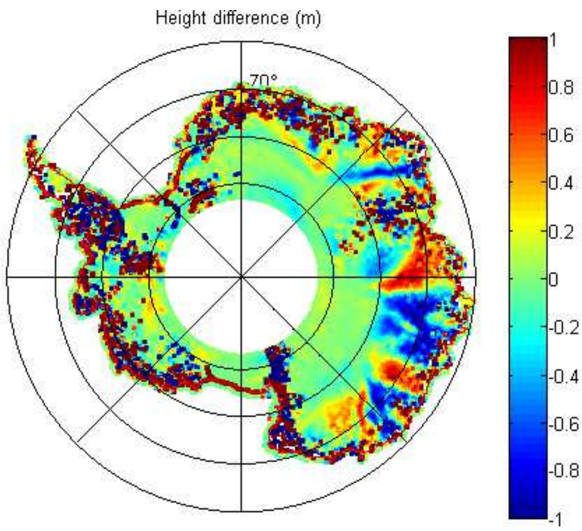


Figure 7a. ENVISAT height differences at cross-overs

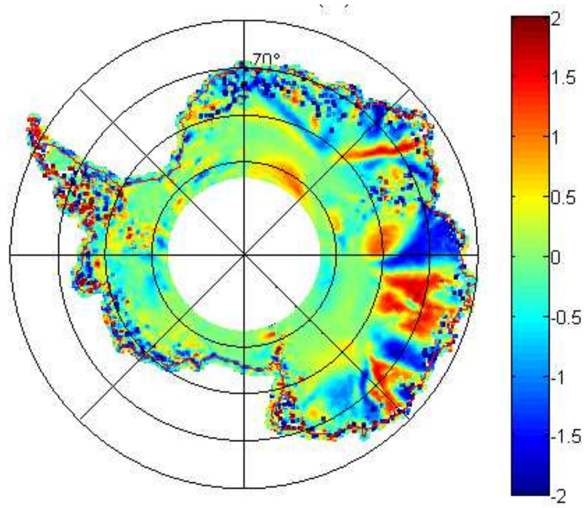


Figure 7b. ENVISAT backscatter differences at cross-overs(dB)

Fig.7a and 7b show exactly the same anti correlation between height and backscatter in the ENVISAT measurements as in the Cryosat2 ones.

In addition, Fig. 8 below shows that the relationship between the height differences at cross-overs and backscatter differences is very linear up to a difference of +/- 1 dB and that the slope is the same for Cryosat2 and ENVISAT (-0.4 m/dB).

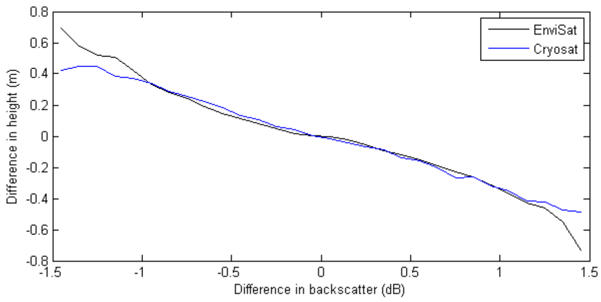


Figure 8. Linear relationship between backscatter and height differences at cross-overs

The spatial patterns for Cryosat (Fig.1) and ENVISAT (Fig.7) are different but this is normal for two reasons.

First, the observed regions are not the same because the maximum latitude reached by Cryosat is much larger (88°) than for ENVISAT (81.5°) and because at lower latitude the Cryosat altimeter is in Sarin mode whose data is not analyzed by CPP.

Secondly, the angle between the tracks at crossovers is very different for ENVISAT and Cryosat because of the different inclination of the orbits. It is linked with the explanation of the physical phenomenon that produces the differences at cross-overs in [2], [3], [4]. We will summarize this explanation in the following.

The root cause identified in the above references is the anisotropy of the surface caused by the dominant winds (Fig.9) coupled with the fact that the radar waves are linearly polarized for all modern radar altimeters.

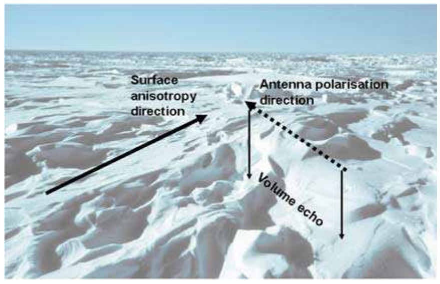
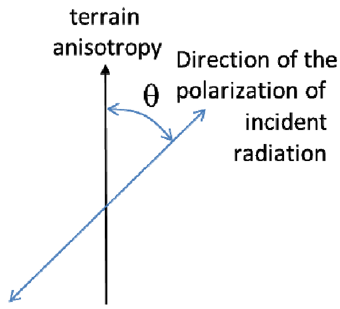


Figure 9. Antarctica surface (from [4])

The terrain (surface and/or subsurface) then acts as the superposition of an isotropic surface and a perfect polarizer whose reflectivity depends on the angle θ defined on Fig.10.



Perfect polarizer

$$r(\theta) = r_0 * \cos^2(\theta) \quad (1)$$

Figure 10. Reflectivity for a perfect polarizer

The geometry of the tracks at any cross-over point is illustrated by the Fig. 11. The ascending and descending tracks are symmetrical with respect to the parallel circle making an angle α with it. The plane of polarization of the radar waves is fixed with respect to the satellite frame so the direction of the polarization is not the same for the ascending and descending tracks. Therefore, if the terrain acts as polarizer, then the reflectivity will not be the same for ascending and descending tracks and the difference in received power by the radar will be interpreted as a difference in backscatter.

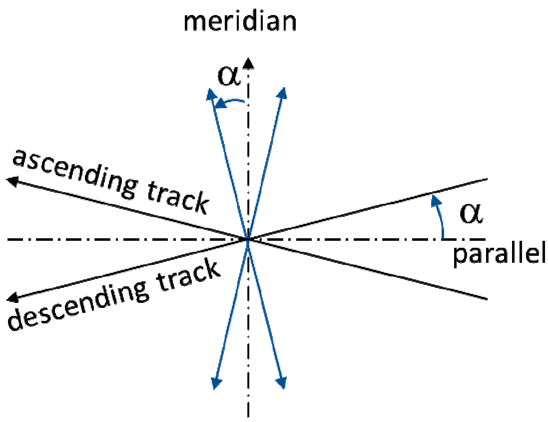


Figure 11. Geometry of the tracks and polarization angles at cross-overs (Cryosat case : plane of polarization at 90° from the satellite tracks)

References [3], [4] and [5] explain the correlation between height and backscatter differences at cross-overs by the fact that anisotropy of the terrain changes the ratio of the energy scattered back by the surface and by the subsurface (volume backscatter).

5. ANALYSIS OVER THE CENTRAL RING

After the analysis of the two main large regions done in section 3, we focus now our attention on the ring seen at the highest latitudes reached by Cryosat (see Fig.1). This region shows an interesting alternation of positive and negative differences which seem rather regularly spaced. Fig. 12 below shows an extract of the backscatter differences at the center of the ring (around latitude 87.6° S). We see that the differences seem to be influenced by the terrain overflown by the altimeter but the sign of the differences is reversed with respect to Fig. 4. This is confirmed by the analysis of Fig.13: there seems to be an inversion of signs of the differences at cross-overs at a latitude slightly above 87° S.

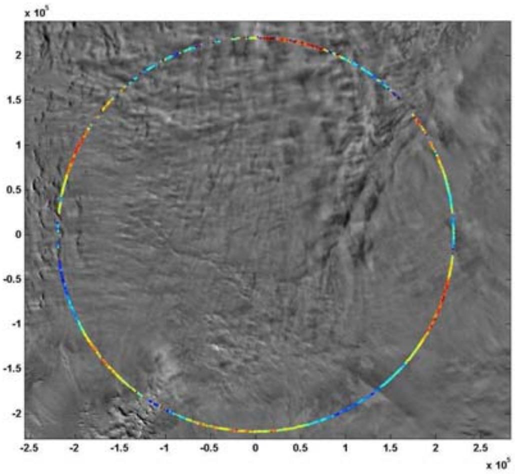


Figure 12. Backscatter differences at cross-over at latitude 87.6 deg over the MODIS MOA image (750 m)

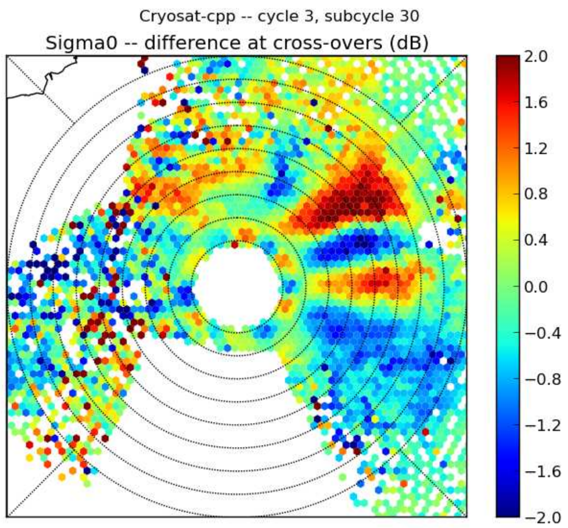


Figure 13. Backscatter differences at cross-overs. Parallels drawn for latitudes 88° S, 87°, 86°, …, 80° S

The angle between the ascending and descending tracks at cross-over points is, for a given orbit, a function of the latitude of the cross-over point only. This makes 87.15° S a very special latitude for Cryosat because as shown by Fig.14 below, this is the latitude where the ascending and descending tracks form an angle of 90°.

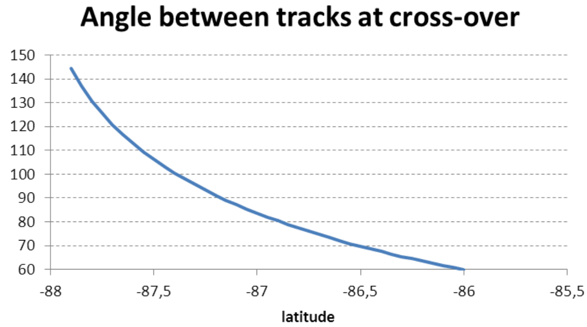


Figure 14. Cryosat tracks at cross-over are orthogonal for latitude 87.15° S

This means that for some reason the effect described in section 4 is modulated by a superposed one which cancels when the angle between crossing tracks is equal to 90°.

When an empirical correction to account for this modulation is applied to a simulation of the anisotropy effect for ENVISAT (Fig.15) the result is much closer to the observations than without it.

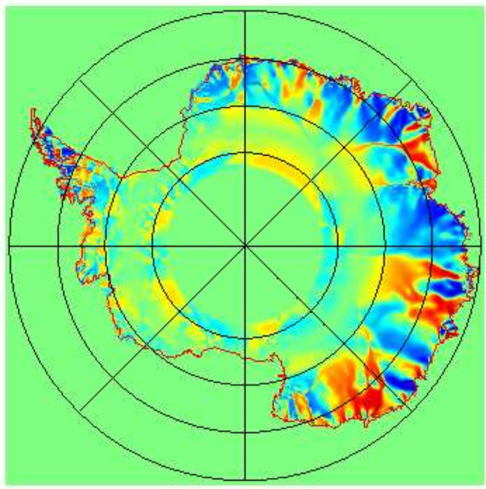


Figure 15. Envisat simulation of anisotropy effect on backscatter with empirical correction for tracks angle at cross-over (to be compared with Fig.7b)

6. IMPACT OF ANTENNA ELLIPTICITY

The Cryosat antenna beam has an elliptic shape [7], [8]. The ratio between the major and minor axis is around 1.10 according to different sources. This could cause some differences at a cross-over point over a sloping terrain. Indeed, it is well known that the altimeter tracks the closest approach point rather than the nadir which is the cause for the need of slope corrections. Fig. 16 also shows that in the case of sloping terrain the signal is shifted away from the nadir direction.

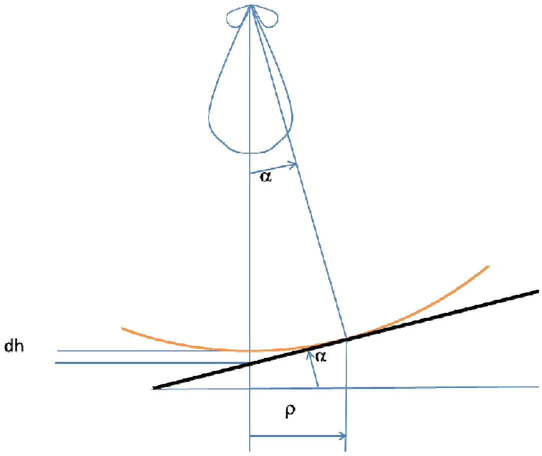


Figure 16. Effect of terrain slope : (1) need slope correction of height,(2) displacement of the direction of the echo in the antenna beam

This means that if the antenna beam is elliptical, the actual gain of the antenna will depend on the direction between the major axis and the direction of the largest slope. In order to quantify this effect, we performed simulations of waveforms and retracking (ice1) for different values of the slope (from 0 to 0.5°) and in the two extreme cases: (1) major axis along the slope direction, (2) minor axis along the slope direction.

Fig.17 shows the result of these simulations. The retrieved backscatter (no slope correction applied) is plotted against the slope of the terrain for the two configurations of the antenna beam (as ratio in dB with respect to the backscatter retrieved for a flat horizontal surface).

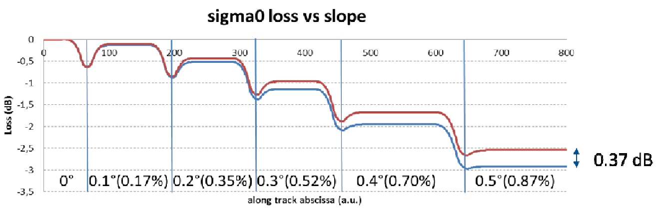


Figure 17. Maximum effect of antenna gain ellipticity on backscatter differences at crossover

The main effect seen on this figure is the slope effect (loss of apparent backscatter coefficient as the slope increases). It also appears that this loss is dependent on the configuration of the antenna beam. However, the difference between these two extreme configurations does not exceed 0.37 dB for the maximum slope simulated (0.5°). This is significant but less than the figures for which we are looking.

7. CONCLUSIONS

This is still a work in progress. Nevertheless, we have shown that the observed patterns are not caused by errors in the POD (Precise Orbit Determination) nor in the ground processing (L1, L2 or Cal/Val).

We believe that these patterns are caused by an effect already seen in ENVISAT data (and ERS). This effect is also now seen in AltiKa data, but with a different signature due to many differences between altimeter measurements in Ka and Ku bands. It is governed by the nature of the observed terrain under the altimeter. It is attributed to a coupling between polarization of radar waves and anisotropy of the terrain

Superposed to this effect, a second major effect is controlled by the angle between the tracks with an inversion of the signs when the track angle is 90° on CryoSat.

The ellipticity of the antenna beam has a lower effect.

From a more methodological point of view, it has been found very useful to use different points of view in order to investigate this question. We used various altimeters, different bands, different orbits, different data processing chains, a mix of altimetry and optical imagery (MODIS MOA) and global versus local and even waveforms analysis. We believe that this multiplicity of points of view will allow us in the future to decouple the various effects that are the causes for the observations discussed at length in this paper.

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8. REFERENCES

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