LONG TERM SURVEY OF ANTARCTICA WITH ALTIMETRY: ERS1/2, ENVISAT, SARAL, THE KEY IMPORTANCE OF CONTINUOUS OBSERVATIONS

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ABSTRACT

The main goal of this presentation is to argue for an extend of the 35-d repeat orbit of the series ERS-ENVISAT-SARAL. Indeed, for almost 20 years radar altimeters surveyed Greenland and Antarctica ice sheets on a 35-day repeat orbit, providing a unique data set for ice sheets mass balance studies. In particular, from September 2002 to October 2010 up to 85 repeat cycles are available thanks to ENVISAT and the whole data set can be along-track processed in order to provide height variability and trend with an adequate space resolution for the objectives of ice sheet survey.

In February 2013, a joint CNES/ISRO mission, SARAL, with the AltiKa altimetric payload on board, was launched on the same orbit (more or less 1 km in the across-track direction but a little more for the first cycles). This allows an extension of previous ERS-1, ERS-2 and ENVISAT missions from ESA, in particular from the point of view of ice altimetry. However, AltiKa operates in Ka-band (35.75 GHz), a higher frequency than the classical Ku-band (13.6 GHz), leading to important modifications and potential improvements in the interaction between radar wave and snow pack.

1. ALONG-TRACK OBSERVATIONS

Analysis of temporal survey may be performed only at crossover points (see for instance [1]) or along-track (see [2]). Of course, the along-track spatial coverage is much denser (around 20 times) than the cross-track one. It thus provides more details and allows to better describe some temporal phenomena. However, because of the across-track surface slope and of the fact the tracks are not exactly the same from cycles to cycles (dispersion within 1 km), the along track process needs to fit four additional parameters (1st and 2nd order of 2D surface slope) than with crossover technique that eliminates (or at least reduces) the surface slope impact. The duration of the repeat mission should then be longer. We will discuss this in section 2. and show that the duration of the ERS-2 and ENVISAT (more than 80 available cycles for both) is long enough to reach the required precision.

The along-track process indeed allows recently to catch with a high space resolution several temporal features related with important glaciological processes. For instance, not only we detect the acceleration of the volume loss of the Pine Island [3] but also we visualize the shift with time of the central part of the glacier toward South. Other small glaciers of the Admunsen sea sector that also exhibit loss acceleration can be as well surveyed. In the Eastern part of the Antarctica ice sheet we also catch the down slope impact of the large emptying of subglacial lake Cook2 [4].

2. PRECISON ON TREND VERSUS NUMBER OF REPEAT TRACK

The aim of this paper is to argue for a long survey on a continuous orbit. We thus perform a simulation in order to estimate the precision on the retrieved height trend with respect to the duration of the mission. The space and time characteristics of trend needed for such a simulation may be derived from along-track observations.

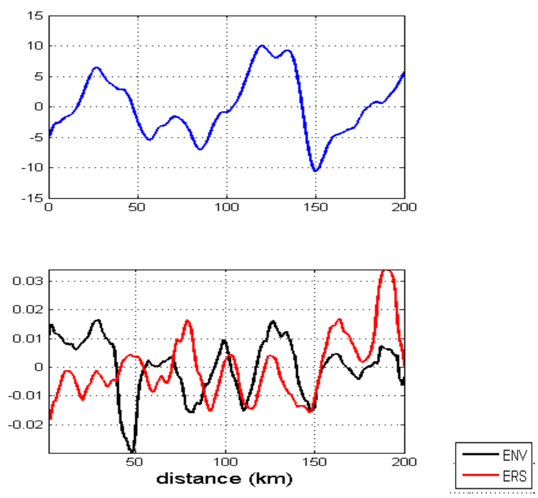

Figure 1: Height profile in Antarctica (up, in m) compared to elevation trend (down, in m/yr) during ERS-2 period (in red) and ENVISAT period (black). From Remy et al. (2013). Note the short wavelength signal in the trend induced by the surface undulations at the 10-km scale.

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From a spatial point of view, the 20-km scale undulations affect the elevation trend, so that this latter has a decorrelation length around 7 km. The Nyquist-Shannon theorem stipulates that a sampling closer than 3.5 km is required. Moreover, one can remark on Figure 1 than these 10-km scale seem to be reproducible between ERS and EnviSat.

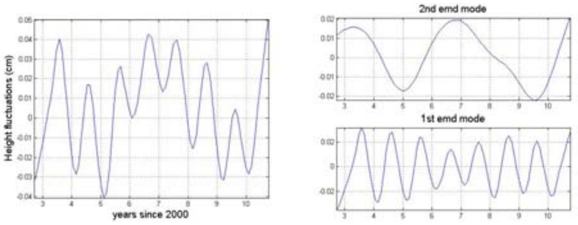

Figure 2. The left figure shows the temporal variability of ENVISAT averaged over the whole Antarctica ice sheet. On the right, we decompose the signal with the help of a Empirical Mode Decompostion (emd) that separate a clear seasonal signal of amplitude 2 cm (bottom) superimposed on a 4-yrs period signal.

On a temporal point of view, the seasonal component is clearly the larger one but a 4-yr component is also visible.

We thus perform a simulation, as explained in Remy et al. (2013) in order to examine the number of required cycles to reach a given precision on the trend retrieval.

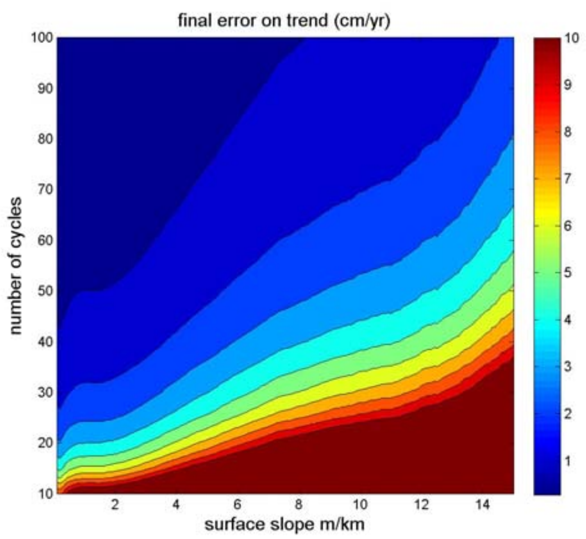

Figure 3: Final error on elevation trend with respect to surface slope and number of cycles.

For a surface slope of 5 m/km, 50 repeat cycles are needed to reach a precision of 2 cm/yr. If we remove from simulation the across-track slope induced error, around 40 cycles are enough. The convergence is thus faster. This shows that cross-over analysis converge toward a good precision more rapidly than the along-track technique.

However, thanks to the 85 repeat cycles of ENVISAT, the across-track slope is now well known around the average track of ENVISAT and ERS-2 so that past (such as ERS2) or future satellites (such as SARAL) will take advantage of it.

3. ALTIKA ON SARAL

On February 25th, 2013, the SARAL/AltiKa CNES-ISRO mission was launched on the same 35-d repeat orbit than previous ERS and ENVISAT ones. The first goal is to extend the historical series of observations provided by ERS and ENVISAT. Moreover, it operates in a higher frequency (Ka band or 36 GHz) so penetration is smaller and it provides new opportunities to better understand the interaction between radar wave and snowpack.

We present here, three preliminary empirical attempts to evaluate the part of energy that it scattered back by the subsurface (volume part) versus the part scattered back by the surface in Ka band altimeter measurements.

First, over the Antarctica ice sheet, the comparison between the backscatter and two of the parameters computed by the Ice2 retracker shows that the leading edge and the trailing edge corrected for the antenna pattern gain and the surface slope are sharper in Ka-band than in Ku-band. This suggests that indeed deep volume echo is less important in Ka-band than in Ku-band.

Second, the first cycles show that the temporal variability is quite impressive since up to 3 dB between two consecutive cycles above the Vostok lake can be detected. At the global scale, we observe up to 5 dB changes between beginning of cycle 1 and end of cycle 4 (from mid March to early August).

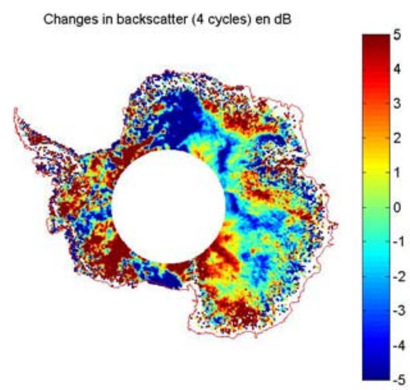

Figure 4: Temporal variations in backscatter (dB) during the four first cycles of AltiKa.

These temporal backscatter variations, mapped on Figure 4 get a clear geographical signal that is in good accordance with the seasonal signal for Ku-band backscatter. This suggests that both Ku and Ka band are well in phase and probably affected by the same seasonal forcing.

Third, it is well known that the difference at crossover points is up to 2 dB in Ku. This effect is controlled by the angle between antenna polarisation direction and surface anisotropy polarisation. It has been previously attributed to a volume modulation either by transmission [5] or by extinction [6]. We were thus expecting to have a reduced effect in Ka band. In fact, this opposite is observed. The cross-over difference between ascending and descending backscatter varies also for Ka band within 2 dB.

We thus observe on backscatter both large temporal variations and difference at cross-over. Both observations suggest a large presence of echo volume. However and happily, for both phenomena the impact on height is relatively less than in Ku-band: around 0.07 m/dB or ten times less than in Ku band. So that, a few tens of repeat cycles should be needed in order to well correct for this artificial variability.

However, as for temporal variability, the impact on height is around ten times letter than for Ku band.

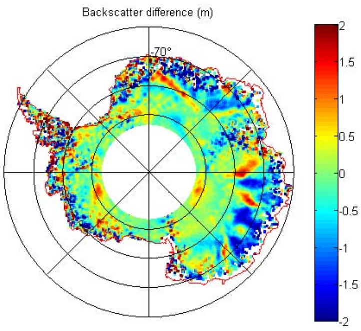

Figure 5: Backscatter difference for Altika/SARAL (dB).

Then, we observe that both the large temporal change in backscatter and the large crossover backscatter difference have only a slight impact on the height. This seems to suggest that volume echo for Ka band is mostly due to ice grain scattering from the upper surface while it was due to both ice grain scattering and internal reflexions for Ku-band with then a greater penetration depth.

4. CONCLUSION

Along-track processing to derive height trend over ice sheet from a repeat track satellite provides a denser data set (20 times denser) than a classical cross-over analysis. This high density offers the opportunity to catch a lot of details, both in space and time, needed to understand well all the processes acting on surface changes. Moreover, the finer sampling directly provides a better accuracy on balance estimation because it helps in the across-track interpolation. However, because of the across-track slope and the repeat-track within 1 km, we need to fit not only the across-track slope but also the curvature. We may add in the fit four unknown so that a longer term observations is then required to reach a good precision on temporal trend. About 50-60 repeat cycles are needed in order to reach the required precision. Happily, the 85 available cycles is enough to reach this requirement.

However, now, with the duration of ENVISAT mission, the across-track slope characteristics are well known and other missions on the same orbit (previous ERS-2 and SARAL/Altika) may take advantage of it. Altika/SARAL, launched in February 2013, the ENVISAT follow-on mission on Ka-band provides thus an extend of previous observation and offers new opportunities to better understand the interaction between the radar wave and the snowpack and may help in the interpretation of previous Ku-band missions.

First results with AltiKa are promising: Waveform shape indeed confirms the weaker depth volume echo. However temporal changes and cross-over differences suggest presence of volume echo on backscatter with a moderate answer of the height. This suggests that ice grain scattering from the upper surface is the main process acting on volume echo, while internal stratification was playing also a role in Ku-band.

5. REFERENCES

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6.ACKNOWLEDGEMENTS

Altika data are available on Aviso website. Envisat mean parameters along track (height, backscatter, two vaweforms shape, 2-D surface slope) and their trend and correction (geographic and radiometric) also.