Land Ice Cal/Val : importance of ice sheets monitoring

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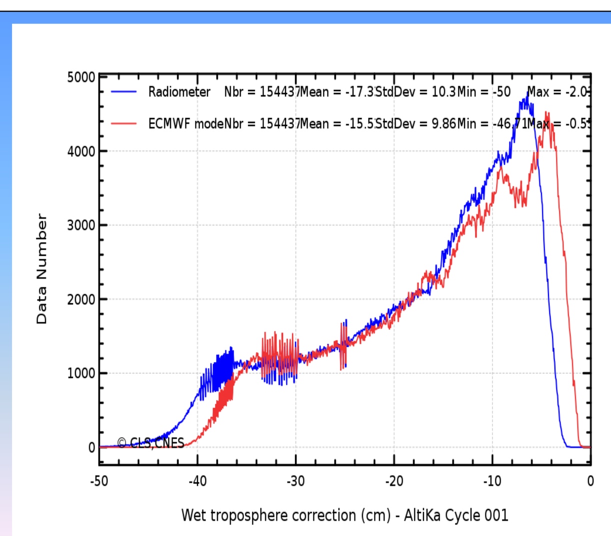
Ice sheets are essential in the world climate, and in the context of the global warming, it is important to understand the interaction between oceans and ice sheets , the effect on them and their contribution to the sea-level rise. We focus here over the world's largest ice sheet, the Antarctic continent. Furthermore, these polar areas are still greatly unknown in their dynamics, their properties, their evolution due to the extreme climate conditions, especially in Antarctica where in situ observations suffer from an irregular spatial sampling. Satellite altimetry resolves this problem by providing regular temporal and spatial samplings. Since 1991, ERS1, ERS2 and Envisat surveyed ice sheets on the same orbit and thus help glaciologists to constrain electromagnetic or climatological models,to retrieve geophysical properties and to estimate the mass volume, equivalent to a sea-level quantity. The monitoring of ice sheets is consequently crucial to analyse accurately satellite observations.

Thus, jointly with CLS, LEGOS and CNES, a Cal/Val tool over ice sheets is being developed in order to obtain a high-level product available to both glacioligists and oceanographers to complete studies and to allow this permanent monitoring. We benefit from the innovative altimetric mission SARAL/AltiKa launched in February 2013 to start this tool and we show here the dense processing we have, the results, and what we can benefit from this powerful Cal/Val tool in the short and the long-term.

Differences and complementarity of CalVal over ocean and land ice

With altimetry, just like over oceans we want to follow temporal variations of parameters Our most relevant parameter to follow ice sheets evolution is the topography (Height) analogue to the SSH or Sea Surface Height. In glaciology, we have a 10 times greater signal in space and time, but 10 times less precise (it is the same signal to noise ratio), moreover it is not the same error budget. It doesn't imply the same analysis. We also need the complete waveform and its parameters (leading edge width, backscatter, trailing edge slope) that are significant to inform us about the snowpack properties or the interaction between the radar wave because we deal with various effects not as predominant over oceans that bias the retrieved height. We name three : the slope effect, the differently-scaled roughness and the penetration. In particular, due to the across-track slope and the temporal changes in the snowpack characteristics, we have to correct for the track position (so-called the ''geo'' correction) and the change in the backscatter (so-called the ''echo'' correction) (see Flament & Rémy, 2012). Finally, atmospherical and geophysical corrections can't always be used (dry troposphere with the radiometer) at the poles and do not have the same range necessarily as the Fig 1(a,b) shows. All these arguments prove a dedicated Cal/Val tool is needed to complement the existing tools over oceans and the adaptation is mainly in the Editing part.



1a

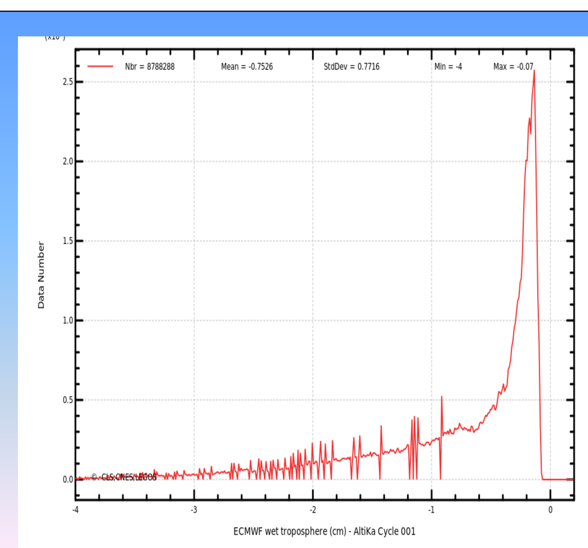

1b

Fig1 : wet troposphere distribution over oceans (a) over Antarctica (b) : large variability over oceans (50cm), on the contrary low values (4cm) over Antarctica

Comparison to models

We may help our analysis by comparing with a DEM and with a waveform simulator over ice sheets to help understand the behaviour of the altimeter over land ice. Also, we can use MODIS (Moderate-Resolution Imaging Spectroradiometer) images, on Fig 4 is plotted the Backscatter in dB for Cycle 2 over CapPrudhomme with the MODIS image of the corresponding area, it may help us to link geophysically the waveform parameters behaviour, for instance by noticing the undulating terrains.

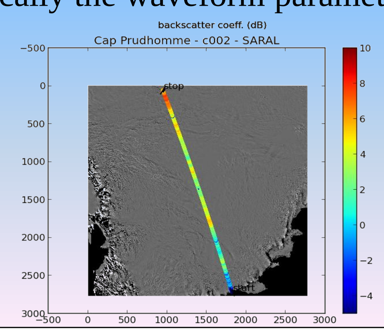
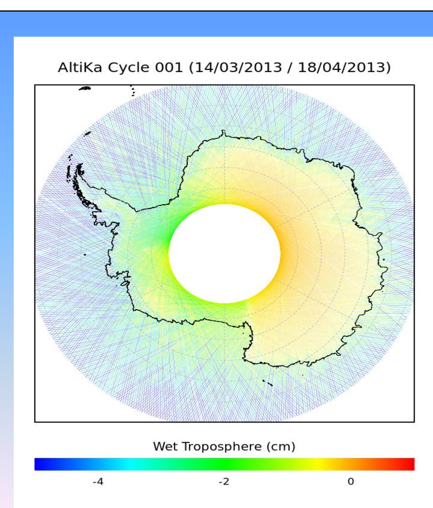


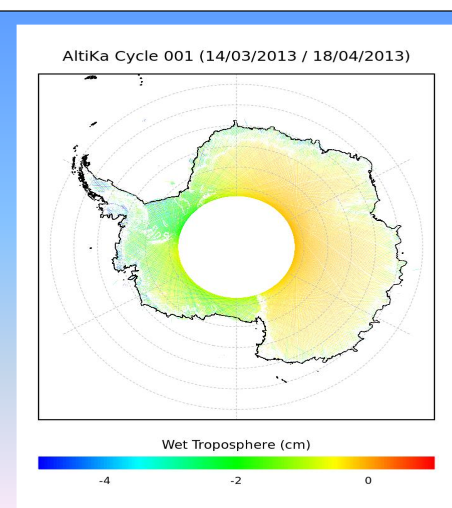
Fig 4 : Backscatter coefficient in dB over CapPrudhomme for Saral (Cycle2, pass 632) with the corresponding MODIS image

Editing = data selection

We complement the studies over oceans which reject land surfaces by isolating our satellite data over Antarctica, we base our selection by a test on the latitude (< -60° S) and on the geoid (corrected altimetric range > geoid + 10m). We see thanks to Fig 3 that we keep our data over Antarctica. We use thresholds on the backscatter but not other waveform parameters as they are limited in the ICE-2 retracking



3a



3b

Fig 3 : before the Editing (a), after the Editing (b)

Multi-mission comparison

Up to 2013, in radar altimetry we were in the Ku-band era : ERS1/2 or Envisat monitored Antarctica at 13.6 Ghz. Saral/AltiKa has innovative characteristics : a better spatial and vertical resolution, a narrower footprint, theoretically a lower penetration depth than in Ku-band and a better sampling in the leading edge width. Moreover, Saral/AltiKa has the same repeat cycle (35 days) and the same repeat orbit (more or less 1.4km at the poles) so we have a temporal continuity at the same location points which is essential. Thus, for land ice as well, Saral/AltiKa is promising. We are able to compare Saral with former missions, for instance Envisat in Ku-band such as the Fig 5 shows. We observe the difference distribution between the elevation retrieved by Envisat and the one by Saral over the Vostok area, a relatively flat surface. The mean is about -1.5 to -2meters which may confirm the penetration, although more Saral cycles are needed. Moreover, at crossover points, due to a polarization effect, the interpretation is complicated.

Moreover we can also use Icesat, a laser altimeter that monitored Antarctica from 2003 to 2009 and is considered completely free from the usual errors we have in radar altimetry. On Fig 6 is plotted the mean difference for the 6-year data between Envisat and Icesat at crossover points on Vostok. It is about -2 meters to -2.5 meters and it becomes positive on coasts (due to the slope effect). The difference is mainly due to penetration over flat areas and by doing the same with Saral, we'll be understanding better this effect over Antarctica.

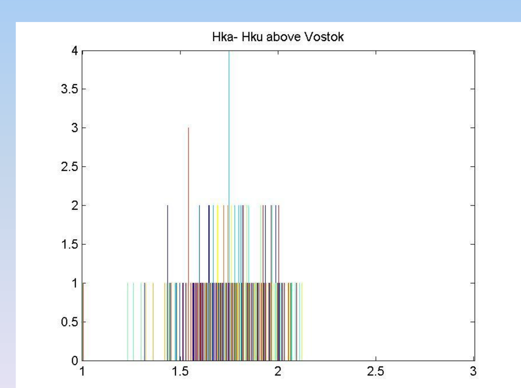


Fig 5: Elevation difference distribution in meters between Saral and Envisat at crossover points at Vostok

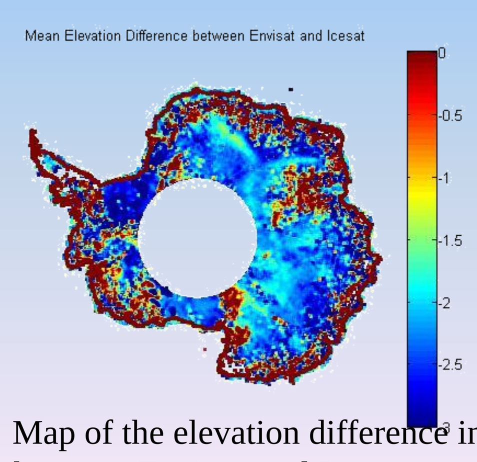


Fig 6: Map of the elevation difference in meters between Envisat and Icesat at crossover points

Instrumental and geophysical monitoring

This dedicated CalVal allows us to have a permanent monitoring for waveform parameters, the geophysical corrections, to observe the different tracking modes… We also do a statistical monitoring at different temporal scales (by day, by cycle, by pass). For example, the Fig 6 shows the mean by day of the retrieved height, we detect instrumental events like the DEM mode in the first cycle.

To observe continually the waveform parameters is essential : we present here the temporal evolution for the backscatter in dB and the leading edge width in meters for the first 3 Saral cycles (SIGDR products) . At the right are plotted the mean values (6-year data) for the same waveform parameters from Envisat plotted at the same scale. For the backscatter, we clearly observe that Envisat retrieves a higher backscatter of about 3dB. We have a different surface echo and a different volume echo in Ka-band as it is not the same frecuency. For the leading edge width, it is 1m lower for Saral than with Envisat, we know that the leading displays the penetration effect so we may suggest we do have a less penetration into the snowpack. For both parameters, we see the same geographical patterns, suggesting the same geophysical effects but not seen at the same frequency. Clearly we need more data from Saral to confirm and learn more about the Ka-band.

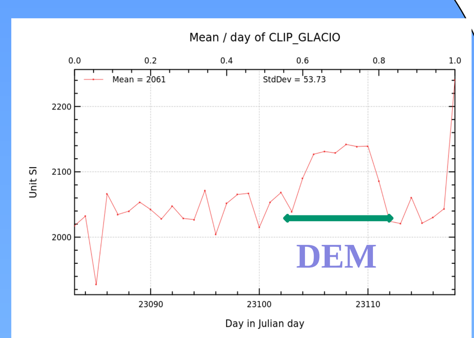


Fig 6 : mean by day for the retrieved height 1st Saral cycle

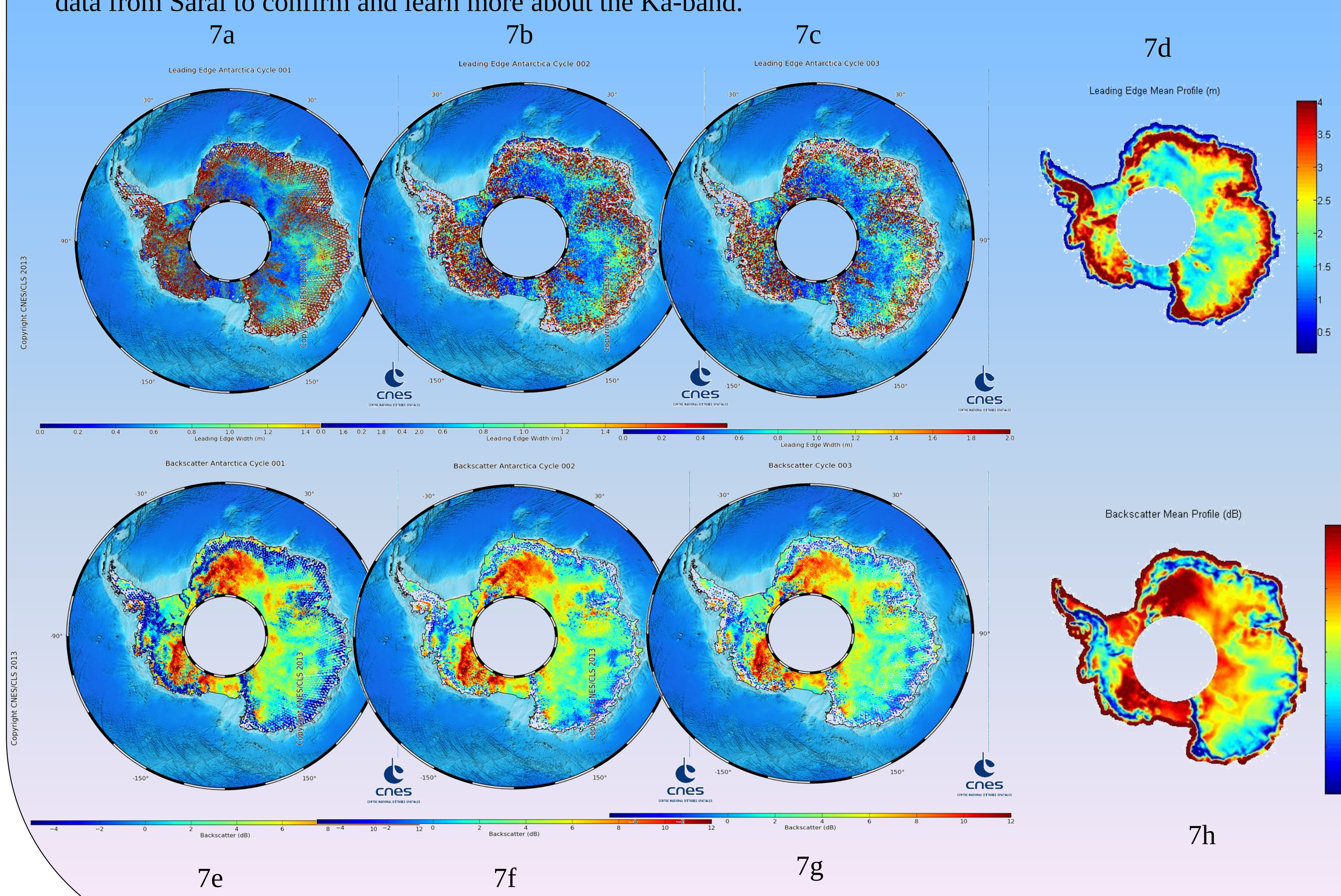


Fig 7: Saral Leading Edge in meters and Backscatter in dB :Cycle 1(a,e),2(b,f), 3(c,g), mean value for Envisat (d,h)

Geophysical analysis, interpretation

As we saw in the 'multi-mission comparison 'and the 'instrumental and geophysical monitoring' parts, we'll be enhancing our analysis by providing a dense processing and a continuous monitoring. If we focus on the backscatter for instance (Instrumental and geophysical monitoring), we noticed impressive cyclic variations, up to 2dB between each cycle, but it seems to have no impact on the surface height a priori. But more cycles are needed to confirm a seasonal signal and establish reliable temporal variations.

Contribution to mission performance assesment and potential anomaly detection

In the frame of the Peachi (Prototype for Expertise on AltiKa for Coastal, Hydrology and Ice) project, we aim to improve the ground processing of altimeter data. By using comparison with models, with former missions and by iterating with experts we thus can also improve the CalVal tool.

What does the ICE Cal/Val provide ? Conclusions and perspectives

- Permanent monitoring : we complete former temporal series and go further in our analysis
- Investigating the Ka-band, we ameliorate our understanding in the Ku-band, the interaction between the radar wave into the snowpack : Peachi project , ICE-2 Validation

An adaptable tool to hydrology for instance, tunable with future evolutions, and a reference for past and future missions

➔ Intercalibration with Icesat, a laser altimeter already used for an Envisat/Icesat comparison(article in prep)
➔ Having at least a 1-year hindsight with Saral/AltiKa data we'll be confirming or disconfirming our preliminary observations
➔ Crossover analysis

The Land Ice Cal/Val associated to Saral/AltiKa is promising for our future studies over ice sheets !

References

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Acknowledgements

The author is granted with a CLS/CNES funding. Thomas Flament is acknowledged for Envisat and Icesat data and the Peachi project team is acknowledged for Saral data.