Ice sheets are essential in the world climate, and in the context of the global warning, 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 on 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 CalVal tool over ice sheets is being developed in order to obtain a high-level product available to both glaciologists 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 done, and what we can benefit from this powerful CalVal tool in the short and the long-term.

Differences and complementarity of Cal/Val over land and 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 (is in the same signal to noise ratio); moreover it is not the same error budget. It denotes we need identity 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 retrieval height. We name three: the slope effect, the differently scalloped 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, atmospheric and geophysical corrections can’t always be used (dry troposphere with the nadir) at the poles and do not have the same range necessarily as in the Fig 1a shows. All these arguments prove a dedicated CalVal tool is needed to supplement the existing tools over oceans and the adaptation is mainly in the editing part.

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 altemeter 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 Cape Prudhomme with the MODIS image of the corresponding area, it may help us to link geophysically the waveform parameters behaviour, for instance noticing the isolating terrains.

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. 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, atmospheric and geophysical corrections can’t always be used (dry troposphere with the nadir) at the poles and do not have the same range necessarily as in the Fig 1a shows. All these arguments prove a dedicated CalVal tool is needed to supplement the existing tools over oceans and the adaptation is mainly in the editing part.

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 altitude (< 150 m) and on the good (correlation alimetric range > 0.9) and bad slopes. We can 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.

Multi-mission comparison

Up to 2013, in radar altimetry we were in the Ka-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 Ka-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 10km at the poles) so we have a temporal continuity at the same location points which is essential. Than, for land ice as well, Saral/AltiKa is promising. We are able to compare SARal with former missions, for instance Envisat in Ka-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 -2 meters 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 annual errors we have in radar altimetry. On Fig 6 is plotted the mean difference for the 6 yearly data between Envisat and IceSat at crossover points on Vostok. It is about ~2 meters to the south and ~3 meters to the north, and the differences are more significant at the edges of the slope. 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.

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 cycle variations, up to 2 dB 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.

References


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