Sentinel-3 Performance improvement for ICE sheets

Malcolm McMillan[1], Mònica Roca[2], Maria José Escorihuela[2], Roger Escolà[2], Pierre Thibaut[3], Andrew Shepherd[1], Frédérique Remy[4], Jérôme Benveniste[5], Américo Ambrózio[5] and Marco Restano[5].

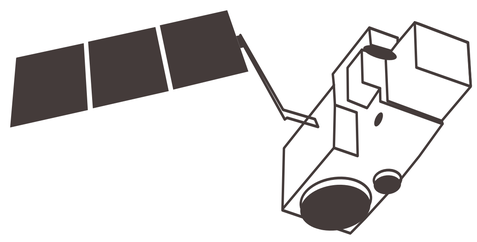
www.seom-spice.org

SUMMARY

SPICE (Sentinel-3 Performance improvement for ICE sheets) is a 2 year study which began in September 2015 and is funded by ESA's SEOM (Scientific Exploitation of Operational Missions) program. In preparation for Sentinel-3, the project aims to contribute to the development and evaluation of novel SAR altimetry processing methodologies over ice sheets. SPICE will primarily utilize dedicated CryoSat-2 SAR acquisitions made at several sites in Antarctica to investigate the expected performance of Sentinel-3 prior to operational data availability.

SPICE will develop and test novel algorithms with the purpose of addressing four high level objectives:

1. Assess and improve Delay-Doppler altimeter processing for ice sheets.
2. Assess and develop SAR waveform retrackers for ice sheets.
3. Evaluate the performance of SAR altimetry relative to conventional pulse limited altimetry.
4. Assess the impact on SAR altimeter measurements of radar wave interaction with the snowpack.

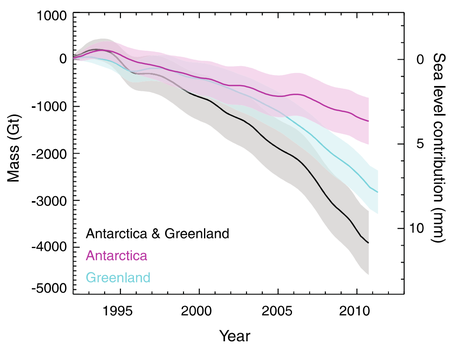


Sentinel-3

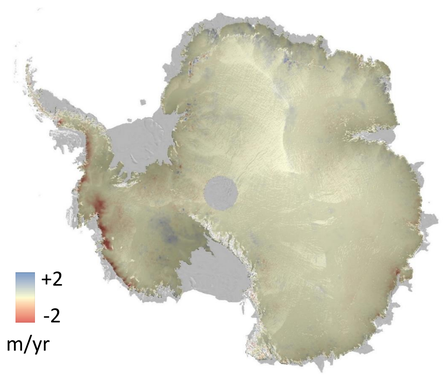
STUDY CONTEXT

During the last 2 decades, the ice sheets of Greenland and Antarctica have contributed ~ 20% of global mean sea level rise. Over this period the rate of ice loss has increased with time, largely as a result of accelerations in ice flow in Greenland and West Antarctica, and enhanced surface melting in Greenland. Current monitoring programs and efforts to understand the future contribution of ice sheets to sea level rise require the development of systematic, long-term satellite records. These must resolve ice sheet variability at the spatial and temporal scales at which these systems change.

Since the launch of ERS-1 in 1991, polar-orbiting satellite radar altimeters have provided a near continuous record of ice sheet elevation change, yielding estimates of ice sheet mass imbalance at the scale of individual ice sheet basins. One of the principle challenges associated with radar altimetry comes, however, from the relatively large ground footprint of conventional pulse-limited radars, which limits their capacity to make reliable measurements in areas of complex topographic terrain.



Ice sheet mass loss since 1992, from Shepherd *et al*. (2012).

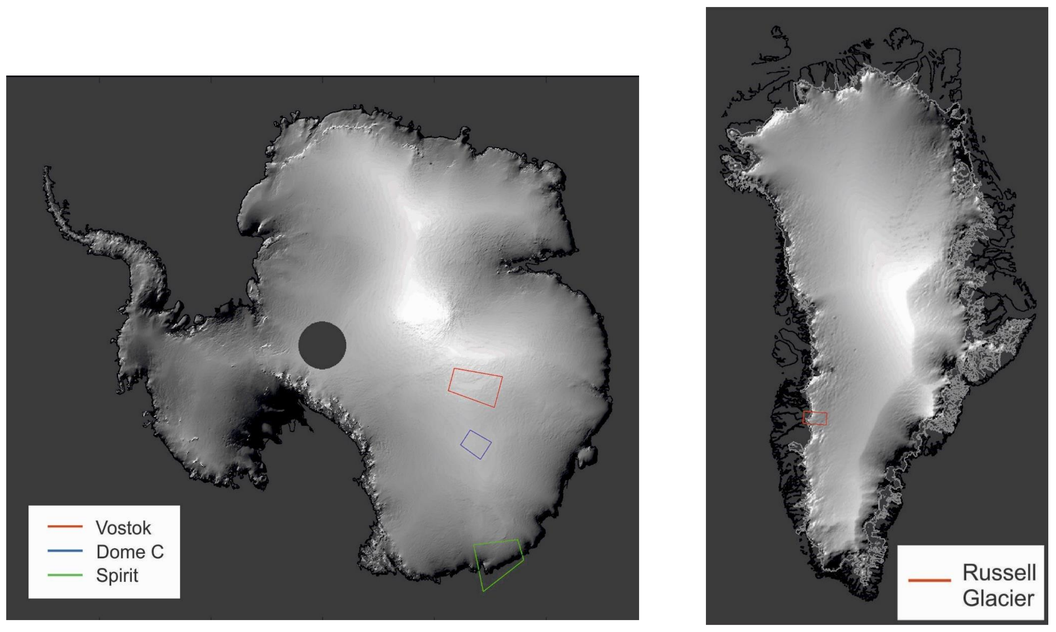


Antarctic elevation change, 2010-2013, from CryoSat-2 radar altimetry (McMillan *et al*. 2014).

In recent years, progress has been made towards improving altimeter ground resolution, through the implementation of Synthetic Aperture Radar (SAR), or Delay-Doppler, techniques. In 2010, the launch of CryoSat-2 started a new era of SAR altimetry, although the first fully global SAR mission has only recently been realised with the launch of the Sentinel-3a satellite. Because of the existing heritage of SAR altimetry, current SAR altimeter processing techniques have to some extent been optimised and evaluated for water and sea ice surfaces. This leaves several outstanding issues related to the development and evaluation of SAR altimetry for ice sheets, which we aim to address in this study.

STUDY SITES

The SPICE study will focus on four study sites. Three of these sites are located in East Antarctica and one is in Greenland.



The location of SPICE study sites in Antarctica (left) and Greenland (right).

In 2014, dedicated SAR acquisitions were made by CryoSat-2 at two inland (Vostok and Dome C) and one coastal (Spirit) site in East Antarctica. During the SPICE study, these data will be used to emulate Sentinel-3 products, test SAR processing developments and evaluate the performance of SAR altimetry over ice sheets.

In Greenland, the Russell Glacier site on the western margin of the ice sheet will be used. The inclusion of this site will enable SAR performance to be assessed in a region undergoing varying surface melt, and backscattering, conditions. Russell Glacier is well suited to the SPICE objectives because of the high volume of airborne altimetry data that has been collected across this region, and which can be used for evaluation. Because CryoSat-2 operates in SAR interferometric (SARIn) mode in this region, pseudo-SAR will need to be generated and evaluated from SARIn Full Bit Rate (FBR) data.

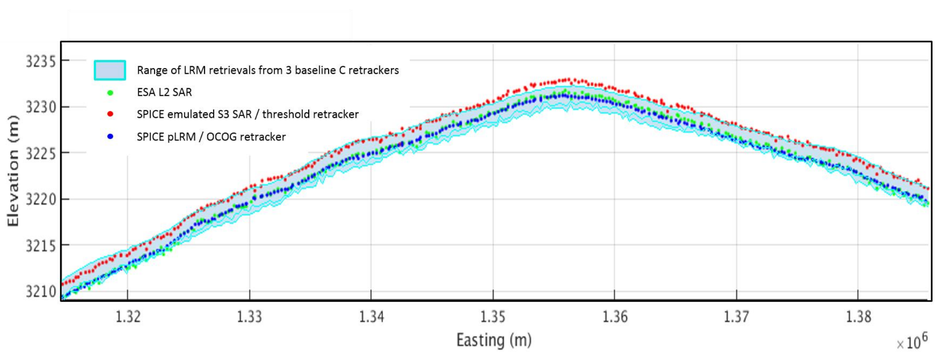
SPICE OBJECTIVES

SENTINEL-3 PROCESSING OPTIMISATION OVER ICE SHEETS

The SPICE study will focus, in part, on SAR altimetry algorithm development and optimisation. SPICE will primarily utilise CryoSat-2 SAR FBR data to emulate Sentinel-3 L1B and L2 data, generate comparative pseudo-LRM products and test new algorithm evolutions.

- **Delay-Doppler Processing (DDP).** SPICE will assess the performance of existing DDP algorithms, and then seek to further develop these DDP methodologies with a view to enhancing performance over ice sheets: (1) Accounting for the antenna pattern at the stack level, so as to consider the angle of each Doppler beam; (2) Focusing the Doppler beams to particular targets of interest; and (3) Cleaning the stacks so that the range bins of Doppler beams with no useful information are removed. SPICE will also investigate the potential to generate a pseudo-LRM product from a closed-burst SAR system.

- **SAR retracking.** SPICE will firstly investigate the performance of existing SAR retrackers at the selected study sites, and secondly, develop two new SAR retrackers for ice sheets.



Preliminary comparison of SPICE emulated Sentinel 3 SAR and pLRM elevations, compared to standard LRM, derived from CryoSat-2 tracks crossing Dome C in East Antarctica. The LRM data were acquired along a near coincident track from the following orbit cycle. All processing solutions are able to resolve a broadly consistent topography.

SENTINEL-3 PERFORMANCE EVALUATION

Because pure SAR altimeter acquisitions are relatively new over ice sheets, it is important to understand the performance of these data, and their ability to deliver reliable measurements of surface elevation.

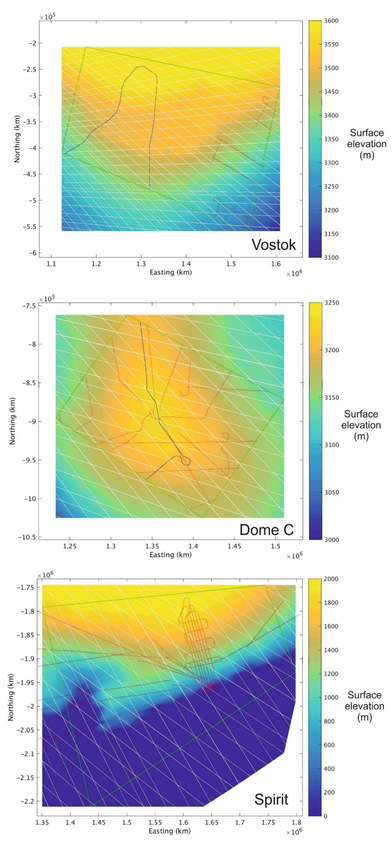
SPICE will evaluate SAR altimetry performance, focusing on two key aspects:

- **Comparison of L2 SAR and LRM.**

  SPICE will conduct a high level evaluation of the relative performance of SAR and conventional low resolution mode altimetry. This analysis will utilize an extensive set of airborne and satellite validation measurements (right) to compare SAR processed with different algorithms, to pLRM and LRM.

- **Radar wave interaction with the snowpack.**

  SPICE will investigate the impact of radar wave interaction with the snowpack on SAR altimetry. Firstly, the effect of backscattering anisotropy will be assessed by comparing measurements acquired from different viewing directions. Secondly, a comparison between CryoSat-2 Ku-band and SARAL Ka-band measurements will be used to investigate radar wave penetration into the snowpack.



Evaluation datasets derived from Operation IceBridge ATM (blue) and Riegl (red) airborne laser altimetry flightlines, and ICESat (white) ground tracks over the SPICE Antarctic study sites. The green polygon marks the boundary of each site.

Shepherd et al., *A Reconciled Estimate of Ice Sheet Mass Balance*, Science (2012).
McMillan et al., *Increased Ice Losses from Antarctica detected by CryoSat-2*, Geophys. Res. Lett. (2014).

(1) Centre for Polar Observation and Modelling, University of Leeds, Leeds, United Kingdom (m.mcmillan@leeds.ac.uk), (2) isardSAT Ltd, Guildford, United Kingdom, (3) CLS, Ramonville Saint-Agne, France, (4) LEGOS, Toulouse, France, (5) ESA ESRIN, Frascati, Italy.