The importance of slope correction for studying Greenland ice change using CryoSat-2

K.M Sejan[1], B. Wouters[1,2], M.R. van den Broeke[1]

1) Institute for Marine and Atmospheric Research, Utrecht, Utrecht University, the Netherlands, 2) Faculty of Civil Engineering and Geosciences, TU Delft, the Netherlands

Melting Greenland Ice Sheet

Melting rate of Greenland Ice Sheet is very important for the estimation of the sea level rise. Satellite radar altimetry is one of the most essential tools for monitoring changes in the mass balance of the world's ice sheets. Developing improved software and algorithms for the estimation of elevation changes with the use of satellite altimetry, such as the CryoSat-2 mission, will allow for a more precise calculation of the ice mass balance.

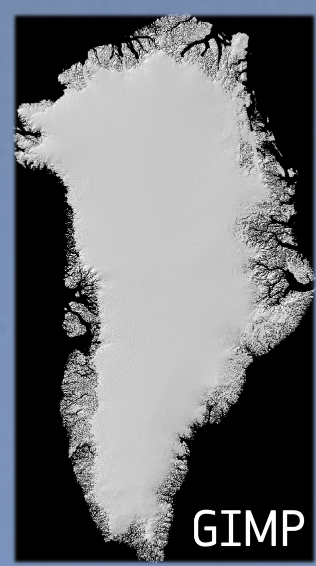
CryoSat-2 satellite
Image: courtesy of ESA

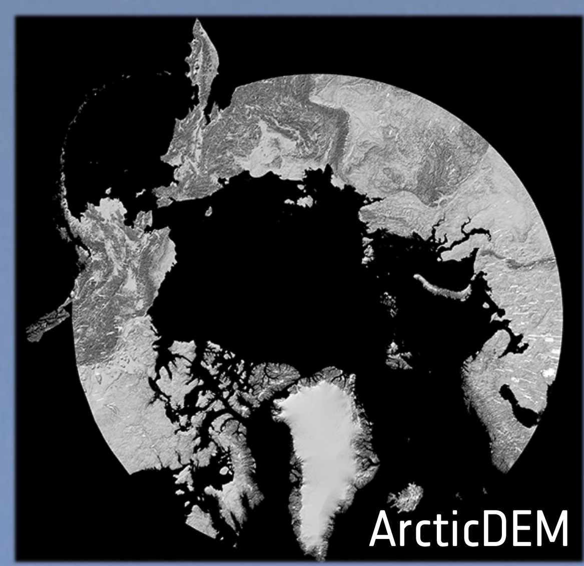
CryoSat-2 mission has been operating for 10 years! Exceeding the planned data collection time by 7 years and providing unprecedented time series of elevation changes of Greenland Ice Sheet.

Why correct for slope in Radar Altimetry?

In altimetry, radar waves are emitted towards the surface where they are reflected, and then recorded by the satellite instruments. Altitude of the satellite and the travel-time of the wavelet is used to estimate the elevation of the surface, called waveform retracking. Here we use the method by Nilsson (2015). Among other challenges, the reflection point of the wavelet is not always at the expected location below the satellite (nadir), but upslope at the point of closest approach (POCA). We correct for this shift with values of the local slope angle (alpha) and slope aspect (beta), using method by Hurkmans (2012).

Digital Elevation Models (DEMs)





We used two different DEMs to calculate local slope angle and slope aspect values, to compare their performance in slope correction of CryoSat-2 data. The ArcticDEM Release 7 (Porter et al., 2018) data have been collected over 2015-2017 period and have a resolution of 2m (we use reduced 32m resolution). The Greenland Ice Mapping Project DEM (GIMP DEM) (Howat et al., 2017) data have been collected between 2009 and 2015, and have a resolution of 30m. Both data sets are created using similar methodology and optical imaging satellites.

ICESat2 – benchmarking DEMs performance

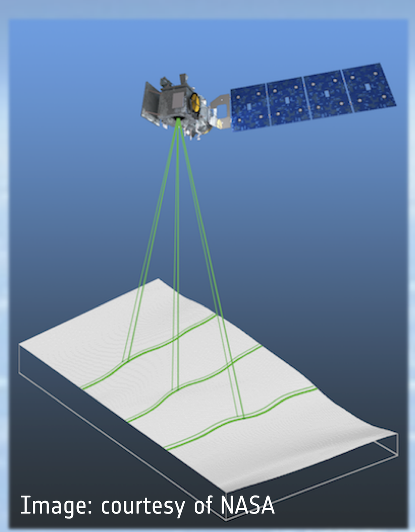


Image: courtesy of NASA

ICESat2 satellite launched in 2018 uses an altimetry instrument with a laser instead of radar antenna. It emits 3 pairs of photon beams, which reflect from the surface and are measured again by the instrument. Photons, in contrast to radar waves, have a much smaller footprint on the Earth's surface, and thus are not affected by the topography. We checked the two sets of slope correction data using ICESat2 data (Smith et al., 2019) corresponding to the same time period (5 days rolling window), and selected by nearest point calculation within 200m.

References

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Preliminary Results

Comparison of CryoSat-2 data to ICESat2 data for the period of April 2019 to September 2019, shows that the slope correction can significantly affect the estimation of surface elevation. Both data sets, corrected with GIMP DEM and with ArcticDEM, almost equally either over- or under- estimate the elevation when compared to ICESat2. CryoSat-2 data correction with ArcticDEM (red), on average, results in underestimation of elevation (Figure 4). Data corrected with GIMP DEM (blue) usually overestimate the elevation. Furthermore, GIMP DEM results seem to have a bimodal distribution, which may be a consequence of the location of the points. In Figure 1, the difference between CryoSat-2 and ICESat2 is shown by its geographical location. The elevation differences in the interior of the GIS tend to be the smallest, whereas the North-East region displays largest variation. Geographical distribution of the elevation differences is very similar for both corrections (Arctic DEM – Figure 1a, GIMP DEM – Figure 1b). A further investigation of the bimodality in elevation differences and its relationship to geographical location will be performed in future analysis.

Air temperature for a KAN_L station at K-transect is shown in Figure 3, where event of melt related to the mid-June 2019 heatwave, subsequent refreezing, and another melt event in mid-July 2019 is indicated. Figure 2, is a time series of the mean elevation difference between CryoSat-2 and ICESat2, for data corrected with ArcticDEM (red) and GIMP DEM (blue). A significant sequence of "under–over-under - estimation" can be seen with Arctic DEM (red), corresponding to the melt and refreezing events seen in Figure 3. This is especially true for temperatures at K-transect, but not so for the CEN station in the NE of Greenland. This relationship will be investigated further in the upcoming study.

Interestingly, a similar relationship is not seen for data corrected with GIMP DEM.

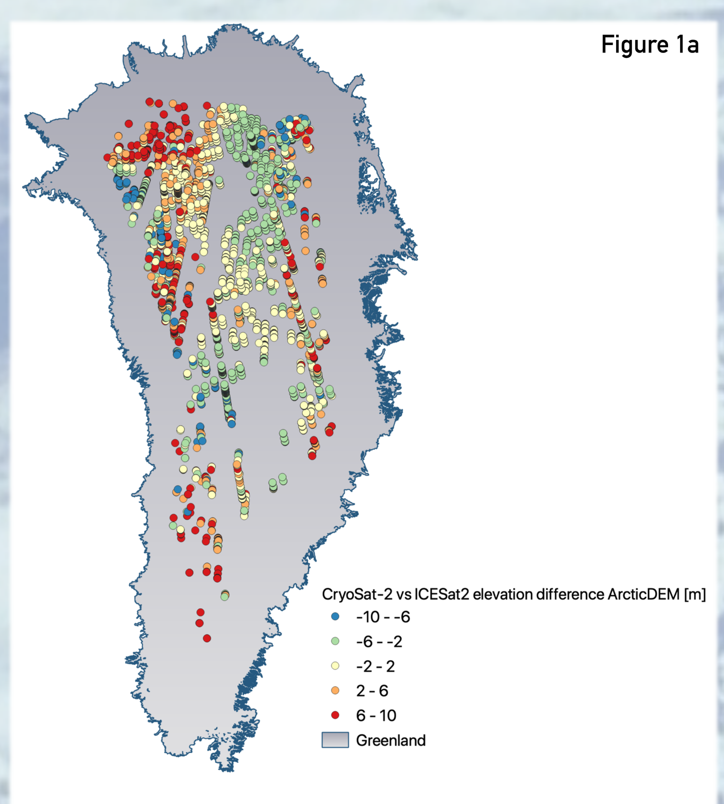

Figure 1a

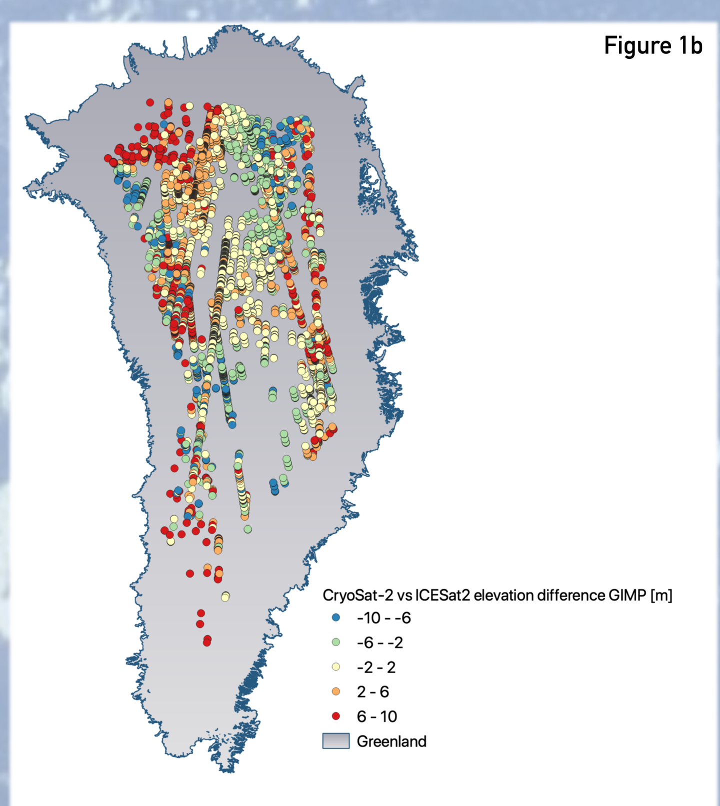

Figure 1b

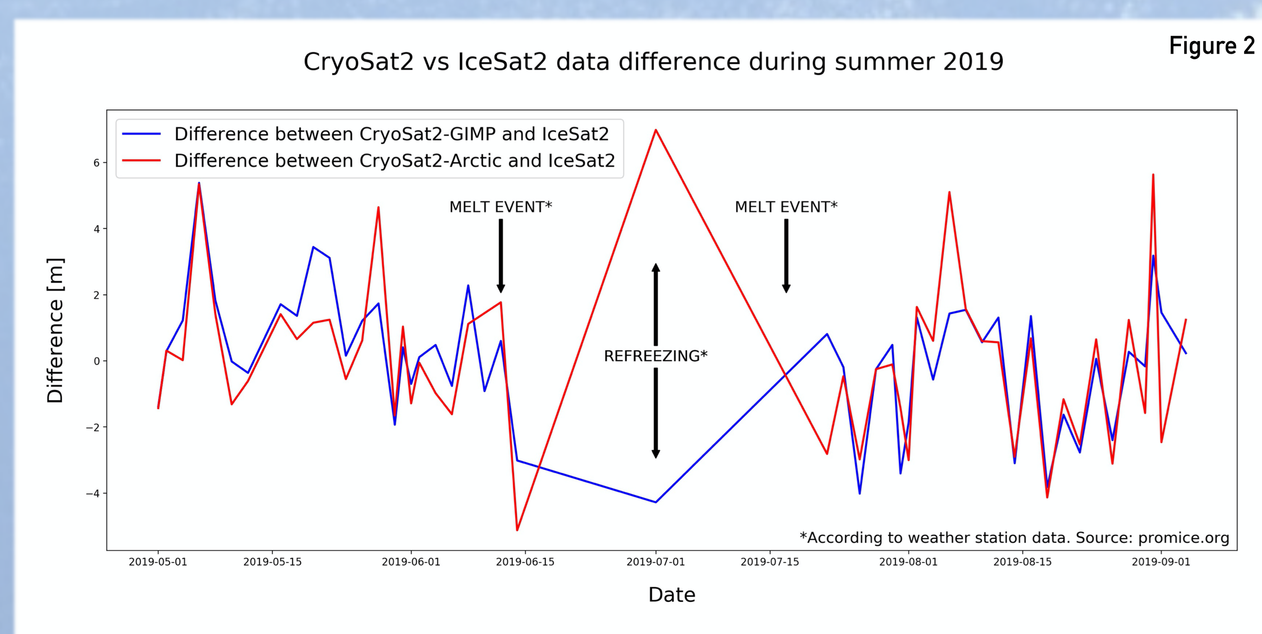

Figure 2

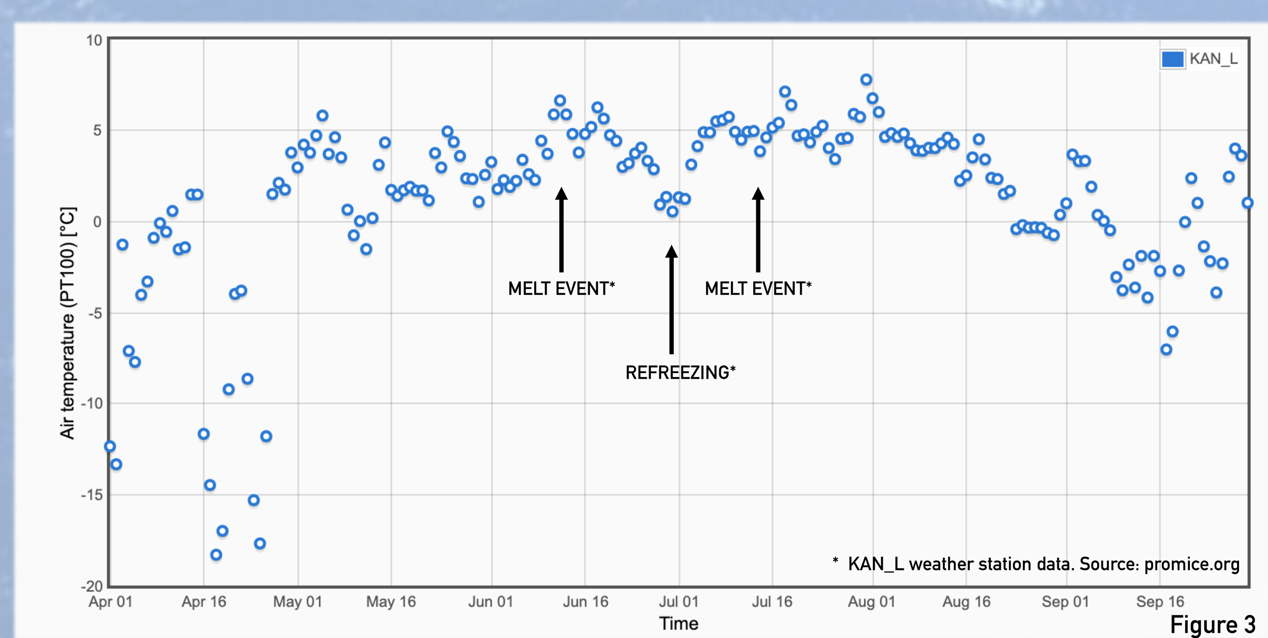

Figure 3

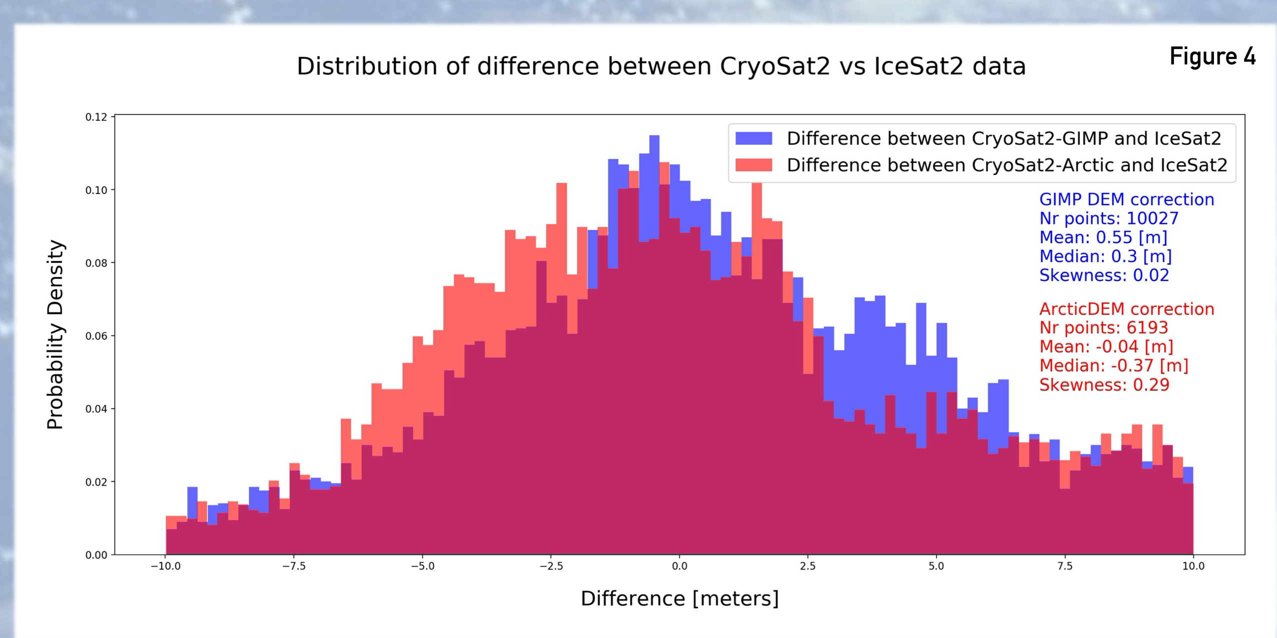

Figure 4