SPATIAL-TEMPORAL VARIATIONS IN SURFACE ELEVATION CHANGES OF ANTARCTIC ICE SHEET OBSERVED USING SARAL/ALTKA DATA

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Abstract

Antarctica ice sheet plays a crucial role in understanding the global climate changes and sea level rise. Improved estimation of the mass balance is now possible with the availability of data from state-of-art space-borne sensors. Present study focuses on elevation changes occurring over Antarctica Ice Sheet, which can be used as an indicator of ice-mass gain/loss. The SARAL/AltiKa (35.75 GHz) radar altimeter 40 Hz Geophysical Data Record (GDR) dataset (2013-2017) of Exact Repeat Mission (ERM) and Geodetic mission (GM) were used for deriving the surface elevation of Antarctica ice sheet. It was observed that error gets minimised by considering average elevation during larger period rather than 35-day cycle-wise monitoring. Results indicated loss of mass, -3 to -6 m reduction in elevation, in the parts of West Antarctica near Amundsen Sea. Whereas, over East Antarctica overall marginal gain of mass has been observed. However, positive and negative patterns observed over entire continent between summer seasons of 2013-14 and 2016-17 demands further investigations and long-term study. Cross-over analysis suggests the role of surface geo-morphology over blue-ice regions on the estimation of elevations. The blue-ice regions need to be treated separately for the improved elevation estimation.

INTRODUCTION

Earth's polar regions are having large portion of area under the ice cover. Greenland and Antarctica together contain about 75% of the world's fresh water. Geographic area of Antarctica is approximately 14 M sq km (98% of which is under ice cover) with an average thickness of approximately 1.6km. This is an indicative of huge fresh water reservoir. If these Antarctica and Greenland ice sheets melts entirely, they have the potential to rise the sea level by approximately 70m. Predicting the future evolution of Greenland and Antarctic ice sheets and their contribution to sea level rise demands for the reliable estimates of the current mass balance of these ice sheets (Martin-Espanol et al., 2017). Probably, altimetry is one of the most powerful tools for ice sheet observations (Remy and Parouty, 2009). Chander et al (2015) have demonstrated the utilisation of SARAL-AltiKa altimeter data to study the ice height variability over Greenland Ice Sheet. Since 1990s, Greenland ice sheet is experiencing the loss of mass (Sasgen et al., 2012), whereas large uncertainties observed in the mass balance of Antarctica remain (Hanna et al., 2013). Present study is focussed on the utilisation of SARAL-AltiKa altimeter data to assess the surface mass balance of Antarctica.

STAUDY AREA AND OBJECTIVE

Antarctic ice sheet region excluding ice shelves was considered for the study. Major objective of the study is to detect the changes in the Antarctica surface height during 2013-2017 period using Ka-band SARAL-AltiKa altimeter data. Another interest of the study is to investigate the difference between the results obtained from Exact Repeat Mission (ERM) and Geodetic Mission (GM) data from AltiKa. Possibility of existence of typical pattern observed over geomorphological feature was also of the interest while taking up this study.

MATERIAL AND METHODOLOGY

SARAL/AltiKa 40 Hz Geophysical Data Record (GDR) dataset of entire ERM (Exact Repeat Mission) phase consisting of 35 Cycle (14th March 2013 to 4th July 2016) and Geodetic Mission (GM) data thereafter (ftp://avisoftp.cnes.fr/AVISO/pub/saral/gdr_t) were utilised for the study.

Various correction factors were considered to derive the corrected range for the determination of surface elevation using equation (1).

$$EL = ALT - R - DT - WT - IC - SET - PTC \quad (1)$$

Where,
EL = Elevation

ALT = Altitude
R = Range
DT = Dry Troposphere Correction
WT = Wet Troposphere Correction
IC = Ionosphere Correction
SET = Solid Earth Tide Correction
PTC = Pole Tide Correction

The high resolution (500 m) DEM produced by National Snow and Ice Data Center (http://nsidc.org/data/nsidc-0304) was used to compute the slope corrected elevations. Slope corrected elevation database at 500x500 grid resolution was prepared for each study cycle and season.

Min-Max analysis on cross-over points was also carried out to investigate the possible impact of geo-morphology on the Ka-band Altimeter.

RESULTS AND DISCUSSION

Advantage of Geodetic Mission Mode over Exact Repeat mission mode

During Exact repeat mission (ERM) mode (Fig1a), in every cycles AltiKa track follows the identical path. Whereas, in geodetic mode (GM), cycles get shifted by defined distance (Fig1b). Investigation of summer seasons of 2013-14 (cycle 7,8,9) and 2016-17 (cycles 103,104,105) indicated that 1.85 times higher area (by combining 3 cycles) was covered by GM mode (Fig 1a) compared to that observed during ERM mode (Fig1a). Hence, larger area covered in GM mode (fig. 1d) compared to ERM mode (Fig. 1c) is an advantage the land ice applications by integrating more than 2 cycles.

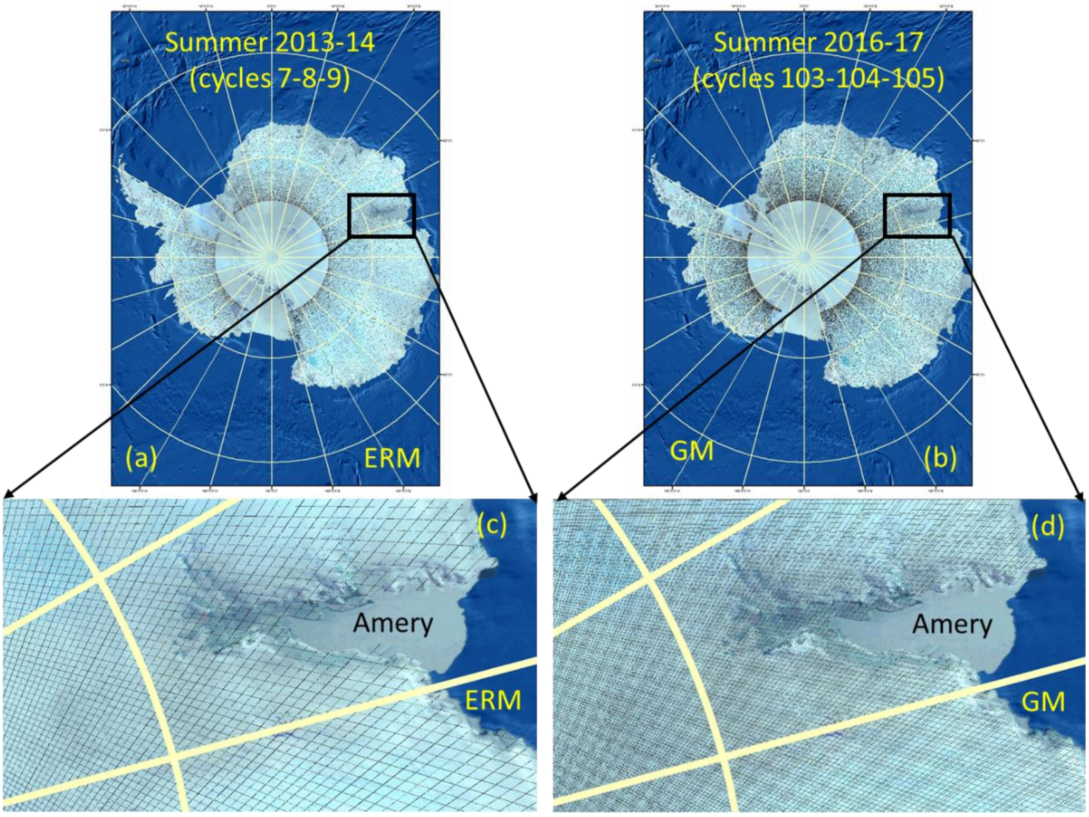

Figure 1. Advantage of Geodetic mission mode (GM) over Exact Repeat mission mode (ERM) of AltiKa. (a) 500m Grid-cells covering ERM data of summer season 2013-14 (cycle-7-8-9); (b) 500m Grid-cells covering GM data of summer season 2016-17 (cycle-103-104-105); (c) Region around Amery ice shelf 2013-14 and (d) Region around Amery ice shelf 2016-17.

5.2 Surface elevation data for winter 2013-14

The elevation data was generated for the winter season of 2013-14, by integrating three AltiKa cycles (13,14 & 15). The derived data was utilised to generate gridded data at 10 km grid, to get the broader picture of the spatial variations. To minimize the data gap, we have carried out median filter processing over 10km gridded elevation data with 3x3 window size. Hence, value represented in each grid-cell is the median elevation value within each 30x30 km window (Fig. 2).

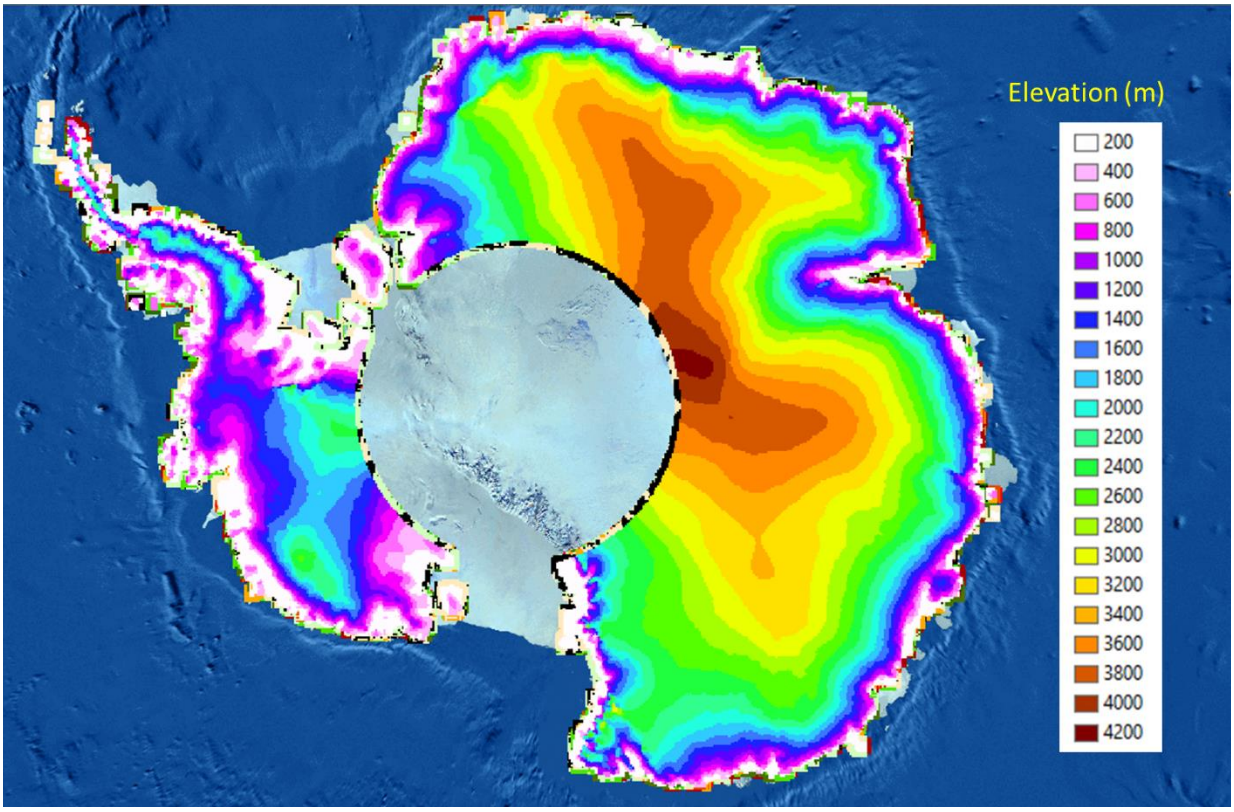

Figure 2. Surface height classified at 200m interval derived for winter season 2013-14 (Cycle-13,14,15). Derived 10km gridded elevation image is 3x3 median filtered image (Data is now available on VEDAS portal *http://vedas. Sac.gov.in* of Space Applications Centre, ISRO)

The obtained data was classified at 200m elevation interval (Fig 2). As observed in the figure elevation over eastern parts of the Antarctica (right side of figure) is much higher than the elevations observed over the western parts of the Antarctica (left side of the figure).

Now, elevation data is available from the VEDAS portal *http://vedas. Sac.gov.in* of Space Applications Centre, ISRO. In the beginning, entire ERM mode data of Antarctica made available for the users and shortly data will be available for GM mode and for Greenland ice sheet.

Change in elevation during 2013-2017 period

Seasonal changes over the Antarctica may not follow exact calendar dates, moreover, 15-20 day variations in onset of season from one-year to another-year is very common. Hence, resultant change combining data of 2-4 cycles, covering specific season, may be more appropriate to investigate surface elevation changes. An attempt has been made to investigate changes obtained by combining 3-cycles (Cycle-103, 104 and 105) covering 2016-17 summer period (Fig.3).

As observed from the figure, reduction in surface elevations near Amundsen Sea (indicated by ‘A’) is more prominent (Fig. 4b) compared to fig. 4a. This could be due to more data points available by integration of data from 3 cycles. Decrease in elevation in Western parts of Antarctica can be attributed to increased presence of warm modified Circumpolar Deep Water (CDW) in Amundsen Sea.

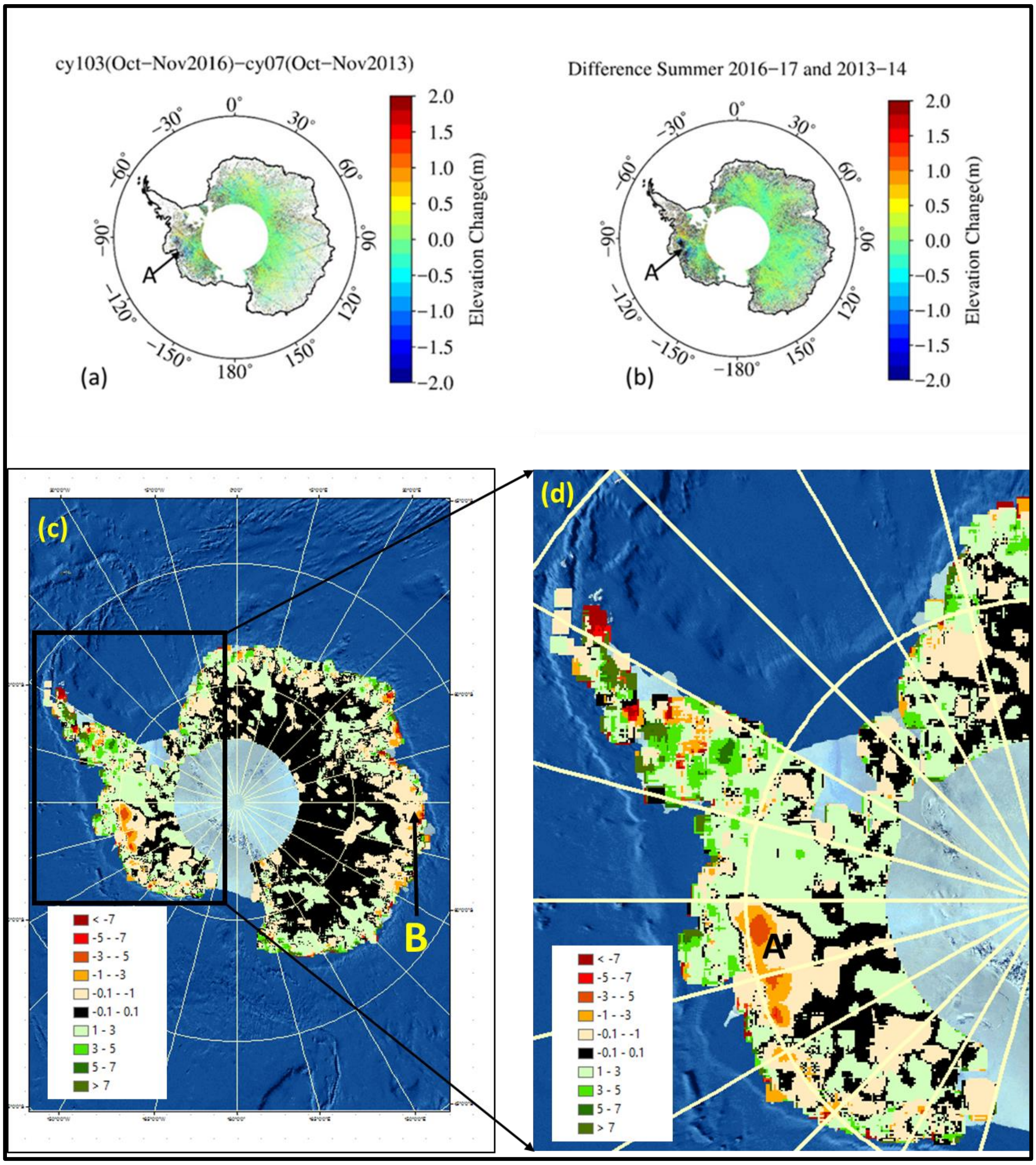

Figure 3. Change in surface elevation (in metre) (a) Between cycle-103 (Oct-Nov 2016) and Cycle-07 (Oct-Nov 2013) and (b) season-wise change considering three cycles covering October-January period 2013-14 and 2016-17. (c) Median filtered (at 90x90km) change in elevation (in m) observed during summer season (2013-14 and 2016-17) (b) Area adjacent to Amundsen-Bellingshausen Sea showing large reduction in height (labelled by A). Region labelled 'B' in East Antarctica also shows negative change.

As observed in the figure 3c, majority of Antarctica shows only marginal change during 2013-14 and 2016-17. Specifically, the inner parts of Antarctica are showing marginal change (or no change as the change is just in between -0.1 to 0.1). However, notable decrease (-3 to -6 m) observed around Amundsen Sea region (labelled with 'A'). Whereas Nearby Ross Sea in East Antarctica (labelled as 'B') increase in elevation has been observed.

As observed in the figure 3d, Western parts show patterns of positive and negative changes. Similarly, negative changes are also observed in the Eastern parts of Antarctica, near Indian Station "Bharati" (labelled as 'B' in Fig 3c). This distribution comprising positive and negative changes in the elevation between summer season of 2013-14 and 2016-17 demands for further investigations.

Investigation of impact of slope and blue-ice condition over height derivation

As we are considering all the points falling in 500 x 500 m grid-cell, the variation of the estimates within a grid-cell play key role in the average estimation (Fig. 5a). We have tried to plot the difference between minimum and maximum elevation observations falling in each grid-cell over DEM derived slope image (Fig. 5b) and MODIS Grain size product (Fig. 5c). It is observed that higher differences are observed over the areas having higher slope and larger grain size. In Antarctica on the sloppy terrain, wind driven blue ice region exists due to effect of high intensity katabatic winds. Similarly, melt-induced blue ice area are being observed around the ice margin.

Results indicate that Min-Max difference is higher over blue-ice regions. Moreover, majority of these blue-ice area shows anomalies (positive-negative change pattern) in the elevation changes in the East Antarctica. We need to investigate the possible effect of geo-morphology of blue-ice regions in the derivations of elevations using waveforms received from Ka-band altimeter. This also indicates the need for better re-tracking of waveforms falling over such geomorphological features.

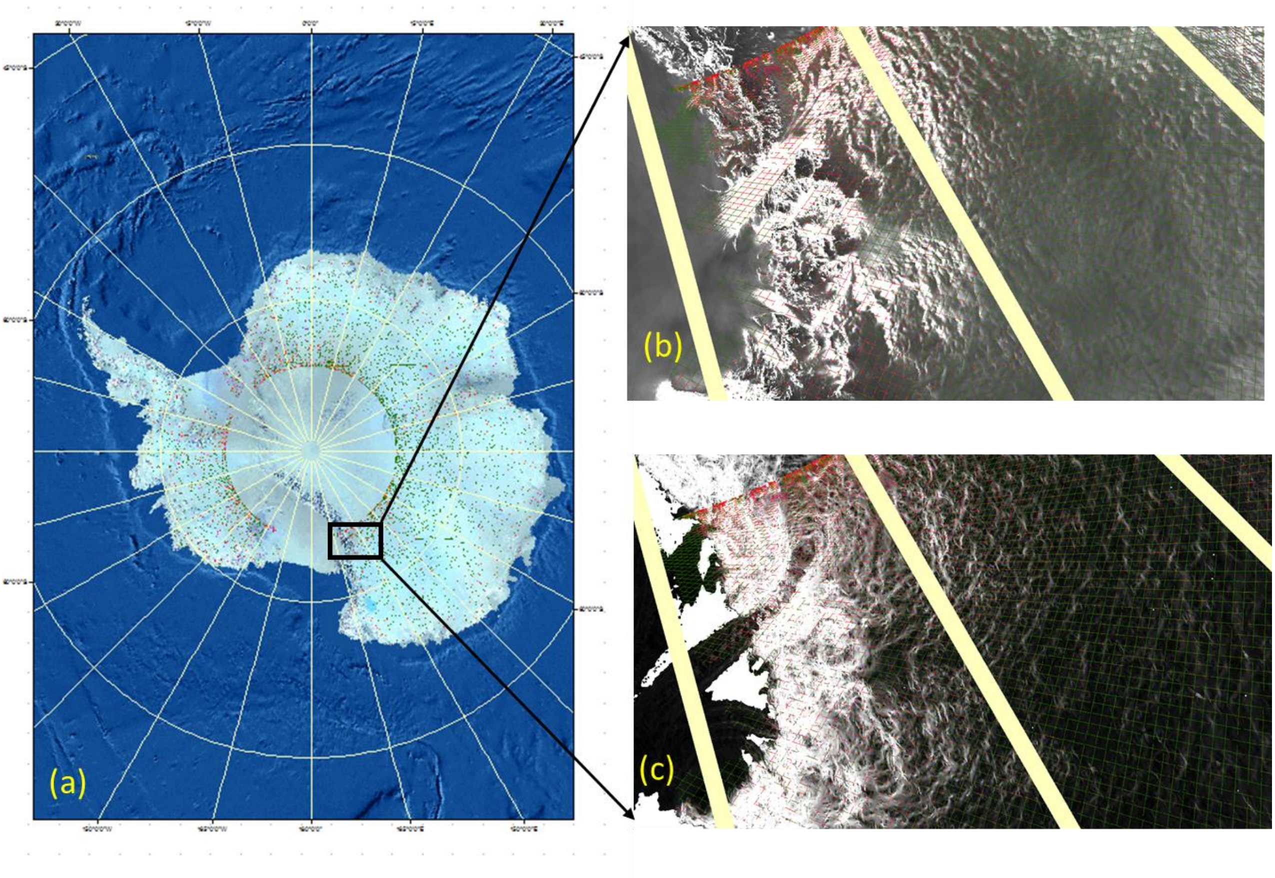

Figure 5 (a)Spatial distribution of difference between minimum and maximum height observation in each grid cell (Red: High difference; Green: Low difference) overlaid (a) over Antarctica; (b) over grain-size image and (c) over Dem derived slope image

CONCLUSION

Comprehensive study has been carried out to derive the slope corrected surface elevations and changes over the surface of Antarctica. AltiKa radar altimeter datasets of 40 Hz Geophysical Data Record (GDR) dataset (2013-2017) of Exact Repeat Mission (ERM) and Geodetic mission (GM) were utilised for the study. Surface elevation and elevation change data grids at 500m interval were derived from the AltiKa cycle-wise and season-wise data. It was observed that the number of grid cells filed by AltiKa data points are 1.85 times higher for GM mode compare to that observed for ERM mode, while combining 3-cycles of summer 2016-17. This indicate the possibility of estimating elevation for larger area with GM data over Antarctica. Results indicated consistent loss of mass, of the order of -3 to -7m, in parts of West Antarctica, particularly near Amundsen Sea. Whereas, over East Antarctica overall gain of mass has been observed. However, over entire ice sheet, patches of positive and negative changes were observed indicating the need for long-tern study. Observations show the positive-negative change anomalies in the estimates of elevations over the regions covered by wind-driven (in area with higher slope) and melt-induced (region around Antarctic ice margin) blue ice area. Such kind of behaviour emphasise the need for development of geo-morphological feature based mechanism to improve the estimation of elevation and changes.

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