Detection of iceberg calving events in Prydz Bay, East Antarctica during 2013 – 2015 using LISS-IV/IRS-P6 satellite data

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Abstract

This study discusses the calving event took place in Prydz Bay of East Antarctica during the epoch of 2013–2015 using high resolution multispectral data from Indian Linear Imaging Self Scanning Sensor (LISS-IV) aboard IRS-P6 satellite. The present study has been conducted on Larsemann Hills, Prydz Bay, East Antarctica. The two LISS-IV images (5.8 m spatial resolution) acquired specifically 384 days apart (December 31, 2013 and January 19, 2015) were utilized to study the significant changes that have occurred in icebergs during this short epoch. A total of 369 common icebergs present in both images were identified for analysing the changes in their dimensions because of surface melting. All of these icebergs were found to have lost mass because of surface melting and ocean forced base melting; therefore, they have reduced in dimension depicted by 12.51% lapse in terms of surface area. In addition, the coastline was visually observed to have retracted, instigated by calving events from the polar ice sheet and generation of new icebergs in Prydz Bay. The average drift distance of these newly formed icebergs from the coastline was found to be 51.59 m. Our analysis estimates that the total number of icebergs decreased by 70, suggesting either the complete disintegration or significant drifting of these icebergs away from the coast during 2013–2015 period.

Key words: Antarctic, icebergs, calving, Resourcesat-2, remote sensing, GIS

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***Abbreviations*:** LISS - Linear Imaging Self Scanning Sensor, ASAR - Advanced Synthetic Aperture Radar, FRS - Fine Resolution Stripmap Mode-1, RISAT - Radar Imaging Satellite, MSS - Multispectral Scanner, TM - Thematic Mapper, CCD - Charge Coupled Device, AWiFS - Advanced Wide Field Sensor, IRS - Indian Remote sensing Satellite

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Introduction

Glaciers and icebergs have always been an area of interest for study because of their significance in the climatic change studies (Kulkarni et al. 2006, 2007). An iceberg is a piece of free-floating ice of fairly large size, which has been once a part of a glacier or ice sheet and is thus made up of freshwater. Therefore, their spatiotemporal drift and decay have an impact on the hydrology, circulation, and biology of the Southern Ocean (Schodlok et al. 2006). Rapid changes to iceberg calving naturally arise from the sporadic detachment of large tabular bergs but can also be triggered by climate forcing (Liu et al. 2015). The issue of concern lies in the rate at which new icebergs are being formed resulting in a retracting coastline and also the rate at which the existing icebergs are losing mass and melting down completely. Wesche et al. (2013) showed that the size of icebergs at the timing of calving depends on the surface structure of the respective ice shelf. Several studies have been carried out for identification and tracking of icebergs. Collares et al. (2015) used an image classification methodology along a series of Advanced Synthetic Aperture Radar – ASAR images, during 261 days in 2009. Another significant study carried out by Srisudha et al. (2013) showed that C-band FRS-1 image mode data from RISAT-1 mission can be effectively employed for the identification and monitoring of ice floes in the polar regions. According to Navalgund et Singh (2011), Resourcesat-1 can be used for effective mapping/detecting the indicators of climate change, study glacier retreat, and changes in polar ice cover.

The objective of the present study was (1) to map calved icebergs in high-resolution LISS-IV images covering the small portion of coastline of Ingrid Christensen Coast, East Antarctica, (2) to determine changes in number and surface area of calved icebergs and (3) changes in coastline over a short time.

Materials and Methods

Study area

The present study was conducted in Larsemann Hills, East Antarctica (*see* Fig. 1) which is located between the Vestfold Hills and the Amery Ice Shelf on the south-eastern coast of Prydz Bay, Princess Elizabeth Land, East Antarctica (69° 30’ 11” S, 76° 19’ 58” E). The region is influenced by strong katabatic winds, which persistently blow from the north-east during the austral summer. The daytime temperature varies mostly between 0° and 10°C during summer months. During the winter months, temperature range between -15° and -18°C (Pendlebury et Turner 2004). Precipitation in this area is generally below 250 mm, which occurs in the form of snow (Hodgson et al. 2001). Few of the glaciers from the study area are undergoing extensive calving causing negative mass balance for the area. Comparison between Multispectral Scanner (MSS) and Thematic Mapper (TM) images shows that an enormous piece of ice, about 26 km long and 16 km wide, broke away from the Polar Record Glacier (located in Prydz Bay) between 1973 and 1989. The iceberg had a surface area of >450 km^2 when it first calved from the glacier tongue (Zhou et al. 2014). Therefore, it is necessary to monitor such calving events from the study area continuously.

Data

Resoursesat-1 is an advanced remote sensing satellite built by Indian Space Research Organization (ISRO), which was launched on October 17, 2003. It has three sensors on board, all of which are push-broom scanners with linear arrays of Charge Coupled Devices (CCDs): a high resolution LISS-IV, a medium resolution LISS-III and Advanced Wide Field Sensor (AWiFS). High resolution (5.8 m) multi-spectral of Linear Imaging Self Scanning Sensor (LISS-IV) obtained from Resource-sat-1 (IRS-P6) was employed in this study. The LISS-IV captures multispectral images in three spectral bands; band-2 (green); 0.52 - 0.59 μm, band-3 (red); 0.62 - 0.68 μm, and band-4 (near-IR); 0.77 - 0.86 μm. The two LISS-IV images were acquired on December 31, 2013 and January 19, 2015 respectively.

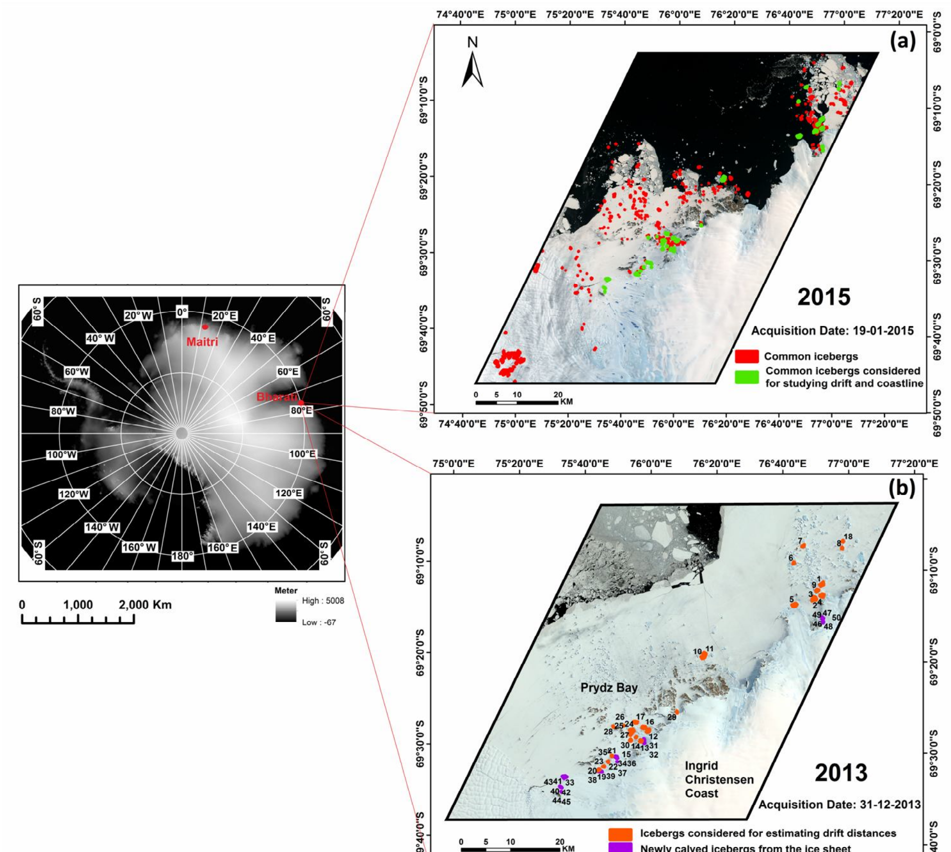

Fig. 1. The location map and extent of study area showing the spatial distribution of total number of common icebergs present in the study area. (a) The LISS-IV image captured in 2015 (mid-January) shows the open ocean because of melting of sea ice (b) Image captured in 2013 (December end) shows the extensive sea ice cover.

Methods

The detailed methodology protocol adapted in the present study is shown in Fig. 2. Two multispectral images captured specifically 384 days apart from LISS-IV enable geospatial analysis of the changes that has occurred in the study area in that period. To align two LISS-IV images geospatially at pixel level, routine image-to-image georeferencing was performed. This ensured an accurate means of comparing various characteristic features present in two images and assured higher geometric accuracy in the analysis processes. Following this, various icebergs present in both the images were mapped using on-screen manual digitization. In this study, manual digitization was found to be the most suitable method of mapping icebergs as we intended to address each identified iceberg separately, study their characteristic features, and do a comparative study. Subsequently, the manually digitized icebergs were classified as rough and smooth based on surface features. Rough icebergs are referred to the ones with heavily jagged surfaces (crevasses and rifts) and on the verge of being disintegrated, whereas the ones, which were without surface structures and visibly appear unlikely to disintegrate, are classified as smooth icebergs. This classification is helpful to understand the role of surface physical structures (*e.g.* crevasses, rifts *etc.*) in the stability/life span (rate of melting and drift rate) of icebergs generated from the ice shelf with dense surface structures against those, which were formed from the ice shelf without surface structures.

Parameter	Quantity (2013)	Quantity (2015)
Total number of icebergs (#)	2304	2234
Total area of icebergs (km^2)	85.19	82.54
Number of smooth icebergs (#)	2231	2201
Area of smooth icebergs (km^2)	71.27	76.34
Minimum area of smooth iceberg (m^2)	304.74	260.52
Maximum area of smooth iceberg (km^2)	2.09	1.95
Number of rough icebergs (#)	73	33
Area of rough icebergs (km^2)	13.92	6.20
Minimum area of rough iceberg (km^2)	0.042	0.047
Maximum area of rough iceberg (km^2)	0.58	0.47
Change in total number and surface area of icebergs from the year 2013 to 2015		
Change in number of icebergs (#)	-70	
Percentage change in number (%)	-3.04	
Change in area (km^2)	-2.64	
Percentage change in area (%)	-3.10	
Statistics for common icebergs present in both the LISS-IV images		
Number of common icebergs identified (#)	369	
Area of icebergs (2013) (km^2)	34.64	
Area of icebergs (2015) (km^2)	30.31	
Change in area (km^2)	-4.33	
Percentage change in area (%)	-12.51	

Table 1. Estimated values for total number of icebergs and total number of common icebergs and pertaining simple statistical values derived from mapping of two LISS IV images to understand the temporal changes from 2013-2015.

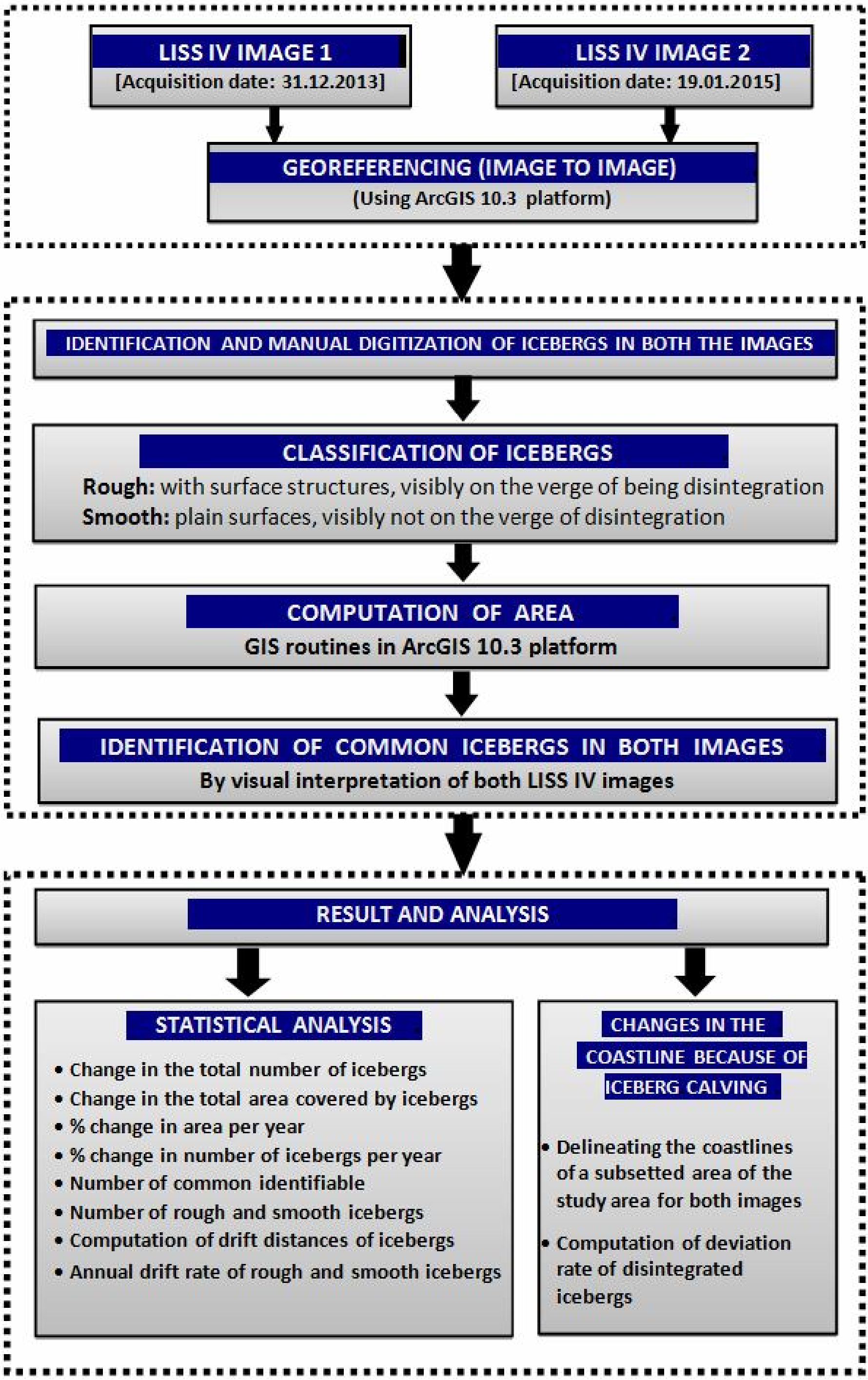

Fig. 2. Methodology adopted for evaluating the iceberg calving using LISS-IV images.

The area occupied by each iceberg was computed for further analysis and comparison (Table 1). The parameters analysed are: (1) change in the total number of icebergs (from the year 2013 to 2015), (2) change in the total area covered by icebergs (from the year 2013 to 2015), (3) change in area per day as well as per year, (4) relative change in area per year, (5) relative change in number of icebergs per year, (6) number of common identifiable icebergs present in both images, (7) number of rough and smooth icebergs in both images (acquired in the year 2013 and 2015 respectively), (8) total area covered by rough and smooth icebergs separately in both images (in 2013 and 2015, respectively), (9) rate of drift of icebergs per year, (10) change in the coastline (from the year 2013 to 2015), and (11) rate of deviation of icebergs separated from the coastline.

The coastline was traced using two LISS-IV images to study spatiotemporal changes in coastline because of calving events. Subsets of both the images were taken and their coastlines were manually digitized to understand the changes efficiently. The icebergs formed by disintegration from the coastline were identified and to understand their drift rates, shortest perpendicular distances from the coast was calculated for each one of the identified icebergs.

Results and Discussion

For understanding the rate of calving, it is essential to compute the surface area of the identified icebergs, which was computed using geographical information system (GIS) routines. The common icebergs present in both images were identified on the basis of their shape, size and texture. Tracking the icebergs from both images, it was found that several icebergs have melted down completely in the span of 384 days or drifted completely out of image extent, which is unlikely, and hence were not found in the image captured on January 19, 2015. Therefore, to ensure an effective and unbiased study of rate of melting, only the common icebergs, which were identifiable in both images, were considered for comparative analysis. All of these common icebergs (369 in number) were found to have lost mass because of surface melting and therefore have a reduced surface area. Also, several among these were visibly found to have deformed. The total surface area of the common icebergs in 2013 was amounted to 34.64 km^2, whereas it was found to be 30.31 km^2 in 2015; causing 11.90% decrease in surface area per year (Table 1). The decrease in surface area is caused by melting of icebergs, releasing fresh water in Prydz Bay. In the 2013 image, a total number of 2304 of icebergs were detected, whereas 2234 icebergs were identified in 2015 image, *i.e.* 3.04% (2.89% per annum) decrease in number of icebergs. In the 2013 image, 2231 smooth icebergs were identified which comprised an area of 71.27 km^2, and 73 rough icebergs were found with a total area of 13.92 km^2. In 2015 image, we found that the number of smooth icebergs has decreased to 2201 in number, while increase in area of icebergs to 76.34 km^2. This is an indication of the extensive calving events from the ice sheet resulting in formation of new icebergs as well as disintegration of existing rough icebergs. The rough icebergs decreased in number and were found to be 33 with a total area of 6.20 km^2 (Table 1). Since the existing rough icebergs were already on the verge of being disintegrated, the decrease in number shows that several of them had melted down completely or drifted away from the coverage of LISS-IV images.

It was observed that a number of the common icebergs have drifted from their respective locations, as seen in the 2013 image (Table 2, Fig. 3). A sample of 30 icebergs was considered and their drift distances were calculated (Table 2 and Fig. 1, Iceberg Ids 1-30 depicted in red colour). The average drift was found to be 333.70 m over a 384 days period. It was found that the rough icebergs had much higher drift rate than that of the smooth ones. The average drift for smooth icebergs was found to be 176.96 m, whereas for rough iceberg it was found to be 490.42 m.

Iceberg Id	Drift distance (m)	Type	Iceberg Id	Drift distance (m)	Type
1	588.98	Smooth	16	282.80	Rough
2	167.94	Smooth	17	47.68	Rough
3	165.70	Smooth	18	347.08	Rough
4	154.80	Smooth	19	354.47	Rough
5	111.31	Smooth	20	234.37	Rough
6	108.43	Smooth	21	443.31	Rough
7	70.35	Smooth	22	66.59	Rough
8	109.64	Smooth	23	1143.60	Rough
9	26.68	Smooth	24	420.50	Rough
10	244.44	Smooth	25	1942.77	Rough
11	70.56	Smooth	26	96.22	Rough
12	66.66	Smooth	27	353.70	Rough
13	83.55	Smooth	28	401.26	Rough
14	666.12	Smooth	29	1107.02	Rough
15	19.22	Smooth	30	114.98	Rough

Table 2. Computation of iceberg drift distances for 30 icebergs under consideration.

Iceberg Id	DFC (m)	Area (m^2)	Iceberg Id	DFC (m)	Area (m^2)
31	6.45	97136.03	41	56.33	15106.44
32	21.59	70121.88	42	8.39	20392.63
33	12.28	411397.00	43	286.50	7682.09
34	80.90	63957.09	44	10.59	16955.12
35	38.31	51172.51	45	14.73	9879.61
36	11.92	51728.16	46	141.08	24045.19
37	4.45	20998.76	47	70.25	75589.87
38	14.15	79112.50	48	40.64	89541.16
39	9.46	26801.13	49	86.12	2543.13
40	52.29	26015.40	50	65.26	859.74

Table 3. Drift distances of newly formed 20 icebergs calculated from coastline along with their surface areas. DFC - Distance from coastline (m).

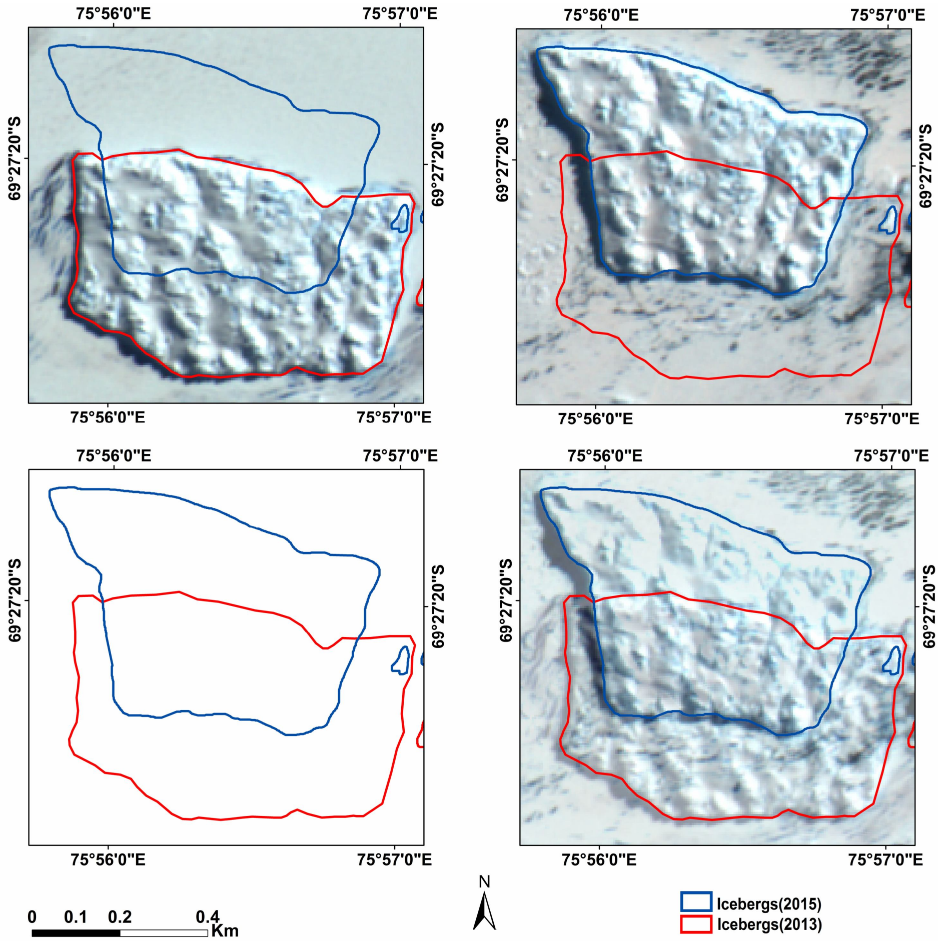

Fig. 3. Displacement of iceberg (Id -17) with a drift distance of 167.94 m. Figure also shows the disintegration of rough iceberg from 2013 to 2015.

Two coastlines were traced using two LISS IV images and it was found that a total of 20 new icebergs (Table 3 and Fig. 1, Iceberg Ids 31-50 depicted in violet colour) were formed by sporadic detachment, which resulted in the retraction of the coastline from 2013 to 2015 (Fig. 4). The total area covered by these 20 icebergs was found to be 1.16 km^2. Although these icebergs were not present in the 2013 image, some of them could be observed to be on the verge of disintegration from the ice sheet. In such cases a prominent ridge could be seen dividing up the new iceberg and the coast (Fig. 5). The average deviation of the newly disintegrated icebergs from the coastline was found to be 51.59 m.

Various environmental factors like ablation, oceanic currents, atmospheric temperature, katabatic winds are believed to be the major cause of iceberg calving. The rapid change in area of the icebergs annually in present study area is a matter of concern. Moreover, the rate of disintegration of icebergs from the coastline is resulting in sudden retraction of the coastline.

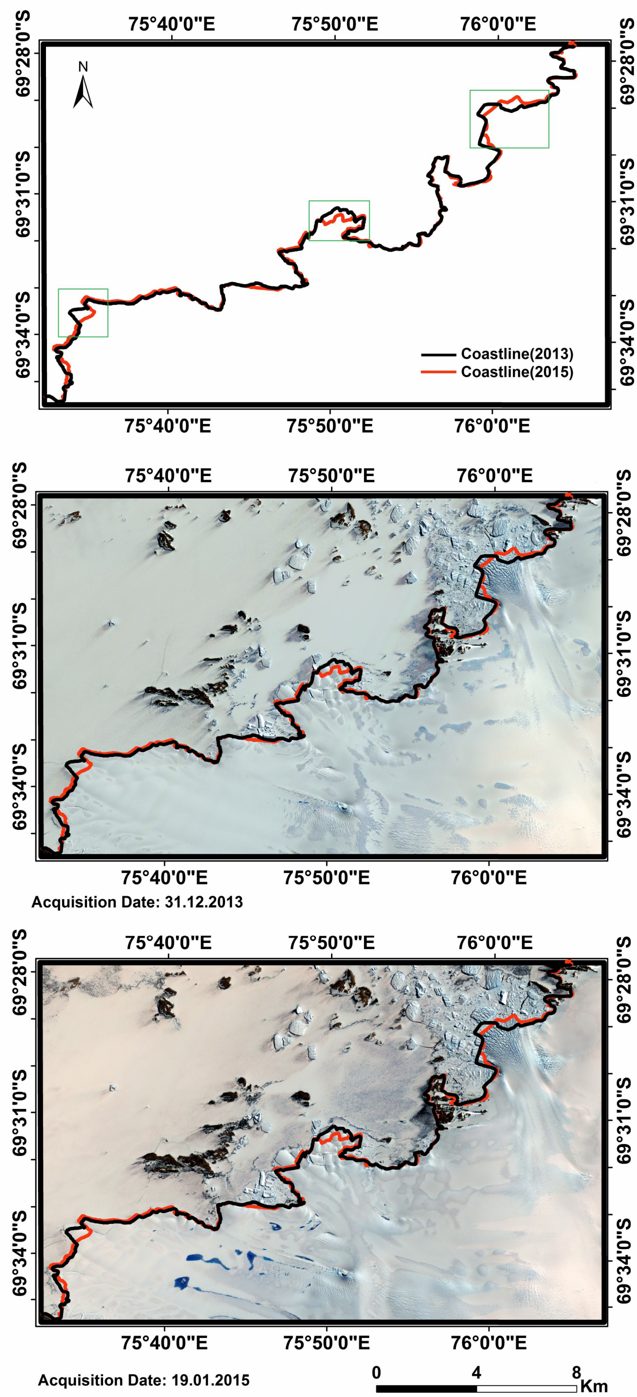

Fig. 4. Variations in coastlines in 2013 and 2015. The maximum retraction of coastline because of calving is highlighted with three green coloured boxes, with retraction distances of 588.56 m, 373.38 m, 385.82 m respectively (left to right).

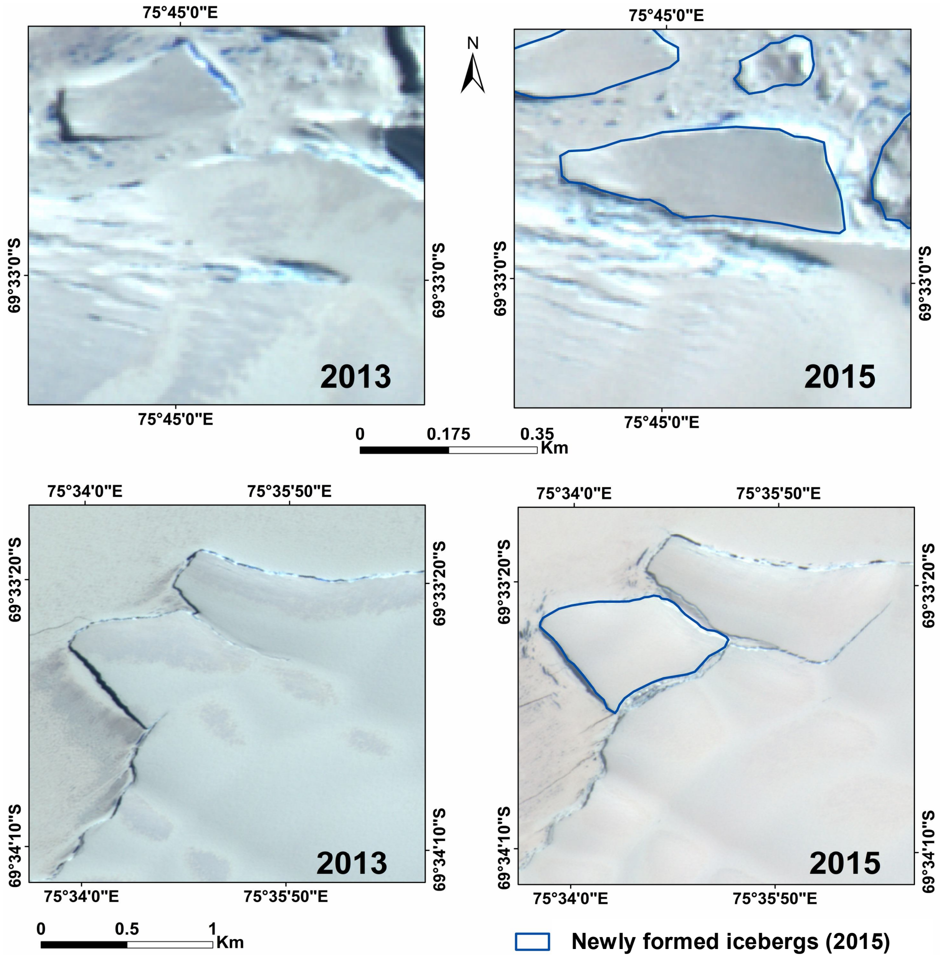

Fig. 5. Formation of new icebergs by disintegration from the coastline (Iceberg Id-38 and 33 in the year 2015).

The Larsemann Hills is generally exposed to the ice-free condition for a mere 3 months (January to March), which facilitates the movement and drifting of icebergs. On the other hand, the persistent sea ice prevents the drifting of icebergs during the rest remaining 9 months. The Larsemann Hills area is marked by persistent, strong katabatic winds that blow from east to southeast during austral summer (Ravindra et al. 2011). During January-March, the katabatic wind driven iceberg drifting can be one of the possible causes of iceberg movement.

Conclusion

This study proved to be efficient in analysing the rate of iceberg calving and iceberg melting in the study area, *i.e.*, Larsemann Hills. Manual digitization technique using GIS routines was used primarily to identify various icebergs present in the study area. High resolution data obtained from LISS-IV on board the IRS-P6 ensured minimal error and thus high accuracy could be achieved. The movement of icebergs can be predicted if they are monitored constantly, which is evitable as there are several research stations in Larsemann Hills and thus there is a constant movement of logistic ships in and around the area, and any stray unidentified iceberg can cause navigation problems. Therefore, continuous observations of calving events using LISS IV images should be conducted for the entire Antarctic coastline to study the iceberg distribution in wider context. For a broader perspective, at least 10 years of continuous monitoring is required for understanding the overall process of calving in the study region. Nevertheless, the study essentially depicts the effective usage of Indian remote sensing satellite for monitoring calving events and iceberg transformations in the study area.

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