TRACKING SELECTED ICEBERG CALVING INCIDENCES IN WESTERN ANTARCTICA USING MULTISPECTRAL SATELLITE DATA

Shridhar D. Jawak[1], Pravarta Mulay[2], Alvarinho J. Luis[1]
[1]Polar Remote Sensing Section, Polar Sciences Group, Earth System Science Organization (ESSO), National Centre for Antarctic & Ocean Research (NCAOR), Ministry of Earth Sciences (MoES), Government of India Headland Sada, Goa - 403804, India. Email: shridhar.jawak@gmail.com, alvluis1@gmail.com
[2]Symbiosis Institute of Geoinformatics, Model Colony, Pune-411016. Email: 94pravarta@gmail.com

KEYWORDS: Calving; Antarctica; Optical data

ABSTRACT

Iceberg calving is the sudden disintegration of large chunk of iceberg from ice sheet, glacier, ice shelf into an ocean. It is necessary to monitor these events, as they play a crucial role in the current dynamics of the Western Antarctic Ice Sheet. The data has been acquired from LANDSAT (4-5, 7 and 8). The description of these events has been categorized into three major categories: to be calved, calved-icebergs and the potential locations that are vulnerable of being calved. Three minor calving events have been discussed in this study. The first event has been reported near Dean Island. The calved off iceberg from the location is having a surface area of 2.98 sq. km. The second event took place near Fletcher Island, where the rate at which the rift is growing is observed to be 0.53 km/year (2002-2009). Visual analysis has played a vital role in predicting the shape (tabular) of the iceberg which is yet to calve. The third event, which is of global attention, has been reported at Larsen C of Antarctic Peninsula, and has calved a huge iceberg. The difference between the lengths is calculated as 39.65 km and 53.42 km for the image dated 15-03-2005 and 08-03-2012 and 08-03-2012 and 02-02-2016 respectively. The rate of growth of the rift is 5.66 km/year until 2012 and 3.11 km/year until 2016. The study mainly focuses on usage of optical moderate resolution satellite data for monitoring and tracking iceberg calving events that can be used as an indicator of climate change.

1. INTRODUCTION

The components of the cryosphere are snow cover, glaciers, ice sheets and ice shelves, freshwater ice, sea ice, icebergs, permafrost and ground ice. Ice sheet is a mass of glacial land ice with more than 50,000 km^2 in extension. The two largest ice sheets on the Earth cover most of Greenland in the northern hemisphere and Antarctica in the southern hemisphere. Ice shelves are permanent floating sheets of ice connected to a landmass whereas icebergs are chunks of ice that are formed on land and float in ocean. They have different shapes and sizes. Iceberg calving is the sudden disintegration of large chunk of iceberg from ice sheet, glacier, ice shelf (Jayaprasad et al., 2014). It is essential to understand this calving process to predict the response of glaciers and ice sheets to climate change. Calving is the result of propagation of fractures upstream the calving front in response to high stress (Jouvet et al., 2017). Once the cracks are opened, the sustained growth of cracks are influenced by normal and shear stress components which exceed threshold; although the normal stress component is often assumed to be a primary control over the shear. Rifts from large-scale detachment boundaries (Walker et al., 2013) and their formation and propagation is a precursor to iceberg calving. Mass is also added to some ice shelves through refreezing of marine ice at their base. The calving of icebergs is also a key factor, in terms of both ice-sheet mass balance and its impact on ocean properties and circulation. It also plays a key role in determining the distribution of both pack ice and fast ice (Vaughan et al., 2013) and are sites of polynya formation. Icebergs are formed either by one of the two processes: (a) the calving of the seaward margins of floating glacier tongues or ice shelves and (b) by the fragmentation of existing icebergs. Surface structures can be traced using aerial photographs and satellite images. Wesche et al. (2013) mapped and classified the surface structures on the Larsen B ice shelf using Landsat-7 Enhanced Thematic Mapper Plus (ETM+) and Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) data. The surface structures are investigated which are visible on Fimbul and Larsen C ice shelves, respectively, using radar and optical satellite images complemented by airborne or ground based radar measurements (Wesche et al., 2013). Low and medium spatial resolution can be used to monitor the iceberg calving events in remote and extremely cold regions (Jawak and Luis, 2017a; Jawak and Luis, 2017b; Sandeep et al., 2017). Amundson (2010), observed that for a fast-flowing outlet glacier Jakobshavn Isbrae in West Greenland, the glacier’s mass loss from calving occurs mainly in summer and is dominated by the calving of full-glacier-thickness icebergs twice a week, which can only occur when the terminus is at or near flotation. This study was carried out with the aid of field-collected data in 2007-2008. Due to the penetration of seawater beneath, the portion of the ice, shelves are disintegrated into small to large tabular icebergs, which were 200 to 300 m thick. These icebergs have a free board of 30 to 50 m and when they move, they tend to lose their flat tops and become domed. All icebergs are reported to be swept westwards around the continent by circumpolar currents near the coast. The icebergs are seen in the region south of 50^0S latitude and their concentration being very high between 60° to 70^0S latitude (Sharma, 2001). Tracking of iceberg calving has been carried also been carried out using SAR data (Jawak and Luis, 2014; Jawak and Luis, 2015a; Jawak and Luis, 2015b). the objective of this paper is to mainly focus on usage of optical moderate resolution satellite data for monitoring and tracking iceberg calving events which can be used as an indicator of climate change.

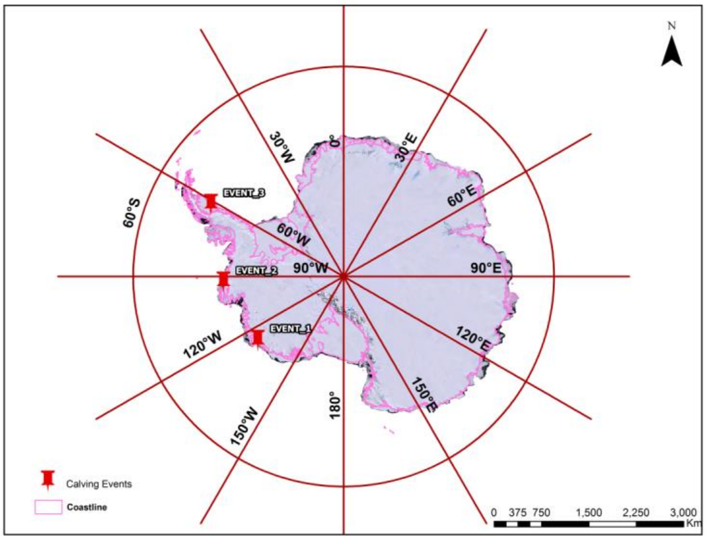

Figure 1. Locations of the events showing iceberg calving over Western Antarctica

2. STUDY AREA AND DATA

The information for tracking the events and analysis of the surface features near Dean Island, Fletcher Islands and the Larsen C Ice Shelf, Antarctic Peninsula has been derived from the satellite images spanning from 1988 to 2017 (Figure 1). The datasets for performing this study has been downloaded using Landsat 8 Operational Land Imager-Thermal Infrared Sensor Collection 1 Level-1, Landsat 7 Enhanced Thematic Mapper Plus Collection 1 Level-1 and Landsat-4 and 5 Thematic Mapper Collection 1 sensors (Table-1) with the spatial resolution of 30 m for the chosen bands. As the ice sheet reaches the coastal area, it extends into the sea in the form of floating ice shelves, which occupy almost the entire peripheral region of the continent.

Table 1. Sensor details

Sensor	Bands	Wavelength range(µm)
Landsat 4-5 TM	Band 1-Blue	0.45-0.52
	Band2-Green	0.52-0.60
	Band 3-Red	0.63-0.69
	Band 4- NIR	0.76-0.90
Landsat 7ETM+	Band 1-Blue	0.45-0.52
	Band 2 Green	0.52-0.60
	Band 3-Red	0.63-0.69
	Band 4 NIR	0.77-0.90
Landsat 8 OLI/TIRS	Band 2-Blue	0.45-0.51
	Band 3-Green	0.53-0.59
	Band 4-Red	0.64-0.67
	Band 5- NIR	0.85-0.88

3. METHODS

Figure 2 depicts the methodology followed for this study. For visual interpretation of the calving events in Antarctica, Google Earth's Historical Imagery Tool has been widely used which provides the time slider to move between acquisition dates. Landsat 7 images are radiometrically corrected. Images that are obtained by sequential across-track scanners (mainly the first Landsat-MSS) occasionally show a stripping effect, especially in the areas of low radiance. It is caused by inter-calibration discrepancies in the sensor detectors, which provide a systematically lower or higher signal than others. The Focal Analysis tool used in Intergraph ERDAS Imagine 2014 can reduce this effect.

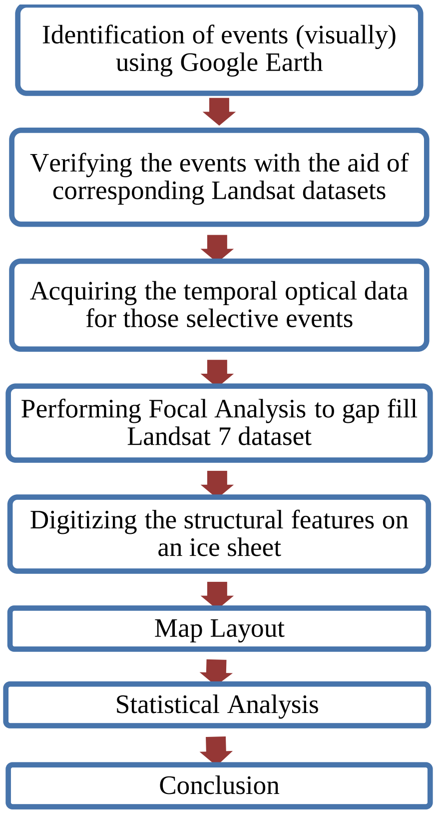

Figure 2. Methodological flowchart.

4. RESULTS AND DISCUSSION

Calving of an iceberg is mainly caused due to development of surface structure like rifts, crevasses and ogives. For the area near the Fletcher Island shown in Figure 3, datasets of the years 2002, 2009, 2012 and 2016 were acquired. On comparing frames, A, B and C (Figure 3) it was observed that the difference between the lengths in the growth of the rift has decreased from 3.72 km in 2009 to 1.83 km in 2012. The rift grew at 0.53 km/year (2002-2009) and 0.61 km/year (2009-2012). Based on visual interpretation, it was observed that the tabular iceberg has calved off. Similarly, the surface structures that are parallel to the calving fronts are typically formed by the rifts, which also indicated a probable shape of iceberg that was also tabular in nature. For the area near the Dean Island, images for 2010, 2011 and 2013 were taken analysed. Although the information was restricted to highlight the optical characteristics, we could still mark the large-scale structures like rifts, crevasses and icebergs. The calved portion comprised an area of 2.98 km^2 with a retreat in the coastline by 4.84 km. For Larsen C we have used images acquired for 1988, 2005, 2016 and 2017 to study the changes in the surface structures and to assess its future instability. According to the recent news, the cracks are said to be dormant for decades, which are stuck in the section of the ice shelf called a suture zone, an area where glaciers flowing into the ice shelf come together. Suture zones are complex and more heterogeneous than the rest of the ice shelf, containing ice with different properties and mechanical strengths, and therefore play an important role in controlling the rate at which the rifts grow. However, after 2014, this crack started to grow rapidly and passed through the suture zones.

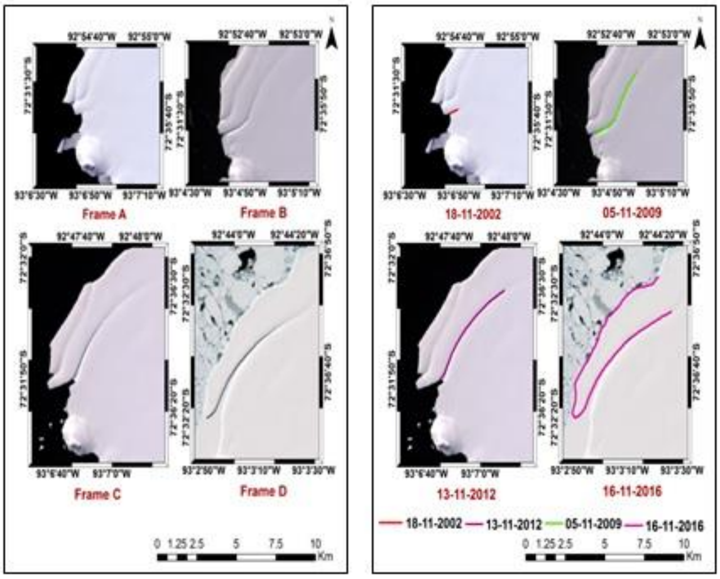

Figure 3. Layouts indicating the growth in rifts.

5. CONCLUSIONS

Examination of optical datasets over the area of interest revealed that the surface structures could be grouped into the three main categories: to be calved, calved icebergs and the potential locations that are about to be calved. There are many iceberg calving events which are into focus, as they are larger in dimensions but the one discussed here are of smaller dimension, except for the Larsen C which led to large amount of mass loss and coastline retreat. Near the Dean Island, the calved portion covered an area of 2.98 km^2 while the predictable shape of an iceberg was tabular in nature near the Fletcher Island. Therefore, the presence of physical structures on an ice sheet plays a vital role in determining the shape of an iceberg. A major issue is the georeferencing of an optical image with complete snow cover and devoid of any sharp features. Fast ice or pack ice is often mistaken as ice sheet, which is floating ice without much thickness.

ACKNOWLEDGEMENT

The authors would like to thank USGS-Earth Explorer for providing the imagery used in this study. We also acknowledge Dr. Rajan, former Director and Dr. M. Ravichandran, Director, ESSO-NCAOR, for their encouragement and motivation for this research.

REFERENCES

Humbert, A.; Steinhage, D., 2011. he evolution of the western rift area of the Fimbul Ice Shelf, Antarctica. The Cryosphere, 5, 931–944.

Jawak, S.D., Luis, A.J., 2014. Prospective application of NASA-ISRO SAR (NISAR) in cryospheric studies: a practical approach, NISAR Science Workshop, 17-18 November, Space Applications Centre (SAC), Ahmedabad, Gujarat, India, November 2014. DOI: 10.13140/RG.2.1.1587.5687. [Oral]

Jawak, S.D., Luis, A.J., 2015a. Potential of SAR imagery for mapping and monitoring iceberg calving events in Antarctic environment, XII International Symposium on Antarctic Earth Science (ISAES 2015), Abstract No. S22-13, pp. 487, Goa, India, July 13-17, 2015. DOI: 10.13140/RG.2.1.3062.1285. [Poster]

Jawak, S.D., Luis, A.J., 2015b. NASA-ISRO SAR (NISAR) imagery for monitoring iceberg calving events in the Antarctic environment, NISAR Science Workshop, 19-20 November, Space Applications Centre (SAC), Ahmadabad, Gujarat, India, November 2015. [Poster]

Jawak, S.D., Luis, A.J., 2017a. Tracking of Antarctic icebergs using optical remote sensing satellite data, MADICE Summer School on Antarctic Climate Variability and Ice Dynamics, 8-11 May 2017, NCAOR, Goa, India.

Jawak, S.D., Luis, A.J., 2017b. Operational monitoring of Antarctic iceberg calving events using Indian remote sensing satellite data, National Conference on Polar Sciences (NCPS-2017), National Centre for Antarctic and Ocean Research, May 16-17, 2017, NCAOR, Goa, India.

Jayaprasad, P., Rajak, D.R., Singh, R.K., Oza, S.R., Sharma, R. and Kumar, R., 2014. Ice calving and deformation from Antarctic Ice margins using RISAT-1 circular polarization SAR data. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(8), p.525.

Jouvet, G., Weidmann, Y. and Seguinot, J., Short-lived speed-up of Bowdoin Glacier captured by VTOL UAV.
Luckman, A.; Jansen, D.; Kulessa, B.; King, E.; Sammonds, P.; Benn, D., 2012. Basal crevasses in Larsen C Ice Shelf and implications for their global abundance. The Cryosphere, 6,113–123.

McGrath, D.; Steffen, K.; Scambos, T.; Rajaram, H.; Casassa, G.; Lagos, J.R., 2012. Basal crevasses and associated surface crevassing on Larsen C Ice Shelf, Antarctica, and their role in ice-shelf instalbility. Ann. Glaciol.,58, 10–14.

Sandeep, C.S., Jawak, S.D., Luis, A.J., 2017. Spatio-temporal study of selected iceberg calving events in Antarctica using Landsat data, National Conference on Science and Technology-Reaching the Unreached, 8th–9th September 2017.

Vaughan, D.G., Comiso, J.C., Allison, I., Carrasco, J., Kaser, G., Kwok, R., Mote, P., Murray, T., Paul, F., Ren, J. and Rignot, E., 2013. Observations: cryosphere. Climate change, pp.317-382.

Wesche, C., Jansen, D. and Dierking, W., 2013. Calving Fronts of Antarctica: Mapping and Classification. Remote Sensing,5, 6305-6322; doi:10.3390/rs5126305.