SYNOPTIC OBSERVATIONS OF CALVING EVENTS IN ANTARCTICA USING SPACEBORNE IMAGES

S. D. Jawak[1,2], S. S. Singh[3,]*, A. J. Luis[2]

[1]Svalbard Integrated Arctic Earth Observing System (SIOS), SIOS Knowledge Centre, University Centre in Svalbard (UNIS), P.O. Box 156, N-9171, Longyearbyen, Svalbard, Norway; shridhar.jawak@gmail.com
[2]National Centre for Antarctic and Ocean Research, Earth System Science Organization, Ministry of Earth Sciences, Government of India, Headland Sada, Vasco-da -Gama, Goa 403804, India; alvluis@ncaor.gov.in
[3]Centre for Land Resource Management, Central University of Jharkhand, Jharkhand- 835205, India; sumedhasurbhi78@gmail.com

Commission V, SS: Atmosphere, Ocean, Weather and Climate

KEY WORDS: Antarctica, Calving, Optical Images, Rifts, Icebergs

ABSTRACT:

Iceberg calving is the detachment of ice from ice shelves or glaciers. Although calving is a natural phenomenon, an abnormal rate of calving can be a threat to ice shelves. Some of the events were so large, that an iceberg of approximately 150x50 km area was calved in a single event. The most recent reported iceberg calving event was Larsen C and it took place in July 2017. In addition to the large and widely reported calving events, there are several small calving events, which are also of great significance and contribute to the overall mass loss from Antarctica. This study focuses on small calving events in Antarctica along various coasts. Three calving events are studied here, all of them have occurred in the past. This study was performed using Google Earth and Landsat satellite imageries. The first event is identified to have occurred at the Knox coast in 2016. Even after the icebergs were calved, they remained intact with the ice shelf due to ice fronts. The second event took place at the Queen Mary Coast in the year 2014. This event was studied from 2009 to 2016 using Landsat satellite images and many rifts were observed. The third event took place at the Princess Astrid Coast in the year 2016. This event was monitored from 2014 and three icebergs were calved between the years 2014 to 2016. This study emphasizes the exploitation of optical satellite data for studying calving events in Antarctica. Various crevasses and rifts are observed on Landsat imageries, which can be the first sign of a calving process.

1. INTRODUCTION

About 90% of ice mass on Earth is in Antarctica. The Antarctic ice sheet covers an area of 14 million km^2 of which about 10% consists of floating ice shelves. Averaging at least 1.6 km thick, the ice is so massive that it has depressed the continental bedrock in some areas to a depth greater than 2.5 km below sea level. If all of the Antarctic ice melted, sea levels around the world would rise about 61 meters (200 feet) (http://science.howstuffworks.com). This would be enough to submerge most of the coastal countries and Islands. It can cause aquifer and agricultural soil contamination loss of forests, loss of wildlife habitat. It can be a disastrous threat for human life and economy.

Iceberg calving is the breaking of ice chunks from the edges of glaciers or ice shelves. It is mainly caused by glacier expanding (Meirer and Post, 1987). It is the sudden release and breaking away of a mass of ice from a glacier, iceberg, ice front or crevasse. The ice that breaks away can be classified as an iceberg. Calving of glaciers is often accompanied by a loud cracking or booming sound before blocks of ice up to 60m (200 feet) high break and crash into the water. Many glaciers terminate at oceans or freshwater lakes which result in the calving of a large number of icebergs. Calving of Greenland's glaciers produce 12,000 to 15,000 icebergs each year alone.

Calving of ice shelves is usually preceded by a Crevasse, (Walker et al., 2013) which turns into rift. The width of the rift increases with time and other influencing factors such as temperature, basal melt, climate change, glacier expanding water pressure at the bed etc. The rift finally leads to breaking of ice from ice shelf or glacier.

<u>Causes of iceberg calving</u>

The causes of iceberg are classified into three orders:

- First Order - It is responsible for the overall rate of calving. The first order cause of calving is longitudinal stretching, which controls the formation of crevasses. When crevasses penetrate the full thickness of the ice, calving will occur. Longitudinal stretching is controlled at the base and edges of the glacier and water pressure at the bed.
- Second Order - It controls the occurrence of individual calving events. It includes melting of waterline, tidal and seismic events, buoyant forces and melt water wedging.
- Third Order – It includes causes such as upward buoyant forces cause ice foot to break off and emerge at the surface. This process is extremely dangerous, as it has been known to occur, without warning, up to 300m from the glacier terminus.

The breakaway of icebergs (calving) delivers ice from glaciers and ice sheets to the oceans, and is major contributor to current sea-level change (Benn, 2014). Iceberg calving from ice shelves is a key process in determining the amount of mass lost from the Antarctic ice sheet, accounting for up to two thirds of the total loss (Jacobs et al., 1992). Calving glaciers can undergo a very rapid retreat following an initial climate signal (Post et al., 1975; Meier et al, 1997), and thereby have the potential to contribute

* Corresponding author.

disproportionately to global sea level rise (Meier and Post et al, 1987; Rignot et al., 2003). An understanding of calving processes is therefore crucial for the accurate prediction of cryospheric response to future climate forcing, and consequent sea level change. The effect of calving events on the ocean system is equally important (Benn et al., 2007; Doake et al, 2001). There are various different terms such as ice sheet, ice shelf, glaciers, fast ice, drift ice etc. that are somehow related with the study of iceberg calving. Remote sensing data helps in analysing these changes over a large temporal scale (Walker et al., 2013; Jayprasad et al., 2014; Thakur, 2017; Anderson et al., 2014; Luis et al., 2017; Jawak et al., 2017a; Jawak et al., 2017b; Jawak et al., 2017c; Jawak et al., 2017d). As satellite, images provide multi-temporal data it is possible to monitor the rate at which the process of calving is occurring.

2. STUDY AREA & DATA USED

The study area is Antarctica, which is the region around the Earth’s South Pole. Antarctica (82.8628° S, 135.0000° E) is Earth's southernmost continent. The southern Pacific, Atlantic, and Indian oceans surround it. It has an area of more than 14 million km^2. The Antarctic ice sheet, the world's largest ice sheet and its largest reservoir of fresh water covers 98% of Antarctica. Averaging at least 1.6 km thick, the ice is so massive that it has depressed the continental bedrock in some areas more than 2.5 km below sea level. Physically, Antarctica is divided in two by Transantarctic Mountains. Western Antarctica and Eastern Antarctica correspond roughly to the eastern and western hemispheres relative to the Greenwich Meridian.

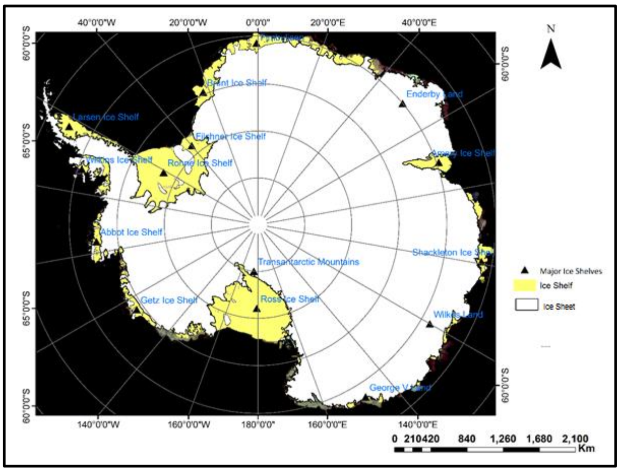


Figure 1. Location of study area

The climate of Antarctic is the coldest on Earth. The mean annual temperature of the interior is -57˚C(-70˚F). The coast is warmer. Monthly means range from −26 °C (−14.8 °F) in August to −3 °C (26.6 °F) in January. Severe low temperatures vary with latitude, elevation, and distance from the ocean. East Antarctica is colder than West Antarctica because of its higher elevation. The datasets for performing this project have 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.

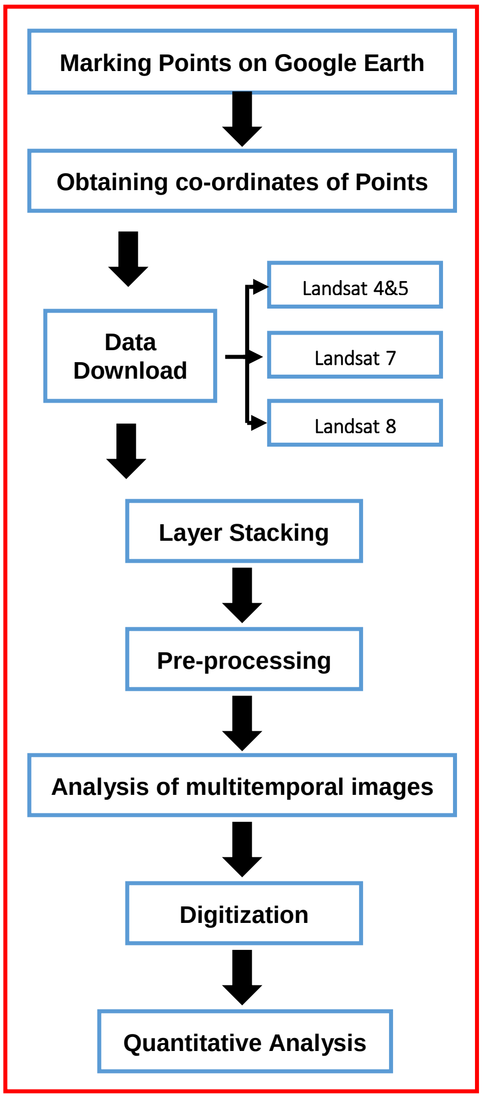
3. METHODOLOGY

The methodology utilized for carrying out this study consisted of three major steps: (1) Marking points & data download, (2) Preprocessing, (3) Digitization & Analysis. Figure 2 depicts the methodology flow chart that includes all the steps followed.

3.1 Marking points & Data download

Google Earth was used for marking calving events. The Historical imagery feature of Google Earth proved very helpful for this task. It consists of global mosaics of Landsat and Sentinel-2 (The Google Earth Blog). Depending upon the temporal images available for that place, this feature would show the changes occurring in that region at that time upon sliding the Timeline bar. This in theory resembles a time lapse. This has been very helpful in differentiating fast ice and ice shelf. The year where significant changes were present were noted. After detecting the events in a particular region, they were place marked. The Google Earth images were of low resolution. It was difficult to differentiate between Fast Ice and Icebergs. Using the Latitude-Longitude information of the place marks, Landsat data for the corresponding events was searched using USGS Earth Explorer. This helped differentiate between fast ice, ice shelf, and the iceberg, further cutting down the non-required placemarks from the list. The Level-1 Geo-TIFF data of the confirmed images were then downloaded.

Figure 2. Protocol devised for the study



3.2 Pre-processing

The stacking of the images followed the extraction of information from the data. The features present in each event were Seawater and Ice which are clearly visible in true color composite (TCC). The dataset being multi-temporal also included Landsat 7 imageries, which consisted of the images with gaps due to SLC failure. On May 31, 2003, the Scan Line Corrector (SLC) failed. This was a permanent failure. After processing the Level-1 data, there was generation of gaps in the image, which lead to the loss of 22% pixels from the original image. The data is still geometrically and radiometrically accurate. (https://Landsat.usgs.gov/Landsat-7). The downloaded data is pre-processed so that information from them can be extracted from the satellite images. As no spectral quantification of each pixel was required, the objective was only to digitize the features present in the image, Focal Analysis tool in ERDAS was used to fill the gaps. This method computes the values of neighbouring pixels and fills in the gaps based on those calculations for a single Landsat 7 scene. (https://Landsat.usgs.gov/filling-gaps-display) The method was repeated until the gap present over area of interest were filled.

3.3 Digitization & Analysis

The latter part consisted of manual digitization of the features that included calving of ice fronts, icebergs, and crevasses of the multi-temporal data. This was used for the final qualitative and quantitative analysis of the data. The length and width of the crevasses were measured. These measurements were used to determine a trend line for these events.

4. RESULTS AND ANALYSIS

Satellite images helped in tracking the events and their progress with their direction and the possible shape of iceberg that will be calved. Analysis of three different calving events at three different coasts of Antarctica.

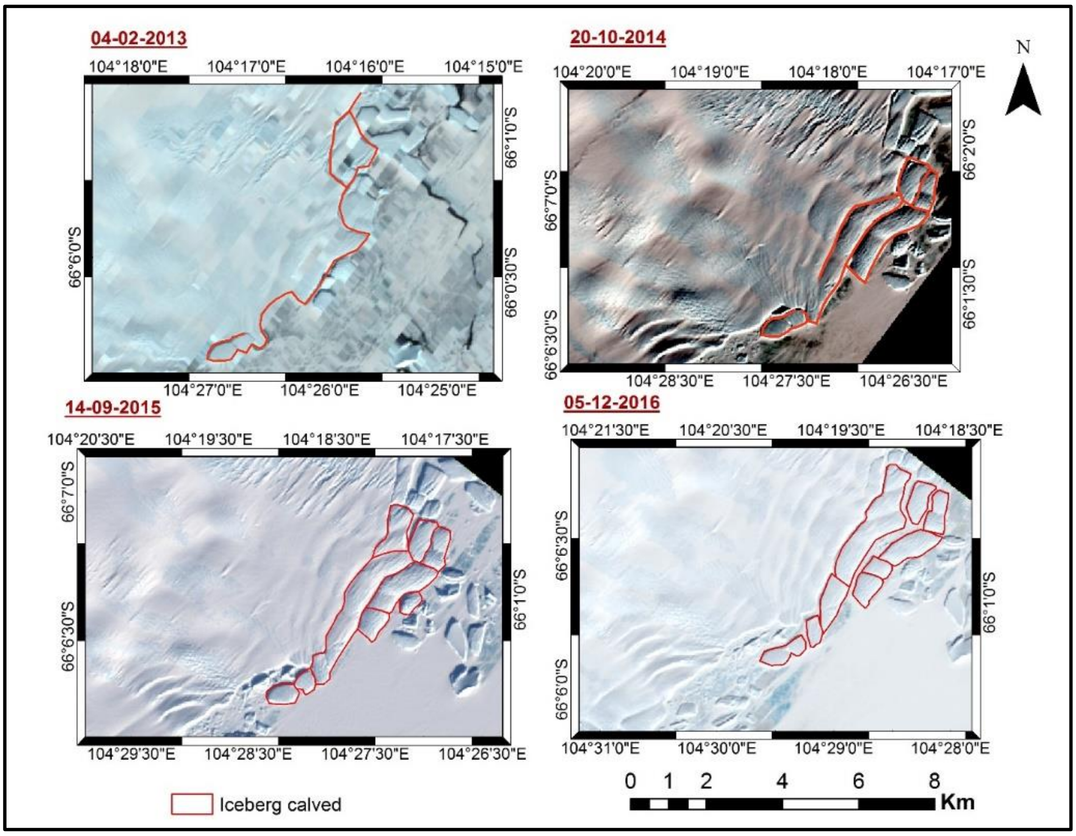


Figure 3. Calving event at Knox coast

The first event took place at the Knox coast; here several small icebergs of total area 6.11 km^2 were calved in the year 2016. The event is monitored from the year 2013, which was the initial stage of formation of crevasses in this place. In 2014, proper crevasses formed that show the shapes of iceberg. In 2016, the iceberg broke into smaller pieces a part of it was detached from the major ice sheet while some icebergs were still attached to the ice sheet even after being calved. Due to fast ice, the calved icebergs were still present at that location. The image of 2016 shows that many more rifts started to appear and will lead to calving of more icebergs in future. Figure 3 shows the occurrence of calving event at knox coast.

The second event that is studied took place at the Queen Mary Coast. Here, an iceberg of 31.05 km^2 was calved in 2014. The event is monitored from 2009 when the length of crevasses was 14.11 km, which increased to 20.58 km in year 2012. The satellite imagery of 2014 illustrates that the iceberg was calved and detached from the major ice sheet. As no clear imageries of the year 2013 were available, no observation in this year was recorded. In 2016, the iceberg moved away from the major ice sheet; however, it still appears on satellite imagery as it was stuck due to fast ice. Many more rifts and icebergs are also present in the imagery of year 2014 and 2016. Figure 4 shows the whole process of calving of iceberg and rifts that are forming in that location.

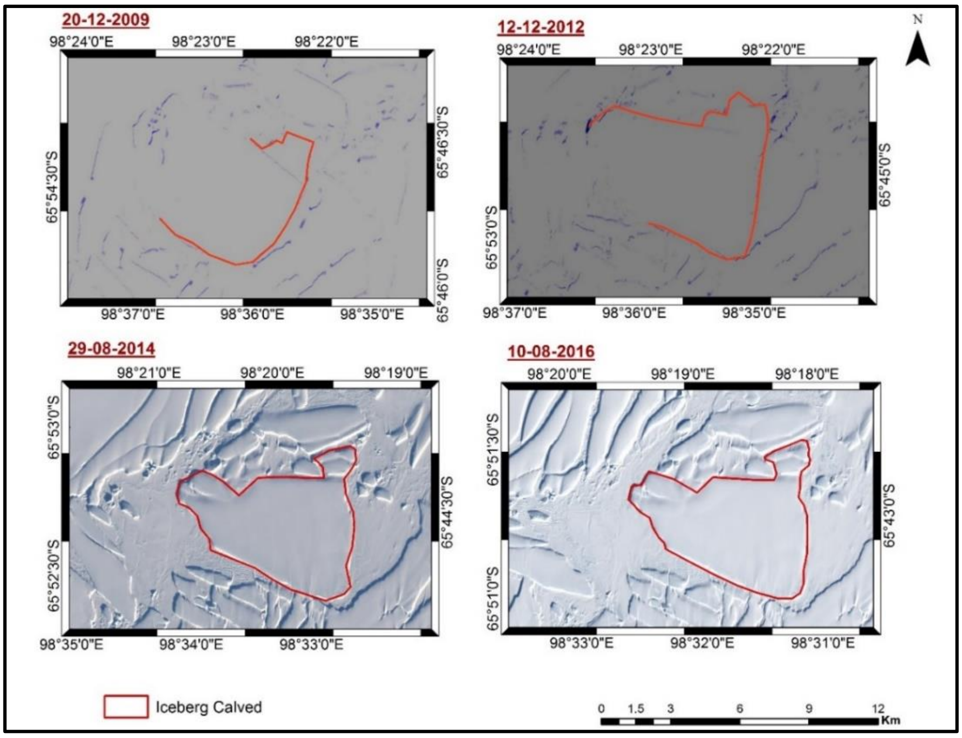


Figure 4. Calving event at Queen Mary coast

The third event took place at the Princess Astrid Coast; three icebergs of area 2.085 km^2, 0.311 km^2 and 1.816 km^2 were calved. The event is monitored from 2014; the smallest iceberg appears clearly to be slightly attached to the second iceberg in 2014 but was not detached from the major ice shelf (Figure 5). No crevasses were present for the other icebergs.

In the year 2015, crevasses started to form and by December 2016, both the icebergs were calved. A total of 4.212 km^2 area was calved at this place from 2014 to 2016. This shows that calving rate is high in this region as two icebergs were calved within a year. In 2014, no rifts were present and in 2015, rifts started to appear until 2016, when both the icebergs were calved.

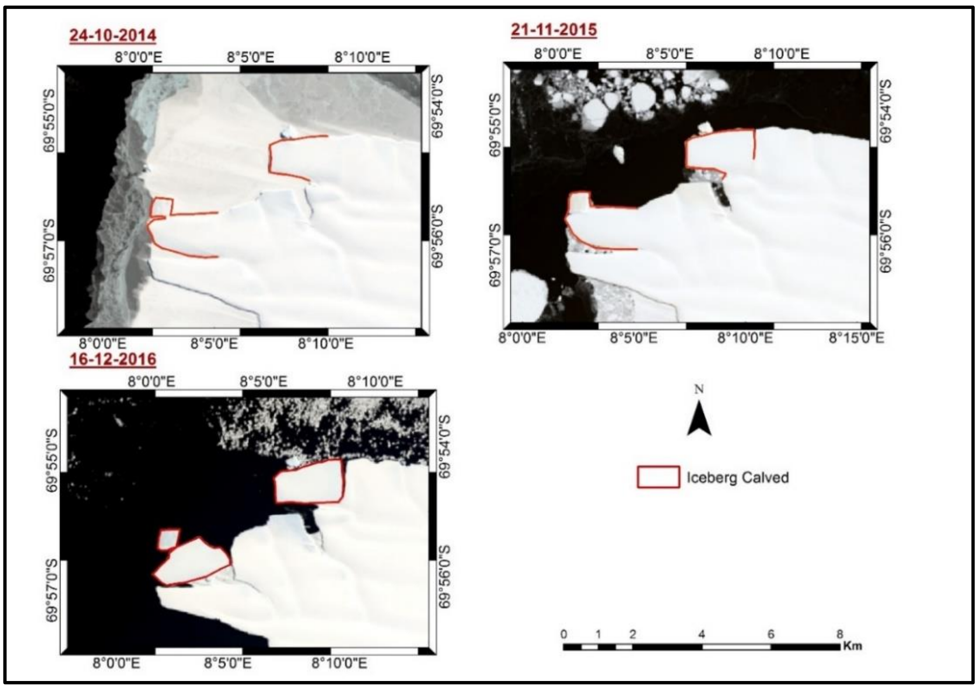


Figure 5. Calving event at Princess Astrid coast

https://doi.org/10.5194/isprs-archives-XLII-5-531-2018

5. CONCLUSION

Calving events are taking place all over Antarctica. Most of the events are minor and not much attention is given towards them. However, these events also have an impact on the environment and they are symptomatic of the local phenomena. In this study, three events have been studied, that have not been reported. All three of them have already been calved. The first event took place at Knox Coast and here the coast is facing various calving events. A total of 6.11 km^2 was calved in three years and many more small icebergs will be calved in future. The second event took place at Queen Mary Coast and here a single iceberg of area 31.05 km^2 was calved within 2009 and 2014. Many rifts and icebergs are present at this place, which will lead to more calving events in future. The third event took place at Princess Astrid coast and three icebergs of a total area of 4.212 km^2 were calved within 2 years. All the locations studied portray signs that many more small calving events will take place in future. In this study, calving of minor icebergs has been observed that are not reported. This study of monitoring calving in Antarctica shows that calving processes initiates with the formation of crevasses, which morph into rifts and finally result in the calving of the iceberg. Much attention is given to major icebergs but it is very important to give attention to minor ones as well. These will give us idea about the local phenomena that are triggering calving. Even though calving is a natural phenomenon, it is very important to understand that the rate at which they are calving in the present time is a very serious issue with respect to the health of the Polar Regions. The major problem was to differentiate between fast ice and ice shelf. Presence of ice over the decades and presence of physical structures are signs that differentiate between ice shelf and fast ice. The study of calving can help us understand the Polar Regions and their unseen processes in a better way.

ACKNOWLEDGEMENTS

The authors would like to thank DigitalGlobe for providing the imagery used in this study. We also acknowledge Dr. Rajan, former Director, ESSO-NCAOR and Dr. M. Ravichandran, Director-in-charge, ESSO-NCAOR, for their encouragement and motivation for this research. The entire experiment, validation, manuscript preparation, and editing of the manuscript was conducted at the ESSO-NCAOR. The lead author (S.D.J) has recently moved to the SIOS, Longyearbyen, Norway.

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