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Discussions

Tracking B-31 iceberg with two aircraft deployed sensors

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Abstract

Icebergs are a natural hazard to maritime operations in polar regions. Iceberg populations are increasing, as is the demand for access to both Arctic and Antarctic seas. Soon the ability to reliably track icebergs may become a necessity for continued operational safety. The temporal and spatial coverage of remote sensing instruments is limited, and must be supplemented with in situ measurements. In this paper we describe the design of a tracking sensor that can be deployed from a fixed-wing aircraft during iceberg surveys, and detail the results of its first deployment operation on iceberg B-31.

1 Introduction

Icebergs represent an environmental hazard to shipping and fixed marine structures, particularly in the circumpolar Antarctic waters and the North Atlantic, near to Greenland, where iceberg density is greatest (Gentleman et al., 1994). Since 1850 there have been 611 recorded collisions between icebergs and ships (Hill, 2005). This threat to maritime safety is expected to worsen as demand for access to these regions increases. Figure 1 shows that the number of tourists visiting Antarctica by ship has been rising since records begin in 1992, and since the global economic crisis in 2007. Figure 2 shows that exploration licenses for drilling for petroleum resources off Greenland have been rapidly increasing, in part due to the diminishing Arctic sea ice and corresponding effects on ease of access for maritime logistics. Furthermore global warming and its disproportionate impact on polar regions have led to increased iceberg populations (Smith et al., 2013). Thus the threat of icebergs colliding with maritime infrastructure is rising, and the ability to track icebergs reliably could in future provide a valuable additional source of information for shipping operations in polar waters.

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2 Existing monitoring strategies

Satellite-based optical sensors produce high-resolution images of icebergs that are used for iceberg tracking, but these are unable to penetrate cloud cover and are dependent on solar illumination. Synthetic Array Radar (SAR) satellite performance is independent of solar illumination and generally unaffected by cloud cover (McCandless and Jackson, 2003), however the spatial coverage of these sensors is limited, frequently resulting in poor temporal resolution. As a result, the database of known locations of large icebergs, as maintained by the US National Ice Centre (NIC), is typically updated every 20 days (Stuart and Long, 2011).

Another satellite-based sensor that can be used for iceberg tracking is a microwave scatterometer. This was first demonstrated in Stuart and Long (2011) with data from the QuikSCAT satellite – large icebergs appear as high-backscatter targets surrounded by lower-backscatter sea water or sea ice. QuickSCAT ceased operations in 2009, but the technique is still used with data from the Advanced Scatterometer (ASCAT) satellite and the recently launched OceanSat-2 Scatterometer (OSCAT). This supplements the NIC database with monthly position updates for large icebergs.

The PolarView website (www.polarview.aq) maintained by the British Antarctic Survey provided a useful portal for polar operators to access SAR images from the European Environmental Satellite (EnviSat). Since 2012 this satellite has been inoperable, however it is due to be replaced with the first SAR Sentinel-1 satellite later this year.

The limited temporal coverage of satellite-based sensors, the dependence of optical sensors on clear skies and solar illumination, and the inability for microwave-based scatterometer sensors to resolve small and medium sized icebergs means that a supplementary method for determining iceberg location is sometimes necessary.

The Newfoundland and Labrador tourism department uses reported visual sightings in conjunction with RADARSAT-2 imagery in order to maintain a separate database of iceberg locations in the region. The International Ice Patrol (IIP) supplements the remote sensing datasets with surveys of the Grand Banks of Newfoundland from

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fixed-wing aircraft and measurements from the World Ocean Circulation Experiment (WOCE) buoys (Murphy et al., 1996). The IIP typically deploys 12–15 of these buoys into the Labrador Sea each year. These buoys are deployed from aircraft as part of the iceberg survey missions, or from ship vessels of opportunity. The trajectory measured by each buoy is then used as the basis of a model for predicting iceberg trajectories that year.

Helicopters have been used on occasion to instrument icebergs with tracking devices (Orheim, 1980; Prinsenberg et al., 2012; Gladstone, 2001), see Fig. 3. However their limited range and payload capacity make them unsuitable for any operations beyond the proximity of a large supporting infrastructure. There are also safety concerns when instrumenting smaller, less stable icebergs (Weeks and Mellor, 1977).

If a fixed wing aircraft had the same ability to instrument icebergs, then the advantages of their increased range, availability and operation costs will allow significantly more icebergs to be instrumented. Furthermore, it would be possible to integrate iceberg instrumentation deployment within existing iceberg survey flights.

3 Aircraft Deployable Ice Observation System (ADIOS)

Over the last three years we have developed and tested an aircraft-deployable sensor for instrumenting glaciers (Jones and Gudmundsson, 2013). This enabled us to instrument heavily crevassed and otherwise inaccessible glaciers. A subsequent extension of this programme has been to investigate the effectiveness of ADIOS for installing tracking devices on icebergs.

Here we briefly discuss the constraints and ultimate design of ADIOS. See Jones and Gudmundsson (2013) for a more complete description.

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3.1 Design constraints

In order to minimise costly and time intensive changes to the aircraft platform, ADIOS is deployed from a standard sonobuoy launch tube mounted 45° to the aircraft floor. This restricts the diameter of the device at the point of deployment to that of the tube. Also the clearance between the launch tube and the interior aircraft cabin roof limits the length of any component of ADIOS prior to being installed in the launch tube (see Fig. 4).

As these devices are dropped on otherwise inaccessible icebergs, they have to be considered disposable, which places constraints on both the cost and the environmental impact of the design.

The obstacles to installing sensors on icebergs apply equally to the challenge of retrieving their data locally. Instead ADIOS must transmit its data to remote servers via a satellite link. Unlike a sonobuoy, which can rely on flotation to ensure its communications antenna is vertical and persists above the surface, this sensor must have a controlled impact angle and speed in order to set its ultimate orientation and depth within the snow. These criteria, in conjunction with local snow accumulation rates, will determine the upper limit of the lifetime of the ADIOS.

The aforementioned size constraints also limits the power source. An effective solar panel or wind turbine will not fit through the launch tube, so the payload has to be powered by a primary battery. In turn this restricts the electronics to consist of only low-power components. The capacity of the power source and the power consumption of the payload will be a limit on the effective duration of the operation of the device.

The device needs to impact the iceberg with sufficient force so as to bury itself even in dense snow conditions. This in turn means ADIOS will rapidly decelerate after impact. The payload has to be resilient to large deceleration forces and survive the impact intact.

In order to ensure ADIOS is safe to deploy from an airborne platform, the trajectory of the device after deployment needs to maximise separation from the aircraft as fast

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as possible. The slowest operational speed of the aircraft we use in this programme is $50\,\mathrm{m\,s^{-1}}$, meaning the device is dropped into an airstream of an equivalent velocity. Thus, whilst the device is within proximity of the aircraft it has to have a small aerodynamic profile in order to prevent the airstream, or turbulence under the aircraft, from deflecting ADIOS back towards the aircraft.

3.2 ADIOS design

The ADIOS is 2.5 m long and consists of a slender 1.5 m mast, a wider payload compartment and a solid aluminium nose cone. The mast and payload compartment are manufactured from poly-propylene, chosen for its impact strength in cold environments. The remaining components are manufactured from aluminium.

In order to ensure that, after impacting with the snow, the payload compartment is subsurface whilst leaving the antenna mast protruding above the surface, four snow brakes are mounted at the top of the compartment. Once the device is buried to a depth of one meter, these snow brakes effectively increase the surface area by a factor of four, and correspondingly its drag in the snow. These snow brakes fold forward and fasten closed during deployment, so as to fit through the launch tube and minimise their aerodynamic effects whilst in proximity to the aircraft. When the device is clear of the aircraft they are released and locked open. The size and shape of these brakes is a tradeoff between their adverse aerodynamic qualities and their ability to stop the device burying to too great a depth.

Without some form of parachute to provide stabilizing drag, during freefall ADIOS will oscillate about its centre of pressure and the horizontal velocity of the device will be largely sustained. Both effects prevent the device from impacting with the ground at 90°. However parachutes can also introduce payload oscillations due to the irregular and fluctuating airflow conditions around and through the surface of the canopy. In the case of solid flat circular parachutes, the airflow separates from the leading edge of the hemisphere in alternating vorticies. Dynamic stability is achieved by controlling

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this airflow with a more advanced canopy shape adapted from the Mars Viking lander parachute (Gillis, 1973).

3.3 Design testing

Over the last two years we have conducted design trials in a vertical wind tunnel and from flights local to two Antarctic stations. These trials were used primarily to improve the design stability and the depth to which each ADIOS unit buried itself. By refining the parachute design, snow brake design and the centre of gravity we were able to ensure each ADIOS impacts with the surface within 10° of vertical and 20 cm of the specified 1 m depth. The final design used a parachute size that set the terminal velocity of ADIOS at $42\,\mathrm{m\,s^{-1}}$.

3.4 Limitations

ADIOS is designed to stand upright within a snow pack at least one metre deep. The majority of Antarctic icebergs travel counter-clockwise around the perimeter of the continent, and accumulate in the Weddell Sea. They are then typically propelled into the Scotia Sea along a northward corridoor, until they enter the Antarctic Circumpolar Current (Stuart and Long, 2011). Until they cross 66° S the average iceberg surface mass balance is positive. Thus Antarctic tabular icebergs are likely to have sufficient snow pack for instrumentation by ADIOS.

The majority of Arctic icebergs form from glaciers on the north-west and south-east quadrants of Greenland. Here snow accumulates between September and May, but then rapidly ablates between June and August (Warren et al., 1998). As a result there is typically little surface snow-pack on Arctic icebergs, so these are less appropriate for instrumenting with ADIOS.

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4 Case study: tracking B-31

In the following section we demonstrate the capability of ADIOS for tracking icebergs by presenting data collected by two ADIOS units deployed on iceberg B-31.

In October 2011 a survey flight (Studinger, 2011a) as part of Operation IceBridge (Studinger et al., 2010) discovered a newly formed rift that appeared to span the entire Pine Island Glacier ice shelf. Subsequent flights showed that the rift was not quite complete, but estimated that a complete separation could occur within months (Studinger, 2011b). It would eventually separate to form iceberg B-31 in November 2013, but 11 months before its birth we had an opportunity to deploy two ADIOS on it.

During the Austral season 2012/2013 we deployed 37 ADIOS on Pine Island Glacier, two of which were west of the rift. This was a unique opportunity to study the birth of an iceberg as well as to evaluate the potential of ADIOS for iceberg tracking.

The ADIOS units we deployed were fitted with a low power single-band GPS receiver. Each unit takes a position fix six times a day, then combines this data with measurements of the GPS accuracy, the unit temperature and the battery voltage. Once a day the data packet is compressed and transmitted over the iridium satellite network. When the available battery power decreases, or GPS reception is no longer possible, the unit enters a low power mode. In this mode the unit intermittently attempts to transmit the last recorded GPS position. The doppler shift in the iridium transmission, measured by the receiving satellite, makes it possible to determine an approximate location in the event that the GPS is no longer operational.

Since January 2012 we have recorded 4152 position reports from 2 ADIOS sensors over a period of 406 days (see Fig. 7).

The first 10 months of this dataset show B-31 calving from the Pine Island Glacier ice shelf. Shortly after its birth, we saw a small part of B-31 (which happened to have an ADIOS on it) break off and separate from B-31. This can be seen in the increasing separation between the two ADIOS (see Fig. 8). The second, smaller iceberg has become part of the ice mélange surrounding B-31. At this point (November 2013, see

Fig. 7) both ADIOS started struggling to get a GPS reception, possibly because they have become partially buried or fallen into a crevasse. Despite this both ADIOS have continued to intermittently achieve a position fix and transmit it.

5 Conclusions

The threat icebergs pose to ships and fixed maritime structures is rising in line with demand for access to Arctic and Antarctic waters. This threat can only be partially mitigated by satellite tracking of icebergs so there is an increasing demand for the ability to track icebergs with in-situ tracking devices.

The Aircraft Deployable Ice Observation System (ADIOS) is particularly appropriate for instrumenting icebergs, and can be deployed from fixed-wing aircraft as part of larger iceberg survey missions. This has been demonstrated with the successful tracking of the B-31 iceberg with two ADIOS instruments. The location data these instruments transmitted provided operational support to the I-STAR C expedition during the 2013/2014 cruise in the Amundsen sea.

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References

Gentleman, J. F., Whitmore, G. A., Moore, M., and Zwiers, F. W.: Iceberg Paths and Collision Risks for Fixed Marine Structures, Springer-Verlag, New York, 1994. 4610

Gillis, C.: The Viking decelerator system – an overview, in: Proceedings of the 4th Aerodynamic Deceleration Systems Conference, AIAA, 73–442, doi:10.2514/6.1973-442, 1973. 4615

Gladstone, R.: A modelling and remote sensing study of Antarctic icebergs, Ph.D. Thesis, University of East Anglia, 2001. 4612

Hill, B. T.: Database of ship collisions with icebergs, www.icedata.ca (last access: July 2014), 2005. 4610

IAATO: IP103: IAATO Overview of Antarctic Tourism: 2012–13 Season and Preliminary Estimates for 2013–14 Season, ATCM XXXVI, 2013. 4619

Jones, D. H. and Gudmundsson, G. H.: Aircraft Deployable Ice Observation System (ADIOS) for instrumenting inaccessible glaciers, J. Glaciol., 59, 1129–1134, doi:10.3189/2013JoG13J112, 2013. 4612

McCandless, S. W. J. and Jackson, C. R.: Synthetic Aperture Radar Marine User's Manual, Chapter 1, NOAA/NESDIS Office of Research and Applications, http://www.sarusersmanual.com (last access: 1 May 2014), 2003. 4611

Murphy, D. L., Viekman, B., and Channel, C.: New gridded currents for the international ice patrol operations area, OCEANS'96, Prospects for the 21st Century, Conference Proceedings, MTS/IEEE, 2, 613–618, 1996. 4612

Olsen, H. K.: NUNAOIL Annual report, http://nunaoil.gl/fileadmin/nunaoil/pdf/Annual_reports/NUNAOIL_Annualreport_2012.pdf (last access: 1 May 2014), 2012. 4620

Orheim, O.: Physical charateristics and life expectancy of tabular antarctic icebergs, Ann. Glaciol., 1, 11–18, 1980. 4612

Prinsenberg, S. J., Peterson, I. K., Holladay, J. S., and Lalumiere, L.: Labrador shelf pack ice and iceberg survey, March 2011, Can. Tech. Rep. Hydrogr. Ocean Sci., 275, 1–55, 2012, http://www.ocean-sci.net/275/1/2012/. 4612, 4621

Smith, K. L. J., Sherman, A. D., Shaw, T. J., and Sprintall, J.: Icebergs as unique lagrangian ecosystems in polar seas, Mar. Sci., 5, 269–287, 2013. 4610

Stuart, K. M. and Long, D. G.: Tracking large tabular icebergs using the SeaWinds Ku-band microwave scatterometer, Deep-Sea Res. Pt. II, 58, 1285–1300, 2011. 4611, 4615

Studinger, M.: Preliminary Science Flight Report 120105, Operation IceBridge Antarctica 2011, IceBridge Flight Documents, 120105, 2011a. 4616

Studinger, M.: Preliminary Science Flight Report 120122, Operation IceBridge Antarctica 2011, IceBridge Flight Documents, 120122, 2011b. 4616

Studinger, M., Koenig, L., Martin, S., and Sonntag, J. G.: NASA's Operation IceBridge: Using Instrumented Aircraft to Bridge the Observational Gap between ICESat and ICESat-2 Laser Altimeter Measurements, Proceedings of AGU, 2010. 4616

Warren, S. G., Rigor, I. G., and Untersteiner, N.: Snow depth on Arctic Sea ice, J. Climate, 12, 1814–1829, doi:10.1175/1520-0442(1999)012<1814:SDOASI>2.0.CO;2, 1998. 4615

Weeks, W. F. and Mellor, M.: Some elements of iceberg technology, in: Proceedings of the International Conference on Iceberg Utilization, 1, NASA STI, 1977. 4612

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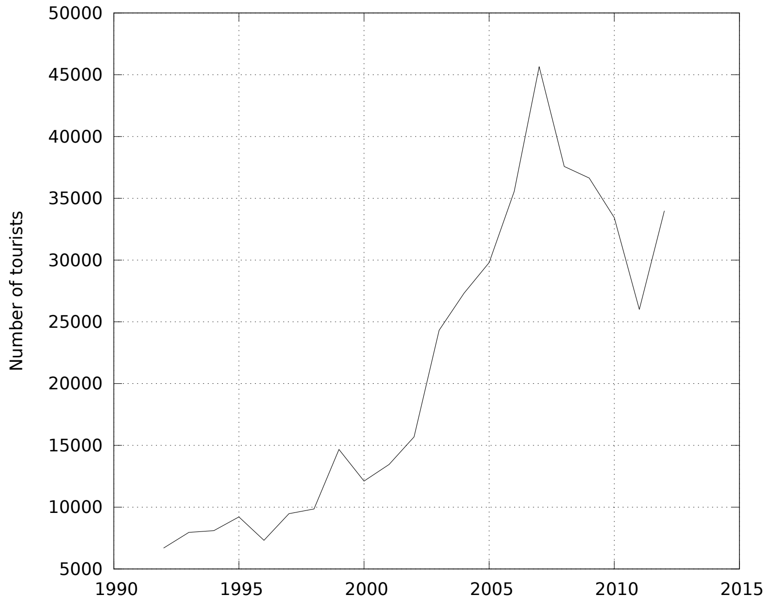

Figure 1. Number of tourists visiting the Antarctic by ship (IAATO, 2013).

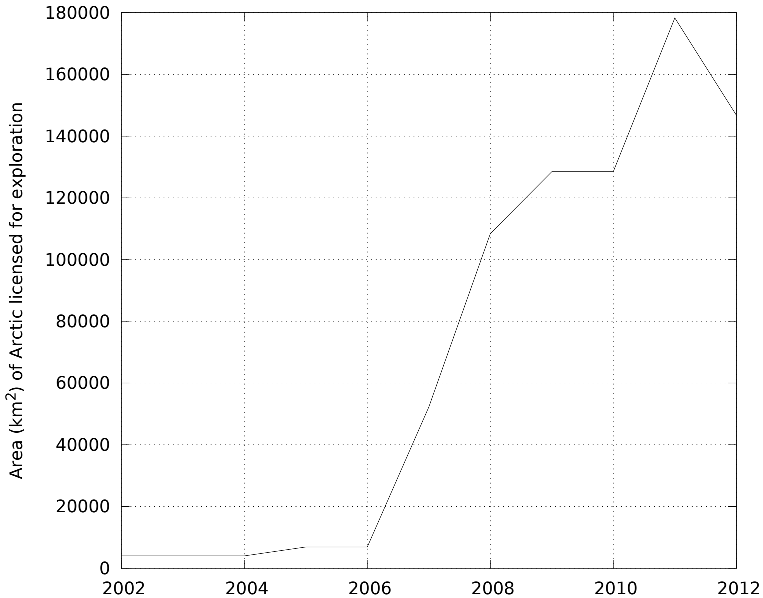

Figure 2. Area of Arctic licensed for oil exploration in Greenland (derived from NUNAOIL annual report 2012 (Olsen, 2012).

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Figure 3. Helicopter landed on iceberg for tracker deployment. Image courtesy of S. Prinsenberg (Prinsenberg et al., 2012).

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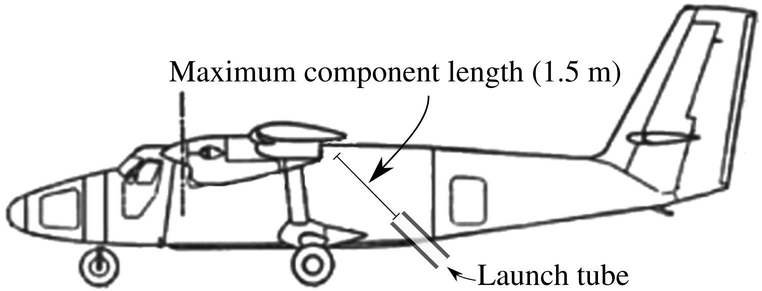

Figure 4. Twin Otter aircraft fitted with sonobuoy launch tube.

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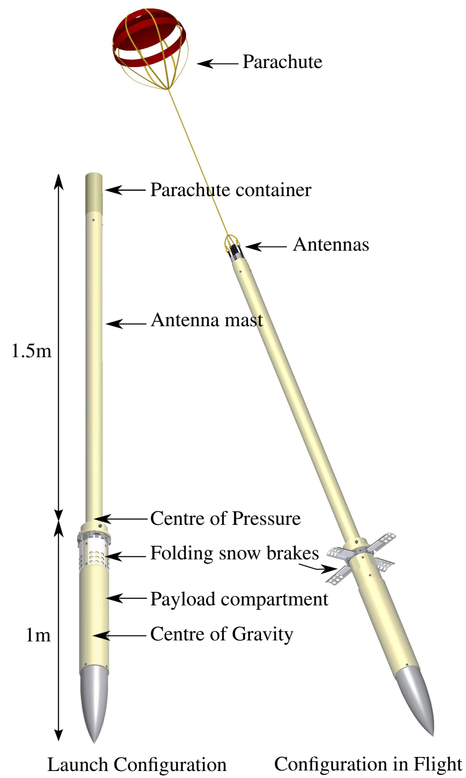

Figure 5. ADIOS design.

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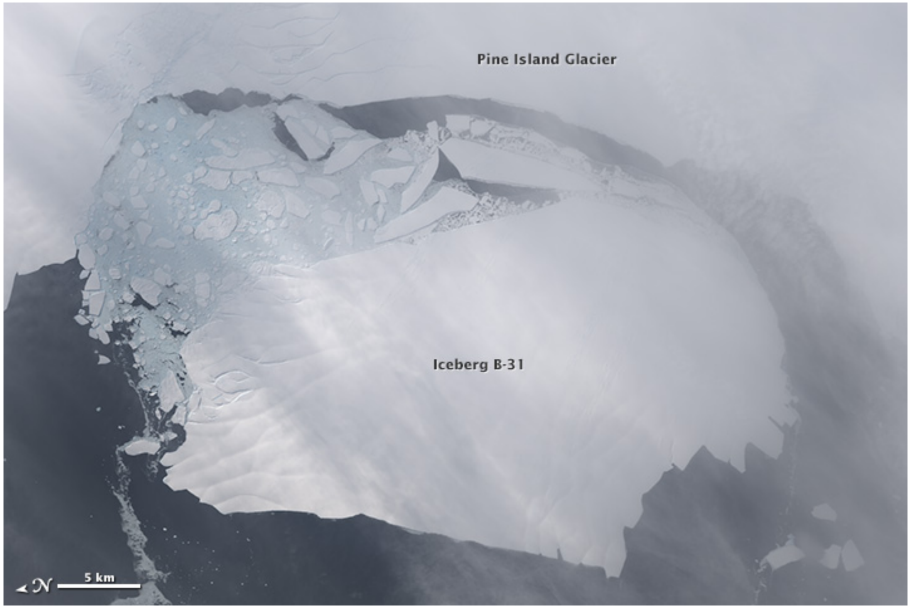

Figure 6. Separation of B31 iceberg from Pine Island Glacier. USGS/NASA. LANDSAT image 13 November 2013.

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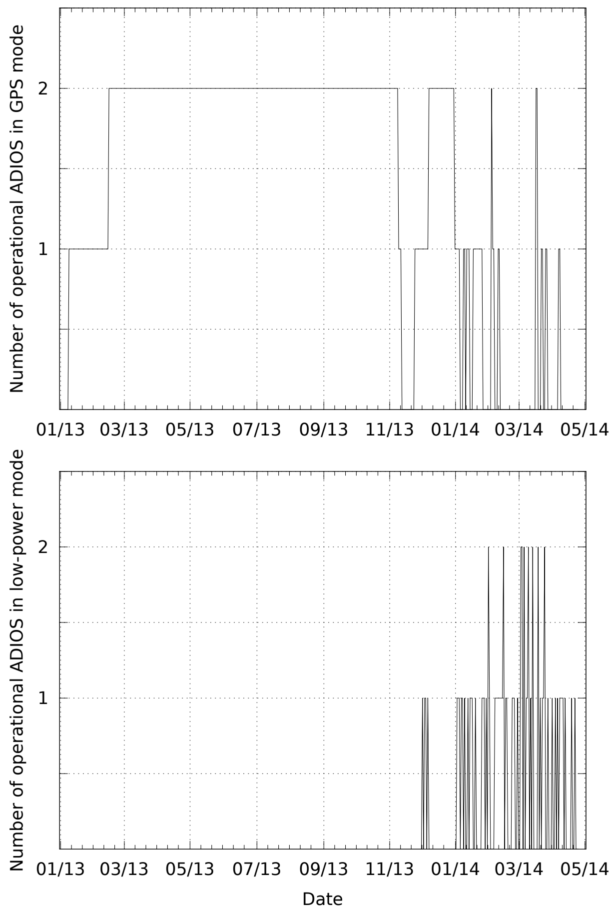

Figure 7. Operational performance of the two ADIOS iceberg tracker units located on iceberg B-31, that calved from the Pine Island Ice Shelf in November 2013.

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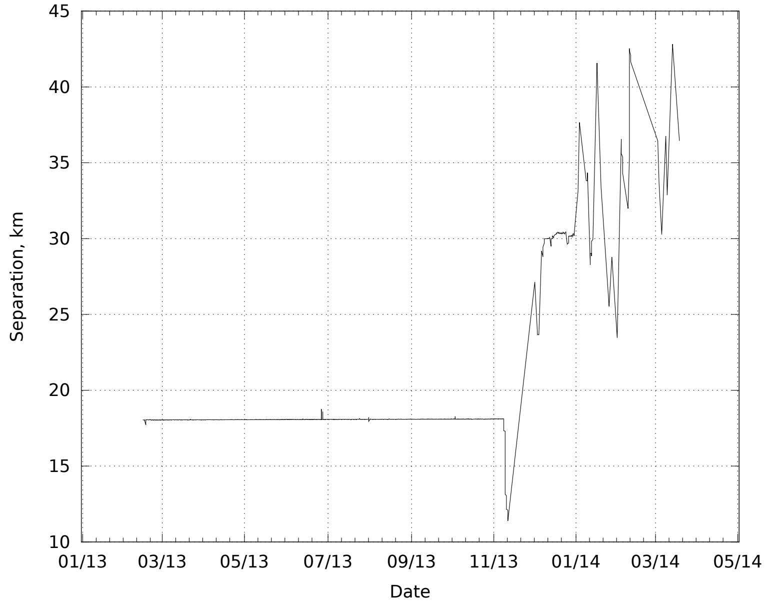

Figure 8. Distance separating each ADIOS.

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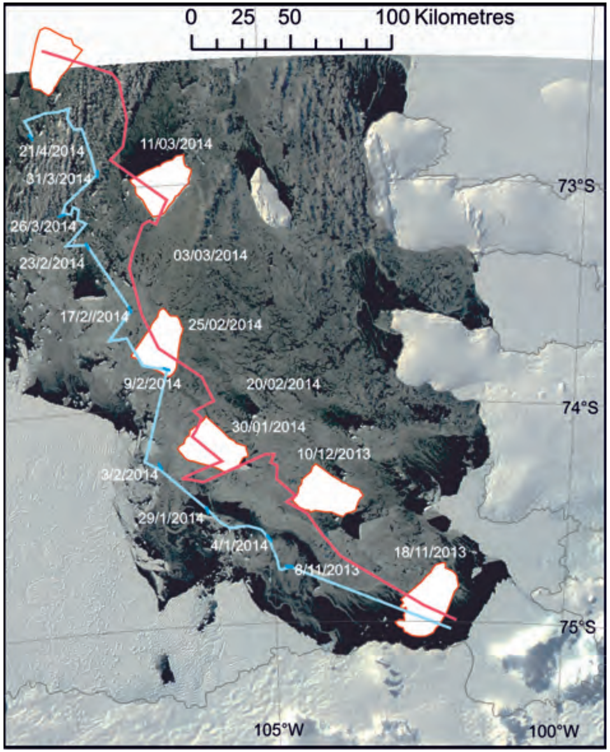

Figure 9. Tracks generated from ADIOS situated on B-31 iceberg. Iceberg outlines derived from Radarsat2 SAR (courtesy MDA) and MODIS optical (courtesy NASA) satellite imagery.

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