Validation of SAR Iceberg Detection with Ground-Based Radar and GPS Measurements

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***Abstract*—Calving of icebergs at the tidewater glacier fronts is a component of the mass loss in Polar regions. Studying the regional distribution of icebergs, their volume, motion, and interaction with the environment is of interest. Here, we present the results from a fieldwork campaign conducted in Kongsfjorden, Svalbard in April 2016, where both satellite and ground-based remote sensing instruments were used to observe dynamics of sea ice, icebergs, and growlers. We used a ground-based radar system, imaging the study area every second minute during five days. During the same observation period, we collected four RADARSAT-2 (RS-2) quad-pol images, that are used for automatic detection of icebergs. In addition, the fieldwork team collected GPS positions of some drifting and grounded icebergs in the fjord to be used as ground-truth data. The comparison and combination of satellite, ground-based radar, and *in-situ* data contribute to cross-validate the results.**

***Index Terms*—Iceberg, sea ice, synthetic aperture radar, polarimetry, detection, ground-based radar, GPS mapping.**

I. Introduction

There are many options for the detection and tracking of icebergs, such as various cameras, satellite, airborne, ground-based radars, and optical sensors, and underwater sonars. The use of data from optical sensors requires suitable cloud and light conditions. This restriction does not hold for radar imagery and hence iceberg detection generally is an important application of radar sensors in Polar regions.

Many studies have shown the advantages and capacities of airborne and satellite synthetic aperture radar (SAR) for iceberg detection and characterization, e.g., [1]–[4]. Dierking and Wesche [5] studied the polarimetric characteristics of icebergs and sea ice using RADARSAT-2 (RS-2) fine quad-pol imagery in Antartica. They studied the potential of different polarimetric parameters to distinguish icebergs, sea ice, and open water. Marino *et al.* [6] proposed an iceberg detector to identify icebergs embedded in sea ice using depolarization ratio of dual-pol SAR data. Akbari and Brekke [3] proposed a new near real-time methodology for automatic identification of icebergs in high resolution C-band polarimetric SAR images. The algorithm adapts to different sea-ice conditions. It tackles high iceberg density situations and heterogeneous conditions in the mariginal ice zone. An efficient, reliable, and fast segmentation-based iceberg detection algorithm was developed. The algorithm was tested with a series of quad-pol RS-2 images covering different sea states, wind conditions, and incidence angles in open and ice-infested water.

The major challenge in iceberg detection is associated with the lack of consistent ground truth data, which can be reliably used for validation of the detection results obtained by satellite remote sensing. The main objective in this study is to detect icebergs/growlers by using satellite SAR scenes and compare the results with near coincident ground-based radar measurements and in-situ observations. The data collection took place in April 2016 in Kongsfjorden, Svalbard. The team conducted a combined satellite, ground-based, and in-situ GPS observations. The aim of this campaign was to collect, process, and compare satellite data, ground-based radar measurements, and in-situ observations. The acquired data cover icebergs, small islands, sea ice, and open water in different dynamic conditions.

In [3], the authors demonstrated the great potential of the proposed algorithm for iceberg detection in open water and/or ice-infested waters using C-band polarimetric SAR satellite. However, comparison with the other sensors and fieldwork remains mandatory for the validation of the data acquired by spaceborne sensors. The data in the field work collected by Ku-band ground-based radar measurements together with the hand-held GPS data offered the great opportunity for comparison, validation, and assement of SAR iceberg detection limitations.

This paper is organized as follows. Section II provides the description of the study area and data collection from satellite, ground-based radar, and ground-truth data. The processing of both satellite acquisions and ground-based radar measurements are covered in Section III. The validation results of the multi-sensor analysis are given in Section IV. Conclusions drawn from the study are presented in Section V.

II. Study Area and Data Collection

The study area is located in Kongsfjorden (Northwestern Spitsbergen, Svalbard), where two tidewater glaciers terminating in Kongsfjorden are capable of delivering icebergs to the fjord. The inner part of the fjord is partly covered by sea ice over winter and spring. The dominant ice type in Kongsfjorden in winter is young ice, later in early spring it is first-year fast ice, and after the onset of melting it is a combination of fast ice and drift ice. Icebergs from adjacent glaciers can be found trapped into the fast ice or drifting in open water.

The satellite data consists of 4 RS-2 Fine quad-pol scenes from both ascending orbits over a range of incidence angles

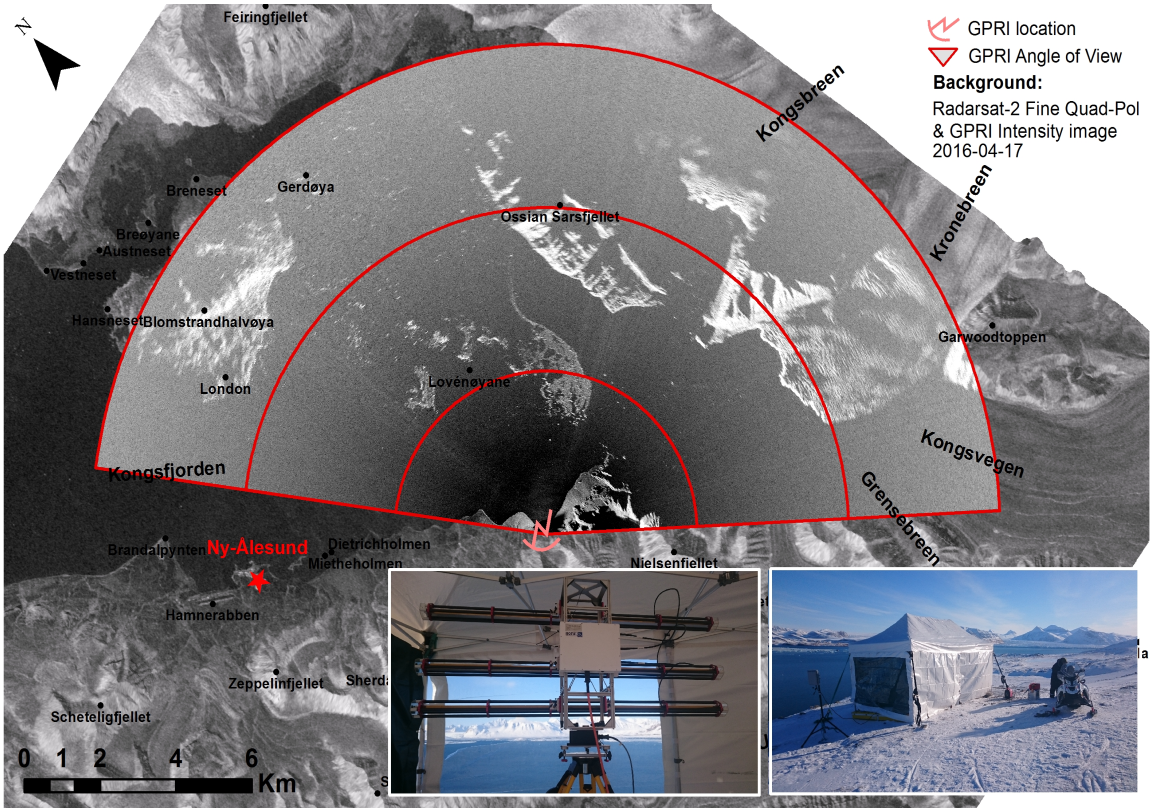

Fig. 1. Background: RS-2 satellite image. The overlay shows an intensity image obtained from the ground-based radar. The red rings correspond to 4, 8 and 12 km of distance from the radar location.

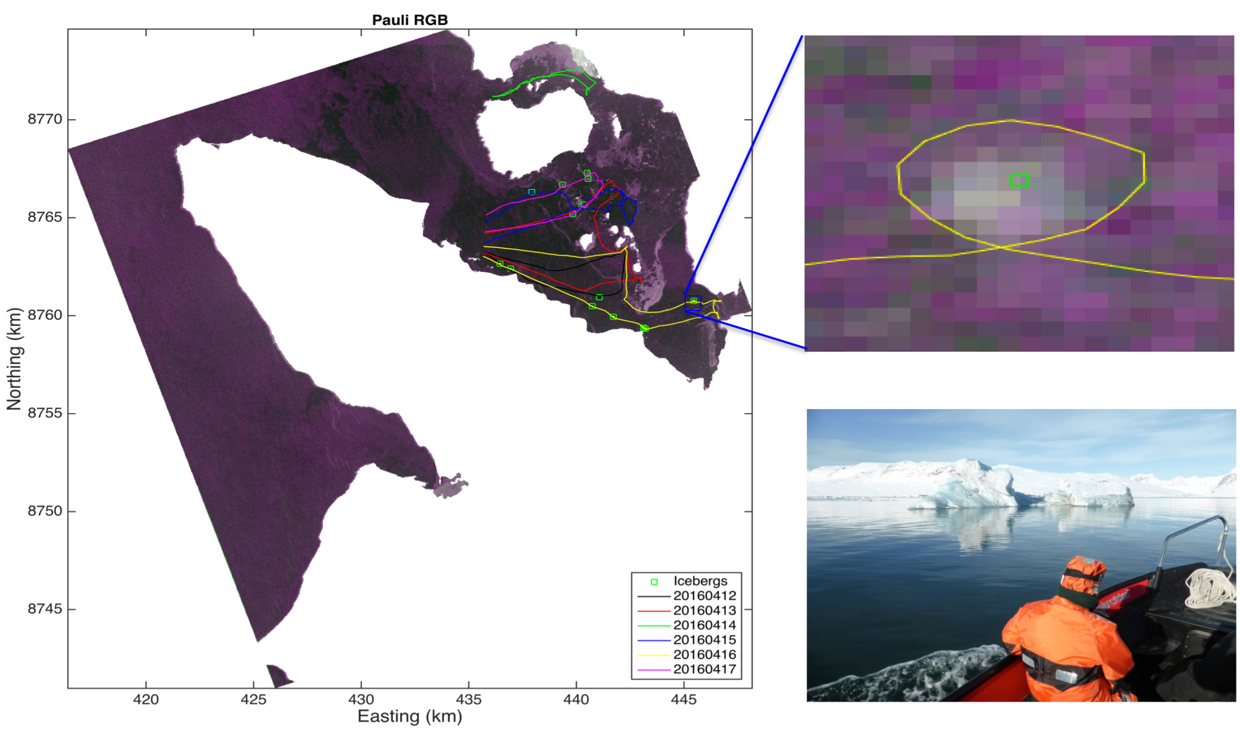

Fig. 2. Geocoded Pauli RGB compositions of the quad-pol SAR acquisition on April 15, 2016, 15:39. White region: land. The figure also presents the boat track and centroids of 17 icebergs mapped by GPS as well as a picture taken from the boat while circum-navigating an iceberg. The inset shows an example of a centroid of grounded iceberg. Photo by Sebastian Gerland, NPI.

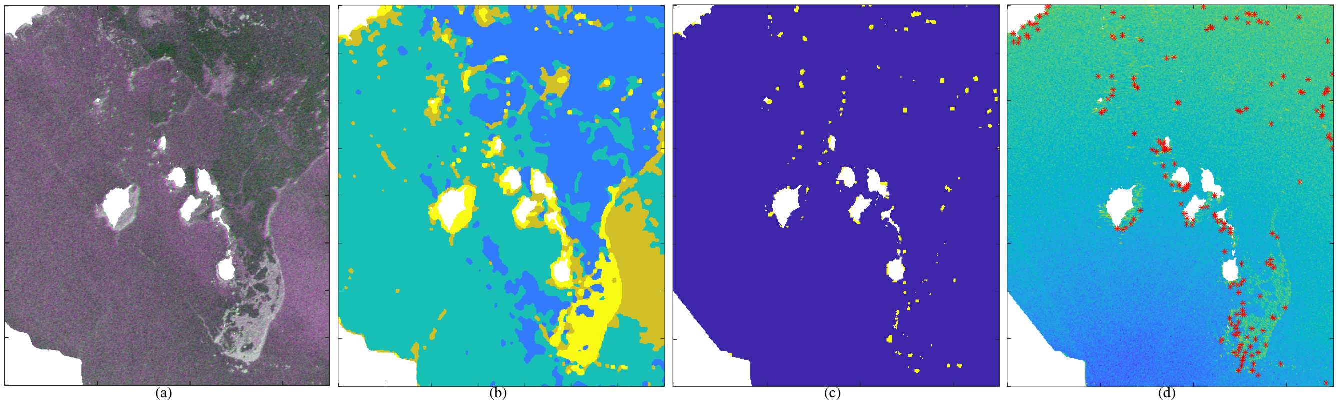

Fig. 3. (a) Geocoded Pauli RGB composite (R=HH-VV,G=HV,B=HH+VV) of the quad-polarimetric RS-2 acquisition on April 17, 2016 multilooked with 16-looks for the ROI. (b) Segmentation results produced by the segmentation processor. (c) Detection mask of RS2 acquisition. Icebergs in yellow, background open water or sea ice in blue, and land in white. (d) Near coincident ground-based radar image of corresponding RS-2 scene within the ROI with the centroids of the detected icebergs.

from 23° to 45°. The images were delivered in a SLC slant-range format which are characterized by a nominal pixel spacing of 5.2 m×7.6 m in slant range and azimuth, respectively, covering approximately 25 km × 25 km. They cover the time span April 15-18, 2016.

The ground-based radar data using Norut's Gamma Portable Radar Interferometer (GPRI) provide high spatial (0.75 m in range, 7 m in azimuth at 1 km distance) and temporal (minute-scale) resolutions. With respect to satellite SAR data, in ground-based radar observations, all images are taken from the same position. The GPRI was installed on a hill, the southern shore of inner Kongsfjorden as indicated with a lightning on the map in Fig. 1. The GPRI has a scanning angle of 170 degrees in order to image most of the fjord. The GPRI data collection started on April 15 at 15:15 (UTC time) and continued to April 19 at 8:00. The radar conducted one sweep every 2 minutes with only one interruption of 4 hours in the early morning of April 16. The GPRI data very beneficial for validation since it can be used to track icebergs over time, and thus allowing to see the history of the icebergs detected by using satellite images, which only provides a snapshot in time.

The in-situ datasets consist of 17 GPS positions of some drifting and grounded icebergs in the inner fjord between April 12-17, 2016 (see Fig. 2). The goal of this mapping is to provide additional validation data for iceberg detection from satellite and ground-based radar measurements. The time differences between the RS-2 acquisitions and the GPS localization of icebergs vary from few minutes to more than a day [7]. These time delays may give information on whether the icebergs are grounded or not.

III. Data Processing

The SLC images are calibrated, multilooked, and geocoded to a Universal Transverse Mercator (UTM) grid to produce the geocoded multilook complex (MLC) covariance images with 20 m pixel spacing and 16 looks. We herein apply the proposed segmentation-based iceberg detection algorithm in [3] on RS-2 images. A land masking is performed with the help of auxiliary data produced by the Mapping Section of the NPI. Input features from the SAR data are first extracted. We then apply an unsupervised segmentation algorithm reported in [8] to group all pixels with similar statistical properties in the same cluster. The input to the segmentation method is a vector containing the log-transformed intensities and multipolarization features from the PolSAR data in the previous step. The automatic segmentation is achieved through an expectation-miximization (EM) algorithm. The segmentation of SAR image results in a number of segments corresponding to distinct regions in the open water, sea ice, or icebergs/growlers. After the unsupervised segmentation, the icebergs are chosen from the output segments by applying a set of parameters based on brightness, geometry, and the shape of the segments. The connected component labeling (CCL) algorithm is finally used to compute connected components for binary images. The final output map is thus a binary image, where each pixel is considered either a part of an iceberg/growler or a part of the background.

Intensity images are extracted from the ground-based radar measurements and converted to the UTM grid with 5m pixel spacing. An adaptive thresholding is sequentially applied on image-by-image to classify pixels as either iceberg or non-iceberg. There are also cases where the radar signatures of icebergs resembled those of deformed sea ice. Therefor we again apply discrimination that uses shape and brightness parameters to distinguish icebergs from other discrete components. The CCL algorithm is also applied to compute connected components for binary images. The final product from the input image is a binary image, where each pixel is considered either a part of an iceberg/growler or a part of the fjord.

Fig. 3 (a-c) shows the results of satellite-borne results (Pauli RGB, segmentation, and final detection map) versus the near coincident ground-based radar image of corresponding RS-2 scene in Fig. 3 (d) within the region of interest with the centroids of the detected icebergs.

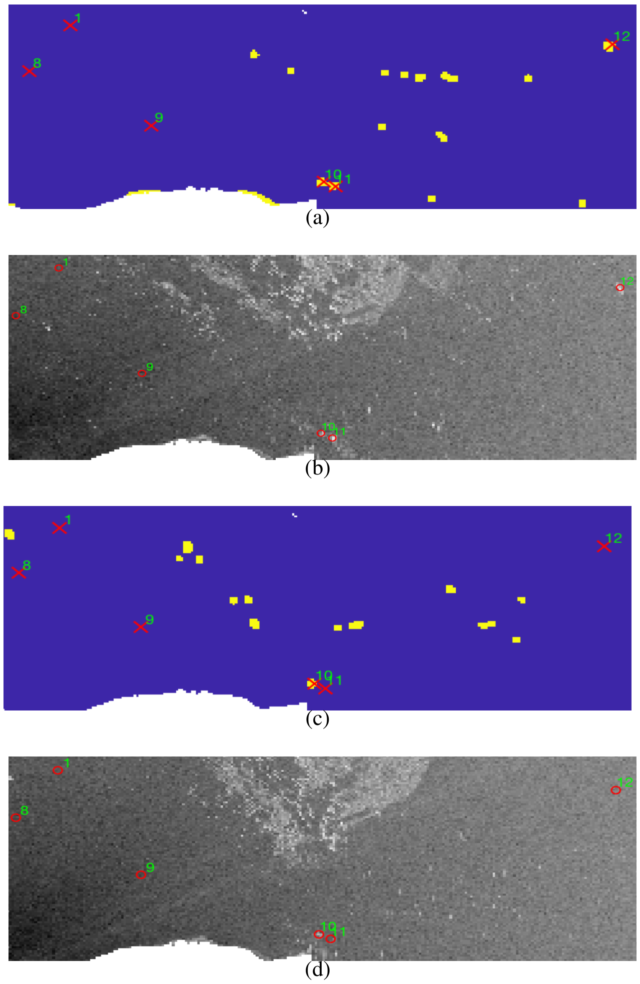

Fig. 4. Three suspected grounded and drifting icebergs labelled #10, #11, #12 mapped by GPS. (a) and (c) RS-2 detections (15 and 18 April). (b) and (d) GPRI Intensity images (16 April, 12:42 UTC and 18 April, 15:51 UTC).

IV. Validation Results

To properly cross-validate the detection results from satellite and ground-based radars, we take the detection results from both sensors. We focus on a region of interest (ROI) in Fig. 3 covering an area of 8 km $\times$ 7 km and 400 $\times$ 350 pixels in size. Table I represents the results for the acquisitions of both SAR and the near coincident ground-based radar. Each row presents the number of detected icebergs for both SAR and GPRI, the number of missed icebergs in SAR, and the detection accuracy in each acquisition. Looking at Fig. 3(d) there are some icebergs or small ice objects detected within young thin ice whereas SAR missed most of them. The same is also visible on the northern cost. This might be due to the incidence angle of GPRI catching sea ice edges and small ice features or higher spatial resolution in near range.

Some of icebergs mapped by GPS could be identified on the detection results by RS-2 scene and GPRI images. For example in Fig. 4(a) and Fig. 4(b), three of GPS-localized icebergs (labelled #10, #11, and #12), which remain stationary for some hours, are identified in both GPRI and SAR while the other

TABLE I
Comparison between ground-based and SAR detections

SAR Scene Date (Time)	N_{SAR}	N_{GPRI}	N_{miss}	DA
15/04/2016 (15:39)	103	154	25	66%
16/04/2016 (15:10)	121	148	29	80%
17/04/2016 (16:21)	95	120	32	77%
18/04/2016 (15:52)	100	121	30	79%

floating icebergs drift during the time interval between the GPS localisation and the radar acquisitions. Iceberg labelled #11 and #12 drift after some hours and this appears clearly in Fig. 4(c) and Fig. 4(d).

V. Conclusion

In this paper, we showed the great potential of the near coincident ground-based radar and GPS measurements to cross-validate iceberg detection from high-resolution C-band polarimetric SAR data.

VI. ACKNOWLEDGMENT

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References

[1] V. Akbari, C. Brekke, A. P. Doulgeris, R. Storvold, and A. Silvertsen, “Quad-polarimetric SAR for detection and characterization of icebergs,” in *Living Planet Symposium*, ser. ESA Special Publication, vol. 740, May 2016, pp. 1–8.

[2] V. Akbari, A. P. Doulgeris, and C. Brekke, “Subaperture analysis of polarimetric SAR data for iceberg detection,” in *2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, July 2016, pp. 5666–5669.

[3] V. Akbari and C. Brekke, “Iceberg detection in open and ice-infested waters using C-band polarimetric synthetic aperture radar,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 56, no. 1, pp. 407–421, Jan. 2018.

[4] D. Power, J. Youden, K. Lane, C. Randell, and D. Flett, “Iceberg detection capabilities of radarsat synthetic aperture radar,” *Canadian Journal of Remote Sensing*, vol. 27, no. 5, pp. 476–486, 2001.

[5] W. Dierking and C. Wesche, “C-band radar polarimetry: Useful for detection of icebergs in sea ice?” *IEEE Trans. Geosci. Remote Sens.*, vol. 52, no. 1, pp. 25–37, Jan 2014.

[6] A. Marino, W. Dierking, and C. Wesche, “A depolarization ratio anomaly detector to identify icebergs in sea ice using dual-polarization SAR images,” *IEEE Trans. Geosci. Remote Sens.*, vol. 54, no. 9, pp. 5602–5615, Sept 2016.

[7] J. Negrel, S. Gerland, A. P. Doulgeris, T. R. Lauknes, and L. Rouyet, “On the potential of hand-held gps tracking of fjord ice features for remote-sensing validation,” *Annals of Glaciology*, pp. 1–8, 2017 (https://doi.org/10.1017/aog.2017.35).

[8] A. P. Doulgeris, “A simple and extendable segmentation method for multi-polarisation SAR images,” in *POLinSAR 2013*, 2013, p. 8 pp.