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Estimating iceberg paths using a wind-driven drift model

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ABSTRACT

Icebergs are hazards to ship traffic and offshore operations. Their monitoring using satellite data is hence important for marine safety and for protection of the marine environment. The repeated search for smaller icebergs in a temporal sequence of satellite images, however, can be time-consuming if the expected drift path of the berg is not known. Computer simulations of iceberg drift can be applied to determine the approximate new iceberg position to narrow the search radius for icebergs. Best suited for this purpose are relatively simple, fast-running models. For three different regions of the Weddell Sea, Antarctica, we used an iceberg drift model driven by wind forecasts and analyzed predicted iceberg positions in comparison to positions retrieved from GPS buoys placed on the icebergs. As an error measure, we took the difference between the modeled and observed iceberg positions and drift angles. As the model was developed for open water regions, we added a sea-ice component. The application of the model was tested on two ENVISAT Wide Swath SAR scenes from the Weddell Sea, simulating and tracking iceberg positions for a period of five days. Although simulation results differ from direct observations of iceberg drift, they are still useful for narrowing the search area for icebergs in satellite images. We attribute the deviations between simulations and observations to the inherent large uncertainties in the input data for the model.

1. Introduction

In operational monitoring of ocean regions, iceberg tracking and drift forecasting are essential tasks for the safety of marine operations. In science, the tracking of icebergs provides the opportunity to test and improve models for simulating ocean dynamics and atmosphere–ocean interactions. In the study presented here, we concentrated our analyses on the Antarctic, motivated by the availability of position data received from buoys deployed on icebergs.

Around Antarctica, a large number of icebergs are drifting along the coastlines. The U.S. National Ice Center (NIC; http://www.natice.noaa.gov/) has been systematically tracking giant icebergs in the entire Southern Ocean since the late 1970s based on satellite data. Regional studies focusing on iceberg tracking were carried out using satellite images (e.g., Aoki, 2003; Gladstone and Bigg, 2002; Silva and Bigg, 2005; Swithinbank et al., 1977), buoys (e.g., Schodlok et al., 2006; Turnbull, 2010) or ship sightings (e.g., Romanov et al., 2012). While buoy data reproduce the paths of drifting icebergs with high temporal resolution (on the order of minutes), satellite imagery and ship sightings provide information on position changes only with large temporal gaps of several hours or days.

The major objective of our study was to improve iceberg tracking using satellite data. Starting at a given iceberg position, models for simulating iceberg drift patterns can be applied as prediction tools to limit the extent of the area in which the new position of the iceberg has to be searched in a sequence of satellite images. This is in particular important for relatively small bergs, i.e., bergs covering only a few image pixels. In such cases, it is sometimes difficult to unambiguously identify one particular berg in every scene of the image sequence.

The fundamental model equation for simulating iceberg drift describes the local balance of momentum between atmosphere, ocean, and iceberg. The force balance is described in Bigg et al. (1997), for example, and considers wind and water drag, the Coriolis effect, wave radiation, the surface pressure gradient and effects due to the presence of sea ice. The majority of studies on simulations of iceberg drift are based on the general drag relationships presented by Smith and Banke (1983). Lichey and Hellmer (2001) took explicitly the influence of sea-ice concentration and strength into account. The study of Rackow (2011) is based on the approach of Lichey and Hellmer (2001) with minor changes, e.g., considering the possibility of icebergs running aground. Allison et al. (2014) used an ensemble forecast approach. Efforts regarding the optimization of simulation models for operational applications were also undertaken, e.g., Kubat et al. (2005) or Turnbull et al. (2015).

For the purpose of iceberg tracking in satellite images, we need simple, fast running models. In this study, we used the analytical solutions of the momentum equation for steady motion published by Crépon et al. (1988). Their iceberg drift model (in the following denoted as 'S-IB') is forced only by the wind velocity and was designed for simulating iceberg drift in open water regions. We calculated the drift of eleven small icebergs in three different regions of the Weddell Sea and analyzed deviations between model results and data obtained from buoys

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that were deployed on those icebergs. In a next step, we extended the model by a simple sea-ice component to consider conditions of ice-covered ocean regions. Since drag coefficients, which are a complex function of surface roughness, keel depth, shape, and mass of an iceberg (Turnbull et al., 2015) are not known with the required accuracy, we conducted a sensitivity study varying the magnitudes of the different drag coefficients. In the last part of this paper, we discuss a practical example of using the model for iceberg drift prediction in comparison to the determination of iceberg position changes between two successive Synthetic Aperture Radar (SAR) scenes.

2. Data and method

2.1. Regions of interest

For a detailed study of iceberg drift, Global Positioning System (GPS) buoys were deployed on several icebergs in three different regions of the Southern Ocean in 1999 (Fahrbach and EL Naggar, 2001). The positions of the three test sites are depicted in Fig. 1, relevant data for each buoy are listed in Table 1. During January and February 1999, the test sites were characterized by different sea-ice conditions. In the Southern Weddell Sea (SWS), the sea-ice concentration was close to one, with ice thicknesses between 1.0 and 1.5 m. In the Eastern Weddell Sea (EWS), only single sea-ice floes were present. The thickness of the few sea-ice floes was less than 0.5 m. The North-Eastern Weddell Sea (NEWS) was ice-free during our study period (Saha et al., 2010).

The general wind and ocean current regimes in the test sites are also different. In the SWS, the Weddell Gyre is the dominant ocean feature (Rintoul et al., 2001). The Coastal Current in the EWS is dominated by a westward flow (Fahrbach et al., 1992). The NEWS region is influenced by the Antarctic Circumpolar Current (ACC) system, with an eastward flow direction (Rintoul et al., 2001). The long-term mean wind directions are southerly for the SWS, easterly for the EWS and westerly for the NEWS (http://polarmet.osu.edu/ACCIMA/MonthlyWind10m.gif).

2.2. Observations

The GPS buoys transmitted the positions of the icebergs at least once a day at noon (using UTC time) until the icebergs disintegrated or the buoys failed or were lost due to iceberg roll-over. The end of position data transmission usually occurs after periods between a few weeks and several years (Fahrbach and EL Naggar, 2001). We started the tracking simulations at the time when the buoy signal transmission was activated (see Table 1, "starting date"). The reason for choosing this early time is that the dimensions of the iceberg were estimated when the buoy was deployed (the corresponding numbers are also given in Table 1). If simulations are carried out at a later time, it is uncertain whether the iceberg size had changed due to melting or break-offs of larger ice chunks. The tracking simulations were continued until noon of the day which is closest to the full period of five days (column "runtime"). It should be noted that the starting dates differ from one another, which means that possible differences of meteorological conditions (wind speed and direction) have to be considered, i.e., the iceberg drift simulations were carried out with the wind conditions valid for the respective iceberg position and the respective time.

2.3. Iceberg drift model

The iceberg model (S-IB) that we employed for our analyses is based on an approach presented by Crépon et al. (1988). They assumed idealized cases that can be described by analytical equations. The ocean is considered as a two-layer system with the upper mixed layer embedded in an ocean that is in geostrophic balance. The authors distinguish

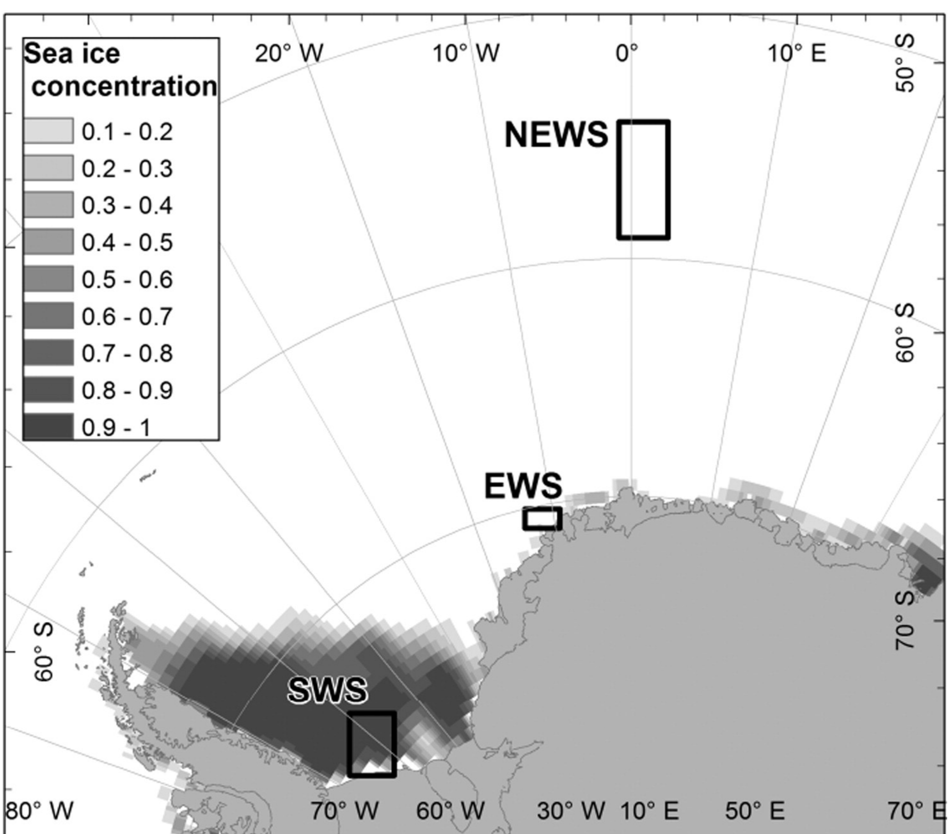

Fig. 1. Three regions of interest in the Weddell Sea. The abbreviations are: NEWS, North-Eastern Weddell Sea; EWS, Eastern Weddell Sea; and SWS, Southern Weddell Sea. The sea-ice coverage presents January mean coverage (Saha et al., 2010). The Antarctic contour lines are taken from Haran et al. (2014).