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Basal melting of A-38B: A physical model constrained by satellite observations

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Abstract

We observed the large tabular iceberg A-38B in the time period from the calving event at the Ronne Ice Shelf in 1998 until its grounding near South Georgia in 2004 by means of various space-borne sensors. The initial ice thickness was determined by radar altimetry, the iceberg shape from radar imaging and optical instruments. The freeboard change at different stages of the drift was derived from ICESat Laser altimeter profiles. The analysis of the satellite data confirms that the decay of A-38B is governed mainly by basal erosion. We then used a numerical model for simulating iceberg melting and fitted the melt rate by varying the turbulent exchange parameters for temperature (γ_T) and salt (γ_S) to match the results obtained by ICESat data. Our results show that the iceberg passed through three melting regimes characterized by iceberg drift velocity: (1) In the Weddell Sea melting conditions are similar to the situation under an ice shelf with strong tidal currents which corresponds to a γ_T of $1.0 * 10^{-4}$ m s^{-1}. (2) In the Scotia Sea, where the iceberg drifts unhindered with the ocean current and is surrounded by its own melt water, γ_T, is $0.4 * 10^{-4}$ m s^{-1}. (3) At the grounding position friction velocity is again high due to tidal currents and γ_T is $1.8 * 10^{-4}$ m s^{-1}. γ_S is set to 0.00505 γ_T in all cases. The analysis shows that ICESat GLAS data together with satellite imagery can provide better estimates of turbulent exchange parameters, which is a step forward in improving the knowledge of fresh water input from melting icebergs into the Southern Ocean.

Keywords: Tabular icebergs; Basal melting; ICESat; A-38B; Turbulent exchange parameter

1. Introduction

Iceberg calving represents a significant negative term of the mass balance of the Antarctic ice sheet. About 2000 Gt of ice per year, half of this due to large tabular icebergs with a major axis greater than 28 km, serve as a supply of comparatively cold freshwater for the upper Southern Ocean (Jacobs et al., 1992). This exceeds the freshwater flux of about 500 Gt due to basal melting beneath the ice shelves (Gladstone et al., 2001; Jacobs et al., 1992). However, a paucity of information about the amount and the intensity of iceberg melting during their drift means that the precise role of icebergs in the freshwater balance of the Southern Ocean is still poorly understood. Depending on environmental conditions these freshwater reservoirs can be transported far north. In the Weddell Sea, for example, tabular icebergs tend to follow the coastal current along the Antarctic Peninsula into the Antarctic Circumpolar Current (Schodlok et al., 2006; Silva et al., 2006; Silva & Bigg, 2002).

Large icebergs can be tracked and/or monitored directly by analysing satellite image sequences gathered with various sensors (*e.g.*, Ballantyne, 2002). The National Ice Center (NIC; Washington D.C., USA) provides an iceberg drift data base for tabular icebergs with a major axis greater than 18.5 km (http://www.natice.noaa.gov/products/iceberg/index.htm). The records began in 1976 and were initially based on visible and infrared satellite data, supplemented with ship or aircraft reconnaissance (Long et al., 2002). In the last two decades radar data became more important, as they are also available during polar night and are unaffected by clouds. The Brigham Young University

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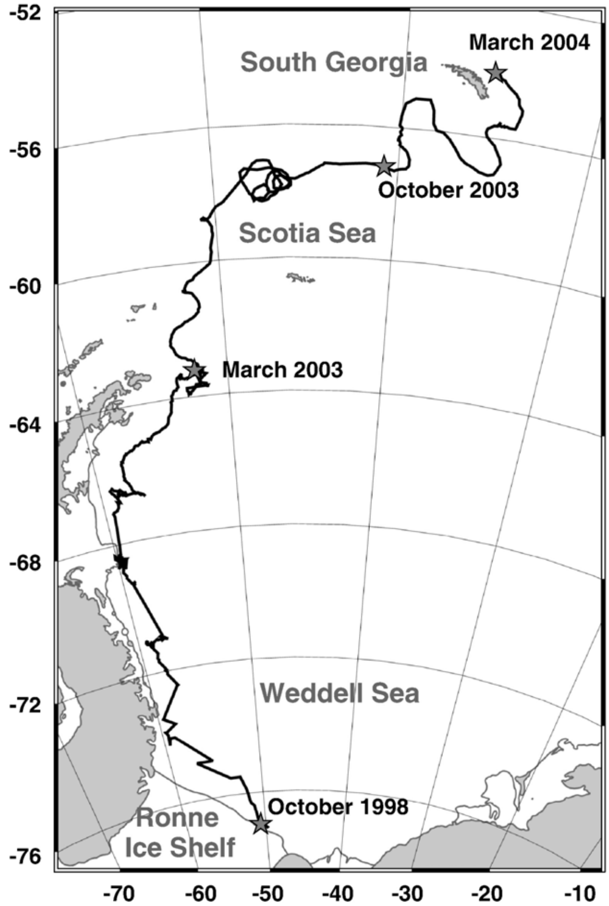

Fig. 1. Map of the Weddell Sea and the Scotia Sea with drift path of tabular iceberg A-38B. The iceberg positions are derived from the iceberg data base (BYU; NIC).

(BYU; Provo, UT, USA) provides a complementary data set based exclusively on radar data (Quikscat, NSCAT, SeaWinds, and ERS 1/2; http://www.scp.byu.edu/data/iceberg/database1.htm).

Studies for small- to medium-sized icebergs exist on a regional scale. Silva and Bigg (2002), tracked this iceberg class by means of ERS SAR (European Remote Sensing Synthetic Aperture Radar) images at the eastern entrance of the Weddell Sea as well as in the south-western Weddell Sea, analysing the drift pattern and iceberg fluxes in these regions. Ground-based studies of iceberg drift by means of GPS buoys for small- to medium-sized icebergs revealed main drift routes and export patterns out of the Weddell Sea and their dependence on sea-ice concentration (Schodlok et al., 2006).

Lichey and Hellmer (2001) successfully simulated the drift trajectory of giant Antarctic iceberg C-7 and showed the dependence of the iceberg drift on sea-ice cover. Above a threshold of 90% sea-ice concentration the movement was found to be governed by sea-ice movement while in open water wind and ocean drag as well as Coriolis force were the driving forces. Other iceberg drift models included iceberg thermodynamics and melting: While Gladstone et al. (2001) modelled small iceberg drift trajectories and the associated freshwater input for the Southern Ocean, Silva et al. (2006) estimated the melt of tabular icebergs assuming idealized iceberg geometry and estimated mean thickness and density. Schodlok et al. (2005) modelled the freshwater input of an idealized iceberg C-7 along its drift path and possible impact on the ecosystem.

Iceberg melting and disintegration is a complex function of iceberg dimension and geometry, ambient water temperature and salinity. At lower latitudes, the freshwater input is expected to increase significantly as the rise in water temperature leads to increased melting and reinforced decay of the iceberg margins. Iceberg drift velocity or the relative velocity of iceberg and ocean is also relevant for the melting intensity as it determines the turbulent exchange between ice and ocean (Jenkins, 1991). The melting is characterized by the turbulent exchange parameters for temperature (γ_T) and salt (γ_S) which are functions of the friction velocity (Kader & Yaglom, 1972). In the iceberg melting studies mentioned above a constant value for the turbulent exchange parameters was used for the entire drift. However, the model studies of Jansen et al. (2005) with a basal melting boundary condition based on the work of Schodlok et al. (2005) overestimated the reduction of freeboard height as the comparison with ICESat altimetry available after the study revealed. In this study we aim to combine the information available from satellite-borne sensors for large icebergs with the more detailed ocean stat information offered by modelling, to yield more precise estimates of how much melting occurs in the different oceanographic regimes transited by drifting icebergs. We used satellite observations, focusing on ICESat surface height data, to obtain realistic estimates for the turbulent exchange between iceberg melt water and the ocean. For our experiment we chose tabular iceberg A-38B, which calved from the Ronne Ice Shelf in 1998. Melt rates are calculated following the model approach for the basal melting of ice shelves by Hellmer and Olbers (1989). The corresponding freeboard heights are then fitted to the measured ICESat profiles by varying the turbulent exchange parameters separately for different iceberg drift regimes.

2. Boundary settings

2.1. Iceberg drift

The subject of our investigations is the tabular iceberg A-38B, which calved off the Ronne Ice Shelf in October 1998. During the course of its drift it was exposed to significant changes in environmental conditions such as surface air and

Table 1
MODIS and GLAS acquisition times and positions of iceberg A-38B

Date	March 2003	October 2003	March 2004
	JD 067	JD 304	JD 079
MODIS Terra acquisition time	11:40	12:45	11:30
MODIS Aqua acquisition Time	17:15	16:45	17:30
GLAS product	Release 18 GLA06	Release 24 GLA13	Release 26 GLA13
GLAS acquisition time	17:46	9:25	4:51
Iceberg position	63.0275° S 52.0172° W	56.2172° S 37.4275° W	54.2138° S 35.3061° W