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Freeboard and mass extraction of the disintegrated Mertz Ice Tongue with remote sensing and altimetry data

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ABSTRACT

In February 2010, the Mertz Ice Tongue (MIT) collapsed and generated a giant iceberg. However, parameters about this iceberg have not been calculated and published in detail. In this study, the freeboard map of this iceberg was generated for the first time using a time-series ICESat/GLAS data. Methods for producing the freeboard map of this iceberg are suggested. Field data for ice velocity were used to relocate the footprints collected by different campaigns. Cross-validation was conducted with freeboards extracted from crossovers observed within 30 days of each other. The precision of the freeboard extraction is approximately ± 0.50 m, when taking one standard deviation as the precision. The freeboard varied from 23 m to 59 m with the mean of 41 m. With assumption of hydrostatic equilibrium (assuming a snow layer depth of 1 m, a snow density of 360 kg/m^3, an ice density of 915 kg/m^3 and a sea water density of 1024 kg/m^3), the minimum, maximum and average ice thickness were calculated as 210 m, 550 m and 383 m respectively. The total ice loss is approximately 8.96×10^{11} tons over an area, 34 km in width and 75 km in length, or approximately 2560 ± 5 km^2. These parameters extracted from remote sensing and altimetry data will provide additional information for studies of the evolution of iceberg, especially in iceberg tracking system.

1. Introduction

Antarctica is the earth's largest ice storage base, containing approximately 88% of the earth's ice mass (Allison, Alley, Fricker, Thomas, & Warner, 2009). Because of their complex links to climate change and direct effects on sea level changes, Antarctic ice changes are of great interests to many researchers (Alley, Clark, Huybrechts, & Joughin, 2005; Zwally et al., 2005). Floating ice shelves and calving outlet glaciers are primary sites of mass loss (Allison et al., 2009). Large icebergs can be generated if ice shelves collapse or disintegrate, as occurred at Larsen A, Larsen B, Wilkins and Mertz Ice Shelves in 1995, 2002, 2008 and 2010, respectively (Cook & Vaughan, 2010; Lescarmontier et al., 2012; Scambos, Hulbe, Fahnestock, & Bohlander, 2000; Scambos, Sergienko, Sargent, MacAyeal, & Fastook, 2005; Scambos et al., 2009). Icebergs play critical roles in many geophysical and biological processes, affecting ship route planning and directly influencing local weather forecasting (Arrigo & van Dijken, 2003; Arrigo, van Dijken, Ainley, Fahnestock, & Markus, 2002; Stuart & Long, 2011). Because of the critical role of icebergs, an automatic iceberg tracking method based on image segmentation technology using Landsat, MODerate-resolution Imaging Spectroradiometer (MODIS) and Huan Jing (HJ) 1B data was proposed by Zhao, Liu, and Gong (2012). An Antarctic iceberg tracking system that uses SeaWinds (a microwave scatterometer) data to deduce the routes of icebergs was built by Stuart and Long (2011). Aside from these geographical locations, however, many other parameters about icebergs, such as their area, freeboard or thickness, remain unmeasured because of the limited use of data by the iceberg tracking system to make these observations.

Remote sensing technology has long been used to identify land-based features. Both microwave and optical sensors such as Envisat-Advanced Synthetic Aperture Radar (ASAR), Radarsat, Landsat, Système Pour l'Observation de la Terre(SPOT), QuickBird and others (Bindschadler, 2002; Fricker, Young, Allison, & Coleman, 2002; Løset & Carstens, 1996; Paul et al., 2013; Scheuchl, Flett, Caves, & Cumming, 2004), have been used for studies of ice change. The area of specific land covers or objects can be measured precisely with the high-resolution images provided by these satellites. However, for ice shelf and iceberg detection, because of the frequent bad weather in the polar regions, microwave sensors are recommended due to their ability to penetrate cloud cover (Stuart & Long, 2011). The freeboard of sea ice in both the Southern and Arctic Oceans was successfully extracted using altimetry data, especially laser altimetry data (Farrell, Laxon, McAdoo, Yi, & Zwally, 2009; Farrell et al., 2012; Forsberg & Skourup, 2005; Kurtz et al., 2008; Kwok & Cunningham, 2008; Kwok, Cunningham, Zwally, & Yi, 2006, 2007; Laxon, Peacock, & Smith, 2003; Laxon et al., 2013; Yi, Zwally, &

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Robbins, 2011; Zwally, Yi, Kwok, & Zhao, 2008). Additionally, ice thickness can be estimated from freeboard data or draft data by assuming hydrostatic equilibrium (Wang et al., 2011). Estimation of ice thickness data is more difficult and has larger uncertainties.

In general, to fully understand the evolution of icebergs, more parameters must be measured with remote sensing techniques. Providing more iceberg parameters for iceberg tracking systems would benefit scientists across multiple disciplines. Oceanographers could predict the heat and salinity exchange more accurately between iceberg and ocean water with models (Ardhuin, Tournadre, Queffeulou, Girard-Ardhuin, & Collard, 2011; Martin, Drucker, & Kwok, 2007) or its effect to sea ice area and thickness in vicinity of iceberg (Martin & Adcroft, 2010). Glaciologist could reveal the revolution of iceberg more completely by comparing the different parameters observed at different times (Silva & Bigg, 2005), evaluate its effect to ship route and avoid the collisions with ships. Ecologists and Biogeochemists could evaluate the effect to phytoplankton decline or bloom with more specific parameters of icebergs (Arrigo et al., 2002; Schwarz & Schodlok, 2009; Vernet, Sines, Chakos, Cefarelli, & Ekern, 2011). Geochemists could better understand the sediment transport, potential iron flux or carbon export caused by icebergs (Lin, Rauschenberg, Hexel, Shaw, & Twining, 2011; Smith et al., 2011).

In this paper, we use Mertz Ice Shelf as an example to measure parameters from a disintegrated section of it using remote sensing imagery and a time-series of laser altimetry data, including area, freeboard map, ice thickness and ice mass. The method of producing the freeboard map production for the iceberg before disintegration is suggested. The ice thickness and ice mass were calculated with a time-series of ICESat/GLAS data.

2. Mertz Ice Tongue

The Mertz Ice Shelf (66°S–68°S, 144°E–150°E) (Fig. 1) is located in King George V Land, East Antarctica (McMullen et al., 2006; Wendler, Ahlnas, & Lingle, 1996), which drains approximately 83,000 km^2 of the grounded East Antarctica Ice Sheet (Rignot & Jacobs, 2002). The ice tongue extends over 140 km from its grounding line to the shelf front and has a width of approximately 30 km at the front (Legresy, Wendt, Tabacco, Remy, & Dietrich, 2004). The ice velocity here is fast, more than 1 km/a (Rignot, Mouginot, & Scheuchl, 2011; Wang, 2012; Wendler et al., 1996), which drains ice at approximately 16.4 Gt/a (Berthier, Raup, & Scambos, 2003). Interdisciplinary research has been performed on the MIT. For example, the tidal currents around the MIT were studied by Legresy et al. (2004) with Global Position System (GPS) data and remote sensing data; they detected a flexure of up to 2 m per day. Based on Interferometric Synthetic Aperture Radar (InSAR) data acquired in 1996, Rignot and Jacobs (2002) calculated a basal melting rate of 17 $\pm$ 6 m/a on the Mertz Glacier in the vicinity of its grounding line. Roberts, Allison, and Lytle (2001) also studied the sensible- and latent-heat-fluxes over the Mertz Glacier polynya using atmospheric data collected in August, 1999. These data suggested a high sea ice production rate there. The interaction between multi-year fast ice and the MIT was detected with altimetry and remote sensing data and the influence of multi-year sea ice on the MIT was confirmed by Massom et al. (2010). Rift propagation on the MIT before its disintegration was measured with GPS data by Lescarmontier et al. (2012).

On February 12 or 13, 2010, a large iceberg calved from the MIT after the B9B ice berg (Tamura, Williams, Fraser, & Ohshima, 2012) collided with the ice shelf. This event triggered multiple changes in this region, including sea ice production changes and phytoplankton blooms (Pyper, Rintoul, Tilbrook, & van Wijk, 2011). Tamura et al. (2012) found that the sea ice production for the Mertz Glacier region decreased from 144 km^3 in 2000 to 134 km^3 in 2011 after the calving because the calving decreased polynya activity. The disintegrated iceberg was reported with an averaged thickness of approximately 400 m and area of approximately 2500 km^2 (http://www.sciencedaily.com/releases/2010/02/100226112732.htm). The detailed freeboard, ice thickness

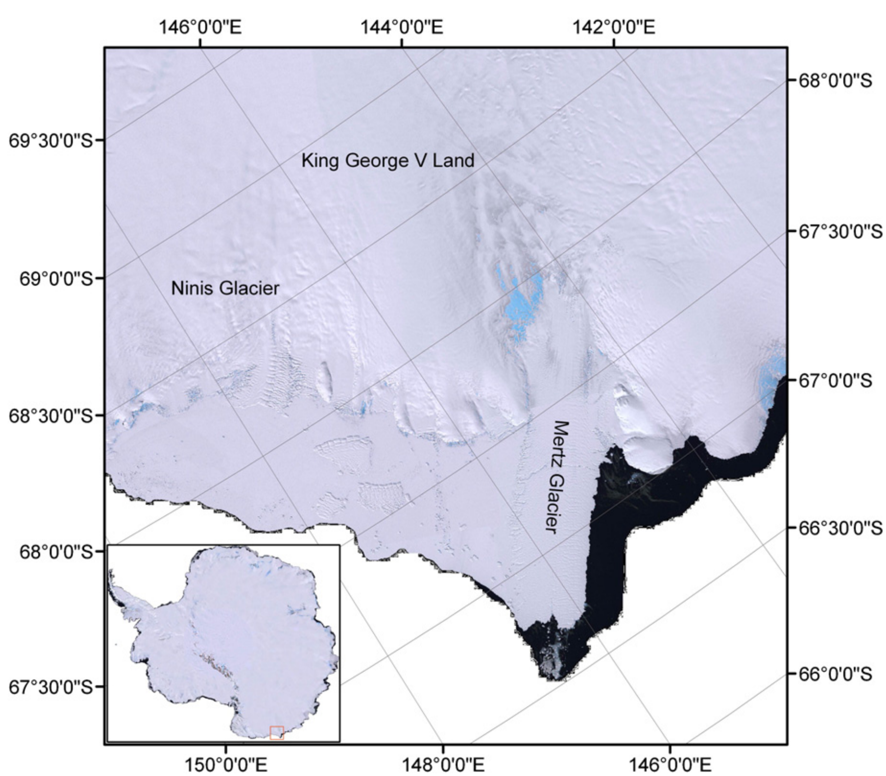

Fig. 1. Location of Mertz Ice Shelf in East Antarctica (Wang, 2012). (Red square indicates the location of Mertz Ice Shelf in Antarctica ice sheet and the background is MODIS Mosaic of Antarctica with a resolution of 250 m. Regions in white are oceans).