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The accuracy of digital elevation models of the Antarctic continent

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Abstract

The accuracy of two widely used digital elevation models of Antarctica was assessed using data from the Geoscience Laser Altimeter System onboard ICESat. The digital elevation models were derived from satellite radar altimeter and terrestrial data sets. The first, termed JLB97, was produced predominantly from ERS-1 data while the second, termed, RAMPv2 included other sources of data in areas of high relief and poor coverage by ERS-1. The accuracy of the models was examined as a function of surface slope and original data source. Large errors, in excess of 100 m, were ubiquitous in both models in areas where terrestrially-derived elevation data had been used but were more extensive in RAMPv2. Elsewhere, the systematic error (bias) was found to be a monotonic function of slope for JLB97, with a more complex, less predictable bias for RAMPv2. The magnitude of the global, slope-dependent, bias ranged from less than a metre to slightly over 10 m but with much larger regional deviations. The random error ranged from about 1 m to over 100 m depending on the DEM and slope. The random error was consistently over a factor two larger for RAMPv2 compared to JLB97.

Keywords: Antarctica; digital elevation model; satellite altimetry; ICESat

1. Introduction

Ice sheet surface topography is an important data set for a wide range of applications from field planning to numerical modelling studies. It can, for example, be used to validate the ability of a model to reproduce the present-day geometry of the ice sheet. It can also be used as an input boundary condition for modelling. Another application that has become increasingly important in recent years is in interferometric synthetic aperture radar (InSAR) processing, which has been used to derive mass balance estimates from ice flux divergence calculations [1,2]. Here, two SAR images are acquired at different times and slightly different locations in space and combined to produce an interference pattern (or interferogram), which is a combination of phase differences due to the motion of the ice surface and its topography [3]. Accurate information on the latter, in the form of a

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digital elevation model (DEM), can be used to remove the (unwanted) topographic signal [3]. Errors in the DEM, however, introduce errors in the estimated motion field and, hence the resultant mass balance. Also required for this type of mass balance study is an estimate of the catchment area or drainage basin for a particular glacier. Again, this information comes from a DEM of the ice sheet [4]. For these and other applications, it is important not only to have accurate topographic information, but also to have knowledge of the errors in the topography. In this paper, we use spatially extensive, decimetre accuracy spot measurements from a satellite laser altimeter (the Geoscience Laser Altimeter System, GLAS, onboard ICESat) to assess the accuracy, both globally and regionally, for the two most ubiquitous and up to date DEMs of Antarctica.

2. Data sets

Until the launch of the first European Remote Sensing Satellite, ERS-1, in 1991, the topography of the Antarctic ice sheet was poorly known, with errors of hundreds of metres and a paucity of measurements [5]. ERS-1 carried onboard a radar altimeter that provided range estimates at 335 m spacing in the along-track direction. In April 1994, the satellite was placed in its geodetic phase comprising a single 336-day cycle, which provided across-track spacing at 60° S of about 4 km. The radar altimeter (RA) data from this geodetic phase were used to derive a DEM with 5 km postings for all areas where there was adequate coverage. South of the latitudinal limit of the satellite (81.5° S), and in areas of steep relief, terrestrially-derived data sets were used [6]. This DEM has been used in a range of modelling and remote sensing studies and was made available through the National Snow and Ice Data Center (www.nsidc.org) and will be referred to as the JLB97 DEM henceforward.

As part of a project to produce a SAR mosaic for the whole of the Antarctic continent, known as the RADARSAT Antarctic Mapping Project, RAMP [7], a second DEM was produced using the same ERS-1 RA data but with a different set of processing algorithms [8]. In addition to using ERS-1 RA data for areas with a slope below 0.8°, the RAMPv2 DEM includes data from a number of other sources, such as GPS, airborne radar, and large scale cartography [9]. These sources were selected to provide a better spatial sampling, and have been used instead of the ERS-1 RA data where available. In areas with slopes up to 1.0°, where no alternative data were available, ERS-1 RA data were used. In areas with higher relief than this, data from the Antarctica Digital Database (ADD) [10] were added. This will henceforward be referred to as the RAMPv2 DEM. Although, both DEMs utilise the same RA data, different processing methodologies were used to extract elevation estimates [11–15], which has led to substantial differences between the two DEMs, even in areas where only RA data are present.

To examine the accuracy of the two DEMs described above, we employed data from the GLAS sensor, launched onboard ICESat in January 2003 [16]. The satellite was initially placed in an 8-day repeat cycle before being moved to a 91-day repeat in October 2003. Originally, it was planned to place ICESat in a 186-day repeat cycle, which would have provided dense coverage of both the Greenland and Antarctic ice sheets up to 86° latitude. Due to a degenerative failure of the three laser sub-systems, the mission operation plan was changed and, in general, GLAS has been switched on for a nominal 33 days of each 91-day cycle. This has provided an across-track spacing of around 45 km at 60° latitude and an along-track spacing of 170 m. The ice sheet elevation product (called GLA12) distributed by the National Snow and Ice Data Center, Boulder, Colorado was used in this study [16]. We used release 18[1] of GLA12 covering two time periods: the laser 1 8-day repeat period from 20-02-2003 to 19-03-2003 and 55 days of laser 2a from 25-09-03 to 19-11-03.

Before undertaking the comparison a number of processing and filtering steps were necessary. First, the GLAS data were referenced with respect to the WGS84 ellipsoid. The data were then filtered to remove samples that might have been contaminated by cloud cover or other atmospheric interference. Data quality flags in the GLA12 product were used to remove data with gross errors, which test for attitude

[1] We use release 18 as more data were available than for release 21, which is probably the final release for laser 2a. Our statistics were nearly identical for both releases for the same orbital time periods.