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Advances in Space Research 50 (2012) 457–470

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Synergistic use of multitemporal RAMP, ICESat and GPS to construct an accurate DEM of the Larsemann Hills region, Antarctica

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Received 4 August 2011; received in revised form 10 April 2012; accepted 4 May 2012
Available online 14 May 2012

Abstract

An enhanced digital elevation model (DEM) of the Larsemann Hills region, east Antarctica, is constructed synergistically by using highly accurate ground-based GPS measurements, satellite-derived laser altimetry (GLAS/ICESat) and Radarsat Antarctic Mapping Project (RAMPv2) DEM-based point elevation dataset. Our DEM has a vertical accuracy of about 1.5 times better than RAMPv2 DEM and seven times better than GLAS/ICESAT-based DEM. The accuracy is improved by validating the RAMPv2 DEM elevation by supplementing with GLAS/ICESat and DGPS survey data, when compared to that of DEM constructed by using GLAS/ICESat or RAMPv2 alone. With the use of accurate GPS data as ground control points reference elevations, the DEM extracted is much more accurate with least mean RMSE of 34.5 m than that constructed by using a combination of GLAS/ICESat and RAMPv2 as true reference. The newly constructed DEM 7 achieves highest accuracy with the least average elevation difference of 0.27 m calculated using 46 ground reference points. Available DEMs of Antarctic region generated by using radar altimetry and the Antarctic Digital Database indicate elevation variations in the range of 50–100 m, which necessitates the generation of local DEM and its validation by using ground truth. This is our first attempt of fusing multi-temporal, multi-sensor and multi-source elevation data to generate a DEM of any part of Antarctica, in order to address the ice elevation change to infer the ice mass balance. Our approach focuses on the strengths of each elevation data source to produce an accurate DEM.

Keywords: DEM; GLAS/ICESat; RAMPv2; GPS; Geostatistics; Spatial interpolation

1. Introduction

Surface topography represented by digital elevation model (DEM) is an important dataset for a wide range of applications, ranging from urban planning to glacier melting. A combination of ground-based measurements and remote sensing data, such as laser altimeter, provides a high resolution data for generating a reliable DEM of the surface. In the recent decade, the availability of satellite radar/laser altimeters on Envisat, Jason, ICESat, and CryoSat, facilitates the monitoring of elevation changes of the Earth's surface in centimeters and mapping the time varying topography of the world oceans and polar ice sheets. Ice Cloud and Elevation Satellite (ICESat) has been used to observe elevation changes in Greenland and Antarctica since the late 1970s (e.g. Zwally et al., 1989; Wingham et al., 1998; Johannessen et al., 2005; Horgan et al.,2011). The Geoscience Laser Altimeter System (GLAS) is the first laser-ranging (LiDAR) instrument for continuous global observations which was flown aboard the ICESat spacecraft in January 2003 (Zwally et al., 2008). GLAS/ICESat-based DEMs of Antarctic at 500 m spatial resolution and Greenland at 1 km spatial resolution have been constructed from the first seven operational periods from February 2003 through June 2005 to generate elevation maps in order to monitor temporal ice volume (mass balance) (DiMarzio et al., 2007). Another DEM was constructed from ERS-1 altimetry for Antarctica at spatial resolution of 5 km by interpolation of about twenty million data points derived from the geodetic phase spanning March 1994 to May 1995 (Bamber and Bindschadler, 1997). On the other hand, Bamber et al. (2009) employed

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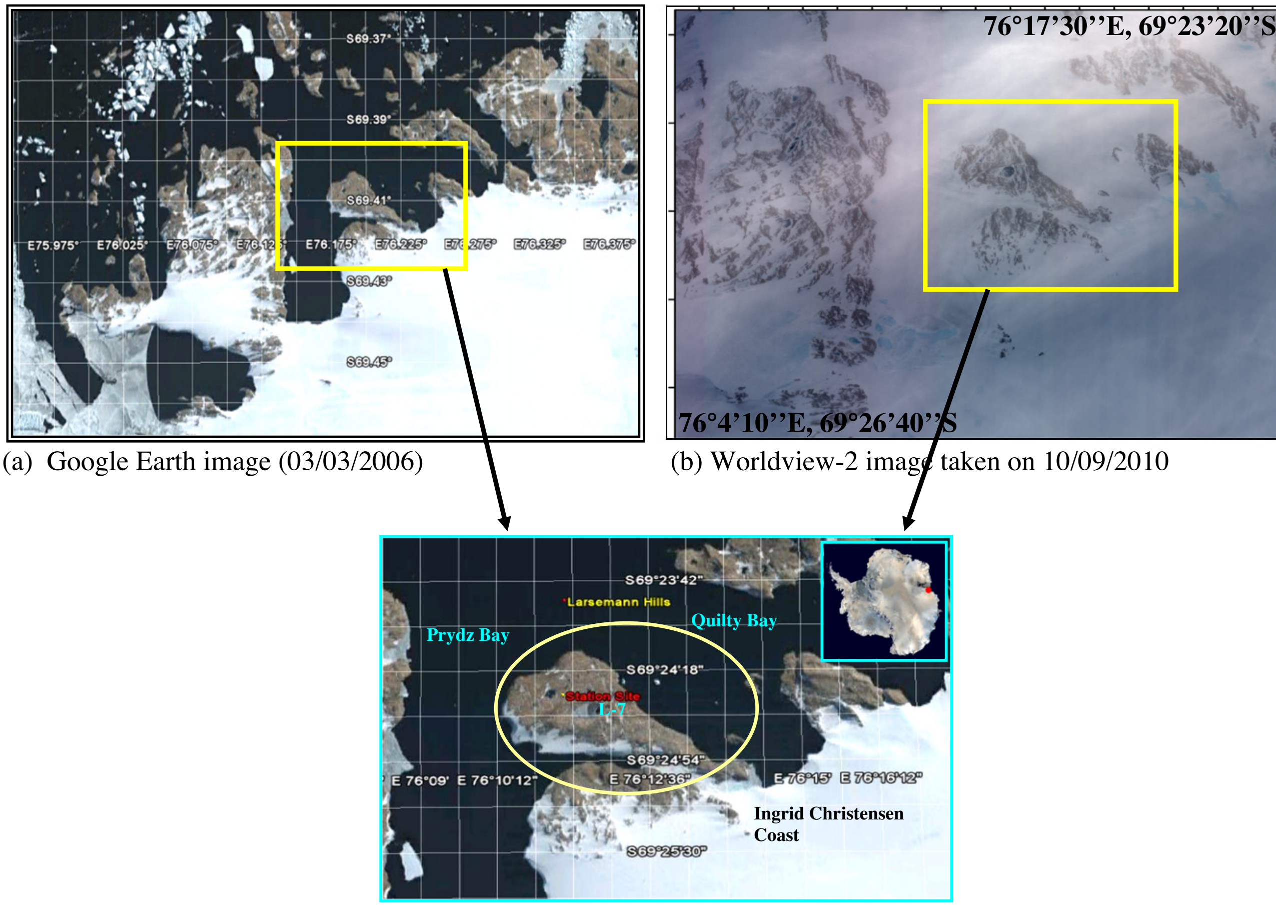
0273-1177/$36.00
http://dx.doi.org/10.1016/j.asr.2012.05.004



(a) Google Earth image (03/03/2006)

(b) Worldview-2 image taken on 10/09/2010

(c) Google Earth image, with grid spacing 18" x 36".

Fig. 1. Geographical location of the study area. (a) & (b) sea ice conditions in the study area; (c) the promontory highlighted in the yellow is the focus of this study, where India's third research station "Bharati" is established. The red spot highlights Larsemann Hills region on Antarctica.

multi-temporal satellite elevation data to generate a 1-km spatial resolution Antarctic DEM by fusing GLAS/ICESat and ERS-1 Satellite Radar Altimeter (SRA) data.

A recent study of the accuracy of published DEMs of Antarctica reported large errors (in excess of hundreds of meters) in areas of higher surface slope such as near the margins of the ice sheet and in mountainous terrain (Bamber and Gomez-Dans, 2005). The accuracy of a DEM depends on spatial interpolation technique or algorithms which vary extensively in their complexity, simplicity of use, and computational expense. Interpolation methods can be broadly defined as being deterministic or probabilistic. Deterministic methods are based only on surrounding values, with algorithms using mathematical formulae to determine the influence of immediate neighbouring values. Probabilistic geostatistical methods rely on spatial autocorrelation and account for distance and direction when determining the importance of surrounding values (Maune et al., 2001). The accuracy of DEMs also varies with changes in terrain and land cover type (e.g. Adams and Chandler, 2002; Hodgson and Bresnahan, 2004; Hodgson et al., 2005; Su and Bork, 2006). By employing ground control points, Hodgson and Bresnahan (2004) categorized LiDAR derived DEM error into four components: (a) LiDAR system measurements, (b) interpolation error, (c) horizontal displacement error, and (d) survey error. The selection of an appropriate algorithm for DEM interpolation is an important decision, especially in uneven terrain of Polar regions, as differences in terrain model elevations may directly affect the estimates of mass balance studies.

Literature survey indicates that the DEM accuracy in terms global statistics (mean error and RMSE) depends on the interpolation methods. Bater and Coops (2009) presented Global statistics for the LiDAR-derived DEM validation. Su and Bork (2006) validated DEMs created by using spline, inverse distance weighted (IDW), and kriging algorithms and found that IDW is the most accurate interpolator, with lower RMSE than those for spline and kriging methods. They also corrected reference points using a total station and differential global positioning system (DGPS) to assess the effects of slope, vegetation and laser scan angle. Lloyd and Atkinson (2002) employed cross-validation and a jack-knife approach to test IDW interpolation and two types of kriging methods. Based upon the