Assessment of Spatial Interpolation Techniques for Generating an Accurate Digital Elevation Surface Using Combined Radar and LiDAR Elevation Data

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***Abstract*—the process of generating a digital elevation surface (DSM) is still long-lasting task with the development in remote sensing (RS) technology and geographic information system (GIS). The procedure is very significant as it provides a true representation of topography in digital format which can be used for analysis or visualisation or both. DSM can be generated through spatial interpolation technique which is a process of estimating the values of a specific attribute at unsampled locations based on the values of the attributes at the sampled locations. This study was conducted to test and analyze the interpolation techniques for deriving a DSM from combined use of radar and LiDAR data in order to demonstrate the level of confidence with which the interpolation techniques can generate a better interpolated continuous surface, and improve the elevation accuracy of DSM extracted by individual data. We used point maps generated from Geoscience Laser Altimetry System (GLAS) onboard Ice-Cloud-Elevation satellite (ICESat) and RADARSAT Antarctic Mapping Project (RAMP) data. Different interpolation techniques were applied to these datasets. Deterministic interpolation techniques such as inverse distance weighted (IDW), global polynomial interpolation (GP), local polynomial interpolation(LP), radial basis function (RBF) and stochastic interpolation techniques such as simple kriging(SK), ordinary kriging (OK), universal kriging (UK), disjunctive kriging (DK) and Co-Kriging were used. A set of 20 ground survey points were used for accuracy assessment to calculate the elevation differences between DSM and accurate ground survey (GPS) points. Accuracy assessment suggests that the DK interpolation provides the most accurate elevation for RAMP-based point elevation data, while RBF and SK works superior for GLAS point elevation data interpolation. It is also evident that OK and UK provide superior results for RAMP+GLAS based point data. In conclusion, the work suggests that DK interpolation techniques provide the most accurate elevation surface as compared to other interpolation techniques used for RAMP-based point elevation data.**

***Keywords*— DEM; GLAS/ICEsat; RAMP v2; GPS; Geostatistics; Spatial Interpolation**

I. INTRODUCTION

The process of generating elevation model in the form of digital elevation surface (DSM) is still under research in the field of remote sensing (RS). The use of RS data (especially altimetry) requires ground truth data for validation. A combination of ground-based measurements with remote sensing data provides sufficient data coverage for the construction of a reliable DSM to demonstrate the surface topography. The recent availability of satellite laser altimetry data from ENVISAT [1], JASON, ICESAT, and CRYOSAT [2] allow the monitoring of sub-meter elevation changes of the Earth’s surface and for mapping the time varying topography of the world oceans and/or polar ice sheets. The cryosphere has a central role in the Earth's radiation due to the presence of ice and snow. Because much of the cryosphere occurs generally in remote locations marked by hostile weather, carrying measurements in these areas is logistically difficult, expensive and life threatening. Increasingly popular satellite RS technology in the last several years has enabled researchers to monitor the polar topography on a regular basis [3]. The Ice Cloud and Land Elevation Satellite (ICESat) was launched in 2003, with the primary mission objective of measuring the elevation changes of the Greenland and Antarctic ice sheets [4]. DSMs can be constructed by digitising existing topographic maps [5] or by using stereoscopic aerial photographs. With the advance of digital photogrammetry, DSMs can be created using stereo image matching techniques [6]. Recent technological developments such as LiDAR altimetry [7] can be used to construct more accurate DSM [8] using several techniques such as digital photogrammetry, interferometry, geostatistics etc.

Geostatistics [9] is a science of predicting unknown values between known values using statistical principles. The predicted values then can be used for spatial interpolation. It is the practice of approximation of the value of properties at unsampled sites within an area covered by observations. The spatial interpolation is the last step of generating DSM from elevation points of different geographical data sources. The accuracy of generated DSM depends on spatial interpolation technique or algorithm used. In this study, the point elevation data was generated from GLAS data [10] and RAMP DEM data. RAMP DEM [11] version 2 DEM incorporates topographic data from satellite radar altimetry, airborne radar surveys, the recently-updated Antarctic Digital Database (version 2), and large-scale topographic maps from the U.S. Geological Survey (USGS) and the Australian Antarctic Division. Data were recorded from 1940s to present, with a large amount of data collected during the 1980s and 1990s.

Various interpolation techniques were applied to the various data sets for their synergistic usage. The goal of this research is to test the interpolation techniques for deriving DSM from RAMP point elevation data and GLAS data, to generate a better interpolated continuous surface, and to improve the elevation accuracy of DSM derived from RAMP point elevation dataset by synergistically fusing with GLAS dataset. RAMP point dataset and GLAS elevation products are employed to test various interpolation techniques like Ordinary Kriging (OK), Simple Kriging (SK), Universal Kriging (UK), Disjunctive Kriging (DK) interpolation techniques, Inverse distance weighted (IDW), Global Polynomial (GP) with Power 1 and 2, Local Polynomial (LP) and Radial Basis Functions (RBF). In the Cokriging technique we used Ordinary Cokriging (OCoK), Simple Cokriging (SCoK), Universal Cokriging (UCoK) and Disjunctive Cokriging (DCoK) [12-13].

In this work, an improved DSM is derived for the Larsemann Hills, east Antarctica (Fig. 1). We compared the DSM generated by RAMP point data and DSM generated by combining the RAMP data with GLAS point elevation data. The output maps in the variety of interpolated surfaces were assessed using highly accurate differential global positioning system (DGPS) points recorded from study area during the 30th Indian Antarctic Expedition to Antarctic (2011-12).

II. MATERIALS AND METHODS

A. Data

We used elevation data from Geoscience Laser Altimeter System (GLAS), which is the first laser ranging (LiDAR) instrument flown on ICEsat in January 2003. GLAS/ICEsat includes a laser system to measure distance, a Global Positioning System (GPS) receiver, and a star-tracker altitude determination system. We used Antarctic and Greenland Ice Sheet Altimetry data (GLA 12) in this research. All datasets were provided in TOPEX/Poseidon datum. The point elevation dataset derived from RAMP DEM with a spatial resolution of 200 m was also used. Version 2 data is improved dataset with new topographic data, error corrections, extended coverage and other modifications. This dataset was provided in WGS84 datum.

B. Data preparation

Data preparation is necessary to carry out for interpolation process based on the experiment methodology of this research. The pre-processing of data was done to derive point maps from GLA 12 data. The data were extracted using the software provided by the National Snow and Ice Data Centre (NSIDC). There are 15 products of GLAS data, however only GLA12 in release 29 data were used in this research. The binary data of these two products were converted into ASCII format by using an IDL program. The Ellipsoid/Datum of these products is converted from TOPEX/Poseidon to WGS 84 by using another IDL program for consistency of datasets. Finally, the DGPS point elevation dataset recorded during Indian Antarctic expeditions were used for accuracy assessment.

C. Interpolation methods

Interpolation methods are classified into two broad groups: deterministic interpolators and stochastic interpolators. The former which includes IDW, GP and LP, and RBF, makes predictions from mathematical formulas that form weighted averages of nearby known values. Different methods use different ways to form the weighted averages. The stochastic interpolators use weighted averages as well as probability models to make predictions. This group includes Kriging and all of its different sub-methods, including UK, OK, DK and SK.

We applied different interpolation techniques to different combinations of datasets. We used OK, SK, UK, DK, IDW, GP and LP with power 1 and 2 and RBF. The IDW, GP, LP, RBF and kriging methods were applied to one variable, such as

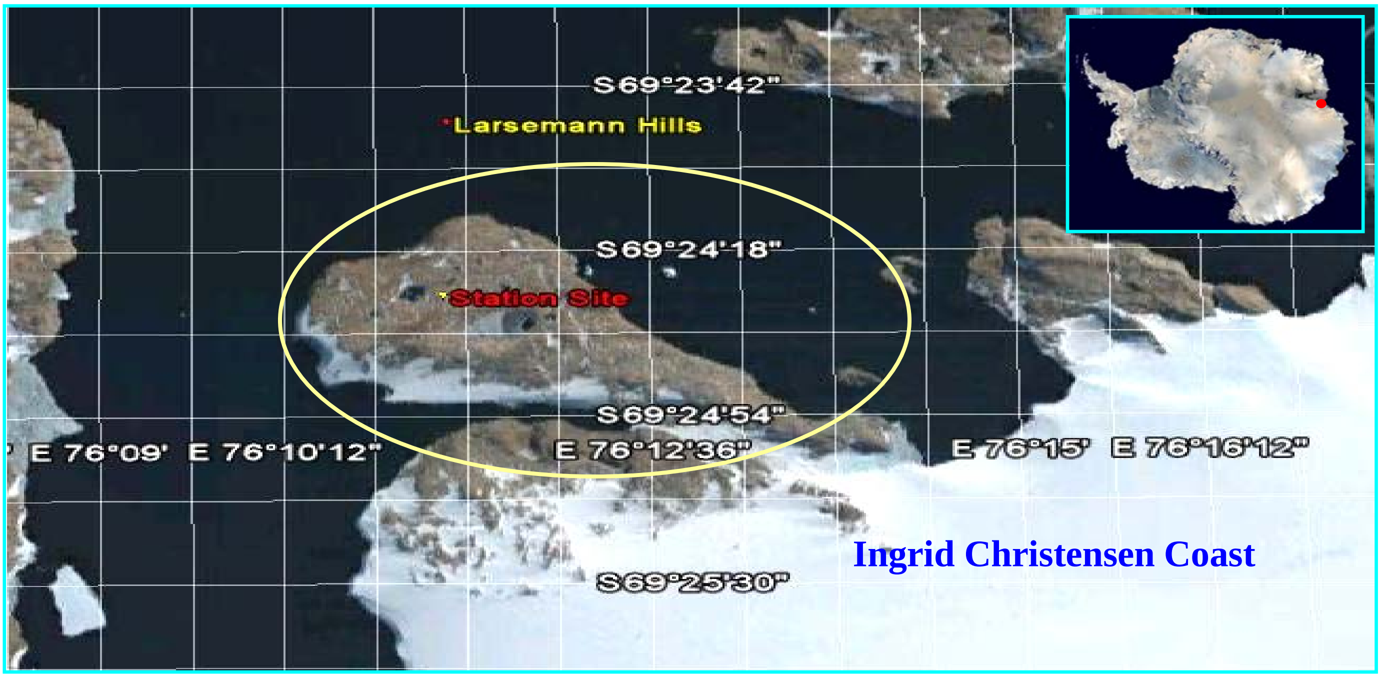

Fig. 1: Geography of the study area. The promontory highlighted in yellow envelope is the focus of this study, where India's third research station "Bharati" is established. The red spot on the Antarctic map on the inset indicates the position of the research area on Antarctica. Source: Google Earth (grid spacing is 18"S by 36"E).

RAMP point data and GLAS point data, and OCok, SCoK, UCoK and DCoK for two variables such as combined RAMP data and GLAS data. ArcGIS 9.2 (Geostatistical analyst) was used for spatial interpolation of point elevation dataset to generate DSM.

D. *Accuracy assessment*

The accuracy of a DSM can be defined as the average vertical error of all potential points interpolated within the DSM surface grid [14-16]. Larger the error (irrespective of sign), the more is the discrepancy in the datasets. The accuracy assessment was done by computing the elevation differences (bias) between generated DSM and ground-truth GPS points.

III. RESULTS AND DISCUSSION

DSM generated by different interpolation methods was evaluated by using highly accurate ground-based DGPS points. The average elevation difference calculated for each DSM interpolated with various techniques is tabulated in Table 1 and 2. The least average elevation difference is highlighted in these tables. The average elevation difference for DSM generated from RAMP point data ranged from 725 to 2.74 m (Table 1). DK interpolation yielded least average elevation difference for RAMP point dataset. GP1 and LP2 methods resulted in most erroneous elevation in negative and positive regions, respectively. The range of average elevation difference for DEM generated from GLAS/ point map was found to be –1293.75 to 30.73 m (Table 1). RBF interpolation method gave a least average elevation difference for this dataset. Cokriging interpolation methods were used to generate DEM from combined point map of RAMP v2 and GLAS/ICEsat. Range of average elevation difference ranged from 66.16 to 21.27 m. OCok method provided a least average elevation difference for this dataset (Table 2).

	RAMP	GLAS
IDW	11.09	74.24
GP1	-725.50	-1293.75
GP2	-479.95	-902.78
LP1	10.95	-116.38
LP2	11.26	182.78
RBF	10.91	30.73
OK	11.11	57.31
SK	9.69	48.46
UK	10.61	70.79
DK	2.74	66.54

TABLE I: AVERAGE ELEVATION DIFFERENCE (m) FOR INDIVIDUAL POINT MAPS. THE LEAST AVERAGE DIFFERENCES ARE HIGHLIGHTED.

Data	OCoK	SCoK	UCoK	DCoK
GLAS + RAMP	21.27	49.40	21.48	-66.16

TABLE II: AVERAGE ELEVATION DIFFERENCE (m) FOR COMBINED POINT MAP OF GLAS+RAMP DATASET. THE LEAST AVERAGE ELEVATION DIFFERENCE IS HIGHLIGHTED.

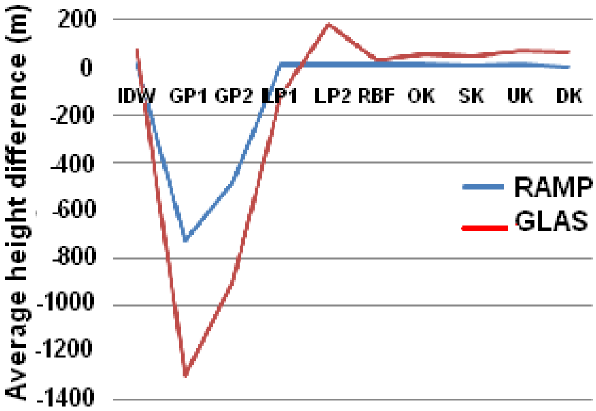

Fig. 2: Average elevation difference for different interpolation methods.

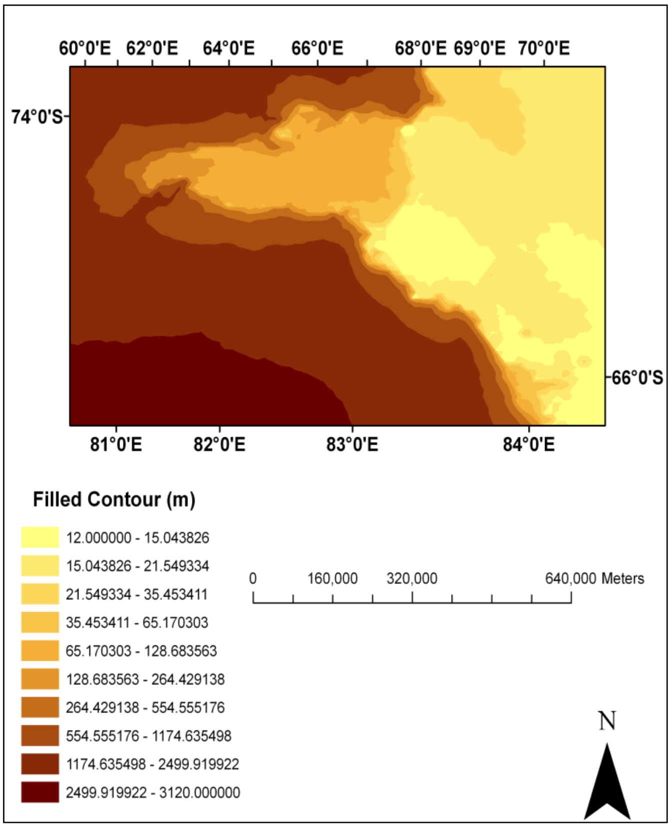

Fig. 3: DSM generated from combined point map of RAMP+ GLAS using OCoK.

IV. CONCLUSIONS

The process of generating digital elevation model in the form of DSM is still under research in the field of RS. The use of RS data (especially altimetry) requires ground-based data for validation. Validation of DSM has been always difficult, especially in regions with limited ground truth points due to limited hours of favourable weather conditions in the Polar Regions. The quality of DSM depends on many factors such as methods of data acquisition, nature of input data, and spatial interpolation methods [12]. Off all these factors, data acquisition and nature of interpolation technique are the most critical factors. We used different interpolation methods for RAMP and GLAS individual datasets and combined dataset. The study illustrates that the DSM generated using GLAS point data provides poor elevation accuracy when compared with the GPS data. The elevation accuracy improved by using a combination of RAMP point data with GLAS data. Based on this work, we infer that the synergistic combination of GLAS with RAMP elevation data produces a better accurate DSM compared to that constructed by using only RAMP or GLAS individually.

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