Exploring Geostatistical Methods to Improve the Altimetry Accuracies of Digital Elevation Models

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Abstract

This article explores computational geostatistical methods to improve the accuracy of the altimetry attribute of Digital Elevation Models (DEMs). The geostatistical procedures, ordinary kriging, kriging with external drift and cokriging, are used to obtain uncertainty representations related to altimetry predictions. The data modeling is performed from existing DEMs, mainly available for free in the internet, and additional high accurate set of 3D sample points. Although the freeware DEMs are dense and generally have good spatial distributions, the accuracy of their altimetry information might not be suitable for many applications. A way of mitigating this problem is to combine the available DEM data along with additional information, coming from reliable sources and having better quality, in the data modeling processes. Generally, high accurate altimetry data are collected, often with a higher cost, in field works at specific points located inside the spatial region of interest. In short, this work aims to integrate spatial elevation information from different through geostatistical methods to obtain better quality DEMs. The methods addressed in this research work were applied to a case study in a Brazilian southeast geographical region.

Keywords: Digital Elevation Modelling, DEM Accuracy, Geostatistics, Kriging, Cokriging.

1. Introduction

Digital Elevation Models (DEMs) are topographic information represented as spatial rectangular grids that are very suitable to be used in Geographical Information Systems (GISs) applications. Many derived products can be obtained from DEMs as, for example, slope and aspect maps, drainage networks, contour lines, profile and volume calculations, etc… (Burroughs, 1987). Spatial modeling developed in GIS environments frequently uses DEMs, or derived products of them, as input information of their mathematical models. Nowadays it is possible to obtain DEM information for free, without financial costs, of almost every region of the earth surface. Although these DEMs are dense and generally have good spatial distributions, the accuracy of their altimetry information might not be suitable for many applications. A way of mitigating this problem is to combine the available DEM data along with other information, coming from reliable sources and having better quality, in the data modeling processes. Elevation information of the earth surface can be also obtained as a set of spatial locations, 3D points, sampled in a geographical region of interest. These samples can be collected with very high vertical accuracy using Global Positioning System (GPS) equipments, for example. Geostatistical tools has been extensively used to analyze and to model environmental attributes represented as a set of sample points of geophysical and geochemical indices, concentrations of soil elements, elevations, temperatures, etc. (Isaaks and Srivastava, 1989; Goovaerts, 1997; Wackernagel, 1998). Some geostatistical procedures allow performing conflations by combining different sources of environmental attributes (Hengl et al, 2008; Karkee et al, 2008). Geostatistical procedures known as kriging and simulation can be used to integrate existing DEMs with sample points of altimetry of the same geographical region. The objective of this integration is to get a more accurate final DEM compared with the original one. In this context, the objective of this article is to explore and analyze geostatistical methods that allow using DEMs along with sample set of elevation points to obtain more accurate results on modeling the altimetry information. It is considered that the points of the sample set have higher vertical accuracy than the original DEM. In this work the geostatistical procedures, Ordinary Kriging (OK), Kriging with External Drift (KED) and CoKriging (CoK), are explored to perform the integrations. A case study is presented with data from a Brazilian southeast geographical region to illustrate the application of the proposed methodology using real information of the earth surface.

2. Methodology

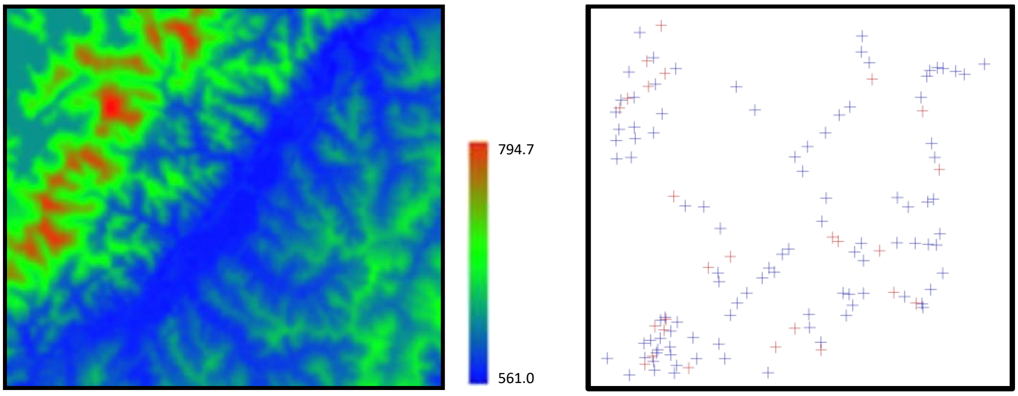
The methodology of this work has the following steps:

1. Create a database for a geographic region of interest in a GIS with basic information: a SRTM data and a set of sample points of high accurate elevations.
2. Perform spatial data exploratory analysis of the basic information.
3. Takeoff trends of the basic information creating residual stationary information.
4. Assess the spatial variation of the residuals through direct and cross semivariograms, empirical and conceptual.
5. Apply the OK procedure in the sample set of elevations using its conceptual semivariogram.
6. Assess the SRTM collocated elevation values related to the spatial position of the sample set of elevations. This was performed using bilinear interpolation over the SRTM grid cells.
7. Apply the Kriging with External Drift and Cokriging procedures using the SRTM and the sample set of elevations.
8. Using an independent sample set of elevation points, perform validations and analyzes of the resulting maps using statistics and root mean square deviation metrics.

3. Case Study

As a case study, the above methodology was applied to a geographic region located in a Brazilian Southeast geographical region. The studied region has the following geographical bounding box: w 46° 4’ 4.98’’ to w 46° 0’ 2.82’’ and s 23° 16’ 2.91’’ to s 23° 12’ 47.23’’. It was used the SPRING GIS (Camara et ali, 1996; Camargo, 1997) and the GsLib (Deutsch and Journel, 1998) softwares to develop the proposed methodology.

Figure 1 shows the spatial distribution of the input data: the SRTM and the set of sample points of the region of interest. It was used 100 sample points, blue marks in the Figure 1(b), for interpolation and 26 sample points, red marks in Figure 1(b), for validation purposes. The set of sample points have approximately 0.1 meter of height (elevation) accuracy while the SRTM height accuracy is about 7 meters for the considered region.

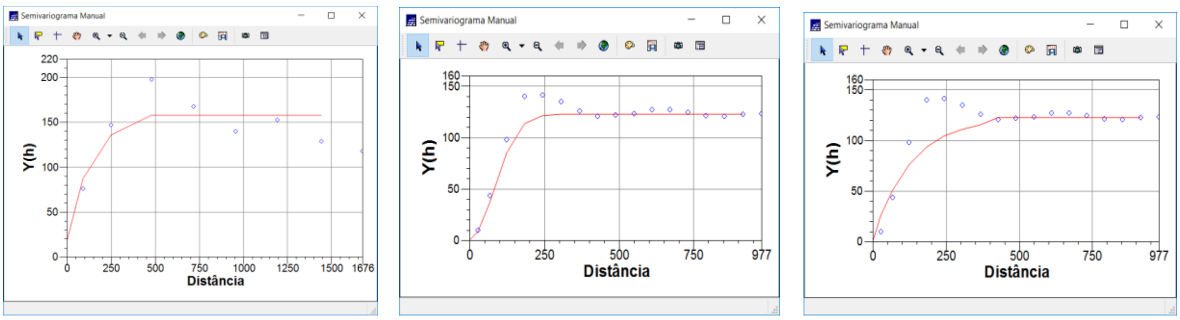


(a) (b)

Figure 1: Input data: (a) SRTM and (b) set of sample points of the study geographical region.

4. Results and Analysis

Direct and Cross Semivariograms of the residuals of the SRTM and of the set of 100 sample points are depicted in Figure 2.



(a) (b) (c)

Figure 2: Direct and Cross Semivariograms of the (a) SRTM, (b) set of 100 sample points (c) set of 100 sample points plus SRTM

Figure 3 illustrates the interpolated maps resulting from Ordinary Kriging applied only to the set of 100 sample points, and from Kriging with External Drift applied to the set of 100 sample points along with the SRTM data that were considered as the external drift. Also the CoKriging procedure was applied to the 100 sample points, considered as primary variable, and the SRTM, as secondary variable. The visual resulting Cokriging map is very similar to that obtained with the KED procedure.

A visual analyze of the maps of Figure 3 shows that the integration of the SRTM, as external drift or as secondary information, allows obtaining a more detailed map than the one that was predicted with the set of 100 sample points only.

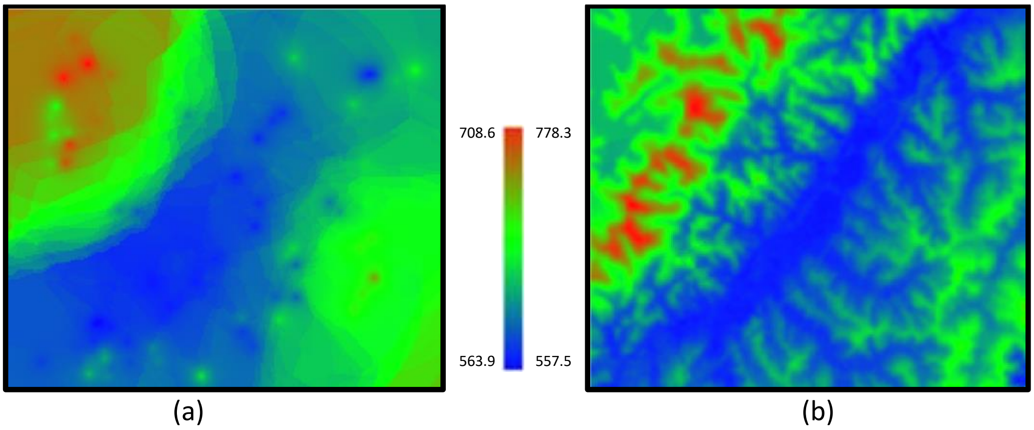


Figure 3: Maps of (a) Ordinary Kriging applied to the set of 100 sample points and (b) Kriging with External Drift applied to the SRTM and the set 100 sample points of the study region.

Tables 1 and 2 report some statistical and RMS metrics related to the accuracy of the resulting predicted maps validated by the set of 26 independent sample points. Table 1 reports percentage of RMS improvement related to the SRTM RMS value while in the Table 2 the improvement is related to the Ordinary Kriging RMS value.

	Mean(m)	**Std. Dev. (m)**	**Correlation**	**RMS**	**Improvement (%)**
SRTM	1.887	6.976	0.983	7.096	0
Krig. Ext. Drift	-0.575	5.418	0.991	5.344	24.69
Cokriging	2.046	6.269	0.986	6.446	9.16

Table 1: Validation results with RMS Improvement evaluated considering as reference the SRTM RMS value.

	Mean(m)	**Std. Dev. (m)**	**Correlation**	**RMS**	**Improvement (%)**
Ordinary Krig	0.065	13.233	0.938	12.977	0
SRTM	1.887	6.976	0.983	7.096	45.32
Krig. Ext. Drift	-0.575	5.418	0.991	5.344	58.82
Cokriging	2.046	6.269	0.986	6.446	50,33

Table 2: Validation results with RMS Improvement evaluated considering as reference the Ordinary Kriging RMS value

Visual qualitative analyzes show very minor differences between the DEMs of the Figure 1a (the original SRTM) and the Figure 3b (SRTM combined with the set of sample points). However, the validation results presented in Table 1 and Table 2 show a significant quantitative improvement in the accuracy, measured by RMS metrics, of the DEMS when the set of better accurate sample points are considered in the predictions. The results show also that the Kriging with External Drift performs better than the Cokriging considering the accuracy improvements.

5. Conclusions

This work explored some geostatistical procedures that allow combining elevation data obtained from different sources and having different representation and height accuracy. It was used 3 different geostatistical methods to process inferences for integrating SRTM DEM data with a set of high accurate set of sample points. The quantitative results of the validation processes show an improvement in the accuracy of the final products obtained when the both information are combined in the data modeling. In the future we intend to use a more numerous set of sample points, mainly for validation purposes, and explore others geostatistical procedures that allow the combination of the two elevation data representation used in this work.

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