SRTM Resample with Short Distance-Low Nugget Kriging

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Abstract: SRTM data is distributed at horizontal resolution of 30 meters for areas within the U.S.A. and at 90 meters resolution for the rest of the world. A resolution of 90m can be considered suitable for small or medium-scale analysis, but it is too coarse for more detailed purposes. One alternative is to interpolate the SRTM data at a finer resolution; it won't increase the level of detail of the original DEM, but it will lead to a surface where there is coherence of angular properties (i.e., slope, aspect) between neighbouring pixels, an important characteristic when dealing with terrain analysis. This work intents to show how the proper adjustment of variogram and kriging parameters, namely the nugget effect and the maximum distance within which values are used in interpolation, can be set to achieve quality results on resampling SRTM data from 3arcsec to 1arcsec. Examples are presented for two areas in southeastern Brazil.

Keywords: SRTM; DEM; kriging; geostatistics; nugget value; variogram; interpolation.

1. Introduction

SRTM is now been widely used as source for DEMs. The data is distributed at horizontal resolution of 30 meters (aprox. 1arcsec) for areas within the conterminous U.S.A. and at 90 meters resolution (aprox. 3arcsec) for the rest of the world.

As a resolution of 90m can be considered suitable for small or medium-scale analysis, it is too coarse for more detailed purposes. If no data is available with higher detail, one alternative is to interpolate the SRTM data at a finer resolution; it won't increase the level of detail of the original DEM, but it will lead to a surface where there is coherence of angular properties (i.e., slope, aspect) between neighbouring pixels (Valeriano et al. 2006), an important characteristic when dealing with terrain analysis.

This work intents to show the use of Short Distance-Low Nugget Kriging (SDLN), where the proper adjustment of variogram and kriging parameters – namely the nugget effect and the maximum distance within which values are used in interpolation – can be set to achieve quality results on resampling SRTM data from 3arcsec to 1arcsec resolution.

Examples will be presented for two areas in southeastern Brazil with distinct geological and geomorphological settings.

2. Study Areas

The first area (Japi area) is located northwest of São Paulo city (fig.1). Local geology consists mainly of Precambrian rocks such as quartzites, gneisses, migmatites, schists, anfibolites and granites (Almeida et al. 1981). The tectonic setting is defined by domains of transcurrent faults and shear zones which control the basement configuration, formation of Terciary sedimentary basins and present-day landforms (Hasui et al. 1978). The main geomorphological feature is the Serra do Japi (Japi Range), a tableland with elevations up to 1300m in the midst of lowlands and small ranges at ca. 700-800m. The present shape of the Japi Range, a plateau gently dipping to WSW, is a remnant of the Sul-Americana (or Japi) planation surface, developed at the Late Cretaceous-Paleogene transition (King 1967, Almeida 1964).

The second area (Mantiqueira area) is located in the Rio de Janeiro State (fig.1); local geology consists essentially of granulites and metamorphic rocks in amphibolite to granulite facies. The tectonic setting is related as the fan-divergent structure of the Paraíba do Sul river valley; it has a NE-SW main orientation with mylonitic foliation dipping towards SE in the north flank and towards NW in the south flank (Dehler & Machado 2002). In the central portion of the structure a high angle shear zone is developed within a transpressive dextral regime (Além Paraíba Shear Zone - Machado & Endo 1993; Ebert et al. 1993).

Regionally the landforms are described as a succession of crests separated by deep valleys, and contains part of the area drained by the Paraíba do Sul river situated between the Serras da Mantiqueira (Mantiqueira Range) and the Brazilian southeastern sea. Main morphological features are associated to fault scarps and fault-line scarps, where the regional offset has brought alongside rocks that respond in a distinct form to the same erosive processes.

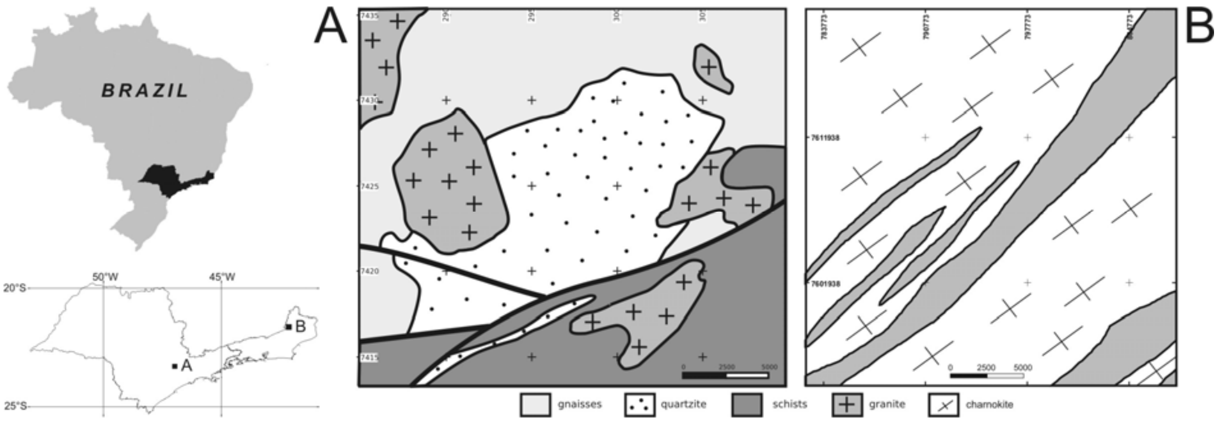

Fig.1: Location and simplified geology of study areas. A) Japi area. B) Mantiqueira area.

3. Methods and Results

The variogram is a tool that allows to describe quantitatively the variation, in space, of a regionalized phenomenon. Elevation data are usually expected to be high spatially dependent (i.e., high similarity of data at short distances) and often have variograms with a region of low slope near the zero distance, that can be best modeled by a Gaussian model (Burrough 1987). According to Valeriano et al. (2006), the noise present in such data, that is, low similarity of data at distances close to the grid size, can be evaluated as the rate of nugget effect in variograms.

Variograms calculated with linear trend residues of topographic data have adequate fits to classical variogram models, which present a clear and defined sill (Valeriano 2002); residues of trend surface analysis are used to guarantee geostationarity of data being modeled.

SRTM elevation data has a theoretical vertical accuracy of 16m (van Zyl 2001, Rabus et al. 2003), and a absolute error for the South America area of 6.2m (Rodriguez et. al 2006). Both study areas are square in shape: the Japi area is 23.4 km wide (260 rows/columns; 67,600 pixels; 547.56 km^2), minimum elevation value of 634m and maximum at 1312m; the Mantiqueira area is 27.45 km wide (305 rows/columns; 93,025 pixels; 753.5 km^2), minimum of 49m and maximum elevation at 965m.

Calculations were made using the **R** statistical language (Ihaka & Gentkeman 1996; Grunski 2002) as base system and the *gstat* package (Pebesma 2004) for geostatistical functions.

The basic idea of the Short Distance-Low Nugget Kriging (SDLN) method to interpolate terrain data is:

- work only with the immediate neighborhood of the predicted point, due the high spatial correlation of the topographic surface.

- to limit the radius of the area within which observations are used for prediction (*maxdist*), in order to work with small data variance and save computational cost;
- use a small value of nugget effect, to avoid smoothing that can obliterate terrain features.

Exploratory analysis of the Japi area, with variograms in four directions show that when the whole area is considered (fig.2a), the variograms have different ranges and sills, but when only the initial part of the curve is taken into account (fig.2b), the curves are very similar, which allows the use of a omnidirectional variogram for kriging, if only short distances from the origin are used.

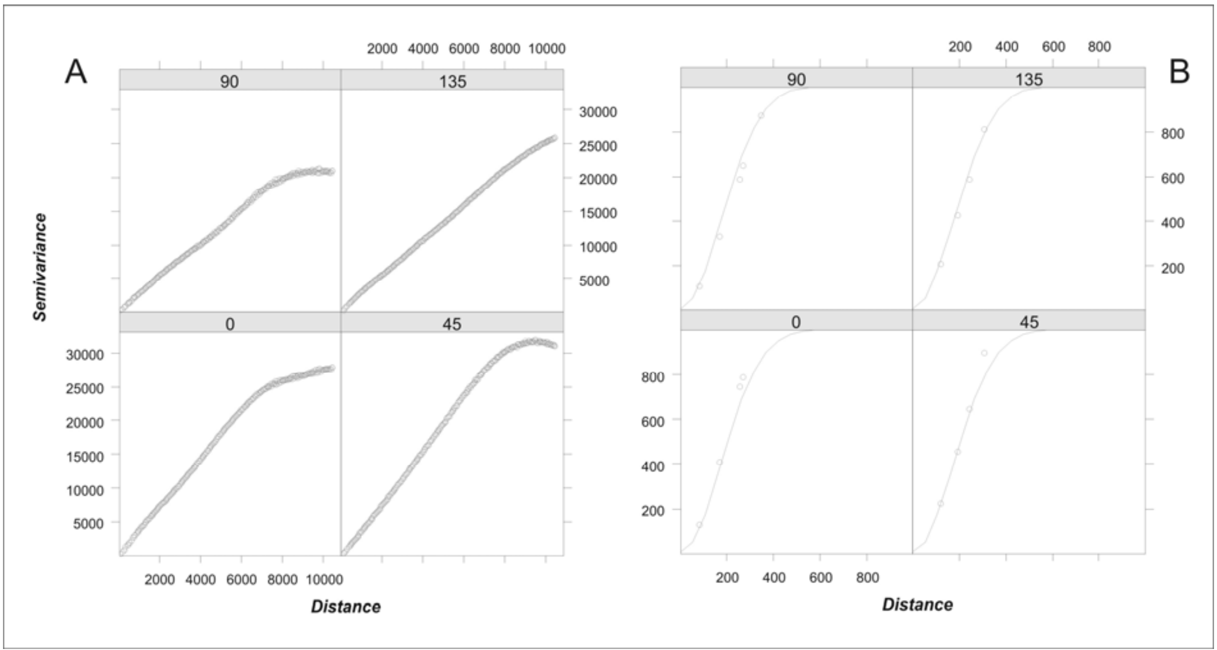

Fig.2: Exploratory analysis of Japi area. a) complete variograms; b) initial portion of the variograms (Guassian model, sill=950, range=245).

Examples of the analysis that were carried out are presented in figs. 3 (Japi area) and 4 (Mantiqueira area); all DEM images are shown as shaded relief maps with lighting positioned at N45° and with 60° of inclination, for a better visualization of the effects of changing variogram parameters in the result surface.

The original SRTM data (3arcsec, ~90m) with noise and linear artifacts visible, is presented in figures 3/4a; the final interpolated surface (1arcsec, ~30m), were the noise and artifacts were removed, can be seen in figures 3/4b. One can also note the higher degree of detail in the interpolated surface.

Figures 3/4c show the computed variogram for the whole area, while figs. 3/4d display the short-distance adjusted variogram with a nugget effect value of $10m^2$. This nugget effect value was determined after the study of SRTM global accuracy from Rodriguez et al. (2006), in which the absolute height error for the South America is defined as 6.2m. If such value represents the 90% error in Gaussian statistics, then the standard deviation (SD) would be around 3m. Since the nugget effect is a measure of the [semi]variance of data, its value will be the square of SD, that is, $9m^2$; the value was rounded up to $10m^2$.

In figures 3/4e-3/4f-3/4g, the results of changing the nugget effect values are presented. Figure 3/4e is a subset of the final interpolated surface with nugget=$10m^2$, fig. 3/4f has nugget=$30m^2$ and fig.3/4g has nugget=$90m^2$. It can be clearly seen how the changes in this value leads to a smoother surface, with less topographical information.

The effects of changing the maximum distance of interpolation (*maxdist*) is presented in figures 3/4h-3/4i-3/4j; Figure 3/4h has maxdist=250m, fig. 3/4i has maxdist=500m and fig. 3/4j has maxdist=1000m. This parameter not only influences the smoothness of the kriged surface, but also strongly determines the computational time involved, since the size of covariance matrices grows up exponentially. In our tests, done in a machine with a Dual-core 1.83 Ghz processor and 2Gb of RAM memory, kriging time has changed from around 10 minutes for maxdist=250m, 1.5 hours for maxdist=500m and 20 hours for maxdist=1000m! One point that must be taken into account is the presence of voids in SRTM data; these voids can be successfully filled by other interpolation

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techniques like the Delta-Surface method (Grohman et al. 2006) or Regularized Splines with Tension (Neteler 2005), one drawback of our method is that voids larger than *maxdist* will not be filled, and will remain as artifacts in the resultant surface.

In figure 5, drainage derived from the interpolated 1arcsec DEM can be compared against drainage from a 1:50,000 topographic map. The good agreement between them shows that the new surface can be used for analysis in this level of detail, unlike the original 3arcsec data.

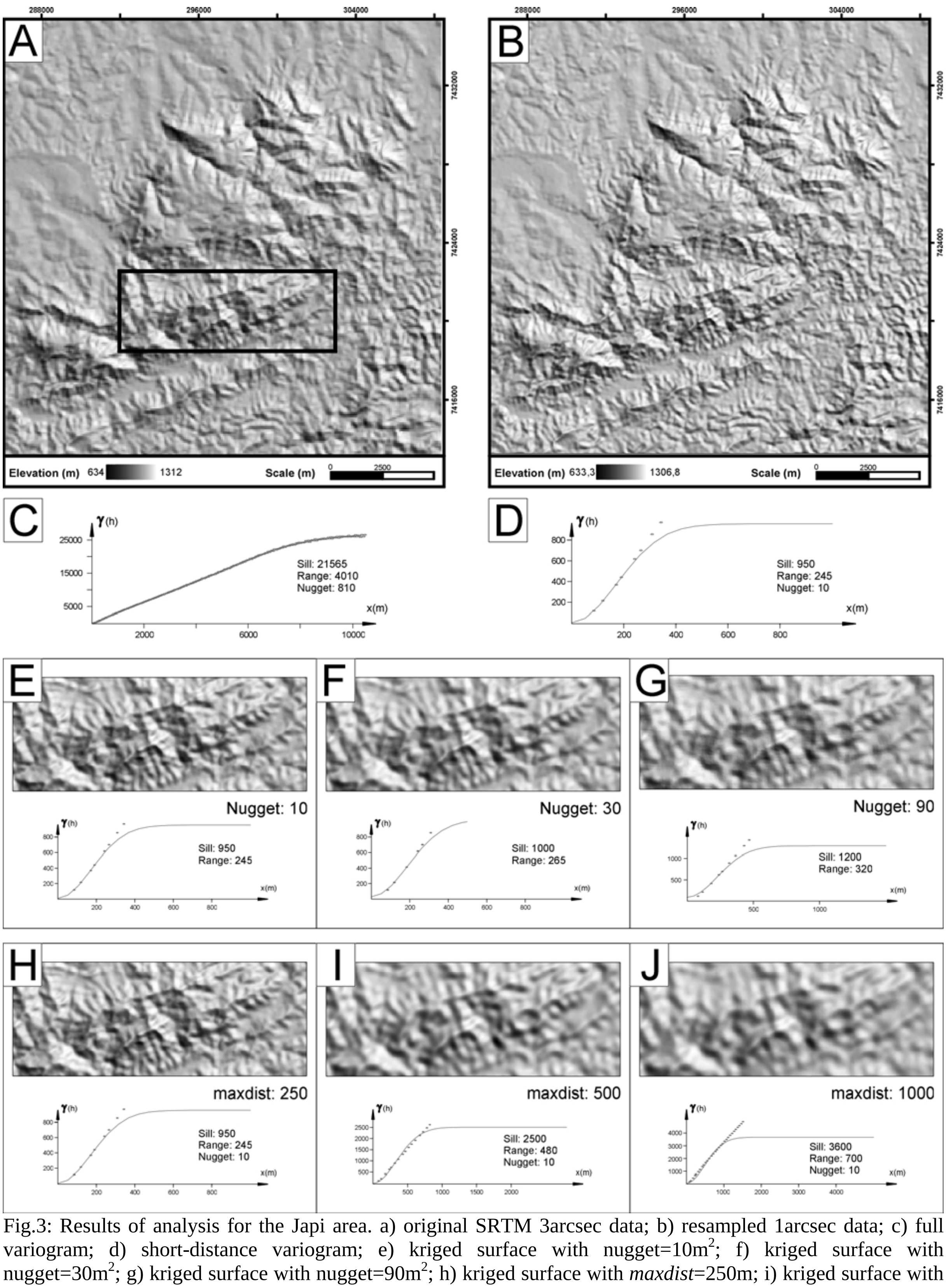

Fig.3: Results of analysis for the Japi area. a) original SRTM 3arcsec data; b) resampled 1arcsec data; c) full variogram; d) short-distance variogram; e) kriged surface with nugget=10m^2; f) kriged surface with nugget=30m^2; g) kriged surface with nugget=90m^2; h) kriged surface with *maxdist*=250m; i) kriged surface with *maxdist*=500m; j) kriged surface with *maxdist*=1000m.

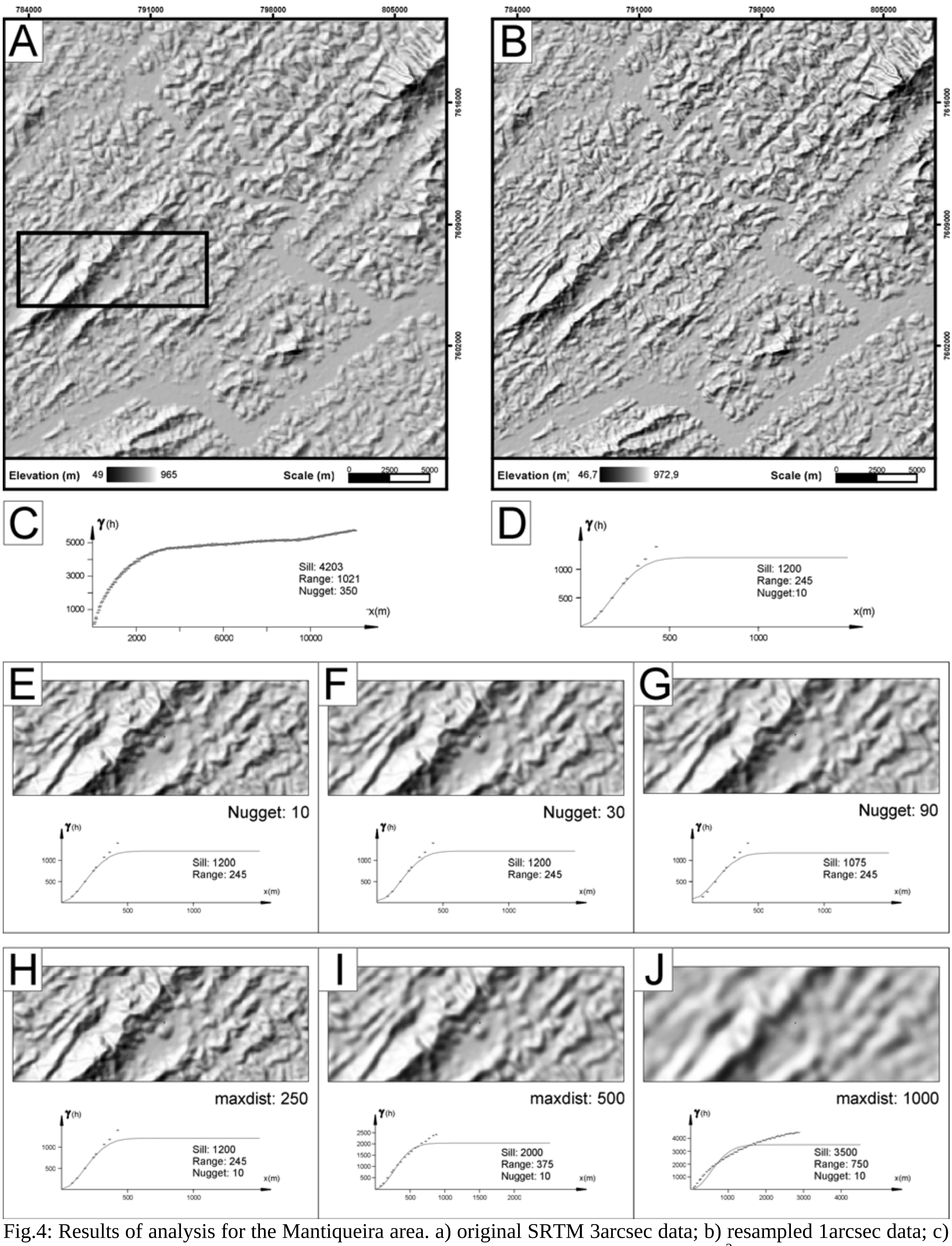

Fig.4: Results of analysis for the Mantiqueira area. a) original SRTM 3arcsec data; b) resampled 1arcsec data; c) full variogram; d) short-distance variogram; e) kriged surface with nugget=10m^2; f) kriged surface with nugget=30m^2; g) kriged surface with nugget=90m^2; h) kriged surface with *maxdist*=250m; i) kriged surface with *maxdist*=500m; j) kriged surface with *maxdist*=1000m.

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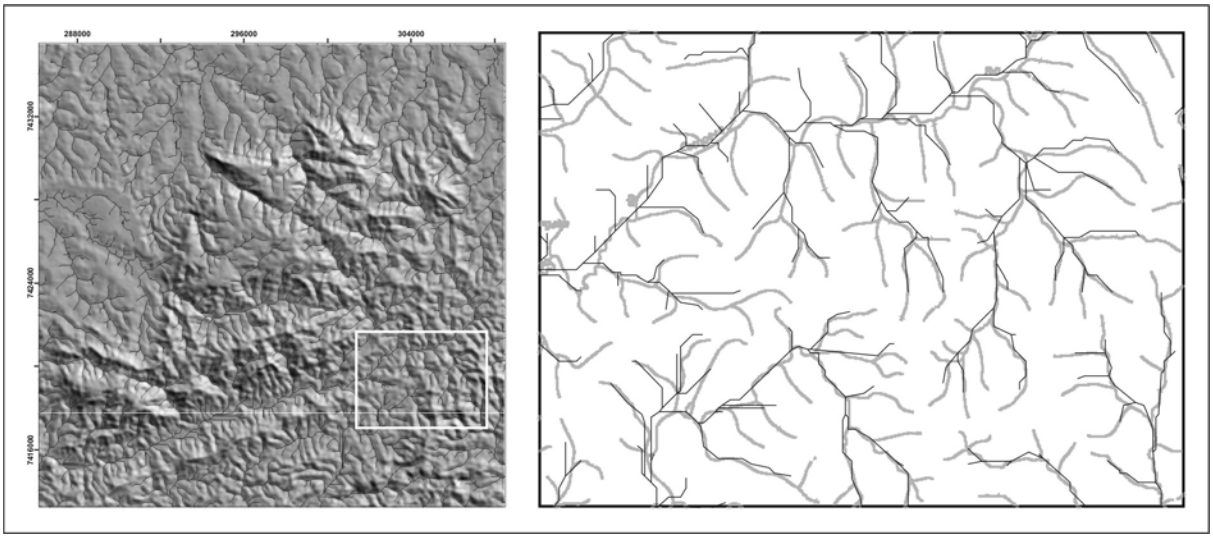

Fig.5: DEM-derived drainages (black lines) overlaid on drainages of 1:50,000 topographic map (grey lines).

4. Conclusions

In this paper we propose the use of Short Distance-Low Nugget Kriging (SDLN) interpolation to resample Digital Elevation Models to a higher resolution. Resample of DEMs with kriging interpolation may be a laborious task, since it involves variogram modeling prior to interpolation and care must be taken on all steps of the process, but the quality of final results were considered satisfactory.

The use of a short *maxdist* value allows the user to perform a good adjust of the variogram model just on the initial part of the curve, but voids larger than *maxdist* will became anomaly areas or will remain unfilled; on the other hand, a larger value of *maxdist* will dramatically increase computational time. Nugget effect will act as a smoothing factor; a value within the range of SRTM vertical absolute error is sufficient to eliminate noise, while a large one may obliterate terrain features.

A comparison of DEM-derived drainages against those in a topographic map indicates that the resultant surface has a level of detail that allows it to be used in analysis up to a 1:50,000 scale.

Although the method presented here is capable of producing clear surfaces, with well-defined peaks and ridges, without noise, and also can remove linear artifacts sometimes present in original SRTM data, it is not suitable for void filling. In case of large voids in the data, one good approach is to first fill the voids and then resample with SDLN.

References

[1] Almeida, F.F.M., (1964). Fundamentos geológicos do relevo paulista. In:Instituto Geográfico e Geológico. Geologia do Estado de São Paulo. Boletim IGG. 41:167-263.

[2] Almeida, F.F.M.; Hasui, Y.; Ponçano, W.L.; Dantas, A.S.L; Carneiro, C.D.R.; Melo, M.S.; Bistrichi, C.A., (1981). Mapa Geológico do Estado de São Paulo – 1:500.000 – IPT, Monografias, 6.

[3] Burrough, P.A., (1987). Spatial aspects of ecological data. In: Jongman, R.H.; ter Braak, C.J.F.; Tongeren. O.F.R. (Eds), Data analysis in community and landscape ecology. Pudoc, Wagenigen, pp.213-251.

[4] Dehler N.M & Machado R. 2002. Geometria e cinemática da aba sul da estrutura divergente do rio Paraíba do sul ao longo da seção areal-três rios, Rio de Janeiro Revista Brasileira de Geociências. 32(4):481-490.

[5] Ebert H.D.; Hasui Y.; Sartorato G.; Almeida S.H.; Costa J.B.S., (1993), Arcabouço estrutural e tectônica transpressiva das faixas móveis da borda sul e sudeste do cráton do São Francisco e da Sintaxe de Guaxupé. Simpósio Nacional de Estudos Tectônicos, 4, Belo Horizonte, Anais, bol. 12:166-171.

[6] Grohman, G.; Kroenung, G.; Strebeck, J., (2006). Filling SRTM Voids: The Delta Surface Fill Method. Photogrammetric Engineering and Remote Sensing, 72:213-216.

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[7] Grunsky, E. C., (2002). R: a data analysis and statistical programming environment – an emerging tool for the geosciences. Computers & Geosciences, 28:1219-1222.
[8] Ihaka, R. & Gentleman, R., (1996) R: A language for data analysis and graphics. Journal of Computational and Graphical Statistics, 5: 299-314
[9] King, L.C., (1967). Morphology of the Earth. (2nd Ed.) Oliver & Boyd, Edinburgh.
[10] Machado R., Endo I. (1993). Cinturão de Cisalhamento Atlântico: um exemplo de tectônica transpressiva neoproterozóica. In: SBG, Simpósio Nacional de Estudos Tectônicos, 4, Belo Horizonte, Atas, 12:189-191.
[11] Neteler, M., (2005). SRTM and VMAP0 data in OGR and GRASS. GRASS-News, 3:2-6.
[12] Pebesma, E. J., (2004). Multivariable geostatistics in S: the gstat package. Computers & Geosciences, 30:683-691.
[13] Rabus, B; Eineder, M; Roth, R; Bamler, R., (2003). The shuttle radar topography mission – a new class of digital elevation models acquired by spaceborne radar. ISPRS Journal of Photogrammetry and Remote Sensing, 57:241-262.
[14] Rodriguez,E.;Morris,C.H.;Belz,J.E., (2006). A global assessment of the SRTM performance. Photogrammetric Engineering and Remote Sensing, 72:249-260.
[15] Valeriano, M.M., (2002). Modelos digitais de elevação de microbacias elaborados com krigagem. Information and Documentation Service (SID), INPE, Technical Report INPE-9364-RPQ/736, 54pp.
[16] Valeriano, M.M., Kuplich, T.M., Storino, M., Amaral, B.D., Mendes Jr., J.N., Lima, D.J., (2006). Modeling small watersheds in Brazilian Amazonia with shuttle radar topographic mission-90m data. Computers & Geosciences, 32:1169-1181.
[17] van Zyl, J.J., (2001). The Shuttle Radar Topography Mission (SRTM): a breakthrough in remote sensing of topography. Acta Astronautica, 48:559-565.

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