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Identifying and correcting oblique striping in the Topodata digital elevation model[(1)]

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ABSTRACT: The Topodata digital elevation model (DEM) is the best DEM available for digital soil mapping (DSM) in Brazil. However, it is not ready to use. We show that the kriging interpolator used to downscale the SRTM DEM from 3 arc-seconds to 1 arc-second spatial resolution increased the double oblique striping (15º and 60º) so common to SRTM DEMs. This is because kriging is quite sensitive to outliers. Besides, the Gaussian model of spatial covariance used in the downscaling enhanced the sensitivity of kriging to outliers, thus enhancing the striping. 2D Fast Fourier Transform can be used to identify whether a destriping procedure need to be employed. The bilinear or cubic resampling methods should be used to warp Topodata DEMs because they are insensitive to the double oblique striping.

Indexing terms: SRTM downscaling, DEM warping, 2D Fast Fourier Transform.

DEMs for DSM in BRAZIL

Terrain attributes are the environmental co-variates most commonly used in digital soil mapping (DSM) (Ten Caten, 2011). One of the reasons is the availability of free DEMs covering the planet such as the Shuttle Radar Topography Mission (SRTM[1]) DEM. The SRTM products cover the Brazilian territory with a spatial resolution of 3 arc-seconds (about 90 m). But since 2011 DEMs with a spatial resolution of 1 arc-second (about 30 m) have become available through the Brazilian National Institute for Spatial Research's Topodata[2] project (Valeriano & Rossetti, 2012) .

The downscaling of the original SRTM DEM from the 3 arc-second to 1 arc-second resolution was carried out using kriging (Valeriano & Rossetti, 2012). DEMs are available in 558 tiles of 1º x 1.5º (3600 rows x 5400 columns), which corresponds to the 1:250,000 quads of the Brazilian Cartographic System. However, because SRTM DEM downscaling did not include new information about the surface, the Topodata DEM contains the same information of the SRTM DEM. Thus, we cannot expect to identify linear features smaller than six pixels, and rectangular features smaller than thirty six (6 x 6) pixels. What Topodata DEM does is to reduce the problems associated with unrealistic features present in the SRTM DEM and to improve the derivation of terrain attributes when high resolution data is not available (Valeriano & Rossetti, 2012).

The approach used to produce the Topodata DEM presents some issues: the same spatial covariance structure was used for the entire Brazilian territory; variography and kriging were performed using data with unprojected coordinates; vegetation offsets were not removed; drainage network was not enforced; and external validation was not employed. On the other side, the Topodata DEM is a product of the joint efforts of a team of Brazilian experts supported by governmental resources, which justify our efforts to use and improve it. Thus, we aimed to test methods to overcome a common issue of Topodata DEMs: the presence of oblique striping. We first identify oblique striping in DEMs and then compare resampling methods to minimize them.

DEM WARPING

Warping is the process through which a DEM is translated from a given projection and datum (e.g., lat/long; WGS84) to another projection (re-projection) and datum (datum transformation) (e.g., UTM; SIRGAS2000) (Keitt et al., 2012). This is achieved using specific equations and resampling methods. Among the most common resampling methods are the nearest neighbour, bilinear, cubic, cubicspline and Lanczos (Dodgson, 1992; Sachs, 2001; Smith, 2011; Studley & Weber, 2011). The nearest neighbour method determines the value of a given output cell by copying the value from the closest input cell. The bilinear method computes the value of a given output cell as the distance- weighted average of the four closest input cells. The cubic method works similarly to the bilinear method, with the difference that a window of 4 x 4 cells is used,

[1] http://srtm.usgs.gov/.
[2] http://www.dsr.inpe.br/topodata.

and the weights are computed using a third-order function of the distance. The cubicspline method is a variant of the cubic method that employs interpolation coefficients that produce smoother results, and the Lanczos method also differs from the cubic method only by using a different mathematical combination of the inputs.

As a general rule, the nearest neighbour method is indicated for categorical data because it does not produce new values (Smith, 2011). The other four methods produce new values and differ in their ability of dealing with aliasing of sharp edges (very common when using the nearest neighbour method), blurring and edge halos (Smith, 2011).

2D FAST FOURIER TRANSFORM

Topodata and SRTM DEMs have different behavior upon warping. To show this we present the real component of the 2D Fast Fourier Transform (2D-FFT) of Topodata and SRTM DEMs. The data used covers a small catchment (1,895 ha) located in Southern Brazil (-29,6652º, -53,8314º; -29,6035º, -53,7677º) (**Figure 1**). The relief varies from plain to mountainous (gradients of 0 to more than 100%), and elevations range from 139 to 475 m.

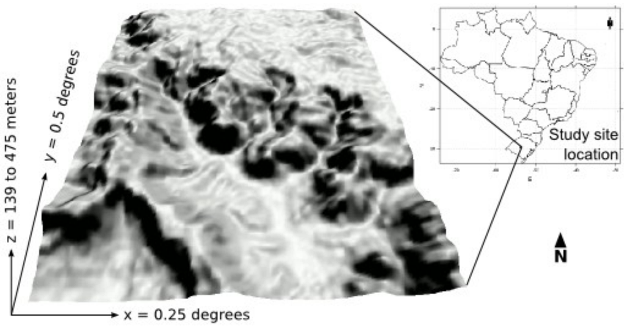

Figure 1 – Location of the study site and the hillshaded Topodata DEM used to compute the 2D-FFT.

The 2D-FFT is a mathematical tool that translates the information from the spatial (image) domain to the frequency domain (Schowengerdt, 2007). An image with high spatial frequency in a given direction exhibits frequent changes of brightness in that particular direction (Richards & Jia, 2006). The elements of an image that characterize high spatial frequency are edges and lines. Depending on the type of image, these elements can be spurious artifacts that resulted from previous image processing. Usually, we are unable to perceive these spurious artifacts in the spatial domain. This is why the 2D-FFT is so useful. Because 2D-FFT provides a way of seeing the underling structure of an image, we can compare it conceptually with the principal components of a multivariate data matrix.

Figure 2 shows the 2D-FFT of the warped Topodata and SRTM DEMs. Warping was carried out using the function `gdalwarp` of FWTools with the nearest neighbour and bilinear resampling methods. The 2D-FFT of the warped DEMs was obtained using the function `i.fft` of GRASS[3].

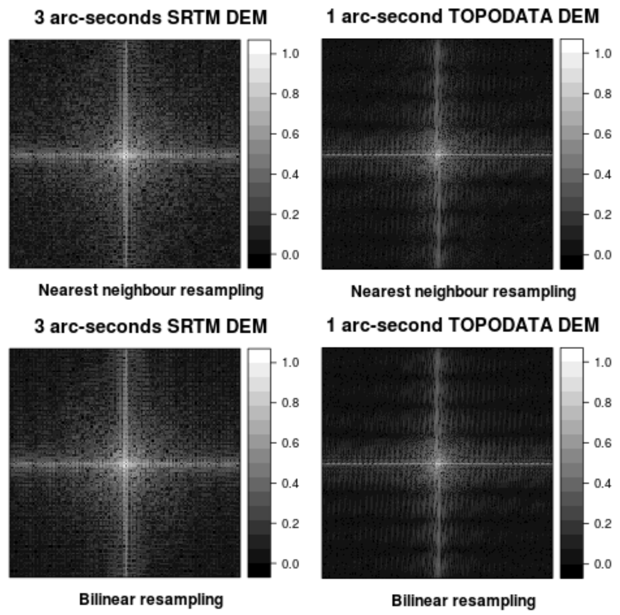

Figure 2 – 2D-FFT of SRTM and Topodata DEMs warped from lat/long/WGS84 to UTM/ SIRGAS2000.

In the case of DEMs, usually there are not many high-frequency elements. When the frequency domain shows the contrary, we need to look for spurious artifacts. **Figure 2** shows evidence of spurious artifacts in the Topodata DEM (right) when warping was carried out using the nearest neighbour resampling method (top). Notice the slightly bright straight line passing through the center of the image (low frequency) with an azimuth of about 60º towards the edges of the image (high frequency). The interpretation is as follows: the Topodata DEM has a feature with a repeating pattern in the azimuthal direction of about 60º. Notice that the warped SRTM DEM (left) is apparently free from this feature. So is the Topodata DEM when the bilinear resampling method was used.

Figure 3 provides a better view of the behavior of the SRTM and Topodata DEMs upon warping. We subtracted the frequency values of the DEMs resampled with the standard bilinear method from the frequency values of DEMs resampled with the nearest neighbour method. Once again the SRTM DEM is apparently free from significant spurious artifacts. There is some noise and the common effect of the edges of the image, which is represented by the vertical and horizontal lines that pass through the center of the image (see the bright

[3] The R script used to perform the analysis can be consulted at http://soil-scientist.net/.

crossed lines in **Figure 2**). But now we have some extra information to evaluate the Topodata DEM. A new high-frequency component appears at an azimuthal direction of about 15º. The interpretation is the same as above. But the spatial pattern of the two high-frequency components of the image (15º and 60º) is quite different. The first has a closer spacing or wavelength (about 330 m) than the second (about 530 m) (**Figure 4**). Because the striping pattern with azimuthal direction of 15º has a smaller intensity (the changes of brightness are smaller), it was not evidenced by the 2D-FFT (**Figure 2**).

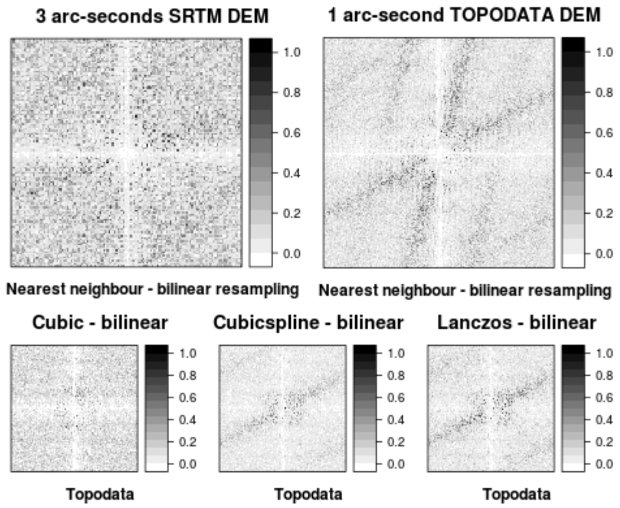

Figure 3 – Difference between the 2D-FFT of DEMs warped using different resampling methods.

The cubic resampling method produced a DEM similar to the bilinear method (**Figure 3**). But the cubicspline and Lanczos methods were only partially efficient. They were able of dealing with the less intense striping (15º), but not with the high-intensity striping in the 60º direction. Based on the empirical evidences that we gathered, the bilinear and cubic resampling methods should be used when Topodata DEM is warped from its original projection and reference system (lat/long/ WGS84) to the official Brazilian reference system (SIRGAS2000) with metric coordinates.

KRIGING and STRIPING in DEMs

The double oblique striping observed in **Figure 4** is a very common feature of SRTM DEMs (Gallant & Read, 2009; Gallant et al., 2011; Perego, 2012). Their occurrence and spatial pattern is closely linked with the orbital paths of the Space Shuttle Endeavour (Gallant & Read, 2009). The presence of striping in DEMs is a major concern in low relief areas because it is usually obscured by high topographic relief (Gallant & Read, 2009), which might have occurred in our study site. Its main negative effect is the creation of parallel depressions that can be regarded as part of the drainage network when automated methods are used to draw the drainage network. Hydrological modeling is unsound under these circumstances. But the question to be answered here is why the warped SRTM DEM is apparently free from striping, while the Topodata DEM shows a double oblique striping (15º and 60º)? We believe that it is related to the method used to downscale the SRTM DEM.

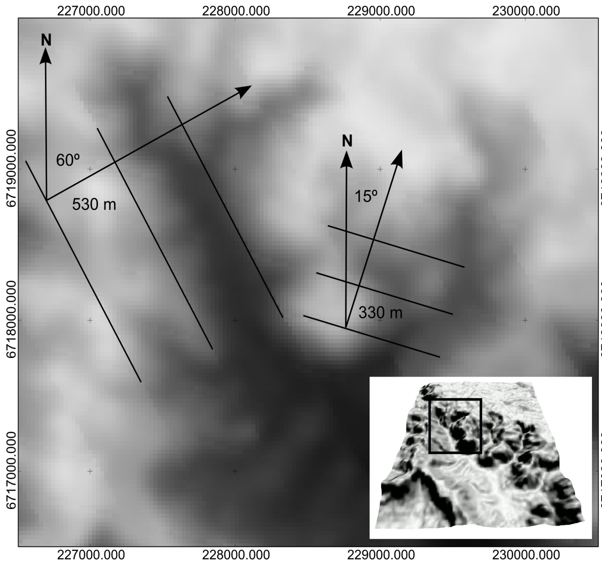

Figure 4 – Excerpt of the Topodata DEM showing the double oblique striping observed when the Topodata DEM was warped using the nearest neighbour resampling method.

We know that there is no such thing as the right model to interpolate elevation data or downscale a DEM. “All models are wrong, but some are useful” (Chatfield, 1995), and kriging is one of the possible interpolators. It is very useful for stochastic simulations, but has some important disadvantages compared to deterministic interpolators such as thin plate splines (Hutchinson, 1989; Hengl & Evans, 2009). First, kriging has an over smoothing effect; second, it does not take into account the hydrological connectivity of a terrain; and third, it is sensitive to outliers and creates many artifacts (Hengl & Evans, 2009).

But kriging can be a satisfactory interpolator for elevation data, depending on the data, and on the variogram model and its parameters. In the case of the Topodata DEM, a Gaussian model without nugget variance and range of 0.0093º was used to downscale the SRTM DEM for the entire Brazilian territory (Valeriano & Rossetti, 2012). This model was selected from a final set of three models with standardized total sill, with the other two being a spheric model (nugget: 0.003 m^2/m^2; range: 0.0060º), and an exponential model (nugget: 0.001 m^2/m^2; range: 0.0083º). The criteria used to evaluate the models were rather subjective and uncertain. A (unknown) number of experts were asked to choose the best model regarding how well the downscaled DEMs represented the relief of forty test sites in the

Brazilian territory, which they were not required to be familiar with. The Gaussian model was chosen because it had a larger ability in defining plateau edges and ridge lines; it gave a better detailing of horizontal curvatures due to the enhancement of dissections over the slopes; it provided a better definition of the small first-order channel dimensions and small concave texture elements; and it was the most sensitive to delicate features in flat areas (Valeriano & Rossetti, 2012).

The criteria used to select the variogram model to downscale the SRTM DEMs answers the question raised three paragraphs above. The double striping artifacts common to SRTM DEMs are “delicate features”, outliers and repeated patterns to which kriging is very sensitive. The Gaussian model and the selected parameters enhanced the sensitivity of the kriging interpolator to these outliers, enhancing the striping effect of the final Topodata DEM. The nearest neighbour method helped enhancing this effect during warping because it promotes strong aliasing of sharp edges.

CONCLUSIONS

The variogram model and parameters used to downscale the SRTM DEM enhanced the double oblique striping in the final Topodata DEM.

The nearest neighbour, cubicsplines and Lanczos resampling method are inappropriate for Topodata DEM warping from its original projection and reference system to the official Brazilian reference system with metric coordinates. The bilinear or cubic resampling methods should be used.

The Topodata DEMs need to be submitted to analysis in the frequency domain before any further processing. The 2D Fast Fourier Transform can help to identify whether a destriping procedure need to be applied to all Topodata products.

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