Analysis and improvement of surface representativeness of high resolution Pléiades DEMs

Examples from glaciers and rock glaciers in two areas of the Andes

Lucas Ruiz
IANIGLA
CCT- Mendoza, CONICET
Mendoza, Argentina
lruiz@mendoza-conicet.gob.ar

Xavier Bodin
Laboratoire EDYTEM
UMR 5204 CNRS / Université de Savoie
Le Bourget-du-Lac, France
xavier.bodin@univ-savoie.fr

Abstract—**High spatial resolution Digital Elevation Models (DEMs) are fundamental datasets to understand the dynamics of Earth surface, such as recent change of the cryosphere, and especially in remote mountainous areas, like the Andes. Here we describe a methodological framework to improve the quality in terms of representativeness of terrain surface for high spatial resolution stereoscopic DEM obtained from Pléiades images. Using as example two DEMs from highly different regions from the Andes, we analyzed the different types of errors present in both DEMs. In order to improve the output DEM a post-processing scheme was designed, following those steps: (1) filling the gaps with a spline interpolation method; (2) elimination of the granular noise with a multidirectional Lee filter; and (3) elimination of the spikes with a slope-based DTM filter. Besides improving the representativeness of both DEMs in terms of terrain feature, the post-processing also improves the accuracy of DEMs in terms of absolute accuracy of elevations.**

I. INTRODUCTION

Glaciers, debris-covered glaciers and rock glaciers are very common cyrospheric landforms in the Andes, and represent important water storage for anthropic uses, such as agriculture, hydroelectric power generation and other industrial activities developed at the foot of the Argentinian Andes. Since a few decades, these cryospheric features are rapidly shrinking, mostly due to an increase in air temperature and a decrease in winter precipitation in the Andes range [1].

The recent availability of high spatial resolution DEMs, like those derived from Pléiades images (from the French spatial agency, CNES), represents a great advantage compared to previous sensors, as their resolution allows to measure volume change and surface characteristics of small glaciers and rock glaciers. Nevertheless, various errors could be propagated into the DEM calculation and limit the full exploitation of high resolution advantages [2]. Among the most common source of errors are speckle noise, anomalous artifacts and no data areas. The first one introduces non-real spatial variation to volume change measurements and higher standard deviation to typical morphometric parameters such as slope, aspect or elevation, which helps to characterize landforms. On the other hand, anomalous artifacts, like holes and/or spikes, could introduce a total anomalous pattern for volume change or in the statistical analysis of morphometric parameters. In the case of no data areas, the main drawback is the lack of information.

Here we introduce a post-processing procedure that intends to (1) assess the presence of different kinds of error, and (2) to use filtering scheme to eliminate the errors. We apply our method on two areas (Fig. 1), which differ in terms of elevation range, slope and surface cover, showing that, in both situations, the post-processing scheme of DEMs improves the representativeness of the surface and the elevation accuracy.

II. MATERIAL AND METHODS

A. *DEM generation and GCP (ground control points)*

Both DEMs were generated using the same methodology, with the triplets of Pléiades images taken on 21-April-2012 on Tronador and on 14-May-2014 for Vallecitos. We used PCI Geomatica (v2013) Ortho Engine module to construct the epipolar images and, then, to construct the DEMs. Output DEM with a 2-m resolution was generated from the pixel values with higher correlation scores between the three DEMs created from the different combinations of images (nadir-back, nadir-front, and back-front).

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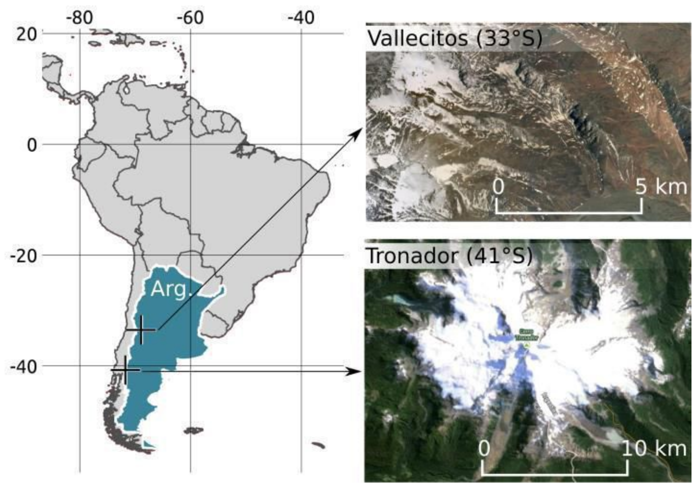

Figure 1. Location of the two study areas in the Argentinian Andes: the heavily glaciated Tronador summit (41°S) and the more rocky Vallecitos catchment (33°S). Imagery from Google Maps.

The first study area (Tronador) corresponds to the Monte Tronador (3475 m asl, 41°09′ S 71°53’W) an extinct volcano of the Wet Andes. Valleys of this region are deep glacial troughs, whereas the upper part concentrates the accumulation area of eight major valley glaciers, in both Argentina and Chile. There is a combination of debris covered glaciers and debris free glaciers, the first ones reach lower elevations (~600 m asl), meanwhile the last ones do not descend below 1500-1400 m asl. Five GCPs were selected to orthorectify the Pléiades images, measured with a Trimble GeoExplorer 6000 Series GNSS receiver on static mode. After differential correction, the horizontal and vertical accuracy of GCPs are 0.1 m and 0.2 m, respectively. Final RMSE (Root Mean Square Error) between the location of the GCPs in the images and on the ground was 0.28 m and 0.48m in X and Y coordinates, respectively. Additionally, 53 tie points with a RMSE of 0.12 m and 0.1 m in X and Y, respectively, were collected in the three images to refine the sensor model.

The second study area (Vallecitos) is a small catchment of the South-east facing flank of the Cordón del Plata, in the Argentinian Dry Andes (between 32°55 and 32°20'S). The altitude are mostly comprise between 3000 and 5400 m asl., and the terrain is characterized by rock surfaces, debris-free glaciers and large portions of debris-covered and rock glaciers [3]. Five GCPs were collected with a dual-frequency Trimble R5 GNSS receiver (horizontal accuracy: 0.015 m, vertical accuracy: 0.028 m). Final RMSE for GCP is 0.49 m and 0.58 m respectively for X and Y, whereas it reaches 0.37 m and 1.19 m in X and Y for the 30 tie points.

B. Representativeness

We consider here the representativeness as a measure of how good a particular DEM represents the different elements or characteristics of a particular region. Because this metric is difficult to quantify and may be confused with the accuracy of the elevation, we use a qualitative approach: this latter first assesses the representativeness of surface features by the output DEMs thanks to a visual inspection using a hill shaded surface model of each output DEM. We also compared the hill shaded model with Pléiades ortho images and terrain photos searching for visual discrepancies.

C. DEM elevation accuracy

To quantify the accuracy in elevation of output DEMs we measure the RMSE between DEM elevation values and several thousands of GPS elevation data collected over bare ground (no ice or forest cover areas) with the Trimble receivers (GeoExplorer 6000 for Tronador, and R5 model for Vallecitos) on dynamic mode. After differential correction, the horizontal and vertical precisions of these ground truth data (GTD) for both study areas are 0.1 m and 0.2 m, respectively.

We use 2301 and 858 GTDs for Tronador and Vallecitos, respectively. In order to avoid pseudo-replication due to the cell size of output DEMs (2m), GTD were resampled to the spatial size of each DEM. When more than one GTD falls inside one cell the mean value was used.

D. Post-processing scheme

To correct the errors found in the qualitative representativeness analysis (see section III; Figure 2 A) the following post process scheme is proposed; (1), filling the gaps (no data areas) with a spline interpolation method, (2) elimination of the granular noise with a multidirectional Lee filter [4]; and (3) elimination of the spikes with a slope based DTM filter [5]. All raster tools are included in the modules library of SAGA GIS (v 2.1). Figures 2 A-D show the improvements in the Pléiades Tronador´s DEM generated by each of the steps mentioned above.

III. Results and discussion

Although the Pléiades DEM reproduces with great details the surface of the glaciers and the rock glaciers, different kinds of errors were identified after the representativeness analysis (visual inspection): (1) holes (cells with no data in highly shadowed areas); (2) granular noise, typically of stereoscopically generated DEMs; (3) spikes (high elevation cells surrounded by lower elevation data) without any spatial correlation (Fig. 2 A).

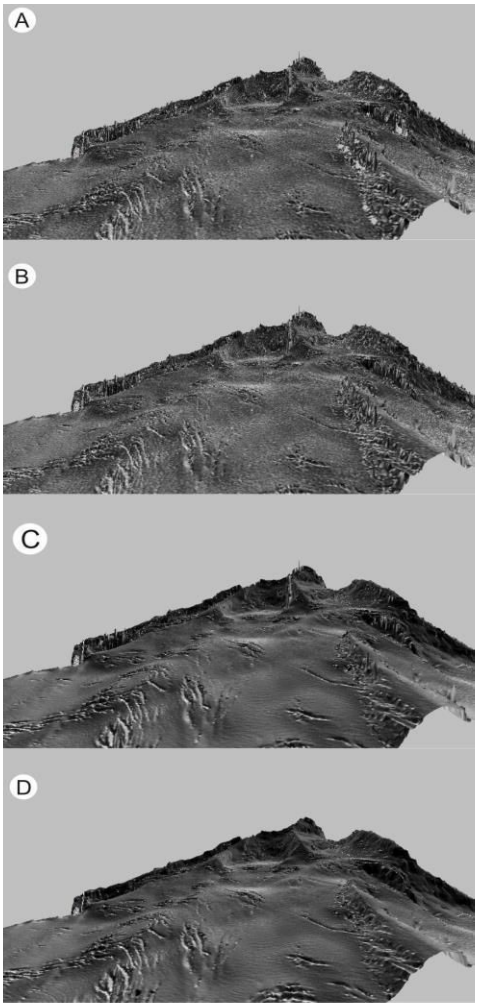

Figure 2. 3D view of Pléaides DEM in the Tronador area shown as a hill shade model: A) without post-processing (note the presence of gaps, granular noise and spikes); B) First step in post-processing, Pléiades DEM with gaps filled; C) Second step in post-processing, Pléiades DEM with speckle noise removed; D) Final Pléiades DEM without spikes, granular noise and gaps. Note the smoothness of ice surface and how well the crevasses are represented.

There are numerous methods to interpolate values in areas of no data, from the most time consuming one, like digitalizing on-screen contour lines, to the most automatic method using numerical interpolation. The best option depends on the objective and on the size of the holes: if the holes are small and do not interference with the region of interest a simple and rapid numerical interpolation methods it is always the best choice. In this context, spline interpolation is preferred to others interpolation methods, like inverse distance weight or nearest neighborhood, because it results in a smooth surface without modifying the original values of pixels adjacent to the voids (Fig. 2 B).

To reduce or eliminate the granular noise advanced filter techniques are required, which identify and eliminate the noise while saving the terrain geometry. The multidirectional Lee filter [6], search for the minimum variance in 16 directions and applies a local mean filter in the direction of minimum variance. The filter is therefore always right-angled to the slope and parallel to the valley system. Thus, the filter eliminates the noise without changing the position and elevation of sharp ridges and deep canyons [4]. The filter eliminates the speckles, preserving small surface features like crevasses or moraine ridges (Fig. 2 C).

Anomalous objects, like spikes, found especially in the Tronador DEM, were created during the generation of DEMs close to high slope areas, like cliff or ridges (Fig. 2A). The slope-based DTM filter we applied to correct this, is based on the observation that a large height difference between two nearby points is unlikely to be caused by a steep slope in the terrain. Although the spikes where already in high slope areas, the filter was able to eliminate it without modified the rest of the high slope areas (Fig.2 D).

When comparing with the GTDs, the elevation accuracy of the Tronador's post-processed DEM (RMSE of the difference between the DEM and the GPS measurements) is 1.08 m, which is slightly better than the one calculated from the only GCP-based raw DEM (1.20 m, Fig.3). In the case of Vallecitos, the RMSE shifts from 3.72 to 3.69 m, displaying a yet unexplained wide distribution of the errors (with three modes around -3, 3 and 5 m, that could be related to artefacts generated by dark pixels in shadow areas).

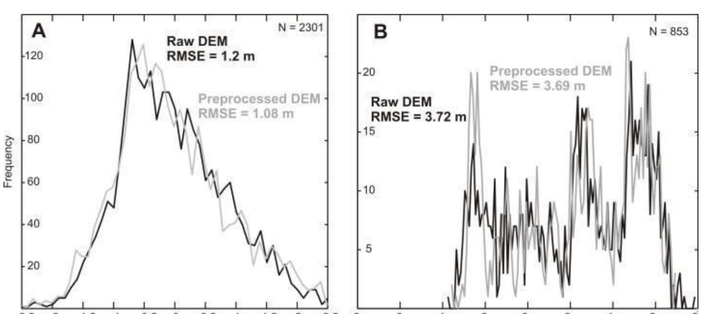

Figure 3. Histograms of differences between DEMs and GTD for Tronador (A) and Vallecitos (B) areas. Thick black line represents the error distribution of the raw (non processed DEM), grey line represents the error distribution of post-processed DEM.

IV. Conclusion

Using a combination of automatic filters we were able to eliminate different sources of error and to improve the elevation accuracy in our DEM by 5% in two very different types of high mountain environments (mostly debris-free glaciers in Tronador area, mostly debris-covered and rock glaciers in Vallecitos). The gain in representativeness, especially for glaciological and geomorphological studies, of such improved high resolution datasets will probably allow the development of many applications in the next years, among which the most promising could be accurate estimation of volume changes and of surface displacements.

Acknowledgment

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