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# Change of land use and soil coverage in the area of influence of natural national park Los Nevados

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**Abstract:** The Nevados National Natural Park (NNNP) and its glaciers El Ruiz and Santa Isabel have been affected by different changes during last decades as land use changes, climate change and changes in extreme events, reason why it has been prioritized to understand its impacts in order to counteract these effects or to delay them. The paper focuses on the recent state of glaciers, moorlands and tropical forests and their changes occurred in the area of influence of NNNP during last decades. This project use remote sensing (Landsat Images) and application of geophysics (Mission Grace) to obtain results. The evaluation carried out from the analysis of satellite images show a notorious retreat of the glacier layer and the geophysical approach has been indicating a reduction of its thickness, keeping in mind that land use and soil covers in the area of influence of NNNP are changing. The reduction of moorlands in favour of livestock and potato crop with its impact on social and environmental aspects is a relevant conclusion. All these changes in general comprise the area of influence of NNNP and have affected its initial dynamics. This analysis serves as a tool for decision makers in the water resources planning and land management in their hydric and social part, based on information of free access as remote sensors images.

**Key words:** Land use changes, soil cover changes, Remote sensing, glacier retreat

## 1. INTRODUCTION

The area of influence of the Nevados National Natural Park (NNNP), located in central Andes of Colombia has been affected by different changes during last decades as land use changes, climate change and changes in extreme events including social and agricultural alterations among many others. This paper seeks to understand the temporal evolution of these changes through the use of remote sensing (Landsat imagery) and the application of geophysics (Mission Grace). The paper focuses on the recent state of glaciers, moorlands and tropical forests and their changes occurred in the area of influence of the NNNP during last decades. It has been demonstrated by some researchers that Tropical Andes glaciers are retreating (Poveda and Pineda, 2009; Marulanda et al., 2016), the analysis was performed using satellite images. This paper presents a geophysical approach to estimate the glacier thickness.

The area of influence of the NNNP has been affected noticeably during last decades and its initial dynamic has changed. Therefore, this study allow us to understand the dynamic of moorlands, glaciers and tropical forests. In general, the glacier retreat is inevitable and the moorlands have been reduced by land change use, especially due to potato crop and livestock, which modifies the water resources availability in the area of influence of the NNNP. The water supplied by the NNNP serves to several communities in the Andean region jeopardizing their future sustainability.

Colombia has currently 6 snowy peaks, 4 are located on the Central Mountain Range of the Andes and are monitored constantly by Institute of Hydrology, Meteorology and Environmental Studies of Colombia (IDEAM) and the Colombian Geological Service (SGC), being these glaciers of special interest because they belong to a chain of active volcanoes which has hindered in some way the acquisition of information. The values of thickness of the glacier layer show a high uncertainty due to variable climatic conditions in the tropical Andes.

The first studies from a point of view of flora and fauna were carried out in glacial zones in Colombia by Friedlader (1926-1927) and Kruger (1918). From a geophysical - geological point of view was Van der Hammen and Krauss (1934) who implemented seismic refraction to evaluate the internal structure of the glaciers associated with volcanoes. During 1986 the Agustín Codazzi Geographic Institute of Colombia (IGAC) through the use of photointerpretation began a series of studies to determine surface changes at glacial zones, a first characterization was obtained in 1994. The IDEAM carried out a technical studies to measure the surface changes in glaciers IDEAM (1993), those study still remains valid. Recently, Euscátegui-Ceballos and Ceballos Liévano (2012) shows the effect of climate changes on glaciers near the equator, evidenced by a clear change in glacier dynamics.

The area of influence of the NNNP presents the same typology to the glaciers studied by Baranowski (1977), who defined these from their geography, temperature and water content, being the Colombian glaciers contained in a group. This characterization highlights the presence of humidity in the ablation zones caused by the atmospheric interaction that melts the glacier and it is one of the main reasons why these studies should be generated in terms of remote sensing information.

The issue of calculating the exact volume of the glacier layer in the country is clear, since gravimetry has only been used in order to measure variations in gravity and indicate changes or contrasts of density, these measurements are carried out by SGC in the El Ruiz Volcano glacier in order to identify alterations inside the Volcano.

The first measurements of thickness of glacier layer in South America were made in Chile using gravimetry in the year of 1986, where thicknesses above 1400 m were estimated considering a subglacial topography inferior to the average level of the sea in the field of North Ice (Casassa, 1987). In Colombia, some studies have been carried out in order to know the thickness of the Earth's crust, such as Camargo (2011) who applied a methodology based on the spectral analysis of the gravitational field. In order to complement this function with the Airy Isostasy Hypothesis (based on the variation of the thickness of the crust considering a distribution of masses along the surface) an expansion of Bouguer Total Anomaly and Topographic Height is obtained a function with a mean square error tendency to zero, that is, it generates the best fit by minimizing the error (Parker, 1981).

Based on the information obtained from the GRACE Satellite for satellite gravimetry. A grid or gravimetric profile was obtained from the area of influence of the NNNP. The data used in the study are applied in order to obtain values of Bouguer Total Anomaly throughout the area then apply Parker's methodology and thus determine thickness values in the earth's crust (Parker, 1981), but especially calculate the thickness in El Ruiz glacier. The estimation of glacier layer thickness is performed using the geostatistical technique of Kriging, which allows to determine the structure of autocorrelation existing among the data.

## 2. CASE STUDY

The area of influence of NNNP is located in the Western Center of the Andean region, covering a surface of 625 $km^2$ as shown in Figure 1. The climate is normally intertropical and is characterized by small fluctuations in interannual temperatures but large daily temperature fluctuations. The rainfall displays a bimodal distribution during the year, due to the influence of the intertropical convergence zone (ITCZ) and the mountainous terrain of the region (Jaramillo, 2005). The temperature is largely a function of the elevation.

## 3. METHODOLOGY

This study will estimate the retreat of the three glaciers located in the NNNP, and its land use and land cover changes, which could affect the water supply of some municipalities in the area of influence. The process consists in relating the geospatial information to the different hydroclimatic variables reported by the stations belonging to the subdivision of ecosystems of IDEAM, present in the area of influence of the NNNP for the period 2000-2010-2015. The Figure 2 shows an outline of the applied methodology for relating geospatial data and hydroclimatic information.

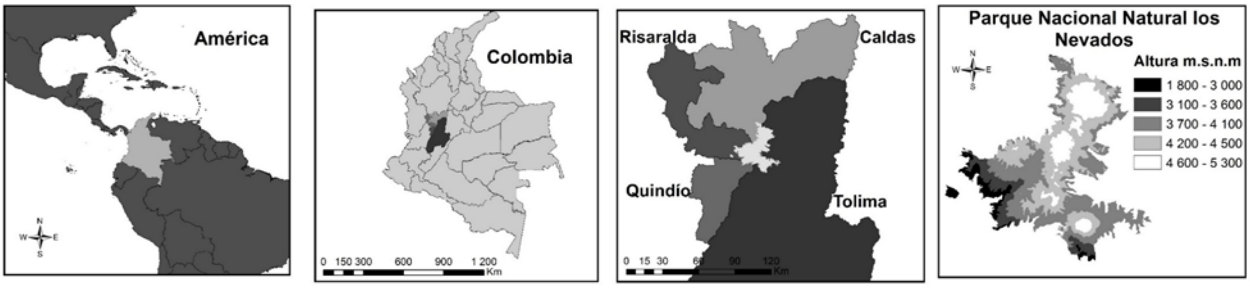


*Figure 1. Location of the area of influence of the Nevados National Natural Park (NNNP).*

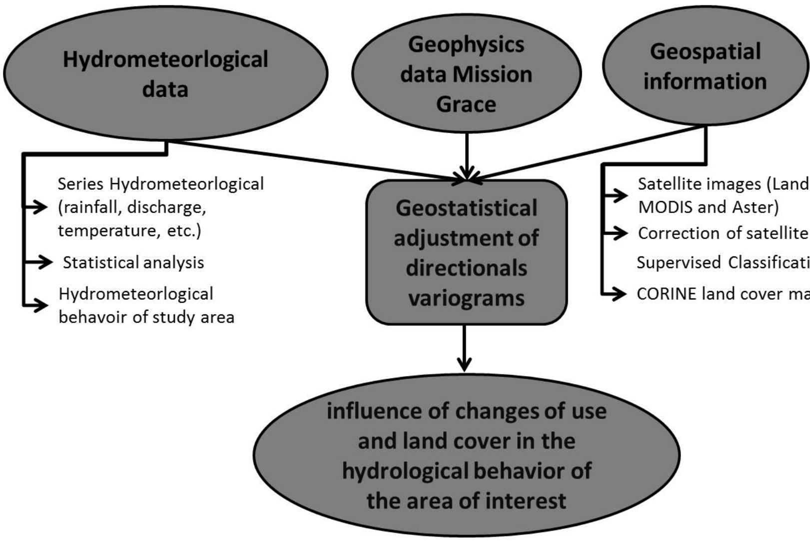


*Figure 2. Methodology analysis of the influence of changes of use and land cover in the hydrological behaviour of the area of interest.*

### *3.1 Geospatial information*

The spatial analysis and the behaviour of the Bouguer anomaly in the El Ruiz glacier are shown through the data of Radar Altimetry and the Satellite GRACE for October of the year 2015. These data are distributed evenly in a grid space of 0.0331 degrees in latitude and 0.0334 degrees in longitude. The database contains a total of 84 records.

### *3.2 Selecting imagery type*

For the construction of land cover and land use maps and subsequent analysis of holdings, it is important to consider the type of sensor, which offers a spatial resolution given by the smallest object captured in the study area (Chuvieco, 1995).

### *3.3 Obtaining the images*

The images are obtained free of charge through the University of Maryland's GLOBAL FOREST CHANGE platform (http://earthenginepartners.appspot.com/science-2013-global-forest).

The images of the Landsat 5 and Landsat 7 were downloaded for the years 2000 and 2010.

### *3.4 Spatial filtering*

For the case study, the spatial filtering was applied from an inspection mask of size 3 x 3, whose function is to contain the components of low spatial frequency of the image (Aldalur and Santamaria, 2002). It was used to improve the contrast between vegetation cover and exposed soil present in the area of influence of the NNNP.

### *3.5 Radiometric correction*

The radiometric correction factor was applied as a function of the values of wavelength captured by the Landsat sensor, which favoured the identification of the covers. It is performed for each band separately as shown below:

$$L = a_1 + a_0 * DN \tag{1}$$

where, L is the radiance that reaches the instrument, $a_0$ is the slope or gain number of counts per radiance change unit, $a_1$ is a constant, offset or bias. Counting value corresponding to the instrument response when the radiance is zero, and DN is the Digital Counting.

### *3.6 Convert radiance to reflectance*

To convert radiance to reflectance the following equation is used:

$$\rho\ (\lambda) = (L*\pi*d^2)/(Ei(\lambda)*\cos(\theta)) \tag{2}$$

where, ρ (λ) is the reflectance at the top of the atmosphere, L is the radiance, d is the ground-sun distance, Ei (λ) is the solar irradiance and θ is the solar zenith angle. The values used to convert the Digital Numbers to Radiance and Reflectance of the ETM Sensor of the Landsat satellite is shown in the Table 1.

*Table 1. Conversion Factors for Radiometric Correction*

| Band | Bias | Gain | Irradiance [W/$m_2$*µm] |
|---|---|---|---|
| 1 | -6.2 | 0.7757 | 1969.0 |
| 2 | -6.4 | 0.7957 | 1840.0 |
| 3 | -5.0 | 0.6192 | 1551.0 |
| 4 | -5.1 | 0.9655 | 1044.0 |
| 5 | -1.0 | 0.1257 | 225.7 |
| 7 | -0.35 | 0.043 | 1368.0 |

### *3.7 Atmospheric correction*

Atmospheric distortions are characterized by spatial and temporal variations, that is, the dispersions are not constant throughout the image, but certain zones may have been more affected than others (Chuvieco, 1995). For this purpose, the FLAASH model was applied in satellite imagery analysis software, using parameters such as orbit height, geographic coordinates of the image center, type of study area (rural or urban), and date and time of the picture.

### 3.8 Geometric correction

It corrects any change of position that the pixels occupy over the physical space that encompasses the image, which modifies only the geographical coordinates of each pixel. The Figure 3 shows the corrected images for the years 2000 and 2010, where the location of the glacier and the retreat suffered in the period of interest is clearly observed.

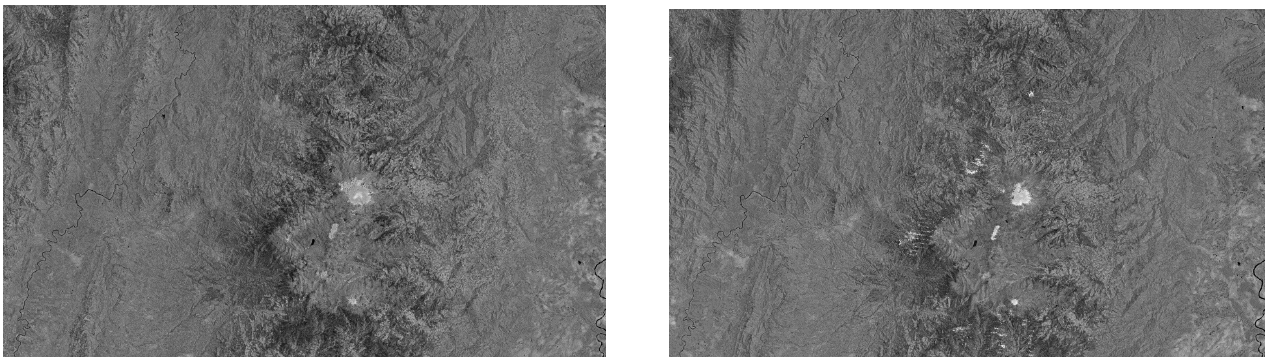

*Figure 3. Corrected images of the years 2000 (upper) and 2010 (lower) RGB combination: 543.*

### 3.9 Supervised classification

The process consists in defining the polygons from the combinations of bands that best highlight the coverage of interest, save the spectral values of the image corresponding to the digitized polygon, and then classification process can be carried out for all polygons. Figure 4 shows the allocation of training polygons for cloud cover and glacier cover.

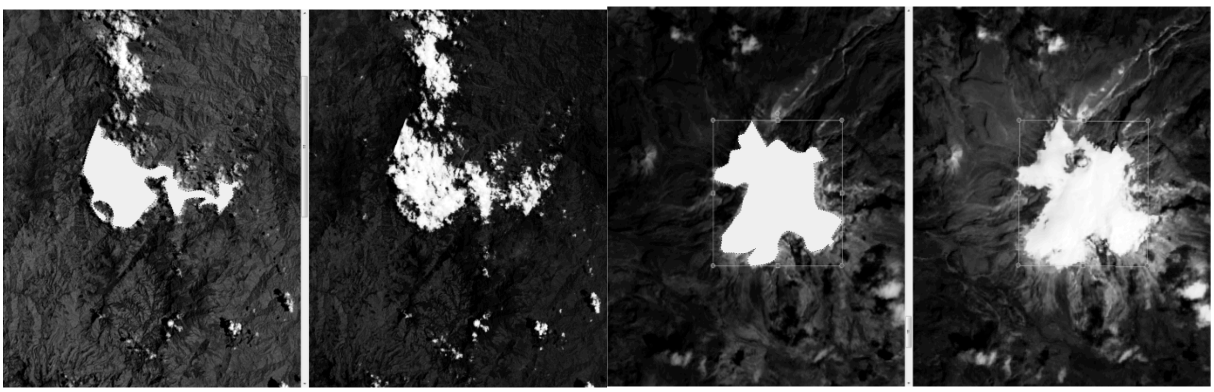

*Figure 4. Assignment of polygons for the clouds cover (Left) and glacier cover (Right).*

### 3.10 Neighbourhood (salt and pepper effect)

It is a matrix interpolation process that allows redefining the contours of the previously identified covers. Figure 5 shows the reduction of the salt and pepper effect in a portion of the image.

### 3.11 Adjustment of the legend according to the national legend

The land covers identified in the area of influence of the NNNP must be adjusted to the standardized cartographic units according to the methodology of the CORINE Land Cover National Legend. The standard suggested by IDEAM proposes three levels of classification composed by 5 covers in Class, 15 for Subclass and 57 in Covers (IDEAM, 2010). The classification level reached according to the Landsat images used and the area of interest was 4 types of covers for class and 8 for the Subclass (see Figure 6).

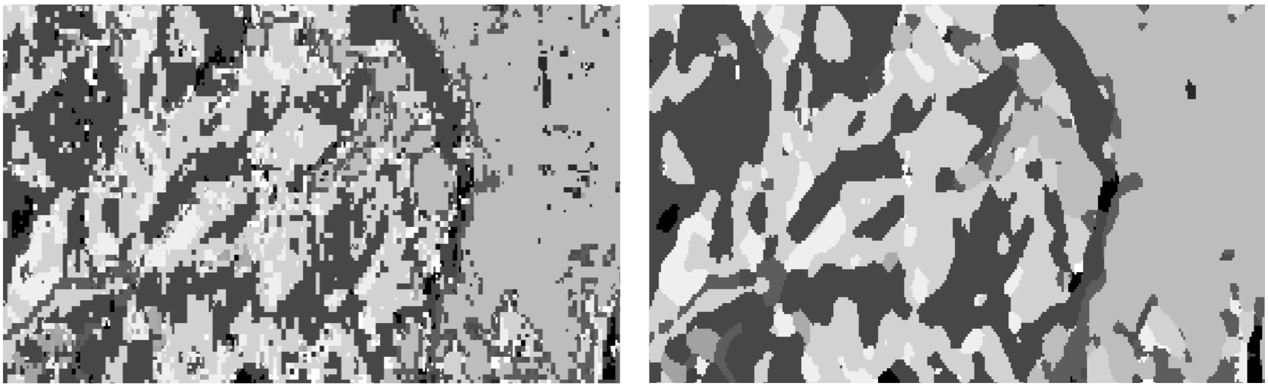

*Figure 5. Image Assigned (Left), Processed Image Neighbourhood (Right).*

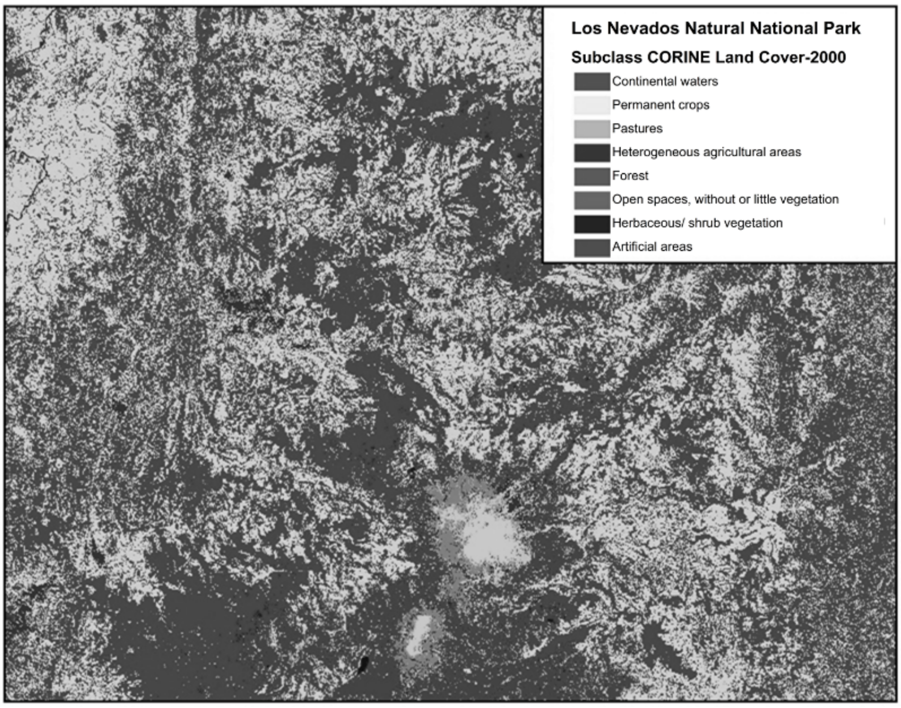


*Figure 6. Subclasses map of land use and coverage in the area of influence of NNNP.*

## 4. RESULTS

Different land use map were obtained and compared according to the methodology of the CORINE Land Cover National Legend, indicating the relevance of land use changes in the NNNP since 2000.

From the Structural Analysis of gravity data (Bouguer Anomaly), used to obtain the thickness of the glacier layer, it was concluded that a trend removal of order two at a global level (100%) has to be carried out, in order to obtain the interpolation map of the prediction values and finally compare the models.

From the geostatistical analysis, the best fit for the semivariogram is the spherical model. The values of this one, as the scatter plot allows to determine the surface and to generate the map of Bouguer Total Anomaly predictions, with the following characteristics: Highest Rank: 0.18699 degrees, Lesser Rank: 0.09574 degrees, Anisotropy: Address 54 (North-East), Sill: 1464.7 and

Nugget Effect: 203.03

The spherical model with Ordinary Kriging method shows the mean error close to zero (0.1201), the mean square error (24.46), the mean of the standardized error is very close to zero (0.004935) Standardized EMC root (0.8533) close to 1. Meanwhile for the spherical model with the Simple Kriging method the corresponding values are: -0.7044, 18.78, -0.01791 and 0.6251 (See Figure 8).

If we compare the values of each model, we can conclude that the best model is the Spherical Kriging Ordinary Model whose equation is:

1464,7*Spherical*(0.18699,0.095742,54.0)+203,03*Nugget (3)

The scatter plots shown in Figure 7, indicate the Error Scatter, Standard Error, and QQPlot for each model, allowing to visually check the differences between each model.

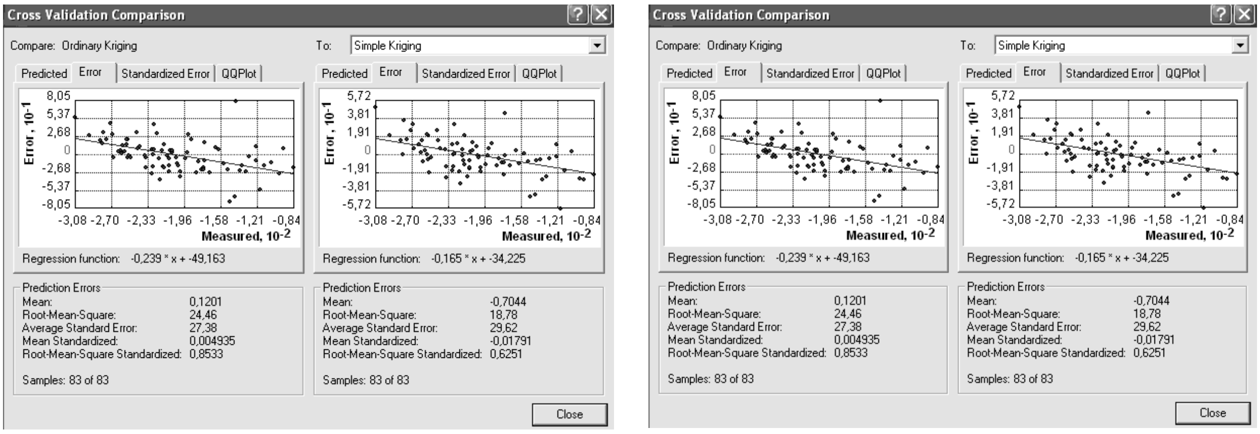


*Figure 7. Comparison Prediction of Ordinary Kriging and Simple Kriging Models (left) and Comparison of Errors of the Ordinary Kriging and Simple Kriging Model (right)*

Taking into account the above and using the Demenickaja (Eq. 4), which takes into account the average thickness of a glacier layer (50 m) with volcanic structures similar to those of El Ruiz in Colombia, and using the density contrast values between Ice (0.92 g / cm3) and rock (2.67 g / cm3), we obtain the general preliminary model of the thickness of the glacier layer, where the expected thickness has higher values, and a lower thickness layer is identified in the Northeast area with values around 5 meters (see Figure 8).

0,05*(1-TANH(0.0034*bouguer)) (4)

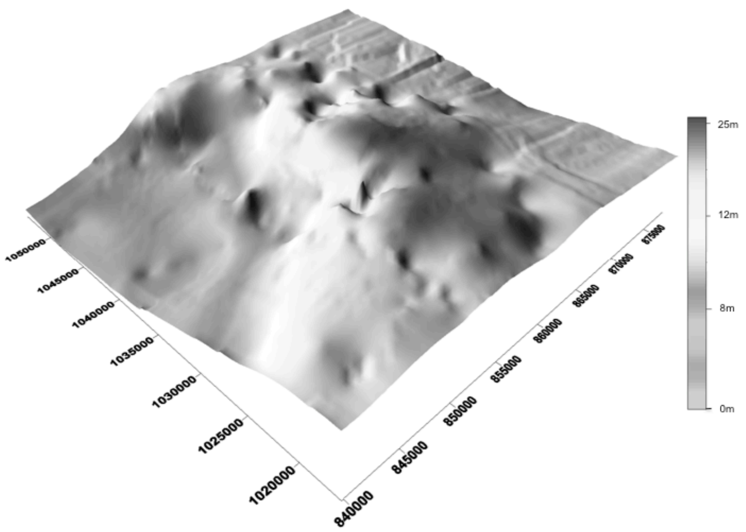


*Figure 8. Preliminary model of the glacier thickness layer at El Ruiz glacier*

## 5. CONCLUSIONS

The Radar Altimetry analysis obtained from GRACE images for 2015 allowed to estimate the glacier layer thickness, with values up 25 meters depth of ice.

The multi-temporal analysis (2000 and 2010) of land use and soil cover changes in the area of influence of the NNNP was obtained satisfactorily. From this analysis was detected a reduction of the Forest and an increment of the Agricultural territory, it also showed the retraction of El Ruiz and Santa Isabel glaciers. The reduction of moorlands in favour of livestock and potato crop with its impact on social and environmental aspects, like the reduction of the hydrologic response and the increase of pollution. This analysis serves as a tool for decision makers in the water resources planning and land management in their hydric and social part, based on remote sensors information of free access.

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