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Estimation of the air temperature in the Mexican high mountains by using of digital elevation model: case of the Nevado de Toluca volcano (Mexico)

INTRODUCTION

Actually, there are various climate change studies based on modelling and simulation (Lorente et al., 2004; Royal Society, 2010; Nolan et al., 2018) both at the mesoscale (Randall et al., 2007; Moran and Boulder, 2018; Paredes-trejo & Olivares et al., 2018) as a microscale (Wu et al., 2006; Fries et al., 2012). The Intergovernmental Panel on Climate Change (ipcc, 2018) indicates that during the years 2006-2015 there was an increase of 0.87°C on a global scale in relation to the pre-industrial era, and this value could become 1.5°C for 2030 generating negative impacts on different types of ecosystems (Cortez et al., 2018). Temperature analysis in mountain environments that do not have climatological stations can be a difficult task, and the elaborated studies can be somewhat speculative if the temperature variable is to be correlated with the characteristics of these ecosystems.

The objective of this work is to estimate the air temperature in the Mexican high mountains by means of a digital elevation model in the Nevado de Toluca volcano, Mexico. In this work, a viable and practical alternative is proposed for the cartographic estimation of the surface air temperature for high-mountain environments, which, as in all ecosystems, their equilibrium depends on the climate conditions. For this task, the most recent data available on air temperature in the region surrounding the Nevado de Toluca volcano has been analysed, which is important because a) it is the fourth highest mountain in the country. b) It has nearby climatological stations whose data periods are an average of 40 years and all are uniformly updated to 2015. c) Its volcanic inactivity allows associating changes in its ecosystems directly with climatic factors. d) It is a mountain close to the large cities in the centre of the country. e) It is the only mountain in Mexico that has a climatological station above 4,000 meters above sea level.

METHODOLOGY

The methodology used is divided into two main parts: first, the calculation of the GVTT in the area of interest based on the average annual air temperature during 2015, as well as for each of its months with the group of stations around the volcano. Second, the spatial interpolation of the air temperature between the groups of stations has been carried out through the obtained GVTT and the use of a DEM (Inegi, 2013) with the elevation values for each point in space and a spatial resolution of 15 meters per pixel. Subsequently, with the ArcGis® 10.4 software, the air temperature map was obtained. The corrected values at sea level were interpolated using the Inverse Distance Weighted (IDW) method, which has been widely used in climatic variables (Rojas et al., 2010; Rodríguez et al., 2013; Olivares et al., 2016). This result yielded an interpolated layer that covers the entire study surface. The GVTT on a DEM was applied once again to adjust the temperature data based on the orography of the volcano; with this, the average air temperature on the volcano was estimated according to its relief and elevation. Considering that the spatial resolution of the final raster mesh depends in turn on that of the DEM, each pixel in the resulting raster layer also has a spatial precision of 15 meters per side. To obtain the modelling and estimation of the air temperature over the surface, the algorithm proposed by Fries et al. (2012) was applied.

In order to verify the accuracy of the modelling, the data provided by the "Nevado de Toluca" station, installed at 4,283 m.a.s.l. at the northwest of the main crater of the volcano, was used. This station has continuous records since 1964, and as the stations used for modelling, its data is updated (Table II).

RESULTS

Based on the data from the surrounding stations, the modelling of the average air temperature in the volcano for the year 2015 and each of its months has been obtained according to figure 4. It can be seen that the temperature behaviour obeys the orographic features and the altimetry of the volcano. Maximum values are observed in the low areas and their valleys, while the highest peaks register the lowest temperatures. The monthly oscillation of the temperature decreases according to the altitude. At 2,570 meters above sea level, 15.9 and 20.0°C are estimated for the coldest and warmest month respectively, while at the top the corresponding values are -0.2 and 2.6°C; that is, 4.1°C of monthly oscillation in the lower zone, against 2.8°C in the summit of the volcano. With the monthly ranges of average temperature observed at the top, mostly above the freezing point, the reason for the lack of permanent snow, only present in the coldest winter months and with the presence of precipitation is understood.

Figure 6 compares estimated values versus observed records. This shows a certain degree of parallelism in the fluctuation of the data throughout the year. The warmest and coldest months recorded, April and December respectively, are clearly matched between the station records and those estimated by the model, the same occurs with the annual mean value. However, February presents a larger discrepancy. The rest of the months have a greater similarity. The statistical tests that were applied to compare the values estimated by the model against those observed indicate similarity to each other. Hence this work could be used in any mountainous region where there are no temperature records in its upper areas, by using climate data of surrounding stations and a digital elevation model.