Preliminary Modelling of Mountain Permafrost on La Ramada Range. Central Andes, San Juan, Argentina.

The altitudinal and spatial distribution of mountain permafrost is strongly influenced by the Potential Incoming Solar Radiation (Funk & Hoelzle 1992) and the geomorphological features are considered one of the factors with less uncertainty for the modeling of the permafrost distribution (Etzelmueller et al., 2001). Potential Incoming Solar Radiation is a morphometric parameter often used to estimate Mountain Permafrost (Oke, 1998; Wilson and Gallant, 2000; Boehner, 2009).

The Ramada Mountain Range, among the highest locations in South America, is part of the Central Andes region in the Province of San Juan, northwestern Argentina. The steep topography, the unstable slopes and the rock characteristics favor the availability of loose materials and the development of large glacier moraines, which is usually related to development of periglacial geoforms. Additionally, the study area has a large number of glaciers, debris-covered glaciers and perennial snow patches. The current developing of glacial environment is very important in the study area with a large number of glaciers, debris-covered glaciers and snow patches.

The goal of this paper is to develop an initial estimate of the areas of possible mountain permafrost in La Ramada Range based on the active rock glacier hypsometry and the potential solar radiation. This is a low cost methodology that can be carried out within a short time frame providing initial estimates for more specific future studies.

We used the lowest elevation of the active rock glacier as approximation to the lowest limit of possible permafrost (UNEP, 2007), and the medium height of the active rock glacier as an approximation to the lowest limit of probable permafrost. Then we combined this information with the potential incoming solar radiation on the area.

We also aim to understand altitudinal and spatial distribution of the glacial and periglacial geoforms present in the study area, its relationship with some climatic and morphometric parameters.

The study region encompasses an area of 2.085 km² and consists of different basins and sectors bordering the highest peaks of La Ramada Mountain Range, with an altitudinal distribution between 2.000 to 6.700 meters. The topography causes great variability in local climate, snow cover and surface processes like erosion, transport and deposition. Therefore the permafrost zone is not limited to height and orientation of hillside, but rather has a more complex distribution, unevenly and asymmetric in the valleys.

We used a three step methodology: First, we use satellite imagery and field information to catalog and delineate glacial and periglacial geoforms. Secondly, we use Digital Elevation Models (DEM) to derive slope, aspect, curvature and roughness. The processing takes into account latitude, topography and the sun elevation and azimuth. We also obtained other composite variables such as sky view factor, heliophany and potential incoming solar radiation. Finally, we analyzed the

correlation between the geoforms distribution and the morphometric parameters to produce a permafrost likelihood model (Trombotto Liaudat et al., 2014)

We inventoried 61 glaciers, 69 covered glaciers, 168 snow patches, 104 cryogenic active rock glaciers, 8 glacigenic active rock glaciers, 95 inactive cryogenic rock glaciers and 17 fossil rock glaciers. We also identified 192 protalus ramparts and protalus lobes. We mapped creeping areas superimposed over older deposits, such as glacial moraines or landslides, in hillside and other solifluction areas. Glaciers occupy an altitudinal range between 4.065 and 6.365 m.a.s.l (average: 5.120 m.a.s.l), debris-covered glaciers 3.770 -5.935 (average:4.550 m.a.s.l.), snow patches 3.980-6.680 m.a.s.l. (average: 5.100 m.a.s.l.), cryogenic active rock glaciers 3.670-5.010 m.a.s.l. (average 4215 m.a.s.l) and glacigenic active rock glaciers 3830-5000 (average: 4270 m.a.s.l.).The altitude of active rock glaciers (cryogenic and glaciogenic) occupies a range between 3.670 to 5.010 m above sea level, and an average height of 4215 m.a.s.l. Considering only the minimum and average height of active rock glaciers we found that the area of probable Permafrost (high likelihood) is 530 km^2 and the area of possible permafrost (medium likelihood) is 620 km^2. This represents 25.4% and 29.7% respectively of the total study area (2.085 km^2).

In addition, we used the 1000 kWh/m2 threshold to separate possible from probable permafrost. The potential direct insolation shows a minimum of ~0 kWh/m2 and a maximum of 2580 Kwh/m2, while the average values on active rock glaciers are 260- 1025 kWh/m2.This method has provided better estimates because the areal distribution of the permafrost is irregular and well correlated with potential solar radiation. This is clear in south facing slopes, lower lying terrain and areas of shade casting which allow glaciers to develop at lower elevations. Low heliophany and potential solar radiation, associated with many hours of cast shadows, are key parameters for the development of glaciers down to 4000 m.a.s.l. and glacial environment to 3700 m.a.s.l., which is well below the regional average for Argentina´s Central Andes.

With this information we corrected our possible permafrost (medium likelihood) extent to 512 Km^2 (above 3.600 m.a.s.l., annual potential solar radiation ≤ 1.000 kWh/m^2 and above 4.200 m.a.s.l., annual potential solar radiation ≥ 1.000 kWh/m^2). The probable area was corrected to 515 km^2 (above 4200 m.a.s.l., potential annual solar radiation ≤ 1000 kWh/m^2). This represents 24.5% and 24.7% respectively of the total study area (2.085 km2).

The permafrost distribution in mountain regions is irregular due to the complex spatial distribution of surface temperatures, insolation and snow cover. Our results contribute to growing evidence that the potential solar radiation has a greater degree of influence on the surface temperature than other variables.

KEYWORDS Mountain Permafrost, Geocryology, Geomorphometry, Incoming Solar Radiation Potential, hypsometry

REMARK / MESSAGE TO THE PROGRAMME COMMITTEE AND CHAIRS

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