

# Downscaling frost risks derivated from MODIS Surface Temperature Using Oro-topographic Descriptors

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## Abstract

In areas with sparse meteorologic networks, MODIS satellite records yield continuous fields of land surface temperatures, allowing to derive climatic indicators like frost risk at a 1-km scale resolution. Unfortunately this spatial resolution is insufficient in complex terrains like mountains. We present a multiple regression model for downscaling such data by using additional oro-topographic descriptors. This model have shown to be efficient in the case of high resolution mapping of frost risk in the Andean highlands of Bolivia.

## Introduction

Moderate Resolution Imaging Spectroradiometers (MODIS) provide reliable surface temperature and emissivity products [1] with time and space resolutions adapted to studying regional and global climate processes. Remotely sensed data find thus a quantity of applications, especially in mapping and modelling climate. But in mountain areas, which represent a quarter of the terrestrial Earth surface, spatial variation of meteorological data is typically high. In these particular environments, climate is one of the most important factors affecting species zonation and key ecological processes. Numerous studies on topoclimate in highlands showed that elevation and slope are the main explicative variables in modelling local climate spatial variability [2]. In particular, these topographic factors control nocturnal cold air drainage and, hence, the distribution of frost risks at the landscape scale [3], [4]. These works also claim for the need to reach better representative spatial information in mountain areas. The aim of our study is twofold i) to show how oro-topographic descriptors other than elevation and slope may explain the spatial distribution of frost risks in mountain areas and ii) to use these descriptors to accurately downscale satellite frost risk estimates to the landscape level.

## Material

The study area was located at the southwest of the Bolivian highlands (19°15'-22°00' South, 66°26'-68°15' West), in a high elevation region (from 3650 to 5900 m) called the Salar of Uyuni because of the presence in its centre of a *ca.*100 x 100 km dry salt expanse. In this geographic context, the main climatic threat lies in radiative frost, occurring during clear and calm nights [5]. The experiments were applied on a frost risk map expressed in a 0-1 probability range on a daily basis for the January-February period, the most critical for radiative frost sensitive flora and fauna in the southern hemisphere. This probability map was calculated using daily MYD11A1 MODIS land surface temperature (LST) products downloaded from the EOS Data Gateway (<http://wist.echo.nasa.gov>).

We used a SRTM DEM with a 90 m resolution and a 16 m vertical precision [6], resampled to 100 m to facilitate the correspondence between the DEM and the MODIS images at 1-km scale.

### A regional regression model

In a GIS environment using Idrisi Kilimanjaro, Envi 4.2. and ArcMap 9.2. softwares, various topographic descriptors were then calculated to examine their potential roles in the spatial determinism of frost and to downscale frost maps closer to the actual scale of frost impacts on ecological processes and human activities. These descriptors were:

- elevation (in meters above sea level)
- latitude (in meters in the UTM 19 South coordinate system)
- slope steepness (in degrees)
- daily potential insolation (DPI, in  $\text{W m}^{-2}$ )
- afternoon potential insolation (API, in  $\text{W m}^{-2}$ )

Both DPI and API were calculated by the Solar Analysis tool, an ArcView GIS extension. They equate to the amount of radiative energy received over the ground [7].

- distance from salars (in meters, log transformed because the strength of the relationship decreases with distance), presenting particular thermal properties [8].
- compound topographic index at a 5% threshold (CTI, dimensionless) quantifying fluid drainage and consequently frosty air layer adiabatic drainage [9], [10].

Moreover, as suggested by [11], two types of landscape positions were discriminated: hills (slope  $> 3^\circ$ ) and flat plains (slope  $< 3^\circ$ ).

Indices	Ranges		Multiple reg. coef.	
	Minimum	Maximum	Plains	Hills
Elevation	2978	6170	5.82	6.21
Latitude	7868554	7871955	0.85	1.42
Slope	0	54	-	-8.28
Daily potential insolation	7524	9553	15.1	5.90
Afternoon potential insolation	3186	5030	16.9	4.70
Distance from salars	0.1	7.32	-9.95	23.4
CTI	0.1	6.4	1.82	2.08
Intercept (Y)	-	-	-1.59	-1.99
Mean residual error	-	-	1.51	1.49

Table 1: Ranges of oro-topographic descriptors observed over the study area and multiple regression coefficients for frost risks with oro-topographic descriptors, in two landscape positions, based on the 5% topographically most homogeneous pixels.

Then, a simple regional regression model was developed in order to examine the relationship between frost risks and topographic descriptors, these latter were aggregated in 10 x 10 pixel clusters (hereafter called "aggregated pixels") and superimposed to the MODIS 1-km images. A heterogeneity coefficient (HC) was then calculated for each 1-km aggregated pixel as (1).

$$HC = \left[ \sum_{i=1}^{100} (TD_{km} - TD_{100m})^2 / TD_{km} \right] / 100 \quad (1)$$

where:  $TD_{100m}$  = topographic descriptor of the 100-m pixel  $i$ , and  $TD_{km}$  = average topographic descriptor of the 1-km aggregated pixel.

HC was calculated for two topographic descriptors (namely, elevation and DPI) in both the flat and hilly areas and, in hilly areas, for the slope steepness factor too. In each type of landscape unit, only the 5% topographically most homogenous pixels were selected to calibrate the topography-frost risks relationship.

Using the Statistica software, a multiple regression was then calculated between frost risks (dependent variable) and topographic descriptors (independent variables) for each landscape unit (see Table 1). A t-test was carried out and validated at a 5% threshold for each independent variable of the regression. The regression models were then used to downscale frost risks from 1-km to 100-m scale: on each pixel of the digital elevation model, frost risks were calculated using the regression equations corresponding to the landscape unit (plain or hill) (see Figure 1). Then the model was validated (see Figure 2).

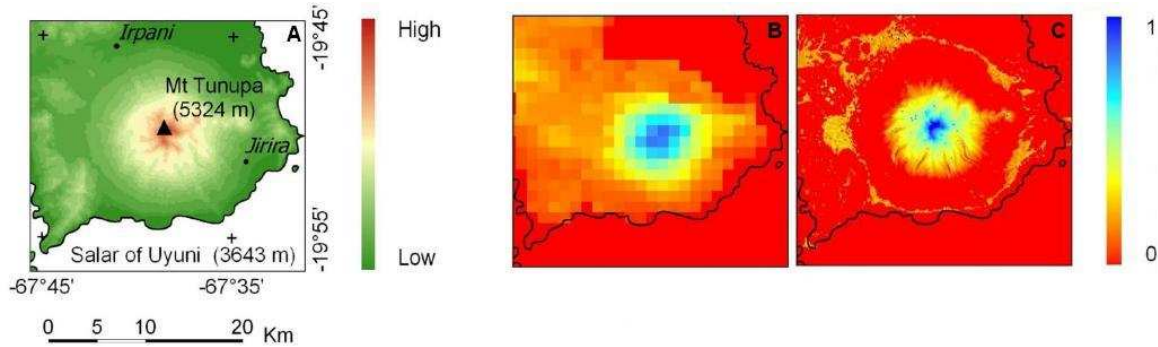


Figure 1: The 100 m resolution SRTM adapted DEM with the principal geographical components (A), the 1 km resolution frost risk map (B) and the 100 m resolution frost risk map of the Tunupa region (C).

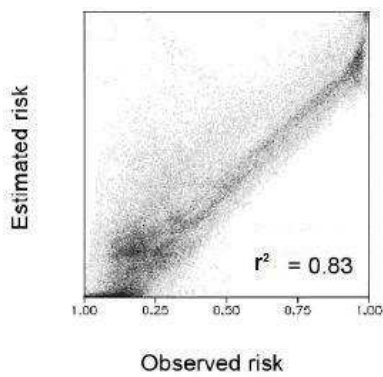


Figure 2: To validate the downscaling procedure, modelled risk maps at 100-m were brought back to 1 km resolution and compared to observed (remotely sensed) risk maps, excluding the aggregated pixels used for calibration ( $n = 54\,001$ ). The relation is quite good:  $r^2 = 0.83$ , without absolute nor relative bias.

## Discussion & conclusion

Multiple regression between frost risks and topographic descriptors showed that the effects of elevation, latitude, and CTI are positive, and roughly similar in the different landscape units (plains or hills). Intercept and residual error values were also comparable between both situations. In contrast, potential insolation indices and distance from the salars affected plains and hills differently, reflecting complex interactions between topographic factors at local scales, such as shadow casting over plains due to surrounding topography.

High resolution maps resulting from the downscaling procedure reveal some of these interactions at landscape scale, and corroborate local peasant knowledge about the beneficial influences of terrain slope or proximity of the salars as regards frost risks [7].

Concerning modelling, the method developed here may be of limited application for downscaling highly variable patterns of precipitation or extreme events, but it appears useful to simulate reliable global warming scenarios in complex regions [12].

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