VARIATIONS OF THE ALBEDO DUE TO CLIMATE CHANGE IN AN ANDEAN REGION OF BOLIVIA

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1. INTRODUCTION

Mountainous systems are interesting for research and practical purposes because they sustain sensitive ecosystems. That sensitivity is due to various reasons, among which the principal is the dependency on hypsometry. Climatic variations are a potential threat to the equilibrium of those systems, but still the challenge is to demonstrate that the threat is real. Glaciers and periglacier areas in steeped regions such as the tropical Andes (latitude $+30^{\circ}$ to -30°) are even more sensitive to climatic variations since ablation and accumulation periods coincide (Wagnon et al., 2001). From the practical, scientific and water resources perspective, the influence of the climatic changes in those systems is worth studying. For this paper, trends in the surface albedo in the last 20 years are estimated from Landsat imagery through the Surface Energy Balance Algorithm for Land (SEBAL) algorithm (Bastiaanssen, 2000). Later, accuracy of the remotely sensed estimations are compared against field measurements obtained from the literature (Gascoin et al., 2009). The objective is to evaluate the impacts of climatic variations in the glacier and periglacier region of the Central Andes in Bolivia (latitude 15.8° to 16.7° South). Assuming that albedo is inversely proportional to the volumetric water content (as demonstrated by field data in Gascoin et al., 2009), the ultimate objective is to infer the potential impact of climatic variations on runoff production and water resources availability.

2. METHODS

The surface albedo is a very important parameter in the analysis of the climatic effects, since it constitutes a modulator of the energy balance of the land surface (Gascoin et al., 2009). To carry field measurements in remote areas such as the Andean region is in general not feasible, for instance the use of data from remote sensors is commonly considered. In this paper, surface albedo estimations are done with the SEBAL algorithm (Bastiaanssen, 2000), based on observations from Landsat imagery. We had preference for the Landsat sensor because the imagery has high resolution (thermal band for Landsat 4 and Landsat 5 Thematic Mapper TM: 120 m; thermal band for the Landsat 7 Enhanced Thematic Mapper ETM+: 60 m), and because no-cost imagery obtained from the United States Geological Service USGS Earth Resources Observation and Science EROS allows temporal analysis for a long period (Landsat TM: year 1984 to year 1987 and year 1996 to year 2007; Landsat ETM+: year 2000 to year 2008). We selected the SEBAL algorithm (Bastiaanssen, 2000) for the remotely sensed estimations because the field data demanded is minimum (Bastiaanssen, 2000), and the products can be potentially used for the analysis of the radiation balance and the estimation of evaporation (out of the scope of this paper).

2.1 Estimation of surface albedo

Calibration of the imagery is done following standardized steps described in detail by Chander et al. (2009). The resultant products are cloud-masked, and at-sensor digital numbers are converted to ground reflectance values (ρ). Topographic information from the Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) project aid the surface albedo estimations. SRTM DEM tiles are constructed and distributed to the public through the USGS EROS Data Center (horizontal resolution 3 arc second or 90m at the equator; absolute height error estimated to be 6.2 m for South America, Rodriguez et al., 2005).

Imagery transformed to ground reflectance is employed to calculate values of albedo at the top of the atmosphere (α_{TOA}) (Equation 1). α_{TOA} is estimated in terms of a weighting coefficient ω_{λ} calculated for each band (denoted as λ) with a standardized form of the mean solar exoatmospheric spectral irradiance (ESUN) (Equation 2). Values for ESUN are specific to the sensor's band, and are taken from Chander et al. (2009).

$$\alpha_{TOA} = \Sigma(\omega_{\lambda} \cdot \rho_{\lambda}) \tag{1}$$

$$\omega_{\lambda} = \frac{ESUN_{\lambda}}{\Sigma(ESUN_{\lambda})} \tag{2}$$

The α_{TOA} values (narrow band albedo) are reduced by an assumed value of the sun radiation reflected from the atmosphere (α_p =0.03, Bastiaanssen, 2000), and then converted to broad band albedo assuming inverse proportionality to the squared atmospheric transmissivity of clear skies (τ_{sw}) (Equation 3). τ_{sw} values are estimated from topographic information as shown in Equation 4, where z is the elevation in meters above sea level.

$$\alpha = \frac{\alpha_{TOA} - \alpha_p}{\tau_{SW}^2} \tag{3}$$

$$\tau_{SW} = 0.75 + 2 \cdot 10^{-5} \cdot z \tag{4}$$

Keywords: Surface Energy Balance Algorithm for Land, surface runoff.

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Fig.1 Location of the points for which surface albedo values are estimated. The geographic latitudes are in degrees (deg.) (Southern Hemisphere) WGS84.

Cloud cover is characteristic, and reduces the utilizable area of the imagery. Thus, instead estimating albedo at every cell, we select locations distributed on contour lines every 500 m, on slopes with similar topographic aspect, as shown in Fig. 1. Results are from estimations at those locations.

3. RESULTS

Daily averaged remotely sensed surface albedo estimations are within an acceptable range with field observations in Gascoin et al. (2009), showing the robustness of the SEBAL algorithm. Variations in surface albedo are not clear in the contour lines 3300 m and 3700 m, since they are located in the tree line transition. On the other hand, locations on the contour lines 4300 m and 4700 m clearly show a negative trend in surface albedo (Fig. 2).

From the inverse proportionality between surface albedo and soil moisture (Angstrom, 1925; Gascoin et al. 2009), the negative trends suggest an increase in surface and subsurface runoff. That may occur as result from an increase in glacier melting caused by glacier retreat, or may also be a signal of the melting of the diurnal or seasonal permafrost (permanent permafrost is unlikely). The increase in soil water content inferred from the reduction in surface albedo might have negative consequences. The negative consequences would appear if the source of the humidity increase is the melting from glaciers and frost soil, since both are not infinite resources. Soil erosion would be the final consequence. The increase in soil water content may also be caused by an increase in surface runoff due to an enhanced precipitation, in whose case the loss of the upper most soil layer would also be understood in an increased risk for erosion.

An increase in the soil water content may also mean an increase in evaporation rates, which from the water budget perspective, and considering the low precipitation recycling efficiency due to the low vegetation density, would mean an increase in losses, and the consequent runoff reduction.



Fig.2 Remotely sensed estimations of surface albedo.

4. CONCLUSIONS

Negative trends in surface albedo for a region with low vegetation density was observed, and the main consequences identified were an increased potential for erosion, higher infiltration and an increased potential for evaporation of the soil water content. From all those perspectives, the consequences in surface runoff appear negative. The main challenge is the quantification of those effects, which is planned to be included within our future publications.

ACKOWLEDGMENTS

The work was supported by the Glacier Retreat Impact Assessment and National Policy Development (GRANDE), under the Science and Technology Research Partnership for Sustainable Development (SATREPS).

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