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Detecting rock glacier flow structures using Gabor filters and IKONOS imagery

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ABSTRACT

While ridges and furrows on the surface of rock glaciers are probably the most characteristic morphological features of this expression of creeping mountain permafrost, this is the first study that examines the utility of texture filters in detecting rock glacier flow structures. Texture features were derived from a Gabor filterbank applied to two panchromatic IKONOS orthoimages from the Chilean Andes, and terrain attributes were obtained in order to narrow down the area of interest and as additional predictor variables. Four classification methods of different complexity (generalized linear model, GLM; generalized additive model, GAM; support vector machine, SVM; Bundling) were applied to three sets of predictor variables (texture attributes, terrain attributes, and the combination of both), and predictive performances were estimated using two spatial cross-validation strategies in terms of the median area under the ROC (receiver operating characteristics) curve (AUROC). Overall, classifiers utilizing texture attributes alone or, usually even better, in combination with terrain attributes outperformed terrain attributes alone, and Bundling (in most cases followed by SVM) showed the overall best performance as a classification method. Cross-validated median AUROC values were mostly between 0.70 and 0.80, or “fair,” in this focused pilot study, but much better results are to be expected at the landscape scale. Permutation-based spatial variable importance measures indicate that Gabor features corresponding to texture wavelengths between 10 and 30 m are the most important predictors, which is consistent with typical ridge spacing on rock glaciers. Confounding occurred mostly in areas with linear erosion features and ridges or scarps in morainic and thermokarst terrain. We suggest that texture filters and the chosen methodological approach are relevant not only for rock glacier mapping but also for delineating debris-covered glaciers and characterizing glacier surfaces, as well as for other geomorphological and cryospheric applications.

1. Introduction

Rock glaciers are cryospheric features that are difficult to detect in remote-sensing imagery because their ice content is generally not exposed at the surface, limiting the utility of optical remote-sensing data for their automatic detection. Similar problems are encountered with debris-covered glaciers. Recent research has focused mostly on the combination of terrain attributes derived from digital elevation models with multispectral optical and/or thermal satellite remote sensing in order to detect ice-debris systems, in particular rock glaciers (Brenning, 2009; Janke, 2001; Piatek, 2009) and debris-covered glaciers (Bishop et al., 2001; Bolch et al., 2008; Kargel et al., 2005; Paul et al., 2004; Shukla et al., 2010). Although each of these approaches offers some level of discrimination between ice-debris systems and their surroundings, classification accuracies still need to be improved, especially in the case of rock glaciers, which are important ice storage systems especially in dry high-mountain areas (Azócar & Brenning, 2010).

Texture filters as an alternative approach to this problem have not yet been studied in this context, and are the focus of this paper. Active rock glaciers, as the geomorphic expression of ice-rich creeping mountain permafrost, typically present characteristic surface patterns with arcuate furrows and ridges as a result of several external and internal factors including their deformation (Barsch, 1996; Haeberli et al., 2006; Kääb & Weber, 2004). Ridges are typically 1–5 m high and between 10 and 100 m apart from each other, often with substantial variation within a rock glacier as well as within a mountain region (Kääb & Weber, 2004).

Gabor filters, as one particular class of texture filters, are a state-of-the-art approach to detecting and discriminating textures, particularly zebra-like or periodic band patterns, from a grayscale image or spectral band (Arivazhagan et al., 2006; Bovik et al., 1990). The Gabor function is a local matched filter, a tunable function parameterized by orientation, frequency, and wavelength. In the remote-sensing context, Gabor filters have been used to differentiate urban land uses (Xiao et al., 2010), and our expectation is that they are

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also useful for detecting flow structures in cryospheric features as well as in lava streams, for example.

Our objective is to assess the utility of Gabor filters in the detection of flow patterns of rock glaciers. We therefore apply state-of-the-art statistical and machine-learning classifiers to features obtained from a Gabor filterbank and determine their performance using cross-validation. The filter parameters that contribute the most to the predictive performance are furthermore determined using a permutation-based variable accuracy importance measure. We apply Gabor filters to the panchromatic band of IKONOS imagery (1 m × 1 m resolution) of two study areas in the Chilean Andes.

2. Materials and methods

After introducing the study areas (Section 2.1) and image acquisition (Section 2.2) at the beginning of this section, we present the texture filters (Section 2.4) and terrain analysis processing steps, including the definition of a more focused area of interest (AOI) within the study areas based on a thresholding of terrain attributes (Section 2.3).

Terrain attributes are used to narrow the study region to a relevant area of interest (AOI); within the AOI terrain attributes are further used as additional predictor variables and as a set of benchmark predictors to which the Gabor-based performance can be compared.

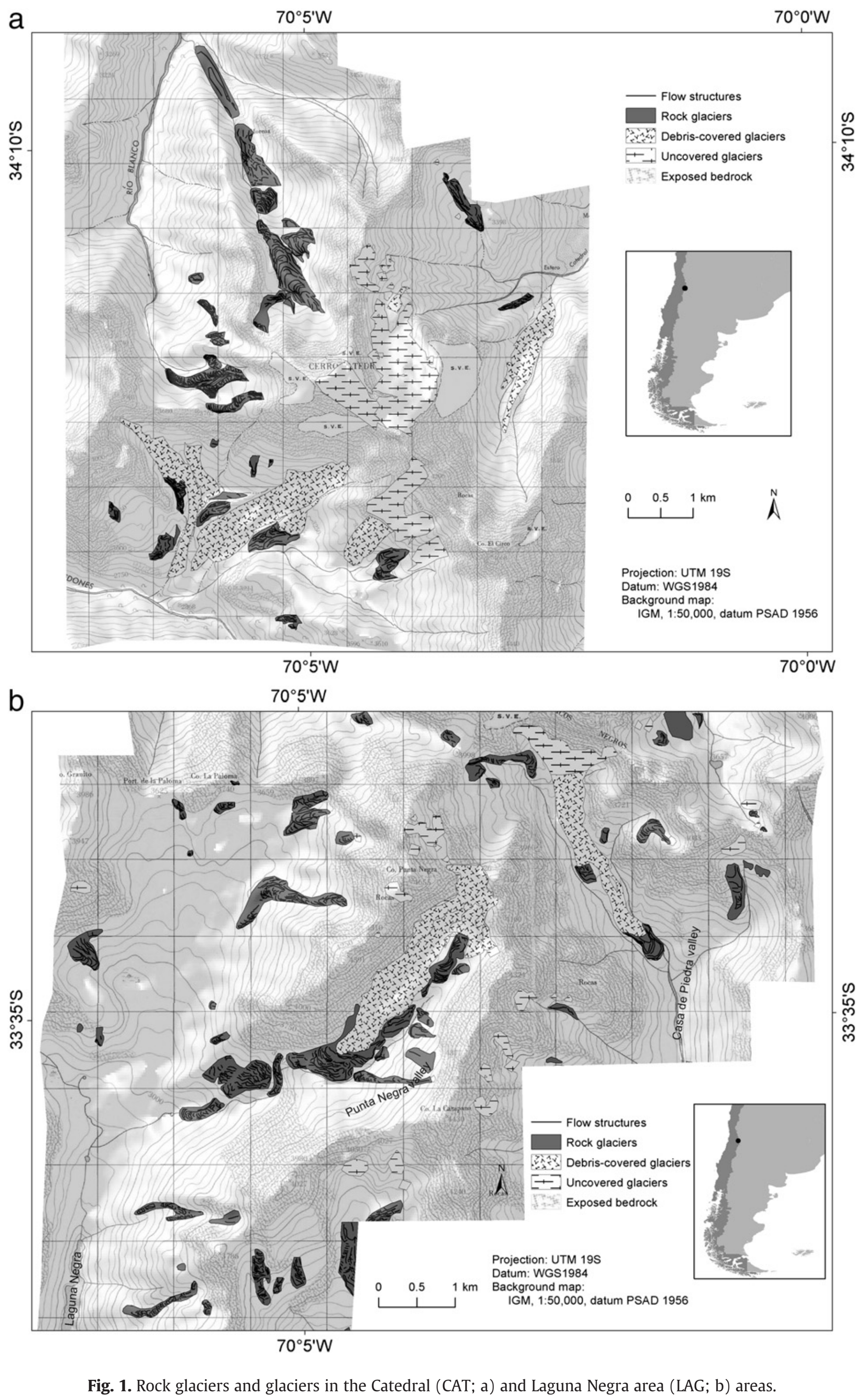

Fig. 1. Rock glaciers and glaciers in the Catedral (CAT; a) and Laguna Negra area (LAG; b) areas.