Improving Downscaling Techniques for Glacier Studies Using Bio-Inspired Algorithms

Application to tropical glaciers in the Peruvian Andes

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***Abstract*— This study aims at improving the performance of interpolation techniques applied to enhance the resolution of climatic information provided by regional models over glacierized areas, characterized by a complex topography and, most often, by the lack of sufficient observational coverage. Our proposal modifies previous methods in that it seeks to optimize the parameters of the vertical profile used to obtain interpolated temperature values on the surface at a given location attending to their agreement with directly interpolated values aloft over the same point. The optimization is achieved through the implementation of a Bio-Inspired Algorithm.**

Keywords- Downscaling; Bio-inspired algorithms; Climate Variability; Glaciers.

I. INTRODUCTION

The sensitivity of tropical glaciers to global climate change has been long noticed [1]. Their particular regime of ablation, essentially continuous throughout the year at their lowest altitude, leads to a fast response of their extent to modifications in their mass balance, hence to climate variations [2]. The Peruvian and Bolivian Andes harbor over 90% of these low-latitude ice packs, that represent a crucial water and energy resource for local as well as for downslope populations, including those in the extremely arid Pacific coast of South America [3][4]. The last thirty years have witnessed the retreat of tropical Andean glaciers at a pace without precedent in the past three centuries since the Little Ice Age maximum [5], posing severe socio-economic and ecological threats in the region. The urgent need for adaptation policies is, however, hampered by the multiple uncertainties that plague future projections of the evolution of the glacio-hydrological system. First and foremost, among the different causes of incertitude is the scarcity of observational records in these topographically complex areas. Regional Climate Models (RCMs) constitute a firm candidate to supply for this lack of climatic information. Their spatial resolution remains, however, low when confronted to the demands of glacio-hydrological studies, and the application of further downscaling techniques on the RCM data has already proven useful [6]. The inability of the RCM to capture the fine details on the surface, on account of its poor representation of the irregular relief and its associated steep gradients, advises against the direct downscaling of surface data, and the advantages of using upper air information for these mountainous regions has been recognized in a number of studies [7]–[10]. The present study follows this approach and attempts to implement an improvement on recent methodologies, based on the optimization of the agreement between directly interpolated upper-air temperatures over the targeted location and their estimation from the vertical lapse rates applied to obtain the surface values. The focus is on temperature over glacierized areas in the Peruvian Andes. The data employed in the analysis are described in detail in section II. Section III introduces the proposed methodology, and the contribution is closed with some final comments on the benefits expected from this technique.

II. DATA

The data to be downscaled in this study comes from a simulation with the atmospheric RCM REMO [11]. It is performed on two domains, with spatial resolution of 50 km and 25 km, respectively, driven at the boundaries by the ERA-Interim reanalysis [12], during the period 1980-2012. Both domains encompass the Peruvian Andes. The results of our downscaling procedure will be checked against observational records in the region provided by the Peruvian National Meteorological and Hydrological Service (SENAMHI).

III. METHODOLOGY

Our methodology is based on the technique described in [10], to which the reader is referred for a more detailed account. The vertical profile of temperature, up to the 500-hPa

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level, at each of the four model grid points closest to the target location is fitted to a piecewise-linear function with two steps. Five parameters characterize this fit at each point: the upper and lower lapse rates, the corresponding intercepts (i.e., temperatures at sea level), and the height of the change point. In [10], these parameters are interpolated bilinearly and used to obtain the downscaled temperature at the point of interest. Here, the bilinear interpolation will be substituted by a weighted mean whose loadings are going to be determined in an optimization procedure. The temperature at the 500-hPa level over the target point is first estimated through a bilinear interpolation of the values at the model grid points. A second estimate of this mid-tropospheric temperature can be obtained from the local vertical profile of temperature, computed, as stated above, as a weighted mean of the profiles at the surrounding RCM grid points. The weights are sought to minimize the difference between the two estimates of the 500-hPa temperature over the target location. The procedure rests on the notion that the modeled upper-level temperature field is both smoother and closer to reality, and therefore should provide an adequate reference to aid in the determination of the local, downscaled, thermal profile.

In the last years, evolutionary computation algorithms, as genetic algorithms, evolution strategies and genetic programming have received a lot of attention with the objective of solving a wide range of non-linear optimization problems. Evolutionary algorithms are search methods inspired by natural evolution which adapt the environment changes to find an optimal solution to a problem through evolving a population of candidate solutions, during a generation based on the fitness values of each candidate and applying techniques of crossover, mutation and selection. Each type of evolutionary algorithm has its own specificities and that make them different one of each other.

The genetic algorithm that is going to be applied to optimize the parameters of the vertical profile used to obtain interpolated temperature values on the surface at a given location attending to their agreement with directly interpolated values aloft over the same point is shown next:

```
BEGIN
Generate initial population of individuals; // individual is a feasible solution to a problem
Compute fitness of each individual; // higher fitness is better solution
REPEAT // New generation
FOR population_size / 2 DO
Select two parents from old generation; // biased to the fitter ones
Recombine parents for two offspring;
Mutate the offspring considering a certain probability
Compute fitness of offspring;
Insert offspring in new generation
END FOR
UNTIL population has converged
END
```

As can be seen, based on their fitness, parents are selected to reproduce offspring for a new generation. Fitter individuals have more chance to reproduce, whereas the old generation dies. The new generation has the same size as old generation. Offspring has a combination of the properties of two parents. If well designed, population will converge to an optimal solution.

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