Project of Strategic Interest NEXTDATA
WP1.6
(Partner: Valter Maggi, UNIMIB)

D1.6.C: Modelli di dinamica e di risposta alla variabilità climatica dei ghiacciai montani, in grado di unire la descrizione del flusso glaciale con le informazioni GIS.

I. INTRODUCTION AND MINIMAL GLACIER MODEL

Theoretical work on glacier dynamics led to the construction of mathematical models for estimating glacier response to different climate change scenarios (Haeberli at al, 1995). The aim of this work is to include a simple version of such models (the so-called Minimal Glacier Models (Oerlemans, 2011), MGM) within a GIS framework, to better understand, evaluate and reproduce the glacier response to climate fluctuations.

The MGM are a simple but effective way of estimating glacier response to climate change and climate variability. In this approach ice dynamics is heavily parameterized and the only dynamical variables is the average glacier length as a function of time. This type of model tries to reduce the complexity of glacier dynamics to a very simple description based on basic physical laws. The scheme in Fig. 1 represents the iterative process of MGM integration: the variation of glacier terminus along the flow-line direction, dL/dt, is the core of the algorithm and it is the output to evaluate glacier evolution.

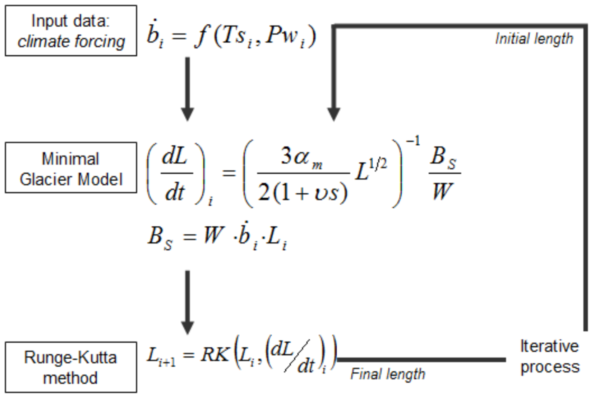

Figure 1: Minimal Glacier Model scheme

The net mass balance is the most important driver of glacier behaviour and describes the amount of mass gained or lost in meters of water equivalent. This input data is determined by the climatic forcing: mainly, winter precipitation (period November – March) and summer air temperature (period May – September). Then, we relate climate forcing to the model inputs by using a bivariate fit from (Fig. 1, Climate forcing):

$$\dot{b}_i = aT_{s,i} + bP_{w,i} + c \quad (1)$$

where *i* represents the *i-th* year, $T_{s,i}$ is the summer 2m air temperature and $P_{w,i}$ is the winter precipitation.

During first and second Ph.D. years, I calibrated MGMs with Geographic Information System (GIS) approach on the Careser glacier (Eastern Italian Alps) and the Rutor glacier (Wester Italian Alps). The aim of my third year is the application of the MGM-GIS on a large amount of glaciers, to formulate an average trends that describe glacier behaviours within the Greater Alpine Region (GAR), as in Fig. 2, following the future climate scenarios. I considered the alps from South-West, with the Saint-Sorlin and Sarennes Glaciers, through the Central glaciers with Jamtal glacier to North-East, with Vernagtferner and Wurten glaciers of Golberg Group (Fig. 2).

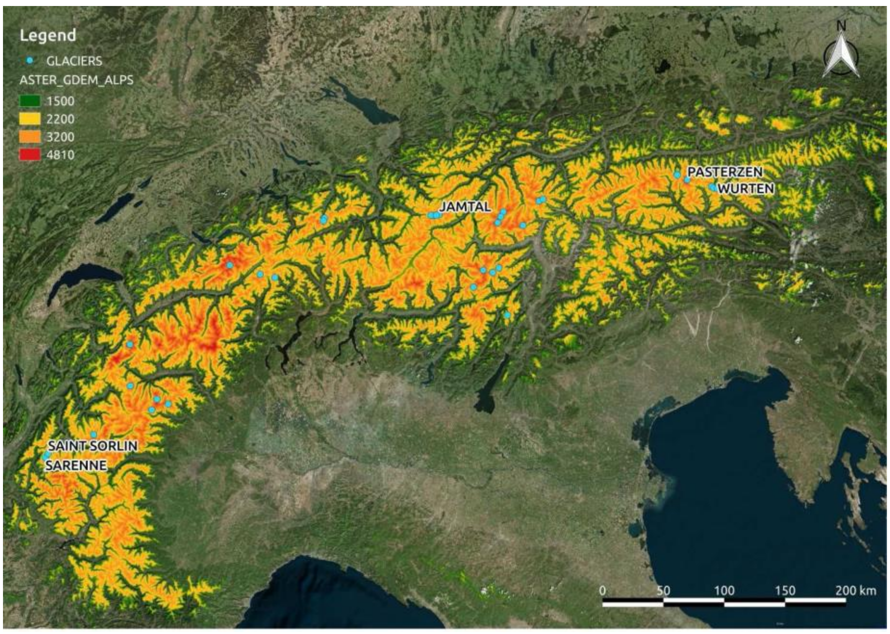

Figure 2: Greater Alpine Region, GIS rendering

II. MASS BALANCE DATASET ANALYSIS

I had to approach this step with the collaboration of bachelor thesis of Matteo Sali.
We focused our attention on the available mass balance data of Alpine glaciers, until 2011. We obtained these series searching for databases (WGMS) and internet catalogues. Focusing our attention on the GAR (Fig. 2), we found 50 useful glacier dataset. Then we divided these glaciers into four sectors following their geographic position, altitude, morphology and orientation. The classification is useful to analysis the average trends (with their characteristic errors) of cumulative mass balance because of the same conditions of the particular climate forcing.
Western glaciers have the most negative trend of all the Alpine glacier (for example Sarennes and Gries). The most conservative glaciers are within the mountain range of Valle d'Aosta, as Grand Etret.
Central glaciers show a good agreement of their mass balance datasets: in view of the heterogeneity of the altitudes and morphology, we can underline the homogeneity of climate conditions.
Central-Eastern glaciers are divided following their altitude. Glaciers lower 3400m (like Careser) shows negative trends as Western elements. Glaciers upper 3400m are inclined to preserve their accumulation area because of their altitude and topography.
Eastern glaciers are smaller than 2 Km^2, except the Pasterze. These shapes and dimensions contribute to generate their preservative and coherent trends, exposed to continental streams.

III. CLIMATE DATASET AND ANALYSIS

I collaborate with master thesis of Luca Maffezzoni to study the climate dataset,
The alpine climate depends to four principal factors: the continentality, latitude, altitude, and local topography. Then, to study the climate behaviours on entire GAR, we focused our attention on a historical climatic research, referring to the period 1951-2013 for 34 referred locations to 34 glaciers, which have at least 8 years of mass balance stored data. The aim is the link between these features, the created sectors in mass balance analysis (Par. II) and the classifications of glaciers following geomorphologic characteristics by DEMs analysis.
To drive the mass balance bivariate function (1) we used the ensembles daily gridded observational dataset for precipitation, temperature and sea level pressure in Europe called E-OBS, produced by the European Climate Assessment & Dataset project (ECA&D). These meteorological data span the period from January 1950 to December 2013 and have a spatial resolution of about 25 km in the area of interest (Haylock et al, 2008). I have auto-scaled temperature and precipitation data to compare different kinds of variables and to reconstruct historical mass balance of 34 glaciers, by function (1). Therefore, we studied for each parameters the different behaviours between the Northern and Southern glaciers, representing climate series and evaluated possible correlations with climatic circulation on GAR.
After analysis, we can confirm that the geographical position is the most important factor of Alpine glacier's health (Evans. I.S., 2006), and although dominated by winds from the west, the alps are unusual in comparison with other mid-latitude regions, where strong linear gradients are found as precipitation diminishes away from west coasts for example in the Western Cordilleras of America (Østrem et al, 1981). This happens because the Alps receive precipitation and winds from various direction (Frei. C. Schär. C., 1998) and the differences is due to east–west elongation of the Alps, their curvature, and the generation or revival of cyclonic systems on the Po Plain on their southern flank (Cantu 1977).

IV. FINAL RESULTS

Afterwards, to drive the MGM for future climate conditions, I used the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset. This data is comprised of downscaled climate scenarios for the globe that are derived from the General Circulation Model (GCM) runs conducted under the Coupled Model Intercomparison Project Phase 5 (CMIP5) and across two greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs): RCP 4.5 and RCP 8.5. The spatial resolution of the dataset is 0.25 degrees (~25 km x 25 km). Each of the climate projections includes the periods from 1950 through 2005 (Retrospective Run) and from 2006 to 2099 (Prospective Run).
From NEX-GDDP dataset I processed and auto-scaled 20 different models for 2 scenarios and 34 glaciers, from which I obtained summer temperature and winter precipitation series for each glacier.

Then, I use the GIS analysis of Luca Maffezzoni and dr. Matteo Mattavelli on the 34 glaciers to obtain the geomorphological input of the algorithm and to set the parameters file. Later I compile the MGM for all glacier, driven by the NEX-GDDP dataset for RCP 4.5 and 8.5.
The results for one glacier is shown for example in Fig. 3, about Hintereisferner Glacier, where are driven the MGM results of the ensemble from 2011 to 2090.

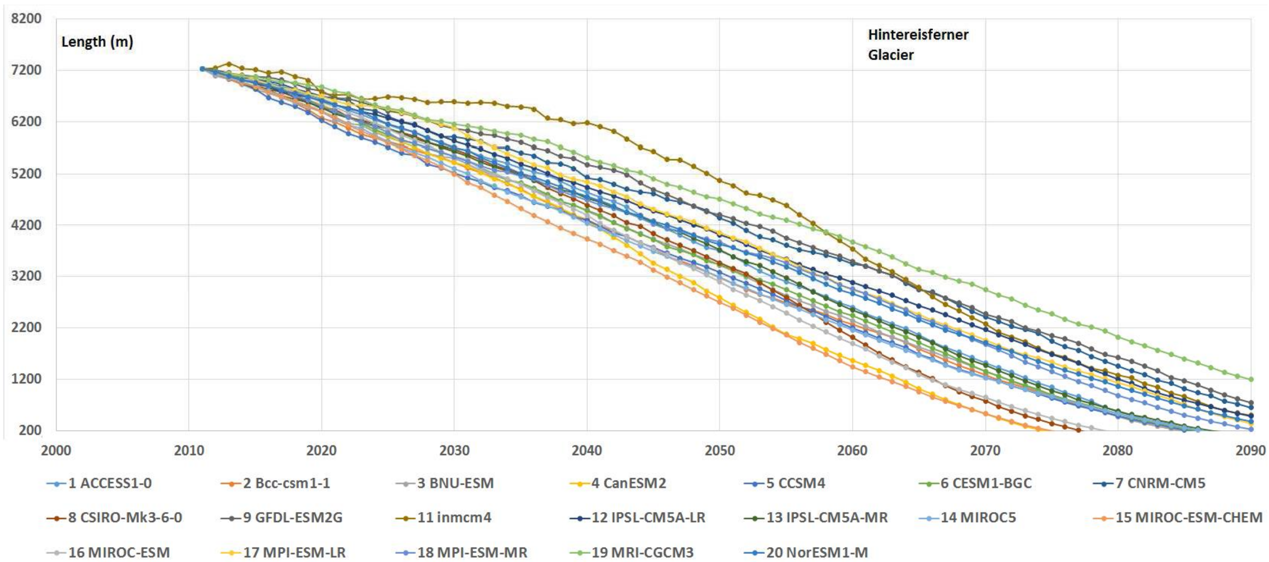

Figure 3: future assesment of Hintereisferner by MGM results, driven by RCP 8.5 scenarios.

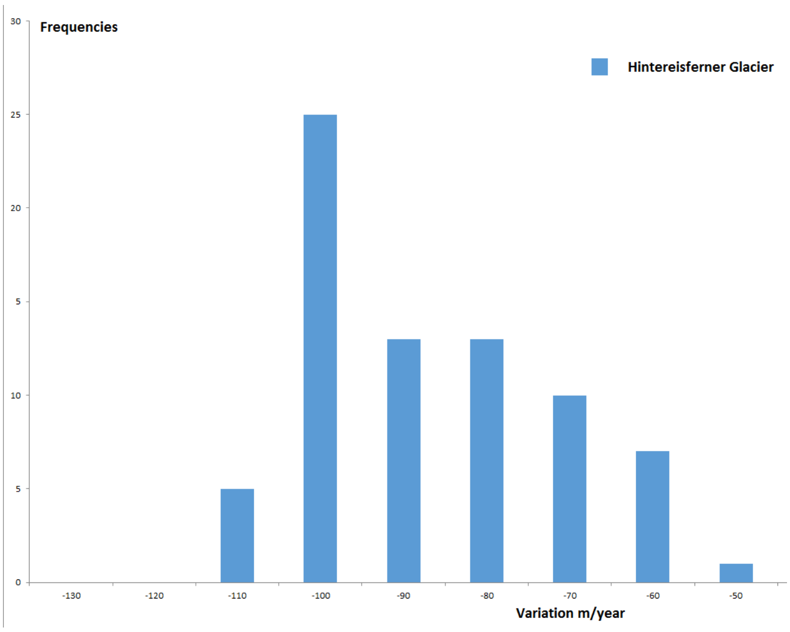

Figure 4: Frequencies of negative variation (m/year) of Hitereisferner glacier.

Therefore, analysing the simulated results of MGM, I can study the gradient of glacier retreat and the average values.
For Hintereisferner glacier (Fig. 4), for example, applying RCP 8.5 I can evaluate an average retreat of about 90 m.

The last step of my Ph.D thesis is the grouping of these results, considering the previous classifications following the mass balance datasets, the climate evaluations by precipitation and temperature variables and the geographic and morphologic state of glaciers. The aim will be the definition of some average retreat equations of glaciers, evaluating average retreat gradients. These results will be presented in final thesis.

V. MGM ON-LINE

The MGM algorithm is developed and adapted to web-user at the website: http://geomatic.disat.unimib.it/mgm.
Following the appropriate guide at web-site, user can upload input glacier parameters to set the initial and contour conditions. Then he can upload the climate dataset (choosing temperature/precipitation series or the mass balance set directly). In closing, after the compiling the MGM algorithm, user can download .csv file with MGM results, composed by three columns: referring years, length simulations and their errors.

VI. R.GLACIO.MODEL ON GRASS-GIS

The aim of this work is to include the MGM within a GIS framework, collaborating with dr. Daniele Strigaro, to better understand, evaluate and reproduce the glacier response to climate fluctuations. The result was the module r.glacio.model (Strigaro et all, 2015). The last formulation derives from a rigorous validation with different types of glaciers and the module will be released as a GRASS-addon under the GNU General Public License (≥ v.2). We make an illustrative application of the r.glacio.model to the Rutor glacier, for which the algorithm was already calibrated (Fig. 5).

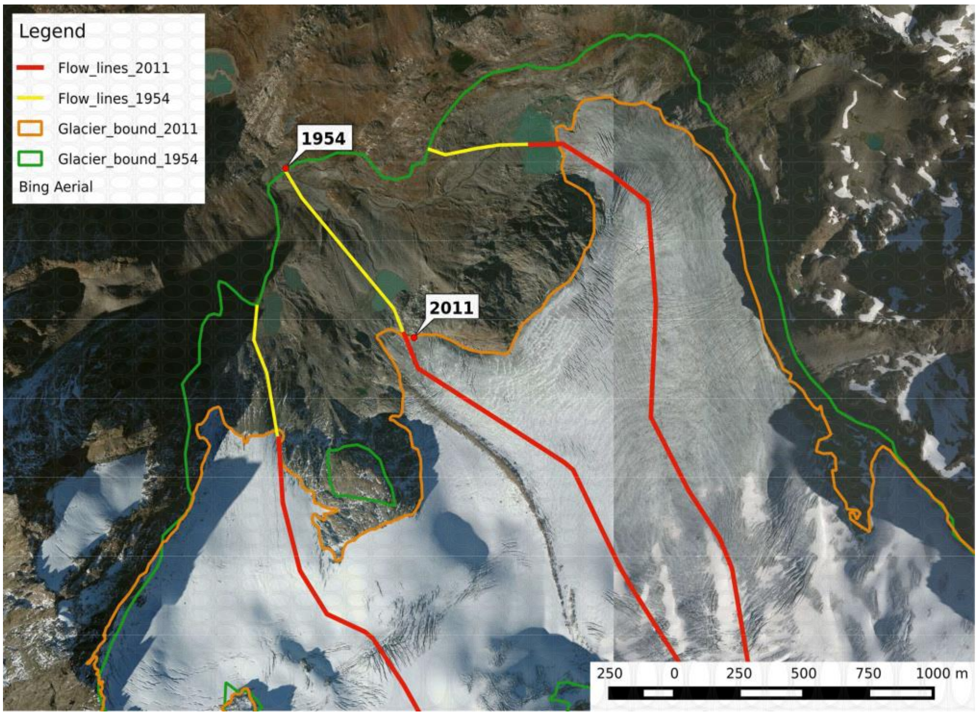

Figure 5: Glacier retreat along Rutor flow lines: results of the r.glacio.model. The yellow lines are the lengths at 1954, then the red lines are the estimated lengths at 2011 applying MGM.

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