Summary of Master Degree by:

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"LA DIGA DEL GHIACCIAIO: CAMBIAMENTI CLIMATICI E PRODUZIONE ALL'IMPIANTO DEL SABBIONE" ("GLACIER DAM: CLIMATE CHANGE AND POWER PRODUCTION AT SABBIONE PLANT")

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INTRODUCTION

The beginning of alpine glaciers' retire coincided with the end of Little Ice Age, the period between XV and XIX century where temperatures in Northern hemisphere were lower of about 0.6 C° (Mann, 2002).

Since middle '800 measured temperatures on Alps increased sensibly respect to global average variation with a +1.4 C° variation (Brunetti et al., 2009), involving a reduction of glaciered area of about 50% (Zemp et al., 2008). Glacier bodies' contraction could bring in future to lack of water in summer for high altitude basins, and it could restrict hydropower production for some plants (D'Agata et al., 2018).

In this master thesis, the case of study was Sabbione dam, built in '50 in high Formazza valley at 2460 m a.s.l., down to homonymous glacier, and we evaluated the impact of climate change on glacier body and hydropower production by the plant which exploits water from artificial lake.

Sabbione glacier, initially formed by an unique body, was studied since the end of XIX century, with "Geologische Karte der Simplon-Gruppe". By 1954 retire, registered by first CGI report to work of geographer R. Pracchi and estimated in 350 m at the front (Casale, 2011), brought the glacier to fraction in 3 parts, Southern, Norther and Central that still persist today. The development of the artificial lake, that submerged part of the Southern glacier, contributed to accelerate glacier retire dynamic: according to a study of Mazza and Mercalli (1991) for the period 1885-1985, and to the pre-quoted study of Casale, retire velocity was 33.8 meters for year during 1952-1985 versus 5.2 m/y during 1885-1952. Mazza and Mercalli estimated volume loss during 1885-1987 of 50% too.

METHODS

Applying an hydrological model to a basin allows to evaluate discharge at the closure point of the basin by using meteorological data as input (here precipitation and temperature), obviating lack of discharge measuremements. Moreover, it allows estimating the incidence factor of discharge main components: ice melt, snow melt and rain.

The model we used, namely *Poli-hydro* (Soncini et al., 2017), was validated through the network of measures in Stelvio park, where cryospheric component in hydrological cycle is particularly relevant, and it can evaluate water mass balance on daily base in a distributed way, namely it considers local variability of parameters of interest. Particularly, we spatialized temperature parameters, which is forced to change linearly with altitude, and soil water content parameters, that depend on land cover. Spatial scale resolution of the model is 25 meters, as the one of *DEM* (Digital Elevation Model) elaborated with LIDAR technology within Italian-Swiss project called HELI-DEM. The high model resolution allows us to evaluate precisely terrain orography, from which we can estimate solar radiation, which depends on exposure, and ice flow dynamics that is related to visco-plastic properties of ice. This dynamic, combined with ice melt estimate, enables to evaluate glacier evolution through retire and it makes possible to compare glacier area output by the model with measured area by aerial images.

To assess thermal gradient we used data from 29 meteorological station on Western Alps, while as input for temperature and precipitation we used data from ARPA station Formazza Pian dei Camosci (FPC).

Since ice melt is possible only when snow is no present, ice melt calibration has to be done necessarily after snow melt calibration. Indeed, using snow depth data on ground from FPC (2009-2017), we could estimate snow melt parameters, and then, implementing hydrological model with these parameters, we were able to assess the day where glacier had no snow cover, that is the condition to have ice melt, and we optimised ice melt parameters comparing model ablation data with ice stakes ablation data (2011-2016). These were installed by a campaign of IMAGEO srl and SMI (Italian Meteorological Society), where they registered average ablation equal to 204 cm/year.

Furthermore, we had to assess initial ice volume to insert as input in the model, and that required to evaluate at first ice extension: to do it we used an ortophoto of 1999, from which we delimited glacier perimeter (measured area 4.2 km^2). To assess local ice thickness we resort to an empirical formula with which we estimated shear stress between glacier and bedrock (Haeberli et al., 1995), and then, combining this result with terrain local slope and undefined equilibrium equation, we computed ice local thickness. The results were processed with a reduction factor to keep in account of low thickness values that glaciers have on tongue and on borders.

To simulate reservoir management and hydropower production we used an optimization model called *Poli-Power* (Bombelli et al., 2019), that maximize revenue considering energy price variation on sub-daily scale.

The two models, hydrological and reservoir management, were initially implemented for calibration period (2000-2017), and after that for scenario simulation (2018-2100).

We validated hydrological model for calibration period though comparing ice perimeters measured by ortophotos and satellite images for years 2007, 2012, 2015 and 2017, with the ones given as output by the model. Energy production data given by the model were validated with productivity value available in literature provided by ENEL. For scenarios simulation we used three different meteorological models *GCM* (Global Circulation Model) with three different hypothesis of radiative forcing increase (RCP 2.6, 6.5, 8.5), suggested by IPCC for a total of nine climatic scenarios that were used as input in the hydrological model.

RESULTS

Glacier evolution forecasted by the model reflects satisfactory measured perimeters as reported in figure 1. Particularly the model was able to reproduce the separation of Southern glacier in two bodies with an estimate error of total ice area for 2017 below 8% (2.9 km^2 by the model *vs* 2.7 km^2 measured), with area loss equal to 36% and volume loss estimated at 56%.

Evaluated average discharge at closure point is equal to 0.90 m^3/s [figure 2], with peak on July (2.3 m^3/s). Main contribute to discharge during summer is provided by snow melt, that in average it’s equal to 32% but has a peak in June with 73%. On the other hand ice contribute is relevant only from July to September, that ss the period according to model where we have glacier retire, with peak in August with 32% of total discharge, and average contribute equal to 11%. Plant energy production estimated for calibration period is 47.0 GWh with just 3.5 % overestimate respect to 45.4 GWh data provided by ENEL, with peak production on July where energy price is maximum. For each scenario we forecasted strong glacier retire, which is expected to extinguish for the end of the century, or to survive as a glacieret with area smaller than 0.4 km^2 [figure 3]. Ice melt contribute decreases as glacier area, and it is already scarcely significant at middle century, while it gets null in the following decades.

Ice melt lack, combined with increase in evapotranspiration, takes to a global reduction of total discharge estimated by the model (-11%). Average precipitation variation is positive (+3%), even if with relevant oscillations between different models, but it is not enough to compensate the pre-told negative effects. Furthermore, temperature rising anticipates snow melt period, which still remains main discharge contribute (37%) even if there is a trade-off between rain and snow. Consequently peak discharge is anticipated even by two months for RCP 8.5 scenarios, where temperature rising is larger. Energy production decreases as discharge, keeping peak production in July, where model expects higher energy price due to air conditioning requirement (Bombelli et al., 2018, submitted).

CONCLUSIONS

Strong glacier retire documented in last century, model results and the opening of several crafts on all glacier area foretell Sabbione glacier extinction in a few decades. That can be related to human activity both in direct way, because of artificial lake development that drowned part of the glacier, and in indirect way, due to climate change (IPCC, 2007). Until now glacier retire has been a benefit for power plant, because it provided water to lake during summer, but soon it will cause lack of discharge that could be compensated by precipitation increase. Regarding this last point there is no univocal response by *GCM* model, making very difficult to assess consistently future energy production.

IMAGES

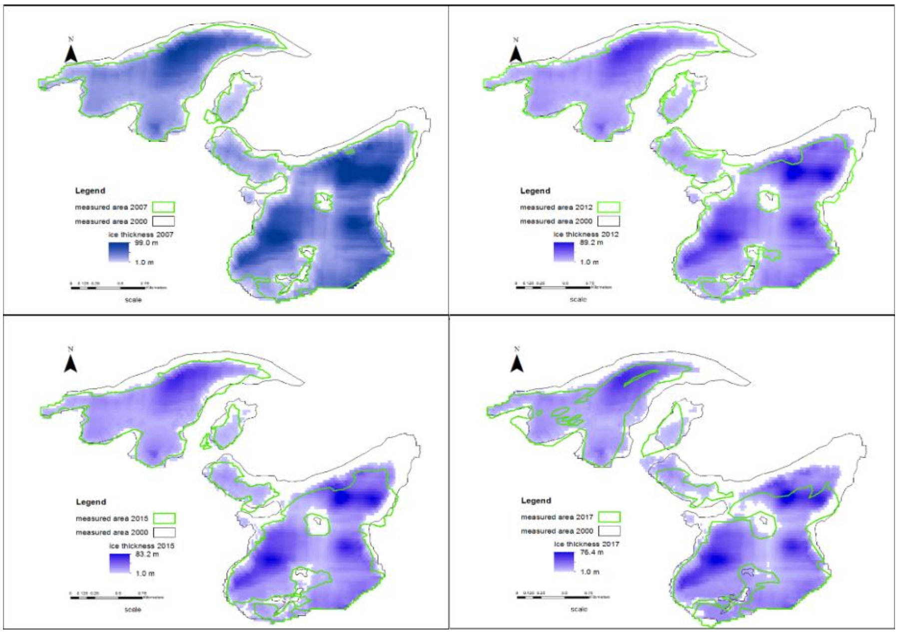

Figura 1 Sabbione glacier evolution 2000-2017, in black measured perimeter for 2000, in green measured perimeter for current year, and in blue model output

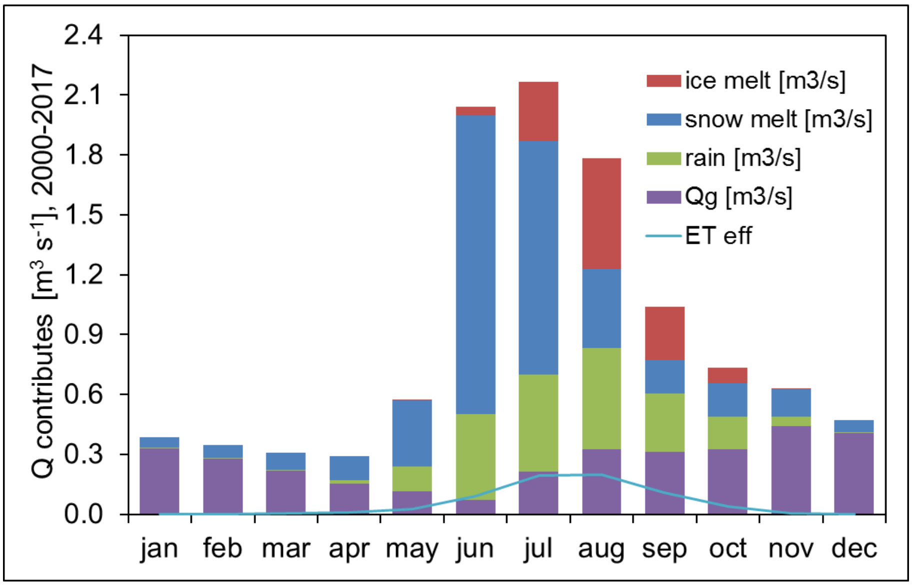

Figura 2 discharge contributes 2000-2017

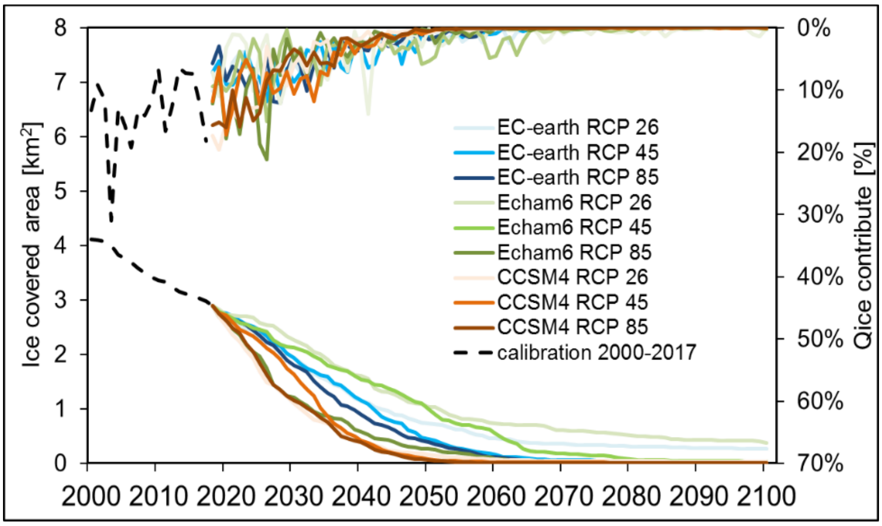

Figura 3 ice area variation and ice melt contribute

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