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EXECUTIVE SUMMARY OF THE THESIS

Seasonal forecast of spring hydropower production by using meteo-hydrological modeling

TESI MAGISTRALE IN ENERGY ENGINEERING – INGEGNERIA ENERGETICA

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1. Introduction

This thesis tries to replay at the question: Seasonal weather forecast models, combined with an hydrological model, are able to simulate the snow dynamics for the purposes of forecast the availability of water in hydroelectrical power plants basins. The case study is the one of 8 hydrological basins in Bolzano province that feed 8 catchments managed by Alperia s.p.a.
Alperia is the operator of all hydrometric power plant and the firm that shared the data used in this study.[5]

2. Locations and instrument

At the beginning of the study the locations and its characteristics are analyzed. The data source for temperature and precipitations were the meteorological stations located inside the hydrological basin. Another instrument used for the analysis was the QGIS software, that helps to visualize on a map the positions of basins, temperature station, rain and snow gauges. [1]

Basins can be composed by one or more hydrological basin. In the second case the catchments are connected in order to create a common reservoir to be exploited later.
Using QGIS software is possible to merge area of hydrological basin, defined by a shape file, with the raster that represent the altitude of each point in a map. Each point of the raster represents the average altitude of a certain area of 100 square meters. Combining the altitude of many points is possible to obtain a grid that represent the altitude of hydrological basins.
From this grid was possible to obtain different information such as altitude, average altitude, hypsographic curve and exposition map. Those last two are useful to understand the morphology and the incoming solar radiation of each basin.
Temperature shows many similarity between basins, in fact the oscillations are mostly related to phenomena that act upon all the basins, with basins in altitude that show a lower average temperature. Precipitation has a limited variability in the winter, showing a common pattern for all the basins, while in spring presents cumulative differences up to 100 mm between nearby basins.

3. Models

The distributed hydrological FEST-EWB model (Flash-flood Event-based Spatially distributed rainfall–runoff Transformation Energy Water Balance model) estimates Snow Water equivalent (SWE) from meteorological input data. This model input can be both observed weather data measured at stations or model forecasted data. This is a temperature based mode.[2]

SWE describes the equivalent amount of liquid water stored in the snowpack. It indicates the water column that would theoretically result it the whole snowpack melt instantaneously. It is defined as product between the snow layer's depth and density.

FEST-EWB quantify both the snow precipitation and melting via a calibrated parameters.

The two weather forecast employed are EPSON meteo and Copernicus Climate Change Service models. They both estimate temperatures and precipitations in their domain. The models produce a forecast every month (C3S) or weekly (EPSON) and the duration of those forecast is 6 months. [3]

EPSON is based on by three different periods of forecast. The first 7 days are predicted by the WRF (Weather and Research Forecast Model) short term numerical model. The latter 42 days are forecasted by SGFM (Seasonal Global Forecast Model). After those two periods the model report the climatology.

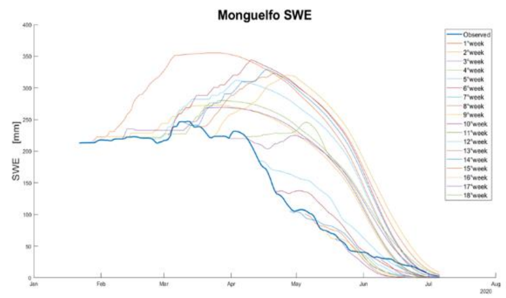

Figure 3.1 SWE dynamics in spring 2020 powered with observed and EPSON forecast + FEST model

The results of the models are shown here, the thick line is the SWE output produced by FEST using as input the observed data at metro station.

The outputs of EPSON are elaborated by FEST to create a SWE forecast (tiny line). Those line starts form the same condition where they are initialized and evolve for 47 days of forecast, then follow climatology (smooth trend).

The same thing was done to the year 2021, but due to holes in measured data the forecast was not good enough. This happened because in the end of each week the meteorological station doesn't reports the final data.

C3S produces a forecast each month, is developed by the ECMWF, the European Centre for Medium-Range Weather Forecasts, provide a long-range outlook of changes in the Earth system over periods of up to 6 months, as a result of predictable changes in some of the slow-varying components of the system.

Seasonal forecasts are started from an observed state of the climate system. Errors present at the start of the forecast (due to the imprecise measurement of the initial conditions and the approximations assumed in the formulation of the models) persist or, more often, grow through the model integration.

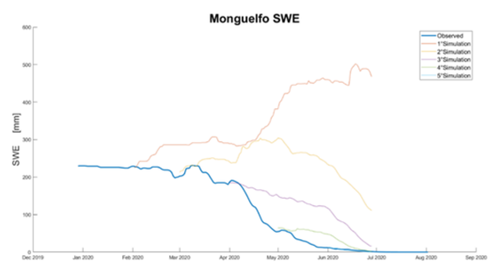

Figure 3.2 SWE dynamics in spring 2020 powered with observed and C3S forecast + FEST model

About C3S, SWE graph above shows the same information as EPSON, but this model is launched once a month, and after 47 days the modes doesn't consider no more the climatology but continue to forecast the variables (visible as the line doesn't become smooth).

The outputs of this model shows in general a better accordance to observed data. There are anyway some forecasts that miss completely the long term trend, such as the first forecast visible in the graph (red line, simulation launched in February).

Are than studied effect of altitude and solar energy upon the reliability of the forecast. As the average altitude grows the temperature forecast become less reliable, while to the one of SWE become better.

Then a comparative analysis between the 1st and 2nd month of forecast is performed. Seems that CES model perform better than EPSON, even if EPSON has more precise data in the first 10 days of forecast.

4. Water results

To go beyond the limitations of models, their error, and the error derived by the combination of them, is fundamental to compare those values with measured volumes data from Alperia at each hydropower plant. Measured data are given in monthly afflux to the basin in m³ so all the data acquired must be translated in this unit of measurement. Water flux form hydrological basin can come form 2 variables. One is the liquid precipitation, and the other is the melting of solid-state precipitation melted. According to the parameters of FEST model reported in chapter 2 all the precipitation that happen at temperature above 1°C is considered liquid, and distributed between liquid and solid between 0 and 1°C. Regarding the snow melting the dynamic is also modeled by the FEST model as function of air temperature (in this case over 3°C.) [4]

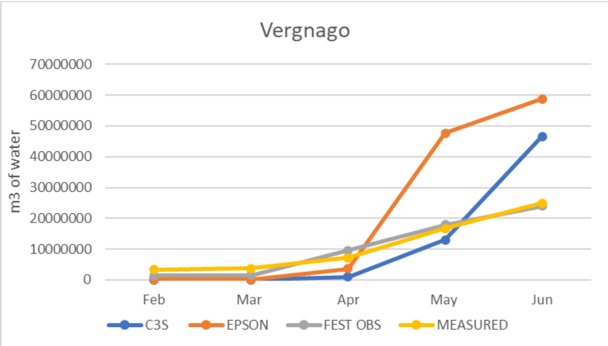

Figure 4.1 Cubic meter of water measured and forecasted

FEST model powered with observed data correctly forecast the water availability, while the combination of weather forecast and hydrological models perform badly.
A first result is the good agreement visible between the observed volumes and the one from the FETS-OBS model, highlighting the correctness of the calibrated parameters.
Especially EPSON model creates a huge overestimation in May and June while C3S underestimate in all the months but June. It is interesting to notice that for the forecast models in February and March the flow to the basins is computed as zero, while the actual intake flow measured by Alperia is not null. FEST model fed with observed data on the other hand found a small, but not null flux. This is true for all the basins except Monguelfo, that is at lower altitude and so temperatures are higher even during winter. In this case the FEST model can guess that the amount of water flow is not zero.
The not null measured water flow can be explained by

- The Presence of some water stored previously in the basins
- A minimum water intake from undergrown water
- A combination of those factors

Another consideration is that both forecast models with FEST underestimate the April water available in comparison to the measured data and FEST-OBS model.
One explanation is that the FEST model uses the degree day parameter to estimate snow melting. In April when the temperature is still low, but the solar irradiation is high some problems can occur in estimation of the melting parameter.
In May EPSON model tends to perform a huge overestimation in every basin. May is the most critical month for this model, where the forecast overestimate up to 4.75 times for Sanvalentino. C3S on the other hand shows 2 different trends: in some basin (Gioveretto, Vernago, Lagoverde and Neves) the model tends to have difficulty to estimate the available water flux and underestimate it. In the other basins (that are at lower average altitude) overestimate the flux but with a imitate absolute error.
In June (the most prosperous month) both models overestimate the flow due to the overwhelming amount of snowmelt that the two models predict as available.
This is misleading because it can lead to a wrong strategy for the firm that would tend to use the water in previous period instead of storing it for remunerative periods.
The overall quantity of water measured and predicted is than compared. This comparation that is not meaningful for water management by itself can be useful for understanding the general ability of forecast systems.
The overall results shows that models globally tends to don't recognize winter water as available, while form April to June their overestimation grows till a value of 3,33 for EPSON model (May) and 2,35 for C3S (June). FEST-obs model has a relatively small difference compared with measurement, but the deviation is almost ever an overestimation.

5. Energy results

Regarding the reservoirs size, basins volume is really variable, it passes from 1,27 to 116 million of cubic meters. For all the basins the reservoir volume corresponds to 30-34 days of operation at maximus flow rate [5].

The first pattern to analyze is the seasonal variability in energy production. From one side there is Vernago, with relatively small variation in the period considered. At the other extreme can be found Gioveretto, with a null production in the winter months followed by a sudden increase in spring.

	Zoccolo	Sanvalentino	Neves	Vernago	Lagopesce	Gioveretto	Lagoverde
Feb	0,43	0,12	0,24	0,13	0,19	0,00	0,00
Mar	0,26	0,10	0,19	0,13	0,06	0,00	0,00
Apr	0,41	0,27	0,24	0,17	0,15	0,74	0,00
May	0,48	0,17	0,21	0,15	0,32	0,64	0,01
Jun	0,57	0,13	0,52	0,16	0,43	0,72	0,85
Mean	0,43	0,16	0,28	0,15	0,23	0,42	0,17

Table 4.1 Monthly capacity factor of the basins and their average

A remarkable information is the capacity factor of the plants. Is interesting the different behavior of basins. Vernago keep a low but constant value while other basin's value is higher than sector average. In other case like Gioveretto or Lagoverde CF can reach value as high as 85% but only after periods of low production.
To forecast potential energy produced by the models the power coefficients given by Alperia were used. A single coefficient is provided by Alperia for each basin. Since those numbers are industry sensitive, they cannot be reported here.

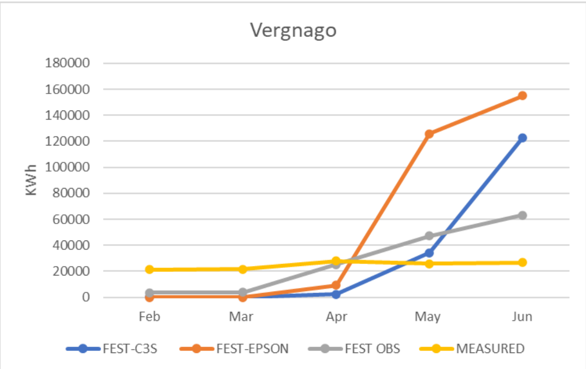

Figure 4.2 Vernago monthly energy production

Regarding the accordance between the FEST model run with observed meteorological data and the produced energy is quite low. In fact, during wintertime, the plant is producing energy from the available water into the reservoir, which the model based on the SWE is not considering. Instead in the summer months, the model is providing more available water (transformed into energy) than the energy the plant can produce (maximum capacity). This excess water can be stored in the reservoir or produces an outflow.
Remain anyway the problem that the model forecast that water as available at least a month later than when it is actually available.
This confirm that the FEST model, being a physical model, is able to accurately simulate and predict the water volumes, and if associated to an energy production rule (that in this case is kept as industrial sensitive) can also correctly estimate the energy production.
A huge limit on this analysis is the comparison between monthly energy generated and the values obtained via coefficient. The values obtained by multiplying the number of cubic meter available in the basins with a reference coefficient is a major source of error, especially when the detailed operational logics and information upon the quantity of water in the basins at the beginning of the season are not known.
The use of a coefficient doesn't allow to speculate about efficiency, and the monthly aggregated data about profitability of energy sold to the market.
Considering the cumulative value of energy produced is evident the accordance between the FEST model with observed meteo data and measured.
Zoccolo, Vernago and Gioveretto presents high errors when the FEST model is run with forecasted data, especially with EPSON-FEST. This combination of model predicts a high quantity of water and so energy available to the basin that doesn't find a feedback in the reality.
The trend is by the way peculiar for each basin. All the Monguelfo's s forecast agrees each other but differ a lot from the value measured. Neves and Lagoverde has an accordance between EPSON and measured data. Sanvalentino shows no evident pattern. Similar to the conclusion of water available, the energy forecasted by the models are underestimated in winter and overestimated in spring. The forecasted models tends to don't predict enough energy production in this period. Even if in this comparison the overall EPSON's overestimation is a tinier, the values remain the highest, followed by C3S and FEST-

Conclusions

A 6 months forecast is well beyond the models possibility, especially when models uses climatology in the latter part. When forecast requested at the models is limited to 1-2 months some interesting information can be extracted.
Between the two model Copernicus forecast seems to be better, with a lower monthly error especially on precipitation. The forecast performed has a reliability that remain high in time, even for forecast longer than a month.
In the first month the overall error is limited, and the results of FEST-C3S model are very similar to FEST-obs. When compared upon the water available at basin the C3S results seems to overestimate its presence, but in a more limited manner than EPSON.
In the second month of forecast the difference between C3S and actual data increase too much to trust in those data to have a precise forecast, but remain anyway an indication of the macro trends of the season, especially regarding cumulative precipitations.
On contrary to C3S, EPSON model has a better behavior in the short run, and in particular for the first 7-10 days.
EPSON model has as advantage over Copernicus the possibility to perform a forecast each week.
Both SWE and snowmelt calculated upon observed, EPSON and C3S data presents the same pattern to don't recognize winter quantity and on the other hand exaggerating the springs ones.

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2. Acknowleggements

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