Monthly and seasonal forecasts in the French power sector

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Abstract

The power sector highly depends on weather and climate. Observations and forecasts of many variables describing the state and evolution of the atmosphere, the hydrosphere and the coastal oceans are used routinely since the early 1980s. But the amount and the complexity of data have increased substantially in the last ten years. In particular, much progress has been made, in the medium-term to seasonal time scales; the development of reliable probabilistic forecasting systems has allowed many improvements in demand and production forecasts. However, there is still a lot to do to improve the science and the forecasts on the one side, and to address the question of integrating long range probabilistic weather forecasts in complex management tools on the other side.

In this paper, we present encouraging results concerning monthly ensemble forecasts of temperature and river discharge in France, and seasonal forecasts of river discharge in French Guiana, which have led to operational applications or may do so in the near future.

1 Introduction

The importance of weather and climate for economic activity has been the subject of many studies (see Dubus, 2012 and references herein). In particular, liberalization of the energy markets, and new constraints driven by the necessity to mitigate and adapt to climate change have imposed important and quick evolutions to the power sector in the last two decades.

Weather and climate variability are important in many aspects: demand depends on temperature; wind, solar radiation and precipitation are obviously the primary determinants of renewable energy production; transport and distribution networks can be affected by extreme winds or snow and frost accretion.

Figure 1 represents the time evolution of power demand and average temperature over France, from November 2009 to March 2010. Power increases when temperature decreases, and vice-versa. The latest observations show that an extra anomaly of -1°C requires an increase in power production of around 2300MW, which corresponds to twice the electricity consumption of a ~1.7 million inhabitant's city (RTE, 2013).

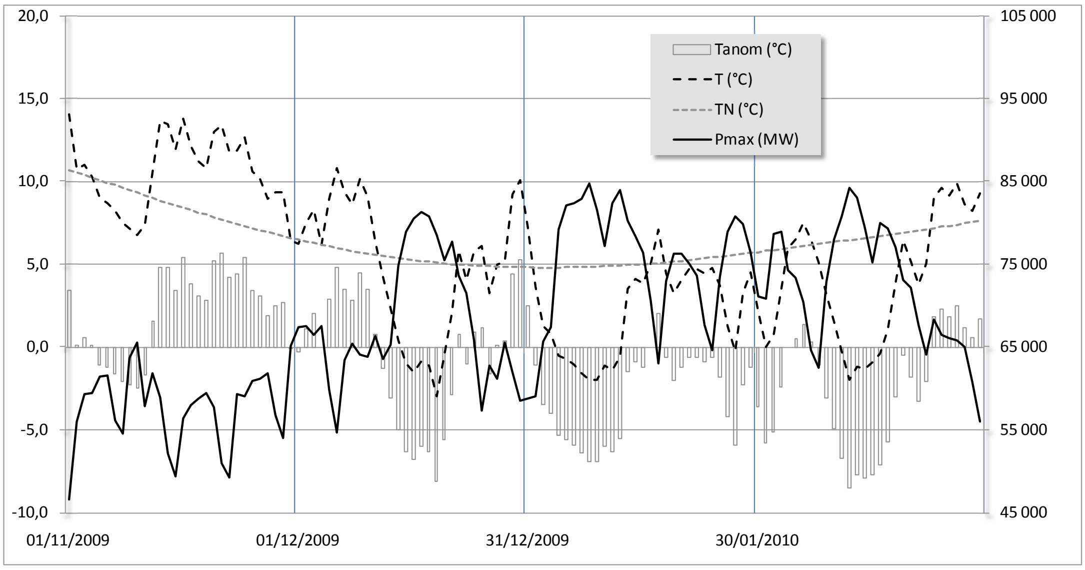

Figure 1: temperature and peak demand in France. Data from Météo-France and RTE (www.rte-france.com): normal temperature (grey dotted line), daily temperature (black dotted line), temperature anomaly (bars) and daily maximum demand (solid black line).

In addition to this strong temperature/demand relationship, power generation depends on weather as well:

- Temperature and river-flow determine the cooling capacities of thermal power plants located along rivers. Summer heat waves and/or low river water levels, as in 2003, can reduce cooling capacity and thus entail a reduction in production capacity (Dubus & Parey, 2009);
- Hydropower generation depends on river flow, and then is linked to the hydrological cycle, and directly to precipitation and snowfall;
- Wind and solar power generation are directly related to wind and solar radiation, and largely influenced by strong and quick variations of these parameters in daily operations.

Of course, the examples of power/meteorology linkages can be multiplied, as almost all activities in the sector depend, in one way or another, on weather and climate variability.

As electricity cannot be stored on a large scale (except in the form of water stocks in large dams), the management of power systems requires demand and production forecasts at different time horizons, ranging from real-time to several months or even years ahead. Short to medium term numerical weather predictions (NWP) are routinely used, but longer-term forecasts are becoming increasingly necessary, in particular for demand forecasting and water stocks management.

This paper is organized as follows: parts 2 and 3 present results about monthly forecasts of temperature and river discahrge in continental France. Part 4 shows first results about seasonal forecasts of weekly streamflows in French Guiana. The last part summarizes the results and focuses on the need to further increase collaboration between providers and users of climate forecasts.

2 Monthly forecasts of temperature in continental France

As power demand in France depends mainly on air temperature, the availability and accuracy of temperature forecasts are very important in the offer/demand balance optimization problem. Both deterministic and probabilistic NWP from Météo-France and ECMWF are used routinely (Dubus, 2010). The EPS forecasts are particularly relevant when the dispersion of the ensemble is significantly different from a Gaussian distribution, and shows bimodal pdfs, as in figure 2. In this example, the use of the ensemble mean (red line on the plot) as a single deterministic forecast would lead to an error of as much as 7.1°C on Feb. 12th (the observed temperature is the green line); the error in terms of power production represents in this case 16,300 MW (16.5 % of France's total installed capacity). But, of course, using ensemble probabilistic forecasts is much less trivial than using deterministic information, and it is particularly complex to integrate such predictions in existing tools, which themselves are very complex.

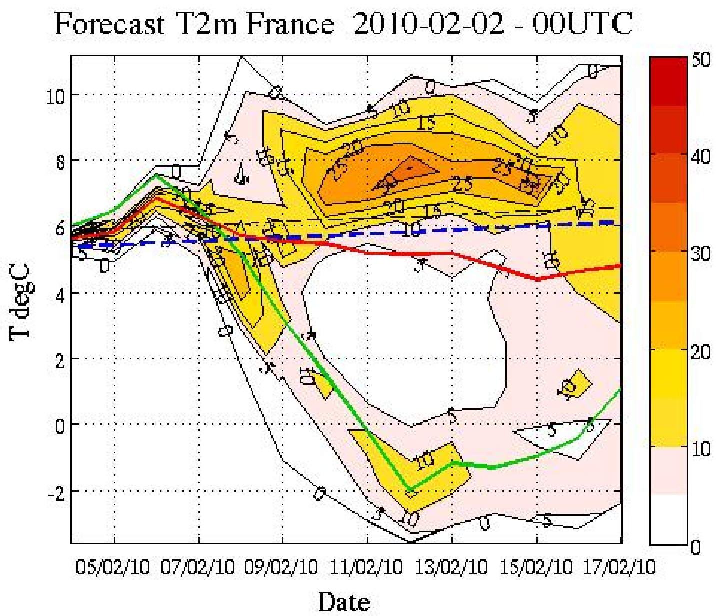

Figure 2: 14-day probabilistic forecasts of temperature over France, from ECMWF VarEPS system. The color intensity represents the percentage of the 51 members forecasting a given temperature. For example, on 02/12/2010, ~35% of the members forecast a temperature of 7-8°C. The red line is ensemble mean. The green line is the observed temperature.

EDF started working on monthly forecasts in 2004, first using only the graphical charts displayed on ECMWF's website. In this first approach, an information bulletin was designed every week during 1 year, and shared with end-users. Positive feedbacks from them pushed forward to make a quantitative evaluation of the forecasts. A more complete and quantitative study was then undertaken, of which only key results are given here. This evaluation is now updated once a year. The most recent one was carried out on forecasts from October 2004 up to April 2012 (395 forecasts) for air temperature, averaged over France. Deterministic and probabilistic scores were calculated and compared to those of 2 reference forecasts[1] (REF1 and REF2 hereafter).

[1] The first one is a historical dataset of 120 years of observed daily data, taken as a reference climatology; the second one is a ~15,000-year time series dataset, obtained with a weather generator.

From a deterministic point of view, monthly forecasts display better scores than REF1 and REF2 up to week 2, throughout the year. The scores continue to be better in weeks 3 and 4 during winter (Dec-Jan-Feb) months (not shown here, see Dubus 2012 for more details).

Figure 3 shows the ROCSS for different events depending on lead time (1 to 32 days), averaged over all forecasts. It is always positive; hence the forecasts are better than climatology throughout the period. When compared to reference forecasts REF1 and REF2, the monthly system is better up to day 20 for all events, although the higher the amplitude of the anomaly considered (either positive or negative), the better the monthly forecasts (not shown here).

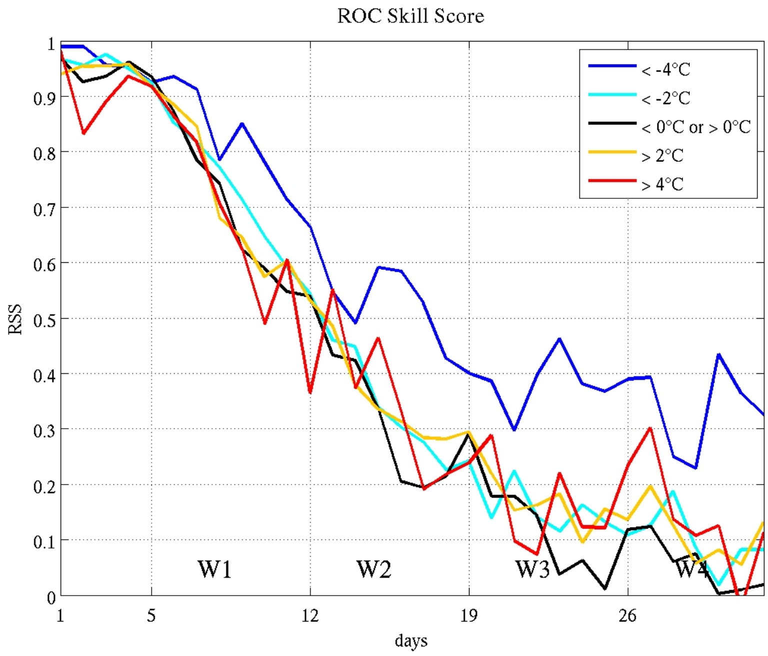

Figure 3: ROC skill scores of monthly temperature forecasts over France, for different temperature anomaly events.

The time evolution of ROCSS for temperature anomaly falling below the 20th percentile of the observed distribution or above the 80th percentile depending on lead time (1 to 32 days), averaged over all forecasts is shown in figure 4.

The high-frequency oscillations show a strong variability and reflect the shortness of the sample (8 years of forecasts may not be enough to compute scores in the distribution tails). Nonetheless, monthly forecasts are better than the reference forecasts for weeks 1 and 2, throughout the year and for both events. The forecast skills vary throughout the year, with a maximum value during winter months (from November to March). In weeks 3 and 4 the conclusions must be moderated, but there is skill up to week 3 and even week 4 in December, January, and February, as well as in summer. This is, however, less evident in spring and fall. Except in June, July and August for week 4 and June-July for week 3, the ROCSS of the monthly forecasts is always positive and most of the time higher than those of the reference forecasts.

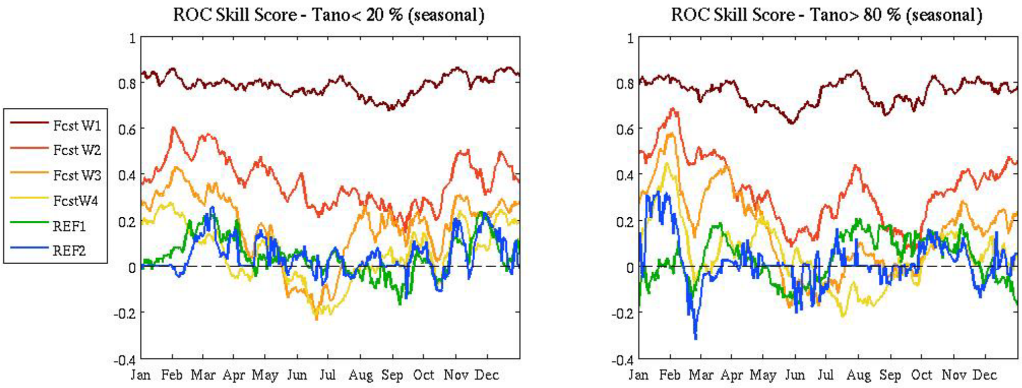

Figure 4: ROC skill scores for each individual week and REF1 and REF2 forecasts.

This study has shown that monthly forecasts provide better information than our current reference forecasts, at least up to week 3 in winter and week 2 over most of the year.

These forecasts have now been used in operations for more than three years. However, due to the complexity of power system management tools, they haven't been introduced explicitly in application models. The temperature forecasts are used as support to decision making, by the people in charge of the whole system's management.

ECMWF implemented a second run of the monthly forecast in late 2011, every Monday. The first analysis show that for a given calendar week, this new forecast improves the one made 4 days before on Thursday. This of course will to be better quantified when a sufficient number of "monday forecasts" will be available. Estimating the economic benefit of these forecasts is difficult, but their usefulness for decision makers is obvious, in particular because the model's skill seems to be the best during strong anomaly events in winter and summer, when the offer/demand balance problem is the most pregnant. For instance, in several occasions, the forecasts suggested to postpone non critical maintenance on production units, to keep the production capacity available to face a cold spell. Power prices are generally high on the market on such cold days, and the information provided by the forecast several days or weeks in advance is then very useful.

3 Monthly forecasts of river flow in continental France

With 25 GW of production capacity (20.6% of EDF's total installed power in France, see EDF, 2012), hydropower is an important component in the French electrical system because it represents a flexible energy stock. Good forecasts of the water incomes several months ahead are therefore essential to get the highest benefit of this flexibility. The question at a given time is to make the best choice between using water to produce energy in response to a peak in demand, or buying energy on the European market and keeping the water available in the future. The problem is both financial and physical, as water has to be shared between different users (energy, agriculture, tourism …) This kind of decision process may clearly beneficiate from monthly to seasonal and even annual forecasts. Operational forecasts of river flow and water stocks are therefore essential.

River discharge forecasts are made using EDF's MORDOR hydrological model (Paquet, 2004). This model is adapted to each watershed on which forecasts are necessary. It is initialized with available observations (water stocks in dams, discharge measured along rivers, estimated snow depth and volume …) and then run using time series of temperature and precipitation for the period of time over which the forecast is done. For short to medium term, they consist either directly in NWP forecasts from Météo-France's ARPEGE and ECMWF's IFS and EPS models, or in indirect forecasts obtained from ECMWF's IFS forecasts and an analog method. This method (Zorita & von Stoch, 1999; Obled et al., 2002) is based on the assumption that for a given large scale circulation pattern, the local precipitation and temperature at a given site will be similar. The method hence takes advantage of NWPs' good forecasting skill of large scale circulation patterns. It uses forecasts of Z700 and Z1000 over North Atlantic/Europe, and analog situations are looked for in the NCEP reanalysis, or in a radio sounding database. For each member of the ensemble forecast, and each day, 50 analog dates are kept, to get finally 2500 dates of similar large scale atmospheric circulation. The local precipitation and temperature observations for these 2500 dates, taken in EDF's database starting in 1953, are then considered as the final forecasts, which are then used in the MORDOR hydrological model simulations.

Longer term forecasts (for 10 days up to several months) use the same MORDOR model, but until recently, only historical times series (1958-present) of temperature and precipitation were available. In mountainous areas, in particular in late winter and early spring, the model shows generally good scores in forecasting discharge over the next 3-4 months, because the flow, for this period of the year, is essentially determined by the initial conditions (explicitly, the snow stock which melts when temperature rises). The sketch is different in plains and during the other seasons, because the flow is then less determined by initial conditions, but rather by direct precipitation. Improving discharge forecasts is then imaginable if the historical time series of temperature and precipitation can be replaced by more skilful forecasts of these parameters.

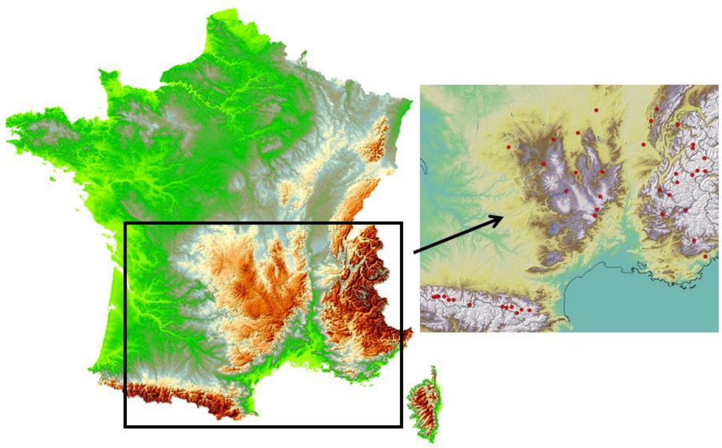

Figure 5: location of the 43 watersheds.

The availability of monthly forecasts at ECMWF naturally raised the question of their suitability for hydropower management. As direct model outputs for precipitation are not skilful after week 1 or 2 over France, the analog method presented above was adapted to generate new forecasts. The study presented here concerns 43 watersheds, presented in figure 5, and forecasts from October 2004 to April 2010 (291 forecast dates).

A comparison of raw ECMWF model precipitation forecasts and analog forecasts shows that the analog method improves the local forecasts of precipitation on average over all basins and forecast dates (Dubus, 2012). Similar results are observed for 2m temperature (not shown here).

River discharge for the 43 watersheds was then forecasted and compared to observations, using 3 different forecasts:

- the discharge climatology (1953-2010): the forecast is always the same for a given date. Referred to as CLIM in the following;
- the current operational method, using historical times series of temperature and precipitation in the MORDOR model. Referred to as REF;
- the new method, same as REF, but where observed times series of temperature and precipitation are replaced by the ones obtained from ECMWF monthly forecasts of geopotential and the analog method. Referred to as ANA.

Figure 6 shows the relative gain in ROC skill score for water flow with the ANA compared to the REF method, for different events, averaged over each week (1 to 4) of the 291 forecast start dates. Except for the middle tercile for weeks 3 and 4, there is a general improvement, in particular in weeks 1 and 2, and for wet events (upper tercile and 90% percentile). A finer analysis shows some differences between seasons and watershed, but the new method is significantly better on average.

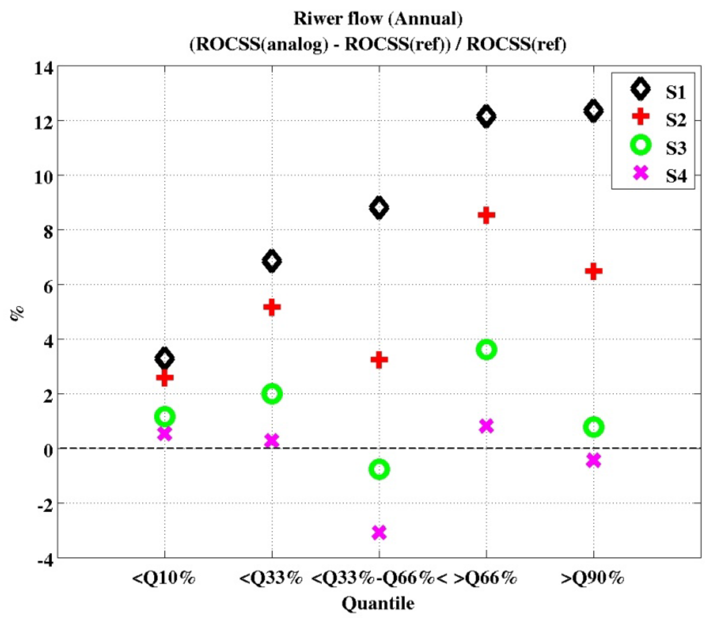

Figure 6: improvement in river flow forecast ROCSS for ANALOG vs. REFERENCE forecasts

Figure 7 shows an example for river Drac at Sautet. It compares forecasts of the monthly cumulated streamflow obtained with the three methods described above, and the observed values (in green), for the 291 start dates. Once again some differences can be observed when looking at other watersheds, but common features are found: first, both REF and ANA methods give better results than the CLIM method, because they are based on the hydrological model, in which initial conditions imprint some predictability. When comparing the two methods using the MORDOR model, the ANA method proves to be more skillful: in particular, it provides a narrower dispersion of the forecasts with respect to the observed time series (REF method). This dispersion is nonetheless sometimes too narrow and there are some outliers, but these generally correspond to extremely high inflows due to specific floods, which are very difficult to forecast more than a few days in advance (end of summer of 2008 for instance). In the case shown, even if ANA does not forecast high enough inflows, the forecast is better than with the REF method.

A very positive result is that the ANA method is much better in forecasting last autumns' very low water levels: the REF method considers the last 52 years of temperature and precipitation, whereas the ANA method only incorporates the most similar examples with respect to the currently forecasted large-scale atmospheric pattern. This is clearly an advantage when the initial conditions differ significantly from the long-term climatological mean.

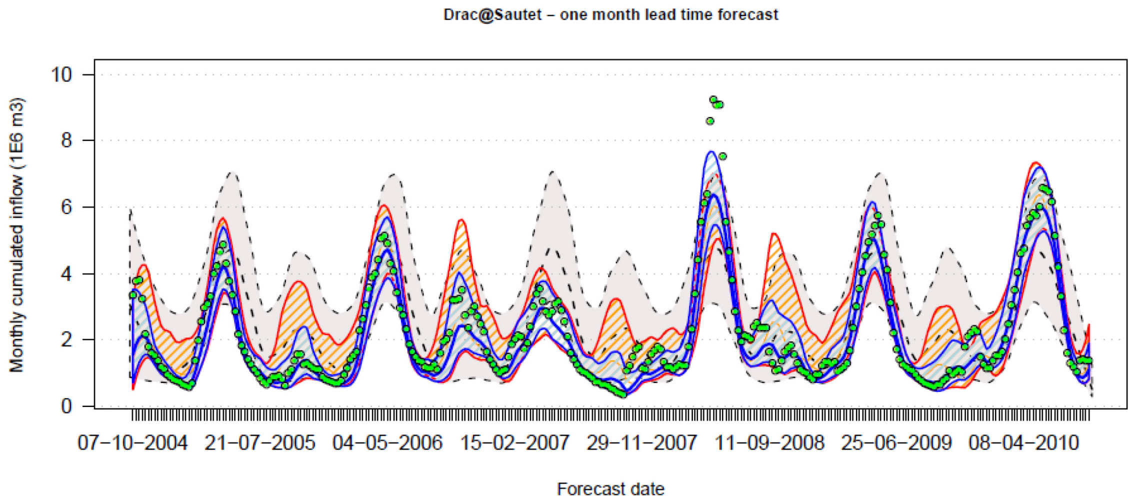

Figure 7: monthly cumulated inflow forecasts for CLIM (grey), REF (orange) and ANA (blue) methods, for the river Drac at Sautet. Green dots are observations.

In summary, the combination of ECMWF's monthly forecasts of large scale atmospheric circulation and the analog method is on average more skillful than the reference approach using historical time series. The results are reinforced due to the fact that we look at an integrated variable (cumulated inflow over the month) in agreement with Troccoli (2010).

Even if difficult to produce, an economic assessment of these forecasts may be done in the next months. Future work will concern the extension to seasonal time scales, in the frame of EU's FP7 project EUPORIAS.

4 Seasonal forecasts of river flow in French Guiana

With a power capacity of 1,200 MW, the Petit Saut dam in French Guiana (figure 8) delivers in average 2/3 of the power consumption of the coastal area. The water stock (310 km^2, 5 billion m^3) management is therefore an essential component for the whole system optimization in the territory. Due to the climatology of precipitation, dominated by the ITCZ position, annual range forecasts of water incomes in the reservoir are necessary to optimally plan the use of the water stock, and manage alternate power sources if necessary. During years of very low water levels, in particular when the rainy season is late or weak, the system managers need to rent power generators and to buy fuel. This represents both a high cost and an environmental problem, due to the fusil fuels emissions.

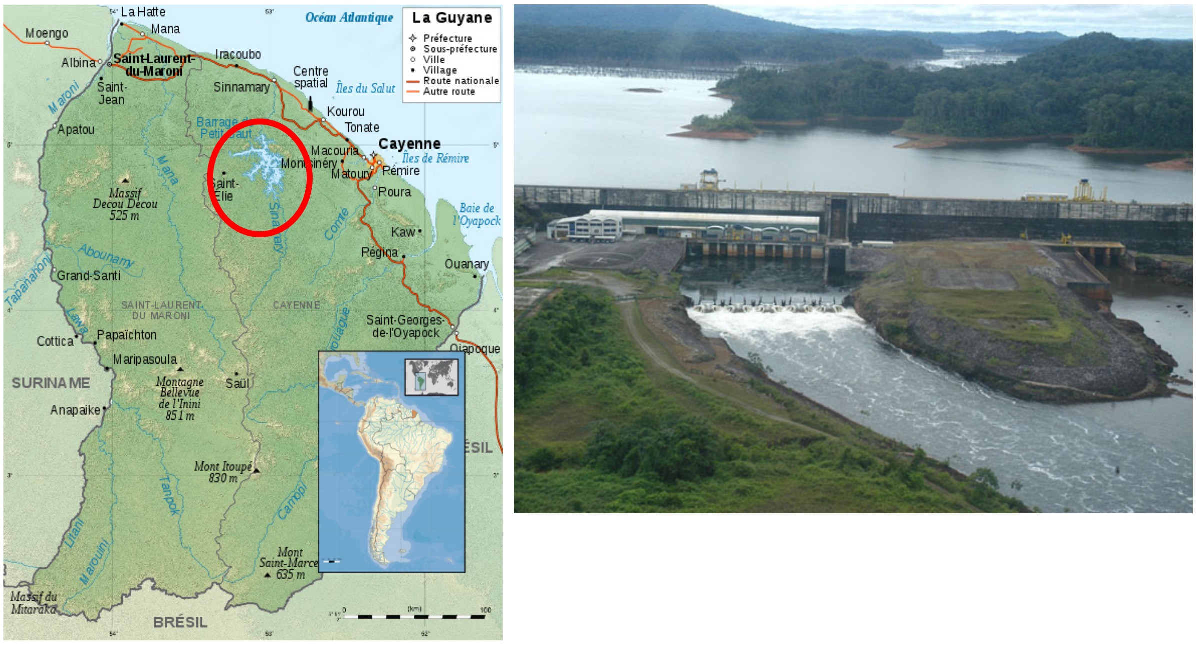

Figure 8: Location of the Petit Saut watershed in French Guiana

Seasonal forecasts are known to be more skilful in tropical regions than at mid-latitudes. A study was then conducted to evaluate the potential improvement they would bring to the management of the Petit Saut dam on time scales from 1 to 6 months. The data used for this study are:

- GPCP climatology for precipitation
- ECMWF seasonal forecasts from system 3 (hindcasts 1981-2005 and operational forecasts 09/2006-08-2010
- Weekly streamflow data from EDF-Guiana

The first part consisted in an evaluation of forecast scores and skill scores over the region for precipitation, and 500 hPa divergence, specific humidity, and geopotential. This evaluation brought positive conclusions and it was then decided to develop a model for the prediction of river flow from seasonal forecasts, keeping only precipitation and 500 hPa divergence. The work was done in collaboration with METNEXT, a joint venture between Météo-France and CDC-Climat (www.metnext.com), using their DECIDE model. This statistical model uses a MARS algorithm (Friedman, 1991) and allows forecasting target variables using predictors, after the model parameters are set during an independent training period. One of the advantages of this model is its flexibility and the possibility to pre-process the predictors in order to reduce the problem dimension, and, hence, the execution times. In the present case, ECMWF forecasts at 1°x1° resolution were used on a large area around French Guiana (62°W-42°W / 10°S-10°N). Tests showed that the best compromise four our model was obtained using as predictors:

- The Southern Oscillation Index (SOI);
- First 2 principal components of streamflow historical data;
- First 3 principal components of precipitation hindcasts mean, and of precipitation anomaly hindcasts mean;
- First 3 principal components of 500 hPa divergence hindcasts mean, and of 500 hPa divergence anomaly hindcasts mean.

The target variable is the monthly mean flow upstream the dam. Figure 9 gives a synthetic view of the results obtained on the verification period, between 09-2006 and 08-2010 (only 21 forecasts), comparing the quality of the seasonal forecasts obtained with the above described post-processing, and the reference forecasting method, which uses the full climatology.

Seasonal forecasts give better results, up to 4 months in advance, for the DJF, JFM, MAM, AMJ, JAS and ASO quarters. Using the climatological distribution of flow is more efficient in MJJ, JJA and NDJ.

For practical applications, it is important to provide the dam managers with weekly forecasts up to several months. METNEXT then used a quantile/quantile regression method to transform monthly values to weekly values. Figure 10 shows an example of the forecasts initialized in November 2007 for February 2008, during which precipitation and flows were very high.

This particular case shows that seasonal forecasts with post-processing can reduce the uncertainty in the forecasts in comparison with the reference method. This of course is not an exhaustive verification, and further work is needed to confirm these preliminary results. Work is under way to use the new system 4 hindcasts and forecasts, in order to make a more robust evaluation of the forecasting chain. In case the usefulness is confirmed, the chain will turn operational in 2013 for a real-time evaluation, in parallel to the current forecasting method.

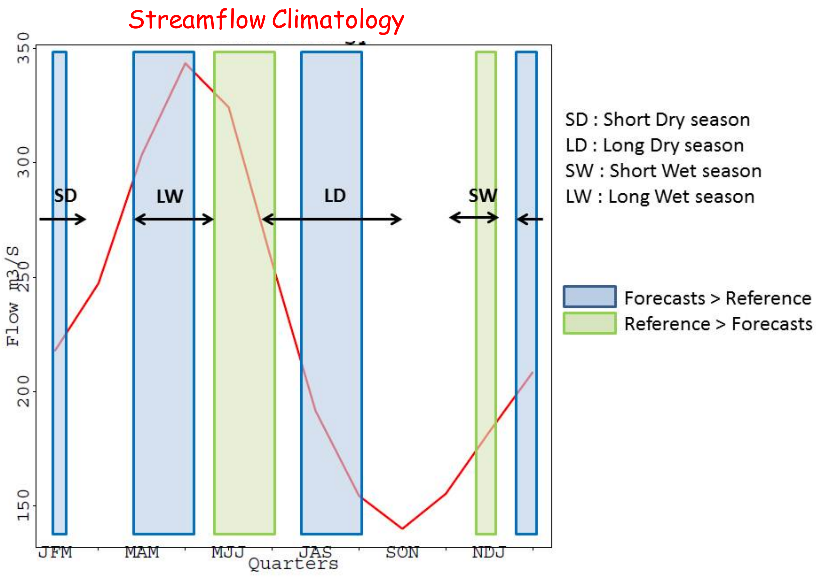

Figure 9: synthetic sketch of forecast usefulness w.r.t reference forecasts. The red line is the flow climatology. Blue boxes hold for periods when seasonal forecasts are more skilful than the reference forecasting method, green boxes when the reference method gives better results.

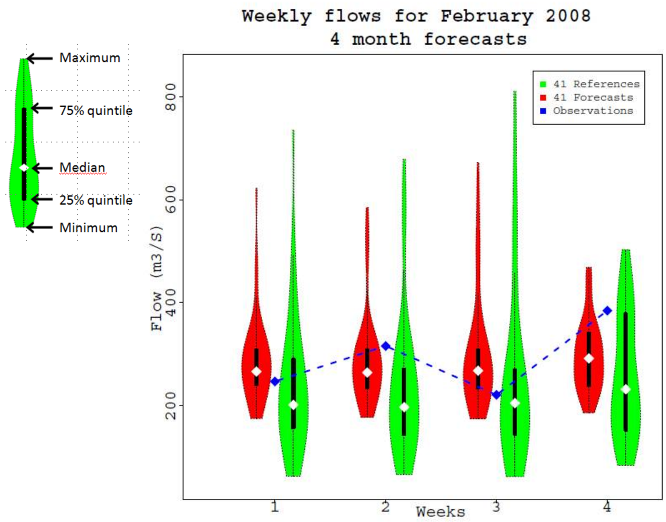

Figure 10: weekly forecasts for February 2008, at lead time 4 months (runs from November 2007). Red "bottles" are forecasts, green bottles are those from the climatological distribution of flow; blue dots are observations.

5 Conclusion

If the power sector has been using NWP for decades, recent evolutions have shown the need of new forecasts, both at short term (for wind and solar power prediction for instance) and longer-term. In particular, temperature and precipitation forecasts, weeks and months ahead, are essential to predict power demand and hydropower production capacities respectively. The examples given in this paper show that recent development in monthly and seasonal forecasting provides an encouraging window of opportunity for operational applications. However, research and development is still needed, first to improve the science and second to tailor the products to operational needs, in respect of the scientific limits. Going further also requires strengthening the relationships between research centers, operational production centers and end-users.

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