SHORT- AND LONG-TERM FLOW FORECASTING IN RIO GRANDE WATERSHED


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Abstract

As part of a research project aimed to improve short- and long-term flow forecasts used in the operational planning of Brazilian hydroelectric power systems, a large-scale distributed hydrological model has been used in combination with observed and predicted precipitation data. This paper summarizes some results obtained at Rio Grande Watershed (145,000 km²), one of the HEPEX test beds. Quantitative precipitation forecasts were provided by regional ETA model and by CPTEC global model, respectively, for short- and long-term forecasts. In the latter, a 9-member ensemble forecast was used. For short-term (time horizon up to 12 days), quality of flow forecasts obtained shows that this methodology could clearly improve operational planning of the hydroelectric reservoirs of Rio Grande watershed. Meanwhile, long-term flow forecasts (time horizon up to 6 months) were satisfactory but still require improvement on the climate forecast.

1. Introduction

In Brazil, hydropower accounts for up to 83% of the total electrical energy production (ANEEL, 2005). An interconnected national transmission network allows the integrated management of the energy produced in hydroelectric dams and others sources by the national system operator (ONS). The decision making process is achieved taking into account the use of optimization models which are strongly dependent on the forecast of energy load and water availability. Currently, flow forecasts are determined using stochastic models based on precipitation and streamflow time series. As part of a research project aimed to improve short- and long-term flow forecasts used in the operational planning of Brazilian hydroelectric power systems, a large-scale distributed hydrological model has been used in combination with observed and predicted precipitation data. This paper summarizes results obtained for short- and long-term flow forecasting in Rio Grande watershed, one of the test beds of the Hydrologic Ensemble Prediction Experiment (HEPEX).

For short-term flow forecasts, observed streamflow data up to the time of forecast issue were used to update state variables calculated by the model, using an empirical data assimilation procedure. Quantitative precipitation forecasts (QPF) for 10 days in advance are used, provided by the regional ETA model from the Brazilian Center for Weather Prediction (CPTEC). For long-term flow forecasts, QPF were produced by CPTEC using the AGCM global atmospheric model (Cavalcanti et al., 2002; Marengo et al., 2005), for
up to 6 months in advance. An ensemble of 9 flow forecasts was obtained based on the ensemble of precipitation forecasts.

2. Methodology

2.1 Rio Grande watershed
The Rio Grande is the main tributary of the River Paraná in its upper basin (Fig. 1), drains an area of about 145000 km$^2$ and is used extensively for hydropower generation. In total, the Rio Grande watershed has an installed capacity of about 7722 MW, which corresponds to approximately 11.7% of the Brazilian total (ANEEL, 2005).

Figure 1 – Location of Rio Grande watershed (a) and of the outlets of Furnas and Água Vermelha catchments (b).

2.2 Distributed hydrological model
The hydrological model used was the MGB-IPH large-scale model, which consists of modules for calculating the soil water budget, evapotranspiration, flow propagation inside a cell, and flow routing through the drainage network (Collischonn et al., 2007; Allasia et al., 2005). The drainage basin is divided into square grid cells connected by channels, and each cell is composed by three reservoirs (groundwater, surface, and subsurface water).

The model was calibrated by changing values of parameters while maintaining relations between land use and parameter values (Collischonn et al., 2007). The multi-objective MOCOM-UA optimization algorithm (Yapo et al., 1998) was used, with three objective-functions: volume bias; Nash-Sutcliffe model efficiency for streamflow and for the logarithms of streamflow.

2.3 Short-term forecast
Quantitative precipitation forecasts were obtained for a time horizon from 1 to 10 days, with a horizontal resolution of about 40 km, from the regional ETA model which is being run operationally by CPTEC (Chou, 1996; Chou et al., 2000). These daily forecasts were produced at weekly intervals and issued every Wednesday, extending from January 1996 to November 2001.

Following the QPF of ETA model, flow forecasts were also calculated on a weekly basis, beginning every Wednesday. The time horizon for flow forecasts extended to 12 days ahead, according to the following procedure: (a) the hydrologic model runs in simulation mode using observed rainfall up to the instant at which rainfall forecasts are issued; (b) observed and calculated flows are compared during a warm up period prior to flow forecast issue and an empirical data assimilation procedure is employed to update model state.
variables; (c) forecasts of flow are calculated for the next 10 days, using the rainfall forecasts from the ETA model, interpolated to the grid-points of the hydrologic model; (d) flow forecasts for the last 2 days are calculated, assuming that there is no further rainfall.

The scenario of perfect precipitation forecast (i.e. considering observed rainfall as forecast) was also considered to assess flow forecasting efficiency unaffected by errors or uncertainties in rainfall forecast (Duckstein et al., 1985; Goswami et al., 2005). The empirical updating procedure consists of applying correction factors to update streamflow along river network and water content in the groundwater reservoir in each model cell (Collischonn et al., 2005; Paz et al., 2007). Weighting factors are used to damp out the correction far upstream from the gauging stations.

2.4 Long-term forecast

The long-term rainfall forecasts provided by CPTEC’s AGCM model were obtained using persisting SST (sea surface temperature) anomalies and 9 initial conditions (an ensemble of 9 forecasts), for a time horizon up to 6 months. Daily forecasts for the period July 1997 to March 2003 with a spatial resolution of approximately 200 km and 28 layers in the vertical were available. A statistical technique based on a transformation of the probability distribution (Hay and Clark, 2003; Wood et al., 2002) was used to correct systematic errors in rainfall forecast, considering the probability distributions of observed rainfall and of model climatology (period 1951-2001).

Long-term flow-forecasting uses rainfall forecasts from CPTEC’s AGCM model interpolated to the model grid-points and begin on the first day of each month, extending for the following six months. Up to the last day before forecasts begin, the hydrologic model is run using observed rainfall data. Each member of rainfall ensemble forecast produces a different flow forecast, thus resulting in a 9-member flow ensemble forecast. Again, the scenario of perfect precipitation forecast was also considered.

3. Results

Hydrological model parameters were calibrated for each sub-catchment, and in both calibration and verification the values obtained for NS and NSlog coefficients were about 0.9 in all but one of them. Values of volume bias were also acceptable, with values less than 0.05% during calibration and less than 7% at validation. In the following sections are presented some general results of short- and long-term flow forecast, respectively, at the outlets of Água Vermelha (139000 km$^2$) and Furnas (52000 km$^2$) catchments, where are located two of the main hydropower installations of Rio Grande watershed.

3.1 Short-term forecast

For short-term flow forecasting, several configurations of the empirical data assimilation procedure were tested, varying the parameter values of such procedure (Paz et al., 2007). In general, the results showed that updating of flow in the river drainage was not important for daily forecasts at Rio Grande watershed, due to the relatively rapid response of the basin and low frequency of observations (one daily). On the other hand, the update of water content in the groundwater reservoir in each cell significantly improved the quality of flow forecasts. Figure 2 shows results at the outlet of Água Vermelha catchment,
using the QPF produced by ETA model (Fig. 2-a) and perfect precipitation forecast (Fig. 2-b). In each graph, the colored traces are consecutive forecasts issued on each Wednesday, for a time horizon up to 12 days. These results were obtained using the best set of updating parameters among those tested, as presented in Paz et al. (2007). The results are relatively good in the sense that the reasonable suitability to forecast the rising and falling of the hydrograph would be very useful to improve the hydroelectric system operational management. In comparison with the stochastic model currently used by ONS (Guilhon, 2007), the combination of climate and hydrologic models lead to a reduction by 10% in the error of the flow forecast at the fourth lead time, and by 20% in the error considering the average of forecast values issued for lead times fourth to ten (Bravo et al., 2007).

![Figure 2](image)

**Figure 2** – Short-term flow forecast at the outlet of Água Vermelha catchment using QPF of ETA model (a) and perfect precipitation forecast (b).

3.2 Long-term forecast
Some results of the long-term ensemble flow forecast at the outlet of Furnas catchment are shown in Figure 3. The 6 graphs in this figure correspond to consecutive forecasts, each of them issued on the first day of a month (indicated by the narrow) and extending for the following 6 months. In each graph, the grey band represents the interval between the highest and lowest flow forecasts obtained from the ensemble of rainfall forecasts, while the black line is the mean of the forecasts obtained from the ensemble. The band shows a relatively wide dispersion of flow forecasts, but in general it includes the observed flow sequence (blue line). The mean value of the ensemble of forecasts can be considered satisfactory when compared with observed flows, given the long lead-time of forecasts.

4. Conclusions
The results obtained with the combination of atmospheric and hydrologic models for flow forecast show potential improvements for hydropower systems management in Brazil. For short-term forecast, this method reduces error by 10% to 20% in comparison with the currently stochastic model used, and there is space for improvement since the hydrologic module represents roughly 43% to 53% of the total error. Meanwhile, long-term flow forecast is more dependent on atmospheric model due to the required long lead time. In the final period of the wet season the atmospheric model did not forecast the rainfall satisfactorily, but the band resulted from the ensemble would be helpful for planning purpose. There is a need for improvement in the ensemble selection based on the flow forecast.
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References


