Predictions in Ungauged Basins: Promise and Progress (Proceedings of symposium S7 held during the Seventh IAHS Scientific Assembly at Foz do Iguaçu, Brazil, April 2005). IAHS Publ. 303, 2006.

Hydrological modelling in Amazonia—use of the MGB-IPH model and alternative databases

ALFREDO RIBEIRO NETO[1], WALTER COLLISCHONN[2], RUI CARLOS VIEIRA DA SILVA[1] & CARLOS E. M. TUCCI[2]

1 *Department of Civil Engineer/COPPE, Federal University of Rio de Janeiro, PO Box 68506, Zip Code 21945-970, Rio de Janeiro, Brazil*
alfredo@coc.ufrj.br

2 *Institute of Hydraulic Research, Federal University of Rio Grande do Sul, Av. Bento Gonçalves, 9500 PO Box 15029, Zip Code 91501-970, Porto Alegre RS, Brazil*

Abstract Different hydrological data sources were tested in this work. These data sources should be used in mathematical models developed for large basins. Precipitation data from the hydrometeorological network of the Brazilian National Water Agency (ANA) and from NCEP/NCAR reanalysis corrected by the Center for Ocean Land Atmosphere (COLA) were used. Climatological data from International Satellite Land Surface Climatology Project (ISLSCP) and from NCEP/NCAR reanalysis were used to calculate evapotranspiration. The Hydrological Model for Large Basins (MGB-IPH) was used to test the alternative databases from COLA/NCEP/NCAR and ISLSCP. The model was applied in the Brazilian portion of the Madeira River basin. The results showed that the daily COLA precipitation series has values very close to the ANA precipitation series for the period 1979–1990. The model simulations showed that the results are quite similar using either ANA or COLA precipitation over the period 1979–1990.

Key words Amazon basin; hydrological data; hydrological modelling

INTRODUCTION

There are several problems associated with the acquisition and distribution of hydrometeorological data that could be used for hydrological modelling in the Amazon. These problems were observed in other large basins, but in the Amazon basin the difficulty is larger because it is a transboundary basin, which lies partly in Brazil, Peru, Bolivia, Ecuador, Colombia and Venezuela. In most cases, it iss not possible to access the hydrological data obtained in these countries. An exception may be Brazil, where direct access to hydrological data collected by the National Water Agency (ANA) is permitted and facilitated through the internet.

While hydrological data such as rainfall, streamflow and meteorological time series are rarely available, spatial information such as soil types, vegetation cover and topography can be obtained from globally available sets such as the FAO/UNESCO Soil Map of the World, or the Digital Elevation Model of the Shuttle Radar Topography Mission (SRTM).

This paper describes some results of a test where globally available surface meteorology and precipitation data sets were used to run a large scale hydrological model. Special attention was given to precipitation data because it is possible to compare them with rainfall recorded by raingauges in Brazil.

Alternative data sources for hydrological modelling purposes have been discussed in some recent research papers. Kite & Haberlandt (1999) used precipitation data, air temperature, air humidity and radiation generated by GCM, regional model NWP (Numerical Weather Prediction) and reanalysis of the National Centers for Environmental Prediction (NCEP) and National Center for Atmosphere Research (NCAR). They used these data to drive a hydrological model in the Mackenzie River basin in Canada and showed that relatively good results can be obtained with data from regional meteorological models.

Arnell (1999) used climatological data with a monthly time step in the hydrological modelling of large basins in Europe. This author used Penman, Penman-Monteith and Priestley Taylor equations to calculate potential evapotranspiration.

Nasonova & Gusev (2005) used hydroclimatological data from the International Satellite Land Surface Climatology Project (ISLSCP) and from Model Parameter Estimation Experiment (MOPEX) in 12 basins in the USA. The results were compared with each other and with recorded values. Results were favorable to the use of global data for regional runoff simulations.

HYDROLOGICAL MODEL

We used a large scale hydrological model called MGB-IPH, from the Portuguese "Modelo de Grandes Bacias" which means "Large Basins Model", and "Instituto de Pesquisas Hidráulicas" according to the institution in Brazil where this model was developed (Collischonn, 2001). Very similar to the LARSIM (Bremicker, 1998) and VIC (Liang *et al.*, 1994) models, MGB-IPH is distributed by cells and runs on daily or hourly time steps. Each cell is divided into blocks, patches, which are formed by the combination of land use, vegetation, and soil type. Each block has a uniform hydrological response to meteorological forcing, in the same way as in the case of Grouped Response Units (GRUs) (Pietroniro & Soulis, 2003).

MGB-IPH uses the Xinanjiang model formulation to calculate the soil water balance (Zhao *et al.*, 1980). Three linear reservoirs are used to represent independent routing of surface, subsurface and groundwater flow through the cell. Flow propagation in the rivers is based on the Muskingum-Cunge method. The potential evapotranspiration is calculated by the Penman-Monteith equation.

STUDY AREA

The study area is located in the Brazilian portion of the Madeira River basin between the streamgauges Porto Velho and Fazenda Vista Alegre where drainage areas are, respectively, 954 285 and 1 288 150 km^2 (Fig. 2); the modelled area is 333 865 km^2. Average discharge of the Madeira River at Fazenda Vista Alegre is about 31 000 m^3 s^{-1} clearly showing that this river is one of the most important tributaries of the Amazon. Figure 1 shows the Amazon basin and the study area in the Madeira River basin.

Most important tributaries of the Madeira River in the simulated reach of the basin are Jiparaná and Aripuanã rivers. Figure 2 shows the study area divided in sub-basins

Fig. 1 Amazon basin and the study area.

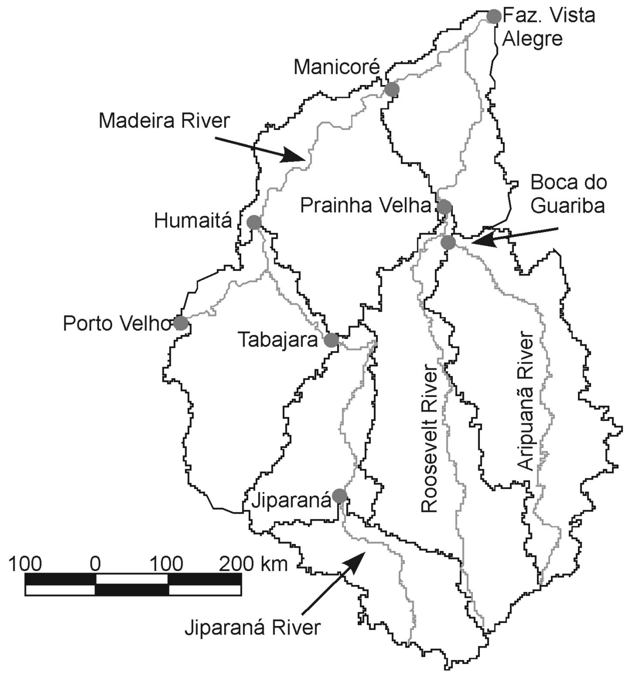

Fig. 2 Streamgauges and respective sub-basins

according to the location of the most important streamgauges of the Madeira and its tributaries, which are described in Table 1. The drainage area of the streamgauges at Madeira River (Humaitá, Manicoré and Faz. Vista Alegre) in Table 1 should be summed to drainage area at Porto Velho to obtain the real value.

Table 1 Streamgauges in the study area.

Name	River	Drainage area (less area at Porto Velho) (km^2)
Jiparaná	Jiparaná	28 798
Tabajara	Jiparaná	59 429
Humaitá	Madeira	110 269
Manicoré	Madeira	167 584
Boca do Guariba	Aripuanã	68 069
Prainha Velha	Aripuanã	133 417
Faz. Vista Alegre	Madeira	333 865

DATA SOURCES

Precipitation data

Two precipitation data sets were used: raingauge data and NCEP/NCAR reanalysis. Raingauge data comes from 60 gauges of the ANA database that are located inside this basin, giving a gauge density of nearly 6000 km^2 per raingauge.

A NCEP/NCAR reanalysis (Kistler *et al.*, 2001) study was made by running atmospheric models in simulation mode using recorded values as initial and boundary conditions. Reanalysis has a disadvantage related to errors caused by the atmospheric model, e.g. its resolution and parameterization, so we used a corrected reanalysis data set by Dirmeyer & Tan (2001), who used recorded data in the whole of South America to correct the values obtained with NCEP/NCAR reanalysis.

The correction used monthly precipitation calculated by Webber & Willmott (1998) in years 1979–1990 and monthly precipitation calculated by Climate Monitoring, Analysis and Prediction (CMAP) (Xie & Arkin, 1997) for the period 1991–1999. The correction equation is the following:

$$[P]_{Y,M,D,H} = \frac{[P_{OBS}]_M}{[P_{NCEP}]_M} \cdot [P_{NCEP}]_{Y,M,D,H} \quad (1)$$

where $[P]_{Y,M,D,H}$ and $[P_{NCEP}]_{Y,M,D,H}$ are corrected and NCEP/NCAR precipitation at a given year, month, day and 6-hour time interval, $[P_{OBS}]_M$ and $[P_{NCEP}]_M$ are the monthly mean recorded precipitation and mean value from the reanalysis for that month. This correction was accomplished by the Center for Ocean Land Atmosphere (COLA) and, for this reason, from now on this precipitation will be identified as COLA. The Madeira basin analysed in this paper was covered by 46 reanalysis data points, where daily precipitation values were available.

Meteorological data for potential evapotranspiration calculation

The MGB-IPH hydrological model uses five meteorological variables to calculate potential evapotranspiration using the Penman-Monteith equation: air temperature, vapour pressure, wind speed, net radiation and atmospheric pressure. These data are very rare in the Amazon, so we used ISLSCP data, which provides a series for the period 1986–1995 of net radiation, vapour pressure and air temperature at monthly time steps. Surface wind speed and atmospheric pressure time series are also available for the period 1988–1989. Monthly mean vapour pressure and monthly air temperature were obtained by interpolation of the values observed in weather stations. Monthly atmospheric pressure and wind speed were obtained by climatic model and net radiation was measured via satellite.

Another database was created by COLA, similar to the precipitation discussed before. The temperature was corrected by Webber & Willmott (1998). Specific humidity was adjusted using temperature. Surface pressure and wind speed were not corrected; NCEP/NCAR reanalysis values were used directly. Net radiation was extracted from *Land Surface Schemes* simulations. Both ISLSCP and COLA data are available at space resolution of 1 degree.

PRECIPITATION VARIATION WITH DIFFERENT DATA SOURCES

Mean precipitation data obtained by the ANA raingauges and COLA corrected reanalysis were compared at the study area. The time series of mean monthly

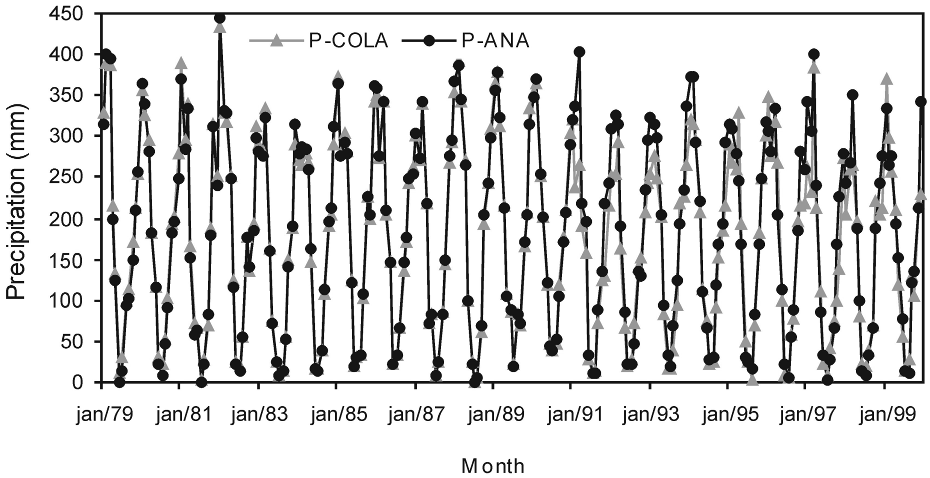

Fig. 3 Monthly mean precipitation at the study area for the period 1979–1999.

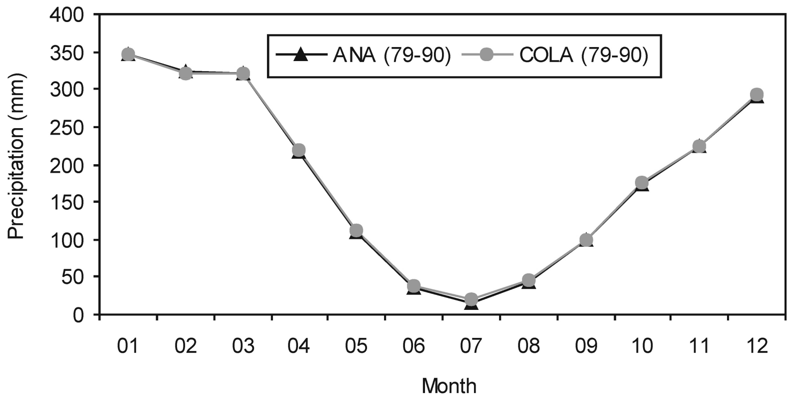

Fig. 4 Monthly mean precipitation variation of long period at the study area (1979–1990).

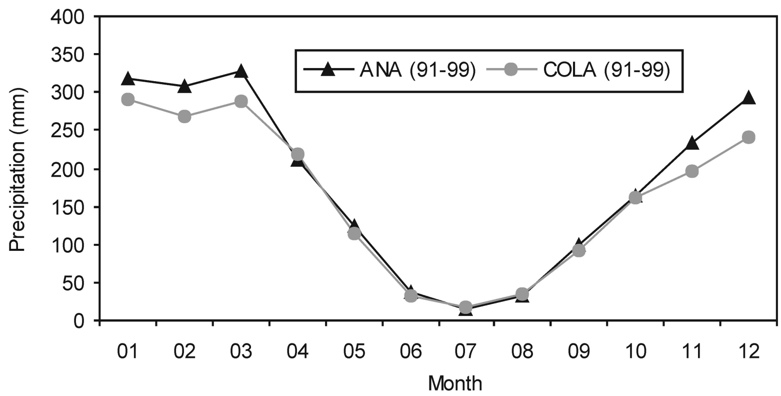

Fig. 5 Monthly mean precipitation variation of long period at the study area (1991–1999).

precipitation from both data sets at the study area for the period 1979–1999 are shown in Fig. 3. After 1991, COLA precipitation is systematically lower than ANA precipitation. This is probably caused because year 1991 marks the change of data sets used to correct the NCEP/NCAR reanalysis: Webber & Willmott (1998) for the period 1979–1990 and CMAP for the period 1991–1999.

The difference of data quality of these two periods can also be observed by plotting monthly mean precipitation for long period in 1979–1990 and in 1991–1999. These graphs are shown in Figs 4 and 5.

POTENTIAL EVAPOTRANSPIRATION VARIATION WITH DIFFERENT DATA SOURCES

The mean potential evapotranspiration at the study area was calculated with ISLSCP and COLA data for the period 1986–1990. Figure 6 shows the monthly mean potential evapotranspiration for two data sources. The results showed that there is a systematic difference between the evapotranspiration calculated with ISLSCP and COLA data. The exception is August and September. The annual mean evapotranspiration is 1278 and 1099 mm year^{-1}, respectively, for ISLSCP and COLA.

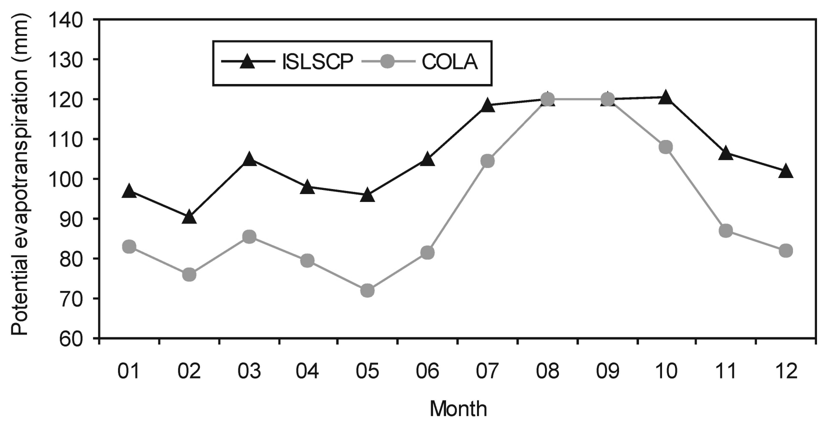

Fig. 6 Monthly mean potential evapotranspiration variation at the study area (1986–1990).

According to Marques *et al.* (1980), actual evapotranspiration in the Amazon basin is between 1146 and 1260 mm year^{-1} and the ratio between actual and potential evapotranspiration varies from 0.7 to 0.8. Following this reference, potential evapotranspiration should be between 1433 and 1800 mm year^{-1}, which means that ISLSCP climatological data provides more realistic values, so this data set was selected to be used in the hydrological simulations that follow.

HYDROLOGICAL MODEL SIMULATIONS

The MGB-IPH model was run during the period 1986–1990, using recorded discharge data at Porto Velho as an upstream boundary condition. From this point downriver to Fazenda Vista Alegre, Madeira River receives water drained from an area of nearly 334 000 km^2 area. Discharge generated in the incremental basin between Porto Velho and Fazenda Vista Alegre is equivalent to 37% of the discharge at Fazenda Vista Alegre.

Two simulations were done: one with ANA and another with COLA precipitation, both with ISLSCP climatological data for the evapotranspiration calculation. Simulation using ANA raingauges was considered as a benchmark. So the model was calibrated only once, using ANA raingauge data, and the same parameter values were used in the simulation with COLA precipitation. The model parameters were calibrated

Table 2 Statistic criteria values.

Sub–basin	ANA precipitation		COLA precipitation	
	R^2	ΔV (%)	R^2	ΔV (%)
Jiparaná	**0.883**	**–9.160**	**0.795**	**–13.781**
Tabajara	**0.845**	**8.588**	**0.879**	**1.646**
Humaitá	0.957	–0.530	0.960	–1.797
Manicoré	0.747	–18.710	0.756	–18.966
Boca do Guariba	**0.606**	**34.246**	**0.727**	**25.757**
Prainha Velha	**0.794**	**8.495**	**0.819**	**1.146**
Faz. Vista Alegre	0.882	0.507	0.890	–0.925

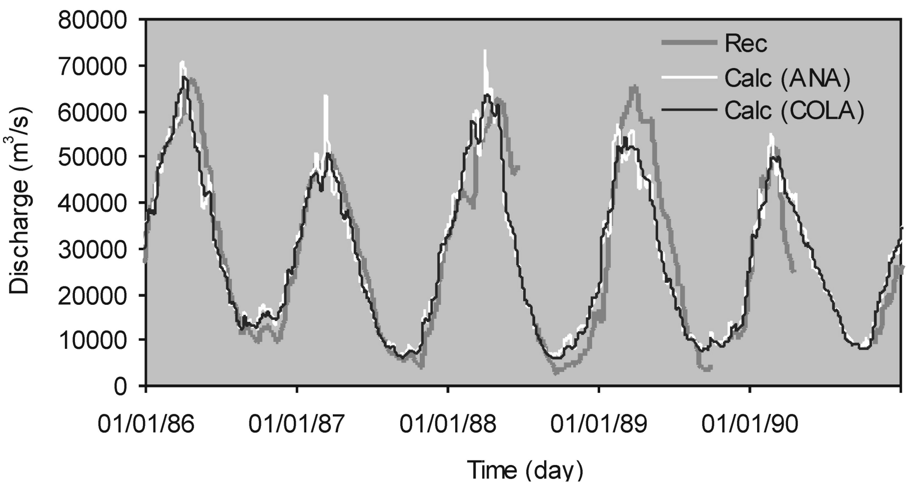

Fig. 7 Recorded and calculated discharge at Fazenda Vista Alegre.

using the trial-and-error procedure and two criteria, the Nash-Sutcliffe efficiency coefficient (R^2) and relative volume error (ΔV).

Table 2 shows the R^2 coefficient and ΔV for all the streamgauges in both simulations and Fig. 7 presents recorded and calculated discharges at Faz. Vista Alegre. The highlighted lines in Table 2 are for the gauges of tributaries of the Madeira where the results are not influenced by the discharge entering at Porto Velho, which was forced into the model. Both the hydrographs of Fig. 7 and the Nash-Sutcliffe values show that the simulation is relatively good, and that the differences between the raingauge and corrected reanalysis data sets are small.

CONCLUSIONS

The precipitation data comparison showed that until 1990, the ANA and COLA databases have very close mean values. This is explained by the correction factors used on two periods: 1979–1990 (recorded data from Webber & Willmott (1998)) and 1991–1999 (recorded data from CMAP).

The potential evapotranspiration calculation showed that the ISLSCP database provides more realistic values if compared with COLA data.

The use of the MGB-IPH model was useful to verify the quality of the COLA precipitation. We observed that, globally, there was no great difference in the result between the simulations accomplished with either ANA or COLA precipitation.

The use of COLA precipitation showed that these data could be used to complement ANA data for the Brazilian portion of the Amazon basin. Following this first application, tests will be done using COLA reanalysis data for the whole Madeira River basin, including basin parts that lie outside Brazil, where it is relatively hard to get precipitation time series.

Acknowledgements The first author acknowledges a scholarship granted by the Brazilian National Council for Scientific and Technological Development (CNPq).

REFERENCES

Arnell, N. W. (1999) A simple water balance model for the simulation of streamflow over a large geographic domain. *J. Hydrol.* **217**(3–4), 314–335.

Bremicker, M. (1998) Aufbau eines Wasserhaushaltsmodells für das Weser und das Ostsee Einzugsgebi*et al*s Baustein eines Atmosphären-Hydrologie-Modells. DSc Thesis, Geowissenschaftlicher Fakultät der Albert-Ludwigs University, Freiburg, Germany.

Collischonn, W. (2001) Simulação hidrológica de grandes bacias. DSc Thesis, IPH/UFRGS, Porto Alegre, RS, Brazil.

Dirmeyer, P. A. & Tan, L. (2001) A multi-decadal gridded meteorological and land surface data set over South America. *COLA Technical Report,* COLA, Calverton, USA.

Kistler, R., Kalnay, E., Collins, W., Saha, S., White, G., Woollen, J., Chelliah, M., Ebisuzaki, W., Kanamitsu, M., Kousky, V., Van den Dool, H., Jenne, R., Fiorino, M. (2001) The NCEP/NCAR 50-year reanalysis: monthly means CD-ROM and documentation. *Bull. Am. Met. Soc.*, **82**(2), 247–268.

Kite, G. W. & Haberlandt, U. (1999) Atmospheric model data for macroscale hydrology. *J. Hydrol.* **217**(3–4), 303–313.

Liang, X., Lettenmaier, D. P., Wood, E. F. & Burges, S. J. (1994) A Simple hydrologically based model of land surface water and energy fluxes for general circulation models. *J. Geophys. Res.* **99**(D7), 14.416–14.428.

Marques, J., Salati, E. & Santos, J. M. (1980) Cálculo da Evapotranspiração Real na Bacia Amazônica Através do Método Aerológico. *Acta Amazonica*, **10**(2), 357–361.

Nasonova, O. & Gusev, Y. (2005) The application of global 1-degree data sets for prediction in ungauged basins using a land surface model. In: *VII IAHS Scientific Assembly* (Foz do Iguaçu, Brazil, 3–9 April 2005).

Pietroniro, A. & Soulis, E. D. (2003) A hydrology modelling framework for the Mackenzie GEWEX programme. *Hydrol. Processes* **17**(3), 673–676.

Webber, S. R. & Willmott, C. J. (1998) South America precipitation: 1960-1990 gridded monthly time series. Center for Climatic Research, Department of Geography, University of Delaware, Delaware, USA.

Xie, P. & Arkin, P.A. (1997) Global precipitation: a 17-year monthly analysis based on gauge observations, satellite estimates and numerical outputs. *Bull. Am. Met. Soc.* **78**(11), 2539–2558.

Zhao, R. J., Zuang, Y. L., Fang, L. R., Liu, X. R. & Zhang, Q. S. (1980) The Xinanjing model. In: *Hydrological Forecasting* (Proc. Oxford Symp.), 351–356. IAHS Publ. 129. IAHS Press, Wallingford, UK.