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CLIMATE CHANGE AND FLOODS IN PARANÁ RIVER BASIN

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ABSTRACT: The Paraná River basin is a major river system in Latin America, with a total drainage area of about 800.000 km², until the confluence with the Iguaçu river. It is situated over six Brazilian states (Minas Gerais, São Paulo, Goiás, Mato Grosso do Sul, Paraná and Distrito Federal), being especially important for hydropower generation (including Itaipu dam), agriculture and human water supply. These water resources uses depends on the rivers and climate issues at the basin. Therefore for better water resources management it is important the knowledge of hydrological processes and its possible responses to climate changes. This study presents the use of the MGB-IPH distributed hydrological model to assess the impact of climate changes on maximum discharges for several control points across the Paraná River basin. Projections of climate variables, from four members of the ETA-CPTEC Regional Climate Model (RCM), under A1B emission scenario, were used to run the hydrological model. The simulated annual maximum discharges (floods) were analyzed throughout four 30-year's time intervals (1960-1990, 2011-2040, 2041-2070 and 2071-2099). Results show in most control points an increase of simulated maximum floods. However considerable discrepancies are showed by different model members, for different return periods and control point locations. Considerations are made about uncertainties associated with data and employed methods.

Key Words: Climate Change, Maximum Discharge, Regional Climate Model

1. INTRODUCTION

Predictions of future climate patterns across the World suggest an intensification of the hydrological cycle, with more rainfall and more evapotranspiration in average (IPCC, 2007; Trenberth, 2006, 2011). In some regions this may lead to an increase in the magnitude and frequency of floods.

Climate change can lead to significant impacts on the hydrological regime. One of the main effects of such changes is felt in the floods occurrence in river basins. The response to these changes requires planning, and therefore for better water resources management it is important the knowledge about the expected future conditions under climate change scenarios.

Numerous studies can be found in literature about modelling of climate change impact on runoff. In most of these studies, general circulation model (GCM) data is used as input into hydrological models to quantify the impacts on hydrological variables (Diaz-nieto and Wilby, 2005; Minville et al., 2009; Taye and P. Willems, 2013; Bravo et al., 2013). However, the spatial resolution mismatch between GCMs outputs and the data requirements of hydrological models is a major obstacle (Xu, 1999; Seaby et al, 2013). Normally, this is resolved by using regional climate models (RCM) that use boundary conditions from GCMs over a limited area to produce higher resolution outputs. Compared with the host GCM, the RCM should be more able to resolve surface orography and hence some of the atmospheric processes that generate extreme precipitation events (Wilby and Fowler, 2010). The main problem of RCMs is the computational cost and thus their applicability is only available for limited regions. That is the main reason why most current climate impacts studies on floods use monthly GCM outputs, and rely on simple techniques to derive daily rainfall scenarios from GCM monthly changes (Barry and Chorley, 2013).

In a recent study by Arnell and Gosling (2013), based on climate projections from 21 GCMs, the authors indicate that much of the key areas for hydropower generation in Brazil, including the Paraná region, there is uncertainty to the sign of the change on runoff. We expect that the use of a regional model with spatial and time resolution compatible to the hydrological events of a watershed will allows a better representation of the basin hydrological behavior. The use of daily weather series generated by ETA will allow to analyze more accurately the events related to extreme flows.

In the present paper we evaluate the possible impacts of climate change on the occurrence of floods in the Paraná river basin. We analyzed maximum discharges (floods) frequency and magnitude under the current and projected climate in the upper Paraná river basin using a distributed large-scale hydrological model, using as input data, time series of climate variables from a RCM.

2. MATERIALS AND METHODS

2.1. Study Area

The Paraná River Basin is one of the major river systems in Latin America. It is of vital importance for hydropower production in Argentina, Brazil and Paraguay. The Upper Paraná River basin (UPRb), down to Itaipu dam, concentrates more than 50% of Brazilian installed hydroelectric capacity currently in operation in the country. Its water is also used intensively for agriculture and human supply. Floods along the Paraná River are not a main concern within Brazil, but floods generated in the upper part of the basin may have impacts on Argentinian cities located along the medium or lower Paraná.

Our modelling encompasses the whole UPRb as showed in Figure 1. However, to summarize we show results at four control points, all defined by major hydropower dams: UHE São Simão, UHE Água Vermelha, UHE Rosana and UHE Itaipu. Figure 1 shows the location of Upper Paraná River basin and the four control points. These locations are coincident with hydropower plants points because they have naturalized (observed) streamflow available information and the model was calibrated to it, and thus we believe results at these locations are more reliable. The selected control points are located at the outlets of the majors rivers that compose the Upper Paraná River basin: the Paranaiba River (at UHE São Simão); the Grande River (at UHE Água Vermelha); the Paranapanema River (at UHE Rosana) and the Paraná River itself at Itaipu.

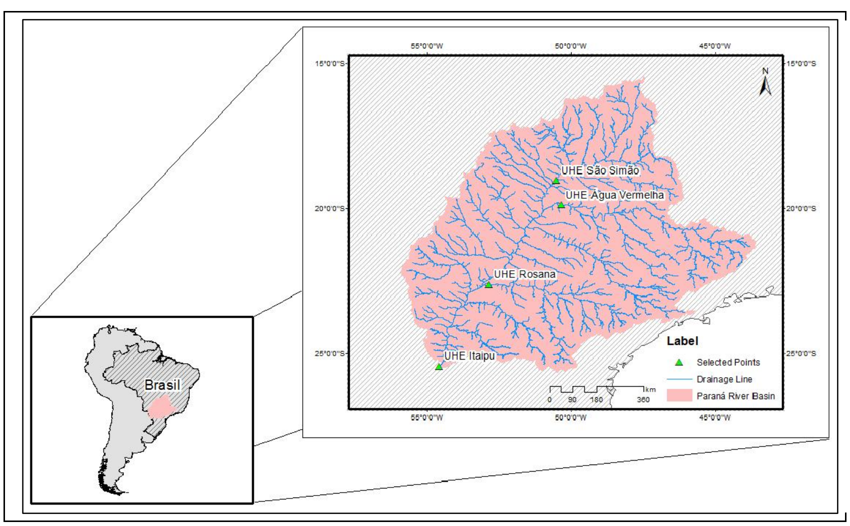

Figure 1: Paraná River basin location and selected control points.

2.2. MGB-IPH Hydrological Model

The MGB-IPH (*Modelo de Grandes Bacias – Instituto de Pesquisas Hidráulicas)* is a distributed hydrological model that uses physical and conceptual equations to simulate the following hydrological process: soil water budget, evapotranspiration, interception, flow generation and flow routing in rivers. A more detailed description of the model is presented by Collischonn et al. (2007) and Fan and Collischonn (2014). The model runs in daily or hourly time step, although some internal calculation processes, such as flow routing in rivers, usually uses smaller time steps. Most of the MGB-IPH model applications have been carried out for hydrologic simulation of large basins using generally daily time step.

The spatial variability of the relief is considered through the use of a Digital Elevation Model (DEM). The spatial variability of vegetation, land use and soil type within the basin are considered using the Hydrological Response Units (HRU) approach. The HRU's are areas of similar hydrological behavior, defined by the combined land use and soil type maps. The soil water balance is performed using a method based on the surface runoff by excess of soil capacity storage that uses a probabilistic relationship between soil moisture and the fraction of saturated soil area. Evapotranspiration is estimated by the Penman-Monteith equation.

The flow generation within the basin and its transport into river network are performed in two steps. First, streamflow is generated within each unit catchment, and then routed to the stream network using three linear reservoirs, each of them representing one type of flow: base flow, subsurface flow and surface flow. The output flows of each reservoirs are summed and routed into the river network using the Muskingum-Cunge method or a full hydrodynamic approach (Paiva et al., 2011).

In this paper, we use SRTM-90m DEM (Farr et al., 2007) to obtain the topographic characteristics. A HRU map with 8 classes was developed based on soil (RADAMBRASIL, 1982) and vegetation (Eva et al., 2002) maps. The rainfall and climate data were provided by Brazilian National Water Agency (ANA).

To calibrate the model were used daily discharge data from several gauging stations provided by ANA as well as naturalized flows obtained by The Electric System National Operator (ONS). We calibrated the MGB-IPH model using data from 1960 to 1990. Verification was carried out in the period …. Based on the comparison of observed and simulated streamflow several performance measures were assessed (Table 1): Nash-Suttcliffe (NS), log-Nash-Suttcliffe (NS*log)* and relative bias or volume error (ΔV).

Subsequently, the model was applied using meteorological data generated bythe ETA-CPTEC model for different time intervals. As results, time series of streamflows for the current climate (period 1961-1990) and future climate (period 2010-2100) were obtained. The comparison of these different simulations results allows to assess the impacts of climate change on maximum discharges in the UPRb.

The results of the hydrologic modeling are presented for each of the four control points.

2.3 ETA-CPTEC Regional Climate Model

ETA-CPTEC (ETA) is a regional climate model (RCM) that used results of the HadCM3 (POPE et al., 2000, GORDON et al., 2000) general circulation model (GCM) as lateral boundary condition for mesoscale simulations. Through the partnership between the Brazilian Center for Weather and Climate Research (CPTEC), Brazilian National Institute for Space Research (INPE) and the Met Office Hadley Centre (Mohc) the ETA was adapted to generate climate change scenarios (Chou et al, 2011, Pesquero et al, 2009) and projections of the following climatic variables: temperature at 2 meters above the earth's surface (° C); dew point temperature at 2 meters above the earth's surface (° C); atmospheric pressure on Earth's surface (hPa); total precipitation (mm); Wind to 10 m (ms-1); medium and shortwave radiation incident at the earth surface (Wm-2).

Under the A1B emission scenario, representing climate and future climate variables were obtained from the Eta RCM. In total 16 different climatic conditions resulting from the combination of 4 members (representing the climate sensitivity with spacial resolution of 40 km) of the ETA model and 4 time periods (Table 1) were considered. The period 1961-1990 represents the current climate. The period from 2011 to 2100, representing the future climate in the XXI century, it was divided into three time-slice of 30 years each.

Table 1: Nomenclatures applied for ETA Model

	TIME INTERVAL			
MODEL	Current(1961-1990)	Fut1(2011-2040)	Fut2(2041-2070)	Fut3(2071-2100)
CT40	CT40_Actual	CT40_Fut1	CT40_Fut2	CT40_Fut3
LOW	LOW_Actual	LOW_Fut1	LOW_Fut2	LOW_Fut3
MID	MID_Actual	MID_Fut1	MID _Fut2	MID_Fut3
HIGH	HIGH_Actual	HIGH_Fut1	HIGH_Fut2	HIGH_Fut3

For the use of daily series of climatic variables generated by the ETA bias removal techniques were applied. According to Teutschbein and Seibert (2012) climate models tend to have systematic errors caused by imperfect conceptualization of the phenomena and processes that govern the climate and the influence of the spatial discretization of the models. In the present work we removed bias in precipitation data using the Quantile-Quantile Mapping (Bárdossy and Pegram, 2011) methodology. Bias in other climatic variables (temperature, wind velocity, solar radiation, relative humidity) was removed by applying the Linear Scaling method (Lenderink et al., 2007).

2.4 Methods

In order to assess possible impacts of climate change on maximum discharges (floods) of the Upper Paraná River basin, we executed three main steps with the hydrologic model: 1) calibration with observed data; 2) simulation using as input time series of the climate variables the output of the RCM after the bias-correction. The simulation time-interval for the current climate was 1961-1990 and for future climate 2010-2099; 3) assessment of results in terms of changes in magnitude and frequency of daily maximum discharge.

The analysis of climate changes on maximum discharges was based on comparing the results of the hydrological modeling procedure at different periods of time, and using data from the different members. The current period was taken as the reference period and modification of the magnitude of flows compared to this period represent changes arising from climate change. Thus, maximum discharges magnitudes of several return periods (TR), in years, computed from model simulated current period (1961-1990) were compared with the flood magnitudes at the corresponding TR based on flows simulated for three future time intervals: 2011–2040 (Fut1), 2041–2070 (Fut2) and 2071-2099 (Fut3). The annual maximum floods were calculated along with their probabilities of exceedance from the current and future periods assuming a log-Pearson type III distribution (Chow et al. 1988; Shabri 2002). Confidence intervals were established for the current period (with a confidence level of 95%) to assess the degree of significance of variations in TR comparing different members and periods.

3. RESULTS AND DISCUSSION

The results of hydrological model calibration are shown in the Table 2.

Table 2: Summary of results of model calibration.

Control Points	Perfomance Measures		
	NS	NSlog	ΔV (%)
UHE São Simão	0.87	0.86	1.0
UHE UHE Água Vermelha	0.94	0.94	1.7
UHE Rosana	0.95	0.93	0.8
UHE Itaipu	0.94	0.94	3.3

After calibration, the hydrological model was applied with input data from the ETA-CPTEC model, and the time series were analyzed in order to obtain maximum discharge values for different return periods (2, 10, 50, 100 years).

The results of the maximum discharge values vs. return period are presented in Figure 2 to Figure 5. In these figures, the dashed lines represent the confidence intervals of results and the straight black line represents the actual behavior of maximums at the location, based in the log-Pearson type III method. Results encompassed by the dashed lines means that there are not enough evidences to rely in the differences pointed between the analyzed futures and the actual maximums behavior. The black line was obtained considering data from 1961 to 1990. The dashed black lines are the 95% confidence interval due to the sample uncertainty. Other colored lines represent the results in future time intervals (yellow line represents results from Fut1; green line represents results from Fut2 and red line represent results from Fut3).

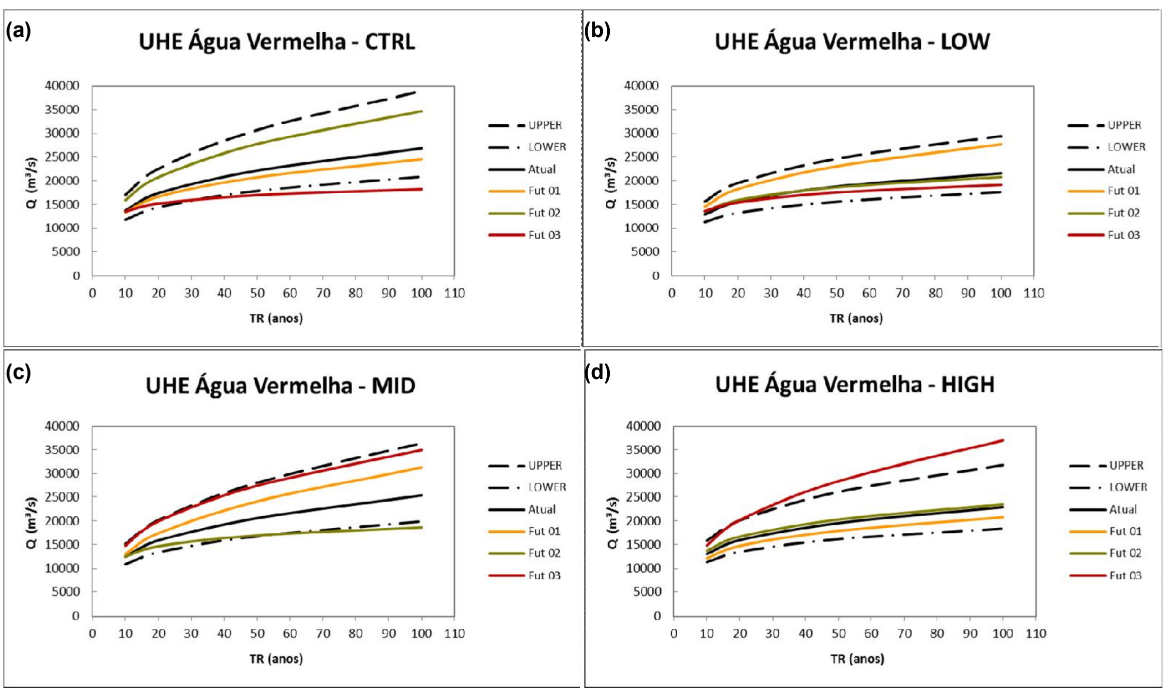

Figure 2: Maximum flow as function of the TR in the current and futures periods at UHE Água Vermelha for members: (a) CTRL, (b) LOW, (c) MID and (d) HIGH. The current period flood frequency and its 95% bounds (respectively thick and dashed black lines).

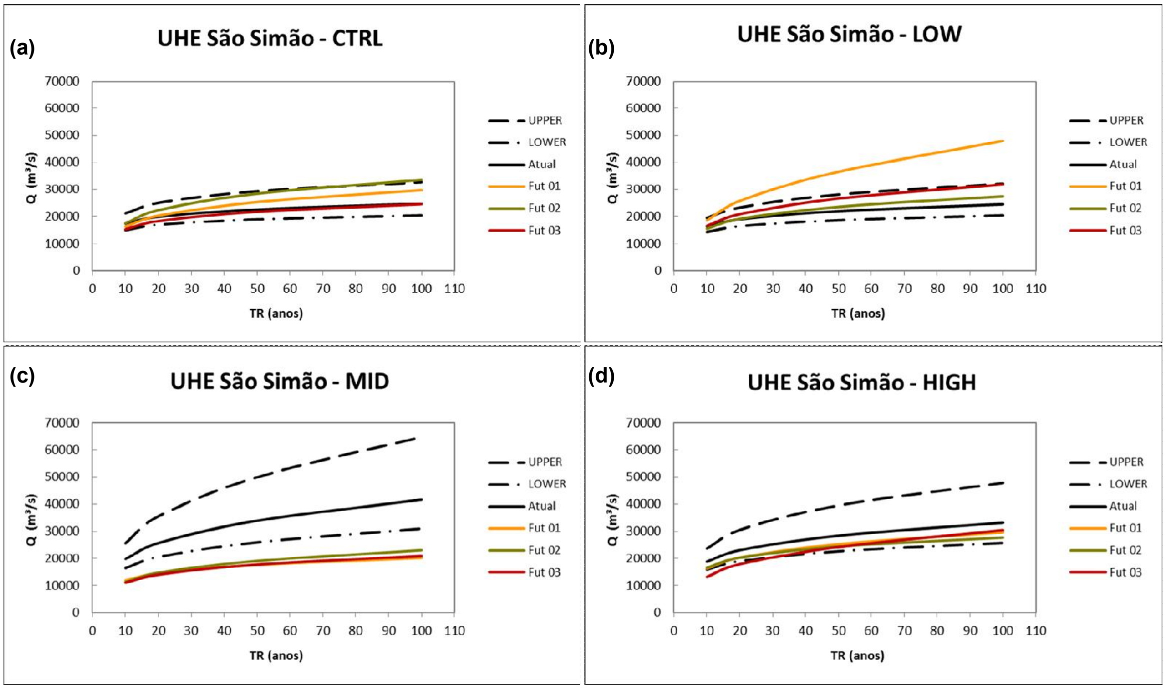

Figure 3: Maximum flow as function of the TR in the current and futures periods at UHE São Simão for members: (a) CTRL, (b) LOW, (c) MID and (d) HIGH. The current period flood frequency and its 95% bounds (respectively thick and dashed black lines).

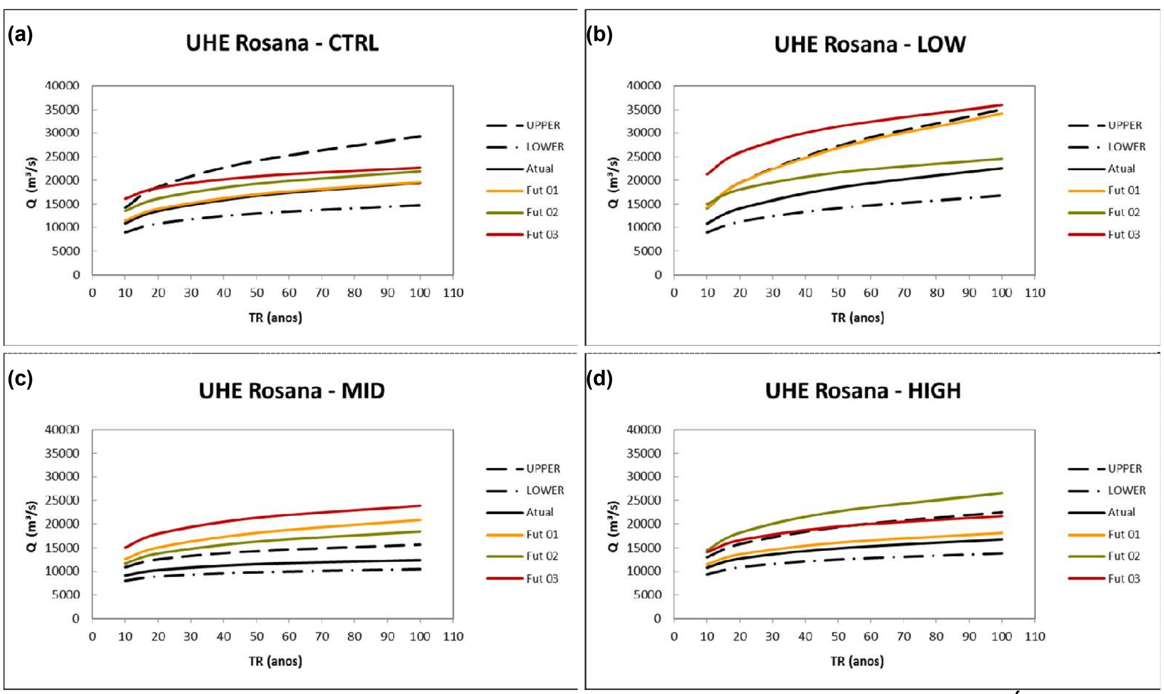

Figure 4: Maximum flow as function of the TR in the current and futures periods at UHE Água Vermelha for members: (a) CTRL, (b) LOW, (c) MID and (d) HIGH. The current period flood frequency and its 95% bounds (respectively thick and dashed black lines).

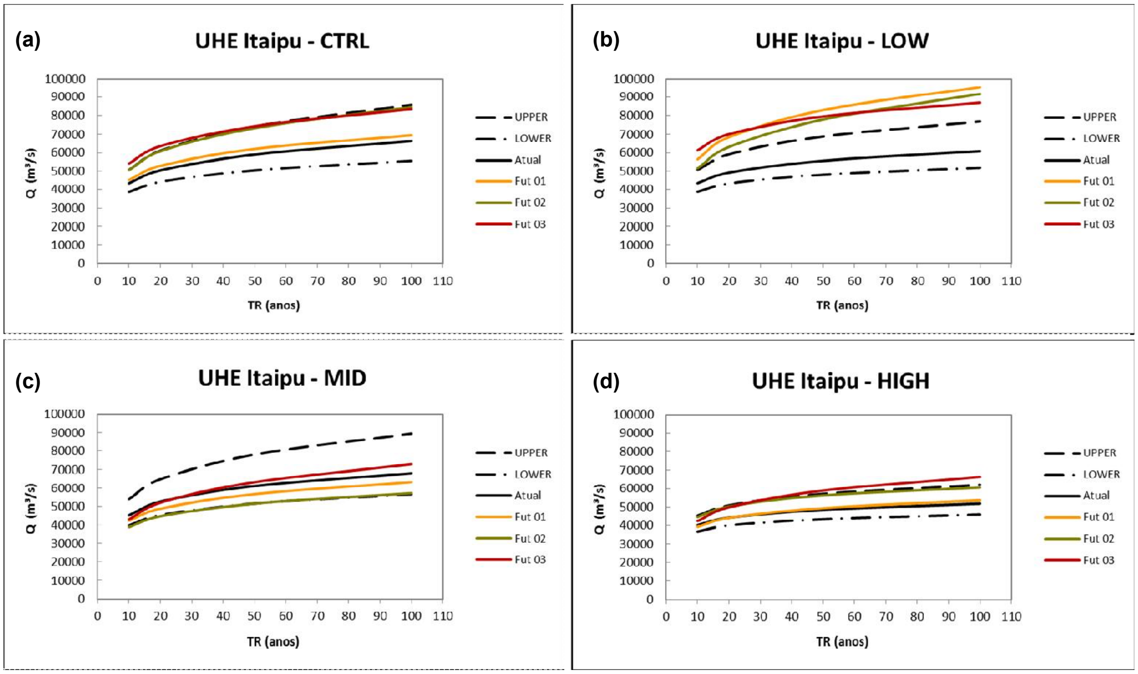

Figure 5: Maximum flow as function of the TR in the current and futures periods at UHE Água Vermelha for members: (a) CTRL, (b) LOW, (c) MID and (d) HIGH. The current period flood frequency and its 95% bounds (respectively thick and dashed black lines).

The Figure 2 shows maximum river discharge obtained at the UHE Agua Vermelha, which is located on the Rio Grande, in the northern part of the Paraná basin. The Figure 2(a) shows results based on future climate projections generated by the CTRL member where maximum river discharge for different return periods are slightly lower during the 2011-2040 period (yellow line) than during the reference period (1961 to 1990 – black line).However, considering data from the next 30 year period (2041-2070 – green line), the maximum discharge is predicted to increase. For the next 30 years (2071-2099 – red line) it decreases again. Both curves for the 2011-2040 and 2041-2070 periods are within the uncertainty bounds for maximum discharges for the reference period (1961-1990), given by the dashed black lines. These results suggest that there is no consistent signal of increasing or decreasing maximum discharges at UHE Agua Vermelha due to climate change, considering the ETA-CPTEC Control member. Some of the periods may have more frequent floods in the future, but other periods may have less frequent floods. In most cases and members, the curves for the future periods are within the uncertainty bounds for the current climate.

On Figure 3, where the results for UHE São Simão location are shown (northern region of Paraná River basin) the members CTRL, LOW and HIGH didn't pointed out significant changes on maximum flows. An exception is the LOW member in Fut1. The MID member at the UHE São Simão location showed a significant decrease on maximums discharge in all futures time intervals. The future maximum discharge values obtained with this member are almost half of the actual values.

On Figure 4, where the results for UHE Rosana location are shown (south-western region of Paraná River basin) results are again significant for the MID member. However, differently to the results at UHE São Simão, at the UHE Rosana place the maximums are pointed to increase (almost double) in the futures. The other members LOW and HIGH also point out that maximum discharge will increases, but only significant at one of the futures time interval.

Finally, on Figure 5, where the results for UHE Itaipu location are shown (outlet of Paraná River basin) the members CTRL and HIGH did not pointed for significant changes on maximum flows. However, the members LOW and MID points to significant and contradictory results. The first one points to a high increase in maximums discharge, where the second one, shows decrease of the maximum discharge in the future.

Results at the UHE Itaipu location are expected to be a summary of the basin, as it is located in the outlet of the Upper Paraná River basin. However, other internal control points showed that the results did not exactly agree with UHE Itaipu in other regions of the basin. This highlights the importance of distributed hydrological modeling and distributed assessments of the results.

Also, based in the significance intervals of the return period assessment, it is possible to interpret that most of the changes pointed by the other members (than MID) are not significant, again with an exception to the Itaipu location changes given by the LOW member. These results suggest that natural climate variability may be more important than climate change.

4. CONCLUSIONS

This study presented an assessment of climate changes impacts on maximum discharge (floods) in the Upper Paraná River basin. The use of daily climate time series generated by ETA-CPTEC to assess extremes streamflows in Brazil can be considered an innovation in comparison to others previous studies in this river basin.

Results show that the impacts on maximum discharges are highly dependent on the model member used to obtain the climate predictions. In almost all control points, results show discrepancies between the intensity and signal of the maximum discharges modification. Control point at Rosana UHE was an exception, where concordance between members was observed, however results were no significant for all of them. In this control point maximum discharges (peak flows) increase under the future climate change scenarios analised.

In most cases projected flood peaks are within the uncertainty bounds of the current climate flood peaks, suggesting that natural variability is at least as important as climate change impacts.

Based in the present results and conclusions, we believe that further studies, with a higher number of climatological models may give a better scenario of possible changes, and may reduce the assessed uncertainties. This will be our focus of next researches in the Paraná River Basin.

5. REFERENCES

Arnell, N. W.; Gosling, S. N., 2013: The impacts of climate change on river flow regimes at the global scale. Journal of Hydrology 486 (2013) 351–364.

Bárdossy, A. and Pegram, G., 2011: Downscaling precipitation using regional climate models and circulation patterns toward hydrology. Water Resources Research, v.47, doi:10.1029/2010WR009689.

Barry, G. R. and Chorley, R. J., 2013: *Atmosfera, Tempo e Clima. 9 ed. Editora Bookman*, Porto Alegre.

Bravo, J.M., Collischonn, W., Da Paz, A.R., Allasia, D., Domecq, F., 2013: Impact of projected climate change on hydrologic regime of the Upper Paraguay River basin. Climatic Change, (DOI 10.1007/s10584-013-0816-2).

Chou SC, Marengo JA, Lyra A, Sueiro G, Pesquero J, Alves LM, Kay G, Betts R, Chagas D, Gomes JL, Bustamante J, Tavares P., 2011: Downscaling of South America present climate driven by 4-member HadCM3 runs. Clim Dyn. doi:10.1007/s00382-011-1002-8

Chow V.T., Maidment D.R. and Mays L.W., 1988: Applied hydrology. Mcgraw-Hill International Editions, Civil Engineering Series.

Collischonn, W.; Allasia, D. G.; Silva, B. C.; Tucci, C. E. M. 2007: "The MGB-IPH model for large-scale rainfall-runoff modelling". Hydrological Sciences Journal, 52, 878–895.

Diaz-Nieto, J., Wilby, R.L., 2005: A comparison statistical downscaling and climate change factor methods: impacts on low flows in the river Thanes, United Kingdom. Climatic Change 69, 245–268.

Eva, H.D., De Miranda, E.E., Di Bella, C.M., Gond, V., 2002: A Vegetation Map of South America. EUR 20159 EN, European Commission, Luxembourg

Fan, F. M.; Collischonn, W. 2014: "Integração do Modelo MGB-IPH com Sistema de Informação Geográfica". Revista Brasileira de Recursos Hídricos (in press).

Farr, T.G., Caro, E., Crippen, R., Duren, R., Hensley, S., Kobrick, M., Paller, M.,Rodriguez, E., Rosen, P., Roth, L., Seal, D., Shaffer, S., Shimada, J., Umland, J., Werner, M., Burbank, D., Oskin, M., Alsdorf, D., 2007. The shuttle radar topography mission. Rev. Geophys. 45 (2).

Gordon, C. C. et al., 2000: The simulation of SST, sea ice extents and ocean heat transport in a version of the Hadley centre coupled model without flux adjustments. Climate Dynamics 16:147–168.

IPCC, 2007. Climate Change 2007. Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovermental Panel on Climate Change. IPCC, Geneva, Switzerland.

Jung I.W., Bac D.H. and Lee B.J., 2013: Possible change in Korea streamflow seasonality based on moulti-model climate projections. Hydrological Processes 27, 1033-1045. Doi: 10.1002)/hyp.9215

Lenderink, G.; Buishand, A.; Van Deursen, W. 2007. Estimates of future discharges of the river Rhine using two scenario methodologies: direct versus delta approach. Hydrology and Earth System Sciences, v. 11, n. 3, p. 1145–1159.

Minville, M., Brissette, F., Krau, S., Leconte, R., 2009: Adaptation to climate change in the management of a Canadian water-resources system exploited for hydropower. Water Resources Management 23, 2965–2986.

Pesquero, J. F.; Chou, S. C.; Nobre, C. A.; Marengo, J. A., 2009: Climate downscaling over South America for 1961–1970 using the Eta model. Theoretical and Applied Climatology.

Pope, V.; Gallani, M.; Rowtree, P.; Stratton, R., 2000: The Impact of new physical parametrizations in the Hadley Centre Climate model. Climate Dynamics 16:123-146.

RADAMBRASIL. 1982. Programa de Integração Nacional, Levantamento de Recursos Naturais. Ministério das Minas e Energia, Secretaria-Geral

Paiva, R.C.D.; Collischonn, W.; Tucci, C.E.M., 2001: Large scale hydrologic and hydrodynamic modeling using limited data and a gis based approach. Journal of Hydrology 406 pages 170–181.

Seaby L.P., Refsgaard J.C., Sonnenborg T.O., Stisen S., Christensen J.H., Jensen K.H., 2013: Assessment of robustness and significance of climate change signals for an ensemble of distribution-based scaled climate projections Journal of Hydrology 486, 479–493

Shabri A (2002) A comparison of plotting formulas for the Pearson Type III distributions. J Technol 36(C):61–74

Taye M. T. and Willems P., 2013: Influence of downscaling methods in projecting climate change impact on hydrological extremes of upper Blue Nile basin

Teutschbein, C.; Seibert, J. 2012. Bias correction of regional climate model simulations for hydrological climate-change impact studies: Review and evaluation of different methods. Journal of Hydrology, 456-457, p. 12–29.

Trenberth, K.E., 2006. The Impact of Climate Change and Variability on Heavy Precipitation, Floods, and Droughts: Encyclopedia of Hydrological Sciences. John Wiley & Sons Ltd. Trenberth, K.E., 2011. Changes in precipitation with climate change. Climate Research 47, 123–138.

Wilby, R.L. and Fowler, H. J. Regional Climate Downscaling. In:. Modelling the Impact of Climate Change on Water Resources. C. Fai Fung; A. Lopez; M. New. (Org.)Willey-Blackwell.

Xu, C.Y., 1999: From GCMs to river flow: a review of downscaling methods and hydrologic modeling approaches. Progress in Physical Geography 23 (2), 229–249.