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► **To cite this version:**

Pauline Enguehard, Pedro Torres Miranda, Alice Fassoni-Andrade, Rodrigo Cauduro Dias Paiva, Ayan Santos Fleischmann, et al.. INUNDATION PROJECTED UNDER CLIMATE CHANGE WITHIN THE CURUAI FLOODPLAIN. XXV SBRH - Simpósio Brasileiro de Recursos Hídricos, Nov 2023, Sergipe, Brazil. hal-04382052

HAL Id: hal-04382052

<https://hal.science/hal-04382052>

Submitted on 9 Jan 2024

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XXV SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS

INUNDATION PROJECTED UNDER CLIMATE CHANGE WITHIN THE CURUAI FLOODPLAIN

Pauline Enguehard¹ ; Pedro Torres Miranda² ; Alice Fassoni-Andrade² ; Rodrigo Cauduro Dias Paiva² ; Ayan Santos Fleischmann^{2,3} ; Frédéric Frappart⁴ ; Frédéric Satgé¹ & Marie-Paule Bonnet¹

Abstract: *Access to water and aquatic ecosystems preservation are among the most important challenges of the 21st century. Hydrodynamic and aquatic ecosystems are dependent on water fluxes in the river and in the floodplains. However, due to their difficult access, these fluxes are poorly understood and a limited amount of data is available to study them. Predictions of flows in rivers and floodplains help to develop sustainable management of water resources and aquatic ecosystems, especially in the Curuai floodplain, at local and global scales. Different climate change scenarios in the Amazon can be used to analyse the hydrodynamic flow response in the floodplain. The MGB software allows access to daily flow data in main rivers of Amazon. The initial simulations are made on 20-year runs from the year 2021 to get the general trend of the discharge evolution in rivers. Three of the twenty-eight possible climate models will be used for the discharge scenarios implementation to conduct a significant effect study of the best (95%), intermediate (50%) and worst (5%) climate model. From the general trend obtained with these three climate models, we will choose three years of interest to study the hydrodynamic effects. Three consecutive 2-year simulations for each of the three climate models will give access to river discharge scenarios. Then, the HEC-RAS software will be used to refine the hydrological inputs in the Curuai floodplain by distributing diffuse discharge in the catchments. With a fine resolution, a local prediction of the hydrodynamic movements can be made.*

Keywords – Amazon floodplains, Climate change scenarios, Discharge projection

INTRODUCTION

Amazon is the world's largest river, fed by numerous tributaries and surrounded by large floodplains. This water storage complex represents a significant part of the hydrological cycle in the basin (Alsdorf et al., 2001; Frappart et al., 2019). Indeed, it plays a key role in the regulation of submersions, flow rates, water quality (Maltby, 1991), evapotranspiration and in biogeochemical cycles (Hamilton et al., 2002). This makes floodplains hotspots of biodiversity because of the life cycle of many fauna and flora species that are synchronized with water cycle (Dudgeon et al., 2006). Nowadays, anthropogenic pressure and climate change are threatening wetlands (*Media Release:*

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Nature's Dangerous Decline 'Unprecedented'; Species Extinction Rates 'Accelerating' | IPBES secretariat, 2019; Moomaw et al., 2018; Renó et al., 2011). Half of the world's wetlands have actually disappeared during the last century (Mitsch & Gosselink, 2007) and so vegetation and fishes hosted in them are endangered.

Evaluation of changes in water supply to the floodplain may be explained by modifications in its supply mode, as well as a different rainfall input and organization of water circulation. To assess these as closely as possible, it is essential to use a discharge model. Indeed, observations are not enough to characterize the future of the floodplain and modeling is a suitable solution to predict the behavior of floods in this region based on historical data and possible evolution of climate. Modeling has been used several times to know better floodplain discharges in the Amazon basin (Bates, 2022; Fassoni, 2020; Ji et al., 2019; Pinel et al., 2020; Wilson et al., 2007) and also at local scale in the Curuai floodplain (Bonnet et al., 2008; Brêda et al., 2020, 2023; Rudorff et al., 2014).

Moreover, time-variations of discharge of the Amazon River system show that significant changes will be induced by local evapotranspiration influenced by deforestation (Coe et al., 2009). Since the recent phase 3b of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP3b ; Lange, 2021) was published, based on output of phase 6 of the Coupled Model Intercomparison Project (CMIP6 ; Eyring et al., 2016), possible evolution of these changes are better identified. The new scenarios are based on a matrix that uses the forcing levels of the Representative Concentration Pathways (RCP) and the shared socioeconomic pathways (SSPs ; O'Neill et al., 2017), a set of five qualitative descriptions of future changes in demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and natural resources. This dataset covers the 1979–2019 period at daily temporal resolution and the entire globe at 0.5° spatial resolution. Future deforestation will also induce changes in soil occupation compared to the previous studies based on data acquired in 1996 (L. Hess et al., 2003) or, more recently, in 2008 (Renó et al., 2011).

In this study, we predict that the impact on large fishery stocks in floodplains will be considerable. Indeed, an important variable for them is the water connectivity with the river and this depends on the flooding events, the humidity, the wind and the occurrence of El Niño-Southern Oscillation events (Pinaya et al., 2016). Information about past connectivity (ANA ; Enguehard et al., 2023) will be used to simulate future connectivity under climate change. This study aims to make projections of the inundation hydrodynamics in the Curuai floodplain and to provide a local and high-resolution maps of the future water supply in the floodplain. The manuscript is divided into the following sections : i) characteristics of the study site, ii) datasets, iii) presentation of the methodology, iv) explanation of the expected results and possible discussion that may be brought from them and v) conclusion.

STUDY AREA

The study is focused on the Curuai floodplain located in the municipality of Obidos (from 1.63° to 2.75° S; from 54.4° to 57° S; Para, Brazil). This vast floodplain of 4,000 km² contains large lakes connected permanently or temporarily to the main river by several channels. The flooded area can vary from 575 km² to more than 2,000 km² during floods; and most important floods have a return period between 5 and 10 years (Bonnet et al., 2008; Calledé et al., 2002). Each year, the storage phase of the floodplain starts between November and January and lasts until May-June. The falling phase begins in July and lasts until November with the greatest volume exported occurring from August to October (Bonnet et al., 2008; Enguehard et al., 2023).

Figure 1 – Study area of Curuai floodplain in the states of Para/Amazonas from 1.63° to 2.75°S and from 53.4° to 57°S
(Background maps: Google Satellite).



DATASETS

HEC-RAS is a software developed by the Hydrologic Engineering Center (U.S. Army Corps of Engineers River Analysis System ; <https://www.hec.usace.army.mil/software/hecras/>) performing two-dimensional unsteady flow calculations. For conducting flow simulation, channel geometry, upstream and downstream boundary conditions, channel resistance and topography are required through HEC-RAS. The large-scale MGB-IPH model uses physical and conceptual equations to simulate hydrological cycles and create time series of water discharge (Collischonn et al., 2007; Pontes et al., 2017; Sorribas et al., 2016) which are used as main upstream and downstream boundary conditions for the floodplain. Existing modeled discharge time series in the Curuai floodplain basins will also be used as inflow (Bonnet et al., 2008). A Manning's roughness coefficient map gives channel resistance based on the wetland cover mapping of Hess et al. (2015). Topography is obtained with MERIT DEM map (Multi-Error-Removed Improved-Terrain DEM; available at http://hydro.iis.u-tokyo.ac.jp/~yamada/MERIT_DEM/).

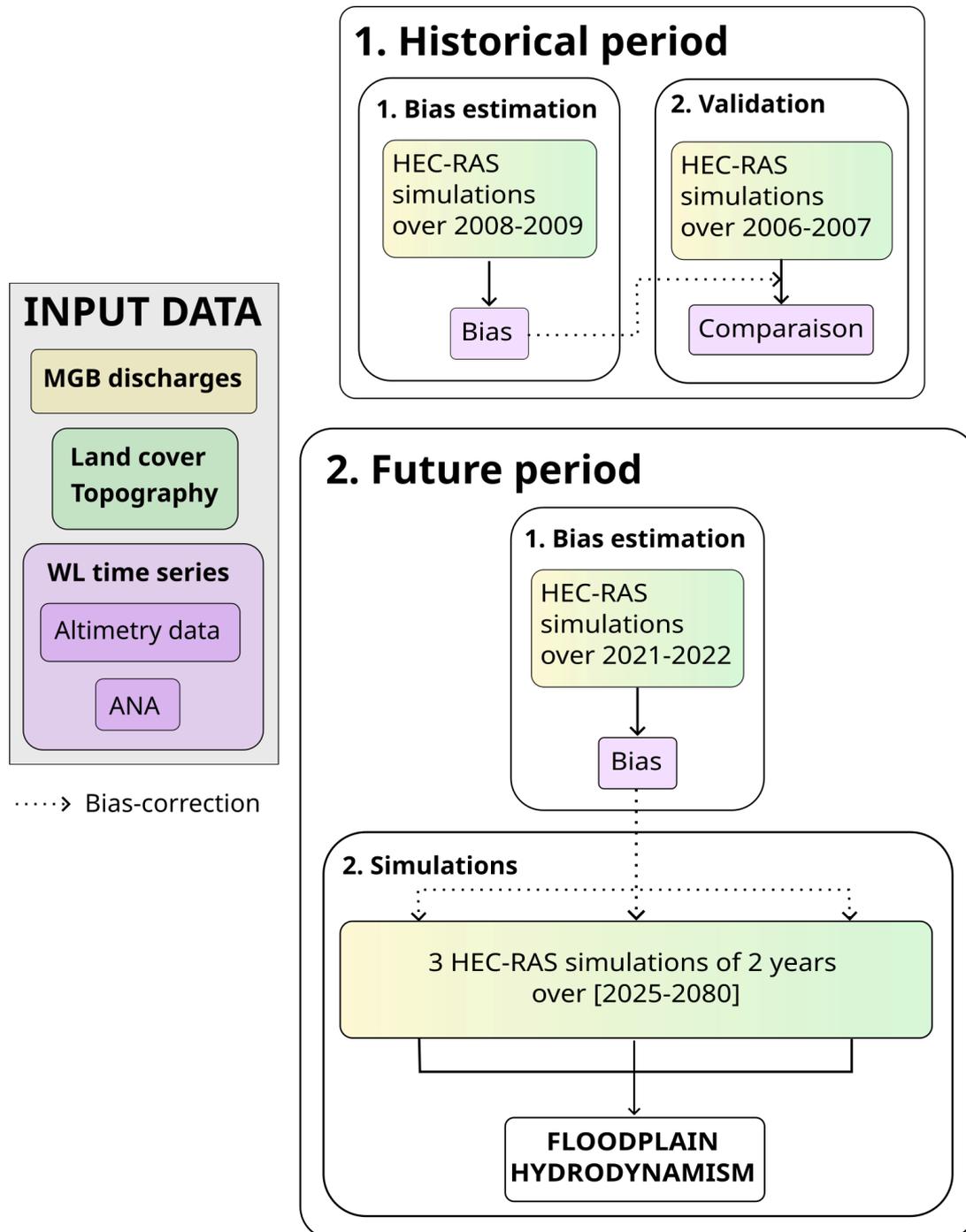
Validation process is made with water level time series from the Agencia Nacional de Aguas e Saneamento Basico observation data (available on ANA website: <https://www.snirh.gov.br/hidroweb/serieshistoricas>) and from a densified water level network obtain from altimetry ENVISAT satellite in the floodplain (Enguehard et al., 2023).

METHODOLOGY

Hydroclimatic scenarios from MGB-IPH are first computed to allow HEC-RAS simulations. The combination of these two models will bring more precise flow discharges in MGB-IPH model and more detailed hydrodynamical fluxes in a local floodplain in HEC-RAS model. The method applied in this study to compute hydrodynamics of the floodplain using HEC-RAS software is summarized in Fig.2. First step consists of achieving the simulations on a historical period (2006-2009) while applying a bias correction to validate results. The bias is calculated as the difference between simulated data from HEC-RAS and the observed data (water level data from floodplain

altimetry network and ANA observations). Then, second step consists in achieving the simulations on several future periods (to be determined) to get the future hydrodynamics of the floodplain with applying the actual bias correction.

Figure 2 – Flow chart of the study methodology. Boxes colours are representing the input data used at each steps.



1. MGB hydroclimatic scenarios

Daily mean discharge in the Curuai floodplain for historical and future periods has been computed with MGB-IPH model and are used as HEC-RAS input data. The model is set to compute scenario results using the Agencia Nacional de Aguas e Saneamento Basico observation data under CMIP6 climate model conditions. To evaluate the impact of climate change, results from three representative climate models are used as HEC-RAS input data. All three are chosen to be best climate models for precipitation simulations as tested in the literature (Jeferson De Medeiros et al., 2022; Monteverde et al., 2022).

2. Historical period

HEC-RAS scenarios are built over the two years 2008-2009 because of the extreme flood and fall of these years (Filizola et al., 2014). For this, terrain data and 2007 MGB-IPH discharge condition scenarios are required. Then, results of water level scenarios are compared to water level in the floodplain and in the river to calculate the bias between the two datasets. To verify the validity of the model, HEC-RAS scenarios are built over the two normal years 2006-2007 this time. Results are bias-corrected and, then, are compared to water level time series in the floodplain and in the river.

3. Future period

For future period, the bias is also calculated for the present period. HEC-RAS scenarios are built over the two years 2021-2022 because of the extreme flood and fall of these years (Filizola et al., 2014). For this, in situ data, water levels in the floodplain and in the river and 2020 MGB-IPH discharge condition scenarios are required. Bias is the difference between water level scenarios and water level observations. To have a good representation of future hydrologic cycles, three interesting years in the middle of the century will be modeled. For each three years, previous year is included as a warm-up year for the model. Results are bias-corrected with present bias and then. For discussion, they can also be compared with projected discharge and water level results from jkyhexisting simulation products (Sorribas et al., 2016).

EXPECTED RESULTS AND DISCUSSION

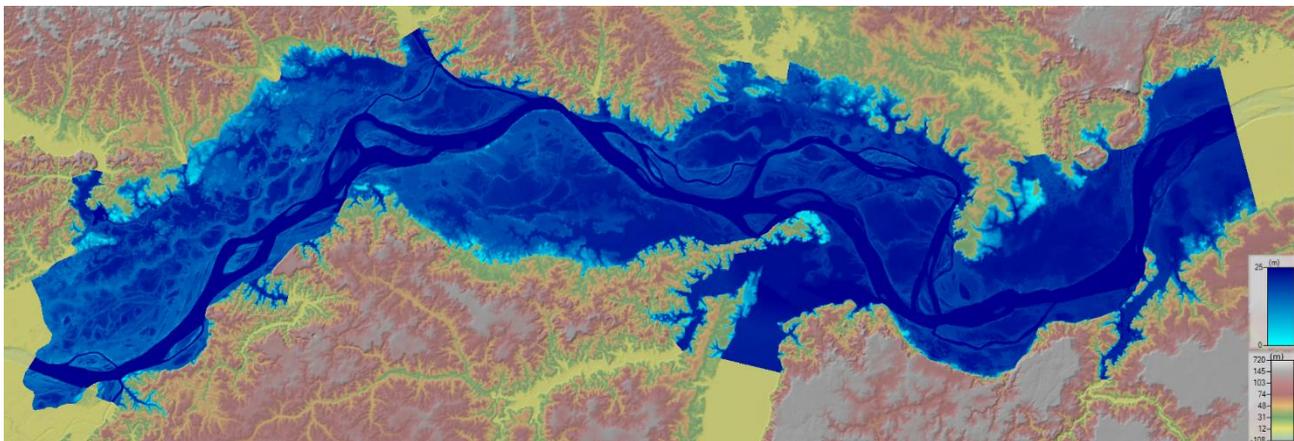
As in Brêda et al. (2023), results show projections for flood discharges in South America based on CMIP5 climate models, we want to use adapted results to CMIP6 climate models and used them to see local hydrodynamic changes in two major Amazonian floodplains. Initial conditions defined by input data need to be precisely explained before scenario simulations to provide a best accurate projections of the hydrodynamic in the floodplains. For that, hydrodynamic changes will be characterized by dimensionless numbers. First one is Froude number which expresses surface waves velocity against flow velocity. Second one is Courant number for express the threshold below which computational instability is observed. If the grid dimension is smaller than the distance traveled in the time step interval by the fastest wave allowed by the equation, the error grows. Numerical movement indicators like speed, direction and magnitude indicators will be also discussed. Figure 3 shows an example of water depth map result made with HEC-RAS model.

Using 25 CMIP5 models for two RCP scenarios 4.5 and 8.5, Brêda et al. (2020) predict a 15% decrease in the mean annual discharge of the Amazon at Macapa for RCP scenario 4.5 and 22% decrease for RCP scenario 8.5. Variations are -9% (RCP 4.5) and -12% (RCP 8.5) for the Solimoes at Manaus, -10% (RCP 4.5) and -13% (RCP 8.5) for the Negro and -14% (RCP 4.5) and -26% (RCP

8.5) for the Madeira. A diminution in the total flooded area is also expected during low-water stages (Pontes et al., 2022; Rudorff et al., 2014; Sorribas et al., 2016).

These changes can have considerable impacts on floodplain filling patterns, water quality and connectivity between the main river and floodplain lakes. The use of the HEC-RAS model will enable us to quantify changes in connectivity. With a less extended flooded area, floodplain lakes would be connected for a shorter period, reducing migration and reproduction time for fishes. HEC-RAS will also permit to identify whether these changes influence the circulation of water masses within the floodplain. The organization of water circulation within the floodplain may have a very high impact on water biogeochemistry, modifying the mixture between lake (from local uplands) and white waters (from the mainstream) (Aucour et al., 2003; Guinoiseau et al., 2018; Moreira-Turcq et al., 2003). It would also operate modifications, depending on the changes in the proportion between the different types of water contribution, such as water flood from the river and surface runoff from the local precipitation in the basin.

Figure 3 – Example of 2007-water depth maximum map result over Curuai floodplain made with HEC-RAS model.



CONCLUSION

This preliminary work is setting up the methodology for a local scale model of the climate change impact in floodplains. Different climate models will be tested to experiment with a large panel of possible evolutions. The HEC-RAS model will give access to high-resolution local hydrodynamics in floodplains and identify changes in hydrodynamic patterns and connectivity between rivers and floodplains, features that govern the biogeochemistry and ecology of floodplains. Our study is a first step towards disentangling the influence of human activities (e.g. dams) and climate change on floodplain characteristics.

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ACKNOWLEDGEMENTS

The first author is grateful to the Occitanie region for funding support and the authors thanks SABERES project (BNP Paribas foundation 2020-2025) and WASACA (Agropolis foundation) fundings. This research is funded in the framework of the BONDS (Balancing biodiversity conservation and Development in Amazon wetlandS) project funded through the 2017–2018 Belmont Forum and BiodivERSA joint call for research proposals, under the BiodivScen ERA-Net COFUND programme, and with the funding organisations French National Research Agency (ANR), São Paulo Research Foundation (FAPESP), National Science Foundation (NSF), the Research Council of Norway and the German Federal Ministry of Education and Research (BMBF). The

authors would also thanks the contribution of the CNES's TOSCA SWOT SWHYM project and the PROGYSAT project (Projet de Coopération Régional d'Observation des Guyanes par Satellite) of the PCIA (Programme de Coopération Interreg Amazonie).