

Climate Change Scenarios in the Pantanal

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Abstract The South America Pantanal is a large floodplain wetland in the center of the Upper Paraguay River Basin, which has a total area of around 360,000 km². Large sectors of the Pantanal floodplain are submerged from 4 to 8 months each year by water depths from a few centimeters to more than 2 m. Changes in rainfall and temperature and also on land use can affect significantly the flood season with severe consequences for downstream inhabitants. However, impact of climate change on wetlands is small so far compared to the damage caused by the lack of management at the local level due to land-use change. In this chapter we assess climate and hydrology variability for the present and projections of climate change using the global climate models from the Fifth Assessment Report (AR5) from the Intergovernmental Panel on Climate Change (IPCC). Projections show that by the end of the century, temperatures can increase up to 7°C and rainfall can decrease in both summer and particularly winter. The possibility of longer dry spells and increased evaporation may affect the water balance in the region. However, uncertainties on climate projections are still high, particular for rainfall.

Keywords Climate change, Drought, Flood, Uncertainty, Wetland

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1 Introduction

The South America Pantanal is a large floodplain wetland in the center of the Upper Paraguay River Basin, which has a total area of around 360,000 km². The Pantanal spreads for about 140,000 km² and is shared among Brazil (80%), Bolivia (19%), and Paraguay (1%). During the summer rainy season (November–March), the rivers overflow their banks and flood the adjacent lowlands, forming shallow lakes and innumerable swamps and marshes and leaving island-like areas of higher ground that inundates as much as 70% of the floodplain until July. Large sectors of the Pantanal floodplain are submerged from 4 to 8 months each year by water depths from a few centimeters to more than 2 m. During the drier winter season (April–September), the rivers withdraw into their banks, but the lowlands are only partially drained. The water leaves via the Paraguay River and eventually into the Paraná River, leaving behind grasslands that support grazing animals.

The Pantanal functions as a large reservoir that stores water from the surrounding plateaus during the rainy season and then delivers it slowly to the lower sections of the Paraguay River, delaying for almost 6 months the maximum flows to the Paraná River, thereby minimizing downstream flooding. As a result, any significant change in the rainfall pattern is likely to have major impacts on the local ecology and socioeconomic relations. The peak flood season for the lower Paraná River basin is 2–3 months earlier than the flood season for the Upper Paraguay River. Without the Pantanal, the two flood seasons would be simultaneous, with severe consequences for downstream inhabitants. Conversely, during dry seasons, the Pantanal continuously releases water, meaning that there is more water available downstream when it is needed most.

Climate change is expected to have serious impacts on the Pantanal, and a range of institutional responses has been developed to mitigate and adapt to climate change [1]. While anthropogenic climate change is expected to have serious socioecological consequences around the globe, in particular for wetland areas, land-use changes also can affect climate and hydrology in the region [2]. The impact of climate change on wetlands is small so far compared to the damage caused by the lack of management at the local level. Lessening the stress on wetlands caused by pollution and other human assaults will improve their resiliency and represents an important climate change adaptation strategy.

2 Climate and Hydrology in Pantanal

The Pantanal is located in a tropical and damp climate zone. The average air temperature is 24°C. The Pantanal is a semiarid region. The annual amount of rain is 1,000–1,250 mm, which corresponds to 67–83% of the rain in the neighboring areas in the states of Mato Grosso and Mato Grosso do Sul. Rainfall shows interannual variability with higher or lower rainwater amounts that have caused either severe floods or drastic dry seasons, influencing the flooding. Large-scale climate phenomena such as El Niño, La Niña, or the variability associated to the Atlantic Ocean as well as regional-scale water balance and soil wetness and soil moisture storage influence the seasonality of floods and droughts in the Pantanal [3].

Although the annual temperature value is relatively constant, the temperature sometimes drops down as far as to -1°C or rises as far as to 41°C . The reason for these thermal contrasts is a north-to-south shift in the air currents between the Andes in the west and the Central Brazilian Plateau in the east. In winter (June, July, and August), this corridor channels the cold winds streaming from cold fronts moving northward and thus causes a distinct temperature drop (called “friagem” in the Pantanal). Sometimes this phenomenon can be experienced up to five times a year, while in some years it does not occur at all. This cooling reaches as far as the Amazon valley. One such instance was in July 1975, when the Brazilian west experienced the “chill of the century”: cold, dry winds blew across the Pantanal at a speed of 40 km/h and the temperature dropped to 0°C in one night [4].

Interannual rainfall variability with higher or lower rainfalls has caused either severe floods or drastic dry seasons. Marcuzzo et al. [5] and Cardoso and Marcuzzo [6] analyzed the monthly trends in precipitation from 1977 to 2006 from 12 rain gauge stations in Brazilian Pantanal. They noticed a moderate decrease in precipitation and a high interannual variability in this region. They showed a gradual decrease for precipitation from decade 1977 to 1986 to decade 1997 to 2006. Garcia and Pedraza [7] analyzed the temporal variation in the total number of days a year with rainfall and the number of days a year with rainfall above the 100 mm threshold at the rain-gauging stations in northeastern Argentina. The results show an increase in both the frequency of daily rainfall, especially during the winter season, and the frequency of days with heavy rainfall starting in the early 1970s.

According to Alho and Silva [8], El Niño and La Niña influence the seasonality of floods and droughts in the Pantanal. Furthermore, the role of land surface processes on the hydrology of Pantanal is highlighted by Clarke et al. [9]. In this regard, Collischonn et al. [10] assessed the flow records from the rivers Paraguay, Paraná, Negro, and Uruguay in the La Plata Basin and rainfall records from other parts of South America. They found strong evidence of changes in the runoff regime of the La Plata Basin during the last 40 years, not all of which can be attributed to land-use change. This increase in annual precipitation in the last 40 years has been more than 10% over most of the region, but in some places it has reached 30% or more [11, 12].

Analysis of the 105-year record of annual flood peaks at Ladário, downstream of the Pantanal wetland, shows strong evidence of serial correlation between flood peaks in successive years, and the sequence of annual flood peaks is well represented by a lag-one autoregression [9]. He found that no direct relation could be established between Ladário flood peaks and the limited records of Pantanal rainfall, nor did there appear to be any relation between Ladário flood peaks and El Niño/La Niña events. The large volume of natural storage within a drainage basin has a marked effect on its regime of hydrologic extremes. This is somewhat responsible for the lower climate predictability on the region, since soil moisture and natural water storage are still not well represented on climate models.

Alho and Silva [8] show that during the period from 1962/1963 to 1972/1973 in the Pantanal, it was unusually dry (see also Assine et al. [13]). This was then followed by a long wet period, which has lasted until the present day. During the 11-year dry period, there were no records of flooding, except for 1965–1966, when 16 cm of water was observed above the zero mark (82.4 m in relation to sea level), and the majority of the flooding peaks were observed between 1 and 2 m. Since 1973/1974, the Pantanal has been experiencing a period of inundations, with the flood gauge reaching its peak at Ladário in 1988, with a 6.64 m reading. This was considered the Pantanal's greatest-ever inundation. This flood period, which has already lasted for 38 years, is the longest recorded for the region and is different from the previous periods in that the phreatic water (the upper surface of the soil that forms the water table) has risen throughout the entire year, which results in lower intra-annual and interannual variation in droughts and floods. Furthermore, the position of the average river watermark has remained between 3 and 4 m and the minimum mark between 1 and 2 m for the greater part of the year.

According to Gonçalves et al. [14], the year with the most memorable floods due to high Paraguay River levels was 1988. During the record flow in 1988, about 95% of the Pantanal plain was flooded. The Ladário station registered, during the outflow of 2007, one of the lowest minimum levels of the last 34 years, that is, 88 cm on 3 November 2007. A dry period between 2010 and 2012 showed 85 cm water level; however, the lowest record was in 1964–1973 with 75 cm. In accordance with the classification by Galdino et al. [15], the flood in the hydrologic period 2007–2008, as well as the floods of the two previous years, may be considered “normal,” that is, when the maximum water level in Paraguay River ranges between 5.00 and 5.99 m in Ladário. According to Fantin-Cruz et al. [16], the highest flood was that of 1995 when the floodplain was flooded to a mean depth of 2.56 m. The median flood event (return period 2 years) produced a mean flood depth 1.80 m and lasted 119 days.

Knowledge of severe floods and droughts, which characterize natural disasters in the region, is fundamental for wildlife management and nature conservation of the Pantanal. Plants and wild animals, for example, are affected by tree mortality in riparian forest after extreme flooding, with consequent habitat modification for wild animals. In addition, human activities are also affected since cattle ranching and ecotourism are economically important in the region, and when seasons with unusual floods or droughts occur, areas with human settlements are impacted.

3 Assessment of Climate Change Projections for Pantanal from Global Models

Various studies analyze climate projections data from IPCC Fourth Assessment Report (AR4) and from downscaling experiments using various regional models forced with some of the IPCC AR4 models. The CMIP3 (Coupled Model Intercomparison Program Version 3) represents an archive from all IPCC AR4 models. Some downscaling experiments have been run for various SRES (Special Report Emission Scenarios), among them A2-high emission and B2-low emission, that represent high and low emissions. The projections for the A2 scenario suggest an increase in temperature of the order of 3.5–4.5°C by the end of the twenty-first century, with decreases in the number of cold nights during winter months and decrease in precipitation between 35% and 45%, with an increase in the frequency of consecutive dry days for the entire region [17–20].

For the Pantanal climate change scenarios, we assess the projections from IPCC models used on the Fifth Assessment Report (AR5), stored at the CMIP5 archive. For the IPCC AR5 model runs, the scenario used is the RCPs *Representative Concentration Pathways* [21] that have replaced the SRES. The RCPs represent radiative forcing, where the RCP2.6 represents a scenario with low emissions and low radiative forcing (similar to SRES B1 or B2). The RCP8.5 represents a larger radiative forcing and is similar to a high emission scenario (SRES A1 or A2).

A comparison between the warming projected by 2100 derived from the SRES scenarios used in IPCC AR4 and the RCPs used in the IPCC AR5 is shown in Fig. 1.

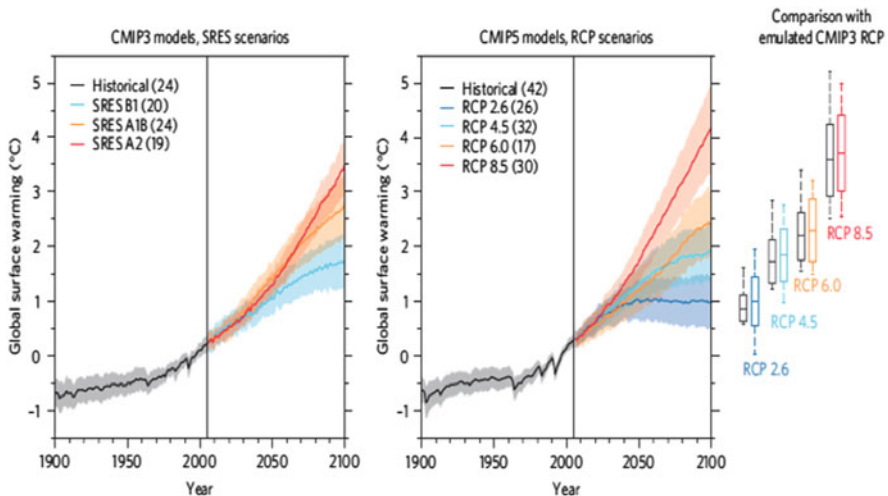


Fig. 1 Changes in mean temperature (*color lines*) and uncertainties (*shades*) relative to 1986–2005 for the SRES IPCC AR4 (*left*) and RCPs of IPCC AR5 (*right*). The number of models is indicated in parenthesis. The *boxes on the right side* of the panel show the mean and the *whiskers* show the standard deviation on the projected warming by 2100 for each scenario [22]

Table 1 List of CMIP5 global models used on this report, showing horizontal resolution (latitude/longitude). The models are organized according to their horizontal resolution [23]

Model	Resolution (latitude/longitude)
CanESM2	$2.8^\circ \times 2.8^\circ$
MIROC-ESM	$2.8^\circ \times 2.8^\circ$
GFDL-ESM2M	$2.0^\circ \times 2.5^\circ$
IPSL-CM5A-LR	$1.9^\circ \times 3.8^\circ$
NorESM1-M	$1.9^\circ \times 2.5^\circ$
CSIRO-Mk3-6-0	$1.9^\circ \times 1.9^\circ$
MPI-ESM-LR	$1.9^\circ \times 1.9^\circ$
CNRM-CM5	$1.4^\circ \times 1.4^\circ$
MIROC5	$1.4^\circ \times 1.4^\circ$
HadGEM2-ES	$1.3^\circ \times 1.9^\circ$
MRI-CGCM3	$1.1^\circ \times 1.1^\circ$
CCSM4	$0.9^\circ \times 1.3^\circ$

The similarities between SRES and RCPs scenarios can be noted, and by 2100 the RCPs seem to show the highest warming.

The CMIP3 and CMIP5 model output is available from the data archives of the Program for Climate Model Diagnosis and Intercomparison (PCMDI, <http://www.pcmdi.llnl.gov>) and the Earth System Grid data distribution portal (ESG, <http://www.earthsystemgrid.org>).

Climate changes simulated in the CMIP3 and CMIP5 ensembles are not directly comparable because of the differences in prescribed forcing agents (e.g., CO₂ and aerosols) between the SRES and RCPs scenarios. Furthermore, the models may respond differently to a specific radiative forcing due to different model-specific climate sensitivities. However, based on the underlying radiative forcing (or CO₂ concentrations), one can compare projected changes in the temperature and precipitation indices and provide an estimate of uncertainty related to the different emission scenarios.

In the following the assessed projections of changes in summer and wintertime temperatures and rainfall from the IPCC AR5 models are shown in Table 1 and consider the RCP8.5 only. Figure 2 shows warming between 4°C and 7°C for the Pantanal region for both summer and winter, and while all months agree in the warming for the 2071–2100, some models have shown warming of up to 10°C and other shows warming between 3°C and 4°C.

For rainfall changes, Fig. 3 shows that in December–February (DJF) summer season, the model ensemble show changes between –10 and +10%, and while some models show increase of about +25%, others reduction between 20% and 30%, suggesting large uncertainties in the rainfall projections. During the austral winter June–August (JJA), the model ensemble suggest rainfall reductions between 30% and 40%, but there is still low consensus, since some models show reductions of the order of 60% and others show increase of about 70%. Therefore, from both regional and global model projections, changes in rainfall during the summer peak and

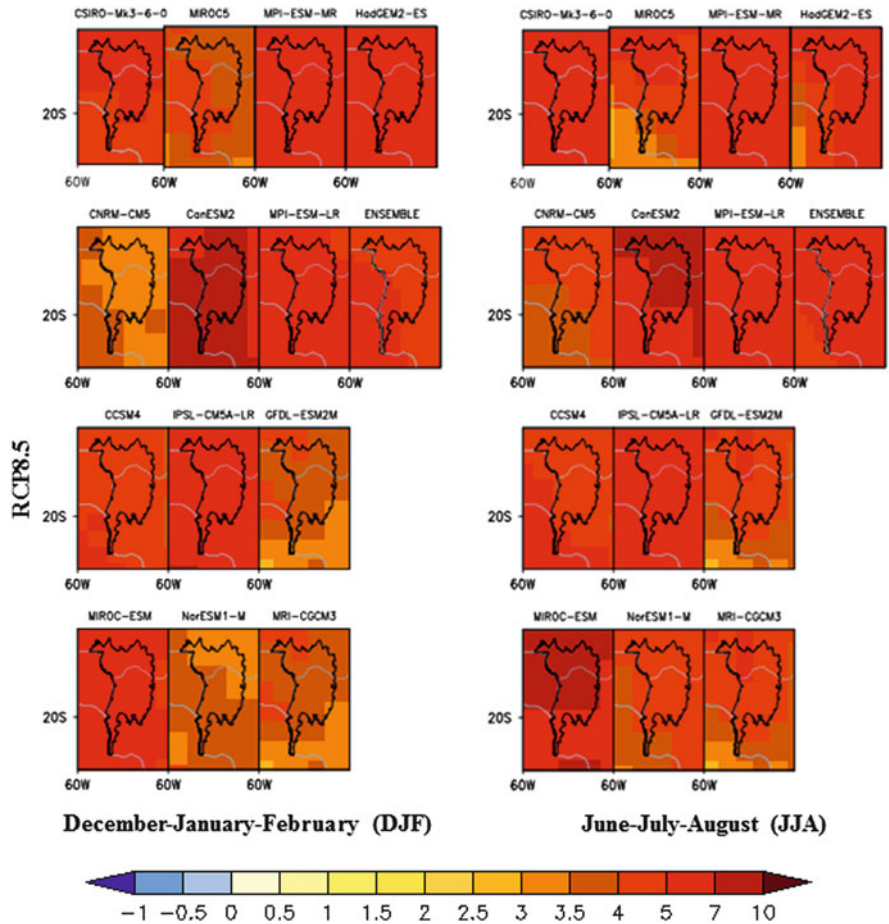


Fig. 2 Changes in air temperature (°C) in Pantanal region for summer (*DJF*) and winter (*JJA*) 2071–2100 relative to 1961–1990 derived from CMIP5/IPCC AR5 global models (listed on Table 1) for the scenario RCP8.5

during the winter dry season are uncertain, as shown by the large intermodel divergence.

The time series depicted in Fig. 4 (a and b, respectively) show that the increases in air temperature are more noticeable in both DJF (summer) and JJA (wintertime) seasons, reaching up to 6°C in 2100 and varying between 3.5°C and 9°C among models. On the near term, up to 2040, the warming could reach 2–3°C, and by 2070, it may reach 4–5°C. Rainfall changes are uncertain (Fig. 4c and d), but there is a slight tendency for reduction in JJA. The tendency is strong on the second half of the twenty-first century (Fig. 4d), but the scatter among model members is extremely large, suggesting high uncertainty on rainfall projections, particularly for the dry season.

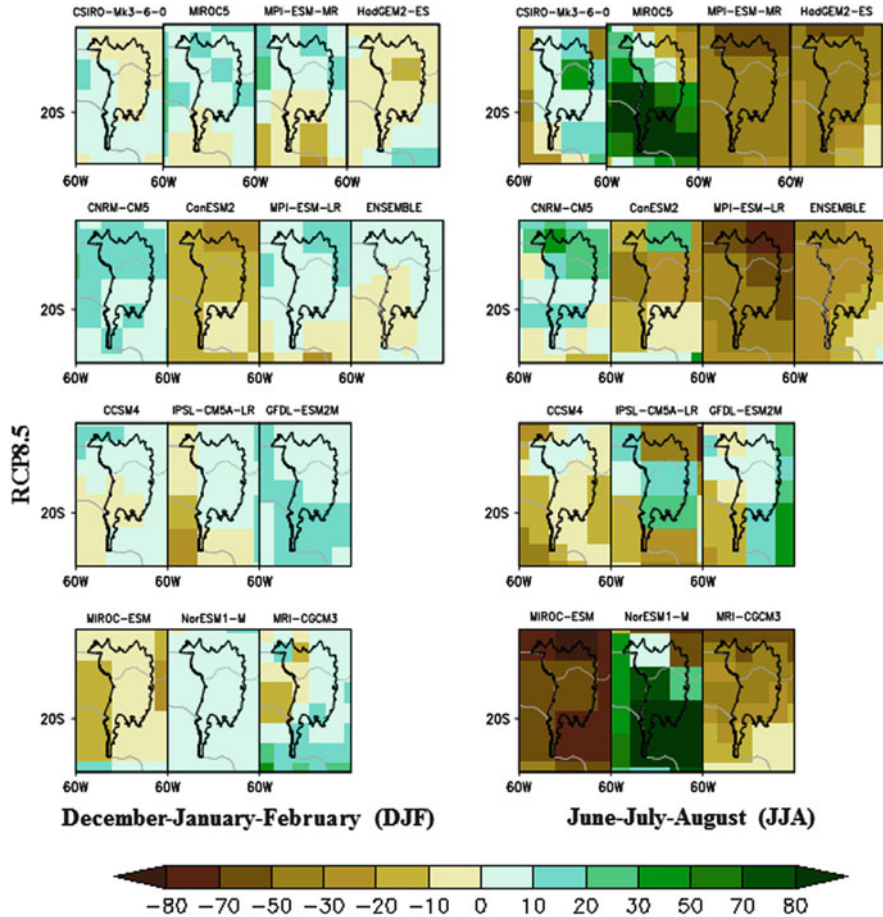


Fig. 3 Same as Fig. 2 but for rainfall (in %)

As for the water balance in the region, with higher temperatures and rainfall reductions by the end of the twenty-first century, Kirtman et al. [24] indicate changes in the components of the water balance derived from the CMIP5 models for the RCP8.5 scenario: annual mean runoff on the region is projected to decrease by about 0.1–0.2 mm/day, and with the reduction in relative humidity by about 4–8%, there is a tendency for evaporation increase by about 0.2–0.4 mm/day and consequently a reduction in near surface soil moisture by about 1–2 mm/day.

On changes in extremes, maximum and minimum temperatures are expected to increase by about 5°C by 2071–2100 relative to 1986–2005, together with an increase in the number of days with warmer nights (by about 70–90 days), with an increase in the number of consecutive dry days by about 20 days, and also an increase in intense precipitation by 10–20%. These scenarios suggest longer dry spells with higher temperatures and water deficiency in the soil, separated by short

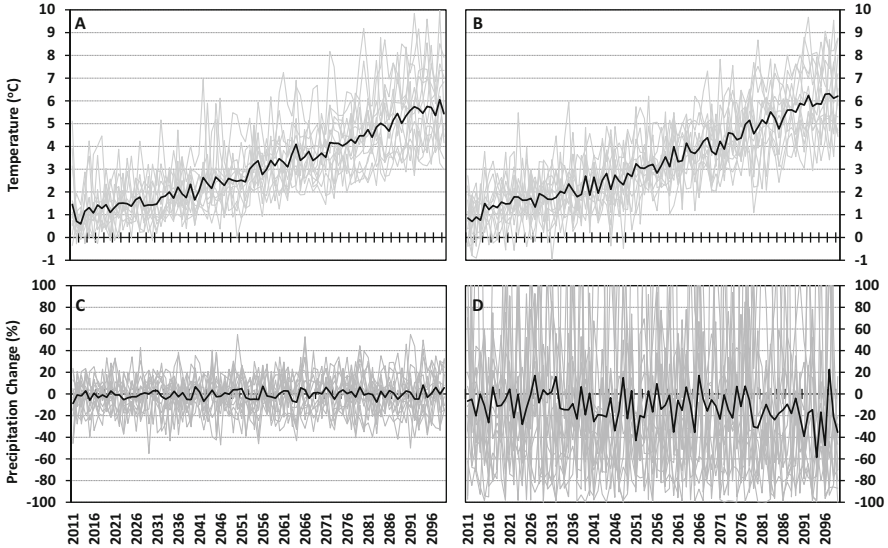


Fig. 4 Time series of air temperature anomalies (a, b) and rainfall anomalies (c, d) with respect to 1961–1990 for the Pantanal region for 2011–2100 (gray lines) and multi-model ensemble (black thick line) under RCP8.5 for austral summer DJF (a, c) and winter JJA (b, d)

intense rainfall episodes for the future. While total rainfall is expected to decrease both in summer and winter and the possibility of increase in soil water deficiency, it is hard to conclude on projected changes on the flood pulse in the Pantanal region for the future.

4 Options for Adaptation and Sustainable Development Under Climate Change Risk

Climate change, conversion of habitat into agricultural use, and upstream uses of water are the greatest threats to the Pantanal. Knowledge of severe floods and droughts, which characterize natural disasters, is fundamental for wildlife management and nature conservation of the Pantanal. In addition, human activities are also affected since cattle ranching and ecotourism are economically important in the region, and when seasons with unusual floods or droughts occur, areas with human settlements are impacted.

Throughout the past two centuries, the Paraguay River watershed and, in particular, the Pantanal have sustained productive activities. This has been especially the case with beef production, since large extensions of natural pasturelands have been used while adapting cattle ranching to the typical flood pulse of the Pantanal. On the other hand, the possible future changes in climate and aquatic ecosystems in Brazil are highly uncertain [25].

In spite of the general information regarding the effect of climate change in wetlands, including the effect in the Pantanal and its watershed, this information is dispersed and insufficient in describing the magnitude of the impacts of climate change in this ecoregion. World Wide Fund for Nature (WWF) started in 1998 a program to assess impacts of climate and hydrology change through conservation programs in both Bolivia and Brazil. Their focus was (a) the identification of impacts and risks associated with climate change, developing and implementing adaptation strategies, and (b) the recognition of sustainable cattle ranching as a conservation and development strategy for the Pantanal. Their final objective is on systematizing existing information and making it available to key stakeholders working on climate change. Having this information organized will also allow identifying where research still needs to advance, as well as designing strategies that reduce the vulnerability of the watershed in face of climate change. Sustainable cattle ranching activities in the Pantanal consistently link environmental protection with economic development in the region. In addition, it reinforces productive practices and traditional cultural values that, in turn, reinforce the Pantanal's identity and become a real opportunity to make the economic interests of cattle ranching compatible with conservation [26].

It is extremely important to develop and propose options for the Pantanal including an integral vision in relation to changes in climate and land use (see also Pott and Silva [27] and Buller et al. [28]) and their synergic impacts on the Pantanal ecohydrological pulses. Assine [29] has shown that natural changes in the Taquari megafan hydrology were accentuated by the land use in the Upper Taquari Basin. On the other hand, Bergier [2] has shown that the runoff/discharge of the rainfall in the uplands has increased due to upland deforestation over the last four decades. As a result, even for less rainy years, the maximum annual flood pulse in Ladário keeps always elevated, usually above 3 m. The upland soil management by agroforestry (see Buller et al. [28]) is therefore very relevant for restoring the natural interannual flood pulse dynamics and to improve the resilience of the wetland ecosystems in the lowlands with regard to future climate change risk.

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