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Impact of ENSO on the Paranaiba Catchment, Brazil

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Synopsis

The impact of El Niño Modoki has been found in the rainy season extremely low discharges events during the MAM at the Fazenda Santa Maria gauge station of the Paranaiba River basin. The stream-flow at the Fazenda Santa Maria gauge station of the Paranaiba River in Brazil shows significant flow during December to May and very less flow during June-October. Extreme events are identified based on their persistent flow for 5 days and more. During MAM season when the seasonal mean streamflows are among the peak, 40% of the extremely low discharge events are occurred during the positive phases of the central Pacific warm pools of this season. However, none of the low-stream-flow events were associated with canonical El Niño events. On the other hand extremely high streamflow events are unprecedentedly associated with the El Niño Modoki years. Most of the high streamflow events are occurred during El Niño Modoki or nIOD phases. Alhough climate variations have direct relationship with the rainfall, streamflow characteristic are considered as the surrogate to rainfall. However, apart from climate variations streamflow are also influenced by the human or nature induced land-use changes need to be examined.

Keywords: Climate variability, Paranaiba River, IOD, ENSO, ENSO Modoki, Streamflow

1. Introduction

The ENSO phenomenon has been influences the climate patterns of the south America, particularly northeastern Brazil,Uruguay and northeastern part of Argentina.The positive anomalies of the sea surface temperature(SST) in the equatorial Pacific increases precipitation in the south of Brazil (Grimm *et al.,* 1998) and decreases precipitation in the northeastern Brazil (Rao and Hada,1990).Similar studies has been made by various other researchers as well. The influences of climate to the streamflows has been studied by Sahu *et al.,* (2011a, 2011b,2012) in their previous studies of Indonesia and found very good correlation of the impact of climate variability to the streamflow. Streamflow plays a major role to the livelihood of the people in a river catchment. Hence the scientific analysis of streamflow is very essential for the present and future generations.

Streamflow is a synthesis of precipitation, evapotranspiration and the rest of the hydrologic cycle components, together with possible anthropogenic influences. Not all the signals present in precipitation are reflected in river flow and vice versa. In this study we investigate the ENSO (El Nino and Southern Oscillation) and ENSO Modoki (Ashok et al., 2007) relationship at the basin scale. In general, it is easier to detect a change in discharge than to directly observe changes in the basic climatic variables. Moreover, we could assume that any signal in the river flow must have a climatic origin. Several studies performed on southeastern South America have used river flows as indicators of climatic variability from the interannual to the secular scale. In essence, we will analyze whether the Paranaiba River flow is a good surrogate in studying the climatic variability of precipitation from the interannual to the secular scale.

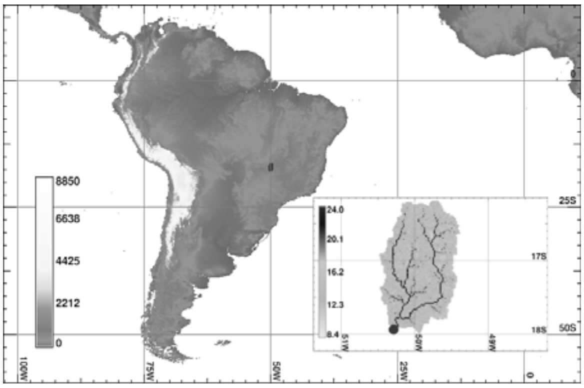


Figure 1 The Citarum river catchment with Nanjung gauge station and three reservoirs, the Saguling, Cirata and Jatiluhar (Juanda) from upper to lower stream respectively.

2. Study Area

The Paranaiba River source lies in the state of Minas Gerais in the Mata da Corda Mountains (19^0 13′ 21″ S and 46^0 10′ 28″ W), of Rio Paranaiba of Brazil, is flowing at an altitude of 1,148 meters. The length of the river is approximately 1,000 kilometers up to the junction with the Grande River both of which then form the Parana River (e.g., IGAM, 2008). The catchment area is approximately 36,000 km^2. The main tributaries of the Paranaiba are the Sao Marcos,the Corumba,the Meia Ponte and the Bois. Major dams on its course are the Emborcacao, Itumbiara and Sao Simao. Cachoeira Dourada near Itumbiara is one the most important hydroelectric power stations in Brazil, providing energy to Goiania and Brasilia. However, Fazenda Santa Maria gauge station (17^0 58′ 51″ S and 50^0 14′ 49″ W, Fig. 1) is in the Upper Paranaiba river catchment and having a catchment area about 16,750 km^2. The Upper catchment is not artificially regulated, thus it is best suited for our analysis to minimize anthropogenic influences on streamflow. This river is the most important resources of water to the Parana River.

3. Data and Methods

The topographic data used in this study were extracted by using ETOPO1 elevations global data. ETOPO1 has a spatial resolution of one minute and has been available from National Geophysical Data Center (NGDC), National Oceanic and Atmospheric Administration (NOAA). The topographic data were composed by basin boundary, slopes, cells distances (distance to the next downward cell), cells areas and cumulative areas. Precipitation data were obtained from ANA (Brazilian National Agency of Water Resources) in two stations: Fazenda Aliança and Maurilândia. Meteorological data (radiation and temperature) were extracted from Hirabayashi et al. (2008) re-analysis. They developed and assessed a global 0.5 degree near-surface atmospheric data from 1948 to 2006 at daily time scale.

Potential evapotranspiration was estimated through the Priestley-Taylor radiation method (e.g., Priestley and Taylor, 1972). This method delivered good estimates of actual evapotranspiration in a small forest. Lu et al. (2005) compared six potential evapotranspiration methods and concluded that radiation based methods performed better than temperature based methods. Furthermore, this method is a good alternative when all the necessary data for the Penamn-Monteith (e.g., Doorenbos and Pruit, 1992) method are not available. Priestley-Taylor radiation method uses radiation data, average daily temperature, air pressure and an empirical constant. Air pressure values were derived from the elevation data and the empirical constant was set to the unit. Flint and Childs (1991) shows values of the empirical constant varying from 0.72 to 1.

As TOPMODEL is a lumped hydrological model, an aerial average daily precipitation and evapotranspiration data were used as input. For this period (1974 – 2005) the mean precipitation value was 3.94 mm with a maximum value of 108.95 mm,

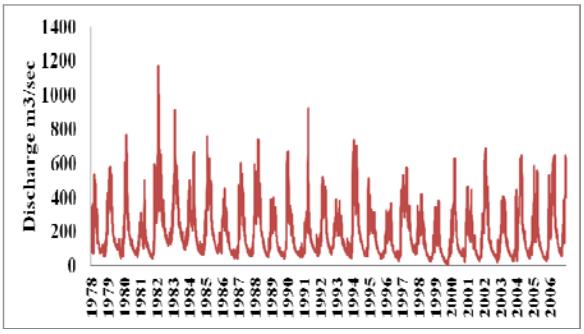


Figure 2 Discharge at Fazenda Santa Maria station from 1974-2008.

whereas the mean evapotranspiration value was 4.11 mm with a maximum value of 6.37 mm and minimum value of 2.34 mm. Daily discharges data were acquired from ANA at Fazenda Santa Maria station. They encompass the period from 1974 to 2005. The last six years (2000 – 2005) of this time series were used for model calibration purpose and the entire time series was used for model validation purpose.

We use observed daily discharge data at the Fazenda Santa Maria gauge station of the Paranaiba River in Brazil for the period from 1974 to 2006 as a primary data set for this study. Daily climatology and anomalies of river discharge are computed from the 33-year data. Extremely high and low discharge events were cataloged based on a threshold; 1.5σ (σ stands for standard deviation) and -1.5σ are set as threshold for extreme high and low discharges, respectively.

The NCEP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research) global atmospheric reanalysis-1 zonal wind (850 hPa) dataset is used from 1 January 1979 to 31 December 2008. The other major dataset used in this study is the global coverage NOAA interpolated of daily averages of outgoing longwave radiation anomalies (here after OLR) data on a 2.5° × 2.5° grid at a standard pressure levels from 1 January 1979 to 31 December 2008. In addition to these the SST anomalies are used from the daily OISST asnalysis version 2 AVHRR-AMSR (Advanced Very High Resolution Radiometer-Advanced Microwave Scanning Radiometer**)** products from NCDC (National Climate Data Center) from 1981 to 2008.

4. Results and Discussion

The hydrograph of streamflow (Fig. 3) at the Fazenda Santa Maria gauge station of the Paranaiba River in Brazil shows significant flow during November to May and very less flow during June-October. The variation in this seasonal streamflow significantly affects the human population (e.g., IGAM, 2008). In figure 2, we can see the linear trend of the streamflow at the Santa Maria stations. The hydrograph of the stream-flow at the Fazenda Santa Maria gauge station of the Paranaiba River in Brazil shows significant flow during December to May and very less flow during June-October (Fig.3).

In this study we tried to find the climate variability impact to the river catchment during the MAM season. Table (1) implies the influences of El Niño Modoki to the Paranaiba streamflow during the high streamflow events which is not usual.. So, it is important to understand the underlying mechanisms that cause that variation. Since the variability of climatic conditions in the Pacific Ocean is a main driver of the rainfall variability over the Paranaiba basin, their roles in river streamflow is explored in this study. A scientific analysis is made to link the streamflow variability with the rainfall and SST and OLR variations over the Pacific Oceans on daily time scale. Because the river stream-flows, unlike the rainfall, are affected by morphological and anthropogenic factors including soil and forestry recharge, sediment deposit, topography and land-use changes besides rainfall.

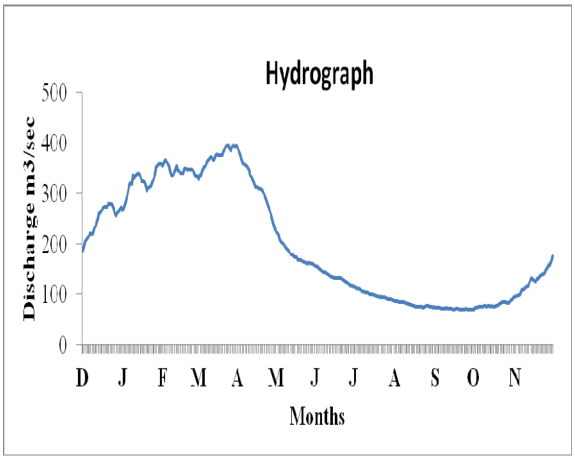


Figure 3 Hydrograph at Fazenda Santa Maria station from 1974-2008.

Table 1 The seasonal extreme a) high and b) low discharges events where each event are selected from the persistent of positive values for 5 days or more.

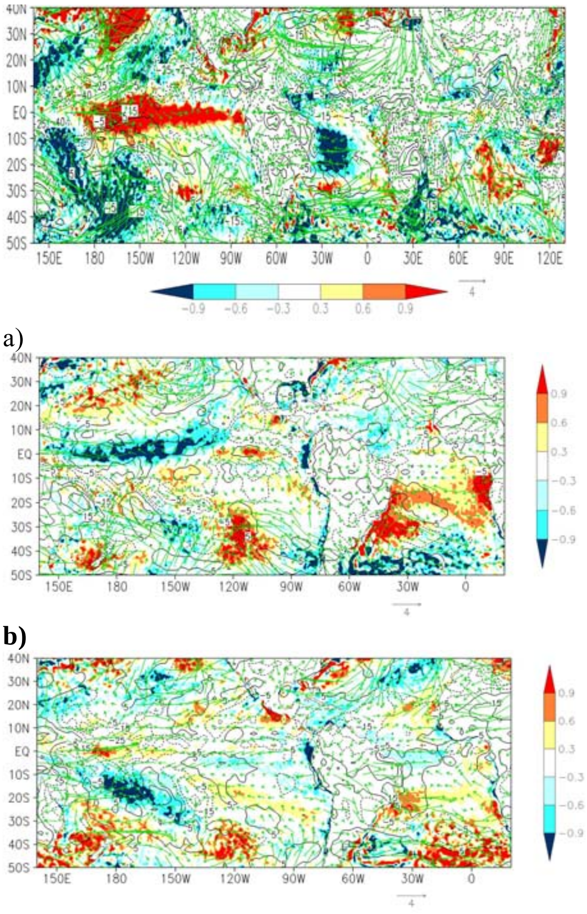
Extremely **High Discharge** Events	Average daily streamflows/ number of days
March-May	
1980	630/16
1982(pIOD,mEl Nino)	606/6
1982(pIOD,mEl Nino)	611/12
1984(mLaNina)	582/11
1985	391/13
1988(La Nina)	510/7
1988(La Nina)	390/15
1991 (mElNino,El Nino)	695/11
1992((mElNino, nIOD)	389/12
1994((mElNino, pIOD)	628/21
1997(pIOD,mEl Nino	293/12
1997(pIOD,mEl Nino)	536/6
2000(LaNina, mLaNina)	602/8
2004(mElNino)	561/18
2006(pIOD,mEl Nino)	552/19

Extremely **Low Discharge** Events	Average daily streamflows/ number of days
March-May	
1981	141/39
1984(mLaNina)	203/7
1986(El Nino, mEl Nino))	253/8
1990(mEl Nino)	294/11
1990(mEl Nino)	220/10
1990(mEl Nino)	138/7
1991((mEl Nino,El Nino)	208/9
1993	319/17
1996(nIOD)	216/5
1996(nIOD)	198/13
1996(nIOD)	123/12
1998	204/5
2001(La Nina, mLaNina)	129/33
2005(nIOD, La Nina)	177/11

The climatology of the Fazenda Santa Maria gauge station shows a very strong coherent pattern with low variability. As mentioned on the table (1) the extreme events for both the high and low discharge cases has been calculated 5 days or more continuous wet or dry periods for one extreme event case.

In MAM for both the extreme high and low events most of the cases are coincides with the ENSO/IOD years. This shows that the seasonal influences on discharges in MAM are influenced by these climate variability. Out of the total 15 high discharge events cases during MAM 9 are influenced by ENSO Modoki. A few extreme high and low events in this season are also influenced by IOD because of frequent occurrence of IOD in recent decades and ENSO is changing to a new type El Niño Modoki, recently identified (Ashok et al., 2007).

In MAM high discharges cases 60 percent events are occurred during the El Niño Modoki years. In low discharge cases of MAM, out of total 14 events 11 events are occurred during either ENSO or IOD years. Among the 11 events seven are occurred during the ENSO Modoki and four are during nIOD year., which implies that both ENSO Modoki and nIOD influenced the extreme low discharges events. In MAM the rest of the extreme low discharges cases about three are occurred during the normal year.



a)

b)

c)

Figure 4 Composite index (includes the exact number of extreme events days 5 days ahead for both the Extreme low discharges cases of SST (shaded), surface wind (vector) and OLR (contoured) for MAM (a) All El Nino Modoki, (b) All La Nina Modoki (c) All Events, respectively. Unit for SST is °C, for wind is m s^{-1}, and for OLR is w/m^2.

In MAM it seems as a mixed trend. Both the ENSO and IOD have influenced the rainfall pattern. Later part of this season can be considered as transition phase as this season is preceded by summer season starting from June-September in the Paranaiba River catchment. In the composite index figure (4a) MAM all El Nino Modoki events taking together as shows the shaded SST the warmer central Pacific with eastern and western sides having warmer El Niño Modoki conditions where as figure (4b) MAM seasons extremely low events with La Nina Modoki influences shows very less signals. However, taking all the events together (Fig. 4c) for the extremely low discharges events of the MAM seasons have not shown any clear signal.

The composite figure 5 for the MAM season extremely low discharge events for all the events taking together (Fig.5a) shown very little signal of La Nina, where as extremely low events with all El Nino Modoki (Fig.5b) shown clear signals and captures well in the composites.

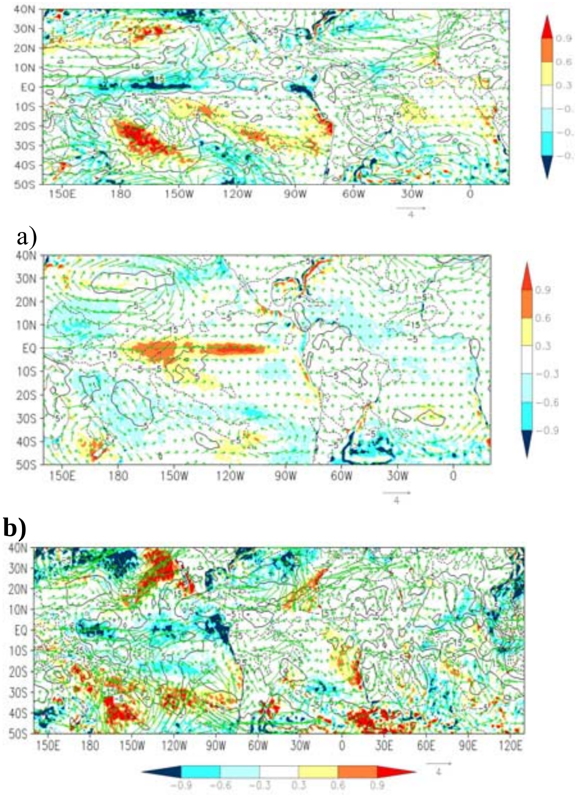


Figure 5 Composite index (includes the exact number of extreme events days 5 days ahead for both the Extreme high discharges cases of SST (shaded), surface wind (vector) and OLR (contoured) for MAM (a) All high events, (b) All El Nino Modoki (c) All nIOD Events, respectively. Unit for SST is °C, for wind is m s^{-1}, and for OLR is w/m^2.

5. Concluding Remarks

The climatology of streamflow (Fig. 1) at the Fazenda Santa Maria gauge station of the Paranaiba River in Brazil shows significant flow during November to May and very less flow during June-October. The variation in this seasonal streamflow significantly affects the human population. So, it is important to understand the underlying mechanisms that cause that variation. Since the variability of climatic conditions in the Pacific Ocean is a main driver of the rainfall variability over the Paranaiba basin, their roles in river streamflow is explored in this study. A scientific analysis is made to link the streamflow variability with the rainfall and SST variations over the Pacific Oceans on daily time scale. The observed discharge data from 1974-2006 (33 years) at the Fazenda Santa Maria, the down most outlet of the upper basin, shows a strong correlation with the El Nino/Southern Oscillation (ENSO) and recently recognized ENSO Modoki events. In the December-February low streamflow events are influenced by El Nino Modoki (Fig. 2a) and high flow events are influenced by La Nina Modoki (Fig. 2b). In March-May high streamflow events are influenced by La Nina and few extreme events are also influenced by La Nina Modoki, whereas this rainy season low flow events are influenced by El Nino Modoki than El Nino. The climate change induced ENSO Modoki events needs further scientific study for La Plata basins for the societal benefits.

Acknowledgements

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ブラジル・パラナイバ川流域へのエルニーニョ南方振動の影響

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要　旨

ブラジル・パラナイバ川ファゼンダ・サンタマリア流量観測所における流量データによると，同河川は 12-5 月間に流量が増加し，6-8 月に流量が著しく減少する。同河川の 3-5 月における雨期における流量減少と El Niño Modoki 現象との関連性について本論文では明らかにしている。本研究における極端流量現象は１週間前の流況状況をもとに定義する。中部太平洋暖水塊の正フェーズの発生時に 3-5 月の流量減少事象の 40%が発生している。しかしながら流量減少事象はどれも通常の El Niño 現象下では発生していない。一方流量増加事象においても El Niño Modoki 現象との間で強く関連しており，ほとんどの流量増加現象は El Niño Modoki もしくは負のインド洋ダイポールモード(nIOD)下にて発生している。気候変動は直接的に降雨に影響を及ぼし，もちろん流量に対して大きな影響を与えるが，流量はまた土地利用変化などの人間活動の影響も受けるためこれについても更なる評価は必要である。

キーワード：気候変動，パラナイバ川，IOD，ENSO,ENSO Modoki，河川流量