# LONG-TERM STREAMFLOW AND RAINFALL FLUCTUATIONS IN TROPICAL SOUTH AMERICA: AMAZÔNIA, EASTERN BRAZIL AND NORTHWEST PERU

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## 1. INTRODUCTION

Streamflow or river levels have been extensively measured in tropical South America from the early 1900's, and several studies have used this data for studies on interannual variability of climate and climate change. Marengo (1995) has demonstrated that most of the rivers i n the Northern coast of Peru, as well as the São Francisco and the Paraiba do Sul rivers in eastern and southern Brazil, respectively, exhibit significant trends towards drier conditions, while rivers and rainfall records from nearby regions such Northeast Brazil or western Amazônia did not show any significant unidirectional trend. At this stage it is not clear whether the negative trends in river streamflow in the above mentioned regions are associated with drier conditions due to a regional climate change, or due to anthropogenic effects that artificially may affect the hydrological series. The Negro and Amazon River series do not show any statistically significant trend at the interdecadal time scale, and it is still difficult to find signals of climatic change in the region due to deforestation. Thus, the purposes of this paper are to analyze the long-term variations of streamflow in rivers in the Amazon basin, eastern Brazil and the northern coast of Peru river records are used to explore the long-term mean variability of the hydrological cycle in the region from the beginning of the century. To assess the presence of trends as well as its direction and the significance of the trends, the non-parametric test of Mann-Kendall (Lettenmaier et al. 1994) has been applied to the historical hydrometeorologic data.

## 2. RIVER AND RAINFALL DATA

Annual and seasonal discharges and rainfall data used in this study were extracted from the archives of the Instituto Nacional de Recursos Naturales, from Peru, and from ELETROBRAS, ELETRONORTE, CPTEC and DNAEE from Brazil (Table 1). To examine the long-term mean trends in the hydrometeorological data, annual seasonal discharge and runoff have been calculated for all the times series, based on the 3-months of the peak rain and streamflow. Once the tendencies or trends have been identified, the direction and magnitude of the trends have been analyzed using the non-parametric test of Mann-Kendall. This test has been widely applied in the detection of trends and in the assessment of the significance of them in river data and rainfall data around the world This test should be directly applicable to hydrological data sets, since the year-to-year correlation of streamflow in a given season with the same season's streamflow in the previous or subsequent year is usually quite low (Lettenmaier et al. 1994).

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## 3. VARIABILITY AND CHANGE OF RIVER RECORDS

### 3.1 *Amazônia (including the Tocantins River)*

The historical records of the Amazonian rivers shown in Fig. 1 indicate that significant consistent trends are absent in the discharges and levels of the Negro, Uatuma, Tocantins and Xingú Rivers. The Mann-Kendall test indicates that these rivers do not show any systematic increase or decrease in their records. In all of them, there are periods of above average discharge from 1945 to 1960 and from early 1970's to early 1980's. Interannual variability of precipitation in Amazonia is large, as revealed by the river streamflow records. A large part of this variability is linked to El Niño events (Marengo 1995, Trichey . The Tocantins River Basin shows an alternance of wet and dry periods is observed, and especially noteworthy are the dry period of 1945-55 and the wet period of 1980-90, which are not observed in the rest of Amazônia

### 3.2 *Eastern Brazil*

Eastern Brazil includes the basins of the Parnaiba and São Francisco rivers and the Northeast Brazil region (Fig. 2). As discussed by Marengo (1995) the records of the São Francisco River at Juazeiro show a systematic decrease since the early 1970's, which would be indicative of drier trends. On the other hand, the registers from the Parnaiba River at Boa Esperança show a tendency for increasing discharges especially during the last 25 years of record. Even though the evidence show statistically significant opposite trends in both adjacent basins, it is somewhat difficult to conclude that a climatic change may be occurring in eastern Brazil, with opposite tendencies in such a relatively small region of the world.

The upward trend detected in the records of the Parnaiba river does not seem to reflect the tendency of rainfall in the upper and middle basin, which do not show any significant trend in either. A careful analysis of the river series indicates that the possible upward trend was driven by anomalously high discharges starting on the middle to late 1970's and ending on

the middle 1980s. For the São Francisco River, the negative significant trends exhibited by the records of the river at Juazeiro are not corroborated by the tendencies of the rainfall, which do not show any significant trend in either direction. A comparison was made between the discharge of the São Francisco River at Juazeiro and at the nearby station of Sobradinho (Fig. 2). From the trend analysis, the river records at Sobradinho for the same season do not show any significant tendency towards dry conditions as indicated by the Juazeiro, and agree more with the rainfall series at the basin. It is possible that the observed tendency toward drier conditions as detected from the Juazeiro records is just a consequence of the extensive water use for agriculture irrigation in the region near Sobradinho, or for hydroelectric generation purposes by using the water falls that the São Francisco river shows after Sobradinho. Rainfall in Northeast Brazil apparently does not show any trends towards drier or wetter conditions from the beginning of the century

### 3.3 *North Coast of Peru*

Marengo (1995) has found trends towards drier conditions in the basins of the Chira and Chicama Rivers in the North coast of Peru. With the availability of more river data in the same region, an analysis of discharge series of the La Leche, Zaña, Jequetepeque, Moche and Viru Rivers (Fig. 3) has indicated that in fact this tendency towards drier conditions is also found in other river records in the region. The Mann-Kendall test is applied to river records in this region indicate the presence of negative trends, from the Chira to the Viru River basins, which are statistically significant at the 95% or 99% significance level for most cases. Comparing the occurrences of very high river discharges in the Northwest coast of Peru before 1945, it is noticed that some of them correspond to strong or very strong events, but also to moderate events. Between 1945 and 1992, 10 El Niño events were reported, with 2 of them strong, one very strong (1982-83), and the rest were moderate. The high river discharges in 1983 and 1987 corresponded to strong events, while the high discharge in 1951 corresponded to a moderate event. Based on the river discharge records in the northwest coast of Peru, and the previous associations between El Niño occurrences and the anomalously high discharges, it is here indicated that the before 1945, episodes of anomalously high river discharges occurred with higher frequency than after 1945. However, this does not imply that strong El Niño were more frequent before 1945 than after.

## 4. ARE THE RIVER TRENDS AND THUS THE REGIONAL CLIMATE CHANGE REAL?

The purpose of this section is to discuss if the "climatic trends" found from the analyses of the São Francisco and Parnaiba Rivers as well as in the river records from Peru are real, or if in fact they are due to non-climatic effects. In the northwest coast of Peru, it is observed a higher frequency of extremely large discharge values from the beginning of the record series until 1945, which seems to be driving the whole time series to show negative trends. The question would be to know the reason of the more frequent anomalous high river discharges before 1945. For the Amazon region, no trends are found even though one may think that increased deforestation in this region may be leading to changes in the regional hydrological cycle.

The basins in the northwest coast of Peru extend from the Andes to the coast, are smaller and narrower than the basins of the Parnaiba, São Francisco, or the rivers in Amazonia and have different conditions of land-coverage and land-use across their basins. The Mann-Kendall test has been applied for detecting trends in river/rainfall data as an indication of a possible climatic change. Our results indicate that for some basins in Brazil this test seems to have no problems (where no trend is noticed), but when a trend is detected, there is a reason for concern if that trend is real. This test assumes that the correlation between annual subsequent discharges is very low. However, there may be other factors that can make this assumption not realistic and make the serial correlation a real problem, at least for some basins.

In very large drainage basin, such as the Amazon, large serial correlation may affect the Mann-Kendall test. The serial correlation arises because of the enormous storage capacity within the basin, so that streamflow and water level records have a long memory (basin-memory effect). Another hypotheses raised up by Hodnett et al. (1996) is based in the Anglo Brazilian Amazon Climate Observation Study (ABRACOS) soil storage observation in Marabá (eastern Amazonia). The records showed that an extended dry year could affect the soil water replenishment in the subsequent dry season. Since the river streamflow in tropical areas is dominated by baseflow, a prolonged dry season might affect the groundwater discharge to the river in the next year. In Manaus, where the dry season is mild, this effect may be negligible.

Increase storage or increased water-loss for irrigation can explain observed trends, and a possible large serial correlation in those cases may also affect the Mann-Kendall test. In this regard, coefficients of autocorrelation have been calculated for several river discharge records: the Negro River at Manaus, the Tocantins River at Tucurui, the Parnaiba River at Boa Esperança, the Xingu River at Belo Monte, the Sao Francisco river at Juazeiro and Sobradinho, the Chira River at Ciruelo and Sullana, the Chicama River at Salinar. Both the Manaus, Sobradinho, Xingu and Chira series do not shown trend, and even though they have very large collecting basins, the correlation between streamflow/levels of two consecutive years is very low, making the Mann-Kendall test suitable for trend analysis in this basins. The Parnaiba shows a positive trend significant at 95% level, however, the autocorrelogram shows that the year-to-year correlation is very large, making this test not suitable for this basin. For the rivers in the Northwest Coast of Peru, the presence of negative trends, significant at 99% level, is not supported by the similar trends in the rainfall regime either. For the Chicama river at Salinar, there is a very large correlation between streamflow of consecutive years. For other rivers in this region, the year-to-year correlation is low and the Mann-Kendall test would indicate that the statistically significant trends found for some of the rivers in the region are real, but the lack of complete rainfall network on the upper basins does not allow us to confirms or not the presence of these trends.

## 5. CONCLUSIONS

Long-range streamflow records were analyzed since the beginning of the century for rivers in eastern Brazil, Amazônia and the Northwest coast of Peru. The analysis of the river data is complemented by the analysis of rainfall data in the basins. The streamflow and rainfall fluctuations were examined separately.

Rivers and rainfall records in Amazônia do not show any significant trend towards drier or wetter conditions. The records of the Negro River at Manaus and the few rainfall stations in the upper and middle basin of this river do not show any significant trend in either direction. The interannual variability of climate in Amazonia is linked to El Niño, with drought during extreme such events. However, the forest appears to be adapted to withstand these large interannual variations in precipitation and the sporadic occurrence of forest fires. Even at the boundaries of the forest, where the interannual variability is more pronounced, migration of the forest border is not observed.

In eastern Brazil, there is evidence that the negative trends found in the São Francisco river at Juazeiro are not explained by the rainfall variation at its upper and middle basin. This negative trend seems to be a consequence of an intense use of its water for generation of energy by taking advantage the water falls between the Sobradinho Dam and the station at Juazeiro. The records of this river at Sobradinho, right outside the Dam and before the water falls do not show any trend. For the Parnaiba River, the significant upward trends seem to be supported by the rainfall records in its middle basin. However, these upward trends seem to be related to extremely large rainfall events in 1980 and 1985, as observed in both series, and this indicate the effect of large peaks in the series on the detection of trends, different from a systematic climate change. The situation in the northern coast of Peru is more difficult to explain. There are not complete rainfall records long enough to explain the negative significant trends in the river records in this region do not exist. Luckily, river series in the Chira River valley helped in explain that the observed negative trends in this river series were due to man-made effects (intensive water use for irrigation) than to climate-induced. The explanation can also be applied to the Jequetepeque River. For the Viru and Chira Rivers, the removal of extremely high discharge values from 1910 to 1945 eliminated the negative trends. This indicates that these extreme high river discharges events at the beginning of this series were driving the variability of the series to show unrealistic negative trends. The data at Chicama and La Leche still show negative significant trends after removing anomalously high values at the beginning of the series. For these two rivers, it is unclear if the records show climate-induced trends in the streamflow.

It is difficult to distinguish climate-induced trends that may exist in the river data series from man-made effects. However, from our analysis the latter seems to be the explanation for observed significant trends towards drier or wetter conditions in eastern Brazil and the northern coast of Peru. In the Amazon basin as well as in Northeast Brazil, hydrological conditions do not reflect any trend in either direction, while they reflect drier or wetter periods at decadal time scales. In the smaller river basins near the coast of Peru, some trends are explained by human activities and water use for irrigation.

From the analysis of trends using the Mann-Kendall test, for both streamflow/level and for rainfall in the upper basin on several rivers in Brazil and Peru, it has been shown that this test may be not suitable for regions under intensive use of water and/or water management or with large basin-memory. At least, it should not be applied to river data alone in a basin. If the null hypothesis in the Mann-Kendall test is rejected there are two possible interpretations: (1) there is a trend, (2) there is a failure in the null hypothesis, such as the assumption of no serial correlation. In cases where there is a substantial serial correlation, it seems incorrect to conclude that (1) is the explanation. For those basins, what we may need is a different test than Mann-Kendall. One way to solve this problem, we think, is that we can apply this test to rainfall records in the upper and middle basins to confirm the trends shown by the river data. At the end, it still will be difficult to explain a trend in rain and streamflow as due to a regional climate change.

Finally, it seems that the hydrology in tropical South America does not show any tendency towards dry or wet conditions since the beginning of the century. Thus, the observed trends appear to be consistent with a constant climate. Any trends in observed annual river discharge that may have resulted from the combination of land-use change, climatic change, and water diversions were not sufficiently large during the period of the study to be detected above the "background noise" of natural climate variations in the climate system.

## 6. REFERENCES


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