Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, p. 1545-1553.

CLIMATE PROXY EVENTS' PATTERNS AND THE RAINFALL VARIABILITY OVER THE BRAZILIAN AMAZON – A STOCHASTIC APPROACH.

P. S. Lucio[1,3]*; A. M. Ramos[1]; F. C. Conde[1]; D. Mendes[2], M. C. Mendes[2]

[1]Centro de Geofísica de Évora (CGE) – Apartado 94, 7000-554 Évora – Portugal.
[2]Faculdade de Ciências da Universidade de Lisboa (FCUL) – Portugal.
[3]Instituto Nacional de Meteorologia (INMET) – Brasília DF – Brazil.

pslucio@uevora.pt, andreara@uevora.pt, fabconde@uevora.pt, dmendes@fc.ul.pt, mcmendes@fc.ul.pt

**Corresponding author address:*
Instituto Nacional de Meteorologia (INMET)
Eixo Monumental Sul – Via S1 – Setor Sudoeste
70680-900 – Brasília DF - Brasil
e-mail: pslucio@uevora.pt / paulo.lucio@inmet.gov.br

Introduction.

The complex interaction of coupled ocean-atmosphere processes is still far from being completely understood, and documented. Although the correlation between precipitation in the Brazilian Amazon and sea surface temperatures (SST) over the Pacific and Atlantic has been documented since the early twentieth century, the impact of each ocean variability on the frequency and intensity of the wet/dry season over Brazilian Amazon and the underlying mechanisms have remained unclear. The mechanisms of climate anomalies in the Amazon basin were explored from surface climatological time series. Interannual variability of seasonal rainfall in the Brazilian Amazon is examined in context of its relationship to El-Niño Southern Oscillation (ENSO), low frequency phenomena such as the Pacific Decadal Oscillation (PDO) and phases of the North Atlantic Oscillation (NAO).

The regional rainfall has been related to high-frequency atmospheric phenomena, such as El Niño and La Niña events, of a statistically significant precipitation anomaly patterns. Non-linear correlations (response) reveal strong relationships, but rainfall patterns are of regional scale. Areas of rainfall exhibiting strong relationships with SST are confined to the equatorial region of the Brazilian Amazon. The best relationships are found either during the season of transition between wet and dry regimes, or entirely within the dry season. It is hypothesized, and results are shown in support, that during the transition seasons, an important contributor to the SST control on seasonal totals is its influence on the timing on the rainy season onset or end. That influence appears to be stronger than the SST influence on the rainy season.

The analysis of Rainfall variability and sensitivity related to decadal and long-term anomaly patterns of rainfall has been carried out. Negative rainfall trends were identified for the entire Amazon basin, while at the regional level there is a negative trend in northern Amazon and positive trend in southern Amazon. Decadal time scale variations in rainfall have been discovered, with periods of relatively drier and wetter conditions, with different behaviour in northern and southern Amazon. Spectral analyses show decadal time scale variations in southern Amazon, while northern Amazon exhibits both interannual and decadal scale variations. Shifts in the rainfall regime in both sections of the Amazon basin were identified and changes in the circulation and oceanic fields suggest an important function of the warming of the tropical central and eastern Pacific on the decreasing rainfall in northern Amazon, due to more frequent and intense El Niño events during the relatively dry period. A complementary application was carried out correlating the rainfall database with the NCEP Reanalysis dataset. Scenarios for rainy station were considered consequence of located storms and they are associated with the Intertropical Convergence Zone (ITCZ) and its seasonal migration. Preliminary results of this research indicate that the precipitation over the Amazon Basin presents interanual variability associated to the ENSO phenomenon, with periodicity of about 20-25 years in frequency of subtropical highs, probably associated to the PDO. Besides, we have found strong anti-correlation, of about 60%, between the Outgoing Long-Wave Radiation (OLR) and annual cycle of precipitation amount over the region. There is an apparent association between SST anomalies in the tropical Atlantic and Pacific and the pentads of onset and end of the rainy season in the northern and central Amazon.

Stochastic Background.

There is a variety of widely-used statistical methods for analysing fields of data which vary in both space and time. These tools can help us systematically parse through data fields. They can be used to characterise typical spatial modes of variability, their time evolution, and the relationships between the various observable. The choice of a statistical method is always subjective and depends on the particular question that one wants to address. Therefore, the results of statistical analysis should be interpreted with caution. A useful concept in extracting a physical phenomenon from the data using statistical tools is to consider the superposition of independent statistical approaches and interprets the results as a clearly defined common property.

The "Principal Component Analysis" (PCA) is a method widely used to find a spatial pattern which explains the maximal variance of the data field. However, PCAs may combine independent but non-orthogonal spatial patterns of variability. Because higher PCAs are forced to be orthogonal to their predecessors, they may not be physically realizable. PCAs are affected by sampling biases in the covariance matrix. A good practical check on robustness is to separately apply PCA to the first and second half of the observed times and then examine the similarity of the two PCAs.

The "Principal Oscillation Pattern" (POP) analysis fits a field of data to an AR (1) process. This is an idealized model of a damped linear response to stochastic forcing. The associated eigenvalues should all have magnitudes less than one and the corresponding eigenvectors (or POPs) describe the modes of variability of the system. The complex eigenvalues indicate damped oscillations and the complex eigenvectors describe the oscillations in the spatial structure of the response. Considering the methods discussed above, only compositing is a nonlinear method. There are more advanced nonlinear methods, one of which is "Cluster Analysis" (CL). In CL the field is usually filtered first using one of the linear methods to reduce the number of spatial degrees of freedom (weather regime partition). Then, in the phase space of the amplitudes of the leading spatial patterns, the region where the system spends most of its time, are determined. These regions are called clusters.

The "Compositing" (C) technique involves constructing an index which correlates with the variability of the phenomenon of interest. Regressing the index onto the data or binning the data according to the ranges of the index, yields composite spatial patterns of variability. It is extremely flexible, able to capture both localized and moving features and to quantify nonlinearities in the behaviour (by comparing opposite phases of the extreme events). However, the choice of the index is highly subjective and there is no set way to determine the most sensible index. Compositing (C) all the events from such a region give the corresponding spatial pattern and some additional temporal information can be obtained by observing the temporal character on the occurrence of events. Changes in large-scale atmospheric flow have an important impact on rainfall variability over the Brazilian Amazon, mostly explained by the North Atlantic Oscillation (NAO) associated with the Pacific Decadal Oscillation (PDO).

The increasing of economic losses, coupled with a raise in deaths due to extreme events, has focused attention on the possibility that these events are increasing in frequency. Short-duration episodes of extreme heat or cold are often responsible for the major impacts on society. Conversely, the location, timing, and magnitude of local and regional changes remain unknown because of uncertainties on future changes in the frequency and intensity of meteorological systems that cause extreme weather and climate events. It is likely that anthropogenic forcing will eventually cause global increases in extreme precipitation, primarily because of probable increases in atmospheric water vapour content and destabilization of the atmosphere.

Experimental Dataset

This work is based on monthly total precipitation time series taken from stations in the Brazilian Amazon (BR Amazon), covering the period 1970-2000. Time series of rainfall at these stations provide a good representation of the Amazonn precipitation. The variability of precipitation is characterised by a strong annual cycle. The maximum rainfall occurs in summer (DJF), with additional significant contributions coming from late spring (ON) and early autumn (M). The total precipitation recorded at each station are highly correlated (≥99%). All the coefficients are statistically significant at the 1% significance level, which is also a clear proof of the dominance of the large-scale forcing of summer (ONDJFM) precipitation throughout the country; the local and regional processes are not strong enough to weaken these correlations.

The spatiotemporal pattern of annual rainfall and the strength of the dry season within the Amazon region are poorly known. Existing rainfall maps are based on the data from full-scale, long-term meteorological stations, operated by national organizations linked to the World Meteorological Organisation, such as INMET in Brazil. Stations with 30 or more years of uninterrupted and reliable recordings are very few, considering the size of the region, and most of them are located along the major rivers. It has been suggested that rainfall conditions away from these rivers are substantially different. An analysis has been made of the records of a network of simple pluviometric sites in the Brazilian part of the region as maintained by the National Agency for Electric Energy (ANEEL) since 1970. The latter data sets were used to draw more detailed maps on annual rainfall, and on the strength of the dry season in particular; average number of consecutive months with less than 100mm, 50mm, and 10mm, respectively. Also, some data were obtained on the spatial expression of El Nino events within the region.

It is well-known that Rainfall patterns in the Amazon change when humans alter the land during deforestation and farming, causing some areas to suffer drought while other areas succumb to floods. Liebmann and Marengo (Interannual Variability of the Rainy Season and Rainfall in the Brazilian Amazon Basin. Journal of Climate, 14(22), 4308-4318, 2001) have analysed the interannual variability of seasonal rainfall in the Brazilian Amazon basin, examining in context of its relationship to sea surface temperatures in the tropical Pacific and Atlantic Oceans. Linear correlations reveal strong relationships, but rainfall patterns are of regional scale. Areas of rainfall exhibiting strong relationships with SST are confined to the equatorial region of the Brazilian Amazon. The best relationships are found either during the season of transition between wet and dry regimes, or entirely within the dry season. It is hypothesised, and results are shown in support, that during the transition seasons, an important contributor to the SST control on seasonal totals is its influence on the timing on the rainy season onset or end. That influence appears to be stronger than the SST influence on the rainy season rain rate.

Teleconnections over BR Amazon.

The Southern Oscillation Index (SOI) is based on the standardized pressure difference between Tahiti and Darwin. The El Niño Southern Oscillation (ENSO) phenomenon is the major cause of year-to-year variations in climate over lower latitudes and one of the most significant causes of global climate change on this timescale. The ENSO is associated with disruption to tropical climates in many regions. The Trans-Niño Index (TNI), which is given by the difference in normalised (1950-79) anomalies of SST between Niño1+2 and Niño4 regions, is used as an optimal description of the character and evolution of El Niño or La Niña. The Pacific Decadal Oscillation (PDO) is a leading index associated to the ENSO phenomenon by taking into account the monthly Sea Surface Temperature (SST) anomalies in the North

Pacific Ocean. In effect, to characterize the nature of the ENSO, SST anomalies in different regions of the Pacific is used (Niño1+2: 0-10ºS, 90-80ºW; Niño3: 5ºN-5ºS, 150-90ºW; Niño4: 5ºN-5ºS, 160E-150ºW; Niño3+4: 5ºN-5ºS, 170-120ºW).

The North Atlantic Oscillation (NAO) is a major disturbance of the atmospheric circulation and climate of the North Atlantic region, linked to a waxing and waning of the dominant middle-latitude westerly wind flow during winter. The NAO index is based on the pressure difference between the Iceland (north) and Azores (south) of the mid-latitude westerly flow. It is, therefore, a measure of the strength of these winds. Strictly, it should only be used for the north hemisphere winter period (DJFM). The NAO exerts a strong influence on year-to-year climate variability and there is evidence of longer-term trends in this phenomenon. It is related to the shorter-term shift between zonal and meridional circulation types that occurs on a day-to-day time scale and is know as the index-cycle.

There is an amazing correlation between PDO, NAO, TNI and SOI with the rainfall over the BR Amazon; Nino3+4 and TNI with the Monthly Range Temperatures (MTR) on the period from Jan/1970 to Dec/2000.

Stochastic Approach

The role of statistics (data analysis) is not so much to summarise what has already happened, but to infer the characteristics of randomness in the process that generated the data set regarding the sequence of its realisations. A useful concept in extracting a physical phenomenon from the data using statistical tools is to consider the superposition of independent statistical approaches and interprets the results as a clearly defined common property.

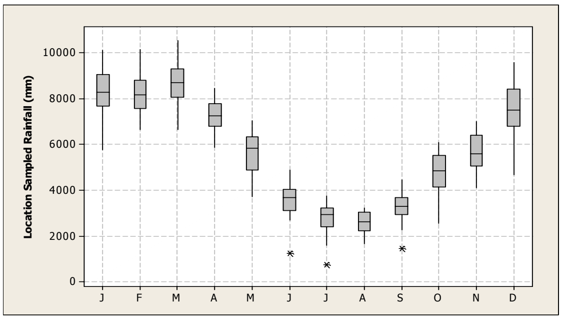
Simply speaking clustering is an algorithm to classify or to group N objects based on attributes/features into K number of group. The grouping is done by minimizing the “distances” between data and the corresponding cluster centroid. Thus the purpose of clustering is to classify the data. There are a lot of applications of the clustering, range from unsupervised learning of neural network, pattern recognitions, classification analysis, artificial intelligent, image processing, machine vision, etc. In principle, we have several objects and each object have several attributes and you want to classify the objects based on the attributes, then we can apply this algorithm. The principle of application of clustering to machine learning or data mining: Each object represented by one attribute point is an example to the algorithm and it is assigned automatically to one of the cluster – the “unsupervised learning” because the algorithm classifies the object automatically only based on the criteria of minimum distance to the centroid.

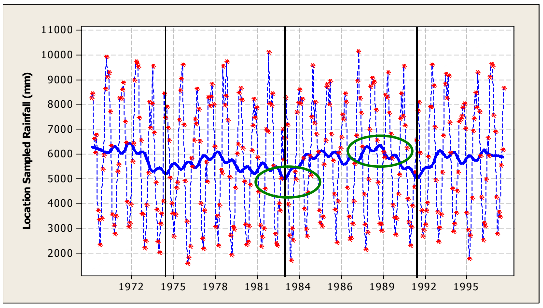
The Embedded Compositing method (CL & C) for Clustering and Fuzzy Clustering are different than Hierarchical Clustering and Diversity Selection in that the number of clusters, K, needs to be determined at the onset. The goal is to divide the objects into K clusters such that some metric relative to the centroids of the clusters is minimized. The metric to minimize and the choice of a distance measure will determine the shape of the optimum clusters (global optimization method). Cluster analyses are used to analyze micro array time-course data for pattern recognition. However, in general, these methods do not take advantage of the fact that time is a continuous variable, and existing clustering methods often group weather pattern together.

We propose a CL & C method for identification and classification of weather based on their temporal expression profiles for cyclic time-course micro array data (Fig.3). This method treats time as a continuous variable, therefore preserves actual time information. We applied this method to a micro array time-course study of rainfall expression at time intervals. Six regression patterns have been identified and shown to fit climatological expression profiles better than cluster analysis. CL & C analysis identified over-represented functional groups in each regression pattern and each cluster, which further demonstrated that the regression method provided more climatologically meaningful classifications of weather expression profiles than the clustering method. Consistency study indicates that regression patterns have the highest reliabilities. Our results demonstrate that the proposed CL & C regression method improves pattern recognition for cyclic time-course micro array data.

Assessing goodness-of-fit - Performance measures.

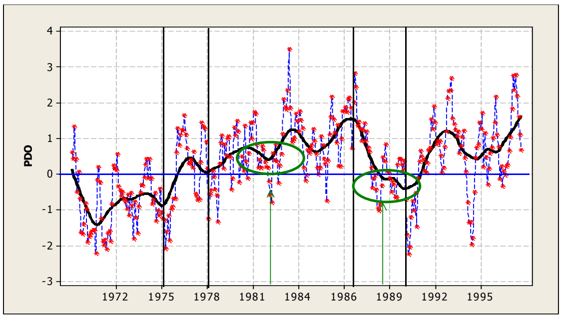
The following statistics were considered to be of interest in comparing the historical record and the simulated record of rainfall. Their successful reproduction can be considered a sign of success for the method. All computed statistics are for daily values and refer to each season. four-moment measures: Mean, Variance, Skewness and Kurtosis. Relative frequencies are the inter-quartiles (Box-Whiskers Plots) of the 28-year record.

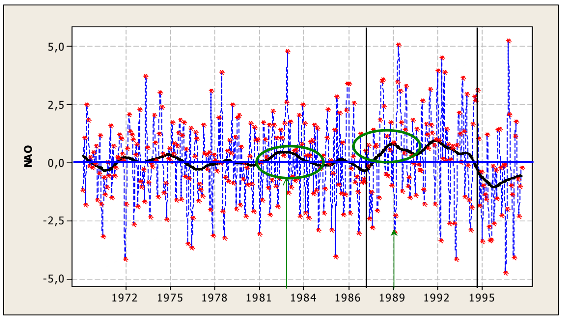


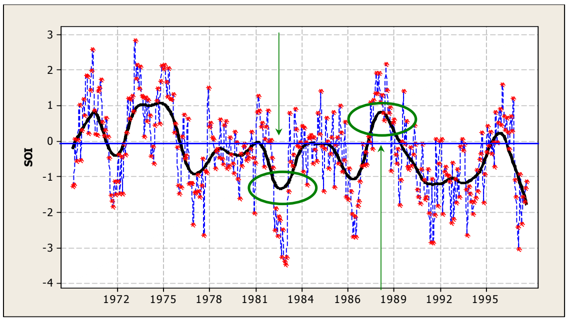


Summary

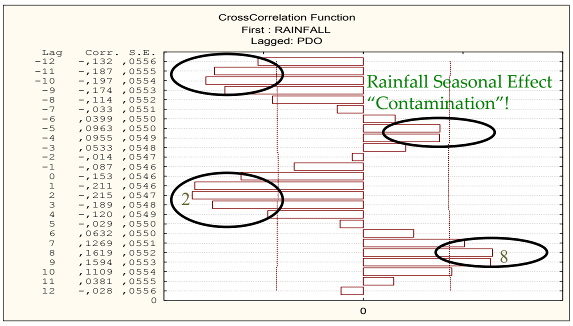
Our results confirm the importance of the North Atlantic Oscillation (NAO) and the El Nino-Southern Oscillation (ENSO) states; for the variability of Portuguese rainfall, a fact which is imposed by the NAO's close relationship with humidity advection, cyclone occurrence, and upper air variability. Changes in large-scale atmospheric flow have an important impact on rainfall variability over the BR Amazon, mostly explained by the North Atlantic Oscillation (NAO) and slighted (intriguing) associated with the Pacific Decadal Oscillation (PDO). Then, the Embedded Compositing Method seems powerful in the empirical prediction of circulation pattern recognition based on four-to-six fundamental weather systems.

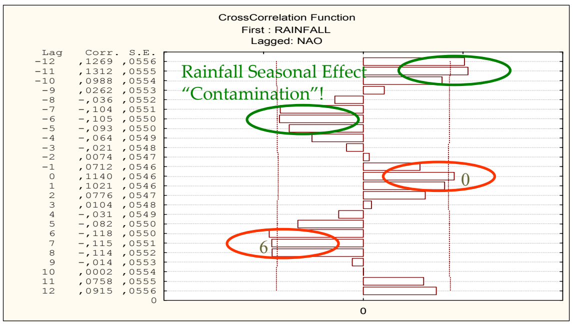


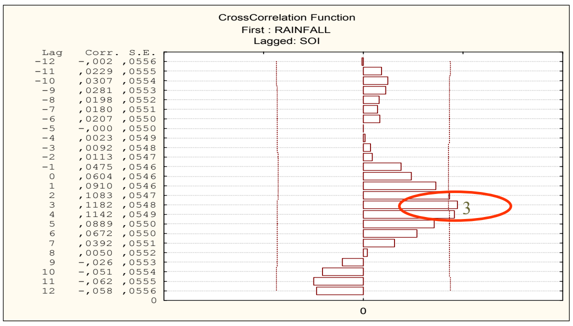




Owing to the strong connection between summer rainfall over the BR Amazon and the large-scale circulation patterns, a keying of the days into a set of non-overlapping large-scale rainfall regimes is particularly meaningful. An information measure was computed so that a maximum discrimination of the rainfall amounts amongst the weather regimes could be achieved. From four-to-six weather regimes were isolated in this manner, and both their statistical and dynamical properties enabled a validation of the clustering strategy. This study also revealed that the frequencies of occurrence of some particular regimes are skilful predictors of summer rainfall over the BR Amazon. Considering basically the Classification and Discriminant principles, the Embedded Compositing method (CL & C) seems powerful in the empirical prediction of circulation pattern recognition based on four-to-six (4-6, where the maximum discrimination of the rainfall amounts amongst the weather regimes is achieved) fundamental weather systems. Outstanding the strong connection with large circulation system patterns the summer rainfall over the BR Amazon is particular significant. Moreover, the frequency and occurrence of particular regimes are considerable (statistical significant) predictors of winter rainfall over the BR Amazon – maybe a high-quality strategy for the assessment of rainfall scenarios.







The PDO, NAO and SOI relations with the Amazonian Rainfall.

The strength and influence of Western Pacific's sea surface temperatures on Amazon rainfall is now well-established. Considering El Nino events we obtain that the rainfall pattern in the eastern equatorial Amazon region of Brazil is very sensitive to sea surface temperature changes. If sea surface temperatures rose, then drought conditions were likely, but if temperatures fell, flooding would result. The Pacific Ocean has a greater influence on rainfall pattern changes than expected.

Acknowledgements: Data Credits: Agência Nacional de Energia Elétrica (ANEEL) – Brazil.

References

Barnston, A., Smith, T. M., 1996. Specification and prediction of global surface temperature and precipitation from global SST using CCA. J. Climate, 9: 2660–2697.

Briggs, W. M., Wilks, D. S., 1996. Estimating monthly and seasonal distributions of temperature and precipitation using the new CPC long-range forecasts. J. Climate, 9: 818–839.

Goodess, C. M., Jones, P. D., 2002. Links between circulation and changes in the characteristics of the Iberian rainfall. Int. J. Climatology, 22: 1593–1615.

Hurrell J. W., 1996. Influence of variations in extratropical wintertime teleconnections on Northern Hemisphere temperatures. Geophysical Research Letters, 23: 665–668.

Hurrell J. W., van Loon, H., 1997. Decadal variations in climate associated with the North Atlantic oscillation. Climate Change, 36: 301–326.

Hurrell JW, Kushnir Y, Visbeck M. 2001. The North Atlantic oscillation. Science, 291: 603–605.

Knippertz, P., 2004. A simple identification scheme for upper-level troughs and its application to winter precipitation variability in northwest Africa. J. Climate, 17: 1411–1418.

Knippertz, P., Christoph, M., Speth, P., 2003. Long-term precipitation variability in Morocco and the link to the large-scale circulation in recent and future climates. Meteorology and Atmospheric Physics, 83: 67–88.

Kutiel, H., Maheras, P. and Guika, S., 1996. Circulation and extreme rainfall conditions in the eastern Mediterranean during the last century. Int. J. Climatology, 16: 73–92.

Muñoz-Dyaz, D., Rodrigo, F. S., 2003. Effects of the North Atlantic oscillation on the probability for climatic categories of local monthly rainfall in southern Spain. Int. J. Climatology, 23: 381–397.

Murphy, J., 1999. An evaluation of statistical and dynamical techniques for downscaling local climate. Int. J. Climatology, 12: 2256–2284.

Osborn, T. J., Briffa, K. R., Tett, S. F. B., Jones, P.D., Trigo, R. M., 1999. Evaluation of the North Atlantic oscillation as simulated by a coupled climate model. Climate Dynamics. 15: 685–702.

Rodo, X., Baert, E., Comin, F., A., 1997. Variations in seasonal rainfall in Southern Europe during the present century: relationships with the North Atlantic Oscillation and the El Niño–Southern Oscillation. Climate Dyn., 13: 275–284.

Rodriguez-Puebla C., Encinas, A. H., Nieto, S., Garmendia, J., 1998. Spatial and temporal patterns of annual precipitation variability over the Iberian Peninsula. Int. J. Climatology, 18: 299–316.

Rogers, J. C., 1997. North Atlantic storm track variability and its association to the North Atlantic oscillation and climate variability of northern Europe. J. Climate, 10: 1635–1647.

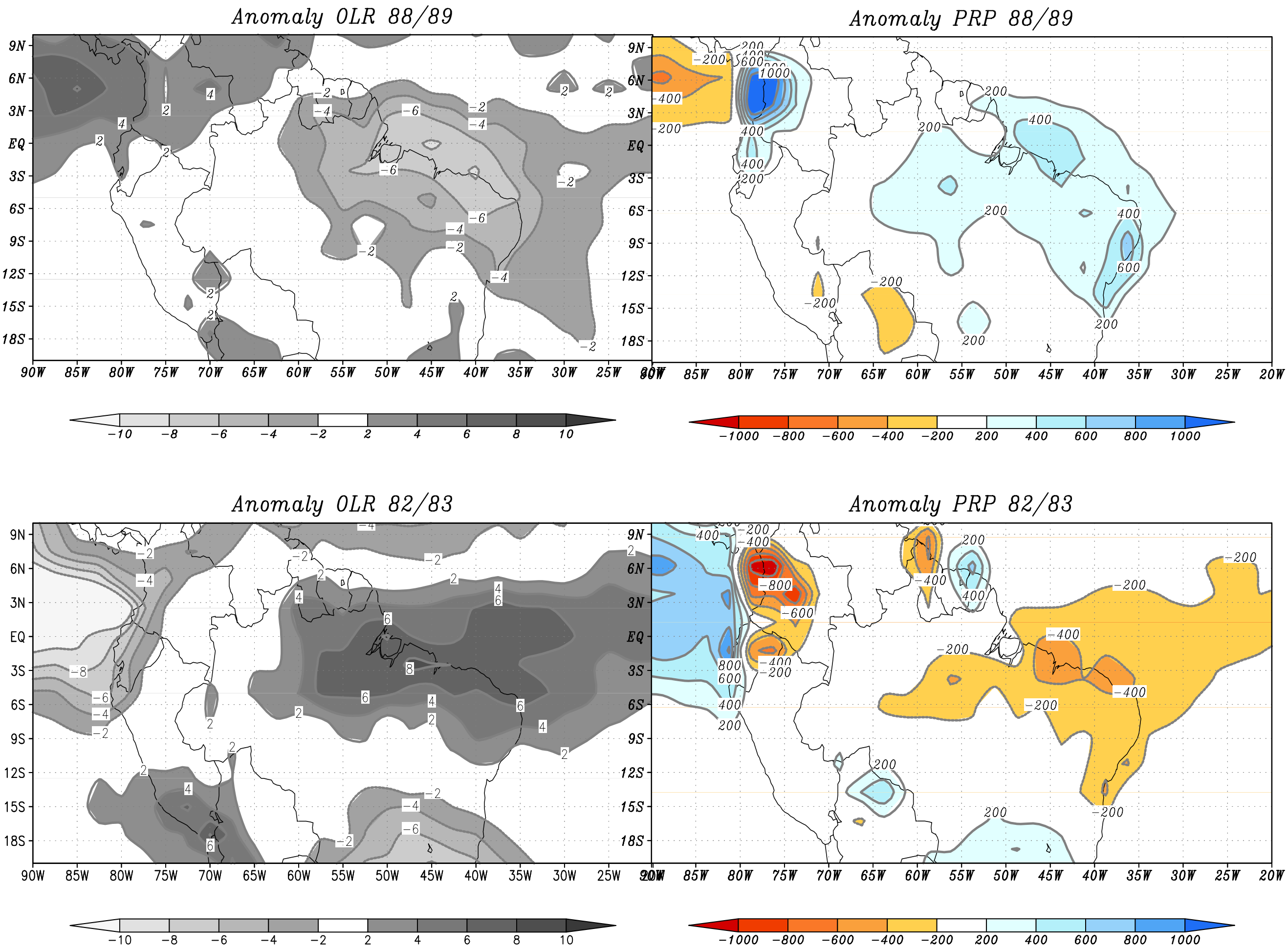
Sumner G. N., Romero, R., Homar, V., Ramis, C., Alonso, S., Zorita, E., 2003. An estimate of the effects of climate change on the rainfall of Mediterranean Spain by the late twenty first century. Climate Dynamics, 20: 789–805.

Trenberth, K. E., Hoar, T. J.: 1996. The 1990–1995 El Niño–Southern Oscillation Event: Longest on Record. Geophys. Res. Lett., 23: 57–60.

Wibig, J., 1999. Precipitation in Europe in relation to circulation patterns at the 500 hPa level. Int. J. Climatology, 19: 253–269.

Wilks, D. S., 1996. Statistical significance of long-range optimal climate normal temperature and precipitation forecasts. J. Climate, 9: 827–839.

Zorita, E., Hughes, J. P., Lettemaier, D. P., von Storch, H., 1995. Stochastic characterization of regional circulation patterns for climate model diagnosis and estimation of local precipitation. J. Climate, 8: 1023–1042.



The regional rainfall has been related to high-frequency ocean-atmospheric phenomena, such as El Niño and La Niña events; and low frequency phenomena, such as the Pacific Decadal Oscillation (PDO). A complementary application was carried out correlating the "monitored" rainfall database with the NCEP/NCAR reanalysis dataset to verify possible divergences relative to the observed data.

Appendix: Rainfall Reconstruction and Homogenisation over the Brazilian Amazon.

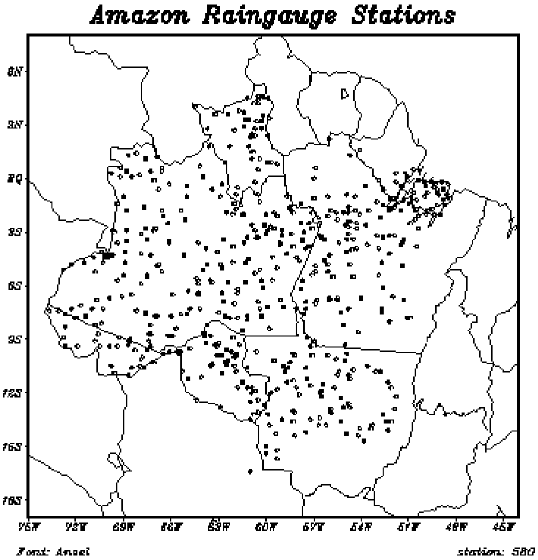
The biggest drawback in long-term meteorological time series analysis is that recorded data available must be gap-filled and quality controlled to provide a reliable continuous homogeneous reference series (where divergences are caused only by variations in weather and climate). A common problem in numerical climate characterization is the spatiotemporal processing (integration or interpolation) of data from different types and different origins or accuracy (the space-time change of support problem).

Data reconstruction is a methodology developed by climate scientists and meteorologists to remove inconsistencies in a time series due to factors unrelated weather, such as station location change, station environment change or change in instrumentation. A reconstructed time series behaves as if the station observed weather throughout its history using its current configuration. Objective: Availability, reliability and homogeneity of the historical series of meteorological data. The development of a continuous and complete daily dataset are useful in a variety of meteorological and hydrological research applications.

One of the major problems in examining the climate record for changes in extremes is a lack of high-quality, long-term data (ground-based meteorological network does not operate over a common time period of adequate length). In general, the biggest drawback is that recorded data available must be gap-filled and quality controlled to provide a reliable continuous reference time series. Besides, adapted correction factors derived from comparison measurements and calibration are crucial.

This section is addressed to procedures for reconstruction and evaluation of rainfall time series obeying a sequential strategy divided in (1) the interpolation considering the cross-correlation and the autocorrelation time-memory; and (2) the spatial interpolation procedure based upon the "optimum distance" between stations.

Daily rainfall from 580 stations placed in the Amazon (Brazil) region from Jan/1970 to Dec/1997.



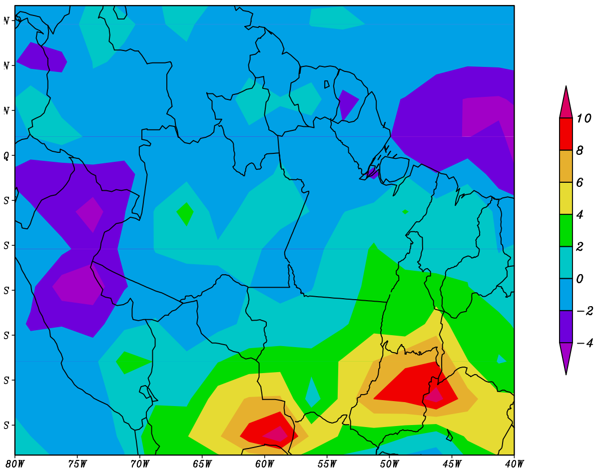
The rain-gauges location of the 580 time series. <u>EXPERIMENTAL</u> <u>DATASET</u>: Daily rainfall from 580 stations placed in the Amazon (Brazil) region from Jan/1970 to Dec/1997.

Rainfall reconstruction.

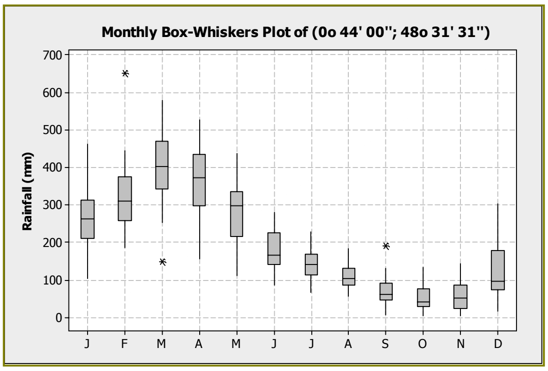
The best way to reconstruct daily precipitation (variable spatially discontinuous and extremely seasonal) time series is based on the consideration that the observation in the position that presents gap (missing values) should be proportional to the observations in the space-time nearest-neighbours (according to a measure of homogeneity proximity) in the target period. This procedure suggests a weighted average taking into account the supplementary stations (neighbours) information and the observations of the target meteorological station.

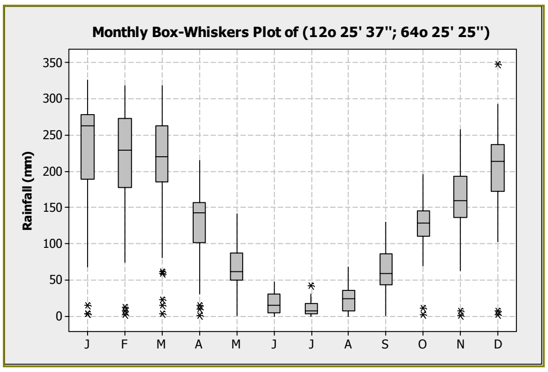
The neighbours of the conditioning point correspond to data patterns that are similar to the pattern at the conditioning point. The neighbours are established by calculating the vector distance between the observations in similar days. Clearly, there is some utility to giving a higher probability to a day that is more similar to the conditioning day than the other "neighbours." Using a weight function that decays smoothly with distance can reduce the sensitivity to the number of nearest neighbours used for recovering. A weight function applied to the nearest neighbours that is natural in a certain sense and the choice of the number of nearest neighbours to use.

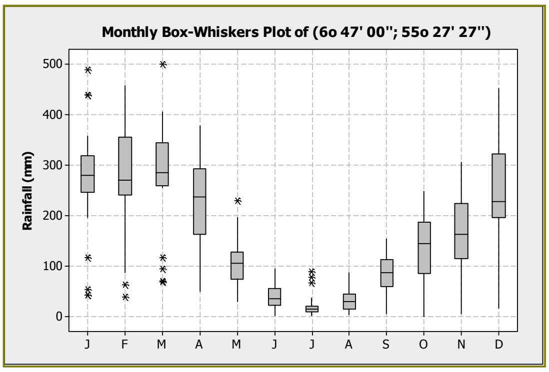
Homogenisation.
To validate this work-algorithm, the diagnostic of homogenised rainfall was accomplished. The spatial distribution of rainfall is summarised by the subjective descriptive four-moment measures: Mean, Variance, Skewness and Kurtosis, giving support to spatial pattern recognition. A number of homogeneity tests with kinds to detect non homogeneities are employed (methods currently used) and the effect of natural variability is established taking into account ensembles of consecutive years. The non-parametric methods were used to test the significance of trends. As expected, this robust reconstruction method has good performance, since more information is introduced in the decision-making system.



The rainfall anomaly based on the reconstructed rainfall time series.

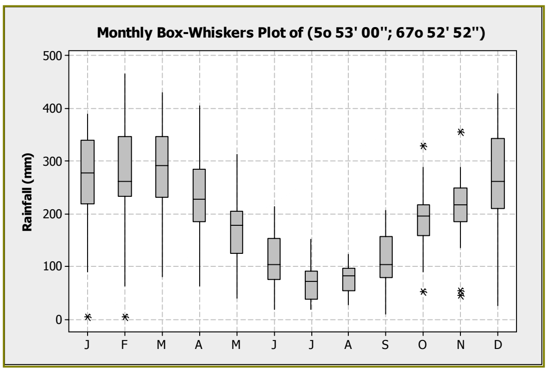






Partially Reconstructed

This work consists on the reconstruction of long-term rainfall series for Brazilian Amazon localities, substantiating the spatial consistency, apparent cycles and respective trends. This approach recognizes very well the mutual dependence between spatiotemporal rainfall variability.



Substantially Reconstructed.