Reconstrucción de la precipitación en Angola en el periodo de Guerra

Angola rainfall reconstruction and rainfall variability during the war period: 1979-2003

Belén RODRÍGUEZ-FONSECA & Joaquim ADOLFO XAVIER

Departamento de Geofísica y Meteorología
Universidad Complutense de Madrid, Spain
brfonsec@fis.ucm.es

Received: 10 July 2009
Accepted: 15 October 2009

RESUMEN
La república de Angola posee una importante falta de datos en las series de precipitación y temperatura observadas *in situ* desde 1979 y hasta 2003, debido a la guerra civil que asoló el país durante dicho periodo. Este motivo acentúa el hecho de que existan sólo unos pocos y obsoletos estudios describiendo el clima de la región, por lo que la mejora del Estado del Arte de la climatología de la lluvia y de su variabilidad es un punto esencial de estudio para el entendimiento del clima tropical reciente. El periodo sin datos tiene lugar tras el *climate shift* de los 70's, tras el cual se han documentado cambios importantes en el clima global. Por todos estos motivos, la reconstrucción de las series de precipitación de Angola es de gran interés. Mediante un conocido método de regionalización estadística, las series de precipitación de Angola se han reconstruido para la estación lluviosa del periodo 1979-2003. Para ello, se ha tenido en cuenta la información atmosférica disponible a través de los reanálisis del NCEP y de índices de teleconexión conocidos con influencia en el Sur del continente Africano. Asimismo, nuevos índices se han calculado en base a las teleconexiones establecidas con los datos disponibles. Las estructuras que definen la variabilidad de la precipitación en Angola en base a las series reconstruidas se han comparado con las obtenidas con datos recientes de precipitación estimados a partir de observaciones de satélite. La información obtenida de este estudio es de gran utilidad y constituye un paso en la mejora del conocimiento de la climatología de Angola y de su variabilidad.

Palabras clave: Precipitación en Angola; variabilidad climática en el Atlántico Sur; variabilidad climática en África meridional; reconstrucción de series de precipitación; regionalización estadística

ABSTRACT
The Republic of Angola has a dramatic lack of in situ precipitation and temperature data since 1979 up to 2003 due to a civil war. Due to this fact, there are only a few and old studies about the climate of the region being the improvement of the state of the Art of the rainfall climatology and its variability, a hot point for the understanding of the tropical climate. The period without data occurs after the *climate shift* of the 70's, for which important changes in the global climate have been documented. For all these reasons, the reconstruction of the Angola precipitation timeseries is of great interest. Using the commonly used methodology of statistical downscaling, the 1979- 2003 rainfall timeseries have been reconstructed for the rainy season, taking into account the available atmospheric information from the NCEP reanalysis and documented teleconnection indices with an important influence in Southern African continent. Also, new indices have been calculated on the basis of the teleconnections established with the available data and the analysis of the work done by other authors. The variability of the reconstructed precipitation has been characterized by calculating the principal modes of the anomalous rainfall and a comparison with a satellite-based rainfall data set has been also performed. The information obtained in this study is very useful and adds new insight for the improvement of the knowledge of the Angola climatology and its variability.
Key words: Angola rainfall; South African climate variability; Southern Atlantic variability; Tropical Atlantic variability; reconstruction of rainfall time series; statistical downscaling

1. INTRODUCTION

The republic of Angola is sited in the south Atlantic tropical region, a feature that makes its study of high interest. Tropical climate effects go further the limits of their frontiers. The tropical radiation budget and the resultant humidity and temperature conditions art the big engine of the General Circulation of the atmosphere. For this reason the knowledge of the tropical climate and its variability is crucial for the understanding of the global climate variability.

The climate of Angola varies from the northern region (Cabinda), with a tropical climate, to the southern region, characterized by almost desert conditions (Namibe). The country is influenced by the Santa Helena Subtropical high and the ITCZ, and nearby an area of high oceanic variability. The Angola-Bengela upwelling region is the focus of a big number of studies about the tropical Atlantic Variability, because it is the source of the so-called Benguela Niños (Florenchie et al., 2003) and it has been recently pointed out as the origin of the so called Atlantic Niño (Zebiak, 1993; Polo et al., 2008). In this way, minimum precipitation amounts take place in the western part of the southern continent, close to the Desert of Namibe, due to the presence of this coastal upwelling.

Also, remotes influences from the Indian and Pacific oceans have been documented in the region (Fauchereau et al., 2003) and Ropelewski and Halpert (1987; 1989) pointed to a positive correlation between the meridional African rainfall and the Southern Oscillation.

Also, the nearby location of the warm Agulhas current illustrates the higher amounts of precipitation in other coastal regions (Jury et al., 2002) and the generation of extended cumulus directly over it.

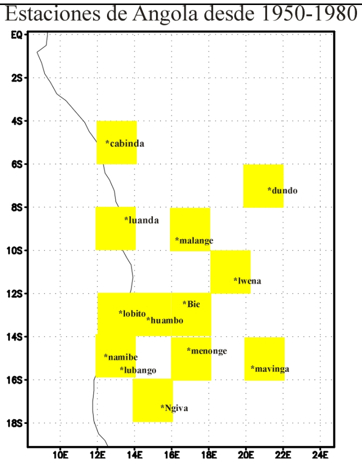
The southern Atlantic climate variability is one of the regions with strongest biases in the seasonal prediction models. This variability is determined, among others, by the position of the ITCZ, the Santa Helena High and the anomalous SST conditions. Due to the location of the Angola region, the knowledge of the rainy season and its variability along the observational period is determinant to give insights to the understanding of the coupled system and thus, the improvement of the seasonal prediction system.

The current rainfall databases over regular grids are based *in situ* data and, for this reason, they are not reliable in those regions with no available data.

Nevertheless, Angola has suffered a dramatic Civil War which began after the end of the war for independence from Portugal in 1975 and continued up to 2002. During this time, most of the *in situ* rainfall information disappeared, with just a few records of observed precipitation.

This is the case of Angola and, for this reason there is a need of data reconstruction over it. Nevertheless, this works does not try to reconstruct the observed precipitation record but yes the seasonal evolution of the rainfall in Angola variability during the rainy season in the war period on the basis of the available data.

The tropical countries host most of the poor populations in the world, in which most of the economy is based on the agriculture. With the new database, a new perspective of the climate variability of the region can be determined and new insights in the study of the seasonal predictability of this under-developed country.



Stations	Coordinates	Period	Height(m)
	coast		
Cabinda	05° 33’ S – 12° 11’ E	1951-80	20
Lobito	12° 22’ S – 13° 32’ E	1951-70	01
Luanda	08° 49’ S – 13° 13’ E	1951-80	44
Namibe	15| 12’ S - |12° 09’ E	1951-80	45
	inland		
Bié	12° 23’ S – 16° 57’ E	1953-70	1702
Dundo	07° 24’ S – 20° 40’ E	1951-80	776
Huambo	12° 48’ S – 15° 45’ E	1951-80	1701
Lubango	15° 54’ S – 13° 31’ E	1951-80	1763
Lwena	11° 47’ S – 19° 55’ E	1951-73	1357
Malange	09° 33’ S – 16° 22’ E	1951-80	1139
Mavinga	15° 50’ S – 20| 21’ E	1951-73	1188
Menongue	14° 40’ S – 17° 42’ E	1951-73	1348
Ngiva	17° 04’ S – 15° 43’ E	1941-60	1150
Saurimo	09° 35’ S – 20° 24’ E		1096
Uíge	07° 35’ S – 15° 00’ E	1956-74	826

Figure 1: Location of the Angola stations used in the study. **Table 1** indicates the *in situ* precipitation and temperature stations together with the location and the availability of data

In the next section, the data used in the analysis and the teleconnection indices, both known and designed for this experiment, are described. Next, after a brief description of the Methodology, the reconstructed time series will be shown together with the analysis of the predictors used. Finally, the variability patterns of the precipitation, obtained with different databases and the reconstructed time series, are described.

2. DATA AND METHODOLOGY

In this study, observed data of monthly mean precipitation in the 15 stations from the Angola Meteorological Service with longer available timeseries are used, as it can be seen in Table 1. These rainfall data compose the dependent variable of the statistical multivariate regression model that we will develop in order to have an algorithm to reconstruct the rainfall variability in each of the Angola rainfall station.

As independent variables, the predictors used will be:

1. Monthly means of atmospheric fields from the NCEP reanalysis (Kalnay et al., 1996), as summarized in Table 2.
2. Historical data of SST from the NCEP/Reynolds data base (Table 2).
3. Historical data of rainfall and temperature from the University of Dellaware (Legates, 1989) database (see Table 2).

The different tasks involved in this study, in order to design an optimal reconstruction, were:

- Determination of the model predictors.
- Development of the statistical model.

In this way, for each of the 15 *in situ* stations, the timeseries of the different atmospheric variables (from NCEP reanalysis, see Table 2) for the 4 gridpoints surrounded each of the stations are taken as independent variables. Also, different atmospheric and oceanic indices, dynamically associated with the Angola rainfall or with the southern African region, are also included as independent variables or predictors (see Table 2). These predictors are related to remote teleconnections as El Niño, but also with the local variability as the Angola-Benguela upwelling system and the southern Atlantic ocean (Rouault et al., 2003).

Also, calculating composite maps of different atmospheric and oceanic variables, for high and low rainfall anomaly episodes, different new indices were also defined (see Table 2).

The methodology is based on the "Model Output statistics" (MOS) technique, although in this case we use reanalysis data and not seasonal predictions coming from a model. This is an statistical downscaling technique that requires the use of regression models with more than one factor (Klein and Bloom, 1989) in a way that there is an equation for each of the timeseries reconstructed (one per station) on the basis of the designed predictors (see Table 2). Hence, we create an stepwise regression model, including also the Analysis of Variance, the analysis of the dispersion, the correlation, and the statistical significance (for more further information, please refer to the PhD Thesis of Joaquim Adolfo Xavier).

3. RESULTS

3.1 Application of the Model

The definition of the main predictors with a potential role in the understanding of the Angola rainfall has been a hard task which would constitute the focus of a longer paper. These predictors appears as the result of a deep study of the atmospheric and oceanic predictors obtained with the available data, and also with the inclusion of those obtained by other authors when studying surrounded areas or the entire South Atlantic climate variability. As the main goal of this paper is to summarize the main conclusions about the reconstruction of the Angola rainfall and its variability in the war period, in Table 2 we have just summarized these indices and its definition in case of being defined as the first time.

Once the predictors are defined, a stepwise regression is performed for the period with available data in each of the stations, leaving 10 years of data out of the model for validation. In Fig. 2, the modelled precipitation together with the observed one, for the period with available data, is shown together with a summary of the main predictors used in the model and the correlation coefficient score obtained between the observed data and those simulated with the regression model. The r-squared coefficient gives a measure of the explained variance, so we have selected those stations explaining more that the 40% of the variance.

As it can be inferred from Fig. 2, for some of the stations, the regression model needs the use of remote teleconnection indices, as Huambo, Lobito, Uige and Lubango; which are stations sited in the southern part of the country, under the influence of the Santa Helena Anticyclone. These stations need the inclusion of *El Niño* when performing the stepwise model. The relation between the Santa Helena Anticyclone and *El Niño* has been reported by several authors and its impact in recent decades has increased. The rainfall in the southern part of the country depends of the position of the ITCZ, which determines the rainy season. For this reason, the analysis of the predictors associated to the rainfall for those stations is also important for the improvement of the seasonal forecast of the country, which economy is based on the agriculture.

Other stations need the inclusion of more local phenomenon, as the Agulhas current (Menongue and Huambo and Lubango) and of some atmospheric phenomena in lower tropospheric levels but also in upper levels.

In general the regression model fits the observational record in those stations located in the southern part of the country.

The next step is to validate the model applying it for the 10 years of available observations that we have left out of the analysis. The correlation between the model and the observations (not shown) is good in all the stations shown in Fig. 2, and for these stations, we have made the reconstruction (not shown). For more information, please refer to Joaquim Adolfo Xavier PhD Thesis (Xavier, 2010).

In the next section, the rainfall variability pattern calculated with different databases (NCEP precipitation and Legated and Willmot precipitation) for the observational period, and also with the in situ stations, is described and compared with those patterns obtained with the reconstructed data and the CMAP data set, based on satellite data (Xie and Arkin, 1997)

3.2 Variability of the Rainy Season

Applying the Principal component analysis (PCA) to the rainy season anomalous rainfall (from October to March), the leading spatial pattern, accounting for about

20% of the variability, points out to a one-signed structure with maximum values over the mountainous region of the central Angola (Fig. 3). The pattern resembles the climatological mean pattern and the appearance of a monopolar pattern reflects the influence of a global scale phenomenon with does not care about local features. This mode is related to a strong gradient of sea surface temperature between the tropical Atlantic and Indian Ocean (not shown). Using the available observations from the 15 mentioned stations, the resultant leading mode coincides with that obtained with the Legates and Willmot and the NCEP databases.

Local atmospheric predictors	Atmospheric variables used (in pressure levels): Relative humidity (H); Geopotential height (Z); Aire temperaturer (T); Meridional wind speed (v); Zonal wind speed (u); Vertical wind speed (w) **Levels** 925 hPa, 850 hPa, 700 hPa, 500 hPa, 300hPa, 200 hPa, 100 hPa Variables at the surface: Sea level Pressure (SLP); 2 m temperature (T2) **Data base**:NCEP-reanalysis .**Period**: 1948-2000; **Resolution**: 2.5x 2.5
Observed rainfall and temperature	Legates and Willmott database.**Period**: 1950 a 1996; **Resolution**: 2.5x 2.5
Local oceanic predictors	COADS SST.**Period**: 1950 a 1998; **Resolution**: 2x 2
Remote predictors	El Niño indices (regions 1-2,3,4 y 3-4), Southern Oscillation index (SO), Quasi-bienal Oscillation (QBO), Atlantic Niño index **Period**: 1950-2003
Designed indices from composite maps	Dundo- South Atlantic = -3.0z500(37ºS,10ºE) + 3.0z500(13ºS, 20ºE) in SONDEFMAM Bie- Indian = 1.8z500(15ºS, 20ºE) – 3.0z500(27ºS, 40ºE) in SONDEFMAM Bié- South Atlantic = 1.8z500(15ºS,20ºE) – 6.6z500(35ºS, 8ºW) in SONDEFMAM Mavinga-Indian = -5.4th(17ºS, 12ºE)+6.6th(30ºS, 40ºE) in SONDEFMAM Agulhas current-Lwena = -4.2z850(28ºS, 28ºE) + 1.8z850(10ºS, 20ºE) in SONDEFMAM **Data base**: the indices have been calculated with the NCEP reanalysis
Designed indices from referenced studies	**Oceanic indices** Equatorial Indian ocean (CEI); Warm Angola Current(SST [10ºE-14ºE,9º-16ºS]); Cold Benguela Current(SST [24º S-30º S,10º E-17º E].); Warm Agulhas current (SST [27º S-40º S , 12º E-27º E]); Angola-Benguela frontal zone (ABFZ);[4.5º S-18.5º S, 10 º E]; Tropical South Atlantic (TSA-1, TSA-2 y TSA-3). SST [0-20º S,30º W-10º E] and [5º W-5º E,10º S-20º S] and [10º W-10º E,10º S- 30º S] respectively. **Data base**: the indices have been calculated with the COADS data.
	Atmospheric indices: South Atlantic Ancicyclone1 (SAA-1) SLP (30º S, 10º W) South Atlantic Ancicyclone 2 (SAA-2) SLP (30º S, 10º W) – SLP (10º S, 30º E) Tropical Temperature Throughts (TTT) Z850 (35ºS, 0ºE)-Z850(45ºS, 25ºE) ITCZ: index of the latitud for which the meridional wind is null between 0º and 20ºS Central Equatorial Atlantic (ECAU) Z200 hPa (5ºN-10ºS, 35ºW-5ºW) South Indian Osillation index-1(OIS-1) SLP (55ºE, 33ºS)-SLP(55º E, 6ºS) **Data base**: the indices have been calculated with the NCEP reanalysis

Table 2: Summary of the main indices used as predictors of the multivariate regression model used to reconstruct the seasonal rainfall in Angola during the war period. For further information, please refer to the PhD Thesis of Joaquim Adolfo Xavier.

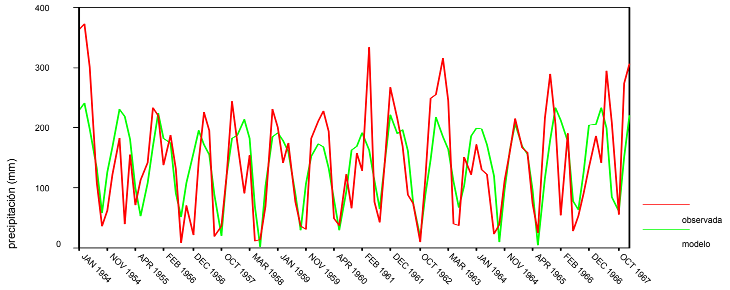
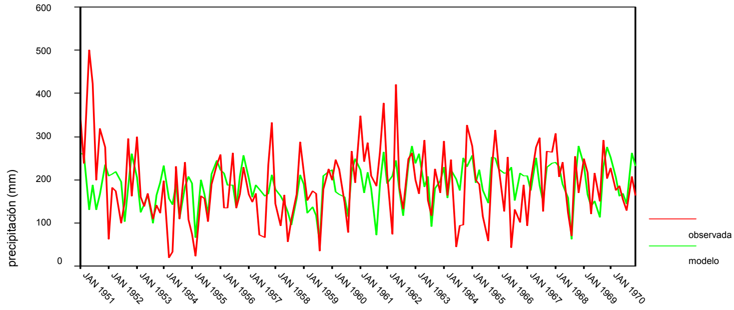
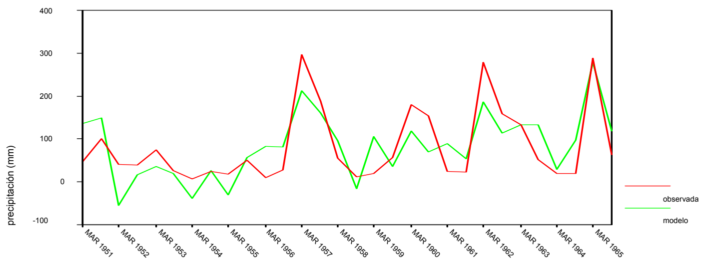
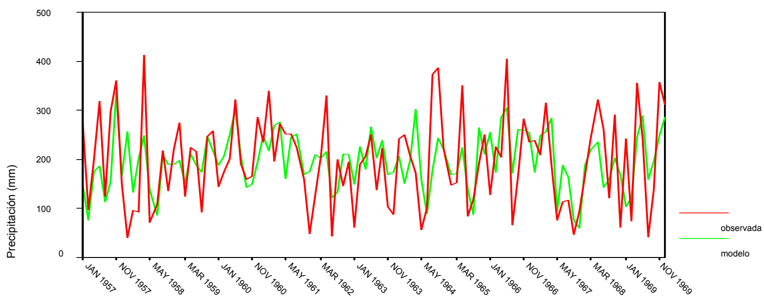
The second EOF (15%) has a dipolar structure with opposite behavior in the NW and the SE regions. This dipolar structure reflects the presence of local effects acting taking into account the orography of the region. In this case, the spatial structure obtained with the observations differs from the corresponding structure obtained with the gridded databases, may be because of the bad reliability of the latter representing the rainfall due to more local phenomena. Finally, the third EOF differences the rainfall in the SW from the NE.

Next step is to analyse the anomalous principal patterns obtained with the reconstructed timeseries in order to test if this new data captures the variability of the regions. Figure 4 represents the three leading EOFs for the reconstructed 1981-1997 period and compares them with those obtained with the CMAP rainfall, a dataset based on satellite measurements from 1979. The leading pattern of the reconstructed series resembles de observed one obtained, within this time period, with the CMAP database. For the rest of the modes, the reconstruction gives some important differences for some particular locations.

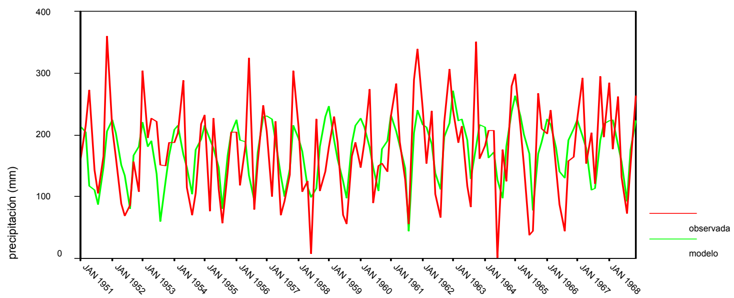
Nevertheless, when comparing the leading pattern with the corresponding one associated with the 1951-1980 one (Fig.3) an important difference appears. In this way, although the pattern describes a one-signed structure with maximum in the central regions, this center of action is located further north in the 1981-97 period. This change in the location of the action center also appears when comparing the pattern obtained with CMAP for the second period with the one obtained with the rest of datasets for the 1951-80 period, a feature that confirm the real change in the location of the action center.

This is also an important finding due to the fact that several works have reported important changes in the global climate after 1970’s (Baines and Folland, 2007), as changes in the Pacific Niño and the tropical circulation.

This result highlights the importance of the reconstruction of the data in Angola also in the understanding of the climate change.

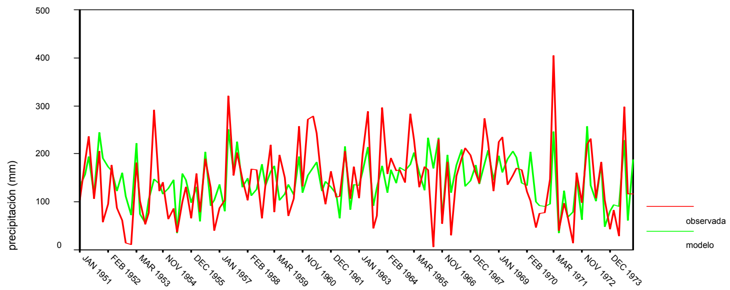
Location: Menongue **Rainy season:** October-April **Predictors**: CAGUST_1 CAGUSTA1 Z700BIE U300NCP1	 r=0.68
Location: Huambo **Rainy season:** October- April **Predictors**: NIÑO_3 CAGUSSTA Z850HUA T100NCP1 H700NCP1 Z300LU NIÑ03 (-1) U700NCP1	 r=0.58
Location: Lobito **Rainy Season:** March- April **Predictors**: Niño_12 Niño_12-2 Niño_3-1 Abfza-1 z700bie	 r=0.85
Location: Uige **Rainy Season:** October- May **Predictors**: U850NCEP1 CBSST_A NIÑO3_2-1 W200NCEP4 H700NCEP1	 r=0.62

Location: Lwena
Rainy Season: October – April
Predictors:
ABFZ_2
T850NCEP1



r=0.65

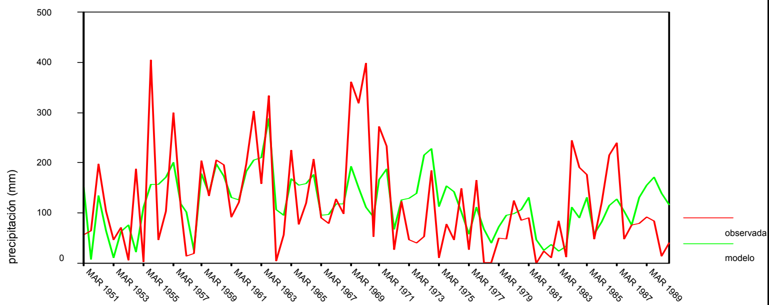
Location: Lubango
Rainy Season: November-March
Predictors:
H700NCEP1
W700NCEP4
W700NCEP2
CAGUST_2
CAGUSTA3
SOI
T200NCEP
Z700BIE



r=0.66

Location: Luanda
Rainy season: March- April

Predictors:
W200NCP3
ANDOSSTA (-1)
U850NCP1
ABFZA (-3)
Z850NCP1



r=0.6

Figure 2: Representation of the reliability of the model. Total rainfall precipitation amounts (mm) for the rainy season, from the available observations (red) together with the obtained with the statistical model (green).

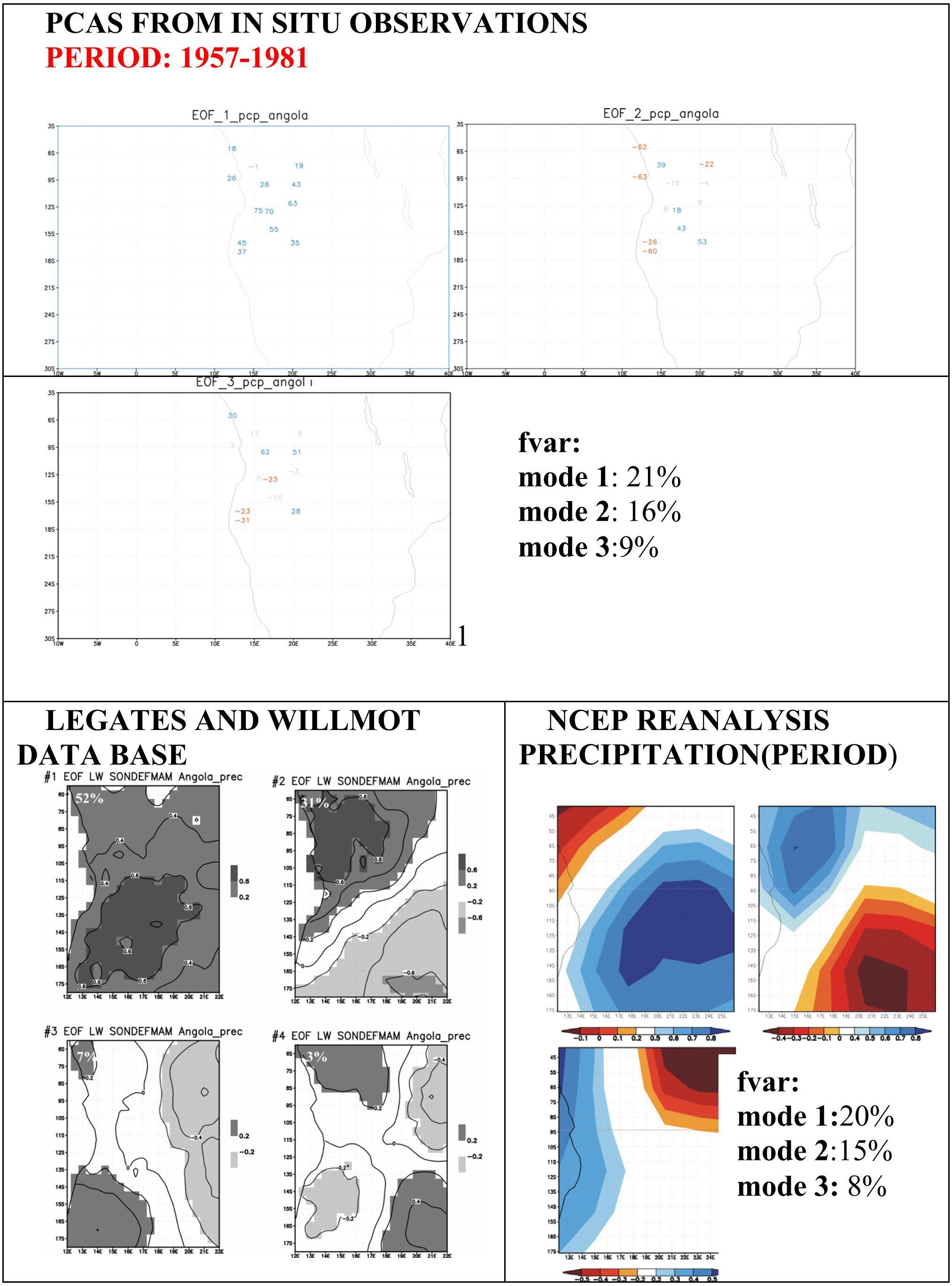


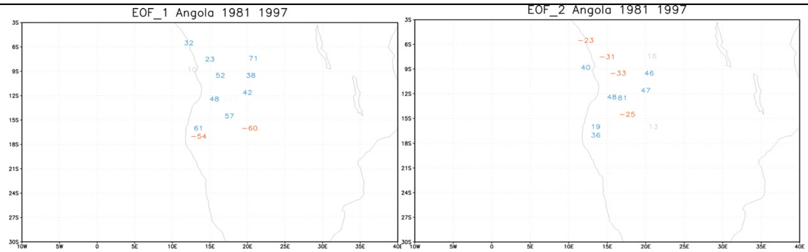
Figure 3: First 3 principal components of the observed precipitation in the different Angola observatories for the period 1953-1977. The results appear in terms of significant correlation maps (top maps are multiplied by 100) evaluated with a T-Test.

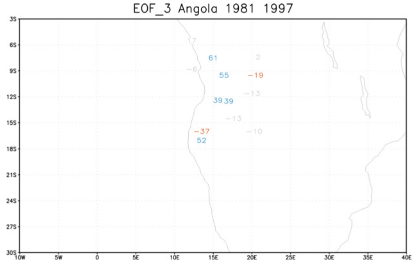
4. CONCLUSIONS

The main results of this paper can be summarized as follows:

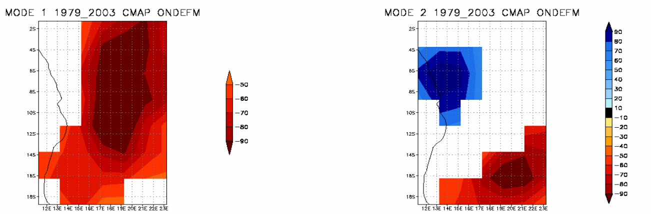
- There is a lack of observations in the Angola country due to the 1975-2002 civil war.
- With the available rainfall data, different dynamical variables have been analysed in order to create atmospheric and oceanic indices that will be used as predictors in the reconstruction of the data.
- A downscaling technique has been designed to fit the available data with a regression algorithm that takes into account the different predictors.
- The obtained regression model is able to reproduce the Angola rainfall in most of the stations, using as independent variables, both remote and local oceanic and atmospheric indices (predictors).
- The validation of the model is good, so the reconstruction of the rainfall has been performed.
- The variability of the rainfall for the decades before the war, can be described by statistical patterns that are consistent regardless of the database used.
- The variability of the reconstructed times series projects on the same patterns obtained with satellite-base dataset for the war period.
- The leading pattern of rainfall in Angola, which is characterized by a one signed structure, has changed the location of its action center after the 70's, coinciding with the so-called climate shift.

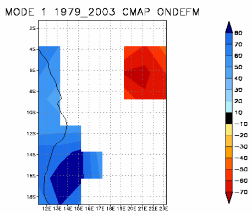
Further analysis is needed to determine the causes of these changes in a country in which the economy depends strongly of the water resources. Also, with the new available data sets and atmospheric reanalysis, the model obtained could be improved and better results should be obtained.





RECONSTRUCTED TIME SERIES
fvar:
mode 1: 23%
mode 2: 17%
mode 3:12%





CMAP 1979-2003
fvar:
mode 1: 23%
mode 2: 18%
mode 3:12%

Figure 4: As figure 3 but for the reconstructed time series (top) and the EOFs calculated with the CMAP data for the same period (bottom)

5. ACKNOWLEDGEMENTS

¿Quien va a querer investigar la variabilidad climática de un país que hace 27 años lucha por sobrevivir de las minas antipersonales, donde no se siembra ni recolecta, donde el ganado no prospera y los elefantes huyen a regiones mas tranquilas?

Joaquim Adolfo Xavier vino de Angola y quiso hacer este esfuerzo. Se encontró en el camino a una mujer ilusionada. Elvira Zurita le dio la oportunidad, como se la había dado años atrás a Abdesselam Zarougui, de hacer un doctorado y contribuir en la formación de un estudiante de un país sin recursos.

Este artículo es un resumen del trabajo llevado a cabo por Joaquim Adolfo Xavier durante el periodo 2001-2004 y ampliado durante el año 2008. Elvira Zurita García y Belén Rodríguez de Fonseca compartieron la dirección de la Tesis de Xavier. Durante estos años todos nos hicimos cómplices en un reto inexplicable, en el sueño de poder hacer una ciencia diferente, y poder ayudar con nuestras herramientas, a la mejora del conocimiento de la variabilidad climática de un país desolado por la guerra.

En 2002 terminó la guerra civil de Angola que había tenido lugar durante 27 años. Xavier deseaba volver a su casa, visitar su hermoso país devastado. En 2004 Xavier volvió a su tierra, con el propósito de regresar en breve a España para defender la Tesis, que ya tenía escrita y presentada al Departamento. Diversas circunstancias le llevaron a ir retrasando su vuelta y en 2008 vino a España unos meses. Sin embargo, de nuevo tuvo que regresar a su país sin realizar la defensa.

Elvira y yo nos ilusionamos con este proyecto. Elvira era la paciencia y la tranquilidad, la calma en la tormenta y la solución en la desesperación.

Xavier regresa en 2010 a terminar este reto, porque sabe que te lo debe Elvira, y para que desde donde estés veas terminado el trabajo paciente de una ilusión cumplida.

6. REFERENCES

BAINES P.G. & C.K. FOLLAND (2007). Evidence for a rapid global climate shift across the late 1960s. *J. Climate*, 20, 2721-2744.

FAUCHEREAU , N., S. TRZASKA, M. ROUAULT & Y. RICHARD (2003). Rainfall Variability and Changes in Southern Africa during the 20th Century in the Global Warming Context . *Natural Hazards* 29, 139-154.

FLORENCHIE, P., J.R.E. LUTJEHARMS, C.J.C. REASON, S. MASSON, & M. ROUAULT (2003). The source of Benguela Niños in the South Atlantic Ocean. *Geophys. Res. Lett.,* 30, 1505.

JURY, M.R., D.B. ENFIELD & J.-L. MÉLICE (2002). Tropical monsoons around Africa: Stability of El Niño–Southern Oscillation associations and links with continental climate. *J. Geophys. Res.,* 107, 3151.

KALNAY E.M., M. KANAMITSU, R. KISTLER, W. COLLINS, D. DEAVEN, L GANDIA, M. IREDELL, S. SAHA, G. WHITE, J. WOOLLEN, Y. ZHU, M. CHELLIAH, W. EBISUZAKI, W. HIGGINS, J. JANOWIAK, MO KC, C. ROPELEWSKI, J. WANG, A. LEETMAA, R. REYNOLDS, R. JENNE & D. JOSEPH (1996). The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.,* 77, 437-471.

KLEIN, W.H. & H. J. BLOOM, (1989). An operational systems for specifying monthly precipitation amounts over the United States from field of concurrent mean 700 mb heights. *Weather and Forecasting*, 4, 51-60.

LEGATES, D.R. (1989). A high-resolution climatology of gauge-corrected global precipitation. In *Precipitation Measurement. Proceedings of the WMO/IAHS/ETH International Workshop on Precipitation Measurement, St. Moritz, Switzerland, Dec. 3–7, 1989*, Sevruk B (ed). Swiss Federal Institute of Technology: Zurich, 519–526.

POLO I., B. RODRIGUEZ-FONSECA, T. LOSADA & J. GARCIA-SERRANO (2008). Tropical Atlantic variability modes (1979–2002). Part I: time evolving SST modes related to West African rainfall. *J. Climate*, 21, 6457–6475.

ROPELEWSKI C.F. & M.S. HALPERT (1987). Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation. *Mon. Wea. Rev*., 115, 1606-1626.

ROPELEWSKI, C.F. & M.S. HALPERT (1989). Precipitation patterns associated with the high index of the Southern Oscillation. *J. Climate,* 2, 268-284.

ROUAULT, M. , P. FLORENCHIE, N. FAUCHEREAU & C. REASON (2003). South East tropical Atlantic warm events and southern African rainfall. *Geophys. Res. Lett*., 30, 8009.

XIE, P. & P.A. ARKIN (1997). Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. *Bull. Amer. Meteor. Soc.*, 78, 2539–2558

ZEBIAK, S.E. (1993). Air–sea interaction in the equatorial Atlantic region. *J. Climate,* 6, 1567–1586.

XAVIER, J.A. (2010). Análisis de la variabilidad pluviométrica en Angola y reconstrucción de las series de precipitación. Directoras: Elvira Zurita García y Belén Rodríguez de Fonseca (en espera de defensa).