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Interdecadal Changes in Ocean Teleconnections with the Sahel

Implications in Rainfall Predictability

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Interdecadal Changes in Ocean Teleconnections with the Sahel

Implications in Rainfall Predictability

Doctoral Thesis accepted by the Complutense University of Madrid, Spain

Springer

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To David and Raúl

Some people feel the rain. Others just get wet.

Bob Marley

We specially need imagination in science. It is not all mathematics, nor all logic, but it is somewhat beauty and poetry

Maria Montessori

Supervisor's Foreword

The understanding of climate variability has been enhanced in the last decades due to the huge amount of available data provided by the most prestigious meteorological centers. These data come from observations, reanalysis, and simulations performed with general circulation models.

The use of this huge amount of data has given the opportunity to the research community to better understand the causes of rainfall variability in regions like the Sahel, which has suffered severe droughts with a society strongly dependent on agriculture and therefore water.

The understanding of seasonal to decadal rainfall variability in this region is one of the most important challenges of climate research, and the Sahel has become a natural laboratory due to its sensitivity to changes in climate.

In recent decades, the ocean has been put forward as the main external forcing on Sahelian rainfall variability from interannual to decadal timescales. The sea surface temperature variability of the Pacific, Atlantic, Indian, and Mediterranean have been demonstrated as potential predictors, enhancing rainfall forecast skill.

Nevertheless, at the beginning of this thesis, there were some important open questions regarding the stability of the SST-Sahelian rainfall links along the observational record. Some works had suggested that the Pacific influence on the Sahel was not stable and had even disappeared after the 1970s. In addition, coupled models still lacked on reproducing mean state and variability of some regions such as the tropical Atlantic, so further analysis was still needed for the correct assessment of seasonal to decadal predictability of Sahelian rainfall.

This thesis started with a cooperational project with the University Cheikh Anta Diop (UCAD) in Dakar and the Universidad Complutense de Madrid.

At that time, we committed to donate a statistical prediction model for seasonal rainfall based on the predicting value of sea surface temperatures (SSTs). Using available grid observational data from SSTs and rainfall, discriminant analysis techniques were implemented together with all the preprocessing in the S^4CAST (Sea Surface Temperature-based Statistical Seasonal foreCAST) model. This model included a study of the stability of the SSTs-rainfall links, and it was able to determine the regions and periods in which each predictor could be used for the Sahel. A cross-validated hindcast was included together with an analysis of the skill.

Roberto Suárez started his PhD working on the design and implementation of this S^4CAST tool. Roberto visited the UCAD department during his 3-month stay, sharing this tool with students and researchers working not only in rainfall variability but also in malaria and coastal upwelling.

Roberto used Sahelian rainfall variability as a benchmark for the model. Key results emerged when analyzing the stability of the rainfall-SSTs links found. At that time, the thesis started to take shape.

The application of S^4CAST to Sahelian rainfall ended with important insights on the influence of the tropics versus the extratropics on the Sahel. On the one hand, results suggested that the tropics counteract their impact on the Sahel acting together during decades in which the intertropical convergence zone was located equatorward. On the other hand, the extratropics, and in particular the North Atlantic and the Mediterranean Sea enhanced their influence in decades in which the ITCZ was located northward. The decadal migration of the ITCZ seemed to be modulated by multidecadal ocean variability.

The thesis conluded with an experiment done with a general circulation model to check the next hypothesis: "the position of the ITCZ, forced by the ocean multidecadal variability, as responsible for the enhanced Mediterranean influence on Sahelian rainfall variability."

A second visit was then planned, and Roberto made a 3-month stay in the Université Pierre and Marie Curie working, under the supervision of Marco Gaetani and Cyrille Flamant, in performing simulations with the IPSL model in which those hypotheses were confirmed.

The implications of the results of this thesis go far from the seasonal forecast. They are also useful when analyzing decadal variability. In this way, under skillful decadal predictability, we can determine the decades in which some particular oceanic predictors can be used in seasonal forecast. Nowadays, the S^4CAST tool is being used by other groups working in crop forecasting, malaria prediction, and upwelling.

Some international important projects such as PREFACE have ended with important conclusions in which the ITCZ has been pointed out as the main actor to be better simulated. Thus, GCMs still need to be improved to better determine the stability of Sahelian rainfall-SST variability links.

This thesis has three different dimensions: a technical dimension, a research dimension, and a human dimension. Working in the Sahel is a gift for a scientist not only for being sensitive to climate variability but also on the impacts that the improvement of its knowledge has on society.

Madrid, Spain
April 2017

Belén Rodríguez de Fonseca

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Colman A, Rowell D, Foamouhoue AK, Ndiaye O, Rodríguez-Fonseca B, **Suárez-Moreno R**, Yaka P, Parker DJ and Diop-Kane M (2017) Seasonal Forecasting in Meteorology of Tropical West Africa: The Forecasters' Handbook (eds D. J. Parker and M. Diop-Kane), John Wiley & Sons, Ltd, Chichester, UK.

Suárez-Moreno R, Rodríguez-Fonseca B, Barroso JA and Fink AH (2018a) Interdecadal changes in the leading ocean forcing of Sahelian rainfall interannual variability: Atmospheric dynamics and role of multidecadal SST background (accepted to be published in the Journal of Climate).

Suárez-Moreno R, Rodríguez-Fonseca B, Gaetani M and Flamant C (2018b) Robust multidecadal modulation of the Mediterranean impact on the Sahel (submitted).

Preface

The West African Sahel is the transition region between the wet equatorial zone and the dry Sahara desert. Year to year, the Sahel alternates an extremely dry season with a strong rainfall regime from July to September. The water resources available during the long dry season depend almost entirely on the intensity of rainfall during the rainy season, also known as the West African Monsoon (WAM).

The WAM presents a marked variability at interannual timescales (e.g., Sultan et al. 2003; Sultan and Janicot 2003), being a major topic of study. The severe drought experienced in the Sahel from the 1970s to the 1990s, and the apparent recovery trend in the recent period, also reveals the pronounced interdecadal variability of the WAM (Hulme et al. 2001; Nicholson 2005; Lebel and Ali 2009).

The WAM system is primarily determined by the northward shift of the intertropical convergence zone (ITCZ) along with a thermal gradient between the Sahara desert to the north and the Guinean Gulf to the south (e.g., Sultan and Janicot 2000; Chiang et al. 2000, 2002; Kushnir et al. 2003; Nicholson 2009). Thus, although land surface processes and internal variability cannot be neglected, the oceanic forcing plays the leading role in the predictability of the WAM (e.g., Folland 1986; Palmer 1986; Fontaine et al. 1998; Skinner et al. 2012; Rodriguez-Fonseca et al. 2015). On the one hand, it is presented as the main driver of the decadal variability (e.g., Janicot et al. 2001; Biasutti et al. 2008; Mohino et al. 2011a; Martin et al. 2013). On the other hand, several observational studies address the interannual oceanic teleconnections from the tropical Pacific (Janicot et al. 2001; Rowell 2001; Joly and Voldoire 2009), the tropical Atlantic (Giannini et al. 2003; Polo et al. 2008; Joly and Voldoire 2009; Nnamchi and Li 2011), and the Mediterranean (Rowell 2003; Gaetani et al. 2010; Fontaine et al. 2011a).

Moreover, recent observational studies put forward interdecadal changes in the interannual sea surface temperature (SST)-forced response of the WAM (Janicot et al. 1996; Fontaine et al. 1998; Mohino et al. 2011b; Rodriguez-Fonseca et al. 2011, 2015; Losada et al. 2012). Nevertheless, the underlying causes of these unstable teleconnections and its consequent implications in Sahelian rainfall predictability have not been addressed so far, this being the leading motivation of the present thesis.

Objectives

The objectives are stated as follows:

- Design and creation of a statistical tool based on the SST capability to impact on climate-related variables, analyzing the nonstationary behavior of the potential teleconnections.
- Application of the statistical tool to conduct an observational analysis of the nonstationary SST-Sahel interannual teleconnections. The leading SST impacts are considered (tropical Atlantic, tropical Pacific, Mediterranean) to characterize the underlying dynamics.
- Characterization and analysis of the role of multidecadal SST variability in driving the nonstationarity of interannual teleconnections, with a special emphasis on those teleconnections that may be dominating Sahelian rainfall variability in the recent period.

Data and Methodology

Different observational datasets have been used in order to avoid data-related uncertainties. Regarding SST, the Extended Reconstructed Sea Surface Temperature (ERSST; e.g., Smith and Reynolds 2004) and the Hadley Center Sea Ice and Sea Surface Temperature (HadISST; e.g., Rayner et al. 2003) databases have been used. For rainfall, a novel dataset of rain-gauge rainfall records across West Africa (Sanogo et al. 2015) has been used for the first time to assess the nonstationary SST-forced response of rainfall in the Sahel. In addition, data from the Climate Research Unit (CRU; e.g., Harris et al. 2014) and reanalysis from the Global Precipitation Climatology Centre (GPCC; e.g., Schneider et al. 2014b) have been used. Moreover, the ERA-20C reanalysis from the European Centre for Medium-Range Weather Forecasts (ECMWF) has been used to explore the atmospheric dynamical processes (Poli et al. 2016).

The statistical methodology used in this thesis mainly corresponds to the maximum covariance analysis (MCA). This technique is widely applied in climate variability to isolate co-variability coupled patterns between two fields (e.g., Bretherton et al. 1992). Based on the ability of the SST as predictor field, the MCA has been applied to analyze the predictability of Sahelian rainfall. Both parametric (t-test) and nonparametric (Monte Carlo) methods have been used to assess the statistical significance.

A series of numerical experiments were conducted by using the Laboratoire de Meteorologie Dynamique Zoom (LMDZ, version 5A) atmospheric general circulation model (AGCM) (Hourdin et al. 2006), coupled with the land surface model Organizing Carbon and Hydrology in Dynamic Ecosystems (ORCHIDEE) (Krinner et al. 2005). LMDZ and ORCHIDEE are, respectively, the atmospheric and land components of the Institute Pierre Simon Laplace Earth system model (IPSL-CM5A) (Dufresne et al. 2013).

Results

The results obtained in this thesis can be expressed in three main blocks:

- The Sea Surface Temperature-based Statistical Seasonal foreCAST model **(S^{4}CAST, Suárez-Moreno and Rodríguez-Fonseca 2015)** has been designed and programmed on the basis of the SST capability to predict phenomena such as the WAM. The S^{4}CAST has been subjected to benchmarking. As a result, the tropical Atlantic (e.g., Polo et al. 2008; Rodríguez-Fonseca et al. 2011) and tropical Pacific (e.g., Rowell 2001; Joly and Voldoire 2009) teleconnections with the Sahel, the El Niño-Southern Oscillation (ENSO) teleconnection with the Euro-Mediterranean sector (López-Parages and Rodríguez-Fonseca 2012; López-Parages et al. 2015) and the tropical interbasin Atlantic-Pacific teleconnection (Martín-Rey et al. 2012, 2014) have been satisfactorily reproduced.
- The S^{4}CAST model has been used to explore the leading interannual SST teleconnections (tropical Atlantic, tropical Pacific, Mediterranean) with the Sahel. Robust nonstationary links have been found, consequently analyzing the underlying dynamical mechanisms. The multidecadal SST background has been found to exert an influence in modulating interannual teleconnections, with the Atlantic Multidecadal Variability (AMV) and global warming (GW) playing an outstanding role (**Suárez-Moreno et al. 2018a, submitted**).
- The Mediterranean influence in the Sahel is found to be nonstationary, increasing its impact during recent decades (**Suárez-Moreno et al. 2018b, submitted**). A set of sensitivity experiments is conducted to show how a multidecadal SST warming in the North Atlantic promotes the impact on the Sahel associated with a warm Mediterranean event, resulting in a rainfall increase. Thus, the Mediterranean and North Atlantic become key factors for the improvement of Sahelian rainfall predictability.

Madrid, Spain Roberto Suárez Moreno

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Contents

1 Motivation . . . 1
References . . . 5

2 State of the Art . . . 9
2.1 Introduction to the General Circulation of the Atmosphere and Oceans . . . 9
2.1.1 The Atmosphere . . . 9
2.1.2 The Oceans . . . 14
2.2 The West African Monsoon: A Coupled Ocean-Atmosphere-Land System . . . 18
2.2.1 The Sahel . . . 23
2.3 Sahel Rainfall Variability and Predictability . . . 24
2.3.1 Rainfall Variability . . . 25
2.3.2 Rainfall Predictability . . . 30
2.4 SST-Driven Sahel Rainfall Variability . . . 32
2.4.1 Patterns of SST Variability . . . 33
2.4.2 SST-Sahel Teleconnections . . . 41
2.4.3 Non-stationary SST Teleconnections . . . 44
References . . . 46

3 Objectives . . . 57
References . . . 58

4 Physical Background . . . 59
4.1 General Concepts on Monsoon Dynamics . . . 59
4.1.1 Differential Heating . . . 60
4.1.2 Pressure Gradient Forces: Thermal Wind Balance . . . 61
4.2 ITCZ Dynamics . . . 64
4.2.1 Moist Static Energy Flux and ITCZ Migrations . . . 65
4.3 SST-Forced Teleconnections . . . 69
4.3.1 Atmospheric Response to Tropical Forcing . . . 69
References . . . 73

5 Data 77
5.1 Observational Data. 77
5.1.1 Rainfall. 78
5.1.2 Sea Surface Temperature 79
5.1.3 ERA-20C Atmospheric Reanalysis 80
5.2 Simulated Data. 82
5.2.1 Sensitivity Experiments with the LMDZ Model 82
References. 83

6 Methodology 85
6.1 Data Preprocessing. 85
6.1.1 Calculation of Anomalies. 85
6.1.2 Data Time Filtering 86
6.2 Discriminant Analysis Methods. 87
6.2.1 The Maximum Covariance Analysis 87
6.3 Statistical Field Significance 90
6.3.1 Parametric Testing 91
6.3.2 The Nonparametric Monte Carlo Method 93
6.4 Stream Function and Velocity Potential. 93
6.5 Representation of the Results. 94
References. 96

7 A Statistical Model Based on Non-stationary Predictors 99
7.1 Model Inputs 100
7.1.1 Loading Databases. 100
7.1.2 Input Parameters 101
7.2 Analysis of Stationarity: The COI Index 103
7.3 Model Outputs 104
7.4 Application of the Model: Benchmark Cases 105
7.4.1 Case Study I: Tropical Atlantic SST – Sahel Rainfall 105
7.4.2 Case Study II: Tropical Atlantic SST – Tropical Pacific SST. 108
7.4.3 Case Study III: Tropical Pacific SST – Sahel Rainfall 112
7.4.4 Case Study IV: Tropical Pacific SST – Euro-Mediterranean Rainfall 115
7.5 Discussion 117
7.6 Code Availability 120
References. 121

8 Interdecadal Changes in the SST-Driven Teleconnections with the Sahel 125
8.1 Data and Methodology. 126
8.1.1 Experimental Setup with the S4CAST Model 126
8.2 Non-stationary Interannual Teleconnections 128
8.2.1 Leading SSTA-Sahel Rainfall Covariability Modes 128
8.2.2 Mediterranean-Sahel 132

8.2.3 Tropical Atlantic-Sahel 134
8.2.4 Tropical Pacific-Sahel 138
8.3 Implications in Predictability 140
8.4 The Potential Role of Multidecadal SST Variability 142
8.5 Discussion 147
References 150

9 Modulation of the Non-stationary Mediterranean-Sahel Teleconnection 155
9.1 Observational Data 156
9.2 Statistical Approach with the S^{4}CAST Model 156
9.3 Numerical Experiments with the LMDZ Model 157
9.4 Discussion 169
References 172

10 Concluding Remarks 175
10.1 Main Conclusions 175
10.2 Future Work 178
References 179

References 181

Index 183