

La historia de Chubachi y el Agujero de Ozono: El Modo Ecuatorial. Nueva perspectiva regional y global desde los 70's

The Equatorial Mode. A new regional and global perspective from the 70's

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RESUMEN

El Modo Ecuatorial, o también llamado Niño Atlántico, es el modo más importante de variabilidad del Atlántico Tropical y explica gran parte de la lluvia anómala sobre la costa del Golfo de Guinea en el verano boreal. Este trabajo analiza el Modo Ecuatorial, su dinámica, impactos y teleconexiones, tanto regional como globalmente, desde finales de la década de los 70. La evolución de las anomalías de la temperatura de la superficie del mar asociadas a este modo desde los años 70 muestran un origen relacionado con anomalías del sistema de Altas presiones de Santa Helena y de los vientos superficiales a lo largo de la costa de Angola/Benguela. El desarrollo se asocia con el mecanismo de realimentación de Bjerknes mientras que los flujos de calor superficiales turbulentos ayudan a restaurar las temperaturas superficiales. Este modo además de tener un fuerte impacto en el monzón de África del Oeste en el verano boreal, es un agente importante de teleconexiones atmosféricas extratropicales asociadas con el debilitamiento del modo desde el final del verano boreal al siguiente invierno.

Asimismo, se ha comprobado que, desde los años 70, el origen, desarrollo y decaimiento del Modo Ecuatorial lidera el desarrollo de una Niña en el Pacífico mediante cambios en la circulación zonal de Walker. Muchos trabajos han documentado como, durante las últimas décadas del siglo XX ha tenido lugar una transición climática importante tanto en el Pacífico como en el resto del globo. La causa de estos cambios y su relación con el Modo Ecuatorial es un tema de debate que no descarta el papel de la variabilidad climática natural o la influencia antropogénica.

Palabras clave: Variabilidad del Atlántico Tropical; Modo Ecuatorial Atlántico; interacciones océano-atmósfera; teleconexiones tropicales; El Niño; convección tropical; precipitación en la región del Sahel.

ABSTRACT

The Equatorial Mode, also called Atlantic Niño, is the leading mode of the Tropical Atlantic Variability, explaining a high percentage of the anomalous boreal summer rainfall over the coast of the Gulf of Guinea. The evolution of the sea surface temperature anomalies associated with this mode from the 70's show a starting point in the Santa Helena High Pressure System and in the related alongshore winds in the Angola/Benguela coast. The development of the mode is associated with a Bjerknes feedback mechanism, and the surface heat fluxes help to restore the surface temperatures. This mode, apart from having an important impact on the boreal summer West African Monsoon, is an important agent of extratropical teleconnections in association with the weakening of the mode from the end of summer to the next winter.

From the 1970's the origin, development and damping of the Equatorial Mode or Atlantic Niño leads the development of a Pacific La Niña through changes in the zonal Walker circulation. There are lot of references reporting a climate shift in the last decades of the XX century, not only in the Pacific but also in the rest of the globe. The cause of these changes and its relation to the Equatorial mode is a debated topic that does not rule out the role of the natural climate variability or the anthropogenic influence.

Key words: Tropical Atlantic Variability; Atlantic Equatorial Mode; ocean-Atmosphere interactions; tropical teleconnections; El Niño; tropical convection; Sahelian rainfall.

SUMMARY: 1. Introduction. 2. Data and method. 3. Results. 4. Summary and conclusions. 5. Acknowledgements. 6. References

1. INTRODUCTION

The study of the Tropical Atlantic Variability (TAV) , which includes the interaction between surface winds, Sea Level Pressure (SLP), the Inter Tropical Convergence Zone (ITCZ), Sea Surface Temperature (SST) and the upper ocean is not well understood yet being a current topic of the International CLIVAR¹ program (Hurrell et al., 2006).

At interannual timescales, TAV is known to have two predominant SST modes: the Equatorial Mode and the Subtropical North Atlantic Mode. In particular, the Equatorial Mode (EM, zonal mode or Atlantic Niño) is the first mode of variability of the Tropical Atlantic (TA) Ocean, and owes its interannual variations to the Bjerknes positive feedback mechanism (Bjerknes, 1969; Zebiak 1993). In this way, the mode is characterized by a relaxation in the equatorial trade winds which induces warm water redistribution in the equatorial belt and a weakening not only in the equatorial thermocline slope but also in the heat content zonal gradient (Merle, 1980; Carton et al., 1996). This mode is highly coupled to the equatorial convection over the Gulf of Guinea as part of West African Monsoon (WAM) system.

Recent analyses show how this mode is known to have a marked evolution from the period after the 70's and how it is statistically linked to its Pacific counterpart (Polo et al., 2008). Around this period, a climate shift has been documented for the

¹ Climate Variability and Predictability. It provides a nurturing framework from a range of backgrounds to describe, understand and predict aspects of climate variability.

Pacific and the whole globe (Nitta and Yamada 1989; Trenberth, 1990; Baines and Folland, 2007), reporting changes in the global climate (Vecchi et al., 2006; Seidel et al., 2008) with important impacts on the Indian Monsoon (Kucharski et al., 2007), changes in the Pacific Walker circulation (Vecchi et al., 2006; Krishnakumar et al., 1999); and El Niño-Southern Oscillation (ENSO; Fedorov and Philander, 2000; Wang and An, 2002), among others.

The importance of the changes in the EM in the frame of the climate shift merits a clear description of its evolution, its link to WAM and the extratropical climate and the consequences of its influence on the Pacific ENSO. These topics will be discussed in the present paper.

The paper is organized as follows. Next section includes a description of the data and methodology used in the manuscript, including the AGCM and AOGCM simulations used in the analysis. Section 3 is dedicated to the description of the principal results. The section is divided in three parts: the description of the EM from the 70's, the Atlantic tropical and extratropical response to the Atlantic EM and, finally, the description of the Atlantic-Pacific Niños connection. Section 4 summarized the main results.

2. DATA AND METHODOLOGY

The study is done using SST data from extended reconstructed sea surface temperature (ERSST) dataset (Smith and Reynolds, 2004) and precipitation data from CMAP (Xie and Arkin 1997). The atmospheric regression maps are calculated using data from ERA40 (Uppala et al., 2005).

The EM is determined using a time-varying scheme of the classical Maximum Covariance Analysis, in which the predictor or the predictand field is compiled including all the considered lags in the array. In this way, the mode can be described from its origin, through its development and to its decay (see Polo et al., 2008 and Garcia-Serrano et al., 2008 for more details about the method of the Extended Maximum Covariance Analysis, EMCA).

In order to determine the effect of the EM on the tropical and extratropical atmosphere, a sensitivity experiment has been performed with the UCLA AGCM model, adding the anomalies corresponding to the EM described above to the climatological SSTs (for Positive anomalies, EMP and Negative anomalies, EMN). This experiment was designed in the framework of the AMMA Project, and was also performed by another three AGCMs. The multi-model results were analyzed in two papers (Losada et al., 2009a; 2009b), one focused on the relation EM-WAM, and another showing the influence of the EM in the rest of the tropical oceanic basins.

Finally, for the study of the Atlantic-Pacific Niños connection coupled experiment with the ICTP AGCM (Kucharski et al., 2007) has been performed. The simulations consist in nine runs where the model is fully coupled in the tropical Indo-Pacific oceanic basin (between 30°S and 30°N) and forced with climatological SSTs elsewhere, apart from the Atlantic sector, where the model is forced by ob-

served monthly varying SSTs from 1949 to 2002. Different members differ in the initial conditions. The simulations were performed by Fred Kucharski (ICTP) in May 2008 and were used in Rodríguez-Fonseca et al. (2009a).

3. RESULTS

3.1 Description of the Equatorial Mode

The EM, calculated as a result of the leading EMCA mode between the time-evolving SST over the TA from early spring to autumn and the summer West African rainfall (Polo et al., 2008), describes the warming/cooling over the TA associated with anomalous rainfall over the equatorial belt. The beginning of the mode, in the warm phase, occurs with a weakening of the south subtropical High pressure system (Fig. 1a). As the Sta Helena High weakens, the alongshore winds over Angola/Benguela diminish causing a warming onshore in the upwelling system with an anomalous SST gradient (Figs. 1a-1b) increasing the rainfall there. The SST anomalies over this region might force oceanic Rossby wave propagation westward and equatorward crossing the oceanic basin, which results in warming SST at the equatorial band. The warming of the SST (Figs. 1a to 1d) and the deepening of the thermocline (not shown) occur together with a weakening of the trade winds in a Bjerknes feedback mechanism (Bjerknes, 1969). Thus, while the ocean dynamics seems to enhance the SST anomalies over the equator, the turbulent fluxes are responsible for restoring the temperatures (Polo et al., 2008). The rainfall band suffers an anomalous behavior coherent with the SST anomalies. In summer (Figs. 1e-1f) the shift of the rainfall band occurs onshore of the Gulf of Guinea. Such a feature has been confirmed by Losada et al. (2009a) from a multi-model AGCM sensitivity experiment. Results show that a warming in the equatorial Atlantic leads to a weakening on the SLP gradients in West Africa, thus producing the weakening and the southward shift of the WAM (Figs. 1e to 1f).

3.2 Tropical and extratropical North Atlantic atmospheric response to the Equatorial Mode

As the EM decays, the anomalous rainfall sequences present a progressive weakening in the eastern part of the basin and a clear confinement in the western part, over the Amazon convergence zone. Such a feature has been interpreted as the restoring effect in deep-convection (lower-level convergence and upper-level divergence; Figs. 1f to 1i) of the EM damping, following the thermal forcing evolution. This finding has been shown at seasonal (García-Serrano et al., 2008) and monthly interannual time scales (Losada et al. 2009a). A close relationship between anomalous tropical convection and the ITCZ seasonal cycle seems to be operating during the SST damping, as the remaining precipitation anomaly over north-eastern Brazil reveals a southward migration from SON to DJFM (Figs. 1i-1l).

In addition to the TA precipitation anomalies, significant extratropical signals appear associated with time-evolving EM (Figs. 1f-1l). In particular, scattered

negative anomaly over eastern North Atlantic in JJAS, increasing negative one offshore Florida Gulf coast from ONDJ, and negative precipitation anomalies over Europe during ONDJ and NDJF. An additional EMCA performed with precipitation as time-varying predictand suggests that the latter is not remotely forced by the EM damping; while negative rainfall in the western subtropical Atlantic seems to be rightly related to both EM-decay and Pacific La Niña-establishment (García-Serrano et al., 2008). However, the UCLA-EMP experiment rejects the Atlantic contribution to that subtropical anomaly showing that reinforced Hadley circulation descends more south (offshore northern Brazil). The same simulation confirms that EM damping has not impact on European winter climate, because the forced Rossby wavetrain is trapped into the North African-Asian jet (Fig. 2). This zonal propagation also follows the latitudinal seasonal cycle, and completely circumscribes the globe following the jetstreams structure.

Regarding the connection with the rest of the tropical basins, Losada et al. (2009b) experiments also show how the EM has an influence in both the Indian and Pacific tropical basins, confirming the results of Kucharski et al. (2007) and Rodríguez-Fonseca et al. (2009a). The warming of the TA produces a Gill type response in the atmosphere, with two twin anticyclones in the upper troposphere, to the west of the heating source, and two cyclones to the east. This anomaly propagates eastward as a Kelvin wave, and westward as a Rossby equatorial wave. The influence in the Indian basin produces a subsidence in the Indian Peninsula that leads to the weakening of the Indian monsoonal precipitation. Regarding the Pacific ocean, a warm EM produces anomalous upward motions over the Atlantic Ocean that are compensated with anomalous subsiding motions over the central Pacific, leading to a westward displacement of the maximum location of the downward branch of the Pacific Walker cell and to anomalous divergence over the central Pacific that would favour the conditions for a development of La Niña event in the Pacific ocean.

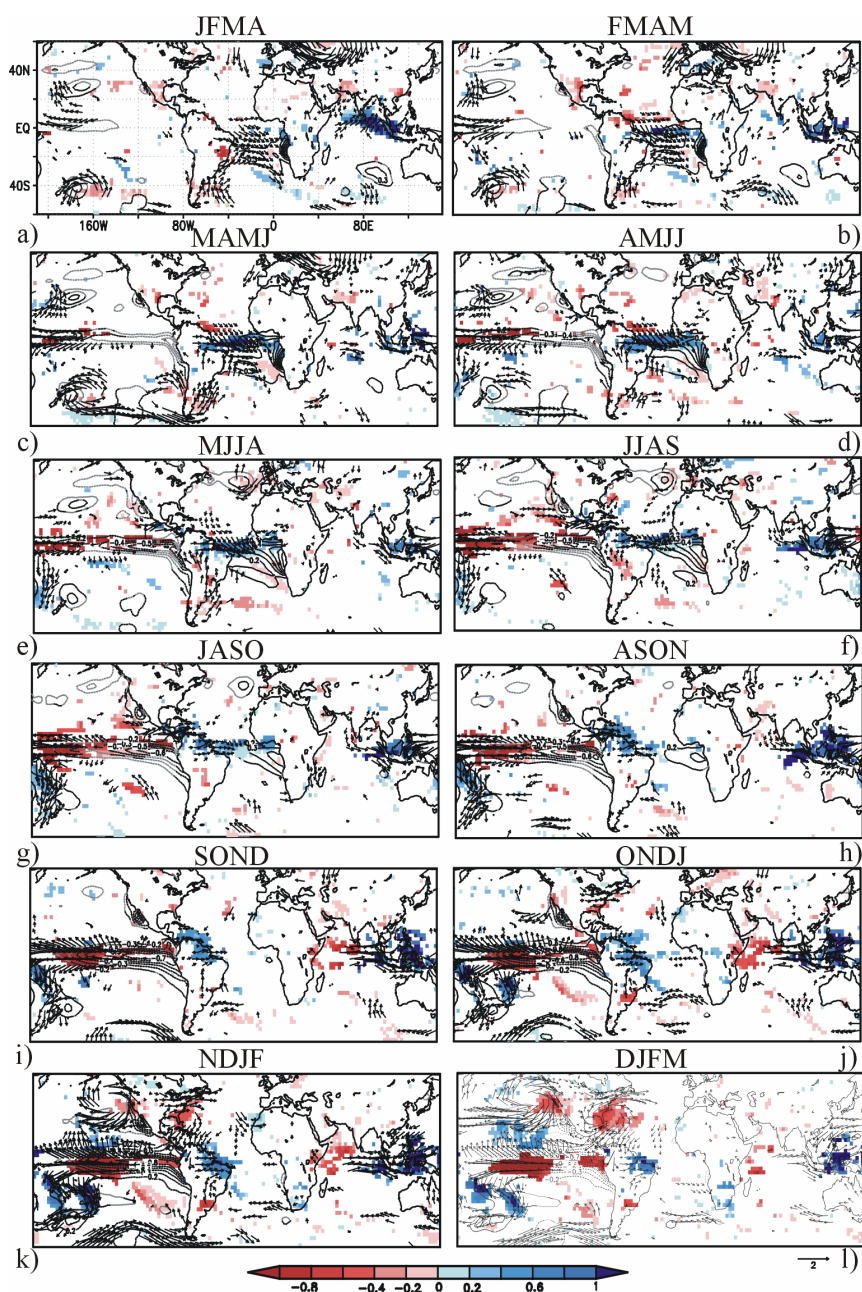


Figure 1. Regression of the WA rainfall-TA SST EMCA leading SST expansion coefficient onto the global precipitation (shaded areas in mm day⁻¹), SST (contour lines CI=0.1°C) and surface wind at 925 hPa (vectors in m/s) from previous late winter JFMA (a) to next winter DJFM (l). Only the statistically significant areas at the 95% confidence level according to a Student's t-test for the effective number of degrees of freedom have been lighted.

3.3 On the recent influence of the Atlantic Niño on the Pacific La Niña and its consequences

Although there are many references pointing out to the absence of link between the Atlantic and Pacific Niños (Wang, 2006), recent observational analysis using data from the end of the 70's have found a statistical relationship between the Atlantic Equatorial mode and the Pacific El Niño and how this relation is maximum when the Atlantic leads the Pacific by 6 months (Keenlyside and Latif, 2007; Polo et al., 2008). The correlation between these interannual phenomena is negative in a way that summer Atlantic Niños would be leading the occurrence of next winter Pacific La Niña and viceversa. The observations reveals that the connection between both Niños is not stationary and it has been established at the end of the 60's (see Rodríguez-Fonseca et al., 2009a), coinciding with a period of Atlantic Multidecadal Oscillation transition (Dong et al., 2006). Rodríguez-Fonseca et al. (2009a) clearly show using observations how, for positive Atlantic EM, there is an increase of the Atlantic surface convergence, divergence in upper levels, enhancement of the upper easterlies and subsidence over the central Pacific, with westerlies closing this anomalous Walker cell over the Panama Channel (Fig. 1). This atmospheric bridge mechanism linking the Atlantic and Pacific tropical basins is also the one obtained with a set of AGCM experiments done with observed SSTs over the Atlantic and a coupled anomaly model over the Pacific (Rodríguez-Fonseca et al., 2009a).

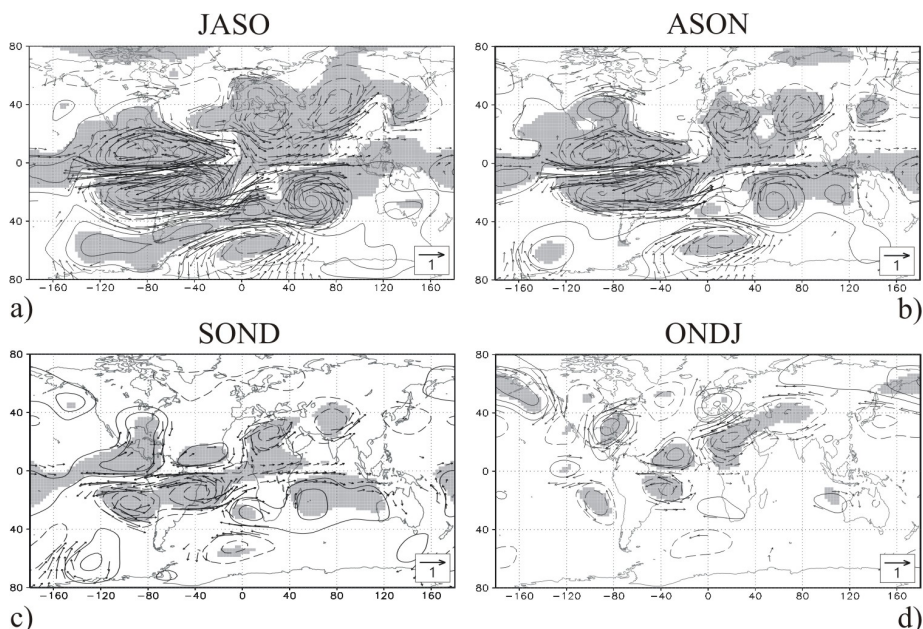


Figure 2. July-October up to October-January, lagging one month as indicated in each title, streamfunction anomalies at 200hPa from UCLA-EMP simulation ($ci=1 \times 10^6 \text{ m}^2/\text{s}$). Shading refers to significant anomalies at $p=0.05$ evaluated with a Student t-test.

Regarding the ocean, the observations show how the anomalous surface divergence over the central Pacific produce an oceanic upwelling Kelvin wave traveling eastward together with a Bjerknes feedback mechanism which rises up the thermocline in the east and sinks it in the west (Rodríguez-Fonseca et al., 2009a). However, the coupled simulation suggests that the processes involved in the eastern Pacific to develop Pacific La Niña (not shown) differ from those in the observations. The model gives more importance to the maximum surface wind anomalies occurring in the eastern, which create negative SST by turbulent heat fluxes and propagates by horizontal advection.

Another consequence of this recent Atlantic-Pacific connection is the change in the WAM-EM covariability modes. The structure of WAM summer precipitation associated with the warm phase of the EM is a dipole with increased (decreased) precipitation in the Gulf of Guinea (Sahel) (Losada et al., 2009a; 2009b). Mohino et al. (2009) show that this dipolar structure holds for the 1957-1978 period. Nevertheless, they also show that when analyzing a more recent period (1979-1998), the EM is no longer related to Sahel precipitation and they suggest that this is due to the concomitant presence of the Pacific La Niña in this later period. Rodríguez-Fonseca et al. (2009b) suggest that there is a global tropical mode, which is phased locked with the seasonal cycle, which explains more than 60% of the squared covariance fraction between SST and WA rainfall, that includes the Atlantic-Pacific connection in relation to the anomalous monsoon development.

4. SUMMARY AND CONCLUSIONS

This paper compiles and resumes all the research done by the TROPA (tropa.fis.ucm.es) group regarding the air-sea interaction, dynamics and impacts of the EM during the last decades of the XX century. In particular, the authors of this paper have gone a step forward determining the specific features of the EM from the 70's, concerning its origin and development (Polo et al., 2008), extratropical teleconnections (García-Serrano et al., 2008) and the impacts on the WAM and tropical oceanic basins (Losada et al., 2009a; 2009b). Large changes in the Amazon convection and in the West African rainfall have been determined (García-Serrano et al., 2008; Rodríguez-Fonseca et al., 2009b). But the most important finding of the TROPA-UCM group has been to physically demonstrate the recent statistical link between the Atlantic Niño and its Pacific counterpart (Polo et al., 2008; Rodríguez-Fonseca et al., 2009a; Losada et al., 2009b).

All these findings point the Atlantic as a determinant basin in the context of the climate shift and the global change. Also these results remark the increasing importance of the TAV on the global climate and on the observed change, from the late 70's, in the global teleconnections. A deeper investigation is needed in order to further understand the origin of these changes and its applications in seasonal predictability.

5. ACKNOWLEDGEMENTS

Hace justo un año bajamos a tomar un café con Elvira y le contamos que habíamos encontrado cómo, desde los años 70, el Niño Atlántico era capaz de disparar una Niña en el Pacífico y las consecuencias que esto podría tener en predicción estacional. Recuerdo cómo le dijimos que habíamos enviado el resultado a la revista *Nature* porque nos parecía un resultado revolucionario e innovador ya que el resto de trabajos coetáneos consideraban el Atlántico Tropical incapaz de impactar globalmente en comparación con el Pacífico y ella nos dijo que no dudáramos en insistir en entender y comunicar aquel resultado. Tuvo una reacción inolvidable ya que mostró una gran ilusión por que hubiéramos encontrado dicha relación y nos propuso colaborar con nosotros en un futuro. Después, como si de un cuento se tratara, nos relató “Las investigaciones de Chubachi y el Agujero de Ozono”. *En los años 70 Chubachi presentaba en un pasillo de un congreso internacional un póster con los registros de las medidas de ozono de un aparato en una base antártica. En su registro temporal se mostraba una clara tendencia a la disminución del ozono. Datos similares, en cambio, eran considerados como medidas erróneas y rechazados por investigadores Estadounidenses. A mediados de los años 80 se comenzaron a acumular pruebas de que a finales del invierno se había formado un “agujero” en la capa de ozono del Polo sur, donde el ozono se había reducido en casi 50%. Así, en 1987, representantes de 43 naciones firmaron el Protocolo de Montreal. Se comprometieron a mantener los niveles de producción de CFCs de 1986, y a reducirlos en un 50% en 1999. A pesar de las críticas y el escepticismo de sus colegas, Chubachi no dudó en presentar sus resultados y en perseverar en entender los datos que obtenía.*

Hace un año enviamos nuestro artículo a *Nature Geosciences*, pasó dos revisiones, luchamos en hacer entender nuestros resultados y, tras un año de esperanzas, nos lo rechazaron. Seguimos perseverando, siempre pensando en Chubachi. Recientemente este artículo ha sido publicado en el GRL. Cuando nos dieron la oportunidad de escribir un trabajo para la Revista de Física de la Tierra no dudamos en hacer un resumen de tal hallazgo y una compilación de todas las consecuencias que este descubrimiento pueda tener. No somos Chubachi, pero te lo dedicamos de Corazón, Elvira.

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