Role of the tropical Atlantic in the climate system

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Outline

1. Role of climatological SST on the position of the ITCZ and regional rainfall (seasonal cycle)
2. Interannual variability and dominant modes of TAV
3. Regional impacts of TAV on the South American and West African Monsoons
4. Teleconnection of TAV with other basins (Pacific and Indian oceans)
5. Other aspects (decadal modulation of the TAV and teleconnections)
Role of climatological SST on the position of the ITCZ and regional rainfall (seasonal cycle)
Interannual variability and dominant modes of TAV
Regional impacts of TAV on the American and African Monsoon systems
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Other aspects (decadal modulation of the TAV and teleconnections)
Tropical Atlantic SST and rainfall seasonal cycle

March-April

July-August

Precip. (mm/day)

SST (°C)
Tropical Atlantic

Wu et al., 2007

(b) Atlantic Climatology

TNA: WES

Bjerknes - JJA

Surface Wind

SST

Precip.
Impact on Rainfall

Tropical Atlantic Population Density & Annual Mean Rainfall

Annual mean rainfall in mm day$^{-1}$
Extent of seasonal ITCZ migration south (April) and north (July)

Rainy Season
MAM

Rainy Season
JJA
Role of climatological SST on the position of the ITCZ and regional rainfall (seasonal cycle)

Interannual variability and dominant modes of TAV

Regional impacts of TAV on the American and African Monsoon systems

Teleconnection of TAV with other basins (Pacific and Indian oceans)

Other aspects (decadal modulation of the TAV and teleconnections)
**Zonal Mode, Equatorial M., Atlantic Niño**  

- Maximum in summer. **Impacts** on Guinea Gulf rainfall (Ward, 1998; Giannini et al., 2003).
- Relation to ENSO (Latif and Grotzner, 2000)
- **Origin:** Western equatorial anomalous winds (Zebiak, 1993; Carton et al., 1996; Ruiz-Barradas et al., 2000)., Sta Helena high pressure system variability (Venegas et al., 1997; Sterl and Hazeleger, 2007; Traskza et al., 2006)
- **Damping:** surface heat fluxes (Frankignoul and Kestenare, 2005)
- Strong interanual component

**Meridional mode, TNA, interhemispheric mode**

- Maximum in boreal spring. **Impacts** south american rainfall (Nobre and Shukla 1996).
- Relation to ENSO (Wang, 2002)
- **Origin:** transequatorial winds, weakening of the NH trades, interhemispheric gradient
- **Development:** WES feedback (wind-evaporation-sea surface temperature)
- **Damping:** seasonal migration of the ITCZ.
- **Strong interanual and decadal component**

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Kushnir et al. (2006). SST, surface wind and precipitation...

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Both modes impact directly in the Atlantic monsoons

South American Monsoon

West African Monsoon

Fig 18a from Zhou and Lau (1998)
Both modes impact directly in the Atlantic monsoons

**South American Monsoon**

- Shading $\rightarrow$ topography.
- Dashed lines $\rightarrow$ easterlies
- (1) The low-level cross equatorial jet
- (2) Northwesterlies
- (3) The Chaco Low (monsoon trough)
- (4) The South Atlantic High
- (5) The South Atlantic Convergence Zone (SACZ)
- (6) Mid Latitude Disturbances
- (7) Bolivian High
- (8) Upperlevel Return Flow.

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**From September to May. seasonal migration of the ITCZ**

- Sep-Nov...Equator
- Dec-Feb...southern region
- March-May:northern region

( Nordeste, Moura and Shukla, 1981, Vera et al, 2006b; Rodrigues et al 2011)

- Liebmann and Mechoso, 2011  Marengo et al., 2012)
Both modes impact directly in the Atlantic monsoons

From June to September, also related to seasonal migration of the ITCZ.

Nicholson et al., 2009, 2013
Xue and Janicot, 2016
Sultan and Janicot, 2003 etc..
South American Monsoon: impacts of the Equatorial and meridional modes

The equatorial mode **retains** the ITCZ to the south increasing rainfall in nordeste

Torralba et al., 2013

The meridional mode **shift** the ITCZ to the north: dipolar pattern

Hastenrath 2006; Kucharski et al 2008
West African Monsoon

Janicot et al., 1998, Okumura and Xie, 2004
Polo et al. 2008,
Joly and Voldoire, 2009, 2010
Losada et al. 2010
Rodriguez-Fonseca et al. 2011, 2015 etc.

The equatorial mode retains the ITCZ to the south decreasing the land-sea gradient decreasing rainfall in Sahel.

The meridional mode strength the monsoonal flow increasing rainfall in Sahel.

Timing: the impact takes place in a different season than in the SAM!!
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Zonal mode

Atlantic Niño impacts on the EuroAtlantic circulation (Haarsma and Hazeleger, 2007)

Atlantic Niño impacts on Indian Ocean and monsoon (Kucharski et al. 2007, 2009 etc.)

Atlantic Niño impacts on Pacific (Keenlyside and Latif, 2007; Rodríguez-Fonseca et al., 2009, Ding et al. 2011, Polo et al., 2008 etc.)
Impact of the Equatorial Mode on ENSO

Rodriguez-Fonseca et al 2009

(c) Z20 and wind stress (NCEP)

(d) Z20 and wind stress (MPI)

Cross correlation: Nino3 Vs Atlantic cold tongue SST

Ding et al 2011
Mechanism for the Atlantic influence on ENSO

Polo et al., 2015

1 The anomalous heating associated with the Atlantic Nino alters the Walker circulation with surface convergence over the central over the central Atlantic and anomalous subsidence over the central-western Pacific.
2 The easterly wind stress over the central-western Pacific pill us the water to the west producing a warming in the western Pacific and shallowing the thermocline to the east.
3 The anomaly at the thermocline propagates as an equatorial Kelvin wave from autumn to winter.
4 As the thermocline shallows, the vertical entrainment cools the surface. The cooler surface induces stronger surface winds.
5 As the surface winds enhance, the surface currents are anomalous westward and the advection contributes to the cooling.
Mechanism for the Atlantic Niño on Indian monsoon

Interbasin mechanism. Gill-Matsuno mechanism (Kucharski et al 2009)

Tropical Atlantic link has been noticed in Yadav, Clim Dyn, (2008), Rajeevan and Sridhar, GRL, (2009), Li et al., GRL, (2008), Losada et al. (2009)

Equatorial heating

(Gill, 1980)

Courtesy of Teresa Losada
Gill-type response leads to upper-level anticyclonic and low-level cyclonic response over South Asia, leading to low-level convergence and increased rainfall. Response is locally enhanced by diabatic cooling in monsoon region.
Teleconnection mechanisms with the extratropics:

Mechanism: Rossby Waves

\[
\frac{d(\zeta + f)}{dt} = 0
\]
Conservation of absolute vorticity (Rossby waves)

Barotropic in the extratropics

Baroclinic in the tropic

(Hoskins y Karoly, 1981; Liu y Alexander, 2007)
Impact on summer rainfall: Losada et al. 2012a

Impact on winter rainfall:

Haarsmah and Hazeleger, 2007
Persistence of anomalies produces a circumglobal response impacting on Europe

Frankignoul and Kestenare (2005)
Meridional mode

Impacts on NAO and European rainfall (Rodriguez-Fonseca and Castro, 2002), Rodriguez-Fonseca et al, 2006; Losada et al 2007)

Impacts on ENSO
Wu et al 2007
Ham et al 2013
Wang et al 2017
Impact of the Meridional Mode on ENSO

**Wu et al. 2007**: north tropical atlantic produces an interhemispheric SST seesaw in spring in the eastern equatorial Pacific that subsequently evolves into an ENSO-like pattern in the tropical Pacific through mediation of the ITCZ and equatorial coupled ocean-atmosphere feedback.

**Ham et al., 2003**: Spring North Tropical Atlantic can influence on anomalous subsidence over central pacific triggering ENSO

**Wang et al 2017**: This relation takes place during positive AMO phases enhancing biennial variability in the Pacific
Impact of the Meridional mode in NAO

Wu et al., 2006, Rodriguez-Fonseca et al., 2006, Losada et al., 2007, Czaja and Frankignoul, 1999, Cassou et al 2004 etc etc...

TNA influences on the North Atlantic Oscillation (NAO) NAO-dipole SST response in spring that changes to a coupled wave train-horseshoe SST response in the following summer and fall, and a recurrence of the NAO in the next winter.
Tropical Atlantic Variability (TAV)

1. The role of climatological SST on the position of the ITCZ and regional rainfall (seasonal cycle)
2. Interannual variability and the dominant modes of TAV; their impact on the American and African Monsoon systems
3. Teleconnection with other basins (Pacific and Indian oceans)
4. Other aspects (decadal modulation of the TAV and teleconnections)
Rodriguez-Fonseca et al., 2009: the Atl-Pac relation is not stationary
Modulations

The Atlantic influence on ENSO varies at mutidecadal time-scales: Rodriguez-Fonseca et al., 2009, Polo et al., 2015, Martin-Rey et al., 2014, 2015

Suárez-Moreno et al., 2018
Non-stationary impact on Nordeste Brazil: stronger impact on negative AMO phases. The Pacific-Atlantic connection enhances rainfall

Kayano et al. 2016: tropical Atlantic SST modes and their relations to north-eastern Brazil rainfall during different phases of Atlantic Multidecadal Oscillation
Indian monsoon–El Niño–Southern Oscillation (ENSO) relationship: normal monsoon season precedes peak El Niño conditions

The relation weakened significantly during the last two decades of the twentieth century. Kucharski et al., 2007. They found how the most important contributor to the interdecadal variability of the ENSO–Indian monsoon relationship appears to be the tropical Atlantic Ocean.

Impact of the Atlantic-Pacific Niños connection on the Indian Monsoon

Counteracting effect in negative AMO phases
Different influence of the ZM in positive and negative AMO periods

Losada et al. 2012a
DIFFERENT CONFIGURATIONS OF ATLANTIC NIÑO? Different impacts

From Losada and Rodriguez-Fonseca 2016
Wang et al.,
2017

NTA influence on AMO positive periods
CONCLUSIONS
The tropical Atlantic SST seasonal cycle influences on the position of the ITCZ and regional monsoons over South America and West Africa.

Two leading modes of interannual variability: meridional mode (MM), peaking in boreal spring; and the zonal mode (ZM), peaking in boreal summer.

Regional impacts:
The MM: reduces rainfall in Nordeste and increases the WA monsoonal flow
The ZM: increases rainfall in Nordeste and reduced Sahel rainfall

Interbasin impacts:
The MM: able to trigger a negative phase of ENSO. 9 month in advance. Hadley mechanism.
The ZM: able to trigger a negative phase of ENSO 6 months in advance. Walker and Gill-Matsuno mechanisms

The ZM-ENSO connection appears in negative AMO
The TNA-ENSO connection appears in positive AMO

The interbasin connections produces non-stationary impacts of the ZM and MM due to the presence of anomalies in the Pacific and Indian ocean
Further analysis (requires to enhance observations!!)

- Relation between modes.
- Changes in its spatial configuration.

- Mechanisms. Seasonality

- Relation between Atlantic Pacific and Indian. Further understanding of timing and mechanisms (TAO RAMA and PiRATA buoys)

- Modulations by changes in the background state (AMV, AMOC etc..)