Connection between the North and South American Monsoons

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Acknowledgement: Hui Wang, Paola Arias, Tong Ren, Adam Bowerman

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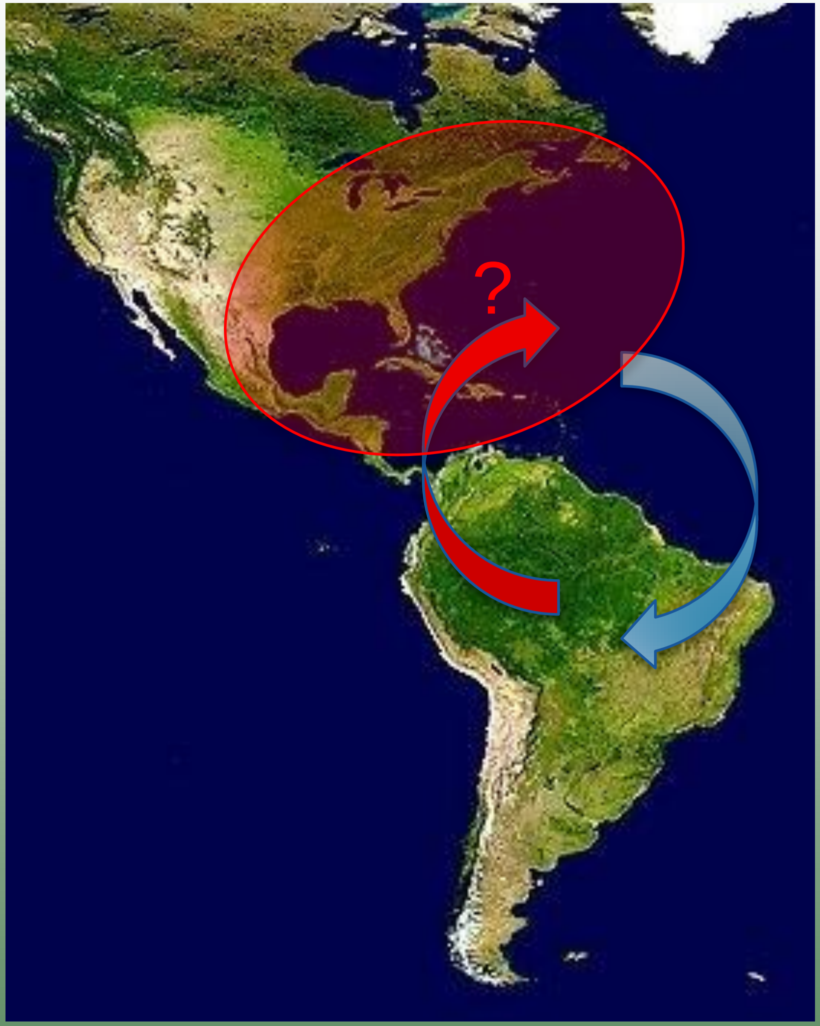
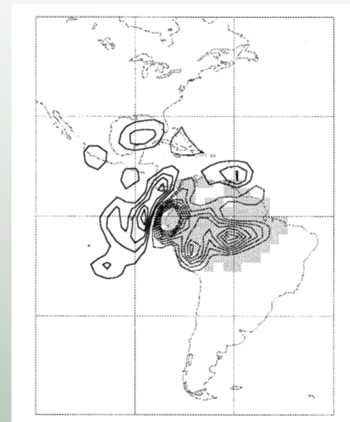


- ***The influences of NAO and northern tropical Atlantic SSTA influence on South American Monsoon has been clearly documented: Moura and Shukla 1981; Robertson et al. 1998; Fu et al. 2001, Marengo et al. 2008; Arias et al. 2015***

- ***The influence of South American monsoon on North Atlantic and North American Monsoon is virtually unknown.***

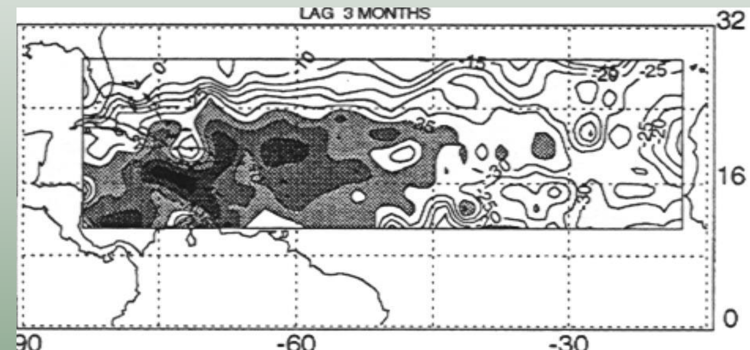
Limited evidence in literature

***Gedney & Valdes 2000:* Atmospheric circulation changes induced by deforestation of Amazonia rainforests**

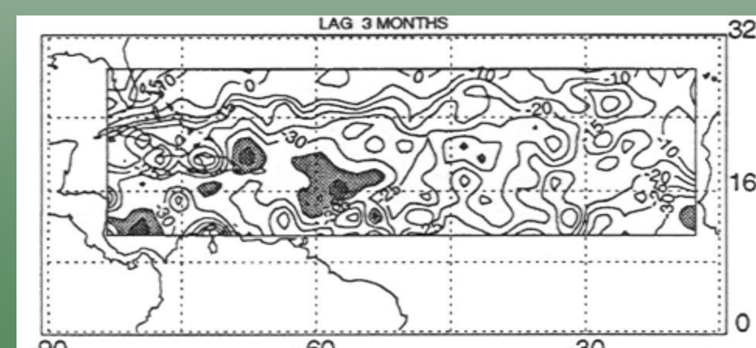


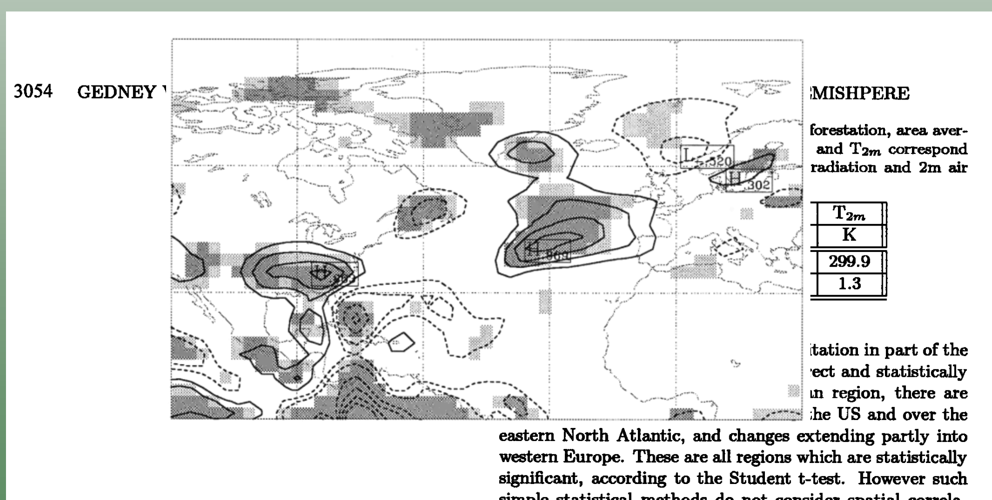
Poveda & Mesa (1997): Atlantic SST anomalies correlate more with anomalies of Colombia River flow, than with Niño3 (1946-95).

Colombia Rivers vs. Atlantic SST



Niño3 vs. Atlantic SST





3054 GEDNEY … MISHPERE

forestation, area aver-
and T_{2m} correspond
radiation and 2m air

T_{2m}
K
299.9
1.3

…tation in part of the
…ect and statistically
…n region, there are
…he US and over the
eastern North Atlantic, and changes extending partly into western Europe. These are all regions which are statistically significant, according to the Student t-test. However such simple statistical methods do not consider spatial correla-

Overarching Science Questions

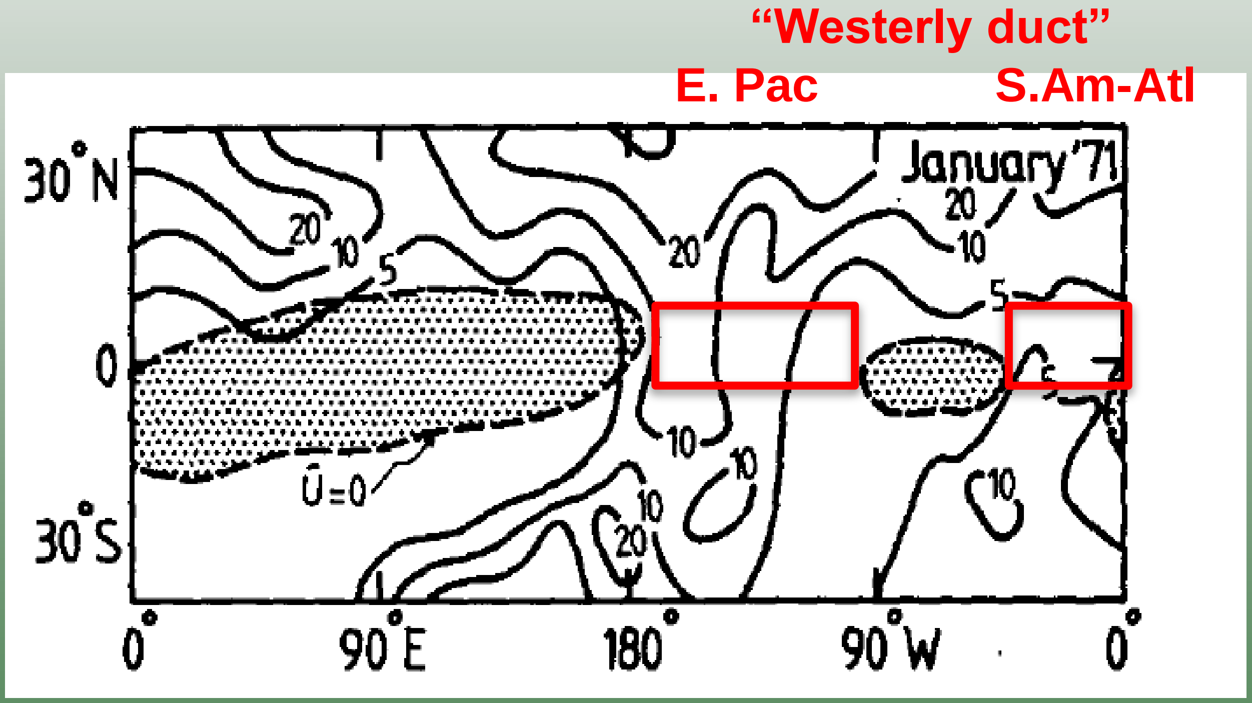
- ***How is South and North American monsoon climate connected?***
- ***Could variation or change of one American Monsoon affect the other?***
- ***If so, what are the mechanisms behind such influence?***

Potential mechanisms

- *Cross equatorial Planetary (Rossby) waves: Charney 1969; Dickinson 1971, Webster and Holton 1982; Tomas et al. 1994, Grimm & Silva Dias 1995; Ambrizzi & Hoskins 1997, limited to December-February.*

  -For Asian monsoon: e.g., Lau et al., 1984, Radok et al. 1957, Lee et al. 2013; Liu et al. 2015, Zhao et al 2018

  -For American monsoons: Gedney and Valders 2000.



Webster & Holton 1982

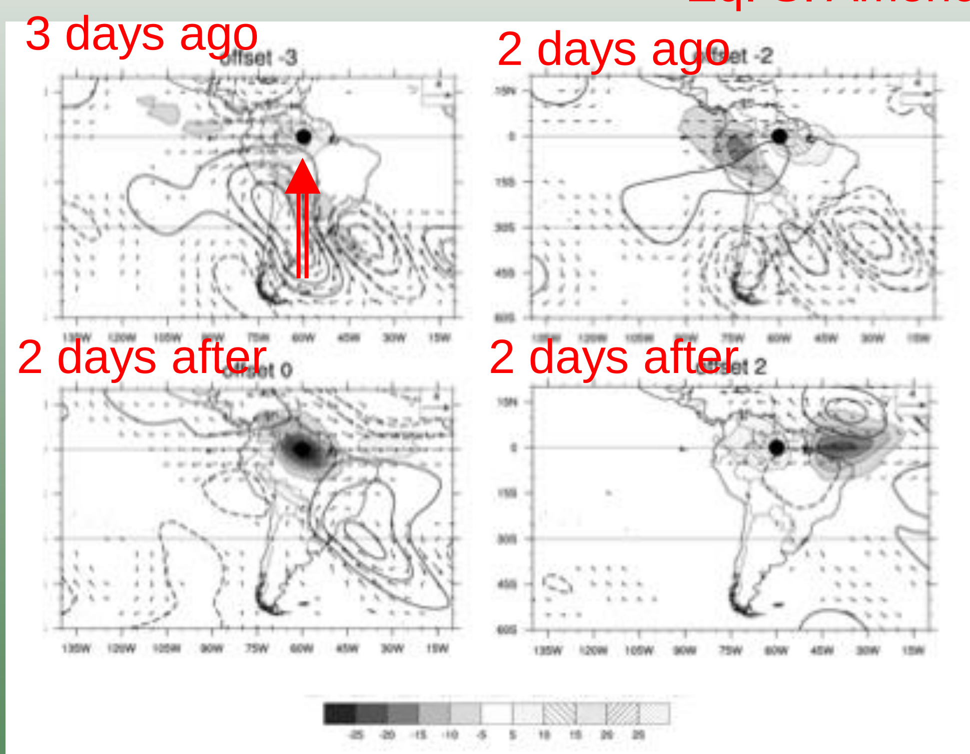
Other possible mechanisms

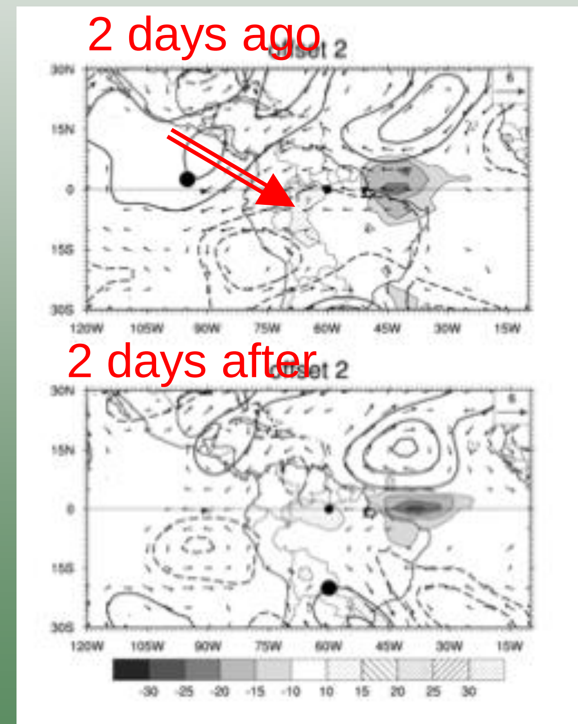
- *Global monsoon and Hadley cell: Trenberth et al. 2000; Wang and Ding 2011*
  - *Influence of NAO and northern tropical Atlantic SSTA influence on low-level moisture transport: Moura and Shukla 1981; Robertson et al. 1998; Wang and Fu 2002, Arias et al. 2015*

- *Kelvin waves generated by latent heating of Amazonia rainfall: Silva Dias et al. 1983, Wang and Fu 2007, Liebmann et al. 2008,* ***except for June-August***

- ***Liebmann et al. 2008: Convective Kelvin waves in the S. America are forced by***
  - ***Rosbby waves from Extratropical S. America and the E. Pacific.***
  - ***Locally generated convection from E. Andes***

Kelvin wave at
Eq. S. America





Hypotheses:

- *Hypothesis-1: Northward cross-equatorial propagation of the Rossby waves generated by diabatic heating of the South American Monsoon can influence the North Atlantic Oscillation (NAO) during austral summer (December-January-February).*

- *Hypothesis-2: Through a shallow cross-equatorial circulation, cold front incursions from extratropical South America can significantly influence weather and climate variability of the tropical and subtropical North Atlantic during austral winter (June-July-August).*

- *Hypothesis-3: Convective coupled Kelvin waves from Amazonia can influence tropical Atlantic surface winds and sea-level height anomalies, especially during austral fall (March-April-May). In doing so, variation of Amazonian rainfall can influence zonal (east-west) mode of Atlantic SST variability.*

- *Hypothesis-4: The onset of SAM contributes to the demise of the NAM during Austral spring (September-October-November).*

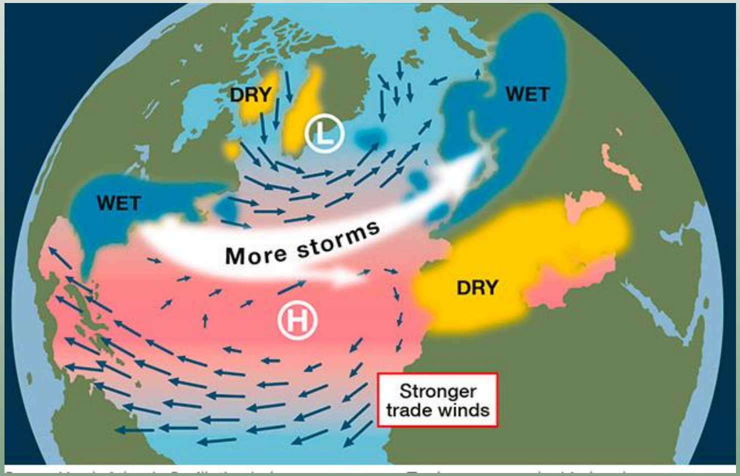
Take Home Message

- ***Weather and climate variabilities over South America are connected to those of North America - Atlantic sector in all seasons***

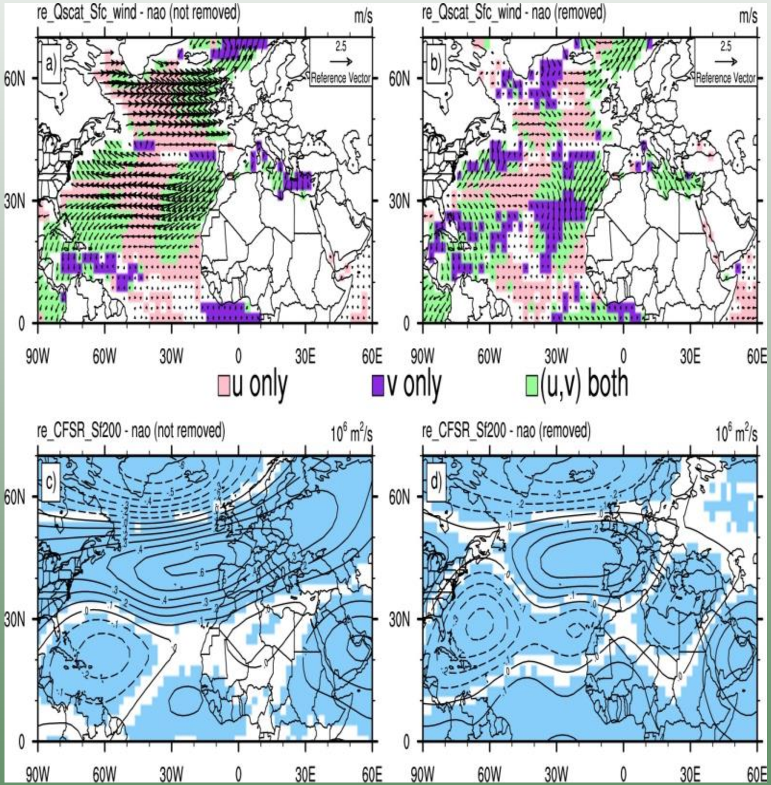
- ***Hypothesis-1:*** ***Northward cross-equatorial propagation of the Rossby waves generated by diabatic heating anomalies over the South American Monsoon can influence the North Atlantic Oscillation (NAO) during Austral summer (December-January-February).***

Circulation patterns related to NAO

Positive NAO



Positive NAO **Negative NAO**



CFSR reanalysis, QuikScat surface wind, DJF, 1999-2008

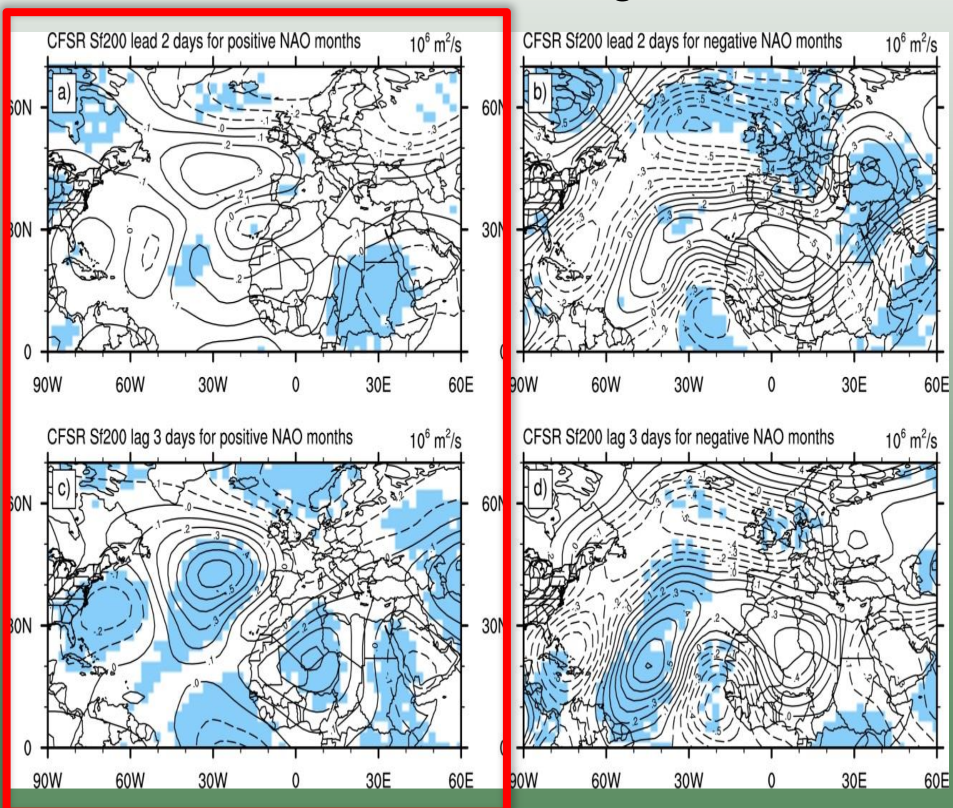
- ***An increase of SAM rainfall appears to enhance positive NAO like anomalous circulation***

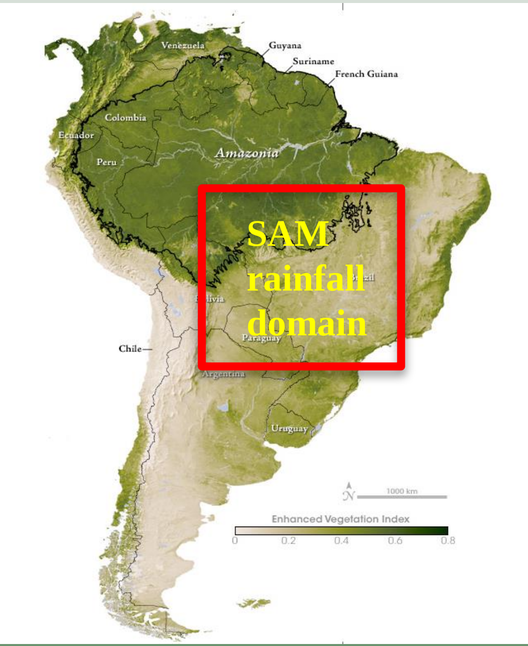
200 hPa Streamfunction anomalies over North Atlantic before and after the positive anomalies of SAM rainfall for the Positive and Negative NAO, respectively.

Positive NAO **Negative NAO**

2 days before

3 days after





CFSR reanalysis, TRMM rainfall, DJF, 1999-2008

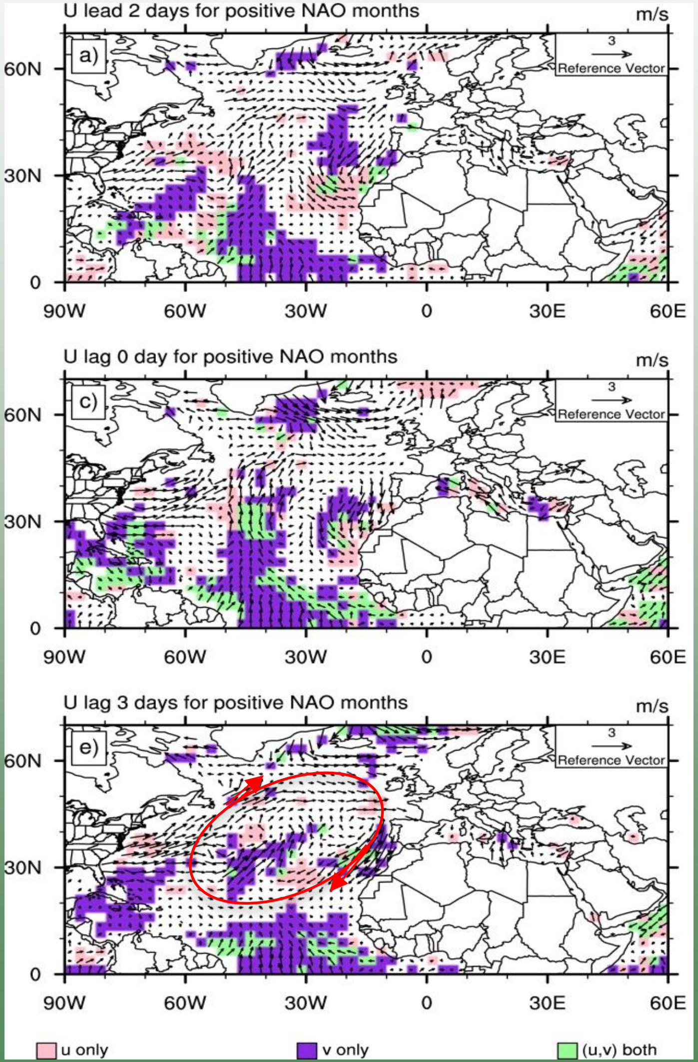
- *A positive NAO like surface wind anomalies appear after an increase of SAM rainfall*

Positive NAO

2 days before

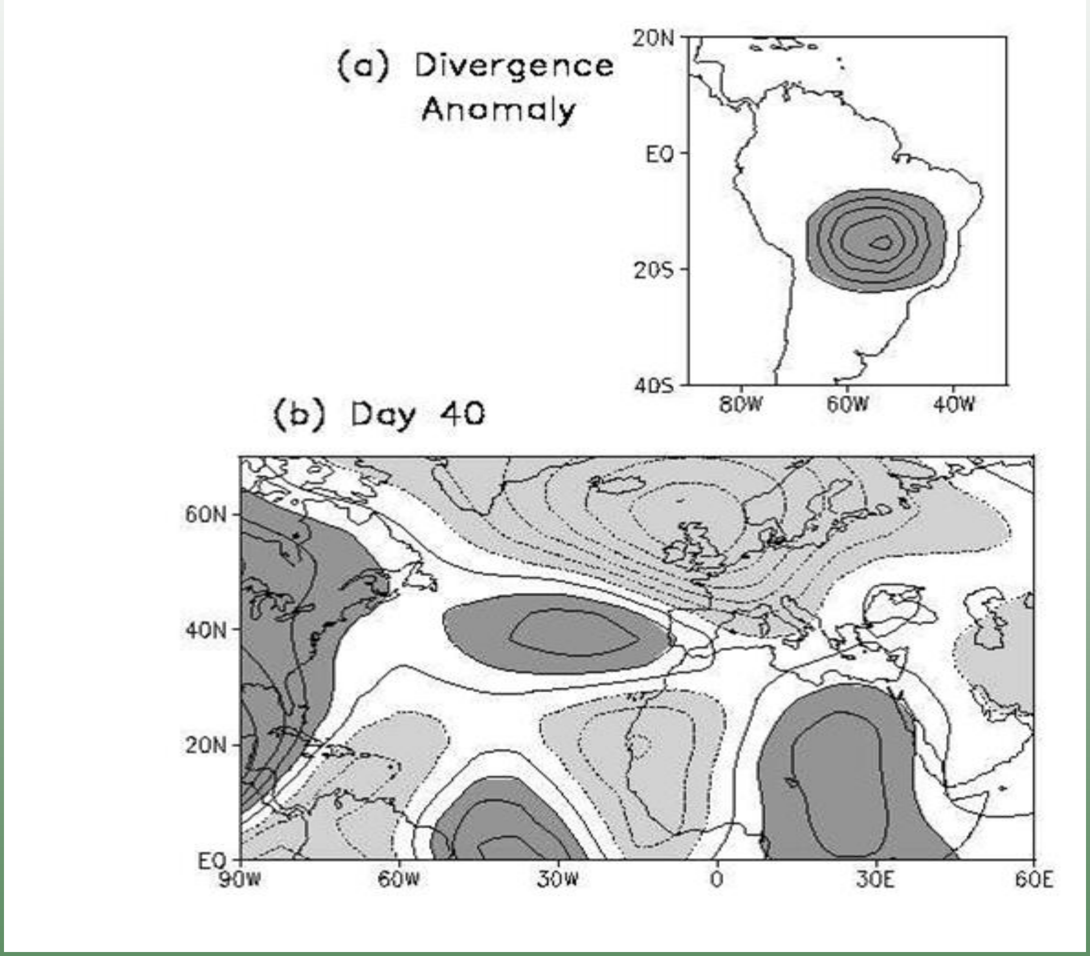
0 day lag

3 days after



QuikScat surface wind, TRMM rainfall, DJF, 1999-2008

- ***Barotropic model experiment showing a positive NAO like response of circulation to South American Monsoon heating for January Mean Flow***



Hypothesis-1: ***Northward cross-equatorial propagation of the Rossby waves generated by diabatic heating anomalies over the South American Monsoon can influence the North Atlantic Oscillation (NAO) during Austral summer (December-January-February).***

Summary of the results:

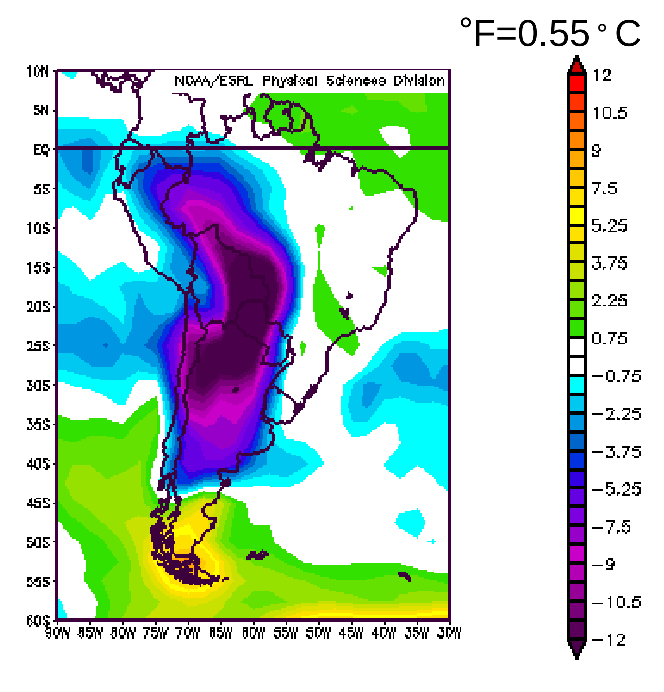
- ***Northward cross-equatorial propagation of the Rossby waves generated by diabatic heating anomalies over the South American Monsoon appears to intensify the positive NAO during Austral summer.***

- ***This influence under the negative NAO phase is not clear.***

- ***Hypothesis-2:*** ***Through a shallow cross-equatorial circulation, extreme cold front incursions from extratropical South America can significantly influence weather and climate variability of the tropical and subtropical North Atlantic during Austral winter (June-July-August).***

Influence of extreme cold front incursions over South America on North Atlantic

An example of the extreme cold front incursion from the extratropical South America



Central Brazil, July 17, 2010

Ratisbona 1976, Marengo et al. 1997; Kousky and Cavalcanti 1997; Garreaud and Wallace 1998; Li and Fu 2006

Define extreme cold front incursions:

- *Cold front incursion: SLP>1020 hPa or top 10% [Garreaud, 2000; Li and Fu 2006]*

- *The southerly cross-equatorial flow (meridional wind at 925 hPa for 5°S-5°N, 65°-75°W): > 2 σ*

- *200 hPa zonal winds over southern hemisphere Amazonia (15°S – 0°, 50°W – 70°W) that are weak westerly (> 2 m s^{-1}), to deep northward propagation of the Rossby wave and associated cold fronts.*

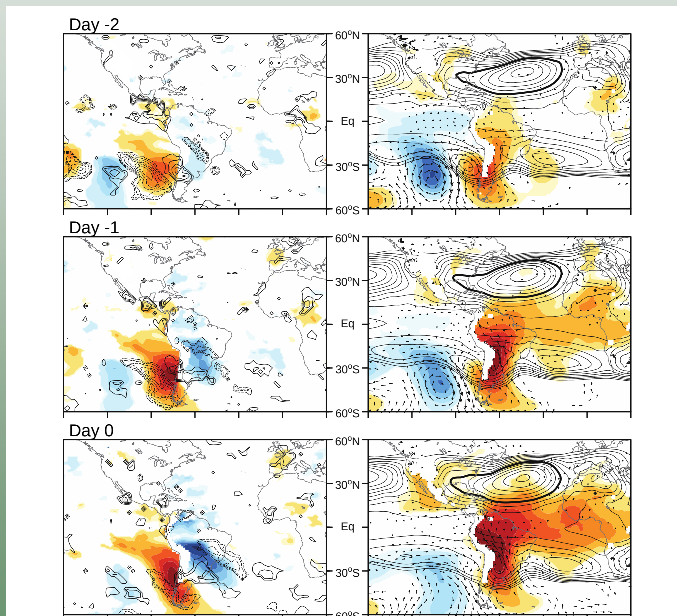
- ***Deep equatorward incursions of extreme cold fronts include strong decrease of temperature and increase of geopotential height in the lower troposphere over the tropical and subtropical Atlantic.***

- *Composite temperature and atmospheric circulation anomalies associated with extreme cold front incursions from extratropical South America*

2 Day before

1 Day before

0 Day

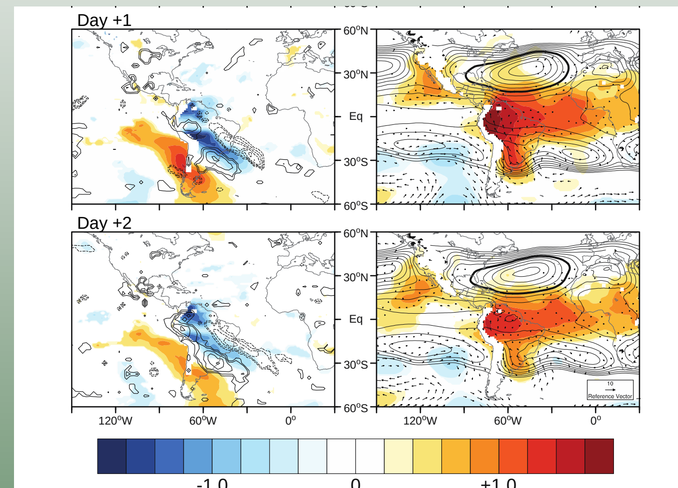


Standardized T'$_{850\ hPa}$ (shades), OLR' (contours)

Z'$_{850\ hPa}$,(shades)
Z$_{850hPa}$ (contours)
V'$_{850\ hPa}$,(vectors)

1 Day after

2 Day after

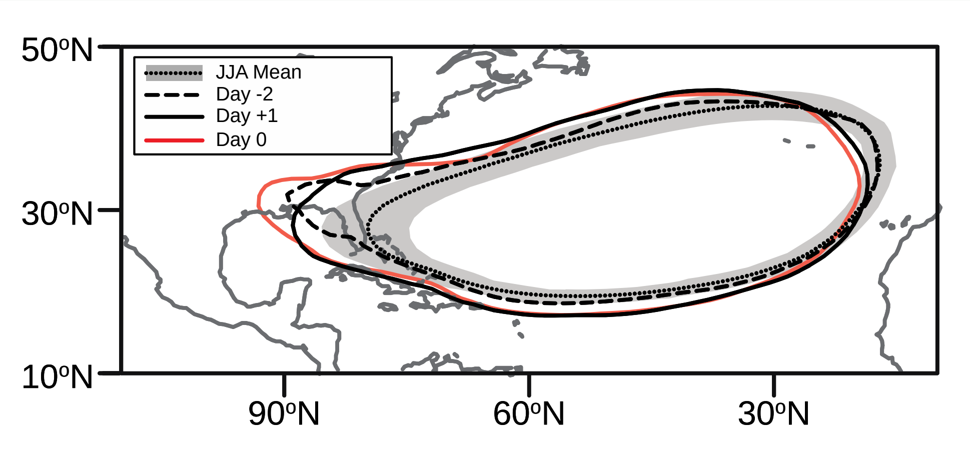


Standardized T'$_{850\ hPa}$ (shades), OLR' (contours)

Z'$_{850\ hPa}$,(shades)
Z$_{850hPa}$ (contours)
V'$_{850\ hPa}$,(vectors)

Bowerman et al. 2018, JGR-A

- ***Extreme cold front incursions lead to significant expansion of the North Atlantic Subtropical High (NASH)***



Standardized T’$_{850\ hPa}$ (shades), OLR’ (contours)

Z’$_{200\ hPa}$,(shades)
Z$_{850hPa}$ (contours)
V’$_{200\ hPa}$,(vectors)

- ***Upper tropospheric westerly enable northward propagation of Rossby waves reaches deep tropics, but limited to Southern Hemisphere***

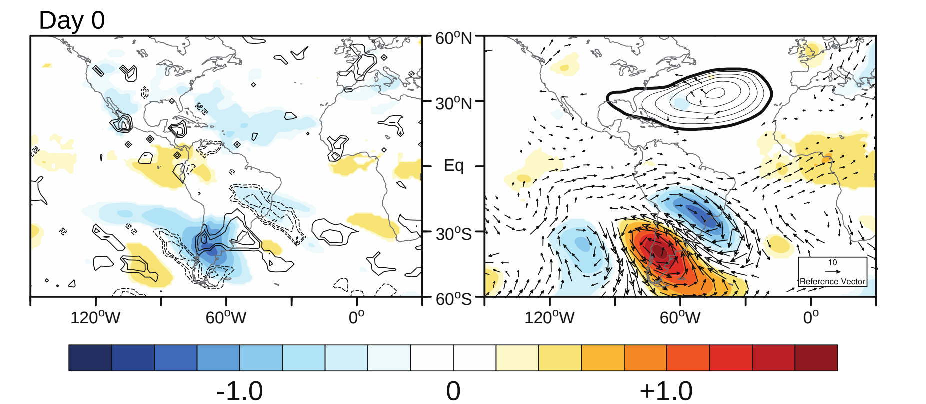


Figure 5: Same as Figure 3 except 200 hPa anomalous fields are shown for Day 0 only, and geopotential height contours in the right panel are shown for 1560 - 1600 gpm at 850 hPa only.

Bowerman et al. 2018

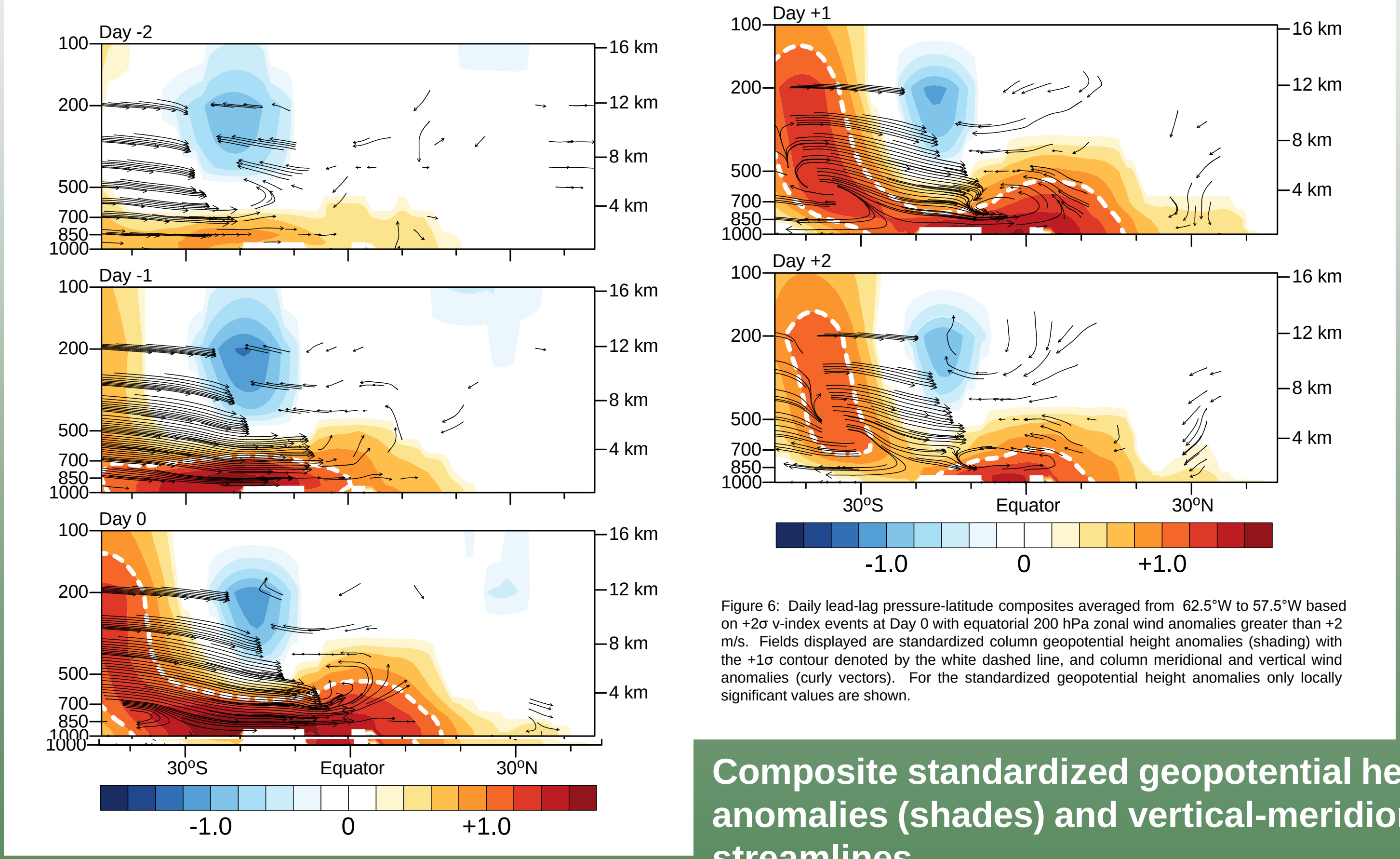
What causes expansion of the North Atlantic Subtropical High?

- ***Northward advancement of heavy and cold air from South America spread into subtropical North Atlantic in the lower troposphere, force a southward return flow in the lower-middle troposphere, and thus lead to a shallow meridional cross-equatorial circulation.***

2 Day before

1 Day before

0 Day



2 Day after

1 Day after

Figure 6: Daily lead-lag pressure-latitude composites averaged from 62.5°W to 57.5°W based on +2σ v-index events at Day 0 with equatorial 200 hPa zonal wind anomalies greater than +2 m/s. Fields displayed are standardized column geopotential height anomalies (shading) with the +1σ contour denoted by the white dashed line, and column meridional and vertical wind anomalies (curly vectors). For the standardized geopotential height anomalies only locally significant values are shown.

Composite standardized geopotential height anomalies (shades) and vertical-meridional streamlines.

Bowerman et al. 2018

- ***Hypothesis-2:*** ***Through a shallow cross-equatorial circulation, extreme cold front incursions from extratropical South America can significantly influence weather and climate variability of the tropical and subtropical North Atlantic during Austral winter (June-July-August).***

Summary of the results:

- ***Deep equatorward propagation of extreme cold front incursions from the extratropical South America during austral winter can significantly reduce temperature and increase pressure in the lower troposphere over the tropical and subtropical North Atlantic, leading to expansion of the North Atlantic Subtropical High during boreal summer.***
- ***Such influence is caused by northward propagation of the Rossby waves in the Southern Hemisphere and a shallow cross-equatorial meridional circulation.***

Implications to North American Monsoon:

- ***Westward expansion of the North Atlantic Subtropical Hight leads to Mexican mid-summer drought and early demise of the NAM (Arias et al. 2012).***
- ***Thus, the extreme cold front incursions from the extratropical South America could contribute to Mexican middle summer drought and early demise of the NAM.***

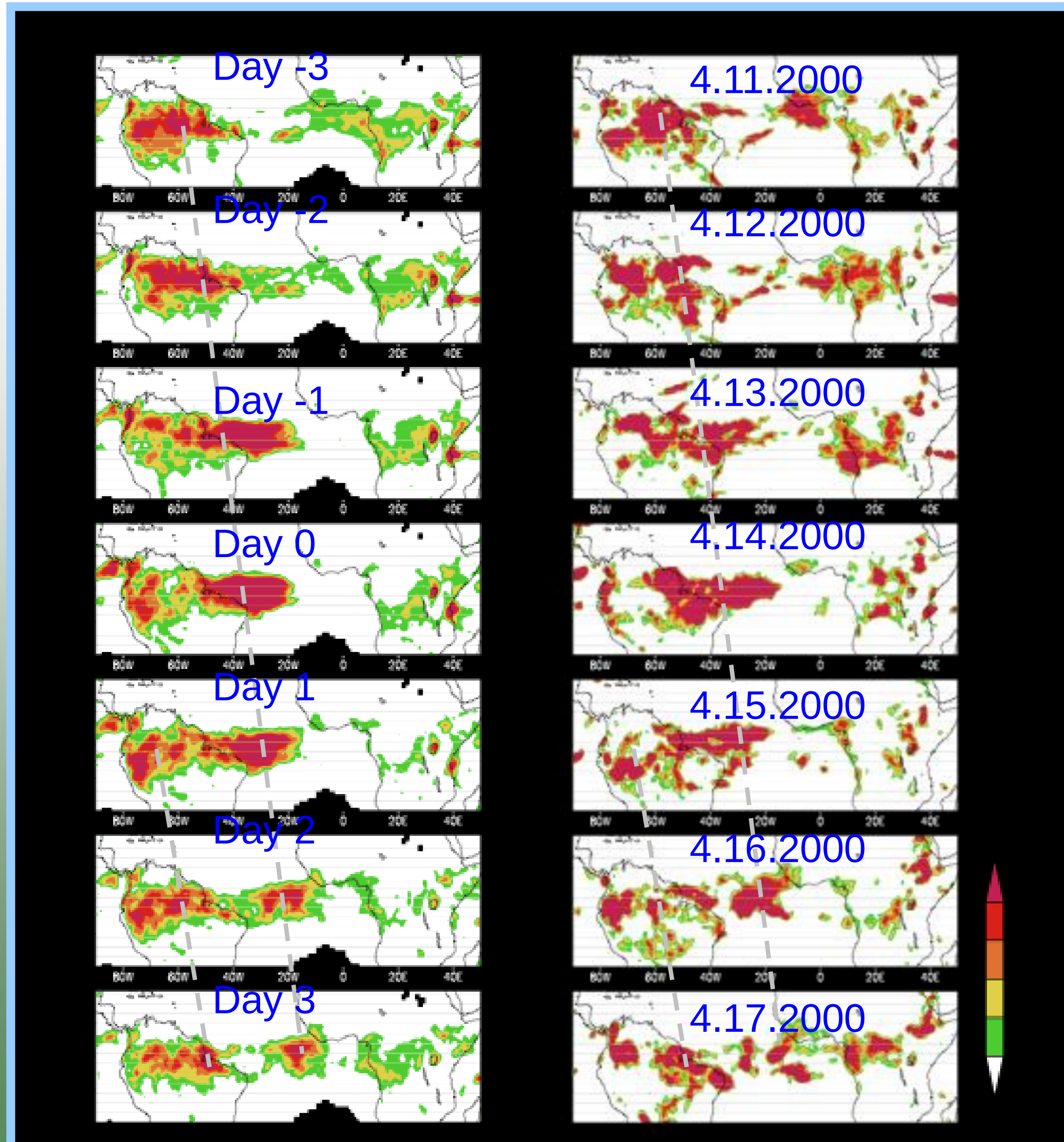
- ***Hypothesis-3:*** ***Convective coupled Kelvin waves from Amazonia can influence tropical Atlantic surface winds and sea-level height anomalies, especially during austral fall (March-April-May). In doing so, variation of Amazonian rainfall can influence zonal (east-west) mode of Atlantic SST variability.***

Convective coupled Kelvin waves originated from Amazon:

Wang and Fu 2007, JC: The leading EOF mode capture the convective coupled Kelvin Wave:

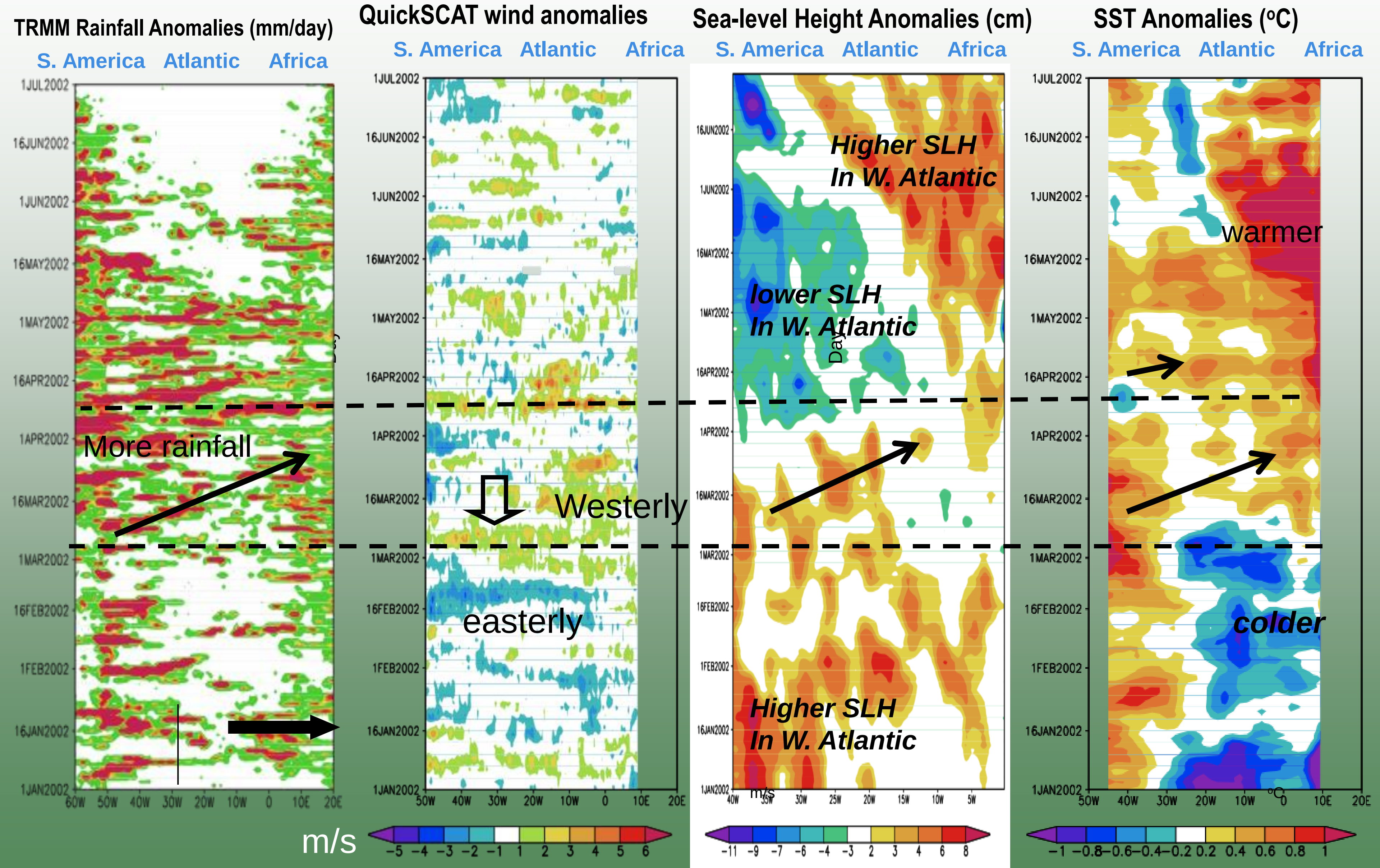
- **Eastward propagating**
- **Phase speed: 15 m/s**
- **Zonal wavenumber 6**
- **Period: 6–7 days**

- Kelvin waves have strong influence on the Atlantic ITCZ .

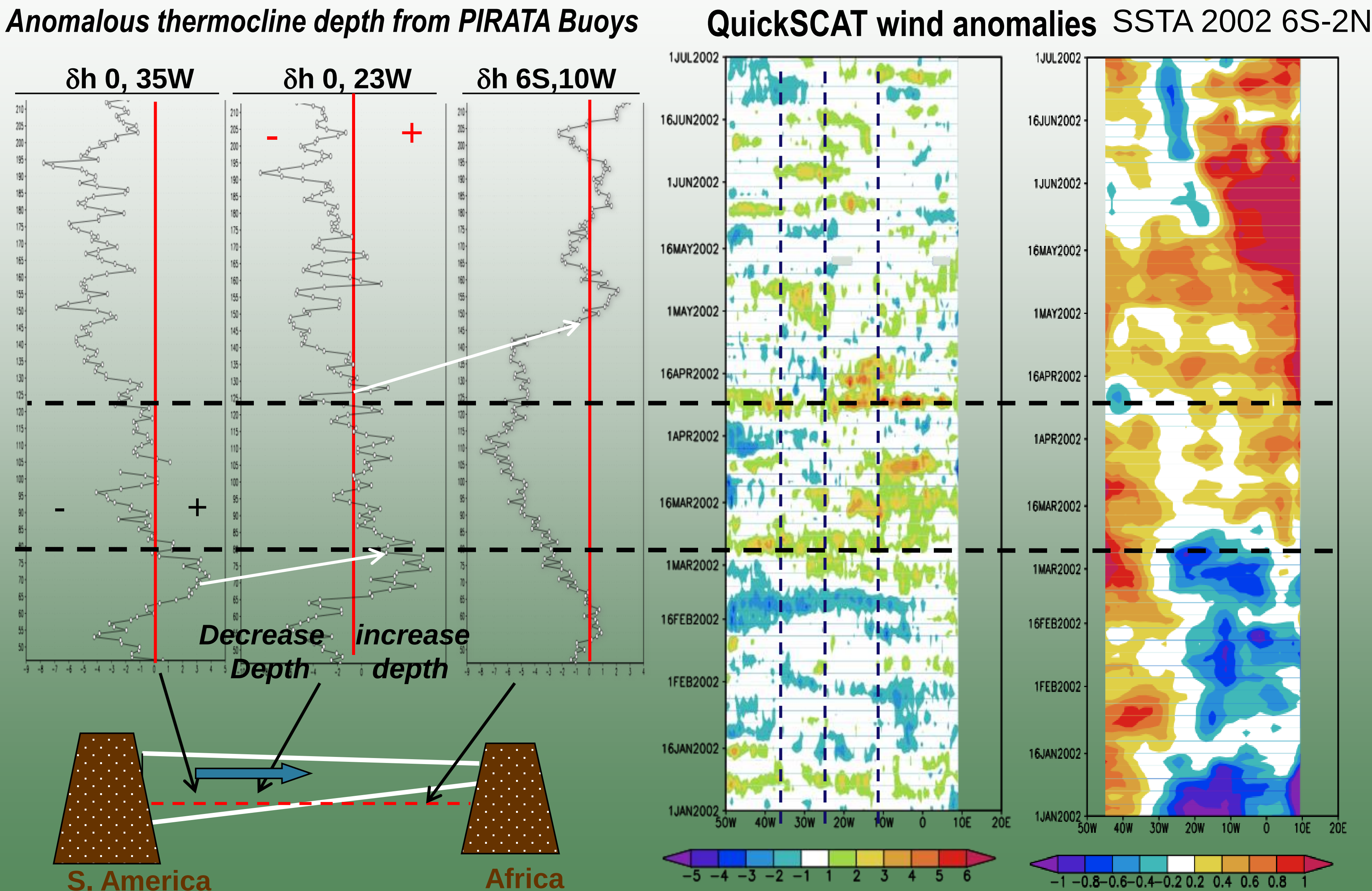


TRMM data, 2000–2003

Kelvin wave originated from S. America ⇒ westerly surface wind anomalies ⇒ increase SLH in E. Atlantic ⇒ warmer SSTA in the E. Atlantic



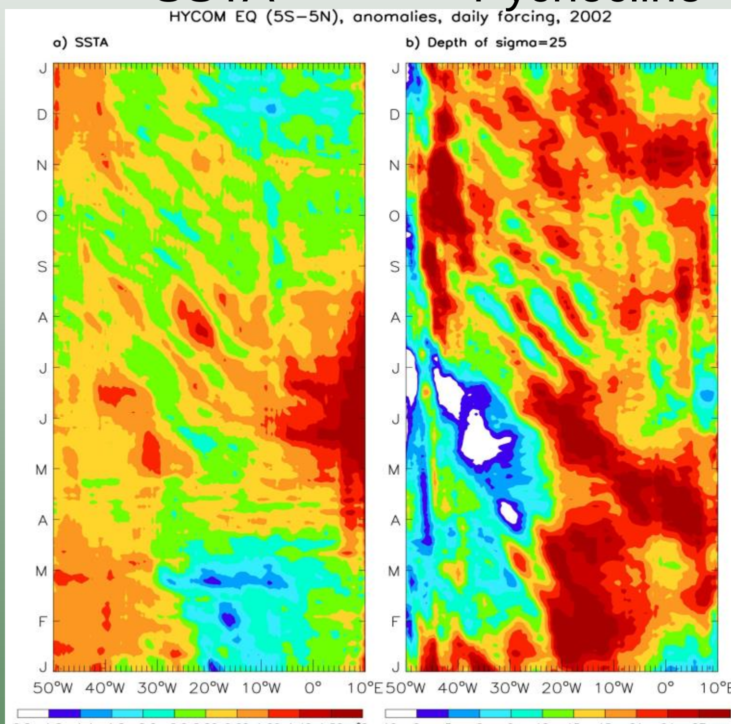
In situ buoy data show changes in E-W slope of the thermocline depth consistent with winds and SSTA:



Ocean model simulation shows that surface zonal wind anomalies associated with convective coupled Kelvin wave generate oceanic Kelvin waves, and trigger the 2002 Atlantic Niño:

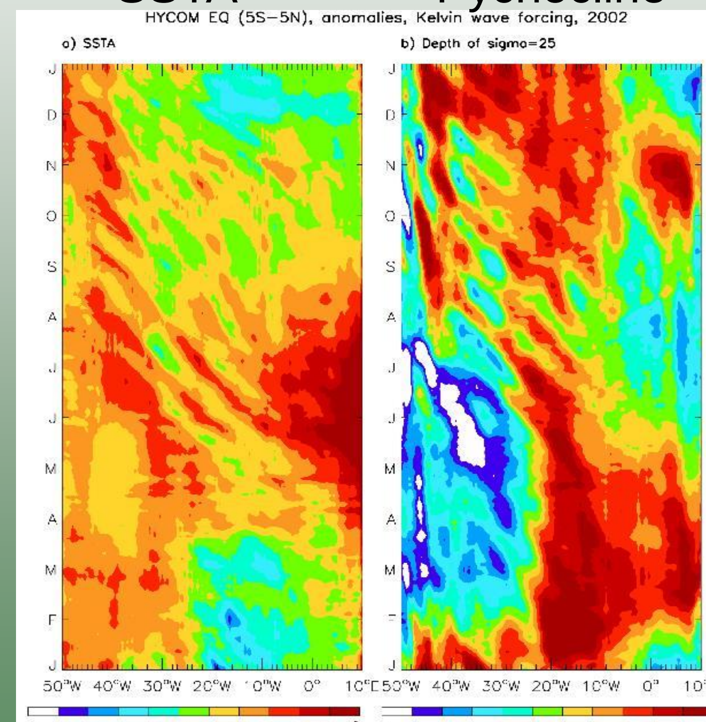
HYCOM forced by daily wind in 2002:

SSTA Pycnocline



HYCOM forced by U’ of Convective Coupled Kelvin wave+daily climateological wind:

SSTA Pycnocline

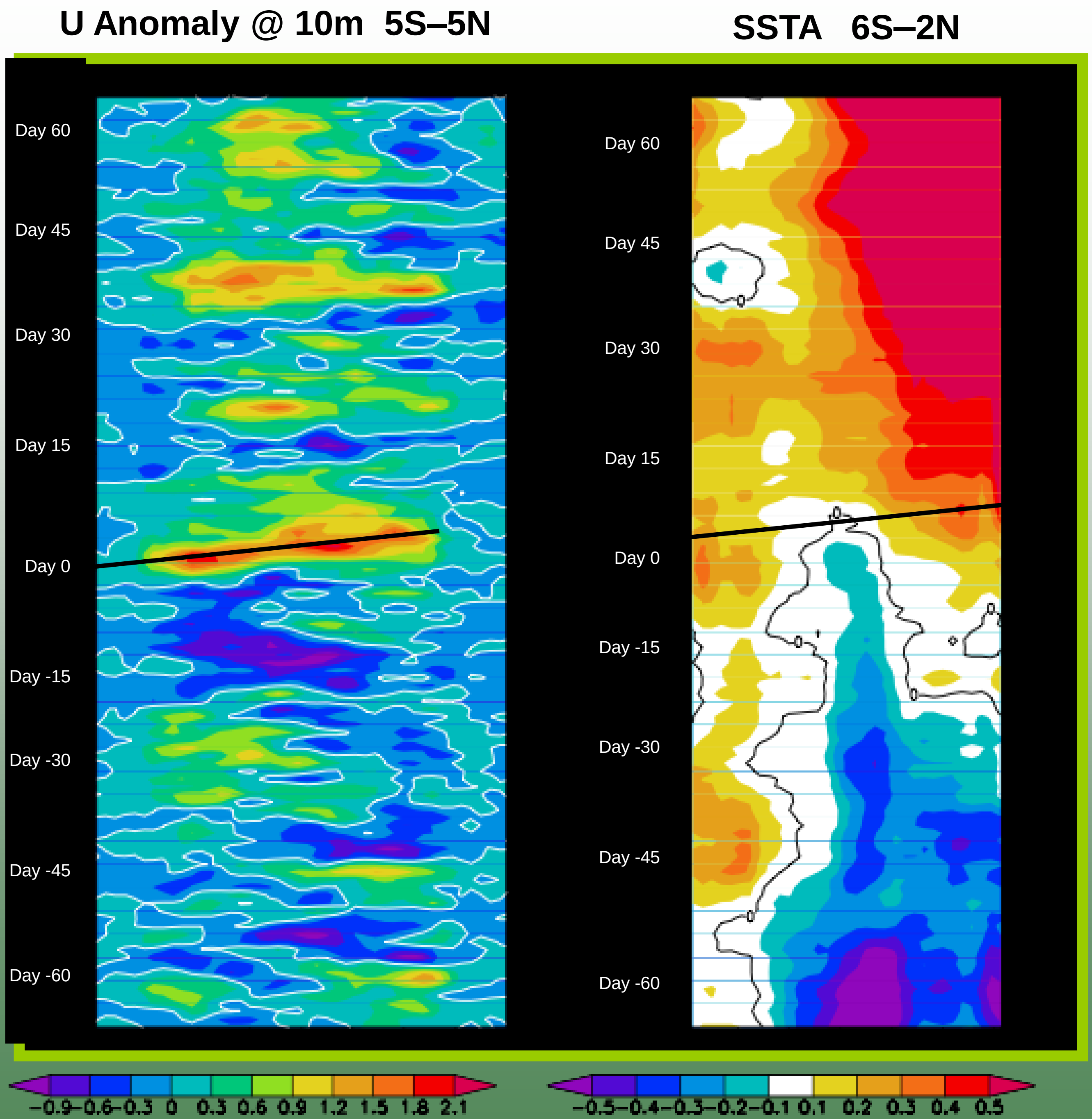


Han 2007

Composite surface wind anomalies and SSTA:

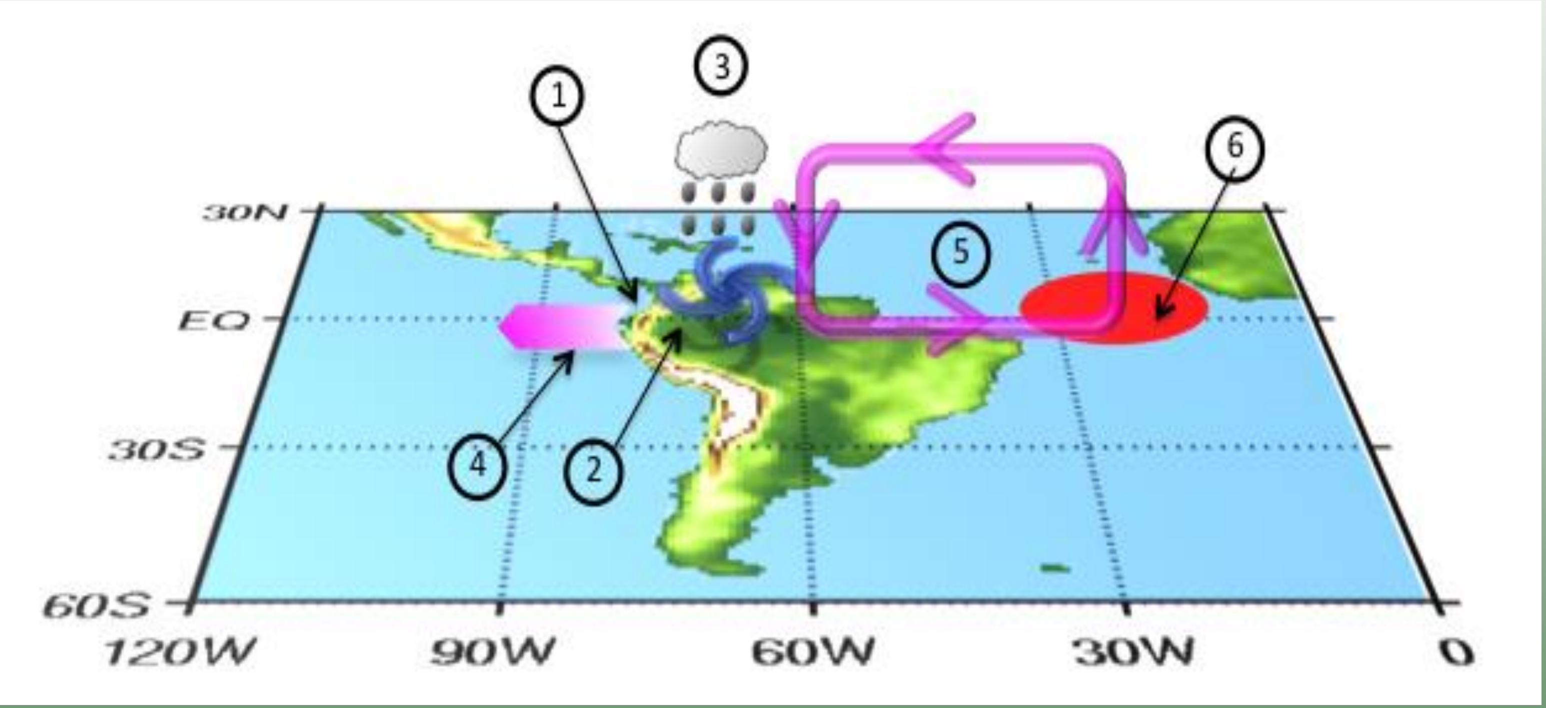
Day -60–Day 60 6 Atlantic Niños,

(1951, 1966, 1968, 1996, 2001, 2002)



Could Amazonia rainfall influence this westerly anomalies?

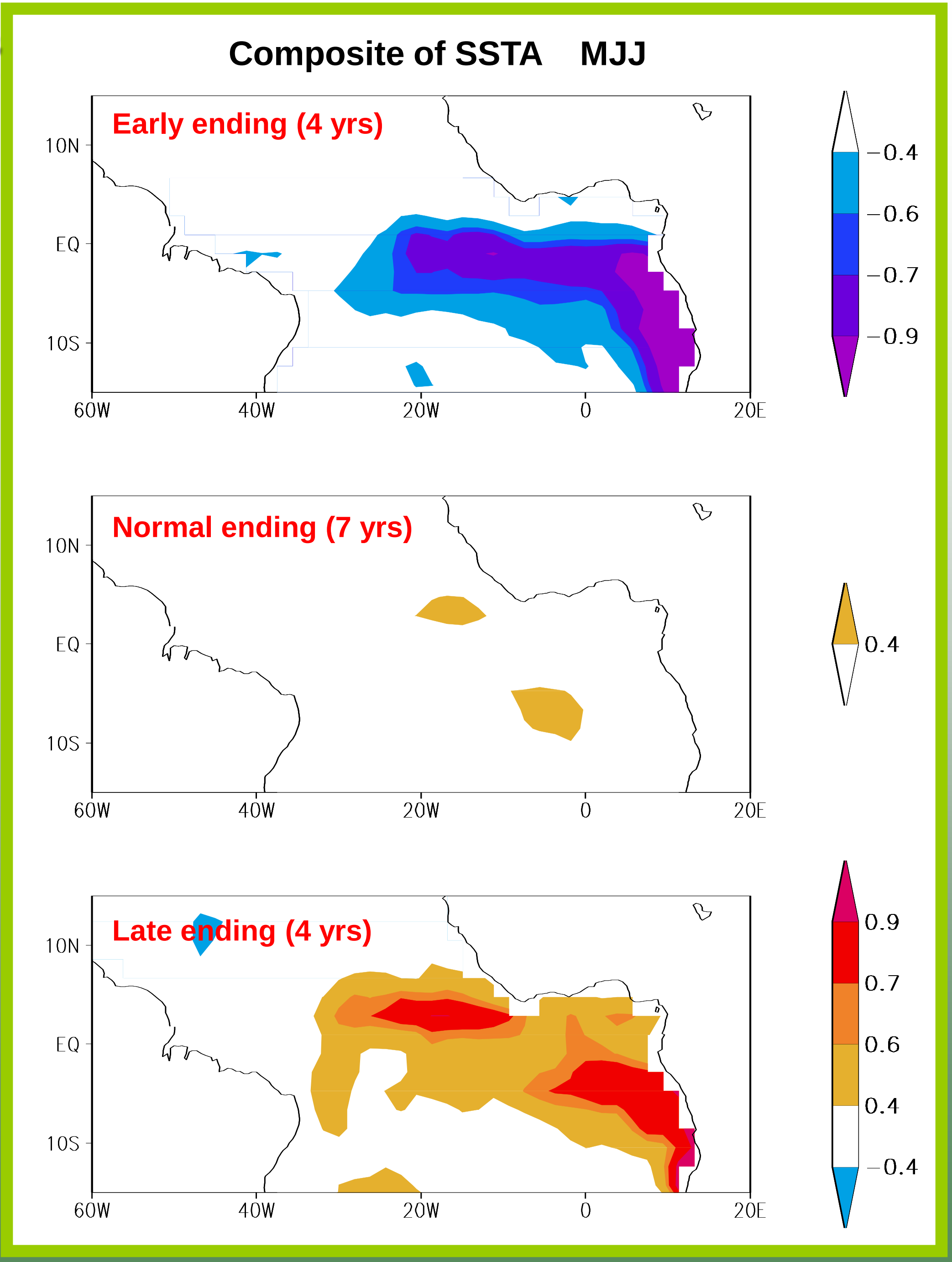
- ***The influence South American rainfall on Atlantic Niño.***



Link between changes in wet season ending in the Amazon and Atlantic Niño:

Amazon Wet season	Atlantic Niño
Early ending in spring Weak Kelvin wave	cold phase in summer
Late ending in spring Strong Kelvin wave	warm phase in summer

Data: 1979–1997



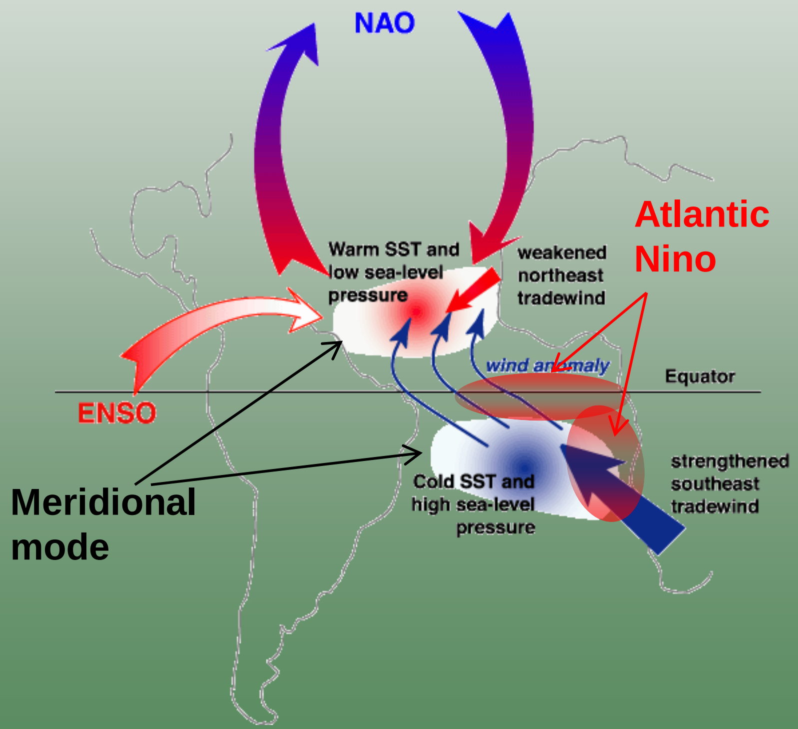
- ***Hypothesis-3:* Convective coupled Kelvin waves from Amazonia can influence tropical Atlantic surface winds and sea-level height anomalies, especially during austral fall (March-April-May). In doing so, variation of Amazonian rainfall can influence zonal (east-west) mode of Atlantic SST variability.**

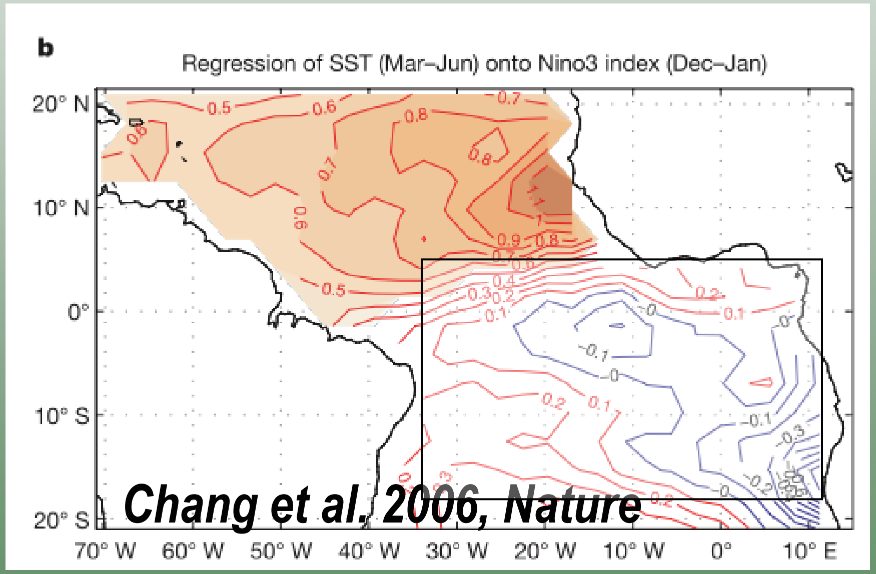
Summary of the results:

- ***Late ending of the Amazonia wet season increases convective coupled Kelvin waves, which propagate eastward, increases westerly surface wind anomalies and sea-level height in the eastern equatorial Atlantic in austral fall. These processes, in turn, can initiate the onset of Atlantic Niños in austral winter (boreal summer).***

Implications

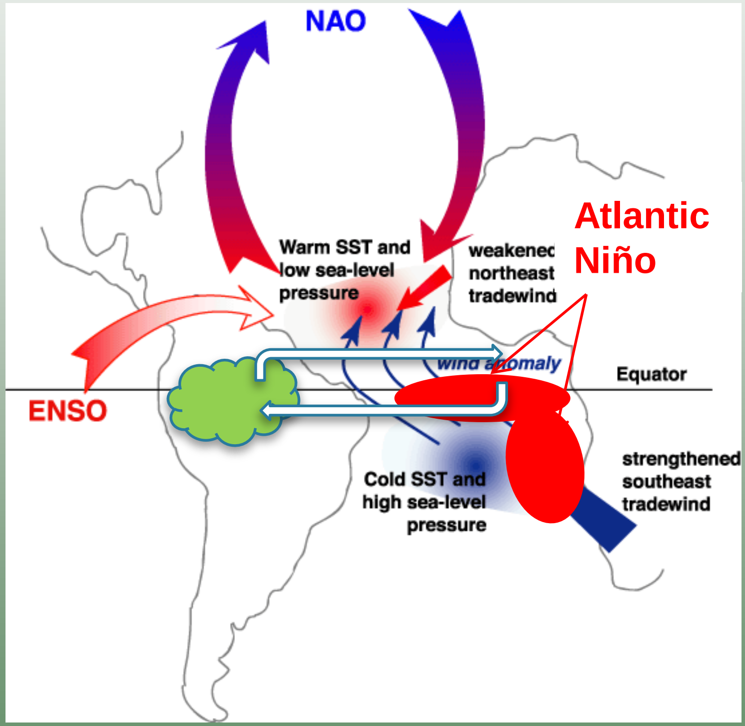
- *Conventional Wisdom: Atlantic Niño is induced by Pacific El Niño.*
- *However, the correlation between Nino index in December-January and Sea surface temperature in the Atlantic Nino area during March-June is insignificant.*





Chang et al. 2006, Nature

- *Late ending of the wet season over Amazonia leads to stronger convective coupled Kelvin waves over the equatorial Atlantic in austral fall, which in turn trigger the onsets of Atlantic Niños in austral winters.*



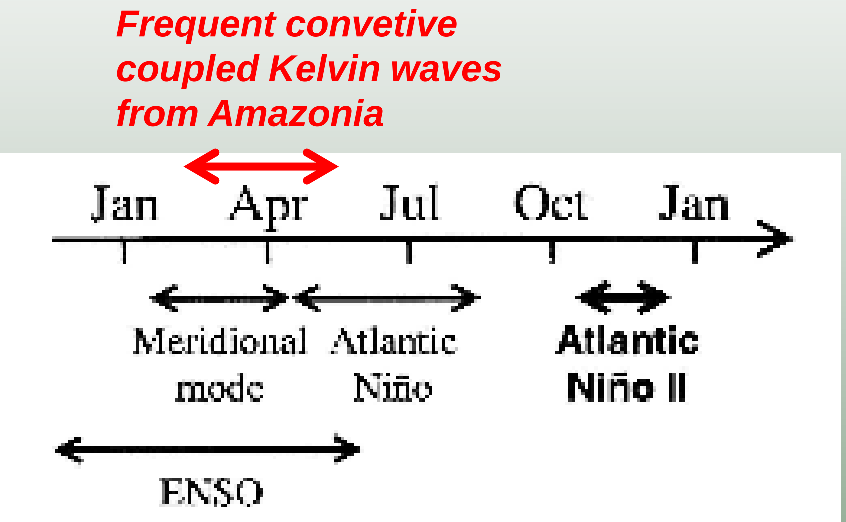
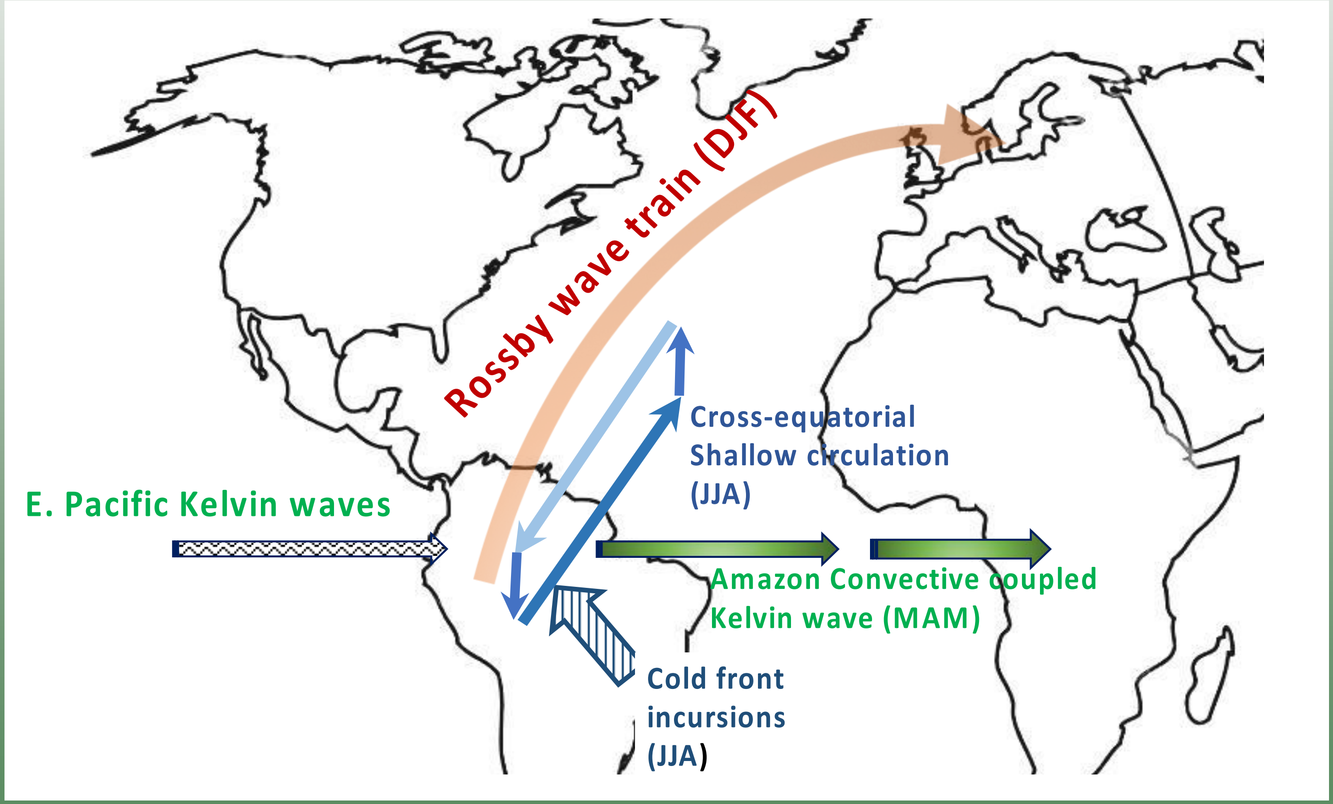


FIG. 16. Seasonality of the dominant modes of climate variability in the tropical Atlantic, modified after Sutton et al. (2000). The present study shows that the Atlantic Niño II fills an important gap in early boreal winter.

Take Home Message

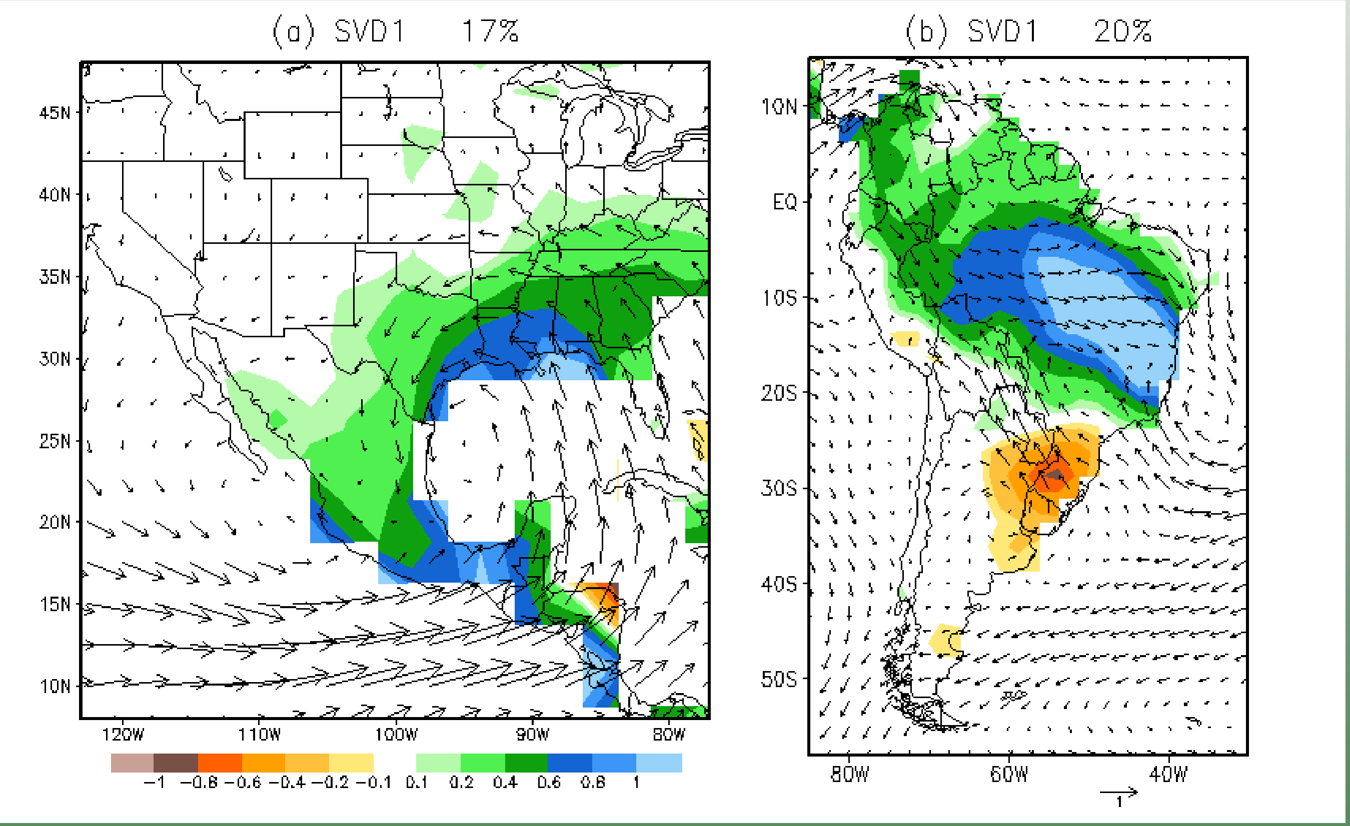
- ***Convection and cold front incursions over South America can influence weather and climate variability over North America - Atlantic sector in all seasons***



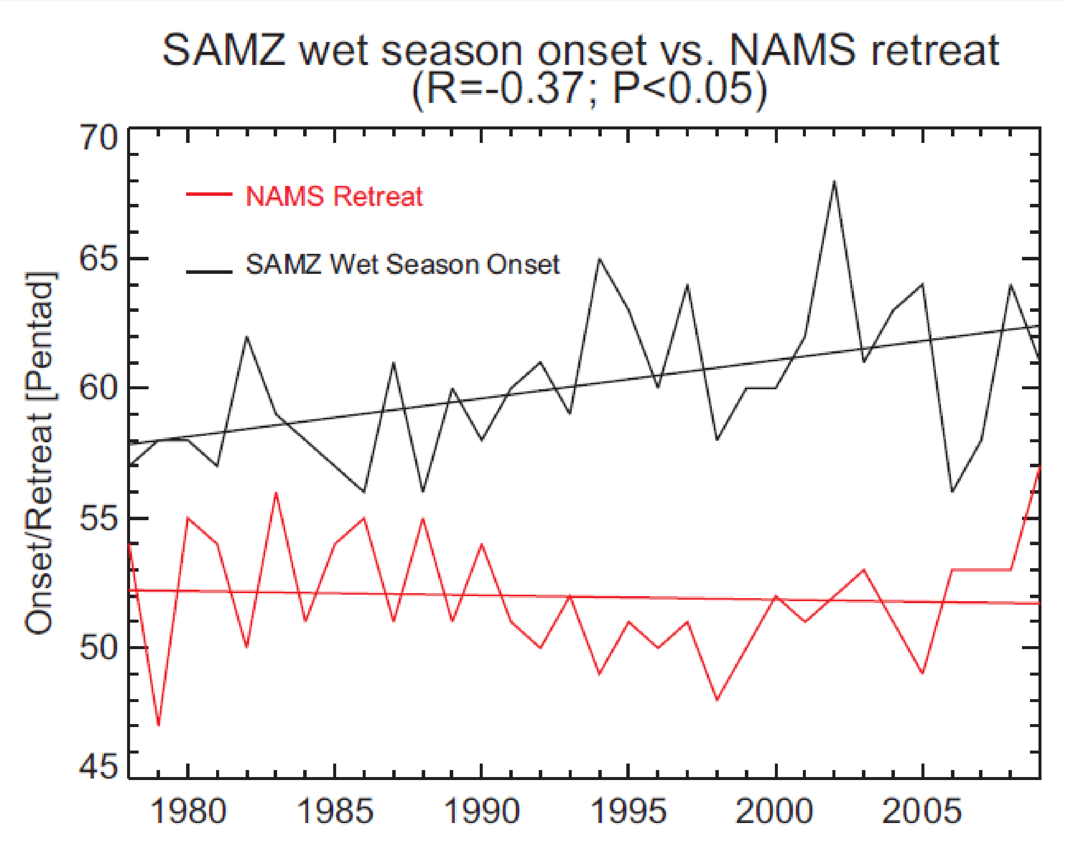
Outstanding Questions

- ***Could the onset of SAM contributes to the demise of the NAM during Austral spring?***

Singular Value Deposition of pentad wind anomalies, Sept-Nov

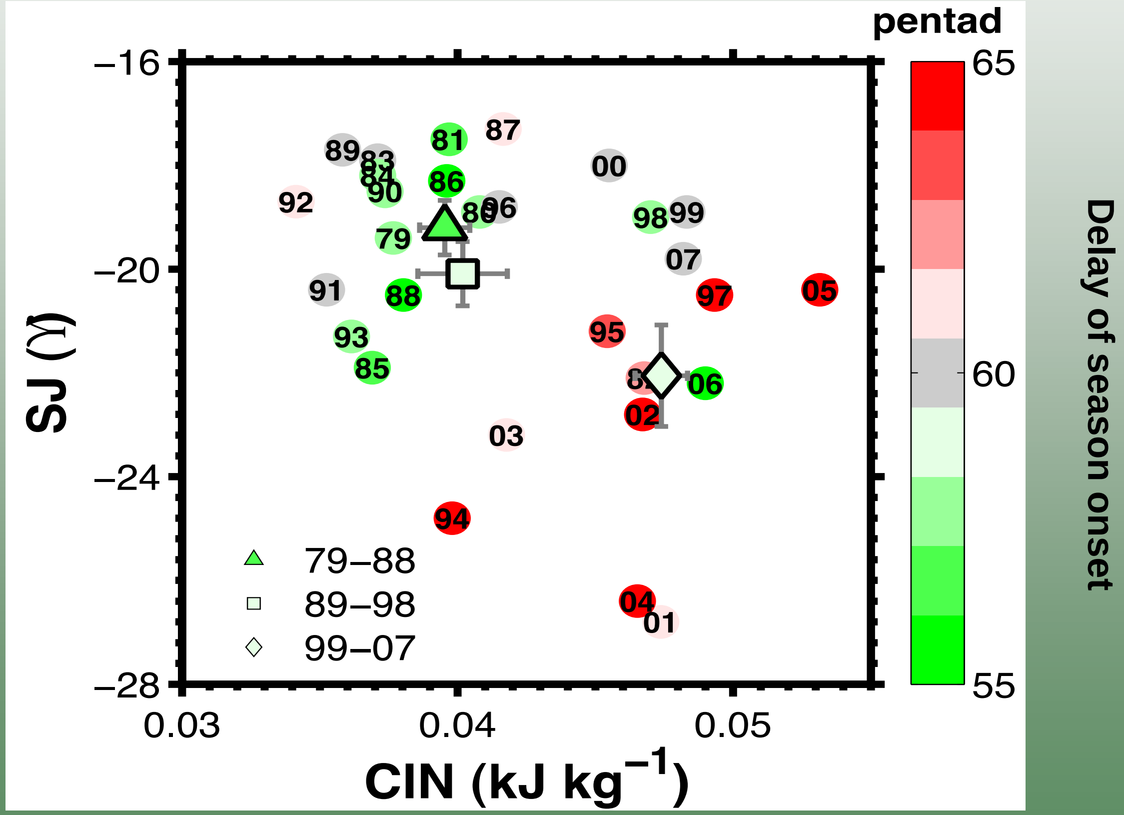


- ***What cause the correlation between the earlier ending of the North American Monsoon and delay of the Amazonian wet season onset?***



Arias et al. 2015, JC

- ***How would rainfall changes over South America, induced by global climate changes, e.g., equatorial contraction of the ITCZ, the poleward shift of the southern hemispheric subtropical jets, regional landuse, and reduced ET in elevated CO_2 environment over Amazonia affect North American-Atlantic Sector?***



Fu et al. 2013, PNAS

and many more questions!


Obrigado!