Influence of the midlatitudes on southeastern South American rainfall and circulation on intraseasonal timescales

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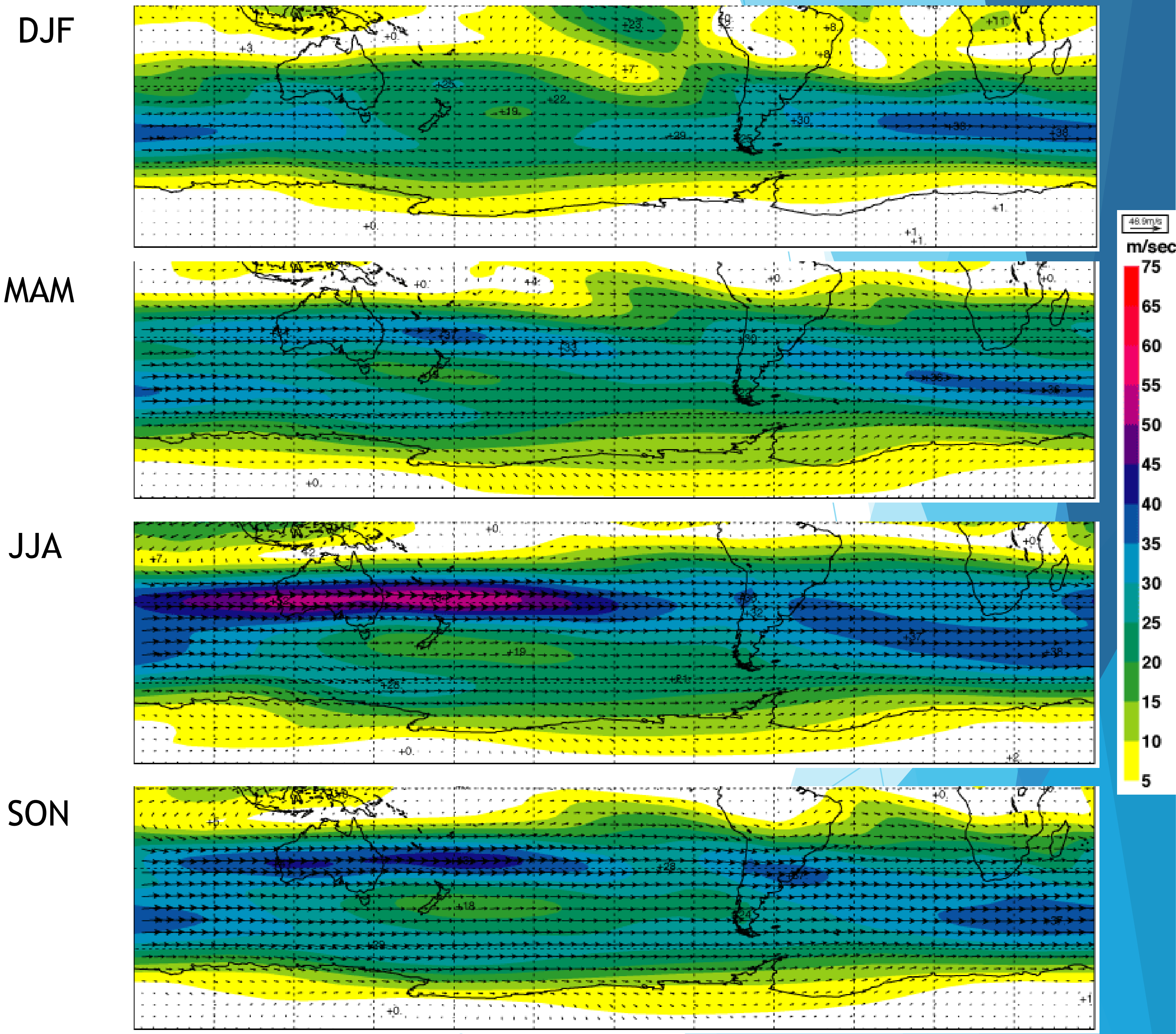
Outline

- Southern Hemisphere climatological features
- SH circulation patterns
  - Southern Annular Mode/Antarctic Oscillation
  - Pacific-South American Patterns
- Rossby Wave Source and meridional propagation in the southern hemisphere
- South American Monsoon System
- Intraseasonal variability in South America
  - Background
  - Variability and leading patterns across seasons
  - Association with wet spells

Southern Hemisphere climatology

Seasonality of SH jets streams

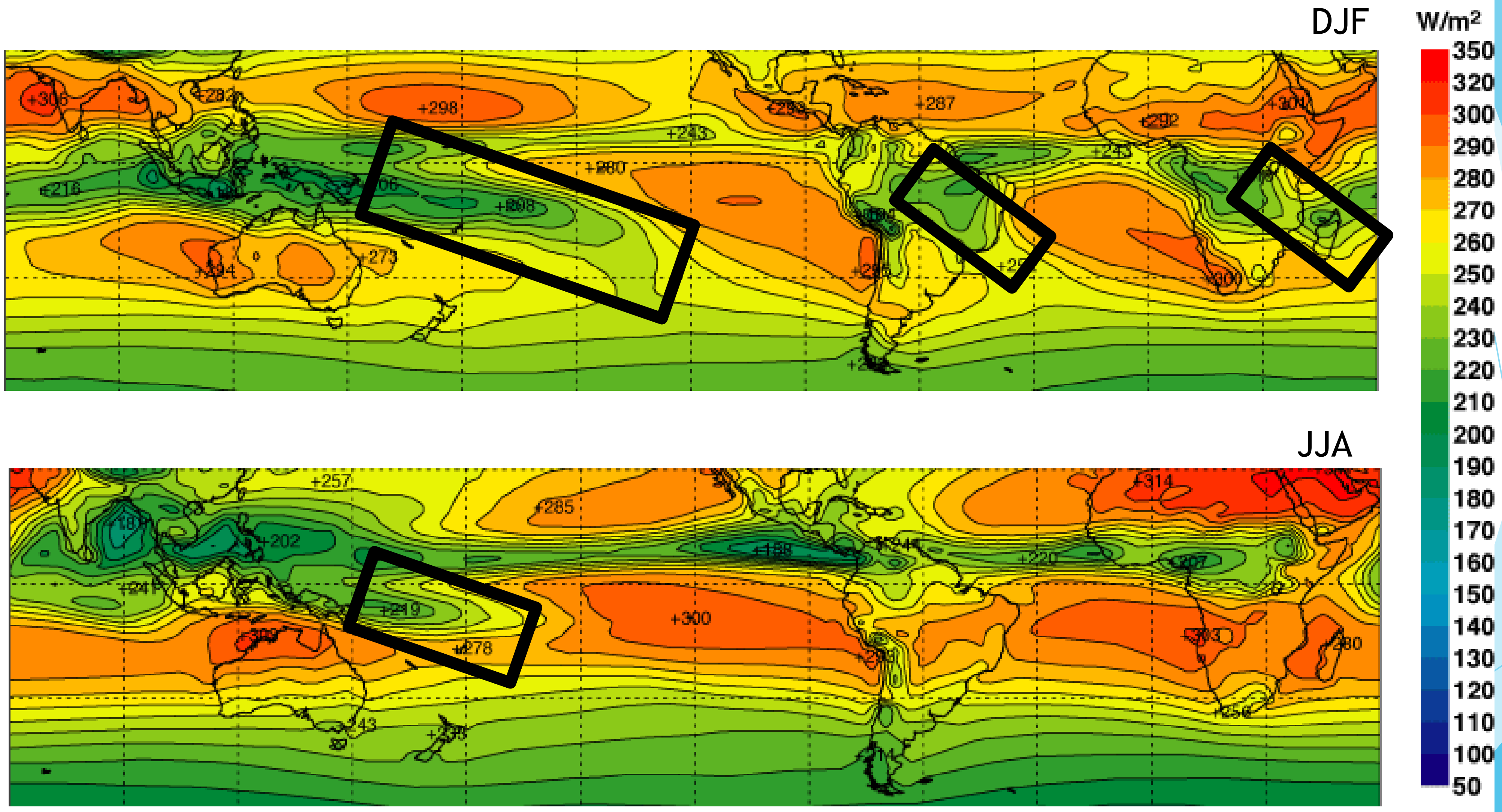
Wind vector and isotachs at 200 hPa



From ERA Atlas

Southern Hemisphere climatology

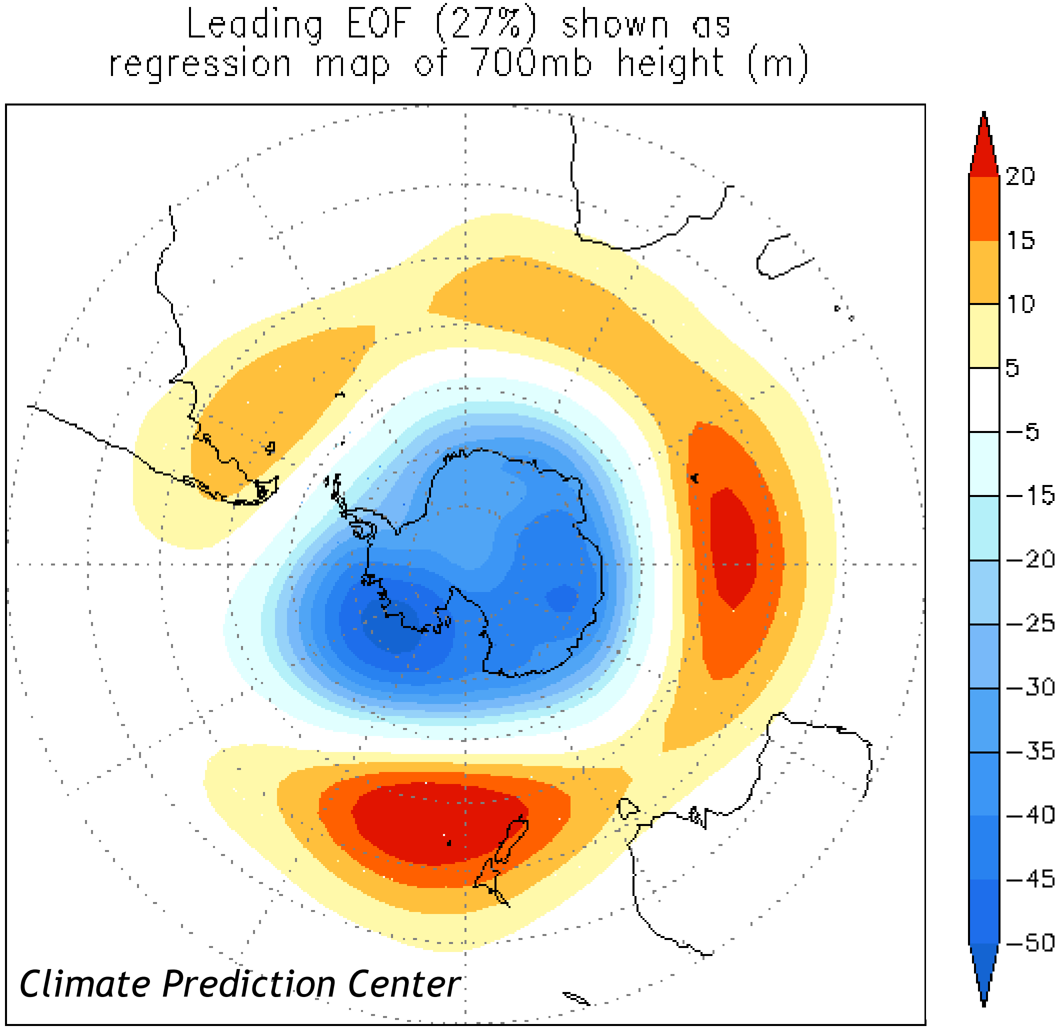
Southern Hemisphere Convergence Zones: SPCZ, SACZ & SICZ



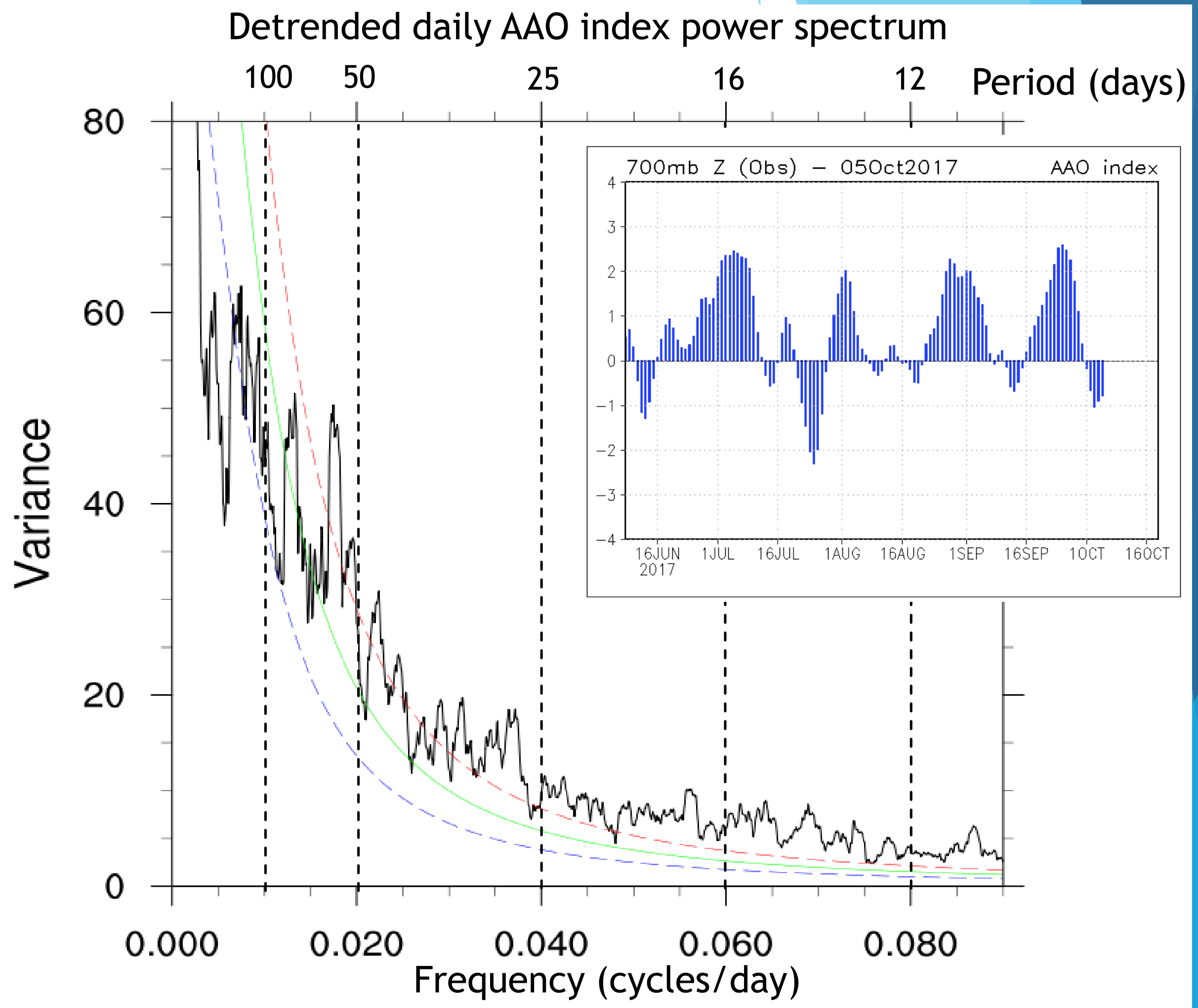
 From ERA Atlas

SH circulation patterns

Southern Annular Mode/Antarctic Oscillation



Leading mode of Empirical Orthogonal Function (EOF) analysis of monthly mean 700 hPa height during 1979-2000 period



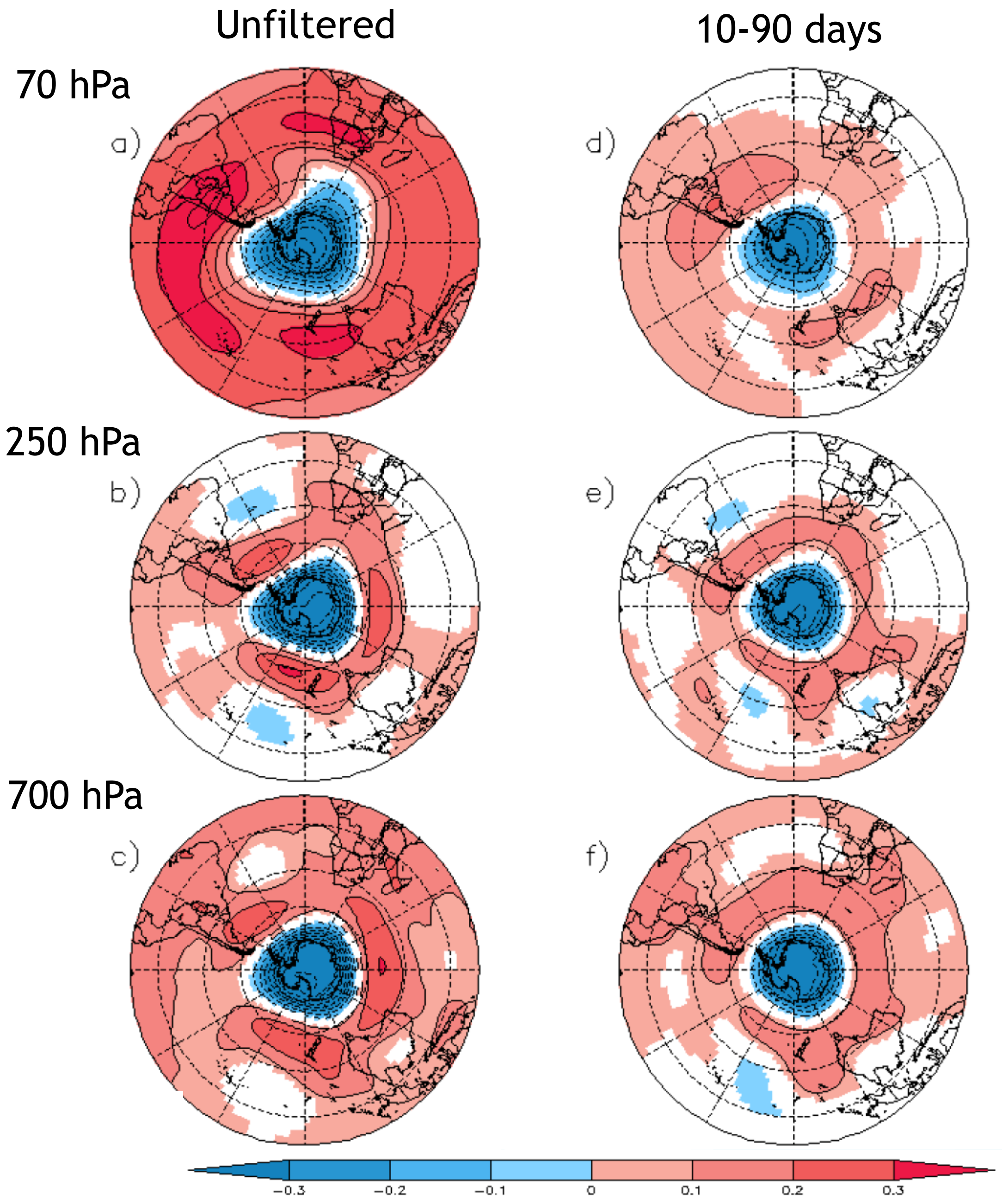
Projection of the daily (00Z) 700mb height anomalies poleward of 20°S onto **the loading pattern of the AAO** → AAO index

SH circulation patterns

Southern Annular Mode/Antarctic Oscillation

Austral winter season.

- EOF1 as correlations between PC1 and geopotential height anomalies.
- Annular mode with barotropic structure
- Leading mode across timescales (also found on interannual time scales)



Di Gregorio Master Thesis 2015

SH circulation patterns

Southern Annular Mode/Antarctic Oscillation

Only studying the DJF season:

- Composites of filtered OLR anomalies (Lanczos, 151 weights, 20-70 days) for negative and positive SAM phases.

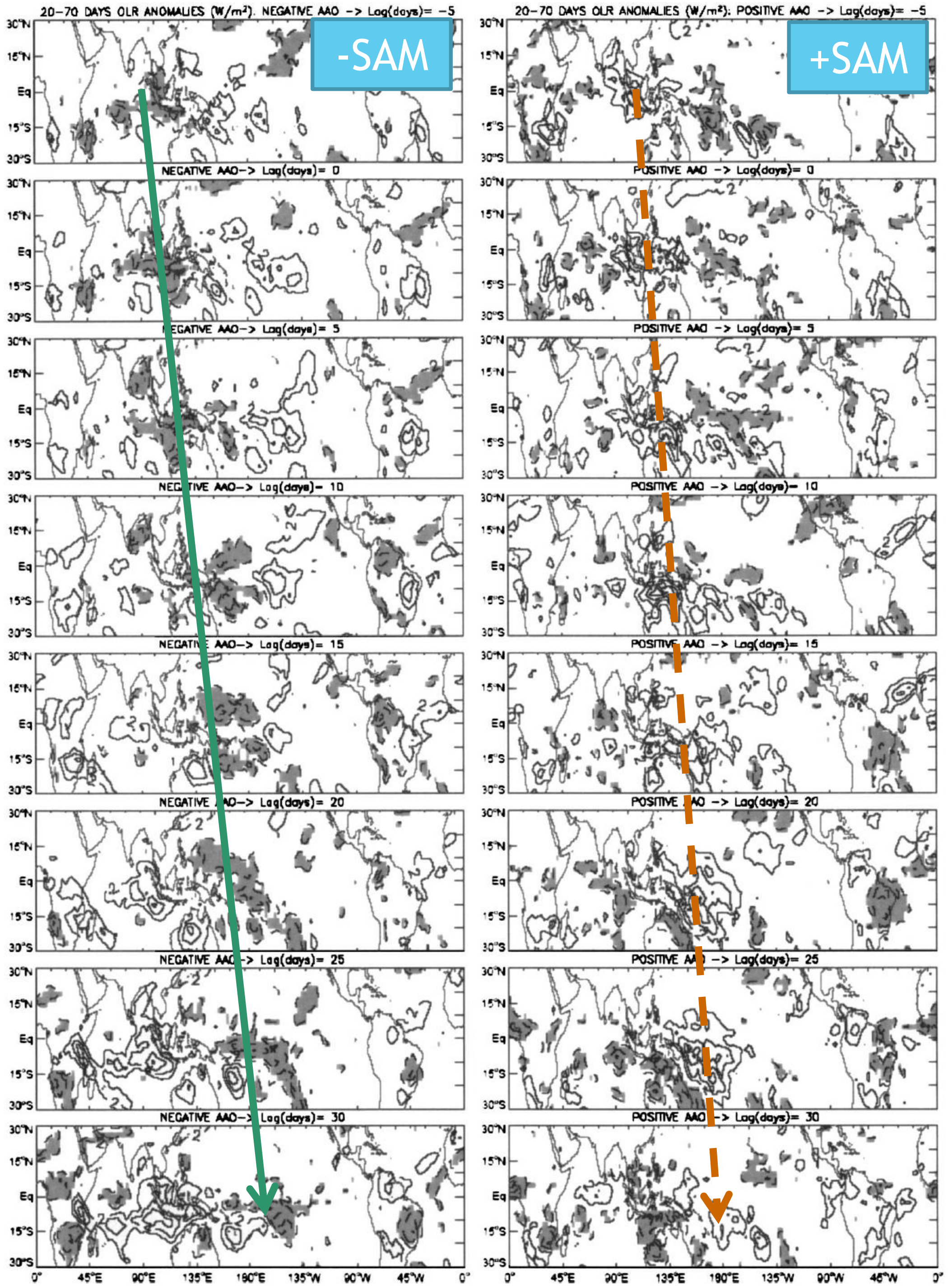
- Observed patterns similar to MJO progression, and those associated to a negative SAM or a positive SAM seem to be opposite.

- Different phases of the SAM also affect the latitude along which cyclones form and propagate.

Day 0

Day 15

Day 30



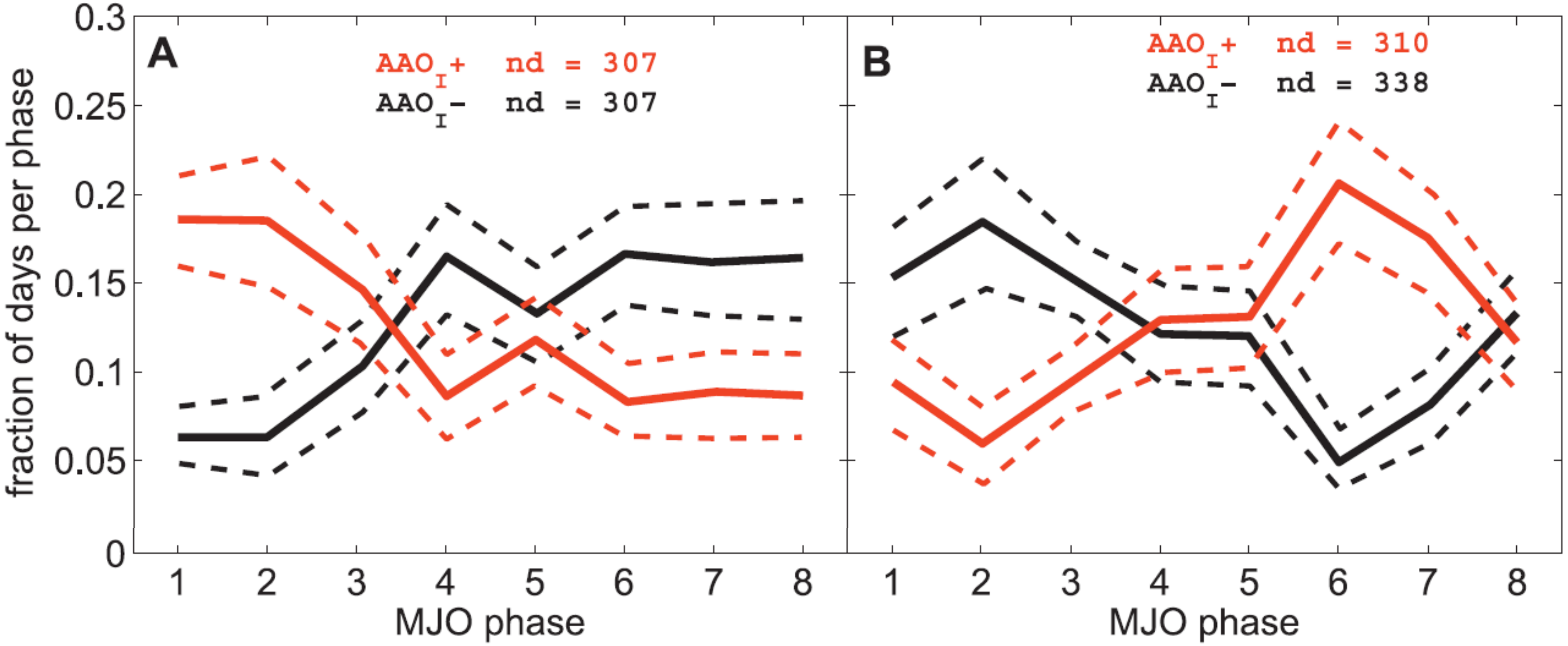
Carvalho et al. 2005

SH circulation patterns

Southern Annular Mode/Antarctic Oscillation

The relationship between the SAM (or AAO) index and MJO changes according to SH season

May-October November-April



Distribution of MJO phases for the positive and negative states of the intraseasonal component of AAO (SAM).

There is a significant contribution of the MJO to the SAM tendency (change over 1 day) on the intraseasonal scale, especially for strong MJO episodes

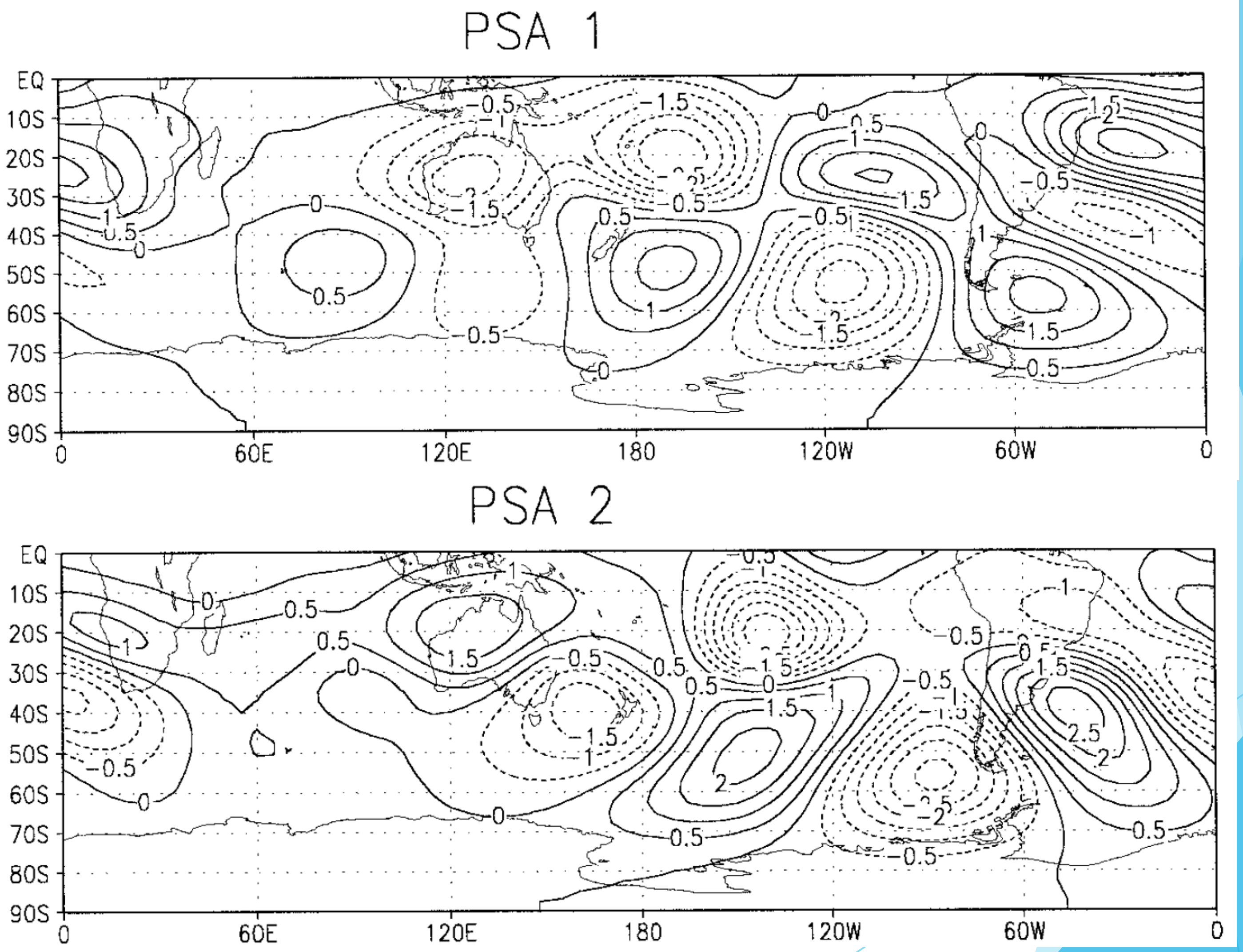
Flateau & Kim 2013

SH circulation patterns

Pacific-South American (PSA) patterns

Austral winter season.

- PSA1 and PSA2 (EOF2 and EOF3) were related to tropical convection.
- Wave number 3
- The patterns appear in the low frequency band (>10 days) and in the IS band (10-90 days)
- Main periods around 36-40 days, but also around 17 days.
- (+)PSA1, (+)PSA2, (-)PSA1, (-)PSA2, (+)PSA1



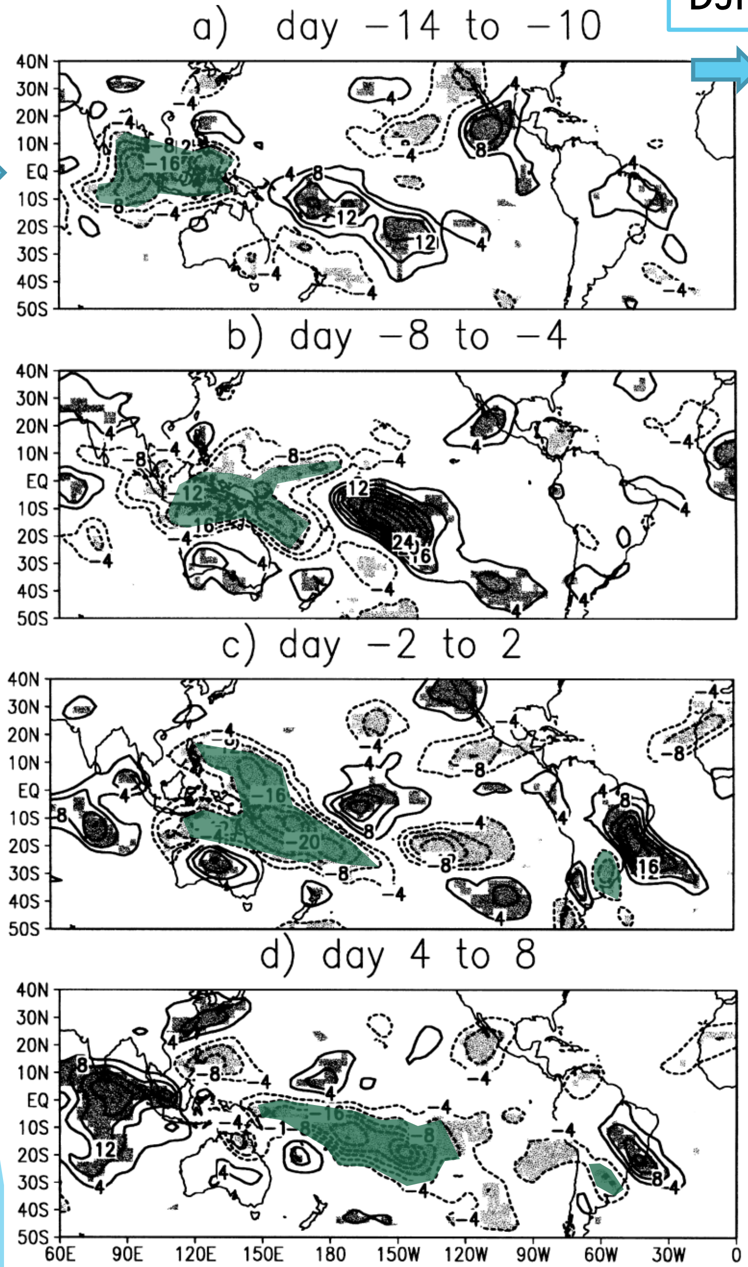
EOF 1 and 2 of 200 hPa eddy streamfunction

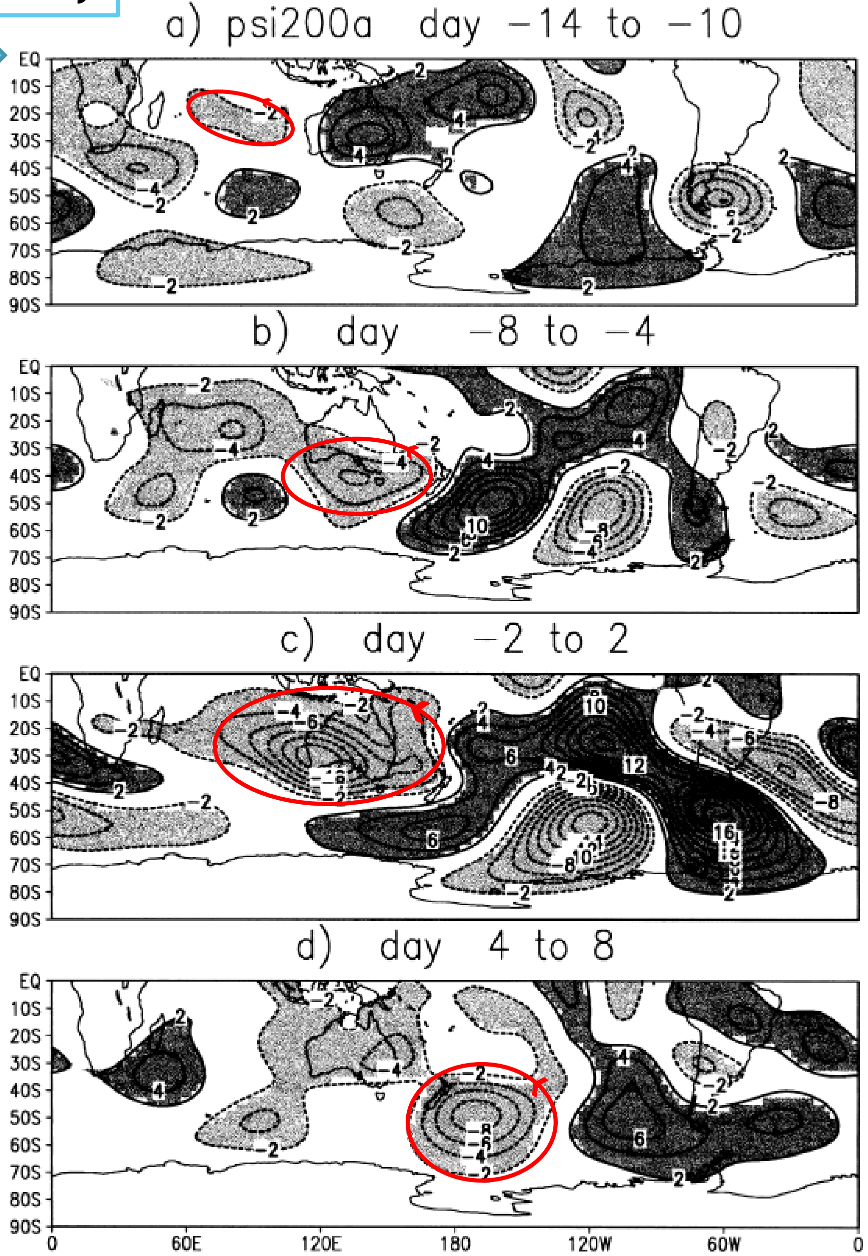
Mo & Higgins 1998

SH circulation patterns

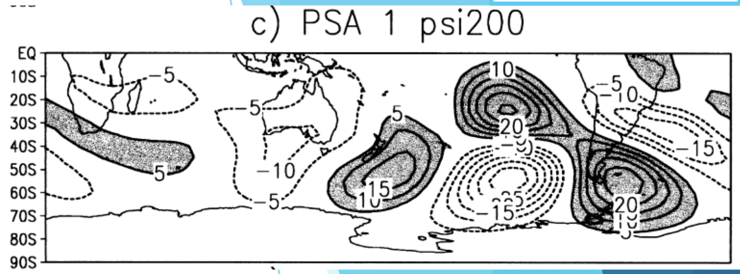
Pacific-South American (PSA) patterns

DJF only





All seasons



IS-filtered OLR (left) and 200-hPa streamfunction (right) composites of positive – negative events for DJF.

Onset for a positive (negative) event is defined as the time when the PSA daily 500-hPa height PC is greater (less) than 1.2 (−1.2) standard deviations.

OLRA complete half a cycle in 24 days ~MJO

Links PSA1-tropical convection (MJO) and convection in South America.

Mo & N. Paegle 2001

Rossby Wave Source

Rossby wave dispersion theory provides the basis for theories on how the tropics influence the extratropics.

Vorticity equation in the upper troposphere, neglecting vertical advection, partitioning the horizontal wind into its rotational and divergent components and expressing each variable as the sum of a basic state component and a perturbation:

$$\underbrace{\frac{\partial \zeta'}{\partial t} + \vec{\bar{\boldsymbol{V}}}_\psi \,.\nabla \zeta' + \vec{\boldsymbol{V}}'_\psi \,.\nabla \bar{\zeta}}_{\text{Propagation of Rossby Waves}} = F + A$$

$$\zeta = \xi + f$$

$$F = -\,\bar{\zeta}\,\nabla.\vec{\boldsymbol{V}}'_\chi - \vec{\boldsymbol{V}}'_\chi.\nabla\bar{\zeta} - \zeta'\nabla.\vec{\bar{\boldsymbol{V}}}_\chi - \vec{\bar{\boldsymbol{V}}}_\chi\,.\nabla\zeta'$$

Forcing F includes divergence terms and advection of vorticity by the divergent flow

Grimm & Ambrizzi 2009

Rossby Wave Source

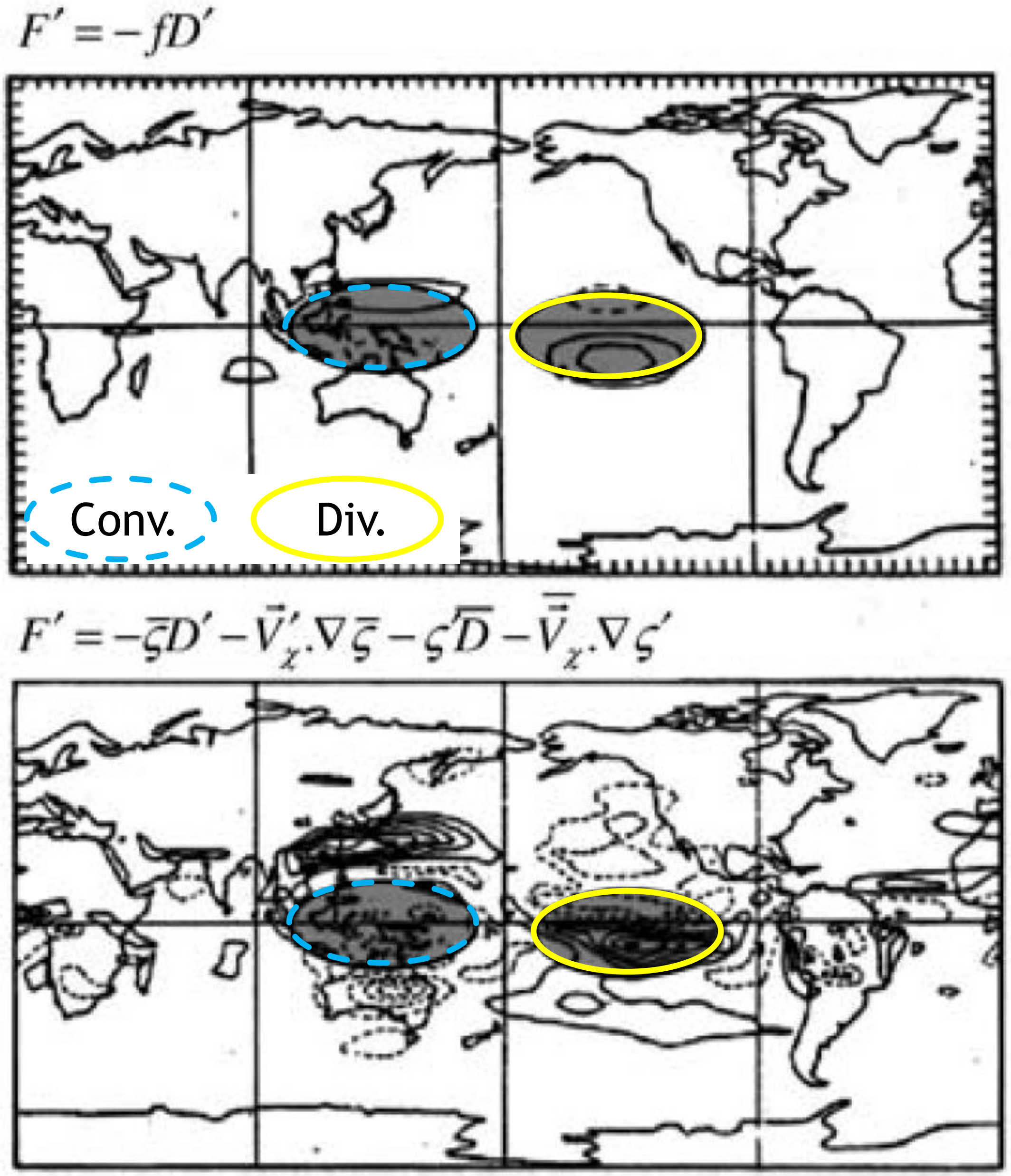
Extension of RWS to the subtropics

$$F_A = -\vec{\boldsymbol{V}}'_{\chi} . \nabla\bar{\zeta} - \bar{\vec{\boldsymbol{V}}}_{\chi} . \nabla\zeta'$$

While the Rossby wave source given by the divergence (or convergence) straddles the equator, the Rossby wave source given by this equation **extends into the subtropical westerly mean flow** (from where waves can **propagate efficiently**) due to:

- the vorticity advection by the anomalous divergent flow in regions of strong mean vorticity gradients, such as subtropical jets

- or to the advection of vorticity perturbations to the subtropics by the climatological divergent circulation in the tropics.



Grimm & Ambrizzi 2009

Rossby Wave Source

Seasonality of RWS

$$S = -\zeta D - \mathbf{v}_\chi \cdot \nabla\zeta = -\nabla \cdot (\mathbf{v}_\chi \zeta)$$

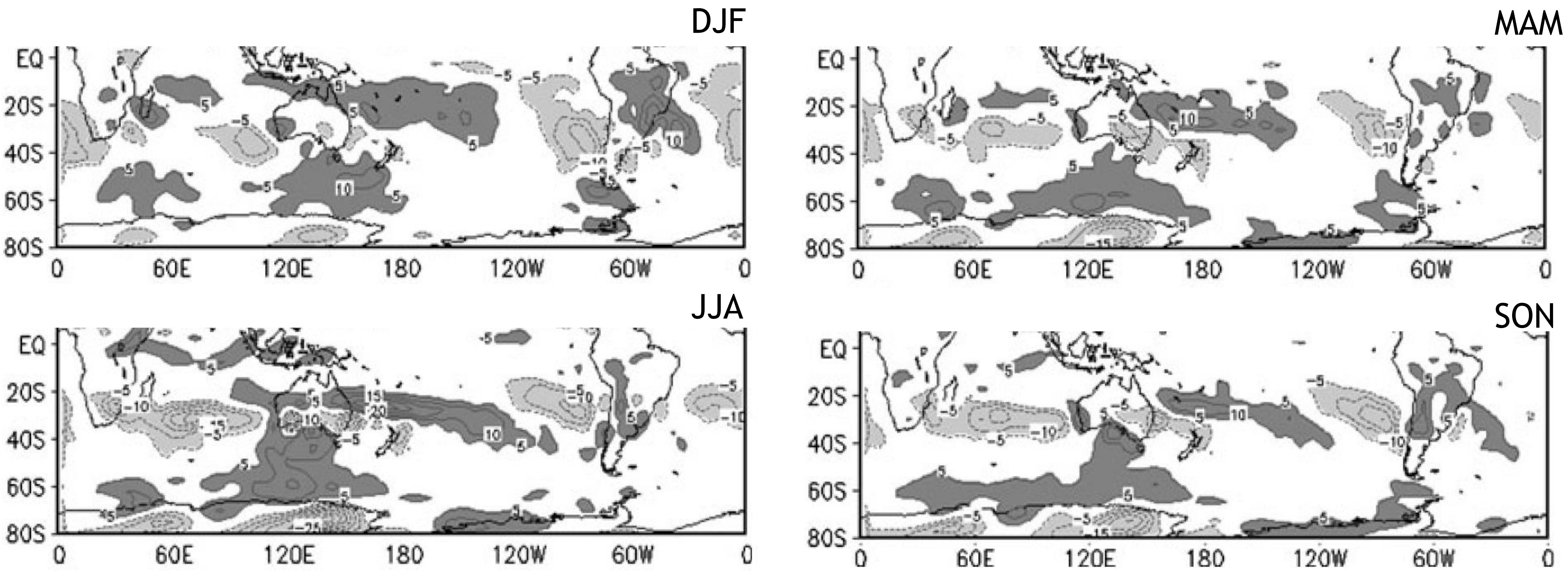


Fig. 4 Average climatological fields (1979–2007) of Rossby waves source at 200 hPa (1×10^{-11} s^{-2}) in **a** DJF, **b** MAM, **c** JJA and **d** SON. The *light and dark shaded areas* represent negative and positive values, respectively

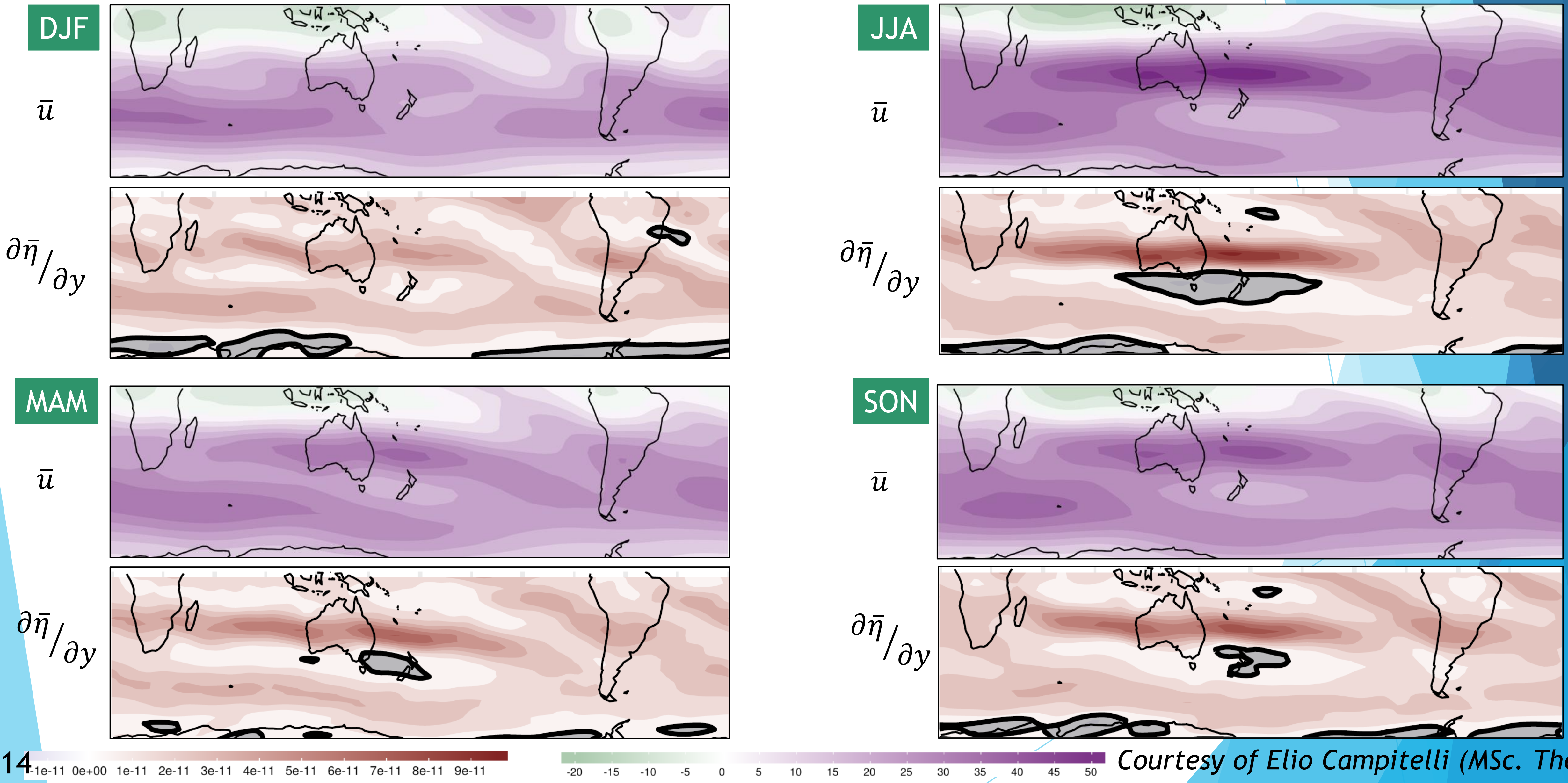
Shimizu and Cavalcanti, 2011

Rossby wave meridional propagation

Southern Hemisphere seasonal conditions

200 hPa, NCEP 1985-2015 monthly values

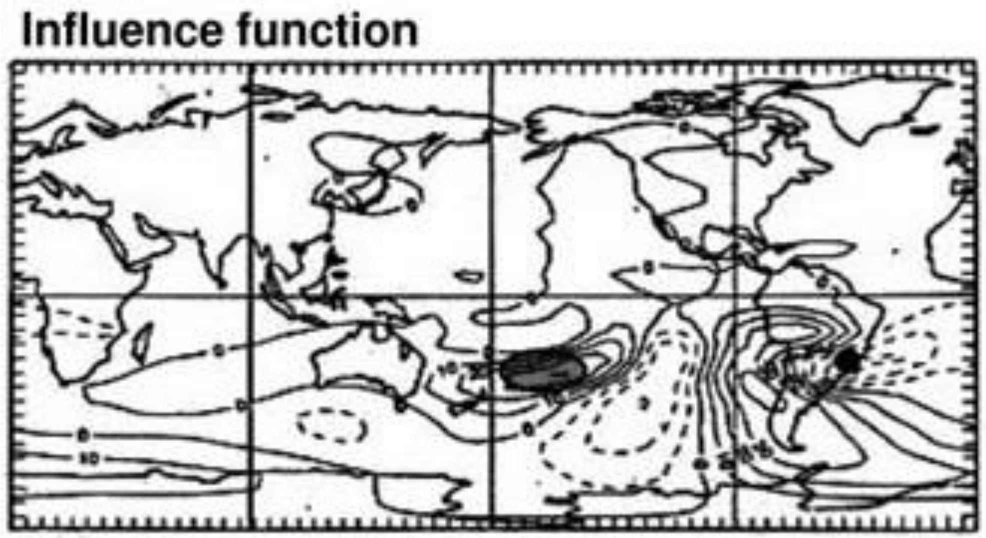
$$\frac{\partial\bar{\eta}/\partial y}{\bar{u} - \omega/k} - k^2 > 0$$



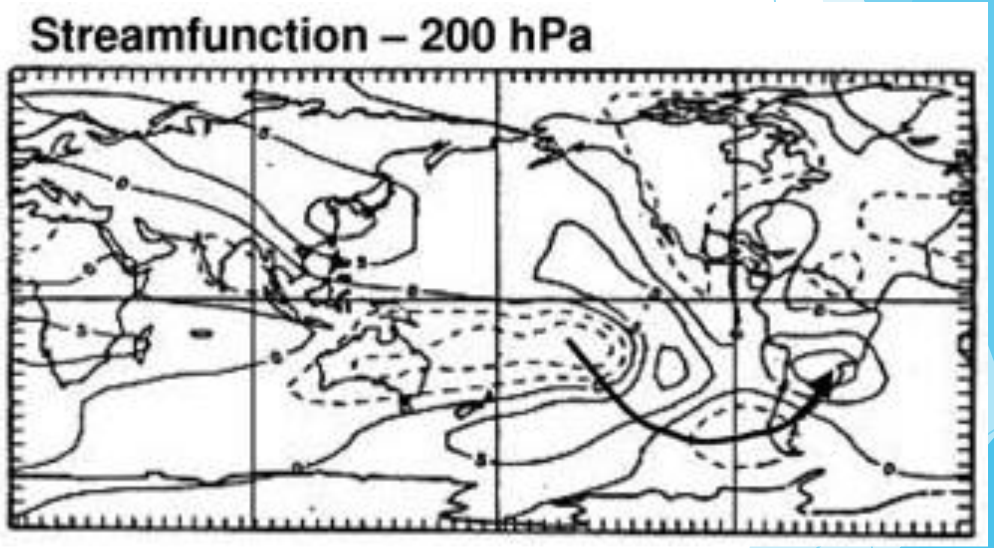
Courtesy of Elio Campitelli (MSc. Thesis)

Influence functions

Influence functions (IFs) identify the regions where the anomalous upper-level divergence has the largest impact on the circulation anomaly around a given point. That is, the IF for the target point with longitude and latitude (λ,φ) is, at each point (λ',φ'), equal to the model response at (λ,φ) to an upper-level divergence located at (λ',φ').



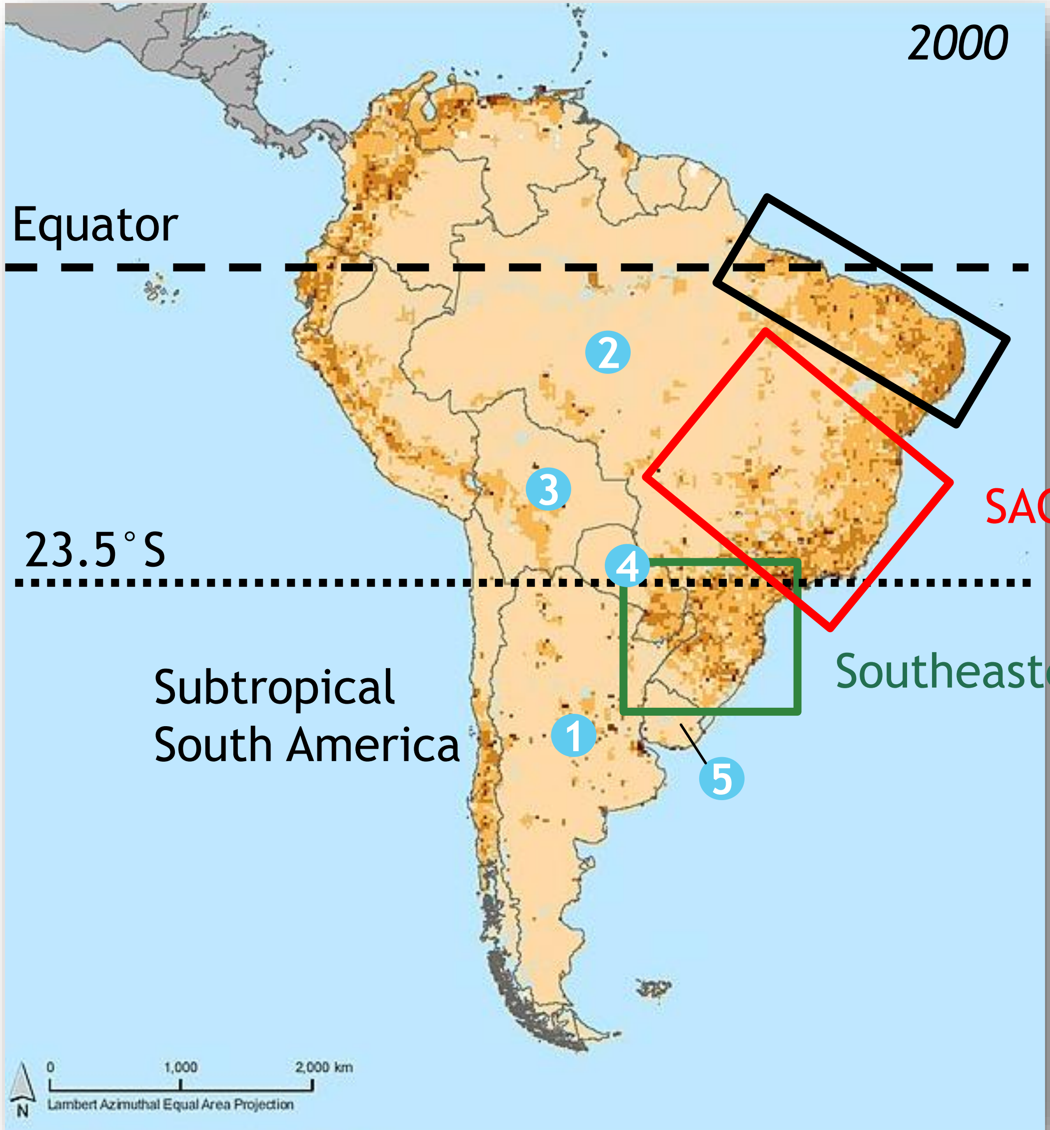
Influence function for the target point at the center of the cyclonic anomaly associated with enhanced SACZ, with the region of maximum values indicated by the shaded ellipse



Resulting streamfunction at 200 hPa

Grimm and Silva Dias, 1995

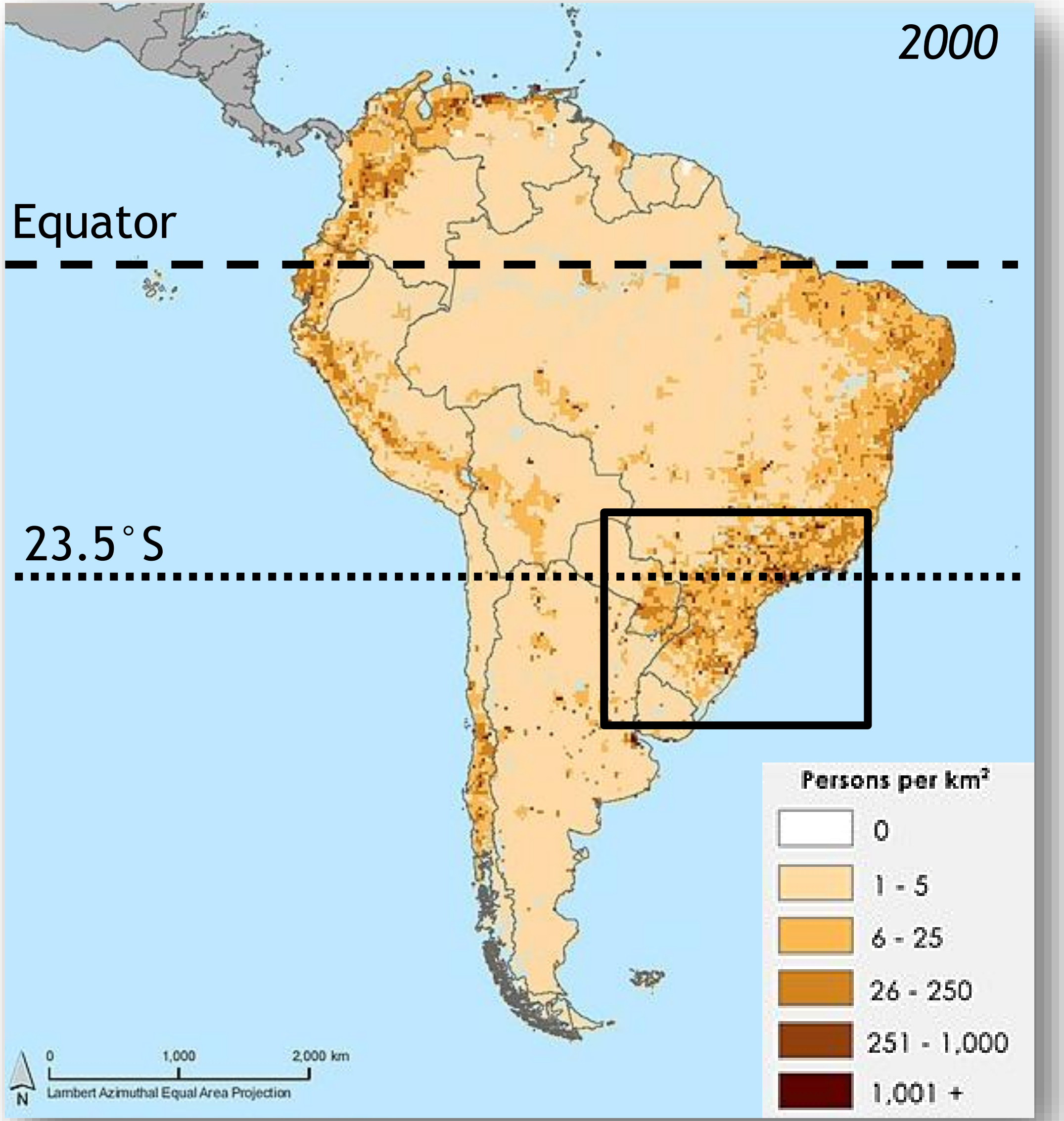
South America: regions for analysis



1. Argentina
2. Brazil
3. Bolivia
4. Paraguay
5. Uruguay

From NASA's Socioeconomic Data and Applications Center (SEDAC)

South America: regions for analysis



- One of the most highly **populated** regions in eastern South America
- Major river basin: La Plata Basin

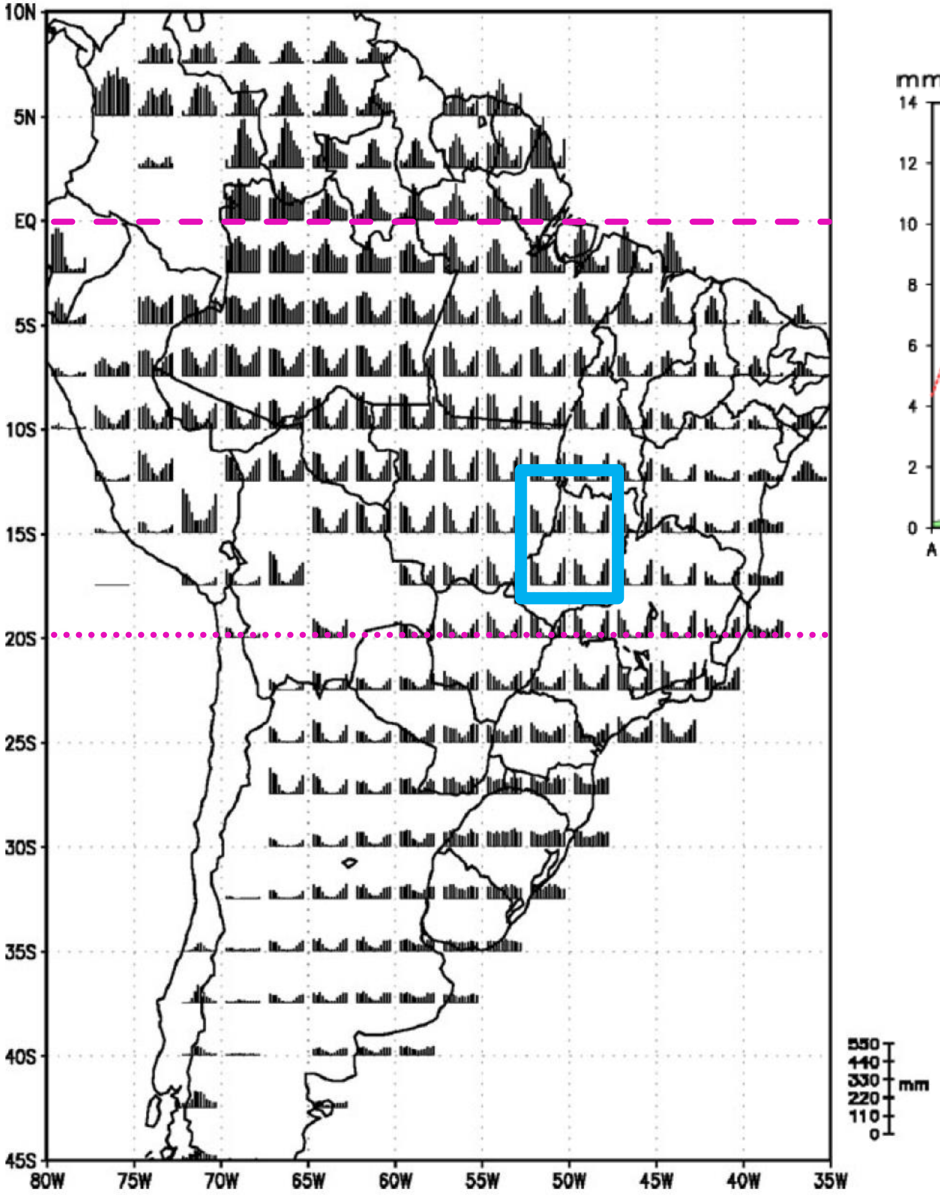
→ One of the largest **food** and **crop producers** in the world. **Agriculture** is the main economic activity in the basin (soybean, maize and wheat are produced at large scale). **Livestock** and **fishing** are also important sources of food and income.

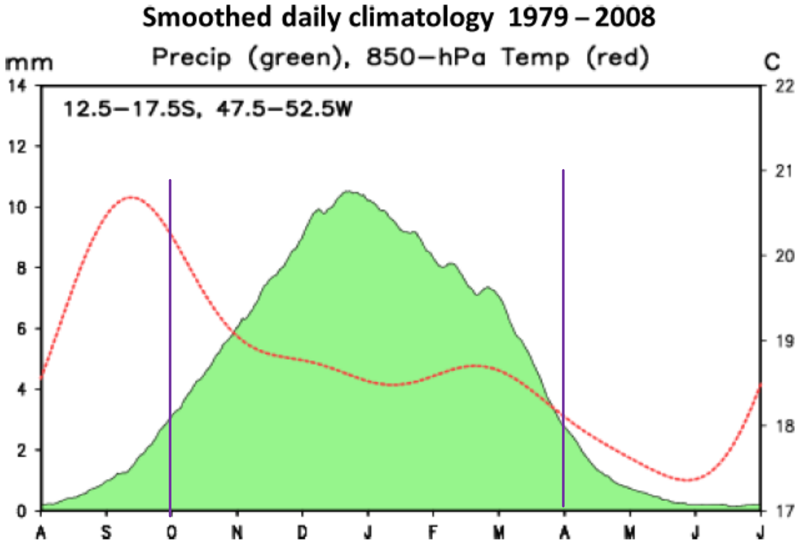
→ 75 dams for **hydropower** generation

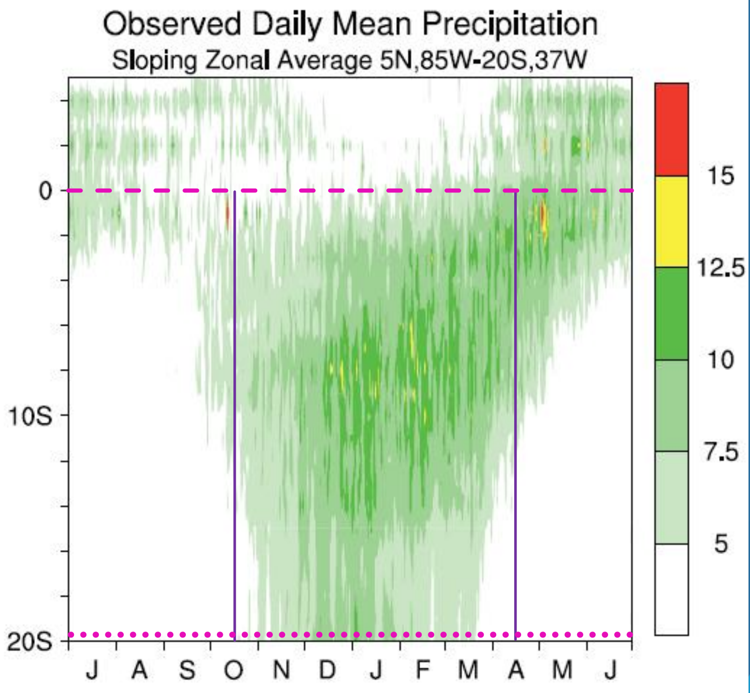
From NASA's Socioeconomic Data and Applications Center (SEDAC)

FAO

South American Monsoon System (SAMS)



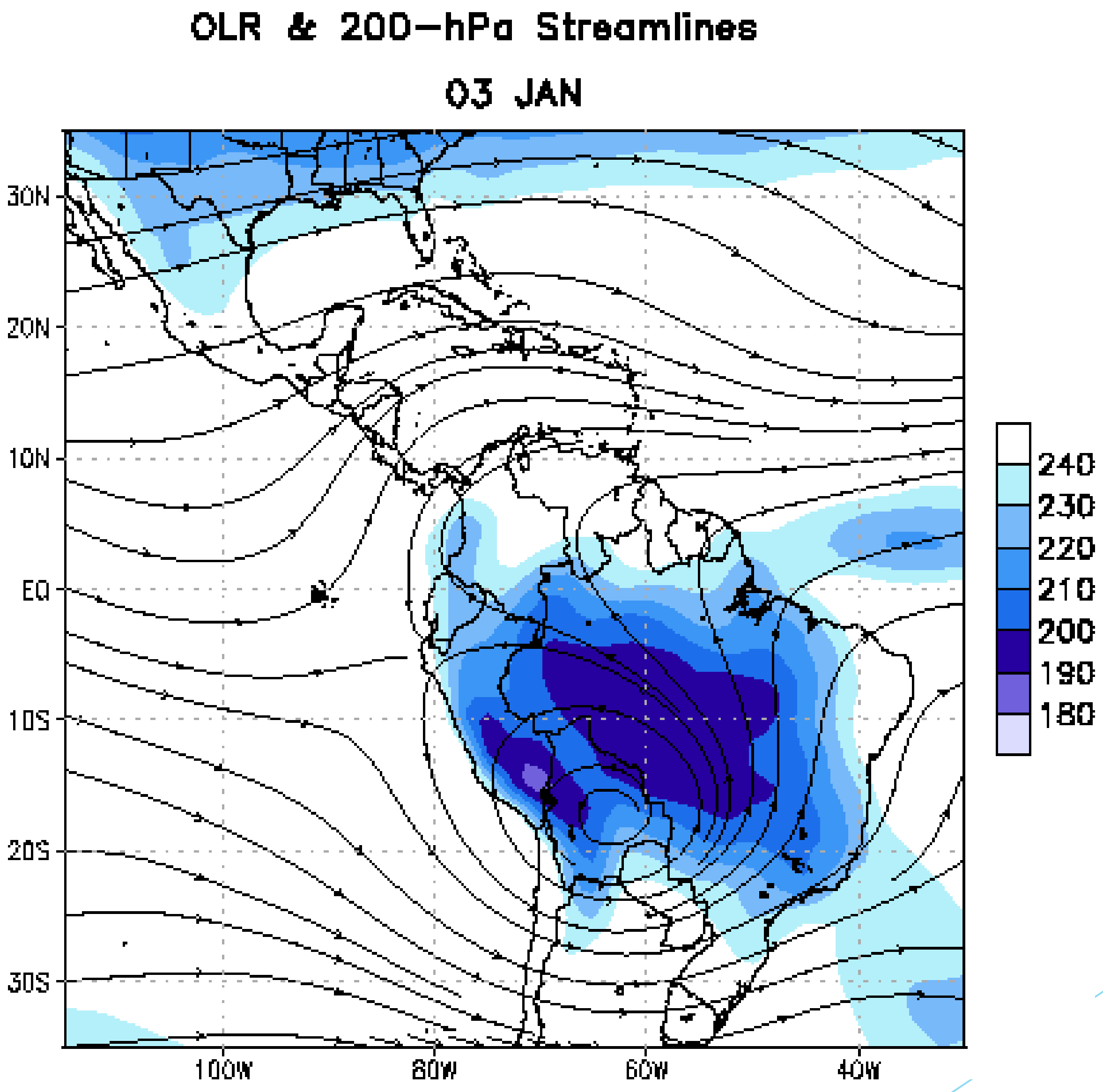




The South American monsoon system (SAMS) is characterized by pronounced seasonality in the rainfall with the wet season in the austral summer and a dry season in the austral Winter.

Vera et al. 2006, Grimm 2011; Marengo et al. 2012; Liebmann & Mechoso 2011

South American Monsoon System (SAMS)



South American Monsoon System (SAMS)

- Main **driver**: **differential heating** between South America and the Atlantic Ocean

- Expanse of South American landmass within tropical latitudes, the South Atlantic to the east and the Andes to the west combine to create SAMS.

- No reversal of the mean surface wind, however, the **seasonal reversal of the circulation** over South America resemble those of a monsoon system **when removing the annual mean.**

- Main **features**: upper-level Bolivian High, the Northeast trough, the low-level Gran-Chaco low and the South Atlantic Convergence Zone.

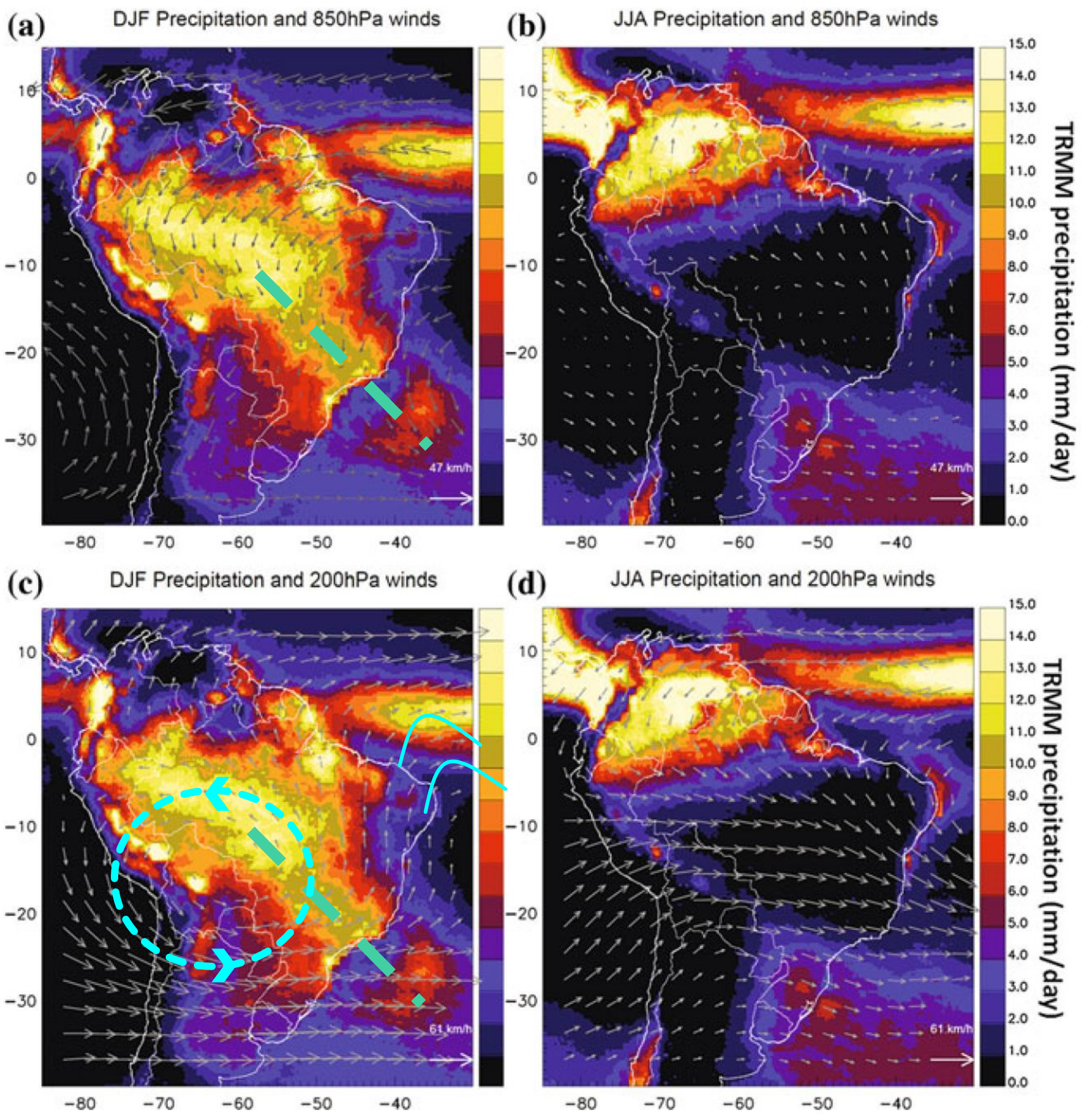


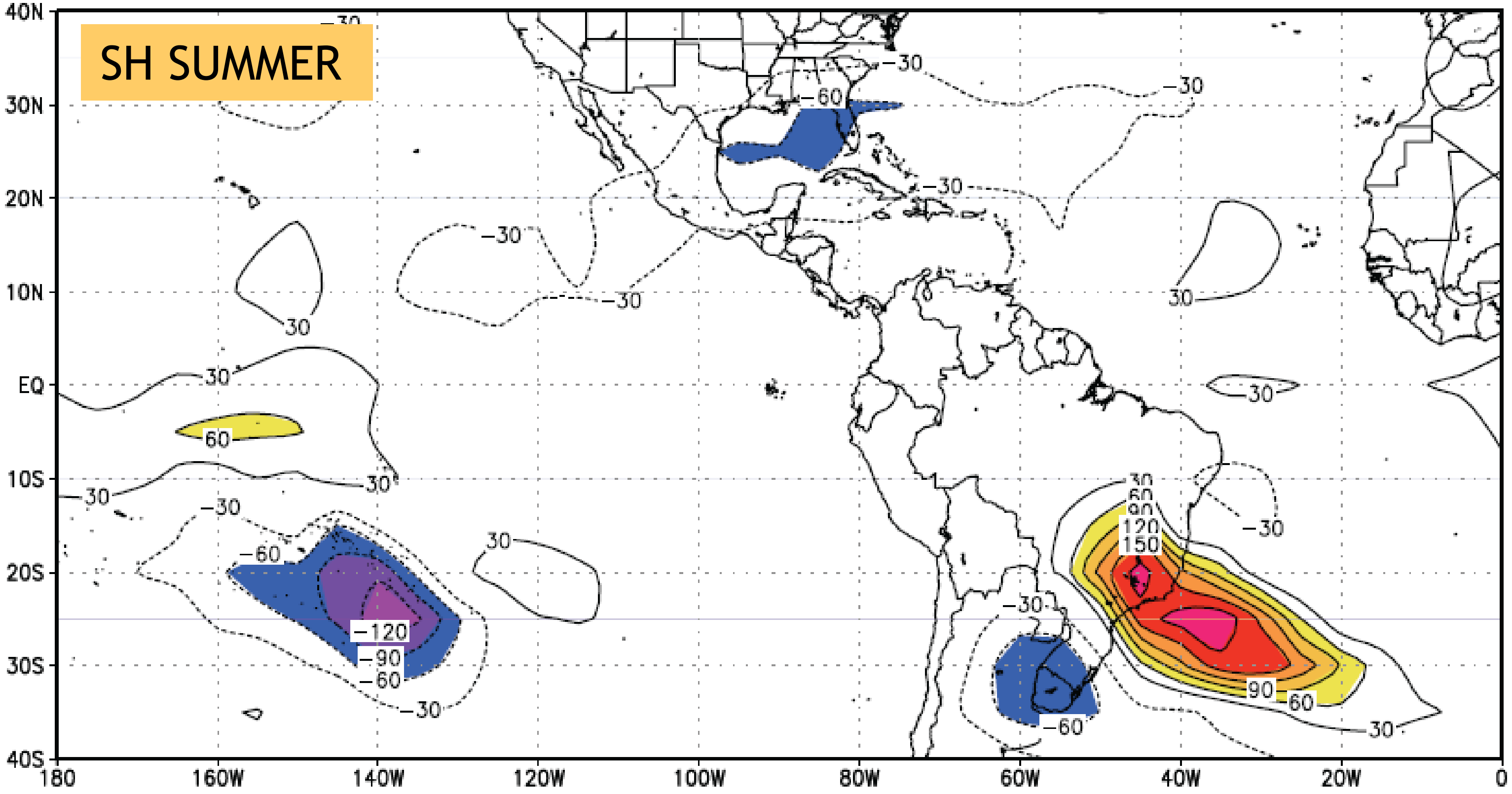
Fig. 6.1 TRMM mean daily precipitation and 850 hPa winds in DJF (**a**) and JJA (**b**); TRMM mean daily precipitation and 200 hPa winds in DJF (**c**) and JJA (**d**)

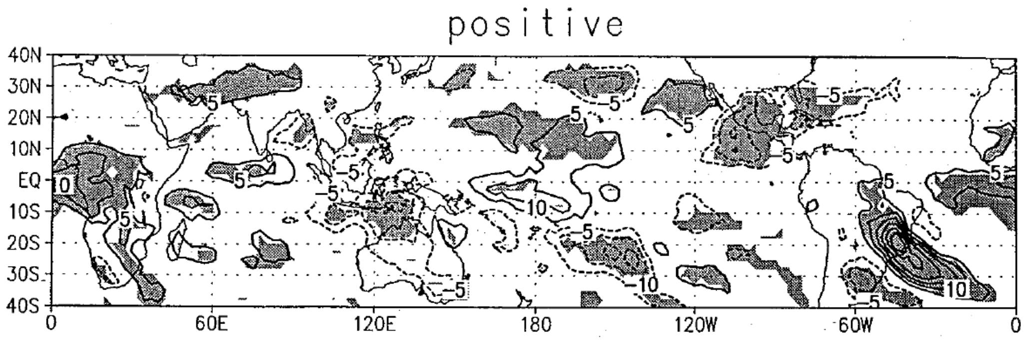
Carvalho and Cavalcanti, 2016

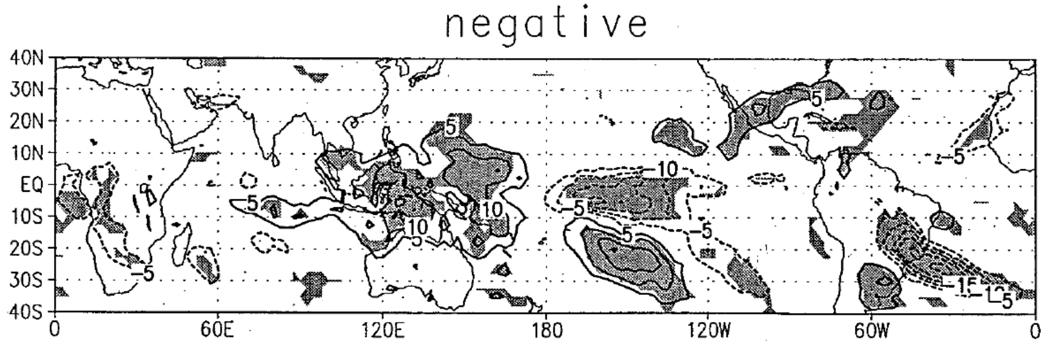
- Nogués-Paegle and Mo find in **REOF5** of **10-90-day filtered OLR** anomalies a **dipole** pattern in South America: South America SeeSaw (SASS) (5.8%)

- Defining events using the PC5, composites of OLR anomalies showed that **tropical convection** in the Pacific ocean might be linked to the activity of the SASS pattern.

REOF 5 *Version of Liebmann & Mechoso 2011*





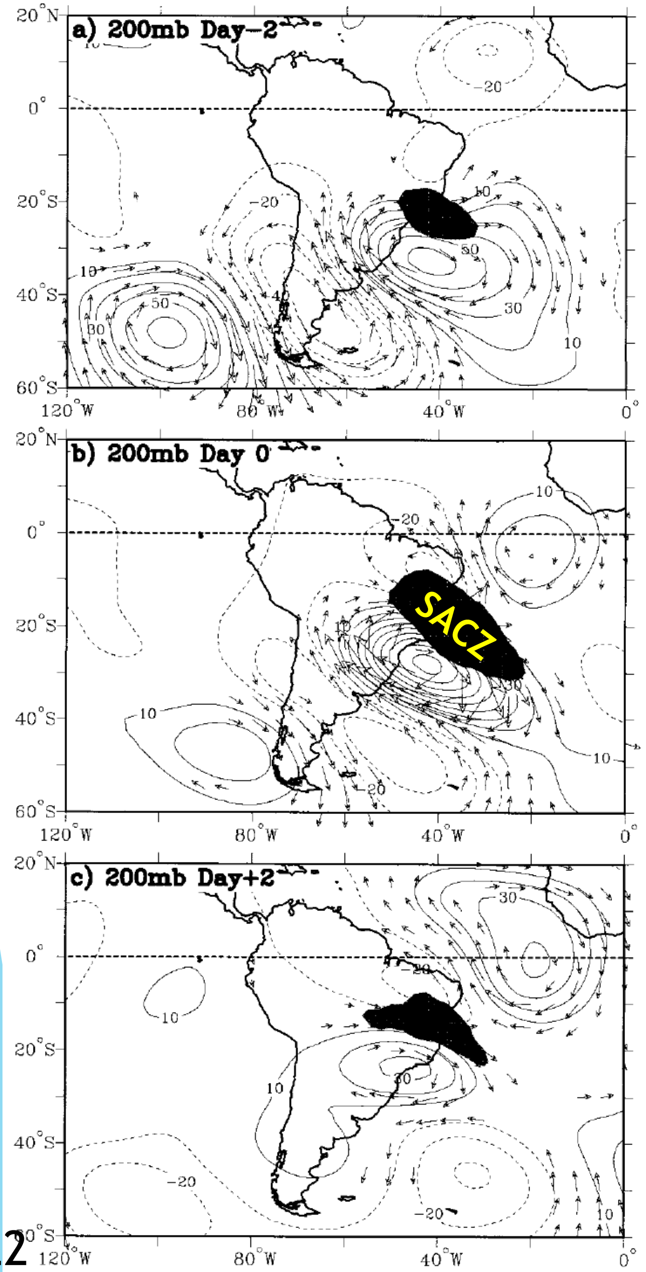


Nogués-Paegle & Mo 1997

IS variability in South America

Liebmann et al. 1999

SH SUMMER

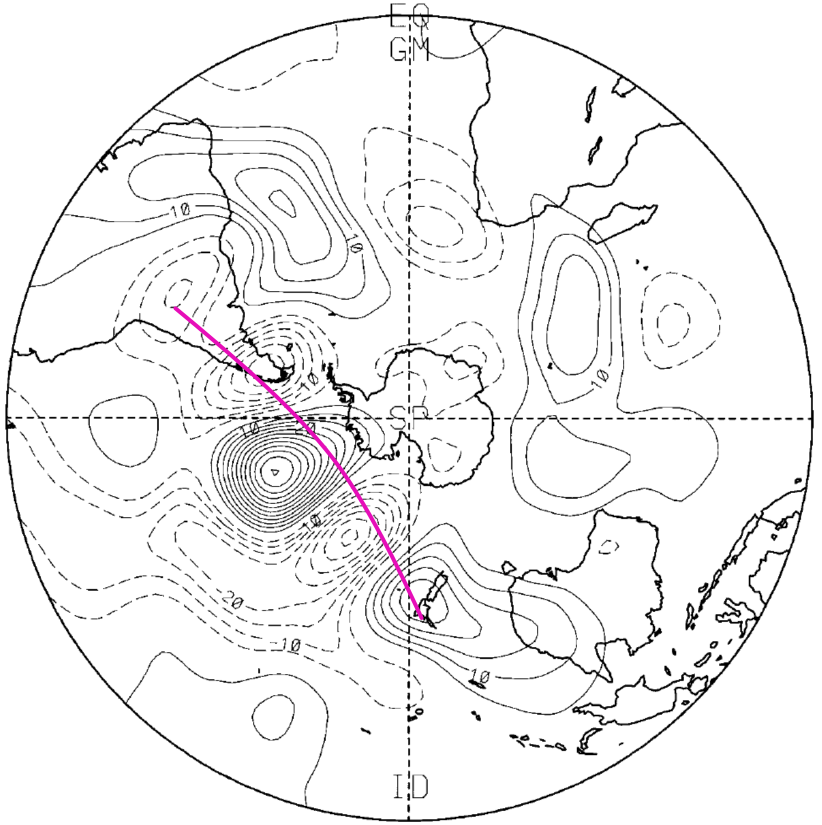


The sub-monthly **(2-30 days)** scale was also studied by Liebmann et al (1999), and found that:

- Episodes of **enhanced** convection within the **SACZ** occur at the **leading edge of upper-level troughs** propagating into the region.
- The **disturbances** are **nearly equivalent barotropic** west of South America but tilt westward with height in the region of the SACZ
- Streamfunction composites showed the path of Rossby wave energy having an **effect on the SACZ from** the **midlatitudes** of the Southern Hemisphere

◀ *200 hPa streamfunction, wind and OLR associated to 2-30-day filtered OLR in SACZ*

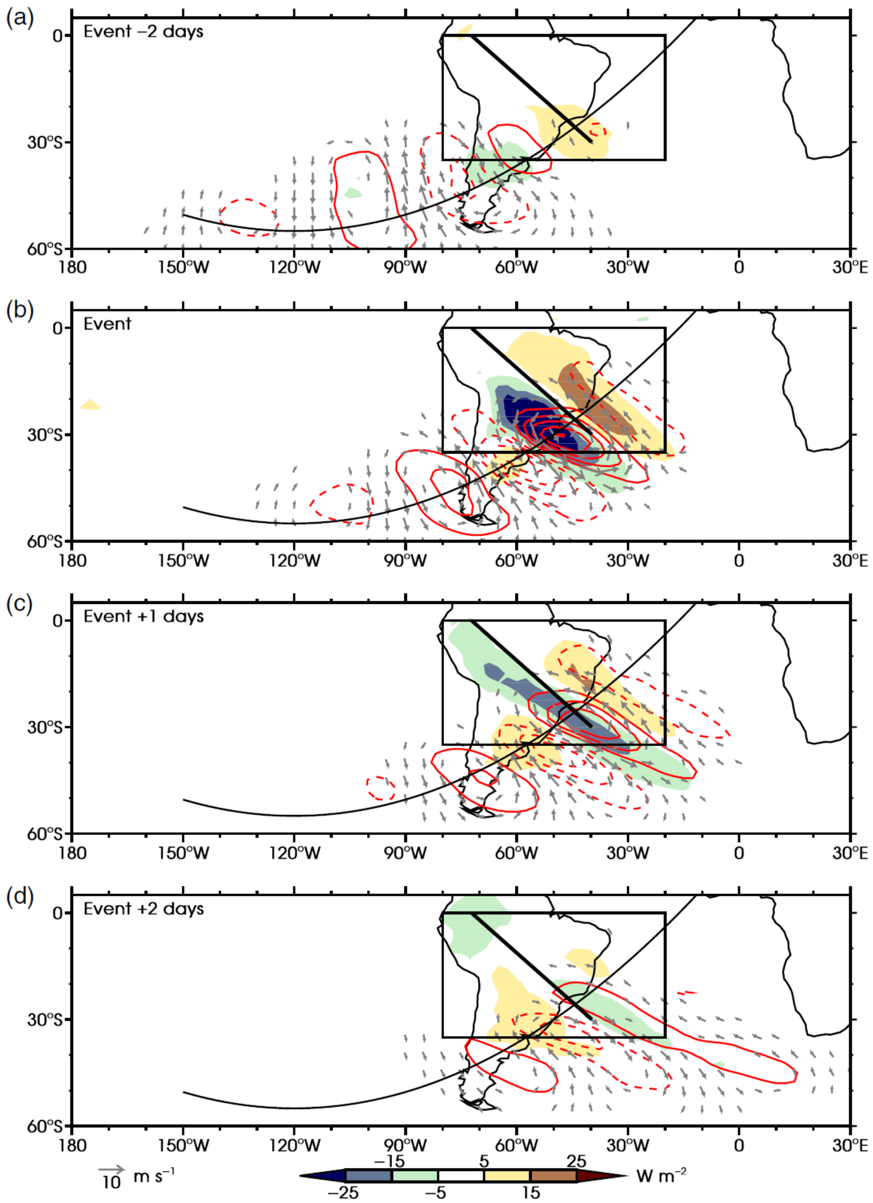
200 hPa streamfunction associated to 2-30-day filtered OLR in SACZ, day -4 ▶



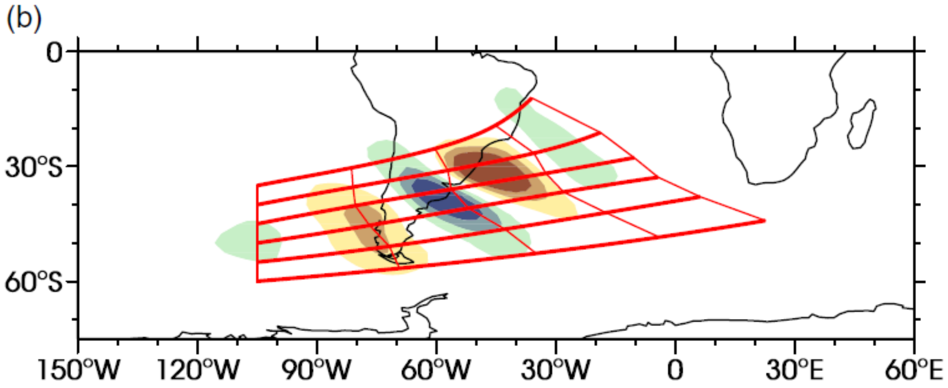
IS variability in South America

Van der Wiel et al. 2015

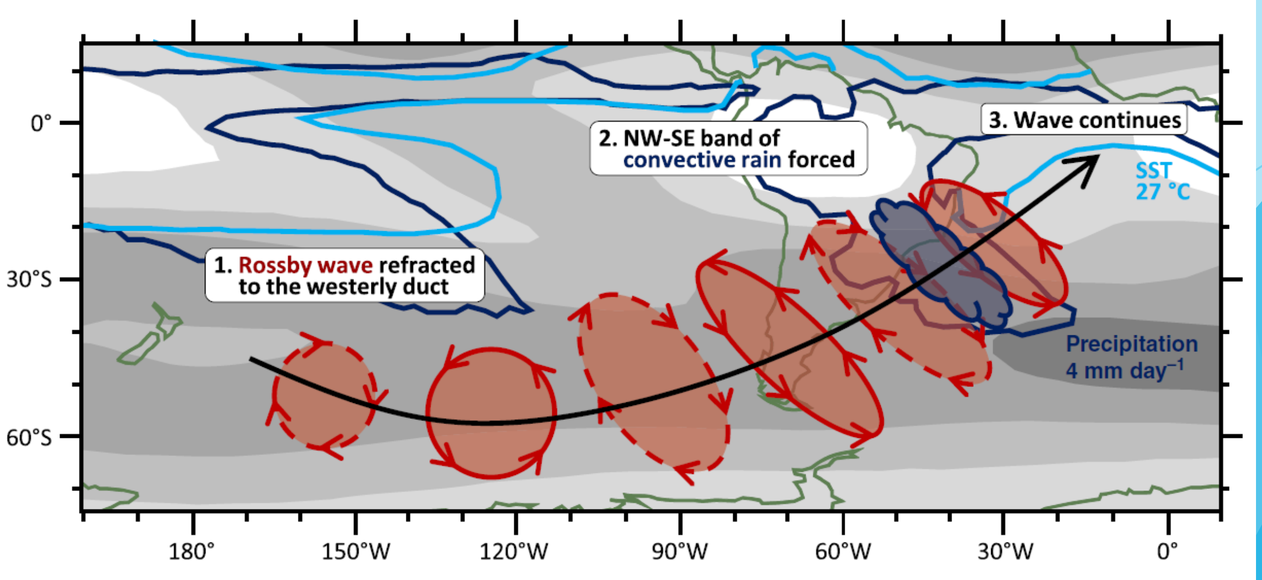
Van der Wiel et al 2015 also studied the **(<20 days)** scale: SH SUMMER



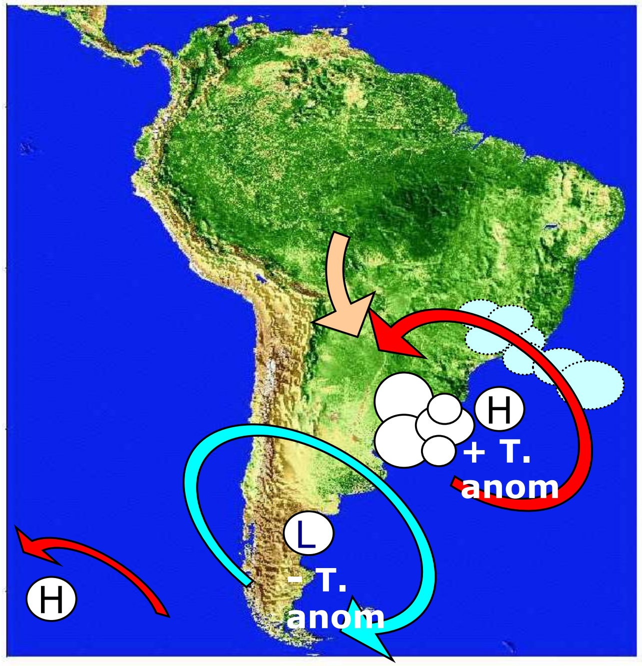
Barotropic RW dynamics can create elongated NW-SE-oriented vorticity anomalies and equatorward propagation that lead to SACZ convection.



Conceptual model

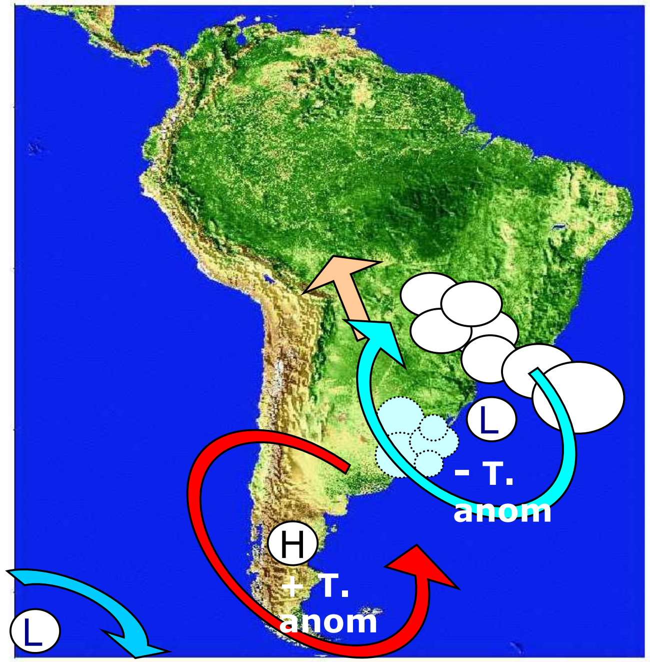


SH SUMMER



▶ **Weakened SACZ**

Intensified Low-Level Jet (SALLJ) poleward progression



▶ **Intensified SACZ**

Inhibited Low-Level Jet (SALLJ) poleward progression

Impacts:

Higher frequency of **extreme daily rainfall events at the subtropics**

(Liebmann et al. 2004)

(Gonzalez et al. 2007)

Impacts:

Higher frequency of **heat waves** and **extreme daily temperature events** at the subtropics

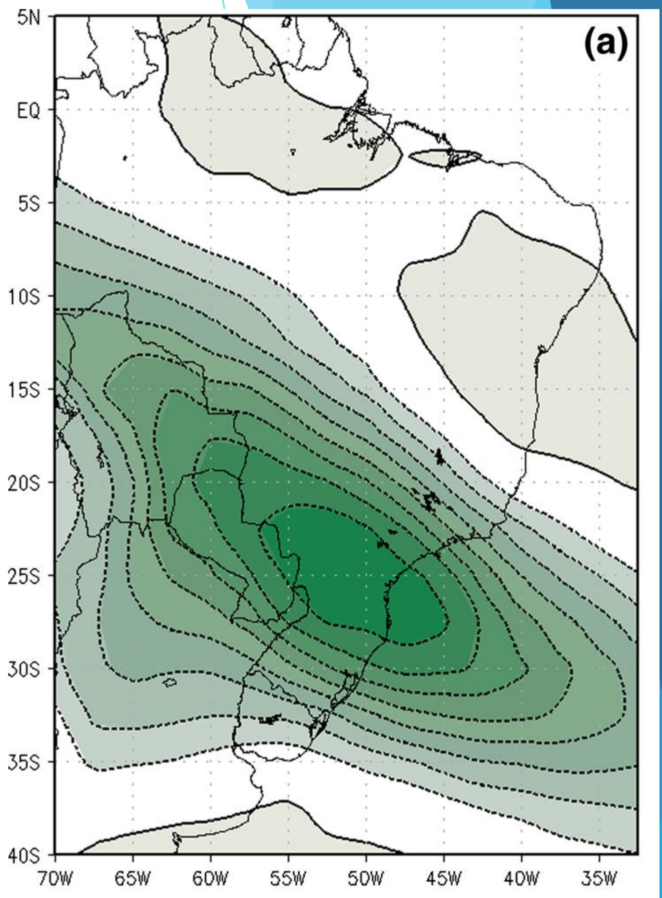
(Cerne and Vera, 2011)

Low-level jet anomaly

Courtesy of Carolina Vera

Methodology

- Period of study: 2 of May – 29 September 1979-2006.
- **OLR** taken from **NOAA** satellite estimates (Liebmann & Smith 1996). Anomalies computed respect to seasonal cycle (smooth climatological day).
- OLR was **filtered** on IS timescales applying a 101-weighted **Lanczos** (Duchon 1979) band-pass filter, with cut-off periods **10 and 90 days**.
- **EOF** analysis applied in eastern South America, using the covariance matrix.
- **Linear lagged regressions scaled to 1 standard deviation** to study the evolution of OLR and circulation anomalies related to the growth of a positive phase of the EOF1 (using PC1 as time series).



EOF1 of 10-90 FOLR (negative geen)

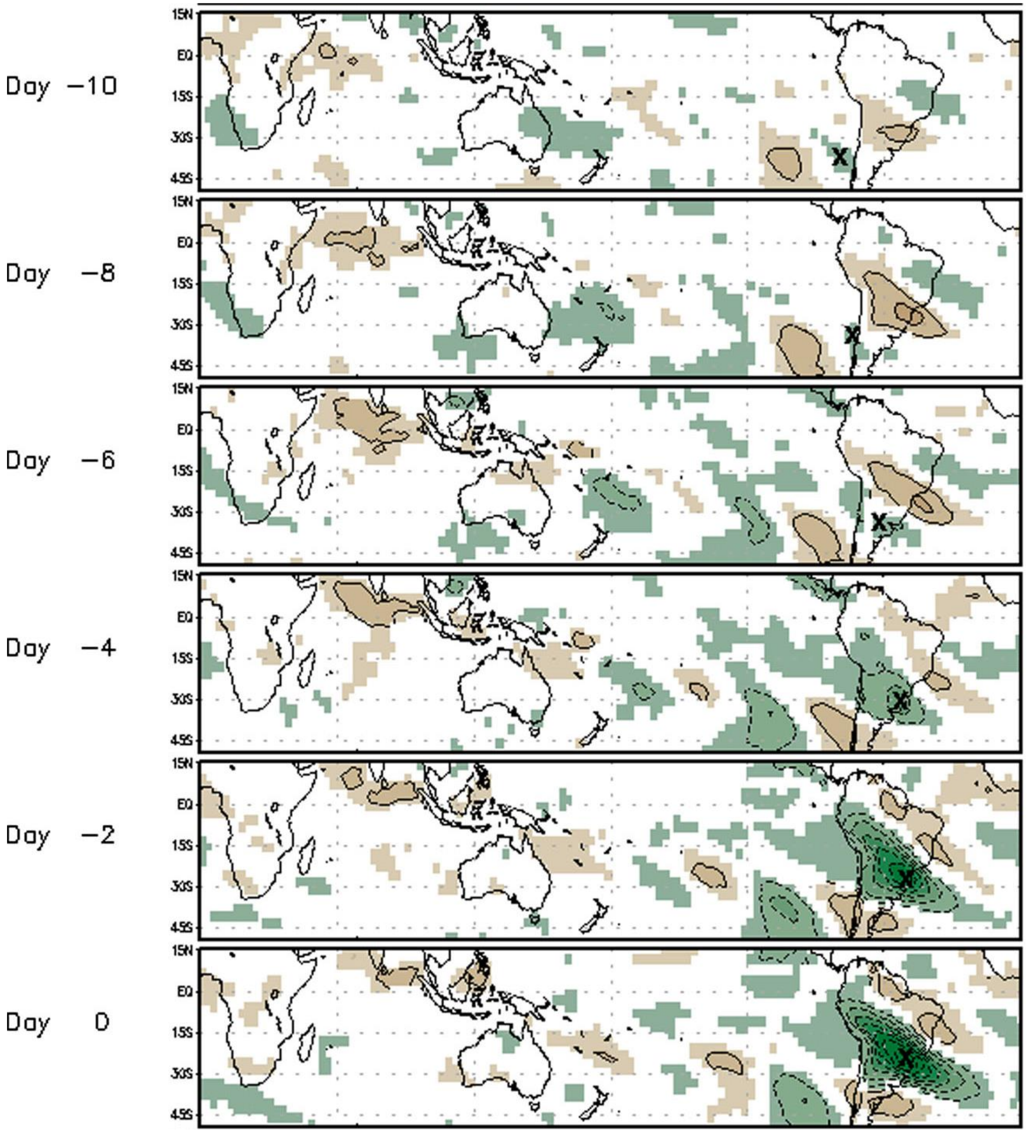
The leading pattern of variability during Winter is a **monopole**. The main periods of variability of the PC1 are around **17** and **30-40 days**.

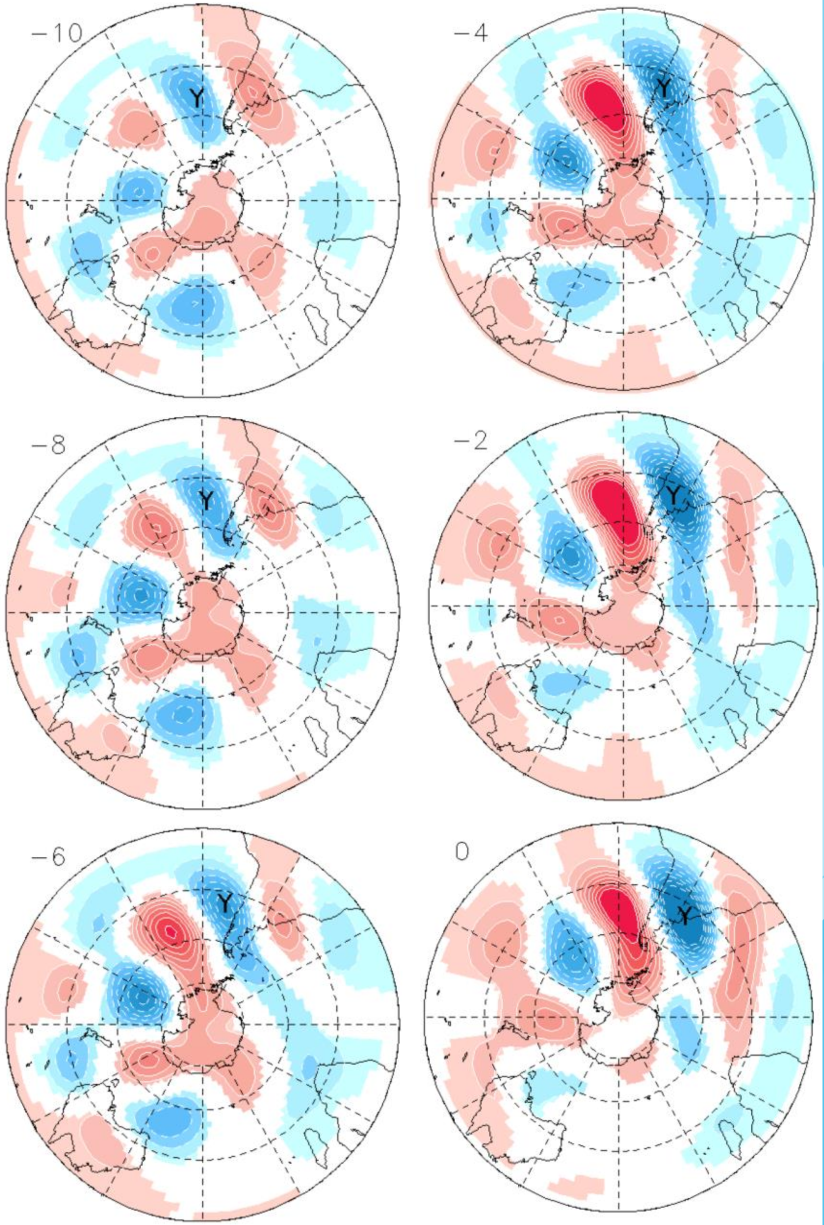
The region of maximum variability may be associated to the position where **cold fronts** become stationary during Winter.

Alvarez et al. 2014

IS variability in South America

May-Sep (extended Winter)



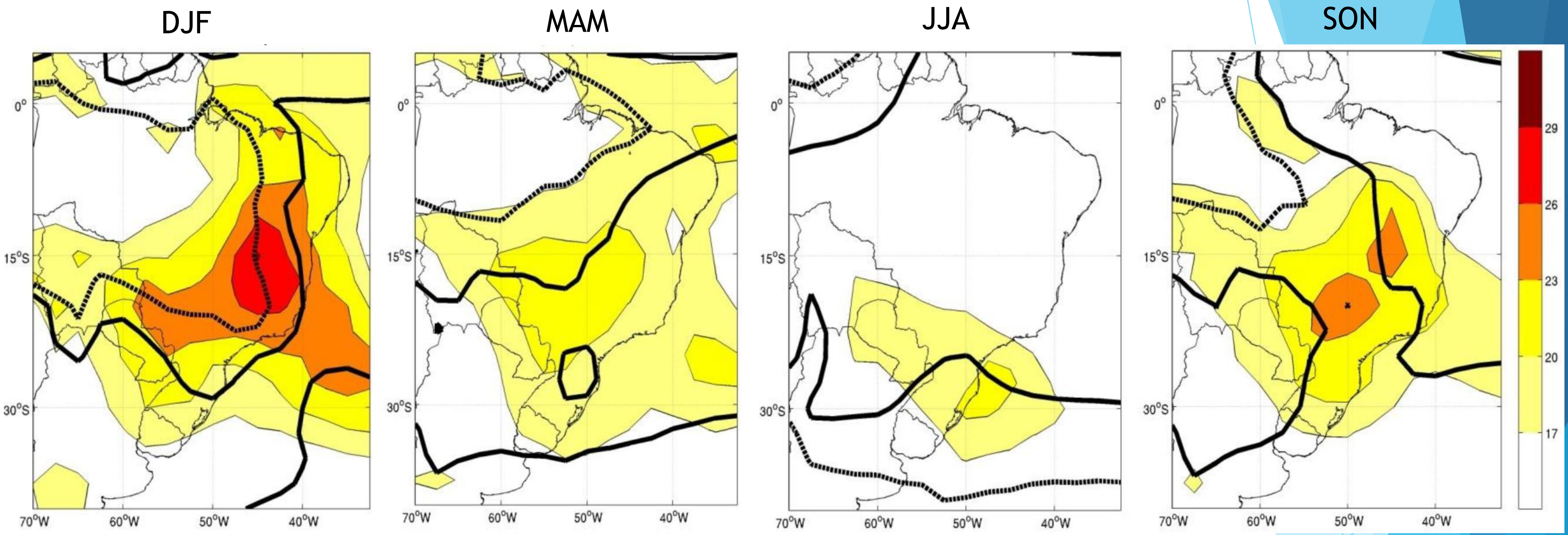


Linear lagged regressions between PC1 and OLR and 250 hPa geop. height

Alvarez et al. 2014

IS variability in South America

Intraseasonal variability of OLR activity

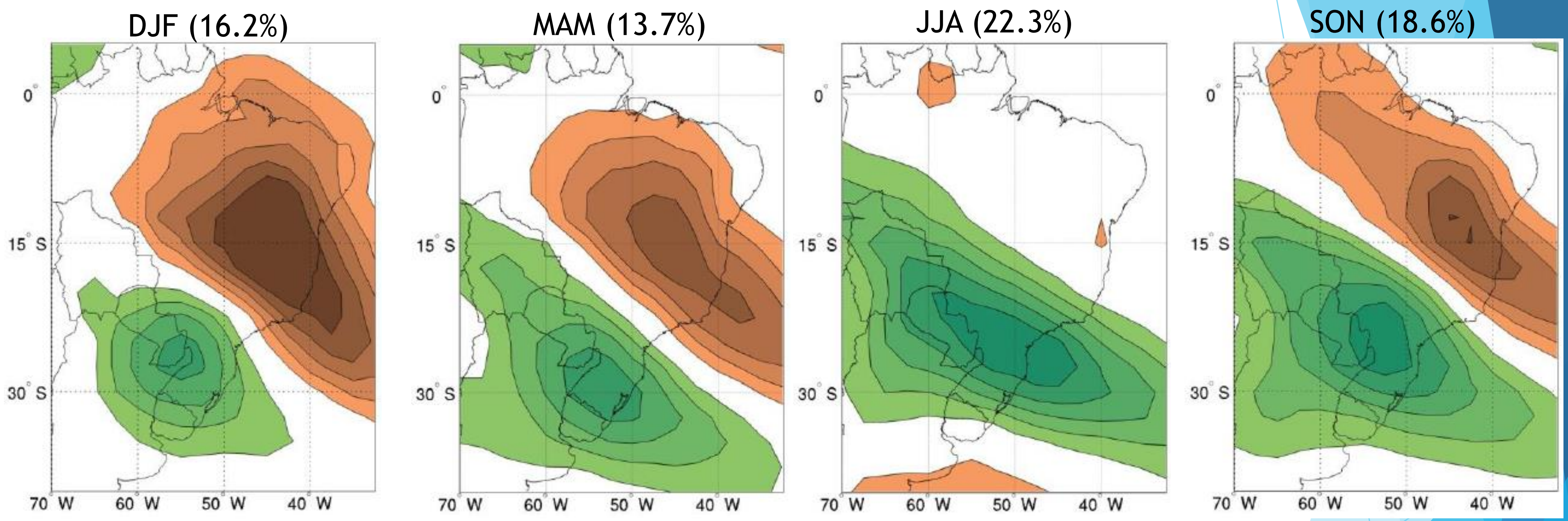


Mean OLR (contours, 240 and 220 Wm^{-2}), and standard deviation of 10-90-day filtered OLR anomalies (shaded).

Alvarez 2016

IS variability in South America

Leading EOFs according to season: Seasonal IntraSeasonal (SIS) Patterns



EOF1 of 10-90-day filtered OLR anomalies according to season

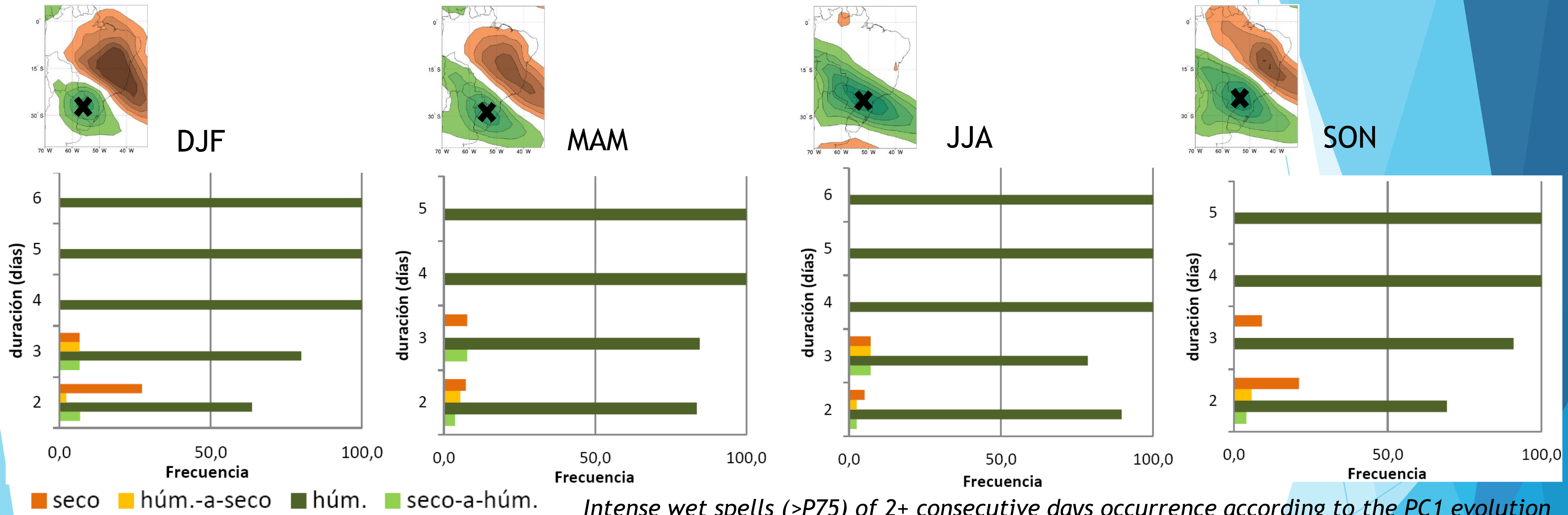
Dipole patterns are observed except during the austral Winter season (JJA), when the SACZ is not active

Positive (or wet) phase is defined when convection is favored in SESA region and inhibited in the SACZ region.

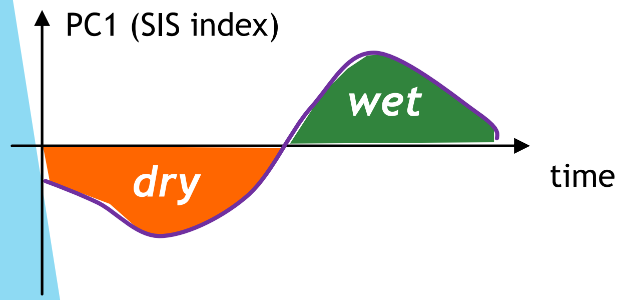
Alvarez 2016

IS variability in South America

Impact of SIS activity on intense rainfall spells



Intense wet spells (>P75) of 2+ consecutive days occurrence according to the PC1 evolution



Very few wet spell occur entirely within a negative (dry) phase

Most wet spells occur during positive (wet) phases of the SIS patterns.

Alvarez 2016

Take-home messages

- The **leading patterns** identified in the Southern Hemisphere circulation and which have an influence on intraseasonal time scales are the **Southern Annular Mode**/Antarctic Oscillation and the two **Pacific-South American Patterns** (wave trains).
- Meridional propagation conditions of Rossby wave trains change across seasons. A **forbidden region** for meridional propagation located south of Australia and in the western Pacific ocean is observed during **JJA** (austral winter). A smaller forbidden region is observed over New Zealand in **MAM** and **SON**.
- There is a pronounced seasonality of rainfall in tropical South America produced by the **South American Monsoon System**, with main features the SACZ, the northeast trough, upper-level Bolivian high and low-level Chaco low.
- Intraseasonal variability of convection/rainfall in South America is associated with a **dipole pattern** in the **summer** (wet) season, and a **monopole** in **winter**. The activity of both patterns is related to the propagation of Rossby wave trains along the Pacific ocean and into South America, which show different seasonal features.
- The activity of the SIS patterns (leading EOF of 10-90 OLR') is related to the occurrence of intense wet spells in the SESA region.

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