Teleconnections between South American monsoon, Benguela Niño, and southern African rainfall

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Grimm, A. M. and C. J. C. Reason, 2011: Does the South American monsoon influence African rainfall?
Journal of Climate, 24, 1226-1238.

Precipitation regimes

1950-2005

Precipitation maxima (SH seasons):

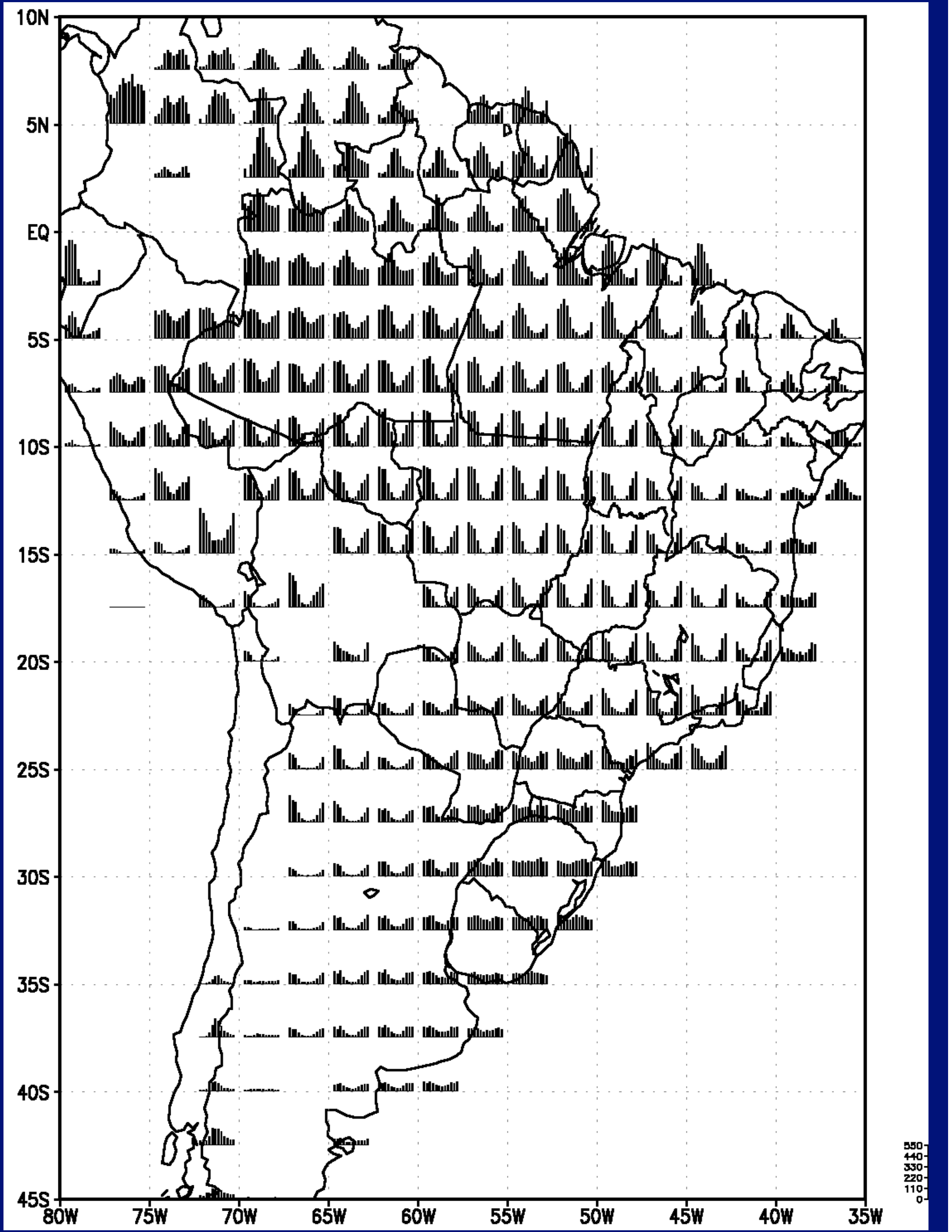
Most of South America: summer, with dry season in the winter, due to the South American monsoon system.

North: autumn and winter, in connection with the annual migration of the deep tropical convection.

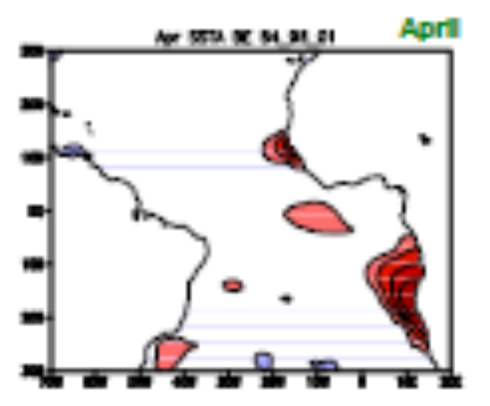
Northeast Brazil: autumn, in connection with the southward shift of the Atlantic ITCZ.

South Brazil: region of transition, where the maximum changes from summer to spring and to winter. The southernsmost region has uniform rainfall distribution because is subjected also to the midlatitude regime in which rainfall is due to frontal incursions associated with extratropical cyclones.

(Grimm, 2003, J. Climate; Grimm, 2009, SERRA)



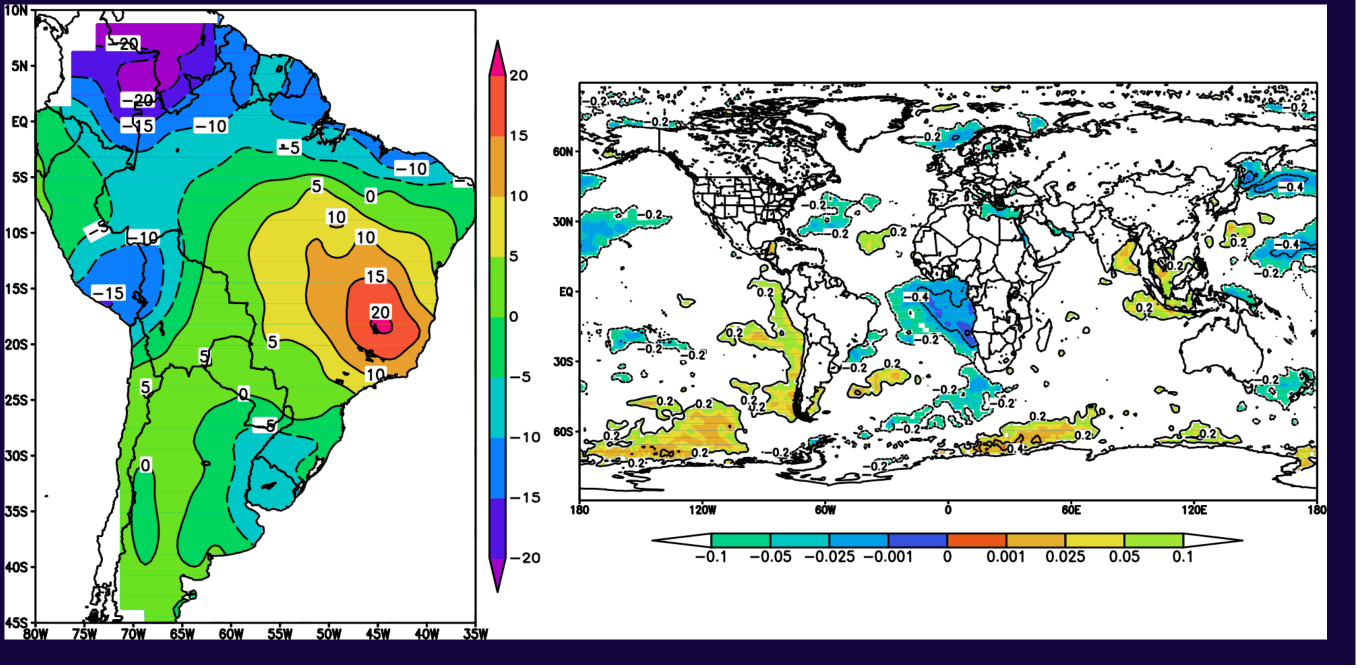
Background



- Benguela Niño/Niña events and their connection with southern Africa rainfall have been documented before. They involve a weakening of the trade winds in the equatorial western Atlantic in the early monsoon, generation of downwelling equatorial Kelvin waves that transport a warming signal toward Africa. They peak in late summer (FMA).

- However, the evolution of these events since the previous spring has never been documented, neither have the previous and concurrent rainfall anomalies over South America been detected or some connection with them been suggested.

- The second mode of annual precipitation variability (14% of the variance and similar to the first summer mode) displays highest correlation with SST anomalies of the Benguela Niño type.

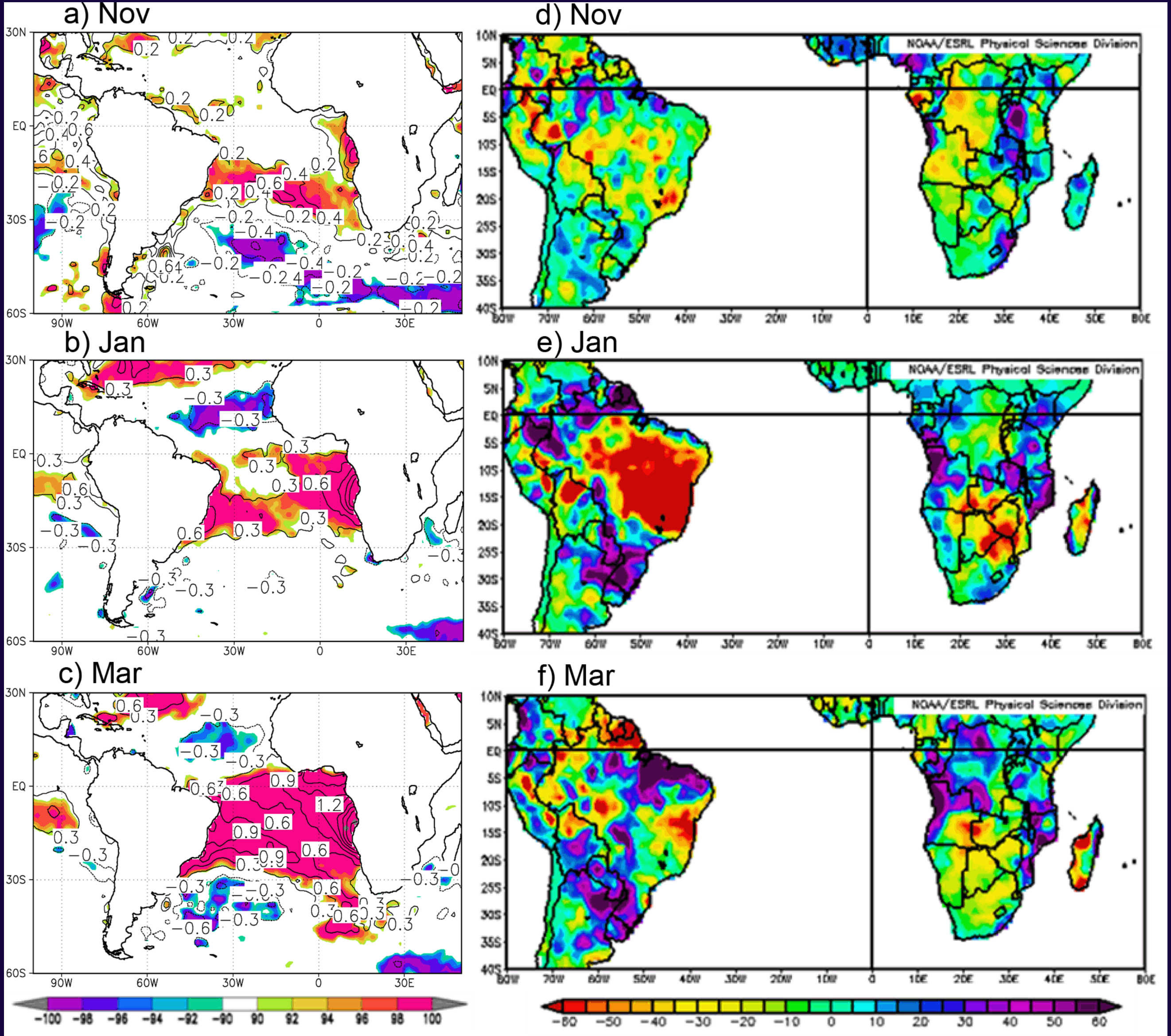


Data and Methods

- Rain gauge data from about 10,000 stations in South America, 1°×1° gridded data from GPCC. Period 1956-2006.
- HAdISST and NCEP/NCAR Reanalysis data are used for SST and atmospheric fields respectively.
- Definition of Benguela Niño (Niña) events: FMA SST standardized anomalies equal or greater than one standard deviation (minus one standard deviation) in a box off Angola coast (10-20°S, 8-15°E).
- Benguela Niños: 1959, 1963, 1965, 1984, 1986, 1995, 1998, 1999, 2001, 2006.
- Benguela Niñas: 1956, 1958, 1972, 1978, 1980, 1981, 1982, 1992, 1997, 2004.
- Differences between atmospheric and oceanic fields during Benguela Niño and Niña events are composited from November through March and their significance is assessed.
- The possible origin of atmospheric circulation anomalies preceding the peak of Benguela Niño that might affect its evolution and the rainfall anomalies in southern Africa is analyzed with Influence Functions (IFs) of a vorticity equation model linearized about a realistic basic state and including the divergence of the basic state and the vorticity advection by divergent wind (Grimm e Silva Dias 1995, JAS, v. 52).
- The influence of anomalous convection observed over South America on Africa (and vice-versa) during Benguela Niño/Niña events is tested with this model simulations.

Results: Benguela Niño-Niña composites

SST **Precipitation**



Results: Benguela Niño-Niña composites

Geopotencial height 850 hPa

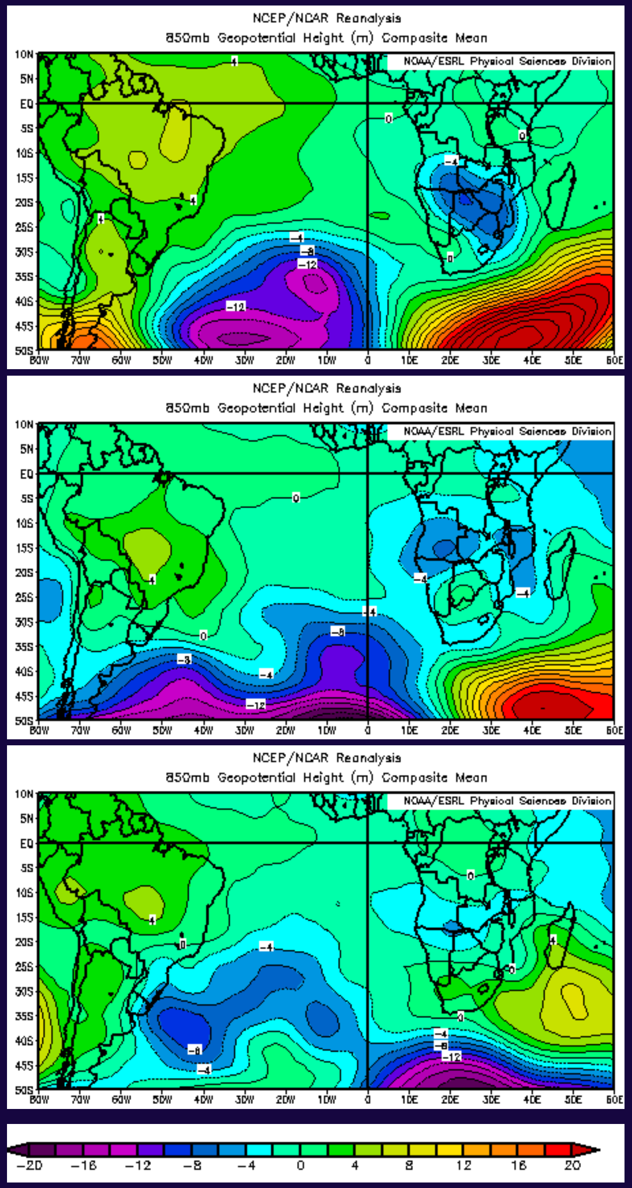
Streamfunction

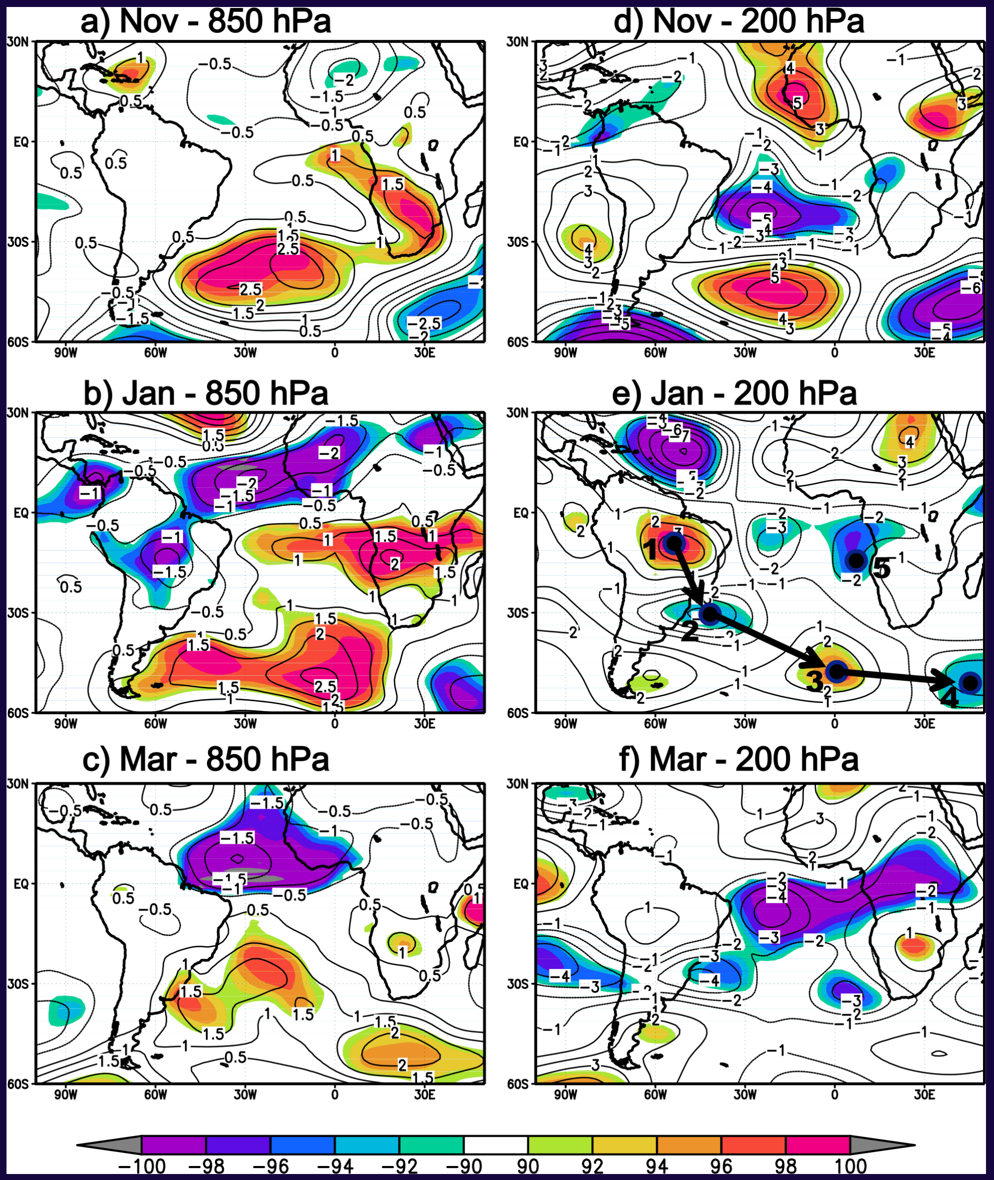
850 hPa **200 hPa**

Nov

Jan

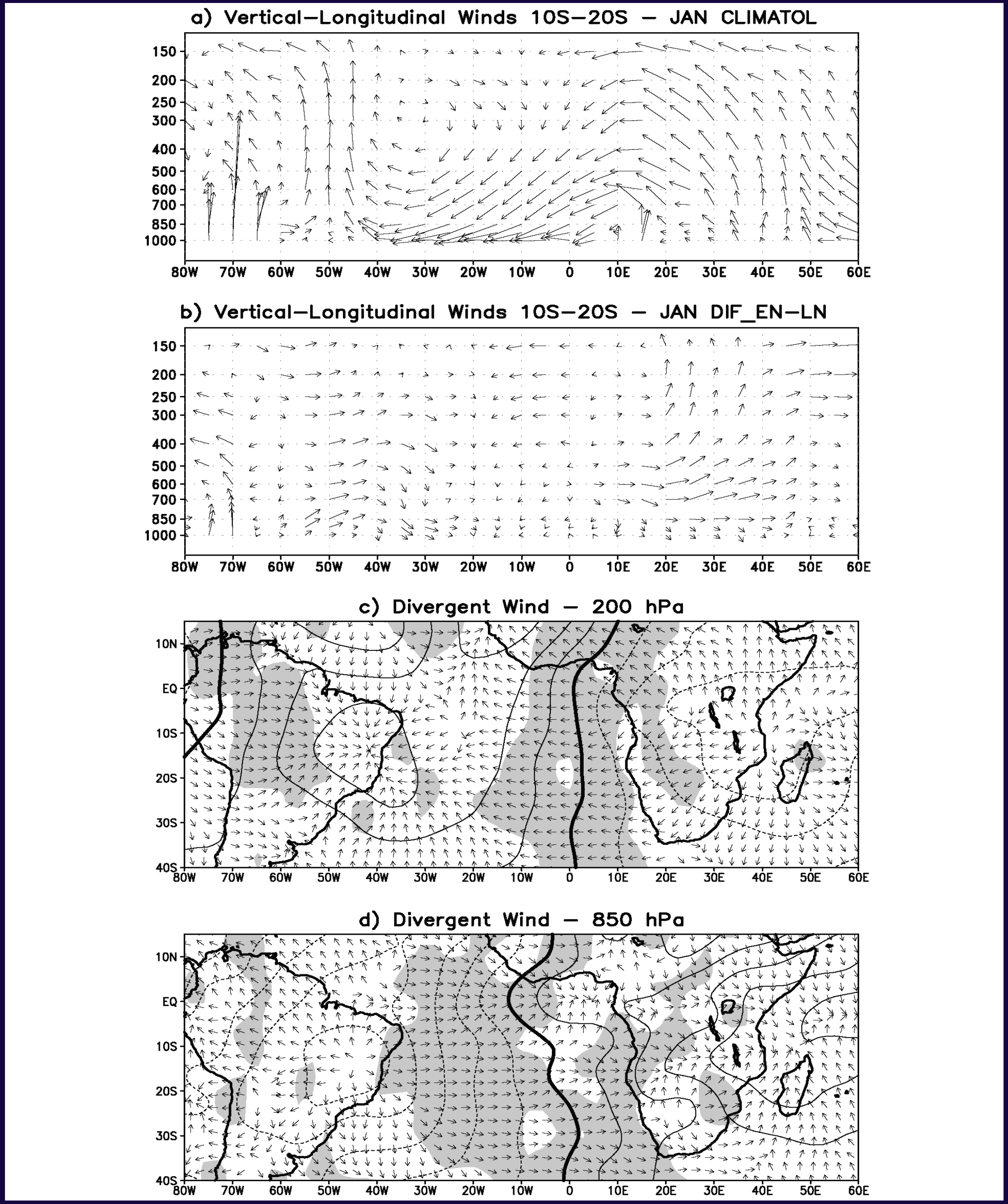
Mar





Results: Benguela Niño-Niña composites

(January)



a) Vertical–Longitudinal Winds 10S–20S – JAN CLIMATOL

b) Vertical–Longitudinal Winds 10S–20S – JAN DIF_EN–LN

c) Divergent Wind – 200 hPa

d) Divergent Wind – 850 hPa

Climatological mean of the zonal and vertical components of the wind averaged over the latitudinal belt 10°-20°S in January.

Difference Benguela Niño-Niña of the zonal and vertical components of the wind averaged over the latitudinal belt 10°-20°S in January.

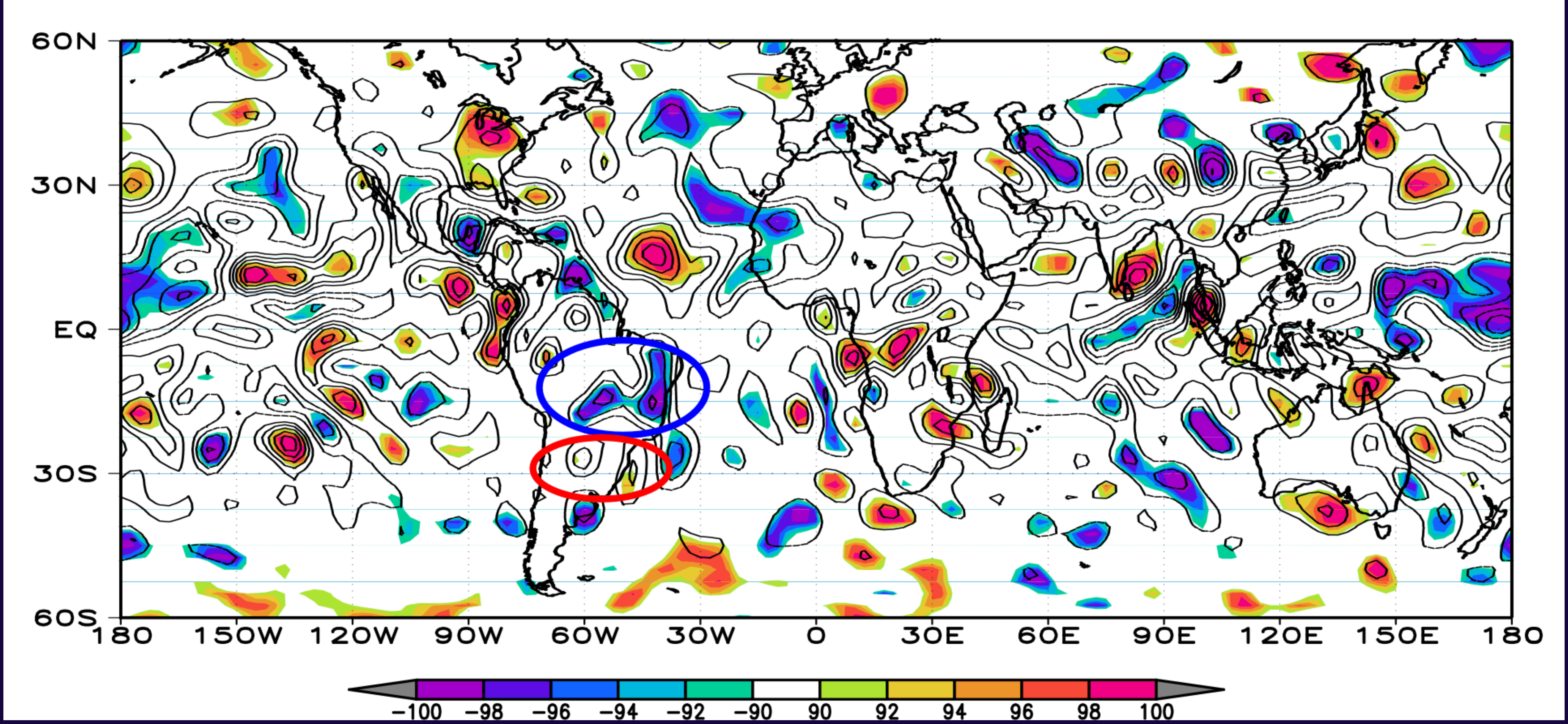
Difference Benguela Niño-Niña of the divergent wind and velocity potential at 200 hPa.

Difference Benguela Niño-Niña of the divergent wind and velocity potential at 850 hPa

Shaded areas have differences in the wind with confidence level better than 90%.

Results: Benguela Niño-Niña composites

(January)



Difference Benguela Niño-Niña of the divergence at 200 hPa in January. The colors indicate levels of confidence better than 90% for positive and negative differences.

Model and Influence Functions

(Grimm and Silva Dias, 1995: J. Atmos. Sci., 52, 3538-3555)

Vorticity equation linearized about a realistic basic state, including the divergence of the basic state and the advection of vorticity by the divergent wind:

$$\frac{d\zeta'}{dt} + \bar{\vec{V}}_\psi \cdot \nabla\zeta' + \vec{V}_\psi' \cdot \nabla\bar{\zeta} + \bar{\vec{V}}_\chi \cdot \nabla\zeta' + \zeta'\bar{D} - A' = F'$$

with

$$F' = -\bar{\zeta}D' - \vec{V}_\chi' \cdot \nabla\bar{\zeta}$$

depending only on the anomalous divergence .

The stationary version may be written as:

$$M\psi' = D'$$

with M a linear operator and ψ’ the anomalous streamfunction.

The Influence Function (IF) for this problem is:

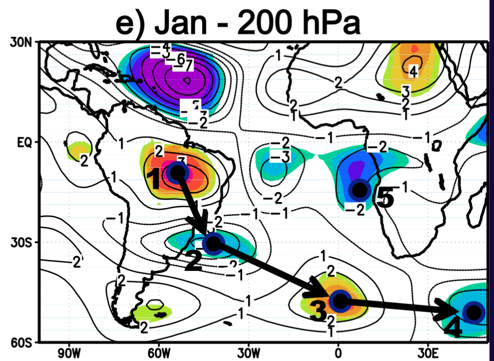
$$G_D(\lambda,\phi,\lambda',\phi') = M^{-1}\left[\delta\left(\lambda,\phi,\lambda',\phi'\right)\right]$$

The IF for the target point (λ,φ) is, at each point (λ’, φ’), equal to the model response at (λ,φ) to an upper-level divergence concentrated at (λ’, φ’).

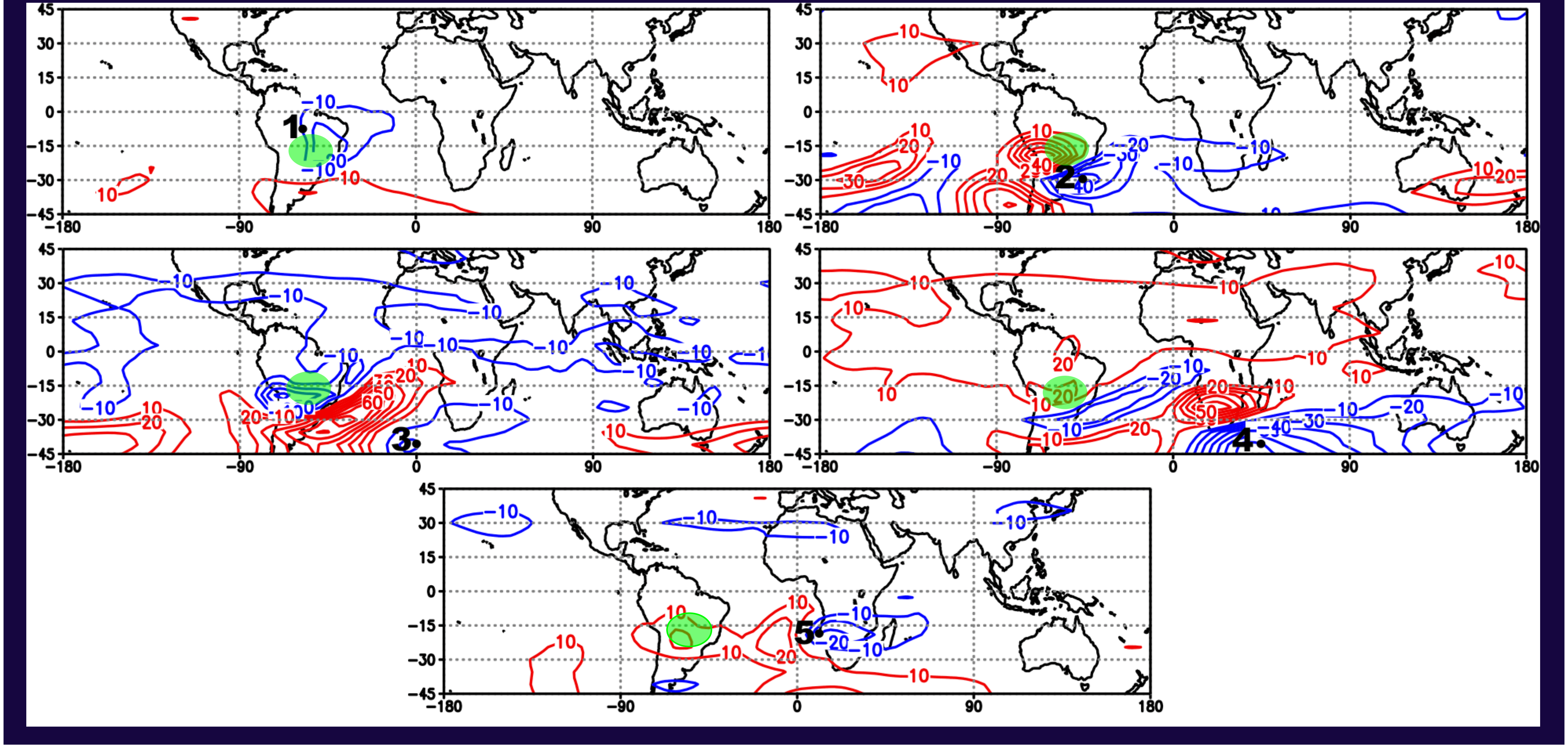
The IF summarizes the efficiency of divergence anomalies with different locations at producing streamfunction anomalies at the target point.

This model is essentially an equation that links the rotational and divergent components of the flow at one pressure level. It is useful as a prognostic model if the divergence can be specified without knowing the vorticity at this level. This is possible in the tropics, since the upper-level divergence is directly related to the tropical heating, but in mid-latitudes the divergence and vorticity are coupled, and therefore it should be applied in an equivalent barotropic level. We use the 200 hPa level.

Influence Function Analysis (January)

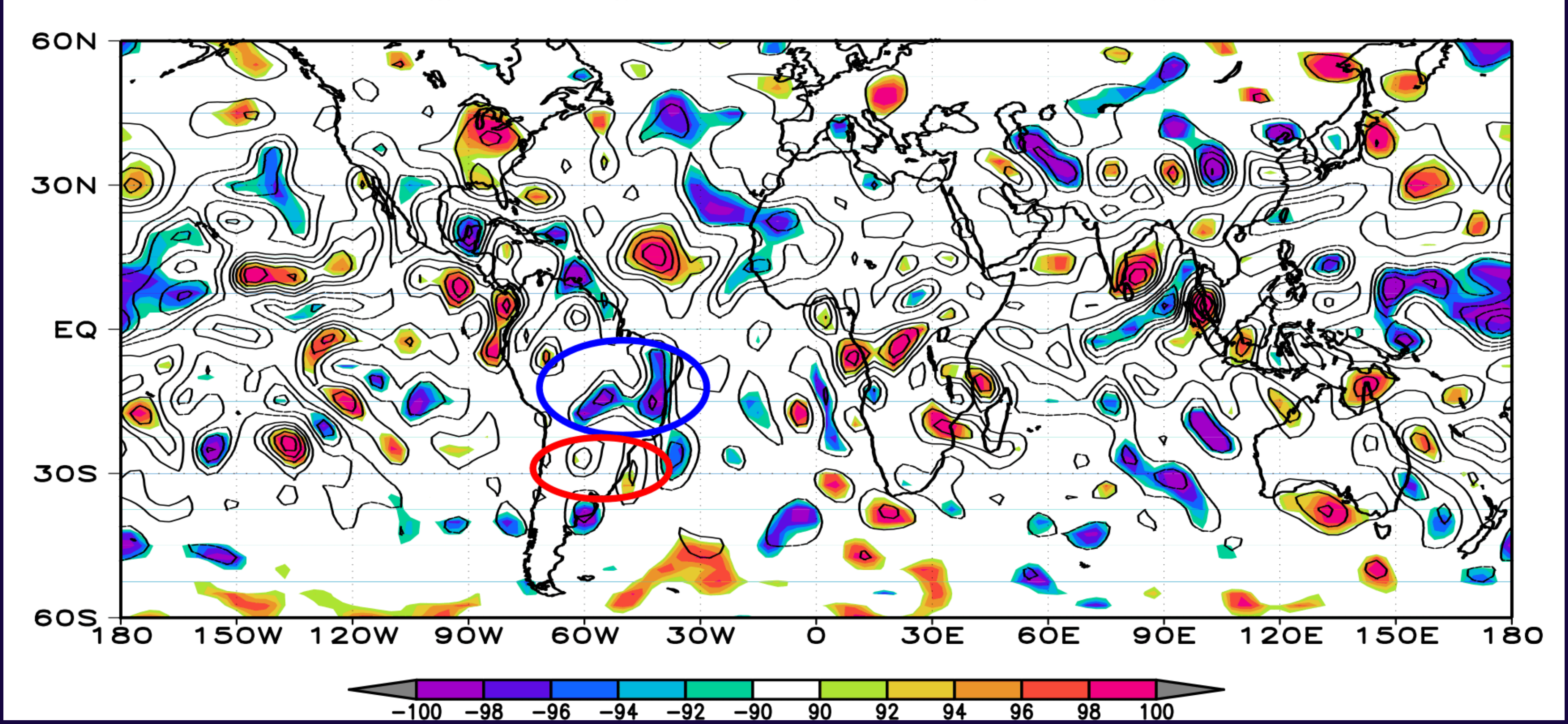


Grimm and Silva Dias (1995, JAS, 52)



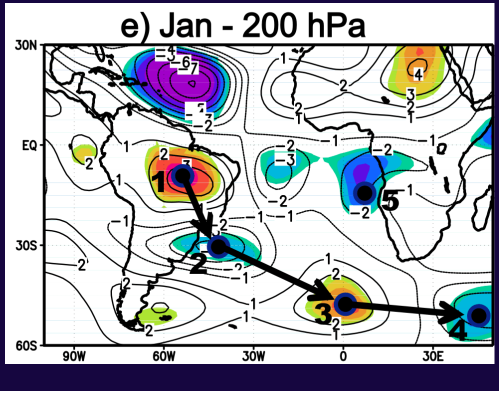
Results: Benguela Niño-Niña composites

(January)



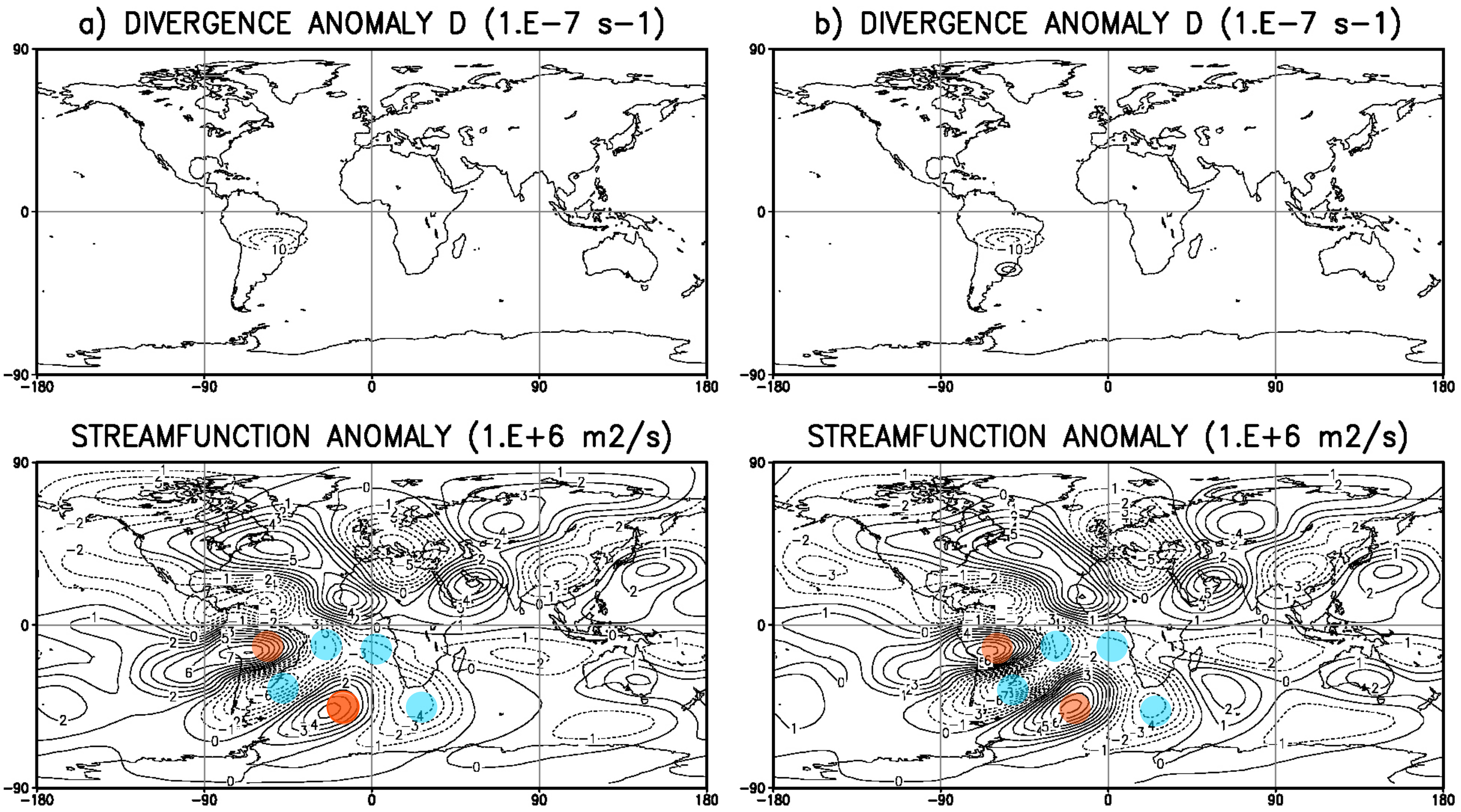
Difference Benguela Niño-Niña of the divergence at 200 hPa in January. The colors indicate levels of confidence better than 90% for positive and negative differences.

Tests with the model (January)


e) Jan - 200 hPa

1

2

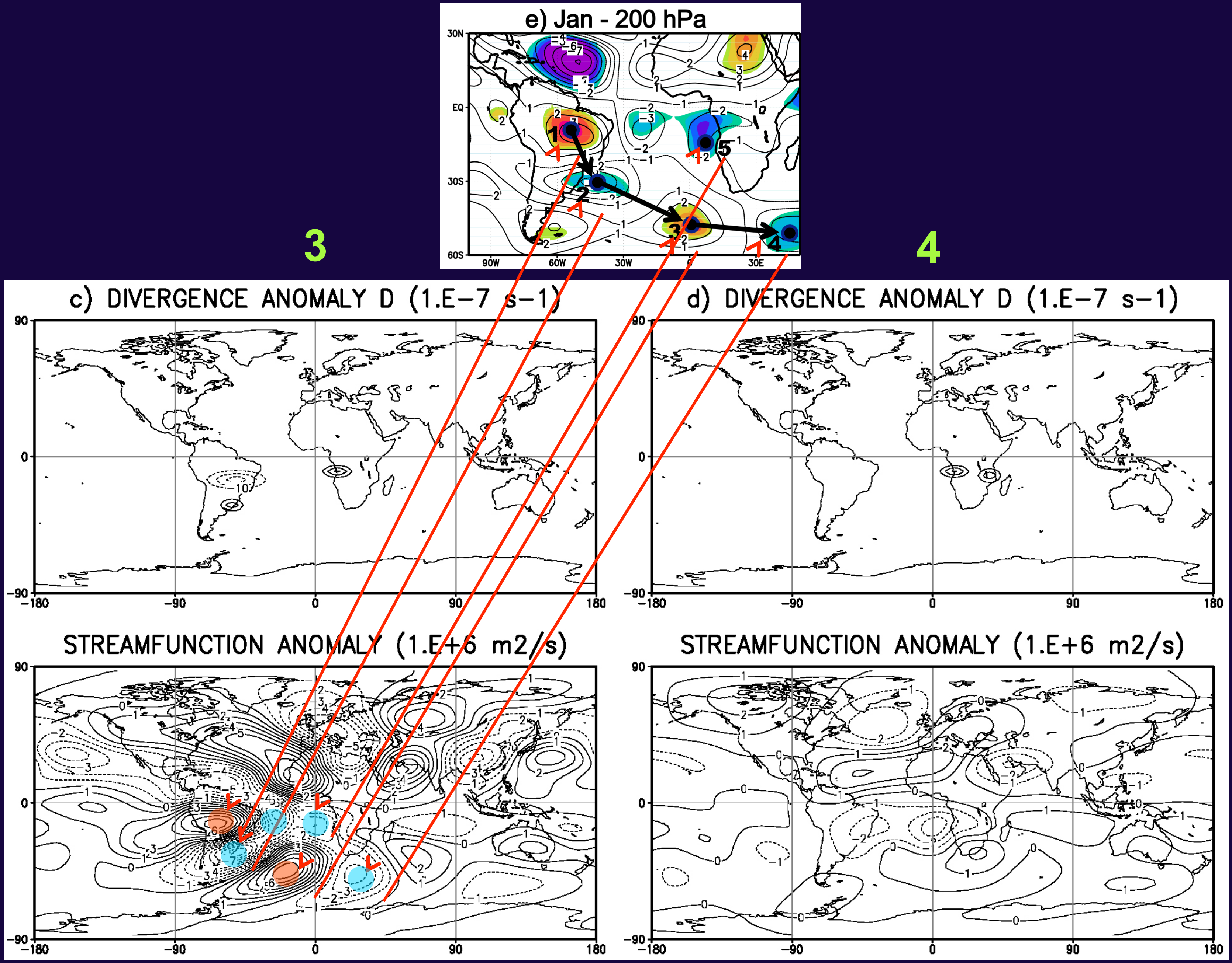

a) DIVERGENCE ANOMALY D (1.E−7 s−1)

b) DIVERGENCE ANOMALY D (1.E−7 s−1)

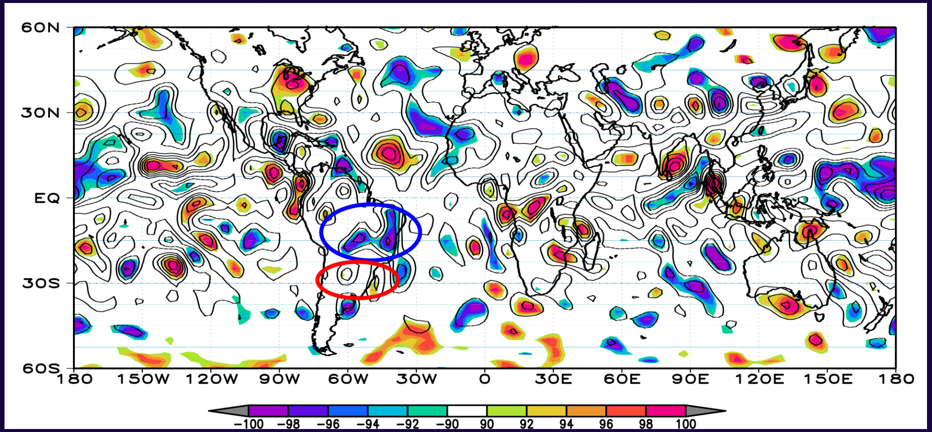
STREAMFUNCTION ANOMALY (1.E+6 m2/s)

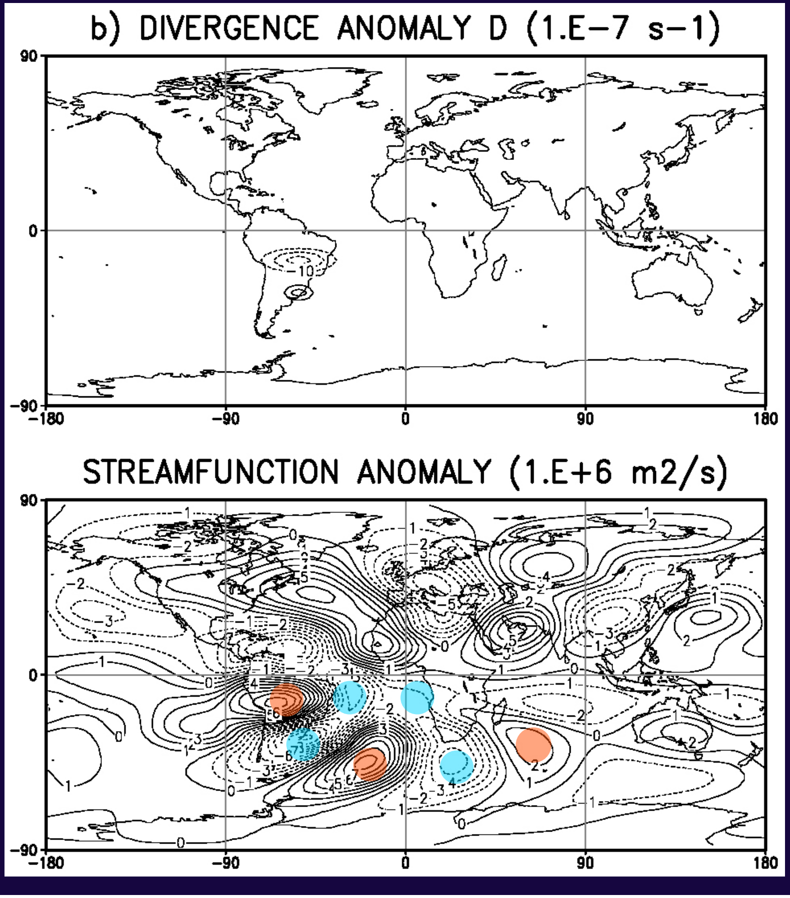
STREAMFUNCTION ANOMALY (1.E+6 m2/s)

Tests with the model (January)

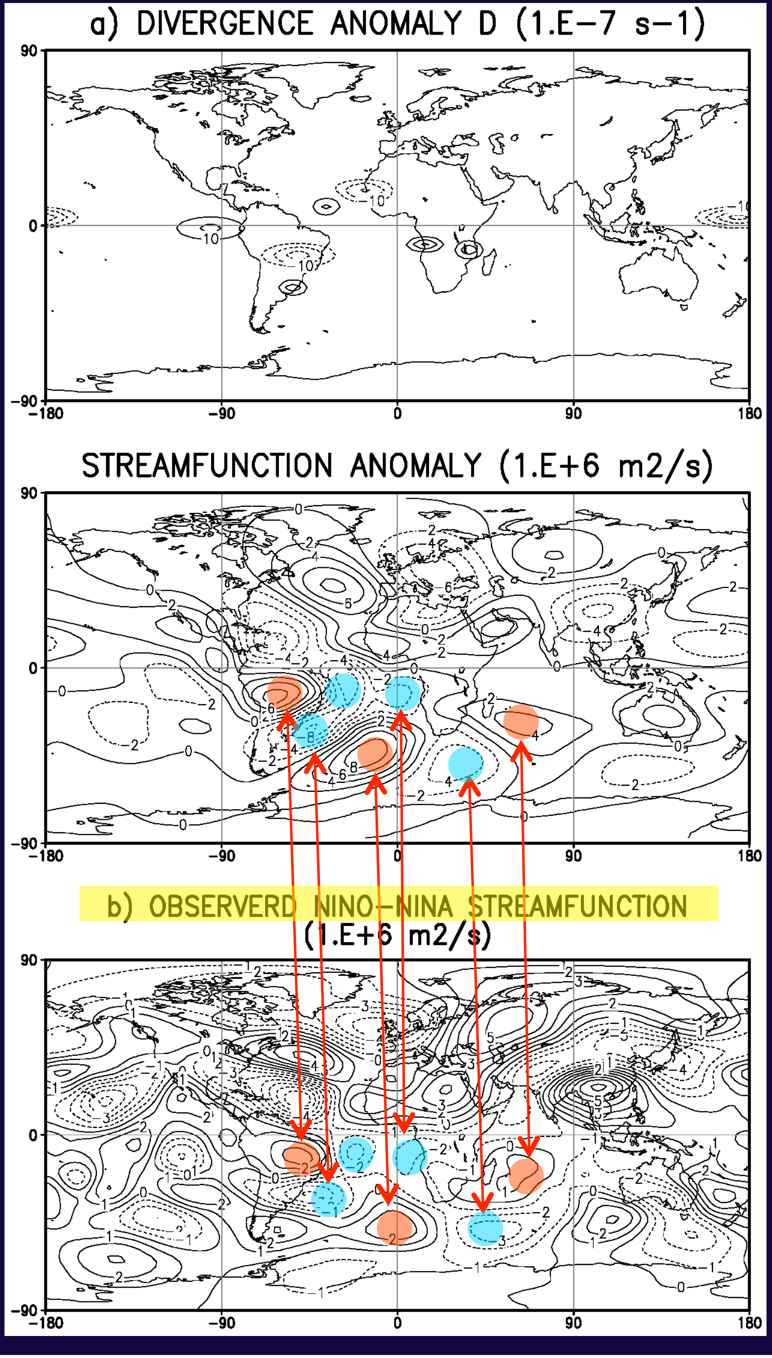


Tests with the model (January)




b) DIVERGENCE ANOMALY D (1.E−7 s−1)

STREAMFUNCTION ANOMALY (1.E+6 m2/s)


a) DIVERGENCE ANOMALY D (1.E−7 s−1)

STREAMFUNCTION ANOMALY (1.E+6 m2/s)

b) OBSERVERD NINO−NINA STREAMFUNCTION (1.E+6 m2/s)

Conclusions I

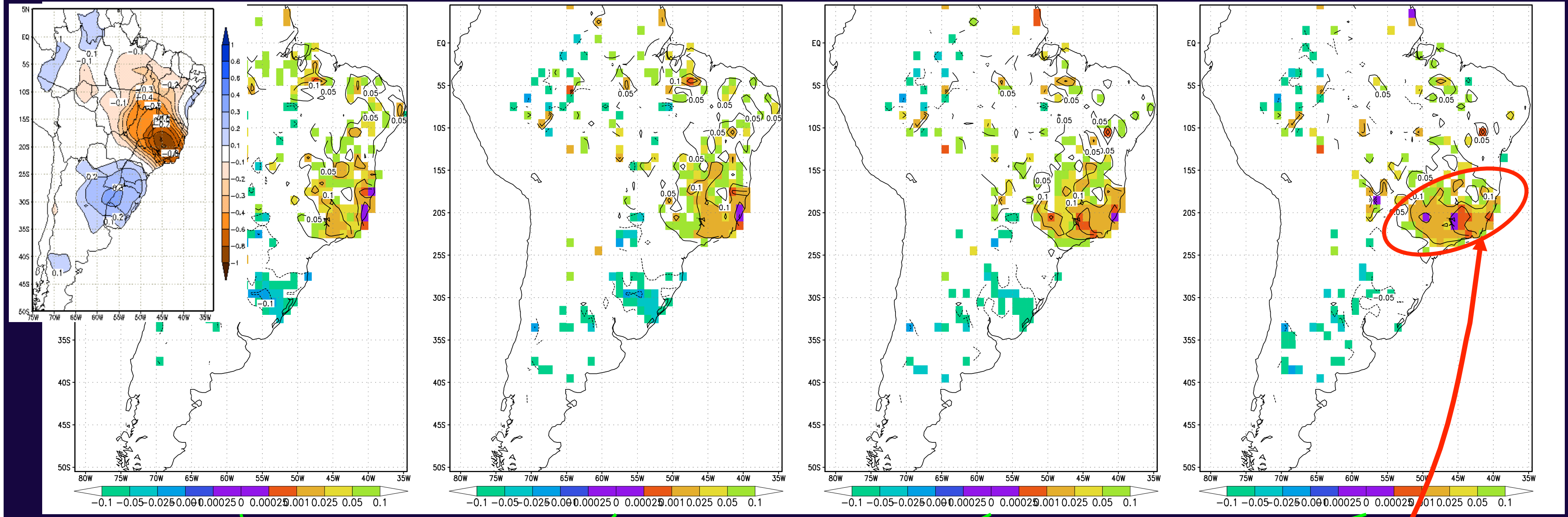
- The observed lag between the strongest anomalies in South America and Africa, influence function analysis and model experiments indicate that these anomalies do not simply have a common origin, but that the South American anomalies influence those in Africa. The former generate circulation anomalies that can affect the African rainfall directly and indirectly (via their influence on SST). The African rainfall and associated upper level divergence anomalies have very little influence on the South American circulation anomalies.

- Although the Benguela Niño - related SST anomalies are able to produce rainfall anomalies over the Angola region, they are not enough to explain the strong observed rainfall anomalies (Hansingo and Reason 2009). Our results show that these rainfall anomalies are most probably enhanced by the perturbations in the Walker circulation produced by the anomalous convection over South America.

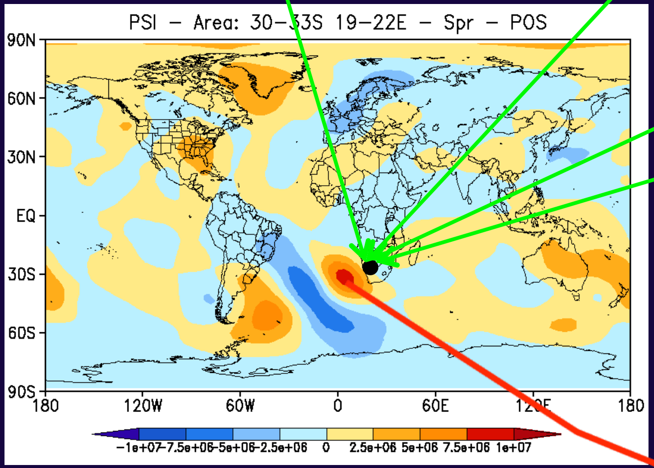
Conclusions II

- The same forcing of the equatorial Atlantic anomalies that initiate the Benguela Niño also yields rainfall anomalies over South America during the summer monsoon, which can then produce circulation anomalies that modulate Benguela Niños. The effect of these circulation anomalies over African rainfall during Benguela Niño can be direct, by modulating uplift over the affected area (around point 5 and inland Africa), or indirect, through their influence on the SST (producing downwelling Kelvin waves, less Ekman transport away from the coast and less divergence in the upper ocean than average, thereby reducing the mean upwelling near the Angolan coast).

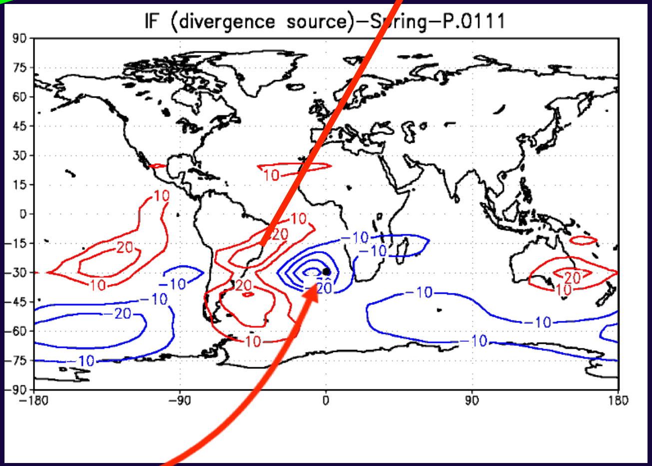
Teleconnections between Intraseasonal Variability



Correlation coefficients between spring precipitation in South Africa and South America for frequencies lower than synoptic. South Africa precipitation lags by 0, 1, 2, 3 days.



Composite of streamfunction anomalies at 200 hPa for the days immediatly before periods of precipitation anomalies above 1 SD in South Africa.



Influence Function - Spring