Diagnostics and attribution of droughts in Brazil

Caio Coelho, CPTEC/INPE

Plan of talk:

- **Part 1. Diagnostics for understanding causes of occurred drought conditions in SE Brazil**
- **Part 2. Investigation of possible human contribution to changes in drought risk**
- **Summary**

Acknowledgments: Denis Cardoso and Mari Firpo (CPTEC/INPE), GrEC/USP, INMET and regional institutions for providing the precipitation data used in this study

References

•**Coelho CAS**, D Cardoso, M Firpo, 2015: **Precipitation diagnostics of an exceptionally dry event in São Paulo.** *Published* 9/7/2015, *Theoretical and Applied Climatology*.

• **Coelho CAS,** CP de Oliveira, T Ambrizzi, MS Reboita, CB Carpenedo, JLPS Campos, ACN Tomaziello, LA Pampuch, MS Custódio, LMM Dutra, RP da Rocha, A Rehbein, 2015: **The 2014 southeast Brazil austral summer drought: regional scale mechanisms and teleconnections**. Published 15/08/2015, *Climate Dynamics*

• **Collaboration involving Univ. Oxford, KNMI, Univ. Melbourne, Univ. Amsterdam, Univ Utrecht, Univ. Columbia, IRI, NASA, Red Cross/Red Crescent Climate Centre , Climate Central:** Friederike E. L. Otto, **Caio A. S. Coelho,** Andrew King, Erin Coughlan de Perez, Yoshihide Wada, Geert Jan van Oldenborgh, Rein Haarsma, Karsten Haustein, Peter Uhe, Maarten van Aalst, Jose Antonio Aravequia, Waldenio Almeida, Heidi Cullen, 2015: **Factors other than climate change, main drivers of 2014/15 water shortage in Southeast Brazil.** *Bulletin of the American Society (BAMS).*

Motivation for these studies

www.cptec.inpe.br

Cantareira System 07/02/2014
(Photo: Reproduction/Globo TV)

Jaguari-Jacareí reservoir, part of Cantareira system in Vargem, 05/2014
(Photo: Nilton Fukuda/Estadão)

Jaguari reservoir, Cantareira system, Bragança Paulista (SP)
(Photo: Nacho Doce/Reuters)

Cantareira system reservoir recorded lowest level for human consumption supply in the last 10 years, 03/2014. (Photo: Reproduction / Facebook / Sabesp)

Death volume pumping system at Jaguari reservoir, Jacareí, 07/2014.
(Photo: Nilton Fukuda/Estadão)

Challenging social questions

Climate event: E.g. precipitation deficit (drought) in a region

- How much precipitation has the region received?
- Is it common for the region to experience such abnormal climate conditions?
- When have similar abnormal climate conditions been observed?
- What has been the observed precipitation pattern in the region in the last years?
- How severe/rare was a particular climate event?
- When does the rainy season typically start and end in a particular region?
- How was the rainy season onset and demise in a particular region in recent years?

- Need to look at historical records to answer these questions

Southeast São Paulo
Monthly precip.: 2013/2014 e 2014/2015

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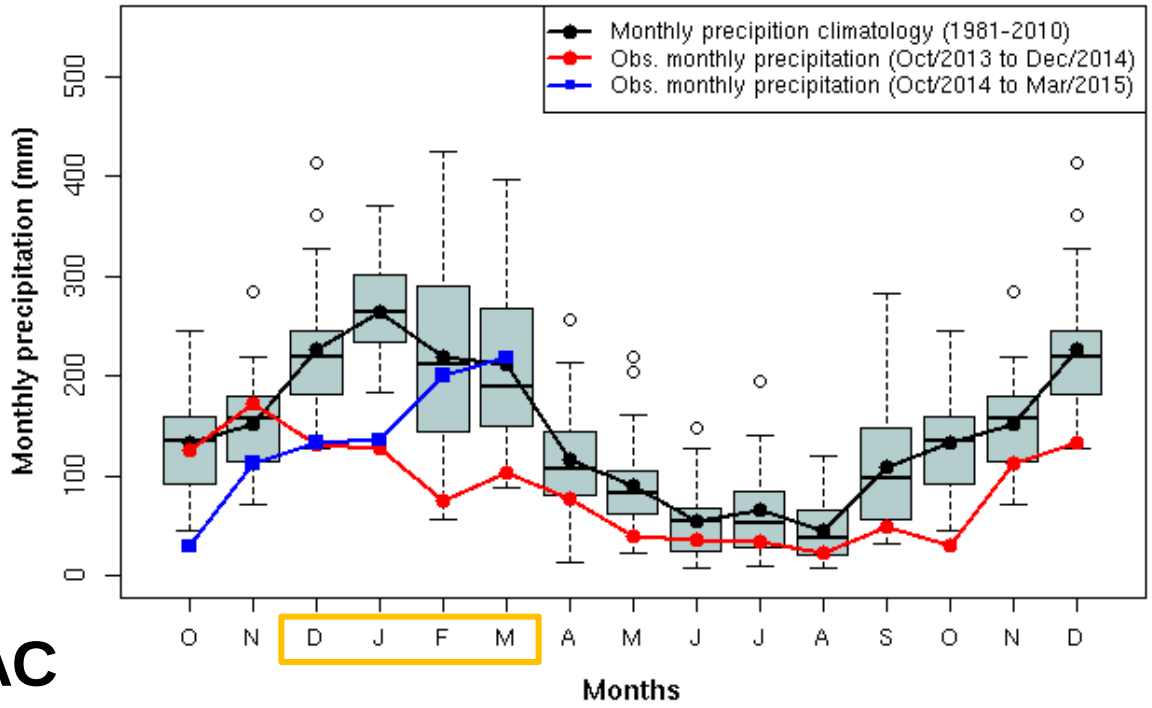
Southeast São Paulo

Monthly precipitation



Coelho et al (2015), TAAC

How much precipitation has the region received?

- **Expressive precip. deficit: Summer (DJFM 2013/2014, SONDJ 2014/2015)**
- **Well below normal conditions: Largest deficits observed in JFM 2014**
- **Water crisis, impacts in water supply for human consumption, agric. and hydropower generation**

Is it common for the region to experience abnormally dry conditions?

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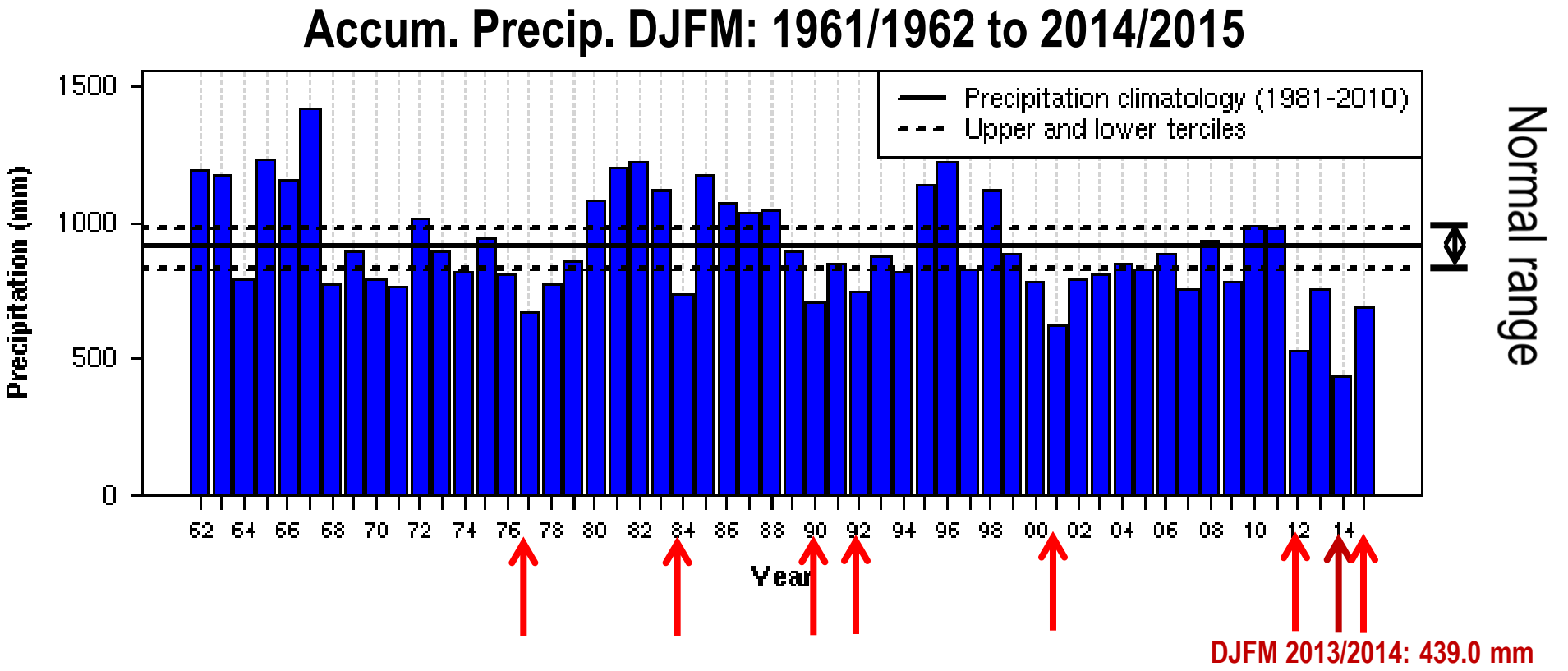

- It is common for the region to experience expressive precipitation deficits
- Similar dry conditions to DJFM 2013/2014 have been observed in 1976/1977, 1983/1984, 1989/1990, 1991/1992, 2000/2001, 2011/2012 e 2014/2015

Normal range: 984.8 - 827.6 mm

Climatological mean (1981-2010): 918.7 mm

What has been the observed precip. pattern in the last years?

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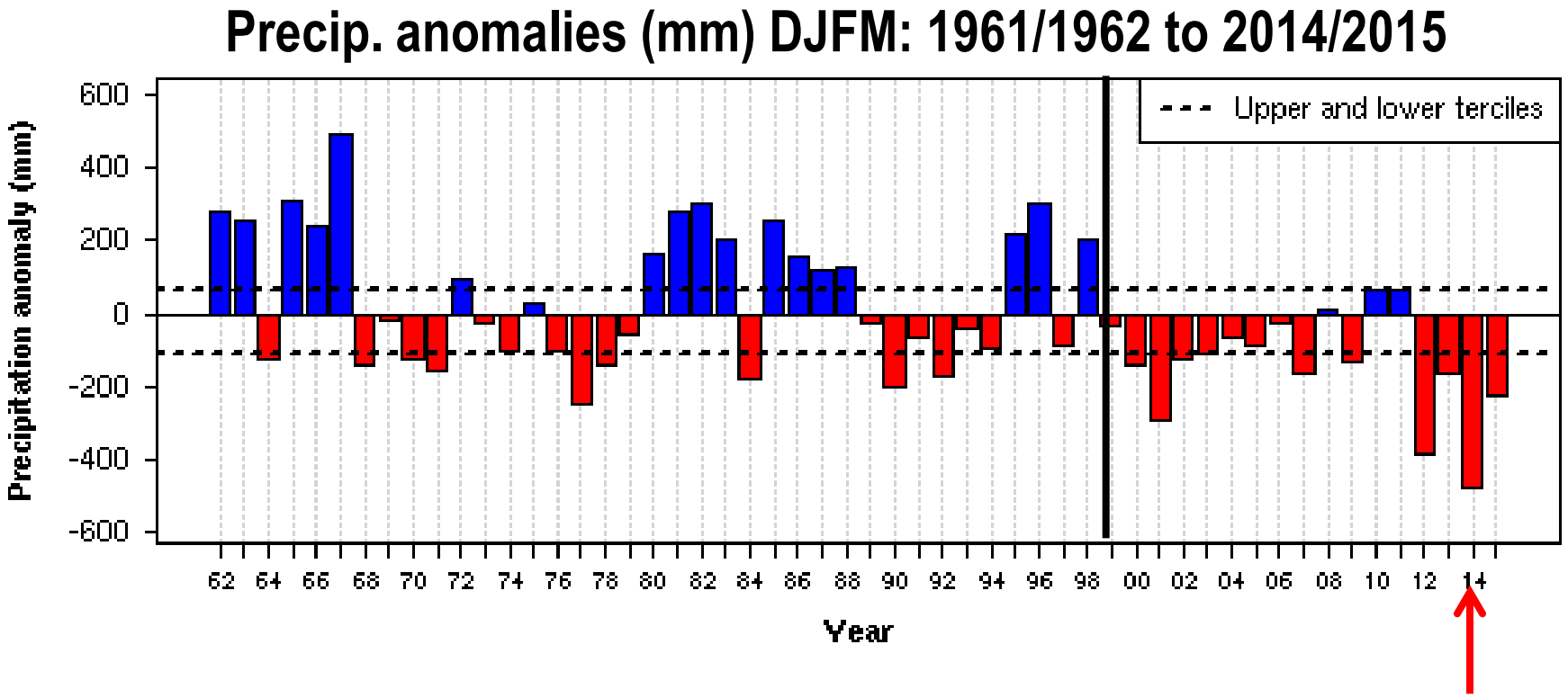

- **Expressive negative precipitation anomalies in 2011/2012 and 2013/2014 (-479.7 mm)**
- **Predominantly drier than normal pattern since 1999/2000**

Anomalies computed with respect to the climatological mean for the 1981-2010 period: 918.7 mm

How severe/rare were the southeast São Paulo summer drought events 2013/2014 and 2014/2015?

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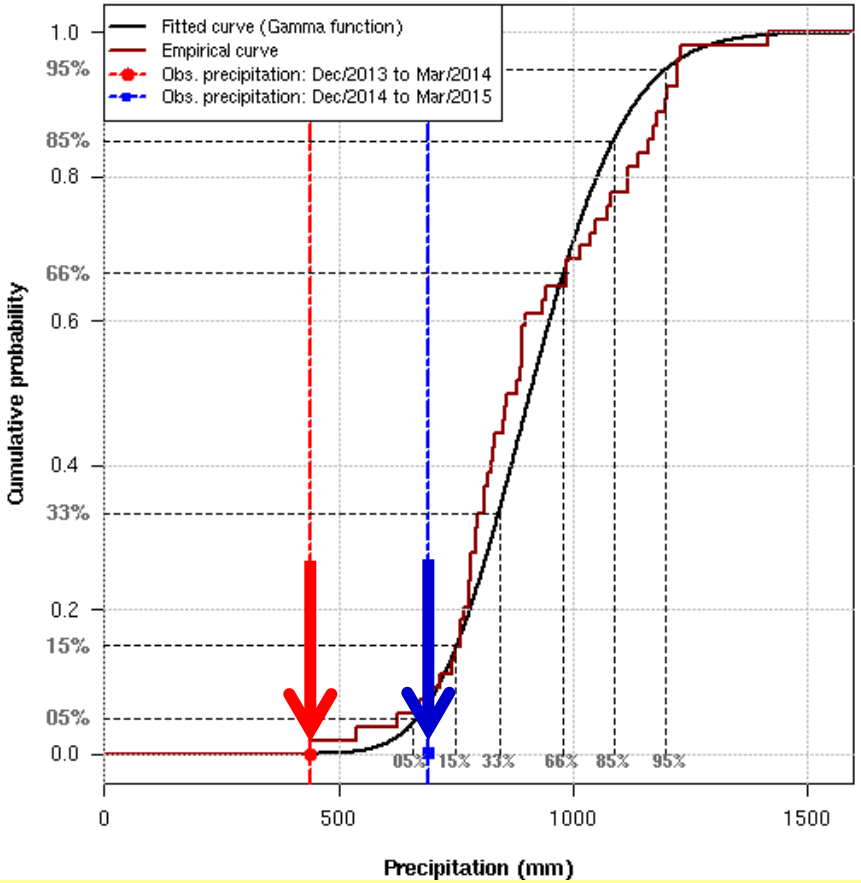
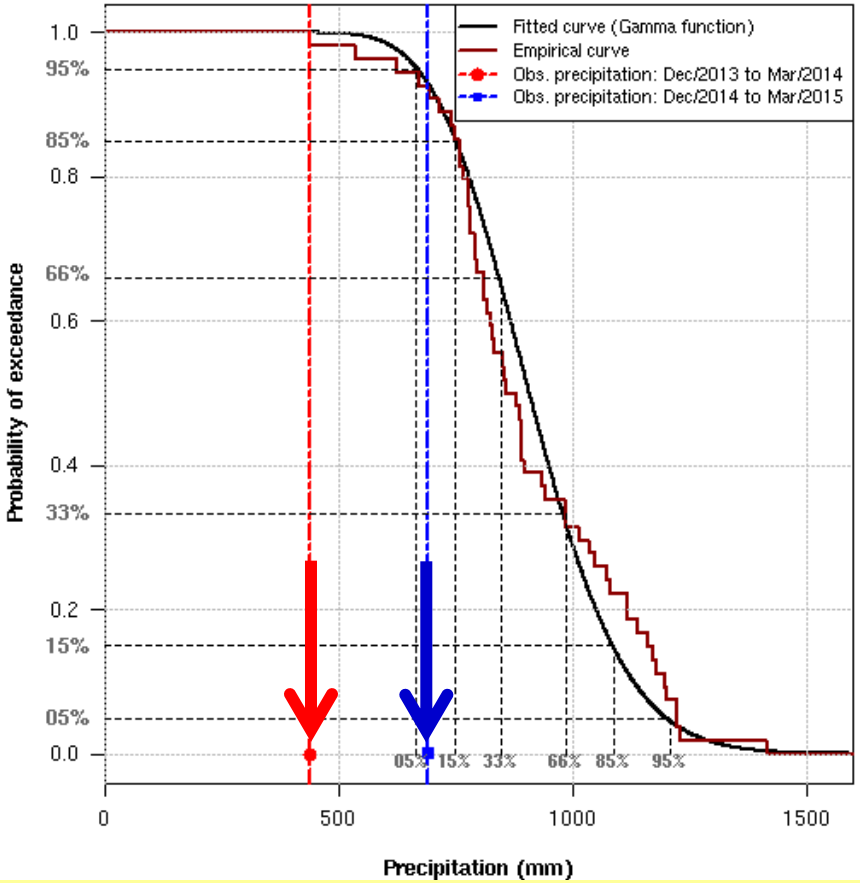
Cumulative precip. distribution
DJFM: 1981/1982 to 2010/2011



Probability of exceedance precip. distribution
DJFM: 1981/1982 to 2010/2011



Observed precip. DJFM 2013/2014: 439.0 mm

Very rare event located in the far tail of the historical precip. distribution

Observed precip. em DJFM 2014/2015: 692.8 mm

How severe/rare was the southeast São Paulo summer 2013/2014 drought event?

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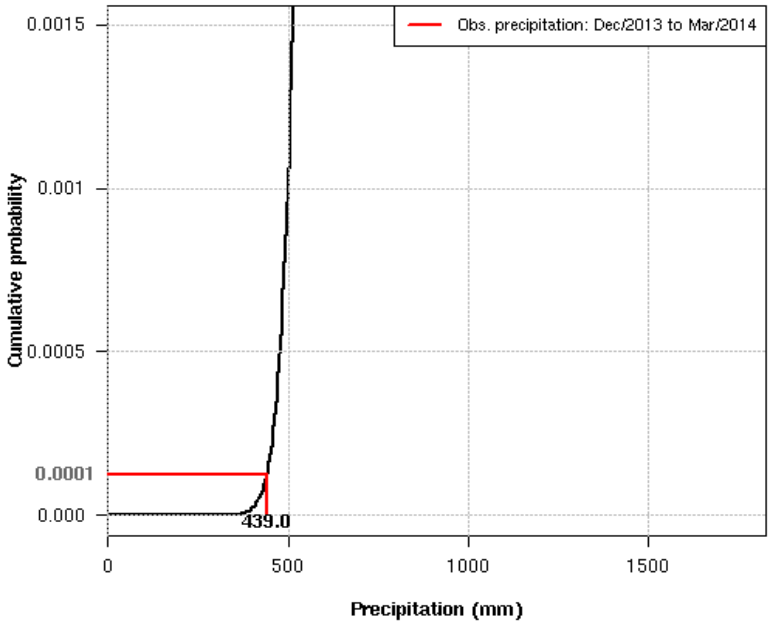
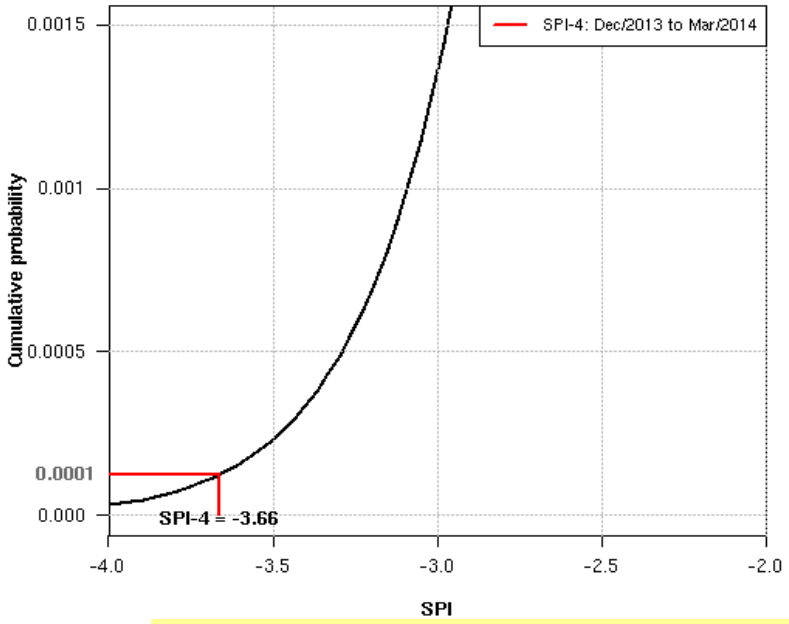
Cummulative (Gamma) precip. ditribution
DJFM: 1981/1982 to 2010/2011



Standardized precip. index (SPI)
DJFM: 1981/1982 to 2010/2011



Summer (DJFM) 2013/2014:
Observed precip.: 439.0 mm
Percentil: 0.01%
SPI: -3.66 (Classified as exceptionally dry)

SPI < -2: Exceptionally dry
-1,99< SPI < -1,60: Severely dry
-1,59 < SPI < -1,30: Very dry
-1,29 < SPI < -0,80: Moderately dry
- 0,79 < SPI < -0.51: Abnormaly dry
- 0,51 < SPI < 0.51: Near normal

How severe/rare was the southeast São Paulo summer 2014/2015 drought event?

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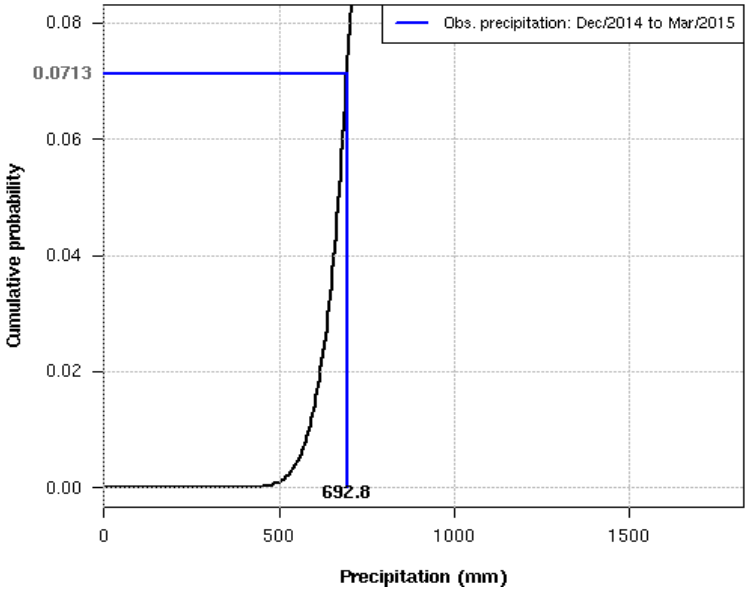
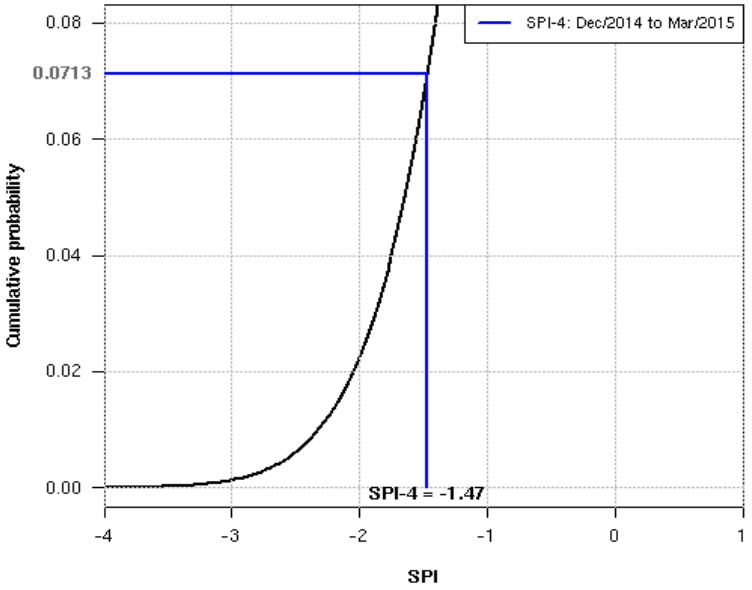
Cummulative (Gamma) precip. ditribution
DJFM: 1981/1982 to 2010/2011



Standardized precip. index (SPI)
DJFM: 1981/1982 to 2010/2011



Summer (DJFM) 2014/2015:
Observed precip.: 692.8 mm
Percentil: 7.13%
SPI: -1.47 (Classified as very dry)

SPI < -2: Exceptionally dry
-1,99< SPI < -1,60: Severely dry
-1,59 < SPI < -1,30: Very dry
-1,29 < SPI < -0,80: Moderately dry
- 0,79 < SPI < -0.51: Abnormaly dry
- 0,51 < SPI < 0.51: Near normal

When does the rainy season typically start/end in the region?

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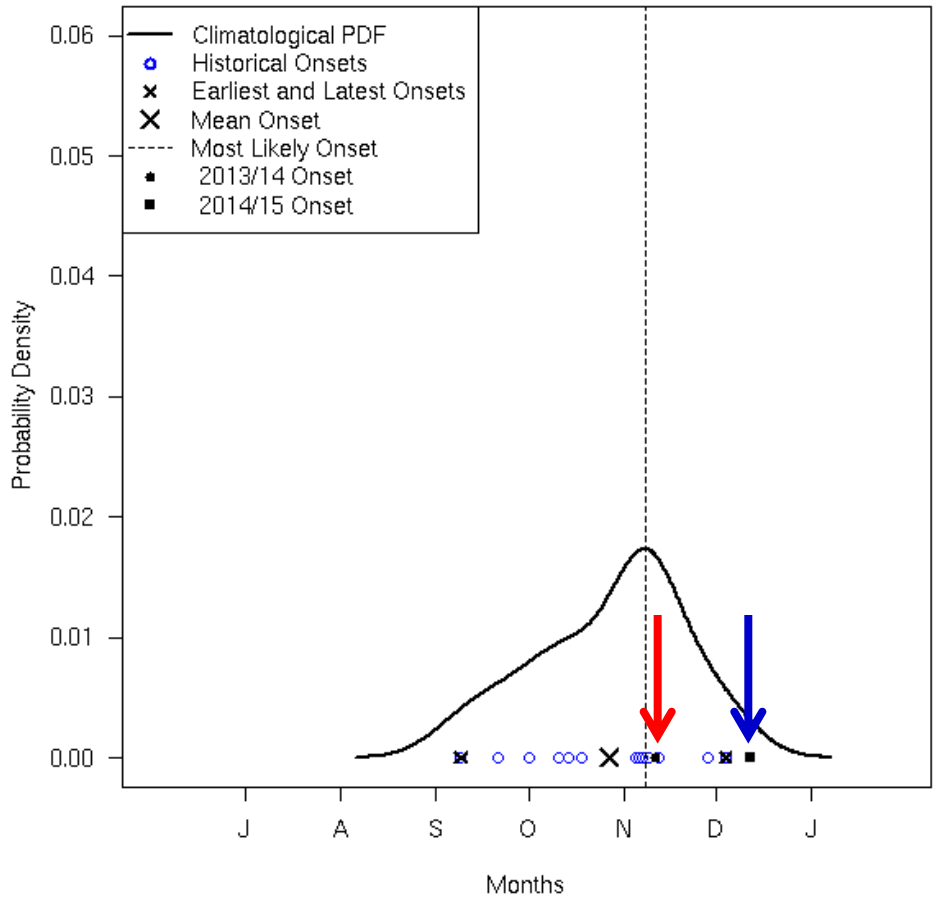
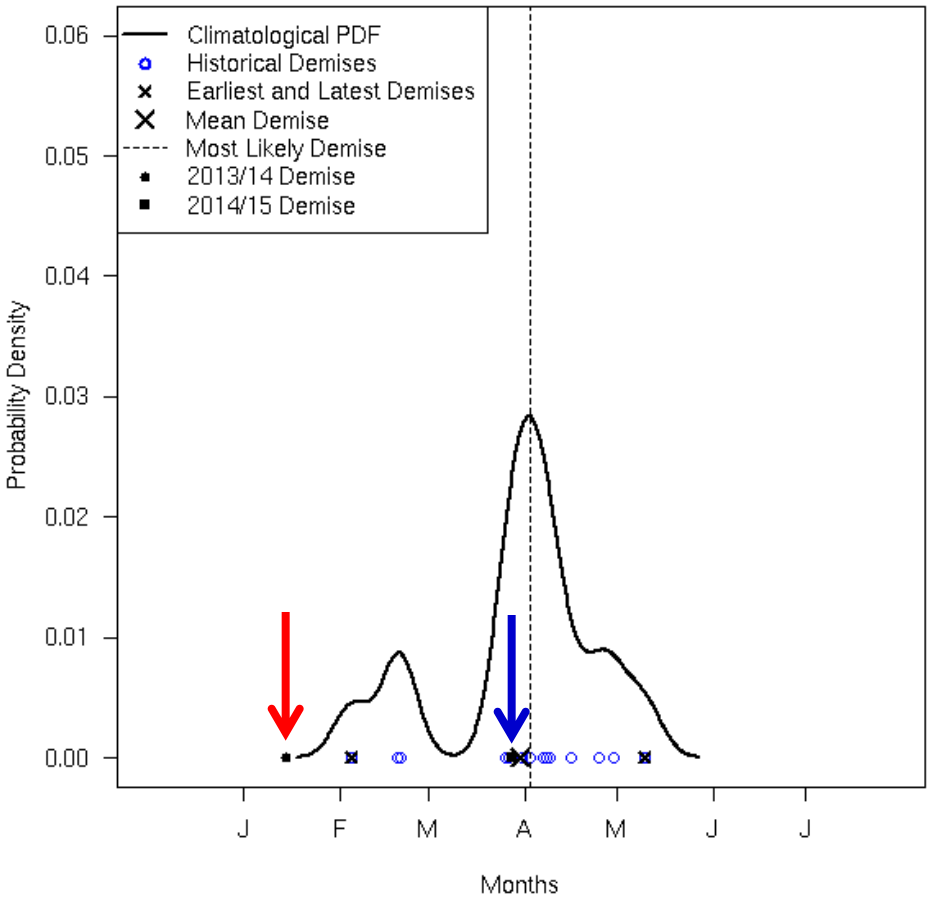
Probability density function : Climatological distribution of rainy season onset dates



Probability density function : Climatological distribution of rainy season demise dates



- **Tipical onset: Mid Out, early Nov**
- **Tipico demise: End Mar, early Abr**

2013/2014: Normal onset, and very early end (absence of SACZ events)

2014/2015: Very late onset and normal end

Challenging question: What caused the summer 2014 drought over southeast Brasil?

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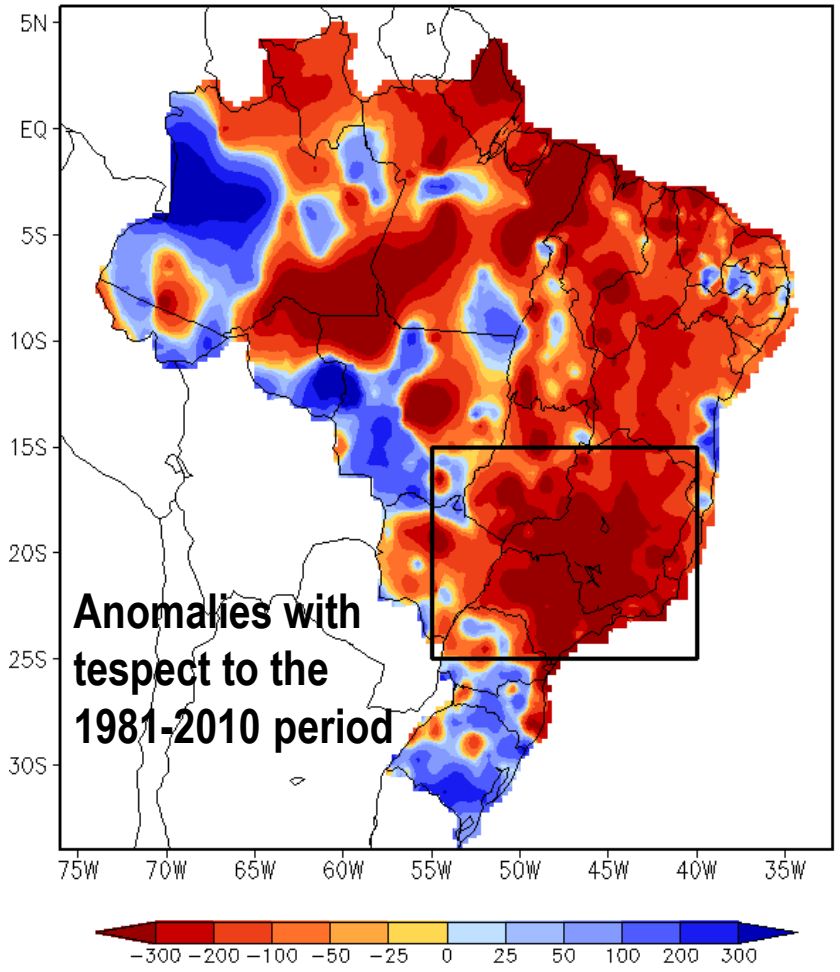
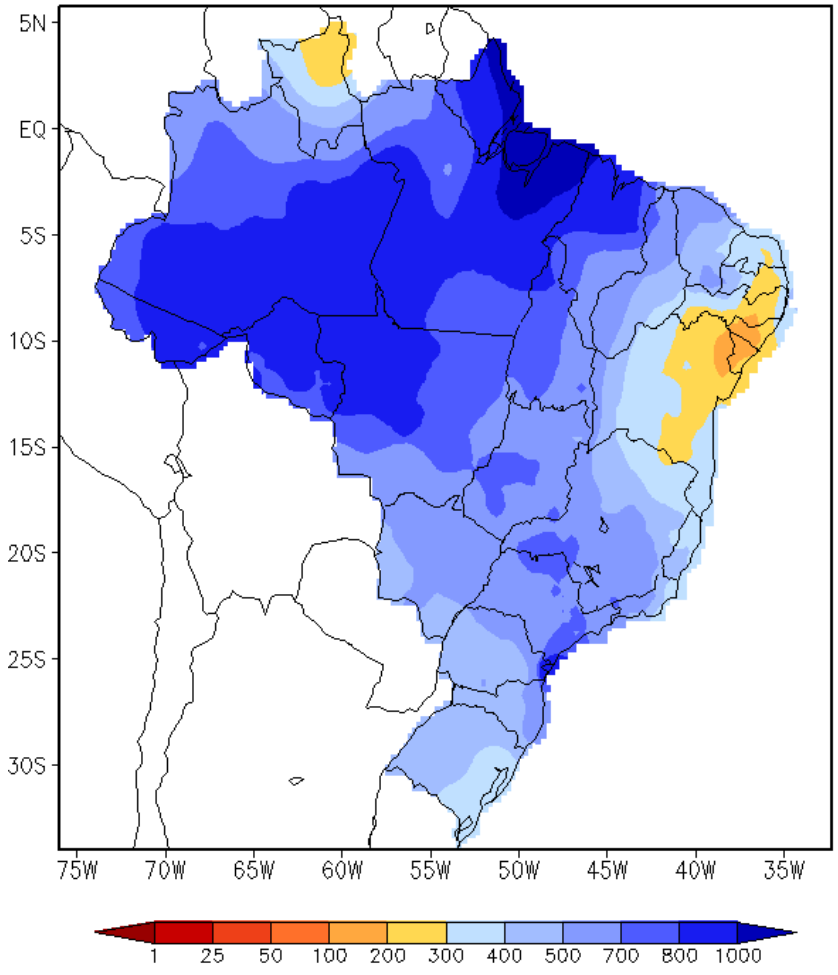
Coelho et al. 2015 . Climate Dynamics

Precip. anomaly (mm): JFM 2014



Climatological precip. (mm): JFM 1981-2014



Expressive precip. deficit over southeast Brazil during 2014 summer (JFM)

Precip. anomaly time series over southeast Brazil: JFM 1961-2014

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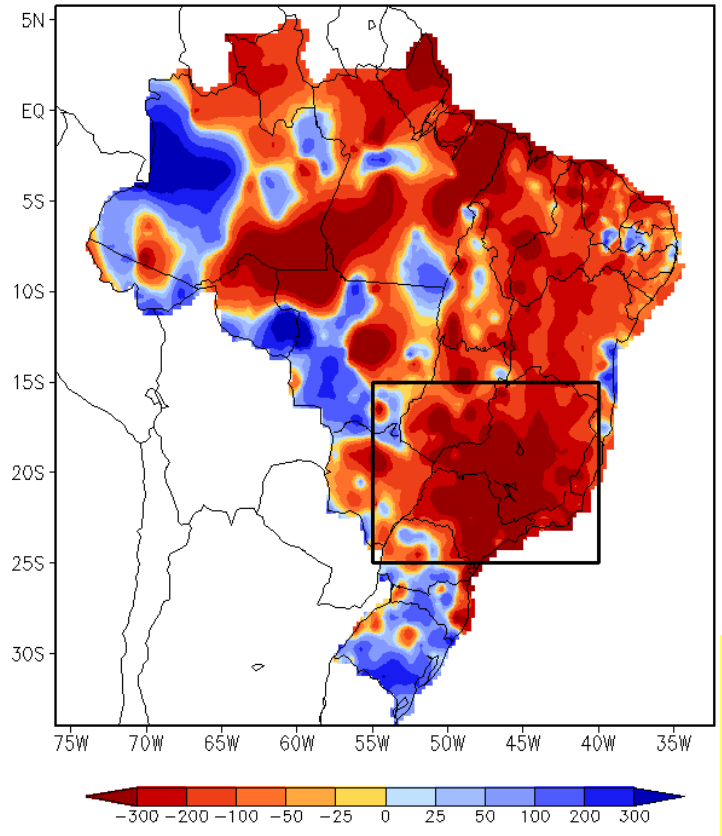
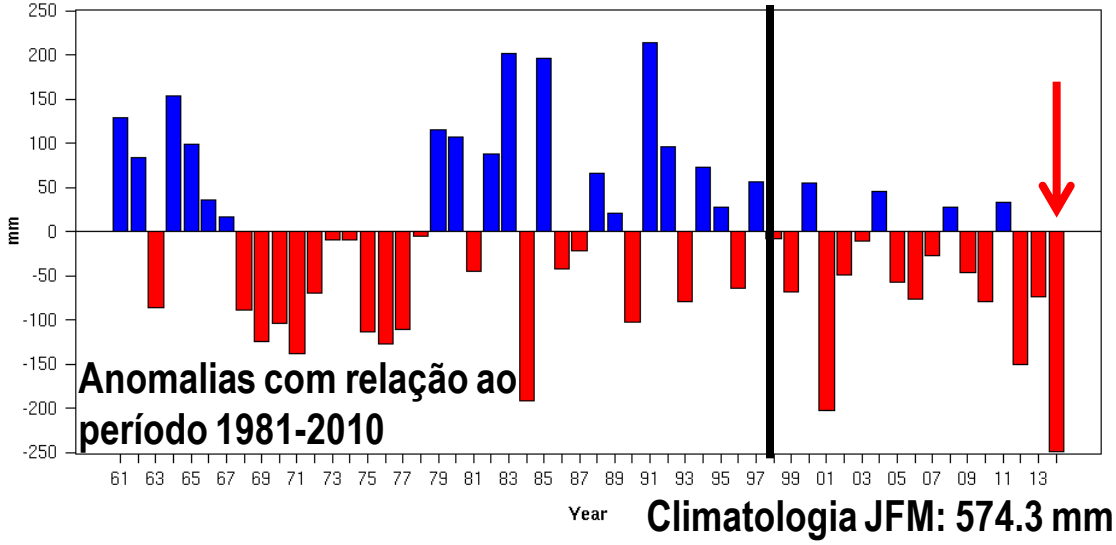
Precip. Anomaly (mm): JFM 2014



Precip. Anomaly time series: JFM 1961-2014
Mean over rectangular area of figure on the left



Climatologia JFM: 574.3 mm

- JFM 2014: Expressive anomaly (-249.7 mm)
- Only 56.5% of historical mean recorded, representing déficit of 43.5%
- Region recording deficit since 1998/1999
- Similar deficit in past years (eg. 2001)

Relevant questions for understanding the causes of the summer (JFM) 2014 drought

- What are the possible mechanisms associated with the observed drought conditions during the 2014 summer over the southeast region of Brazil?

- Would it be possible to identify atmospheric/oceanic teleconnections associated with the 2014 summer drought over the southeast region of Brazil?

In order to answer these questions:

• Investigate relationship between observed precipitation over the southeast region of Brazil and atmospheric/oceanic large scale patterns

Relationship btw precip. Interannual variability and sea surface temperarure: JFM 1961-2014

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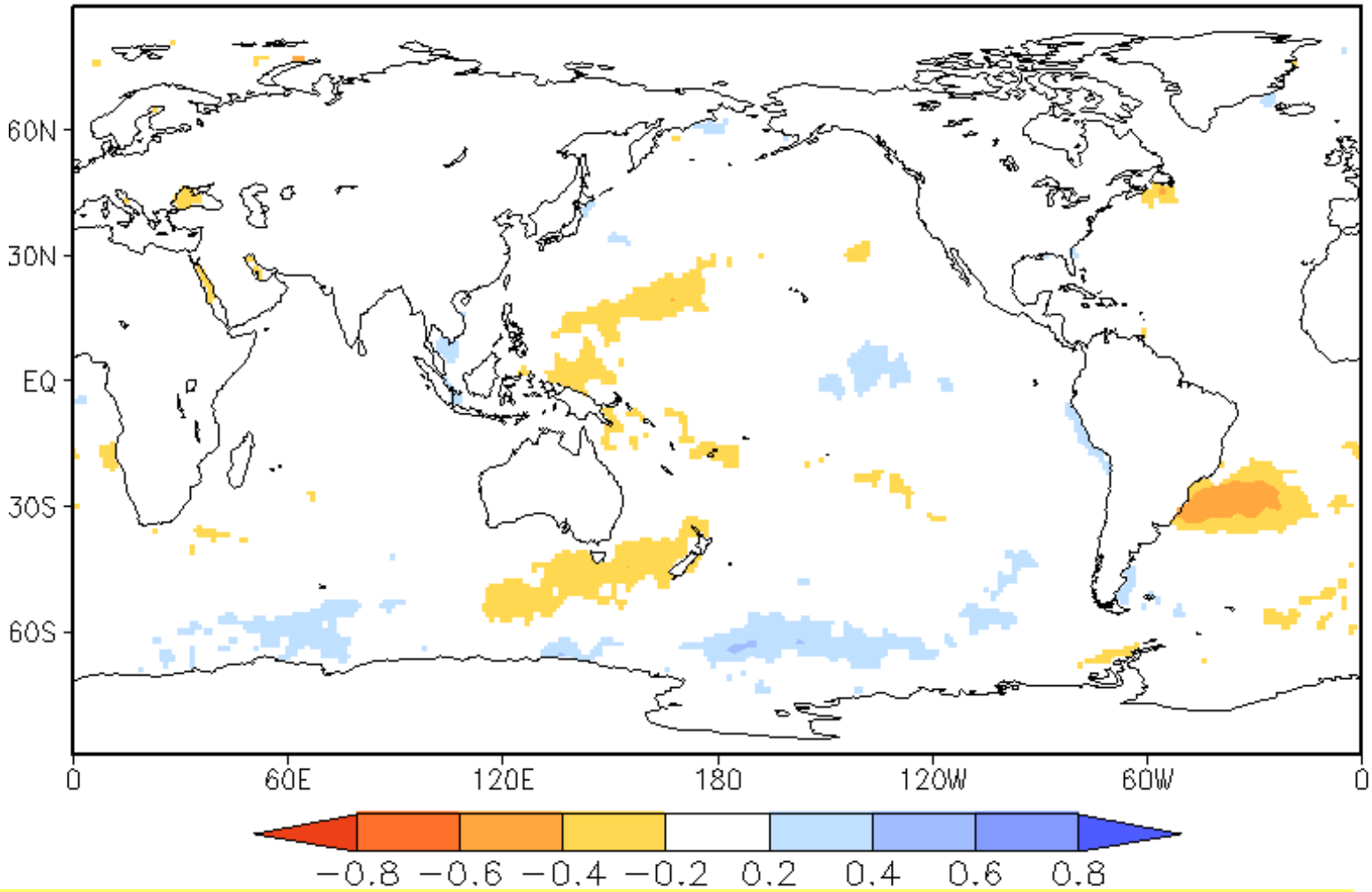
Simultaneous correlation btw SE Brazil precipitation and sea surface temperature: JFM 1961-2014

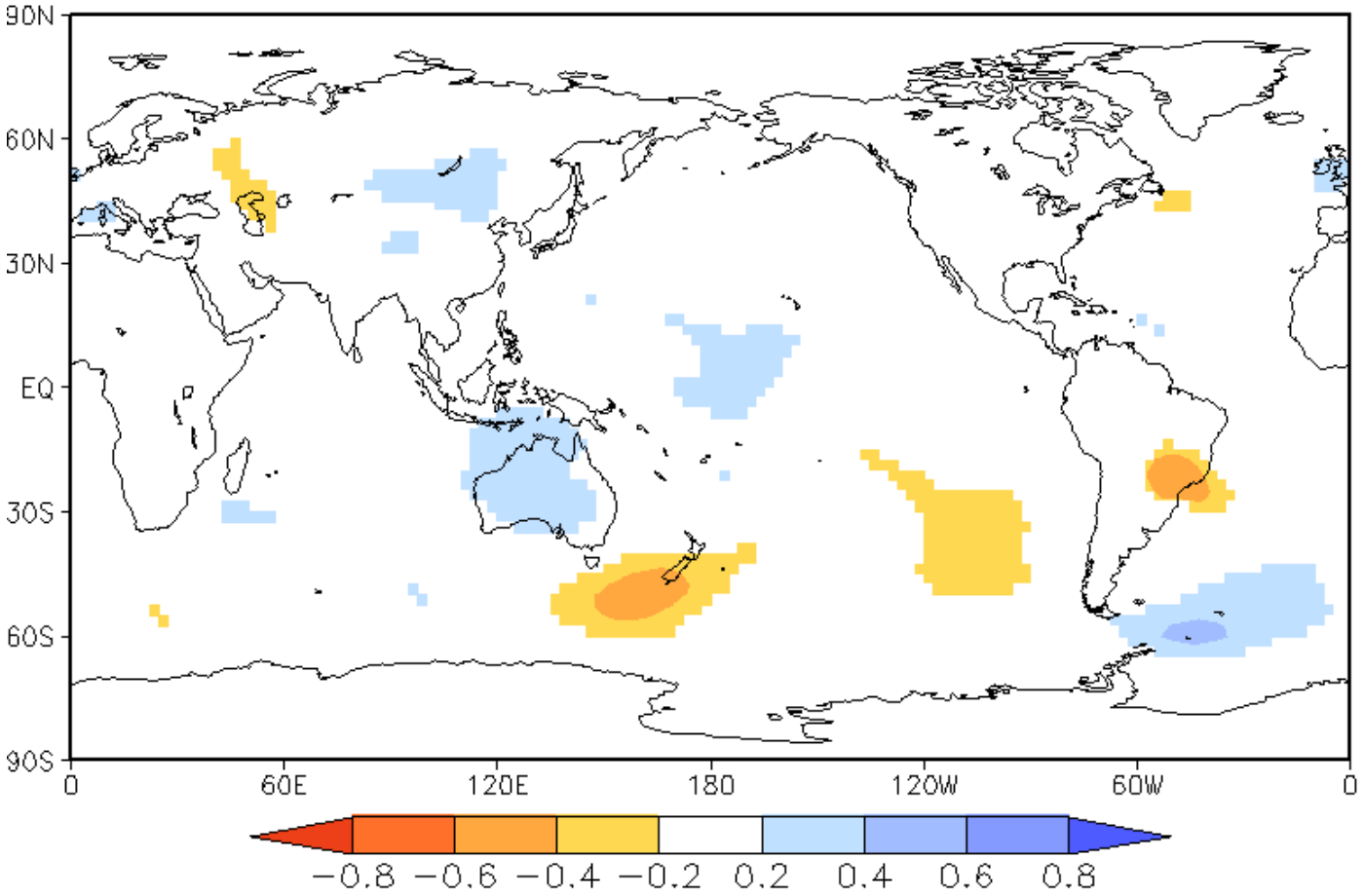


Atlantic ocean near the coast of S/SE Brazil: negative correlation

Relationship btw precip. Interannual variability and geopotential height (850 hPa): JFM 1961-2014

www.cptec.inpe.br

Simultaneous correlation btw SE Brazil precipitation and geopotential height (850 hPa): JFM 1961-2014



- SE Brazil and Alantic coast, SE Pacific: negative correlation
- South Atlantic near southern South América: positive correlation

Relationship btw precip. Interannual variability and geopotential height (200 hPa): JFM 1961-2014

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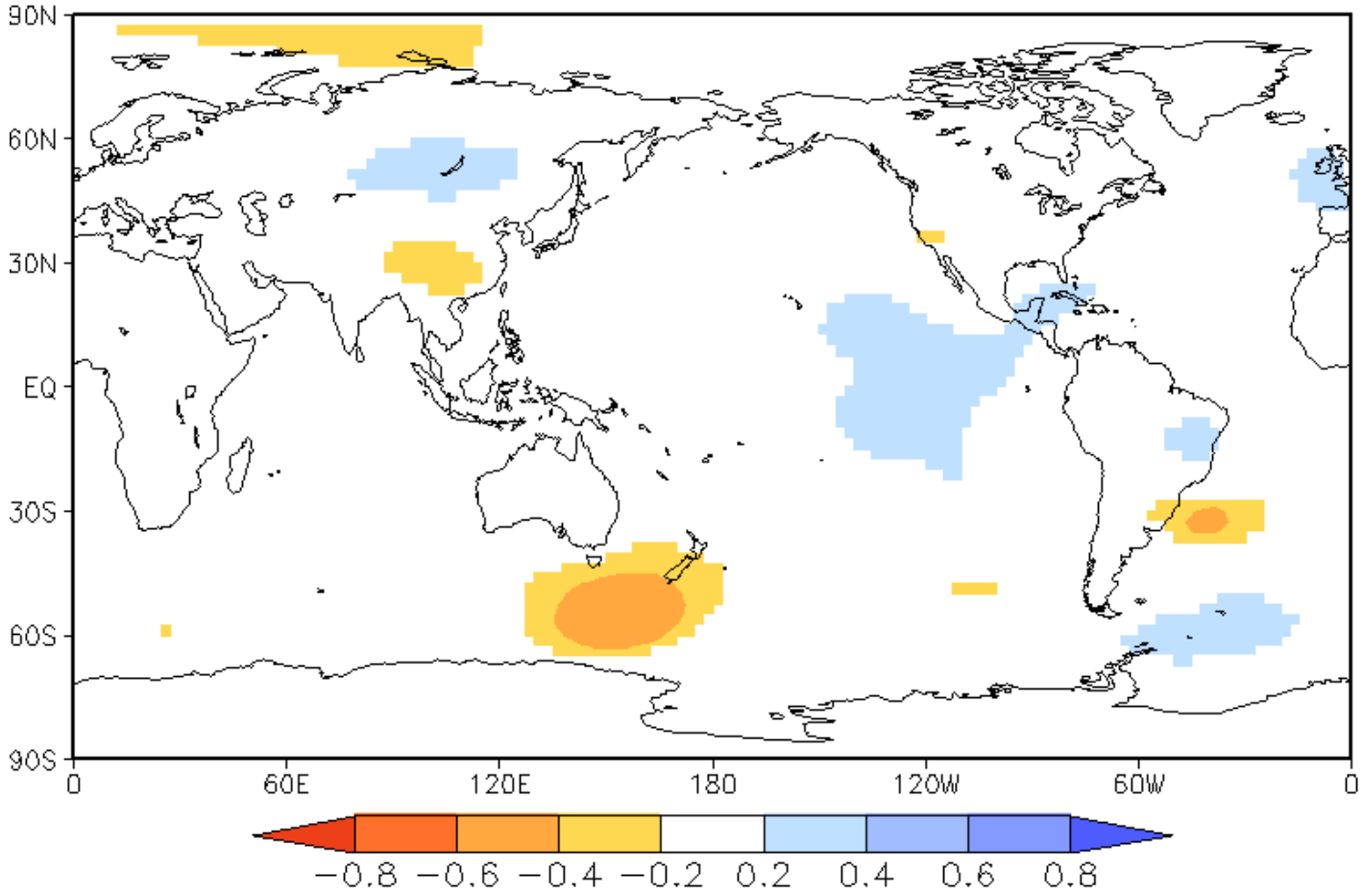
Simultaneous correlation btw SE Brazil precipitation and geopotential height (200 hPa): JFM 1961-2014



- SE Brazil and Alantic coast, SE Pacific: negative correlation
- South Atlantic near southern South América: positive correlation

What happened during JFM 2014?

Diagnostics of the observed oceanic and atmospheric circulation patterns during the JFM 2014 drought event

Sea surface temperarure and geopotential height (850 hPa) anomalies: JFM 2014

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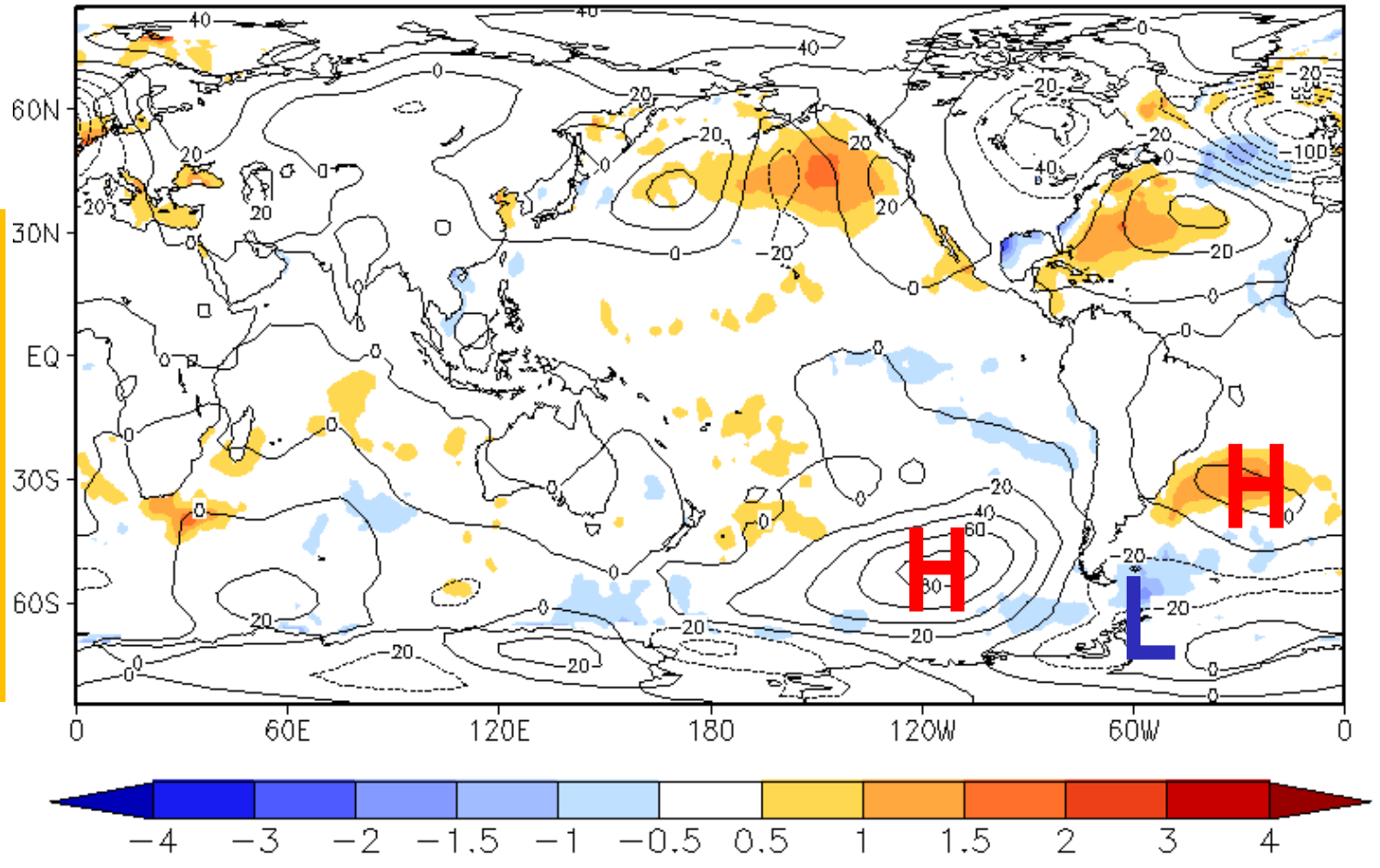
Positive SST anom. over the Atlantic and anomalous circ. pattern over the Pacific and Atlantic: Most important characteristics of SE Brazil drought in accordance with correlation analysis



- Positive sea surface temperature anomalies over the Atlantic near the S/SE Brazil coast
- High pressure anomalies over Atlantic and Pacific; Low pressure anomaly over South Atlantic

Outgoing longwave radiation (top of the atmosphere) and geopotential height (200 hPa) anomalies: JFM 2014

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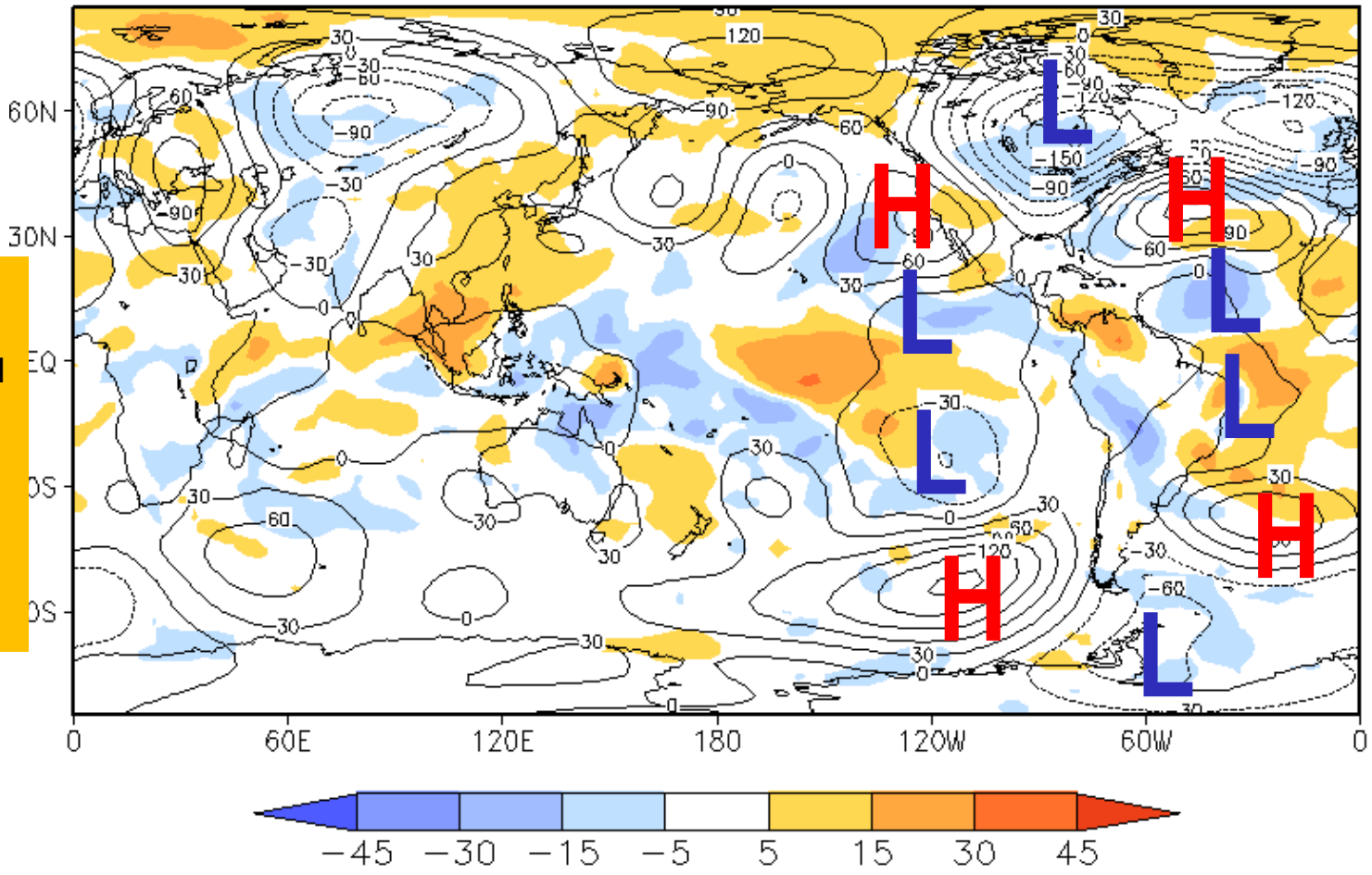
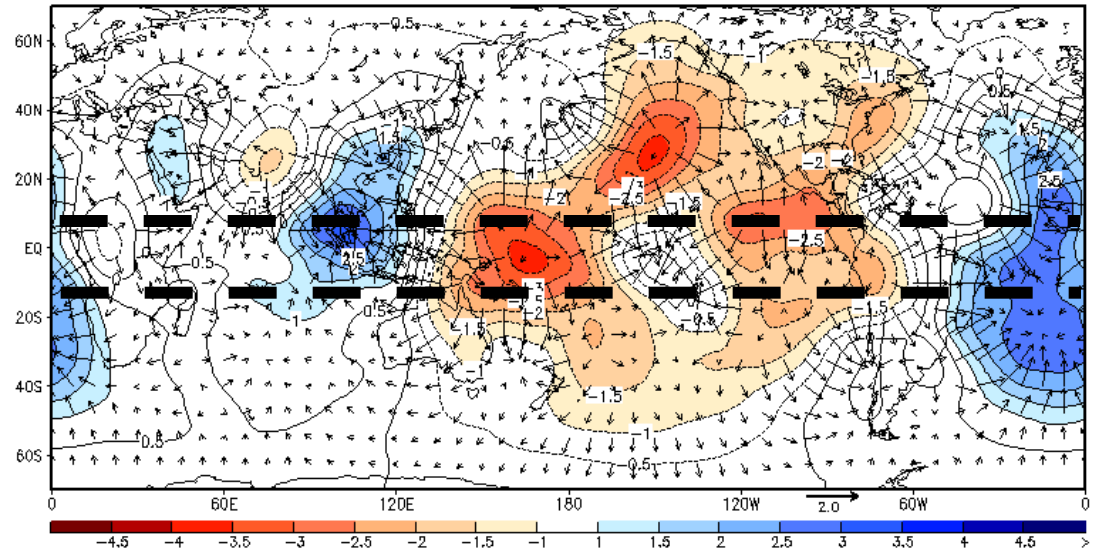


- Tropical teleconection (Walker cell)
- Upper level converg. and subsidence (central Pac.)
- Tropical-Extratropical teleconnection (Hadley cell and Rossby wave with barotropic structure)

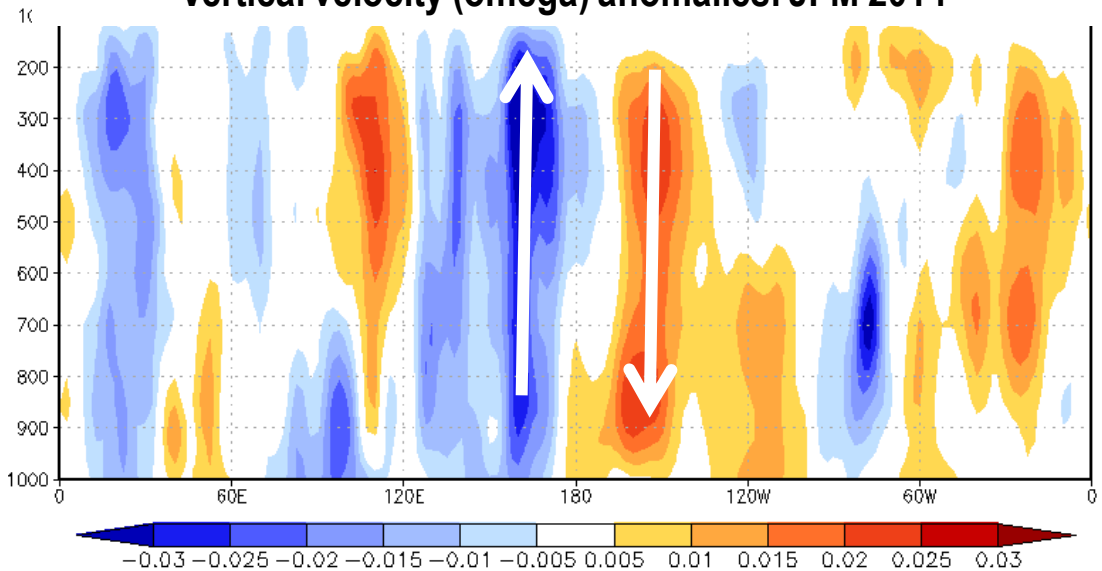
- Positive OLR anom. (SE Brazil); Negative OLR anom. (Northern Australia); Positive OLR anom. (central Pacific)
- Wave pattern (U shaped) apparently connecting upper level converg. and descending vert. motion (célula Walker)

Velocity potential and divergent wind anoms (200 hPa) And vertical velocity anoms 10ºS-10ºN: JFM 2014

Velocity potential and div. wind anomalies (200 hPa): JFM 2014



Vertical velocity (omega) anomalies: JFM 2014



- Neg. velocity potential anoms to the west of the date line: anomalous ascending motion and divergence at high levels
- Pos. velocity potential anoms to the east of the date line: anomalous descending motion (subsidence) and convergence at high levels
- Walker cell at the equator: tropical teleconnection
- Consistent with OLR pattern: favorable conditions for convection to the west of the date line, and unfavorable conditions for convection to the east of the data line

OLR and geopotential height anoms (200 hPa) and vertical veloc. anoms. 130°W-110°W: JFM 2014

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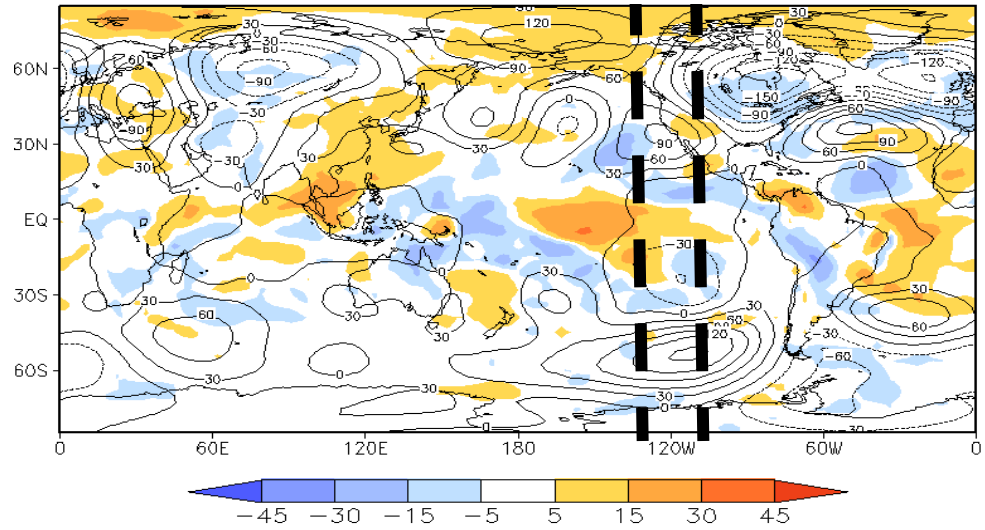
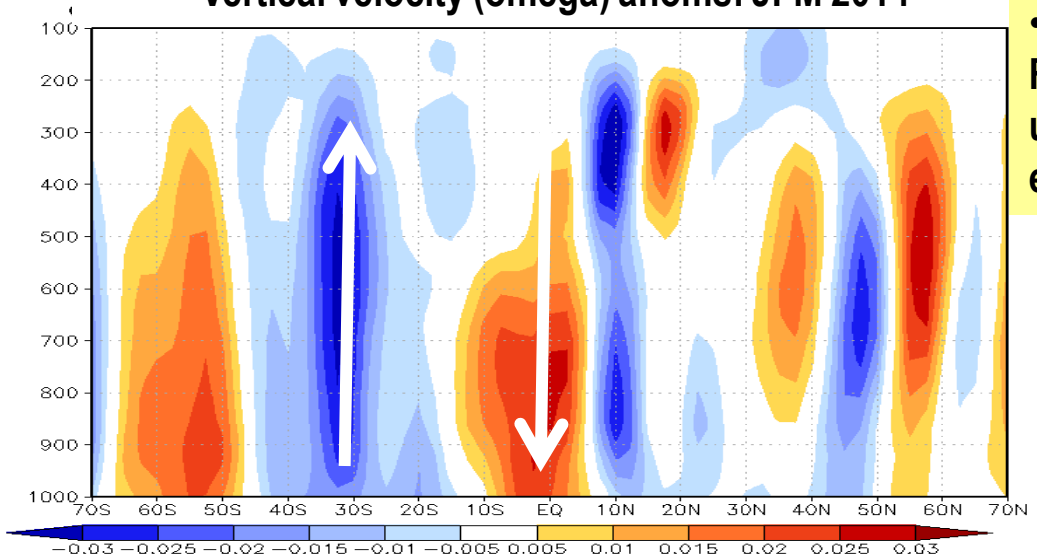
OLR and geopotential height anoms. (200 hPa): JFM 2014



Vertical velocity (omega) anoms: JFM 2014



- Neg. vert. velocity (omega) anoms at 30°S: ascending vertical motion
- Pos. vert. velocity (omega) anoms at the equator: descending vertical motion
- Hadley cell: tropical-extratropical teleconnection
- Consistent with OLR pattern:

Favorable conditions for convection at 30°S, and unfavorable conditions for convection near the equator

Rossby wave source/sink (200 hPa): JFM 2014

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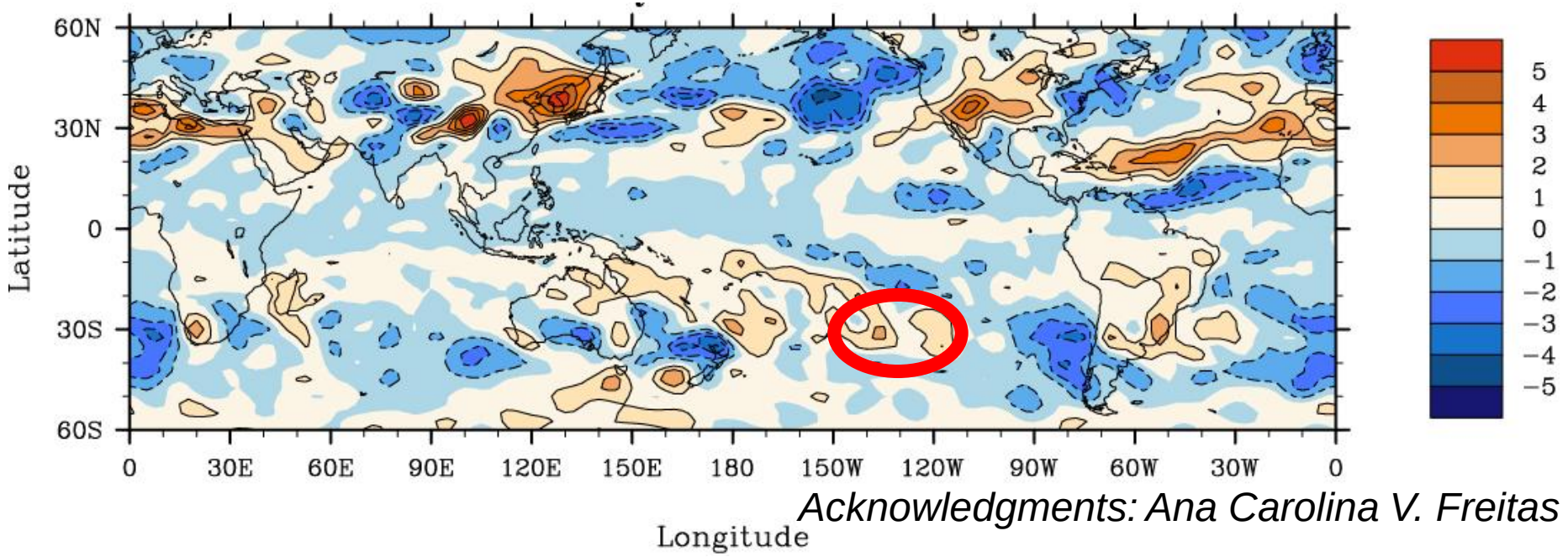

Acknowledgments: Ana Carolina V. Freitas

- **Vorticity anomalies advected to extratropical latitudes where Rossby waves can be generated**
- **Central Pacific region (30°S, 150°W-110°W), Hadley cell ascending branch (where negative OLR anomalies were identified), appear as importante Rossly wave source region: extratropical heat source**

Zonal wind, meridional vorticidade gradiante, K_s (200 hPa) and Rossby wave paths: JFM 2014

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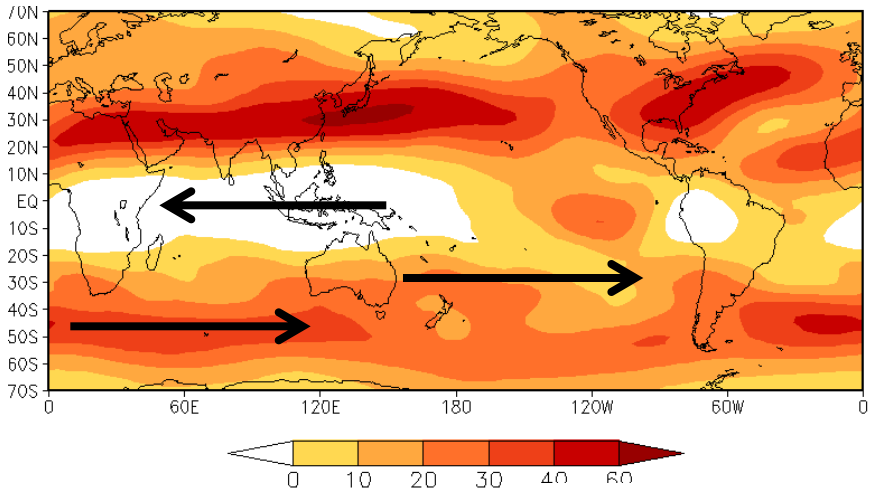
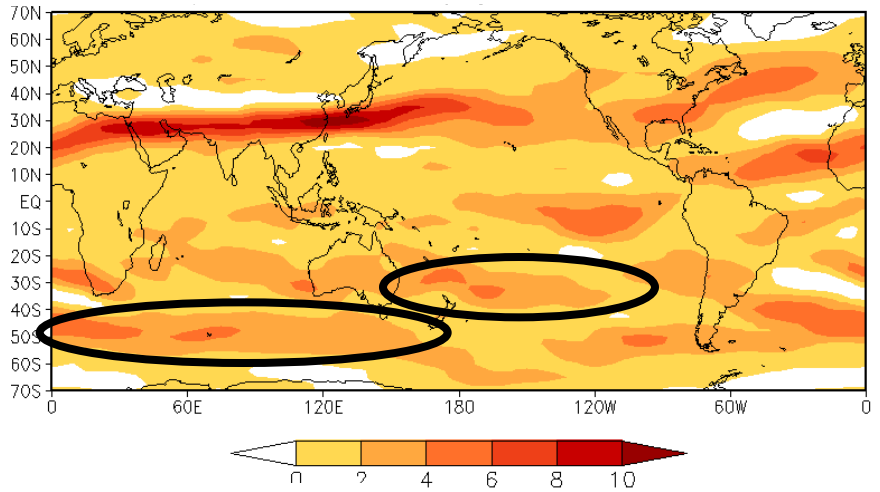
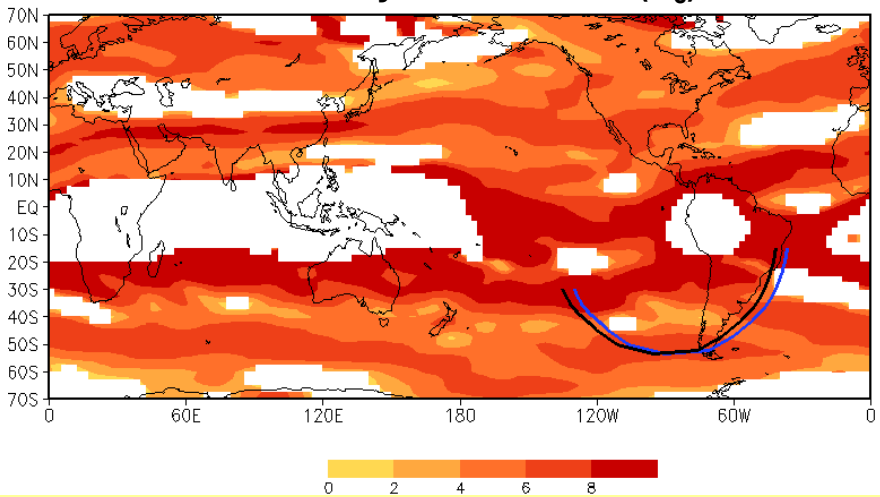
Zonal wind (m/s)



Meridional vorticity gradient (10^{-11} $s^{-1}.m^{-1}$)



Stationaly wave number (K_s)



Acknowledgments:
Simone Ferraz

• **Rossby wave paths (ray tracing, K=3) starting from the region identified as Rossby wave source ilustrating extratropical teleconnection from the Pacific to South America**

Vertical velocity (omega) anomalies between 15°S and 25°S: JFM 2014

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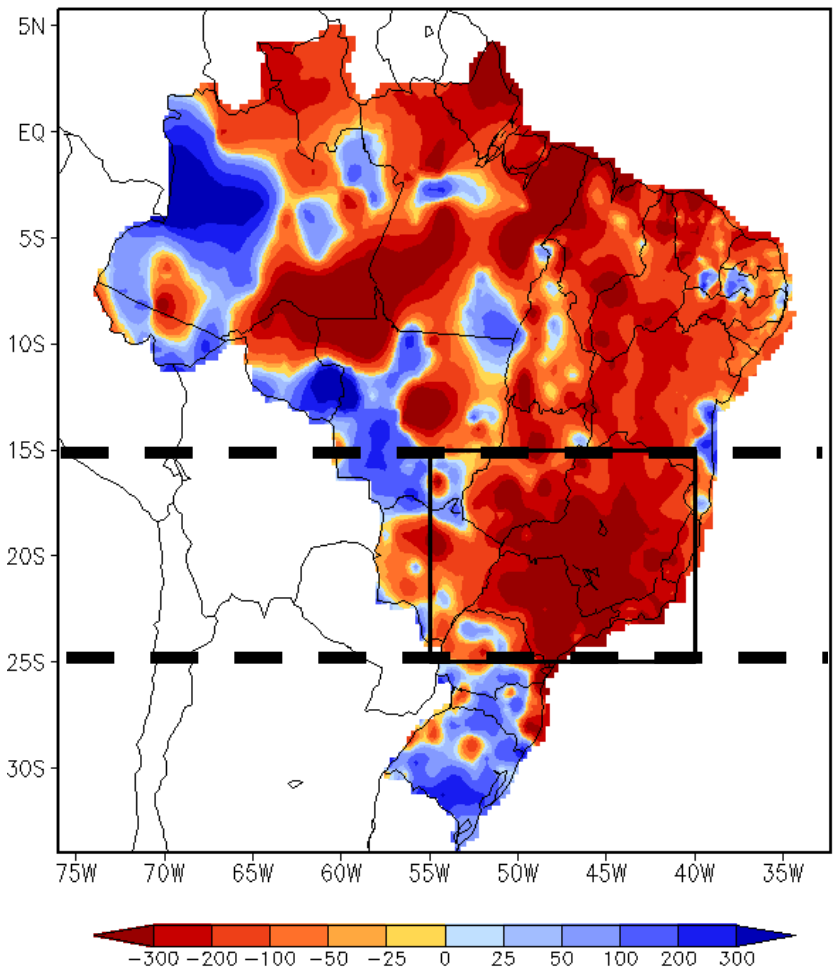
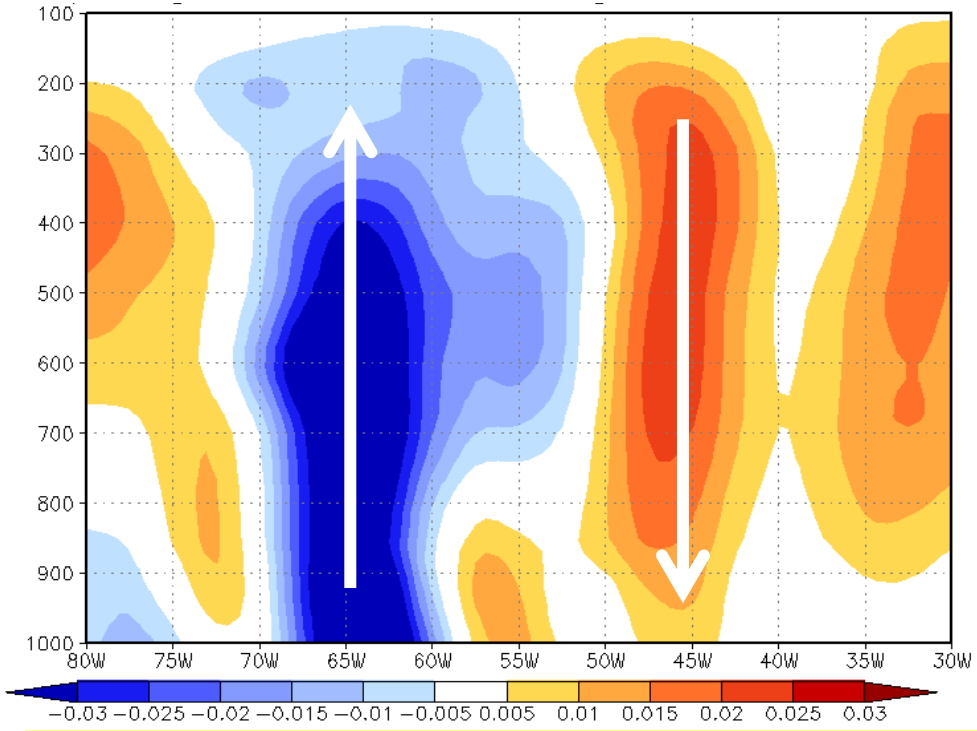
Precip.anomaly (mm): JFM 2014



Subsidence region consistent with precip. deficit

Vert. velocity anoms. JFM 2014: ave. btw. 25°S - 15°S



- Pos. anoms. btw 50°W and 30°W (SE Brazil region and Atlantic): anomalous descending vertical motion (subsidence unfavorable for cloud formation and precipitation)
- Neg. anoms. btw 70°W and 60°W (Paraguay, SE Bolivia and N Argentina): anomalous ascending vertical motion (favorable conditions for convection)
- Local Walker cell

Vertical velocity (omega) anomalies between 55°W and 40°W : JFM 2014

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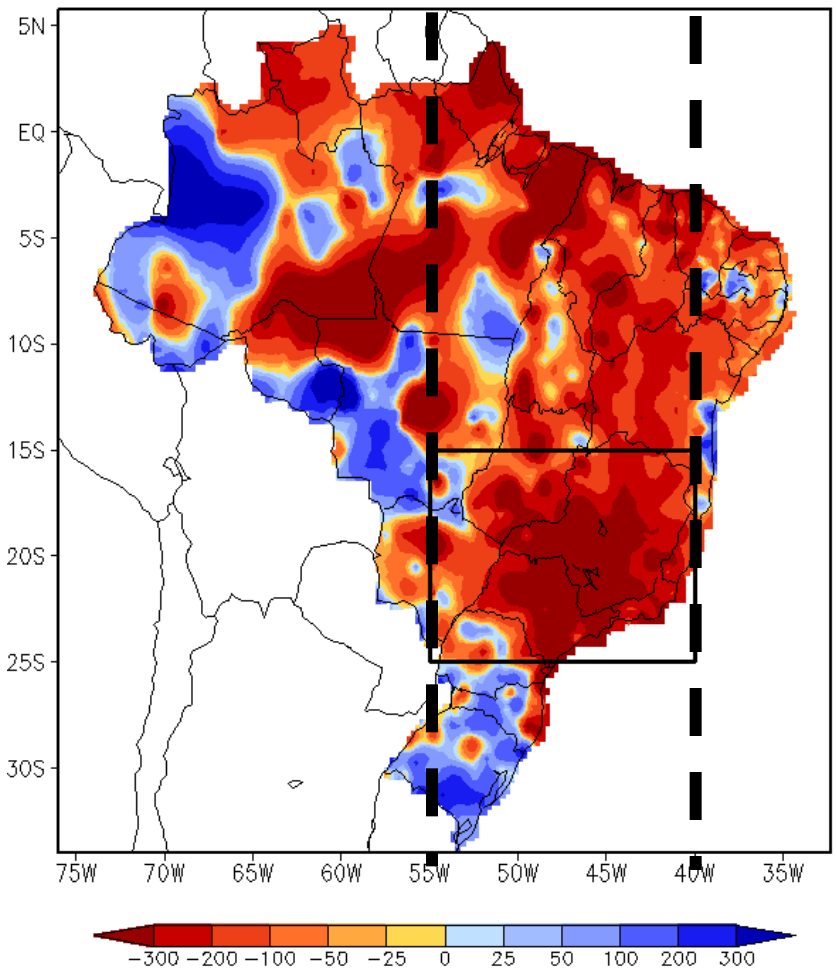
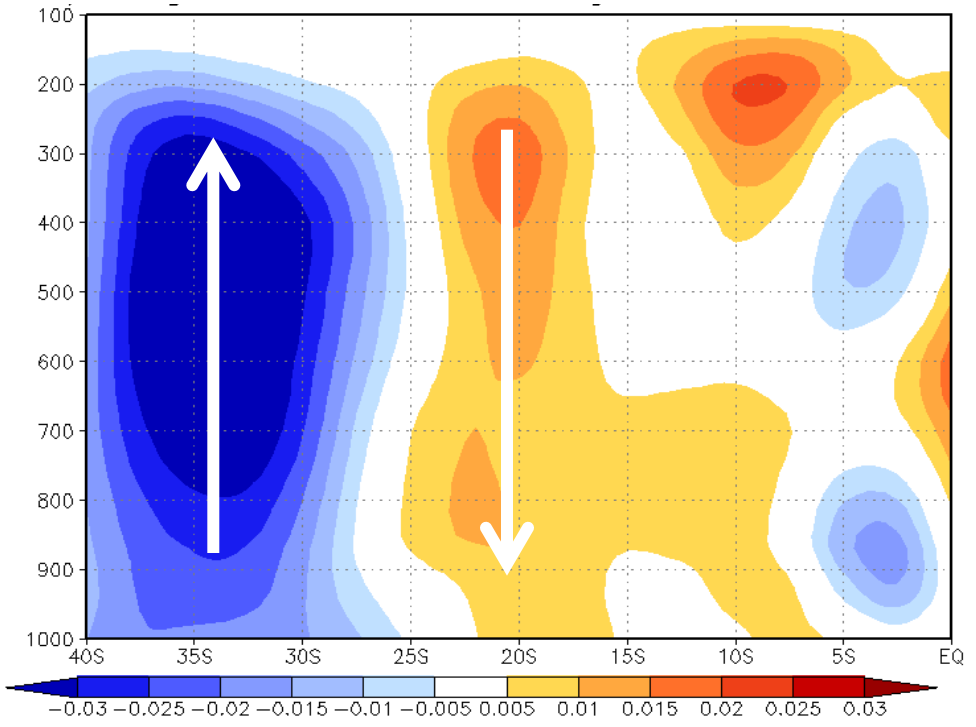
Precip.anomaly (mm): JFM 2014



Subsidence region consistent with precip. deficit

Vert. velocity anoms. JFM 2014: ave. btw. 55°W - 40°W



- Pos. anoms. btw 5°S and 25°S (NE and SE Brazil regions): anomalous descending vertical motion (subsidence unfavorable for cloud formation and precipitation)
- Neg. anoms. btw 28°S and 40°S (Atlantic): anomalous ascending vertical motion (favorable conditions for convection)
- Local Hadley cell

Specific humidity and circulation (850 hPa) anomalies: JFM 2014

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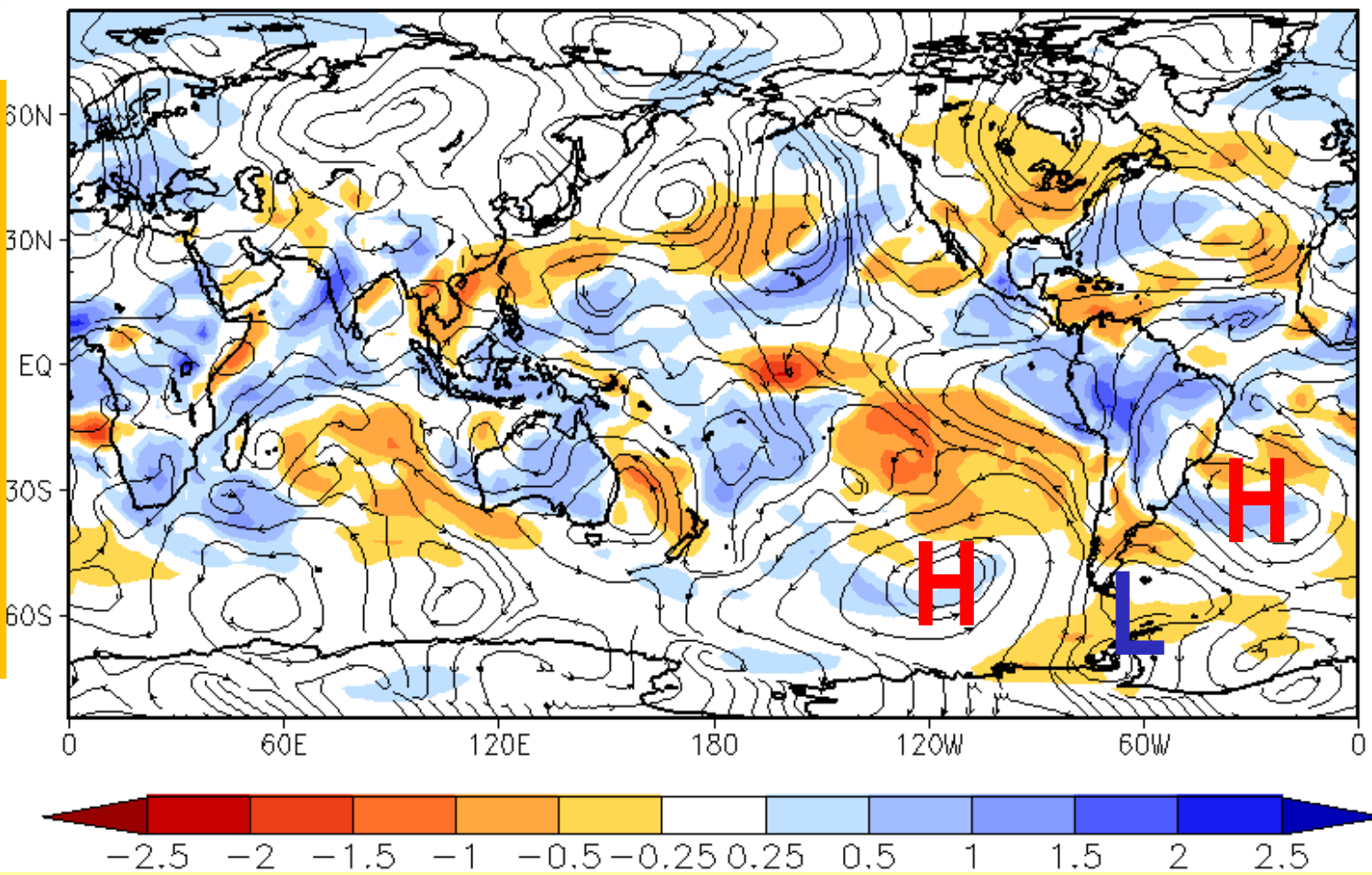
- High pressure blocks low pressure (frontal systems) trajectories
- High pressure over warm Atlantic contributes to maintain surface ocean heating due to prevailing clear sky conditions (direct solar radiation over ocean surface)
- Absence of humidity transport towards SE Brazil: reduction of SACZ events



- Anoms: Anticiclonica (high pressure):Pacific and Atlantic; ciclonic (low pressure): South Atlantic anticiclonic anomaly extends over SE Brazil
- Positive humidity anomalies (Amazon), and negative humidity anomalies (SE South America)
- Northerly anomalous humidity transport: from Amazon towards the South
- Atlantic anticiclone circ. anom favours transp. of neg. umidity anomalies towards SE Brazil

What have we learnt with this analysis of the 2014 southeast Brazil drought?

Equatorial heat source north/northeast of Australia

↓ Tropical teleconnection (Walker circulation)

Upper level convergence and subsidence in central/eastern equatorial Pacific

↓ Tropical-extratropical teleconnection (Hadley circulation and Rossby wave)

Stationary u-shaped wave-like pattern towards South America

↓ Barotropic wave structure

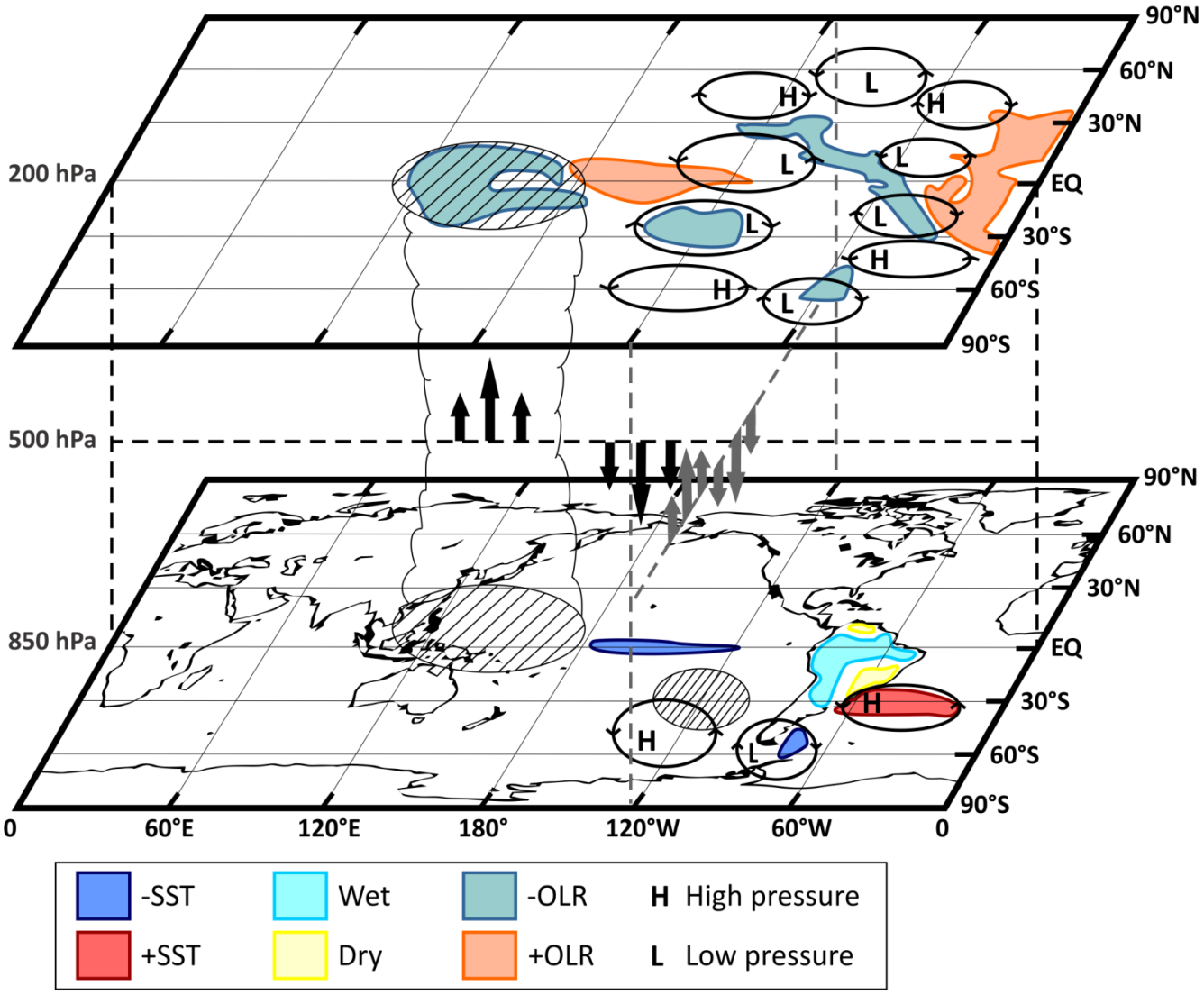
Anomalous high pressure centres over Pacific and Atlantic in the vicinities of South America, and anomalous low pressure centre in southern tip of South America

↓ Blocking high pressure, radiative and humidity transport effects

Anomalous Atlantic high pressure centre blocks migration of low pressure (frontal) systems and favours maintenance of warm sea surface temperatures near the coast of southeast Brazil. Associated anomalous anticyclone circulation extends over the southeast region of Brazil and transports drier than normal air from the Atlantic towards the southeast region of Brazil and more humid than normal air from the Amazon toward southern Brazil. Consequently, less South Atlantic Convergence Zone episodes are observed.

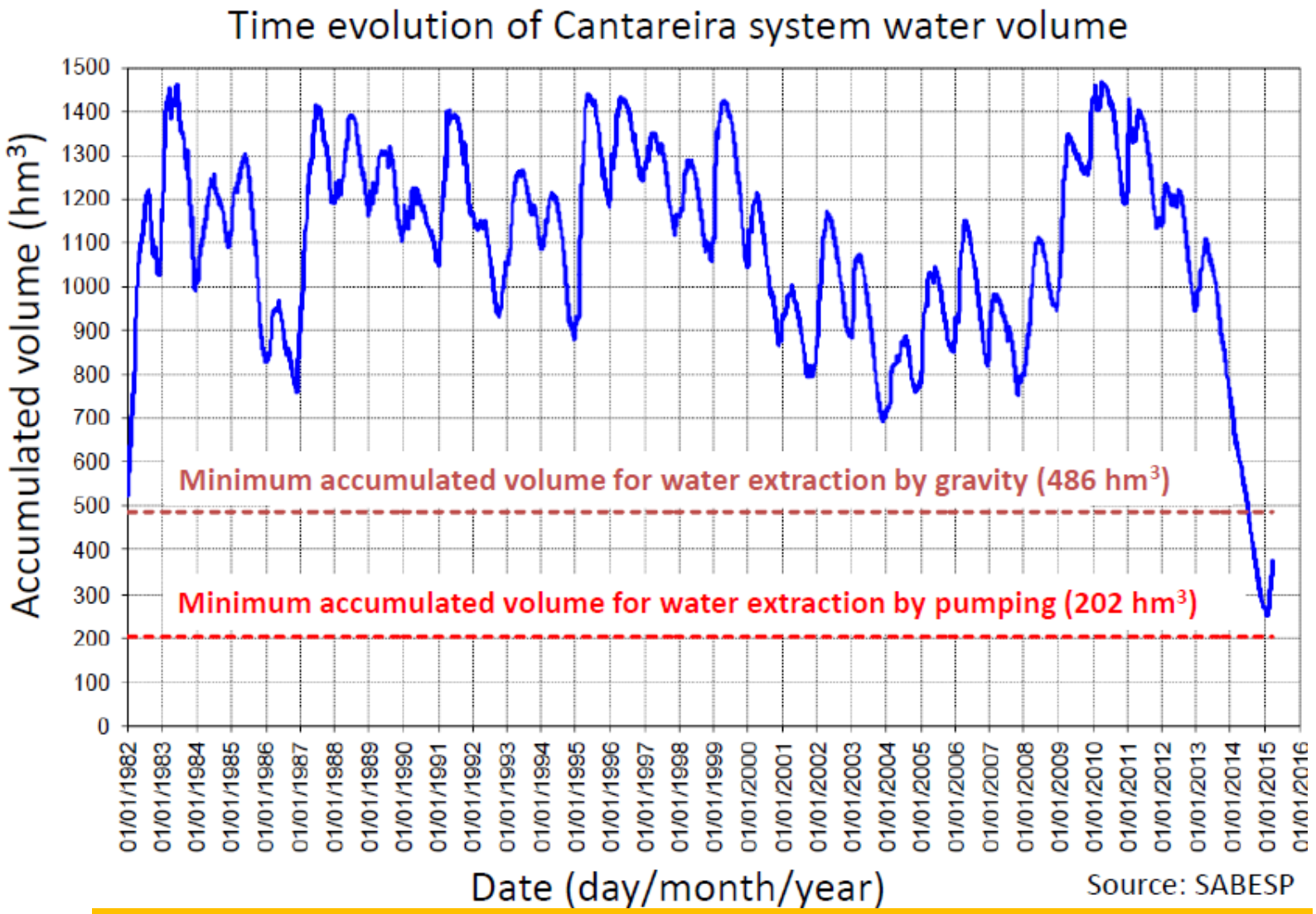
Schematic diagram for the occurence of the summer 2014 southeast Brazil drought

www.cptec.inpe.br



What is the role of human-induced changes in our climate in the 2014/2015 water shortage?

www.cptec.inpe.br



Strategy: Investigate this using three independent methodologies

Observed precipitation conditions during the 14-month period Jan 2014 to Feb 2015

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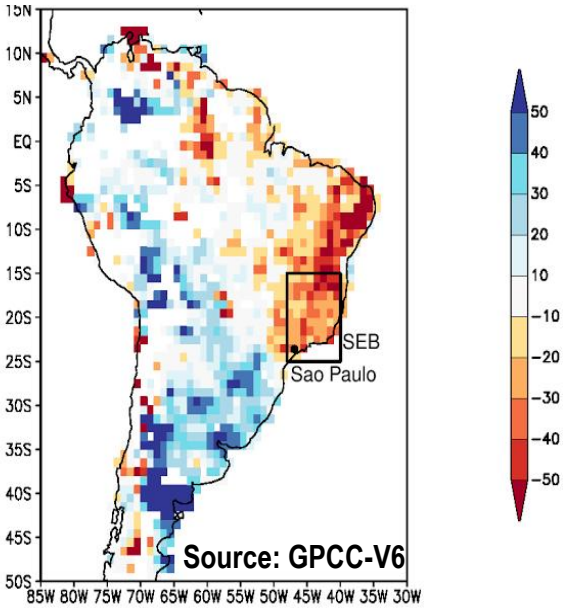
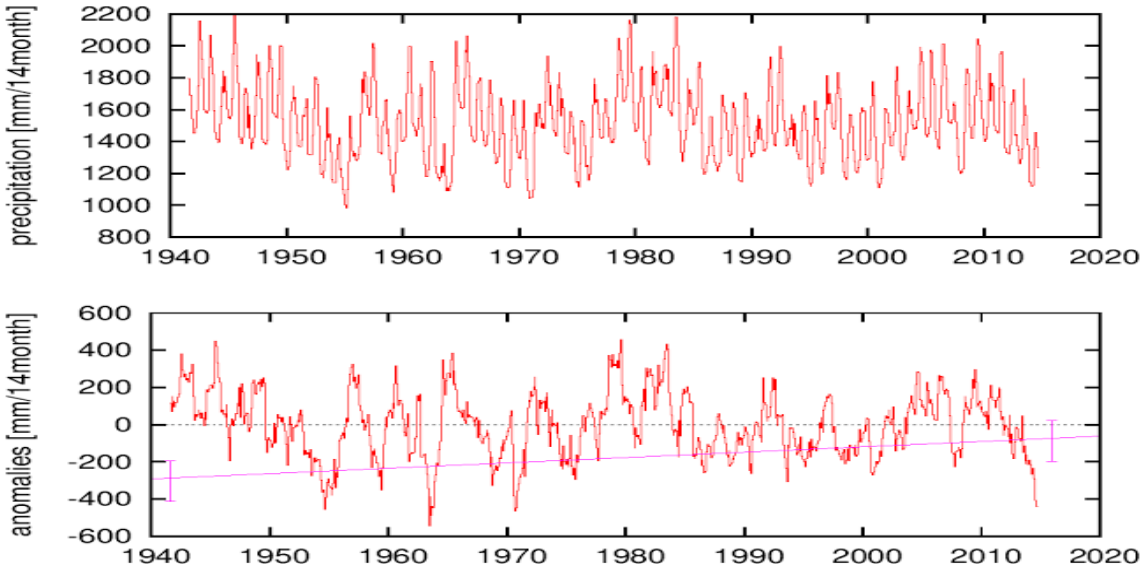
Jan 2014 to Feb 2015 precipitation anomaly [%]

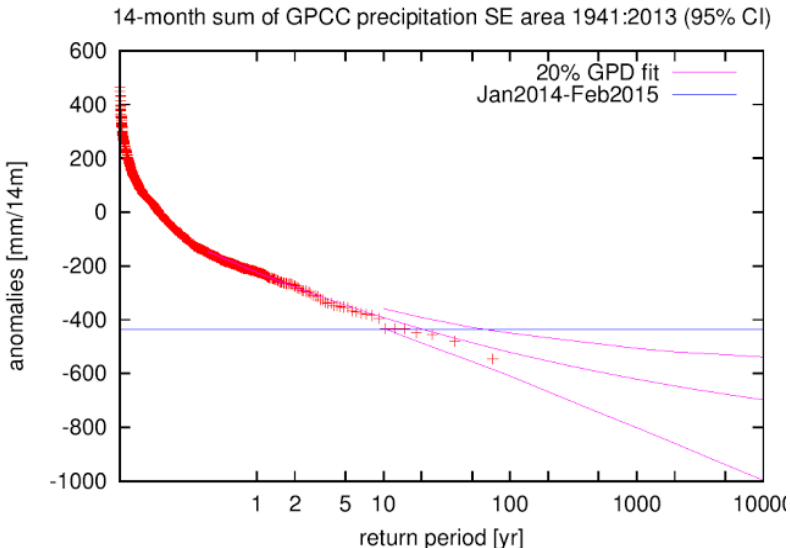




How does SEB precip. behaved in previous years?

- 2014/15 SEB deficit is similar to previous events
- 1963, 1970 and 1954 more severe than current
- GPD fit to the driest 20% records:

The Jan2014–Feb2015 deficit (435 mm) return period is about 20 years



Investigating possible precip. and precip. minus evap. (P-E) changes in climate simulations

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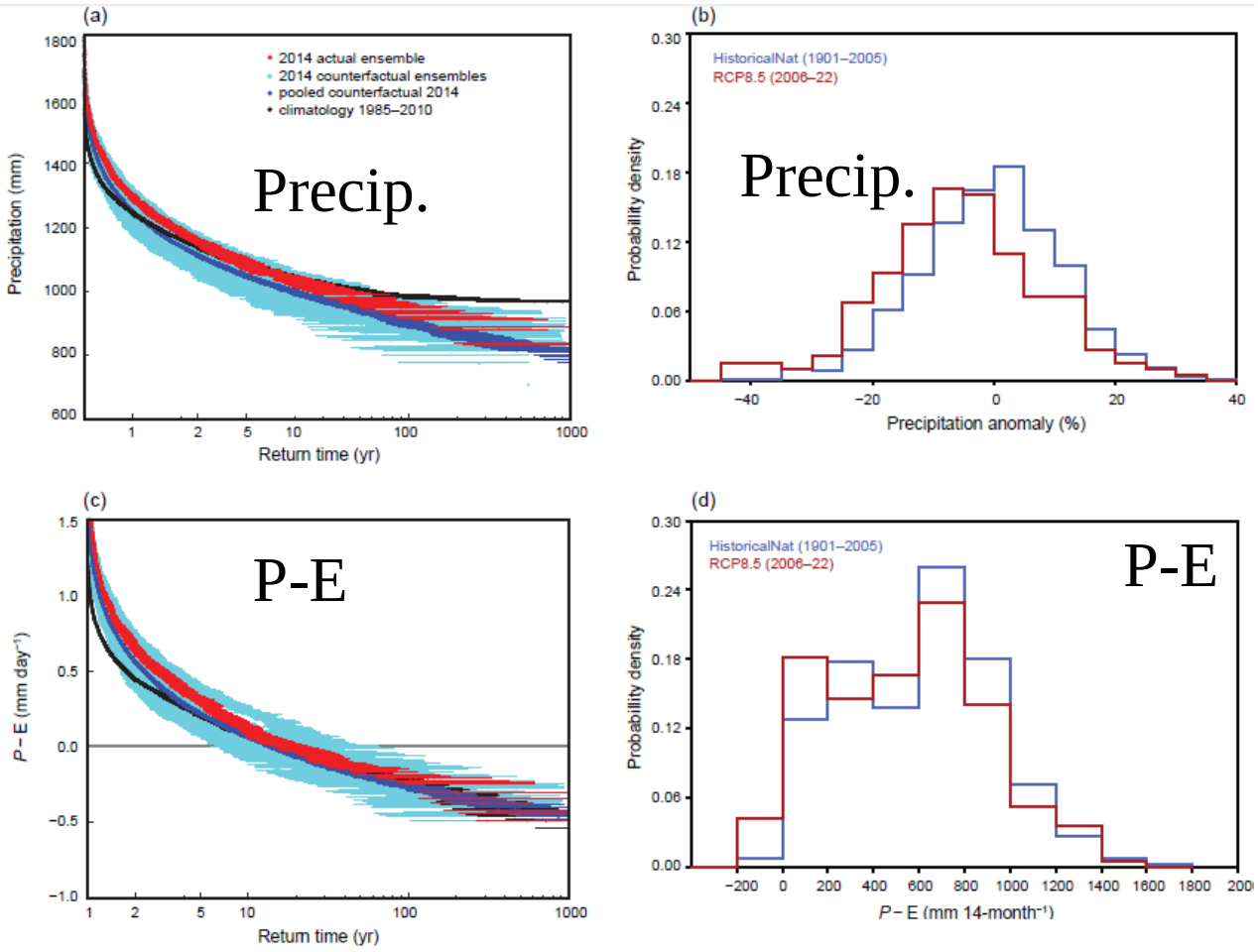
How does climate risk change due to human activities?

- Distributed computing framework weather@home used to run the Met Office Hadley Centre AGCM HADAM3P
- Simulate possible precipitation and P-E in two different model ensembles representing:

1) obs climate cond. of 2014/2015 (red lines in panels a and c),
2) counterfactual conditions under pre-industrial greenhouse gas forcings and 11 different estimates of SSTs without human influence (dark blue line in panels a and c)



• Dry precip. extremes *less* likely due to human greenhouse gas emissions: 1 in 20 year precipitation deficit event like the 14-month 2014/15 event has become approx. a 1 in 30 year event

• No detectable change in P-E due to human-induced climate change: increase in evaporation cancels the increase in precipitation (also confirmed by similar analysis of CMIP5 models)

Population and water consumption time evolution in the Metropolitan region of São Paulo

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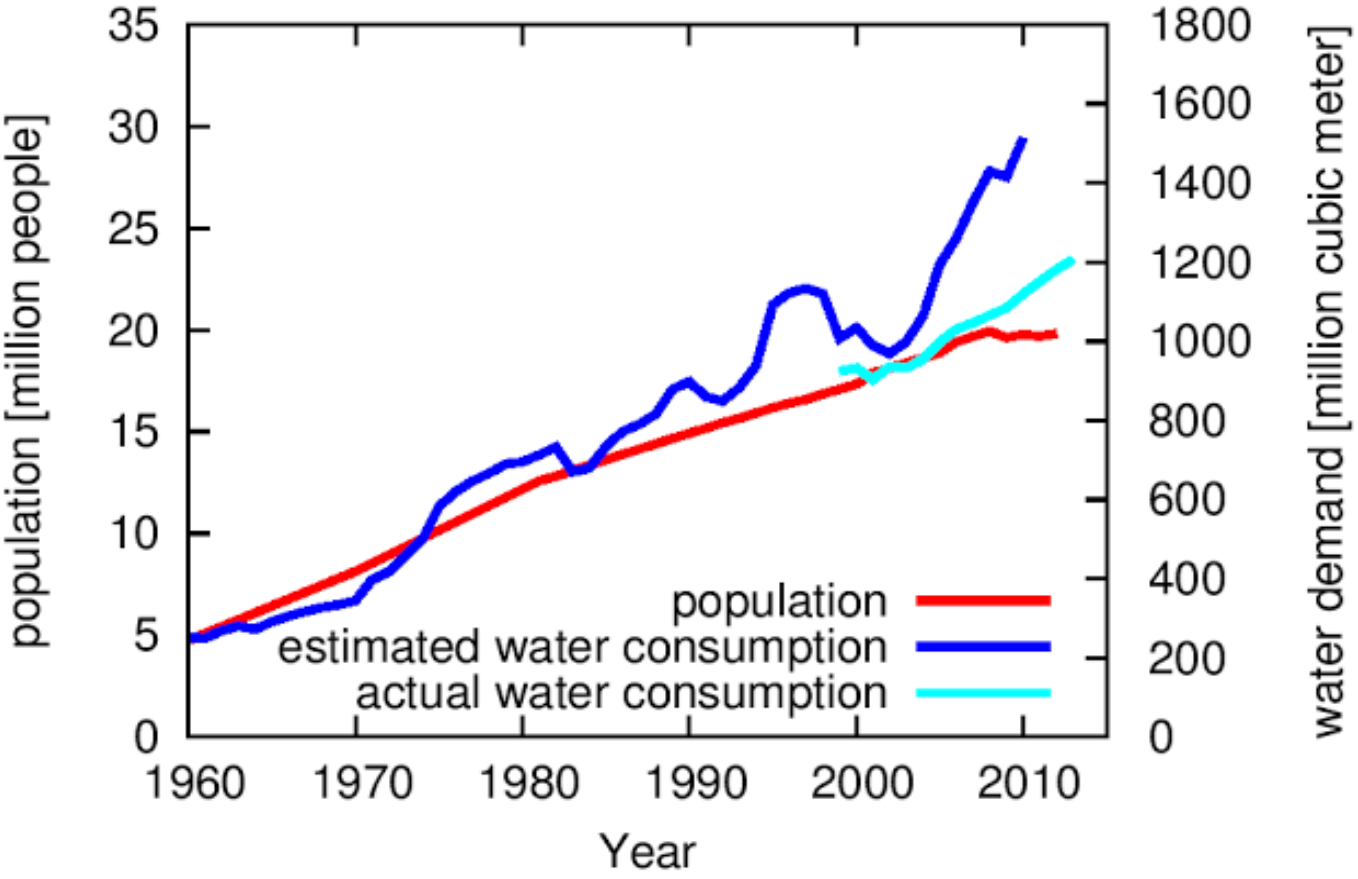
If climate risk has not suffered major changes due to human activities, what contributed to the observed impact (water shortage)?



Increasing population and water consumption, not climate change, was most likely the main contributor to the 2014/2015 water shortage in São Paulo

Summary

- SE Brazil region experienced a remarkable drought period

- Water crisis leading to several questions and social impacts

- Summer 2013/2014: classified as exceptionally dry with very early rainy season demise (absence of SACZ episodes in 2014)

- Summer 2014/2015: classified as very dry (less severe than 2013/2014)

-Region experiencing precip. deficit since late nineties

- Causes of summer 2014 drought:

-Teleconections (tropical and extratropical) leading to anomalous high pressure system over the warm Atlantic ocean near SE Braziil region, which block frontal systems, favoring maintainance of warm sea surface temperatures (solar radiation) and unfavoring SACZ formation

- Was is possible to detect the human contribution to the 2014/2015 drought?

- Not possible to detect contribution on climate risk. Increase in population and water consumption were most likely the main factors behind the established water crisis in São Paulo in 2014/2015

Thank you for your attention!