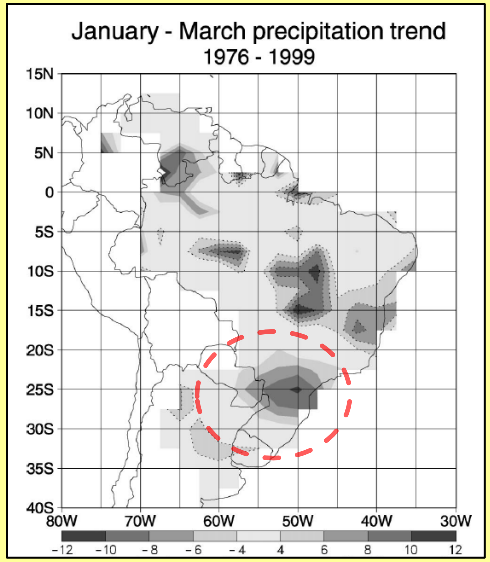
The influence of the Atlantic Multidecadal Oscillation on the eastern Andes low-level jet and precipitation in South America

Charles Jones
Dept. of Geography and Earth Research Institute
University of California, Santa Barbara CA

Acknowledgements: Professor Leila Carvalho, Dept. of Geography University of California Santa Barbara

Precipitation Changes in South America

Liebmann et al. 2004:
- **Significant positive trend in Jan-Mar precipitation**
- **(rain gauge data)**



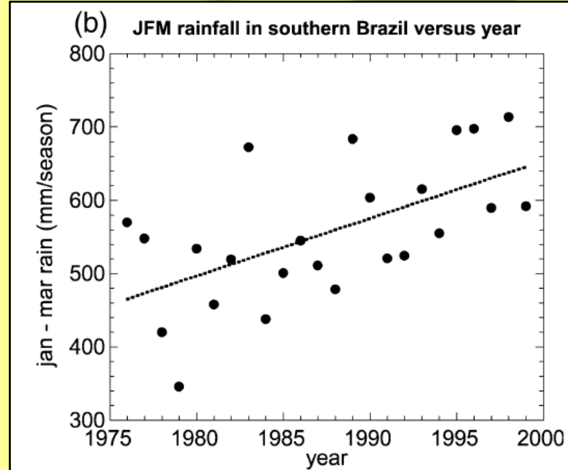
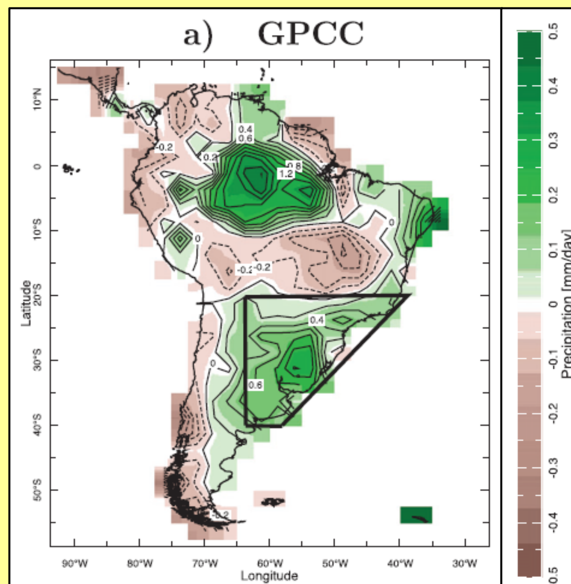
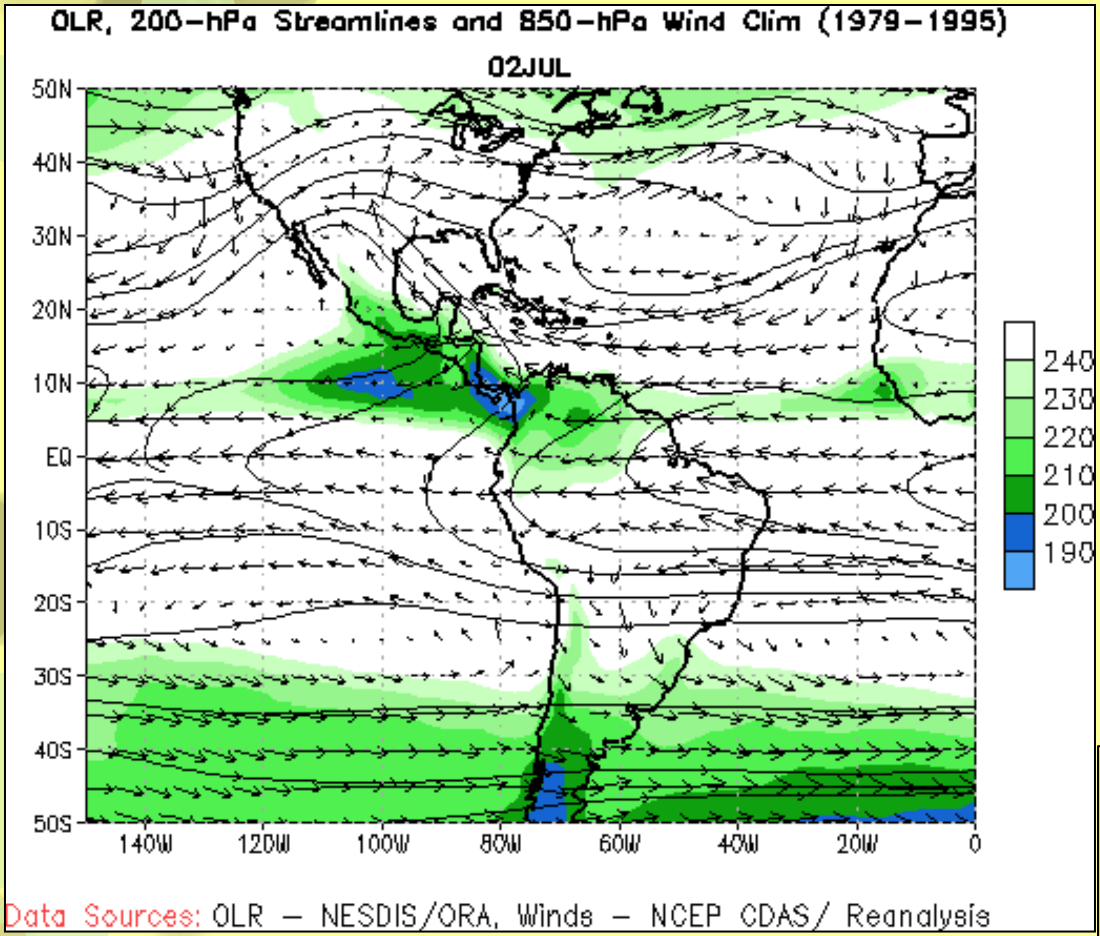


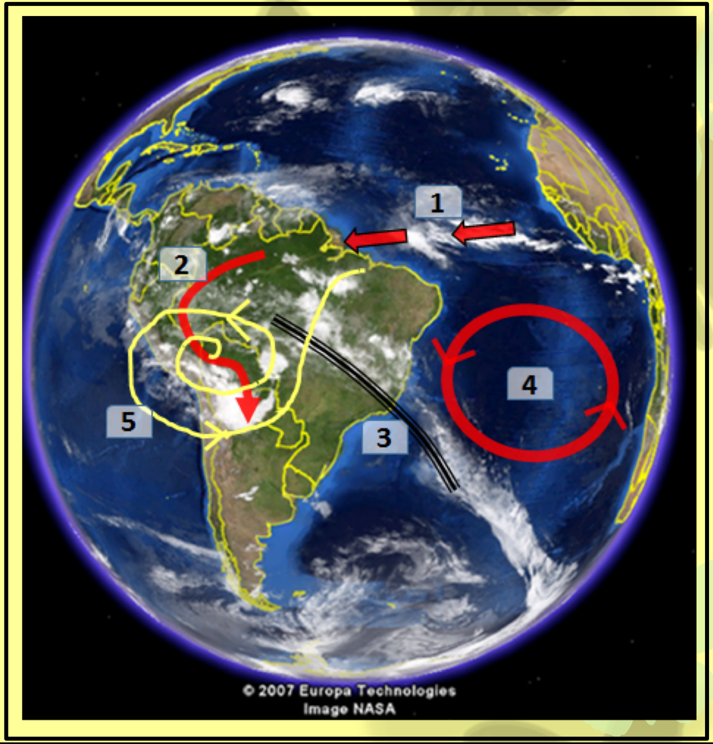
FIG. 3. (a) Climatology of monthly rainfall in southern Brazil (mm month^{-1}). (b) JFM rainfall (in mm season^{-1}) in southern Brazil vs year. Dashed curve represents linear, least squares fit.

Seager et al. 2010:
- **Positive trend in annual precipitation**
- **Warm SST in subtropical Atlantic**
- **Cool tropical Atlantic (AMO^{-})**



South America Monsoon System (SAMS)



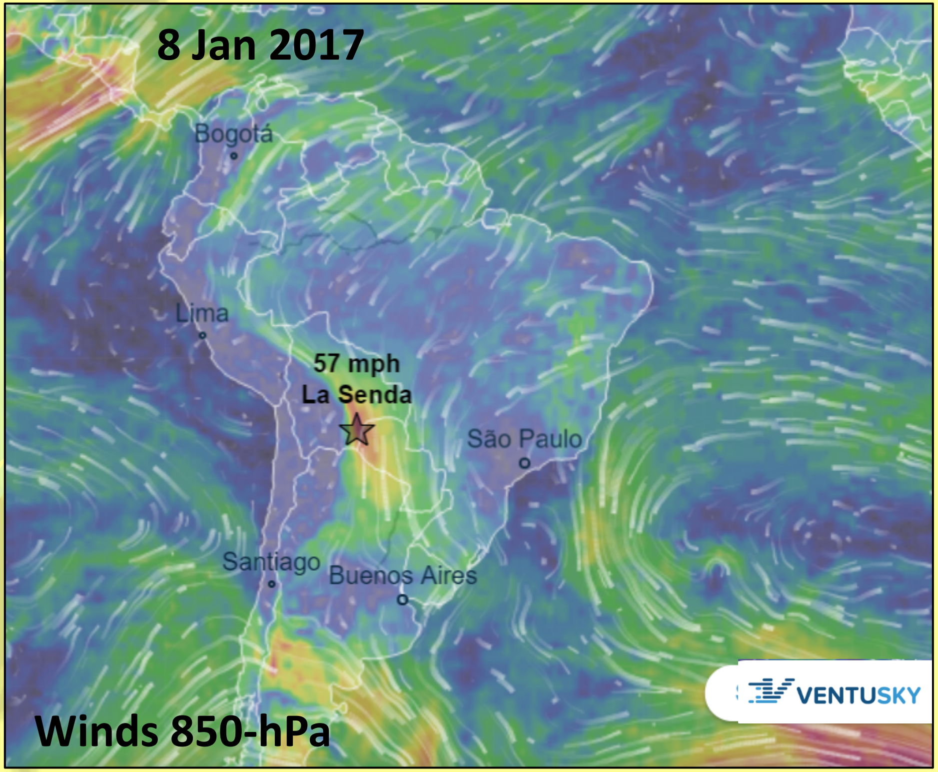


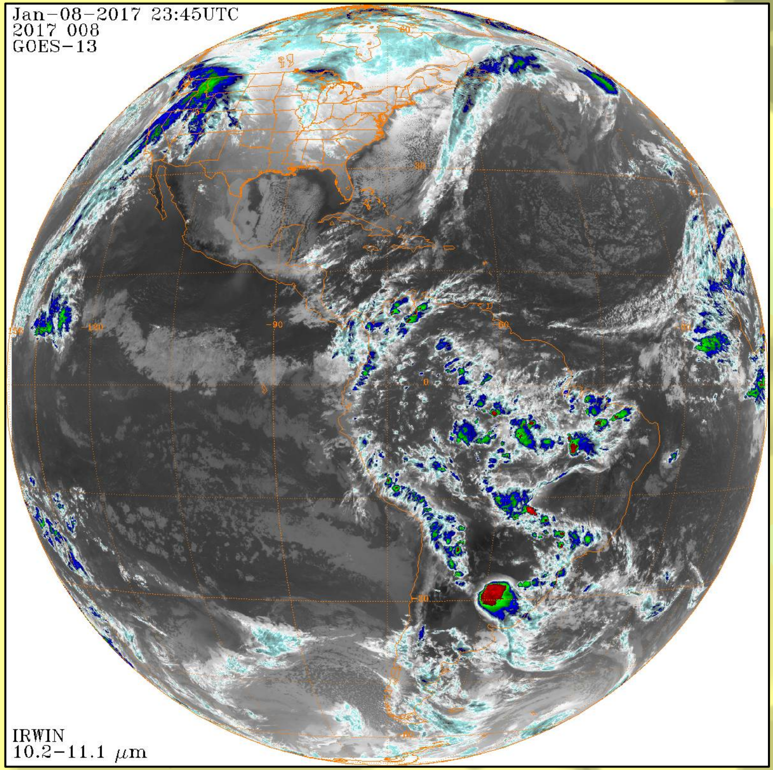
1. Easterly winds
2. South America low-level jet (SALLJ)
3. SACZ
4. South Atlantic subtropical high-pressure
5. Upper-level Bolivian High

Jones, C., and L. M. V. Carvalho, 2013: Climate change in the South American Monsoon System: present climate and CMIP5 projections. *Journal of Climate*

South America Low-level Jet (SALLJ)

- Low-level jet: maximum winds 500-1600 m a. g.
- Max wind speeds near Bolivia ("Andes elbow")
- Nocturnal: maximum winds 8 PM- 2AM Bolivia local time
- Transports large amounts of moisture
- Form mesoscale convective complexes
- Present year round (<u>unlike Great Plains LLJ</u>)

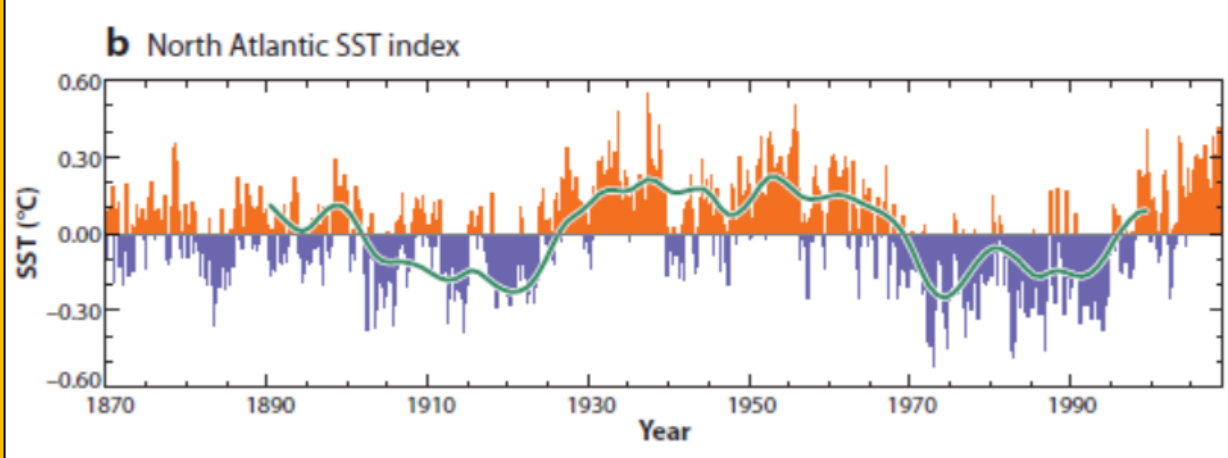


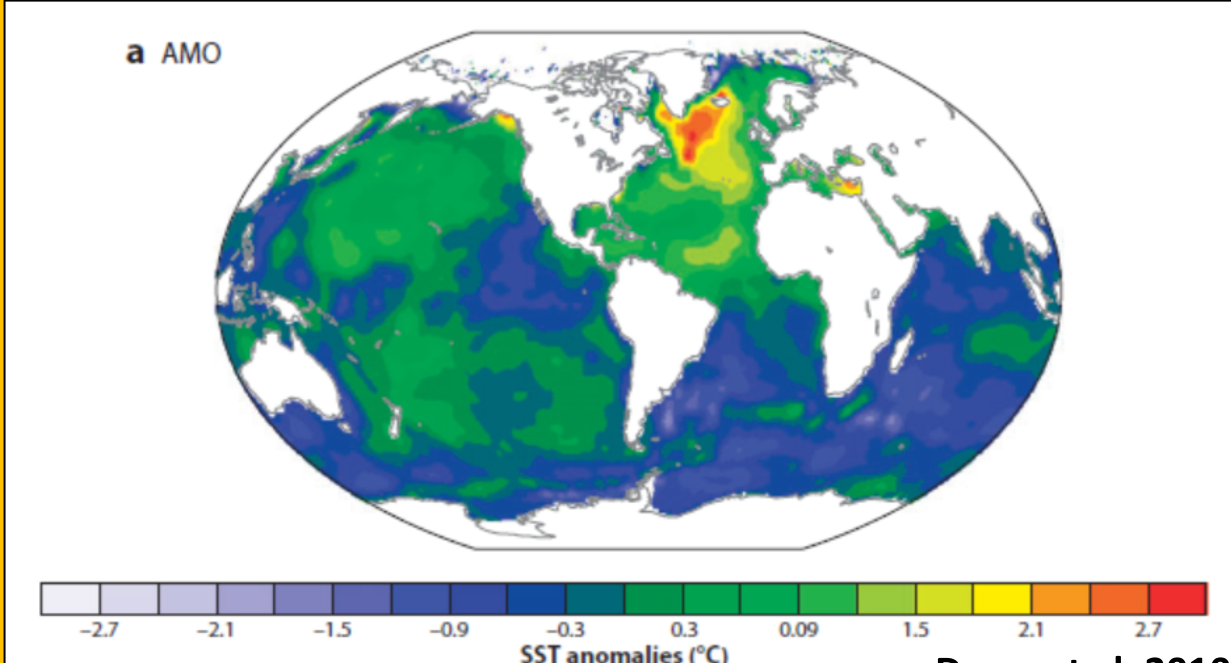


The Atlantic Multidecadal Oscillation (AMO)

AMO

- Positive/cold phase ⇒ warm/cold North Atlantic
- Instrumental record: 60-80 year period
- Positive: ~1924-1965
- Negative: ~1966-1996
- Precipitation changes Sahel, southeast US, northeast Brazil
- Natural mode of Atlantic Meridional Circulation (AMOC)
- Paleoclimate evidence
- In a few coupled models [e.g., HadCM3, Knight et al, 2006]





Deser et al. 2010

Multidecadal variations in South America

Several studies show significant influence of the AMO on precipitation variability in South America:

- **Northeast Brazil [e.g., Kayano et al. 2014, 2016, 2018]**
- **Positive trend in La Plata River Basin [e.g., Seager 2010]**
- **Speleothem records in Botuvera, southern Brazil show 60-80 yr variations [~8000 years record; Bernal et al. 2016]**
- **Discharge sediments in La Plata River drainage show 60-80 yr variations [~4500 years record; Chiessi et al. 2009]**

The AMO, SALLJ and Precipitation in South America

AMO = Atlantic Multidecadal Oscillation

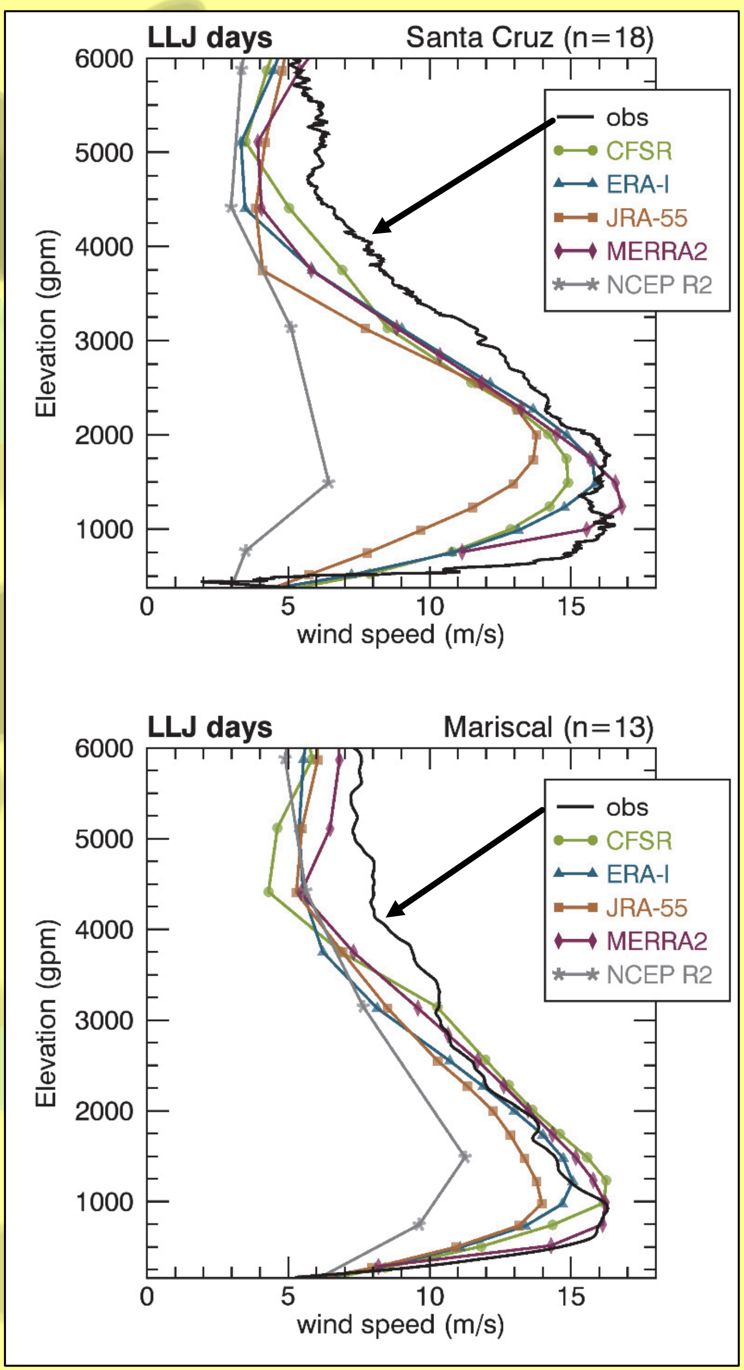
- **Is the AMO related to decadal-to-multidecadal variations in the SALLJ?**
- **How does the AMO relate to the SALLJ and precipitation variations in South America?**

Jones, C. and L. M. V. Carvalho, 2018: The influence of the Atlantic Multidecadal Oscillation on the eastern Andes low-level jet and precipitation in South America. *Nature Clim. Atmos. Sci*. (In Press)

Data

- European Centre for Medium-Range Weather Forecast Reanalysis of the 20th Century (ERA20C)
    - 3-hourly, ~125 km
    - January 1900- December 2010
    - U, V at 850-hPa, 700-hPa and precipitation
- ERA20C assimilates only surface and mean sea level pressure, and surface marine wind observations

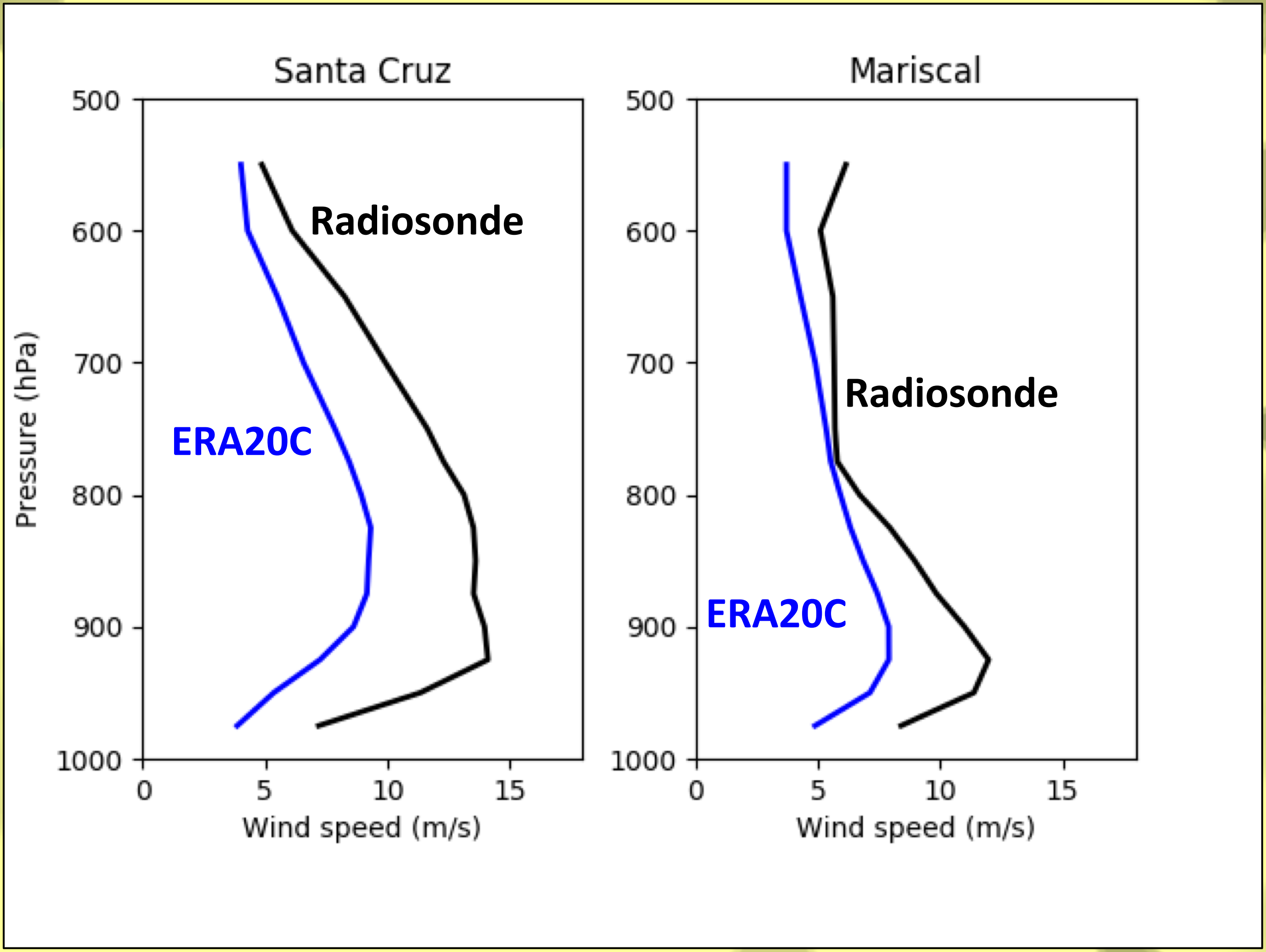
➡ **How reliable is the ERA20C over South America?**



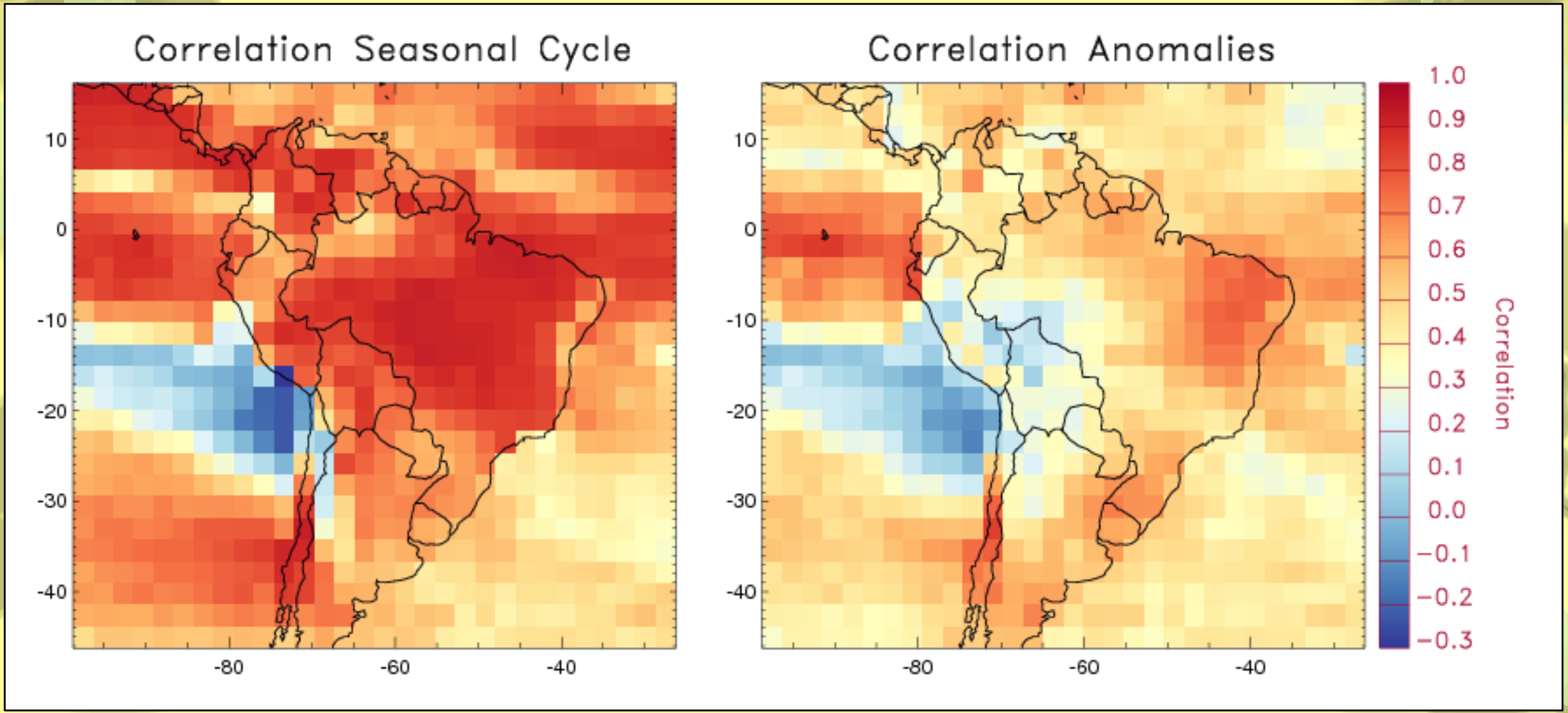
Vertical profiles of mean wind speed (m s^{-1}) at 06 UTC near Santa Cruz (*top*) and Mariscal (*bottom*). Profiles are averaged over all SALLJ days identified during the SALLEX field campaign for which observations are available. Radiosonde profiles are in black and reanalysis profiles are colored according to the legend.

Climatology, variability and recent changes in the SALLJ *Montini et al. (2018), JGR (submitted)*

Mean vertical wind speed profiles over Santa Cruz de la Sierra (Left) and Mariscal Estigarribia (right): January-February 2003



Correlation between ERA20C and GPCP precipitation during January 1979-December 2010



Correlation with rain gauge data (1900-2010):

- **Fortaleza 0.77**
- **Quixeramobim 0.75**

Methods

- European Centre for Medium-Range Weather Forecast Reanalysis of the 20th Century (ERA20C)
  - 3-hourly, ~125 km
  - January 1900- December 2010
  - U, V at 850-hPa, 700-hPa and precipitation
- Detrend 3-hr time series
- Identify SALLJ occurrences with modified Bonner criteria:
  - Northerly winds at 850-hPa $\geq$ Pth ms^{-1}
  - Vertical wind shear [850-700] hPa $\geq$ Pth ms^{-1}
  - v-wind < 0
  - v-wind > u-wind

- Where Pth are 75th seasonal percentiles
  - 6-hourly reanalysis
  - Determined for each location (Santa Cruz, Mariscal) separately
  - Determined for each season separately

Methods

- **Daily SALLJ occurrences in Santa Cruz and Mariscal**
  - **(1 Jan 1900 – 31 December 2010)**
- **Normalized monthly SALLJ index:**

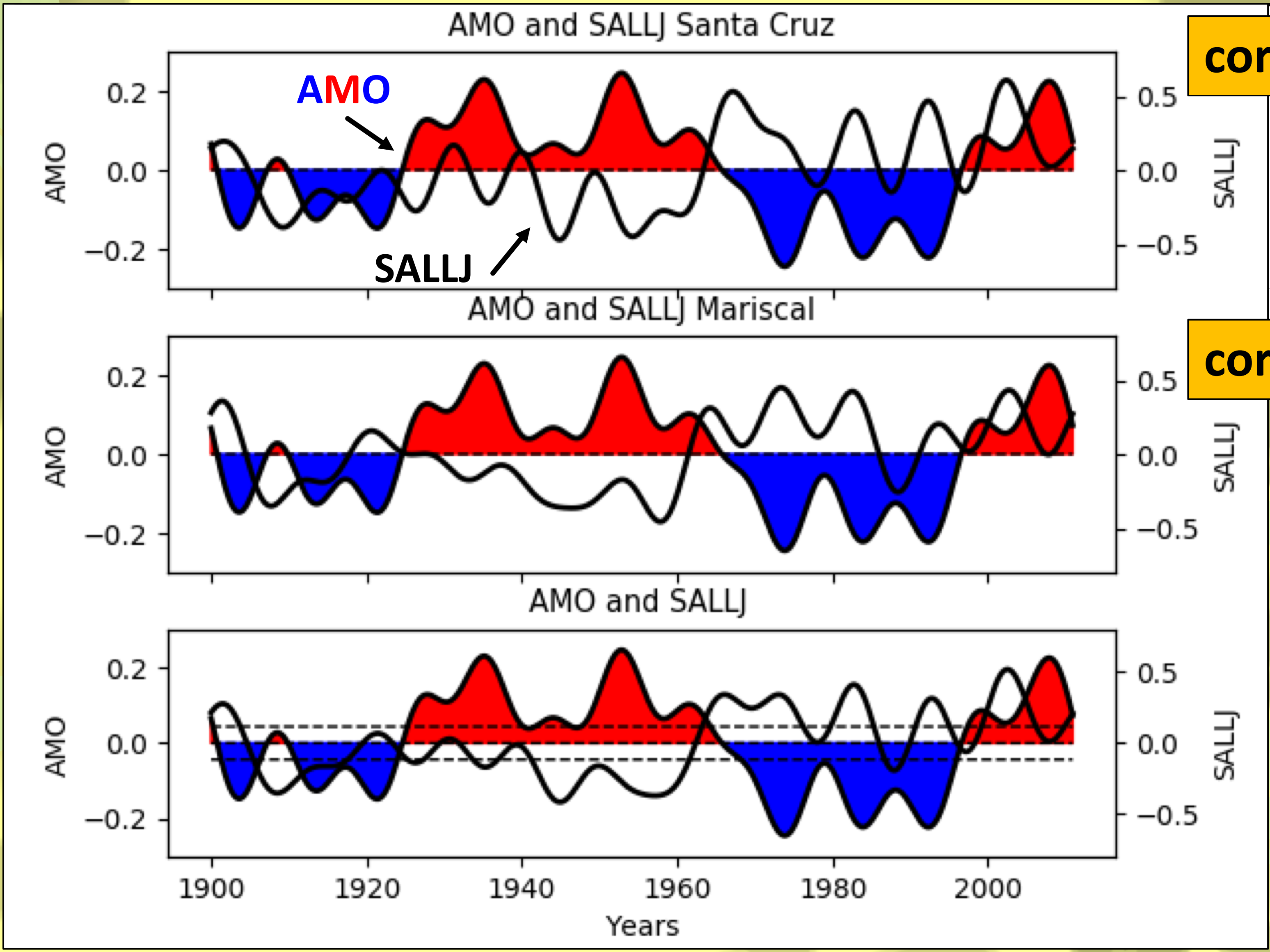
$$SALLJ_{index}(t) = \left[\frac{N\ (t)}{CN}\right] x \left[\frac{VS\ (t)}{CV}\right]$$

N (t)≡ number of SALLJ days in the given month
CN ≡ climatological number of SALLJ days in the month
VS ≡ mean wind speed (850-hPa) of the SALLJ days in the given month
CV ≡ climatological wind speed (850-hPa) of SALLJ days in the month

- **Apply low-pass filter retaining variations > 8 years**

AMO index from Trenberth & Shea: detrended 10-year low-pass filtered (SST) anomalies (HadISST data) over the North Atlantic basin

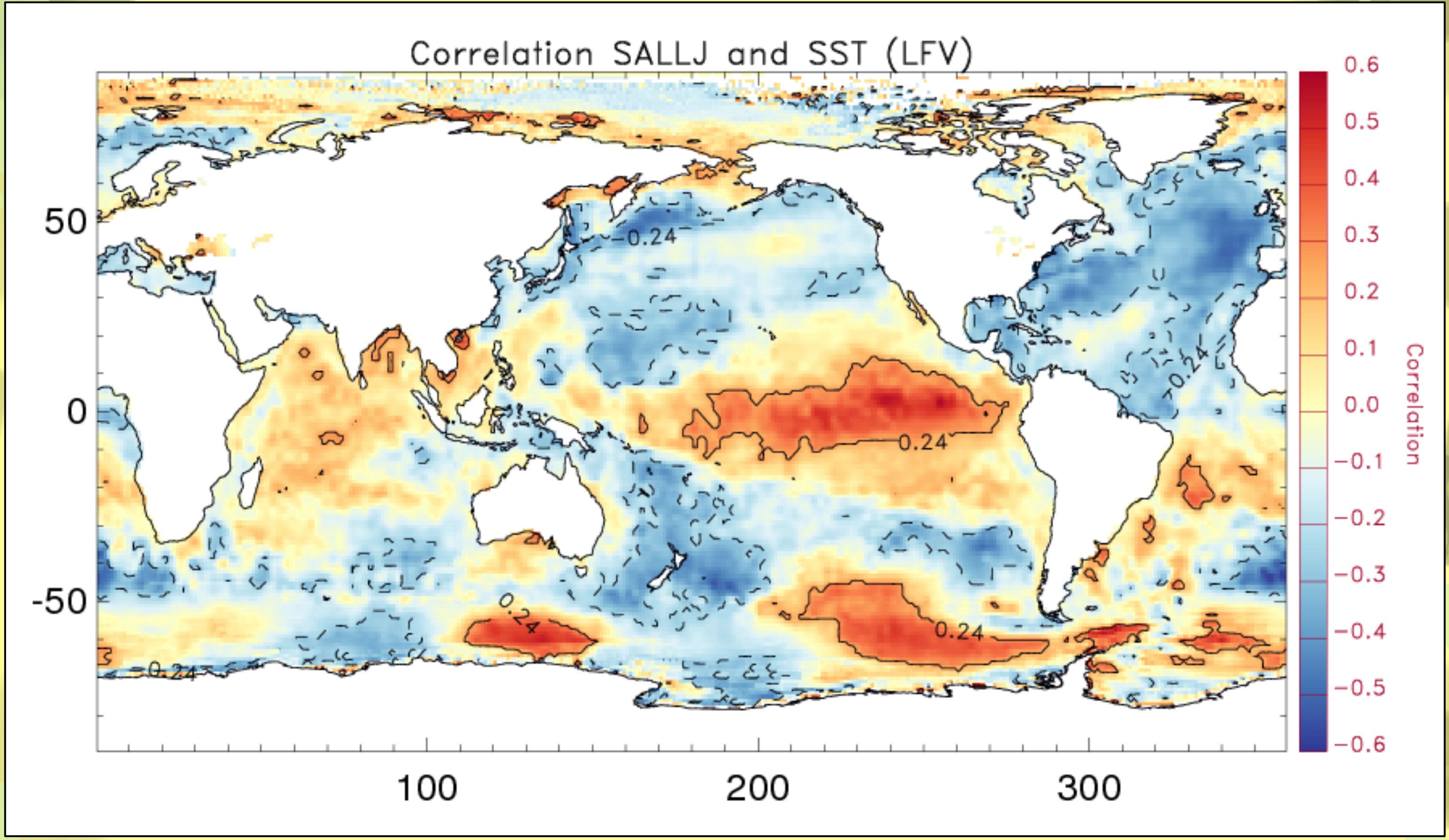
The AMO and SALLJ



cor=-0.35

cor=-0.40

Correlation SALLJ index and SST



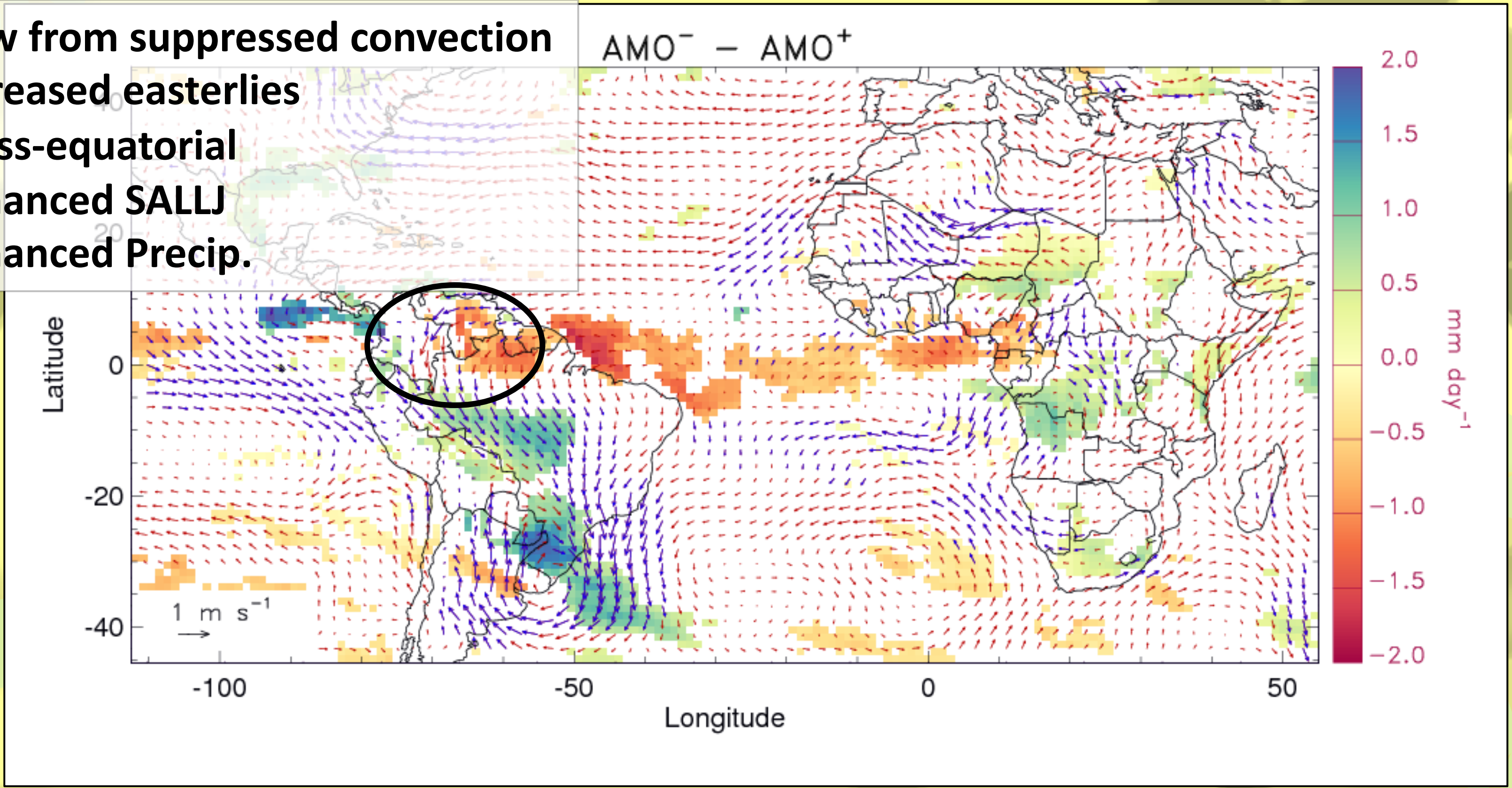
- SALLJ index: no trend, filtered > 8 years
- SST anomalies: no trend, filtered > 8 years

AMO, SALLJ, Circulation, Precipitation

Difference winds (850-hPa) and precipitation [with trends]

AMO$^-$ Nov 1965 – Aug 1996 minus AMO$^+$ Sep 1924 – Oct 1965

Outflow from suppressed convection
- ○ Increased easterlies
- ○ Cross-equatorial
- ⇒ Enhanced SALLJ
- ⇒ Enhanced Precip.



→ Statistically significant

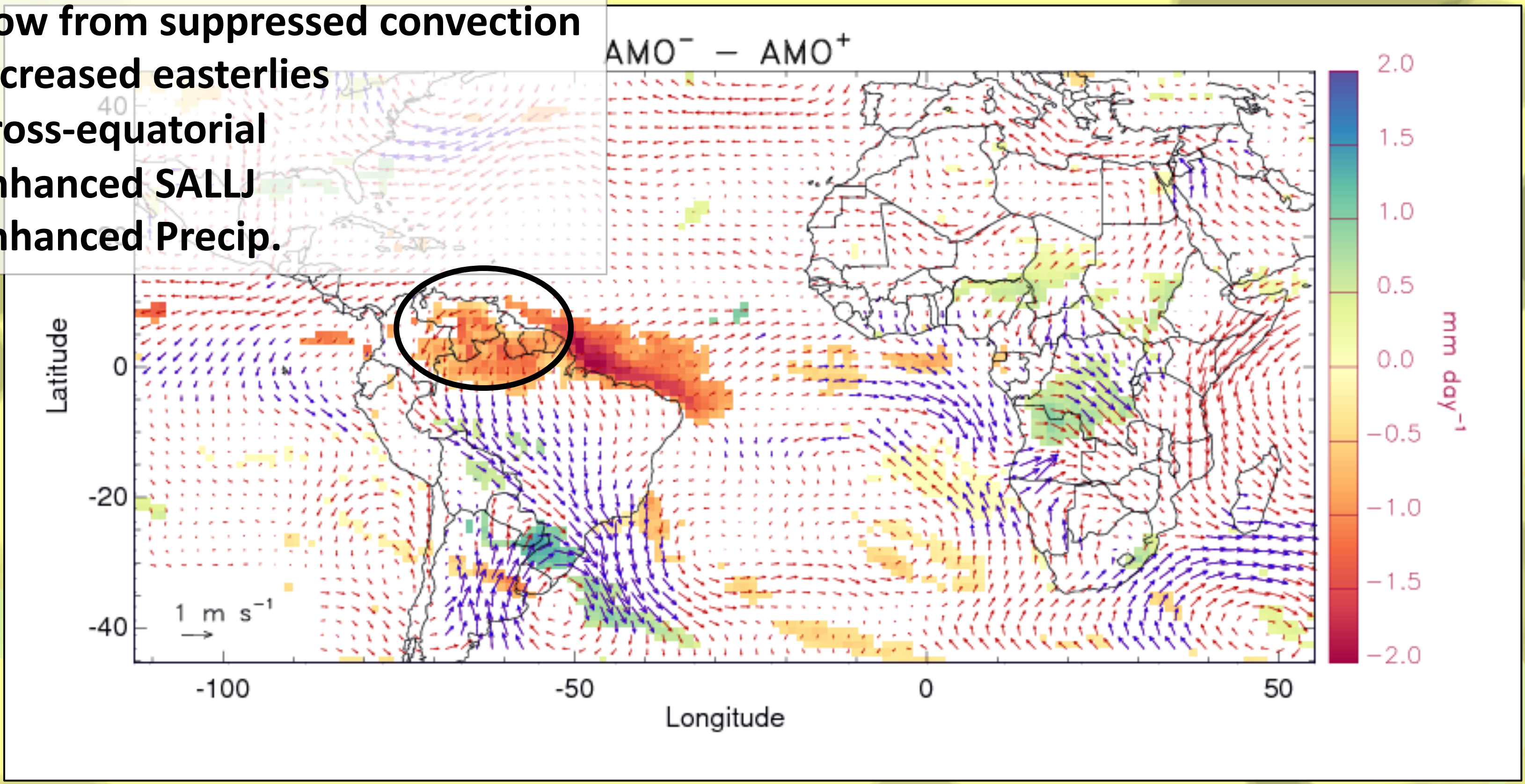
AMO, SALLJ, Circulation, Precipitation

Difference winds (850-hPa) and precipitation [no trends]

AMO⁻ Nov 1965 – Aug 1996 minus AMO⁺ Sep 1924 – Oct 1965

Outflow from suppressed convection

- ○ Increased easterlies
- ○ Cross-equatorial
- ⇒ Enhanced SALLJ
- ⇒ Enhanced Precip.

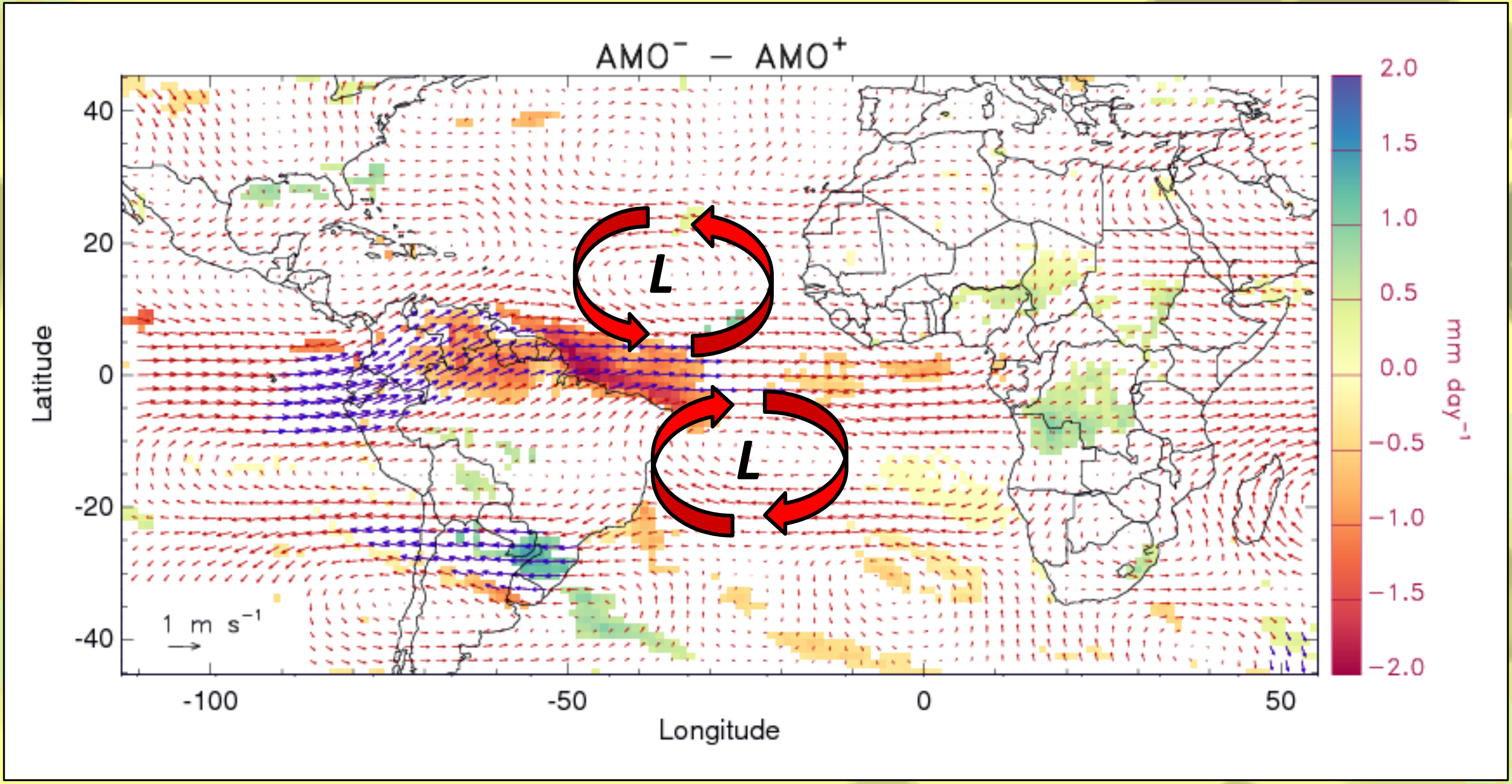


Statistically significant

AMO, SALLJ, Circulation, Precipitation

Difference winds (200-hPa) and precipitation [no trends]

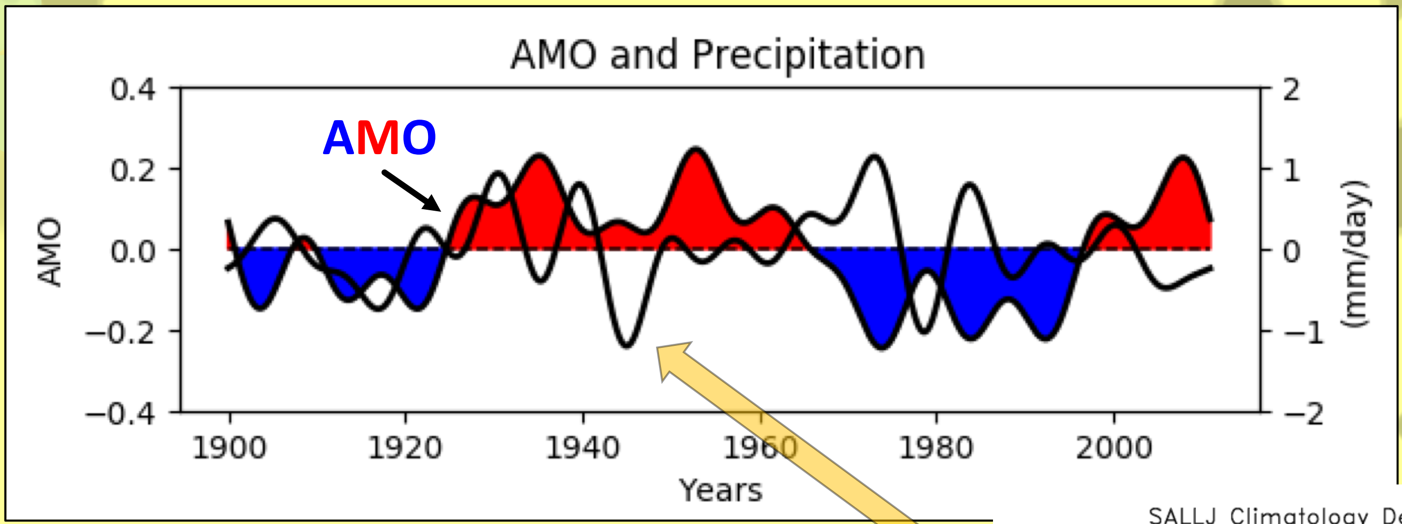
AMO⁻ Nov 1965 – Aug 1996 minus AMO⁺ Sep 1924 – Oct 1965

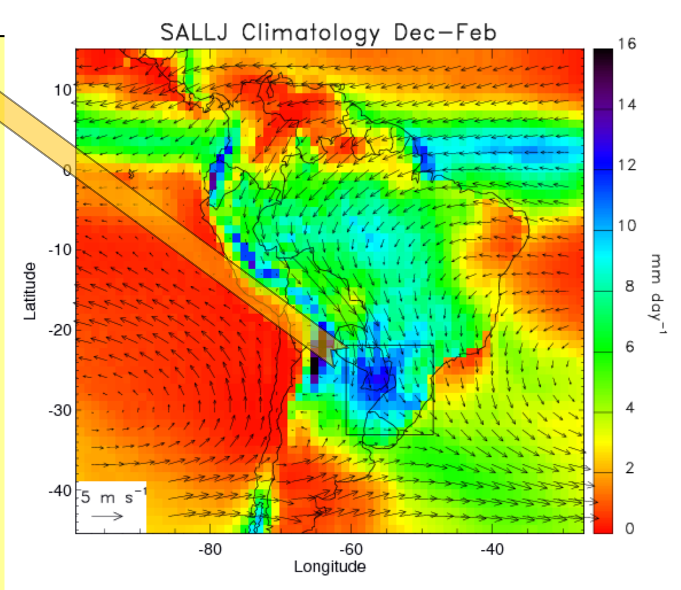


Statistically significant

Consistent with model experiments during AMO⁻ [Seager et al. 2010]

AMO, SALLJ and Precipitation





Precipitation during SALLJ days

- **No trend**
- **Filtered > 8 years**

- **Overall correlation small (-0.19)**
- **During AMO$^-$ $\Rightarrow$ -0.49**

Conclusions

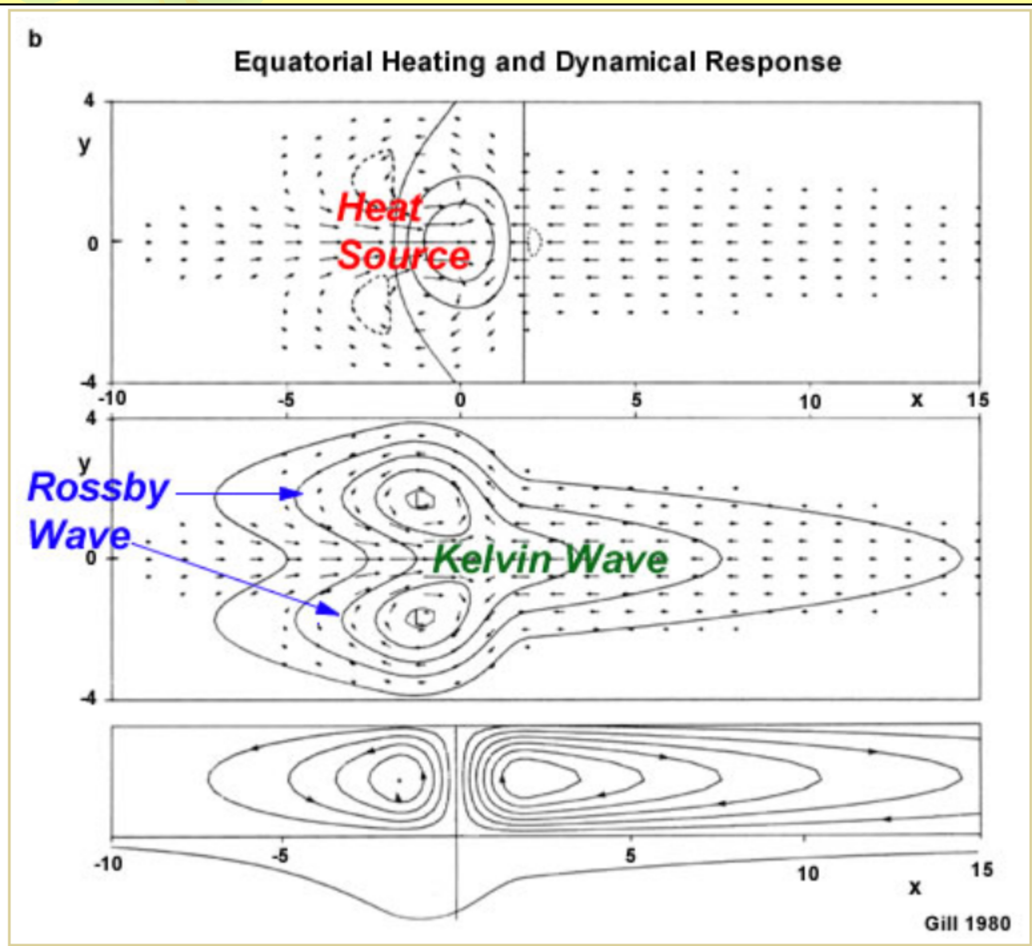
Remarkable influence of the AMO on decadal-to-multidecadal variability of the SALLJ:

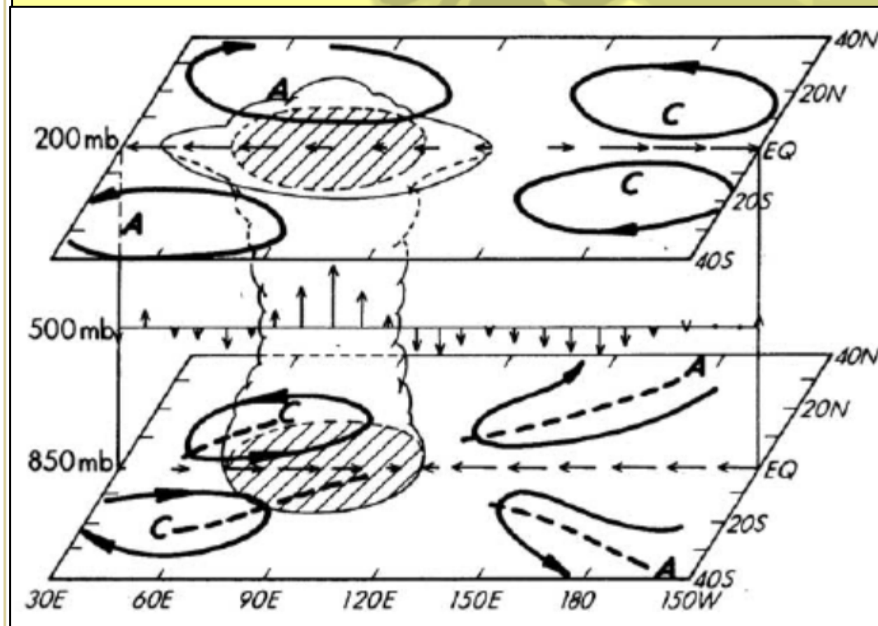
- **Negative AMO phases ⇒ negative precipitation anomalies over northern Amazon and Atlantic ITCZ**
- **Increased cross-equatorial flow & outflow over the negative precipitation anomalies ⇒ enhanced SALLJ**
- **Enhanced SALLJ ⇒ cyclonic circulation & enhanced precipitation over southern Brazil, Paraguay, northern Argentina**
- **Dynamical mechanism to explain decadal-to-multidecadal variations in precipitation (paleo records) in southeast South America**

Tropical heating at the equator

Some simple solutions for heat-induced tropical circulation

By A. E. GILL
Department of Applied Mathematics and Theoretical Physics, University of Cambridge





Rui and Wang (1990)

Mechanisms of the SALLJ

- Deflection of trade winds crossing Amazon basin
- Purely local, topographically generated feature, driven by dry dynamics, possibly modified by moist convection on the Andean slopes
- externally forced feature, produced by variations in the pressure field in northern Argentina: cross Andes flow from Pacific
- Propagation of low-level wind bursts from the North Atlantic toward the La Plata basin through the Amazon basin

Vera et al. (2006)

Theories for the Great Plains LLJ (nocturnal)

- **Heating/cooling over sloping terrain (Holton 1967): Diurnal heating cycle on the sloping Great Plains generates vorticity baroclinically that leads to diurnal oscillation in BL winds**

Horizontal temperature gradients → **Vertical shear in geostrophic winds**

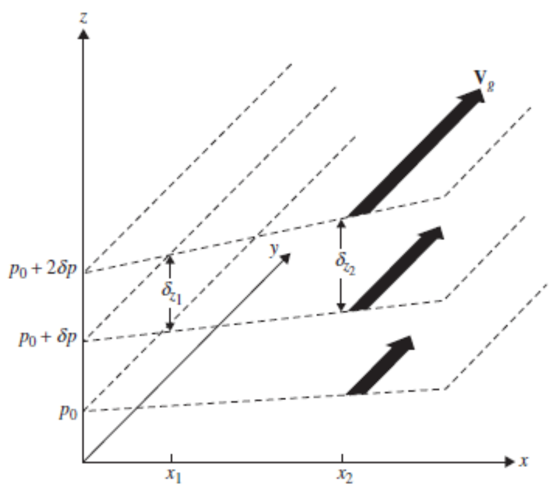


FIGURE 3.8 Relationship between vertical shear of the geostrophic wind and horizontal thickness gradients. (Note that $\delta p < 0$.)

$$\begin{cases} \dfrac{\partial u_g}{\partial z} = -\dfrac{g}{fT}\dfrac{\partial T}{\partial y} \\ \dfrac{\partial v_g}{\partial z} = \dfrac{g}{fT}\dfrac{\partial T}{\partial x} \end{cases}$$

Shapiro, A., et al., 2016: A Unified Theory for the Great Plains Nocturnal Low-Level Jet. *J. Atmos. Sciences*, 73, 3037-3057.

Theories for the Great Plains LLJ (nocturnal)

- Heating/cooling over sloping terrain (Holton 1967): Diurnal heating cycle on the sloping Great Plains generates vorticity baroclinically that leads to diurnal oscillation in BL winds

Diurnal oscillation in thermal wind

$$\frac{\partial T}{\partial x} < 0$$

$$\begin{cases} \dfrac{\partial u_g}{\partial z} = -\dfrac{g}{fT}\dfrac{\partial T}{\partial y} \\ \dfrac{\partial v_g}{\partial z} = \dfrac{g}{fT}\dfrac{\partial T}{\partial x} \end{cases}$$

Assume u_g=0

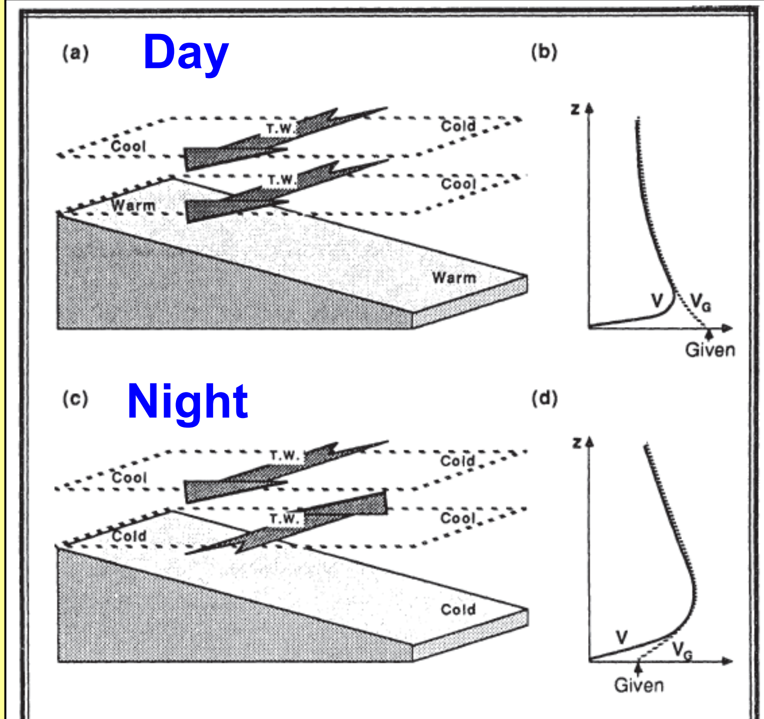
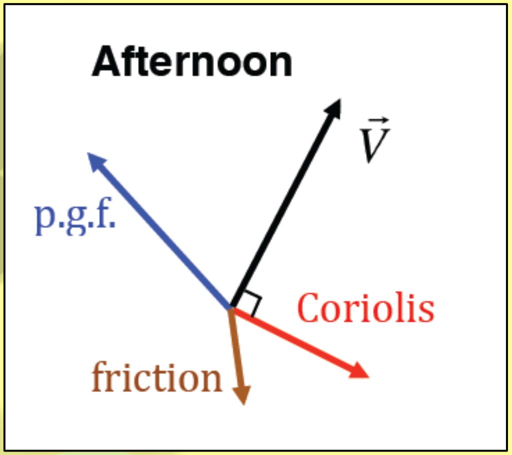


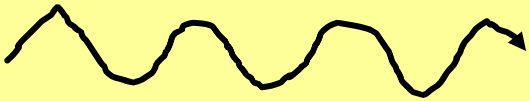
Fig. 12.17 Diurnal oscillation of the low level jet due to thermal wind (T.W.) forcings over sloping terrain.

Shapiro, A., et al., 2016: A Unified Theory for the Great Plains Nocturnal Low-Level Jet. *J. Atmos. Sciences*, 73, 3037-3057.

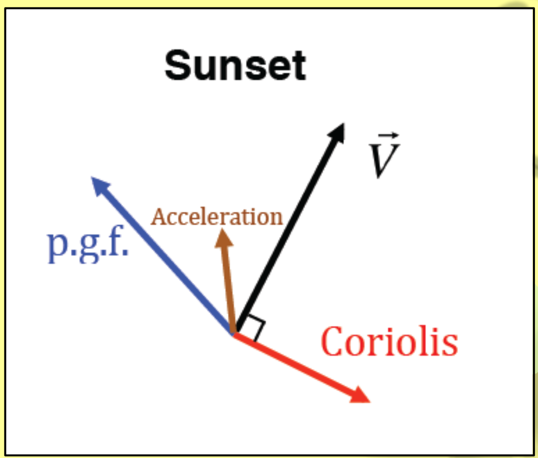
Theories for the Great Plains LLJ (nocturnal)

- ❑ <u>Mountain-blocking</u> (Wexler 1961): Blocking of easterly trade winds by the Rocky Mountains yields strong southerly jet
- ❑ <u>Inertial Oscillation</u> (Blackadar 1957): Sudden decrease of frictional stress in the boundary layer (BL) around sunset destroys Ekman balance and accelerates air parcels.





Turbulent stresses decreases, friction ≈ 0



Shapiro, A., et al., 2016: A Unified Theory for the Great Plains Nocturnal Low-Level Jet. *J. Atmos. Sciences*, 73, 3037-3057.

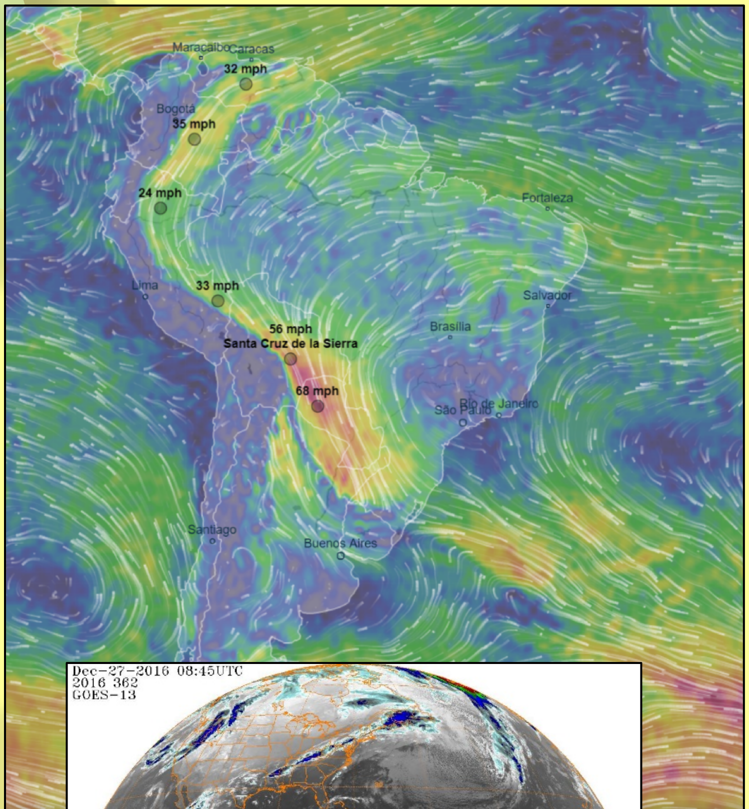
Climate Variability and Change in South America

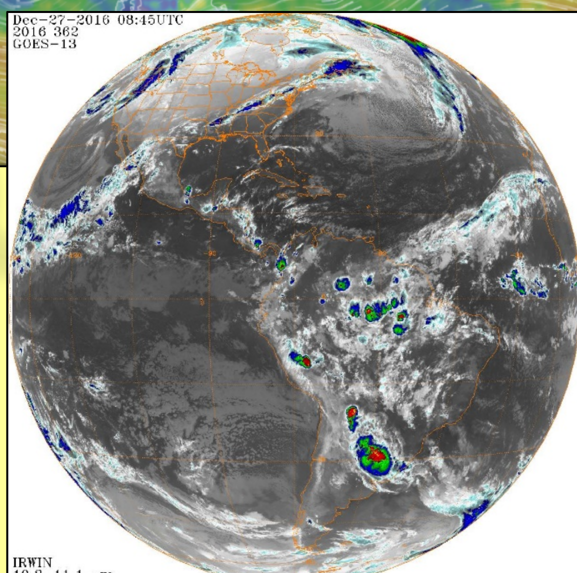
How will climate change in South America in the coming decades?

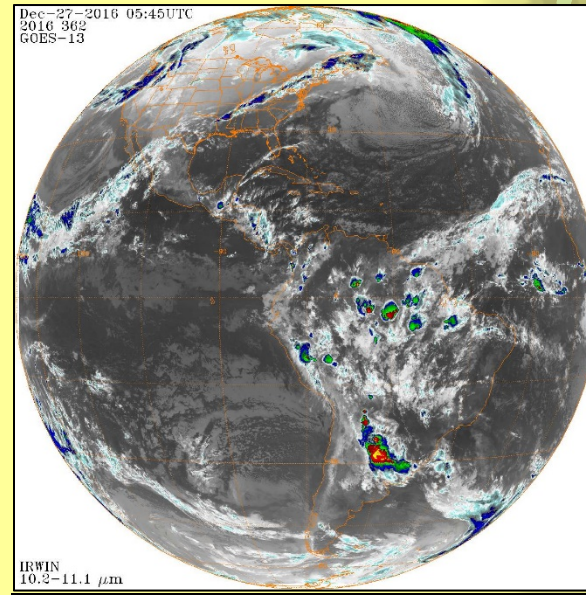
- ***How does natural climate variability on decadal-to-multidecadal scales work in South America?***
- ***How strong is the anthropogenic climate forcing relative to natural variability?***

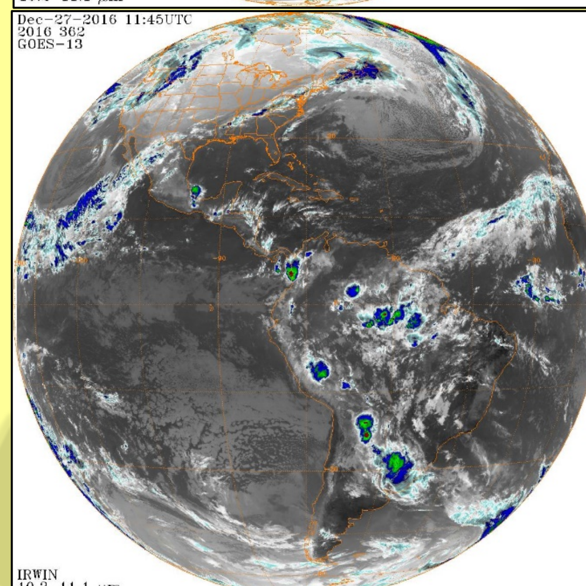



South America Low-level Jet (SALLJ)









SALLJ Climatology: Early Studies

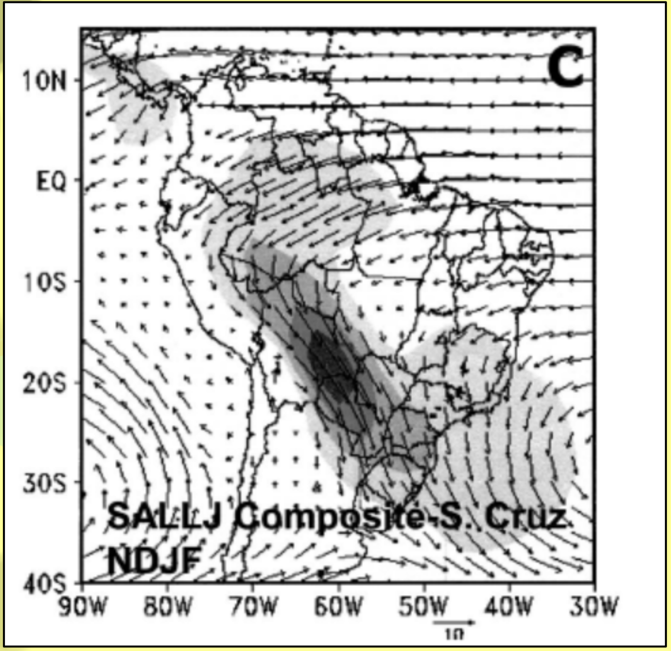
Marengo et al. 2004

- Used NCEP/NCAR reanalysis
- Bonner criteria used for the Great Plains LLJ
  - Northerly winds at 850-hPa ≥ 12 ms^{-1}
  - Vertical wind shear [850-700] hPa ≥ 6 ms^{-1}
  - v-wind < 0
  - v-wind > u-wind

1st Generation Reanalysis!

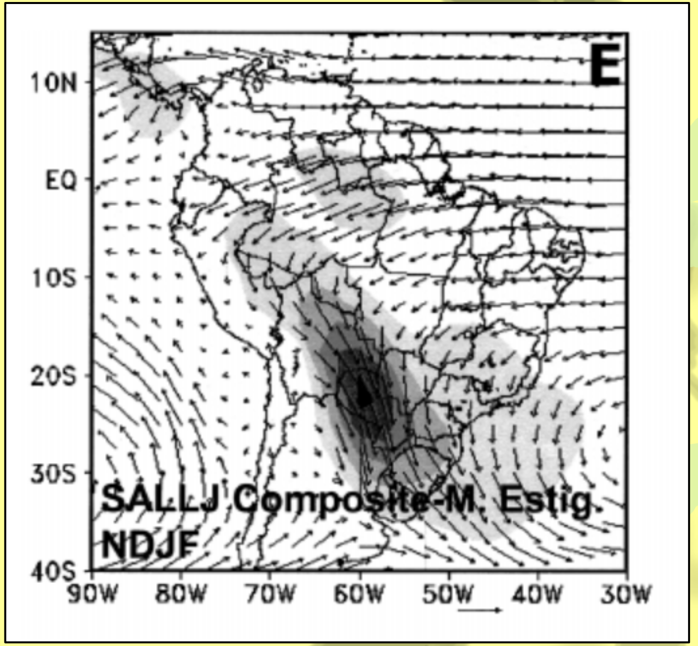
Fixed thresholds!

Santa Cruz Bolivia



Winds 850-hPa Austral Summer

Mariscal Paraguay



Marengo, J. A., et al., 2004: Climatology of the low-level jet east of the Andes as derived from the NCEP-NCAR reanalyses: Characteristics and temporal variability. J. Climate, 17, 2261-2280.