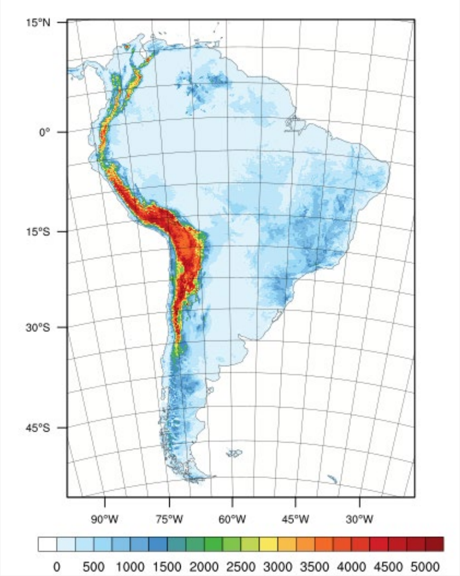
Convectively Coupled Waves over Tropical South America in CESM



WRF - Fei Chen

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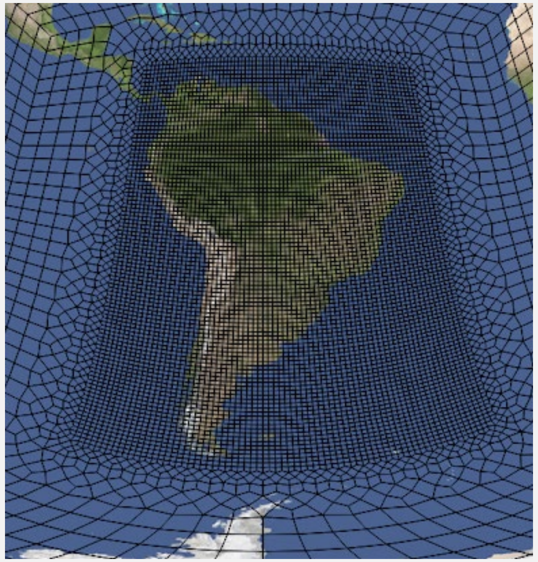
AMWG 2021



CESM - Patrick Callaghan

Motivation

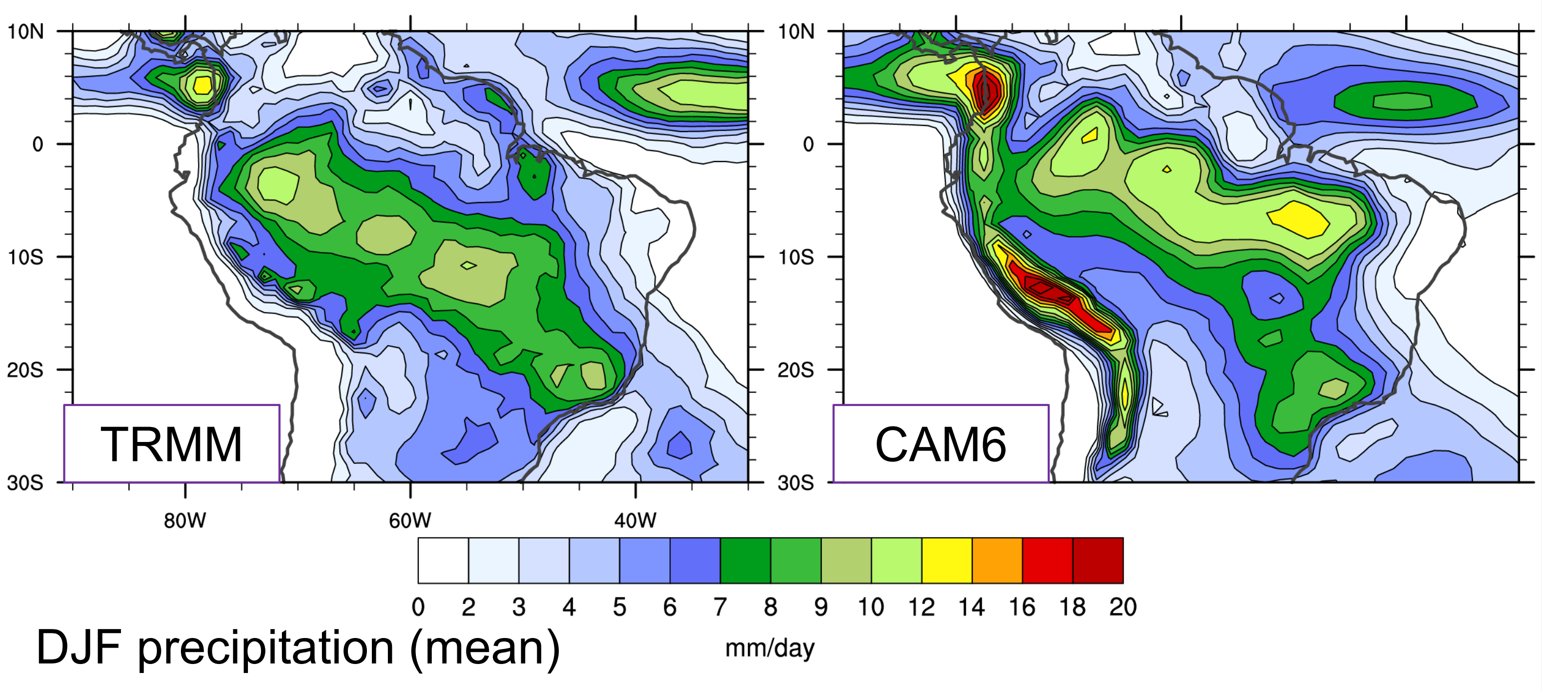
General

- South American affinity group at NCAR
- Importance to tropical climate and weather extremes
- A piece of the larger convectively coupled wave landscape
- Less studied than other regions (yet strongest Kelvin wave region)

South American Simulation with CESM (and WRF)

- How will CESM and sustain wave activity?
- Will there be interaction with the Andes?
- Increased resolution
- Explicitly resolving convection

South American Climatology



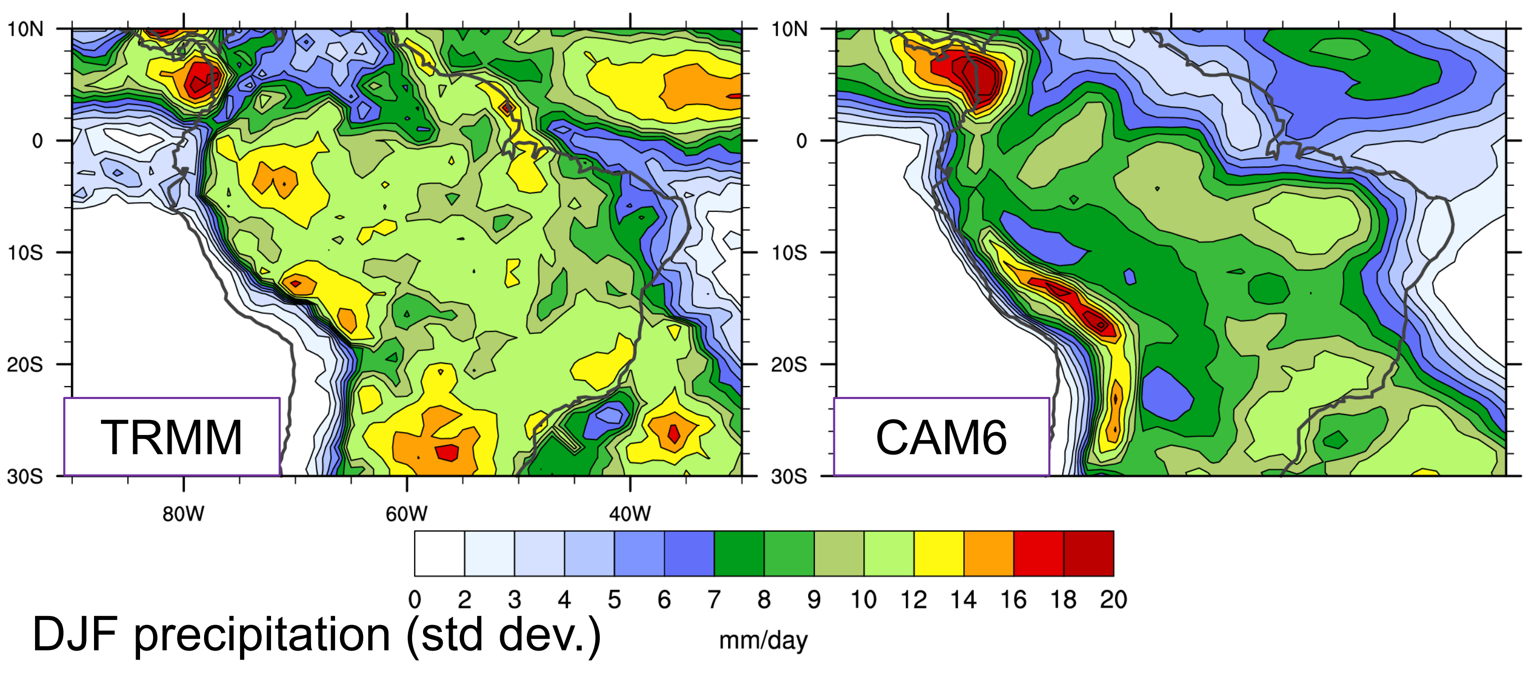
Community Earth System Model

- Community Atmosphere Model (CAM6)
- Parameterized deep convection
- Global historical simulations (79-05)
- Free running, not forecasts
- Prescribed Sea Surface Temps.
- 1 deg (110km), 32 vertical levels
- Sub-seasonal analysis
- Daily data for DJF

Mean Precipitation

- Locked to high topography
- ITCZ features ~captured
- Dominant south-east/north-west max.
- Too far north, spurious Nord-est max
- Dry tongue alone the Andes

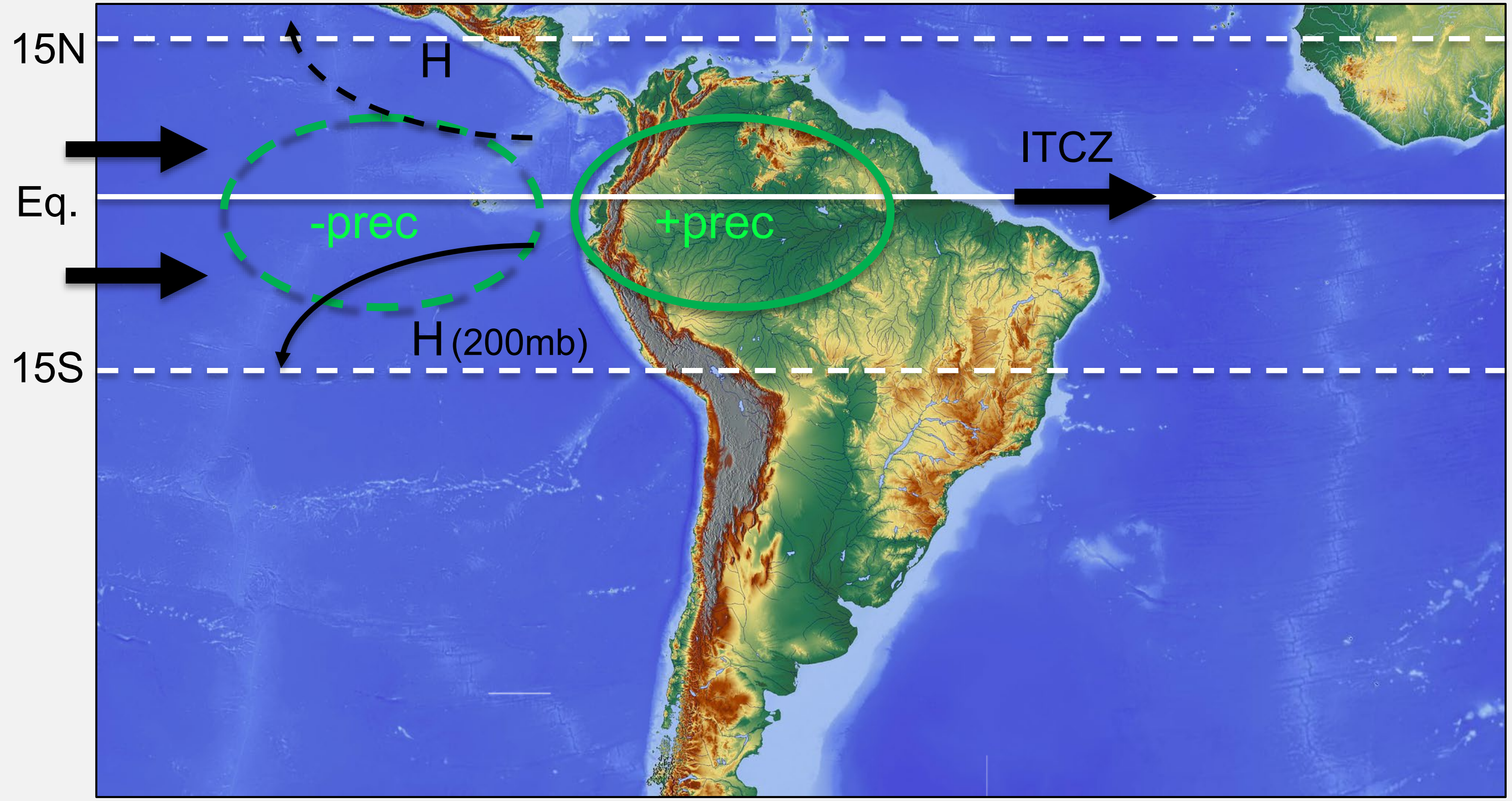
South American Climatology



Standard Deviation (unfiltered daily)

- More evenly distributed over the tropics
- CAM6 weaker everywhere
- Apart from over topography
- **Can we identify the source of this variability?**
- **Tropical Wave Variability?**

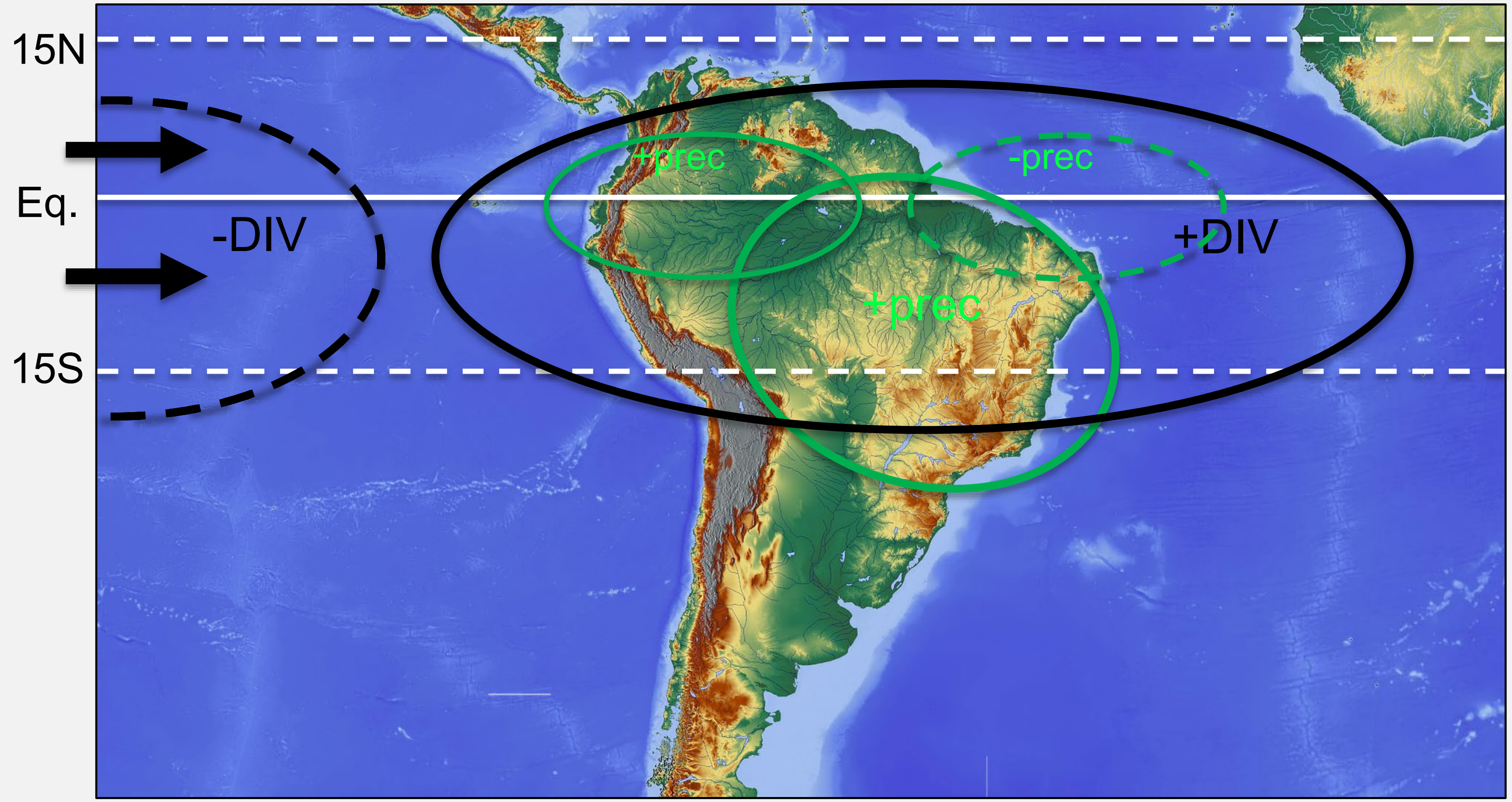
Observed Tropical Wave Variability Over South America



Non-local tropical Kelvin Waves

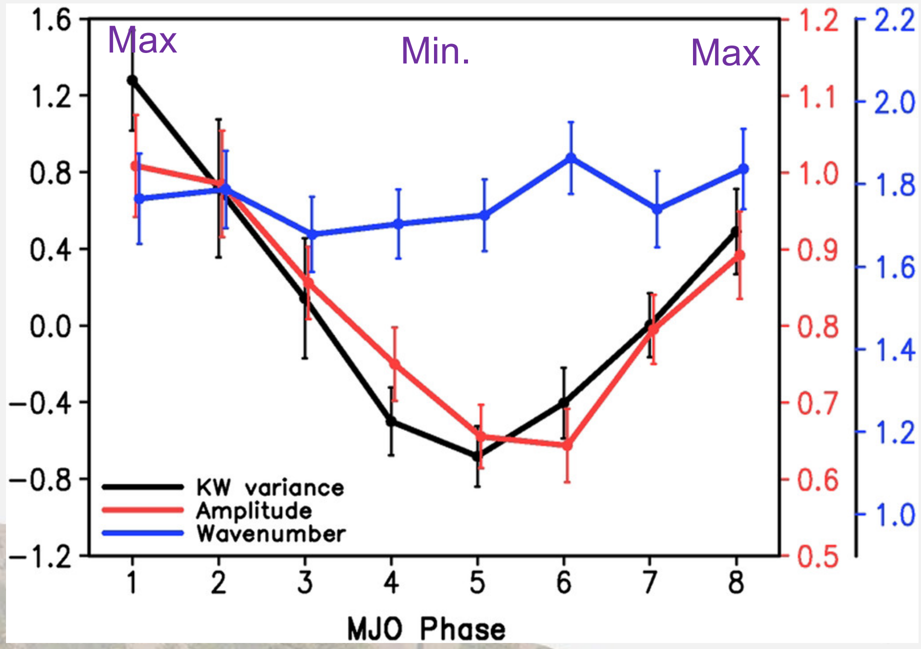
- **Globally, Kelvin Wave convective variability is a maximum over S. America**
- Kelvin waves are precursor to intense Brazilian rainfall events (Liebman et al., 2011)
- From the Pacific they are upper level disturbances (Liebman et al, 2009)
- Can be blocked by Andes at lower levels
- Related to E. Pacific SST (Liebman et al., 2011)

Tropical Wave Modes Over South America

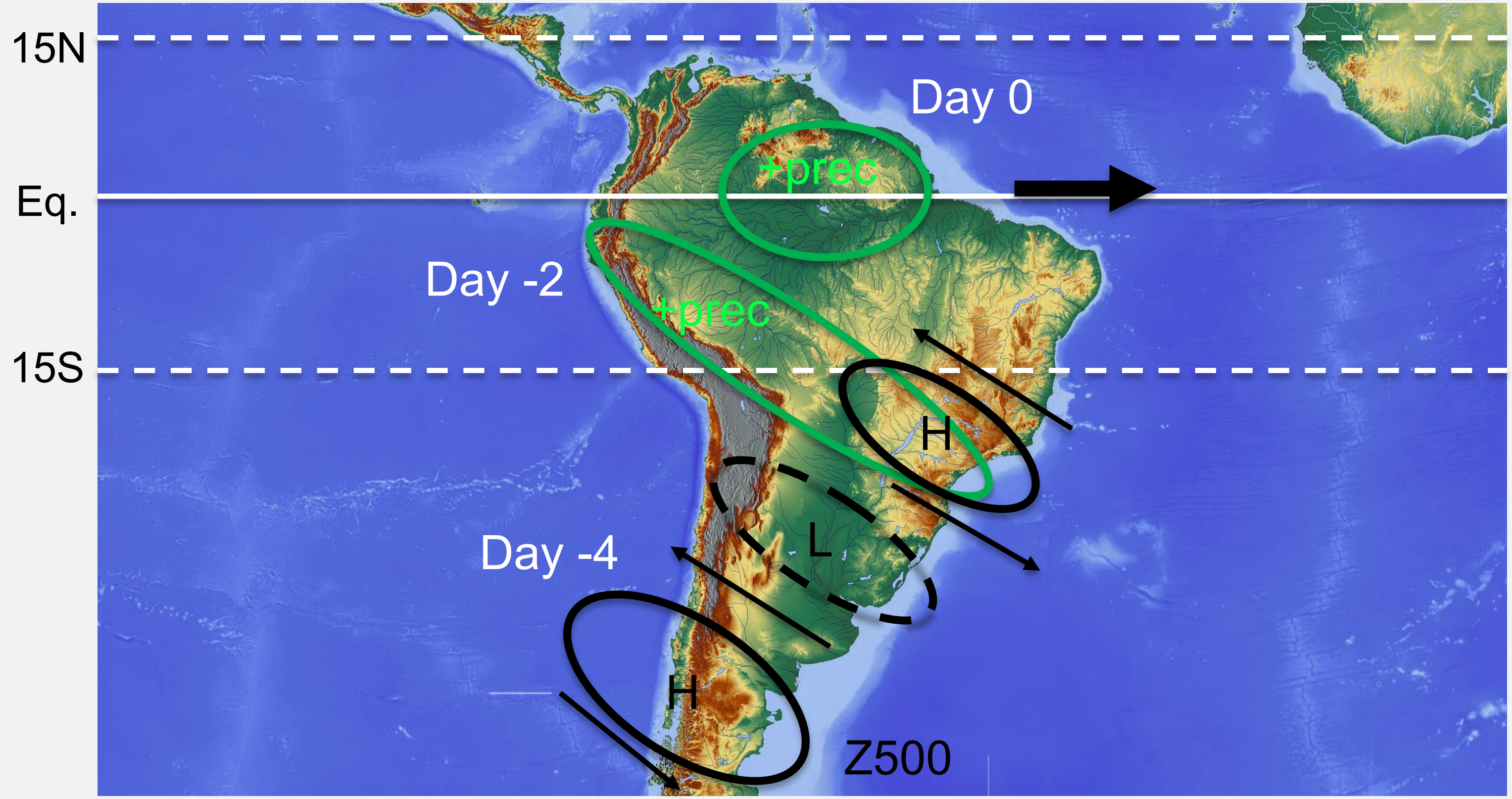


MJO Events

- Exerts influence over the Kelvin Wave envelope strength (Guo et al., 2014)
- Upper level destabilization
- Impacts amplitude and vertical wave structure



Observed Tropical Wave Variability Over South America

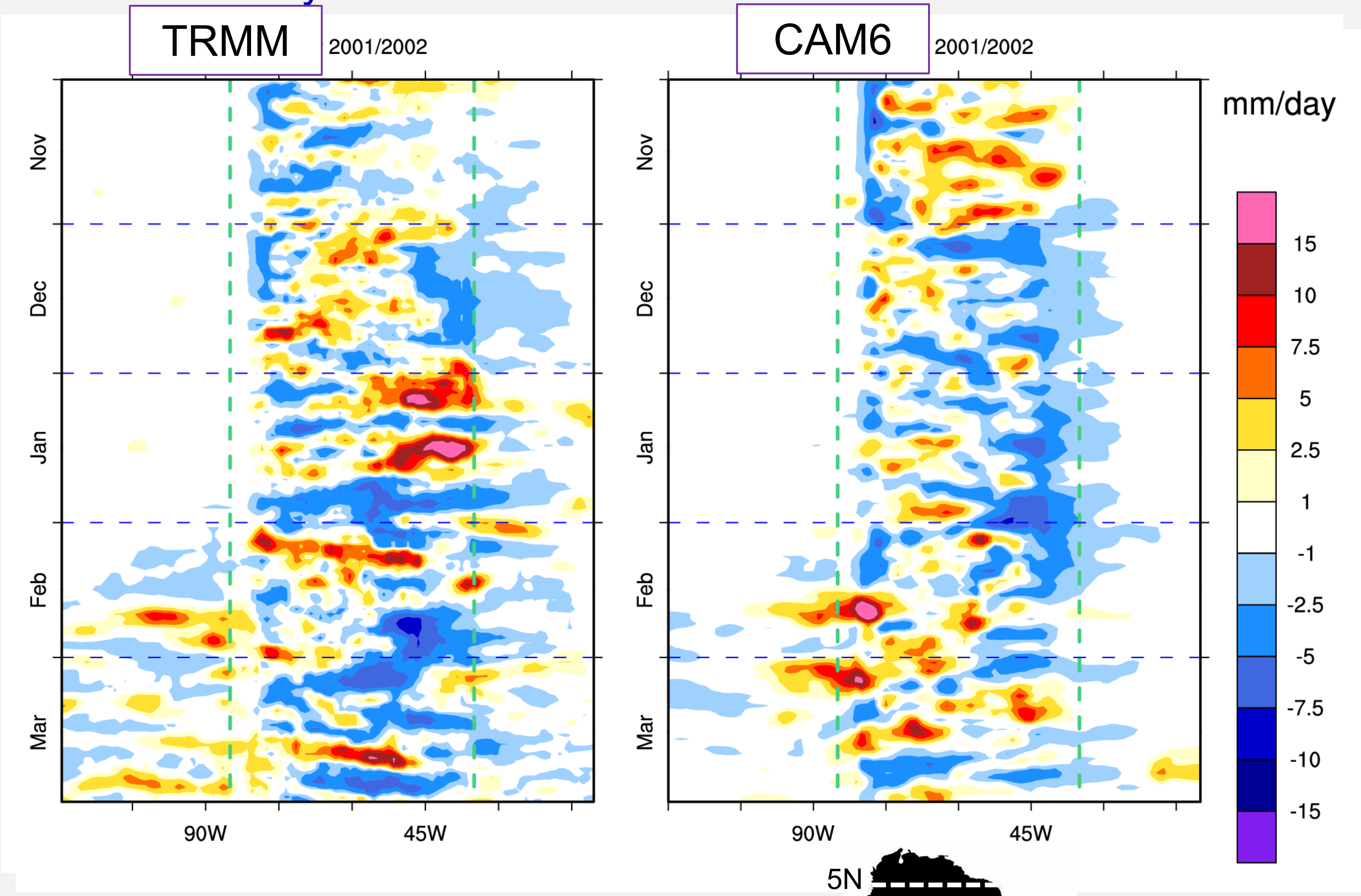


High latitude triggered Kelvin Wave

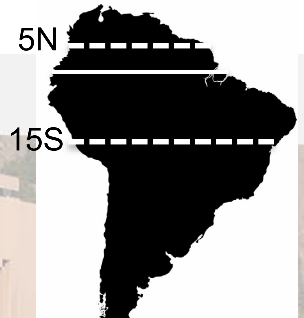
- Transient incursions of midlatitude air (Garreaud and Wallace, 1998)
- Equatorward advection of destabilizing flow
- Organized convection along the cold surge front (Garreaud, 1998).

Tropical Modes of Variability Over South America

Neutral ENSO year



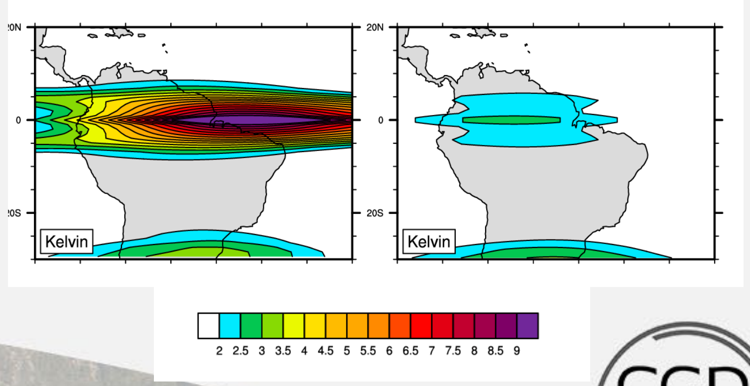
MJO Kelvin Eq Rossby Inertial GW



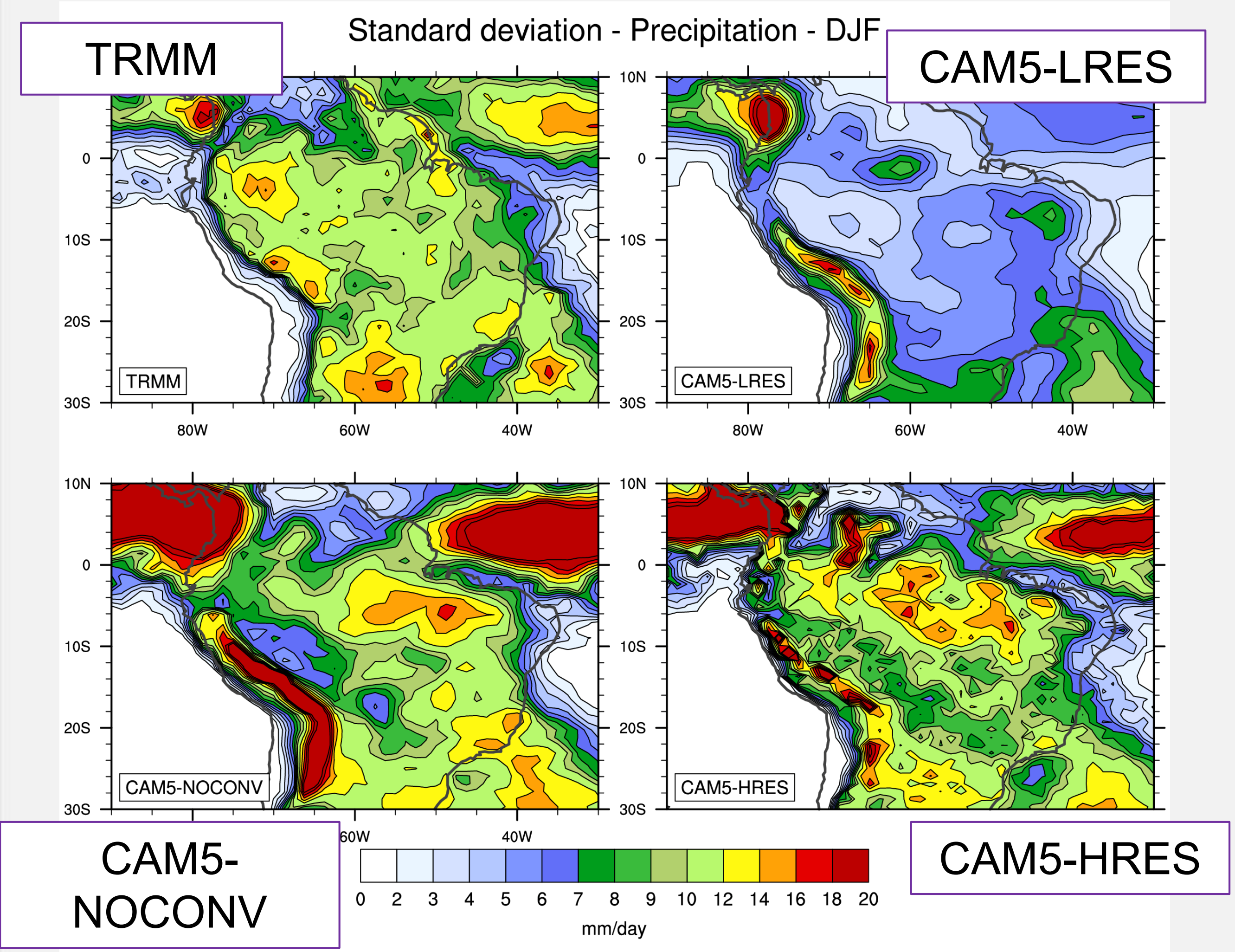
Model Versus Observations

- DJF wave guide average (15S-5N)
- Multiple wave events (east and west) embedded in MJO convective envelope
- In general CAM6 has weaker variability
- MJO and Kelvin waves are dominant over central South America
    - Non local
    - Local
    - Local, triggered by MJO
    - (local triggered by northward cold surge)

TRMM CAM6



Variance Dependencies



South American CESM (CAM6) Simulations

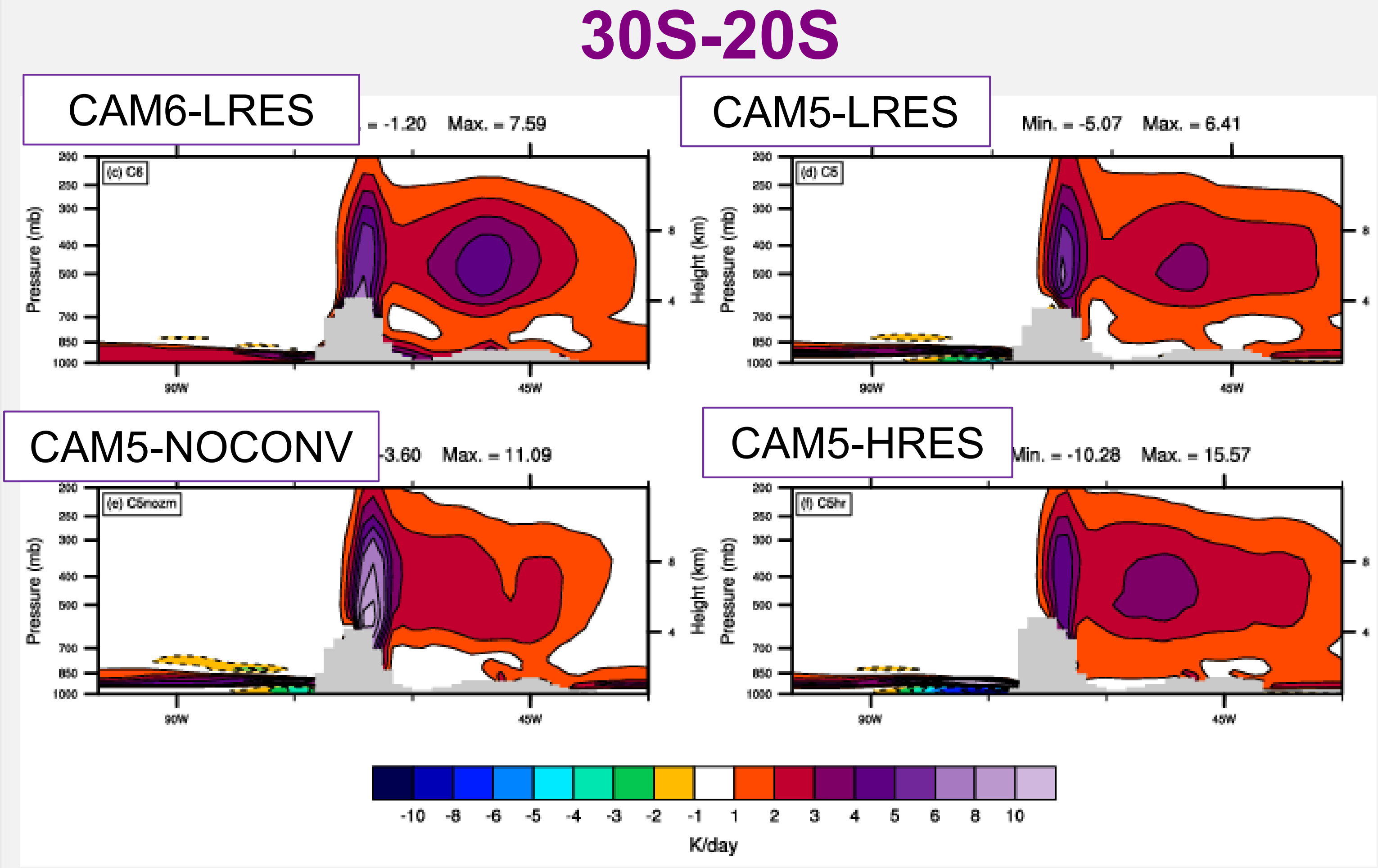
- High resolution down to 4km
- No deep convection
- CAM5 simulations see significant dependencies on both these

- High-resolution (25 km): Increased variance
- Orographic dependencies remain

- No Deep Scheme (100km): Increased variance
- Excessive over-orographic Andes variance
- Excessive ITCZ variance

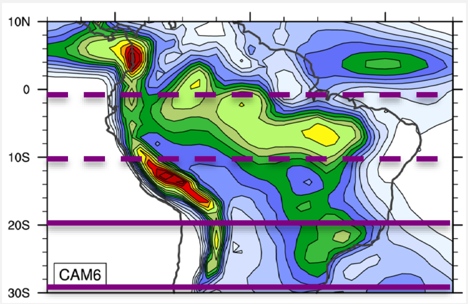
- *How will it behave a 4km?*
- *Are these increases related to wave activity?*

Orographic Dependencies



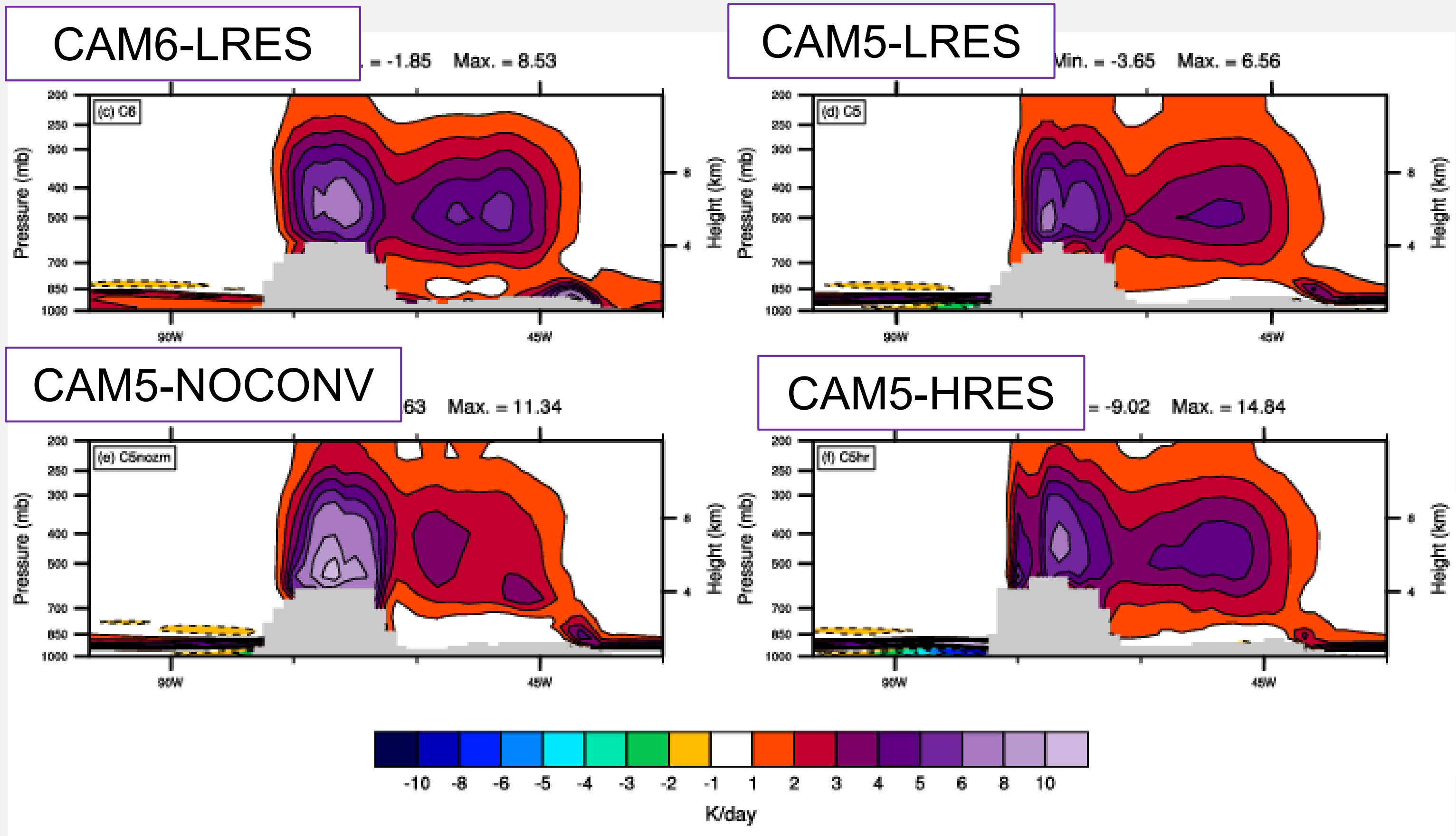
Process Tendencies

- Total moist phys. processes (K/day)
- Strongest maximum over Andes



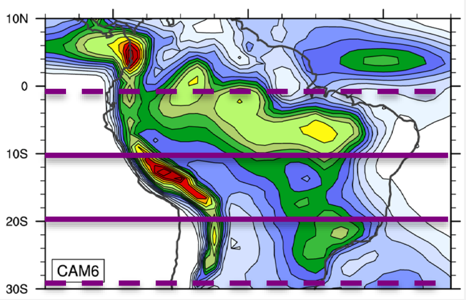
Orographic Dependencies

20S-10S



Process Tendencies

- Total moist phys. processes (K/day)
- Strongest precip. bias



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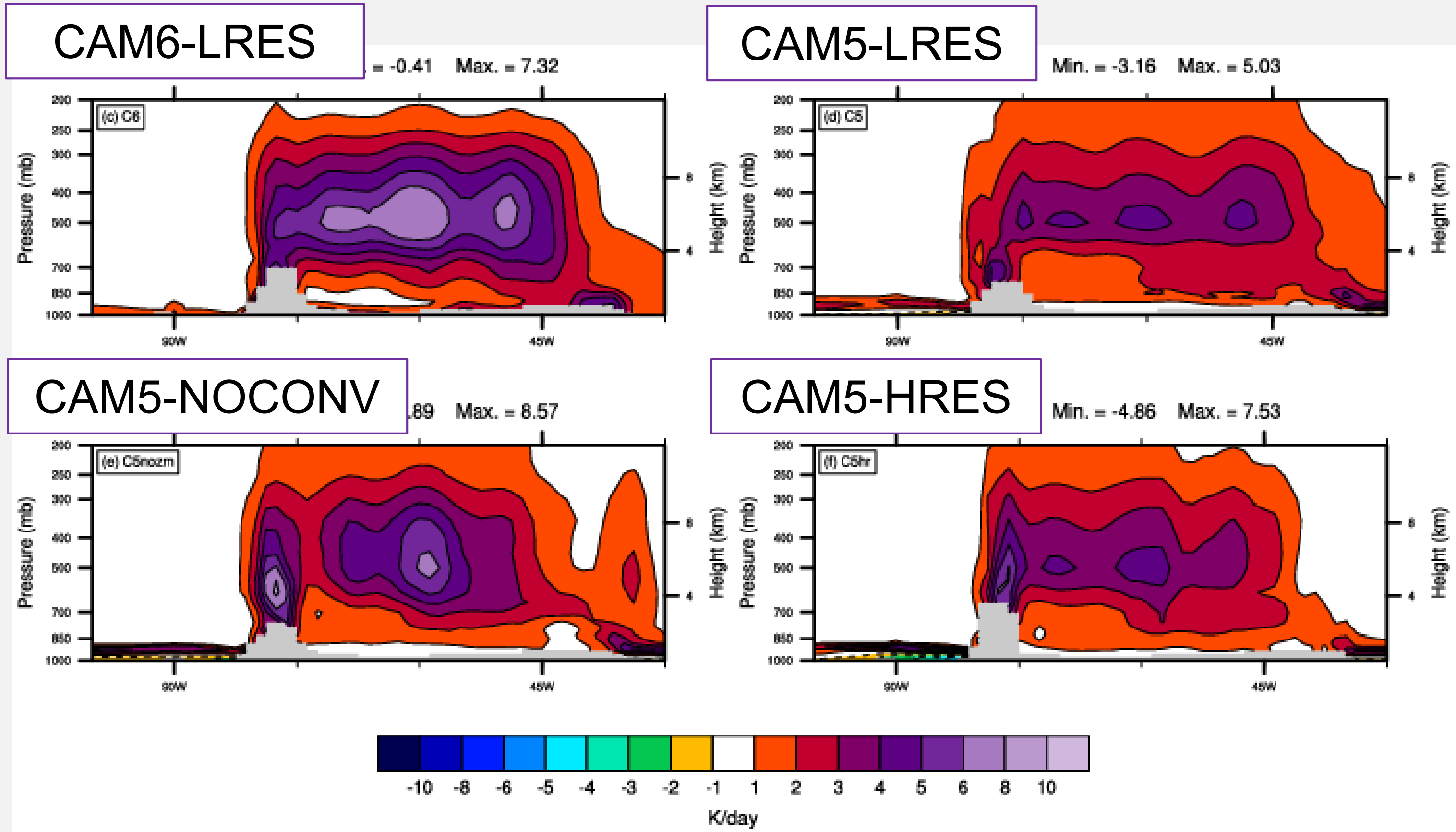
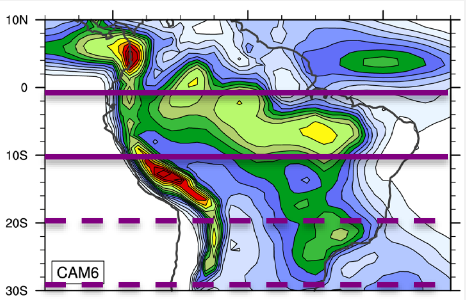
Orographic Dependencies

10S-0N



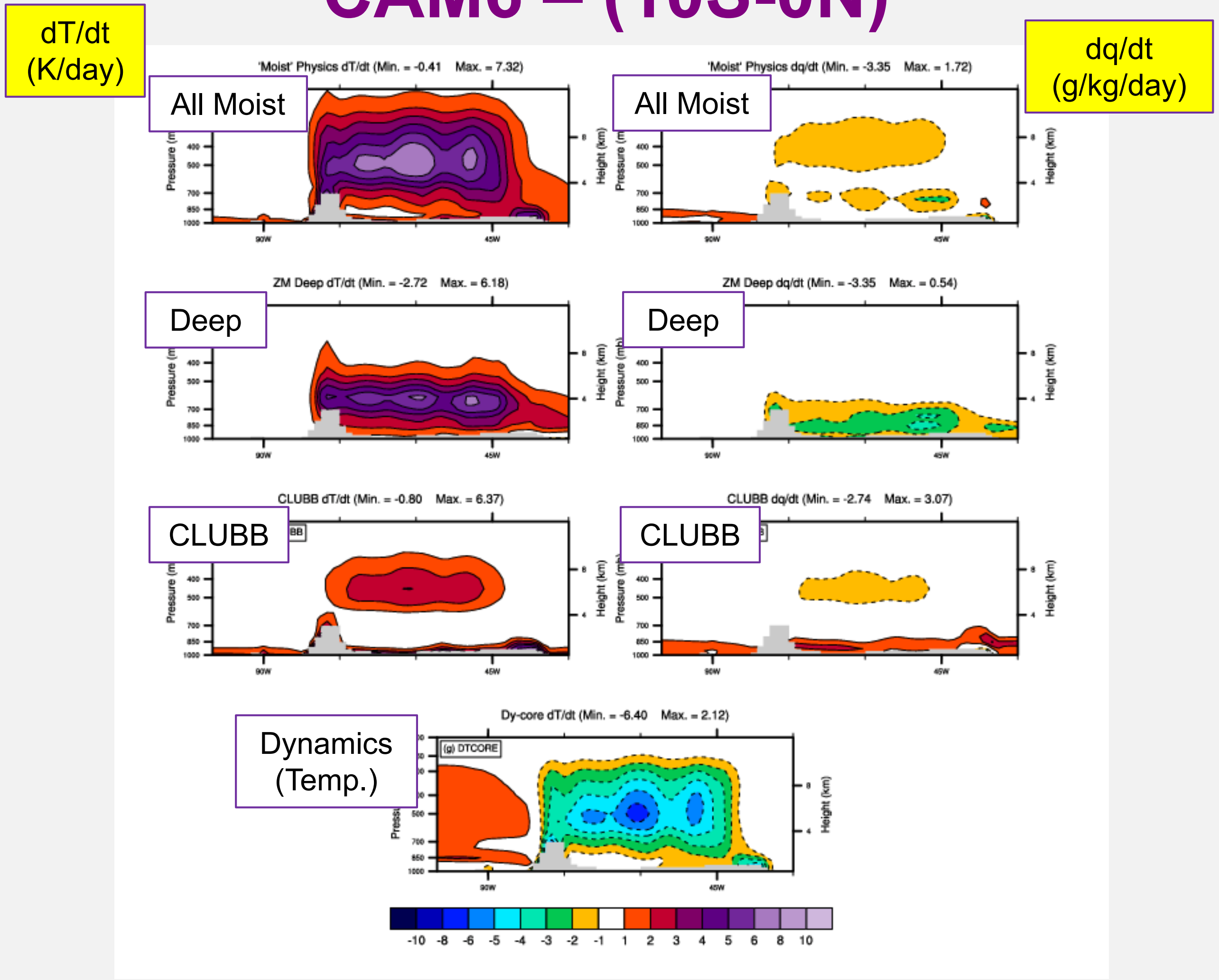
Process Tendencies

- Total moist phys. processes (K/day)
- Continuous maxima across S. America
- No-ZM retains Andes maximum



Orographic Dependencies

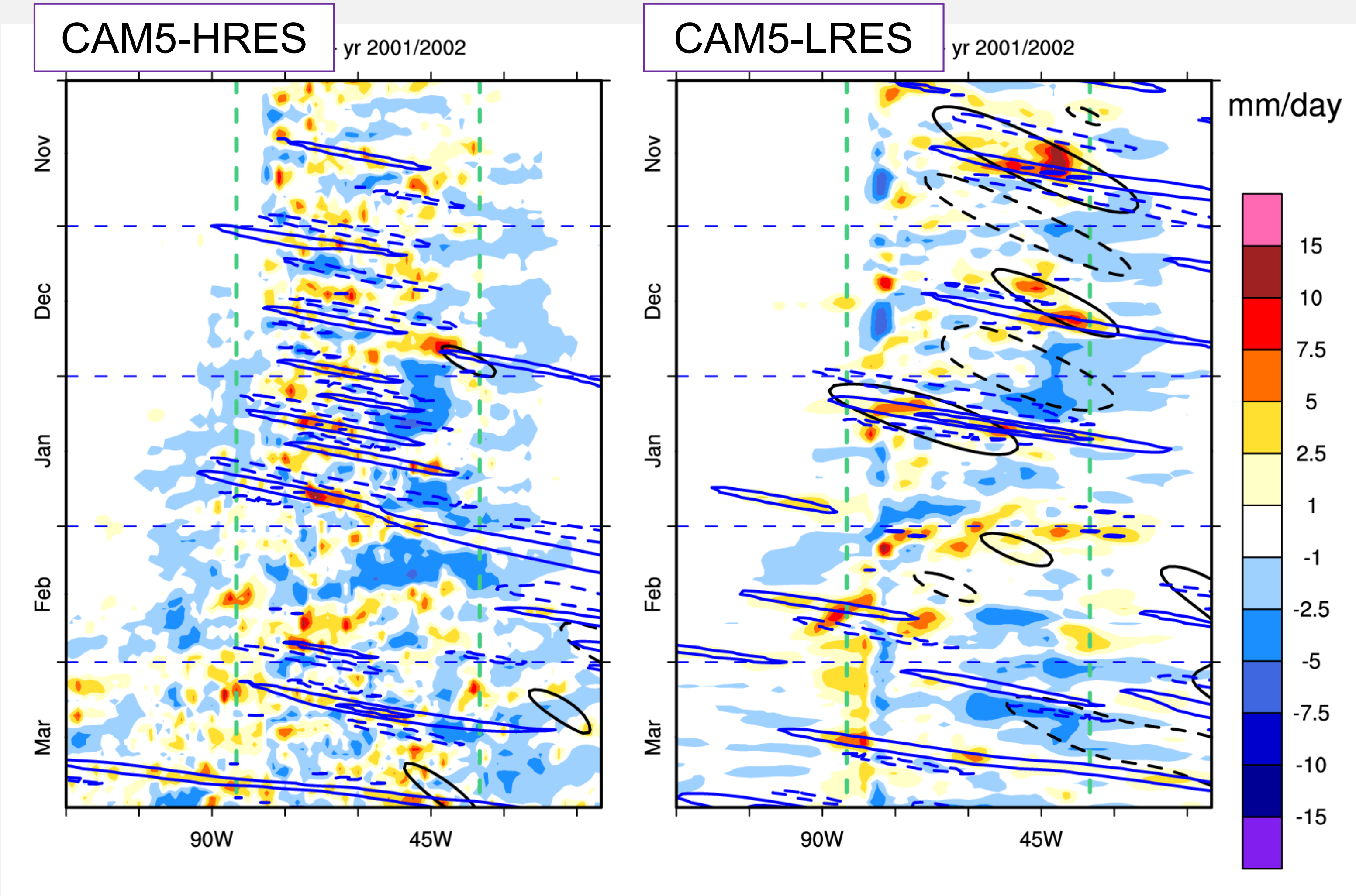
CAM6 – (10S-0N)



Individual Parameterizations

- Primary moist processes
- ZM is shallow(er) than in CAM5
- CLUBB impacts weak in lower troposphere
- ‘Assists’ ZM in upper troposphere
- Budget more dominated by CLUBB further South.

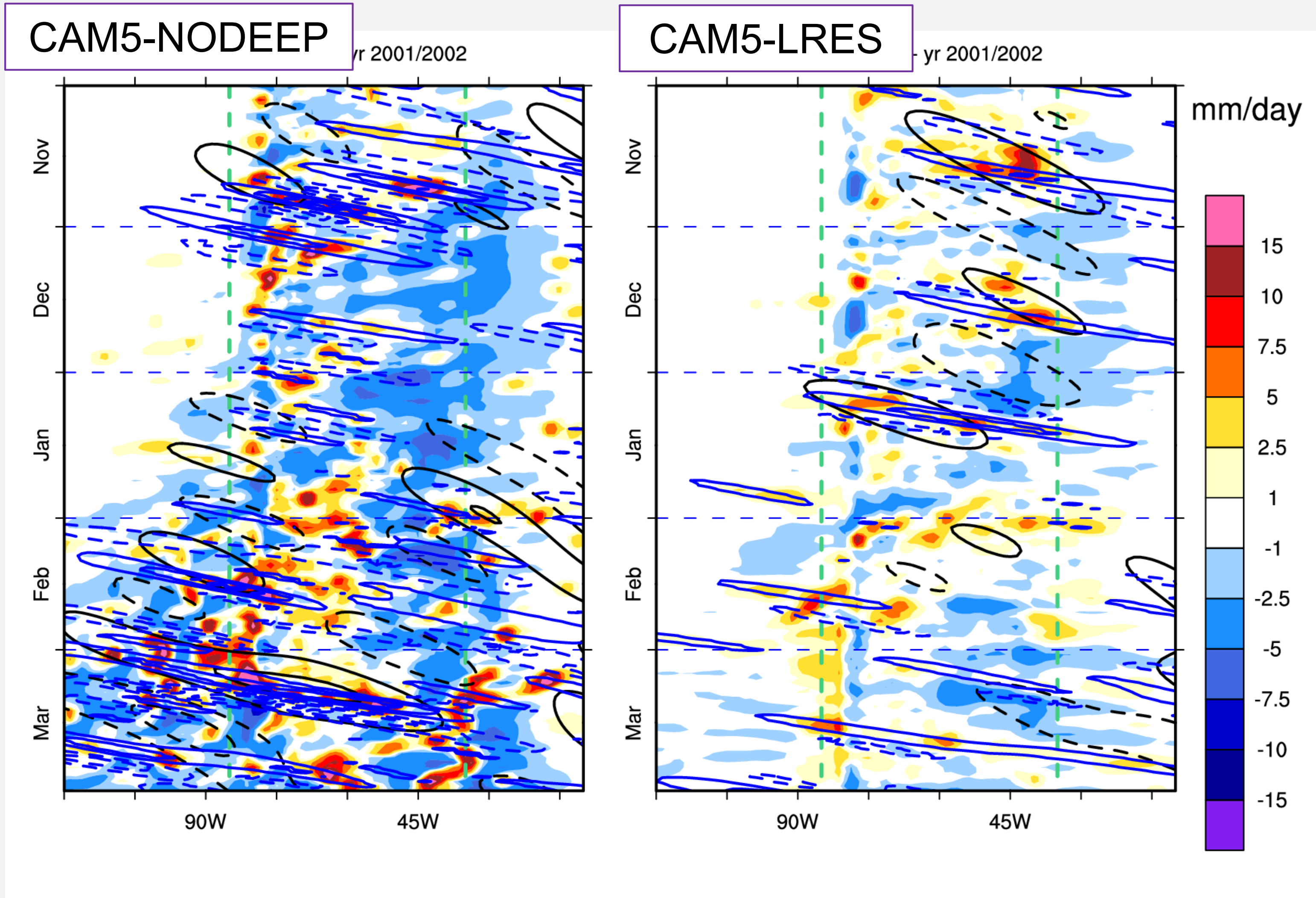
Tropical Wave Variability Model Sensitivities



High Resolution?

- 25 km vs 100 km (still L30)
- Deep convection parameterization scheme still on
- Smaller scale Kelvin waves

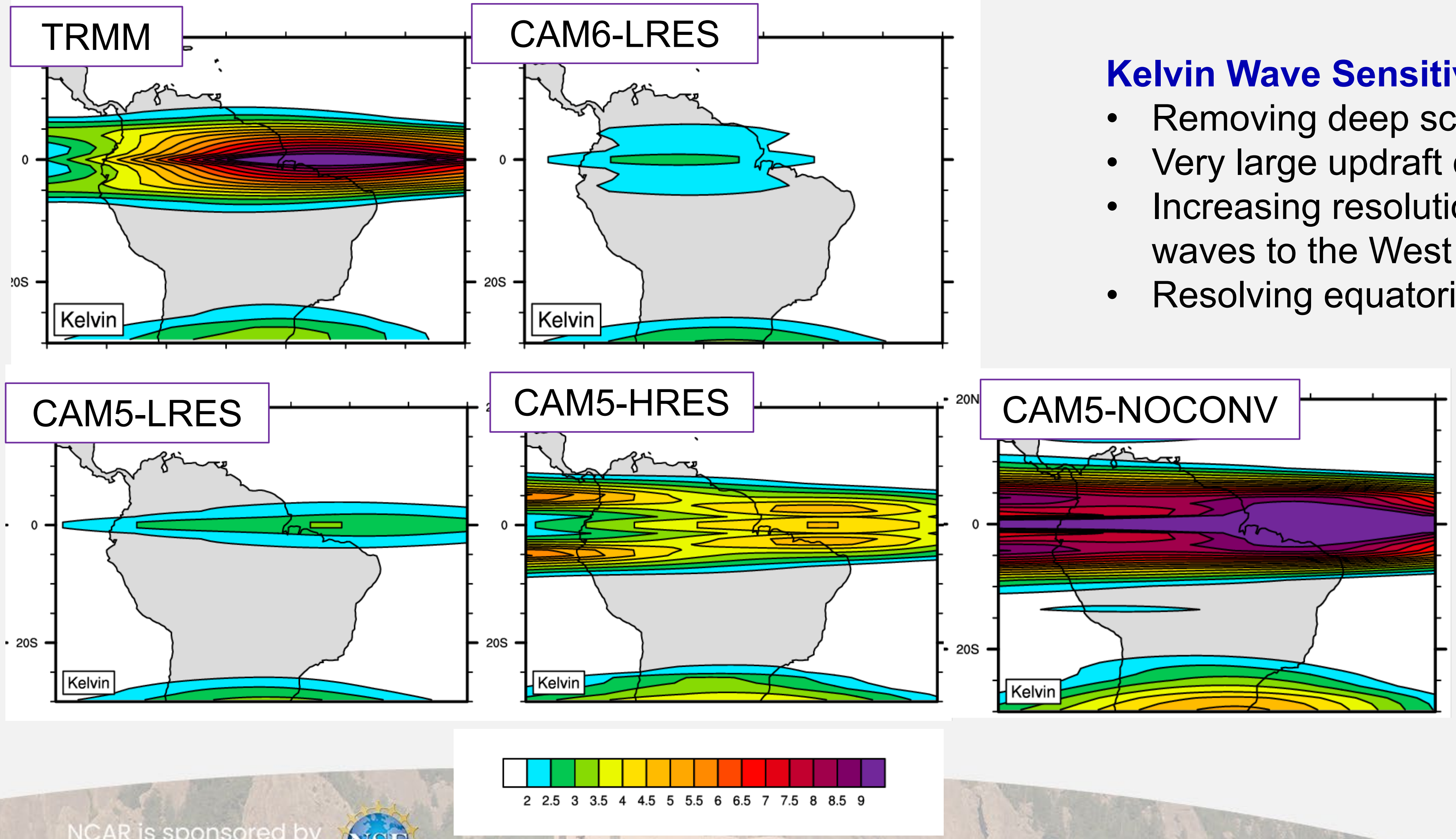
Tropical Wave Variability Model Sensitivities



Resolved Convection

- Deep convection parameterization turned off
- 100 km resolution

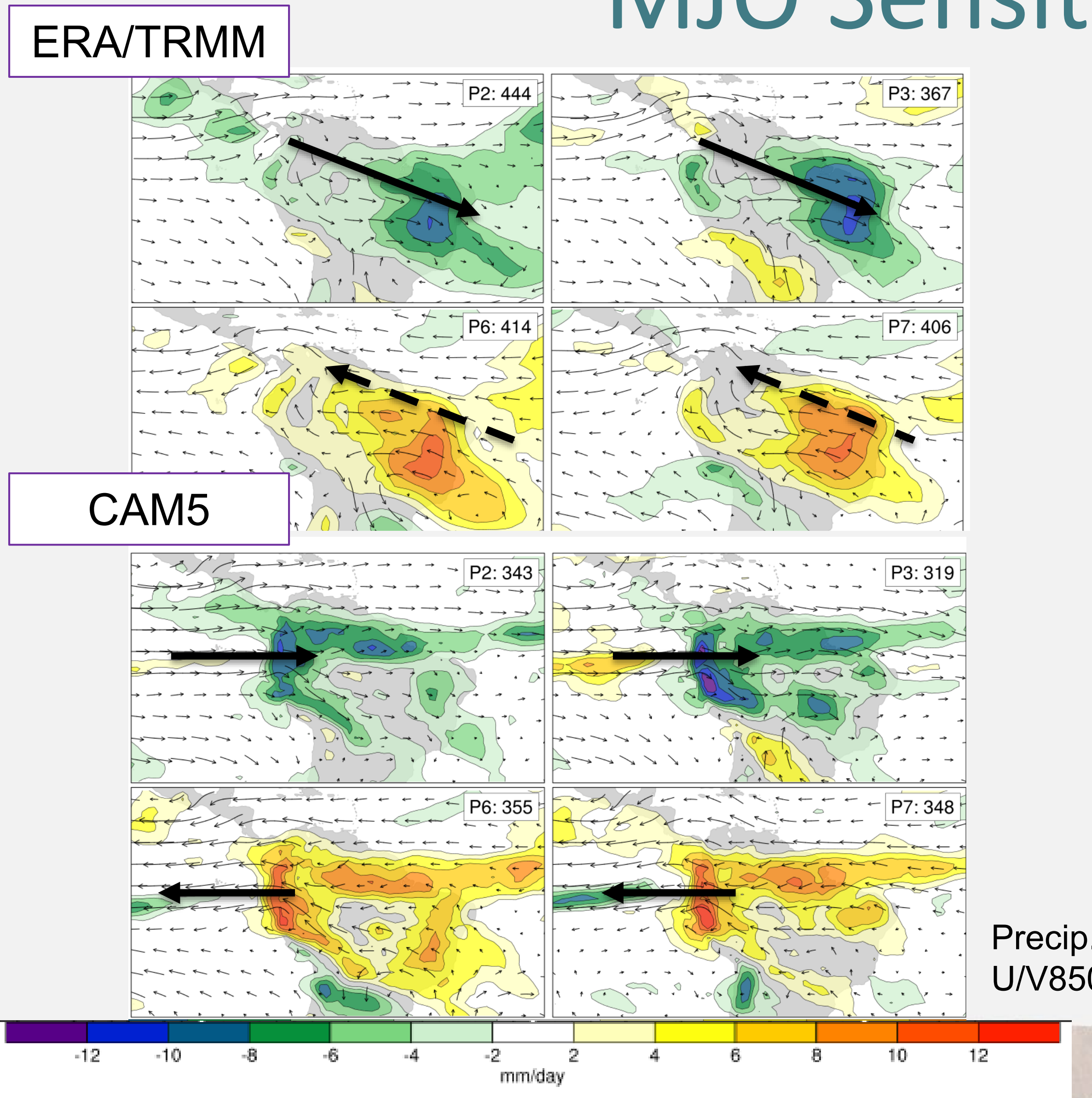
Kelvin Wave Sensitivity Summary



Kelvin Wave Sensitivities

- Removing deep scheme intense response
- Very large updraft coupling?
- Increasing resolution -> strongest Kelvin waves to the West of Andes
- Resolving equatorial wave dynamics?

MJO Sensitivity Summary



Precip.
U/V850mb

Interaction with orography

- Minor observed interaction with Andes in weak and string phases
- Maximized impact in East Brazil
- Mostly within-ITCZ response in CAM5
- Is it dominated by envelope Kelvin waves?
- Would improved interaction with the Andes improve the regional distribution of the envelope?

Summary

- What might we expect for CESM South American WC experiment suite (25/12/6/3km)?
- Three primary propagating modes we want to capture (MJO/Kelvin wave)

- CAM6 has reasonable convective sub-seasonal variability (better than CAM5)
- Insufficient activity likely associated with a lack of Kelvin waves

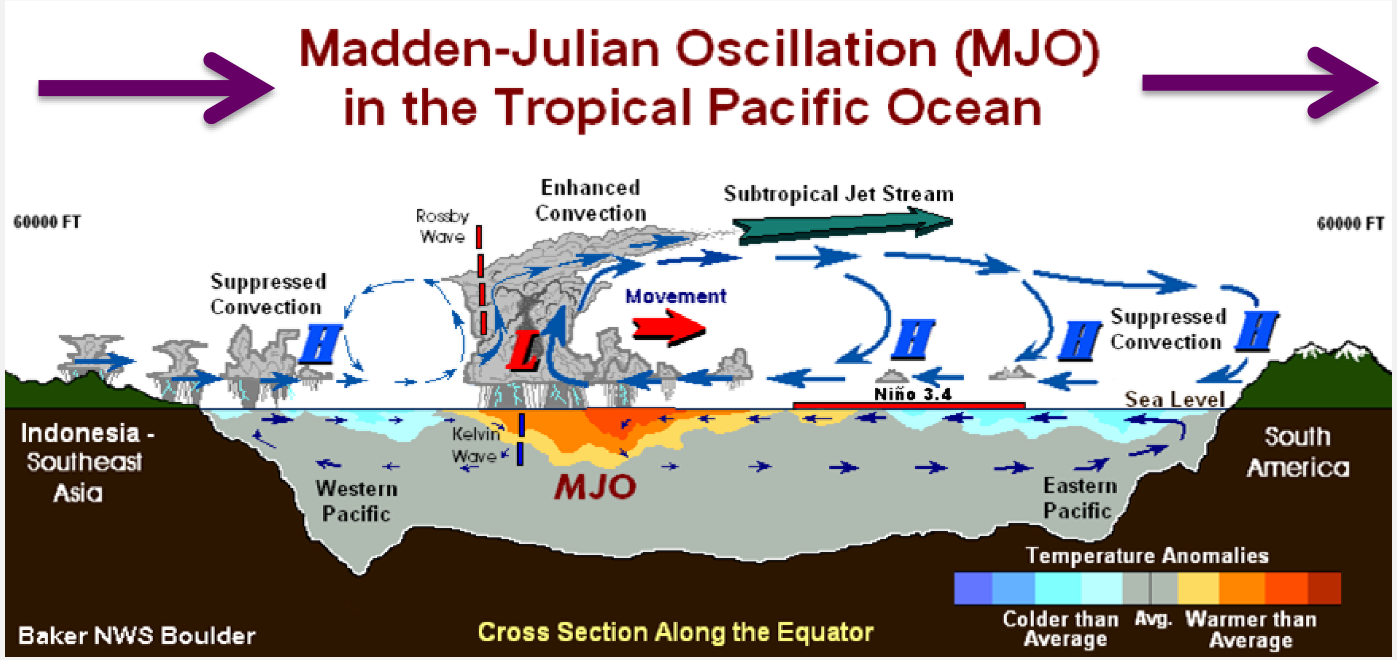
- We test increasing resolution and turning off deep convection
- Increase in sub-seasonal convective variability both changes
- ‘No-deep’ configuration does so through intense strengthening tropical Kelvin waves

Orography

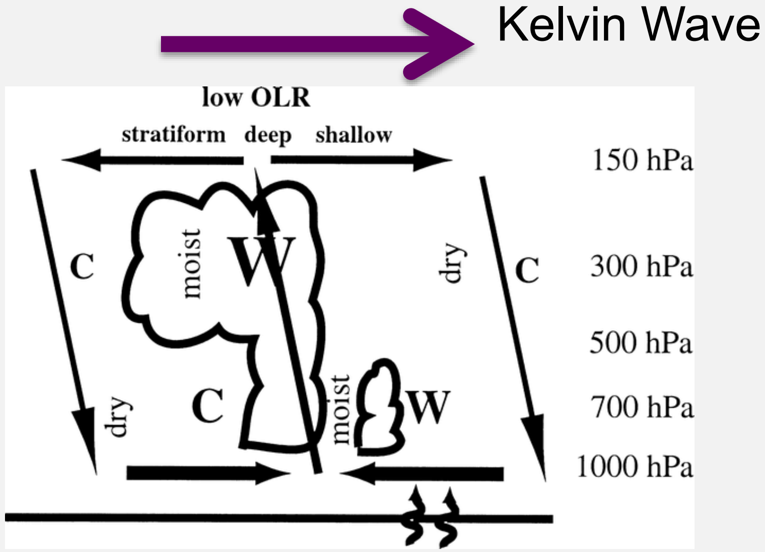
- In all cases there is a strong dependence of (mean/std) precipitation on orography (hydrostatic?)
- Strongest without deep convection, but does not impact wave Kelvin Wave activity
- But for MJO, composite flow traverse the Andes directly rather than detouring North

Madden Julian Oscillation (MJO) and Kelvin Waves

- The MJO is the dominant mode of sub-seasonal variability
- Circumnavigates the globe on 20-100 period (strongest in N. Winter, intermittent)
- Important role in climate and extreme weather in the tropics (cyclones/monsoons)
- Kelvin wave are a less moisture dependent, narrower, principle propagating mode

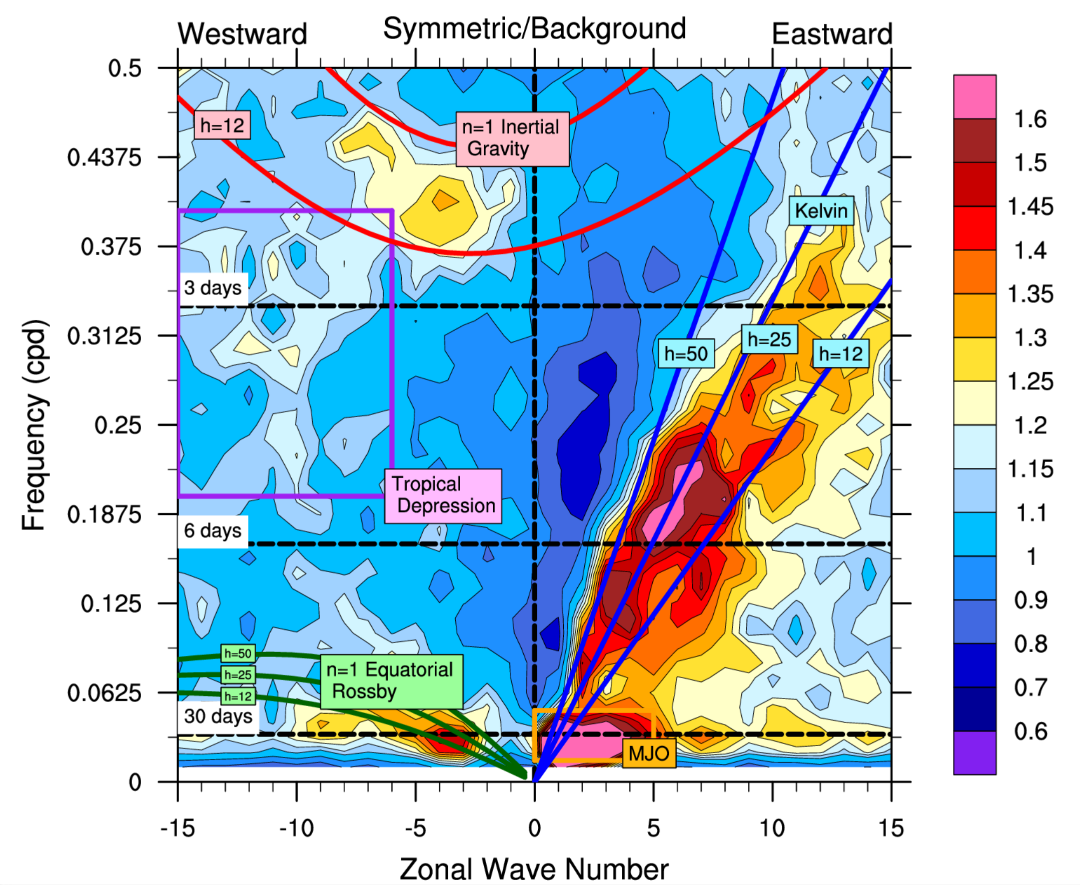


Vitart (2017)

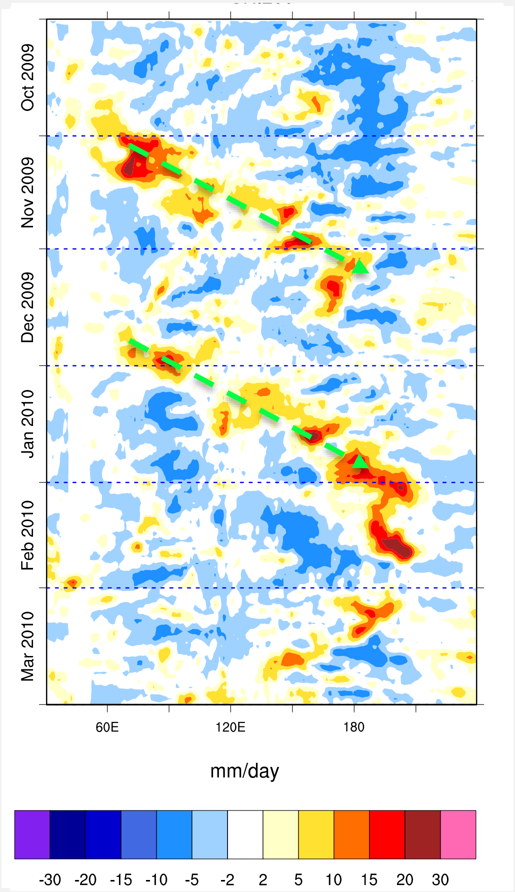


Straub and Kiladis (2003)

Tropical Wave Variability



Wheeler and Kiladis (1999)

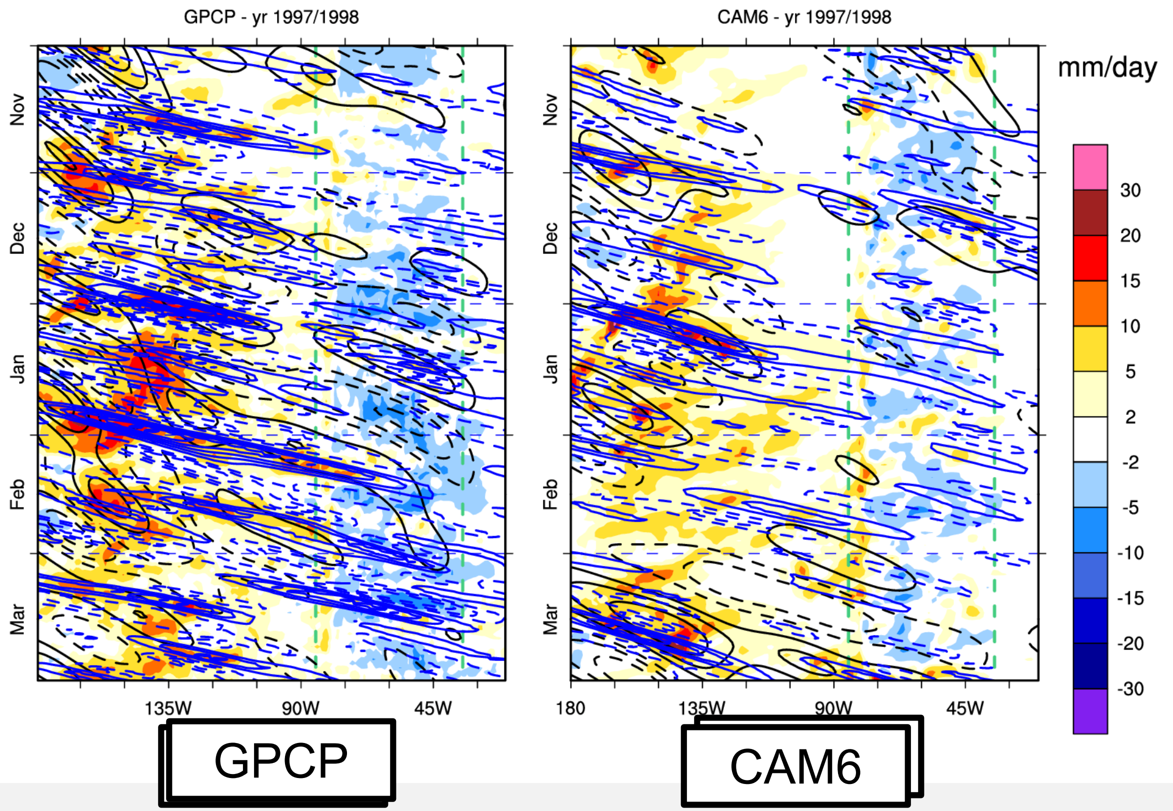


Modes of Variability Spectra

- Convectively coupled to vertical dynamic structure
- Real world equivalents to shallow water system
- Explain or associated with much of tropical convective sub-seasonal variability inc. tropical cyclones, monsoons

Dependence on ENSO Phase

La Nina (99/00)



El Nino year

- SST and convection extend into E. Pacific

- **Obs.** Mean impact on suppressing S. Am precip.
- BUT Wave activity propagates across E. Pac
- **CAM6** Weaker propagation into E. Pacific
- BUT mean imprint of ENSO on S.Am is weaker

La Nina

- More similar to neutral year
- Locally forced waves and wave packets (via MJO)

Liebmann et al., 2009 – Most active Nov-Apr. 2 type 1) From a pre-existing wave, 2) triggered locally from C (Amazon) and S. S. American. From the Pacific they are upper level disturbances (are they blocked by the Andes?. From the South the upper level trough generates a cold surge. As a wave train propagates over he Andes, it advects cold air northward. Subsequently triggers precipitation within the equatorial evolution. The interannual variability of the Pacific-originating events is related to sea surface temperatures in the central–eastern Pacific Ocean.

GARREAUD AND JOHN M. WALLACE, 1998 - Transient incursions of midlatitude air to the east of the Andes Mountains into subtropical and tropical latitudes. Upper tropospheric ridge/trough/ridge structure moves equatorward over 5 days at about 10 m/s. Contributes up to 25% of the summer precipitation over Amazon.

Liebman et al: 2011: Kelvin wave are precursor to intense Brazilian rainfall events