Convectively Coupled Waves over Tropical South America in CESM

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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?

![DJF precipitation (std dev.)](image)

TRMM

CAM6
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

$$\begin{align*}
\text{Max} & - \text{Min} & - \text{Max} \\
\text{KW variance} & \text{Amplitude} & \text{Wavenumber}
\end{align*}$$
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

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)
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 at 4km?
  - Are these increases related to wave activity?
Orographic Dependencies

30S-20S

- CAM6-LRES: Min. = -1.20, Max. = 7.59
- CAM5-LRES: Min. = -6.07, Max. = 6.41
- CAM5-NOCONV: Min. = -3.60, Max. = 11.09
- CAM5-HRES: Min. = -10.20, Max. = 15.57

Process Tendencies
- Total moist phys. processes (K/day)
- Strongest maximum over Andes
Orographic Dependencies

**20S-10S**

- **CAM6-LRES**
  - Min. = -1.85  Max. = 8.83

- **CAM5-LRES**
  - Min. = -3.65  Max. = 6.56

- **CAM5-NOCNV**
  - Max. = 11.34

- **CAM5-HRES**
  - Min. = -0.02  Max. = 14.84

**Process Tendencies**
- Total moist phys. processes (K/day)
- Strongest precip. bias
Orographic Dependencies

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

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?

Precip. U/V850mb
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

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

Wheeler and Kiladis (1999)
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