Decadal Modulation of ENSO and the Linkage to Tropical Pacific Decadal Variability

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Decadal Modulation of ENSO

What are the fundamental mechanisms of decadal ENSO modulations?

- Does the ENSO modulate with tropical Pacific decadal variability (TPDV)?
  - Do the ENSO properties other than the amplitude modulate?
    - Are the modulations of El Niño and La Nina symmetric?
  - What causes TPDV in the first place?
Community Climate System Model Version 4 (CCSM4)

CCSM4
1300-yr PI Control Simulation

- Ocean, atmosphere, land & sea ice models
- 1° resolution
- Preindustrial GHGs
- Variability = Natural

El Niño
La Niña

Niño-3.4 Index (Yr 900-1100)
Tropical Pacific Decadal Variability (TPDV)

EOF analysis of tropical Pacific SST (>10yr) → Global regressions on PCs

CCSM4 1300-yr run

TPDV1 (47%)

TPDV2 (24%)

Frequency & duration of El Niño

ENSO amplitude & asymmetry

Slab Ocean 500-yr run (No ENSO)

TPDV1 (38%)

TPDV2 (18%)

Contours: SLP (0.1 hPa), Precipitation (0.2 mm/day, WET/DRY)

ENSO
TPDV1 – Frequency and Duration of El Niño

Dec Niño-3.4 SST

> +1σ → El Niño
< −1σ → La Niña
(σ = 1.27°C)

Niño-3.4 Index

TPDV1 > 0

El Niño

TPDV1 < 0

La Niña

130

126

4

81

46

35

63

60

3

99

32

67
Role of Interbasin SST Gradient in El Niño Modulation

Relative warmth of the tropical Pacific
↓
Westerly wind anomalies in W Pacific
↓
Deepening of thermocline in E Pacific
↓
More frequent & persistent El Niño

TPDV1

Mar-May Eq. Pacific Thermocline Depth ($\sigma$)

TPDV1 > 0

TPDV1 < 0

Jan-Mar $\nabla$SSTA* = Pacific − Indian/Atlantic ($\sigma$)

Dec Niño3.4 ($\sigma$)

r(x,y)=0.8

* Regression on Dec(-1) Nino-3.4 index removed
TPDV2 – ENSO Amplitude and Asymmetry

- **TPDV2 > 0**
  - Warmer E Pacific
  - Southward shift of ITCZ
  - Eastward shift of El Niño anomalies
  - Stronger & shorter El Niño
  - Stronger & longer La Niña
  - Stronger ENSO Asymmetry (pattern & duration)

- **TPDV2 < 0**

- **Difference x 2**

**La Niña**

**El Niño**

**Surface Winds (m/s), Precipitation (0.2 mm/day, WET/DRY)***

**ETS (°C)**
ENSO modulates with the two leading modes of TPDV.

- Various properties of ENSO modulate.
  (Amplitude, frequency, duration and El Nino-La Nina asymmetry)

- Modulations of El Nino and La Nina are asymmetric.
  (El Nino appears more sensitive to TPDV.)

- What causes TPDV in the first place?
Role of Stochastic Atmospheric Forcing from the S Pacific

Slab Ocean
500-yr run
(No ENSO)

TPDV1 (38%)

TPDV2 (18%)

Pacific-South American (PSA)

PSA2

CAM4
300-yr run
(No SST Variability)

S Pacific SLP EOF1 (32%)

S Pacific SLP EOF2 (21%)

Surface heat flux
(W/m²)

-6.0 -4.0 -2.0 0.0 2.0 4.0 6.0

Contours: Sea Level Pressure (1 hPa)
Hypothesis

Stochastic Variability of PSA & PSA2

TPDV

ENSO

CCSM4

Atmosphere

Ocean

PSA & PSA2 heat flux anomalies from CAM4

Amplitude of heat flux anomalies is adjusted for decadal variability and kept constant in time.

100 yr x 3 members for each of PSA and PSA2 forcing
Mean State and ENSO Changes in the **PSA** Experiments

**PSA Forcing**

**TPDV1**

**Slab Ocean PSA Experiment (100 yr x 1)**

**El Niño Frequency**

**La Niña Frequency**

PDF (%)

- SST (°C)
- SLP (0.1 hPa), Precipitation (0.2 mm/day, WET/DRY)

# of Events / 100 yrs

- Control

#1, #2, #3
Mean State and ENSO Changes in the PSA2 Experiments

PSA2 Forcing

TPDV2

Ensemble Mean Response

E Pacific warms only in 2 members

SST (°C)

SLP (0.1 hPa), Precipitation (0.2 mm/day, WET/DRY)

ENSO Amplitude

Monthly Nino-3.4 S.D. (°C)

∇(Mean SSTA) = E - W Pacific (°C)

#1

#2

#3

Control
Summary

Stochastic PSA variability

TPDV1

Stochastic PSA2 variability

TPDV2

Frequency & Duration of El Nino

Interbasin SST Gradient

Zonal SST Gradient

ENSO Amplitude & Asymmetry
Additional Slides
TPDV in CCSM4 vs Observations

CCSM4 1300-yr run

HadISST 1870-2017 (quadratic trend removed)

Last Millennium Reanalysis (PAGES2k + CCSM4) 0-1850CE

TPDV1 47%

TPDV2 24%

r(AMO)=-0.37
r(ENSO)=+0.40

r(AMO)=-0.06
r(ENSO)=+0.81

r(AMO)=-0.09
r(ENSO)=+0.15

r(AMO)=-0.37
r(ENSO)=+0.40

r(AMO)=-0.09
r(ENSO)=+0.15
Mean State and ENSO Changes in the **NPO** Experiments

**NPO Forcing**

**TPDV2**

**Ensemble Mean Response**

**SST (°C)**

SLP (0.1 hPa), Precipitation (0.2 mm/day, WET/Dry)

**TPDV2**

**El Niño Frequency**

PDF (%)

# of Events / 100 yrs

**La Niña Frequency**

Control

#2 #1 #3

#1 #2 #3