Climate Sensitivities of ENSO

Bridging theory, observations, and modeling

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Thanks to: Gabriel Vecchi, Qian Song, and Anthony Rosati
“Other worlds” in CGCMs

SST (°C)

Precip (mm/day)

τx (dPa)

Temperature (°C) at Equator
Assim (1980–1999), CM2.0 (bias shaded)
Mixed layer temperature anomaly tendency equation

\[ T'_t = -u'T'_x - u'T'_x - (u'T'_x)' - v'T'_y - v'T'_y - (v'T'_y)' - w'T'_z - w'T'_z - (w'T'_z)' + \text{eddy} + Q'_\text{sfc} \]

Key to understanding impact of background state on ENSO.
Mixed layer temperature anomaly tendency equation

\[ T'_t = -u'T_x - uT'_x - (u'T'_x)' - v'T_y - vT'_y - (v'T'_y)' - w'T_z - wT'_z - (w'T'_z)' + \text{eddy} + Q'_{\text{Sfc}} \]

Key to understanding impact of background state on ENSO.
ICM Control Run

(d) $\tau_x = 0$
3.1yr at 121°W

180° 120°W
ICM: Impact of trade wind strength

(a) $\tau_x = -0.1$
1.2yr at 142°W

(b) $\tau_x = -0.06$
1.7yr at 137°W

(c) $\tau_x = -0.02$
2.9yr at 127°W

(d) $\tau_x = 0$
3.1yr at 121°W

(e) $\tau_x = 0.02$
3.5yr at 119°W

(f) $\tau_x = 0.04$
4.6yr at 119°W

Weakening equatorial trades
Blocking the Indonesian Throughflow:

Change in mean SST (degC)
Blocking the Indonesian Throughflow: Anomaly patterns (regressed on NINO3)
Stochastic forcing: A role for the Indian Ocean

Daily west-Pacific zonal stress from 10 AM2 runs

Observed SST forcing
Stochastic forcing: A role for the Indian Ocean

Daily west-Pacific zonal stress from 10 AM2 runs

Observed SST forcing

Warm East Indian
Summary

1) CGCMs: “Other Worlds”

2) Mixed layer heat budget & “frequency budget”

3) ICM: perturbations seed feedbacks, which alter ENSO

4) CM2: flux anomaly patterns sensitive to background

5) WWBs, nonlinearity, and a role for the Indian Ocean
Equatorial adjustment to off-equatorial stress
ICM: Different climate perturbations, similar effects

Overlay of all perturbations

SSTA amplitude at 5yr: 2°C

\[
\begin{align*}
\text{imposed equatorial } \tau_x & \text{ (barie)} \\
\text{imposed heat flux down (W/m}^2) \\
\text{imposed westerlies} & \text{ (ºE)} \\
\text{imposed easterlies} & \text{ (ºE)} \\
\text{imposed off-equatorial } \tau_x & \text{ (barie)} \\
\text{imposed } \tau_y & \text{ (barie) at 100ºW}
\end{align*}
\]
CM2 anomaly patterns: Wind stress

\( \tau_x \) regr on NINO3 SSTA

NINO3 SST spectra

ERA40

1979–2001

no CMT

CMT

CM2.1 without CMT (0101–0160)

CM2.1 with CMT (0001–0200)

\((\circ C)^2 / \text{octave}\)
CM2 anomaly patterns: Surface heat flux

Mean Shortwave at Surface (W/m²)

Anomalous Shortwave at Surface (W/m²)

NINO3 SST spectra

Obs (ERSST 1903–2002)
A600 Model (100yr)
B600 Model (100yr)
A wide variety of products
ICM: Mixed layer heat budget

Least damped mode: 2°S–2°N

(a) net\_flux\_a  (b) uptm  (c) umtp  (d) uptp

(e) dT/dt  (f) vptm  (g) vmtlp  (h) vptp

(i) hmix\_a  (j) wptm  (k) wmtlp  (l) wptp
Hybrid CGCM mixed layer heat budget

HGCM ENSO: 2°S–2°N
Impact of weakening equatorial zonal stress