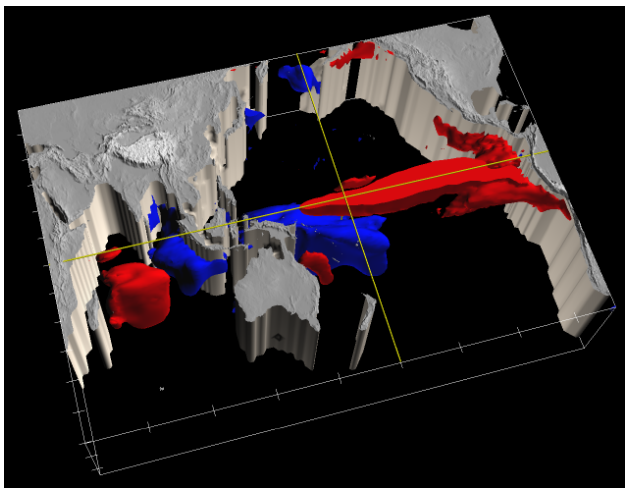
Simulation and Prediction of El Niño at the Geophysical Fluid Dynamics Laboratory



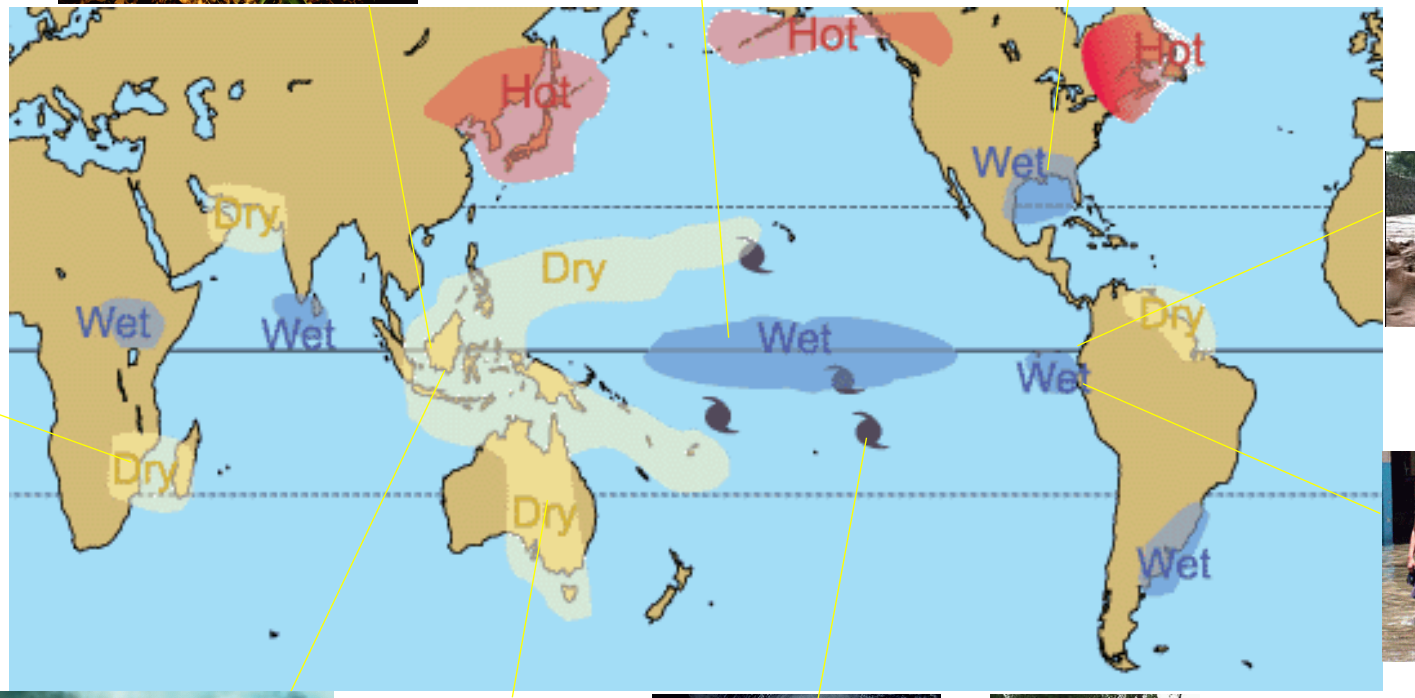
Andrew Wittenberg
GFDL/NOAA

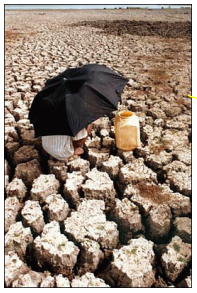
with

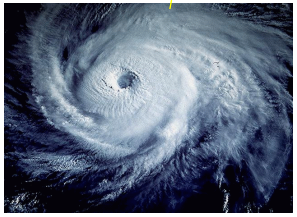
G. Vecchi, T. Rosati, M. Harrison, S. Zhang, I. Held,
R. Gudgel, and the GFDL Model Development Teams

Email: Andrew.Wittenberg@noaa.gov

Global Impacts of El Niño







New GFDL CGCMs: CM2.0, CM2.1

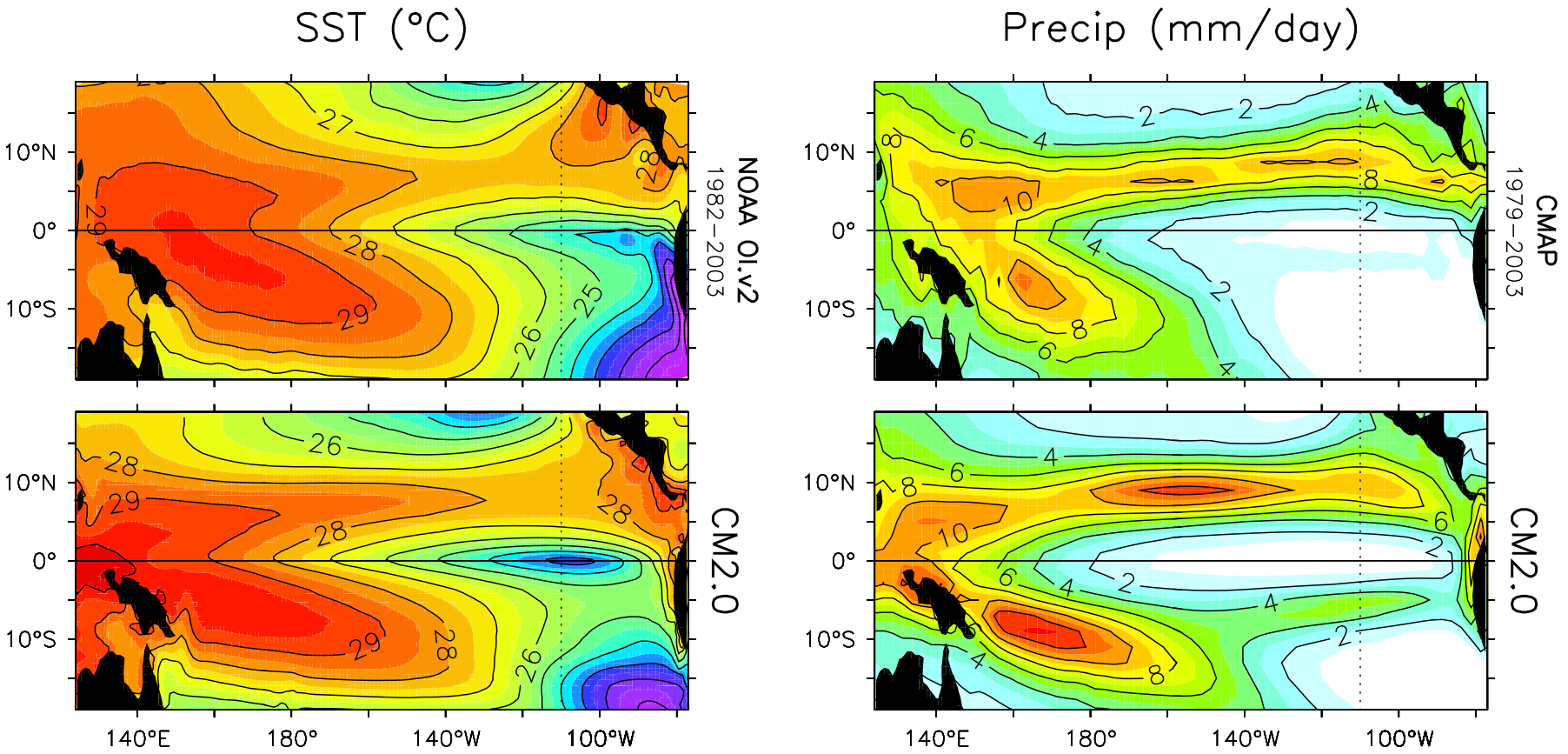
Atmospheric models:

- dycores: B-grid (AM2p12), finite volume (AM2p13)
- $2.5^\circ \times 2^\circ \times$L24, hybrid vertical $\sigma \rightarrow p$
- K-profile PBL (Lock et al., MWR 2000)
- RAS convection
- cumulus momentum transport (CMT)

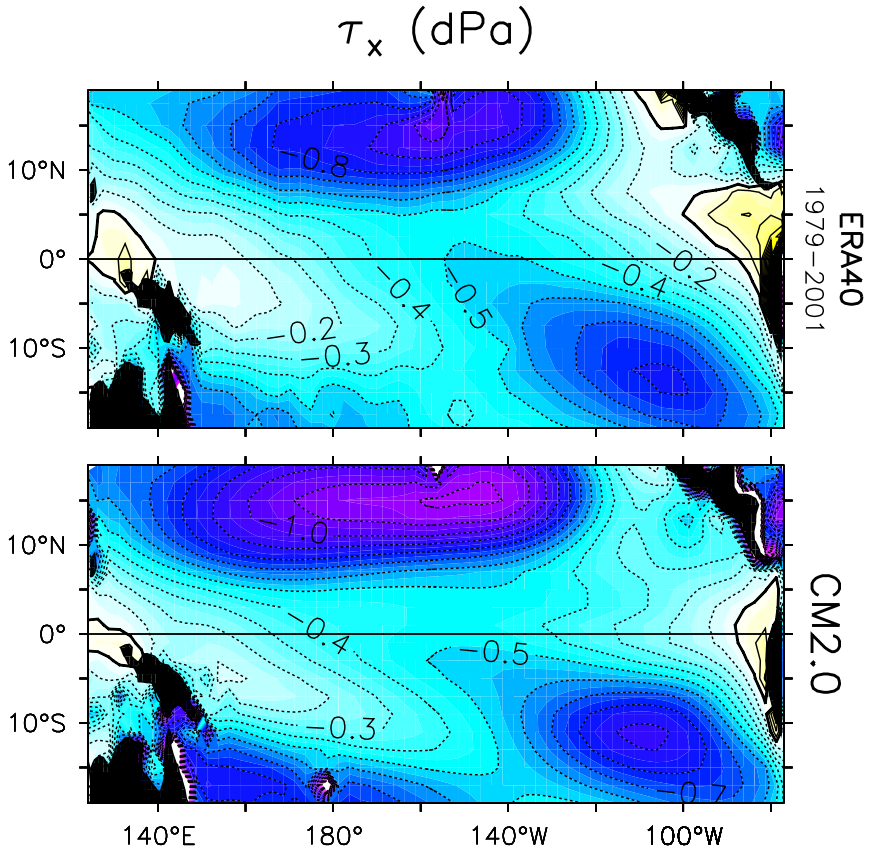
OM3 ocean model (MOM4):

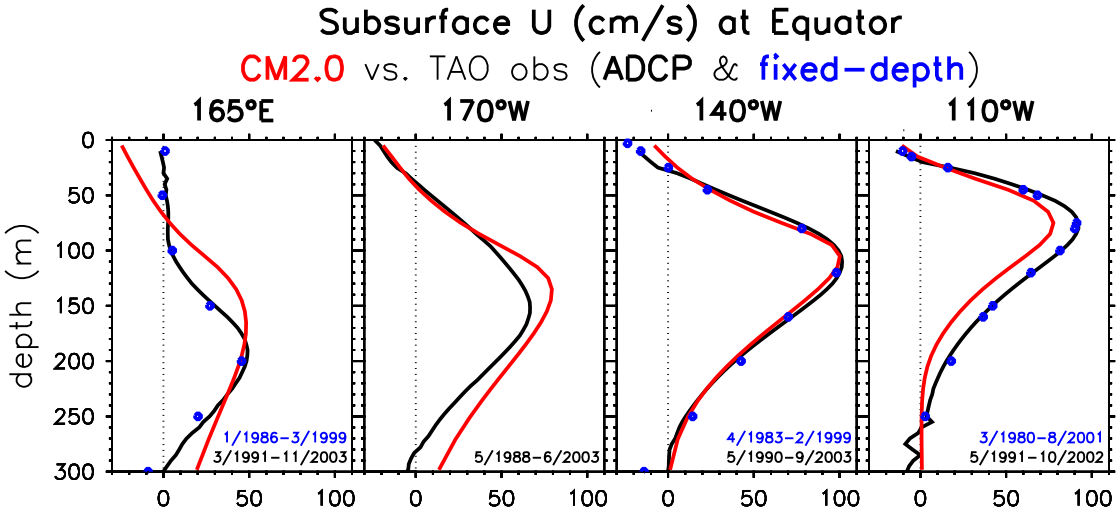
- 50 z-levels, $1^\circ \times 1^\circ$, $\Delta y \rightarrow 1/3^\circ$ at equator
- KPP, neutral physics, anisotropic viscosity
- diurnal insolation, ocean color
- free surface, fresh water fluxes
- wind stress feels surface currents

Annual mean climatology

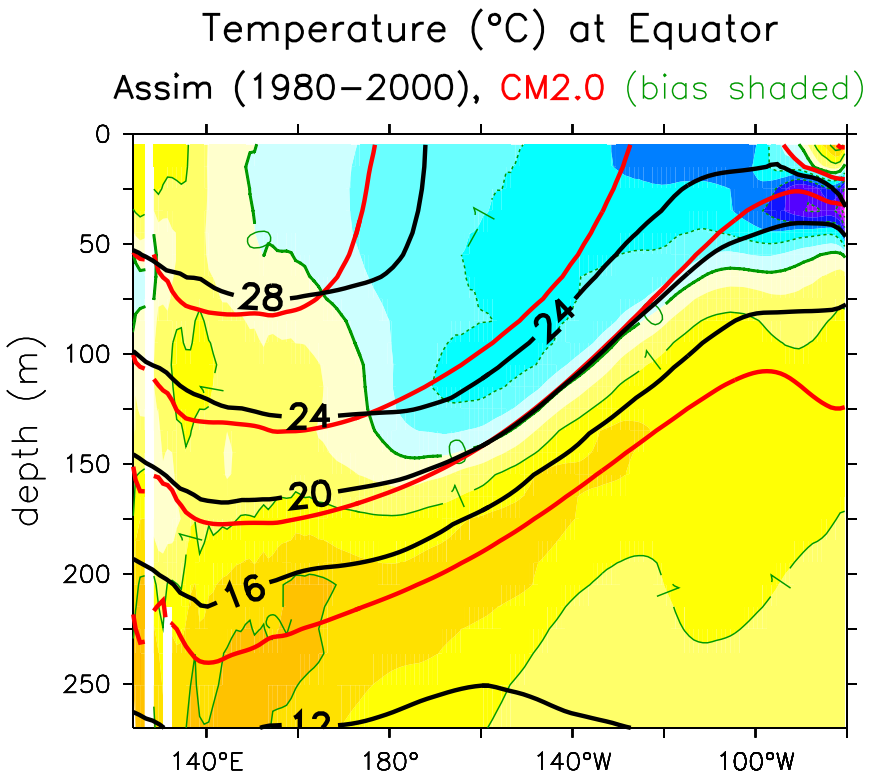


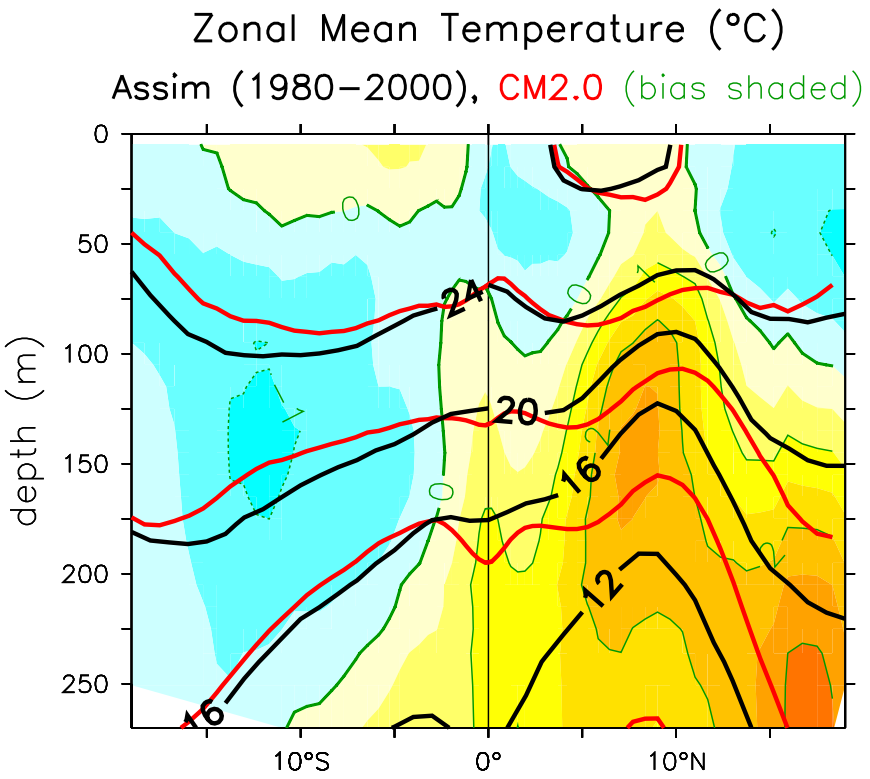
Annual-mean zonal winds & currents



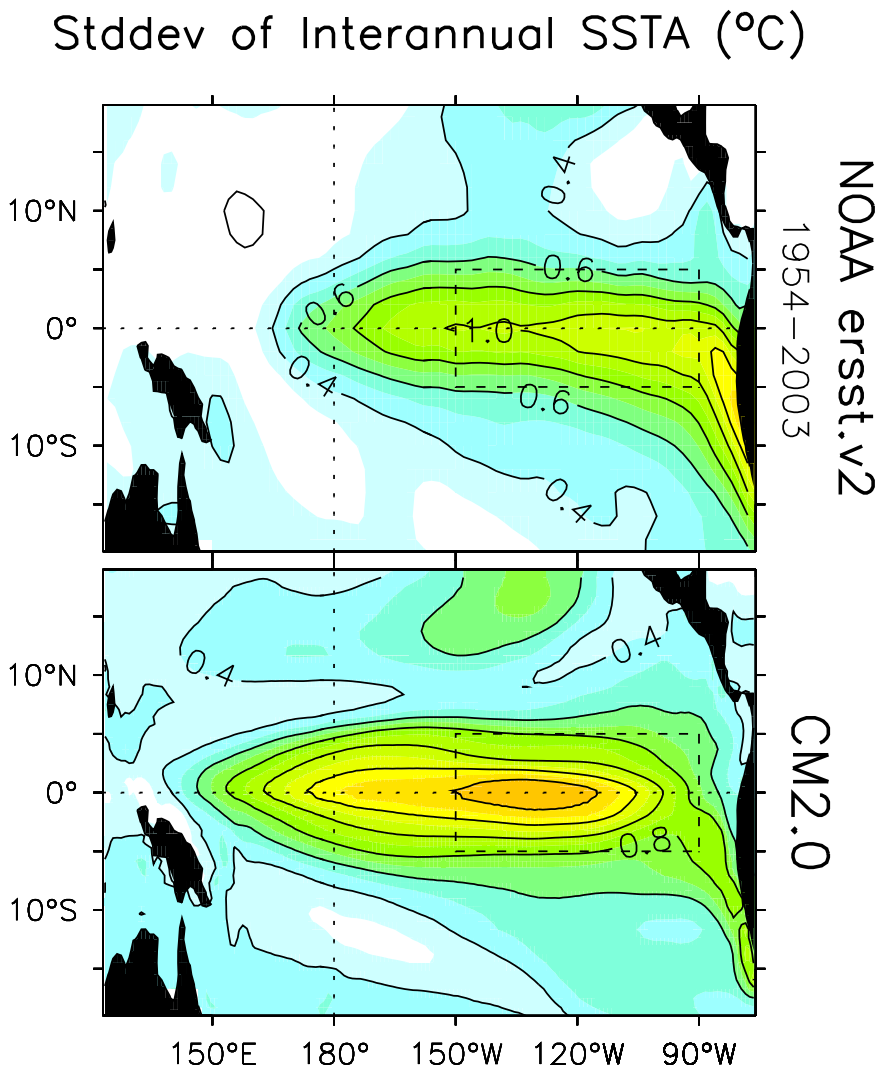


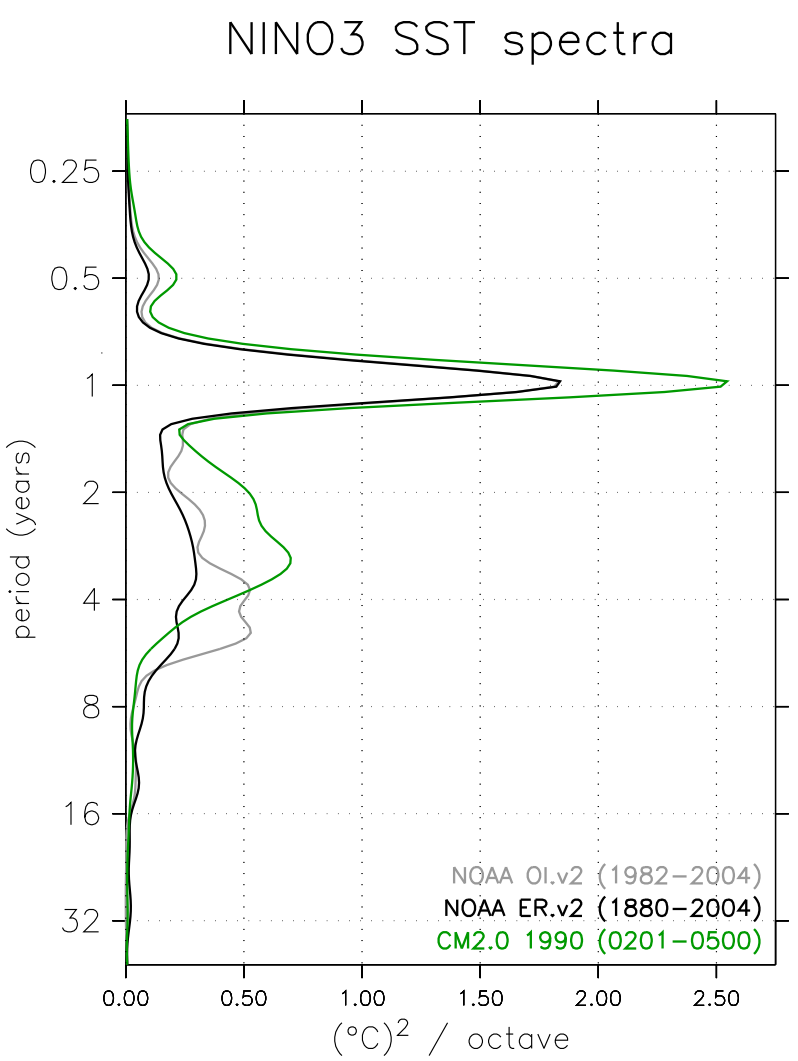
Annual-mean subsurface temperatures



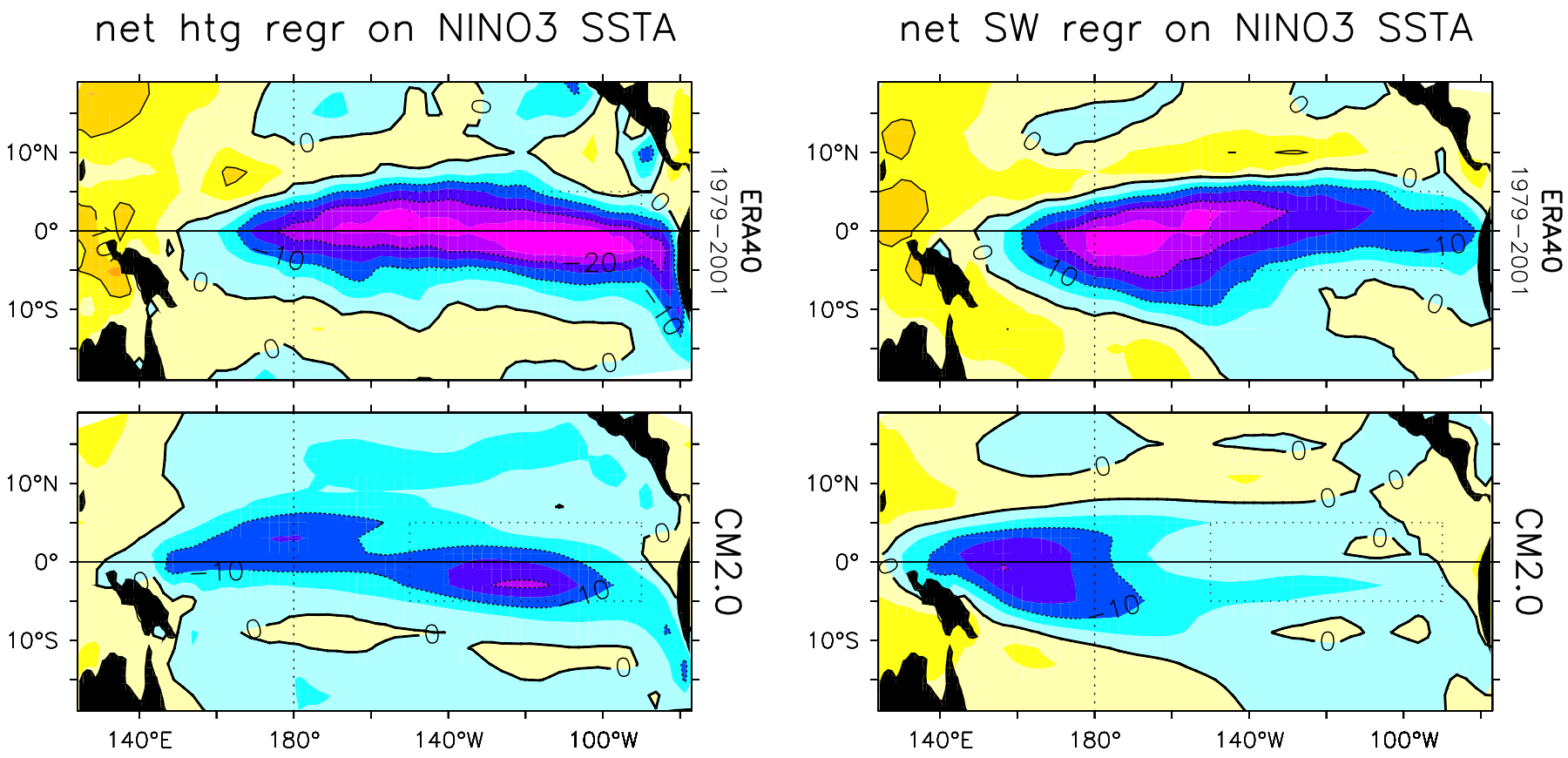


Simulated ENSO variability

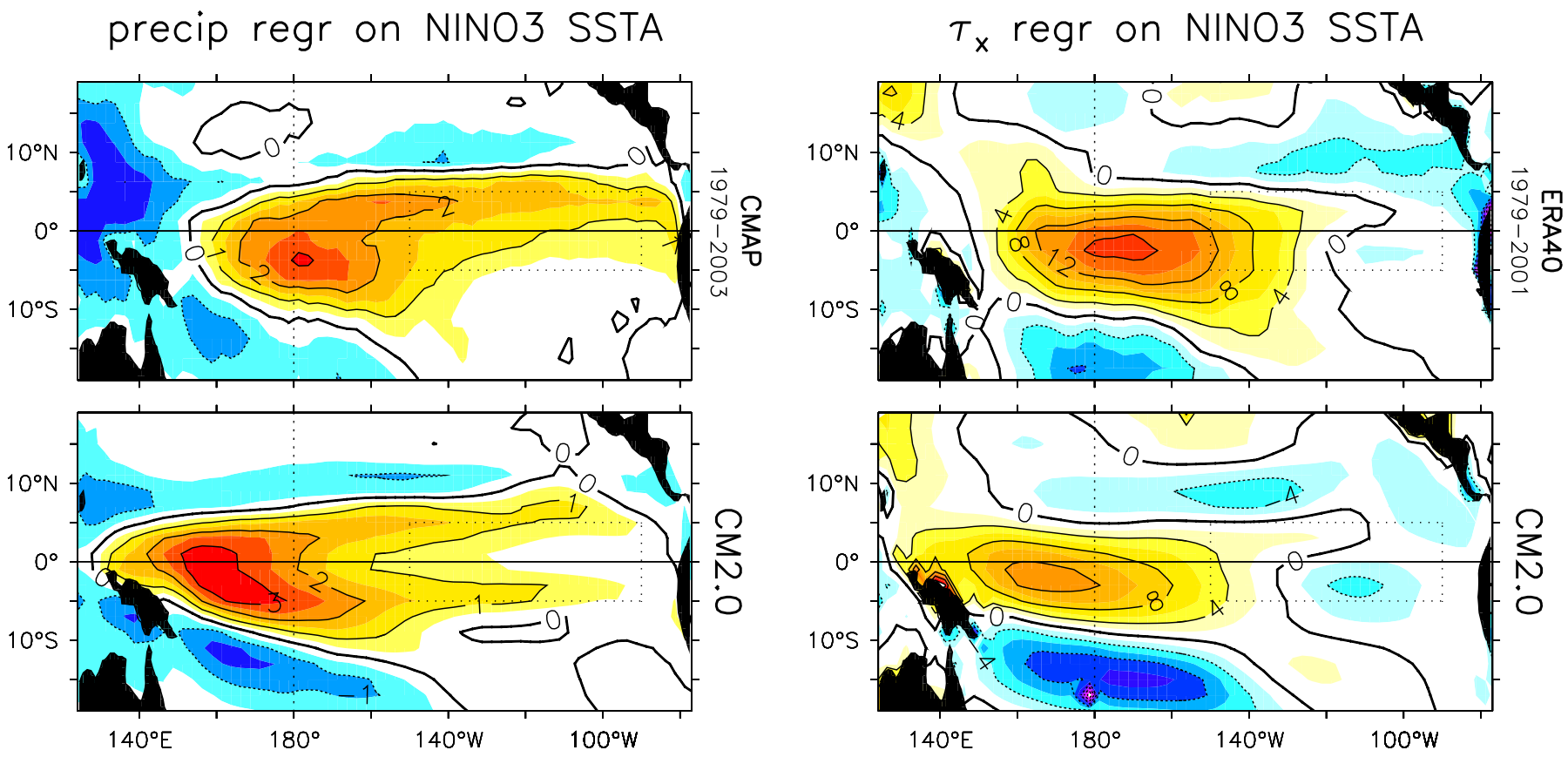




ENSO surface heat flux anomalies



ENSO rainfall & wind anomalies



Cumulus Momentum Transport (CMT)

Parameterization: Add a vertical diffusion of horizontal momentum where cumulus convection occurs.

$$K_{cu} = \frac{\gamma M_c d}{\rho}$$

M_c = cumulus mass flux from RAS

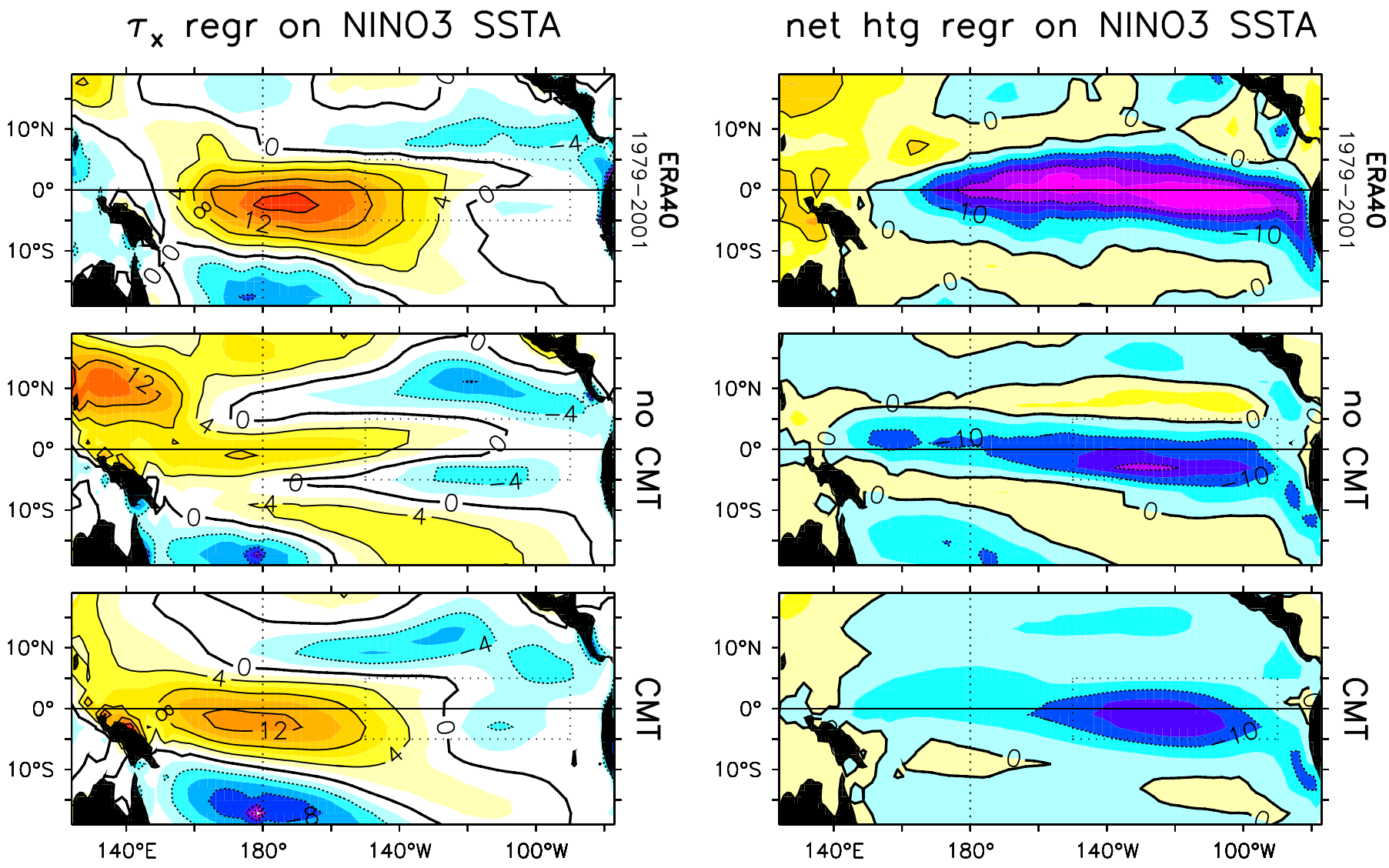
d = depth of convection

ρ = density of air

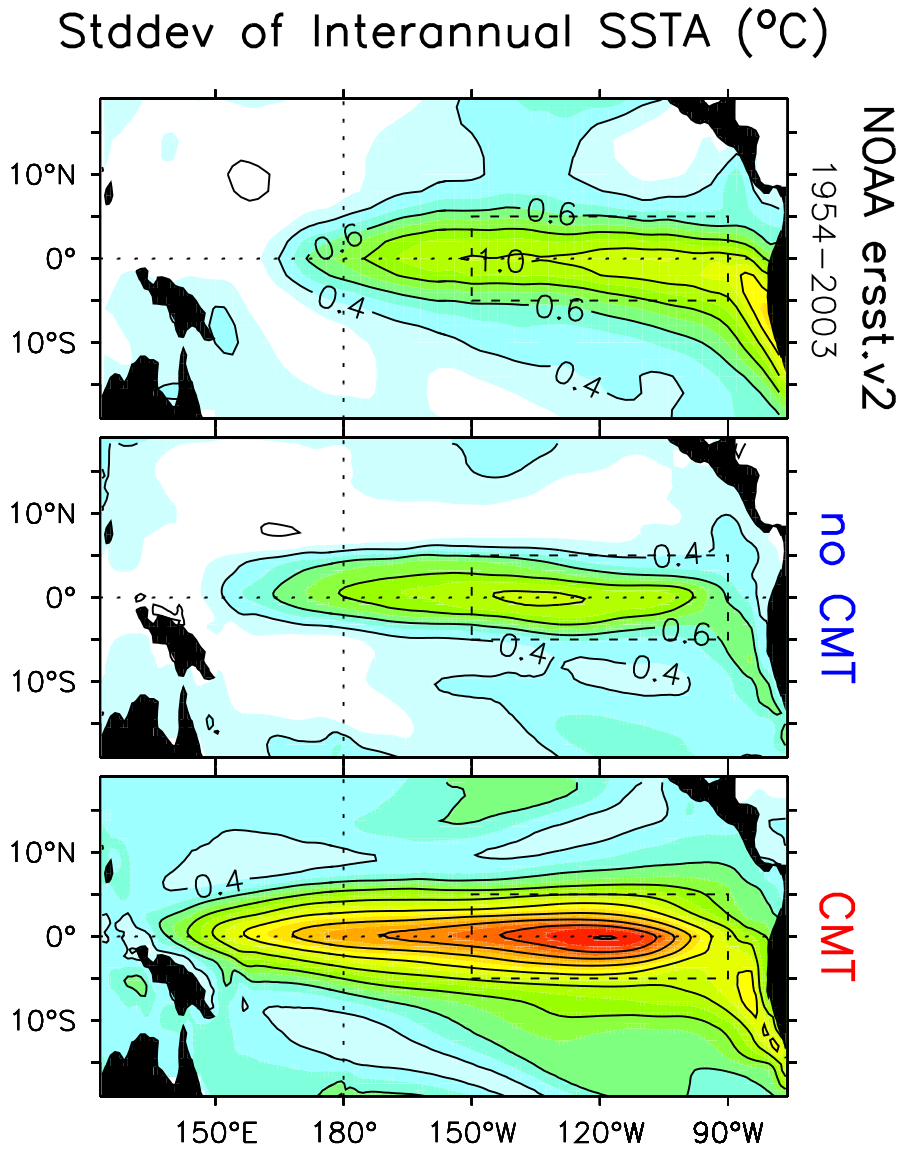
γ = tuning parameter

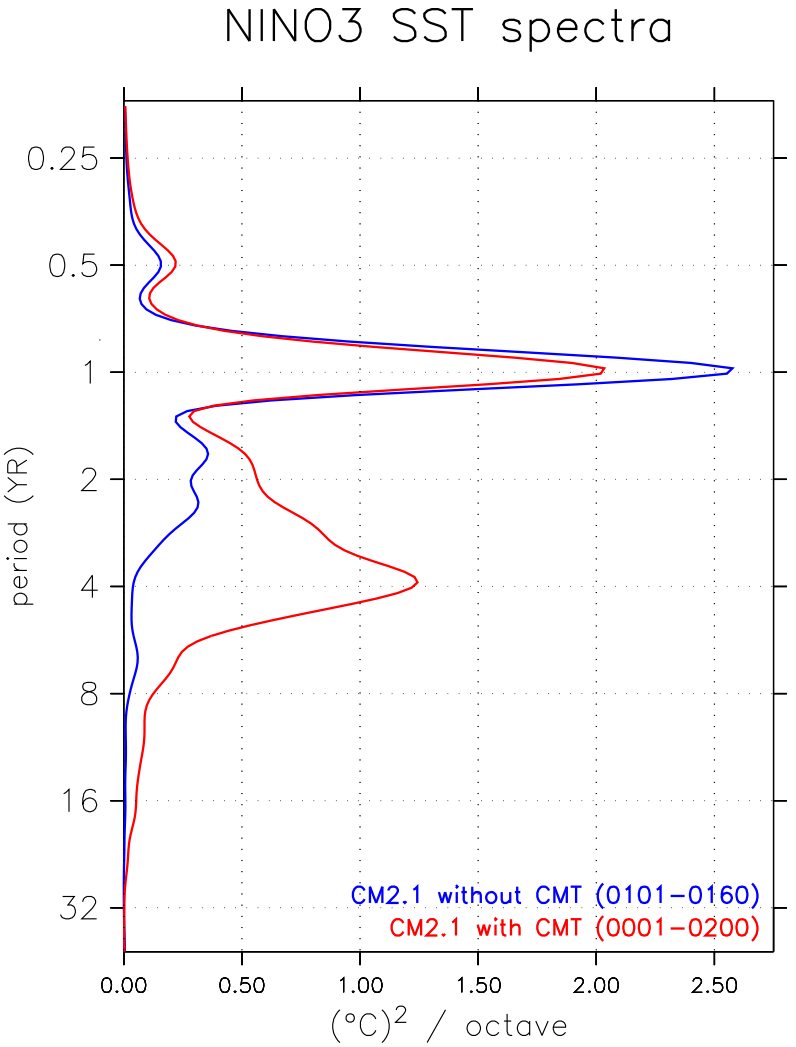
Cloud resolving models (Mapes & Wu, JAS 2001) suggest $\gamma \approx 0.1$–0.2.

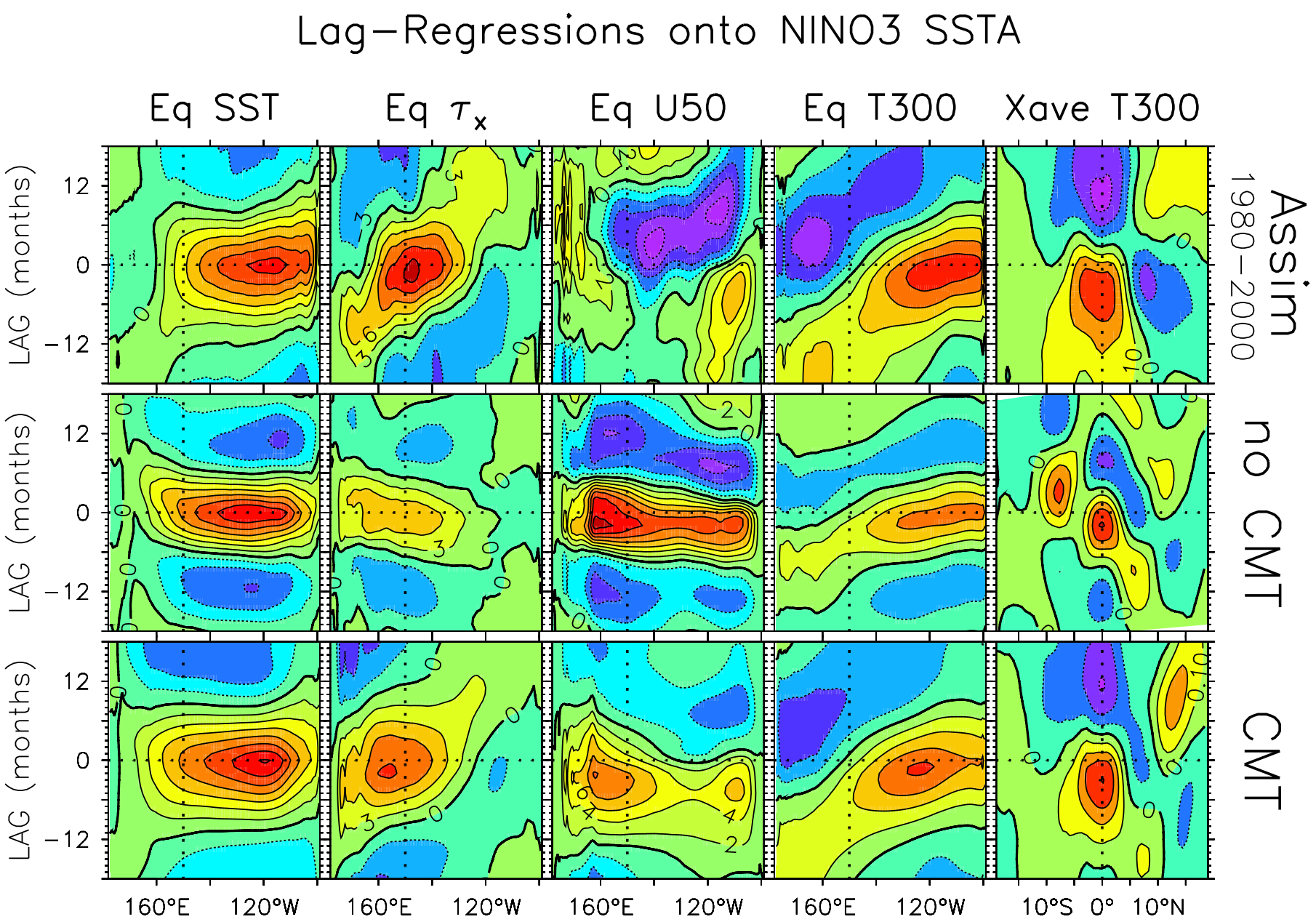
Impact of CMT

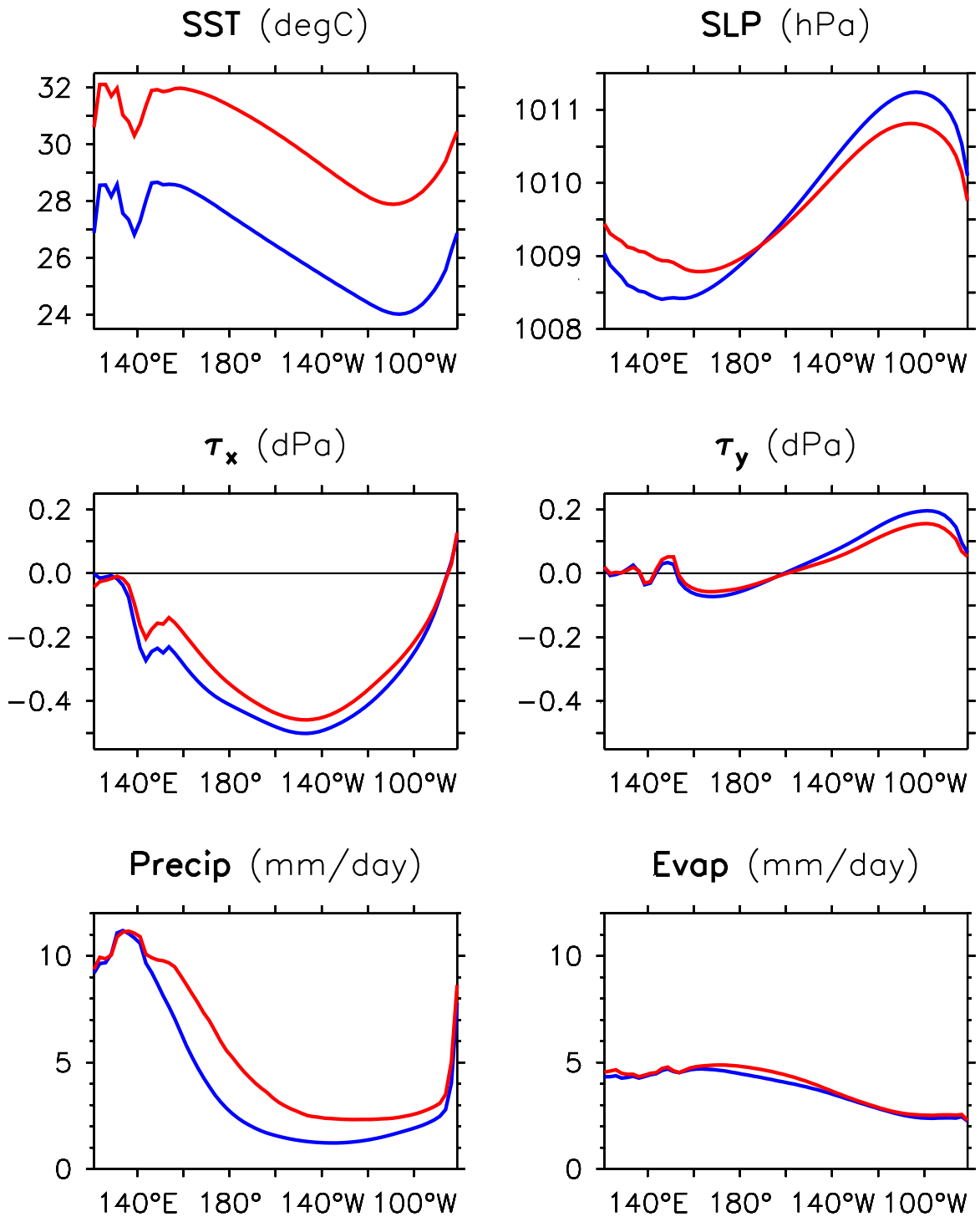


Impact of CMT



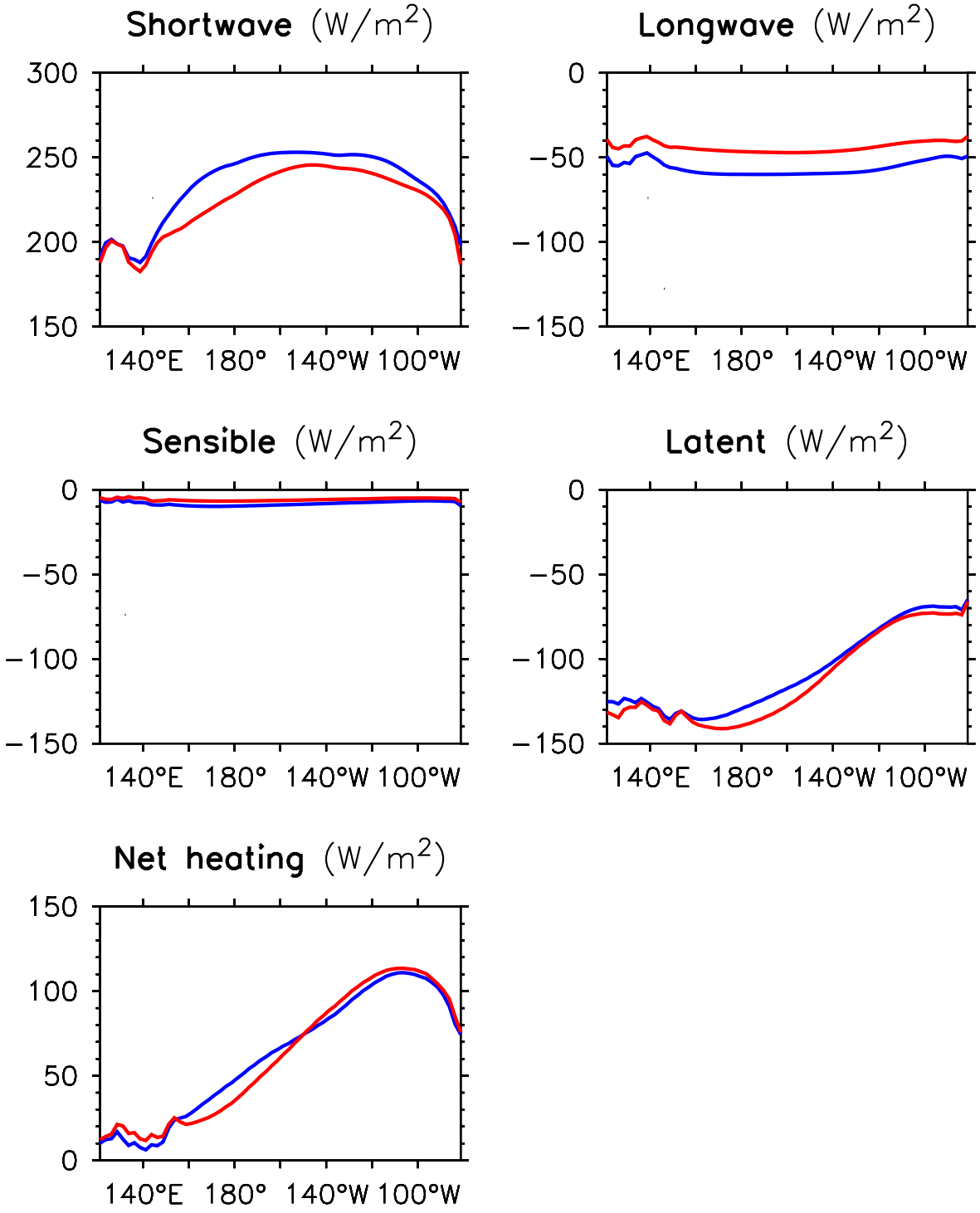



Lag–Regressions onto NINO3 SSTA
Eq SST
Eq τ_x
Eq U50
Eq T300
Xave T300
LAG (months)
12
0
−12
160°E
120°W
10°S
0°
10°N
Assim
1980–2000
no CMT
CMT

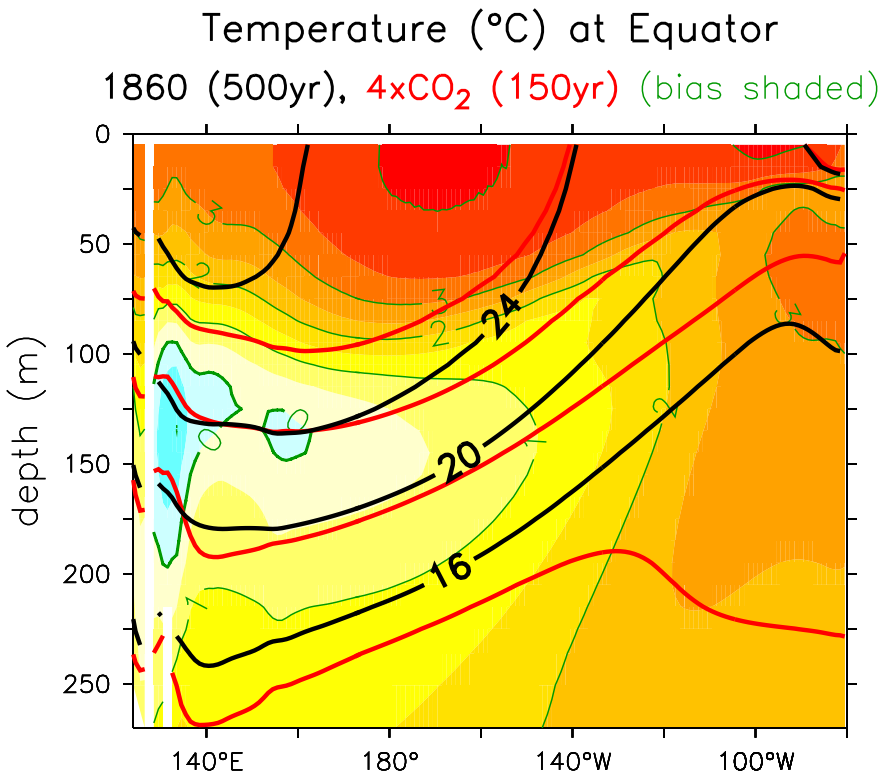

Pacific annual–mean fields, averaged 5°S–5°N
1860 (0001–0500), 4xCO2 (0151–0300)
SST (degC)
32
30
28
26
24
SLP (hPa)
1011
1010
1009
1008
τx (dPa)
0.2
0.0
−0.2
−0.4
τy (dPa)
0.2
0.0
−0.2
−0.4
Precip (mm/day)
10
5
0
Evap (mm/day)
10
5
0
140°E 180° 140°W 100°W

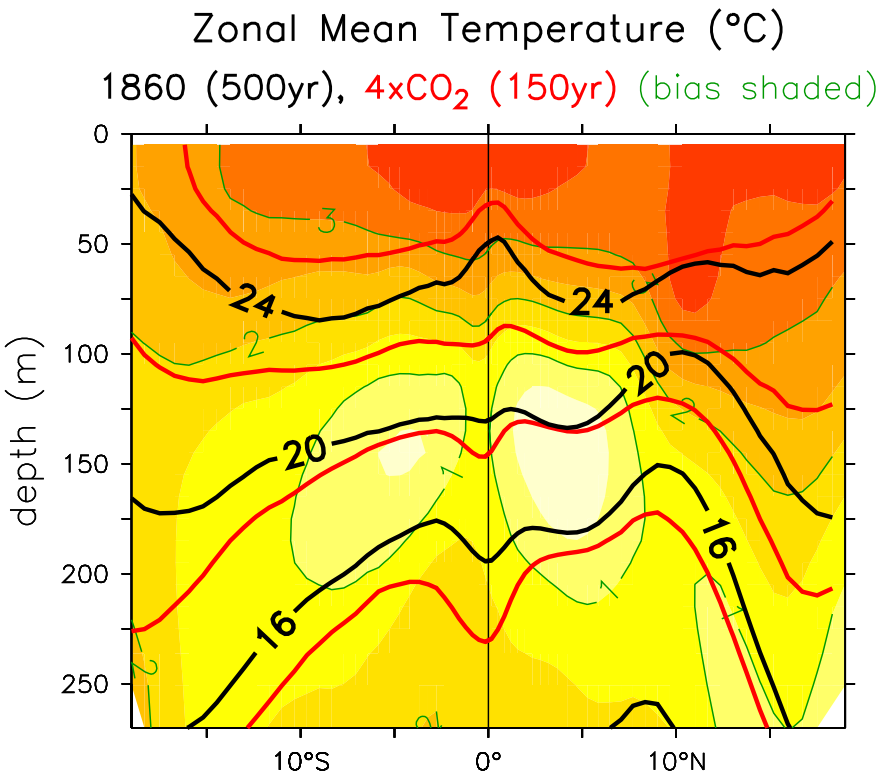
Pacific annual−mean fluxes, averaged 5°S−5°N

1860 (0001−0500), 4xCO_2 (0151−0300)

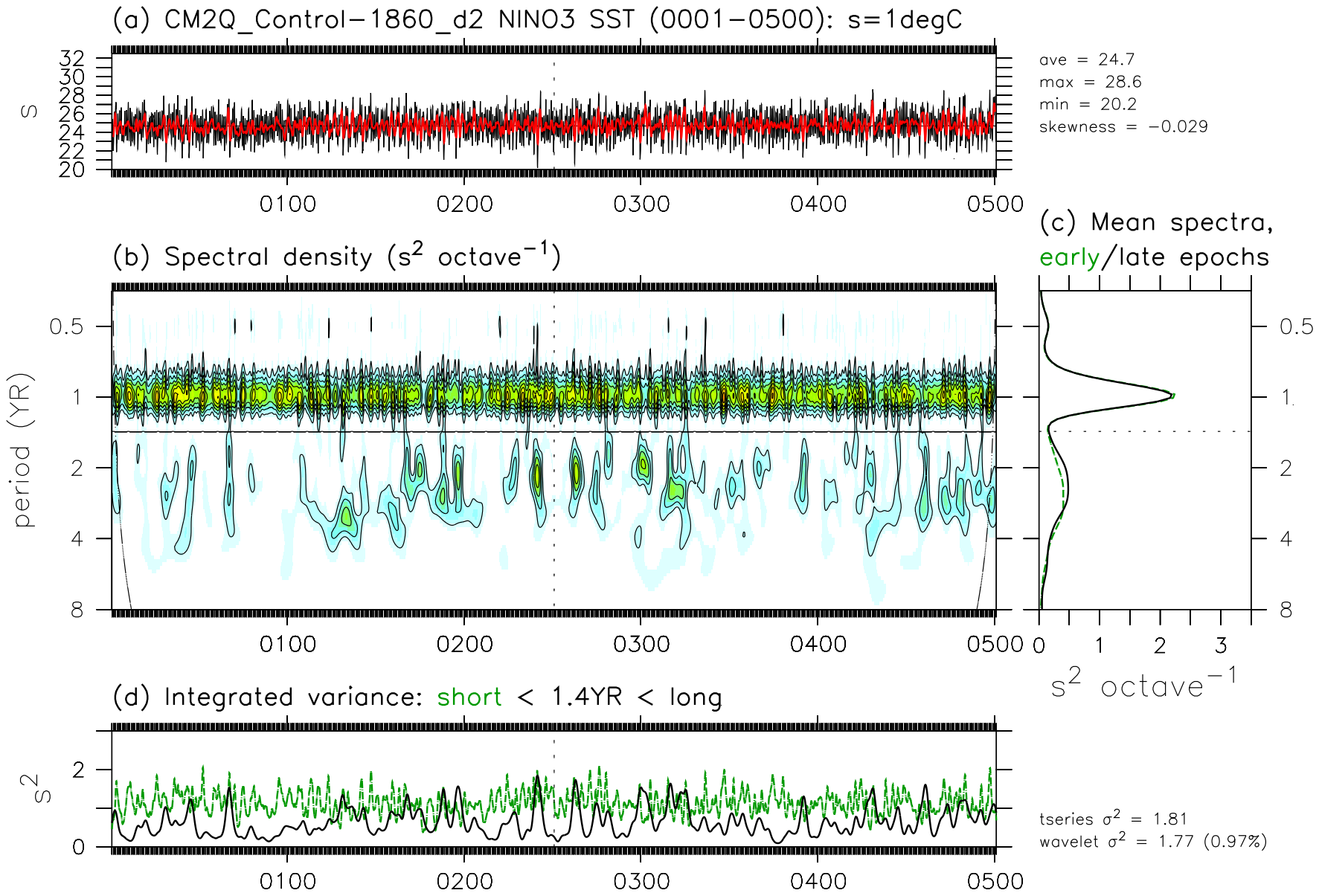


Change in annual-mean subsurface temperatures

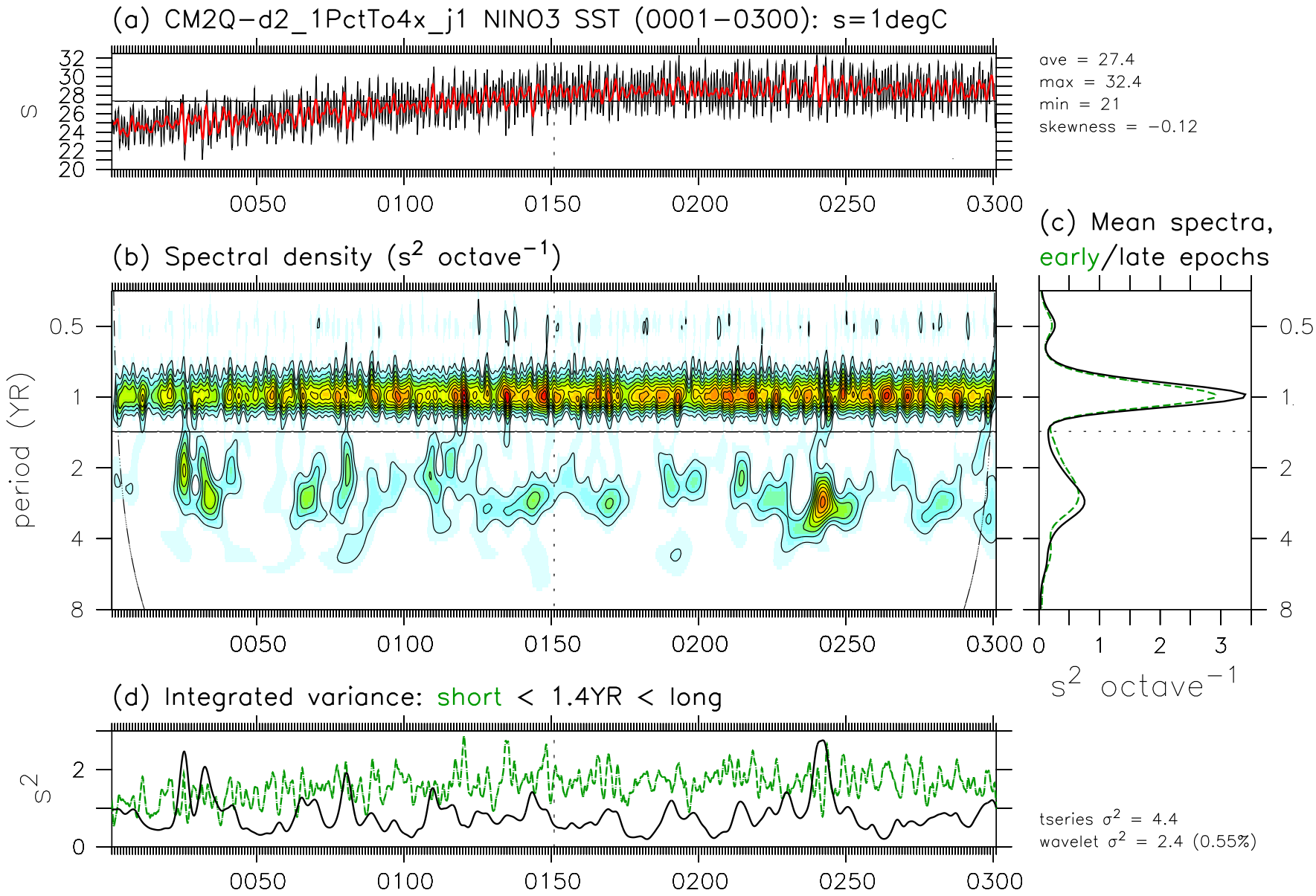


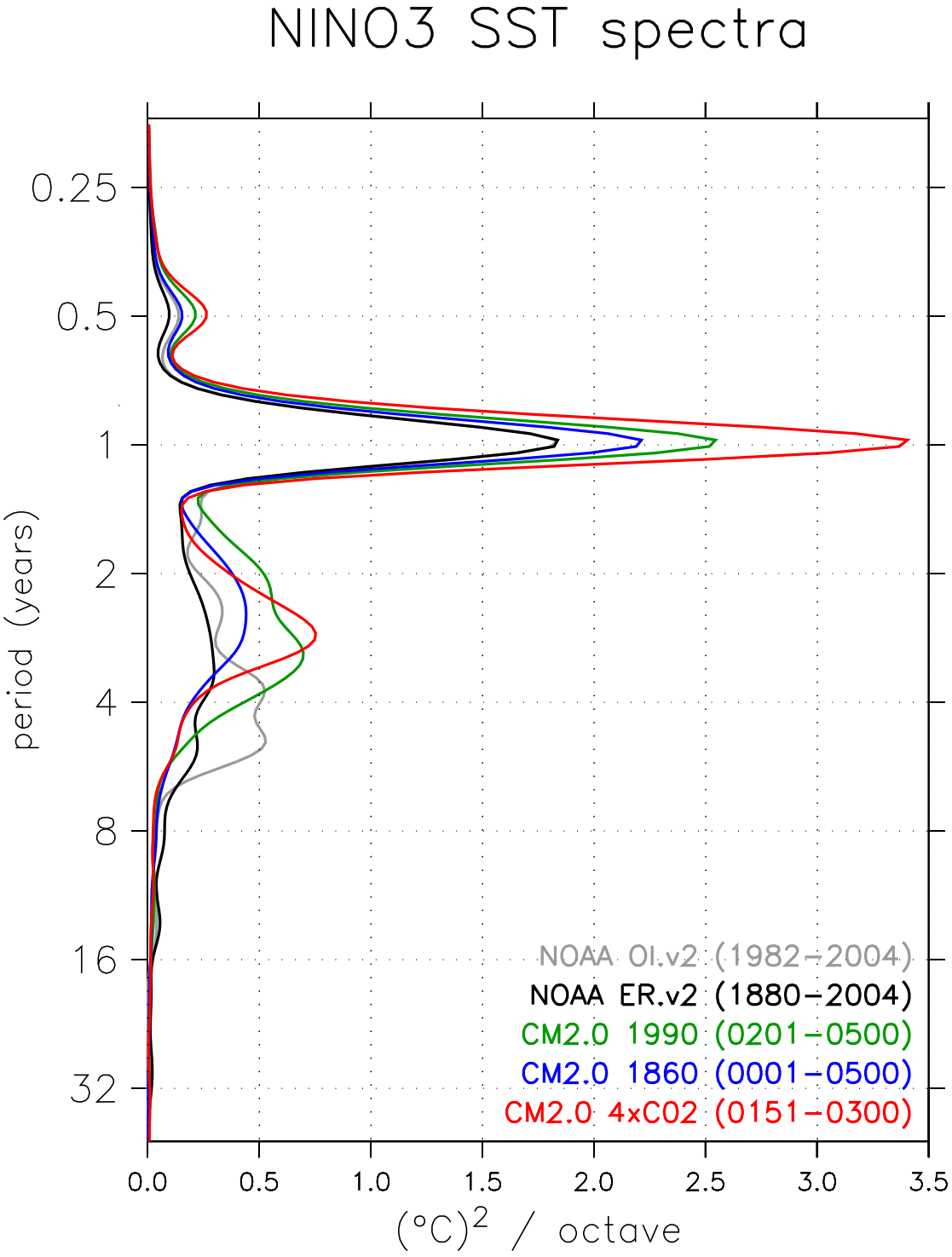


NINO3 wavelet spectrum: 1860 control run



NINO3 wavelet spectrum: CO_2 increasing 1%/yr, to 4x




NINO3 SST spectra
0.25
0.5
1
2
4
8
16
32
period (years)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
(°C)2 / octave
NOAA OI.v2 (1982–2004)
NOAA ER.v2 (1880–2004)
CM2.0 1990 (0201–0500)
CM2.0 1860 (0001–0500)
CM2.0 4xCO2 (0151–0300)

Ocean Data Assimilation at GFDL

state estimation - model evaluation - forecast initialization

3D Variational (3DVAR):

- stationary error covariance
- routinely used for ENSO forecasts
- available at http://nomads.gfdl.noaa.gov

4D Variational (4DVAR):

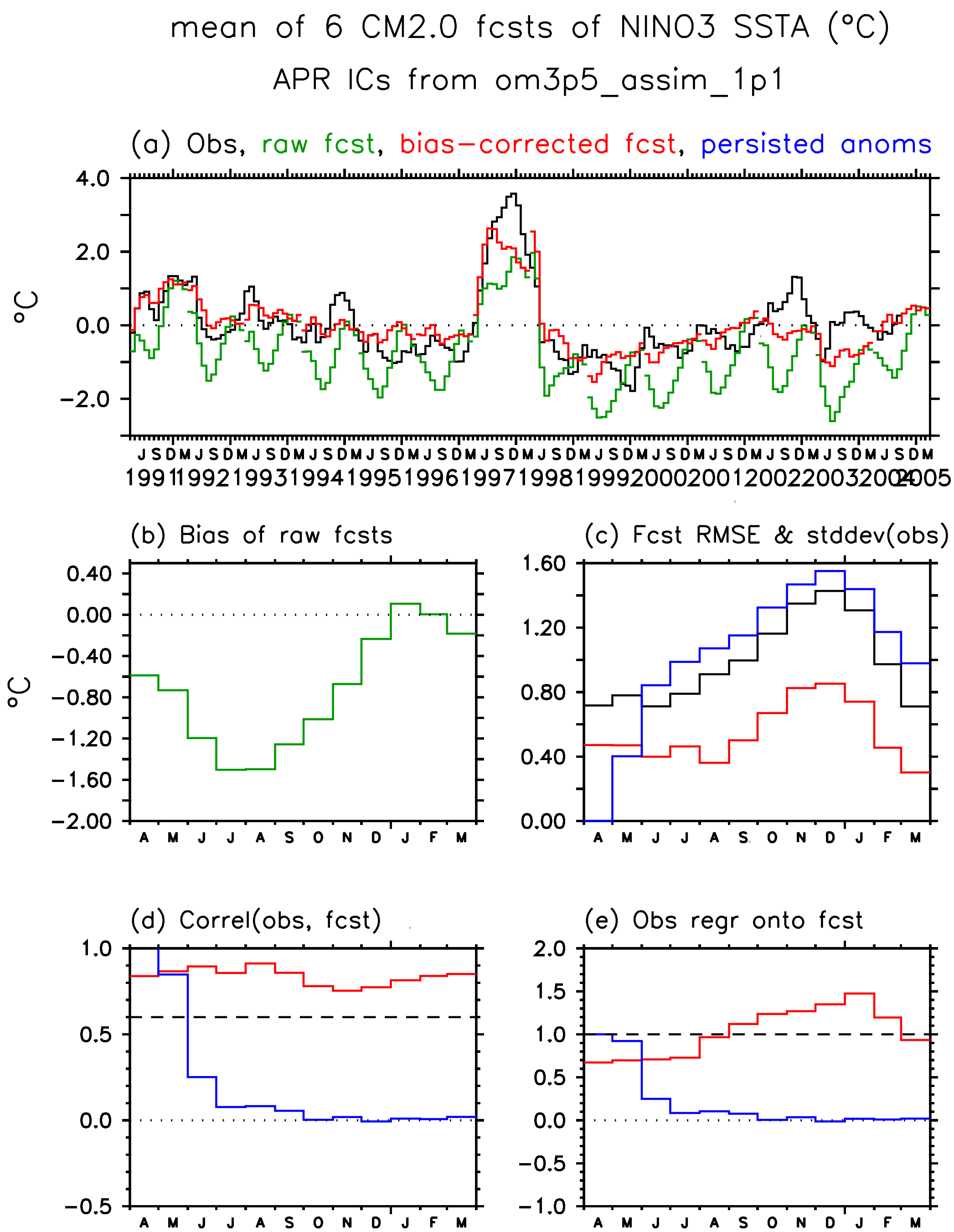
- strong constraint to model equations
- no sources/sinks
- adjoint $\longrightarrow$ sensitivity studies

Ensemble Adjustment Kalman Filter (EAKF):

- fully nonlinear evolution of covariance matrix
- testbed for coupled data assimilation

Beware model bias . . .

GFDL ENSO forecasts

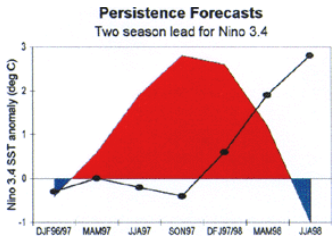


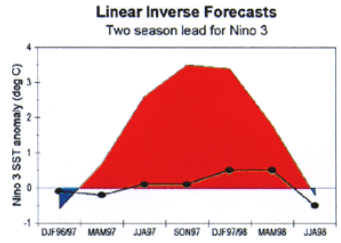
http://www.gfdl.noaa.gov/ rgg/si_workdir/Forecasts.html

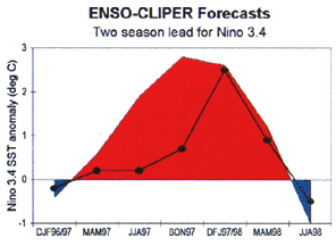
Forecasts of the 1997/98 El Niño

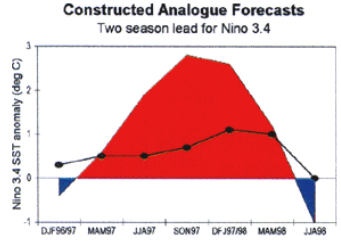
(Landsea & Knaff 2000)

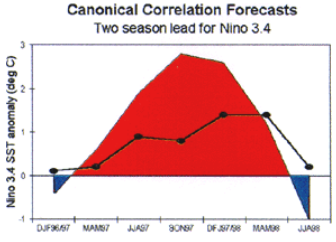
Statistical Models

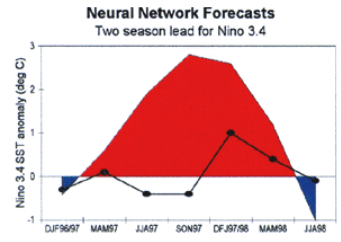


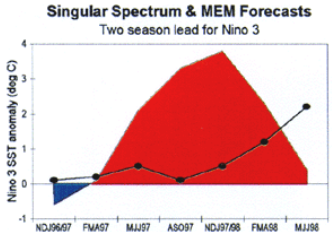


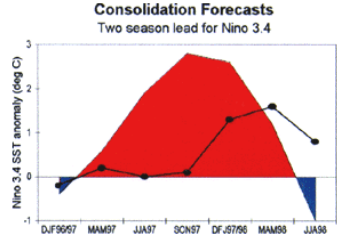




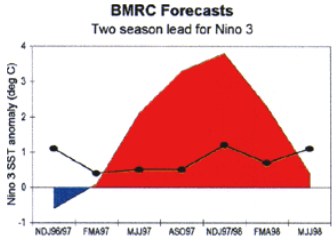


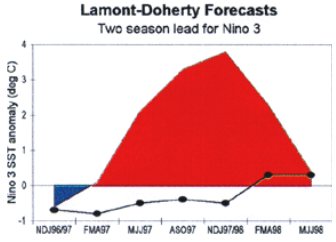


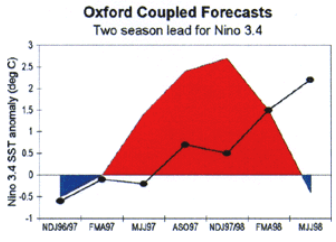




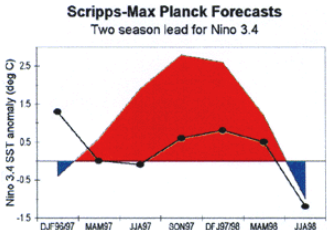
ICMs



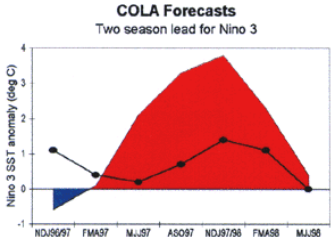


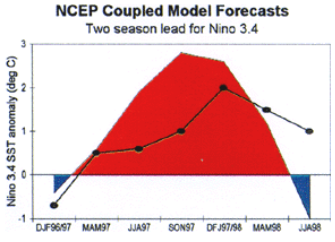


HGCMs



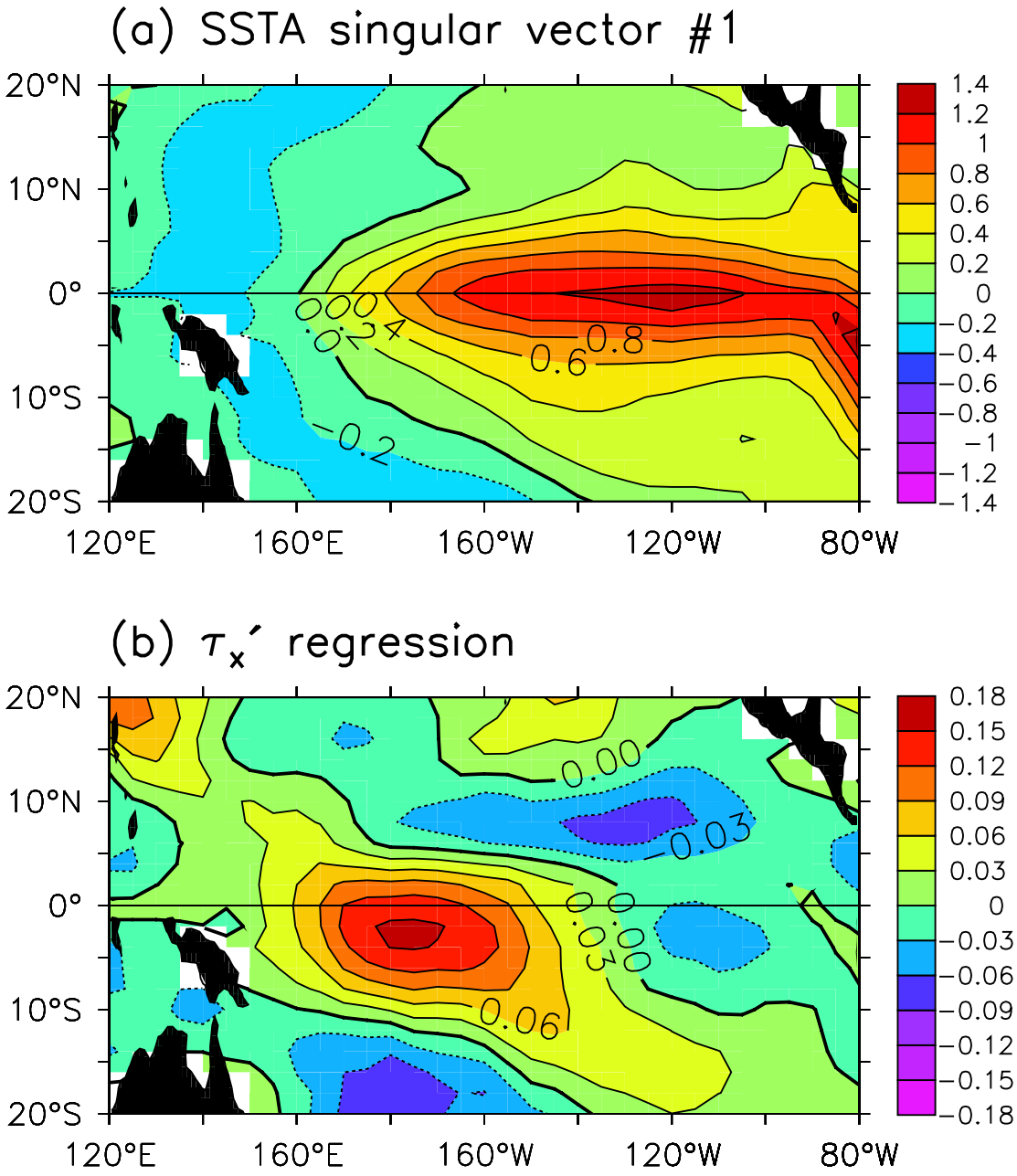
CGCMs



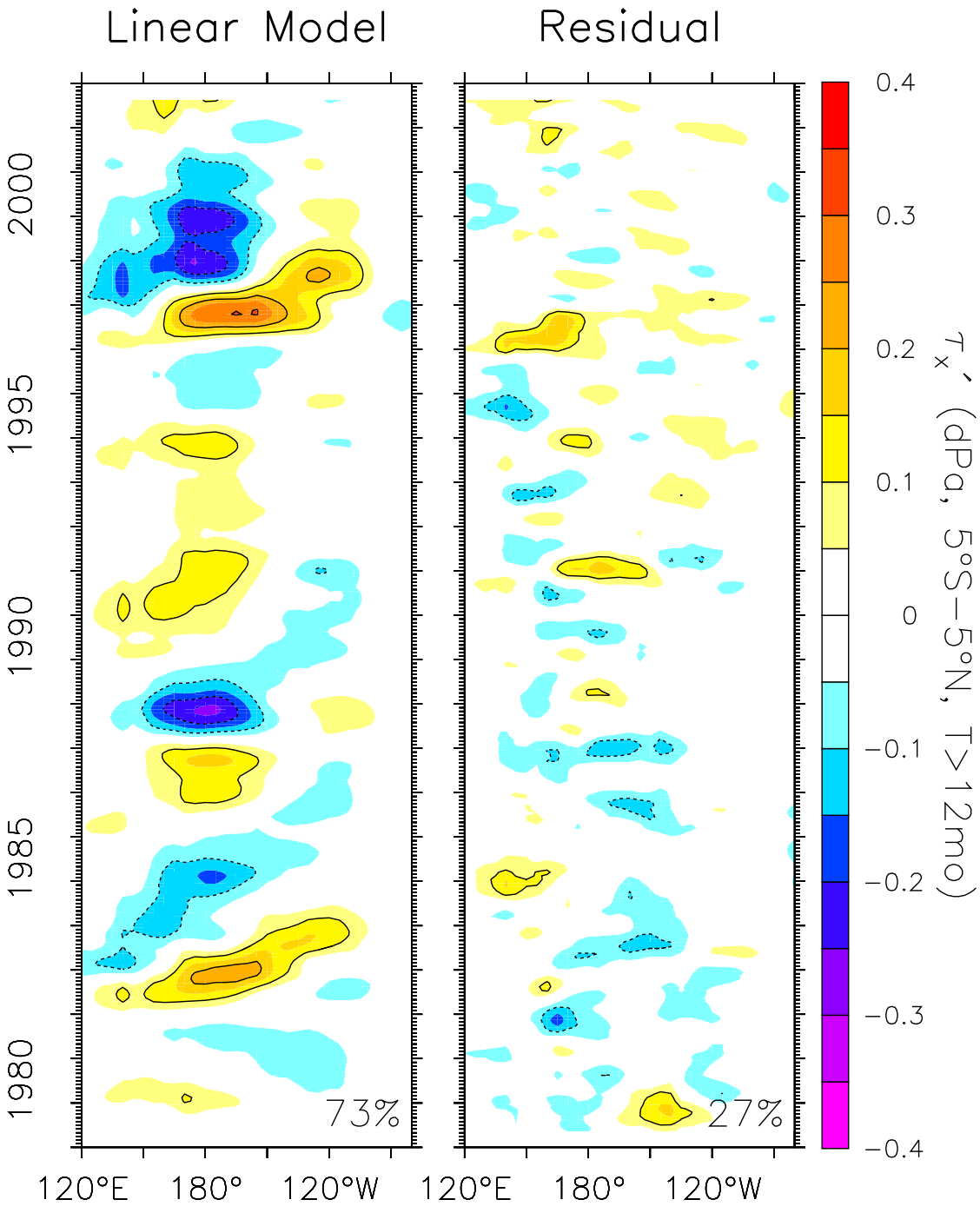


Statistical Atmosphere (Mode 1)

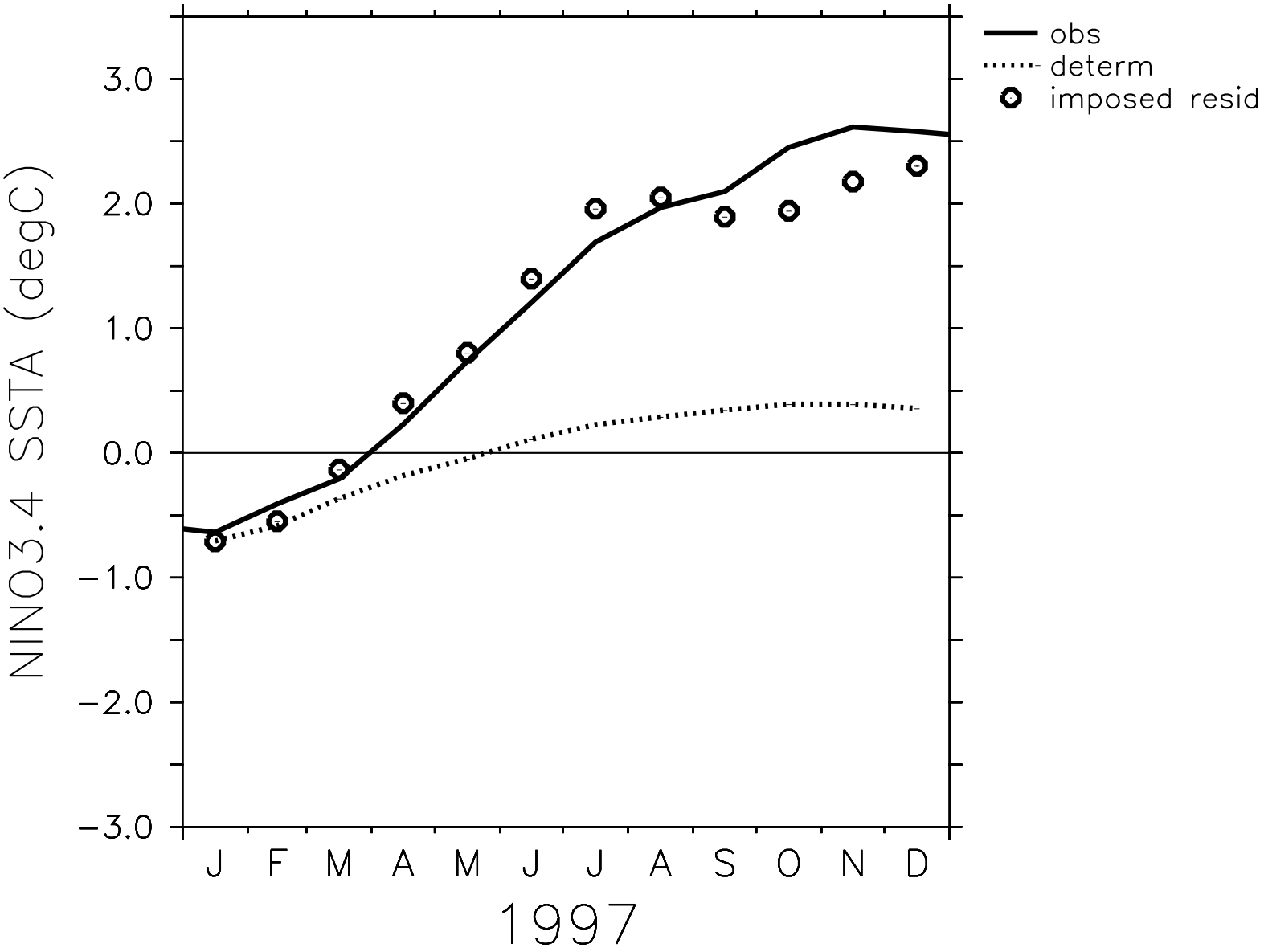
SST and wind stress from NCEP2 (1979–2002)



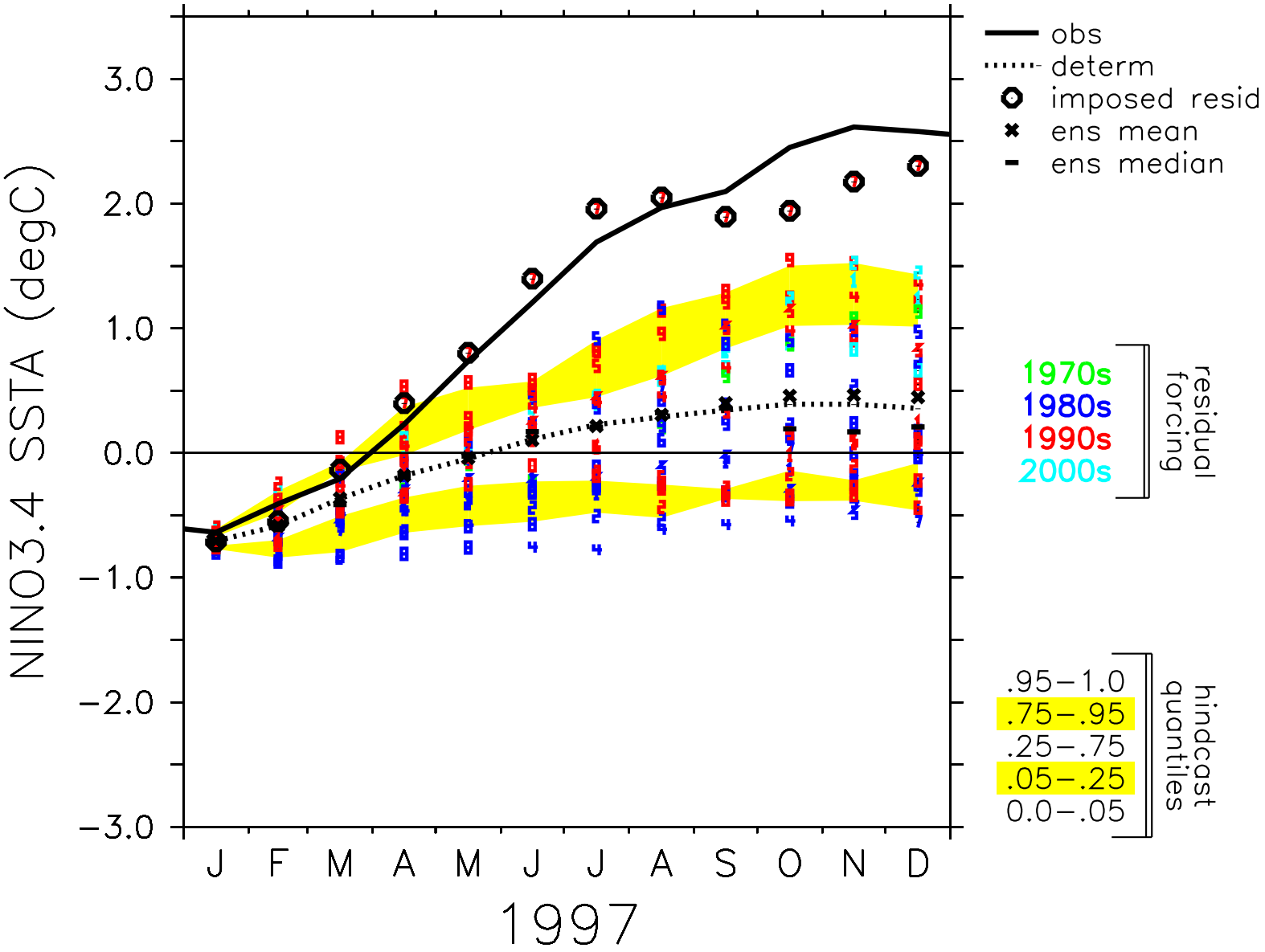
Wind stress decomposition: Low-pass NCEP2 obs



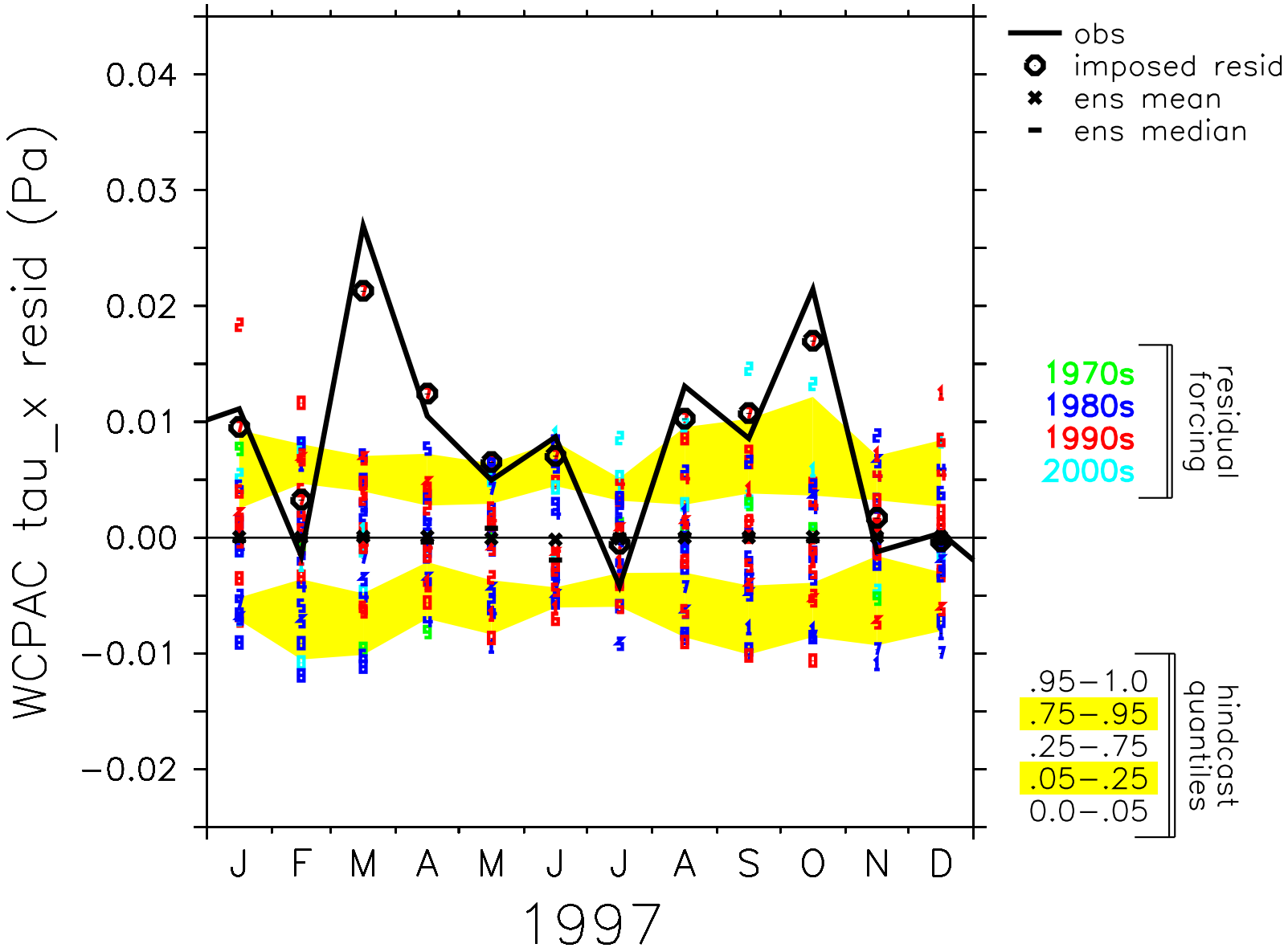
Deterministic forecasts of east Pacific SST anomalies



Stochastic forecasts of east Pacific SST anomalies

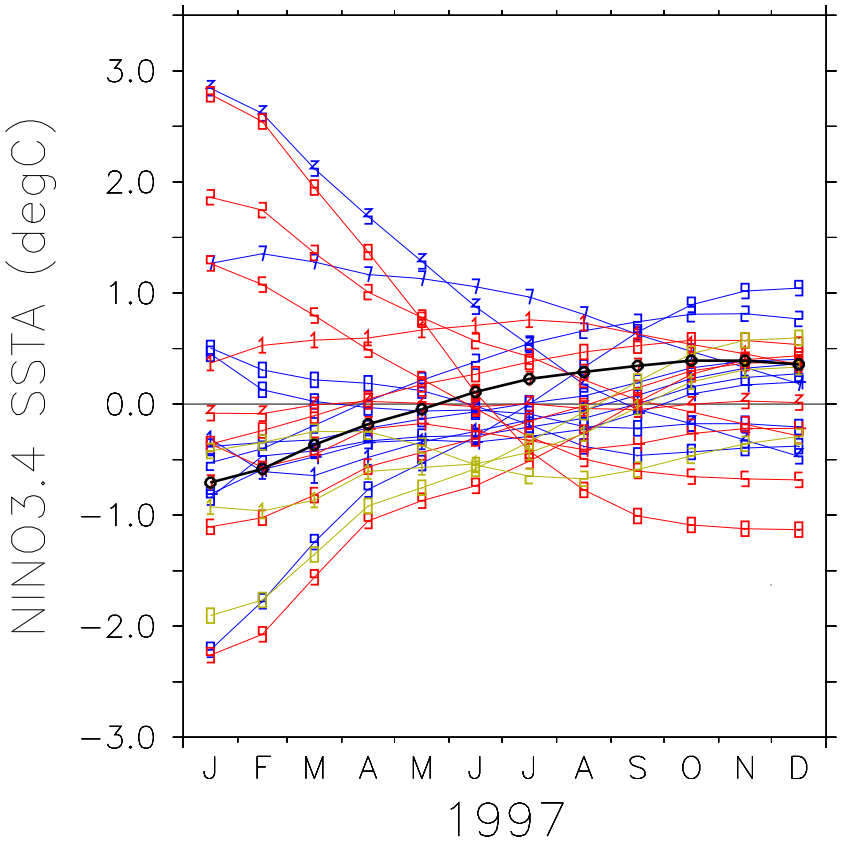


NCEP2 residual zonal wind stress

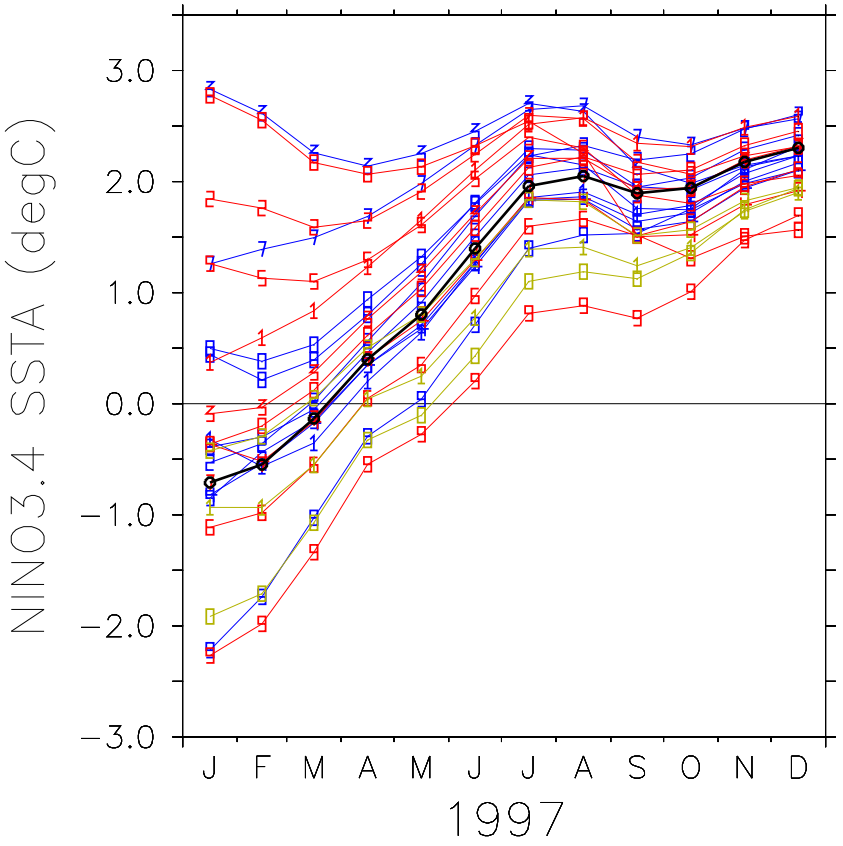


Evolution of random initial conditions

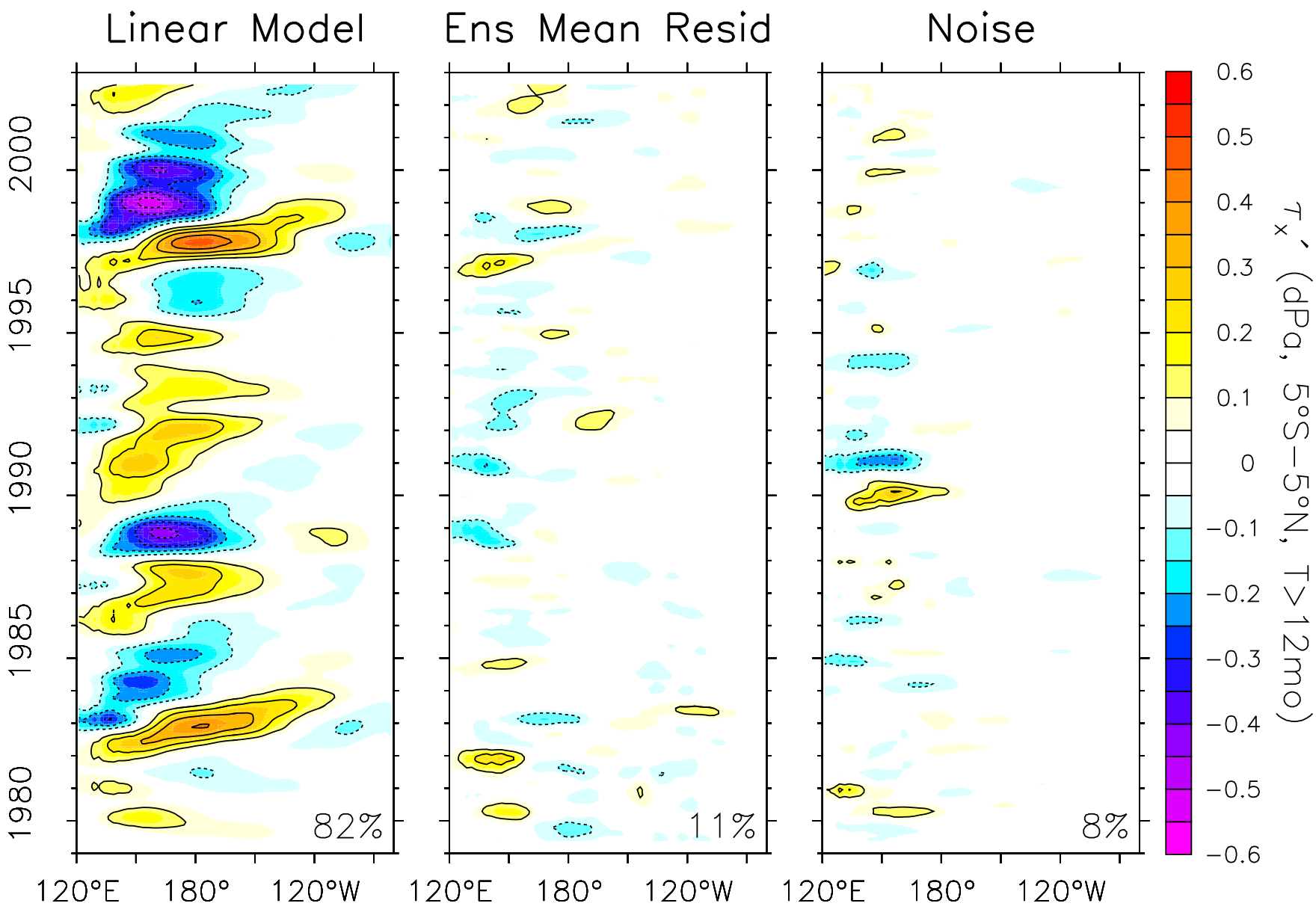
No forcing



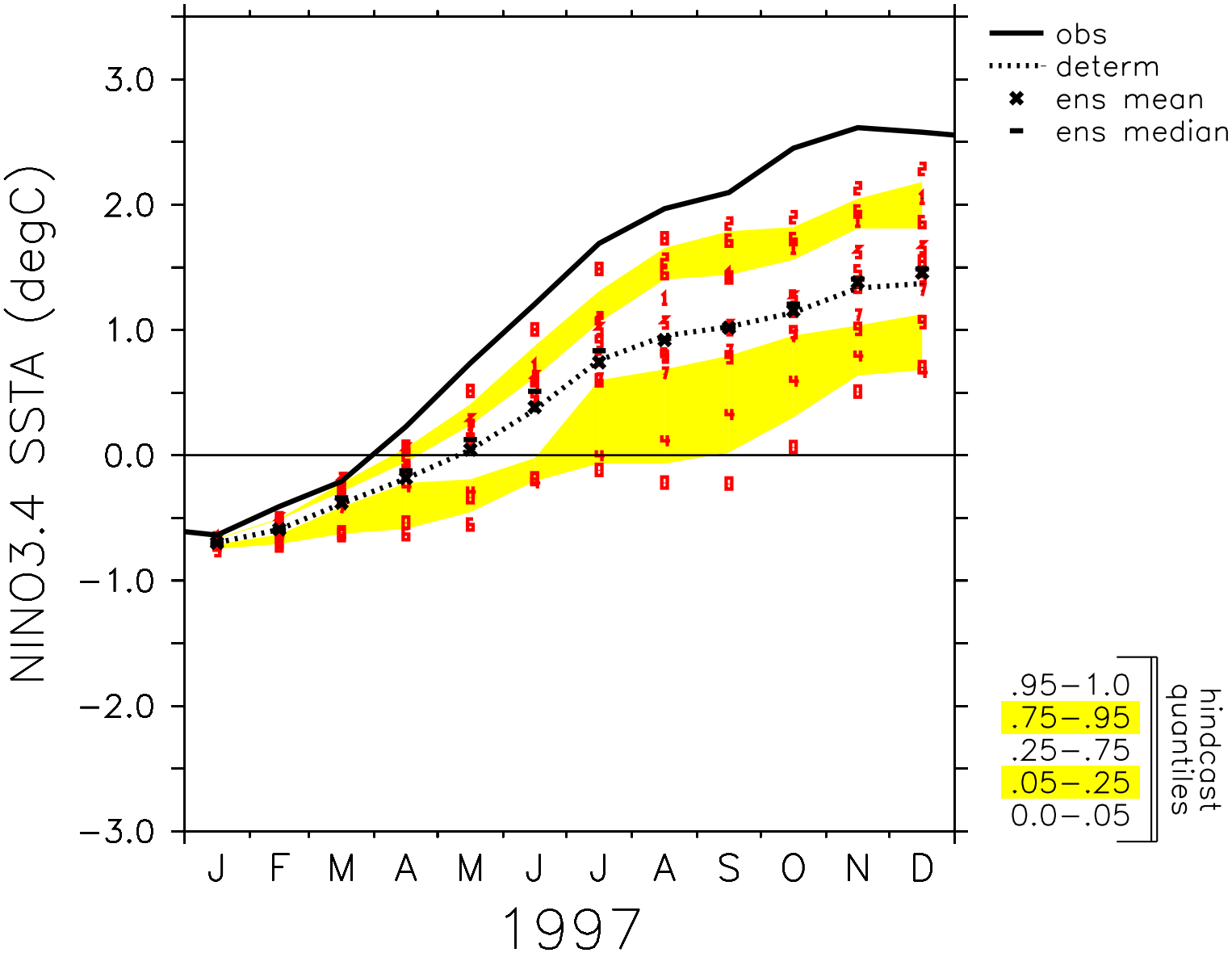
Forced by 1997 residual



AGCM wind stress decomposition: Low-pass

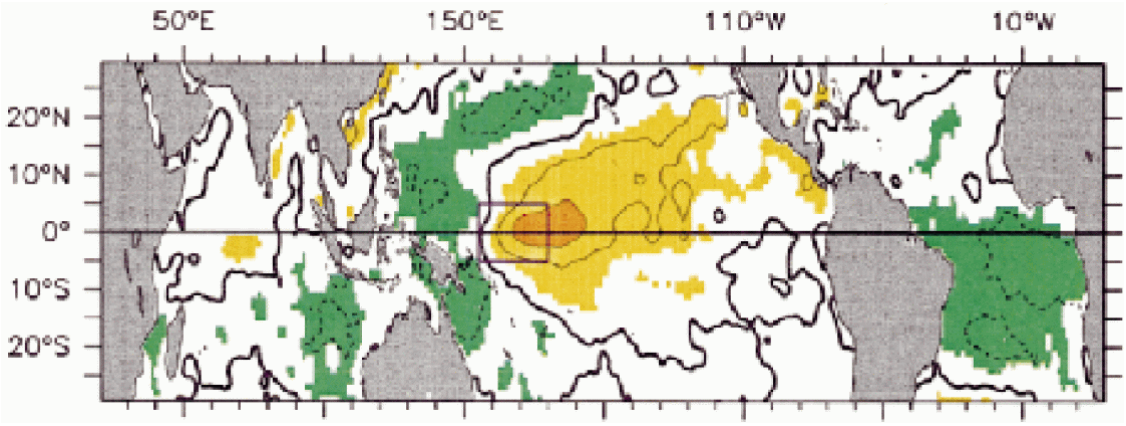


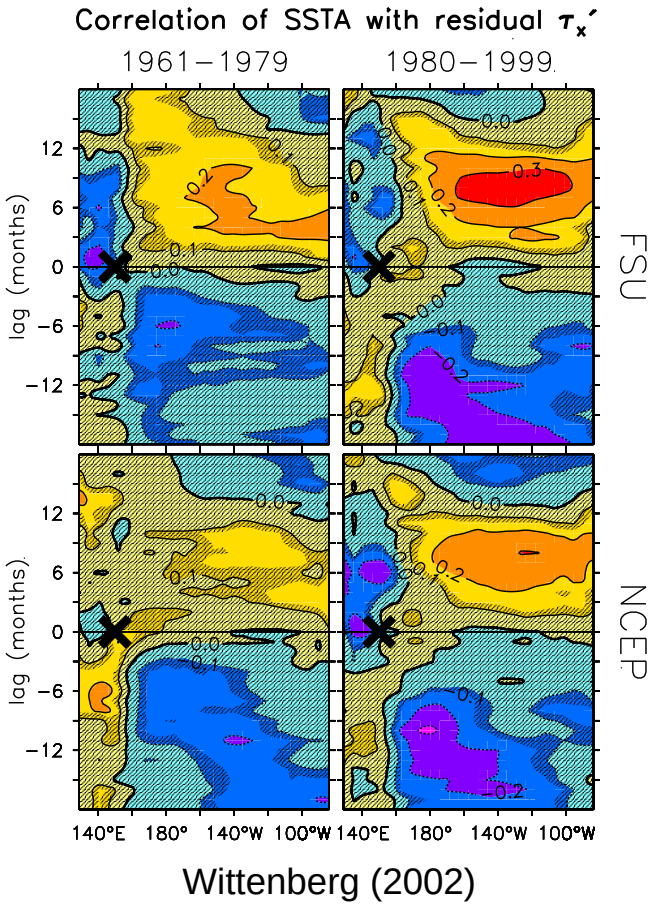
“Cheatcasts” forced by AGCM stress residuals



What drives the WWEs?

non-ENSO composite of WWE SSTAs (Vecchi & Harrison 2000)

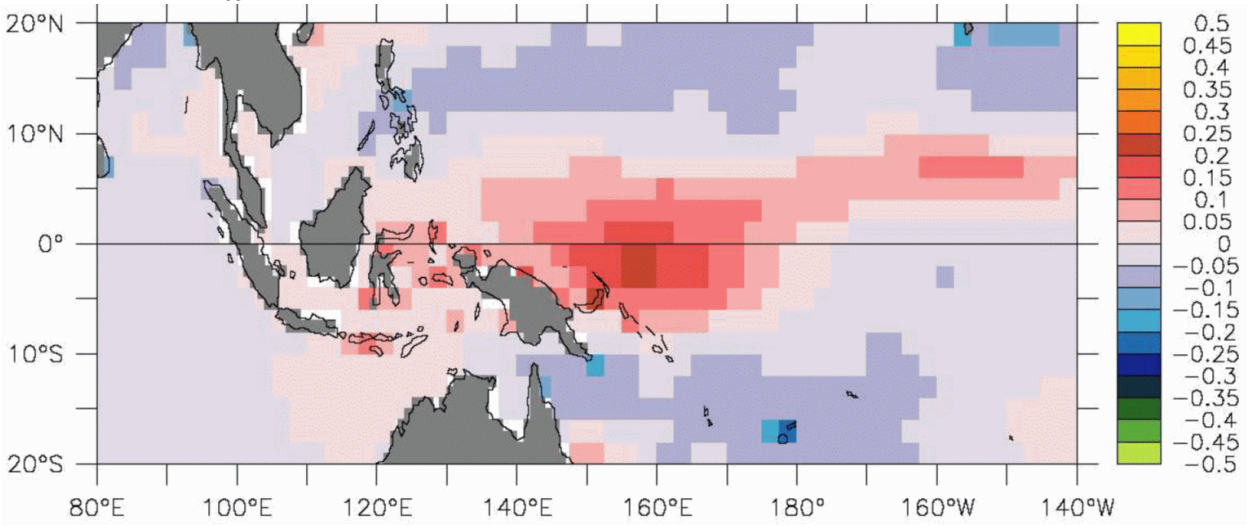




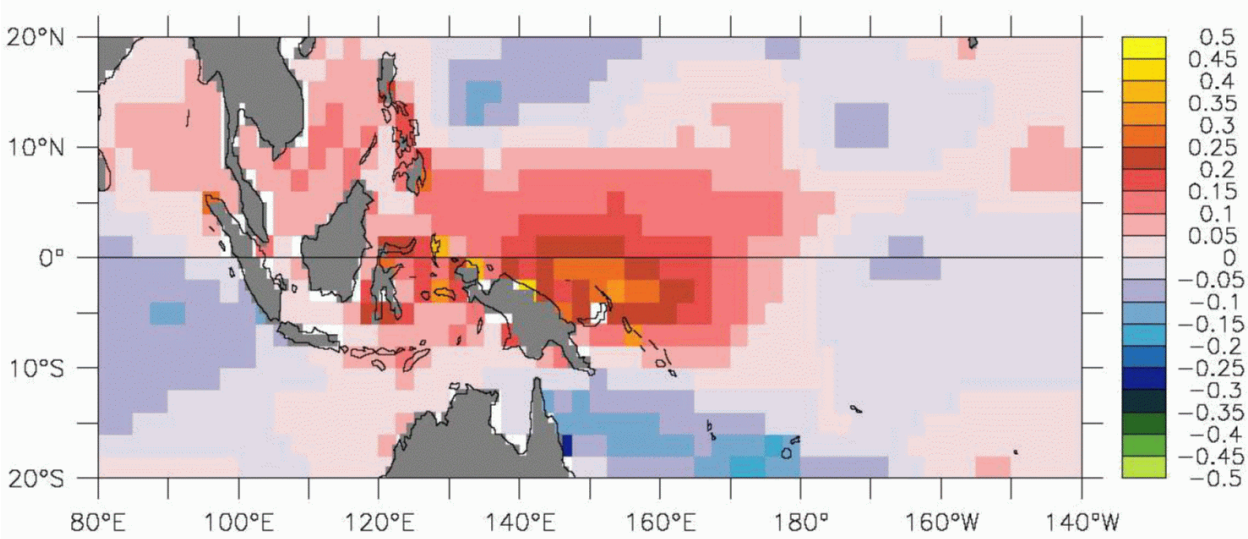
Wittenberg (2002)

- linked to eastward SSTA gradients in west
- connected with large-scale warming

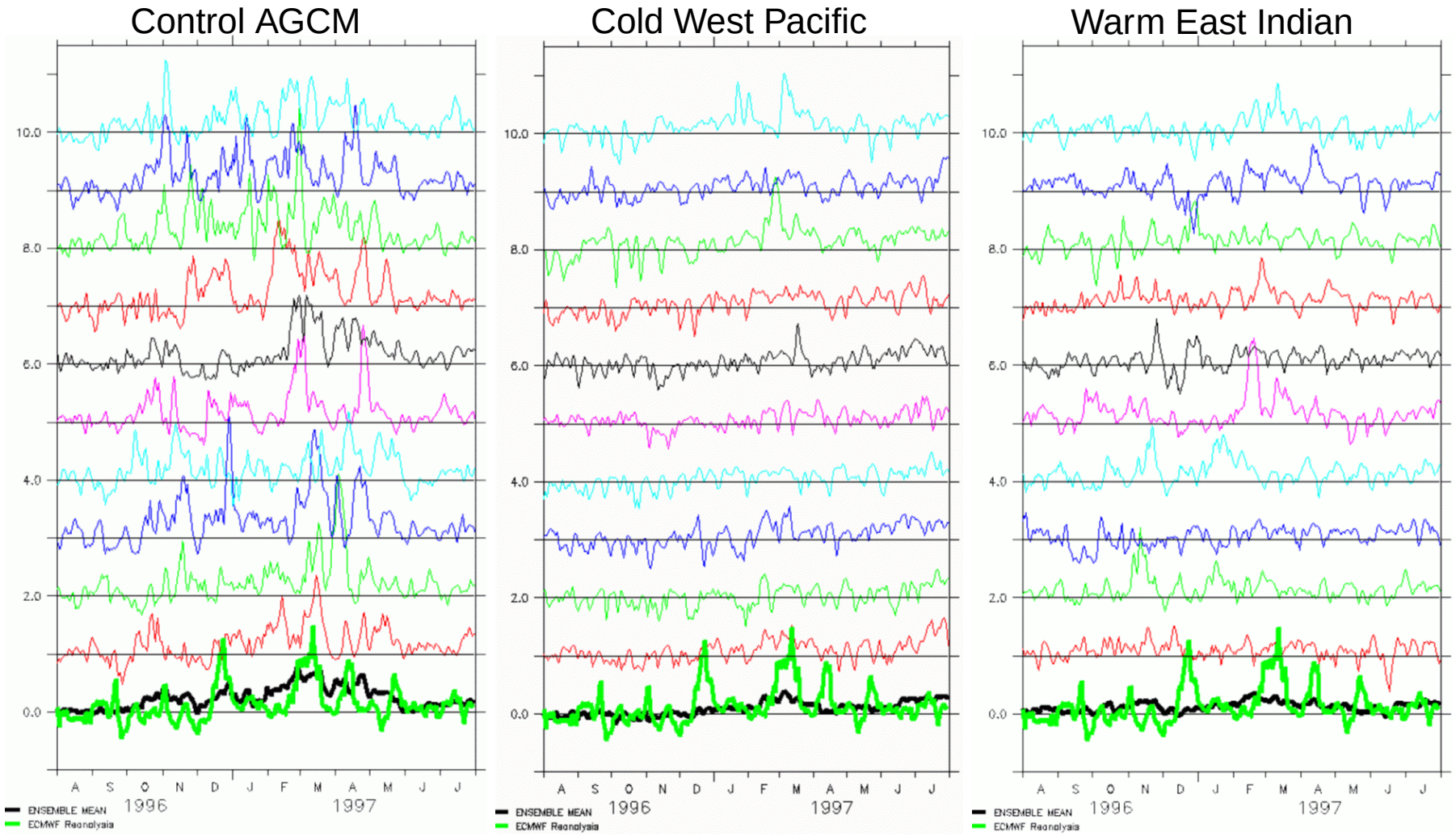
τ_x' driven by Pacific precursive SSTA



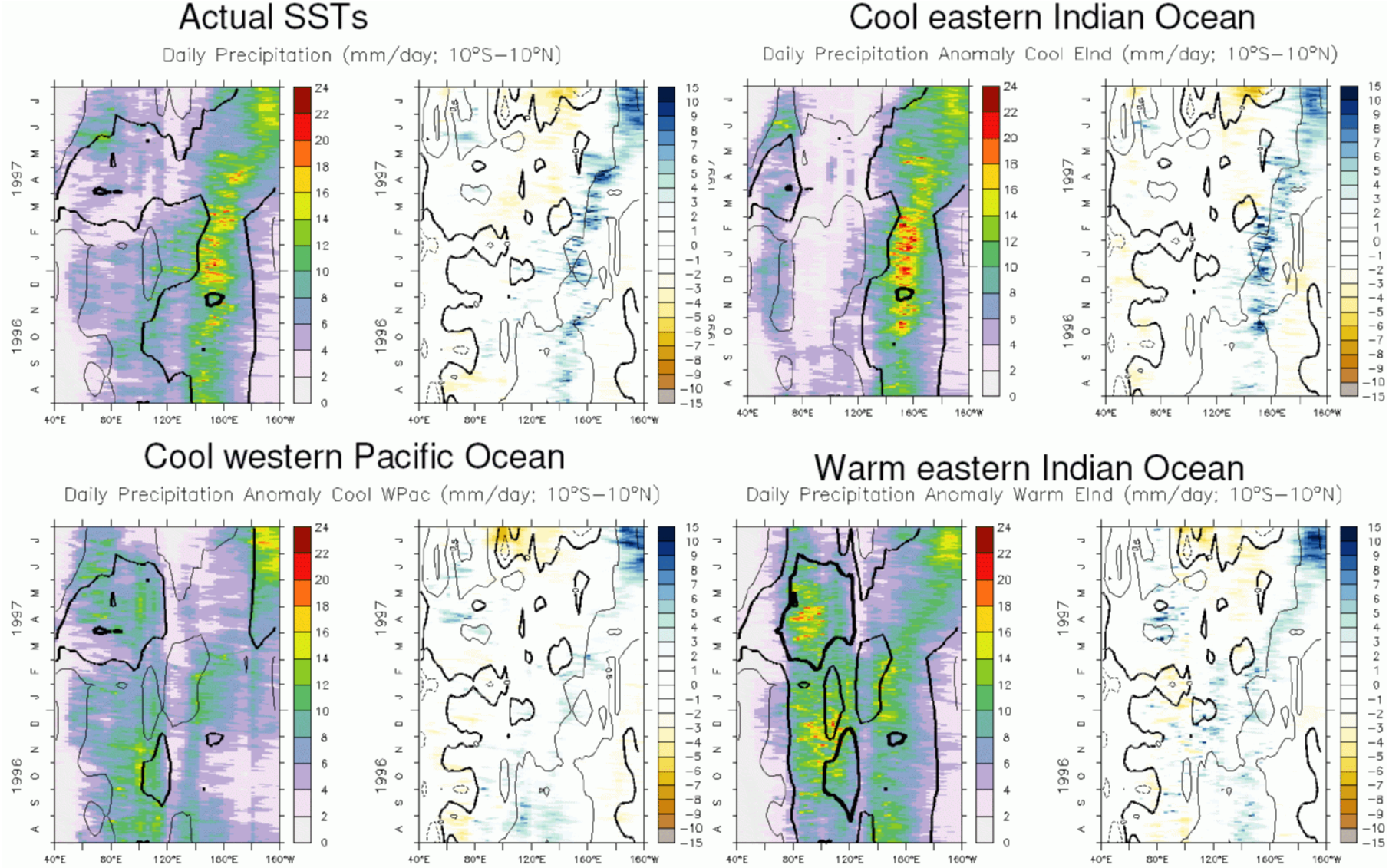
τ_x' driven by IndoPacific precursive SSTA



Background SST affects the WWEs



Background SST affects convective anomalies



Summary of ENSO activities at GFDL

1. Coupled model development
   - CM2.0, CM2.1
   - hybrid model

2. ENSO sensitivity (CMT)

3. Climate change

4. Data assimilation & real-time forecasts

5. Predictability
   - role of stochastic forcing
   - importance of nonlinearity
   - role of background state, Indian Ocean