Climate Modeling at GFDL

Leo Donner
GFDL/NOAA, Princeton University

CERES Science Team, Princeton, 4 May 2005

Geophysical
Fluid
Dynamics
Laboratory

Princeton, New Jersey

GFDL Climate Modeling

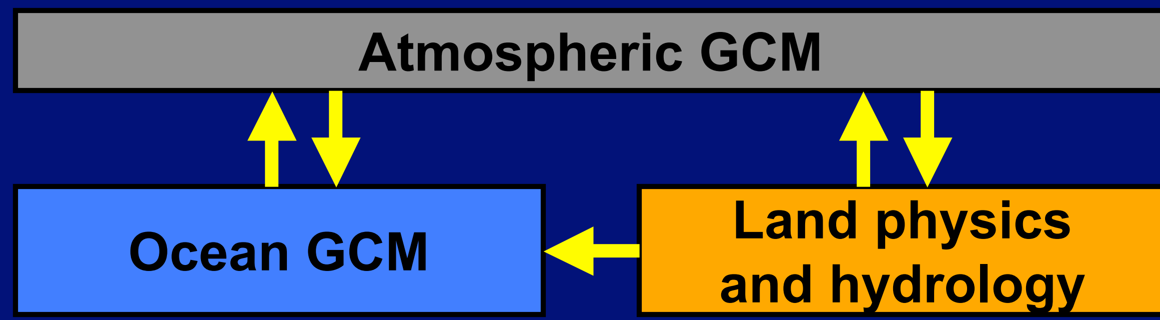
- Climate modeling in the context of earth-system modeling
- Current status of GFDL atmospheric and coupled modeling
- Recent research on atmospheric dy-cores
- Early earth-system model results

Geophysical
Fluid
Dynamics
Laboratory

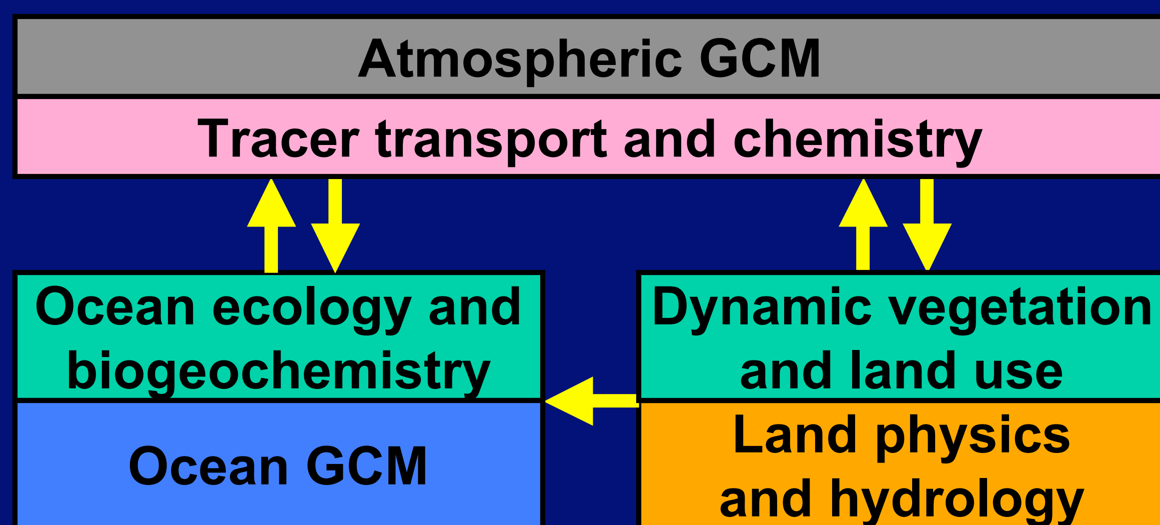
Princeton, New Jersey

What is an Earth System Model?

Climate Model



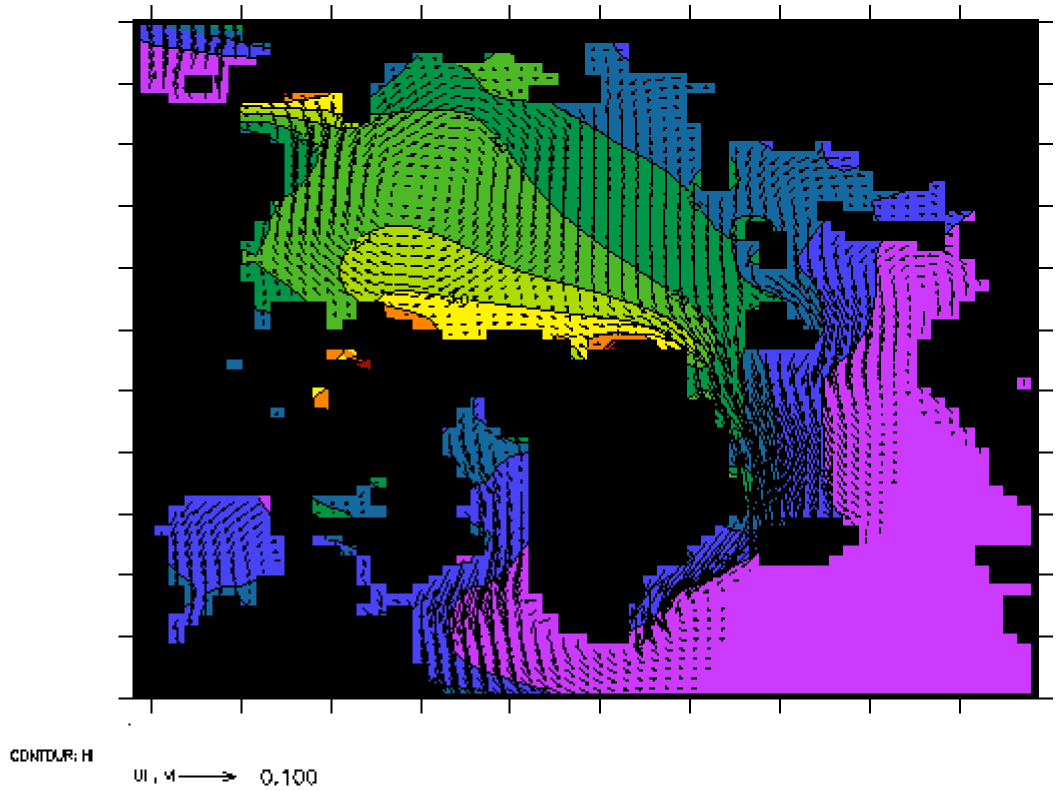
Earth System Model



from John Dunne, GFDL

Sea Ice Simulator (SIS)

- Full sea ice dynamics with elastic-viscous-plastic rheology.
- N-category ice thickness distribution scheme.
- Three layer vertical thermodynamics (one snow; two ice) with physical treatment of brine pockets in upper ice layer.



from Mike Winton, GFDL

Ocean component of the CM2 models

igher resolution (~1 degree, 50 levels)

xplicit free surface (real freshwater fluxes)

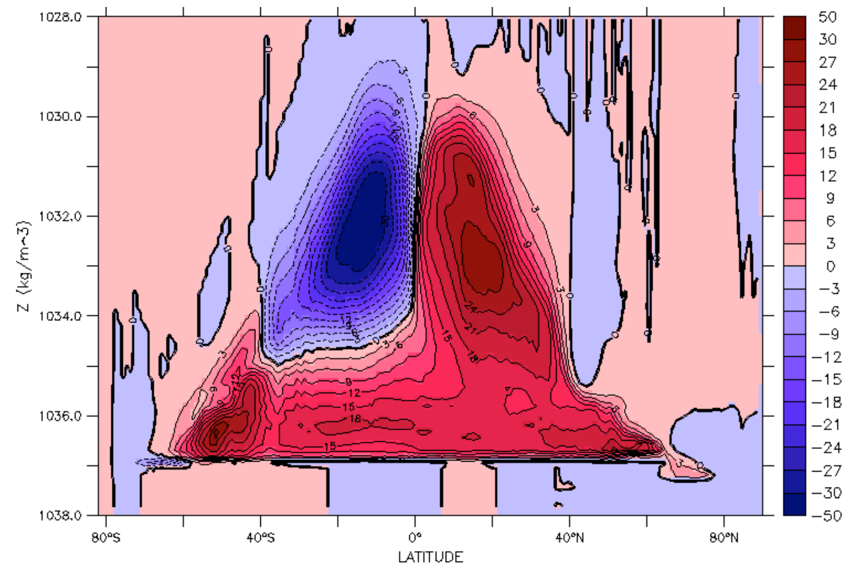
ripolar grid (Arctic throughflow)

nisotropic viscosity (realistic Equatorial currents)

orizontally varying eddy mixing (distribution of convection)

from Anand Gnanadesikan, GFDL

xplicit mixed layer.



T−cell y−volume transport on pot_rho (Sv)(running sum on Z)

Overturning in density space shows pole-to-pole connection

Land Model: LM2

- 3 water stores: snow, root zone, ground water
- 18 soil temperature levels to 6-m depth
- Stomatal control of evaportranspiration
- Surface parameters functions of 8 soil and 8 vegetation types
- Latent heat storage in soil

Geophysical
Fluid
Dynamics
Laboratory

Princeton, New Jersey

Atmospheric GCM: AM2 (GFDL GAMDT, 2004, *J. Clim.*)

- B-grid, 2° lat x 2.5° lon; 24 levels; model top ~ 40 km
- SW radiation (Freidenreich and Ramaswamy, 1999, *JGR*)
- LW radiation (Schwarzkopf and Ramaswamy, 1999, *JGR*)
- Liquid cloud radiative properties from Slingo (1989, *JAS*)

Atmospheric GCM: AM2 (GFDL GAMDT, 2004, *J. Clim.*)

- Ice cloud radiative properties from Fu and Liou (1993, *JAS*)
- Sulfate, hydrophobic and hydrophilic carbon, dust, and sea salt from MOZART chemical transport model
- Prognostic cloud liquid, cloud ice, and fraction (Tiedtke, 1993, *JAS*)

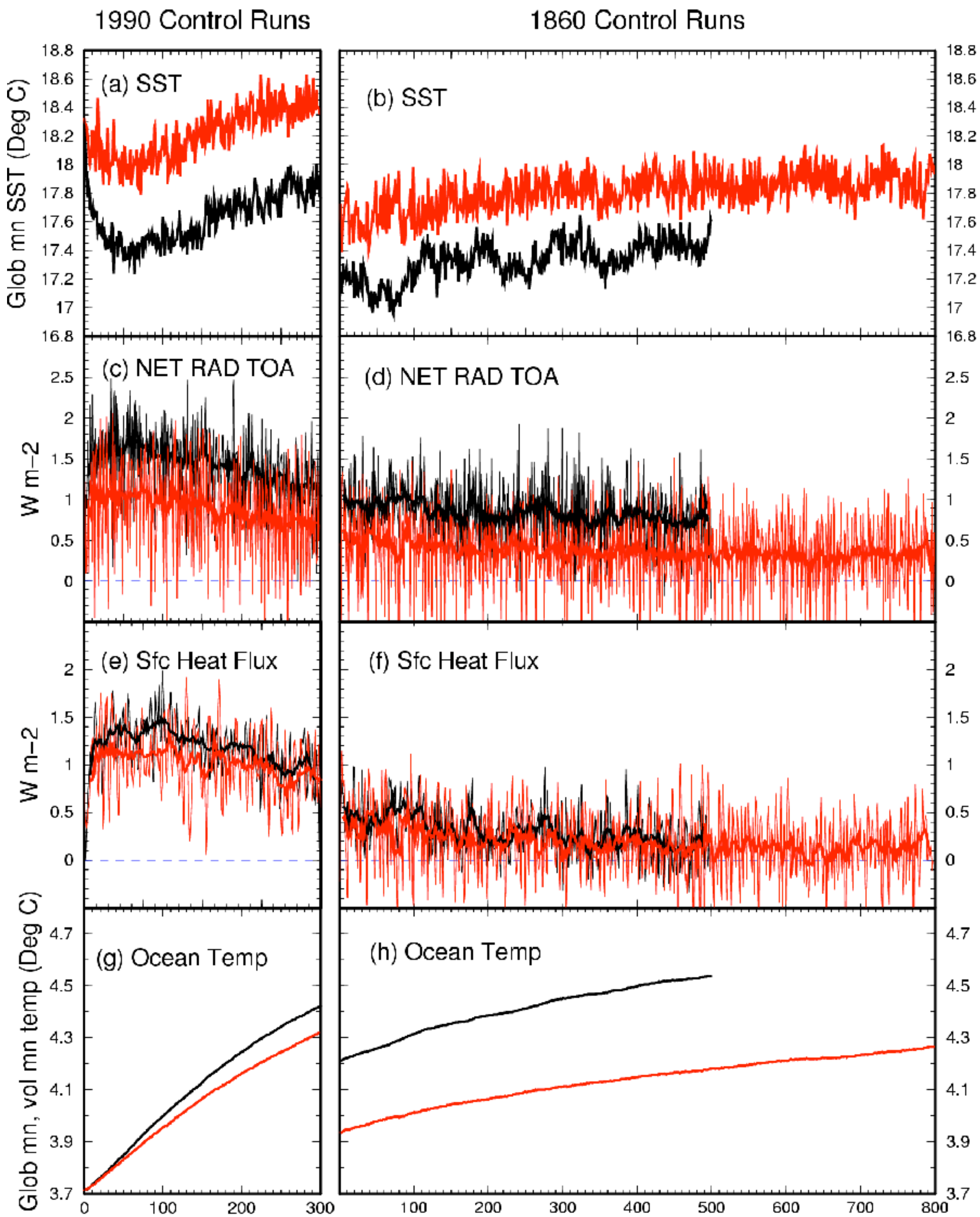
Atmospheric GCM: AM2 (GFDL GAMDT, 2004, *J. Clim.*)

- Bulk cloud microphysics (Rotstayn, 1997, *QJRMS*)
- Relaxed Arakawa-Schubert convection (Moorthi and Suarez, 1992, *MWR*) with low-entrainment deep clouds suppressed (Tokioka *et al.*, 1988, *J. Met. Soc. Japan)* and diffusive momentum transport

Atmospheric GCM: AM2 (GFDL GAMDT, 2004, *J. Clim.*)

- Convective boundary layers with K-profile and prescribed entrainment (Lock *et al.*, 2000, *MWR*)
- Enhanced mixing in stable PBL
- Orographic gravity-wave drag (Stern and Pierrehumbert, 1988, AMS *NWP Conf. Proc.*)

GFDL Coupled Climate Models
CM2.0 (B grid)
CM2.1 (FV)



Delworth *et al.* (2005, *J. Clim.*)

Mean Fields in AM2/CM2 with B-grid dynamical core

Geophysical
Fluid
Dynamics
Laboratory

Princeton, New Jersey

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

Annual, Zonal-Mean Temperature Diff
AM2-NCEP/NCAR Analysis (K)

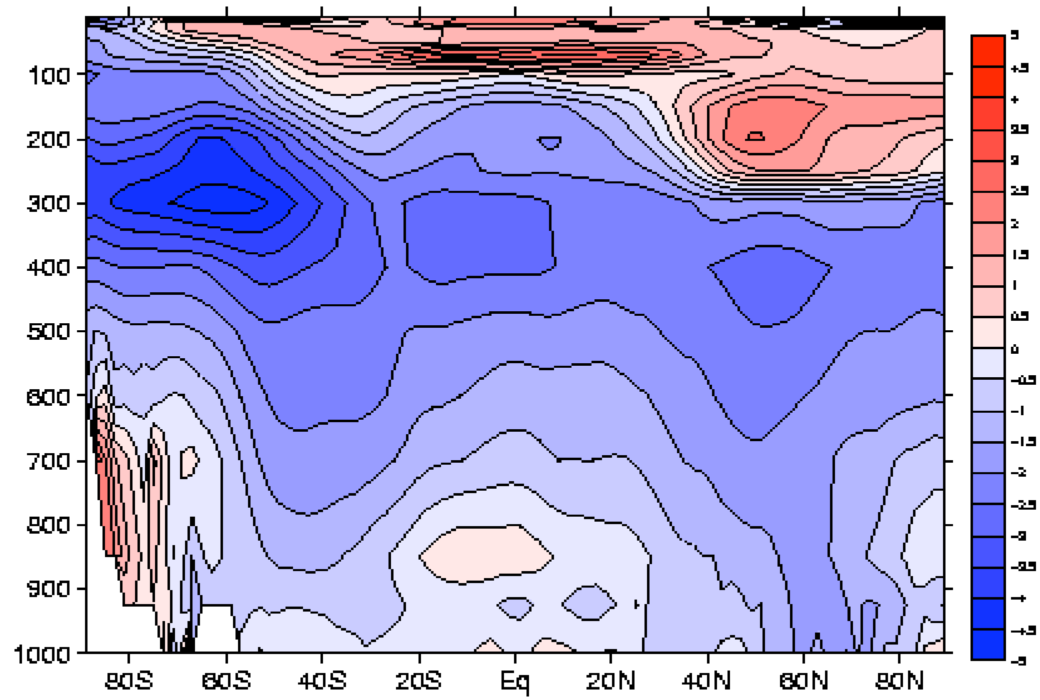


Figure 1. Long-term annual and zonal mean temperature difference between NCEP/NCAR reanalysis climatology and AM2/LM2 (AM2/LM2 minus NCEP). Contour interval is 0.5 K.

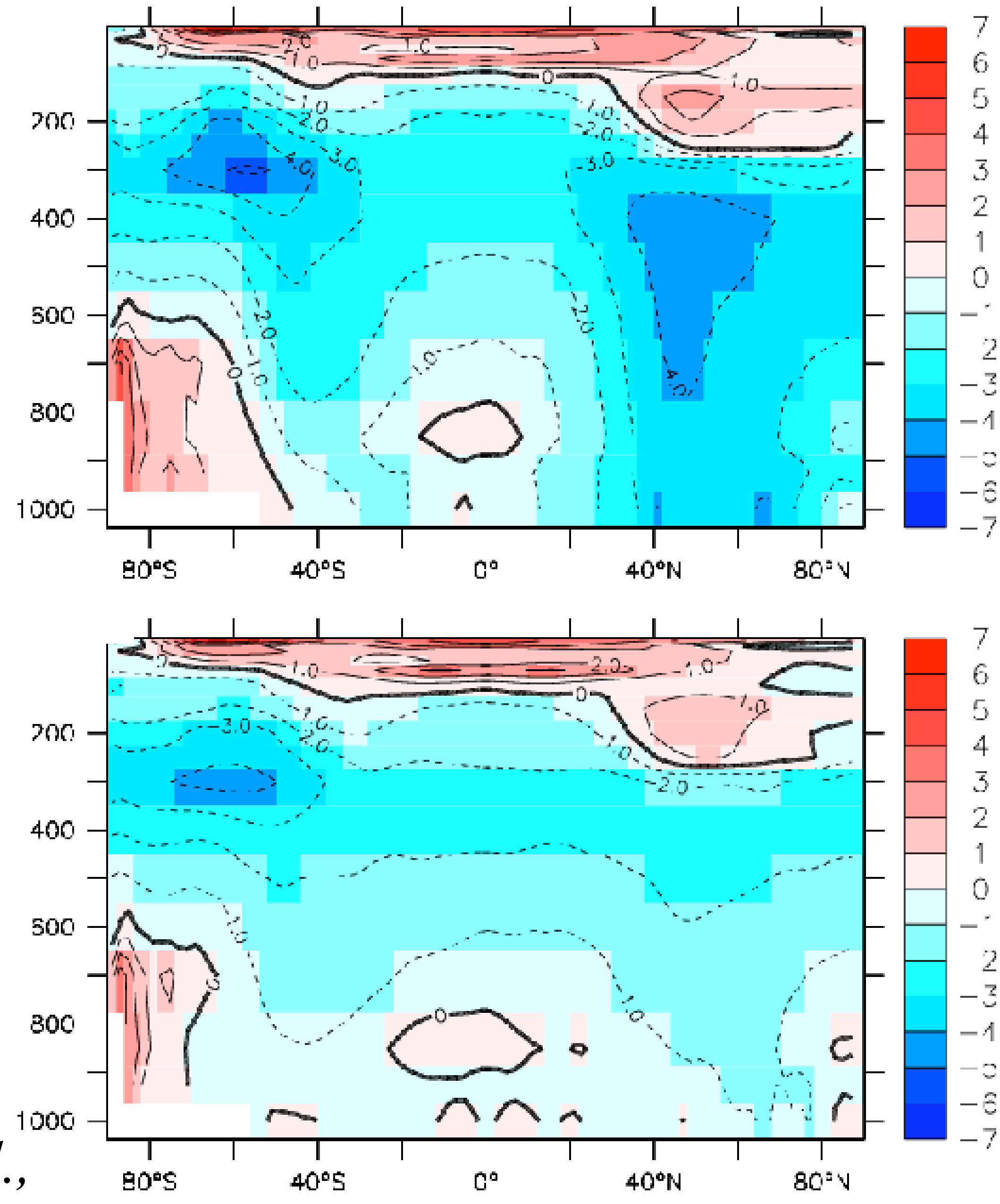
GFDL GAMDT (2004, *J. Clim.*)

Coupled

Temp Diff (K)
CM2-NCEP

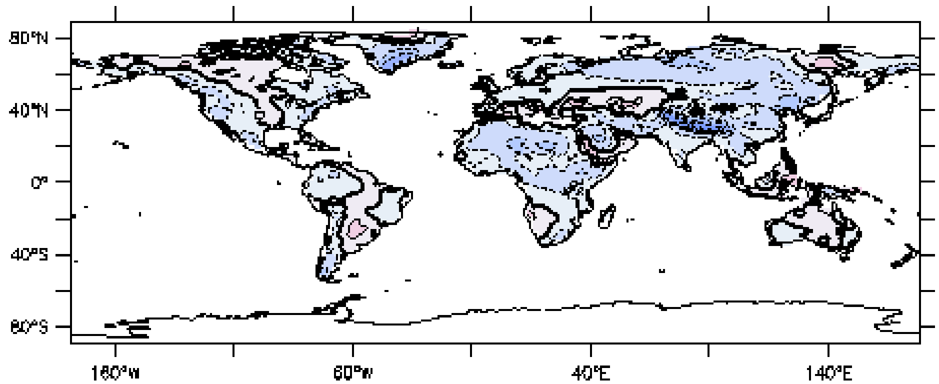
Atmosphere

Temp Diff (K)
AM2-NCEP



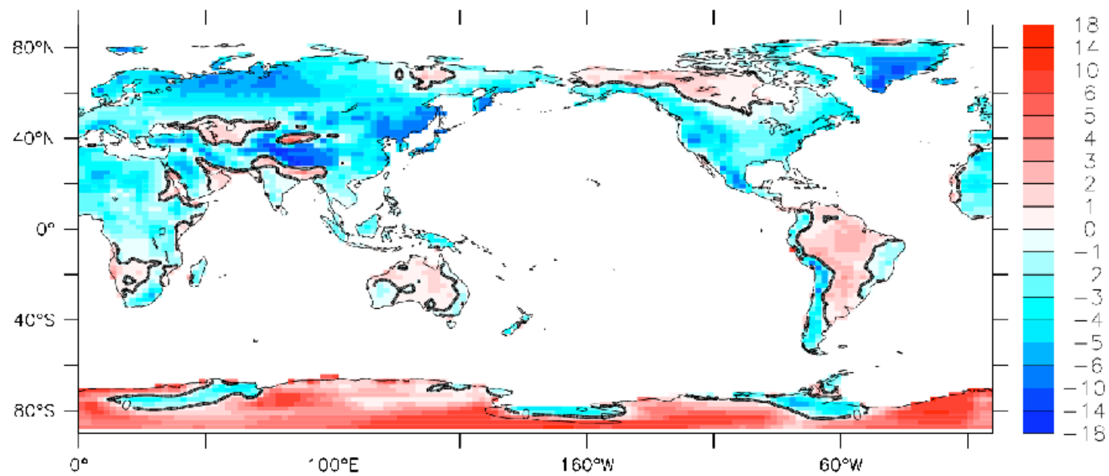
Delworth *et al.*, 2005, *J. Clim.*

SFC Temp AM2-CRU (2K contour)



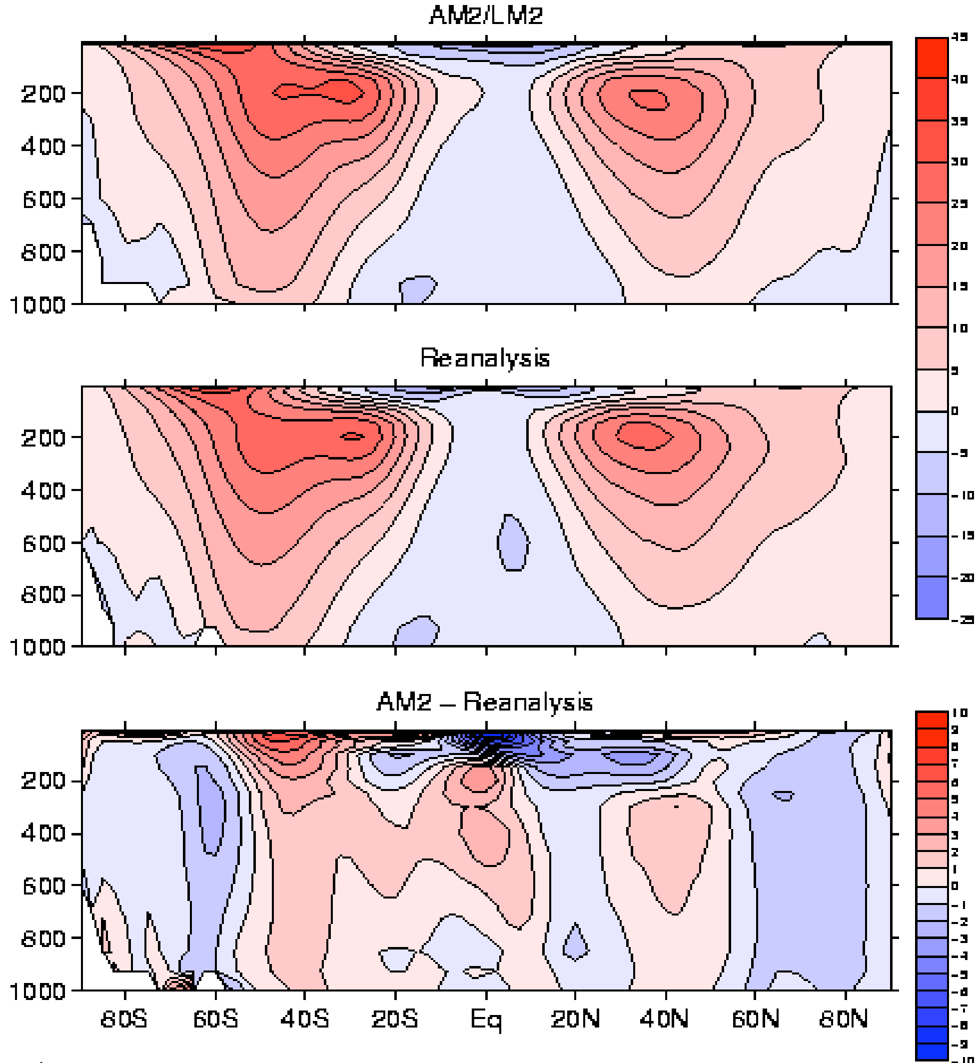
GFDL GAMDT (2004, *J. Clim.*)

SFC Temp CM2-Jones



Delworth *et al.* (2005, *J. Clim.*)

Zonal, Annual-Mean Zonal Wind Diff (m/s)
AM2-NCEP/NCAR Analysis

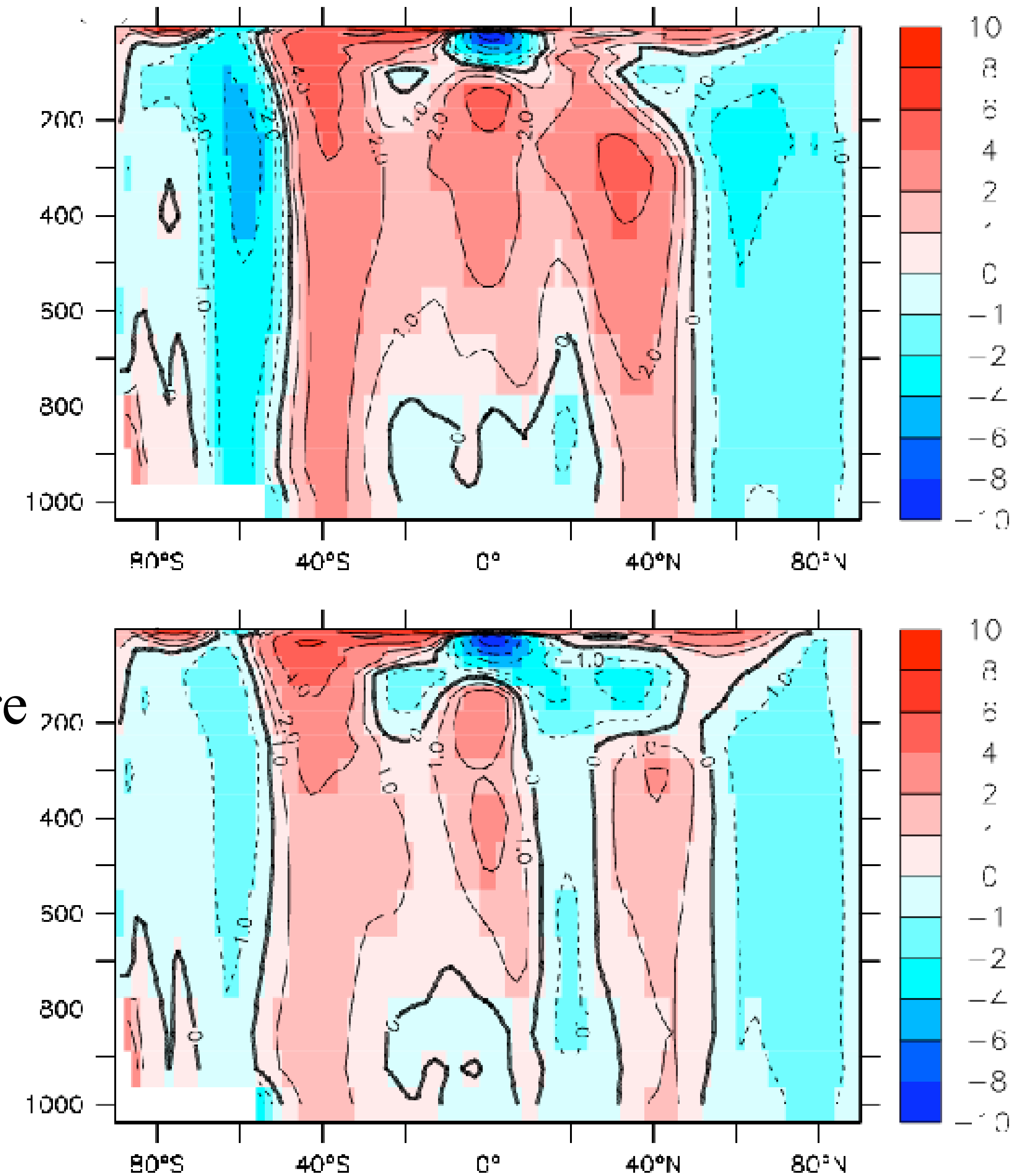


GFDL
GAMDT
(2004, *J. Clim.*)

Figure 4. Long-term annual and zonal mean zonal wind in m s-1 for (a) NCEP/NCAR reanalysis, (b) AM2/LM2, and (c) AM2/LM2 minus NCEP. Contour interval is 5 m s-1 in (a) and (b) and 1 m s-1 in (c).

Coupled

Atmosphere



Zonal Wind Diff, AM/CM-NCEP (m/s)

Delworth *et al.* (2005, *J. Clim.*)

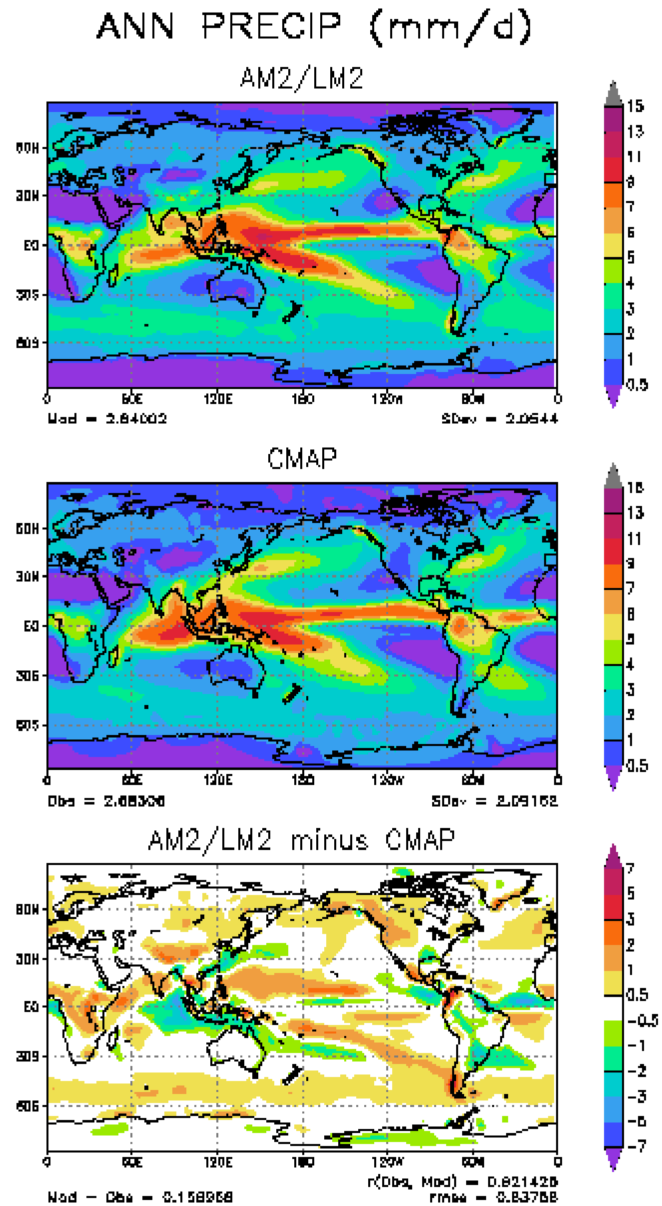


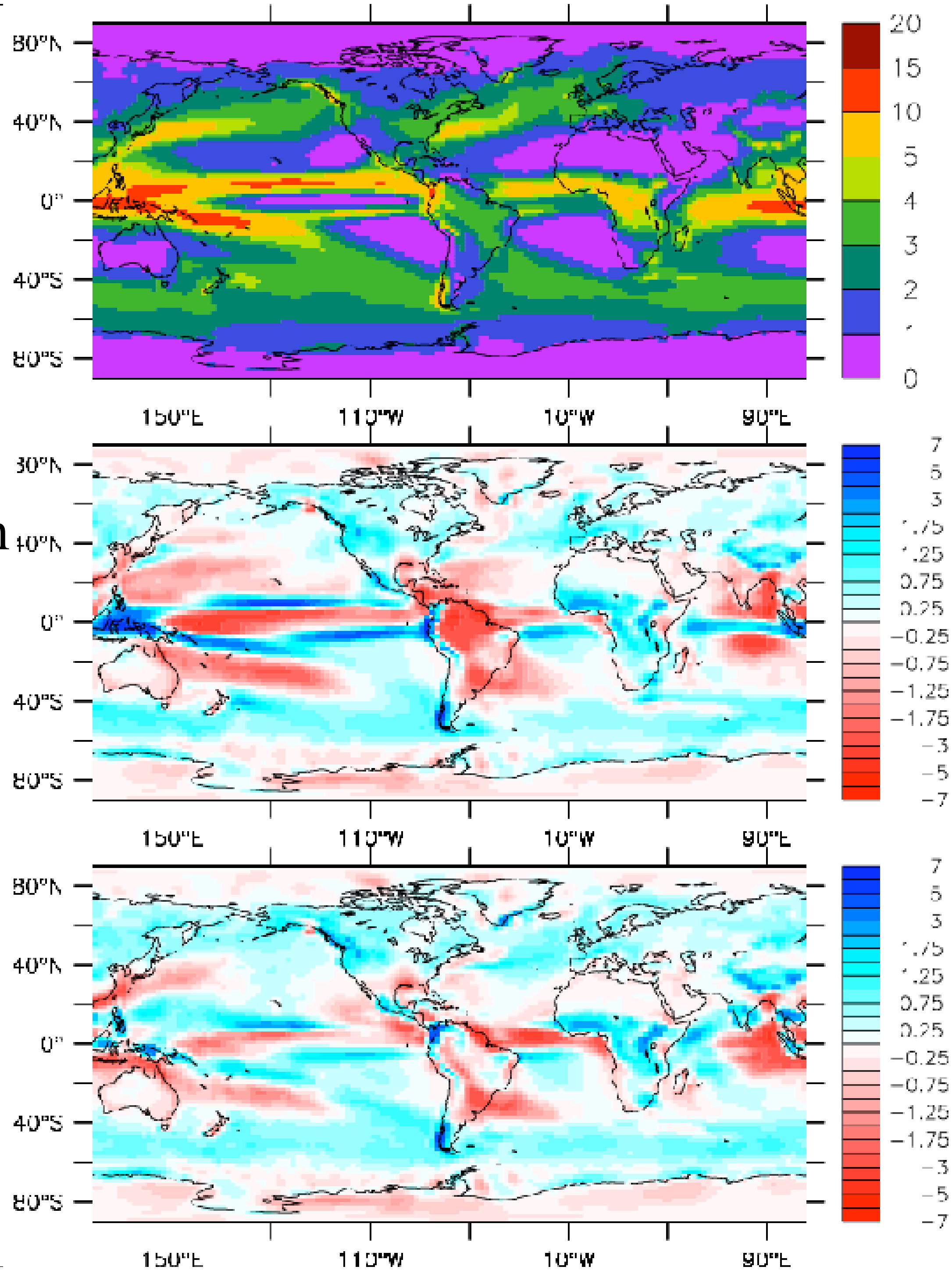
Figure 8. Annual long-term mean precipitation in mm d^{-1} for (a) AM2/LM2, (b) CMAP observations, and (c) AM2/LM2 minus CMAP. Statistics at the bottom of (a) and (b) include the global mean and standard deviation. Statistics at the bottom of (c) include the difference in global means, the correlation coefficient, and the root mean square error.

GFDL GAMDT
(2004, *J. Clim.*)

Coupled

Coupled-
Xie and Arkin

Atmosphere-
Xie and Arkin



Precipitation
(mm/day)

Delworth *et al.*
(2005, *J. Clim.*)

GFDL GAMDT
(2004, *J. Clim.*)

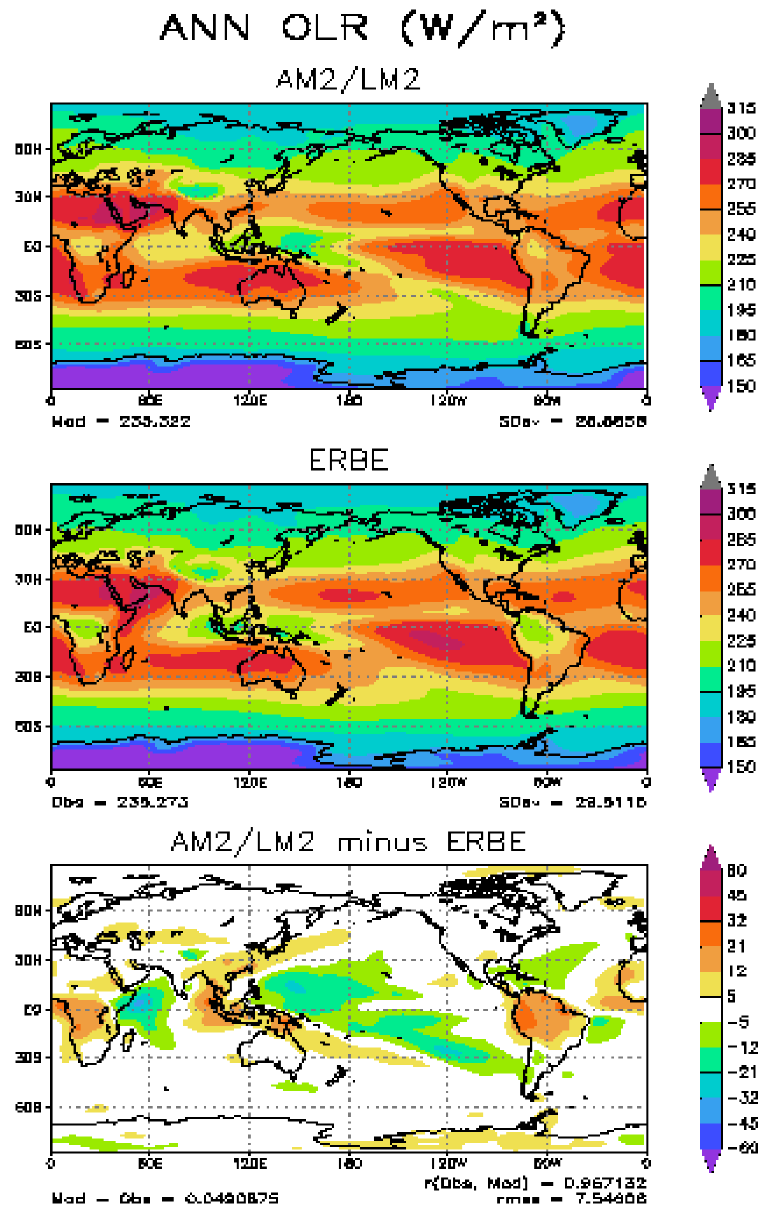
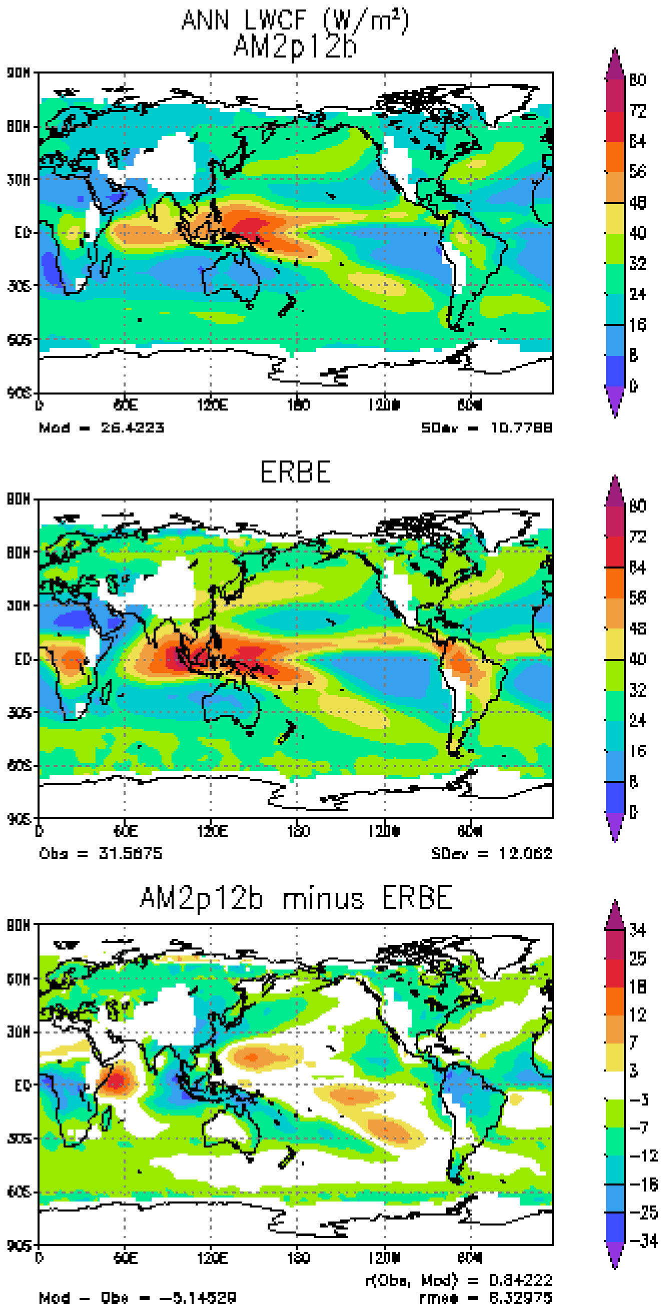


Figure 9. Annual long-term mean outgoing longwave radiation (OLR) in W m^{-2} for (a) AM2/LM2, (b) ERBE observations, and (c) AM2/LM2 minus ERBE. Statistics at the bottom of (a) and (b) include the global mean and standard deviation. Statistics at the bottom of (c) include the difference in global means, the correlation coefficient, and the root mean square error.


ANN LWCF (W/m²)
AM2p12b
Mod = 26.4223
SDev = 10.7788
ERBE
Obs = 31.5675
SDev = 12.062
AM2p12b minus ERBE
r(Obs, Mod) = 0.84222
rmse = 6.32975
Mod - Obs = -5.14529

TOA

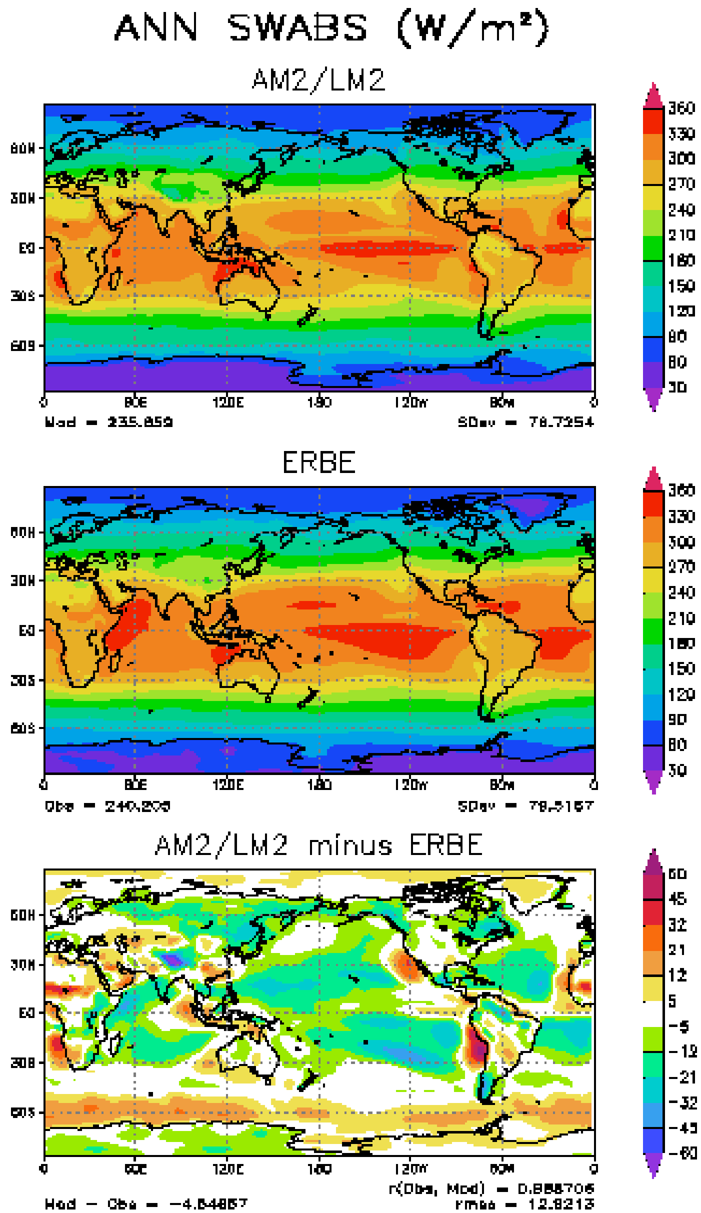
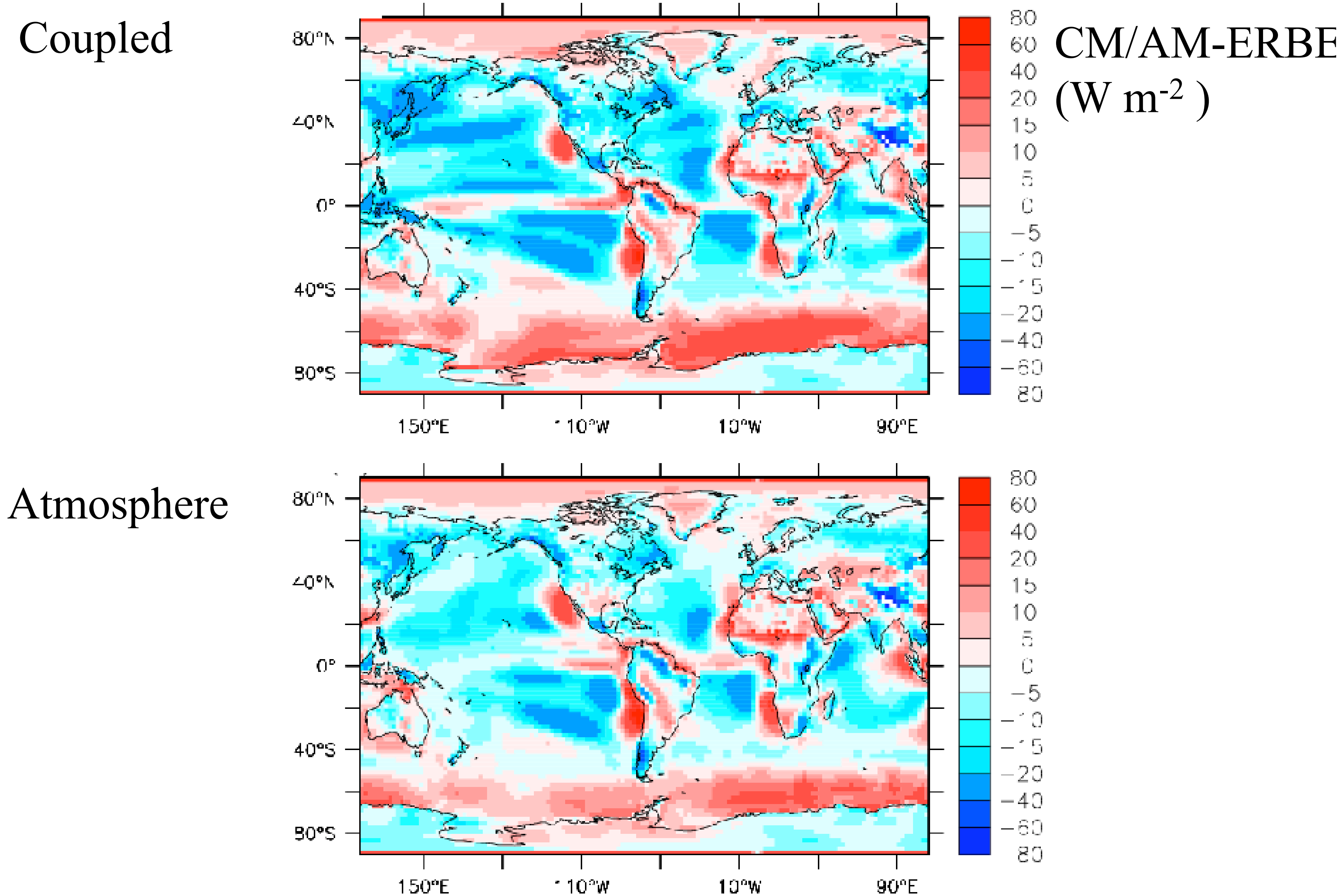


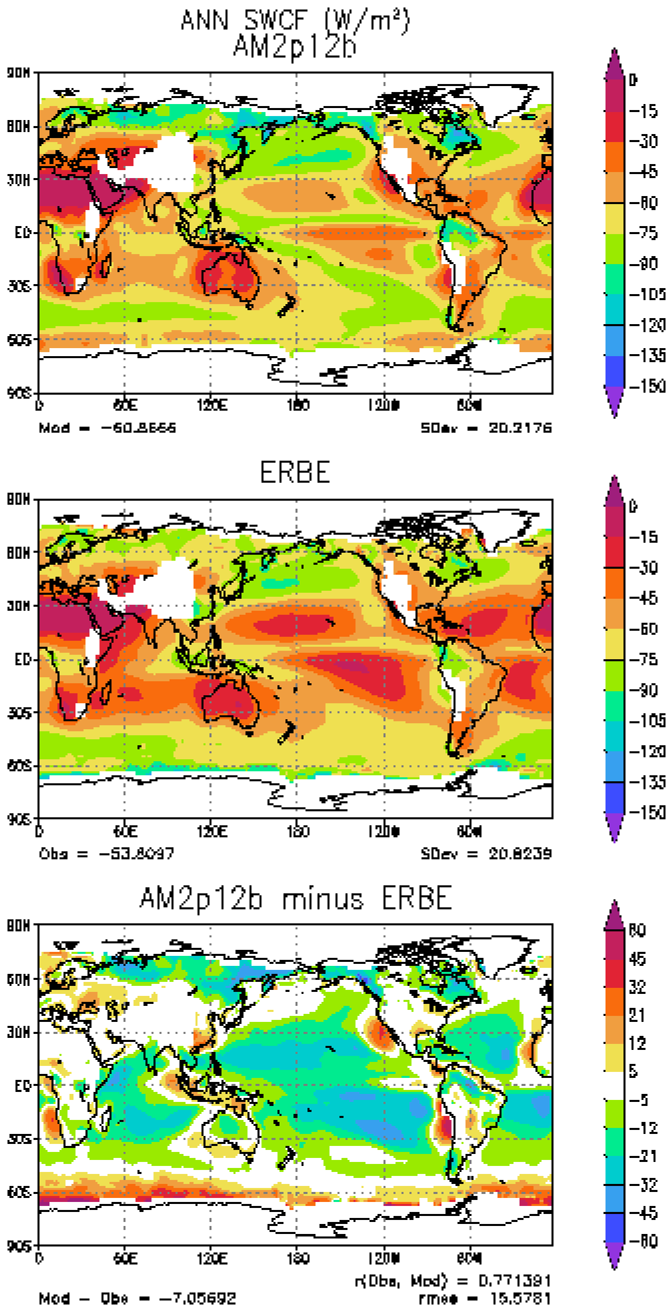
Figure 10. Annual long-term mean absorbed solar radiation (SWAbs) in W m⁻² for (a) AM2/LM2, (b) ERBE observations, and (c) AM2/LM2 minus ERBE. Statistics at the bottom of (a) and (b) include the global mean and standard deviation. Statistics at the bottom of (c) include the difference in global means, the correlation coefficient, and the root mean square error.

GFDL GAMDT
(2004, *J. Clim.*)

Annual-Mean TOA Absorbed Short Wave



Delworth *et al.* (2005, *J. Clim.*)


ANN SWCF (W/m²)
AM2p12b
Mod = -60.8666
SDev = 20.2176
ERBE
Obs = -53.8097
SDev = 20.8239
AM2p12b minus ERBE
r(Obs, Mod) = 0.771391
Mod - Obs = -7.05692
rmse = 15.5781

GFDL GAMDT
(2004, *J. Clim.*)

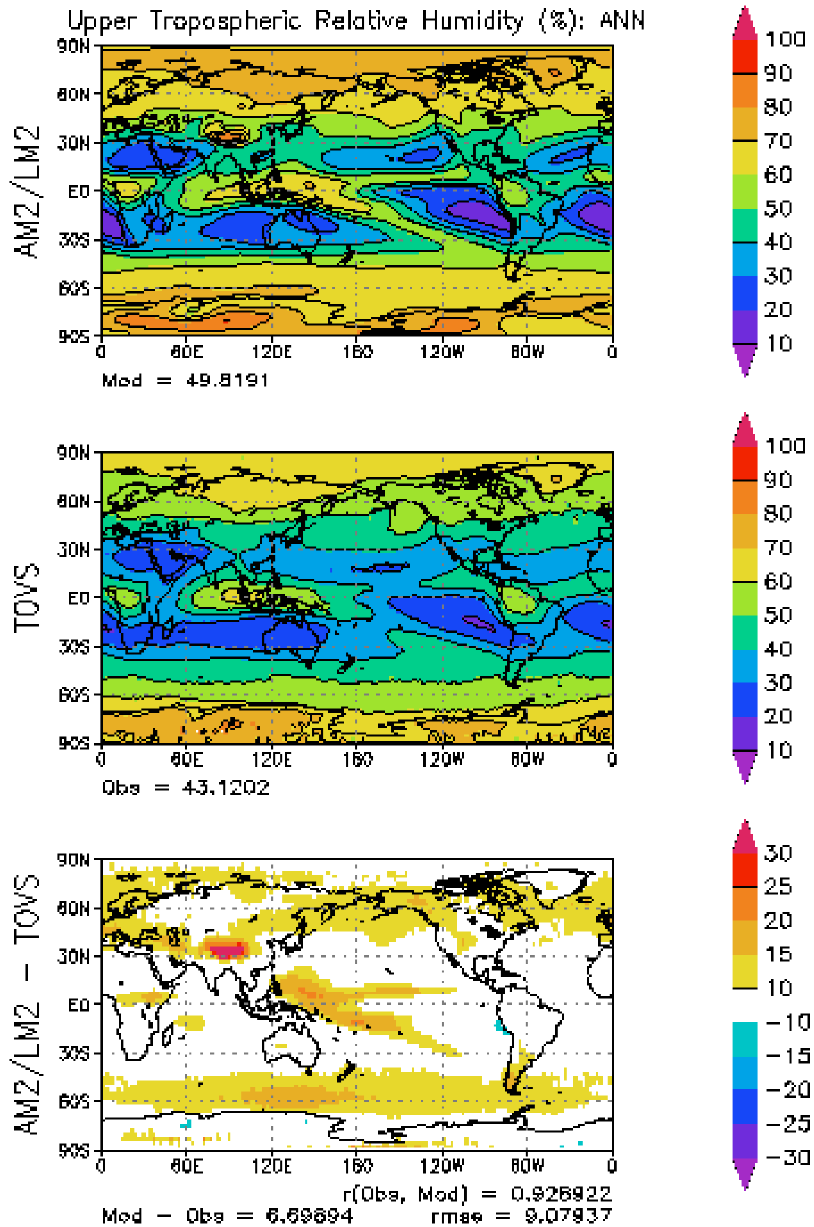


Figure 12. Annual long-term mean upper tropospheric humidity in percent for (a) AM2/LM2, (b) TOVS observations, and (c) TOVS minus AM2/LM2. Statistics at the bottom of (a) and (b) indicate the global mean. Statistics at the bottom of (c) include the difference in global means, the correlation coefficient, and the root mean square error.

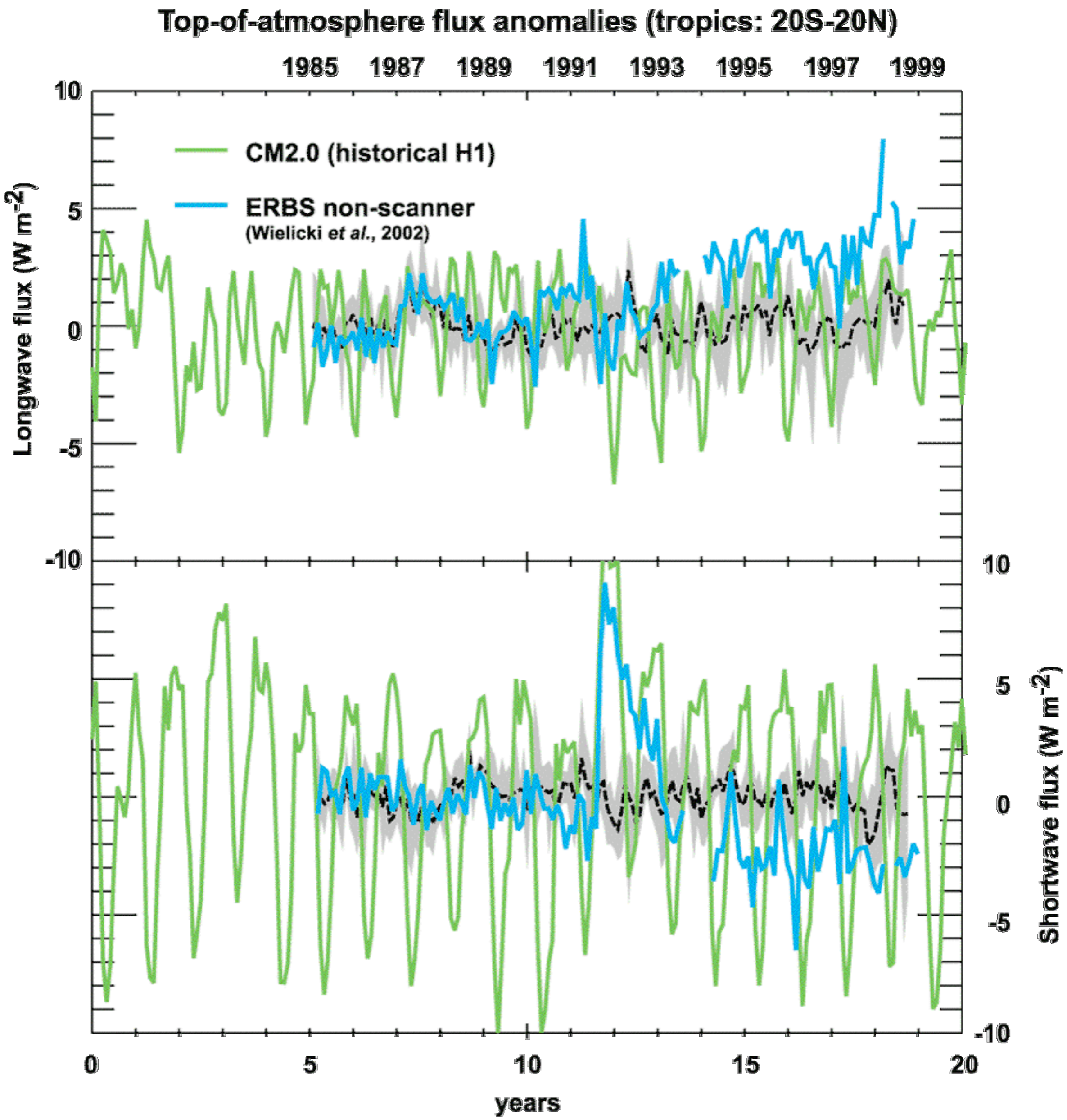
Variability in AM2/CM2 with B-grid dynamical core

Geophysical
Fluid
Dynamics
Laboratory

Princeton, New Jersey

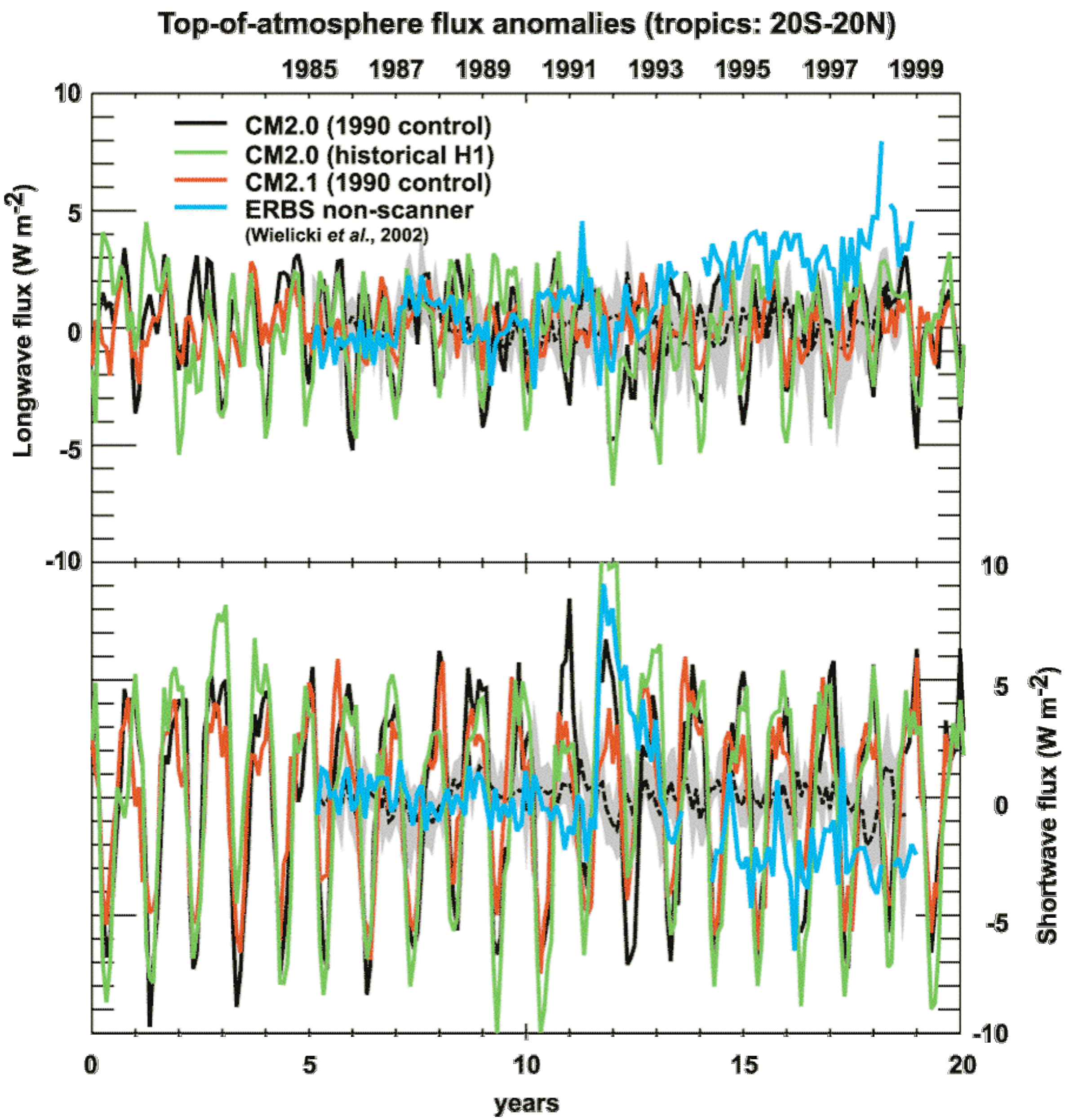
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

Tropical energy budget variability

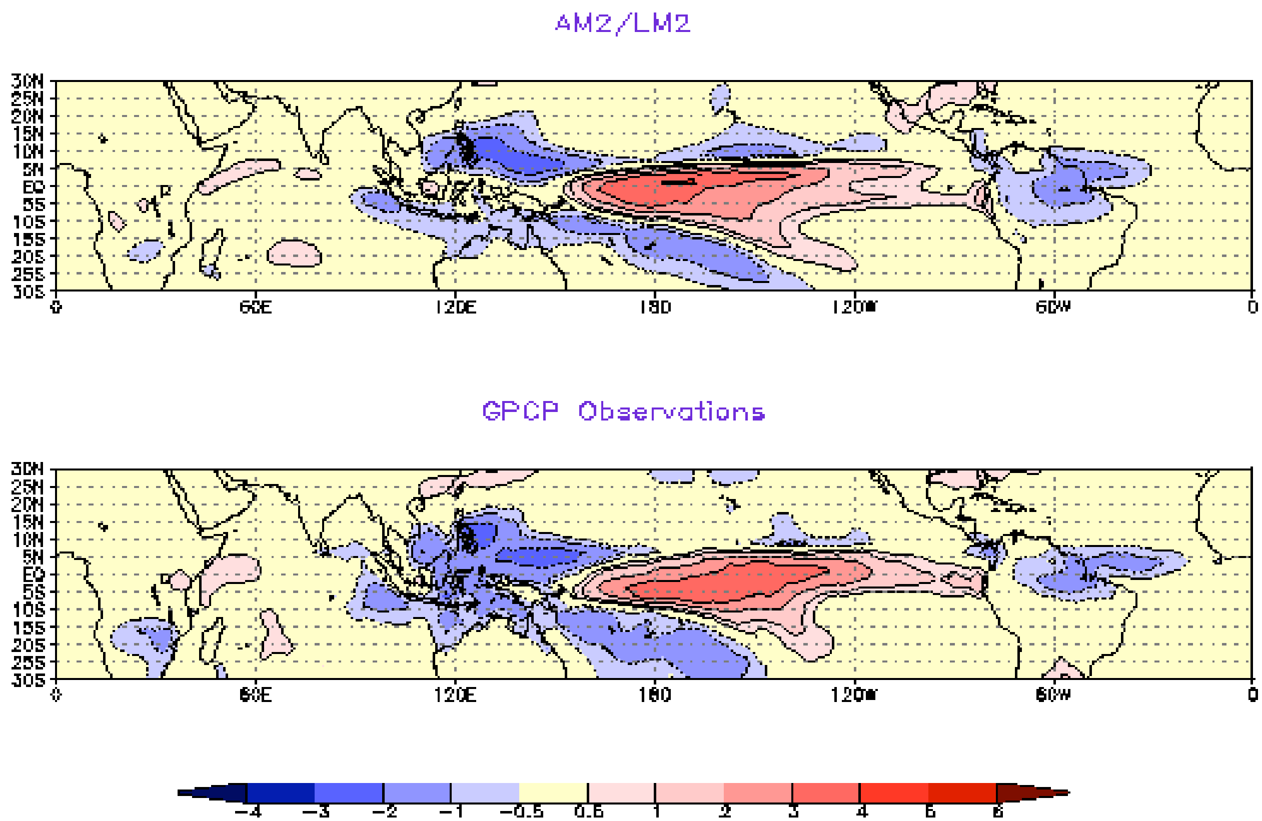


from Eric Wilcox

Tropical energy budget variability



from Eric Wilcox

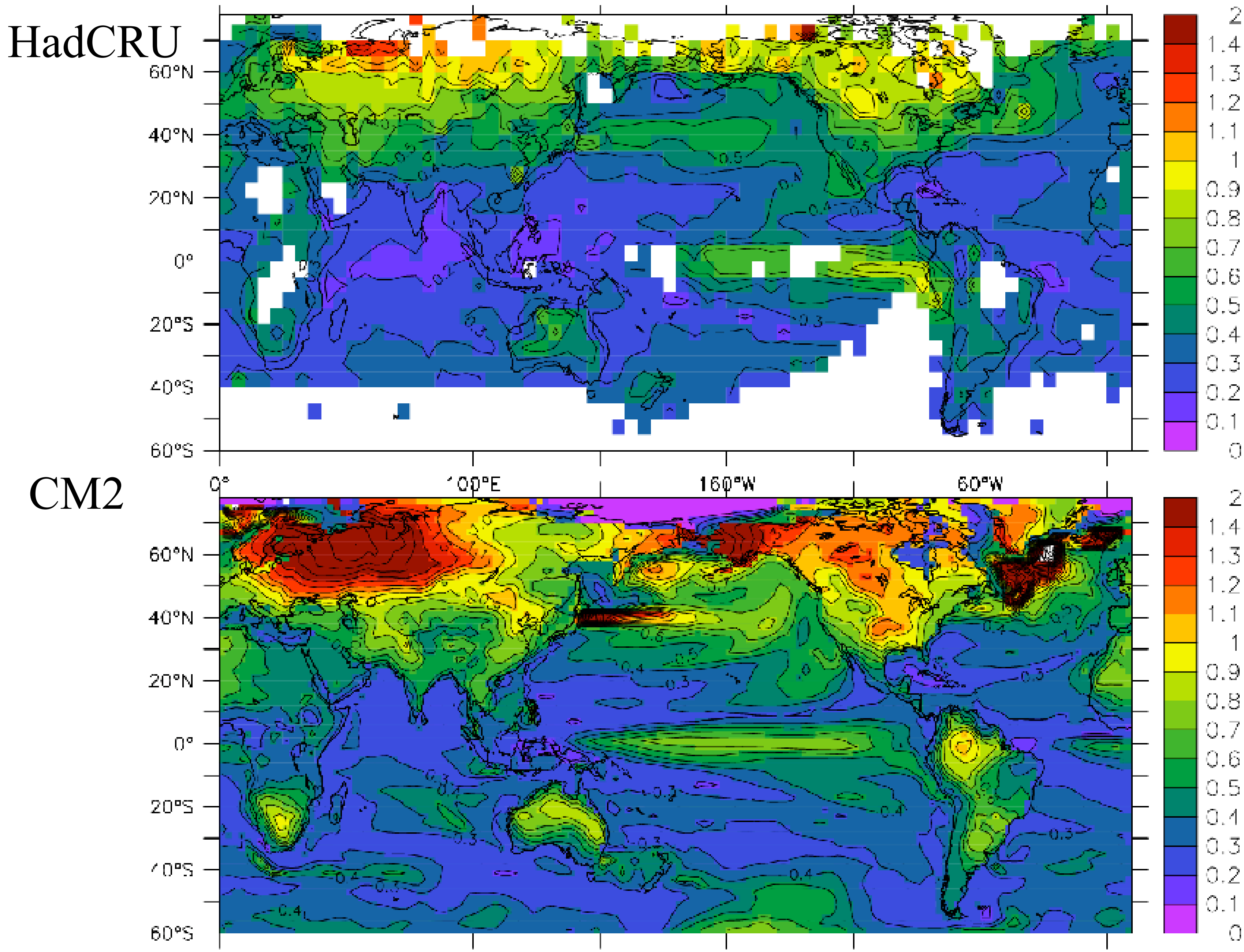


NINO3 Precipitation Regressions

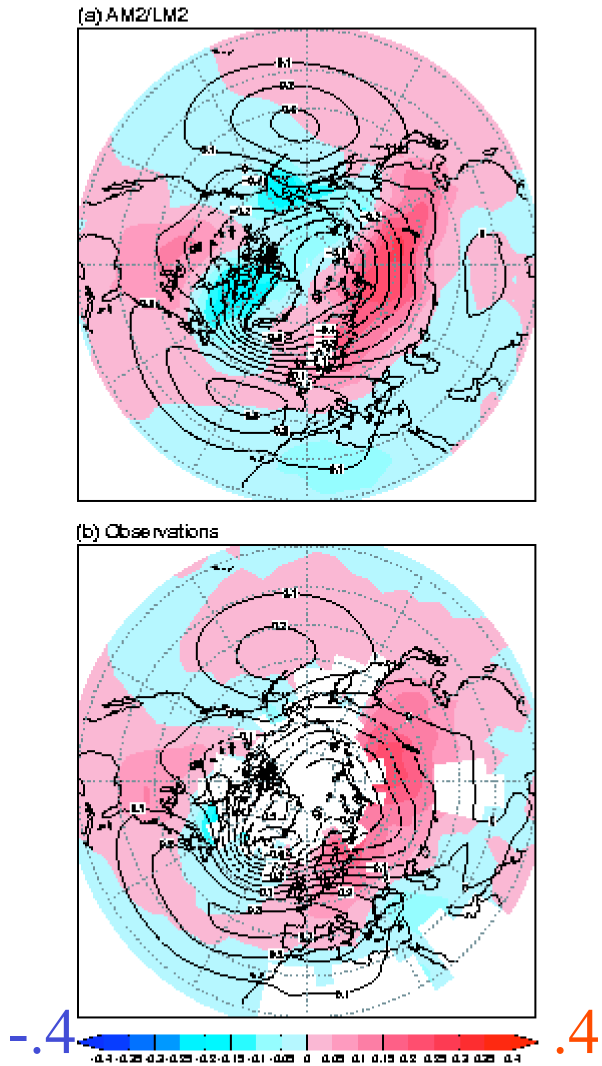
Figure 13. Distributions of the regression coefficients of precipitation rate versus the standardized NINO3 SST index, as computed using the ensemble mean of the 10-member AMIP-style integrations with the AM2/LM2 for 1951-2000 (upper panel) and the GPCP dataset for 1979-2000, both for the December-January-February season. Contour interval: 1 mm d^{-1}. Zero contour is omitted. Contours for -0.5 and +0.5 mm d^{-1} are inserted.

GFDL GAMDT (2004, *J. Clim.*)

Standard Deviation Annual-Mean Surface Temperature (K)

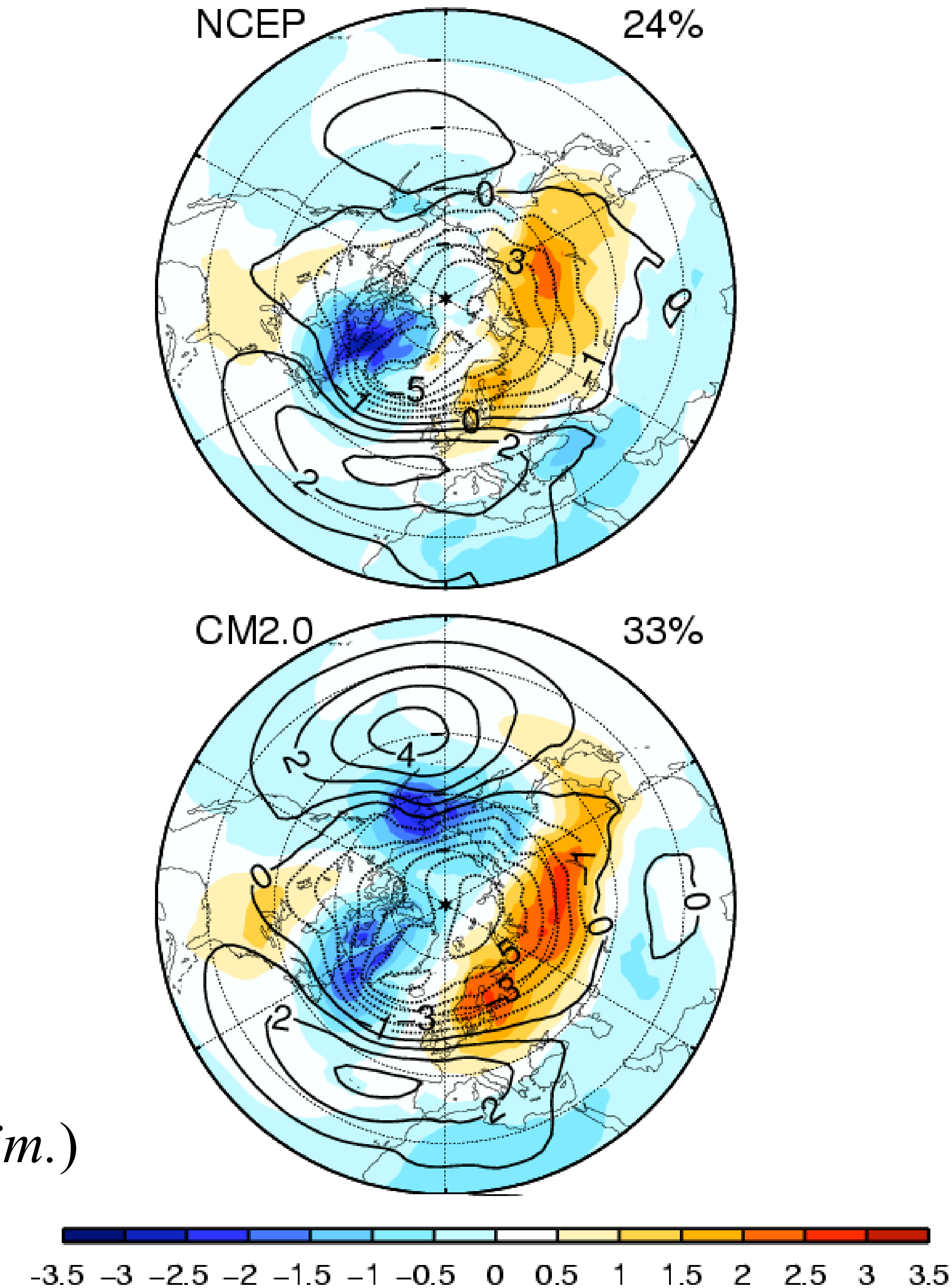


SLP (contours) and Surface Temperature (shading) Anomalies Associated with 1-hPa Increase in Index of the Northern Annular Mode



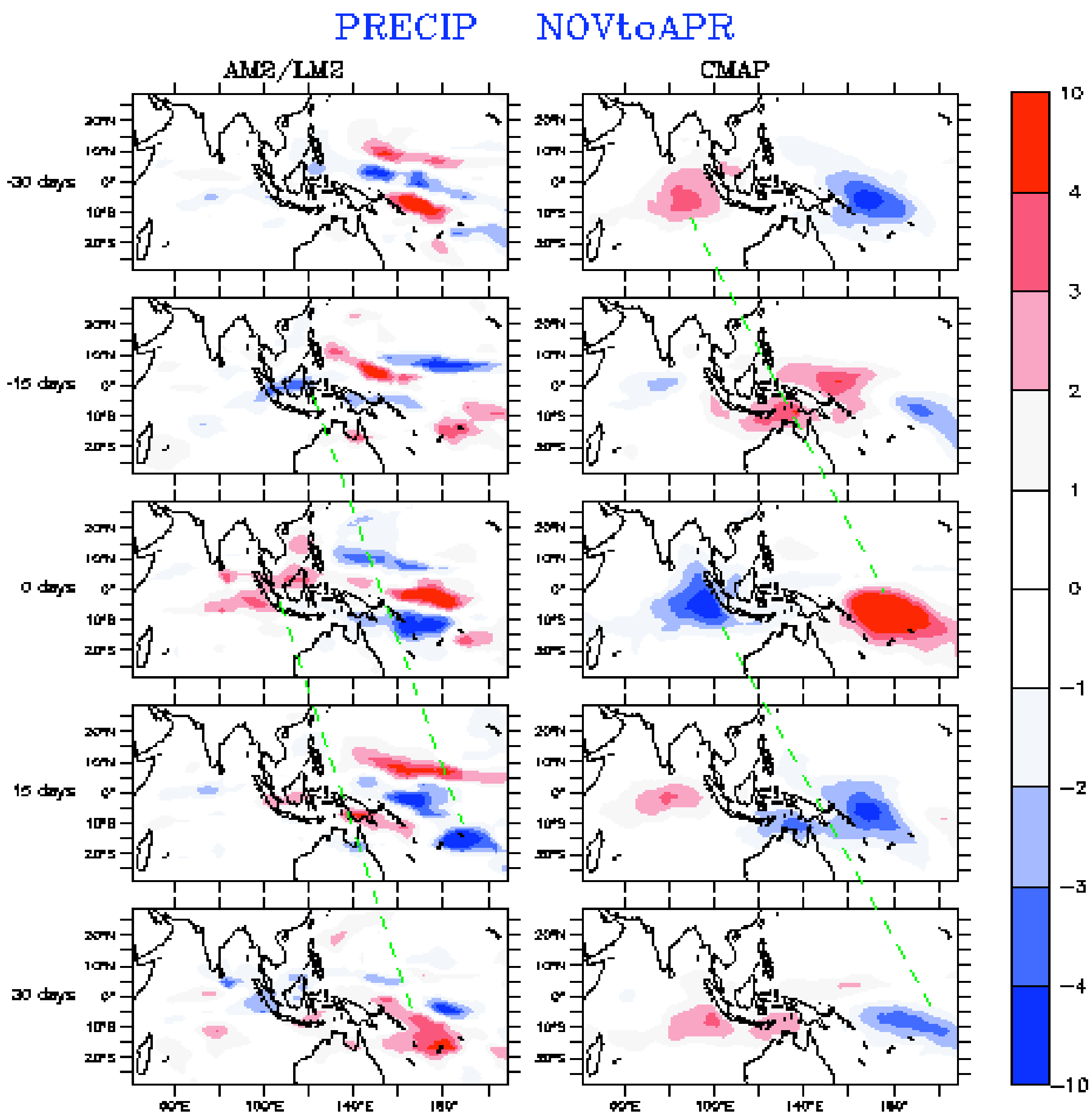
GFDL GAMDT (2004, *J. Clim.*)

Anomalies of SLP (contours) and surface temp (shading) associated with 1 std dev of NAM index



Delworth *et al.* (2005, *J. Clim.*)

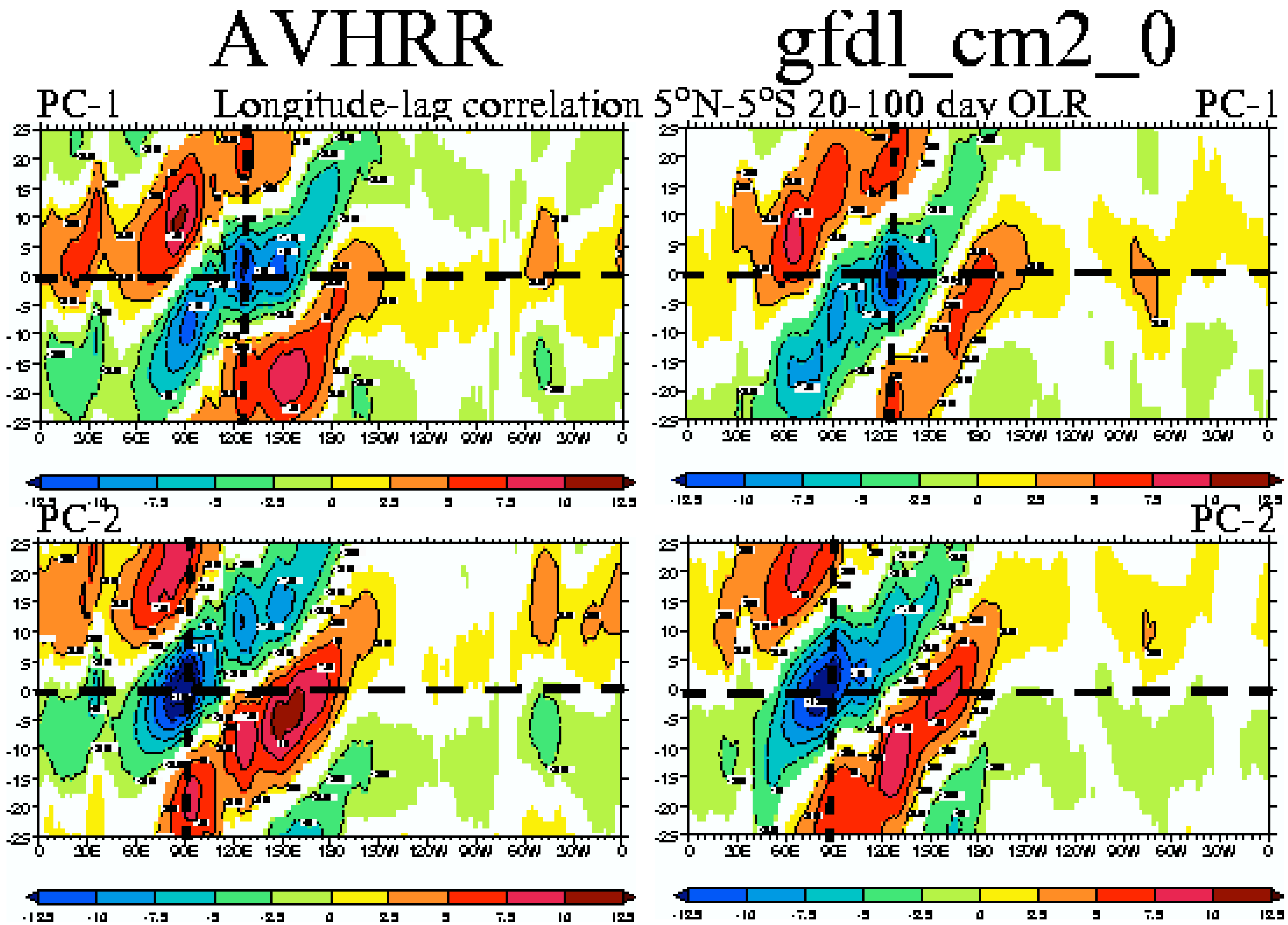
MJO (lagged 30-90 day filtered precipitaiton)



GFDL GAMDT (2004, *J. Clim.*)

Figure 20. Composite Northern Hemisphere winter (November-April) Madden-Julian Oscillation from 30-90 day filtered precipitation in mm d^{-1}. Maps based on AM2/LM2 are shown in the left column and those based on CMAP observations in right column. Sequential maps are 10 day means centered on lags of -30 days, -15 days, 0 days, +15 days, and +30days. The superimposed green dashed lines indicate propagation of the disturbance. Note that the values for AM2/LM2 values have been enhanced by a factor of 2.

Madden-Julian Oscillation in Coupled Model

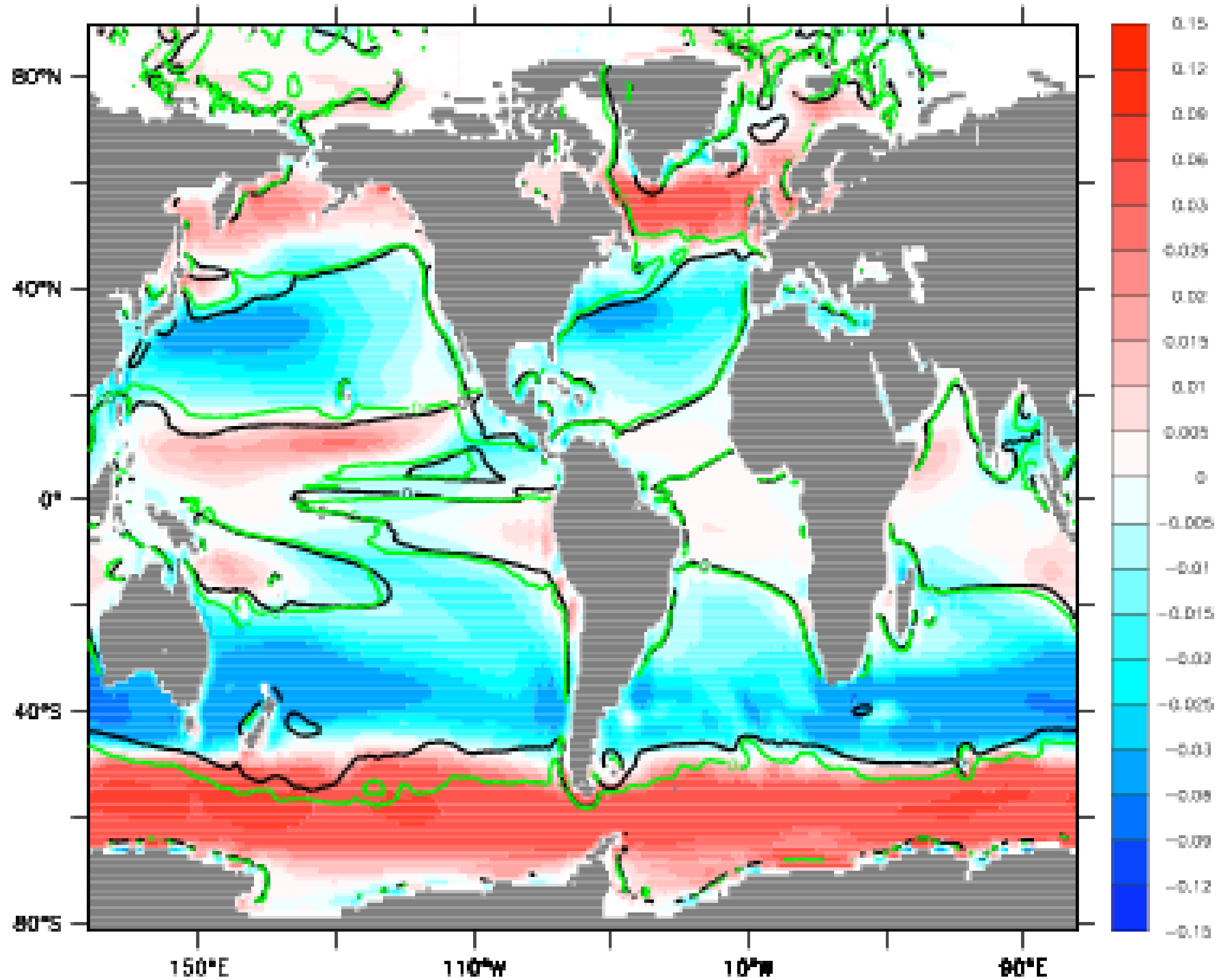


from Ken Sperber, PCMDI

Dynamical Core

Recent experiments have compared the B-grid dynamical core (Arakawa and Lamb, 1977, *Meth. Comp. Phys.*) and finite-volume (FV) dynamical core (Lin, 2004, *MWR*). Substantial changes in surface wind stresses and sea-surface temperatures resulted. CM2.1 is coupled model with FV dy-core.

Difference in Annual-Mean Zonal Wind Stress, FV-B grid (N m^{-2})

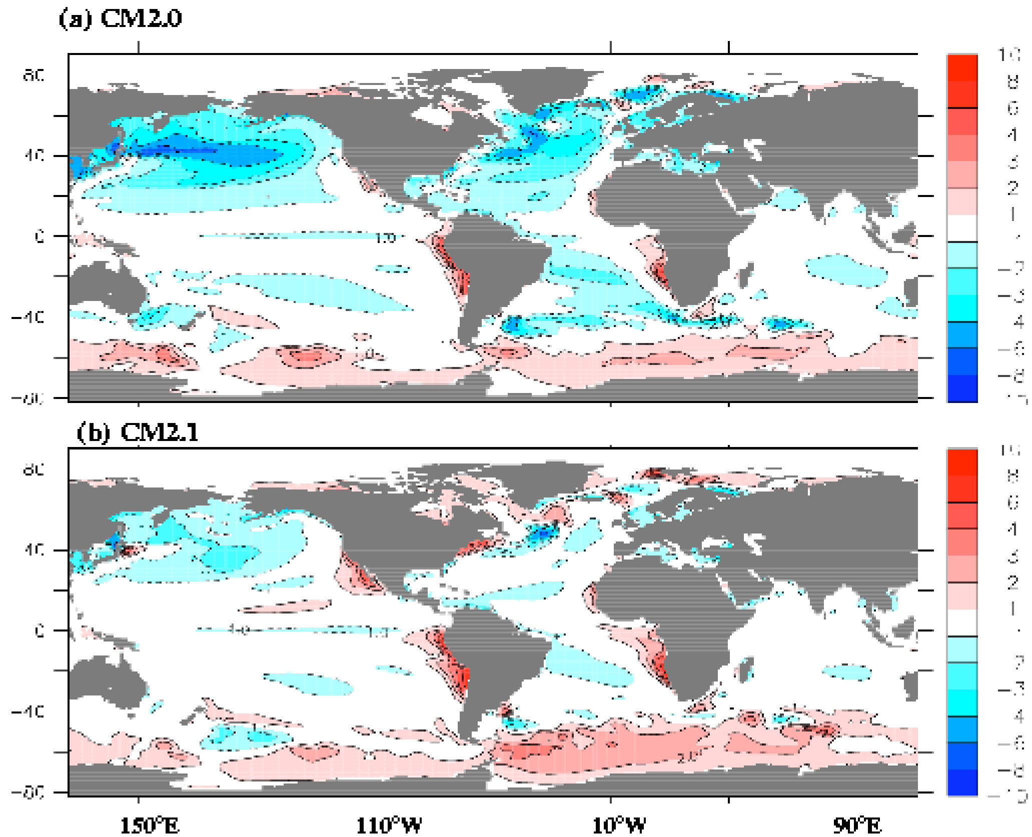


Delworth *et al.* (2005, *J. Clim.*)

CM 2.0/2.1 Annual-Mean SST-Reynolds SST (K)

B grid

FV

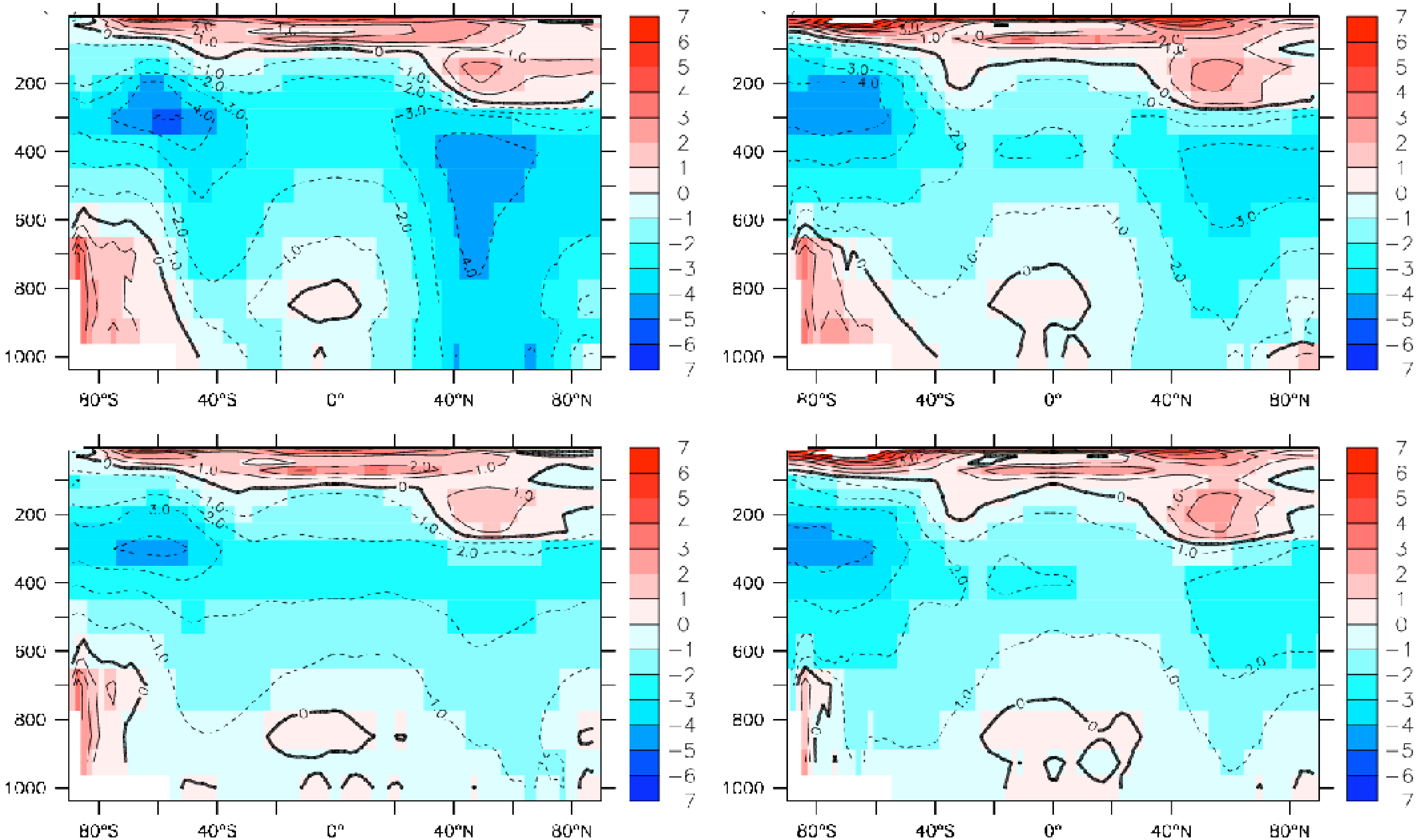


Delworth *et al.* (2005, *J. Clim.*)

Annual Mean Temp Diff, AM/CM-NCEP (K)

B grid | FV

Coupled | Coupled



Atmosphere | Atmosphere

Delworth *et al.* (2005, *J. Clim.*)

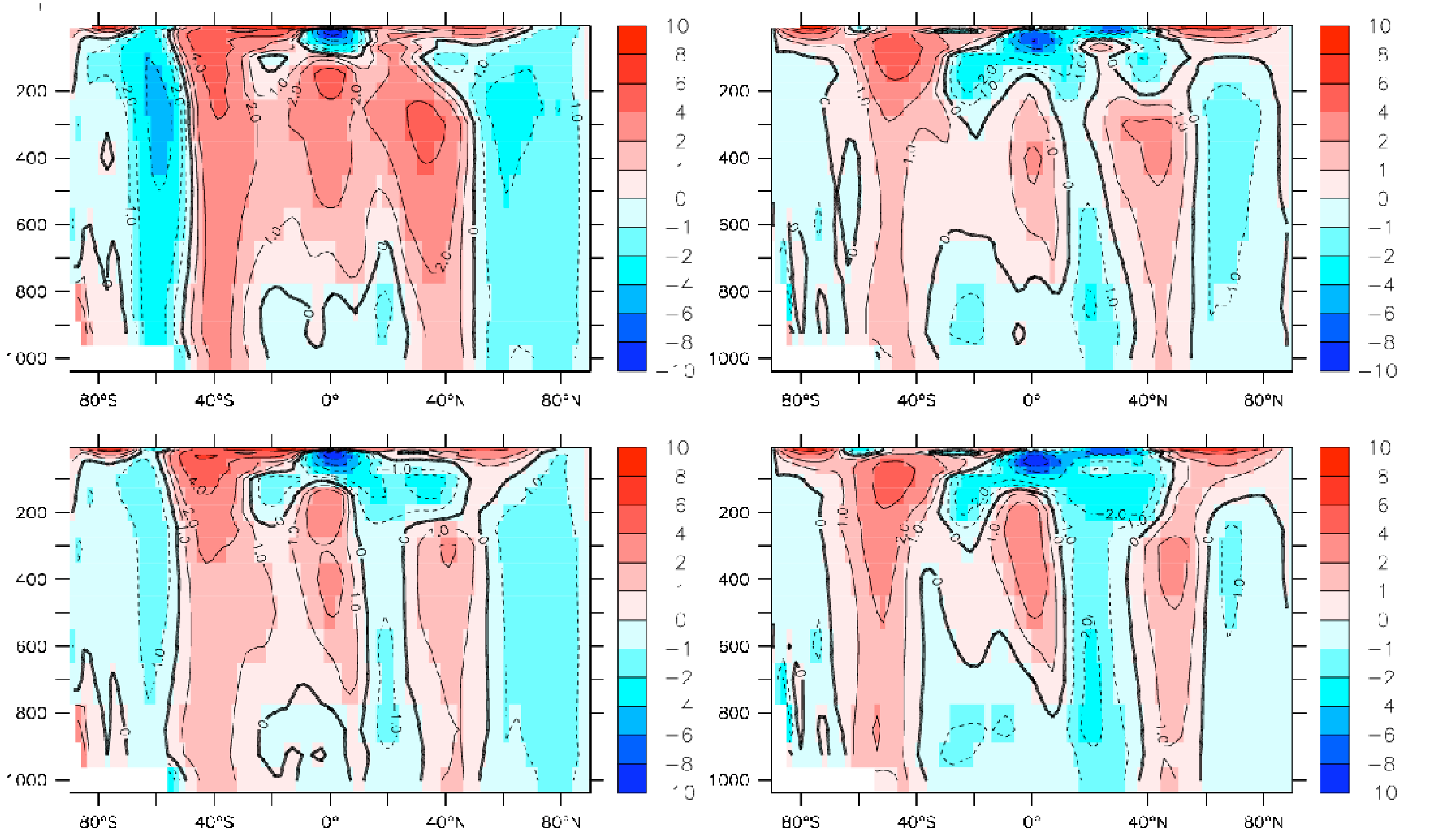
Annual-Mean Zonal-Wind Diff, AM/CM – NCEP (m/s)

B grid

FV

Coupled

Coupled



Atmosphere

Atmosphere

Delworth *et al.* (2005, *J. Clim.*)

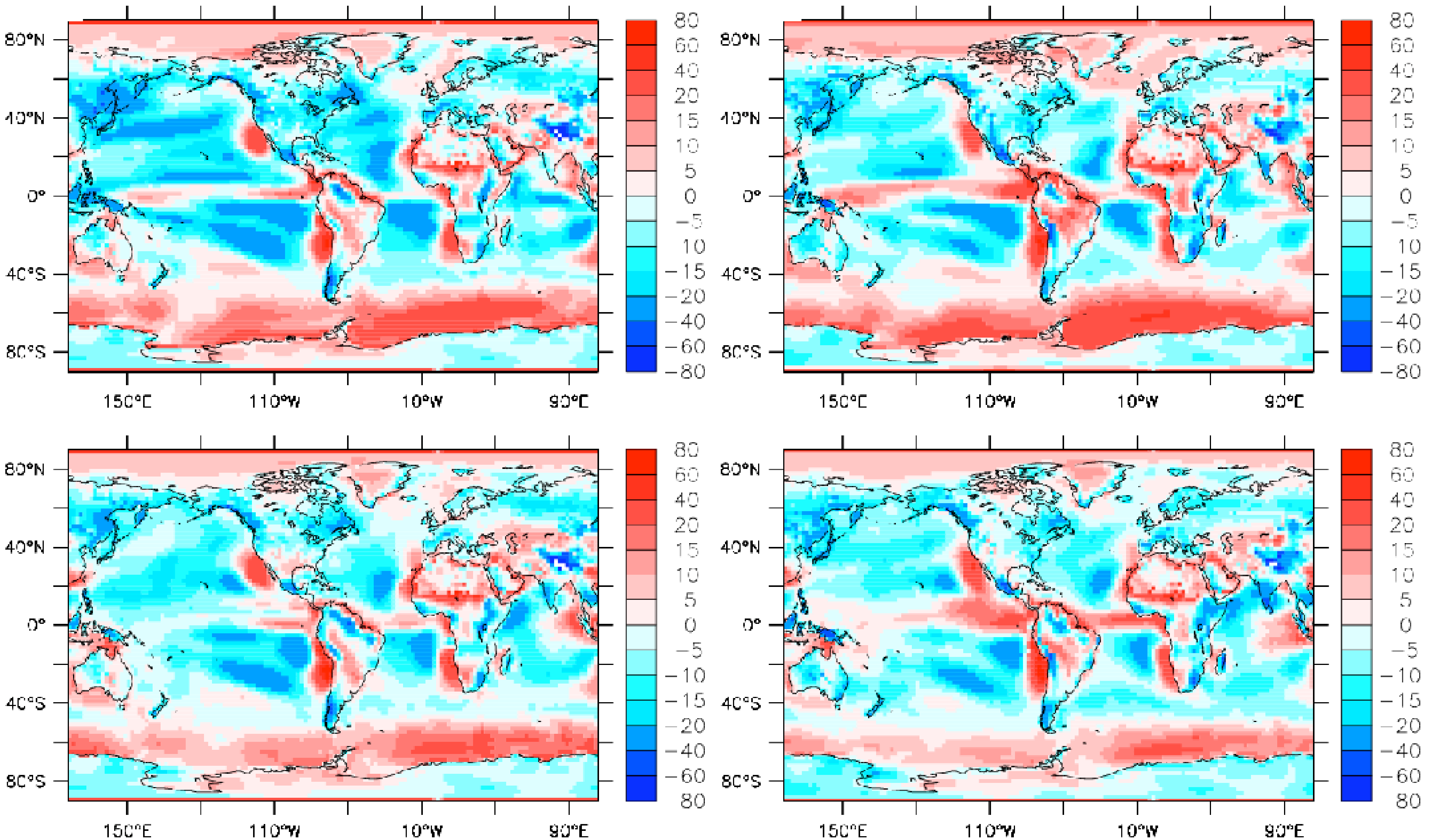
Annual-Mean TOA Absorbed SW Diff, AM/CM –ERBE (W m^{-2})

A
B grid

FV

Coupled

Coupled



Atmosphere

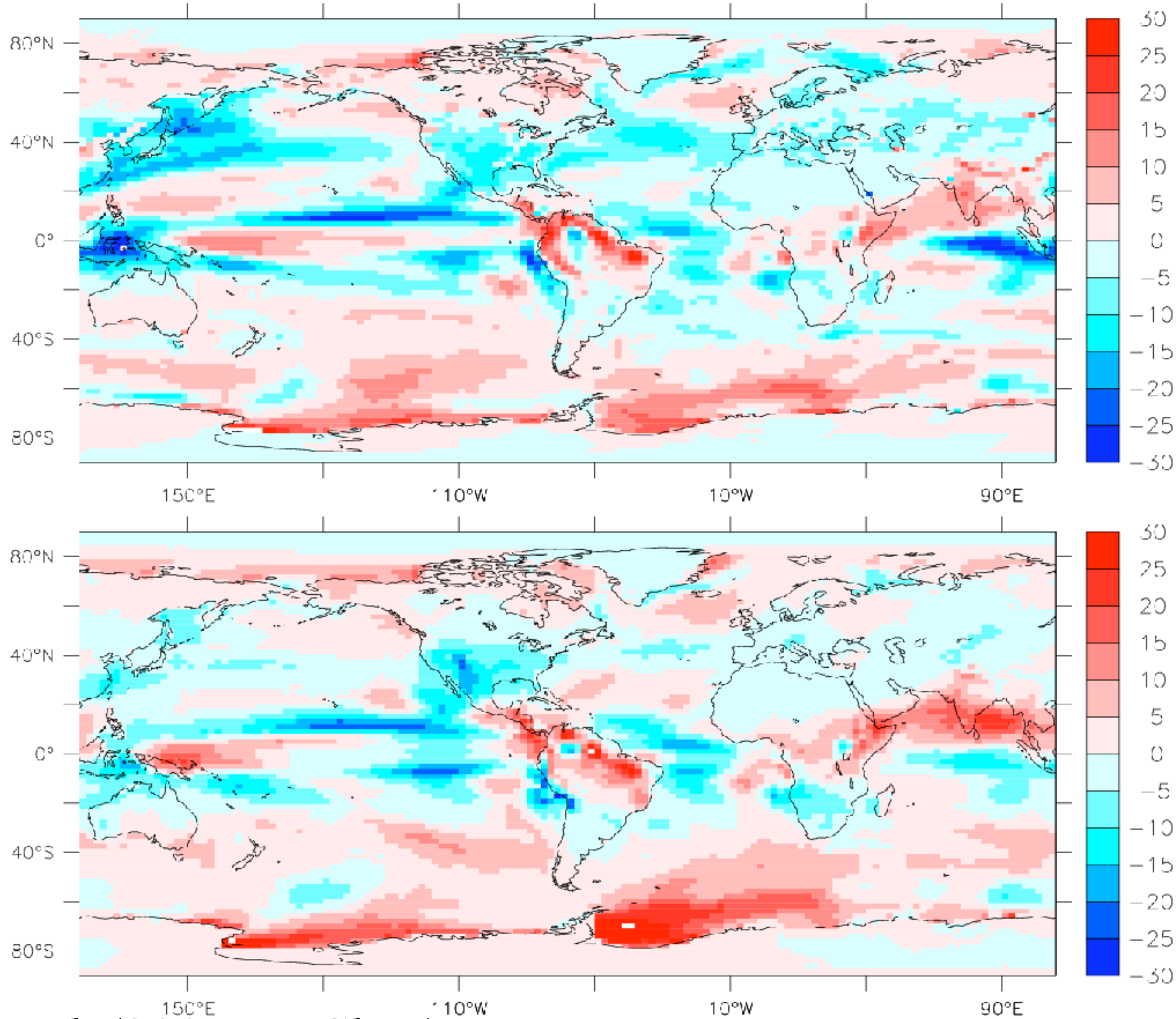
Delworth *et al.* (2005, *J. Clim.*)

Atmosphere

Annual-Mean TOA Absorbed SW Diff, CM-AM (W m^{-2})

B grid

FV



Delworth *et al.* (2005, *J. Clim.*)

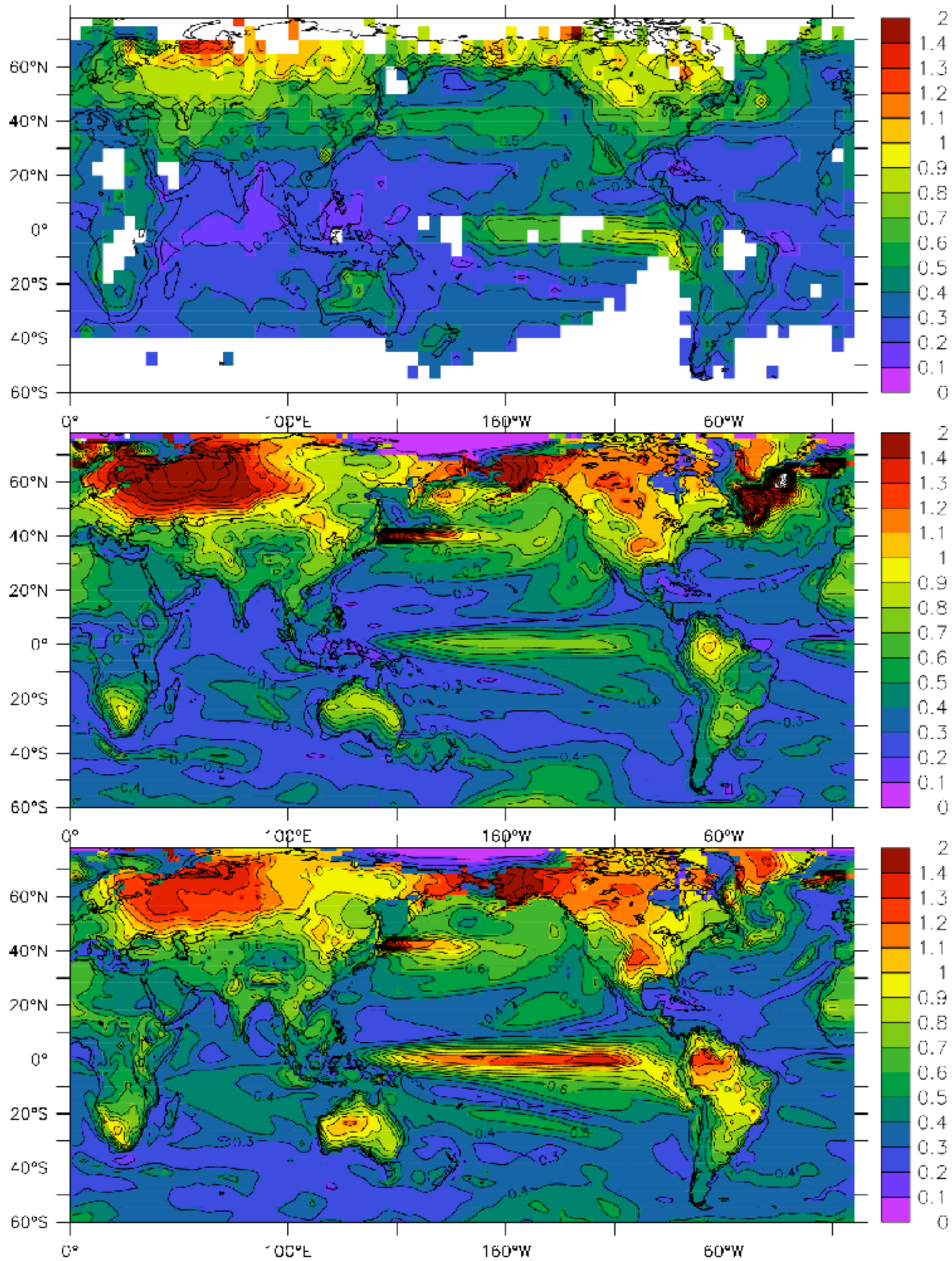
Standard Deviation CM Annual-Mean Sfc Temperature (K)

HadCRUT2v

B grid

FV

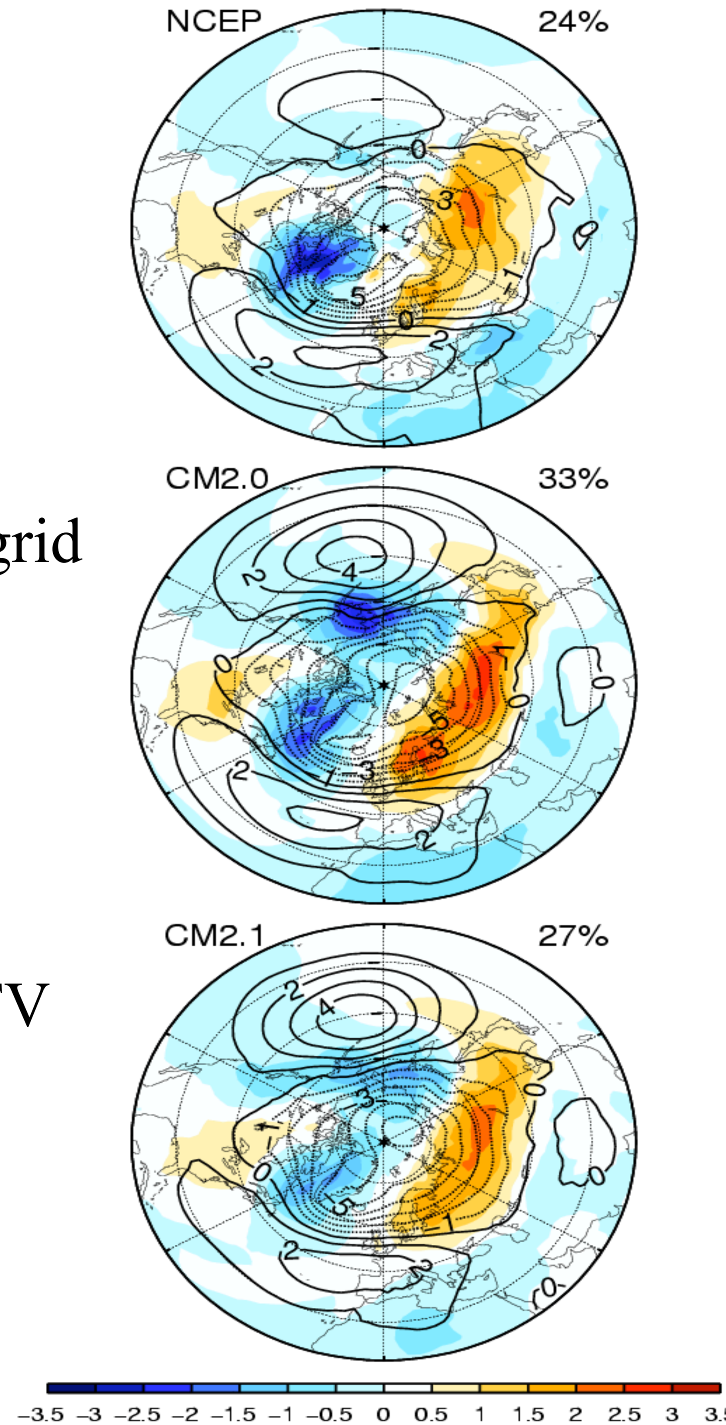
Delworth *et al.* (2005, *J. Clim.*)



Anomalies of SLP (contours)
and surface temperature (shading)
associated with 1 std dev
in NAM index

B grid

FV



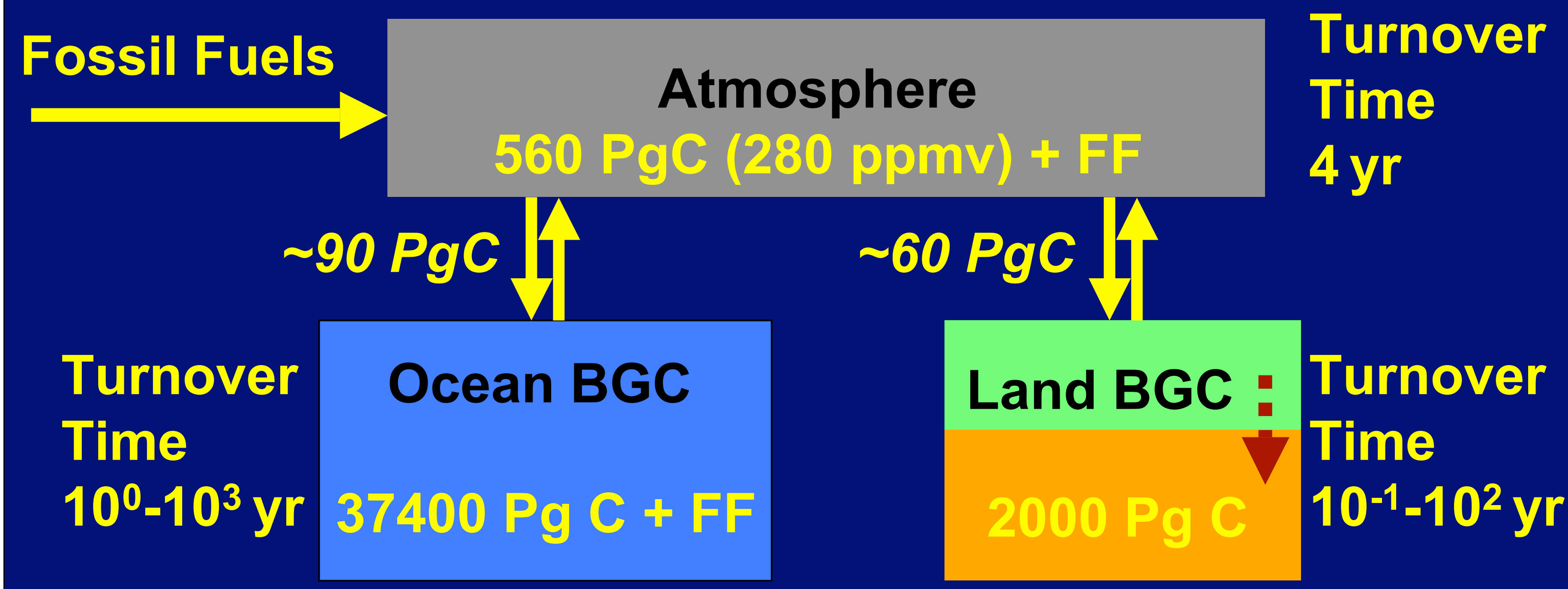
Delworth *et al.* (2005, *J. Clim.*)

Earth-System Model: Early Results

Geophysical
Fluid
Dynamics
Laboratory

Princeton, New Jersey

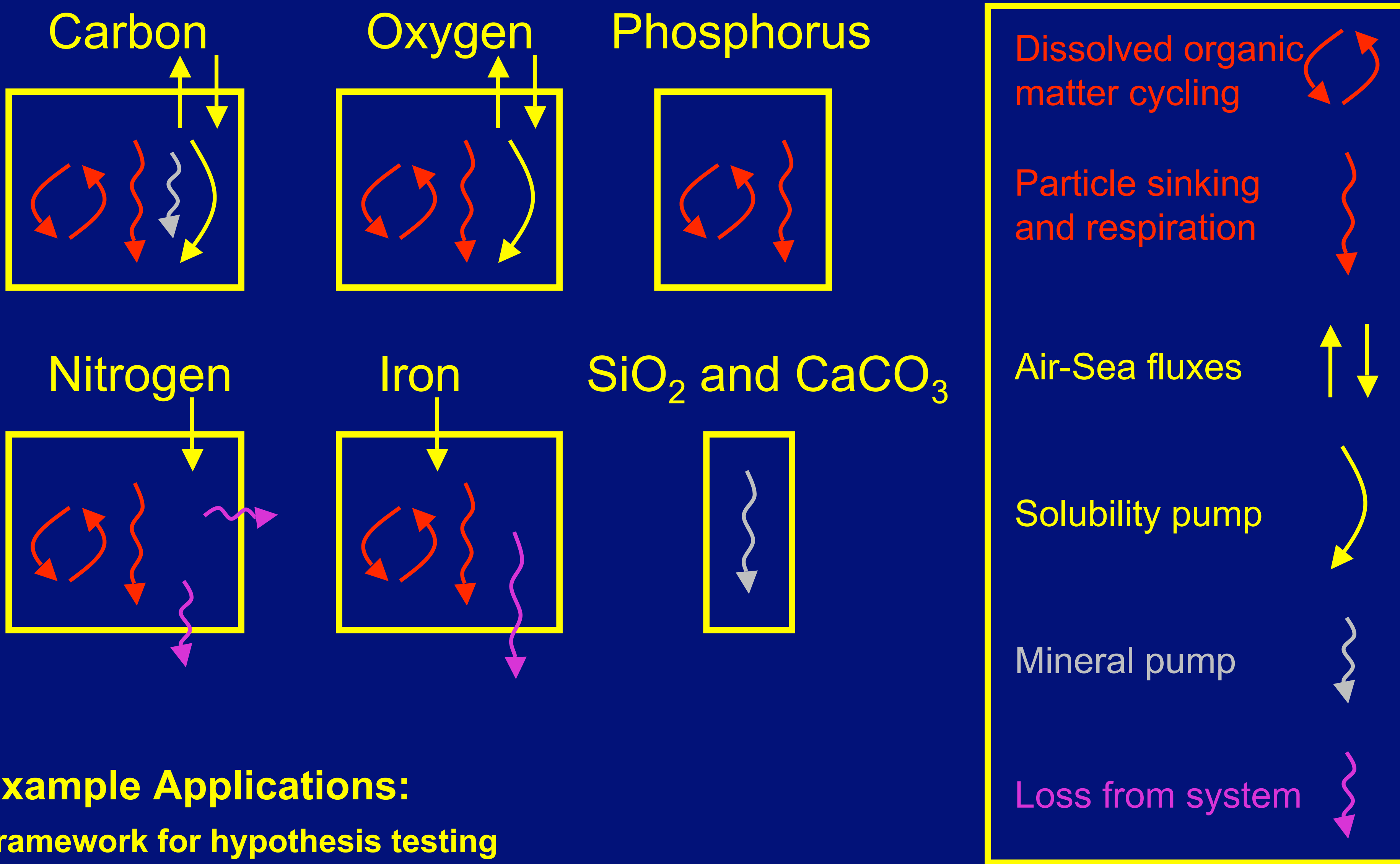
Carbon in the Earth System Model



from John Dunne

…equilibrium takes 10^3-10^4 yrs

Ocean Biogeochemical Model



Example Applications:

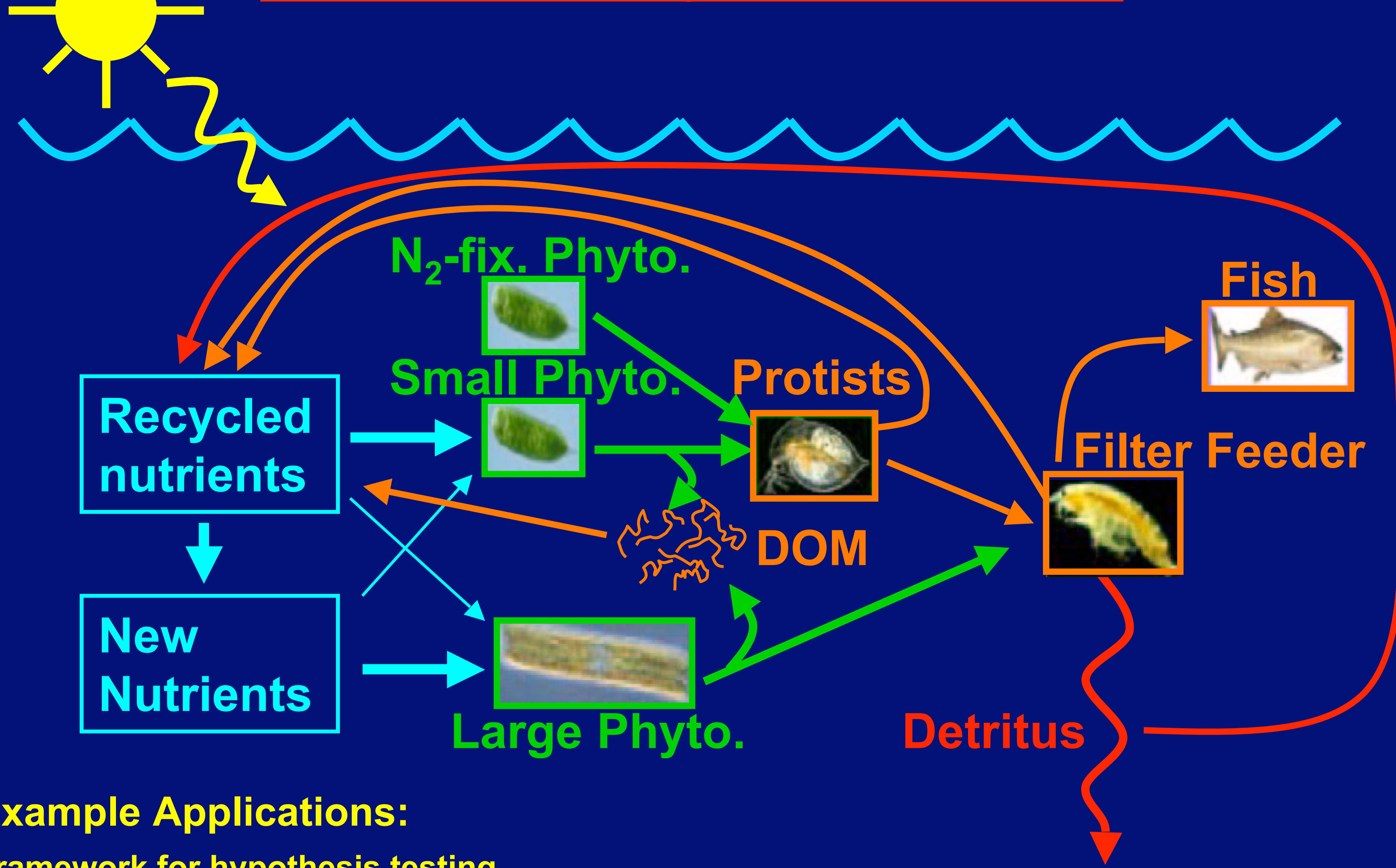
Framework for hypothesis testing

Assessment of temporal variability

Climate sensitivity and interactions

from John Dunne

Ocean Ecosystem Model



Example Applications:

Framework for hypothesis testing

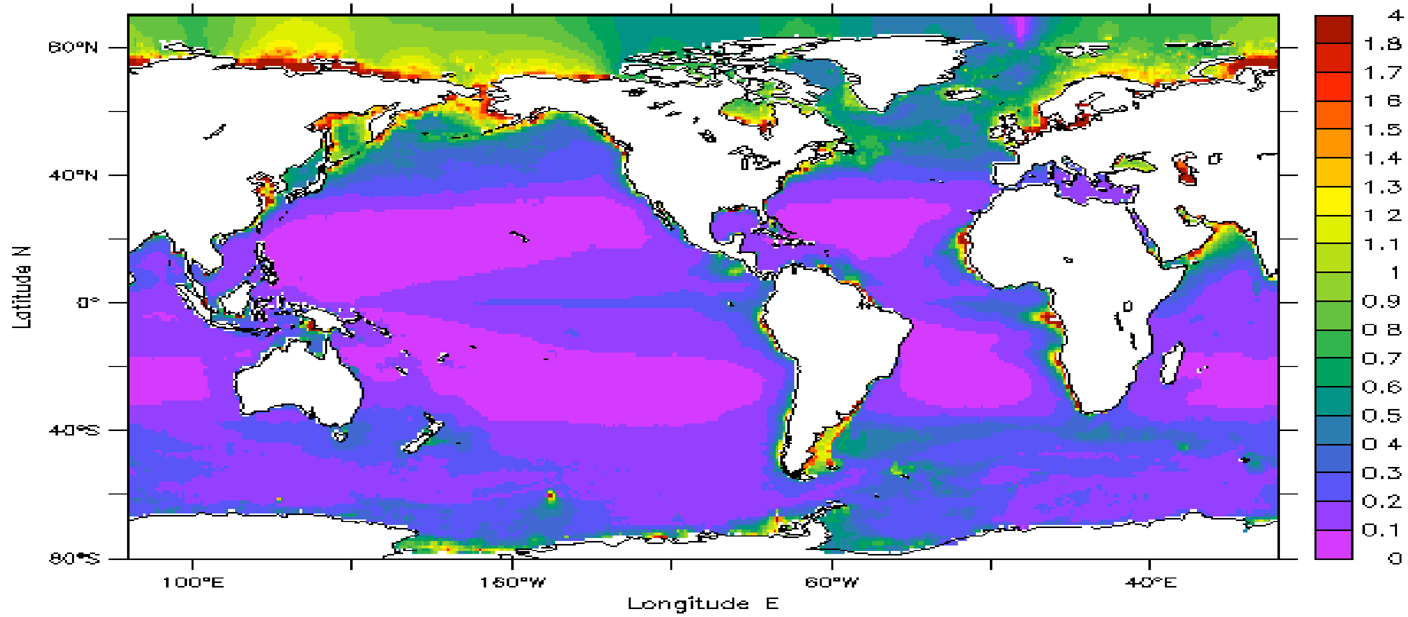
Assessment of temporal variability

Climate sensitivity and interactions

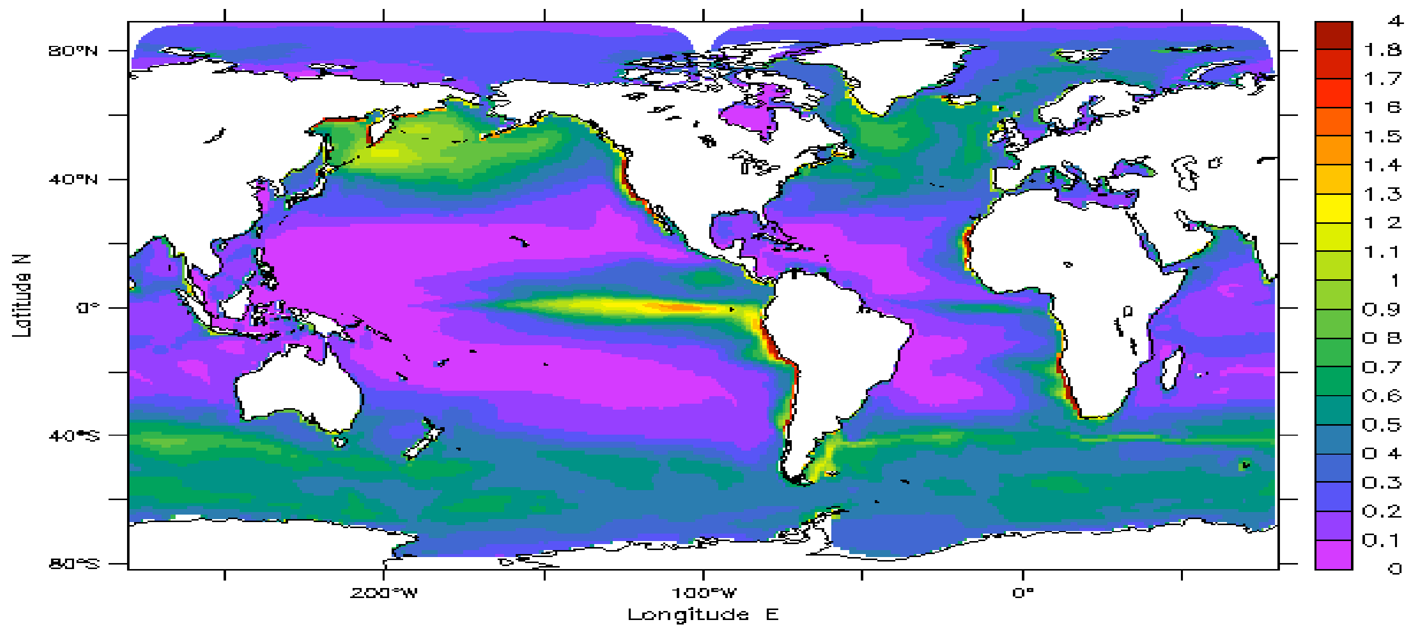
from John Dunne

Satellite Chlorophyll Comparison

SeaWiFS Satellite

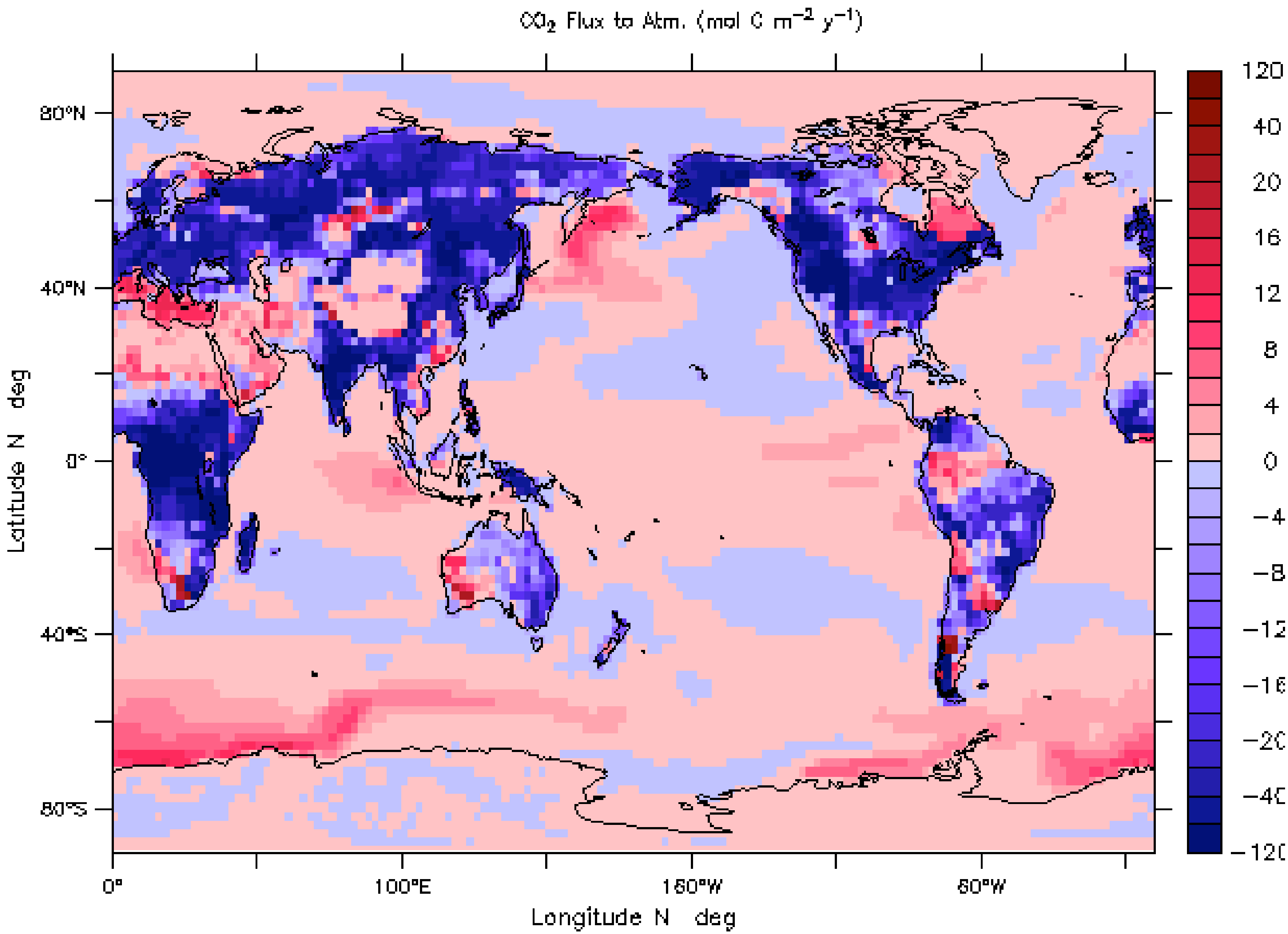


GFDL Model



from John Dunne

Prototype CO_2 Spinup (Year 7)



Summary

- GFDL current coupled climate model is being employed to study intra-seasonal to inter-decadal variability.
- Recent atmospheric research has emphasized dy-core. FV changes wind and ocean stress patterns substantially.
- Early stages of incorporation of coupled climate model in earth-system model are underway.