The Role of AMOC Variability in Climate

(AMOC-SST association and the Atmospheric Response)

Yochanan Kushnir

Mingafng Ting, Naomi Naik, Cuihua Li, In-Sik Kang*,

Richard Seager, & M. Cane

Cooperative Institute for Climate Applications and Research

Lamont-Doherty Earth Observatory

Columbia University | Earth Institute

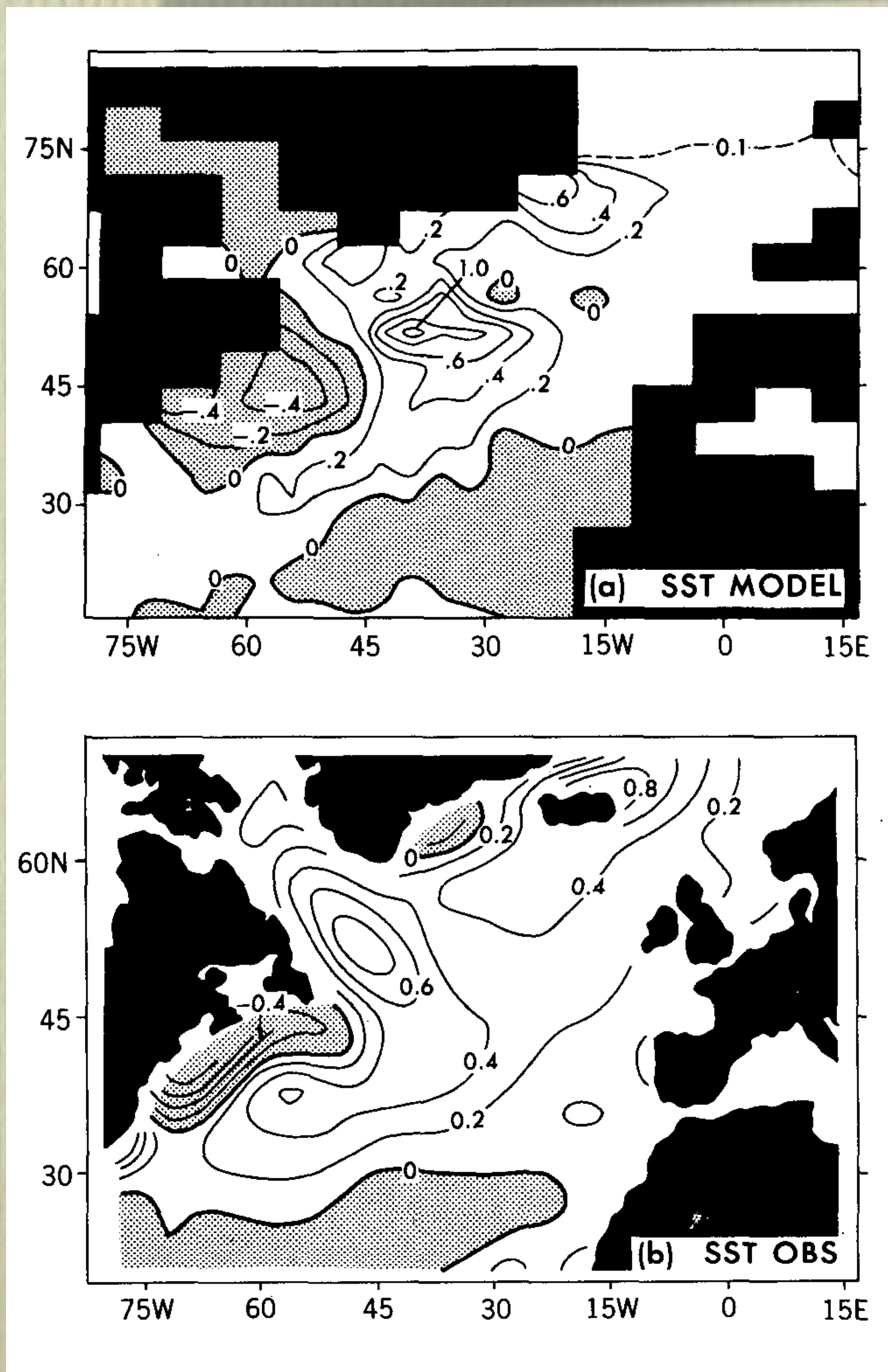
* *On sabbatical from Seoul National University*

2010 U.S. AMOC Annual Meeting / June 2010, Miami

Outline

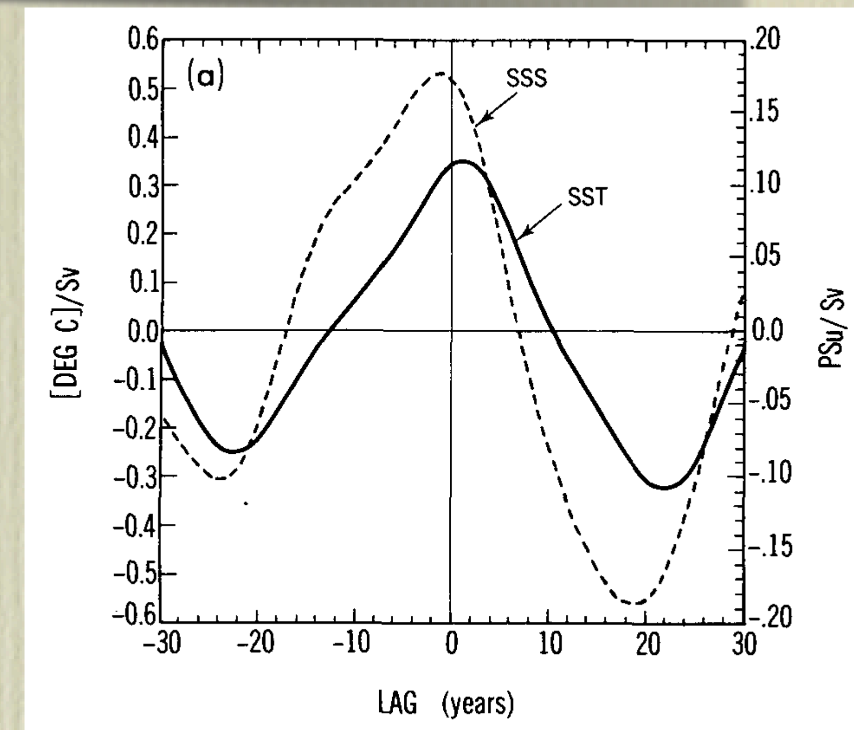
- The relationship between AMOC variability and SST
- Observed and modeled impact of AMOC-related Atlantic SST variability on climate
- Mechanisms of atmospheric response to AMOC variability

AMOC and SST Variability - 1



Delworth et al. (1993): Coupled model SST for strong overturning *minus* weak overturning

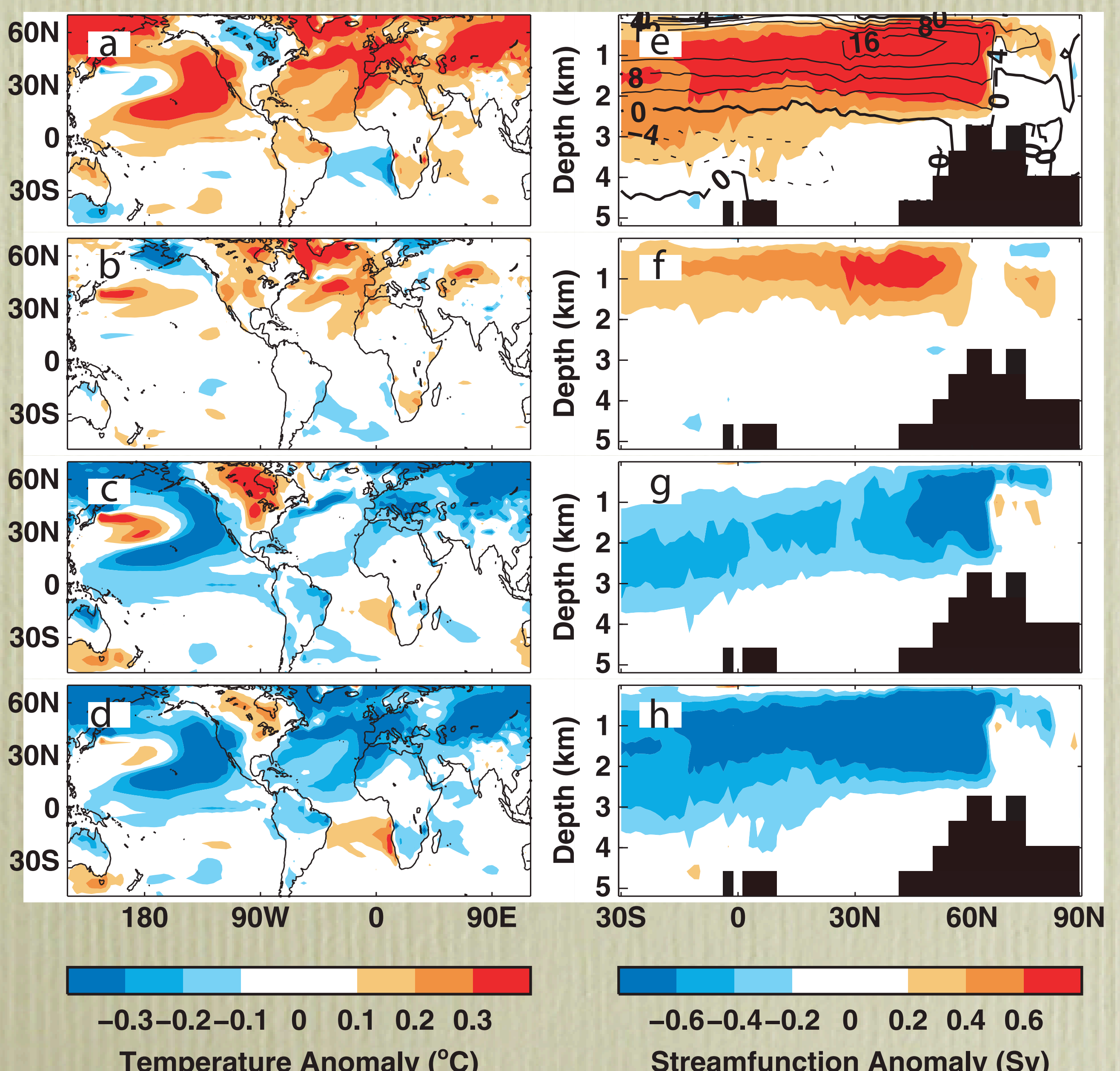
Observed SST: 1950-1964 *minus* 1970-1984, two contrasting intervals in AMV "cycle" (from *Kushnir, 1994*)

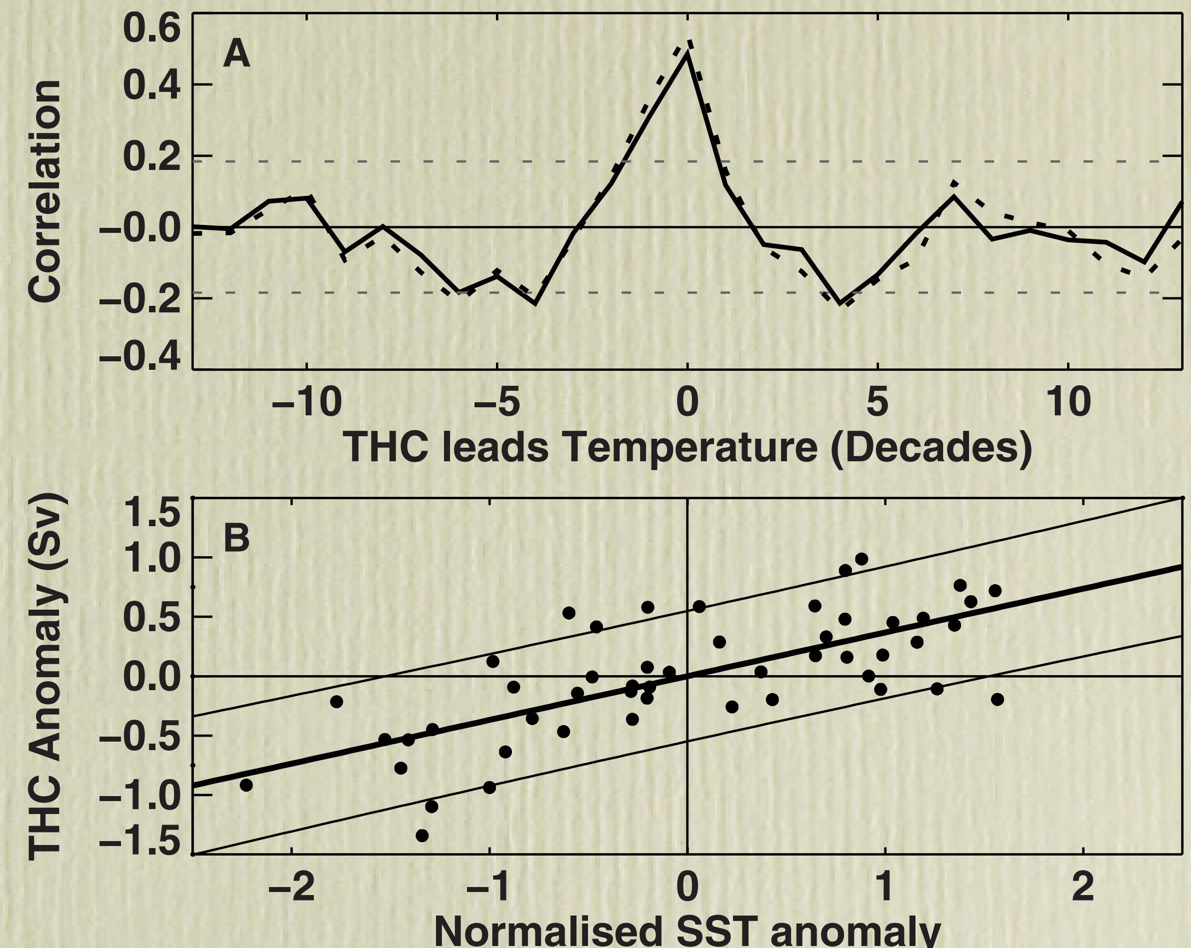


Coupled model lag-correlation between subpolar gyre SST and SSH and an AMOC index (peak AMOC linked with warm SST)

AMOC and SST Variability - 2

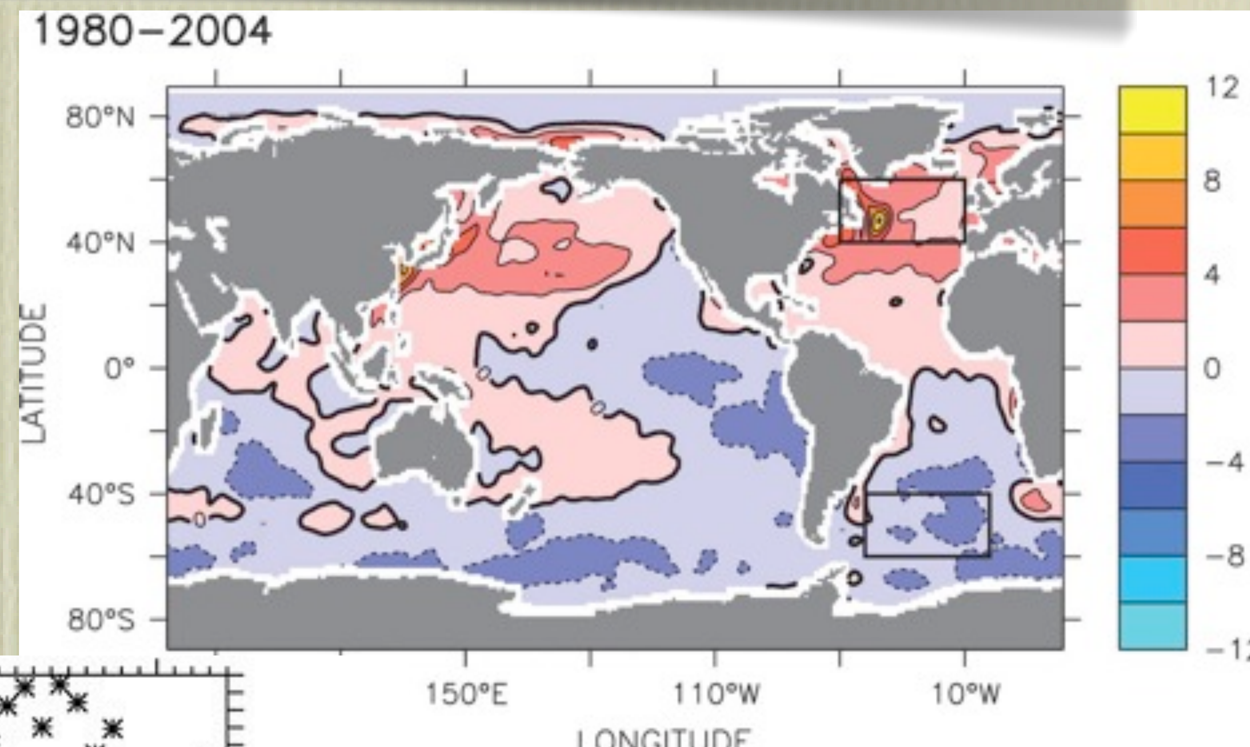
Knight et al. (2005): Joint MTM-SVD analysis of simulated decadal surface temperatures and AMOC in HadCM3.



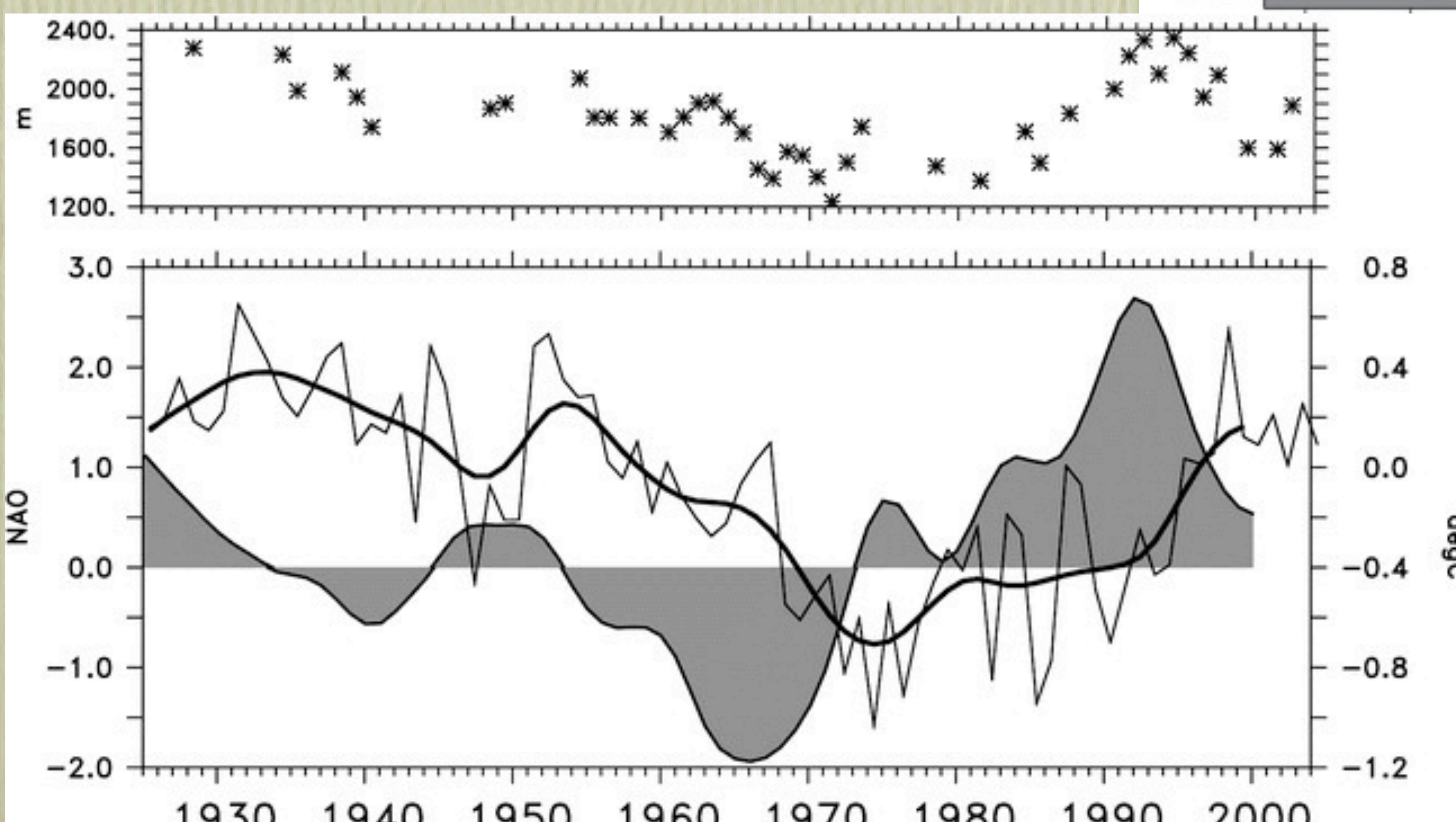


Knight et al. (2005): (A) Cross-correlation between decadal AMOC anom. and global Ts; (B) decadal AMOC anom. vs. No. Atl. SSTA

AMOC and SST Variability - 3

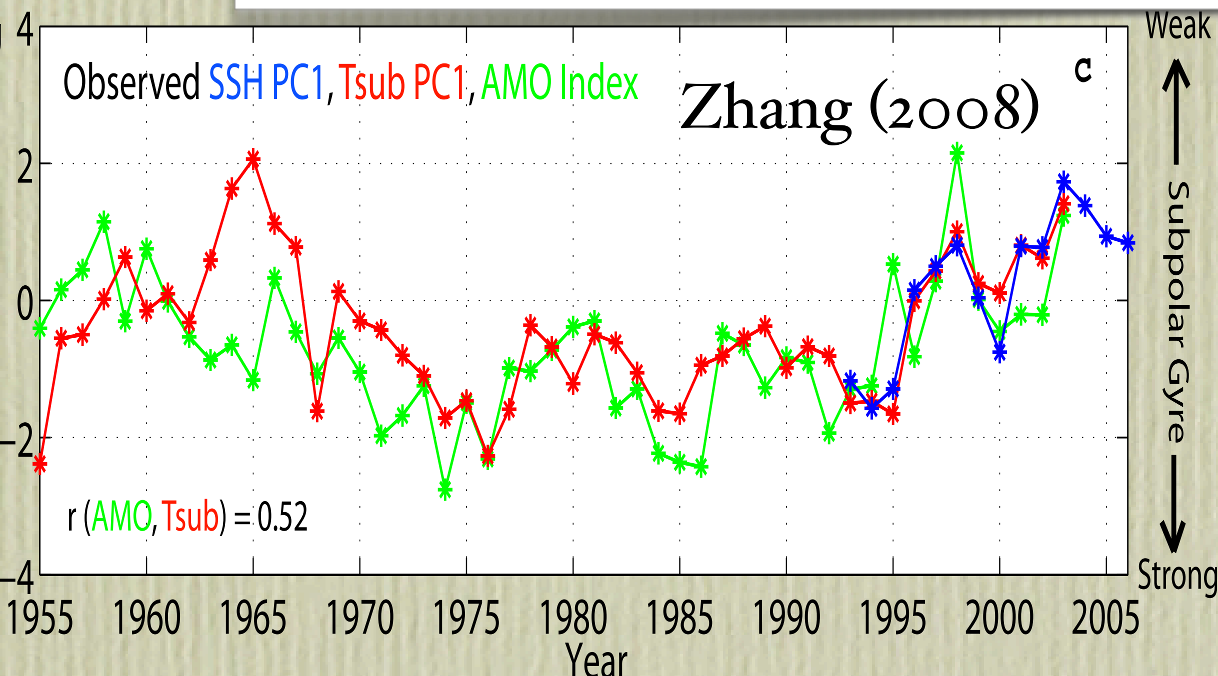


Latif et al. (2006): an observed SST-based index for AMOC (line) compared to the NAO index (shaded curve) and to the LSW layer thickness (in m - stars) from Curry et al. (1998).



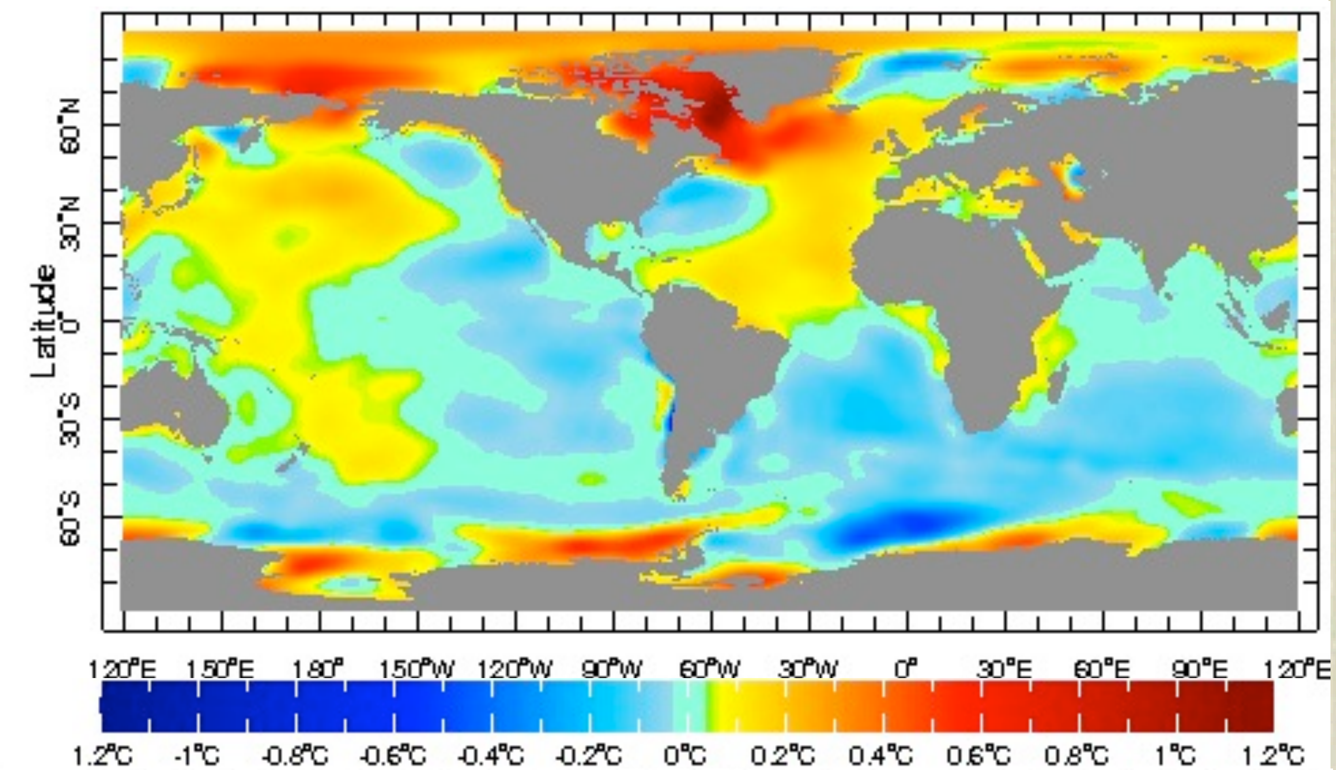
Trend in annual SST 1980-2004 (°C/century) after removing the corresponding globally ave. value showing regions used to calculate the AMOC index (*Latif et al., 2006*)

AMOC and SST Variability - 4

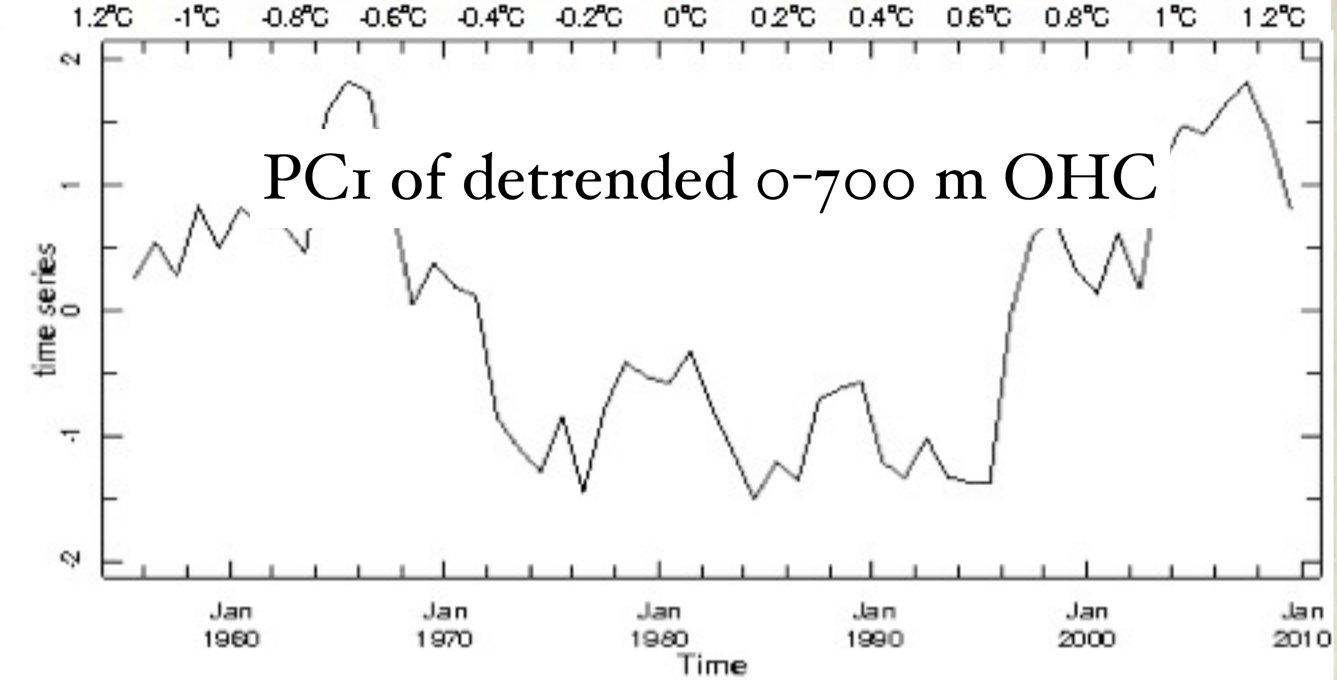


By studying obs and model output, *Zhang (2008)* showed that EOF 1 of 400m ocean temperature provides an *in-phase* proxy for AMOC variability

regression of SST on PC 1

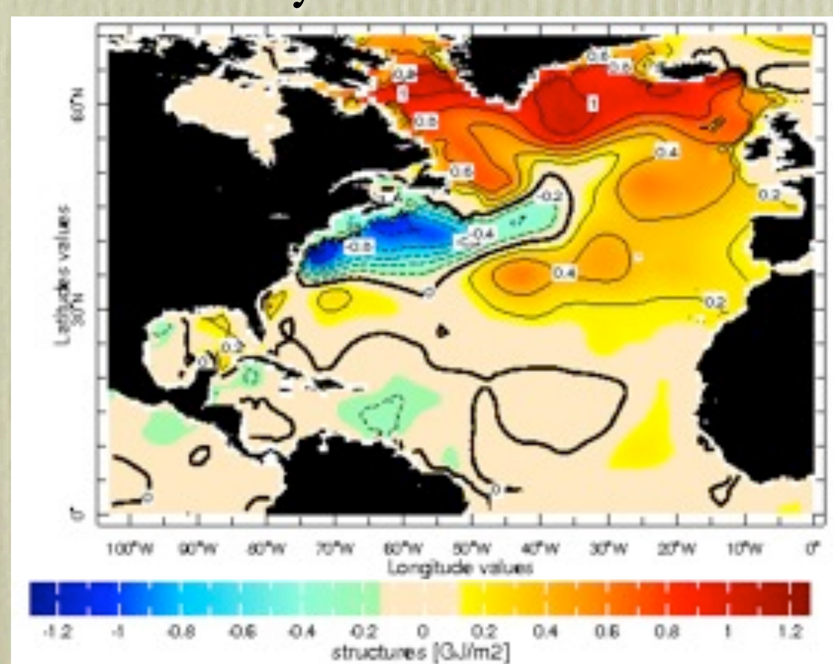


1.



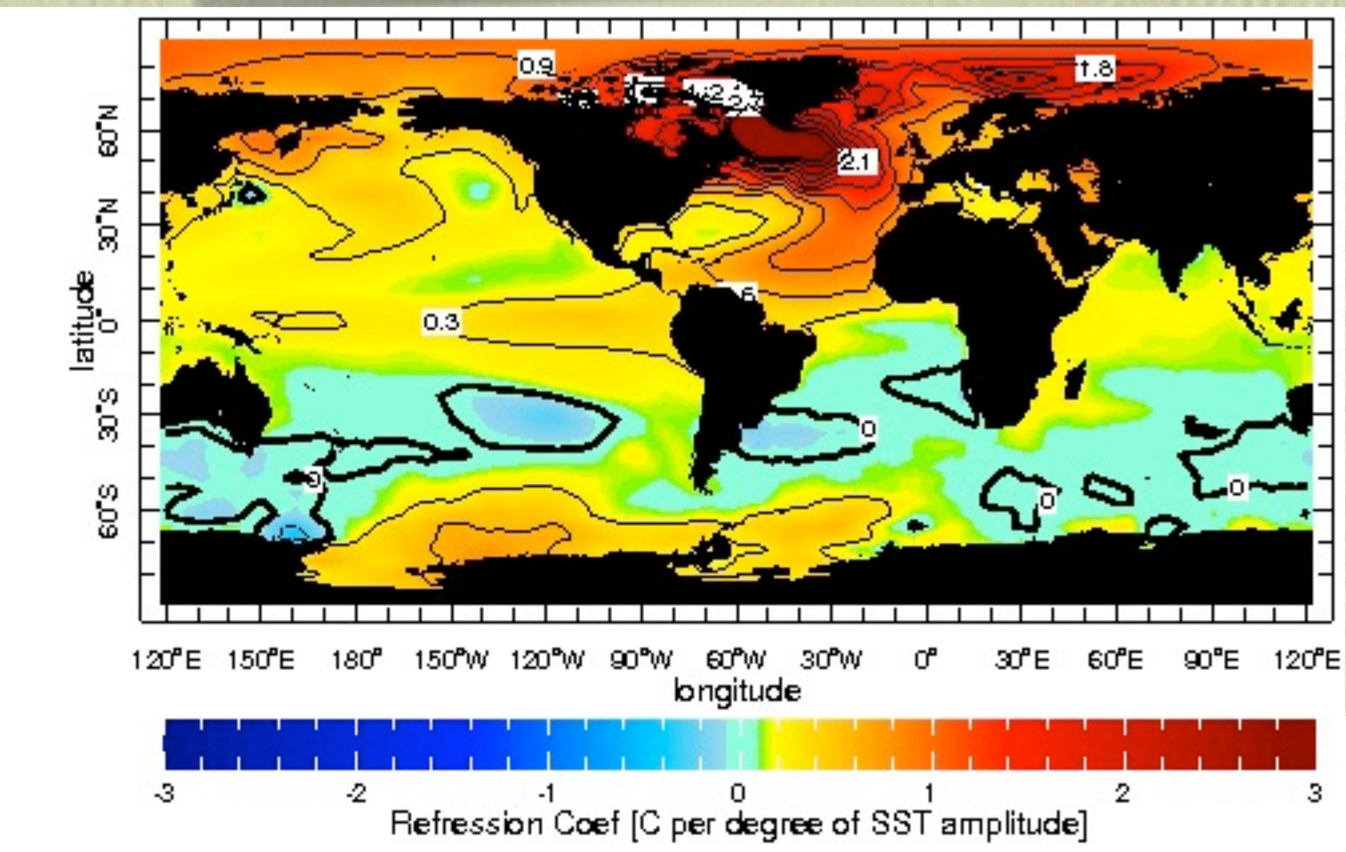
1.

Leading EOF of detrended 0-700 m OHC (GJ/m²)



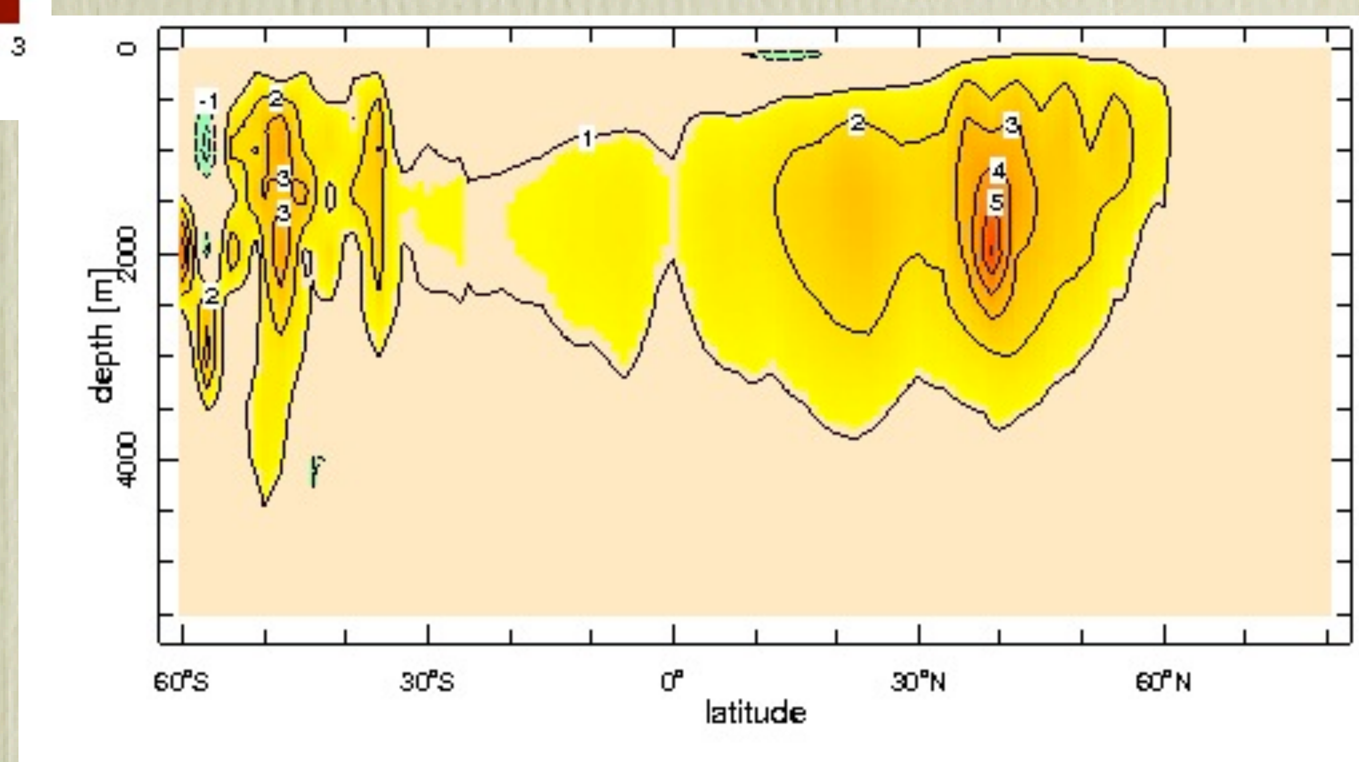
Tuesday, June 8, 2010

AMV in AR4 CGCMs



The regression of annual-mean surface air temperature (in °C/°C) on an AMV index* averaged over the output of 20 AR4 pre-industrial control runs.

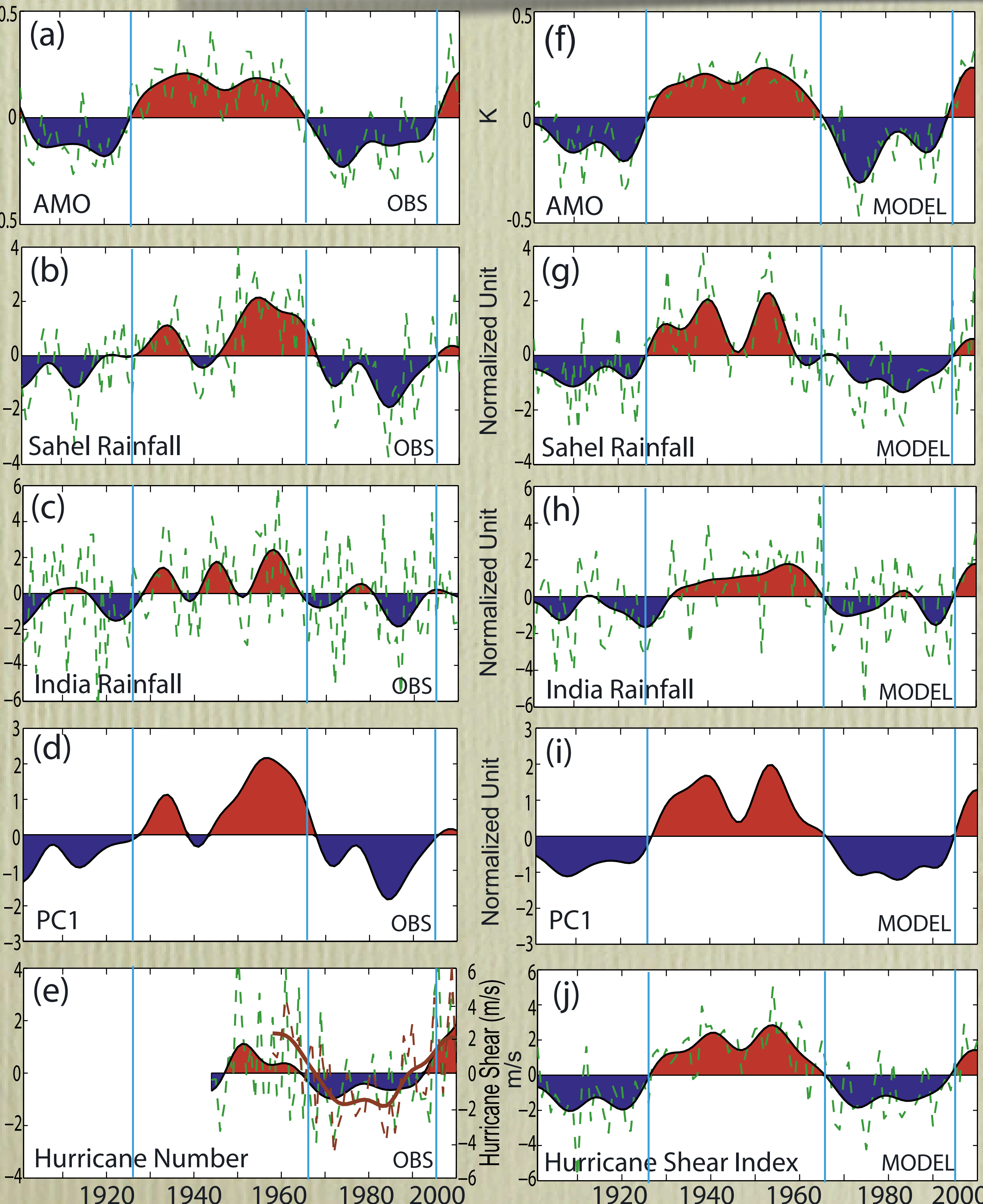
* *Area weighted SST in the No. Atl. 0-60°N and 75-7.5°W*



Same as above but for the models' AMOC streamfunction (in *sv/°C*)

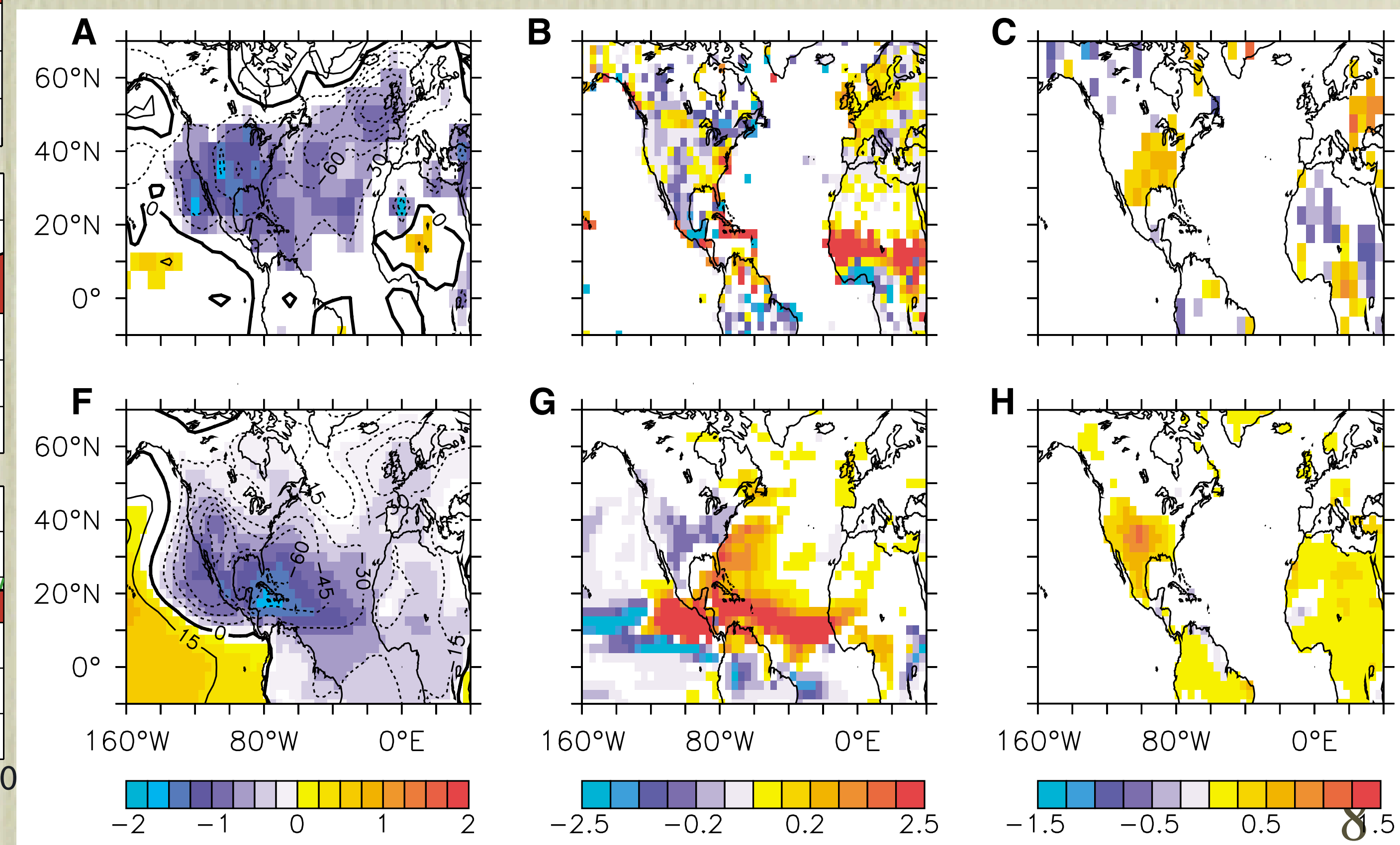
Tuesday, June 8, 2010

Observed AMV impact

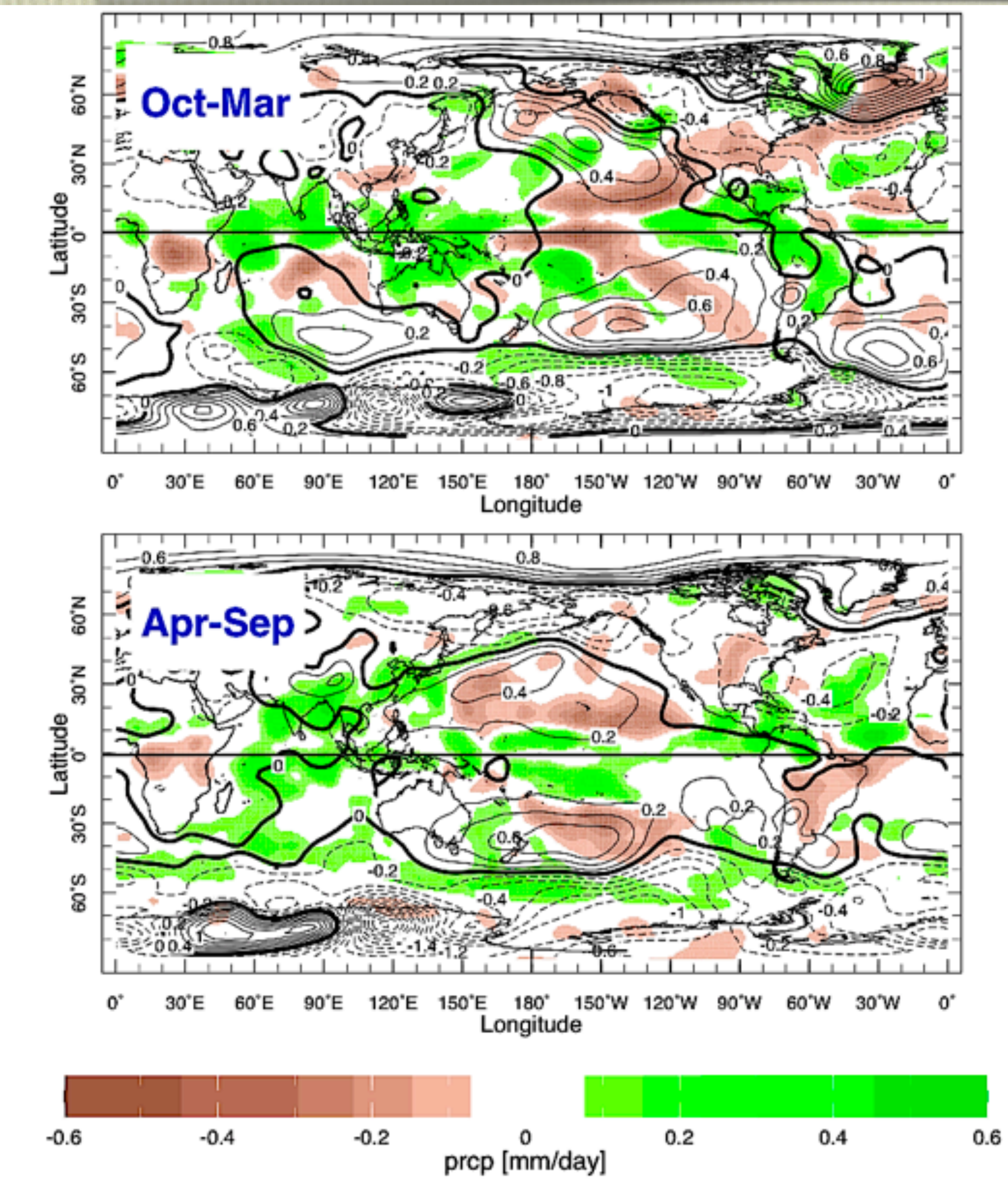


Zhang and Delworth (2006): Time series of Sahel and West+Central India rainfall, and of number of Atlantic hurricanes, exhibit AMV time scales and GCM indicates causality

Sutton and Hodson (2005): **A-C**, Sea level pressure, precipitation and surface air temperature associated with AMV cooling in the 1960's (1931-60 *minus* 1961-90). **F-H**, same for a GCM simulation.



Association with TNA SST variability

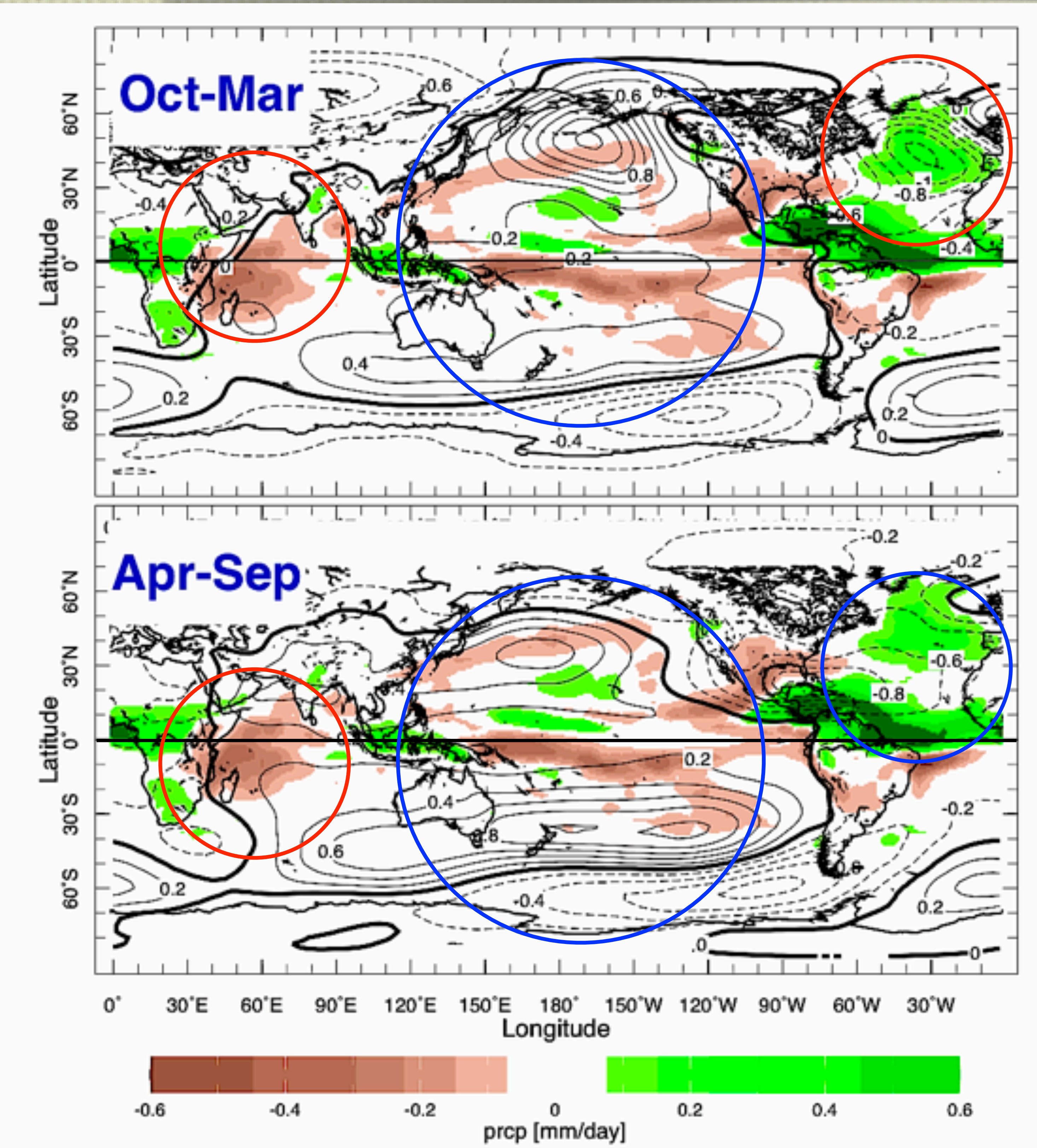


The impact of AMV is caused mainly by related changes in the north tropical Atlantic (NTA) SST.

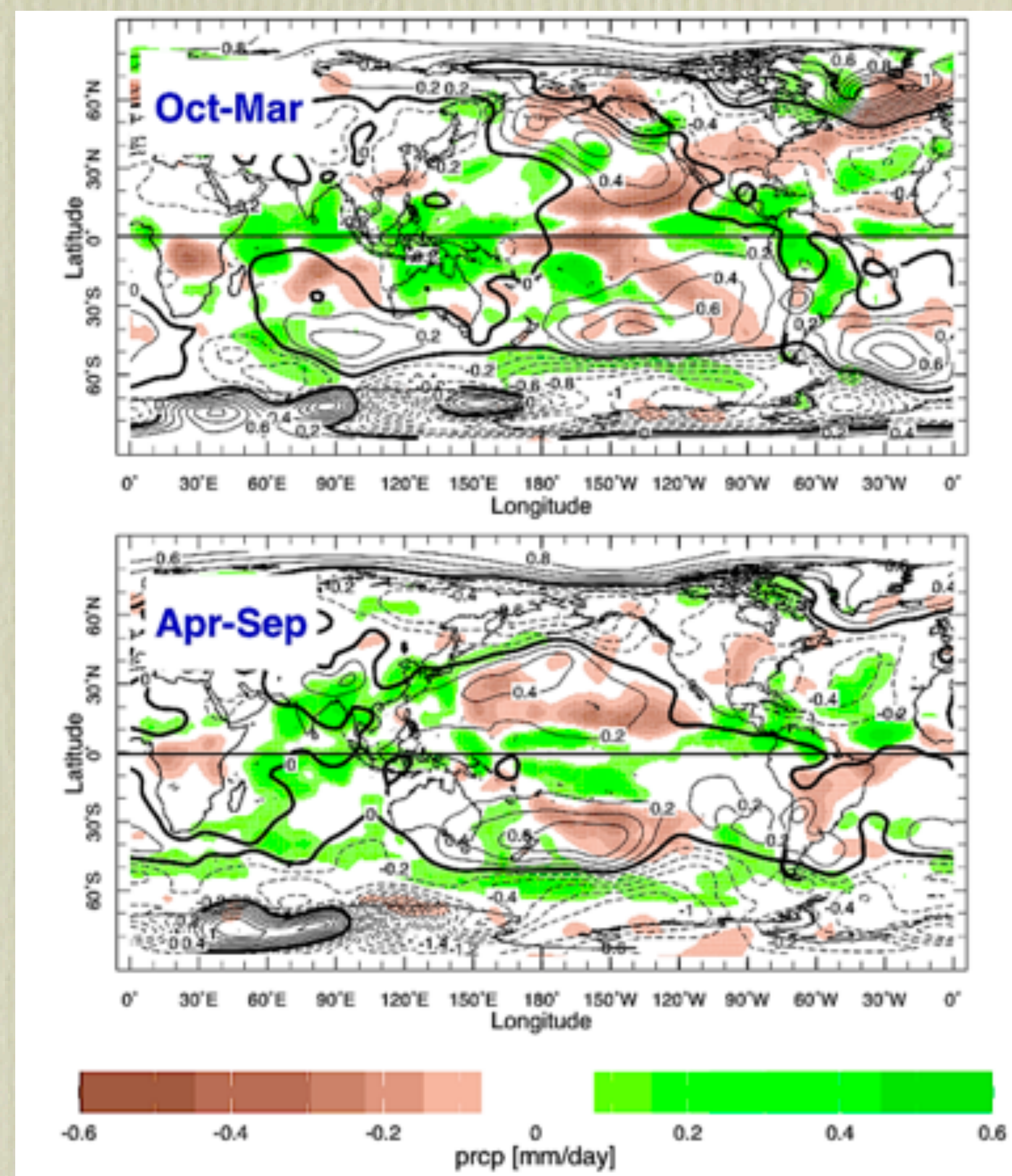
Kushnir et al. (2010): Observed* Sea level pressure (SLP, contours, mb) and precipitation (colors) associated with TNA SST variability 1979-2007. The effect of tropical Pacific SST (ENSO) was "removed" using simultaneous multiple regression analysis.

** SLP is from the NCEP-NCAR Reanalysis and precipitation from GPCP (smoothed in space with two passes of a binomial 1-2-1 filter).*

Model Response to AMV SST



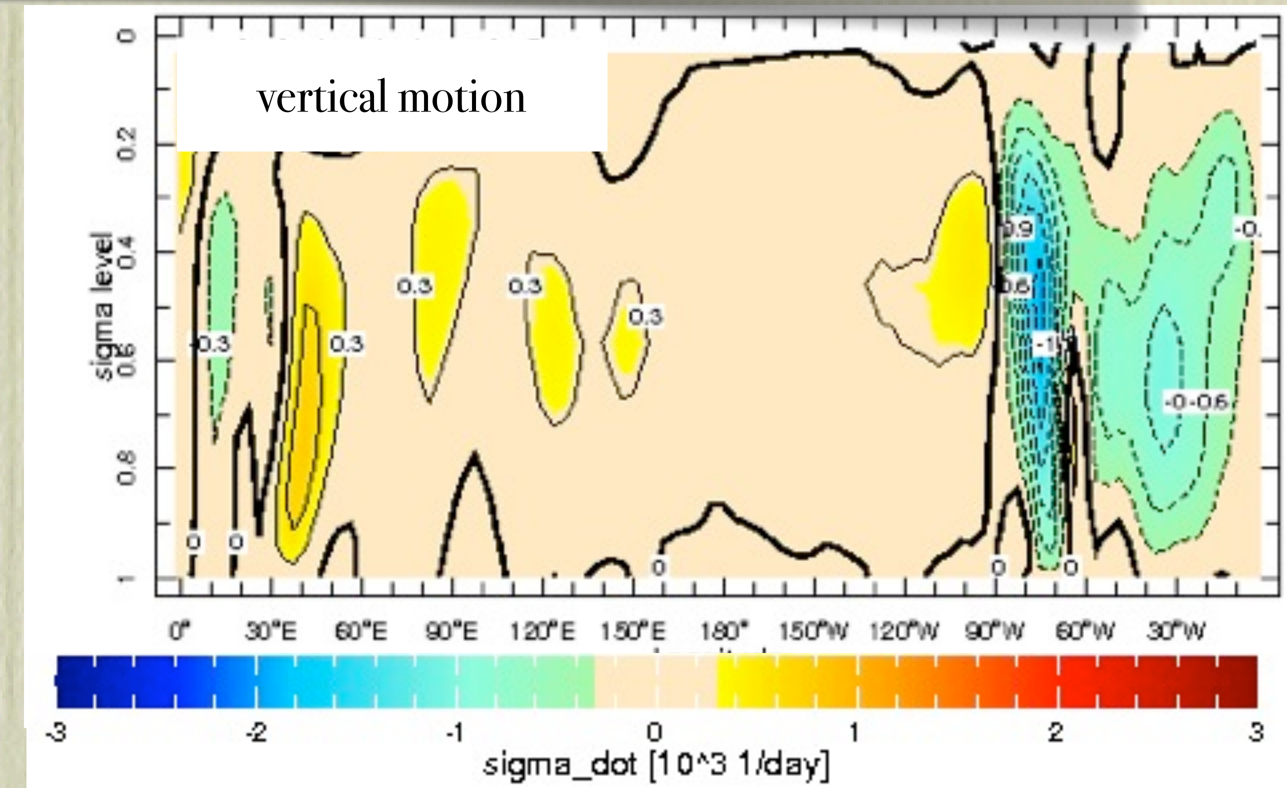
Kushnir et. al. (2010): *(left)* CLIVAR Drought Working Group (DWG), multi-model SLP and PPT response to **warm-cold** AMV SSTA. (*below*) Figure from the previous slide

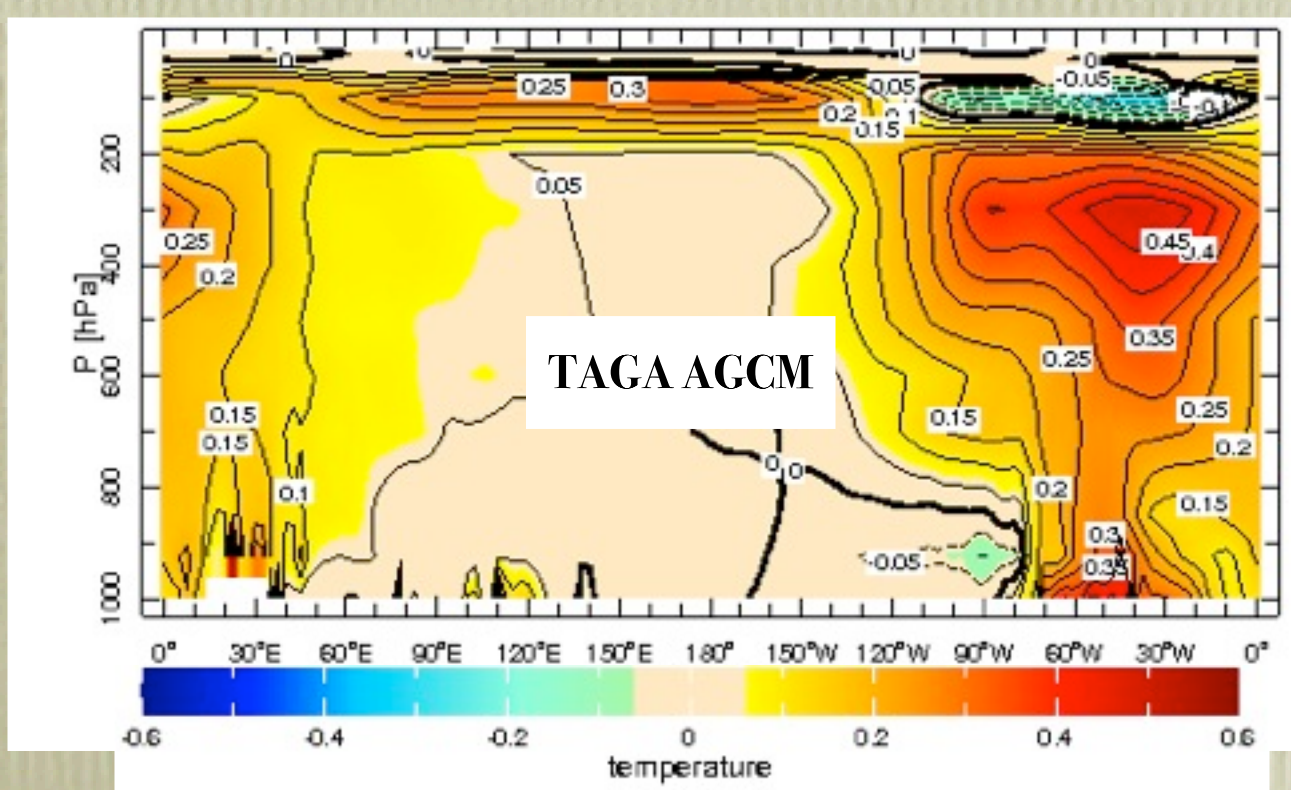


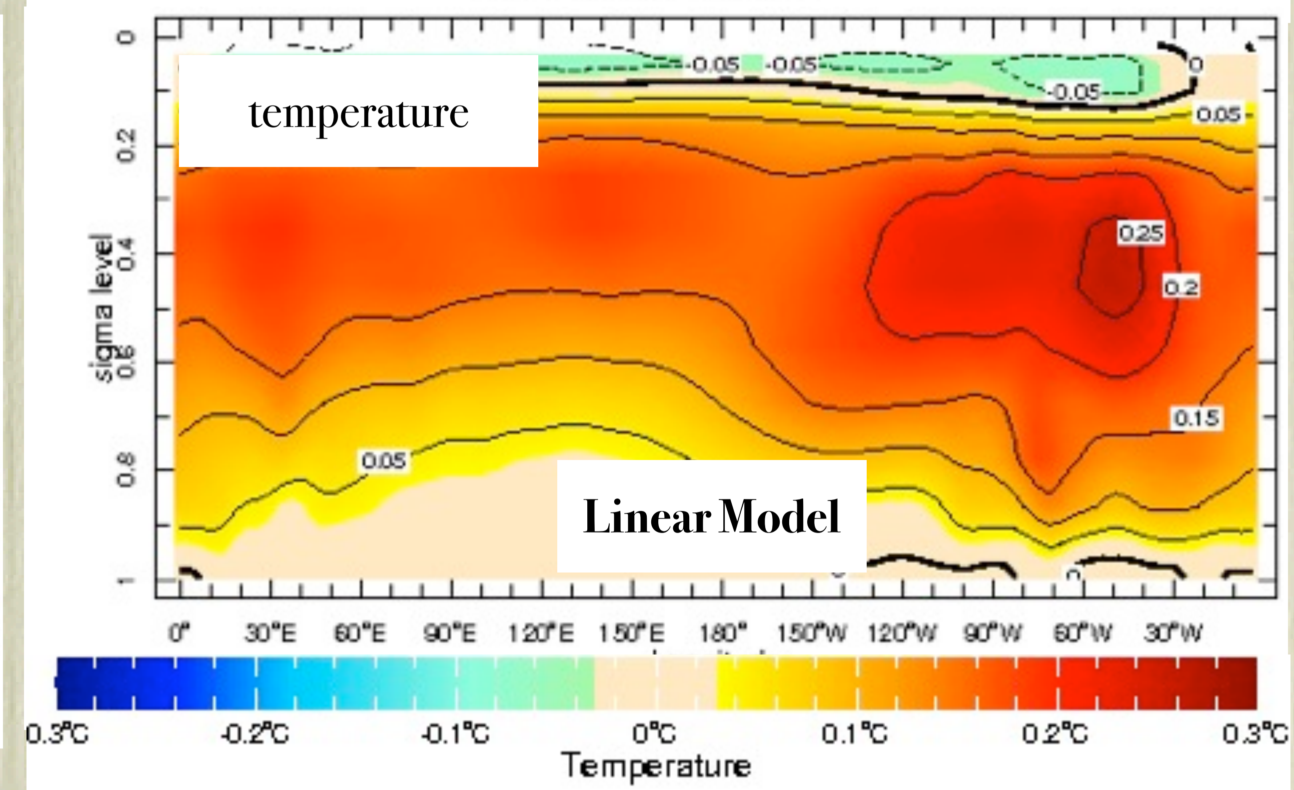
Mechanisms of Atmospheirc Response

Kushnir et. al. (2010): In an AGCM (below), when AMV is in a warm phase, increased convective heating over the tropical Atlantic stabilizes the entire tropical Atmosphere leading to suppressed convections elsewhere. A linear model simulation with tropical Atlantic heating only (on right) supports this response.

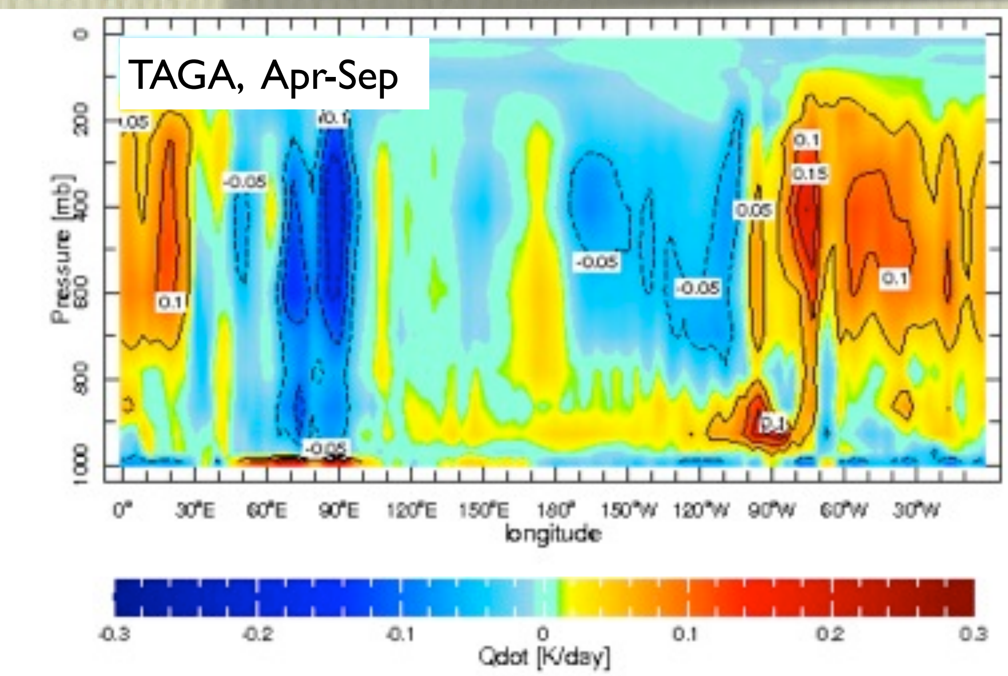
However, this is not what we find in the summertime in a coupled model (why?)





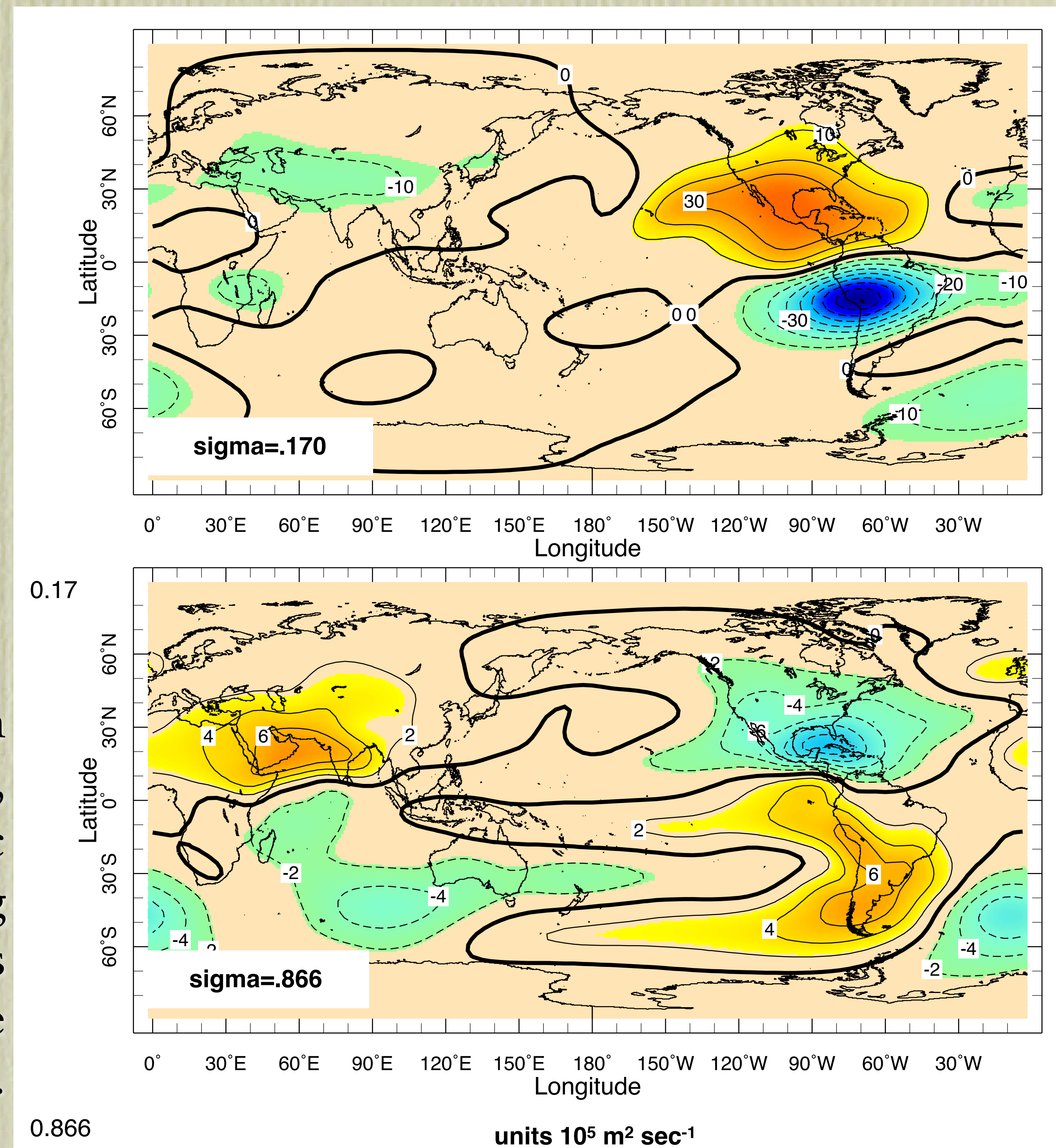


Mechanism of Atmos. Response - 2

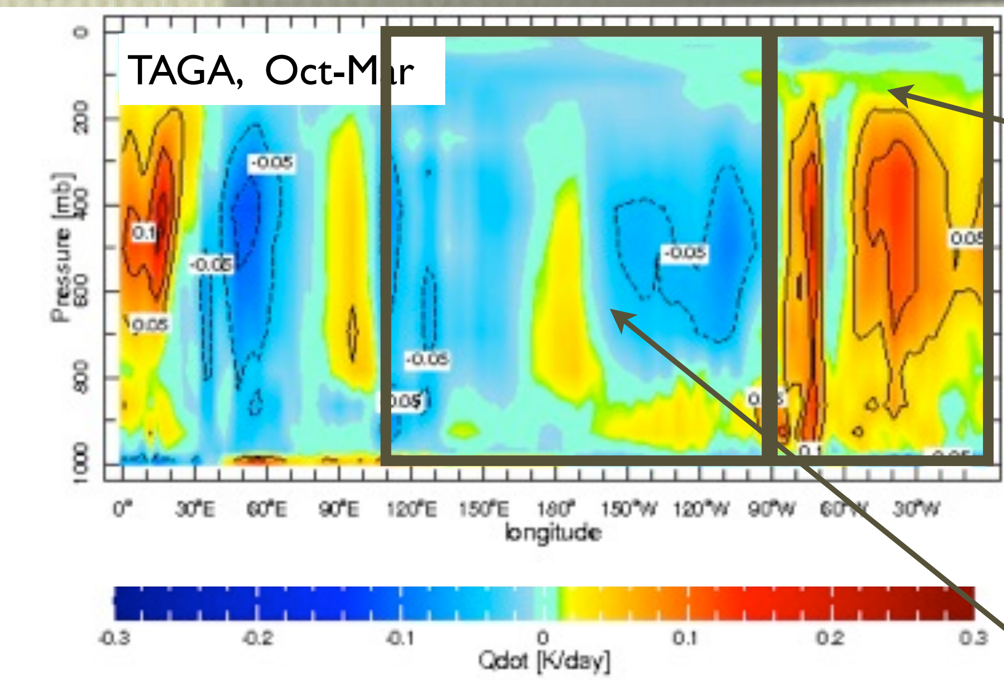


Kushnir et al. (2010): A linear GCM is forced with the tropical heating field from a "TAGA" AGCM run

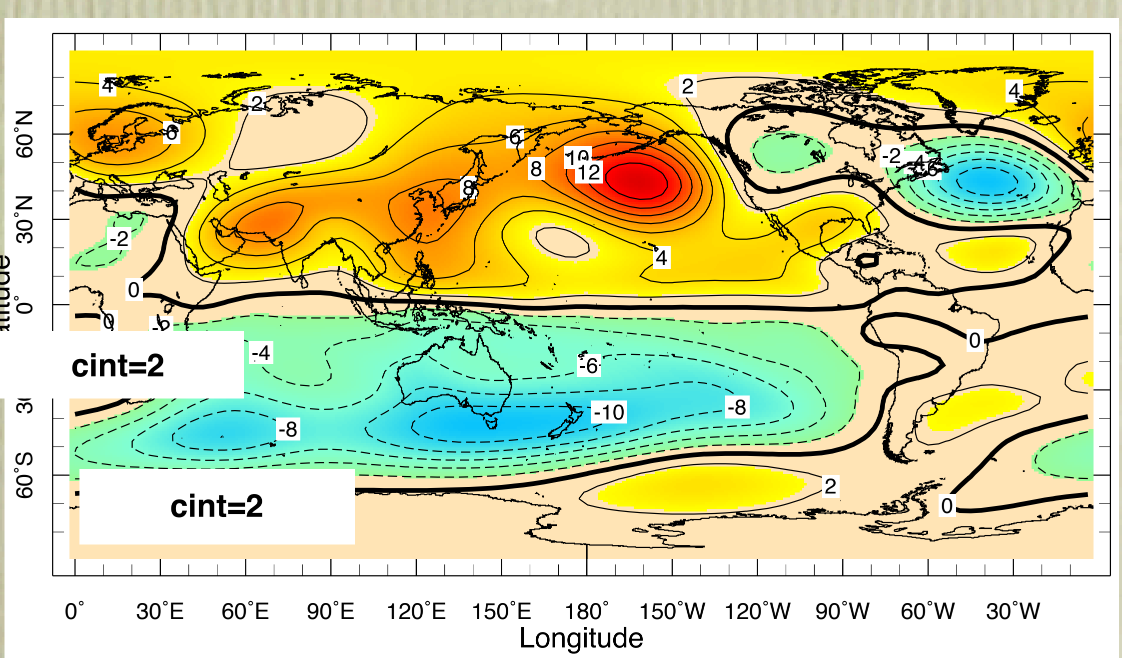
Summer streamfunction shows a "Gill response", with low tropospheric cyclone pair straddling the region of anomalous convective heating in the western No. trop. Atl.

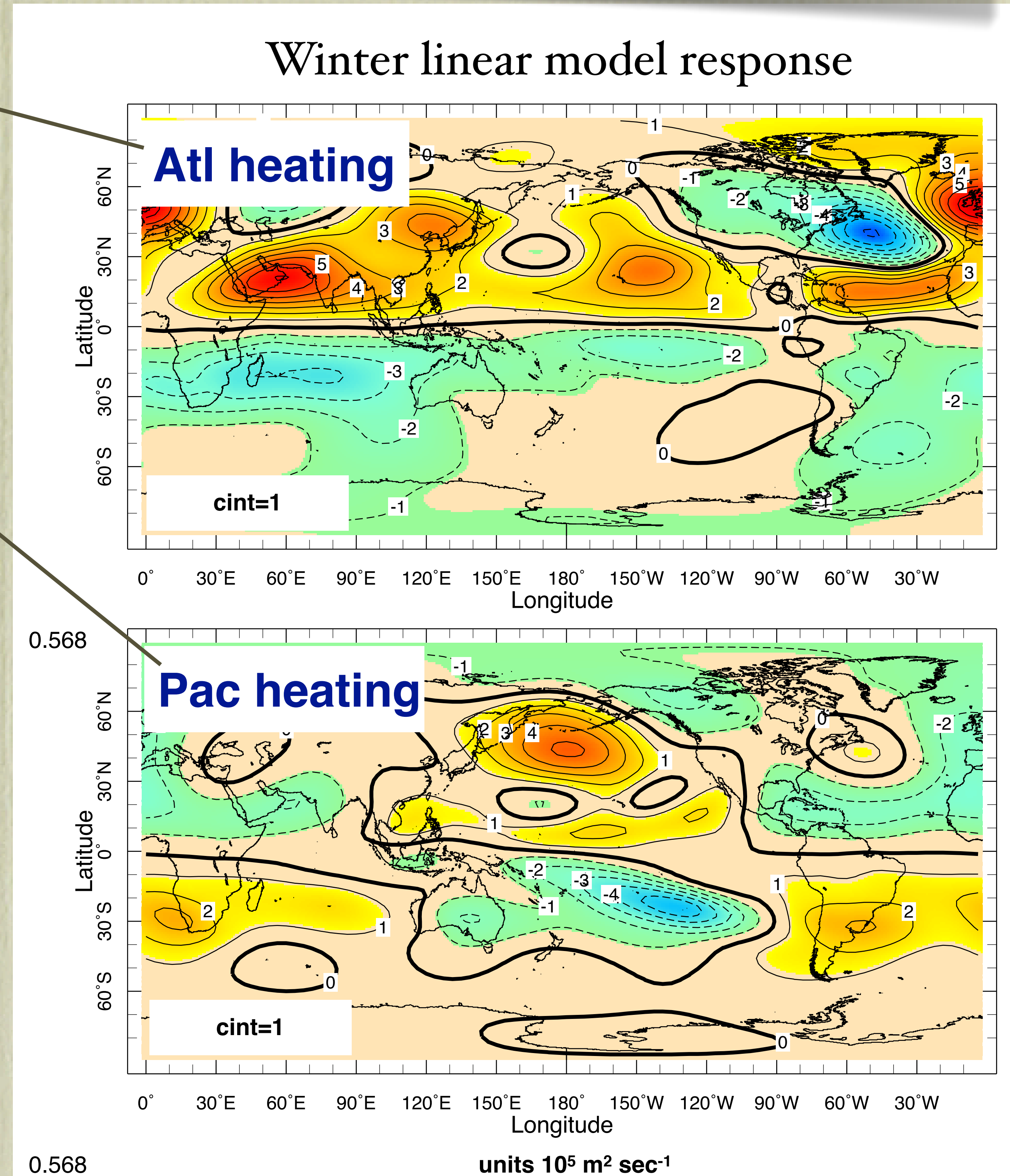


Mechanism of Atmos. Response - 3



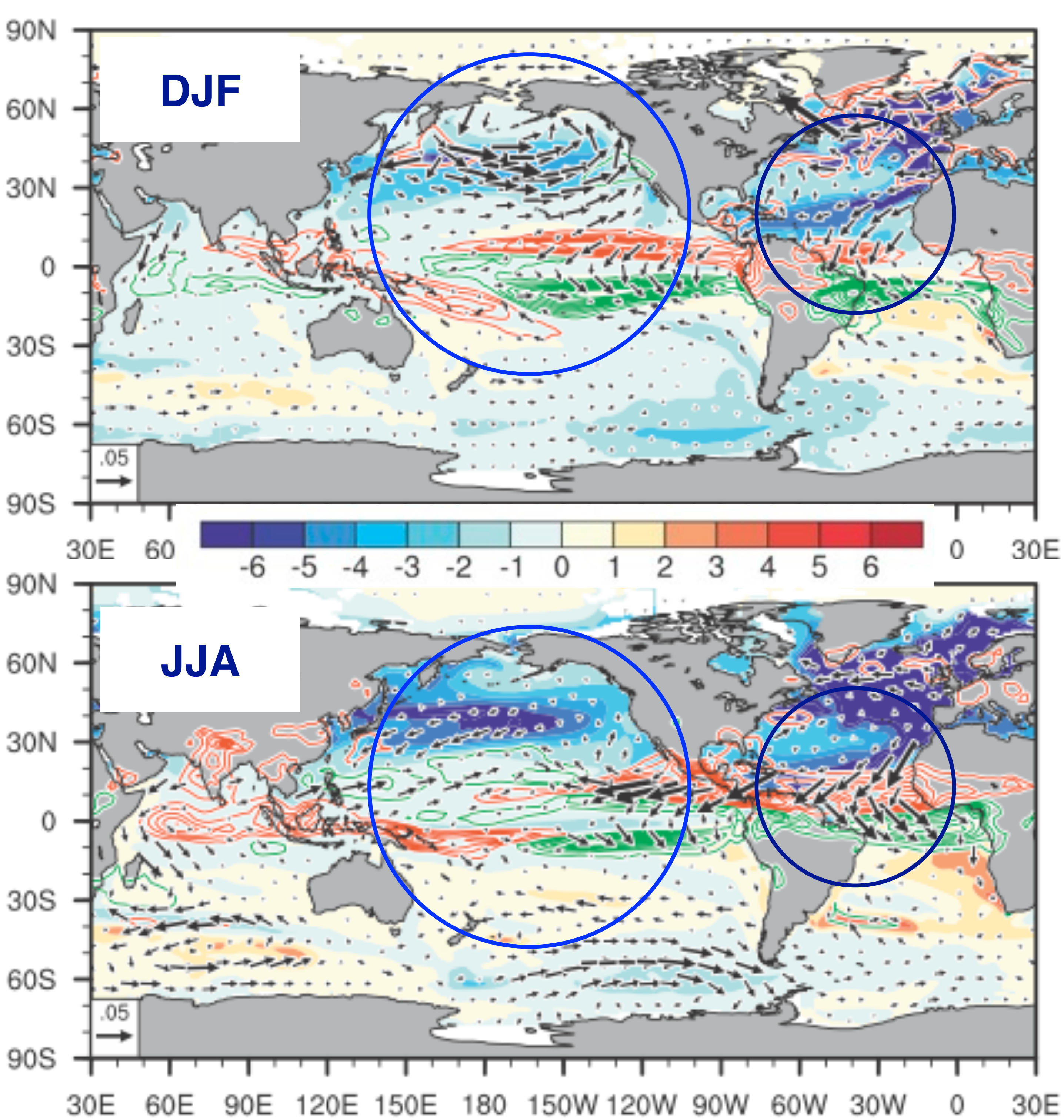
Kushnir et al. (2010): "TAGA" AGCM winter heating (top) and mid-trop streamfunction response (bottom) .



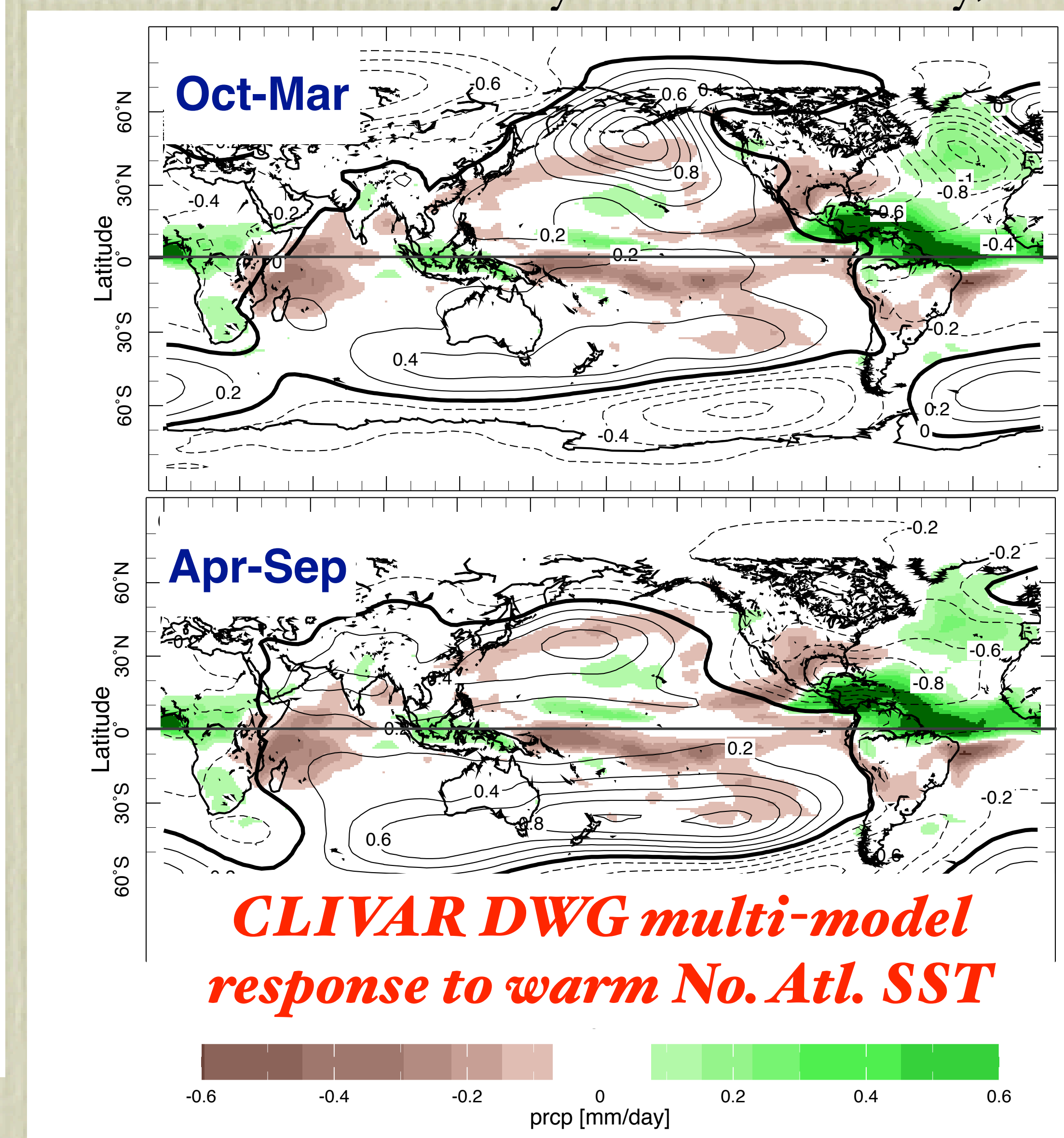


AMOC Collapse

Okumura et. al. (2009): Typical CGCM (here GFDL CM2.1) response to a 1-Sv AMOC water-hosing experiment: SST (color), surface wind stress (vectors, N/m²), and precipitation (green contours > 1.0 mm/day and orange contours < -1.0 mm/day intv. 1.0 mm/day).



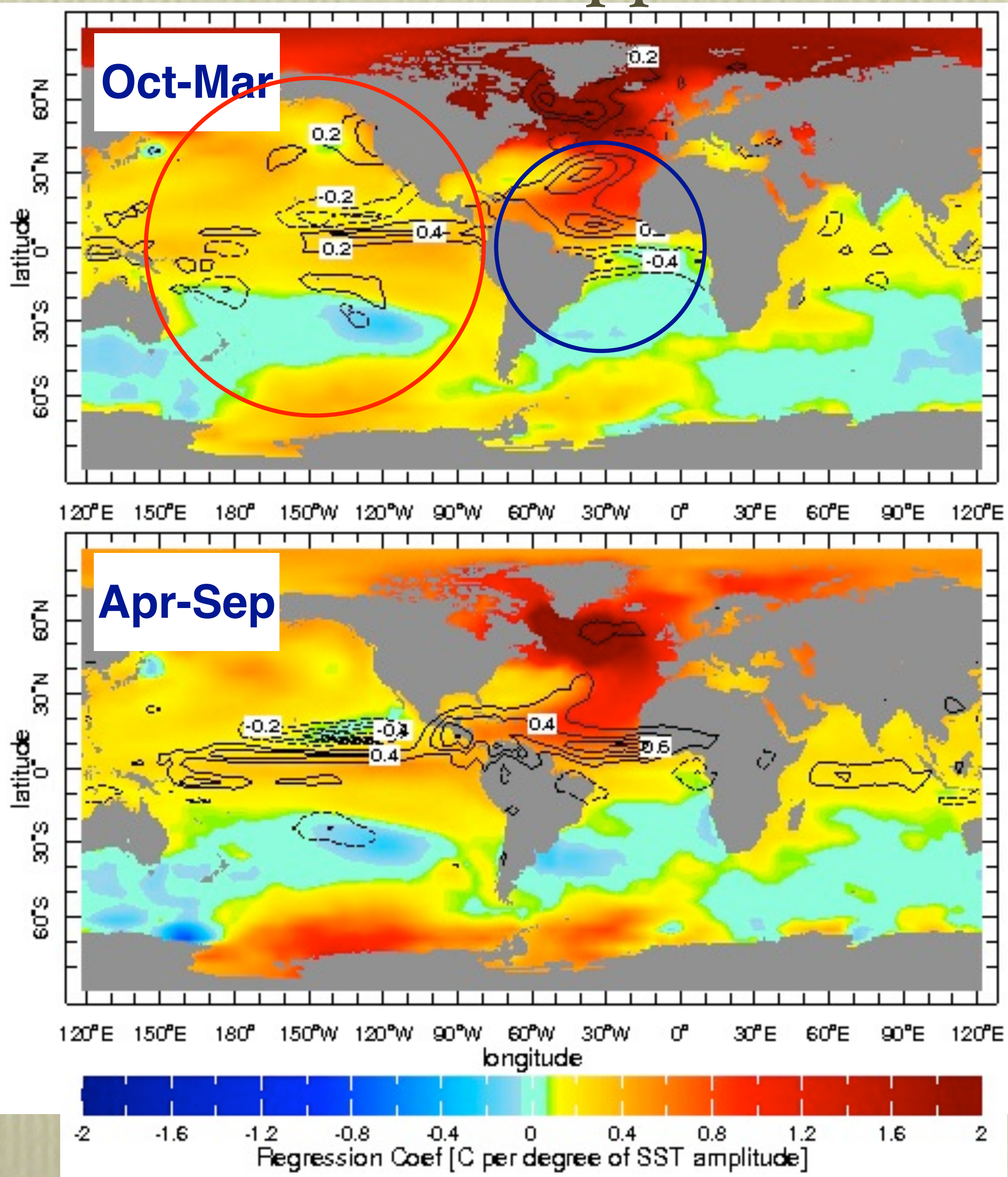
Response to COLD No. Atl. SST



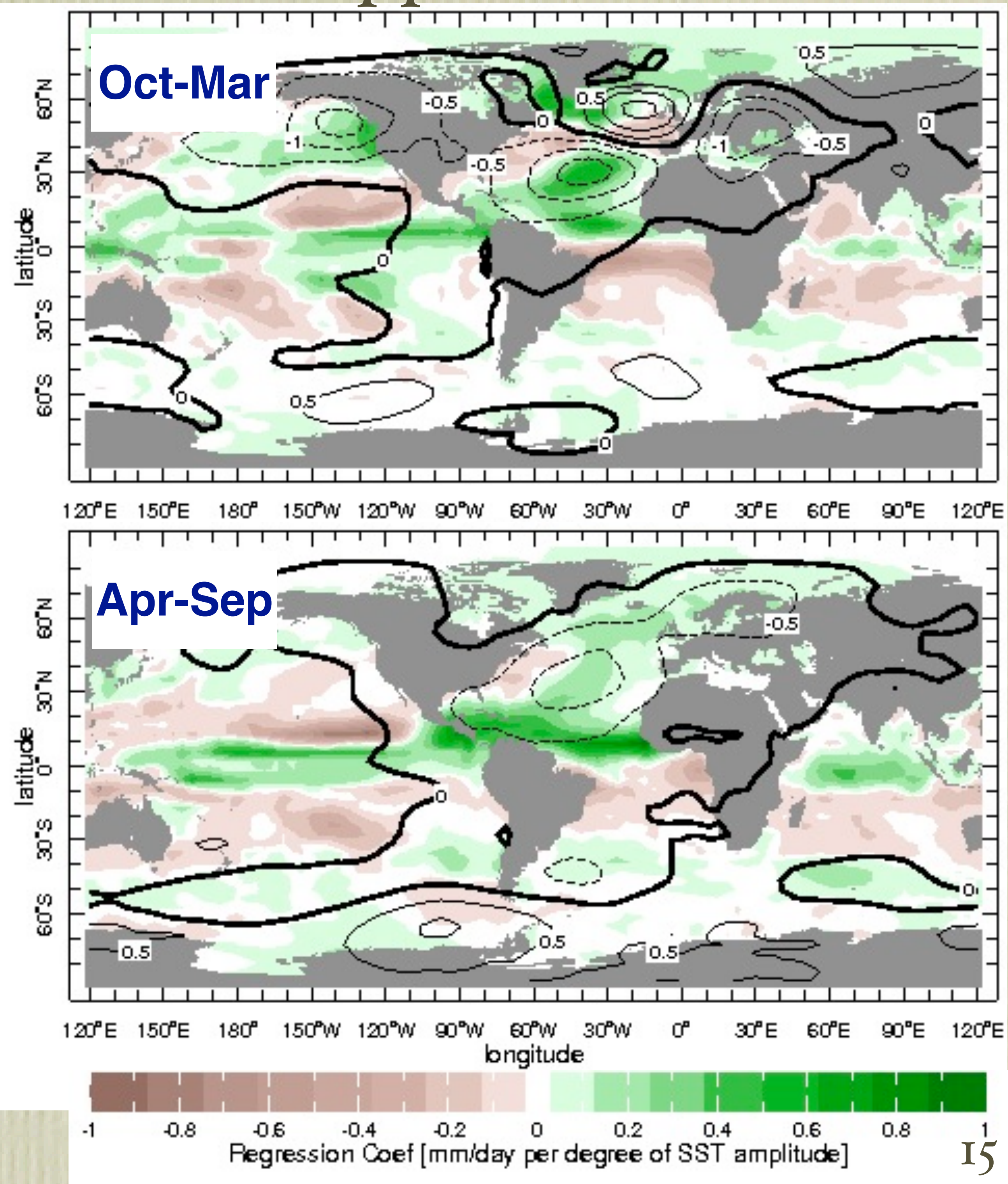
CLIVAR DWG multi-model response to warm No. Atl. SST

AMV impact in AR4 CGCMs

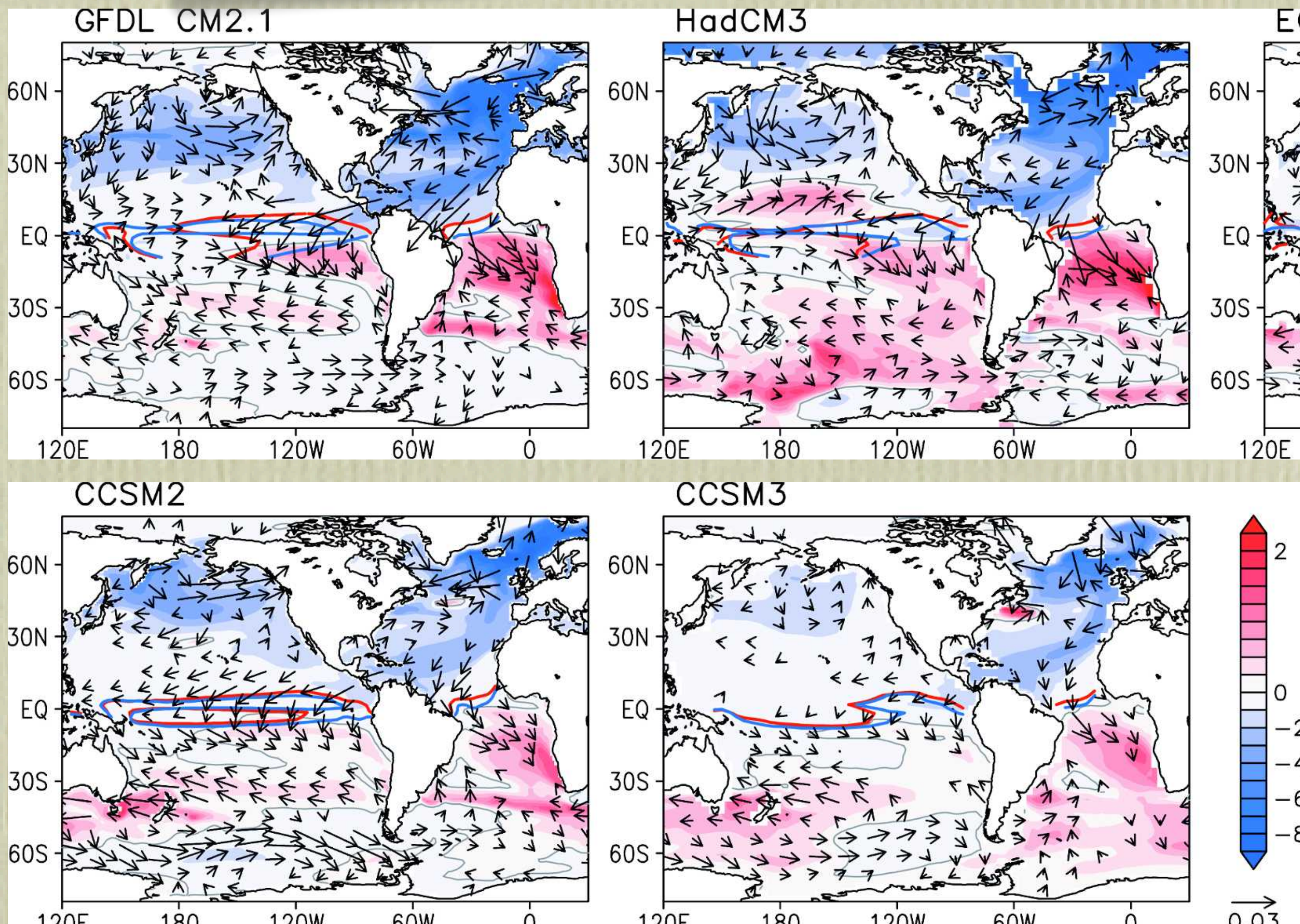
SST & ppt



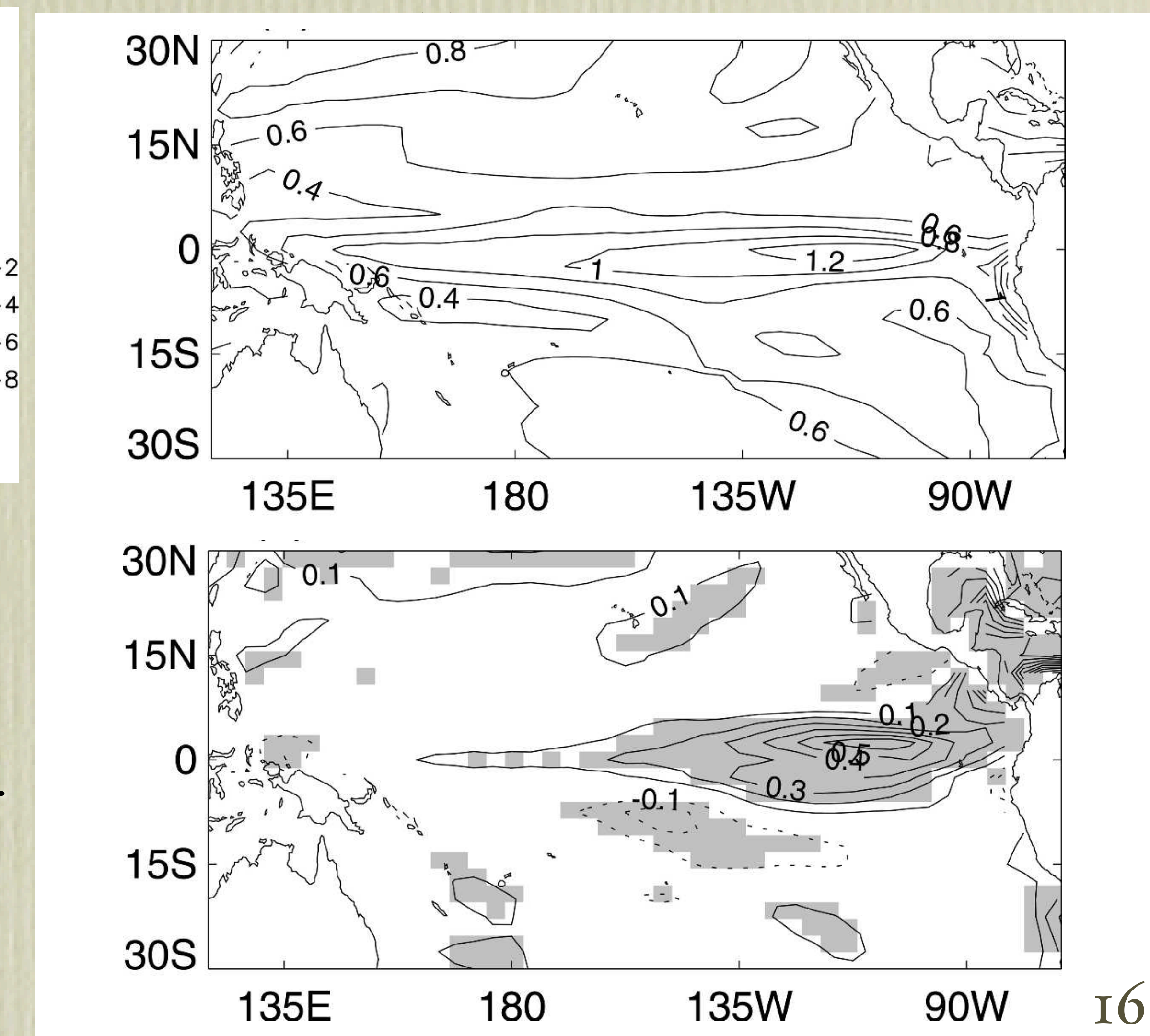
ppt & SLP



AMOC Collapse and ENSO

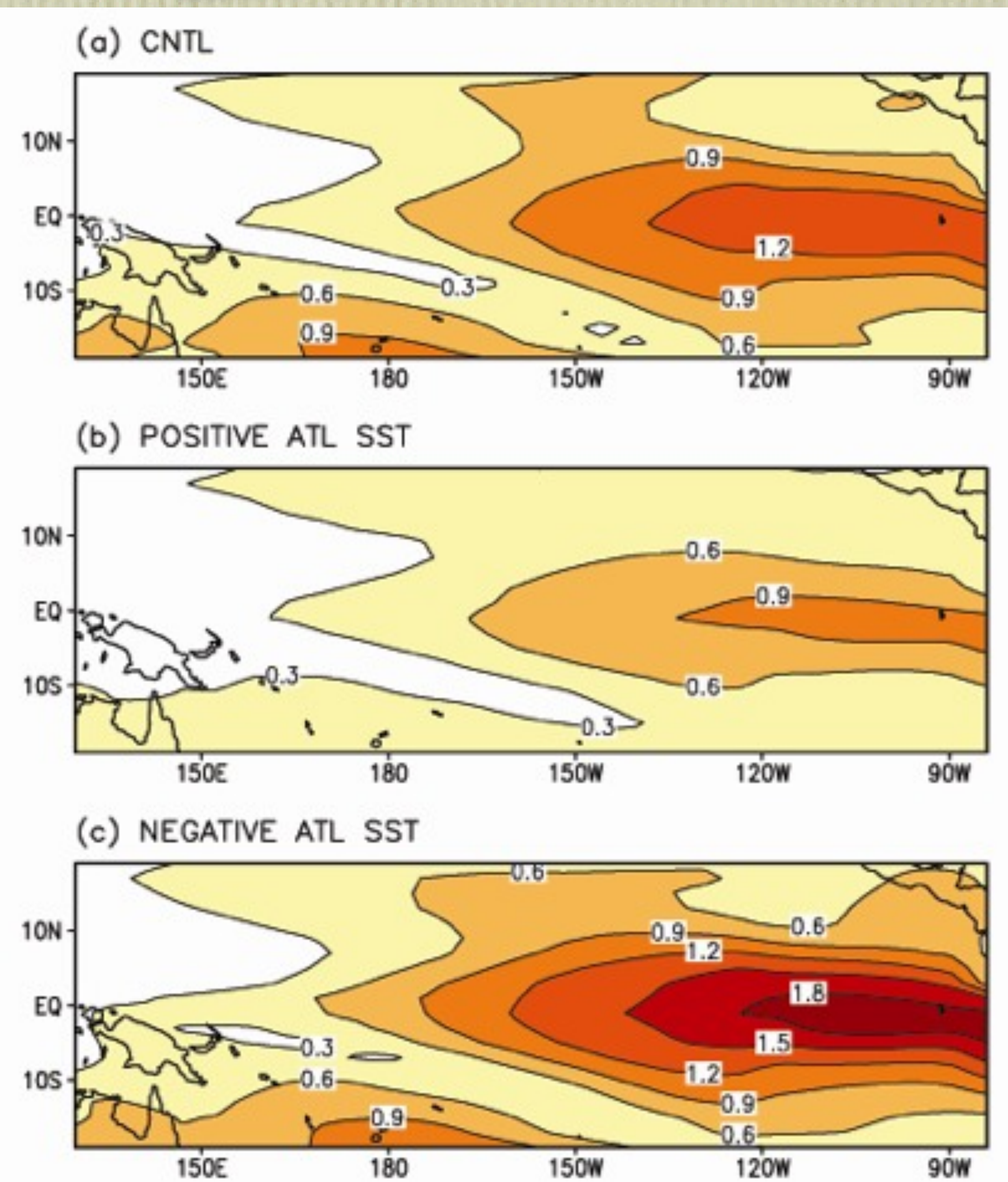


Timmermann et al. (2007): Changes in surface windstress and in PPT in response to an AMOC "collapse". ITCZ shifts south and the annual cycle of SST weakens.

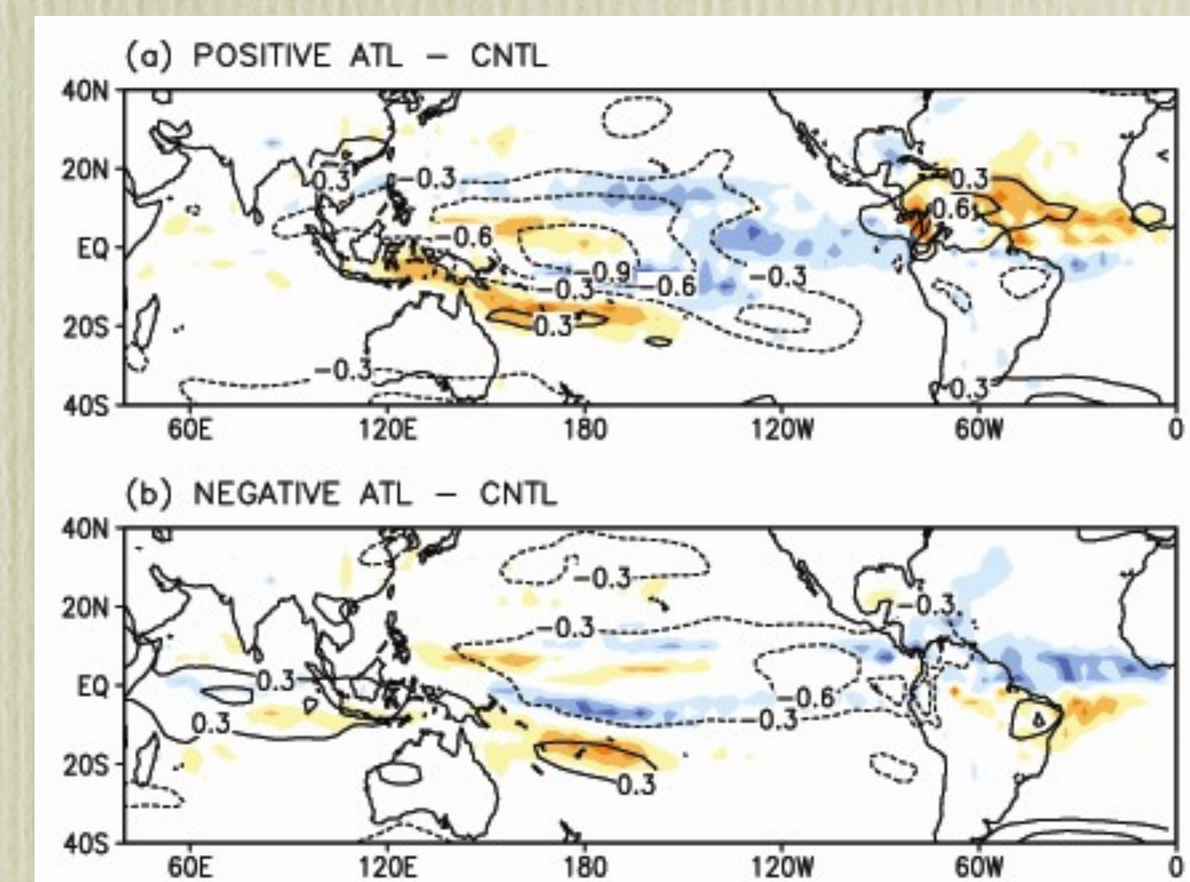


Dong and Sutton (2007): Std. dev. of monthly trop Pac SST in HadCM3 and the change after a substantial weakening of AMOC.

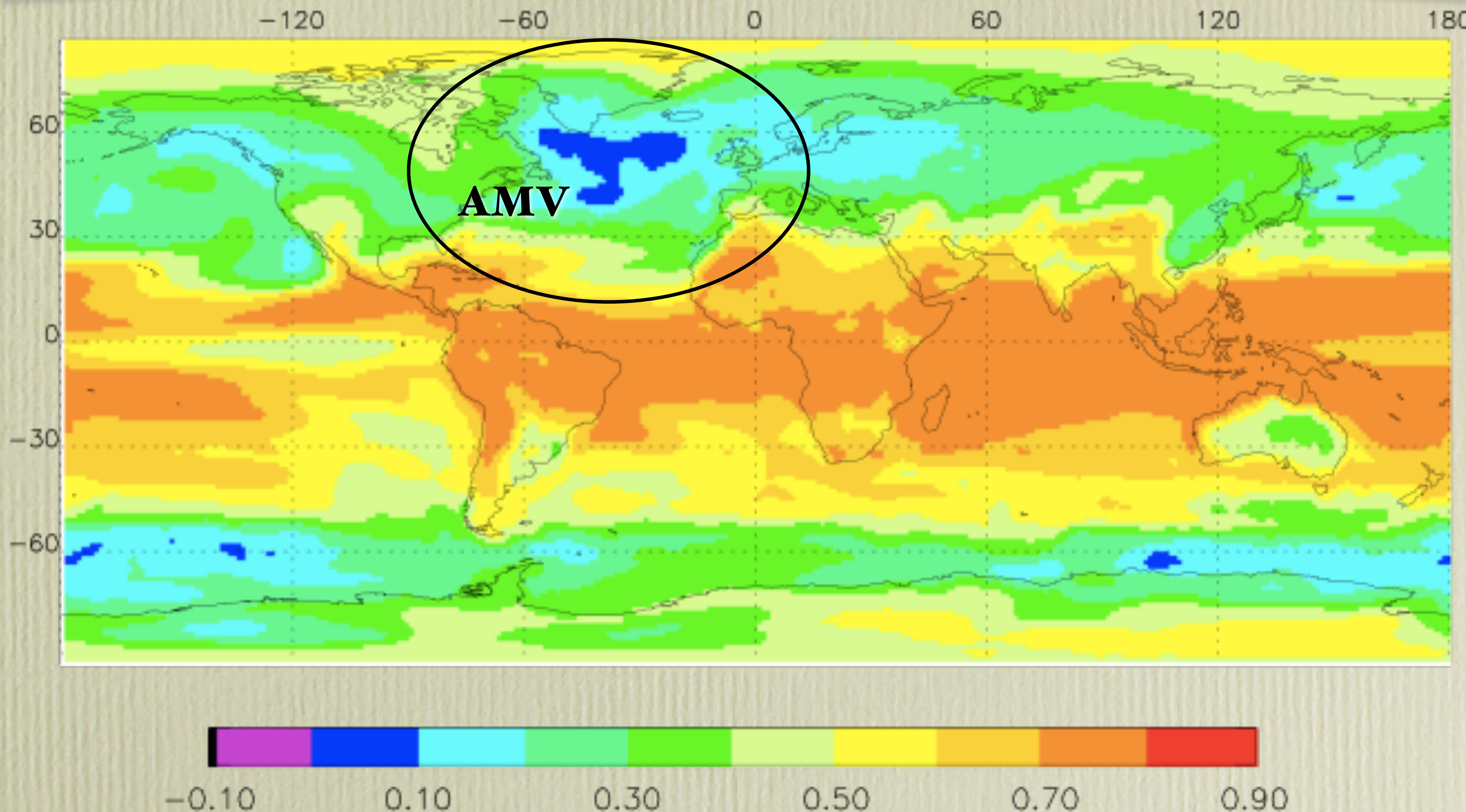
AMV and ENSO



Preliminary results from an integration of the SPEEDY AGCM coupled to the Zebiak-Cane ENSO model and forced with a positive and negative 0.5 K SST anomaly in the tropical Atlantic

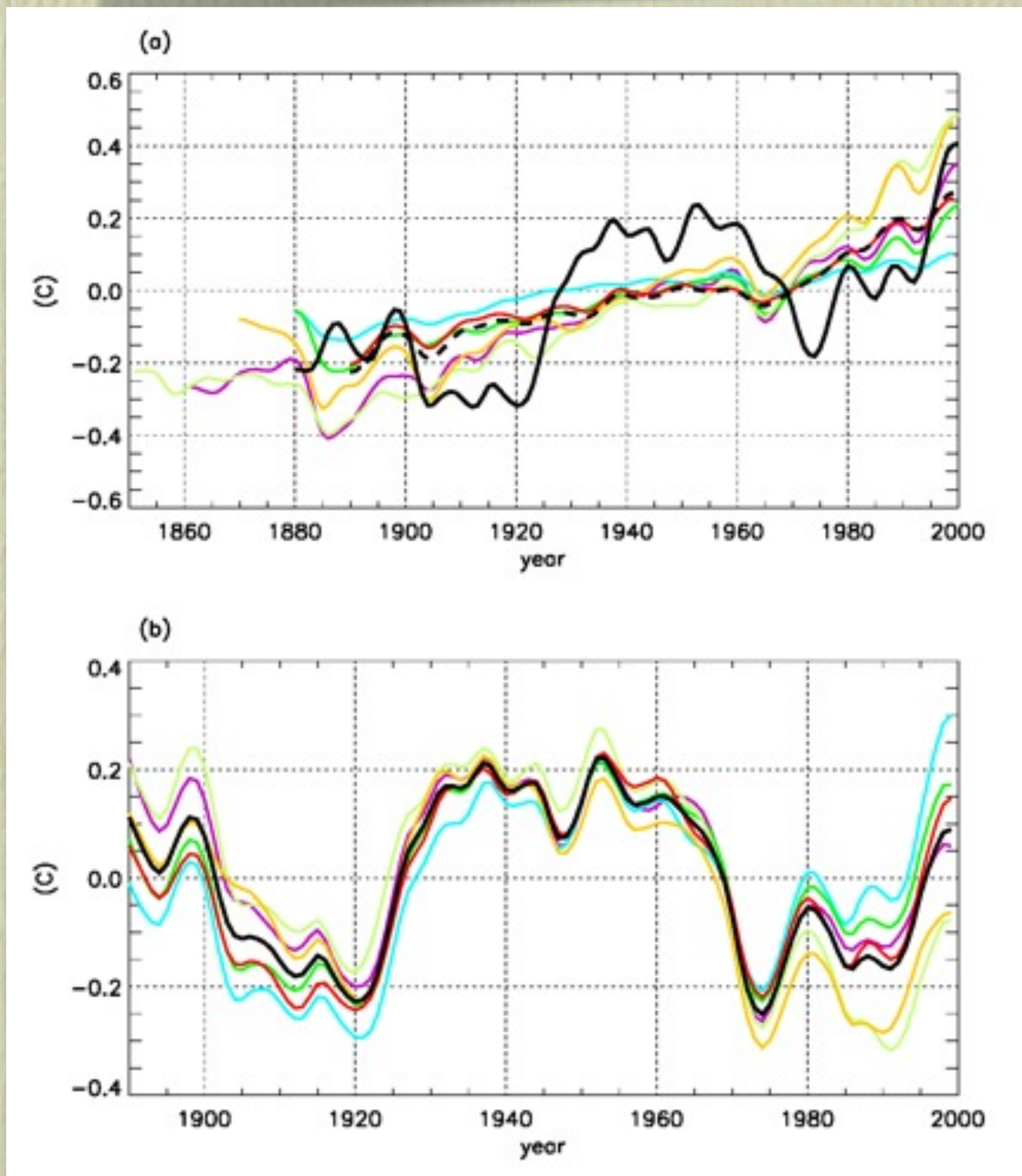


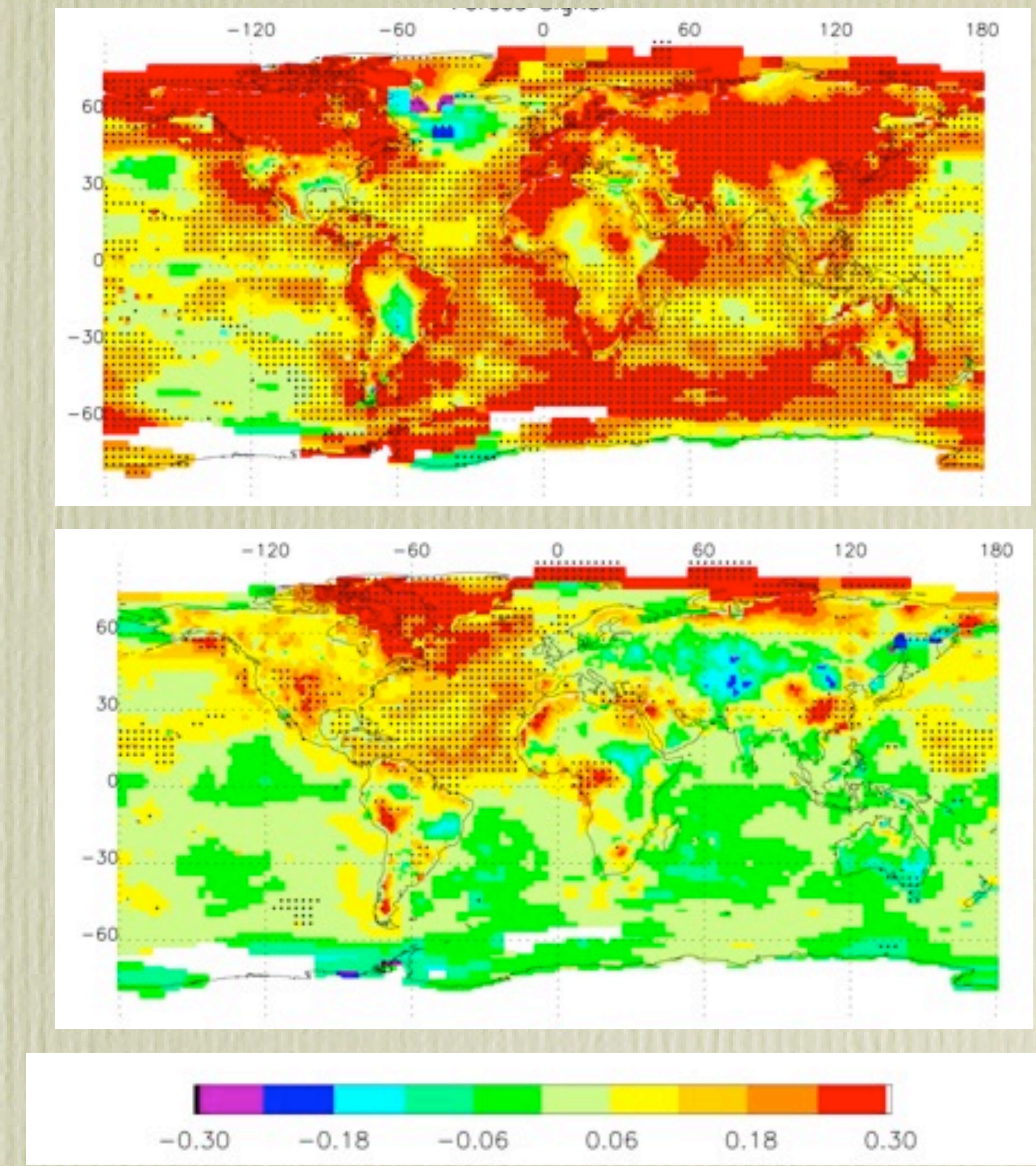
Forced & Natural Variability



Ting et al. (2009): Ratio of externally-forced to total variance of decadal surface temperature variability in CMIP3 models. Results are based on 6 model ensemble with ≥ 4 realizations each.

AMV in the 20th Century

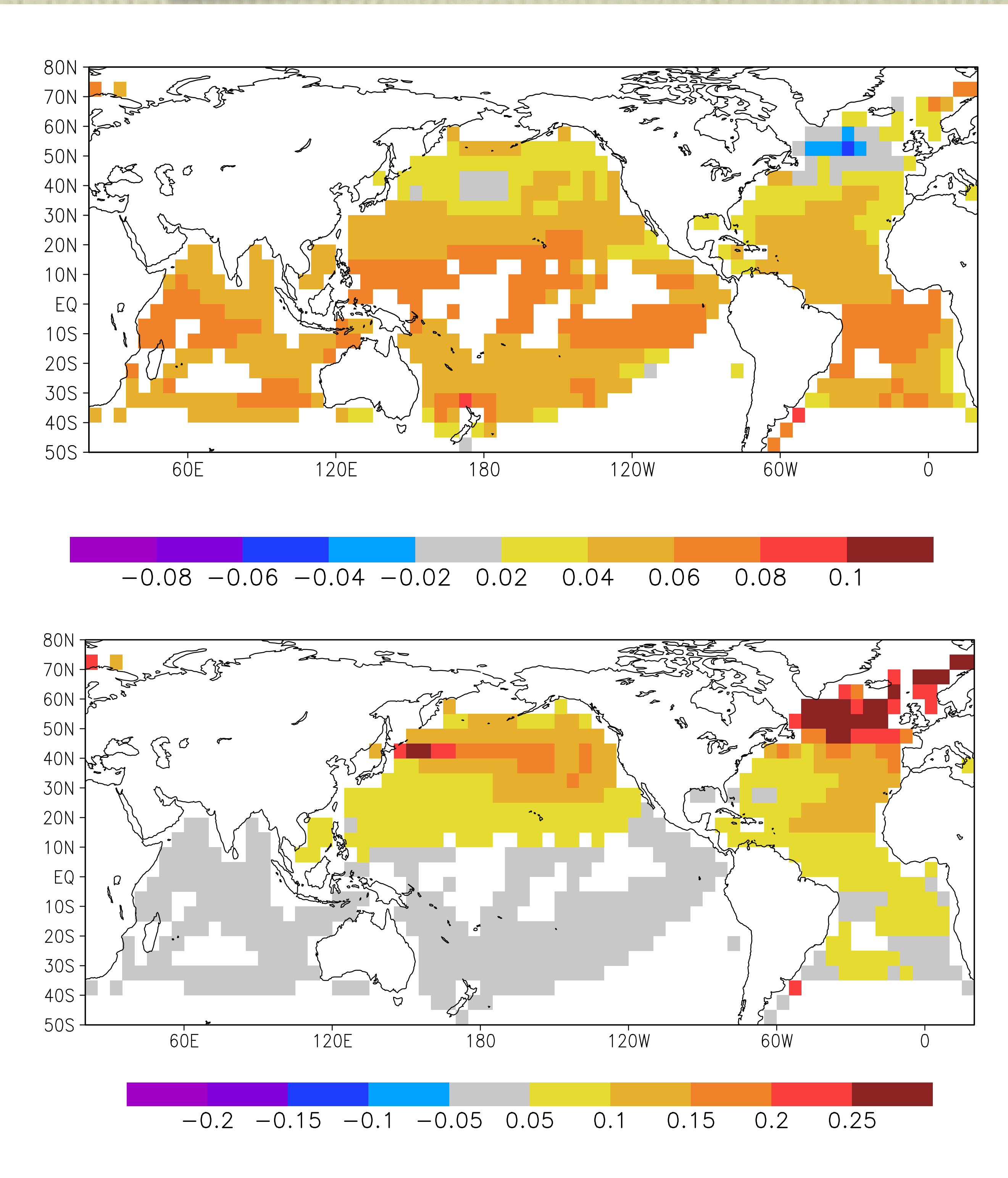


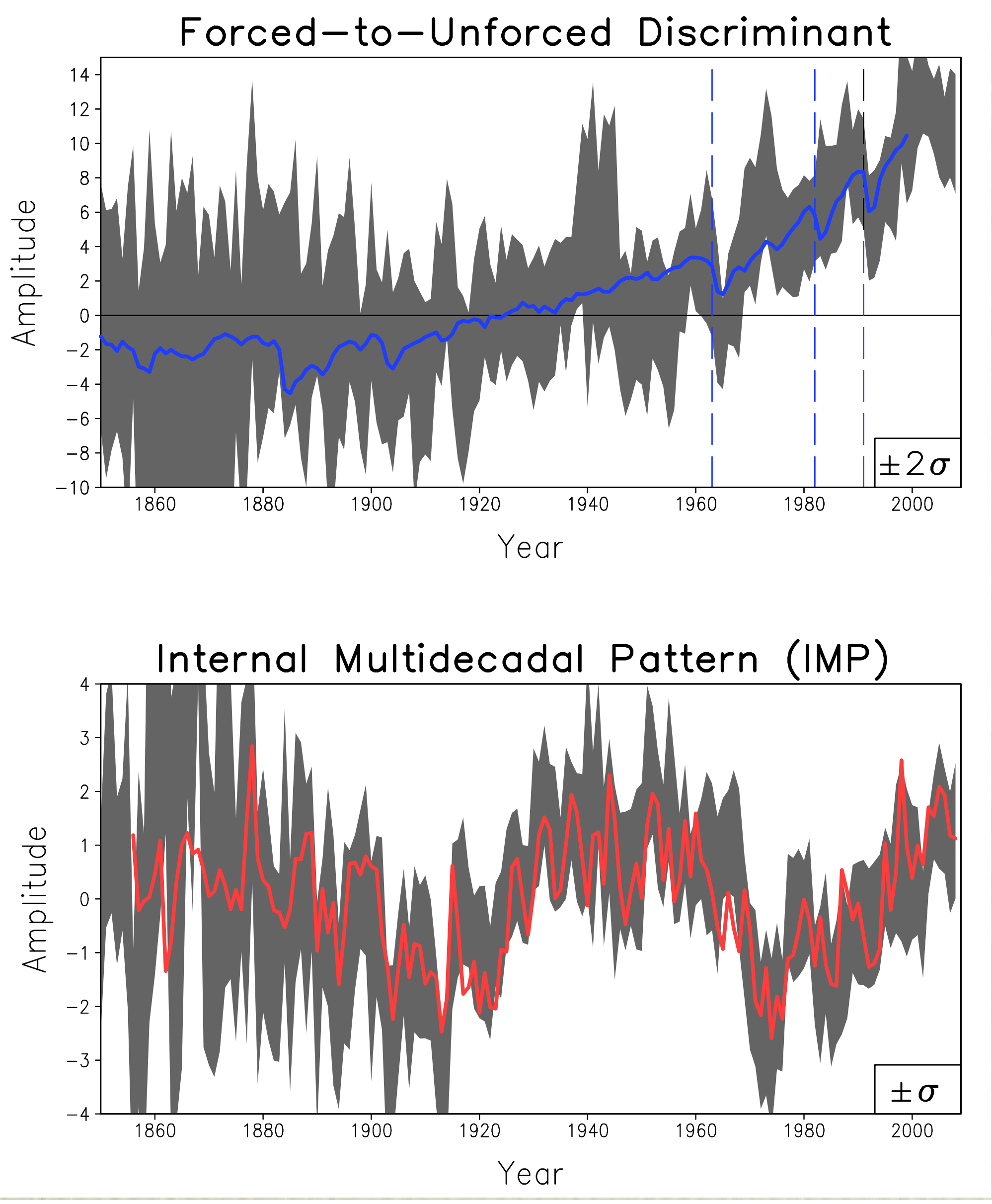


Ting et al. (2009): CMIP3 models and S/N maximizing EOF analysis are used to linearly separated between the externally forced variability and the AMV.

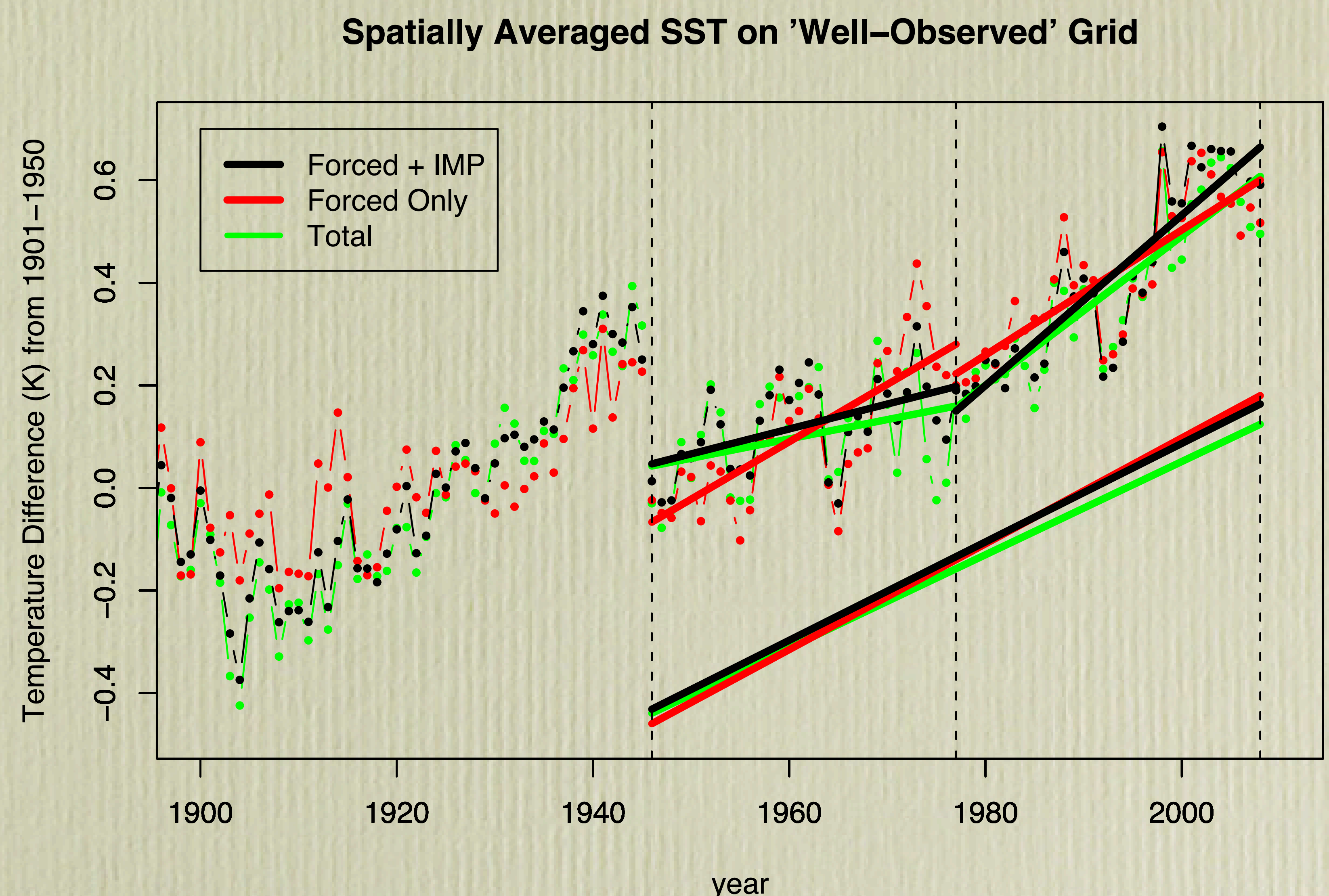
Forces and Internal Variability

DelSole et al. (2010): Use a multivariate analysis method with obs and AR4 models to separate internal decadal variations from the monotonic rise in observed annual-mean SST variability. *Left*: the patterns; *below*: the time series.





AMV and Global Warming Trend



Del Sole et al. (2010): The spatially averaged sea surface temperature on the "well-observed grid" for observations (green dots), as reconstructed by the sum of the forced component and IMP (black dots), and as reconstructed by the forced component only (red dots). The amplitudes are relative to the 1901-1950 mean amplitude. The best fit linear trends for the periods 1946-1977, 1977-2008, and 1946-2008 are shown as solid lines, with the trend for the last period offset by -0.4K for clarity.

Summary: AMOC-AMV

- AMOC variability leads to low-frequency changes in SST with a spatially coherent pattern (AMV), that is well simulated in forced and unforced coupled model:
  - The regions where the signal is large (and significant) are also strongly affected by high-frequency atmospheric forcing*.
  - There is no agreement between models and observations regarding the time scale of the variability.
  - The temporal relation AMOC-AMV is not uniform across models.
  - All these detracts from the ability to use SST for monitoring AMOC change (though it is a good diagnostic tool).

** Recent studies show that such high-frequency perturbations can lead to rapid growth of multi-decadal AMOC perturbations*

Summary: AMV impact

- AMV affects climate in and around the Atlantic Basin:
  - The impact of AMV is caused mainly by related changes in the north tropical Atlantic (NTA) SST.
  - Within the Atlantic and the surrounding land masses, models (coupled and uncoupled) simulated the observed AMV impact quite well.
  - There are discrepancies between models regarding the impacts outside the Basin, on Pacific climate and on the Indian summer monsoon, which should be addressed through further study.
  - In models, a substantial weakening of AMOC (negative AMV) leads to increased ENSO variance.
- Need to better quantify AMV related variability relative to other variations (e.g., ENSO, PDV, external forcing) for use in predictions and assessments.

Summary: AMV and GW

- AMV strongly affects global short-term (decadal) trends:
  - Global temperature trends over 10-30 years are affected by internal variability.
  - This impact is more readily discernible by examining the spatial pattern of the trend.
  - To "remove" this trend from the global mean this spatial pattern needs to be considered and a model (numerical or statistical) of the free variability is needed (*Ting et al., 2009; Campo and Sardeshmukh, 2010; DelSole et al., 2010*).