# Climatic impacts of long-term North Atlantic SST Variability: A brief review

Yochanan Kushnir and Mingfang Ting

*Columbia University, Lamont-Doherty Earth Observatory*

*Palisades, New York*

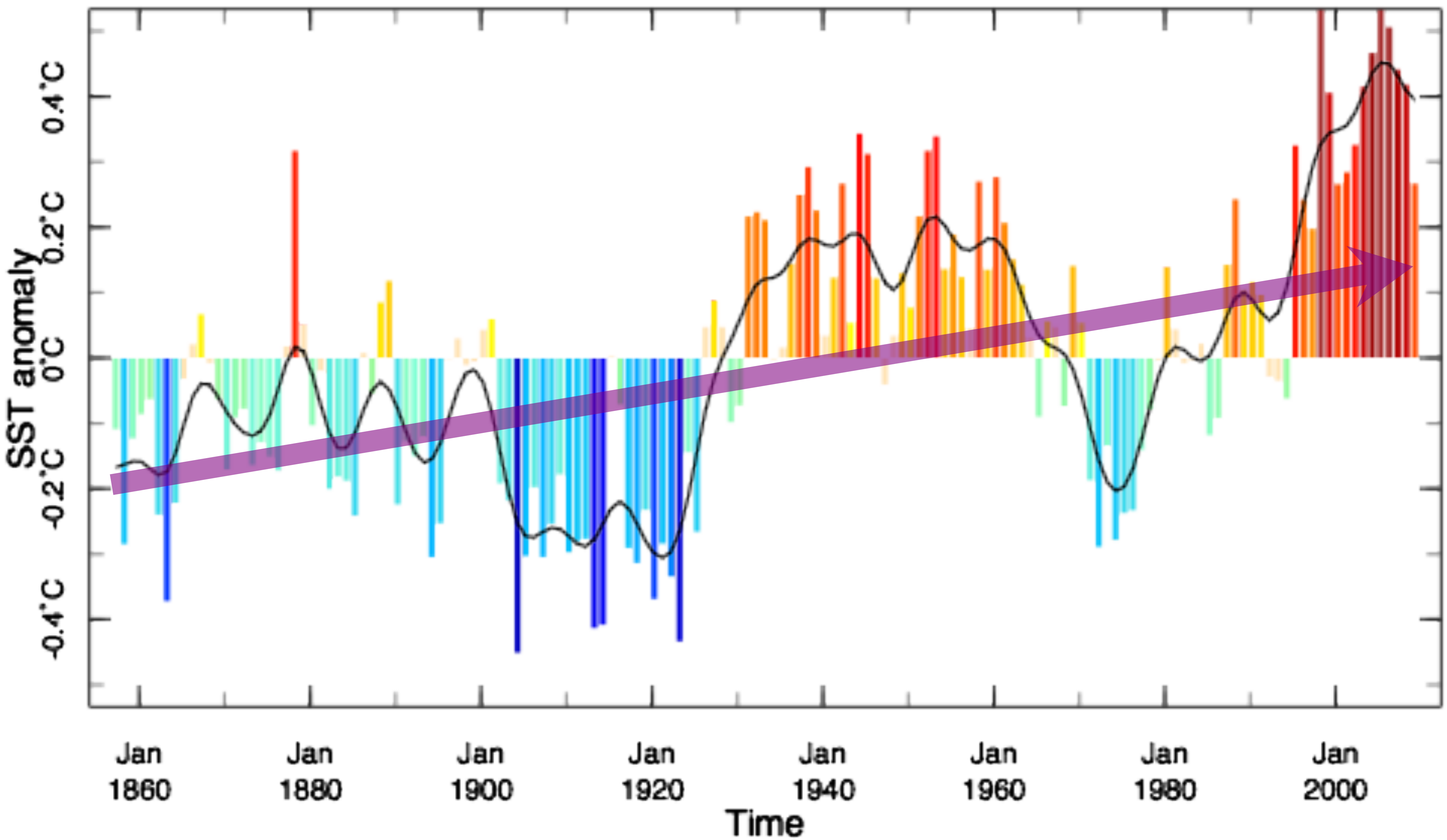
2013 U.S. AMOC/U.K. Rapid International Science Meeting - AMOC Variability: Dynamics and Impacts
Baltimore Maryland, July 2013

# A USAMOC program near-term goal

- *Further study is required to understand the connections between AMOC/North Atlantic SST and climate variability elsewhere, the physical mechanisms of these teleconnections, and the related impacts on humans and ecosystems.*

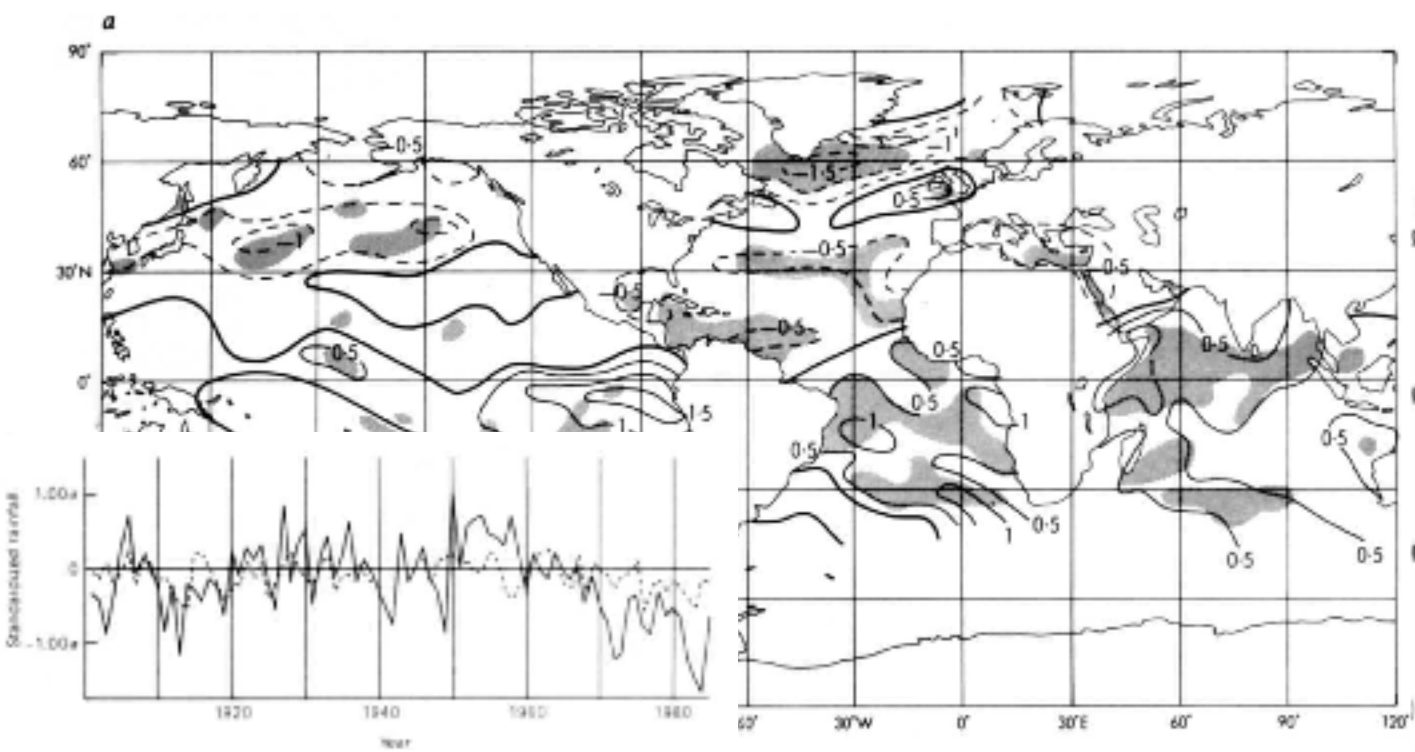
# Atlantic multidecadal variability

# North Atlantic observed SST variability

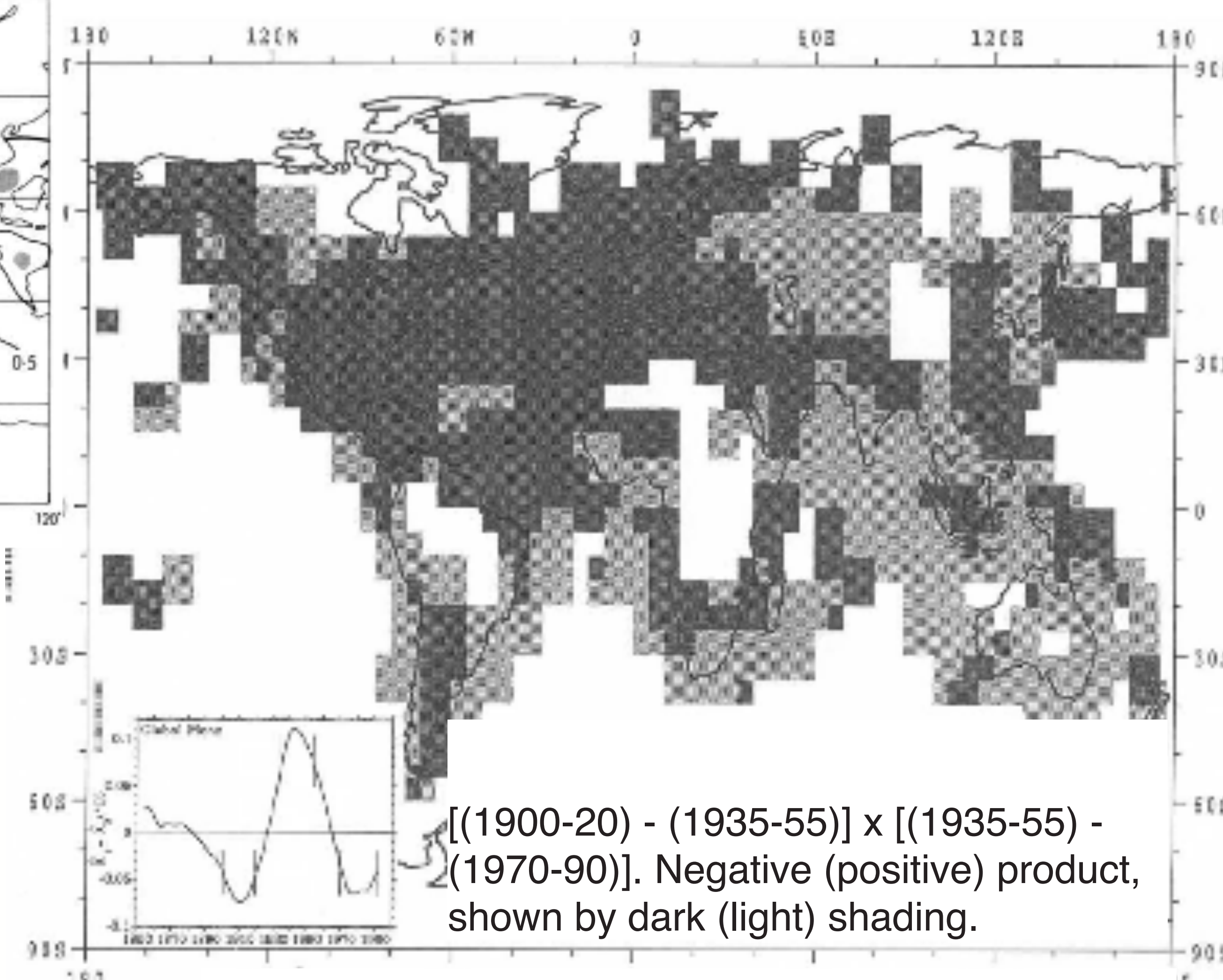



North Atl. (eq. to 60°N) averaged SST anomaly, 1856-2009:
*Color bars show the annually averaged SST anomaly, the solid line is the 10 year lowpass anomaly.*

# Atlantic Multidecadal Oscillation: a distinct pattern of low-frequency surface temperature variability

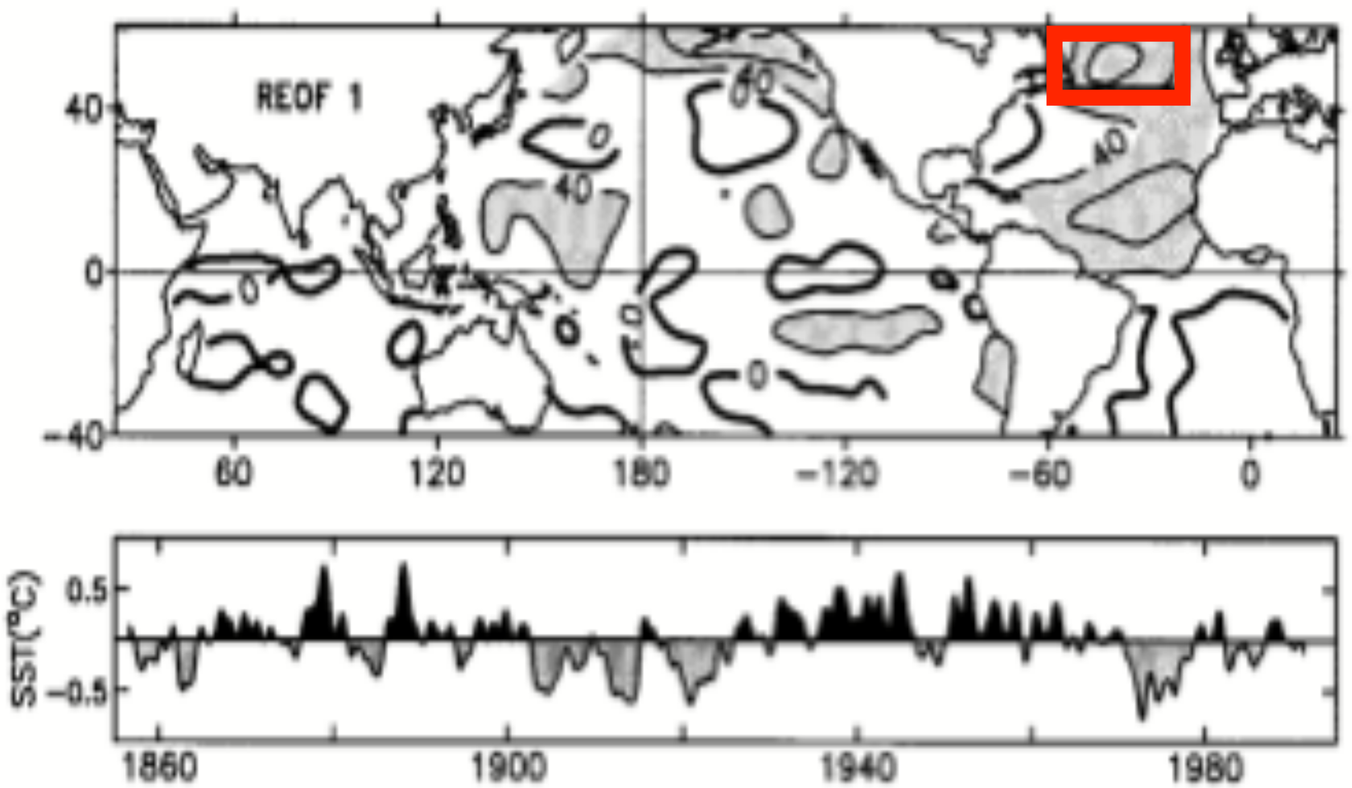



*Folland et al. (1986): SST EOFs*




[(1900-20) - (1935-55)] x [(1935-55) - (1970-90)]. Negative (positive) product, shown by dark (light) shading.

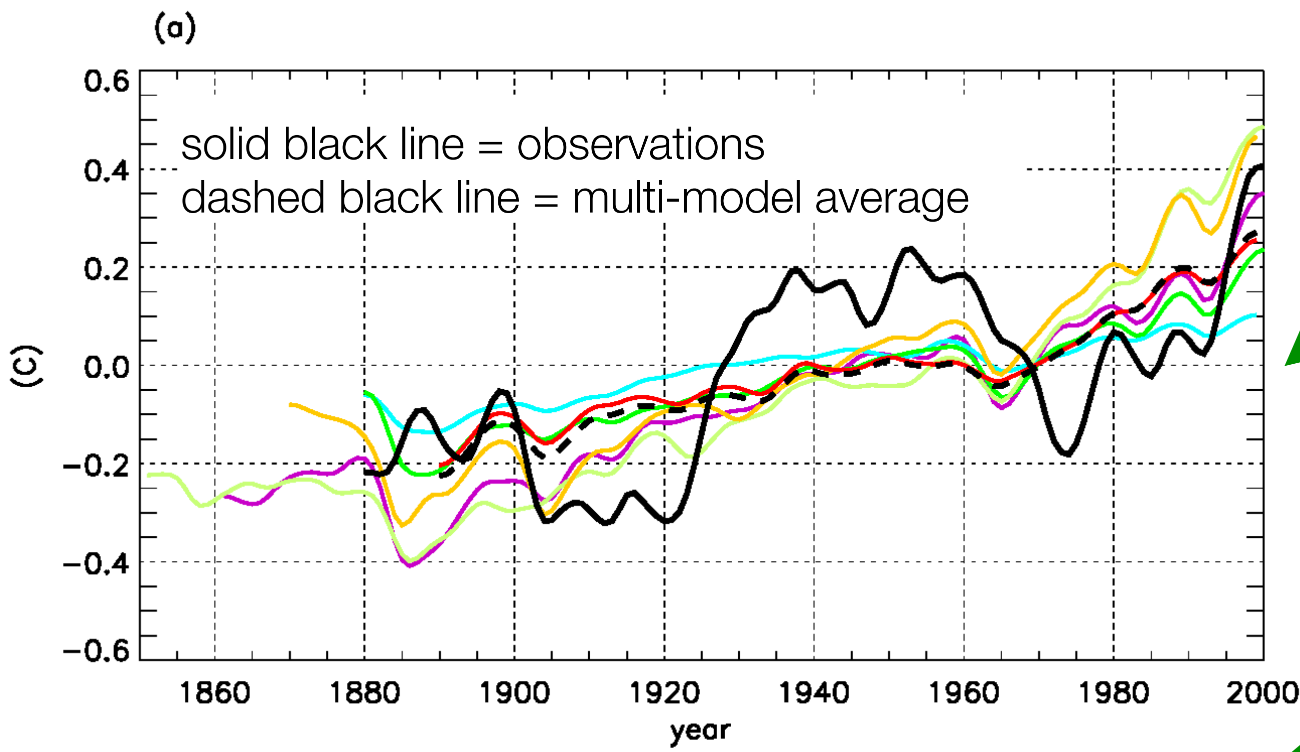
*Schlesinger & Ramankutti (1994): multichannel SSA of Ts*

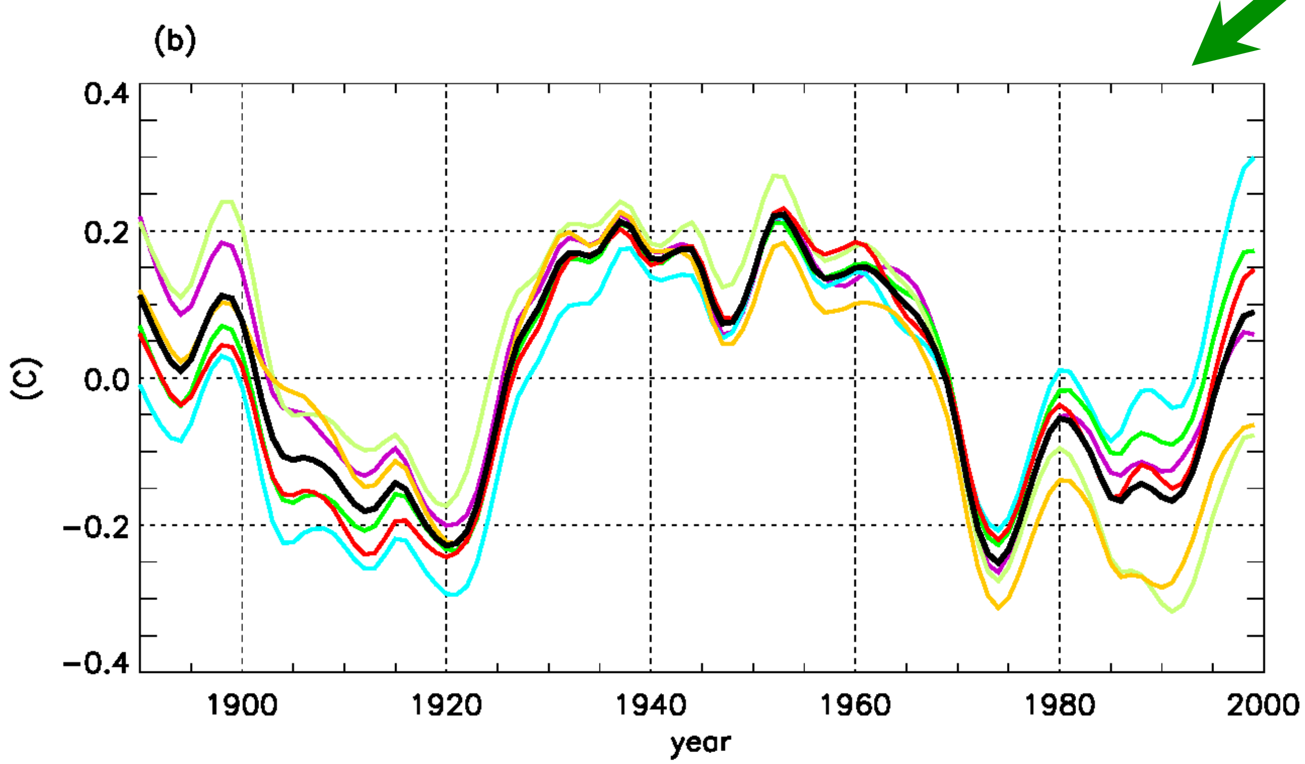


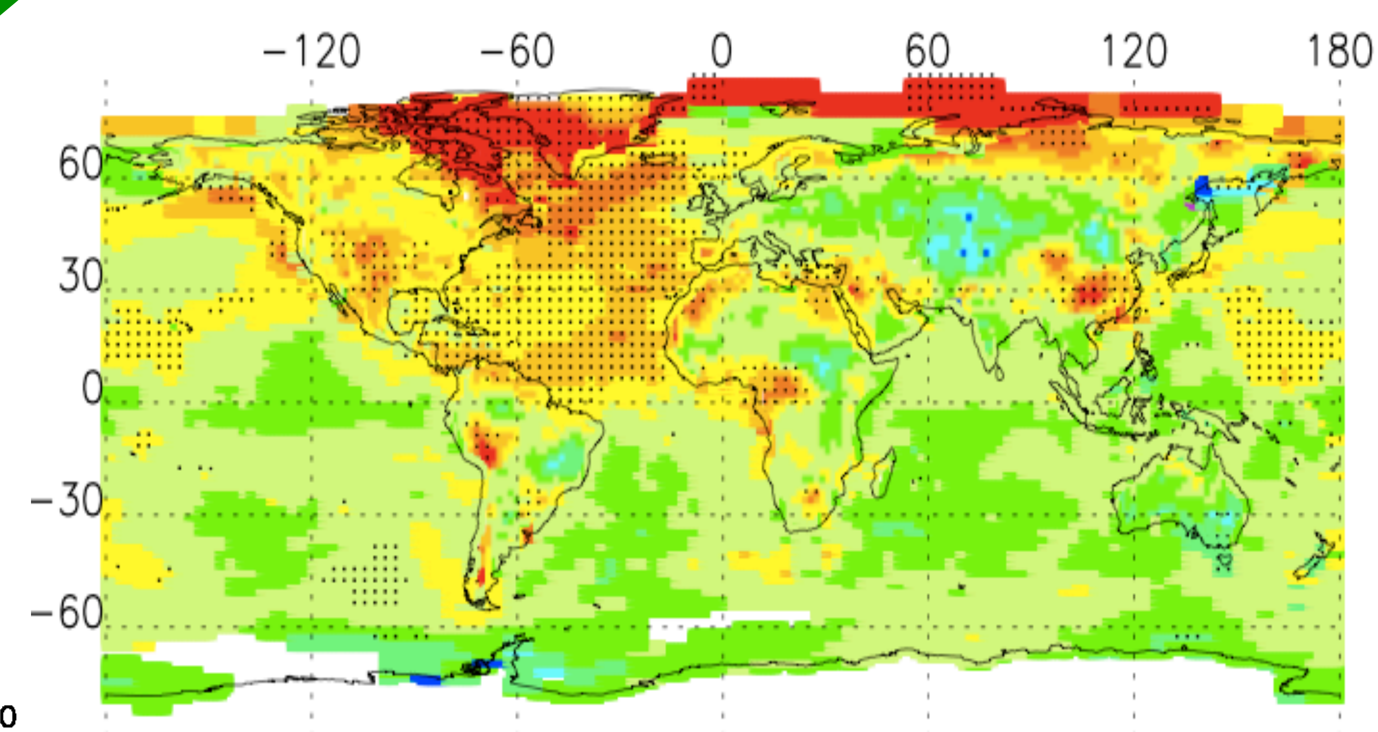

*Mestas-Nuñez and Enfield et al. (1999): First rotated EOF of the non-ENSO*

# Separating forced and internal Atlantic multidecadal variability

*Ting et al. (2009)* applied S/N maximizing PCA to 9 CMIP3 Coupled models that provided multiple 20th century realizations to estimate the **externally forced** change and subtracted it from the observed No. Atl. SST average to estimate signal of **internal variability**.



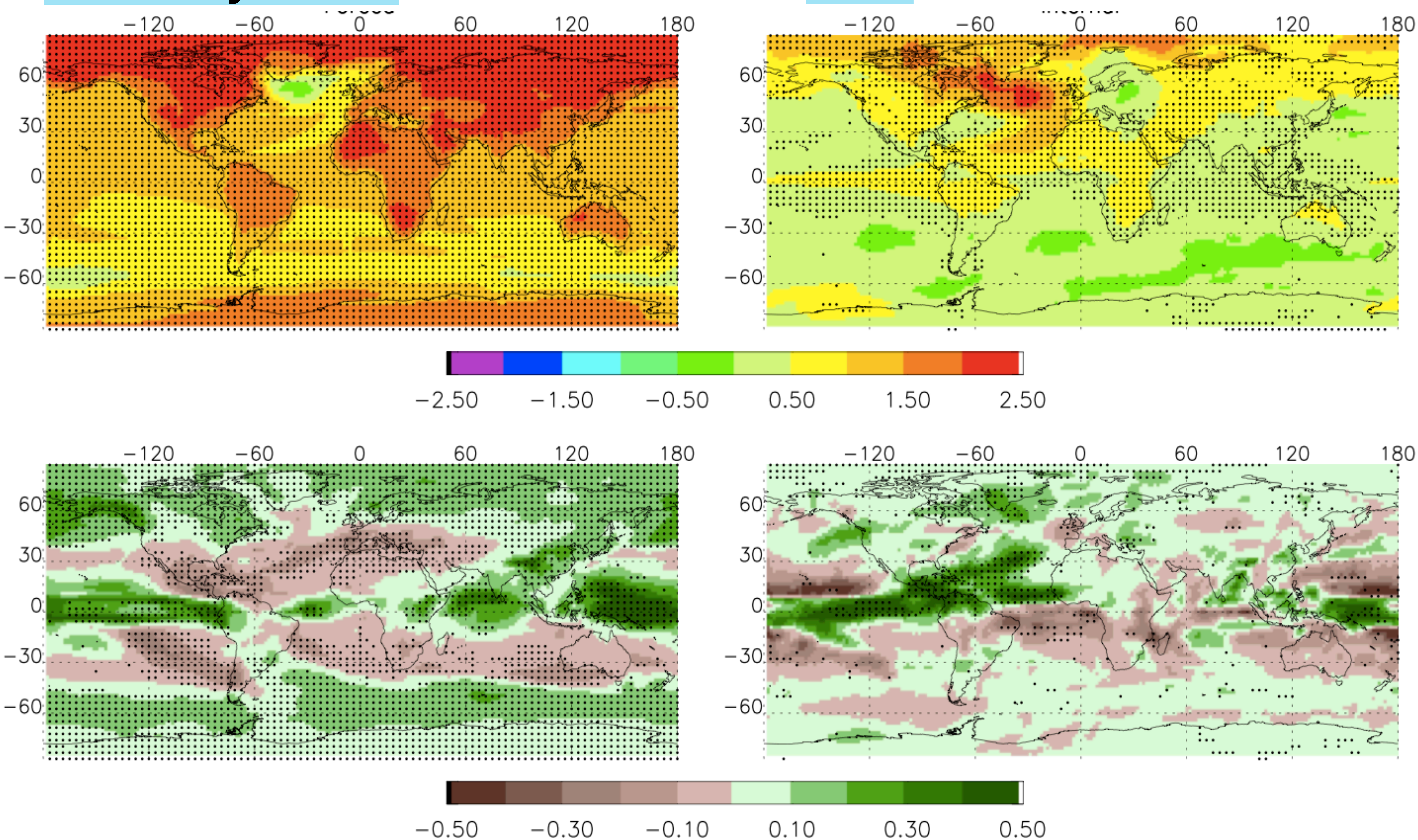



# CMIP3 20th century variability

*Ting et al. [ 2009; 2011]*

**Externally forced** **AMV**



# Ocean role in AMV - link to AMOC

# Bjerknes (1964) in *Atlantic air-sea interactions* ...

... pointed out that there are two patterns of Atmo/Ocean variability in the North Atlantic - fast and slow. The slow (multi-year) pattern displays spatially uniform SST variations and a different ocean-atmosphere relationship than the fast one.

*Interannual variability is driven by atmospheric wind fluctuations:*
*strong westerlies ⇒ cold subpolar gyre*
*weak westerlies ⇒ warm subpolar gyre*

*Multi-yeat variations are driven by changes in ocean heat transport:*
*Uniform warming of No. Atlantic ⇒ weak subtropical anticyclone (& weak westerlies in the north)*

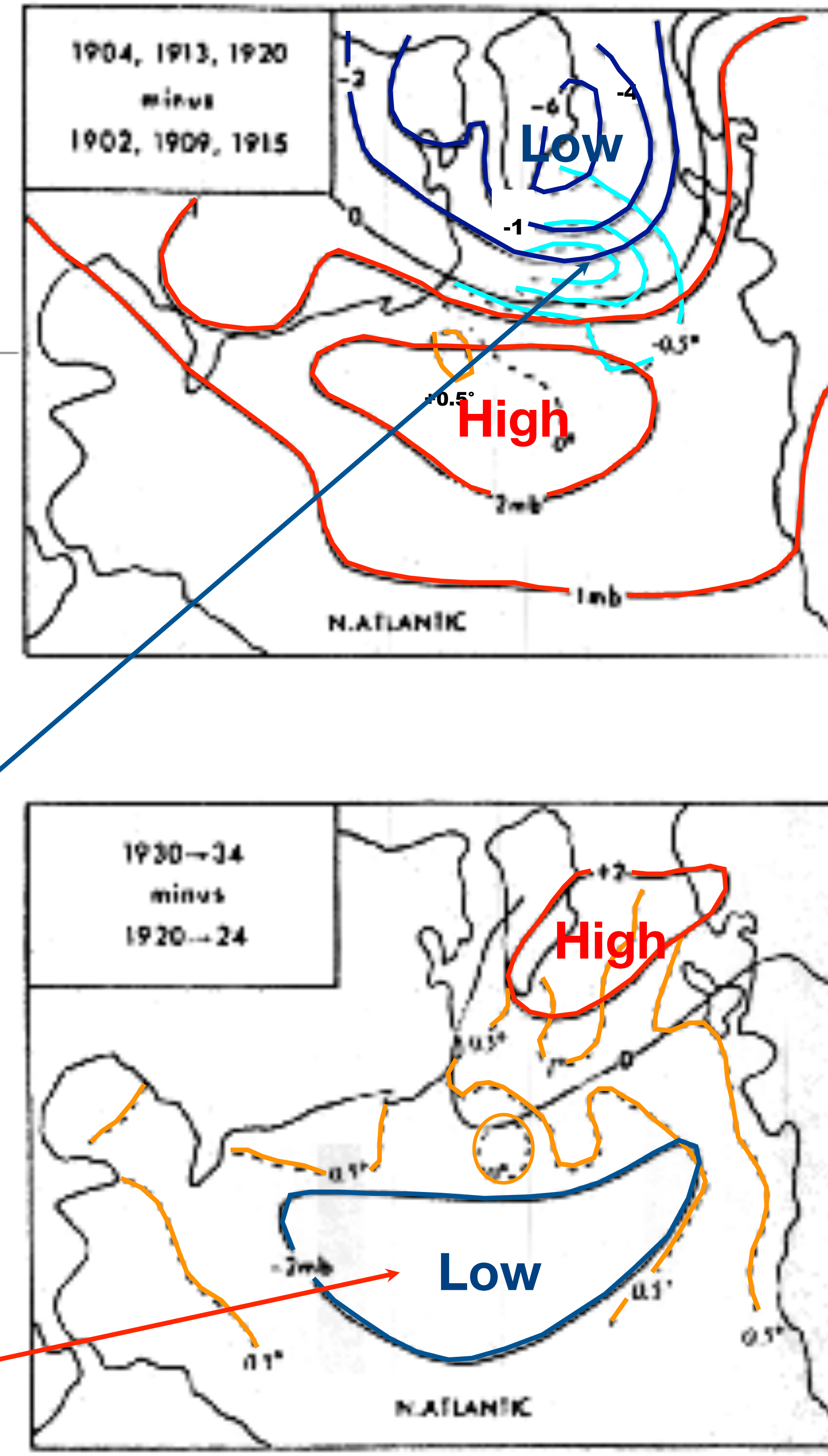


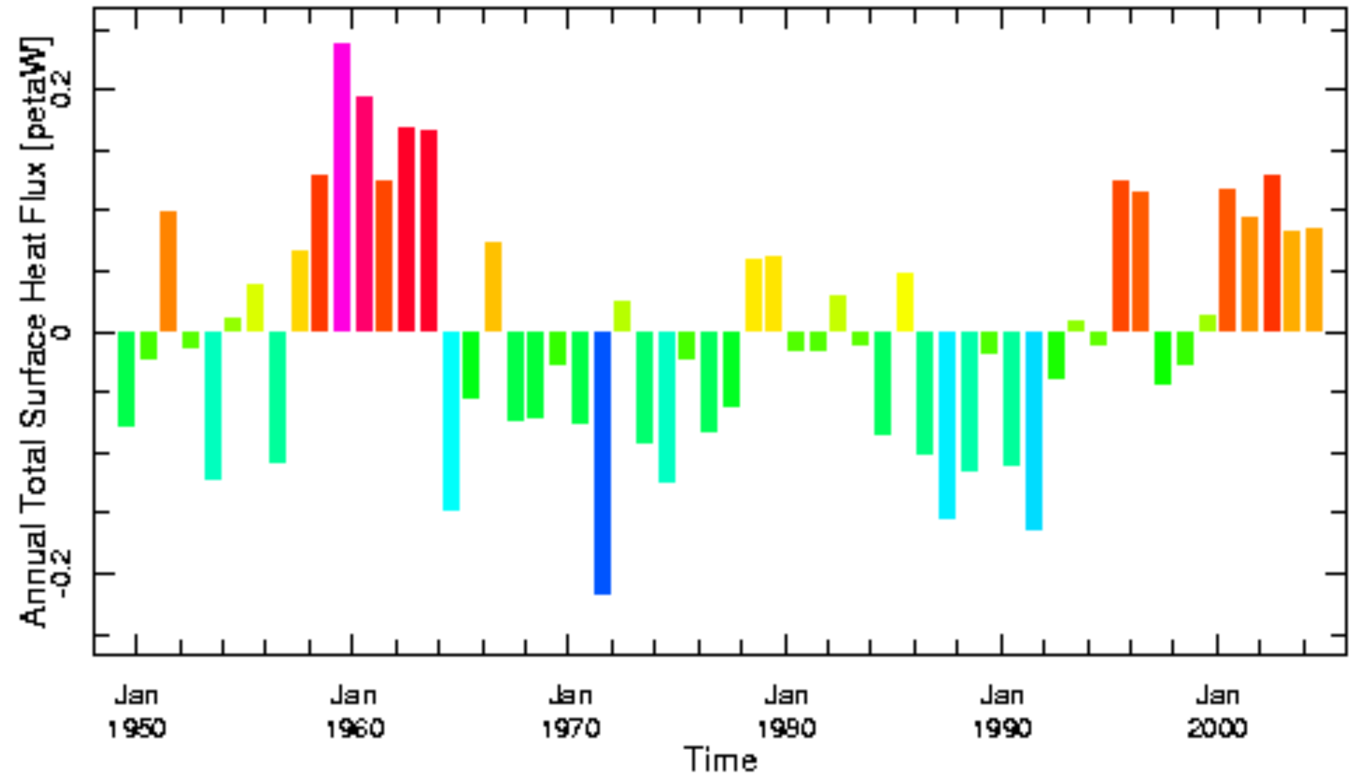

Fig. 4. *SST* and surface pressure anomalies from Bjerknes (1964). (a) The difference between isolated years of high and years of low North Atlantic Index, where the North Atlantic Index is defined as the difference surface pressure between the Azores and Iceland. (b) The difference between an average over a period of persistent high index and a period of persistent low index (1920–1924 minus 1930–1934).

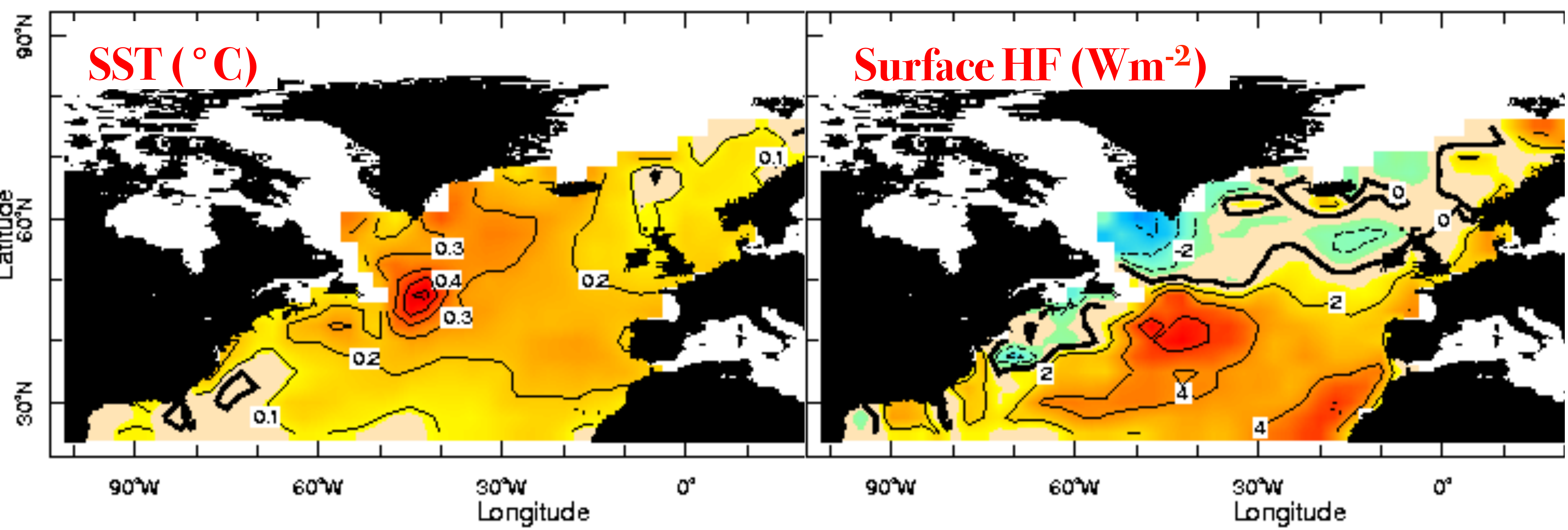
***Figure from Bryan and Stouffer (1991) after Bjerknes (1964)***

# O/A surface heat flux and the AMO

*NCEP reanalysis O/A fluxes support Bjerknes hypothesis: On multidecadal timescales the atmosphere is heated by a warm ocean surface possibly forced by the convergence of ocean heat transport (AMOC?)*

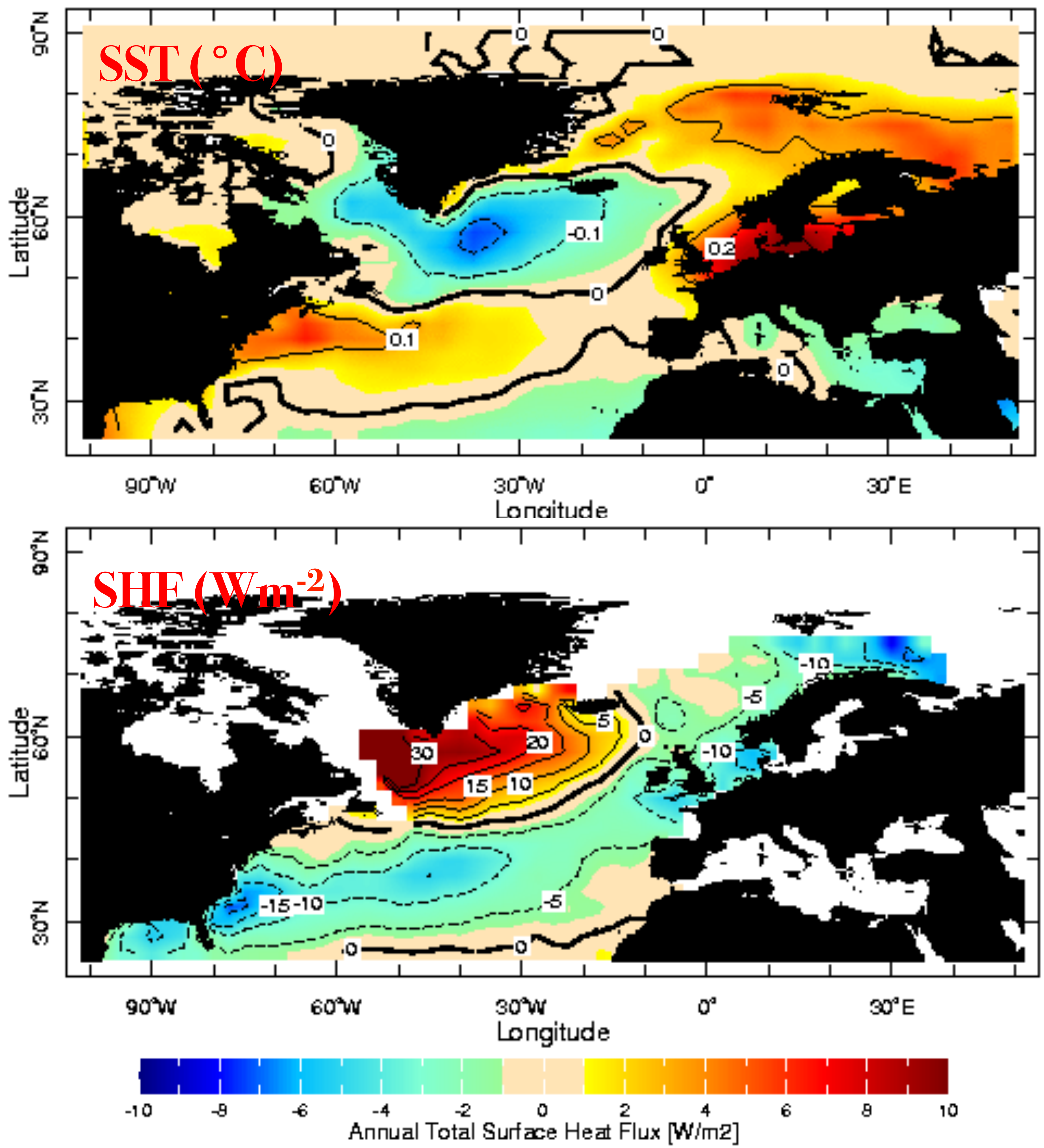
***Surface upward O/A HF from NCEP-NCAR Reanalysis***



# Inter-annual variability

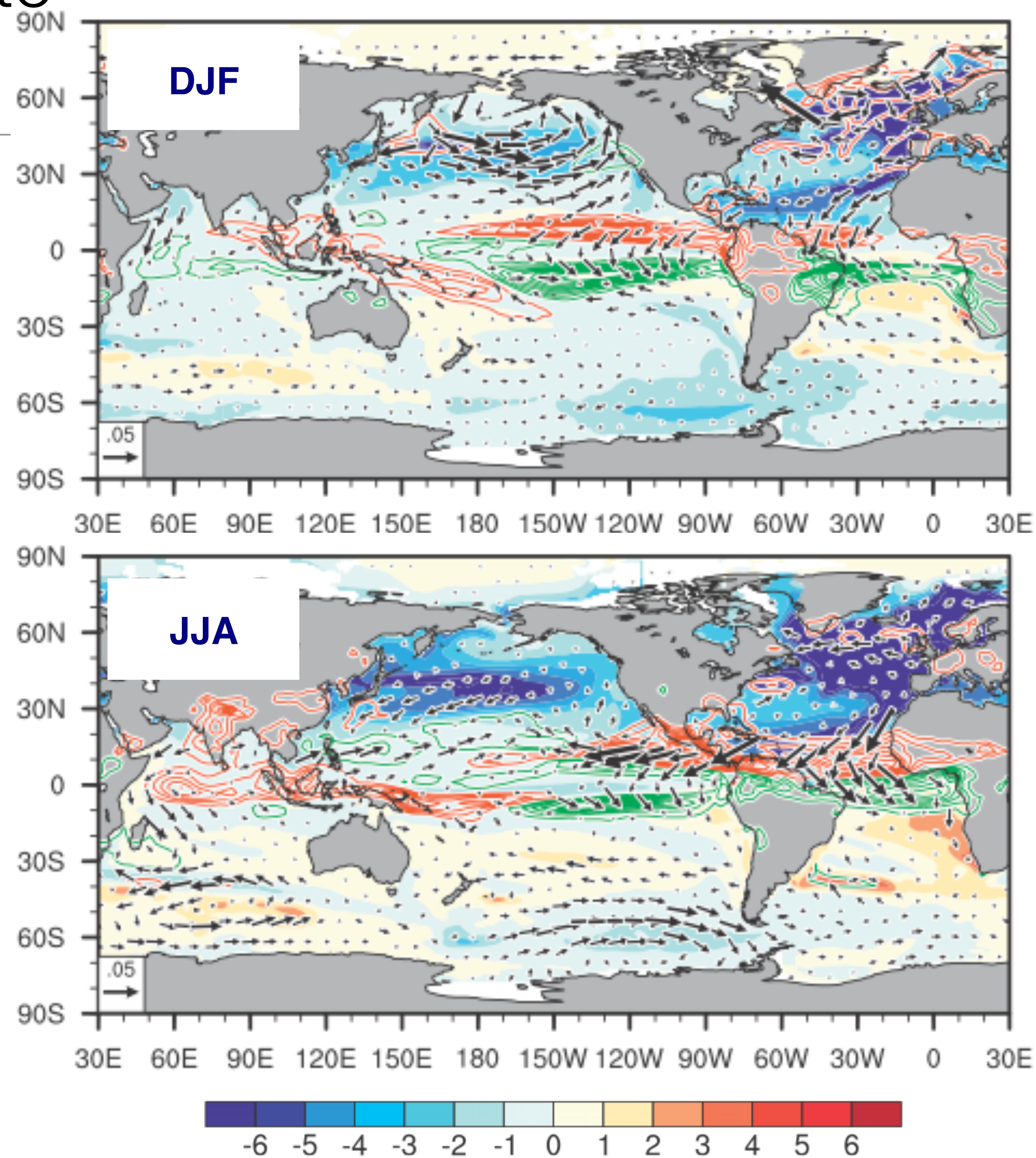
**THE OCEAN IS COOLED & WARMED BY ATMOSPHERIC CONTROLLED SURFACE HEAT FLUXES & OHT BY EKMAN TRANSPORT**



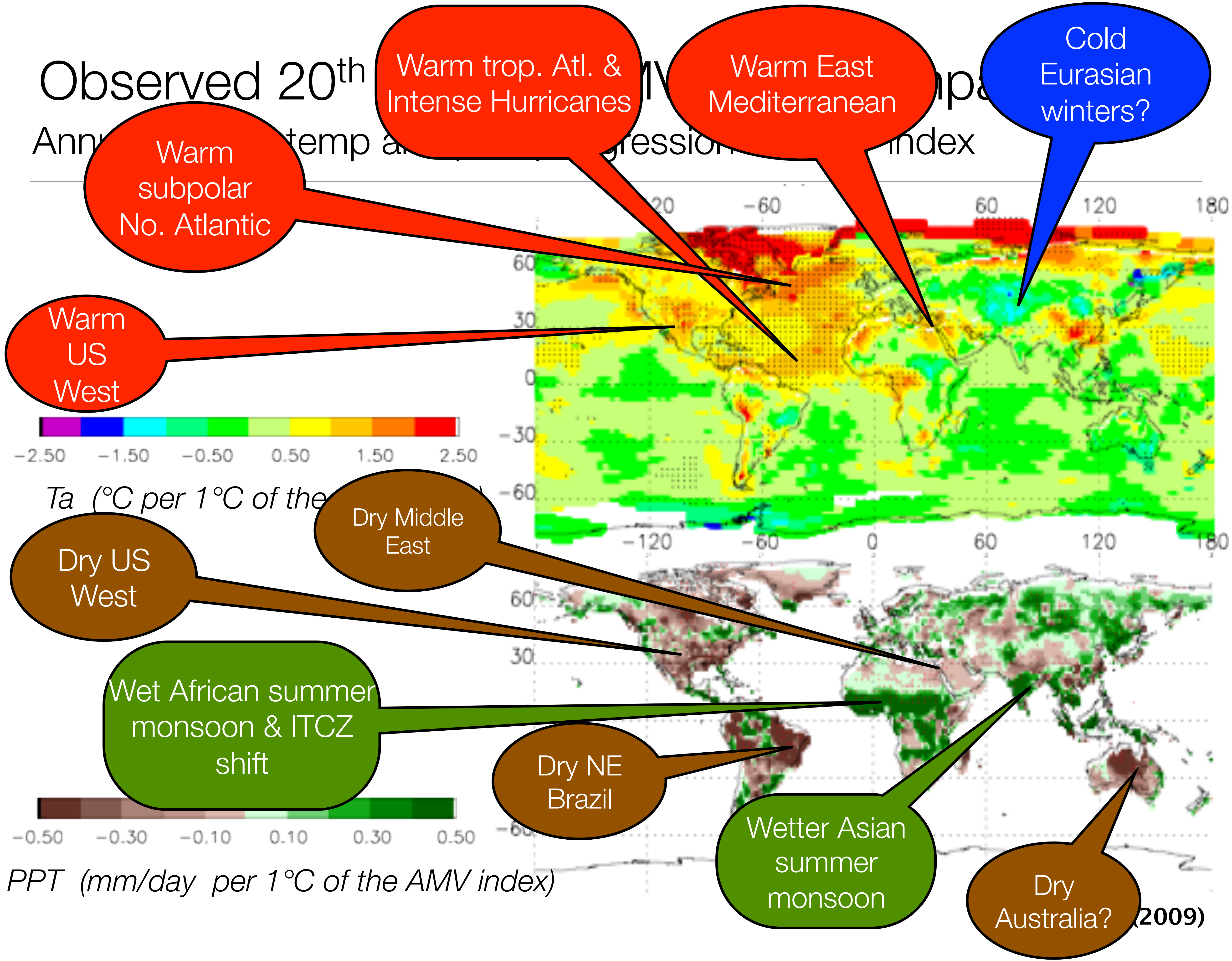

Regression on the NAO index show that surface heat fluxes forced by the atmospheric wind variations are linked with SST warming where heat loss to the atmosphere is reduced and cooling where heat loss is increased.

# Surface response to AMOC collapse

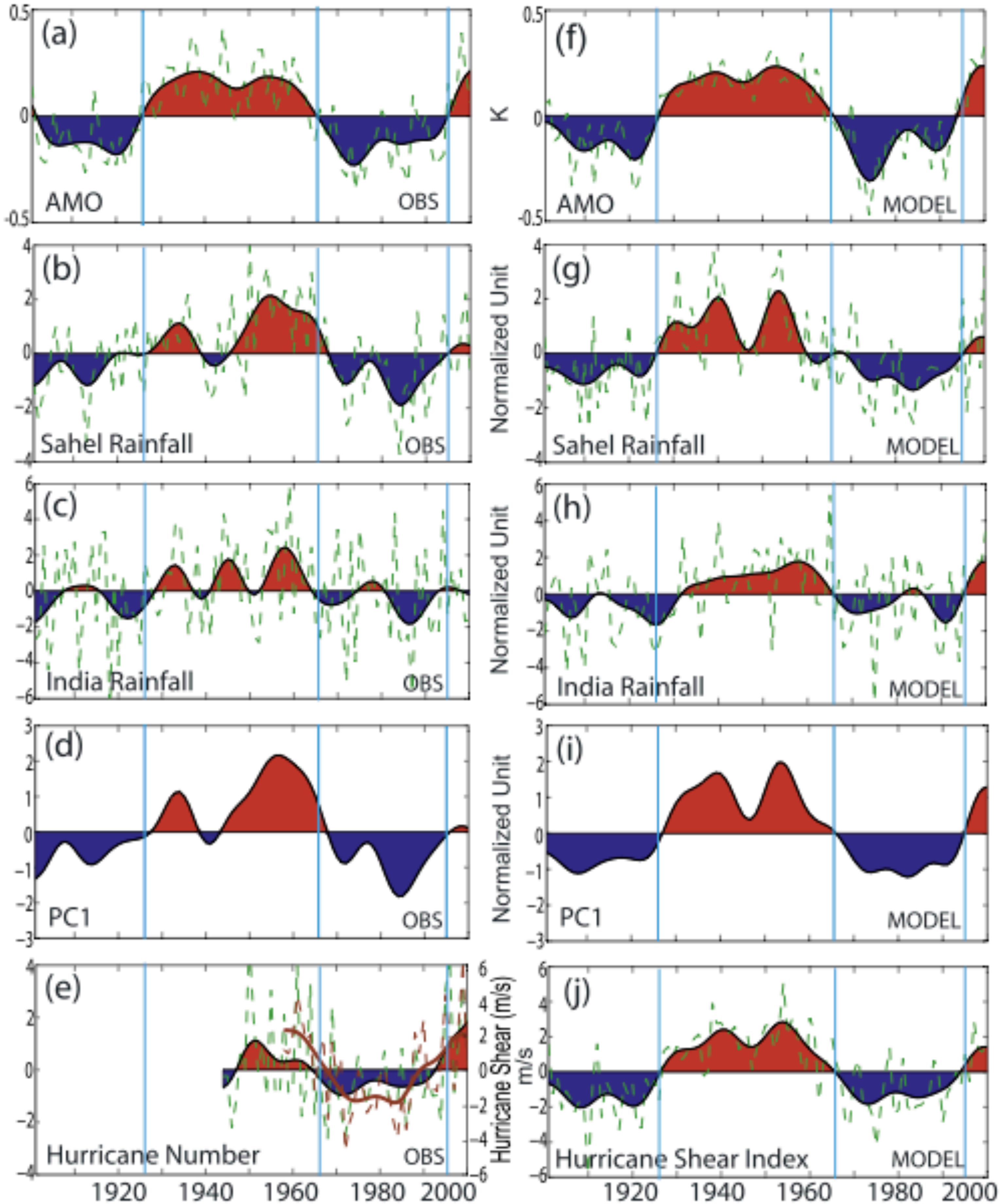
- Typical Coupled GCM (here GFDL CM2.1) response to a 1-Sv AMOC water-hosing experiment: SST (color), surface wind stress (vectors, N/m2), and precipitation (green contours > 1.0 mm/day and orange contours < -1.0 mm/day intv. 1.0 mm/day).
- *Okumura et. al. (2009)*



# Climatic impacts of AMV



Observed 20th
MV
pa
Ann
temp a
gressio
index
Warm trop. Atl. & Intense Hurricanes
Warm East Mediterranean
Cold Eurasian winters?
Warm subpolar No. Atlantic
Warm US West
-120 -60 60 120 180
60 30 0 -30 -60
-2.50 -1.50 -0.50 0.50 1.50 2.50
Ta (°C per 1°C of the
Dry Middle East
Dry US West
-120 -60 0 60 120 180
60 30 -60
Wet African summer monsoon & ITCZ shift
Dry NE Brazil
Wetter Asian summer monsoon
Dry Australia?
-0.50 -0.30 -0.10 0.10 0.30 0.50
PPT (mm/day per 1°C of the AMV index)
(2009)




# Modeling AMV impacts

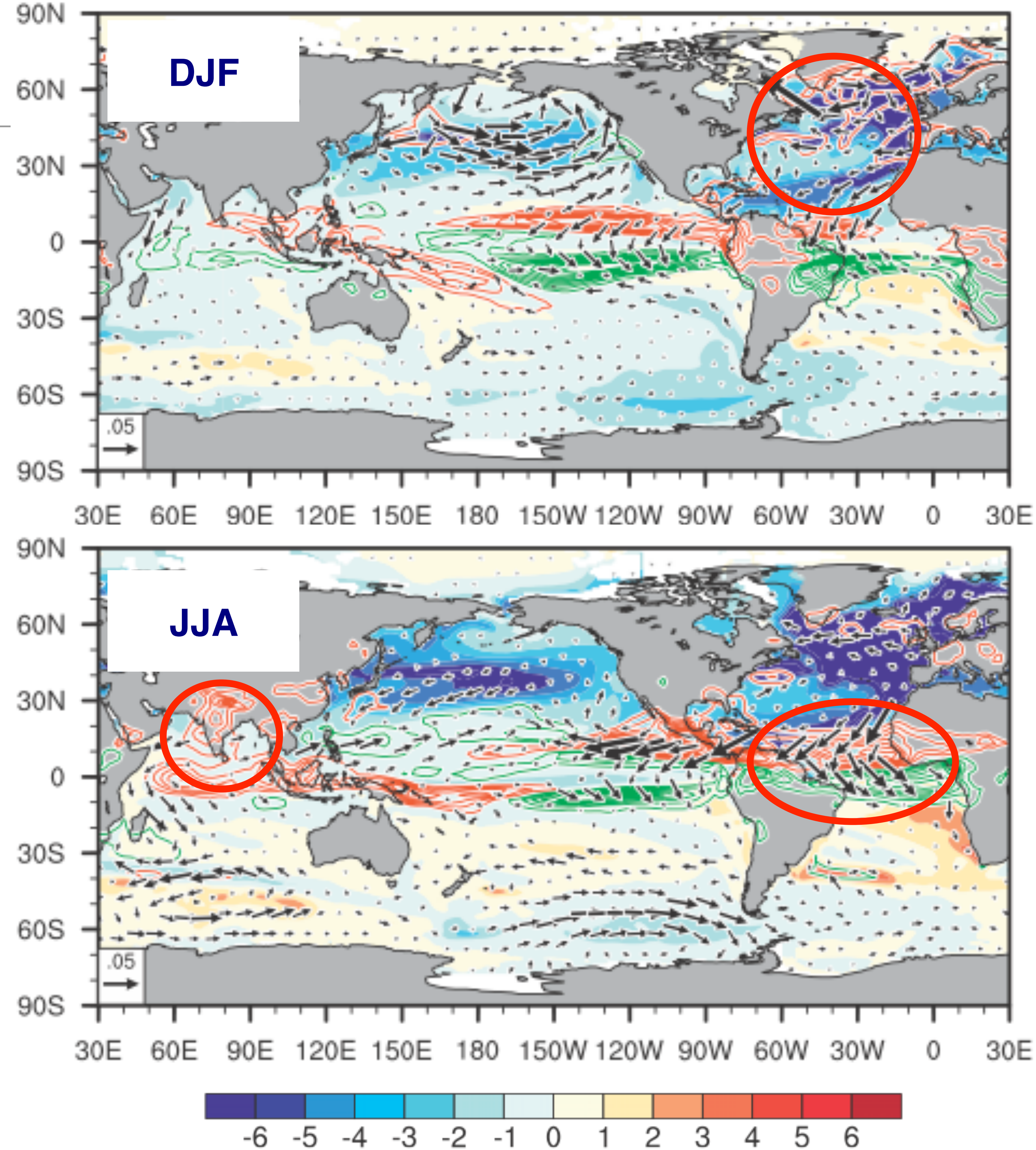
Time series of Sahel and West +Central India rainfall, and of number of Atlantic hurricanes, exhibit AMV time scales.

A coupled GCM with imposed AMV SST change indicates these changes are caused by AMV.

*Zhang and Delworth (2006)*

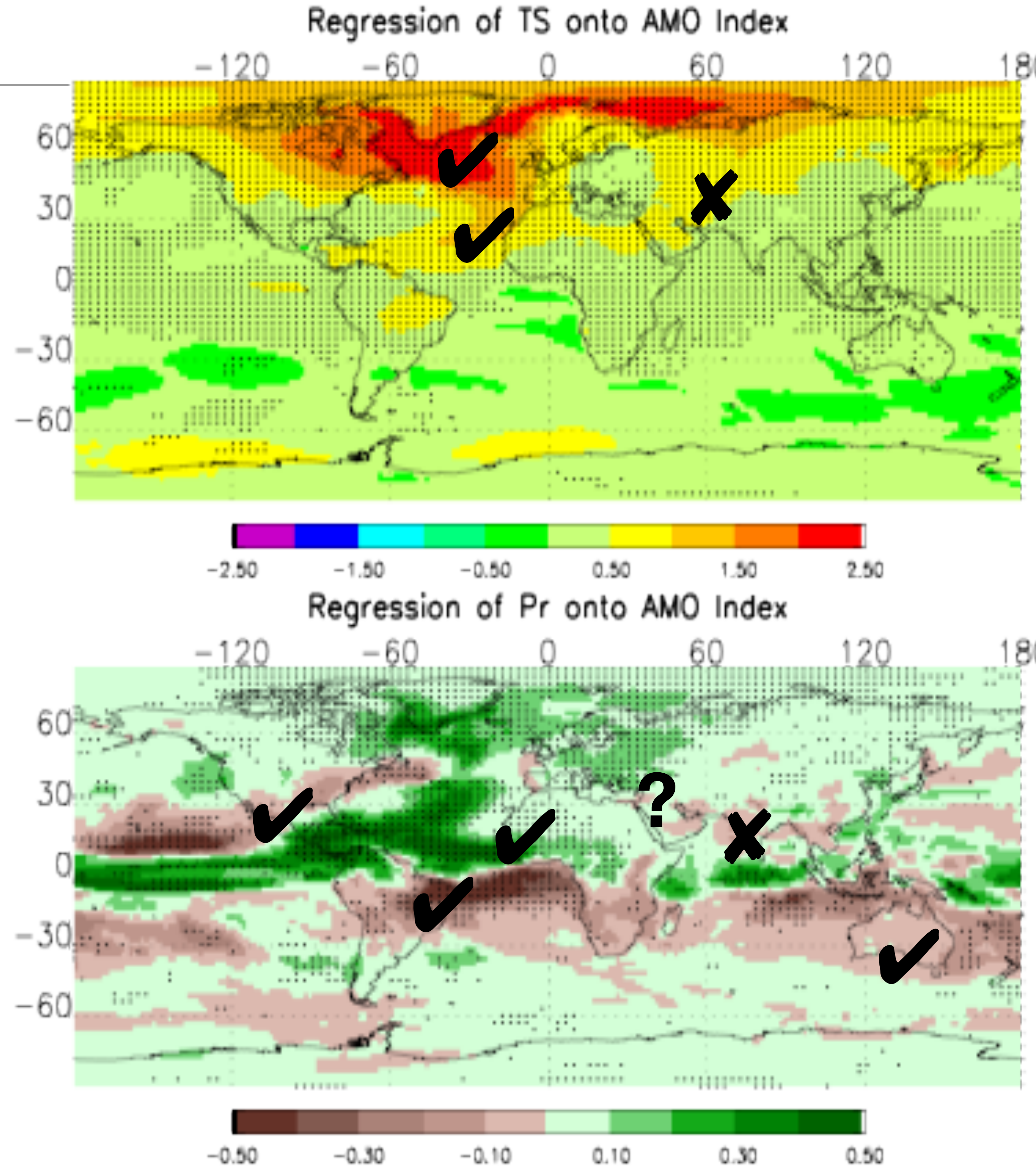
# Response to AMOC collapse

- Typical Coupled GCM (here GFDL CM2.1) response to a 1-Sv AMOC water-hosing experiment confirms AMOC-AMV link and the climatic impacts.
- SST (°C, 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).
- *Okumura et. al. (2009)*



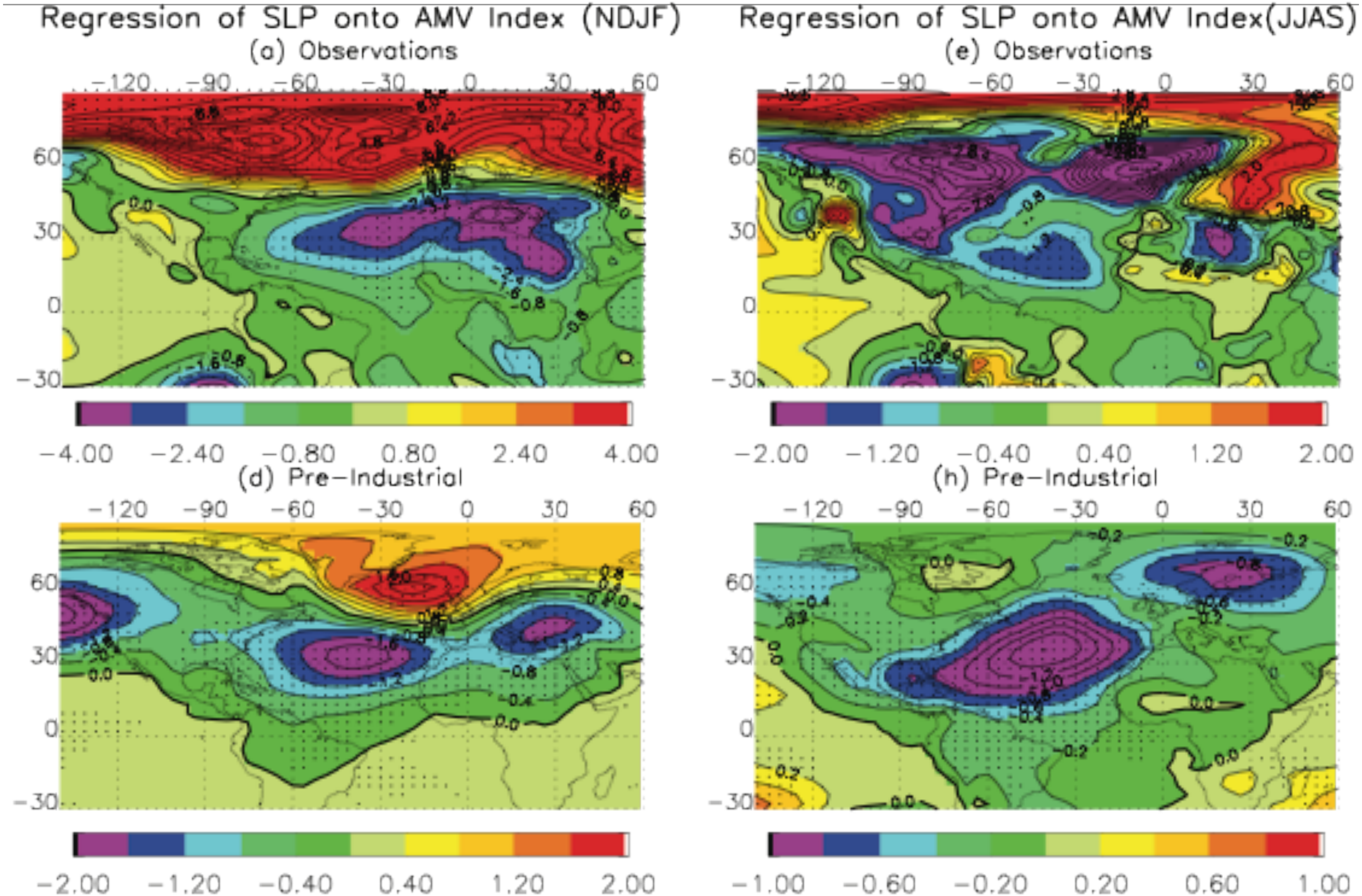
# CMIP5 multi-model AMV simulation

- There is a broad model agreement regarding the global surface temperature pattern associated with AMV.
- There is no model agreement on timescale (for most model timescale << observed).
- The similarity in the surface temperature pattern in the North Atlantic indicates a common underlying atmospheric or oceanic or coupled mechanism (AMOC related?)



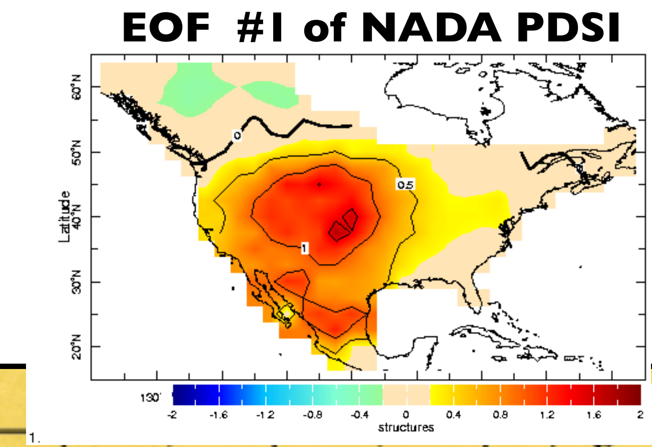
# Atmospheric circulation changes

(*Ting et al., 2013*)

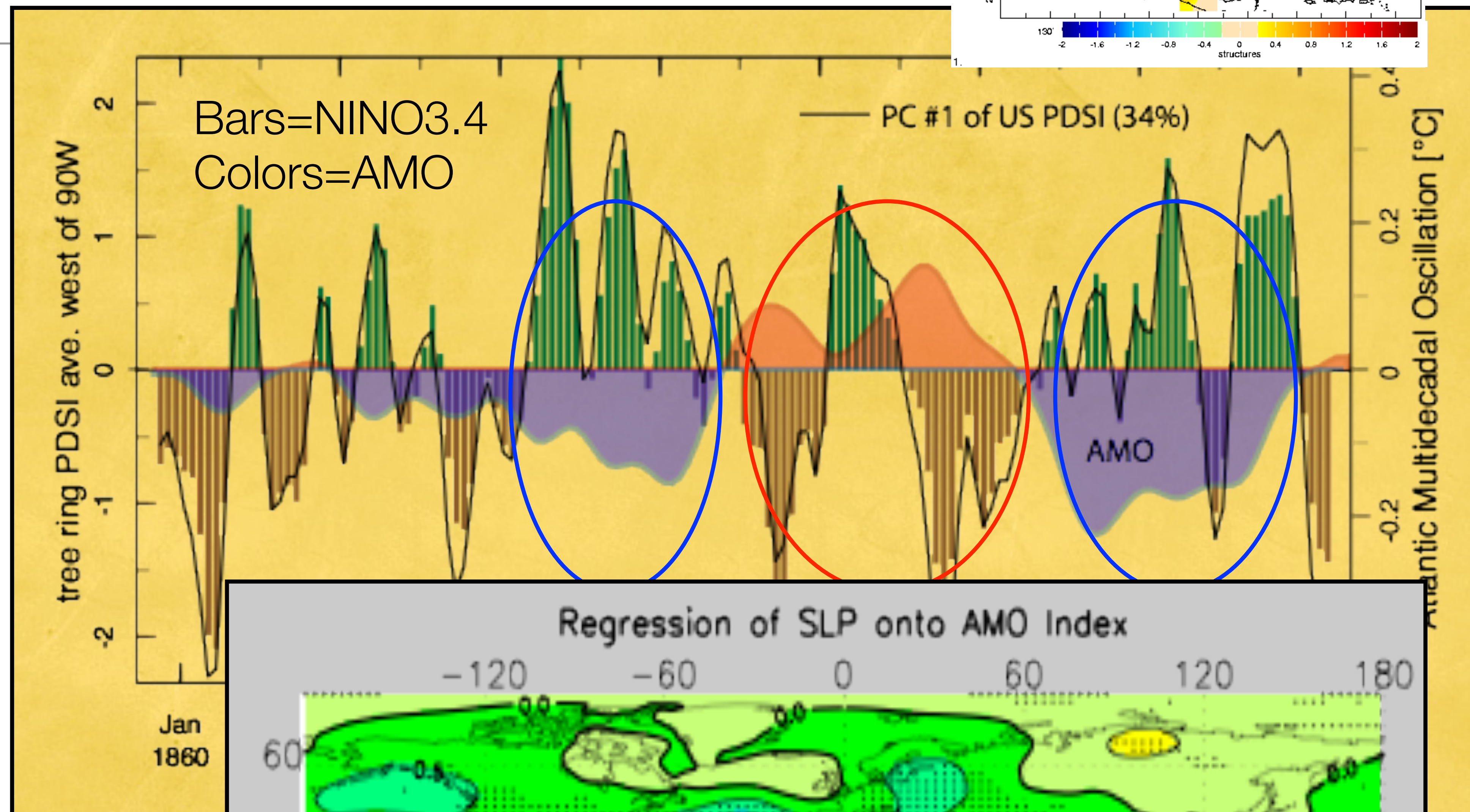


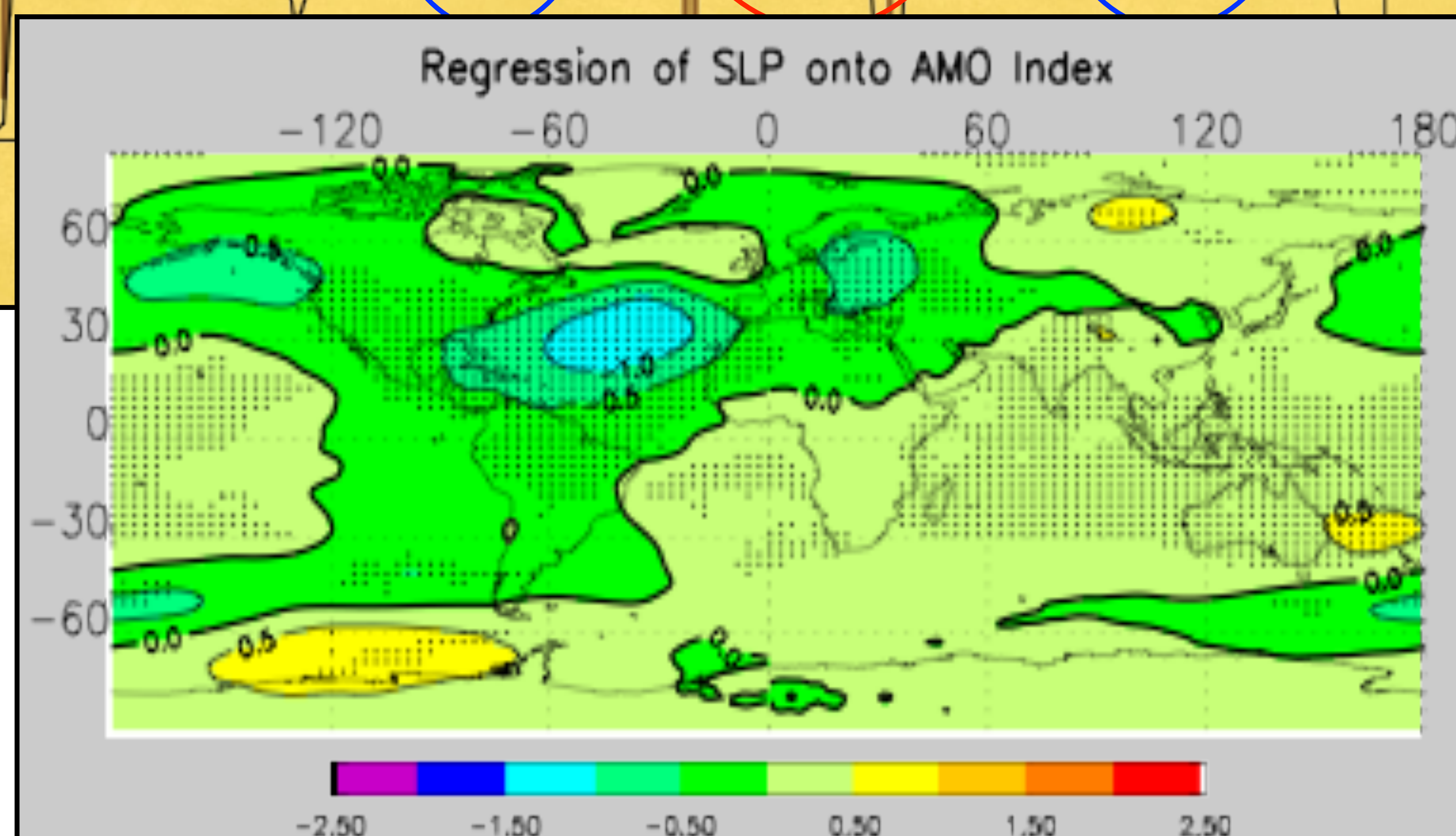
# Mechanisms

# AMV and North American Drought




Western U.S. PDSI (reconstructed from tree-ring chronologies by *Cook et al., 2004*) exhibits positive correlation with ENSO and negative correlation with detrended North Atlantic SST (*Kushnir et al., 2010*)

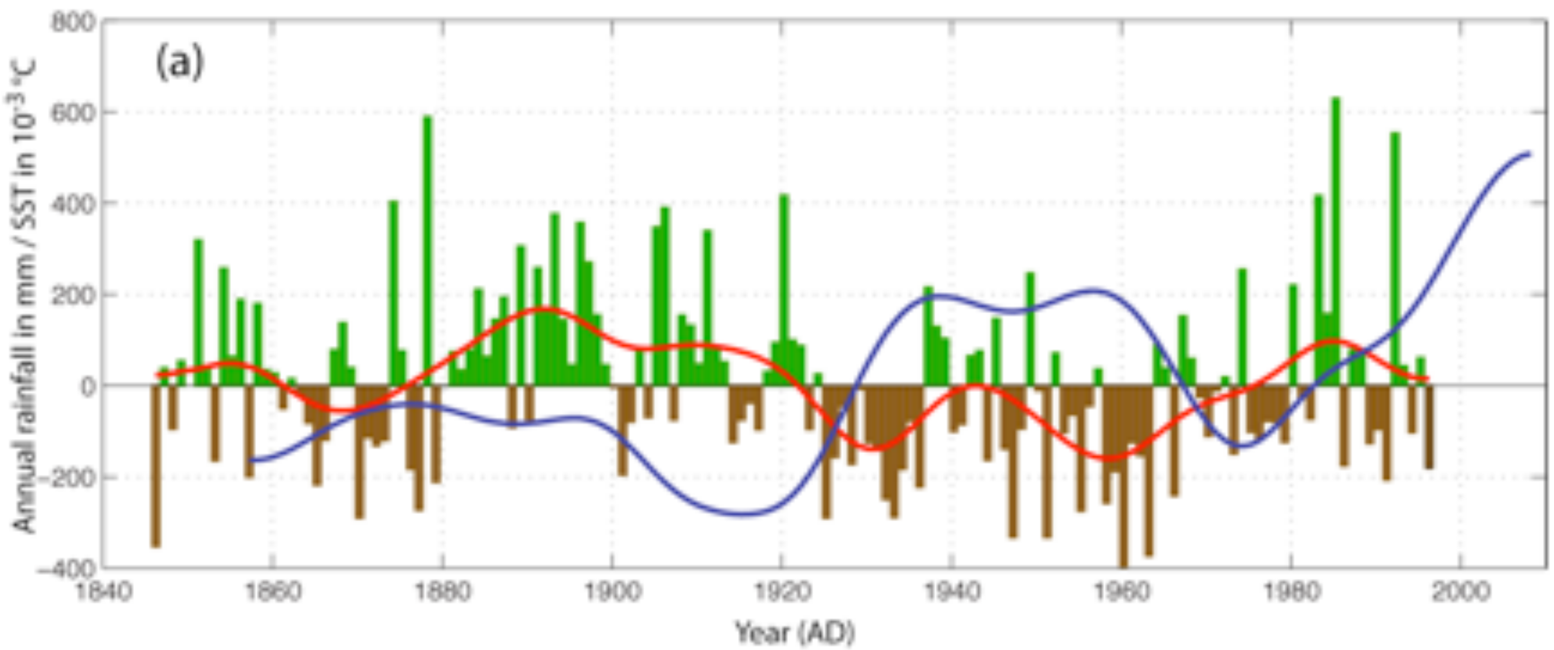



AMO impact on US West precip is related to the weakening of the Atlantic subtropical high (seen here in the annual mean CMIP5 multimodel control regression on the AMO index).

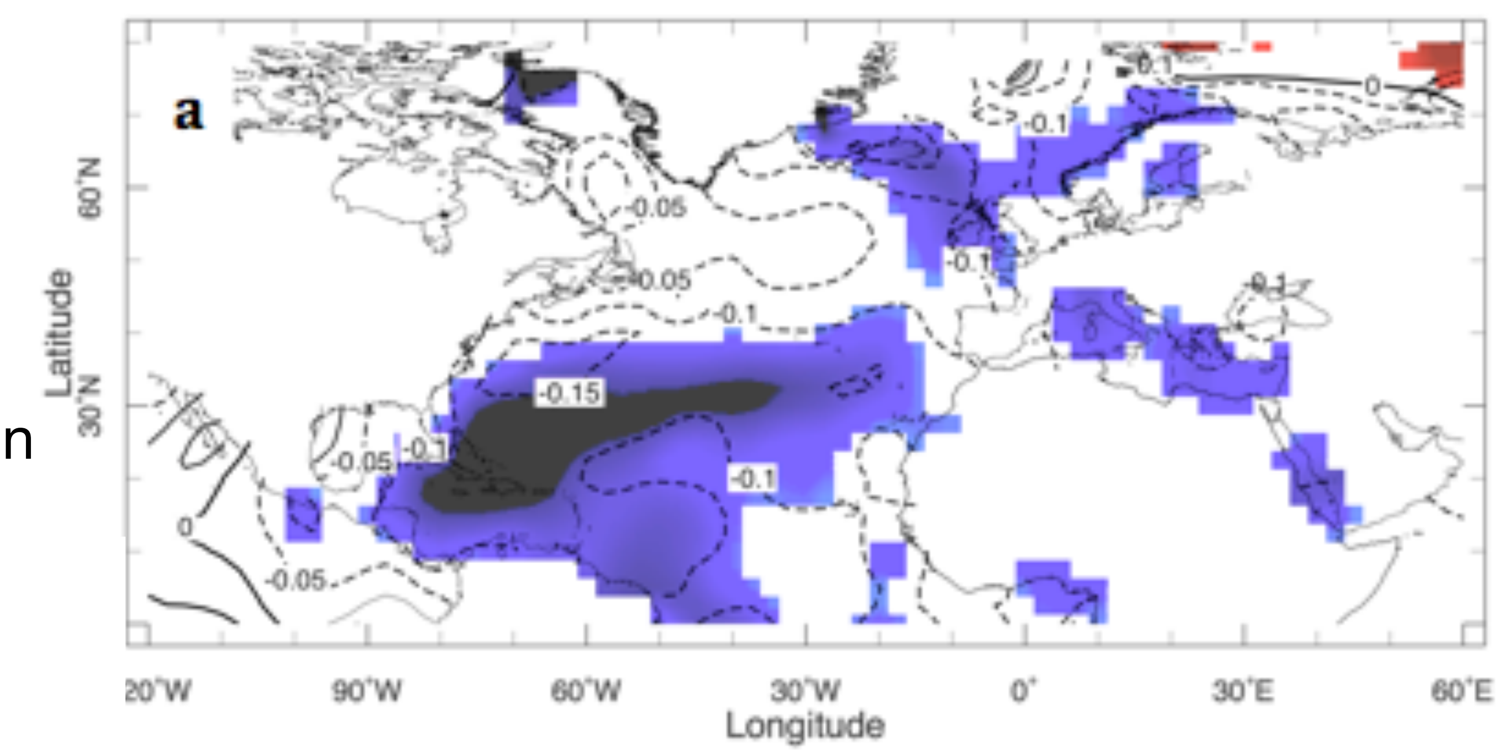
# Levant rainfall responds to AMV

Kushnir and Stein (2010)



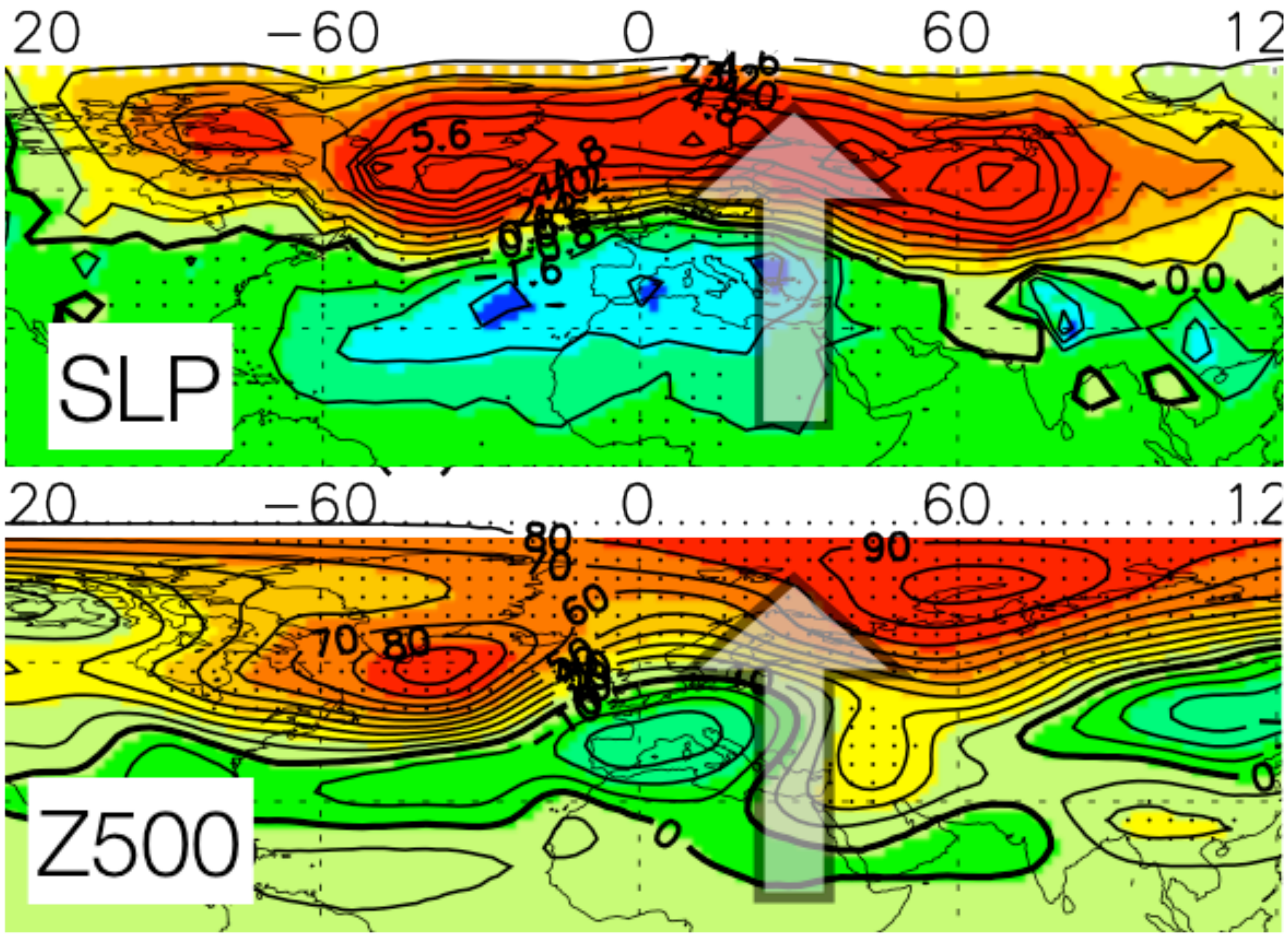

Jerusalem annual (October-September) prcp anomaly: annual (color bars in mm) and low-pass filtered (red line); low pass filtered SST anomalies averaged over the extratropical North Atlantic (30°N to 70°N) in units of $10^{-3}$ °C (in blue). Anomalies are wrt 1961-1990.

The regressions of SST on Jerusalem precipitation. Colors indicate regions where the values are significant at the 10% level (non-directional). Data filtered with a 10-yr low-pass. Units are °C per one standard deviation of the filtered seasonal precipitation time series (~110 mm/yr).




**Cold No. Atl. ⇒ Wetter Levant**

# AMV influences the west-east Mediterranean seesaw

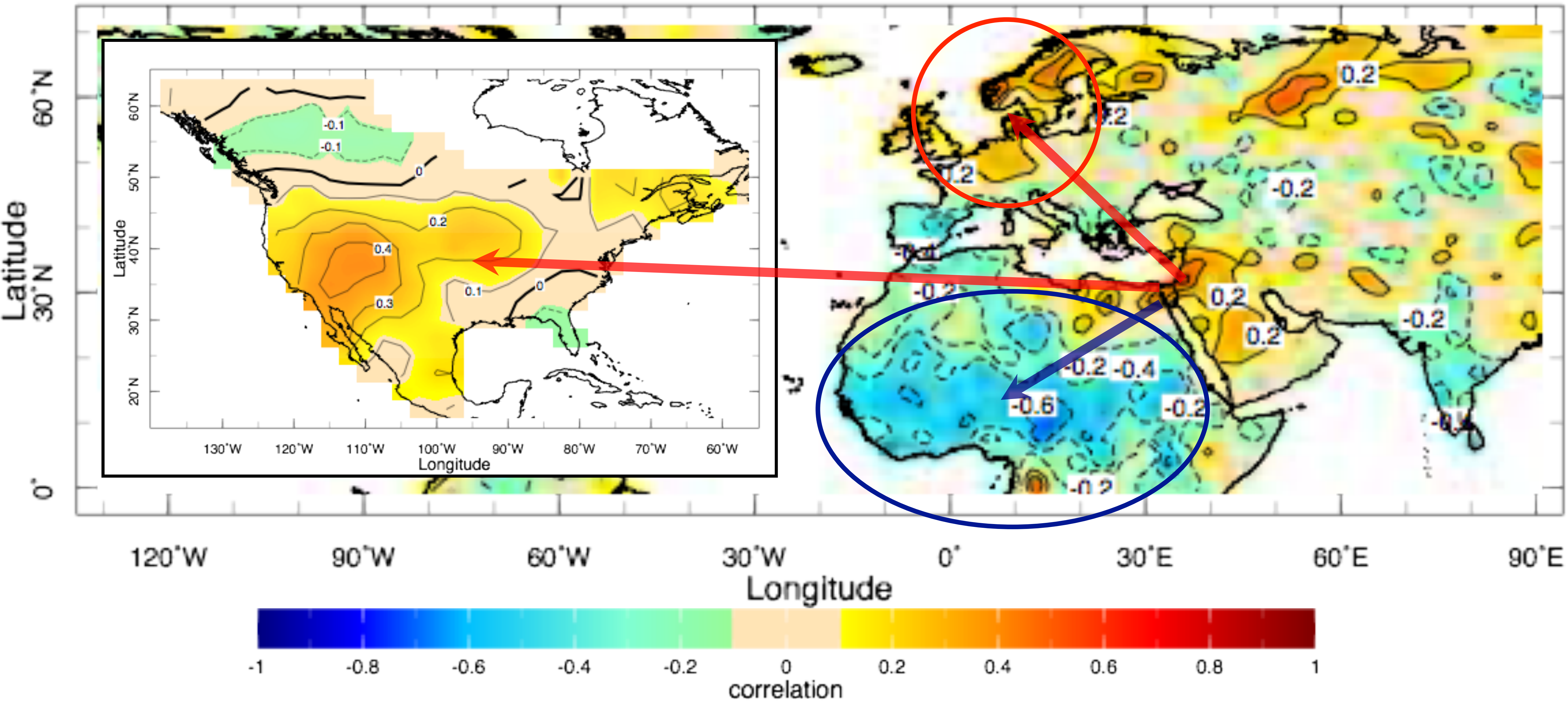



When the AMV is in its warm phase both surface and upper level flows over the Eastern Mediterranean are southerly and cold air incursions from Europe are blocked, leading to reduced cyclogenesis in the and relatively dry weather in the Levant.

The situation is reversed when the Atlantic is cold.

# Jerusalem hemispheric precip teleconnections point at an "Atlantic governor"

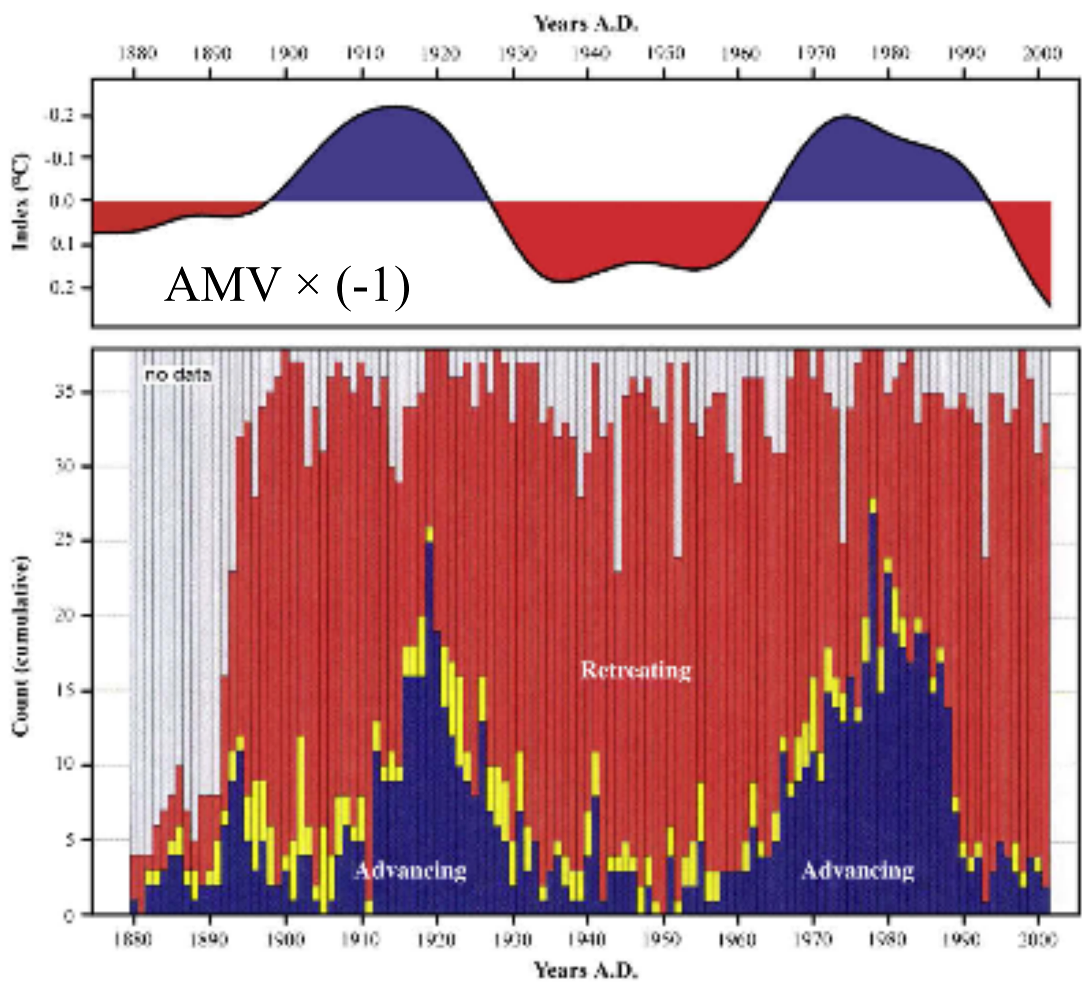
Kushnir and Stein (2010)



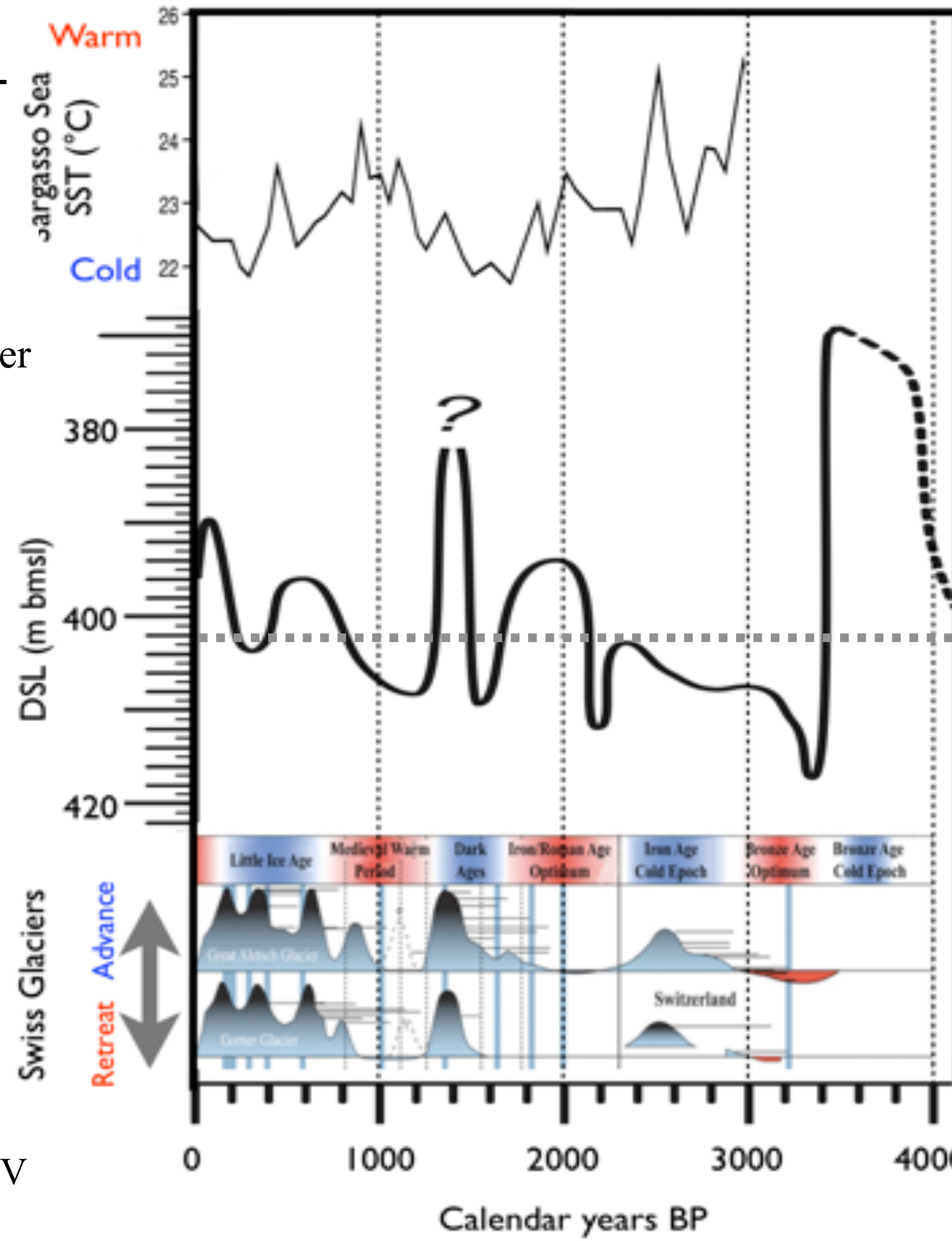

Annual (Oct-Sep) Jerusalem precipitation correlated with precipitation in surrounding land areas. Time series were smoothed by 1 pass of a binomial filter. Precipitation from GPCC 1930-1995. A correlation of 0.38 is significant at the 5% level (non-directional) assuming every fourth sample in the record is independent of the other (*Kushnir and Stein, 2010*).

# 4ooo yr record of DSL-AMV teleconnections

Dead Sea level (DSL) compared with the record of reconstructed Sargasso Sea SST(Keigwin et al., 1995) and Alpine glacier advances and retreats (Schaefer et al., 2009 after Holzhauser et al., 2005).

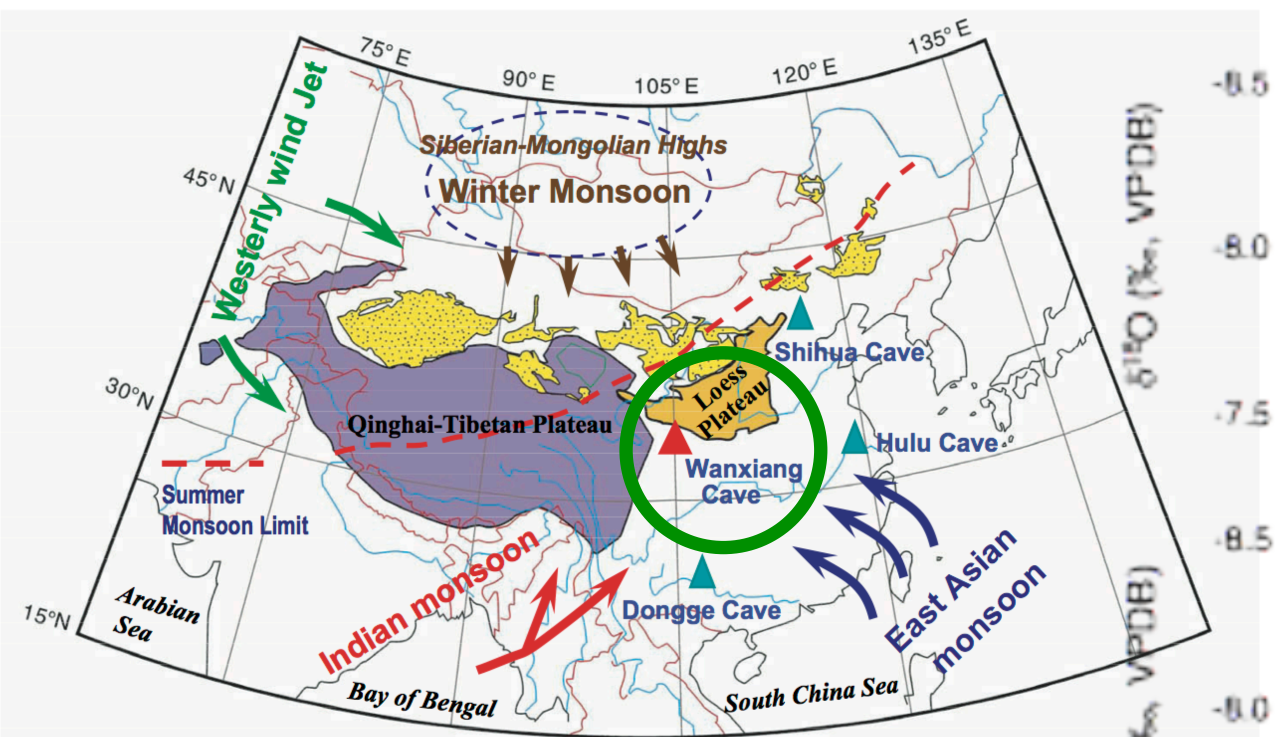


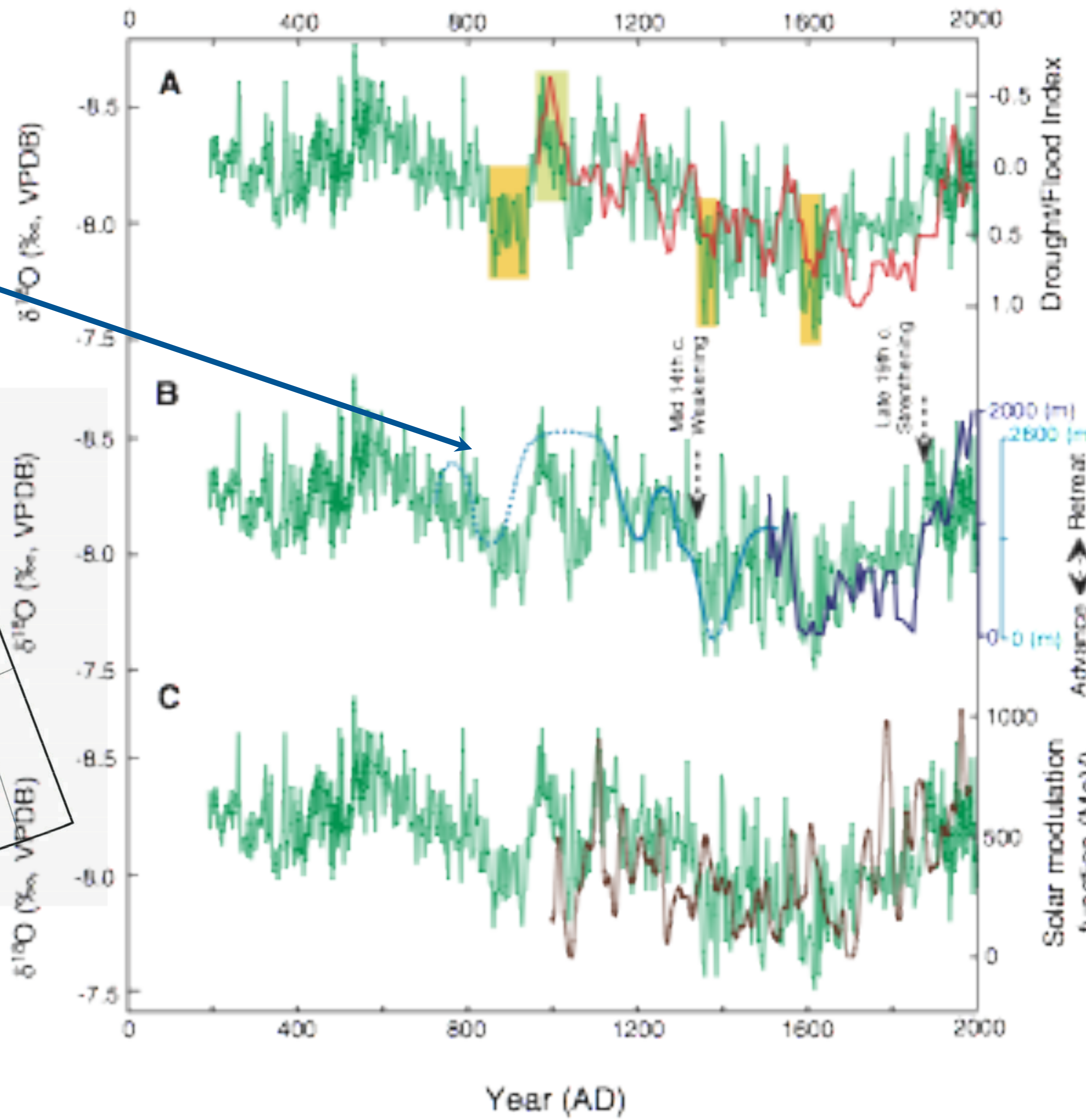

Alpine glaciers advances and retreats track AMV fluctuations (Denton and Brocker, 2008)



# AMV-East Asian monsoon connection

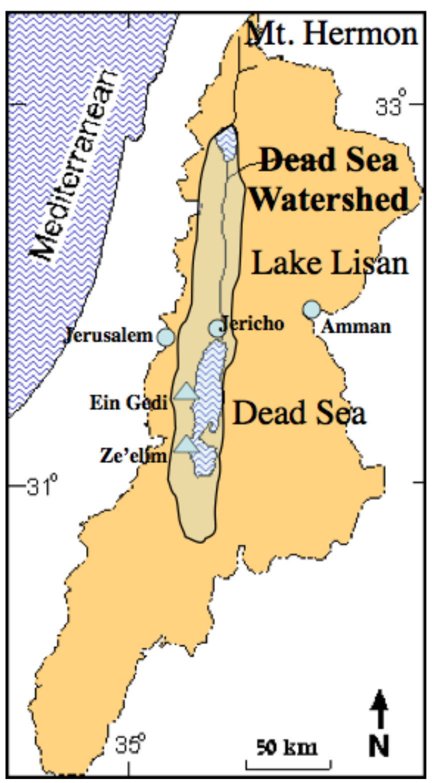
*Zhang et al. (Sceince, 2008)*
Comparisons among Wanxiang Cave, hig-res $\delta^{18}O$ the Longxi drought/flood index, Alpine glacial records, and solar irradiance during the Common Era.

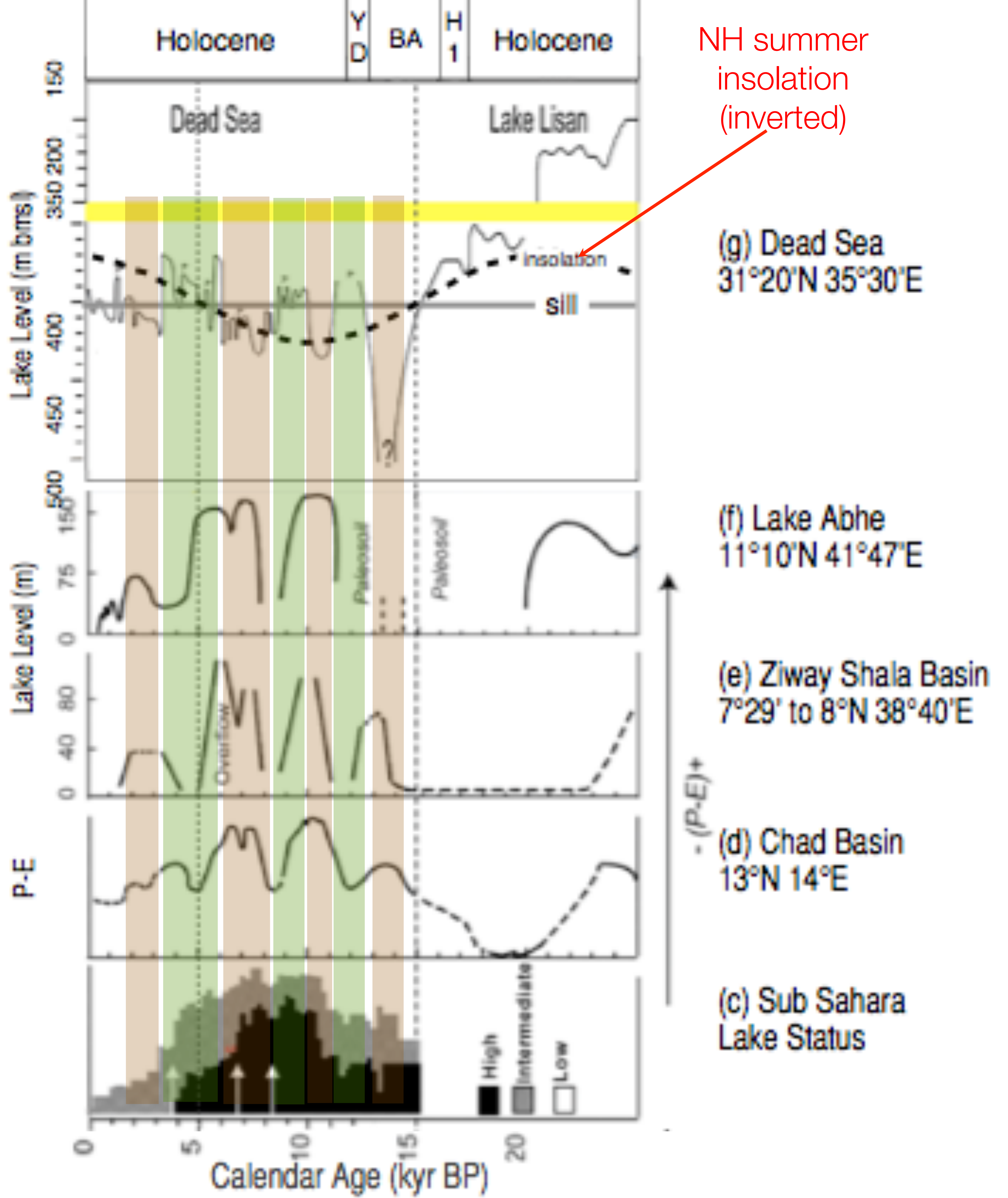


# Holocene Millennial Tele-connections

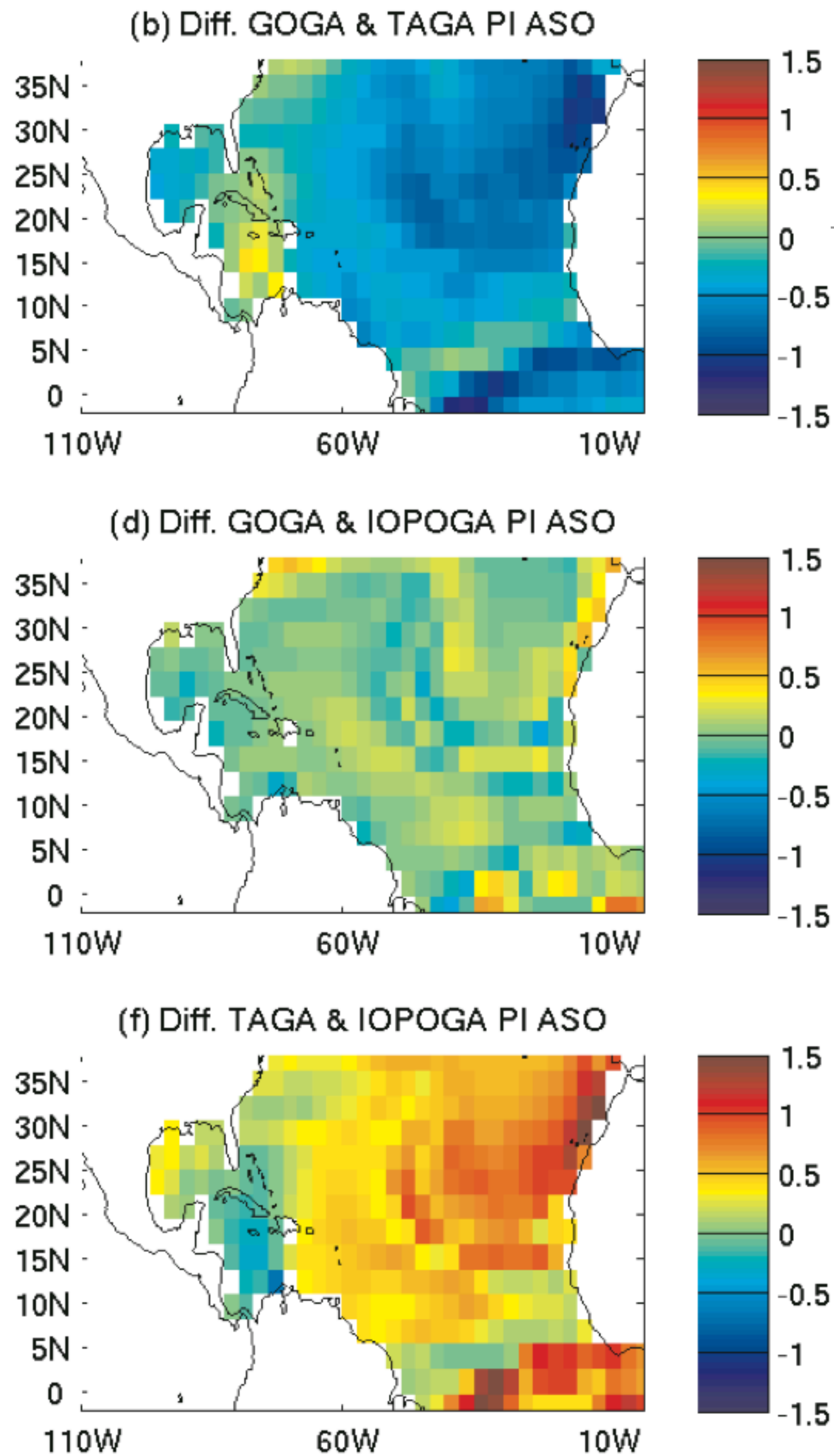
Holocene Dead Sea level variations display anti-phase relationship with sub-Saharan lake levels on epochal and millennial time scales.

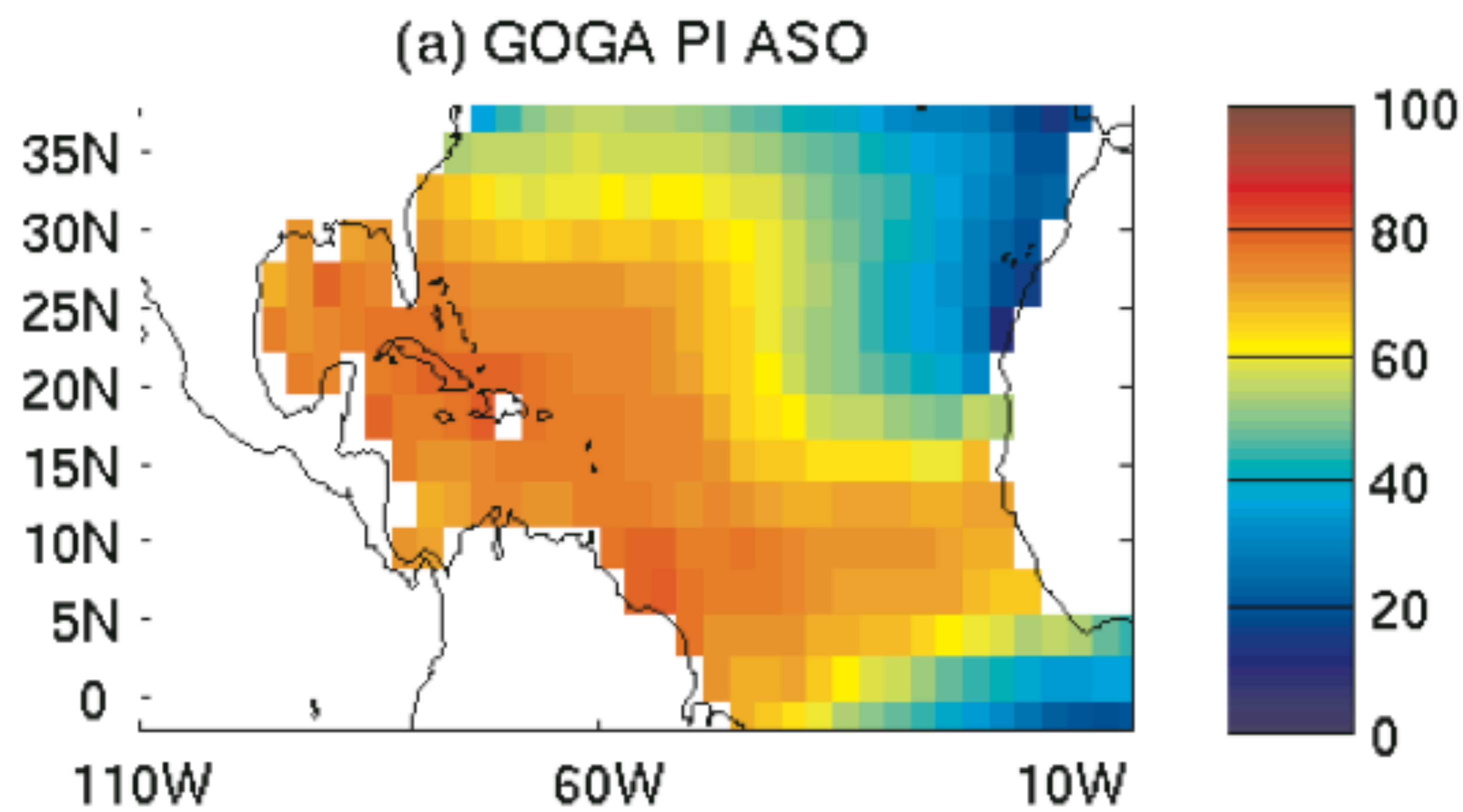



Kushnir and Stein (2010)

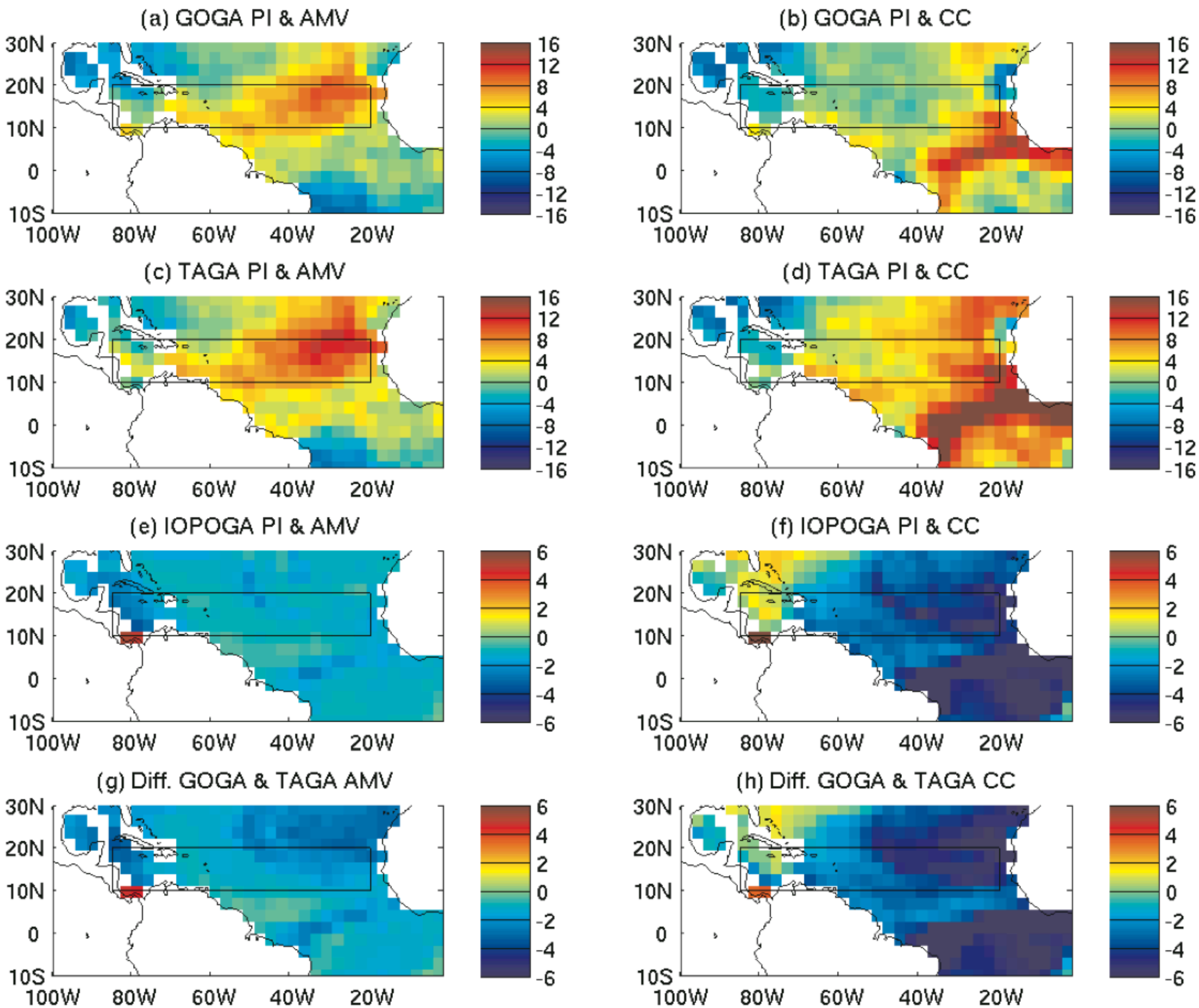
# Tropical Atl. hurricane PI response to remote forcing




- Ensemble mean, 1856 - 2006 climatological PI (m/s) for the peak hurricane season ASO in the tropical Atlantic for (a) GOGA simulation. Differences between climatological PI in ASO for (b) GOGA and TAGA, (d) GOGA and IOPOGA, (e) TAGA and IOPOGA.

# Impact of local and remote forcing on internal and externally forced Atlantic PI variability




Regression of anomalous ASO PI (m/s) on AMV (left panels) and climate change (CC) indices (right panels). Regression pattern of AMV and GOGA (a), TAGA (c), and IOPOGA (e) . Regression pattern of CC index and GOGA (b), TAGA (d), and IOPOGA (f). The difference between the PI regression patterns in GOGA and TAGA are shown in (g) and (h) for the AMV and CC patterns, respectively. The region of the main development region (MDR) is indicated by the black box.

# Summary

- AMV is a prominent low-frequency phenomenon acting on a broad range of time scales and is likely the surface expression of AMOC variability.
- AMV impact climate in and around the Atlantic Basin as far as the South Atlantic and Asia and affests decadal variations in global surface temperature and precipitation.
- AMV played an important role in orchestrating significant multidecadal to millennial variability across the NH and beyond, throughout the past.
- Questions:
  - What are the dynamical mechanisms involved in shaping the AMV, particularly its tropical arm?
  - What is the response of AMV to different sources of external forcing: solar, volcanoes, $CO_2$, aerosols?
  - How do we build on the emerging predictive skill?