The Atlantic Multidecadal Oscillation: Impacts, mechanisms & projections

David Enfield, Chunzai Wang, Sang-ki Lee
NOAA Atlantic Oceanographic & Meteorological Lab Miami, Florida

Luis Cid-Serrano
Dept. Statistics, Universidad de Concepción, Chile

<u>Some relevant publications:</u>

Enfield, D.B., A.M. Mestas-Nuñez, and P.J. Trimble, 2001: The Atlantic multidecadal oscillation and its relationship to rainfall and river flows in the continental U.S.. *Geophys. Res. Lett.*, 28: 2077-2080.

Goldenberg, S.B., C.W. Landsea, A.M. Mestas-Nuñez, and W.M. Gray, 2001: The recent increase in Atlantic hurricane activity: Causes & implications. *Science*.

Enfield, D.B., and L. Cid-Serrano, 2006: Projecting the risk of future climate shifts. *Int'l J. Climatology*, 26: 885-895.

Wang, C., S.-K. Lee, and D.B. Enfield, 2008: Climate response to anomalously large and small Atlantic warm pools in summer. *J. Climate* 2437-2450.

Atlantic Oceanographic & Meteorological Laboratory
National Oceanic & Atmospheric Administration

In this talk, we shall ….

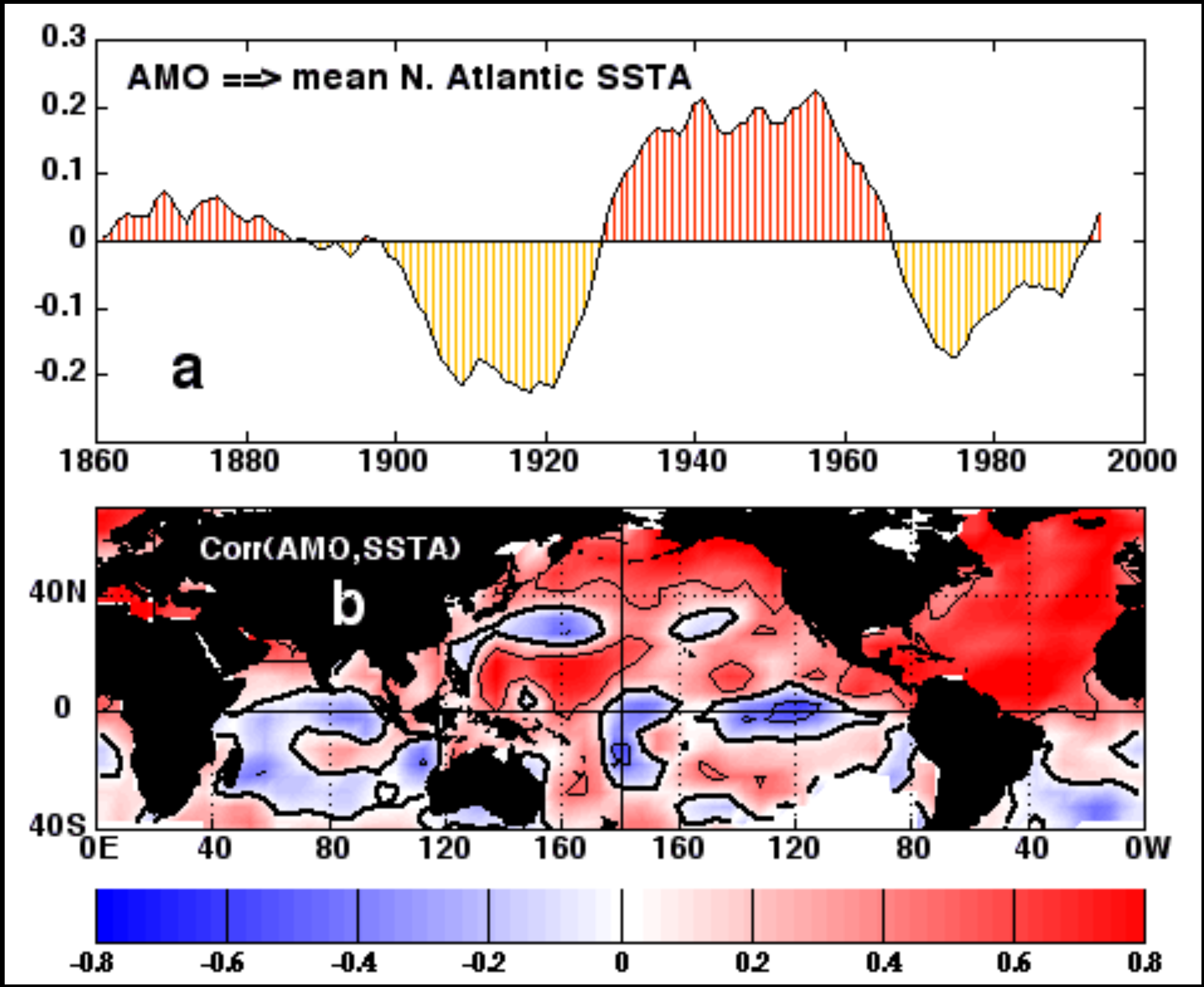
… describe the AMO & importance to climate & water resources,

… discuss proposed mechanisms for AMO & its impacts

… discuss the prospects for model-based predictions,

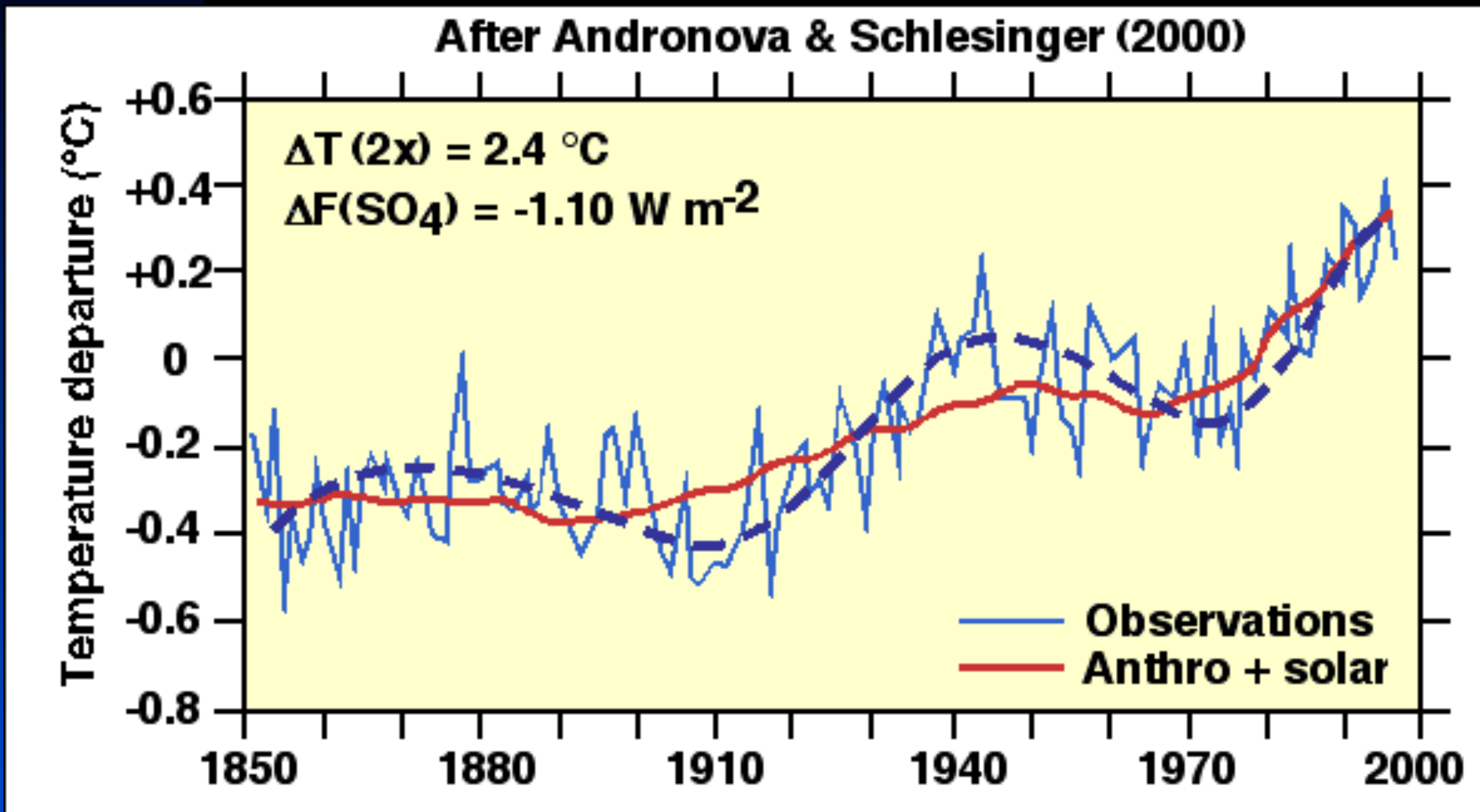
… show how probability analysis of proxy reconstructions can allow us to make risk projections for future AMO regime shifts,

… A multidecadal oscillation of SST found mainly in the North Atlantic — the Atlantic multidecadal oscillation (AMO)



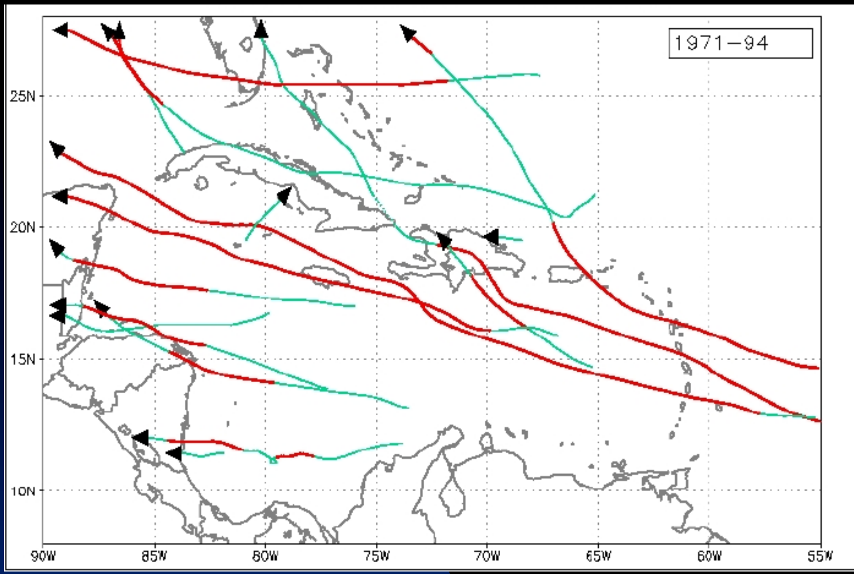
Global warming model w/ greenhouse gases & solar forcing (red)

- …residual fluctuations (blue) not explained by GHGs (red)
- …implies that residual reflects natural fluctuations in SST

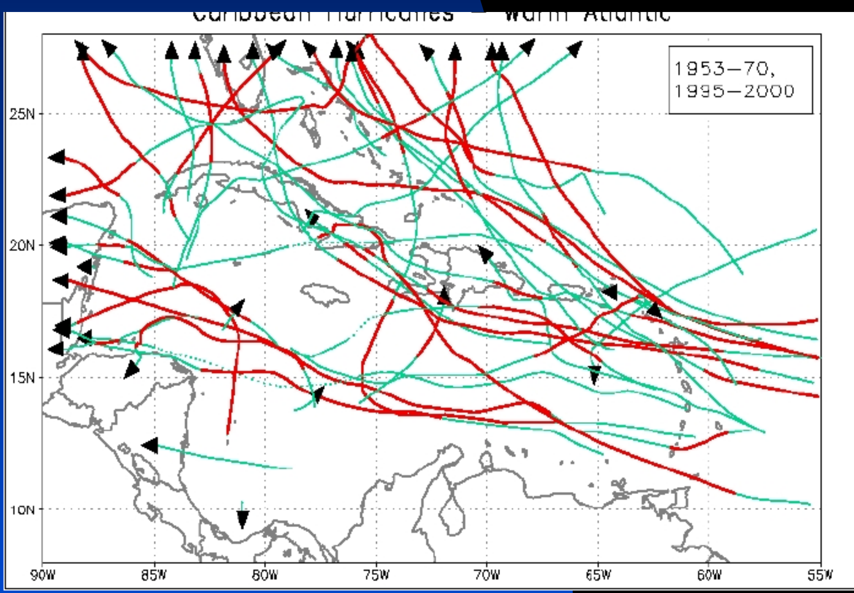


NOAA Atlantic Oceanographic & Meteorological Laboratory

Cool Atlantic



Warm Atlantic



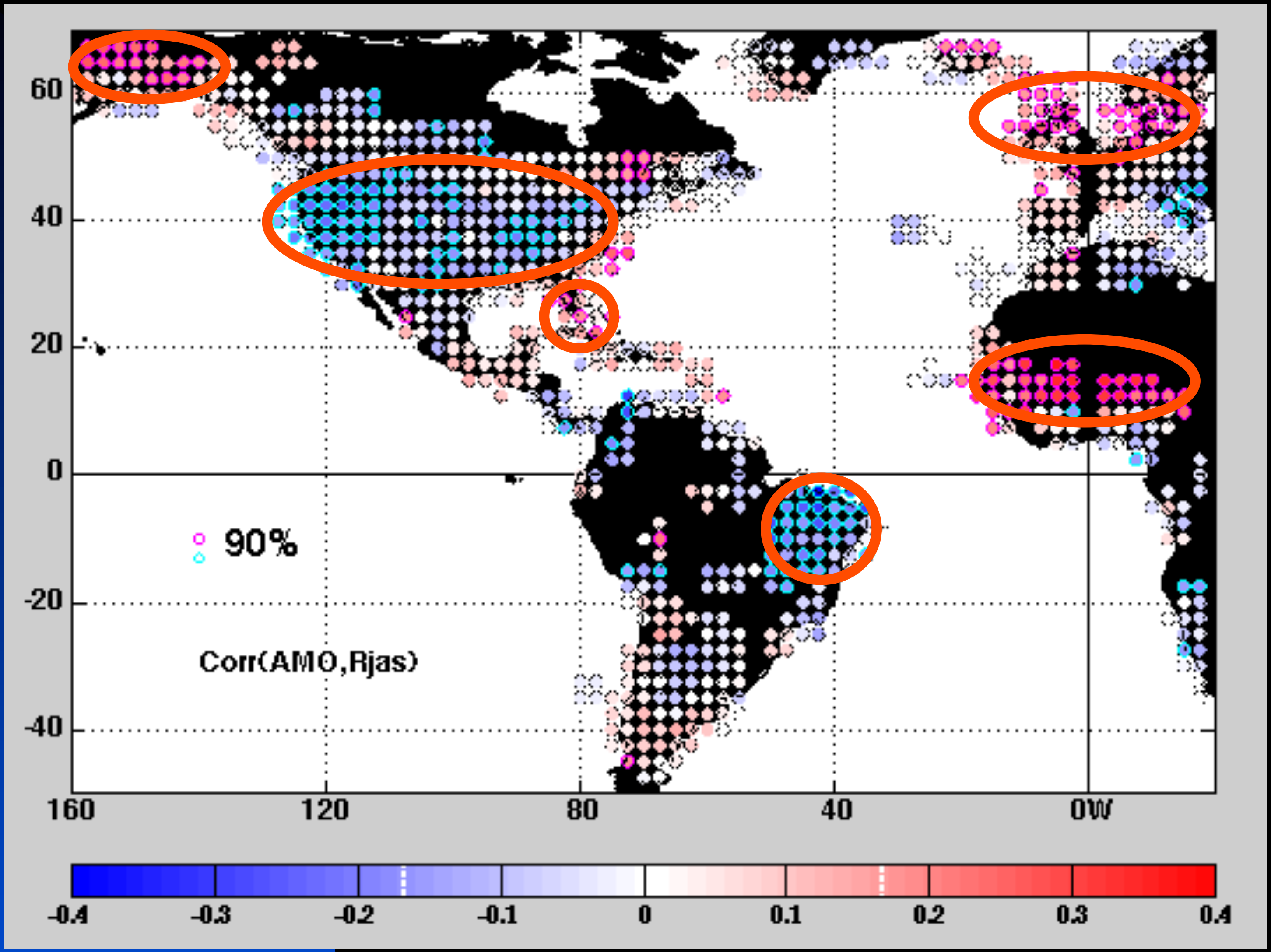
Goldenberg et al. (Science, 2001)

- 1971-1994 ==> 25 years of AMO cool phase.
- Only 15 major hurricanes and US landfalling hurricanes are infrequent.
- Then: Windstorm insurance is cheap. Underwriters and actuaries are unaware of climate risk shifts.

- 1953-1970 & 1995-2000 ==> 25 years of AMO warm phase.
- 33 major hurricanes and frequent US landfalling hurricanes.
- Now: Windstorm insurance skyrockets. Wide public consciousness of the AMO-related shift in risk.

NOAA Atlantic Oceanographic & Meteorological Laboratory

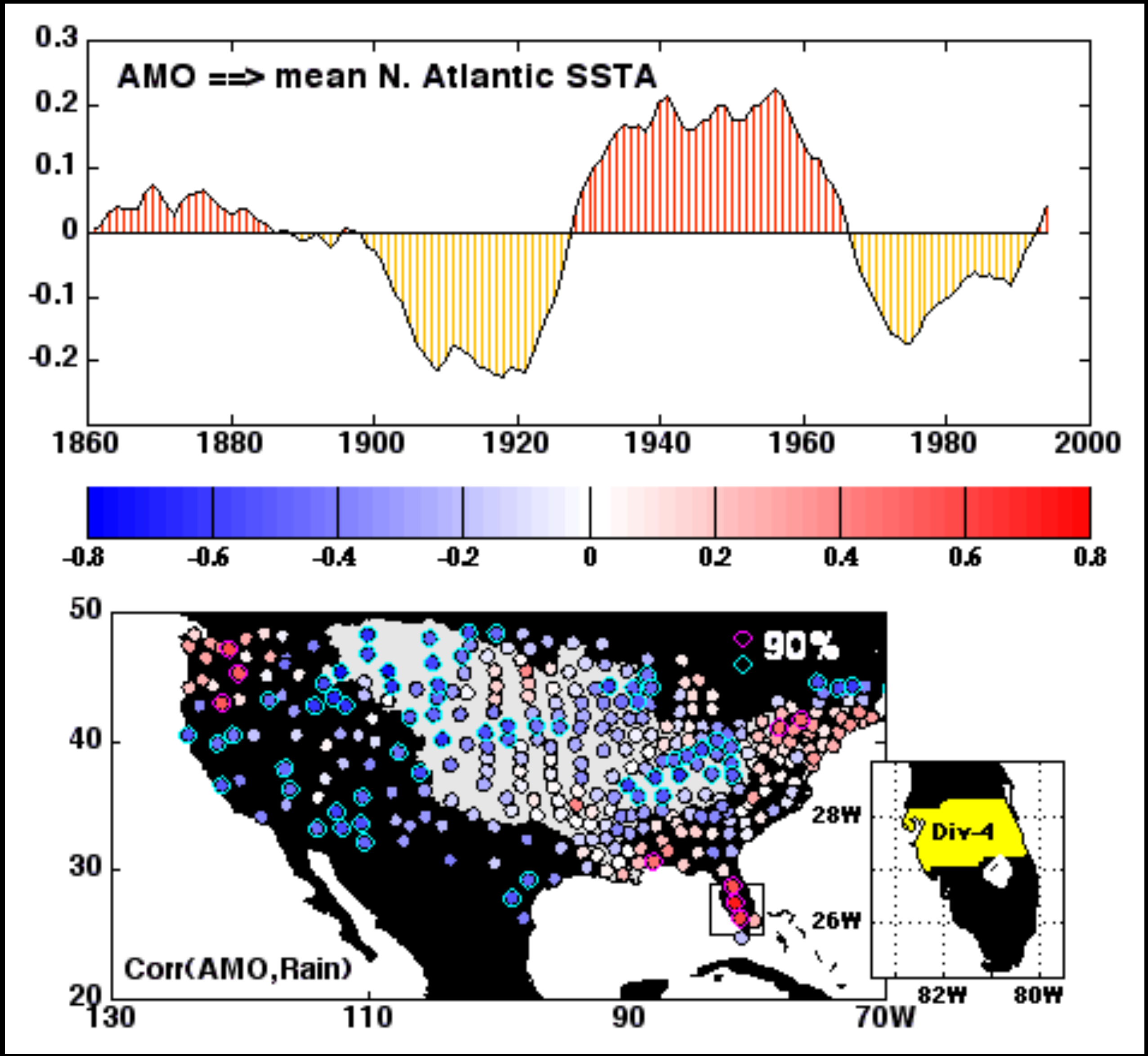
Correlation of AMO vs. July-September rainfall



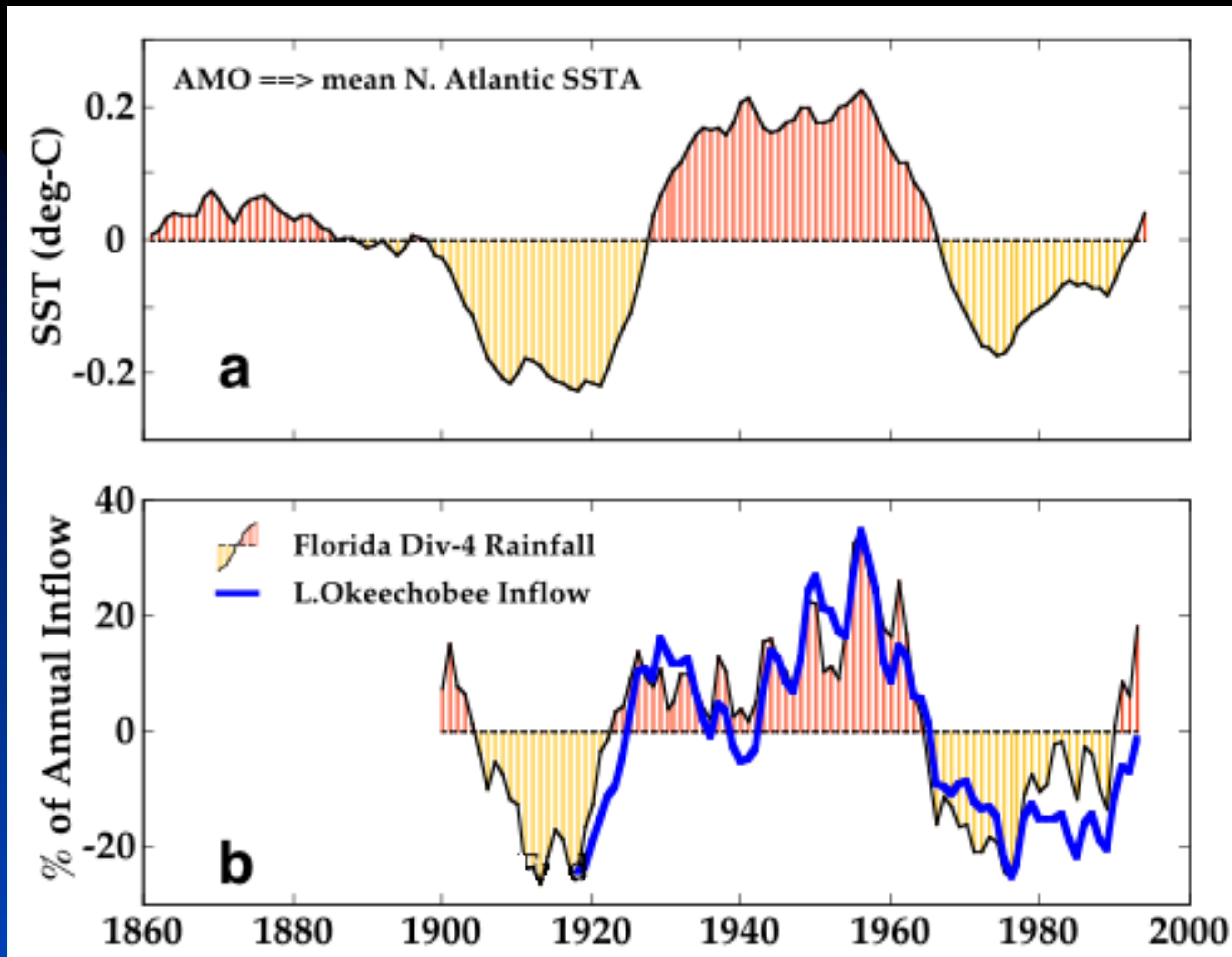
NOAA Atlantic Oceanographic & Meteorological Laboratory

Correlation of AMO with U.S. divisional rainfall (1895-1999)

Enfield et al. (2001)



Lake Okeechobee inflow vs. AMO

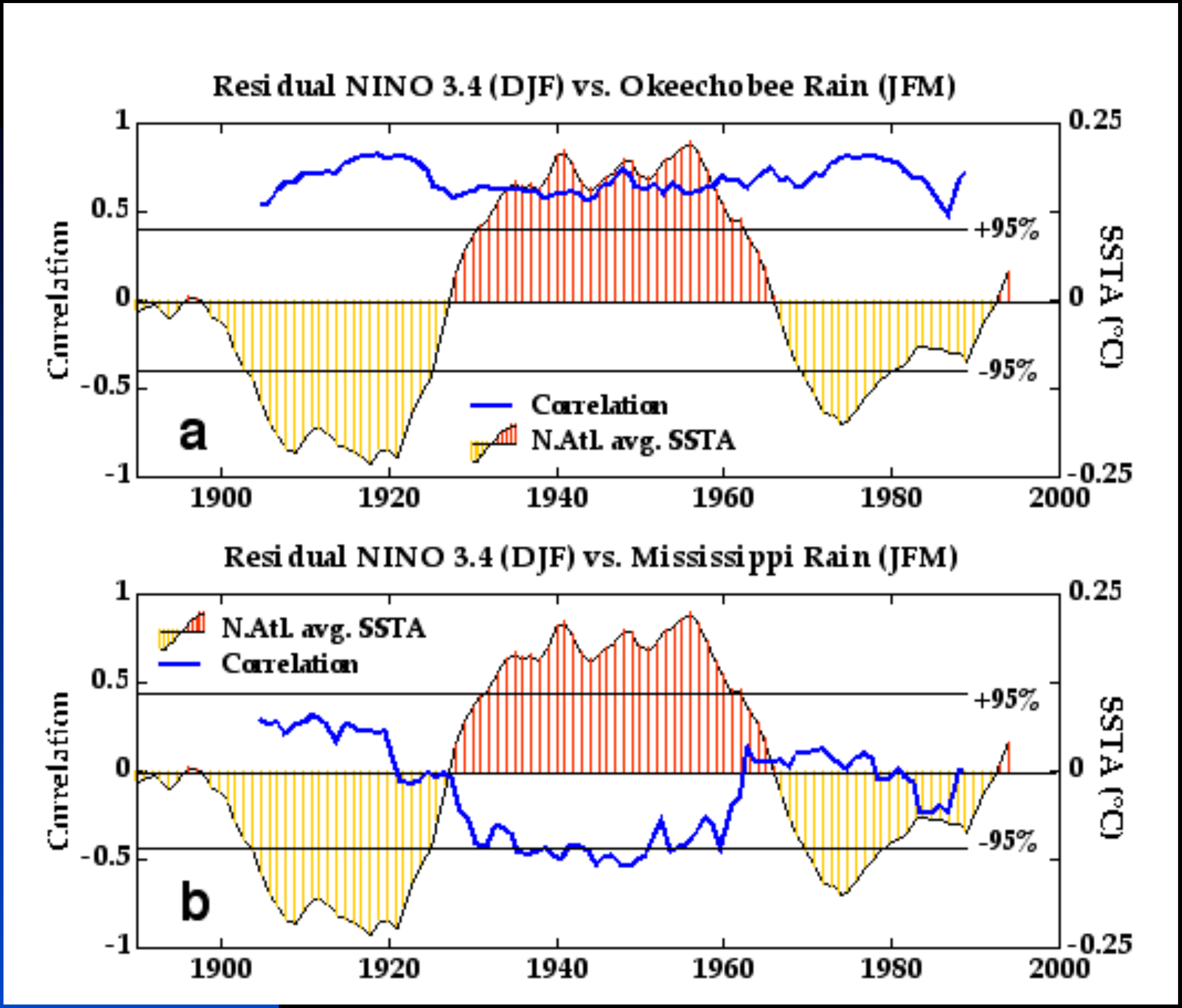


NOAA Atlantic Oceanographic & Meteorological Laboratory

SW Florida WMD Report (2003)

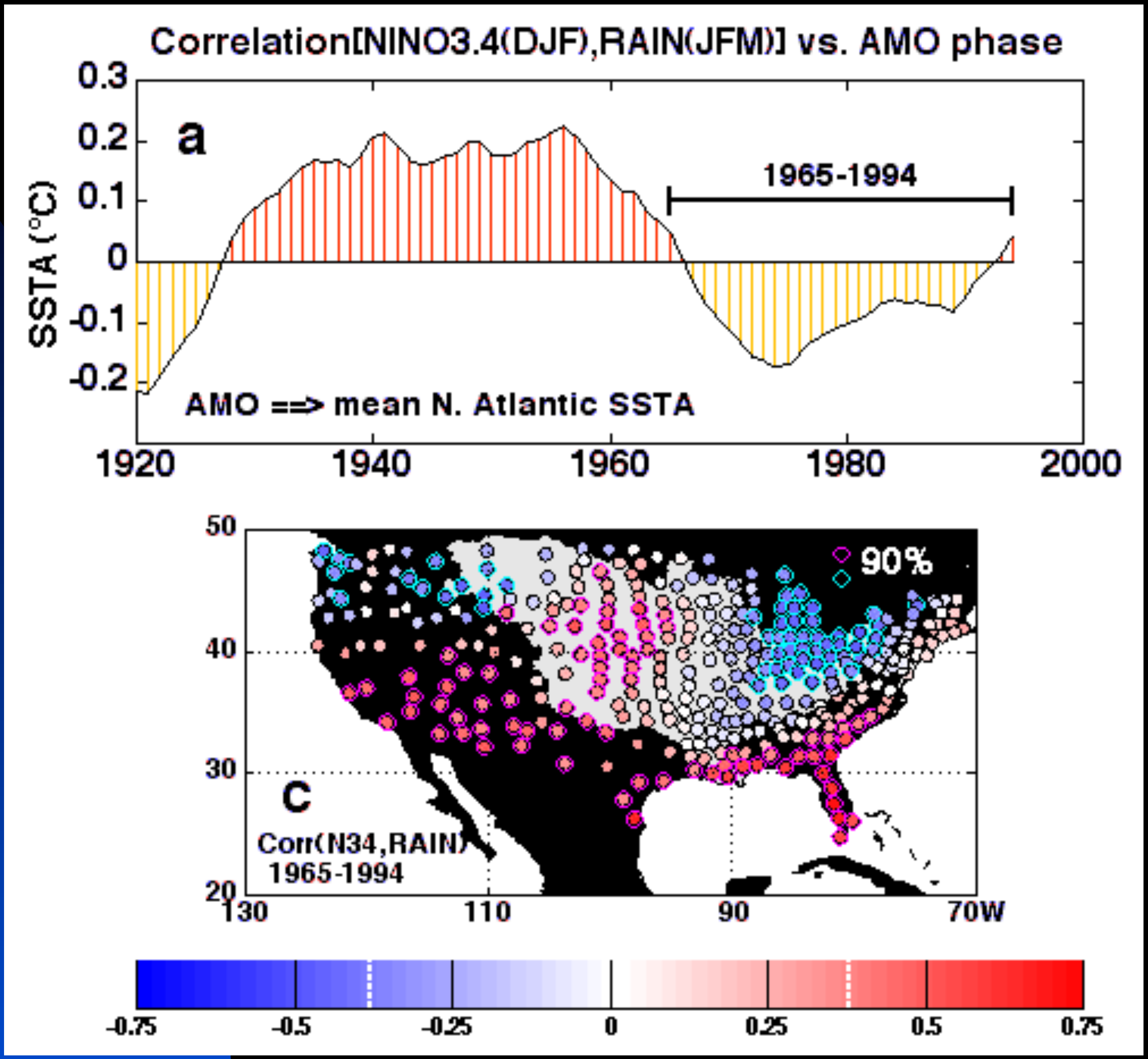
Long-term variation in Rainfall and its effect on Peace River Flow in West-Central Florida

20-year running correlations



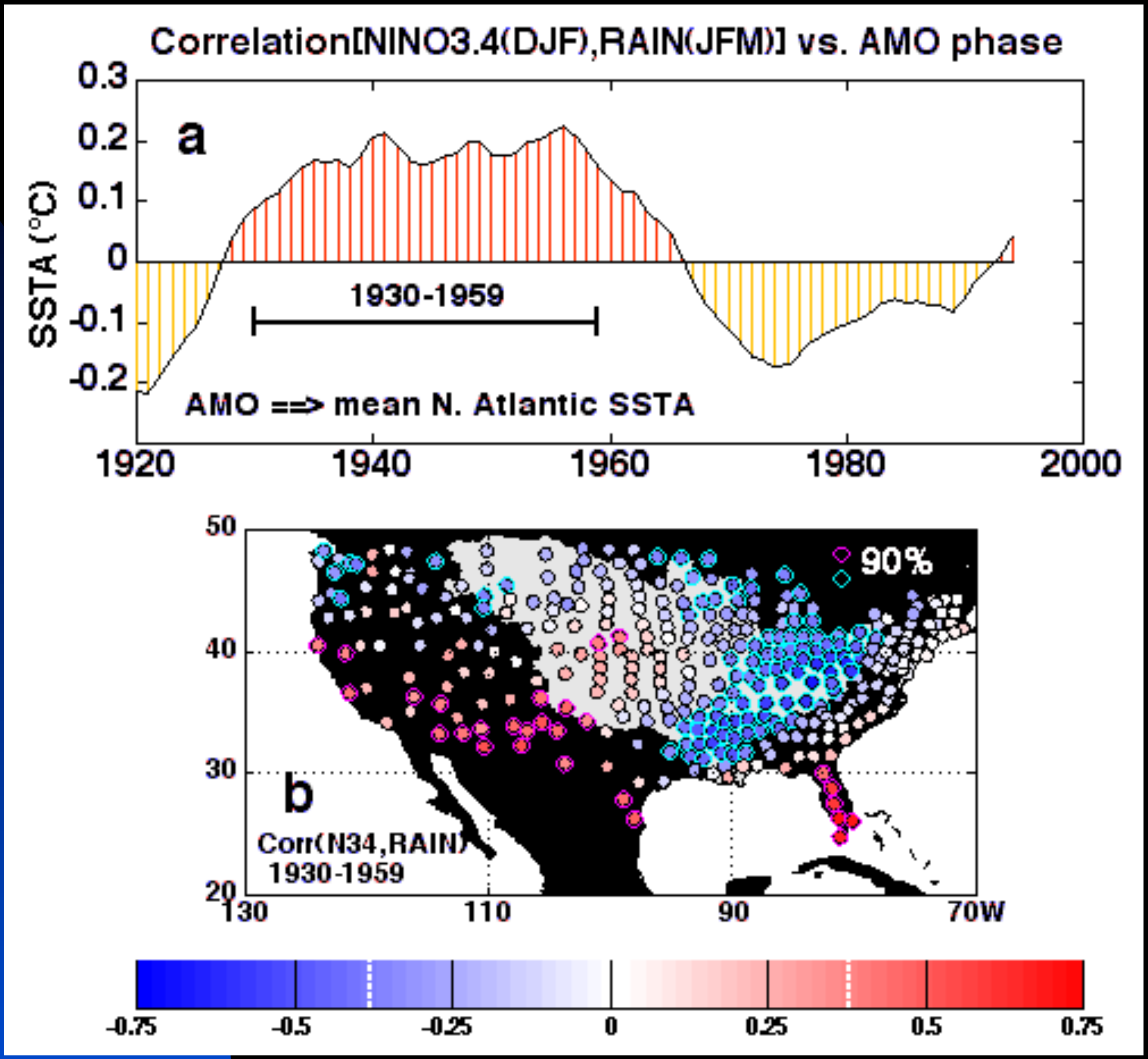
NOAA Atlantic Oceanographic & Meteorological Laboratory

AMO⁻ ==> 1965-1994



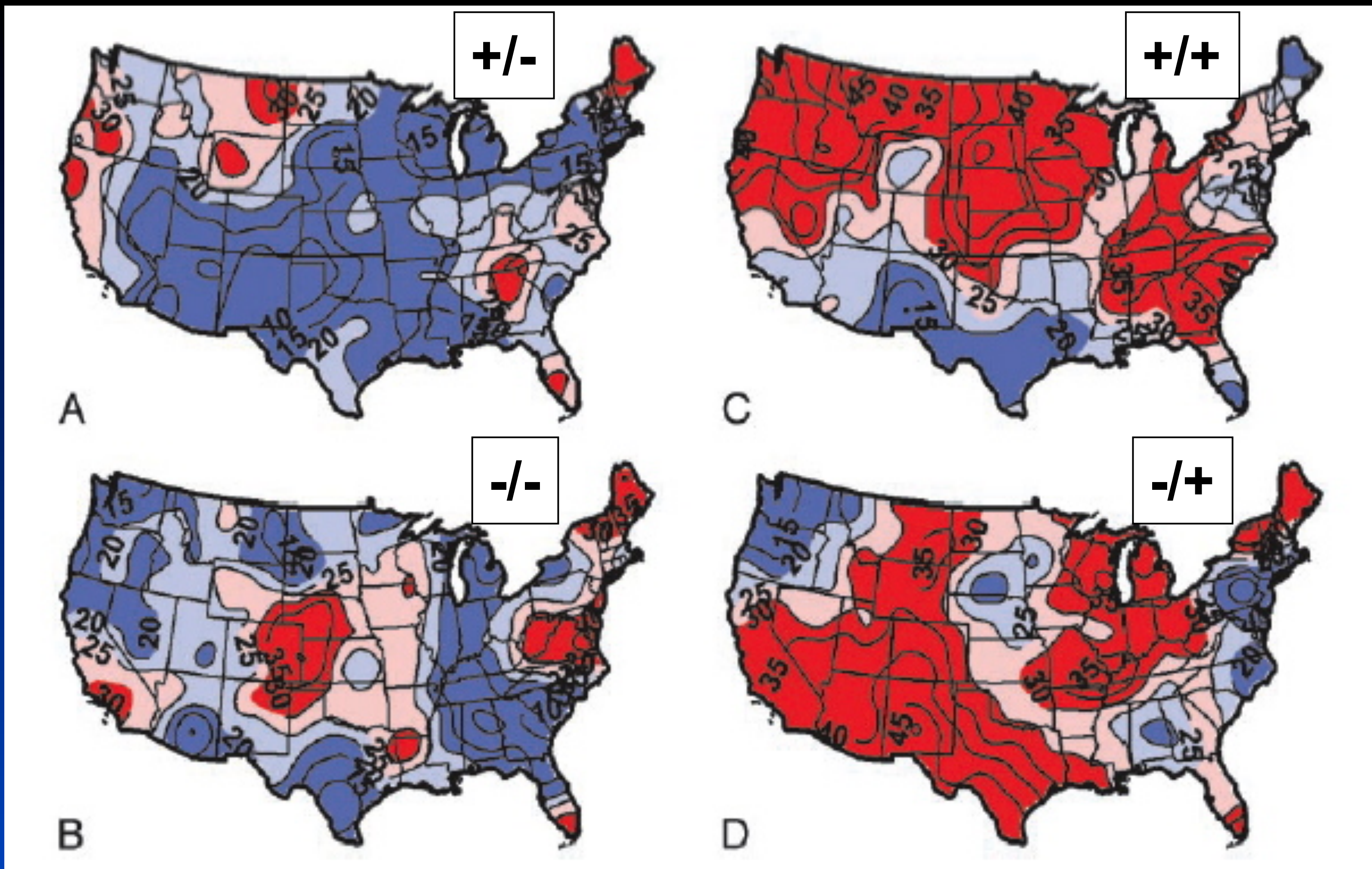
NOAA Atlantic Oceanographic & Meteorological Laboratory

AMO+ ==> 1930-1959



NOAA Atlantic Oceanographic & Meteorological Laboratory

Together , PDO/AMO govern US mega-droughts

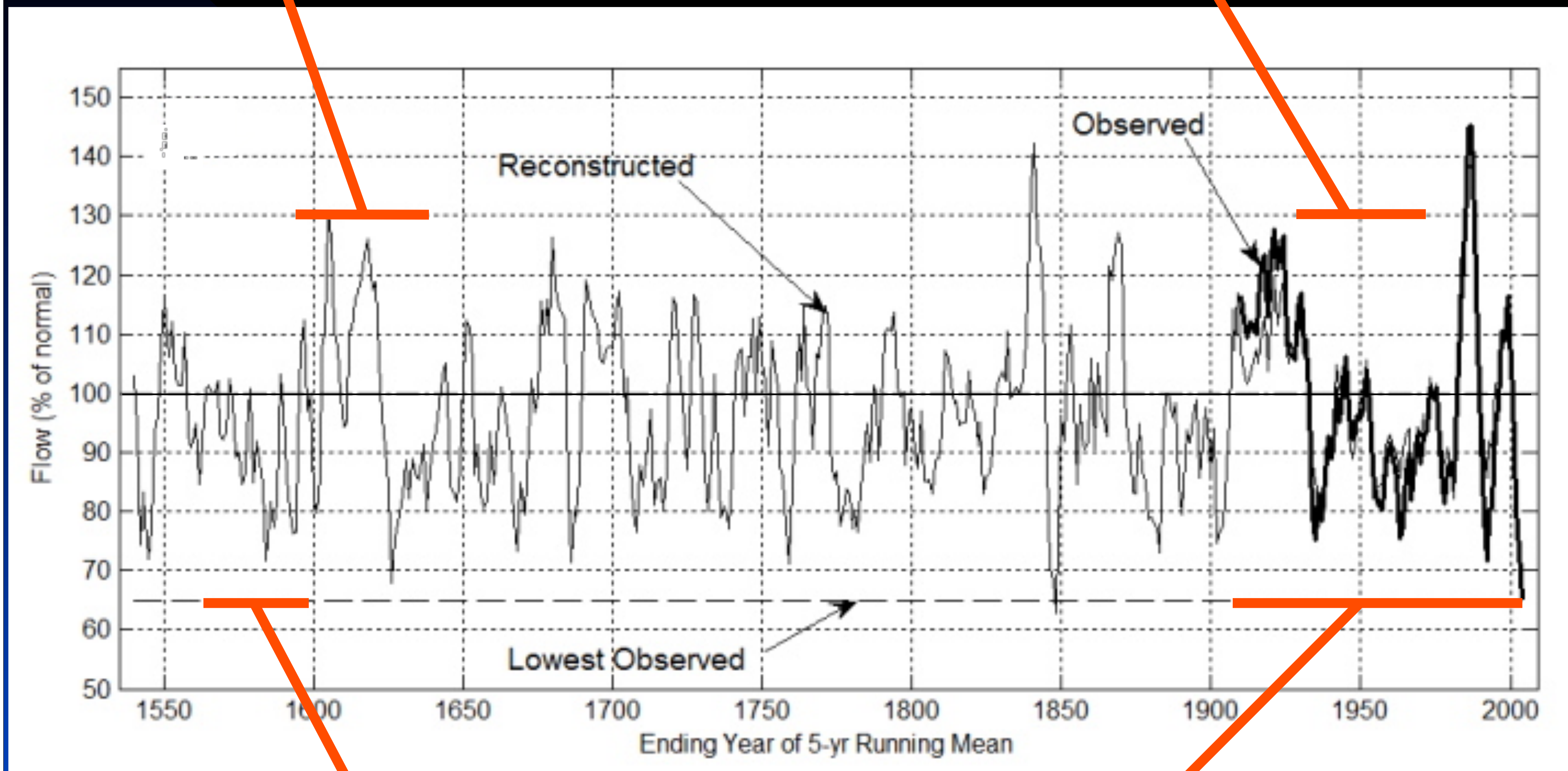


McCabe et al., 2004

Lees Ferry (dark) & reconstruction (light)

Good water supply, low AMO

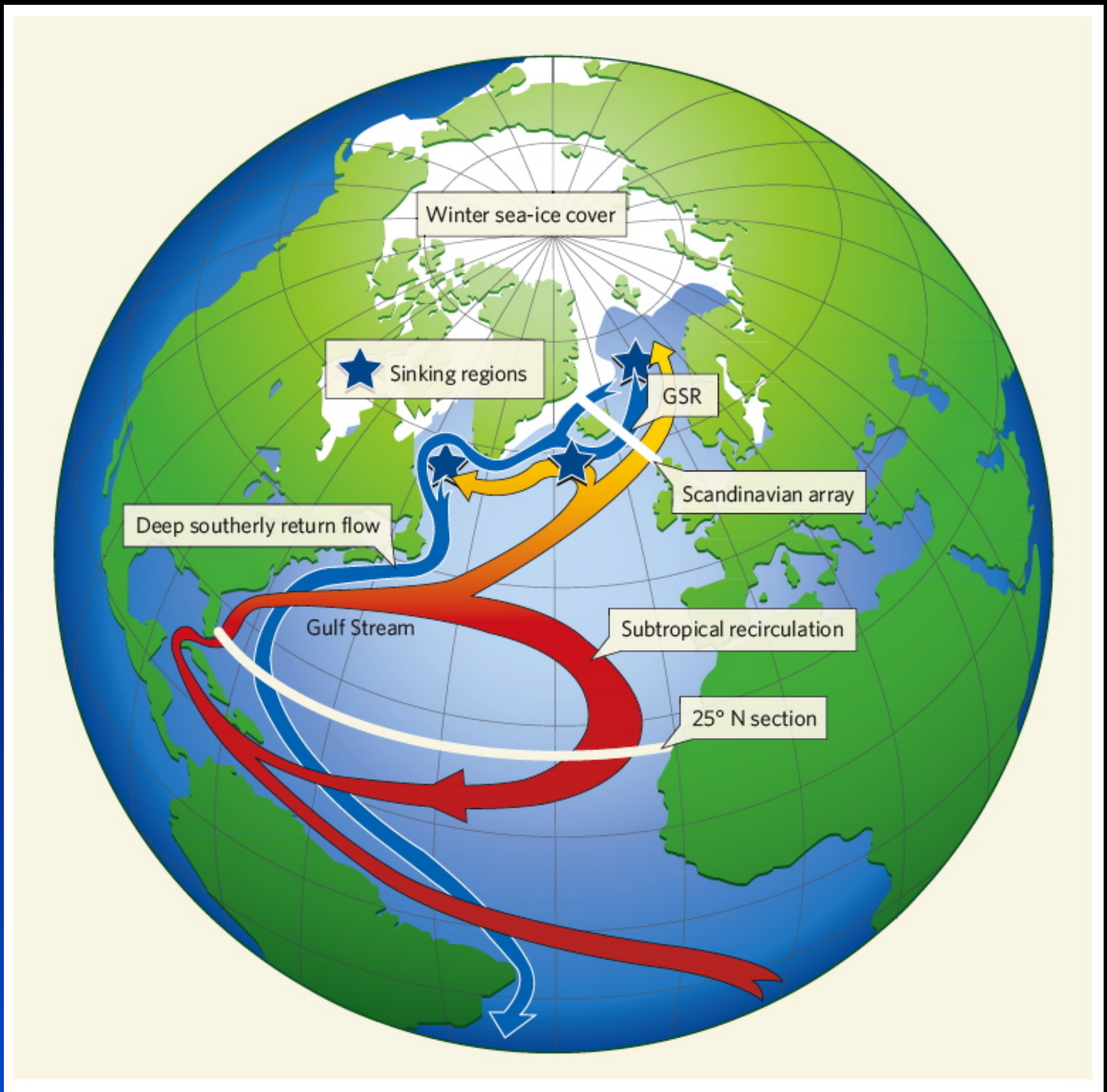
2 severe droughts, high AMO



Severe drought, high AMO

High-quality calibration

NOAA Atlantic Oceanographic & Meteorological Laboratory



Coupled numerical models suggest that the engine for the AMO involves the Meridional Overturning Circulation (MOC) of the Atlantic Ocean…

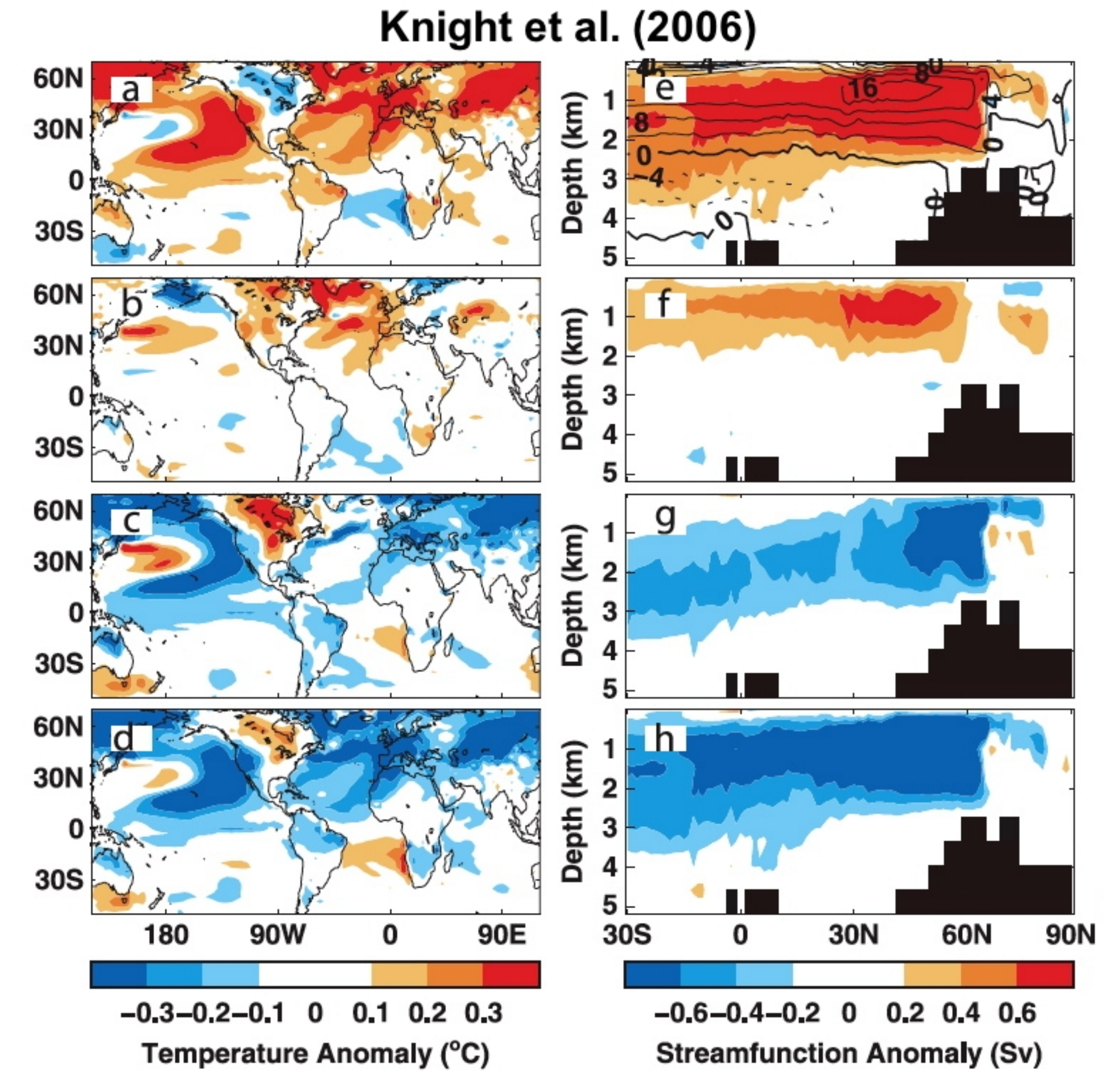
…aka the “global conveyor belt”

References:

Delworth and Mann (Climate Dynamics, 2000)

Knight et al. (GRL, 2005)

AMO <==> Overturning circulation (A-MOC)



Coupled GCMs with a dynamical ocean & without external foring suggest that the engine for the AMO involves the Atlantic Meridional Overturning Circulation (A-MOC) …

<u>References</u>:

Delworth (1993)
Delworth and Mann (2000)
Latif et al. (2004)
Knight et al. (GRL, 2005)

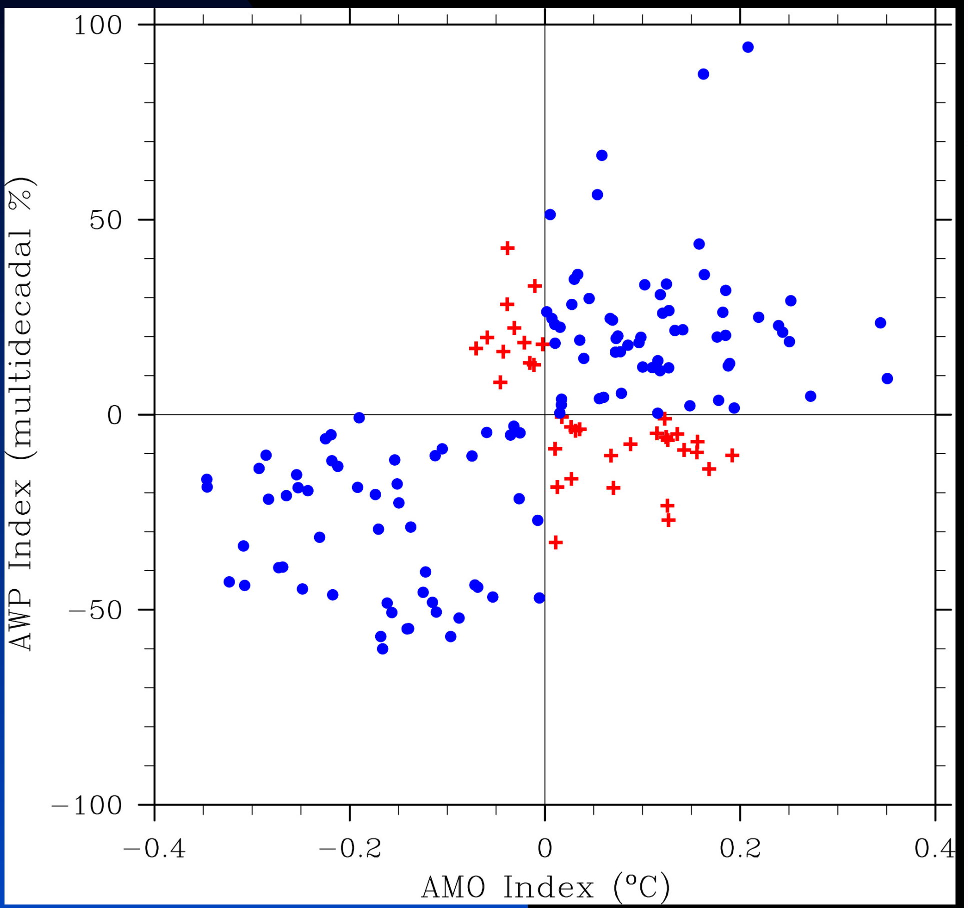
The A-MOC mechanism is also consistent with observations …

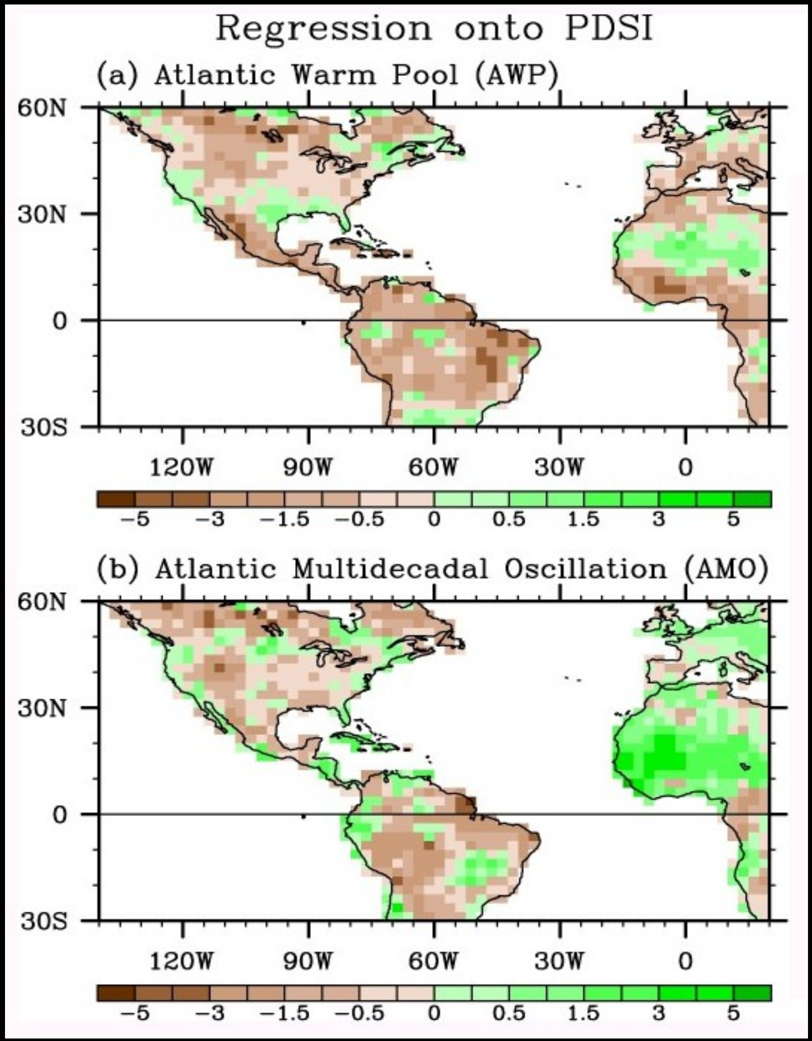
<u>Reference</u>:

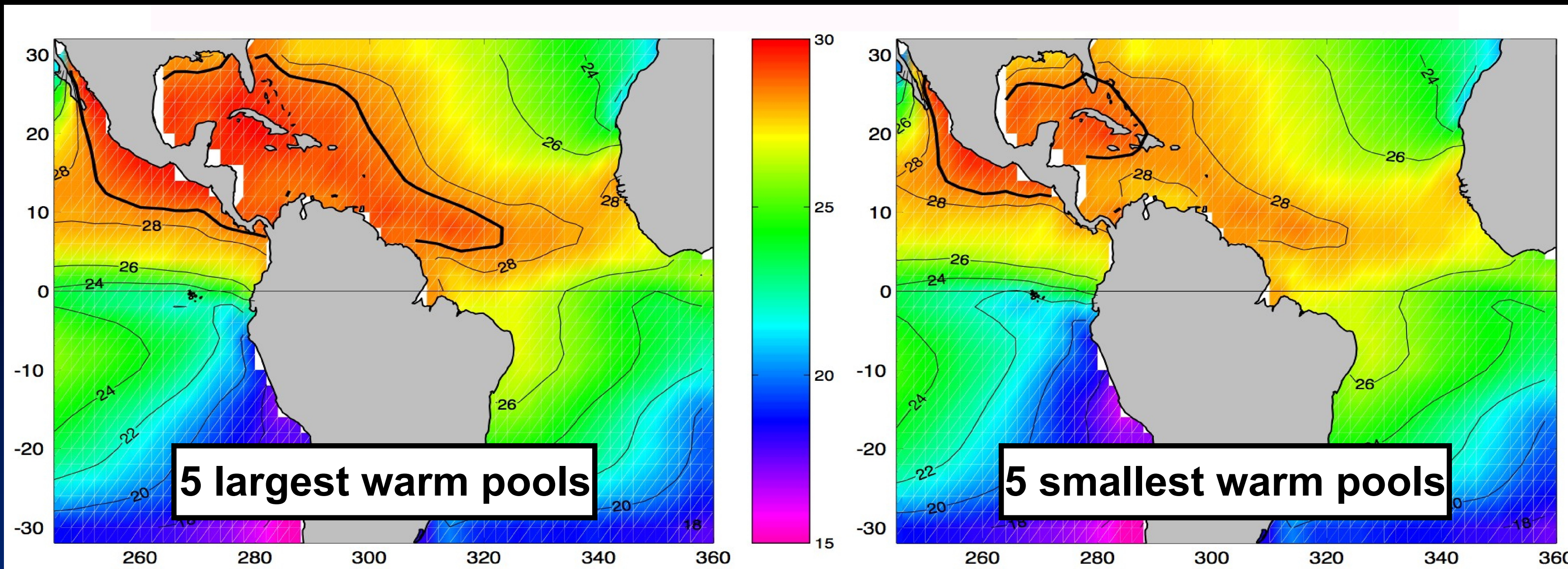
Dima & Lohmann (2006)

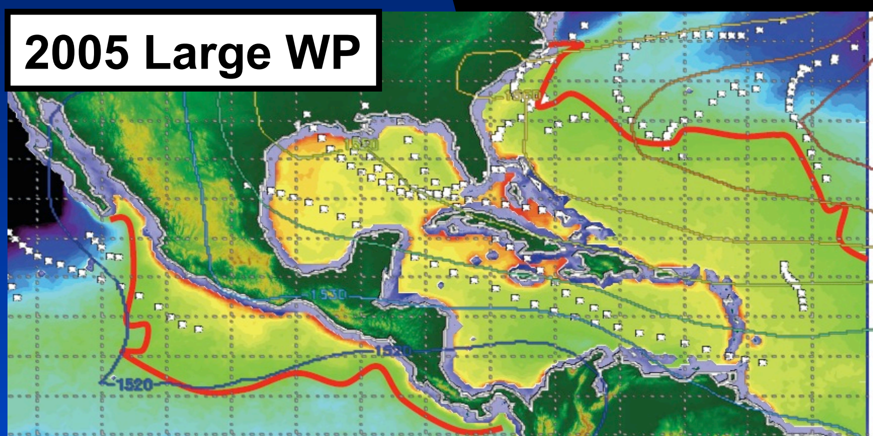
AMO & AWP ==> similar impacts
Rainfall regressions very similar

80% of large (small) AWPs occur during AMO+ (-)

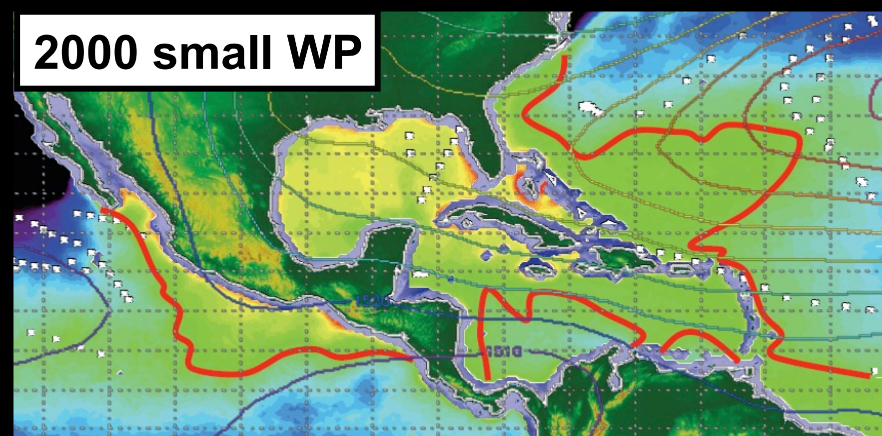






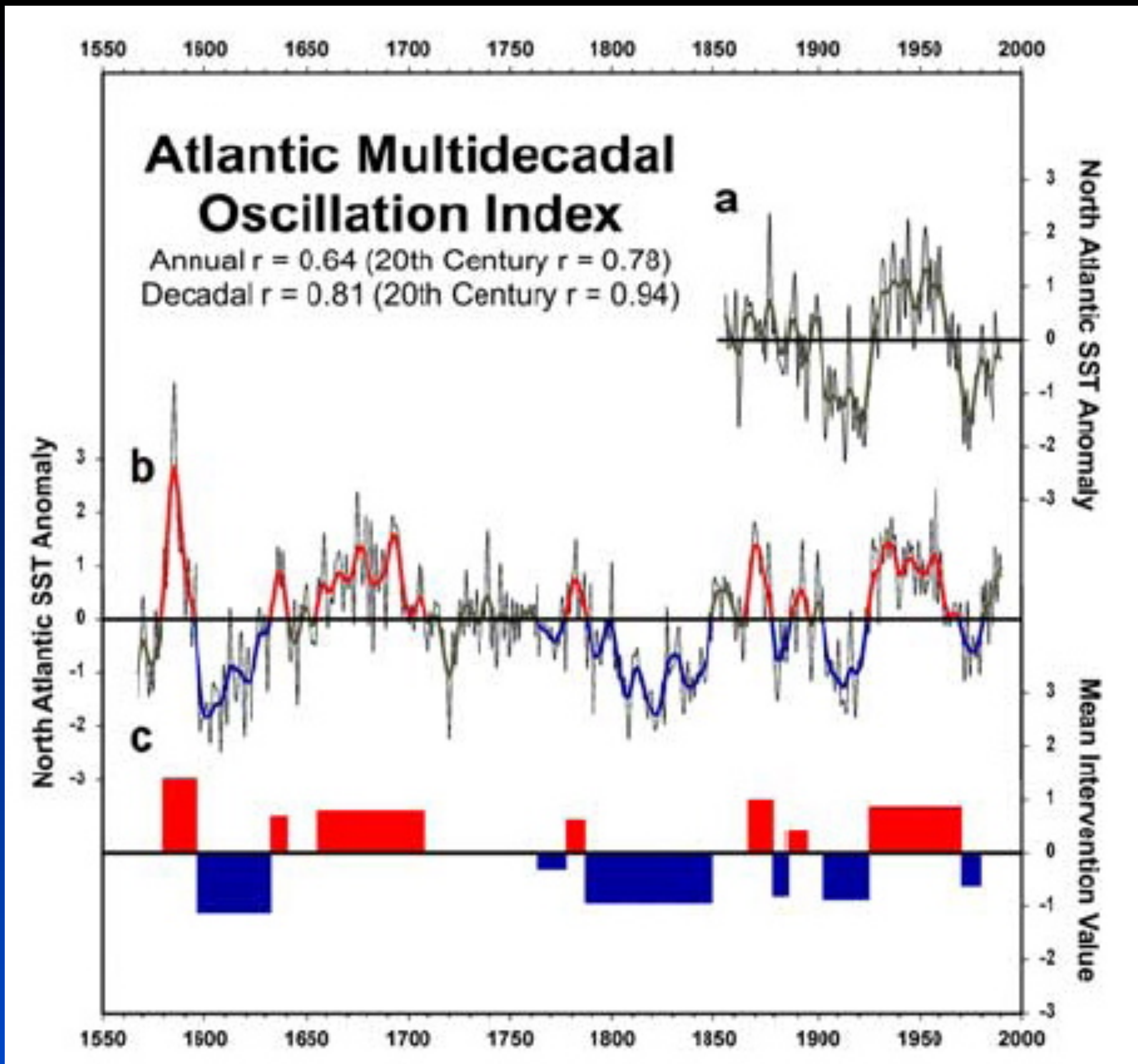


TMI SST (28.5C red) and >50 knot TCs and Z850



TMI SST (28.5C red) and >50 knot TCs and Z850

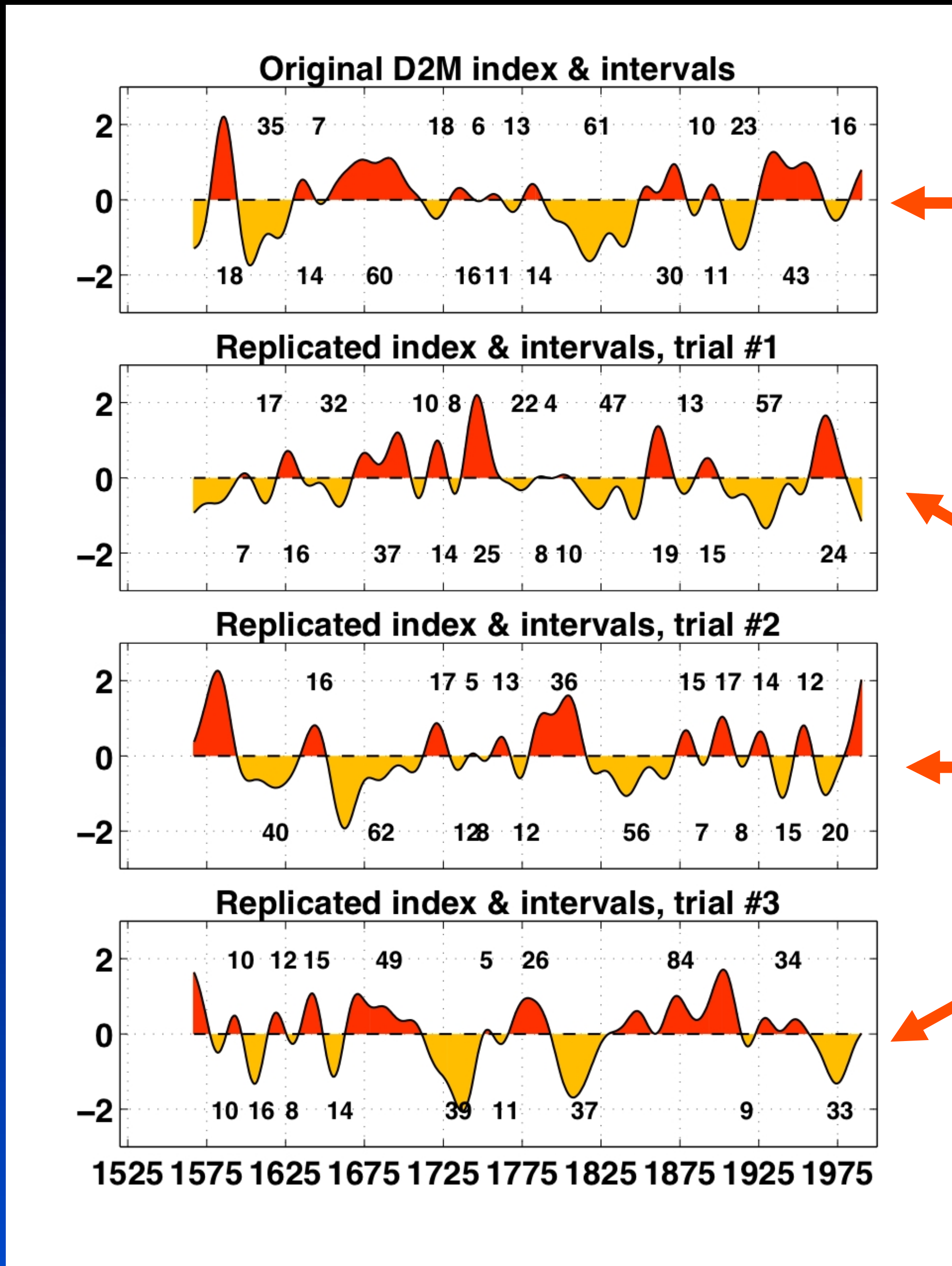
Gray et al. (2004) AMO reconstruction



Eastern US and European tree rings have been “calibrated” to give an extended 425-year index of the AMO.

The extended AMO proxy (b) correlates highly with the instumental index (a) and allows us to identify long and short regime intervals of the AMO (c).

Strong evidence that the AMO is a natural climate mode, not anthropogenic.



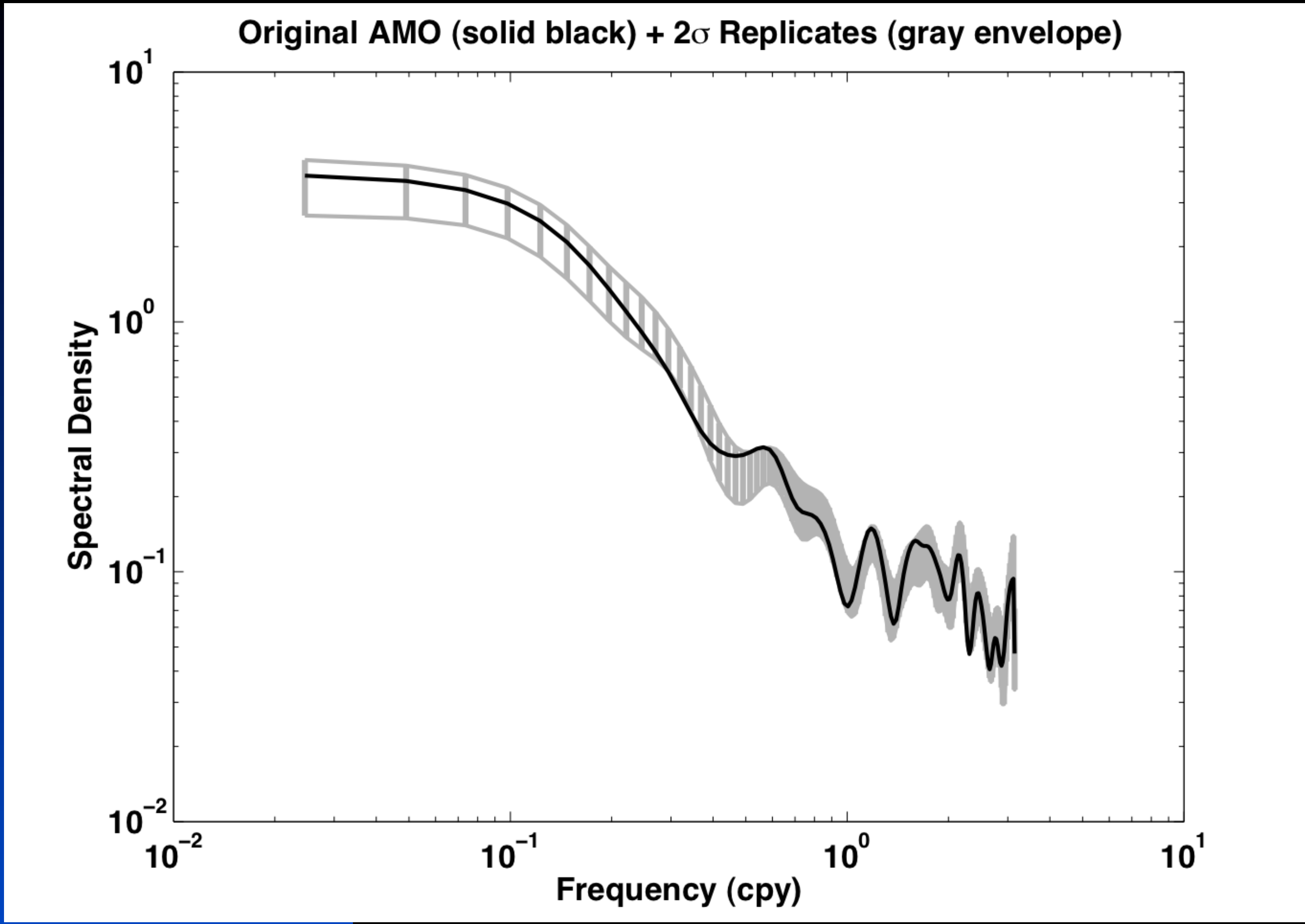
Gray et al. low-pass series

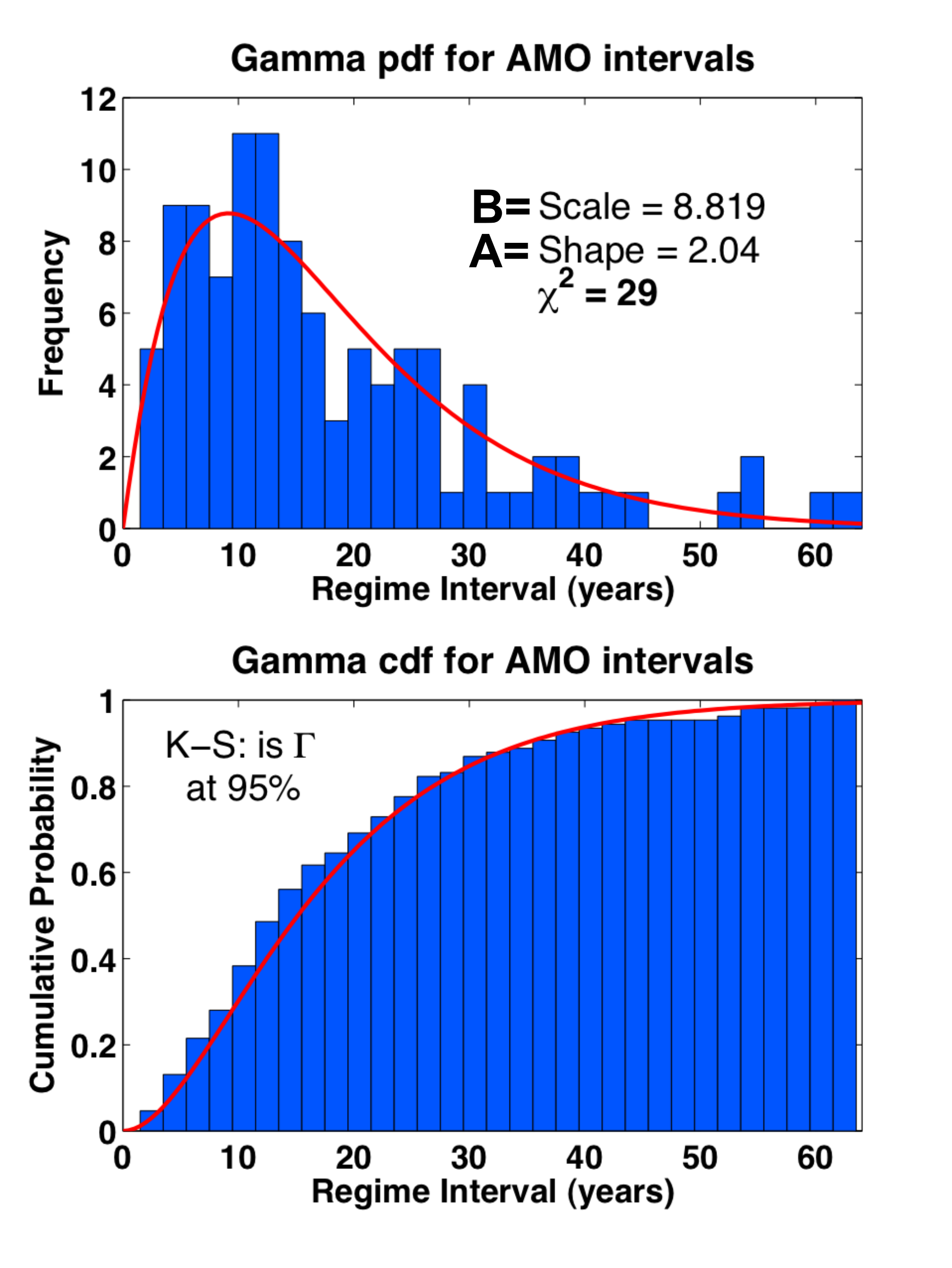
Spectral randomization Ebusuzaki (1997)

Monte Carlo resamplings (many times)

Spectral resamplings reproduce the original spectrum

… but their expected correlation is zero





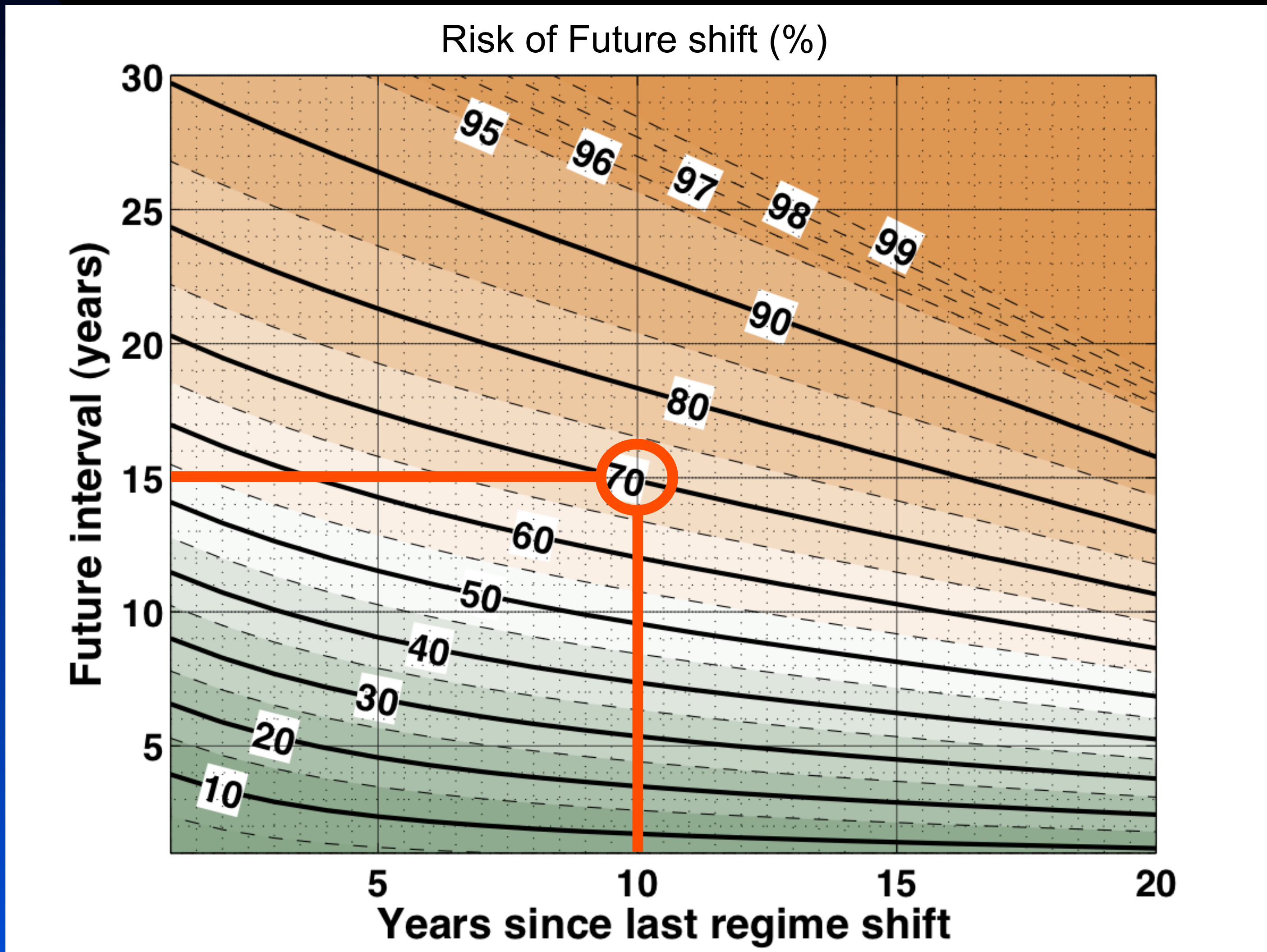
By doing a Monte Carlo resampling of regime intervals in the Gray et al. extended AMO index, we get a histogram of AMO regime intervals (blue), which can be successfully fit by a Gamma (Γ) distribution (*PDF*, red).

A K-S goodness-of-fit test of the *CDF* usually shows the fit to be valid. Assuming that the future distribution is unchanged, we can compute the probability of future regime shifts from the estimated Γ parameters (*A,B*).

Let t_1 = years since last shift; t_2 = years until the next shift

We now compute the conditional probability for t_2 given t_1

$$P(t1 < T \le t1 + t2 \mid T > t1) = P(t1 < T \le t1 + t2) / P(T > t1)$$
$$= (\Gamma[t1 + t2] - \Gamma[t1]) / (1 - \Gamma[t1])$$



Conclusions…

- The AMO appears to be a natural climate oscillation that has probably existed for centuries and which probably involves fluctuations in the overturning circulation of the Atlantic Ocean.
- The AMO exerts a strong influence on rainfall and hurricanes in the Western Hemisphere, and we see larger Atlantic warm pools during AMO(+) than during AMO(-). This may be the mechanism by which many climate impacts occur.
- Although progress is being made in using global models to diagnose the AMO, we probably can't realistically expect useful numerical predictions of AMO reversals in the near future.
- Application of probability analysis to proxy records allows us to make risk projections for future climate regime shifts, subject to assumptions about stationarity. This approach may prove useful for long-horizon applications such as water management and insurance risk during the next 2-3 decades while better models are being developed.