Distinguishing Forced and Internal Multi-Decadal Variability in the North Atlantic and their Climate Impacts

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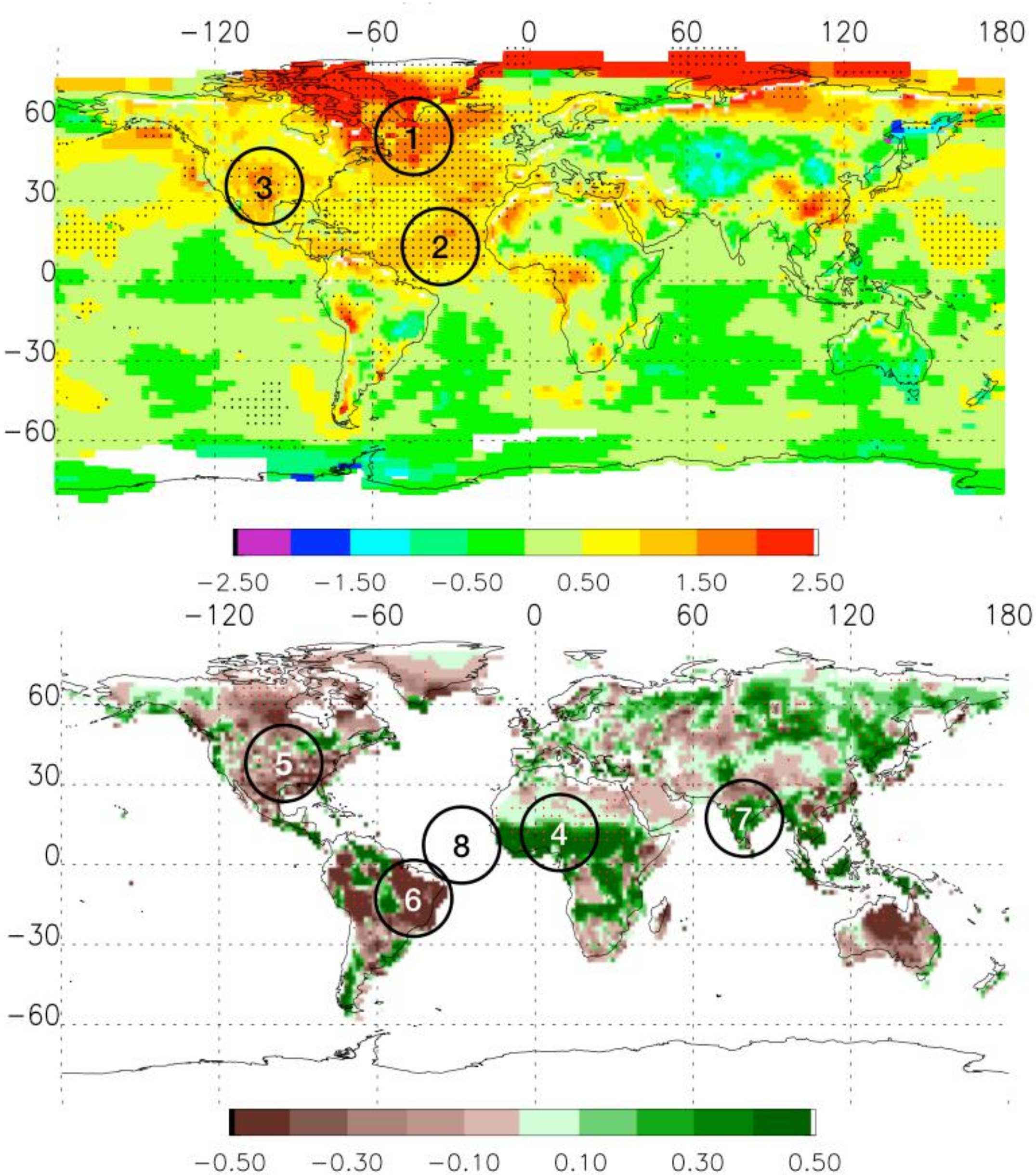
Outlines

- To what extent is observed Atlantic multidecadal variability externally forced?
- Impact on North Atlantic hurricane activity - AMV vs. Radiative Forcing
- AMV mechanism and prediction: NAO and AMV linkage
- Summary

Dominant Features of the AMV and Its Climate Impacts

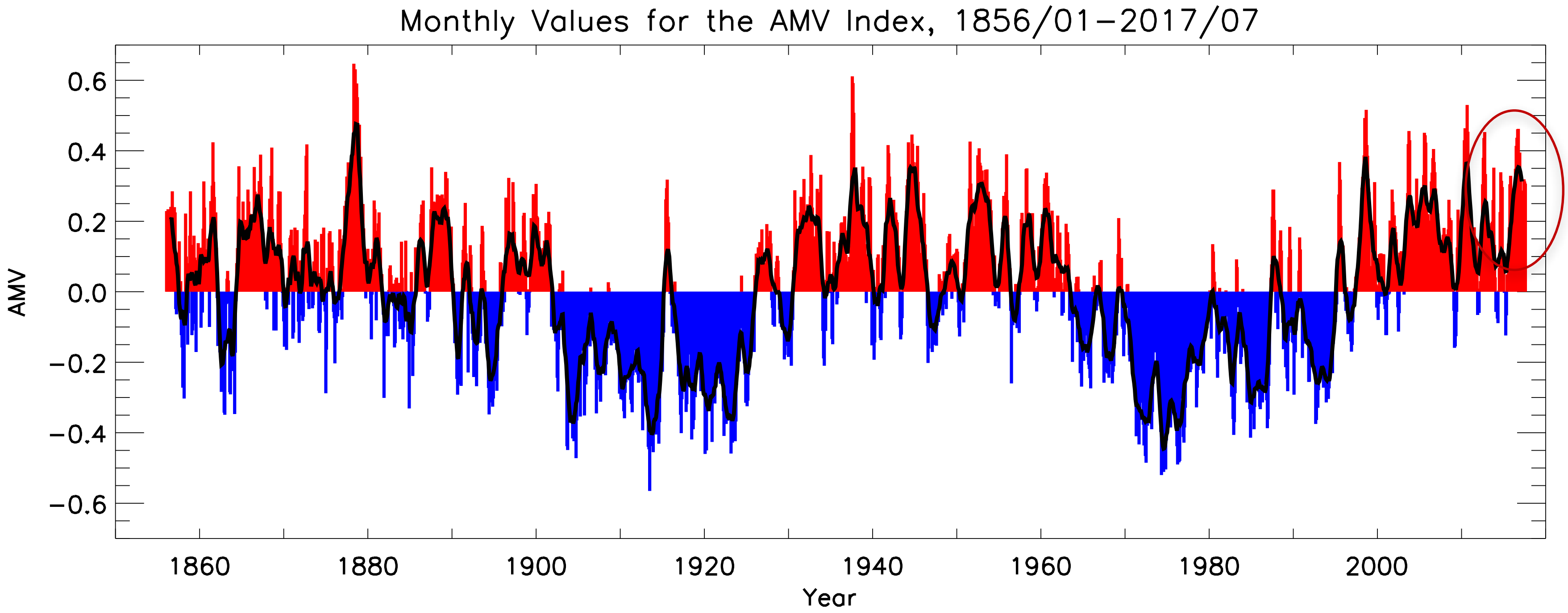


Annual mean SST and surface air temperature (in ℃ ℃$^{-1}$, Top panel) and precipitation (in mm day^{-1} ℃$^{-1}$, bottom panel) regressed on SST averaged over the North Atlantic domain. Also shown are the associate prominent climate anomalies: (1) and (2) AMV horseshoe pattern composed of a large subpolar SST anomaly arching into the tropical region; (3) significant warming of western U.S. and Mexico; (4) Wetter sub-Saharan Africa; (5) Drier central and western U.S.; (6) Drier N.E. Brazil; (7) Wetter Indian summer monsoon; (8) Northward shifted tropical Atlantic ITCZ and intensified tropical storm activity. Stippling indicates statistical significance.

(Figure from Ting et al., 2009).

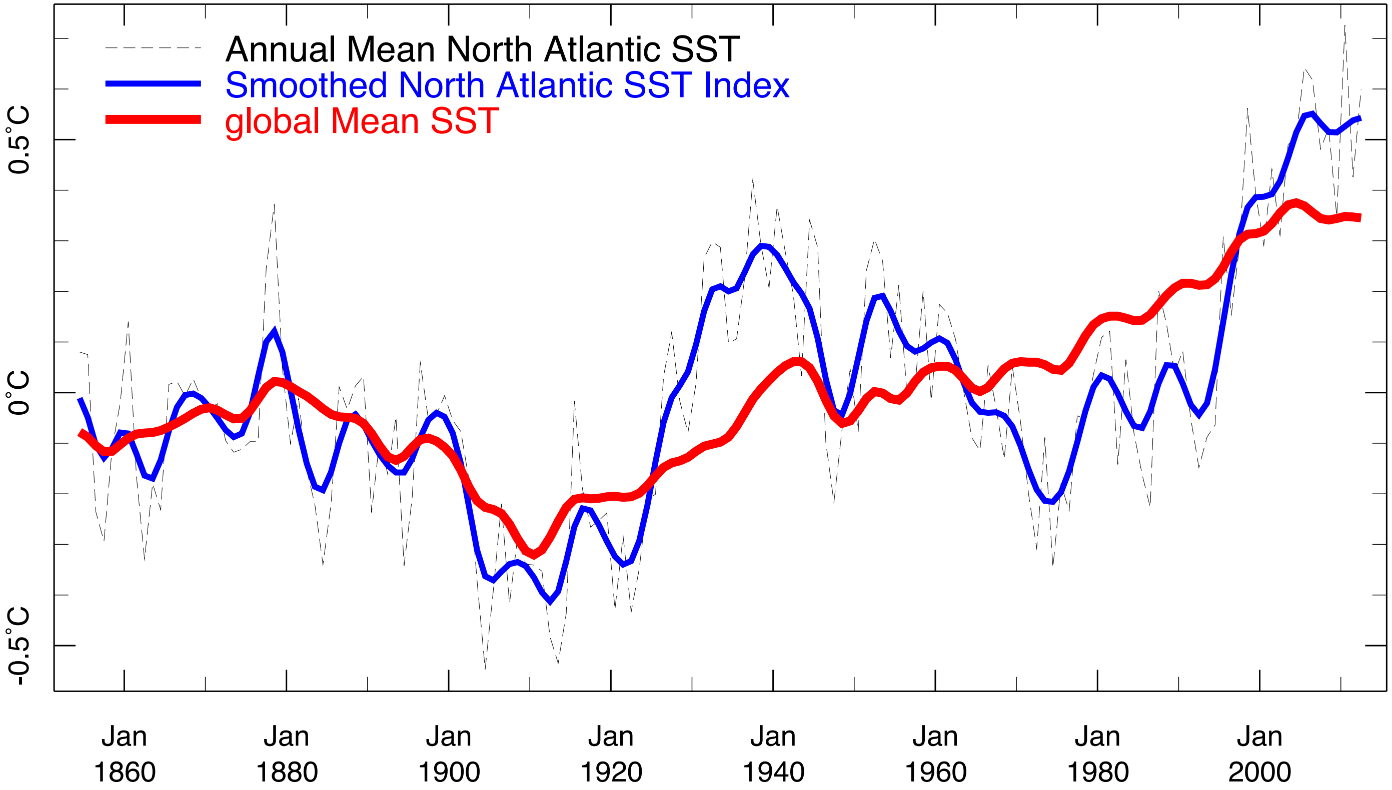
Monthly Atlantic Multidecadal Variability Index from 1856–2017

Data Source: NOAA Earth System Research Lab based on Kaplan SST (https://www.esrl.noaa.gov/psd/data/timeseries/AMO/)

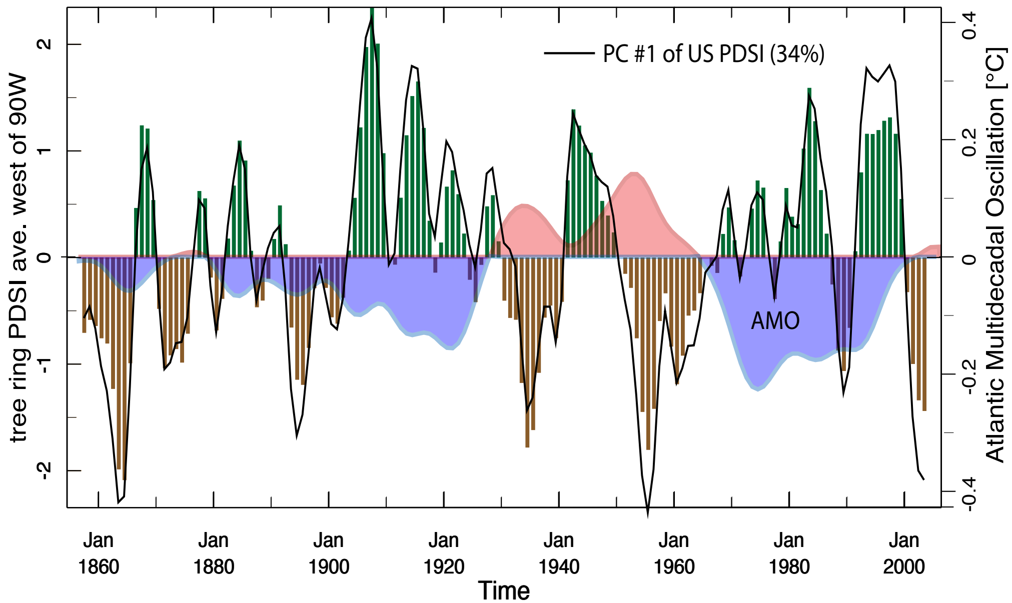


To what extent is 20th Century North Atlantic multidecadal variability externally forced?

ERSST, 1854 - 2012



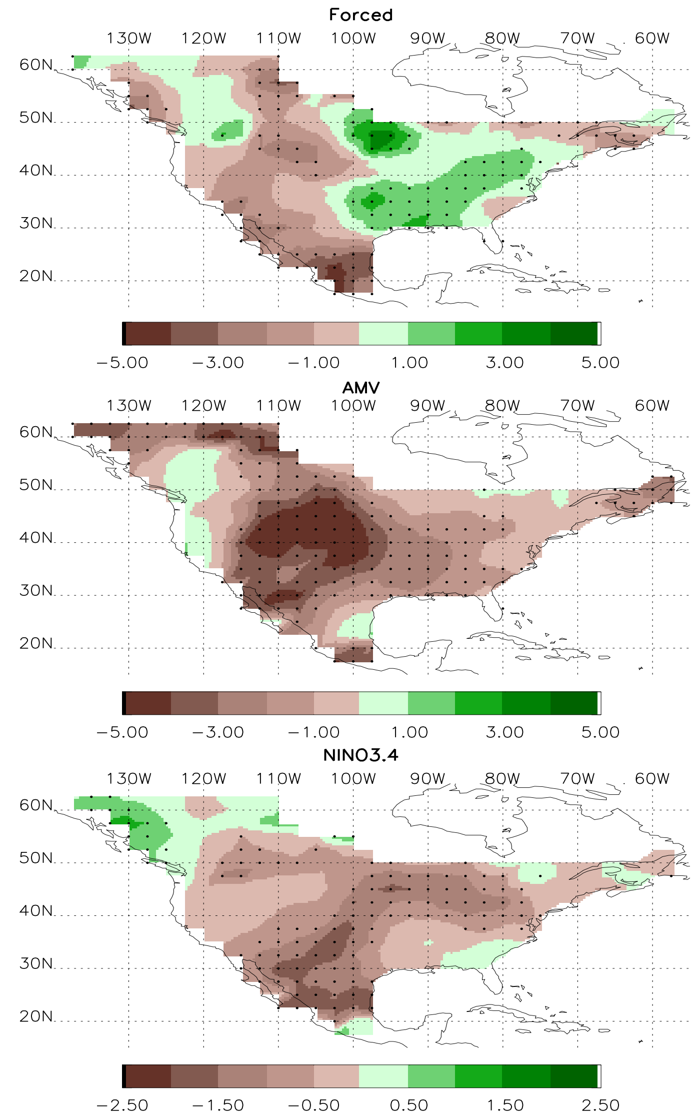
Palmer Drought Severity Index (PDSI) Versus AMV



PDSI data from (Cook et al., 2004) North American Drought Atlas based on tree ring

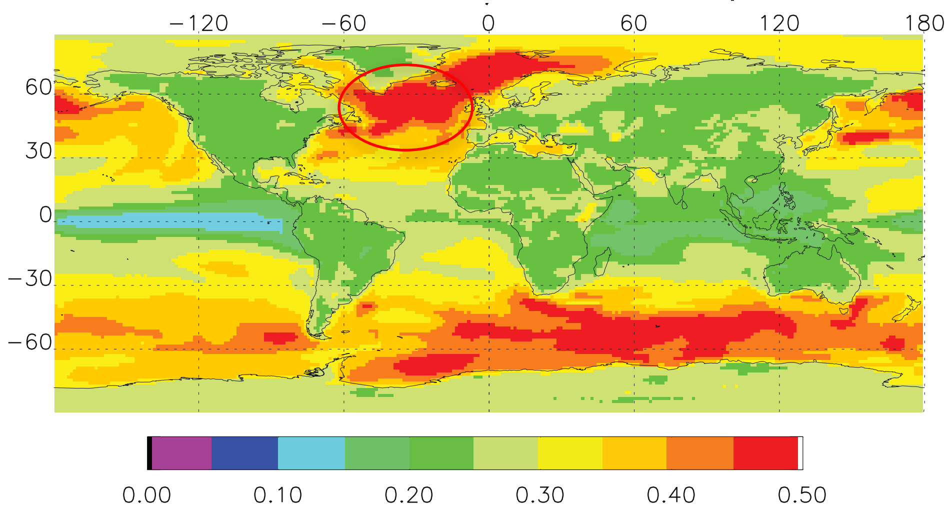
- **Forced warming, positive AMV and La Niña all contribute to drought conditions in the U.S., but the impact of AMV tend to be more significant and wide spread.**

Regression coefficients: PDSI onto radiatively forced SST (top), AMV index (middle), and negative NINO3.4 index (bottom)

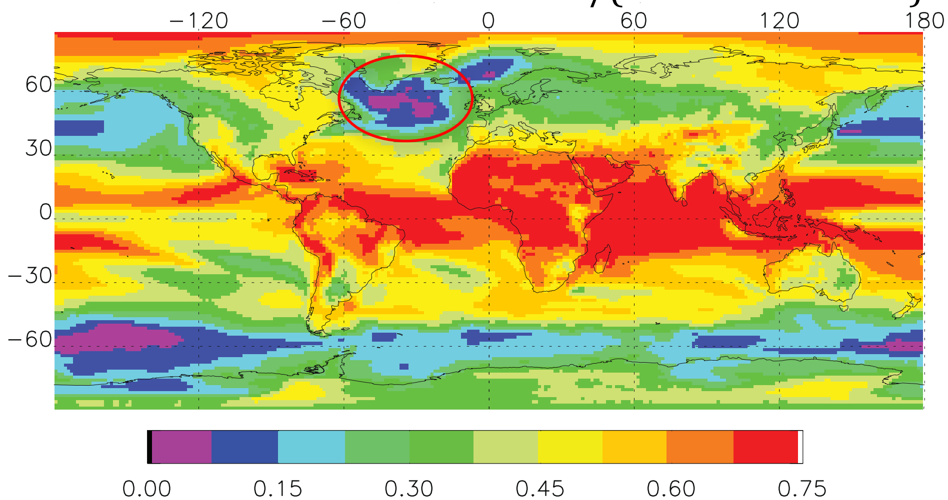


Internal Decadal vs. Forced Variability

Internal Variance Ratio for Ts: Decadal/Total



Forced Variance Ratio: Forced/(Forced + Decadal)



- The North Atlantic, North Pacific, and the Southern Oceans are regions of high internal decadal and longer time scale variability.
- Decadal and longer time scale variability is relatively weak over land.
- Externally forced variance to total variance ratio is low in regions of high decadal internal variability

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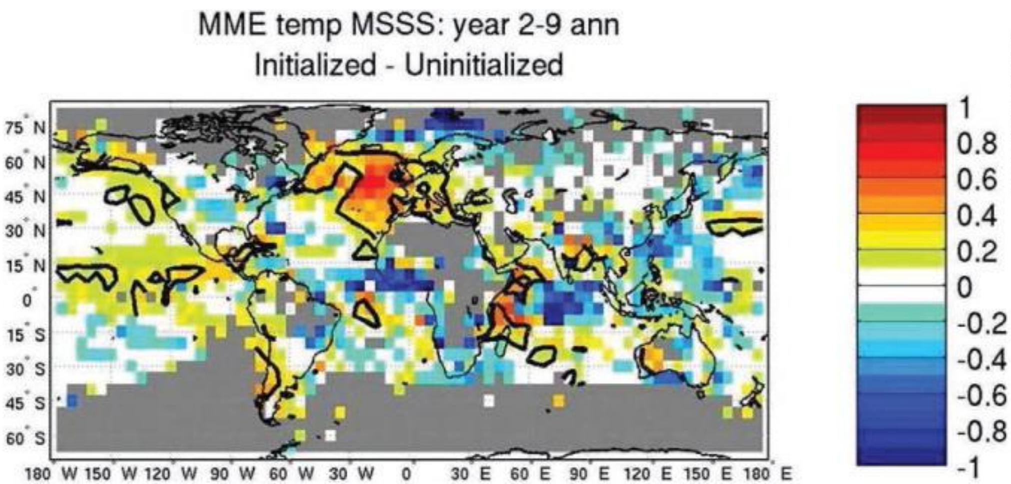
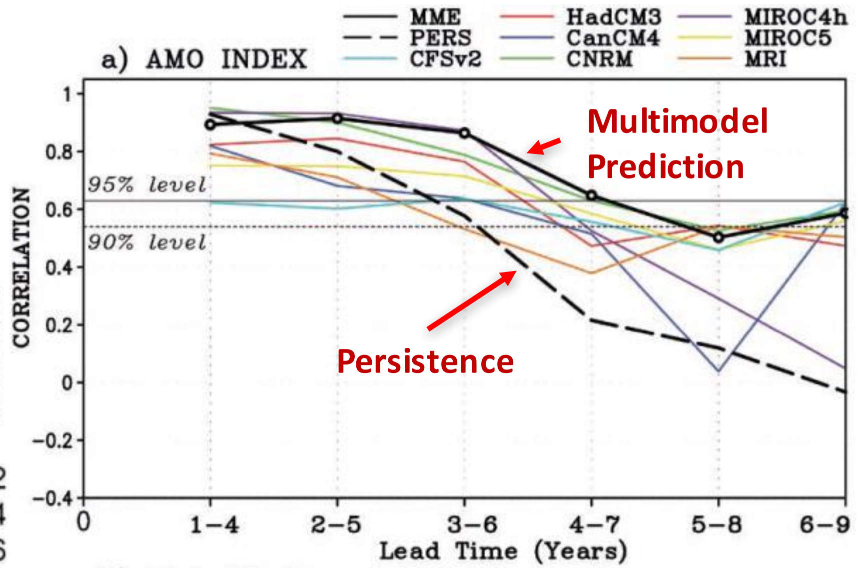
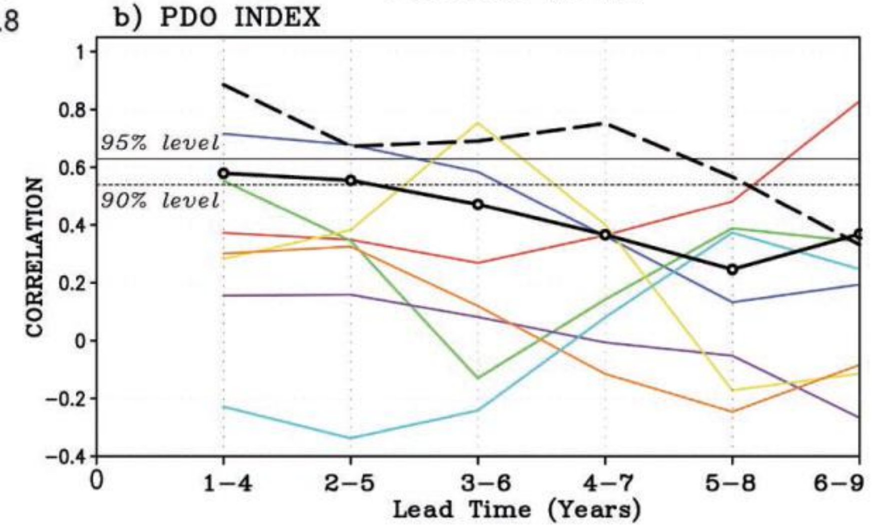
Predictive Skills in the Atlantic Ocean



Goddard et al., 2012: A verification framework for interannual-to-decadal predictions experiments. Climate Dyn.





Both Figures taken from Meehl et al., 2014: Decadal Climate Prediction, An Update from the Trenches. BAMS

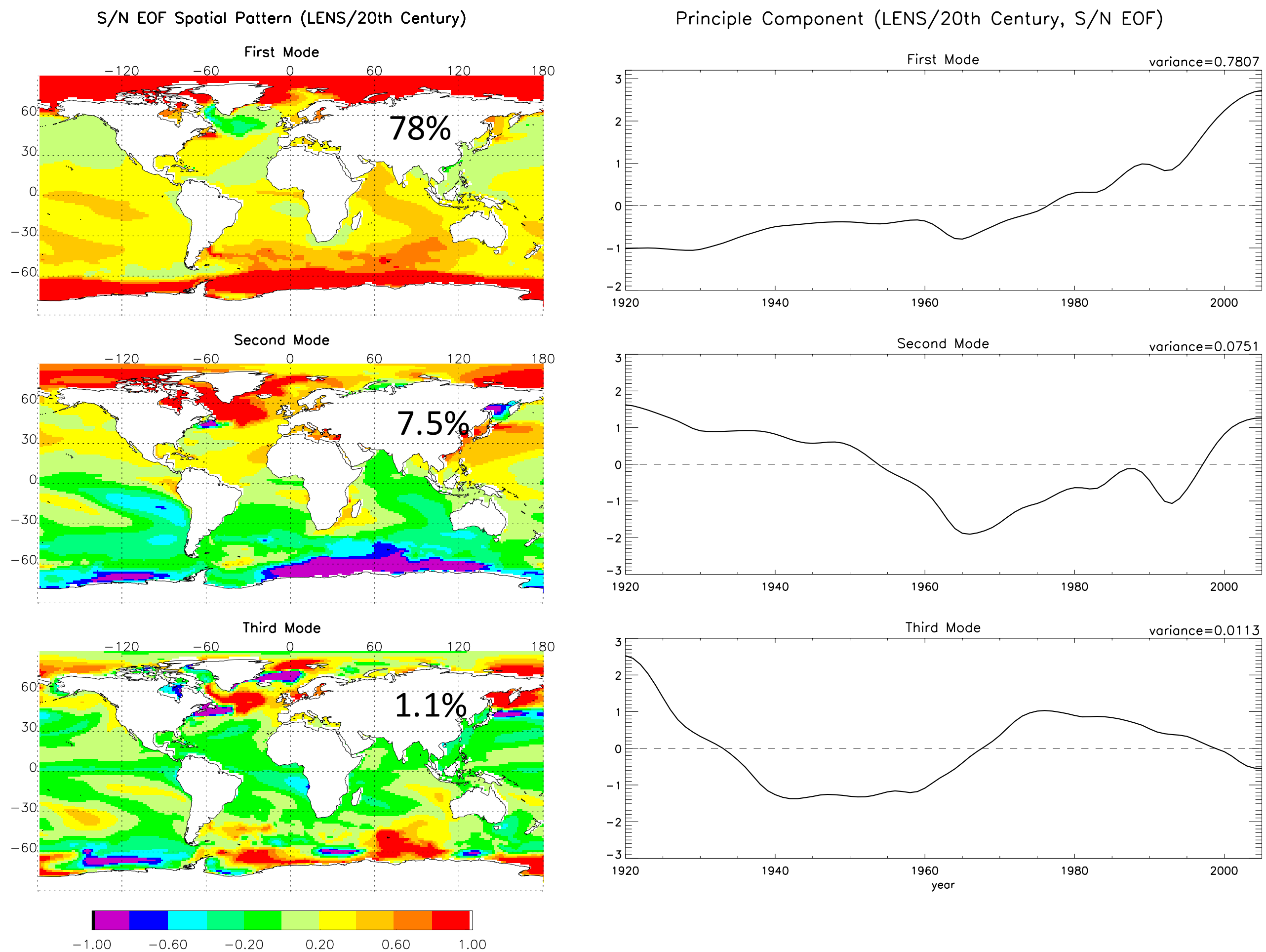
Kim et al., 2012: Evaluation of short-term climate change prediction in multi-model CMIP5 decadal hindcasts. GRL

How can one distinguish the radiatively forced and the internally generated Atlantic SST variability in models and observations?

S/N EOF Analysis Performed on NCAR LENS Global SST

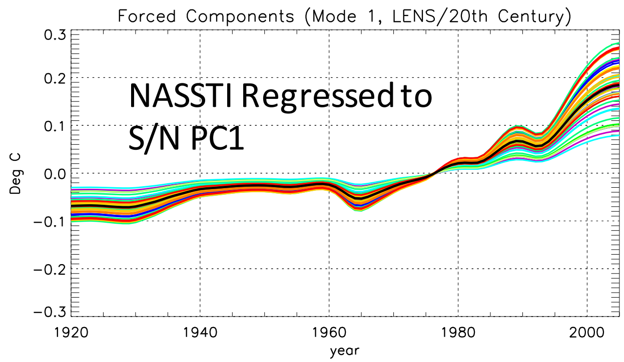
- Mode 1 – 78%, hemispheric symmetric warming
- Mode 2 – 7.5%, hemispheric asymmetric mode, reflecting more of the aerosol forcing?

Ting et al., 2009, 2011

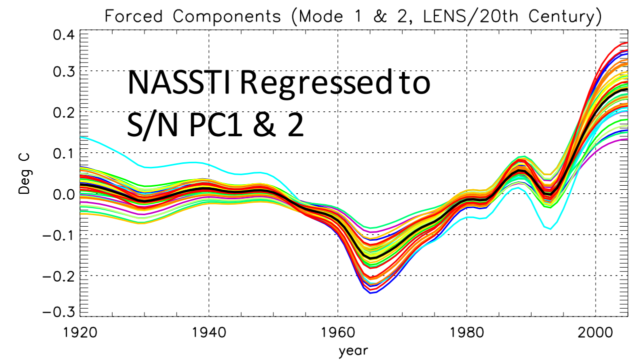


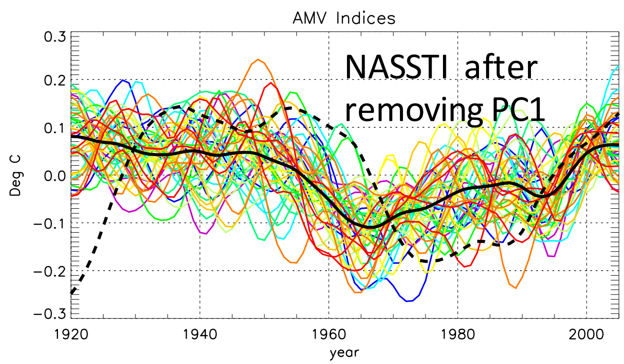
LENS: Large Ensemble Simulations
NCAR LENS: 42 ensemble members with historical radiative forcing from 1920 to 2005

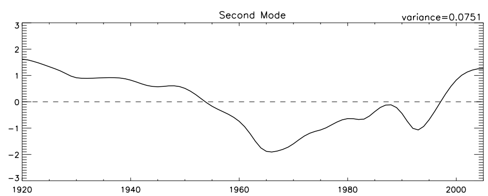
Forced and Unforced North Atlantic SST Index (NASSTI)

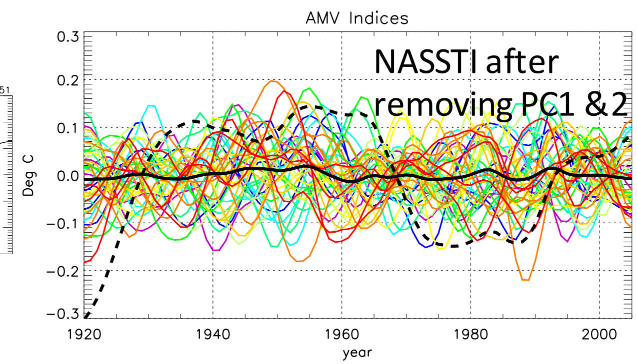


- Forced NASSTI variability can be largely removed with both modes 1&2 taken out
- AMV of individual ensemble member is not highly correlated with observations





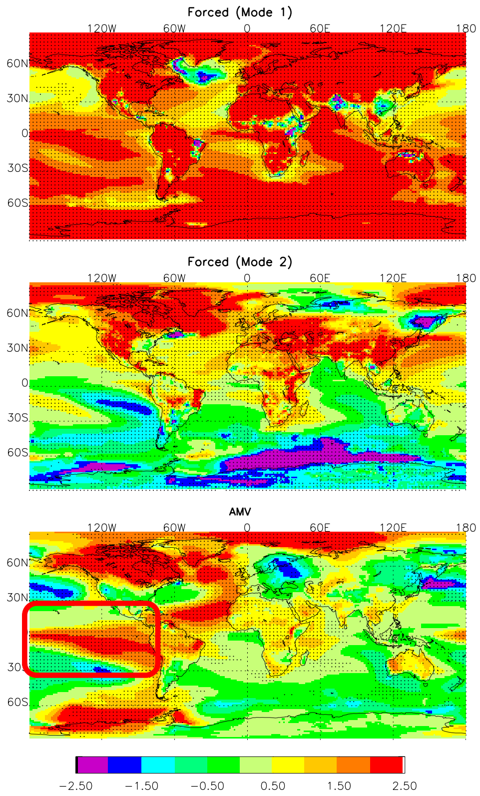




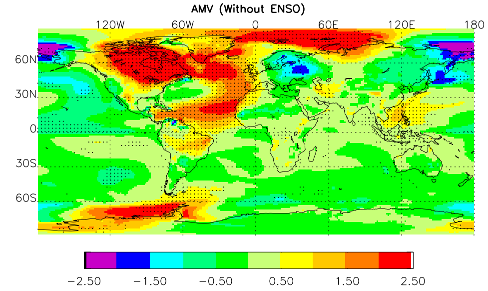
Dashed: observed Color: Individual ensemble member Solid Black: ensemble mean

Spatial Patterns of Forced Mode 1 &2 vs. AMV

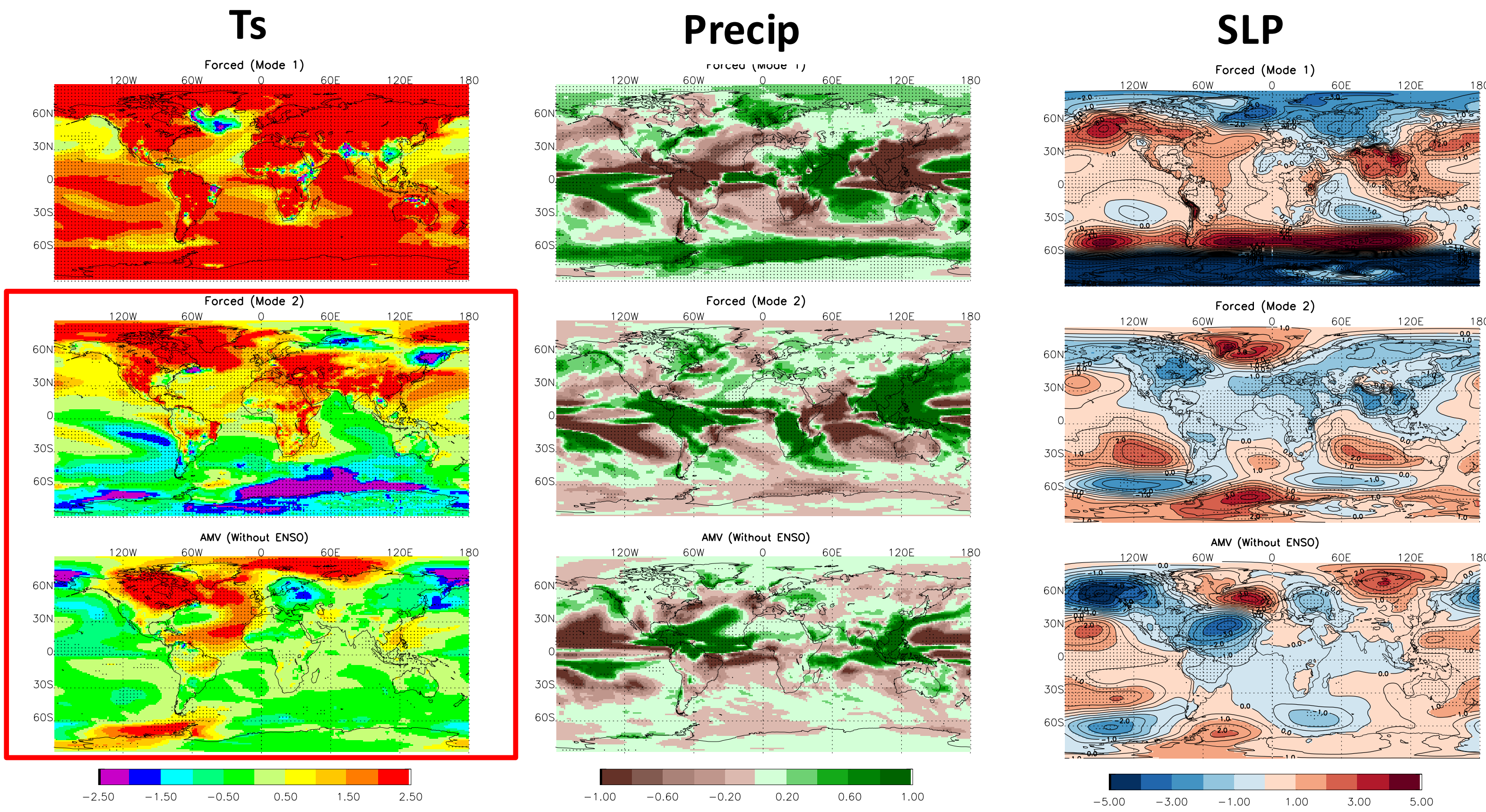
Ts



AMV w/o ENSO

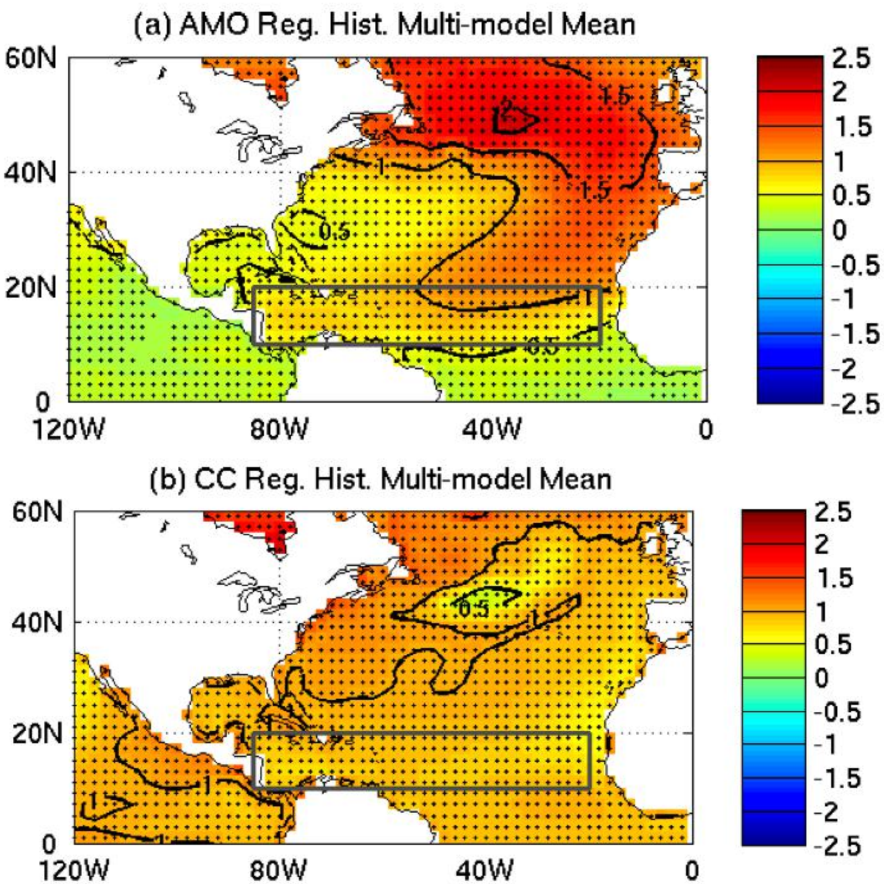


Spatial Patterns of Forced Mode 1 &2 vs. AMV w/o ENSO

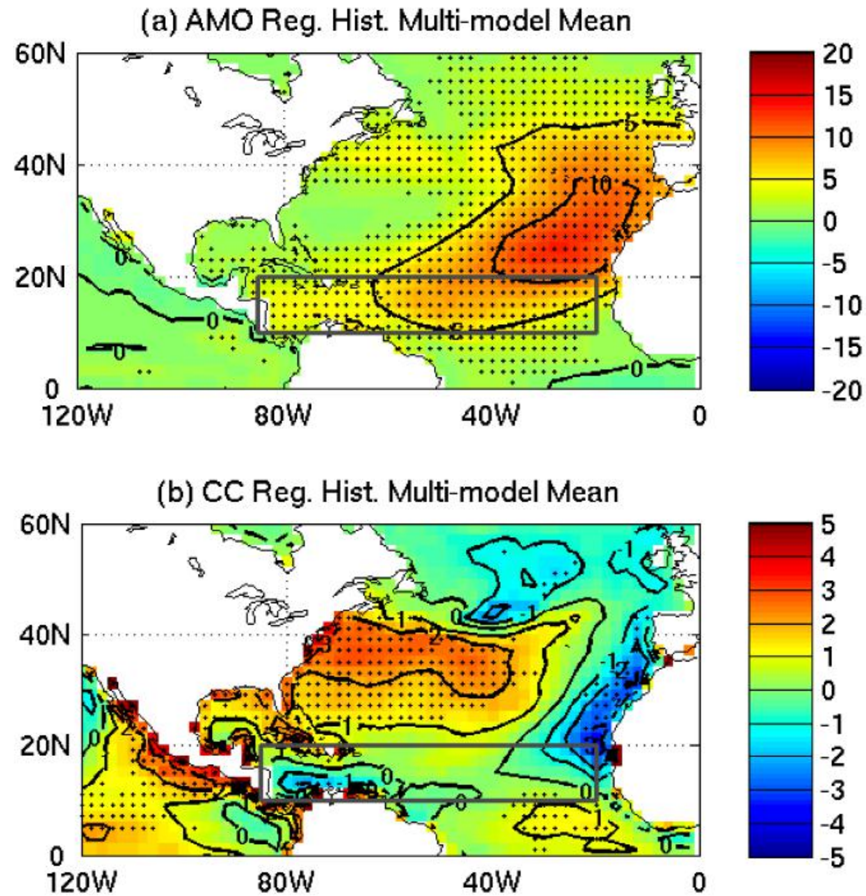


What are the link between forced and internally generated Atlantic SST and Atlantic hurricane activity?

SST Regressed to AMV and Climate Change



Hurricane PI Regressed to AMV and Climate Change

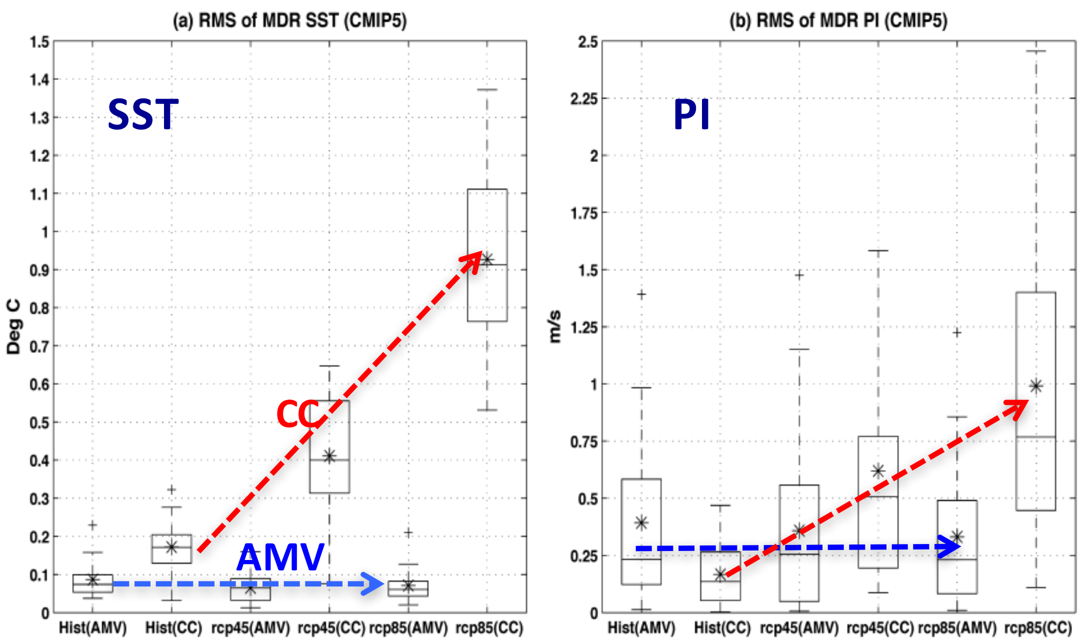


Ting, M., S. Camargo, C. Li, Y. Kushnir, 2015: Natural and Forced North Atlantic Hurricane Potential Intensity Changes in CMIP5 Models. J. Climate.

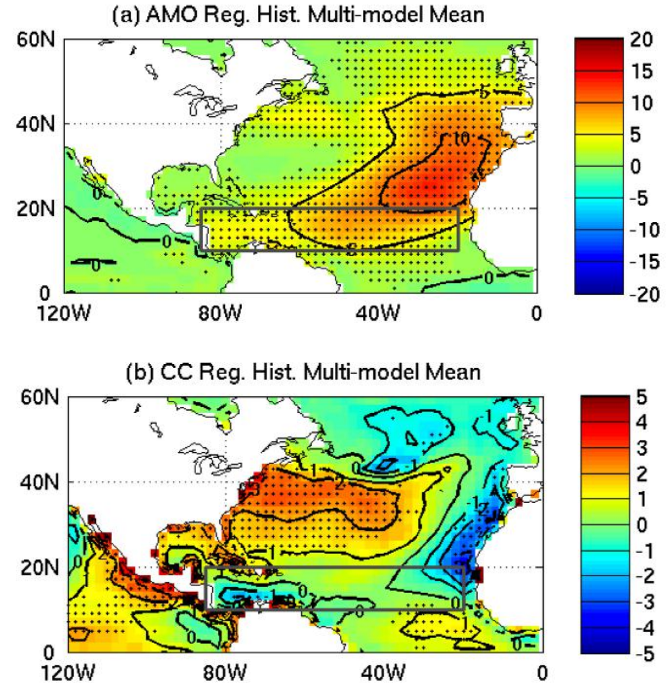
How sensitive are hurricane Potential Intensity (PI) change to SST: AMV vs. Climate Change

MDR PI change per degree of SST anomalies for AMV and CC (in m/s per degree of SST)

		Historical	RCP4.5	RCP8.5
AMV	25%	1.9414	1.1263	1.9469
	50%	**3.9295**	**4.1974**	**3.6513**
	75%	6.2901	8.4434	6.2211
CC	25%	0.3018	0.4825	0.4590
	50%	**0.7440**	**1.2522**	**0.9773**
	75%	1.6086	1.9293	1.2986



Hurricane PI Regressed to AMV and Climate Change



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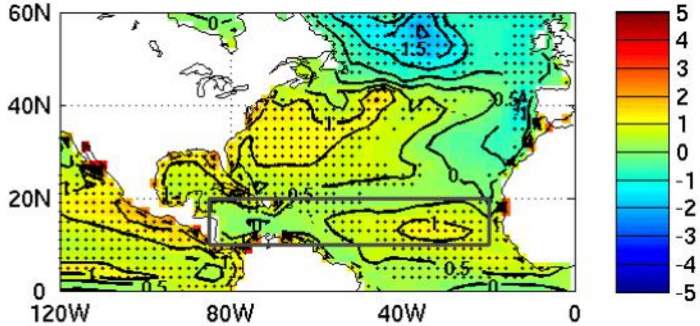
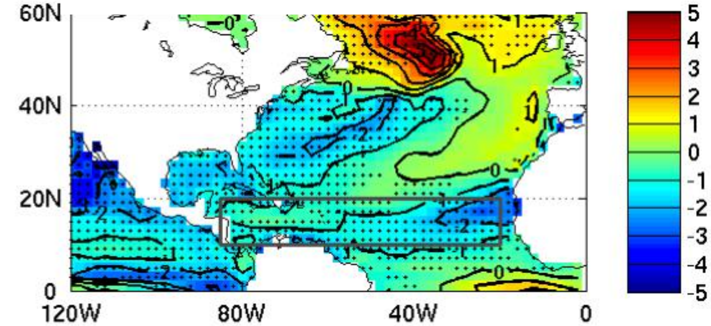
What about aerosols?

PI Regression GHGs



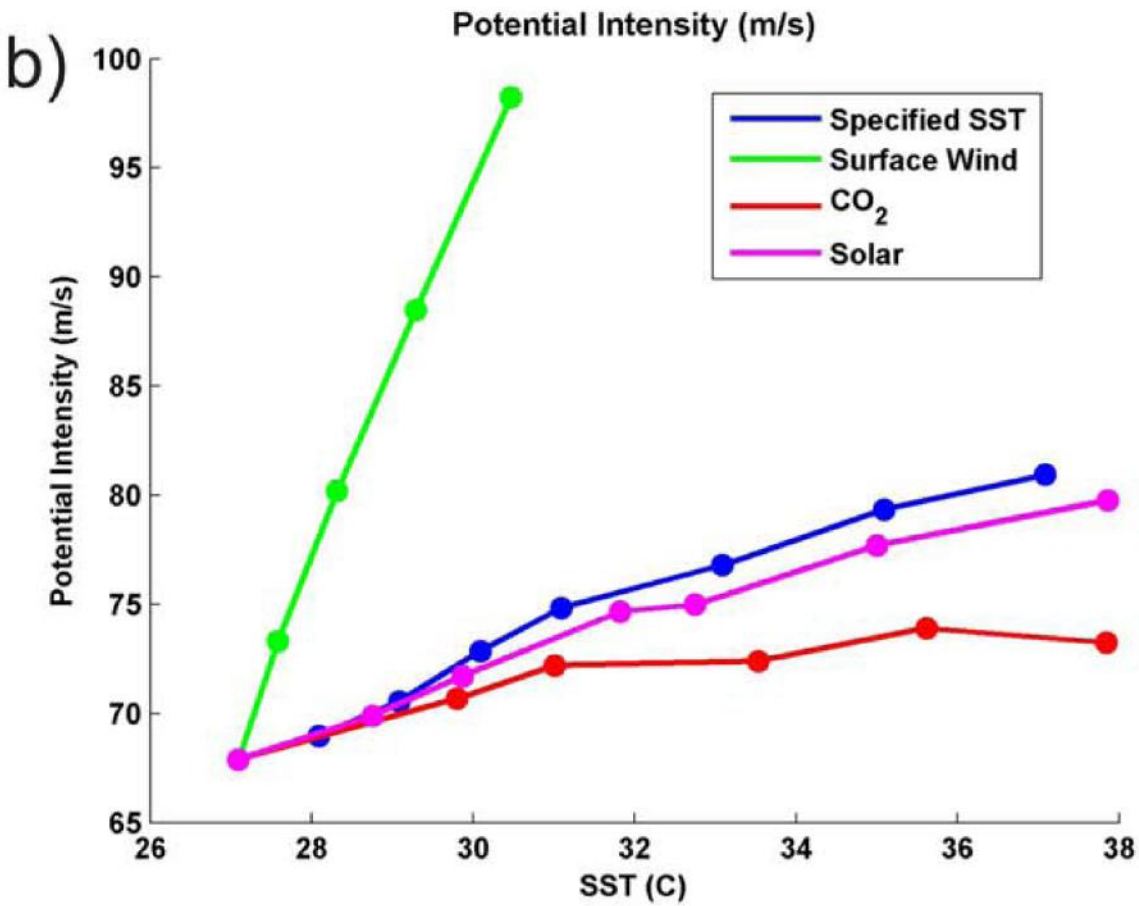
PI Regression Aerosols



MDR PI change per degree of SST anomalies for Aerosols and GHGs (in m/s per degree of SST)

		Aerosol	GHG
CC	25%	1.1852	0.5723
	50%	**2.1501**	**0.6468**
	75%	2.4852	0.9580

- *The patterns of PI change due to aerosols are substantially different from the corresponding AMV*
- *Aerosol-forced SSTs are more effective in causing PI changes than the corresponding GHG-forced SSTs*



Sensitivity of Potential Intensity to SST for:

- Specified SST
- SST forced by changing surface wind
- SST forced by changing CO2 concentration
- SST forced by changing solar constant

From Fig. 2, Emanuel and Sobel, 2013, Journal of Advances In Modeling Earth Systems

What's next?

- AMV-related SSTAs, or coupled ocean-atmosphere *internally generated sea surface temperature anomalies*, tend to be much more effective in causing hurricane intensity change than that due to radiative forcing such as GHGs and aerosols.
- What are the **mechanisms and predictability** of the internally generated decadal and longer time scale SSTAs?
- What are the relationships between the **North Atlantic Oscillation (NAO) and AMV**? Between NAO and hurricane Potential Intensity (PI)?

AMV Mechanism: Link between AMV and NAO

- Is AMV simply a response to NAO white noise forcing as shown in Clement et al. (2015)?

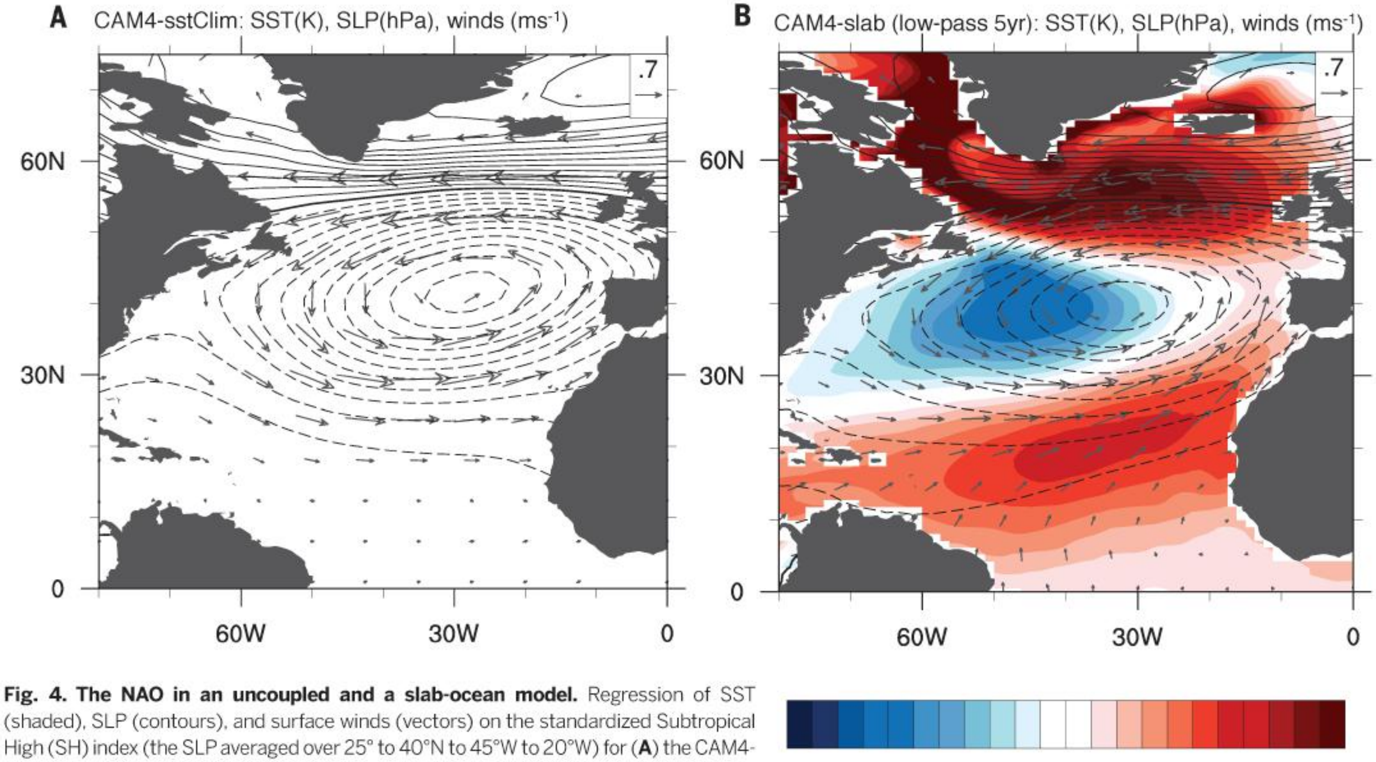
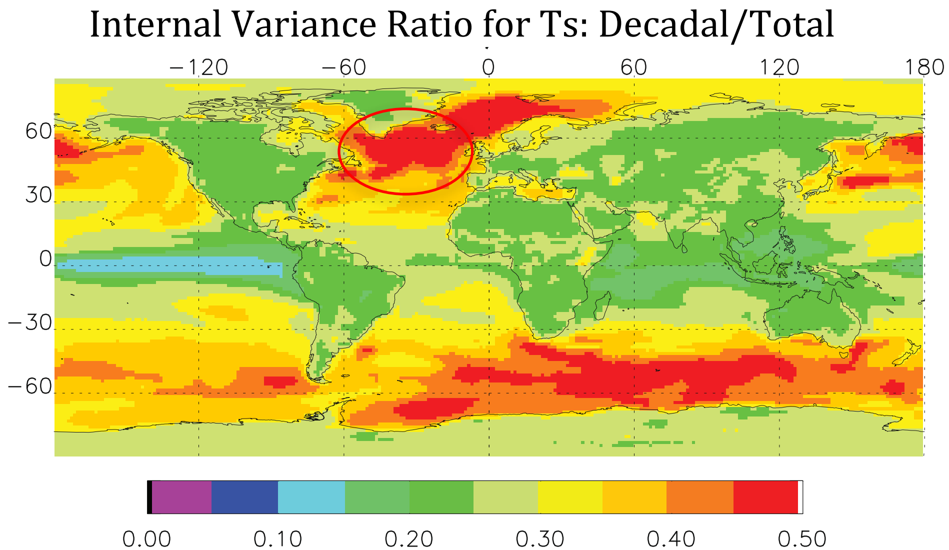
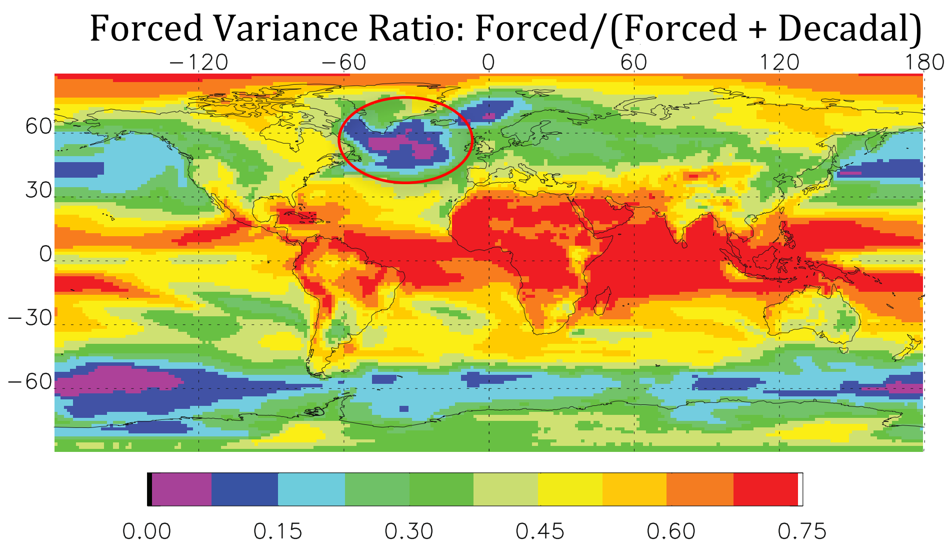


Fig. 4. The NAO in an uncoupled and a slab-ocean model. Regression of SST (shaded), SLP (contours), and surface winds (vectors) on the standardized Subtropical High (SH) index (the SLP averaged over 25° to 40°N to 45°W to 20°W) for (**A**) the CAM4-sstClim simulation, in which the SSTs are fixed and set to climatology and (**B**) the CAM4-slab simulation that includes thermal coupling. In (B), the SH index is filtered using a low-pass Lanczos filter to remove variability in the sub–5- year time scale. Units are of °C, hPa, and m s^{-1} per standard deviation of the SH index. SLP contours range from −4 hPa to 4 hPa, with intervals of 0.25 hPa.

Internal Decadal vs. Forced Variability





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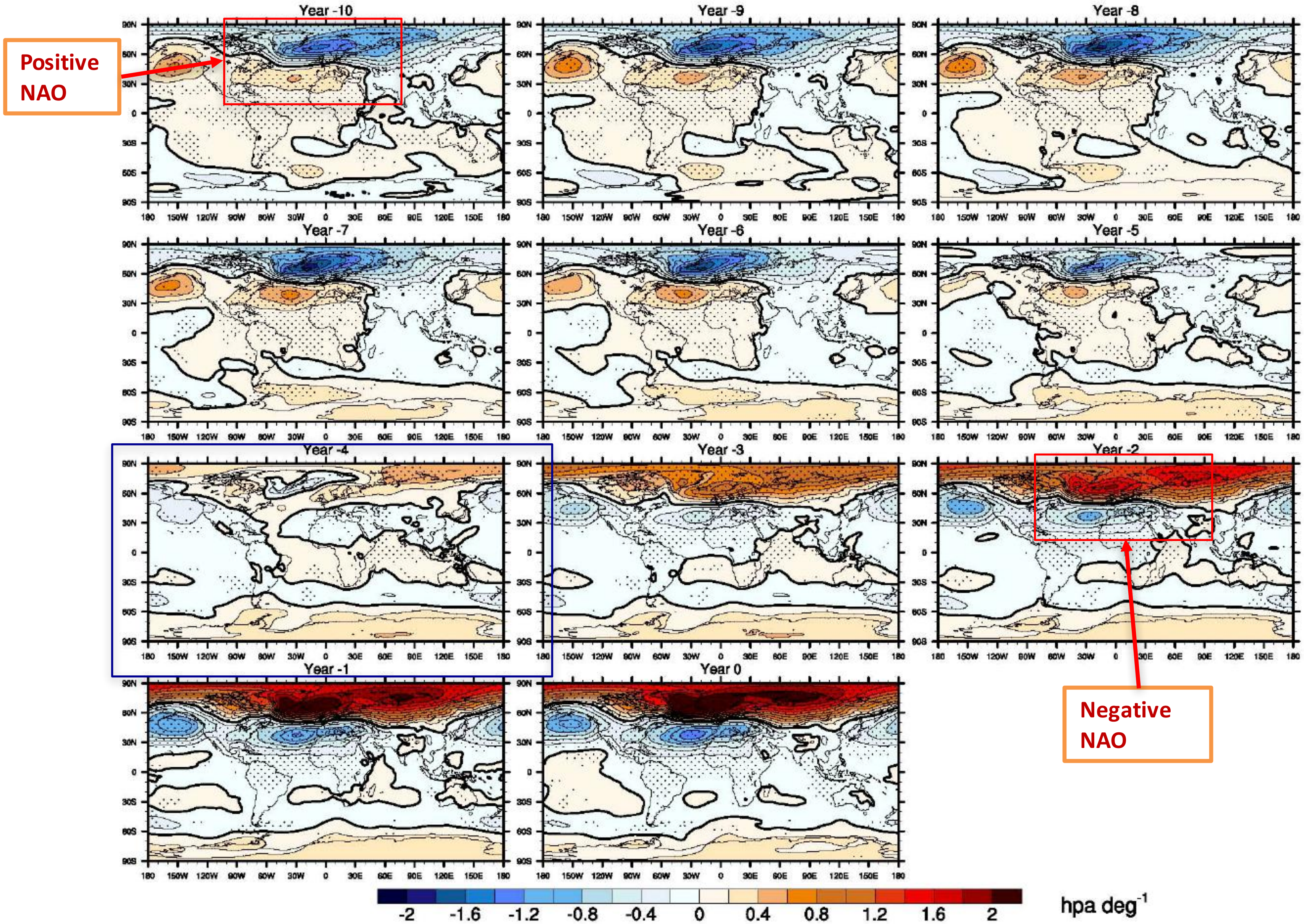
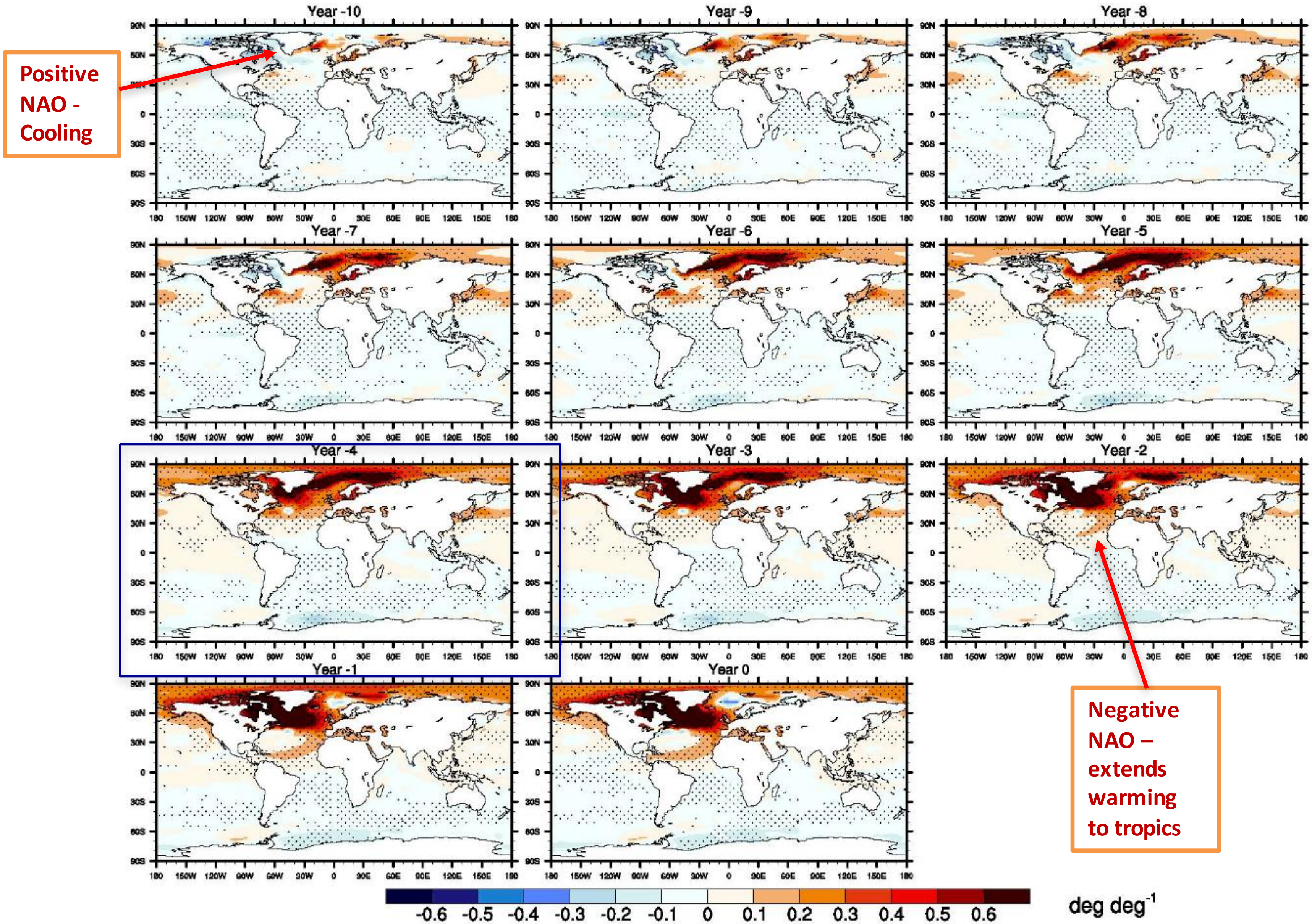
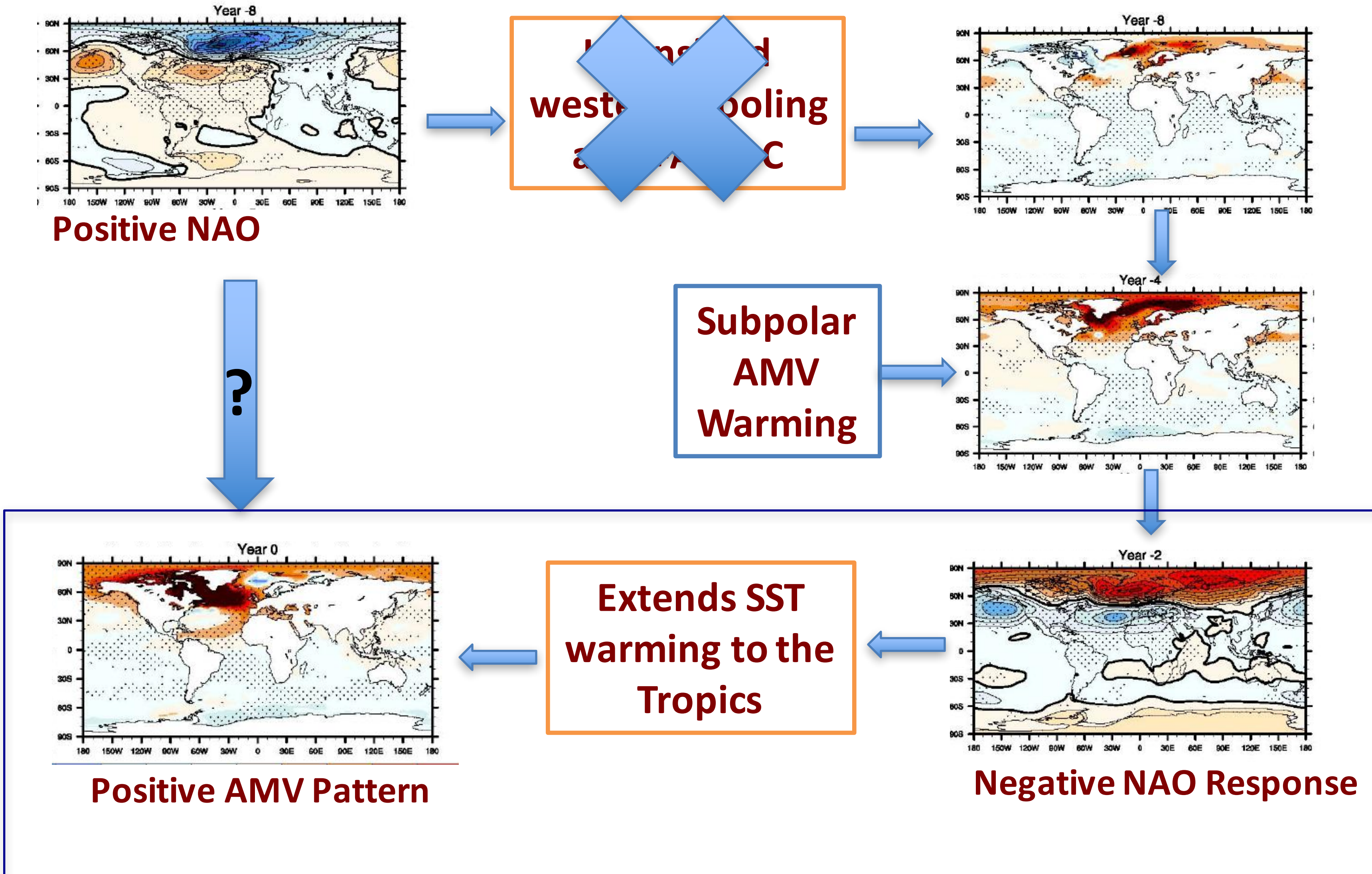
SLP Regression onto subpolar AMV SST: CMIP5



SST Regression onto subpolar AMV SST: CMIP5

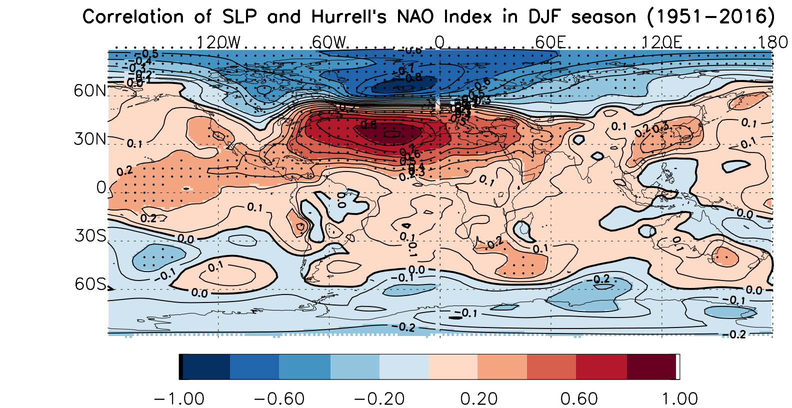


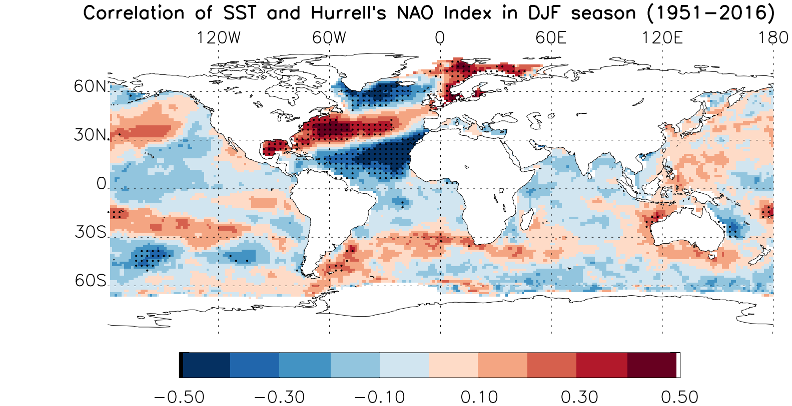
Possible AMV-NAO Relationship in Observations and CMIP5 Models

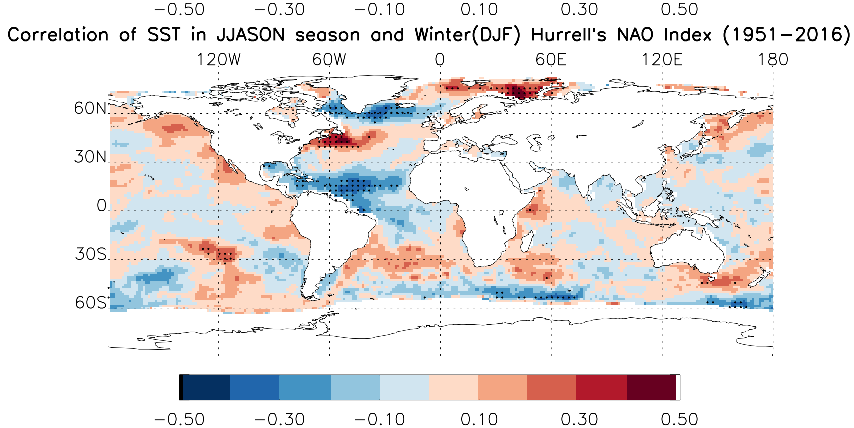


Link between winter NAO and hurricane PI on Subseasonal-to-Seasonal time scales

Obs. DJF NAO (based on correlation for 1951-2016)

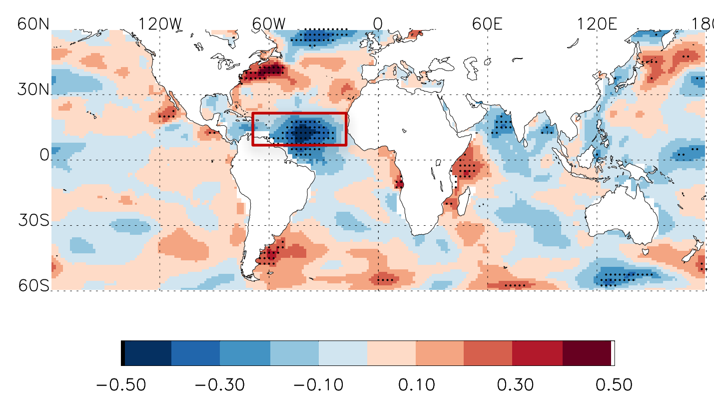




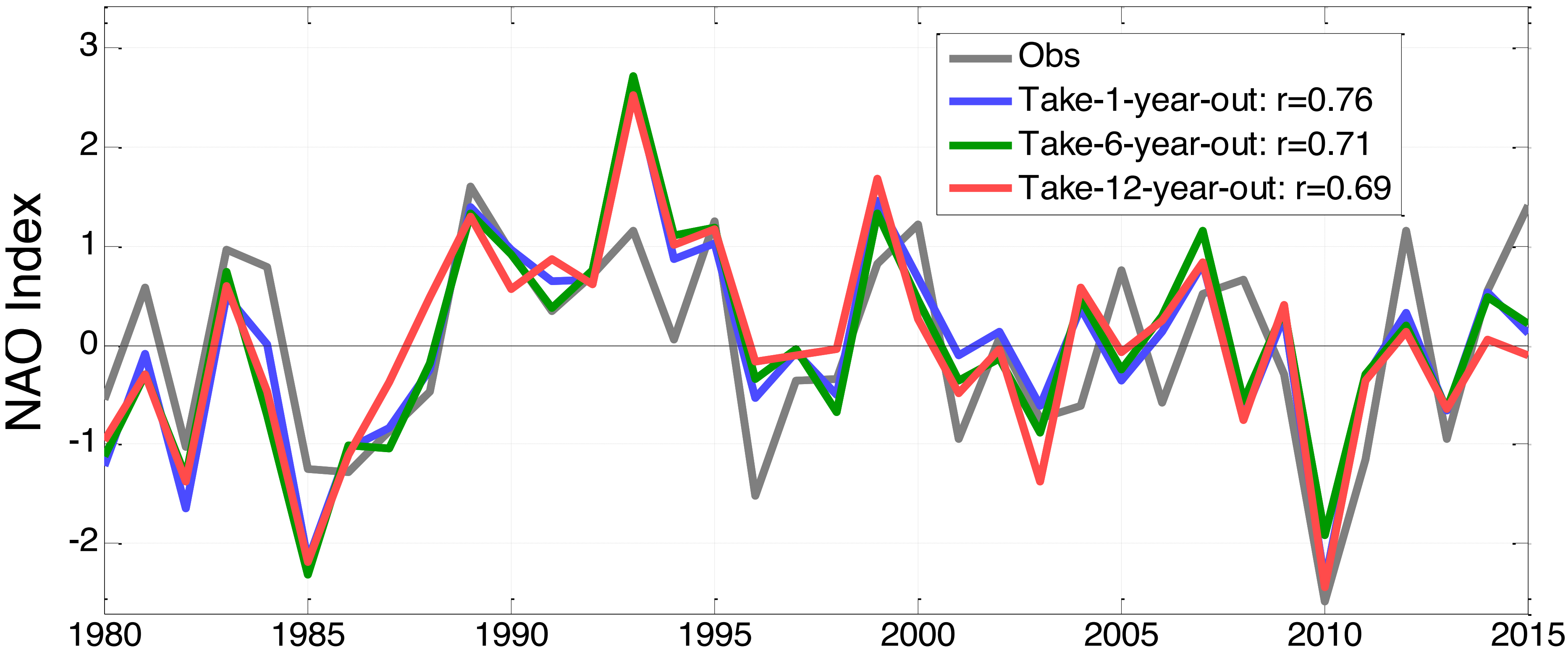


- *Negative NAO leads to enhanced hurricane potential intensity in the following hurricane season*
- *Recent works indicate robust winter NAO predictability from sea ice, SST and stratospheric circulation using statistical model (Wang et al., 2017) and dynamical models (Scaife et al., 2014; Dunstone et al., 2016).*

Correlation between DJF NAO and JJASON PI



Winter (DJF) NAO Forecast using a Multiple Linear Regression (MLR) Model with Three Predictors (Oct SIC PC1, Oct Z70hPa PC2, and Sep SST PC3)



Wang, Ting and Kushner, Scientific Reports, 2017

Summary

- There is a **distinct AMV SST pattern** that can be separated from the radiatively forced SST pattern due to natural and anthropogenic radiative forcings
- Hurricane potential intensity is **more sensitive to the internally-generated AMV SST** than radiatively forced SST due to differences in the surface energy balance.
- Mechanisms of the internally generated AMV seems to be linked to the coupled processes between the ocean and atmosphere in the Atlantic, including **atmospheric NAO forcing, meridional overturning ocean circulation, and atmospheric response to AMV SST anomalies**, leading to decadal and longer time scales variability, which may provide a path for dynamical model predictions of these decadal SST anomalies.
- On shorter time scales (subseasonal to seasonal time scales, S2S), **winter NAO forcing can be a useful predictor for hurricane PI** in the North Atlantic.