North Atlantic Hurricane Potential Intensity in CMIP5 Models: Anthropogenic Forcing versus Atlantic Multidecadal Variability

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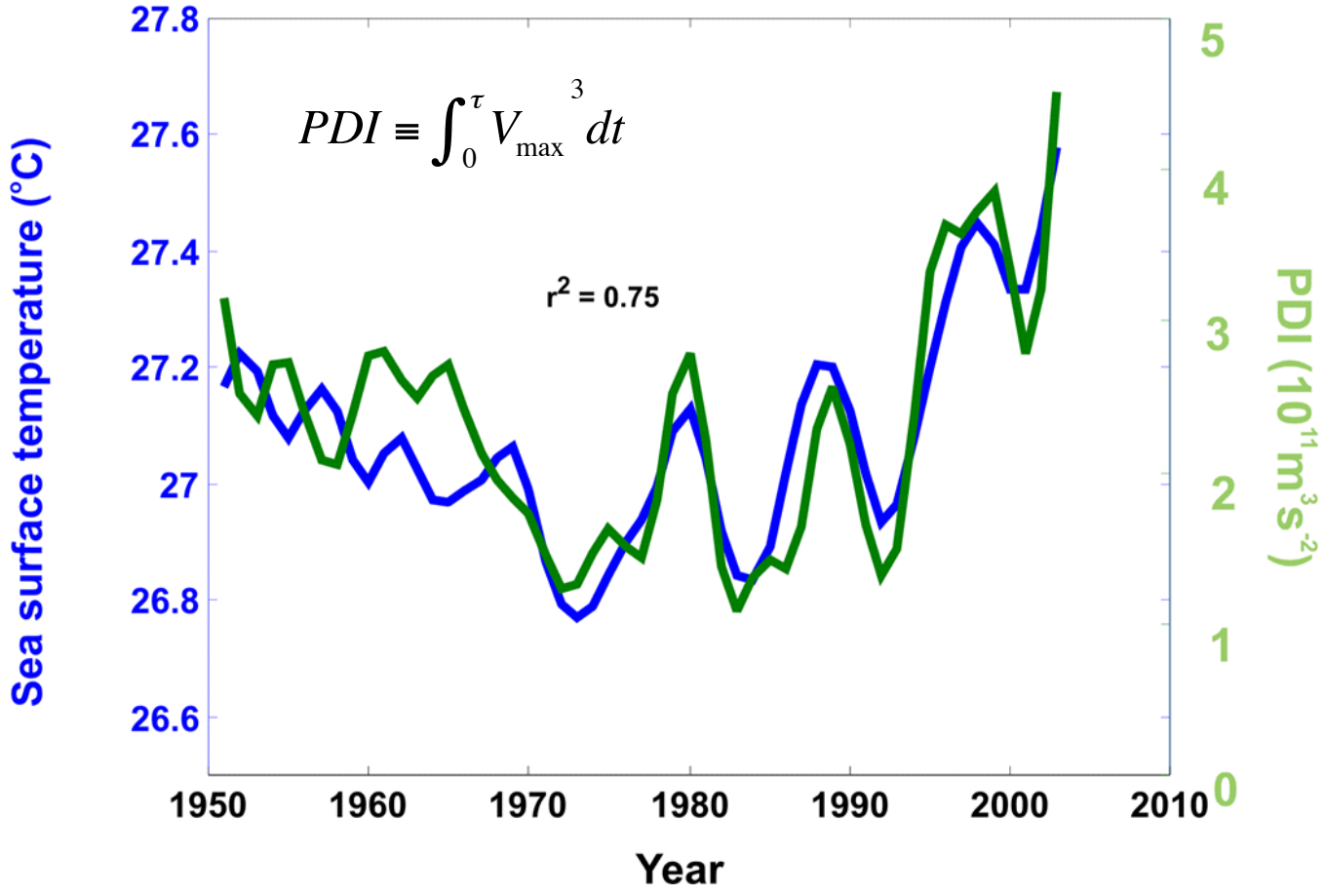
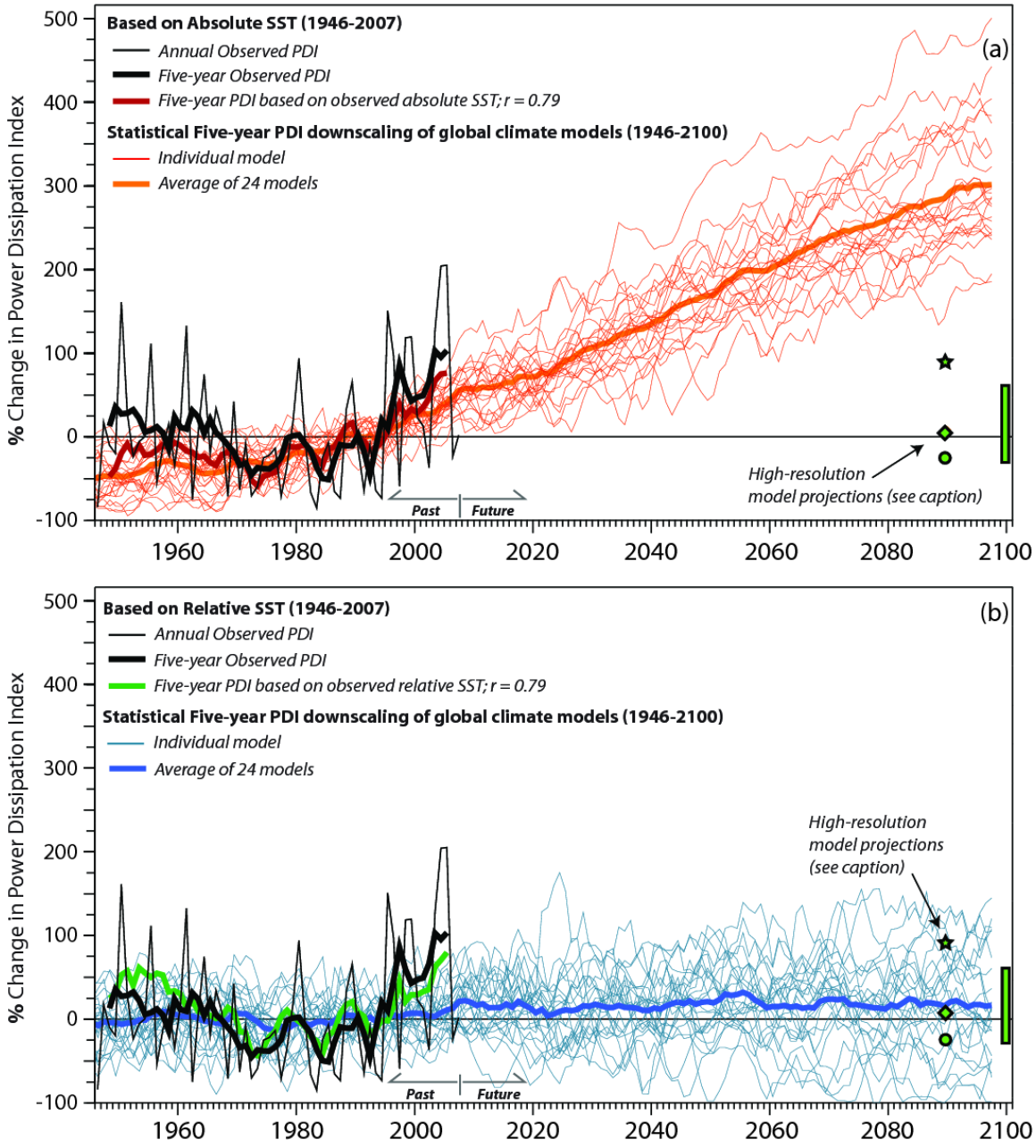
Motivation: How does Atlantic hurricane intensity respond to climate change versus AMV?



Emanuel, 2005: Increasing destructiveness of tropical cyclones over the past 30 years. Nature

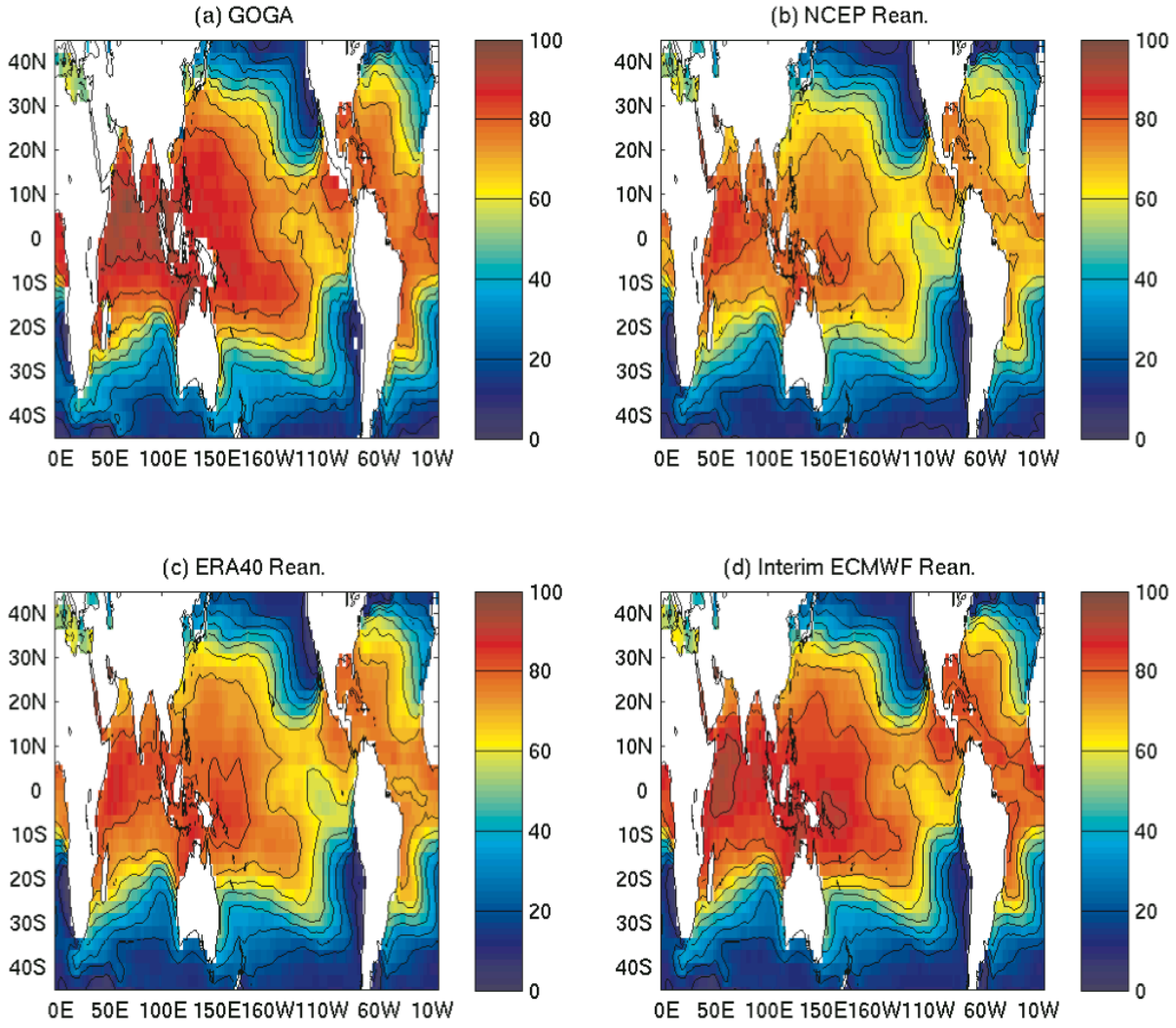


Vecchi, Swanson, and Soden, 2008, Science

Questions:

- Can we understand the 20th Century PDI & SST relationship by natural climate variability such as the AMV?
- How does hurricane intensity change (rather than PDI) associated with AMV and climate change?
- How much of the hurricane PI changes in the late 20th Century can be attributed to climate change versus AMV?

Hurricane Potential Intensity in AGCM with Prescribed Global Observed SST



$$V_{pot}^2 = \frac{C_k}{C_D}\frac{T_s}{T_0}\left(CAPE^* - CAPE^b\right)$$

C_k: exchange coefficient for enthalpy

C_D: drag coefficient

T_s: SST

T_0: outflow temperature

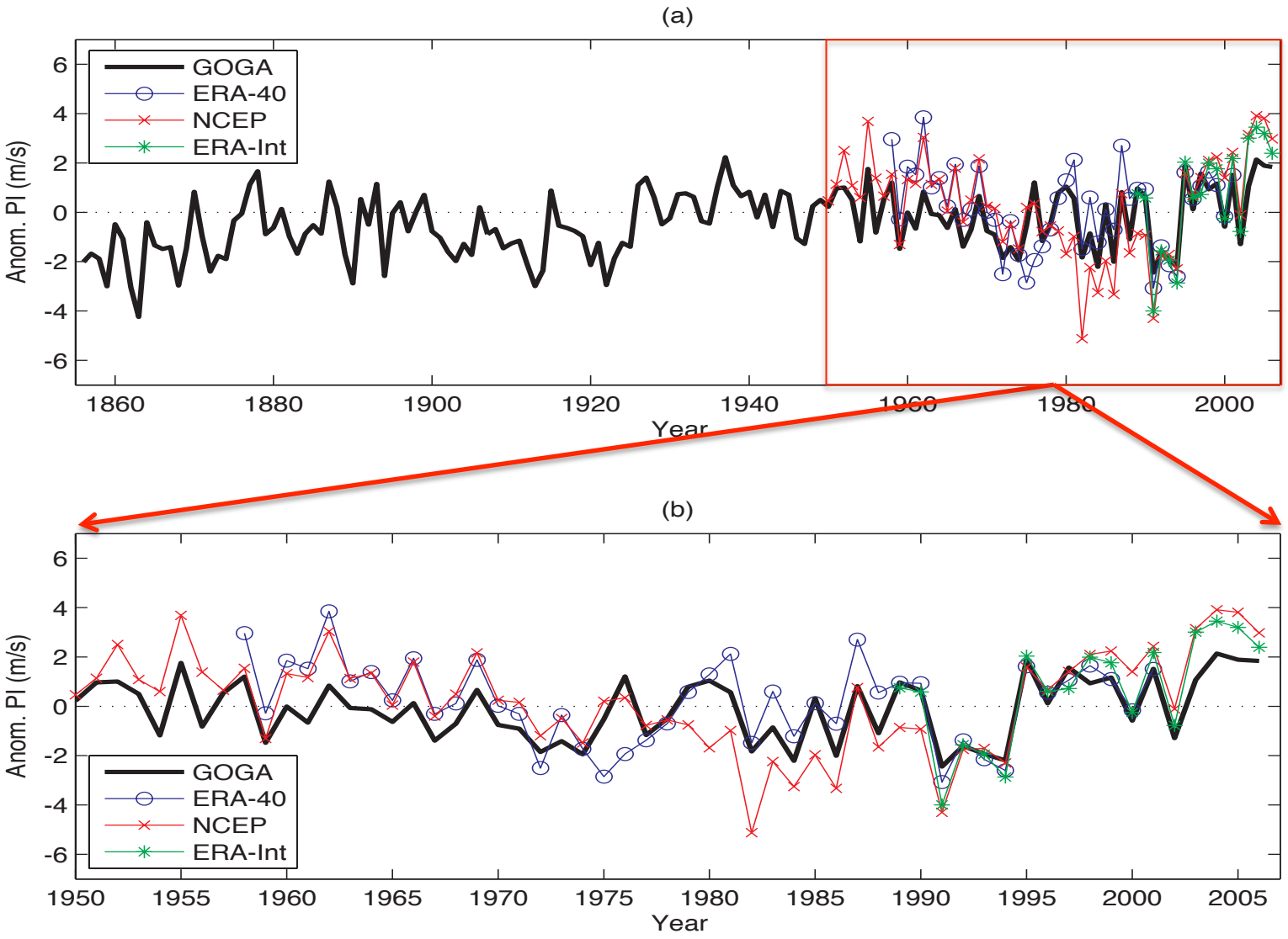
CAPE: Convective Available Potential Energy

CAPE*: saturated CAPE at maximum wind radius

$CAPE^b$: CAPE for the ambient boundary layer

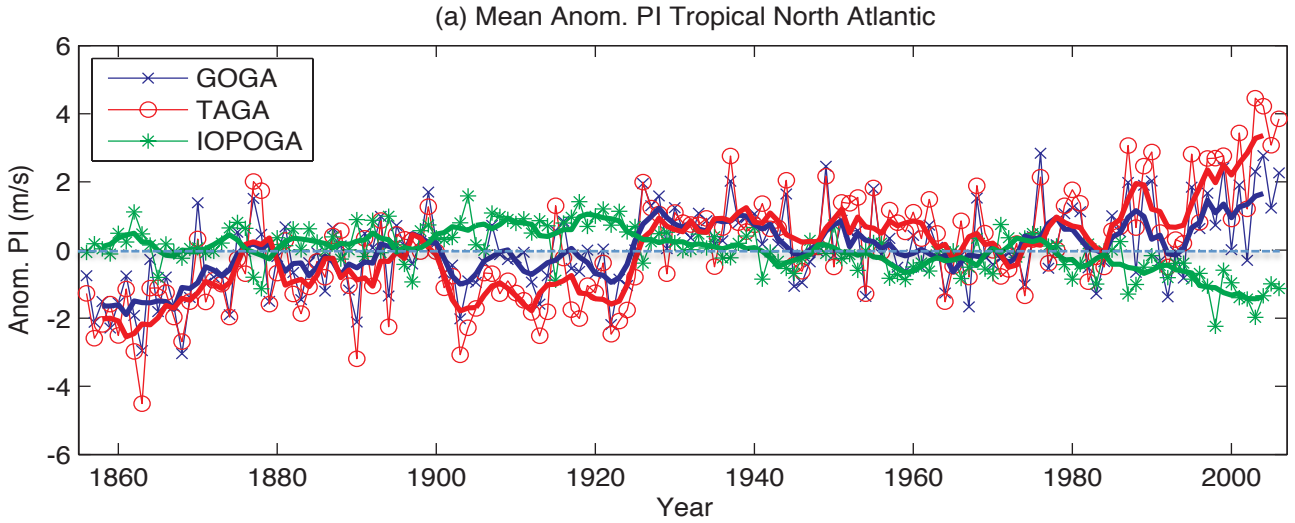
Camargo, Ting, Kushnir, 2012, Climate Dynamics

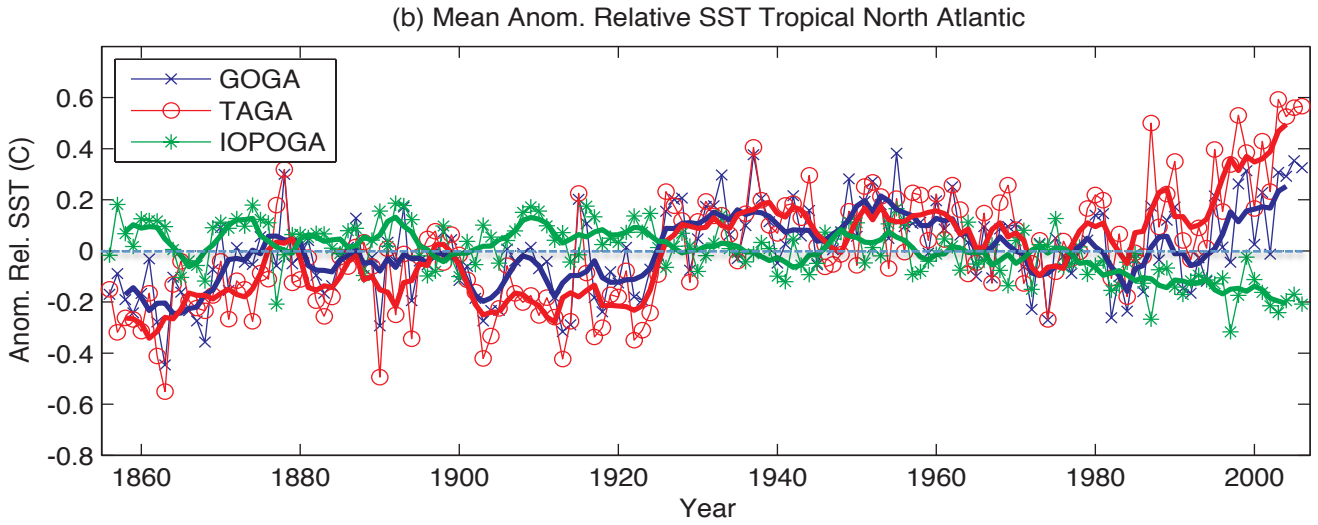
Mean anomalous PI (m/s) in the North Atlantic main development region (MDR) for JJASON hurricane season



Camargo, Ting, Kushnir, 2012, Climate Dynamics

Tropical North Atlantic Anomalous PI (m/s) and Relative SST in ASO





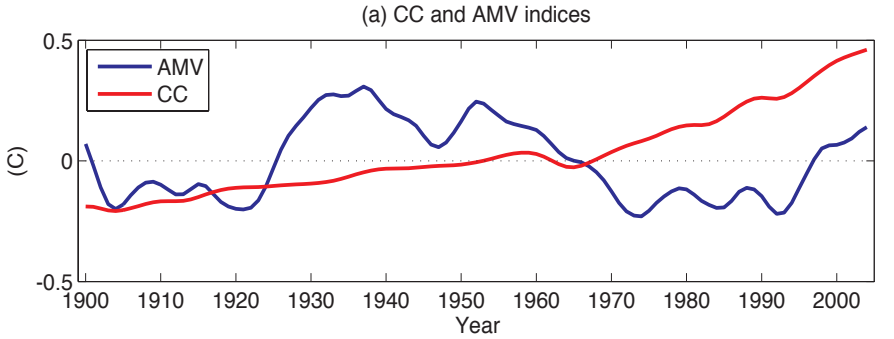
GOGA: AGCM with prescribed observed SST over global oceans

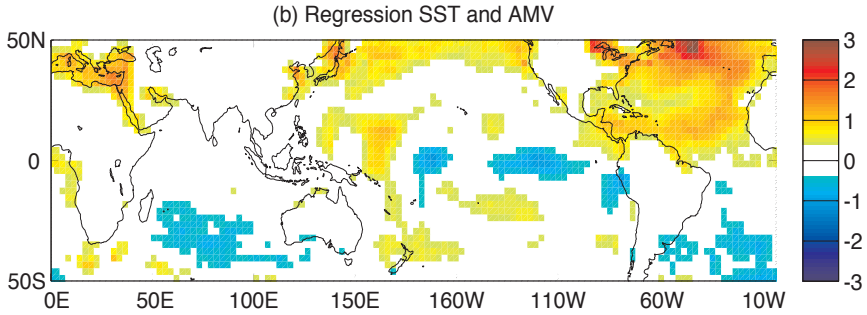
TAGA: AGCM with prescribed observed SST over the tropical Atlantic domain

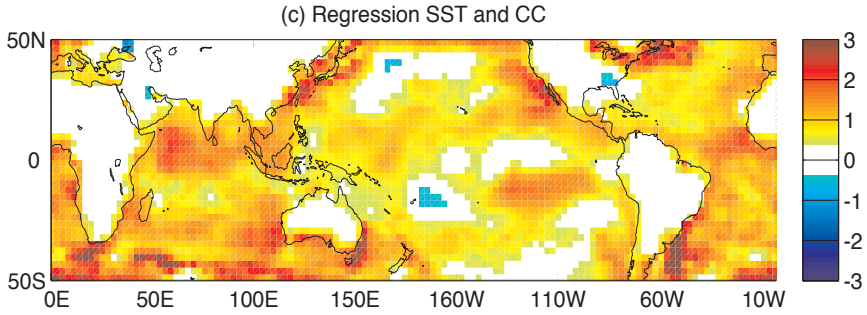
IOPOGA: AGCM with prescribed observed SST over the tropical Indian and Pacific Oceans

Camargo, Ting, Kushnir, 2012, Climate Dynamics

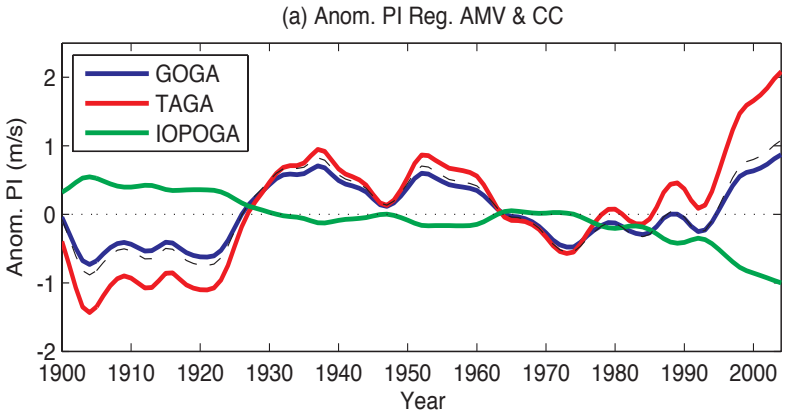
AMO vs Climate Change

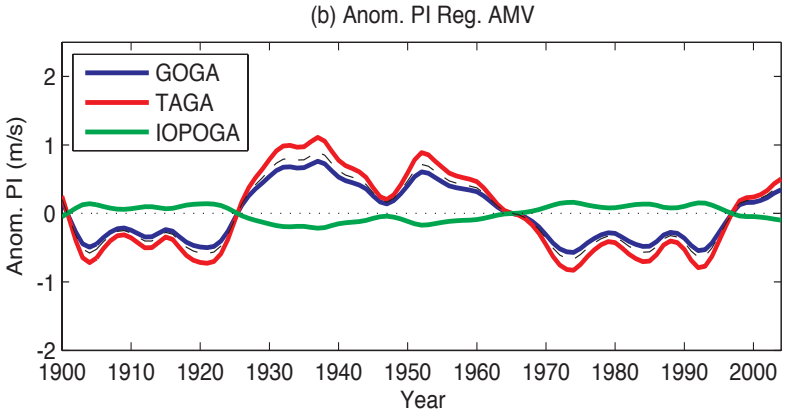


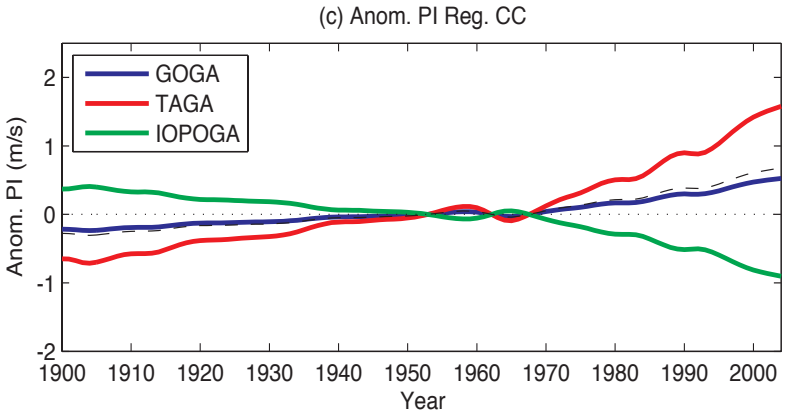




Camargo, Ting, Kushnir, 2012, Climate Dynamics







Summary of AGCM results

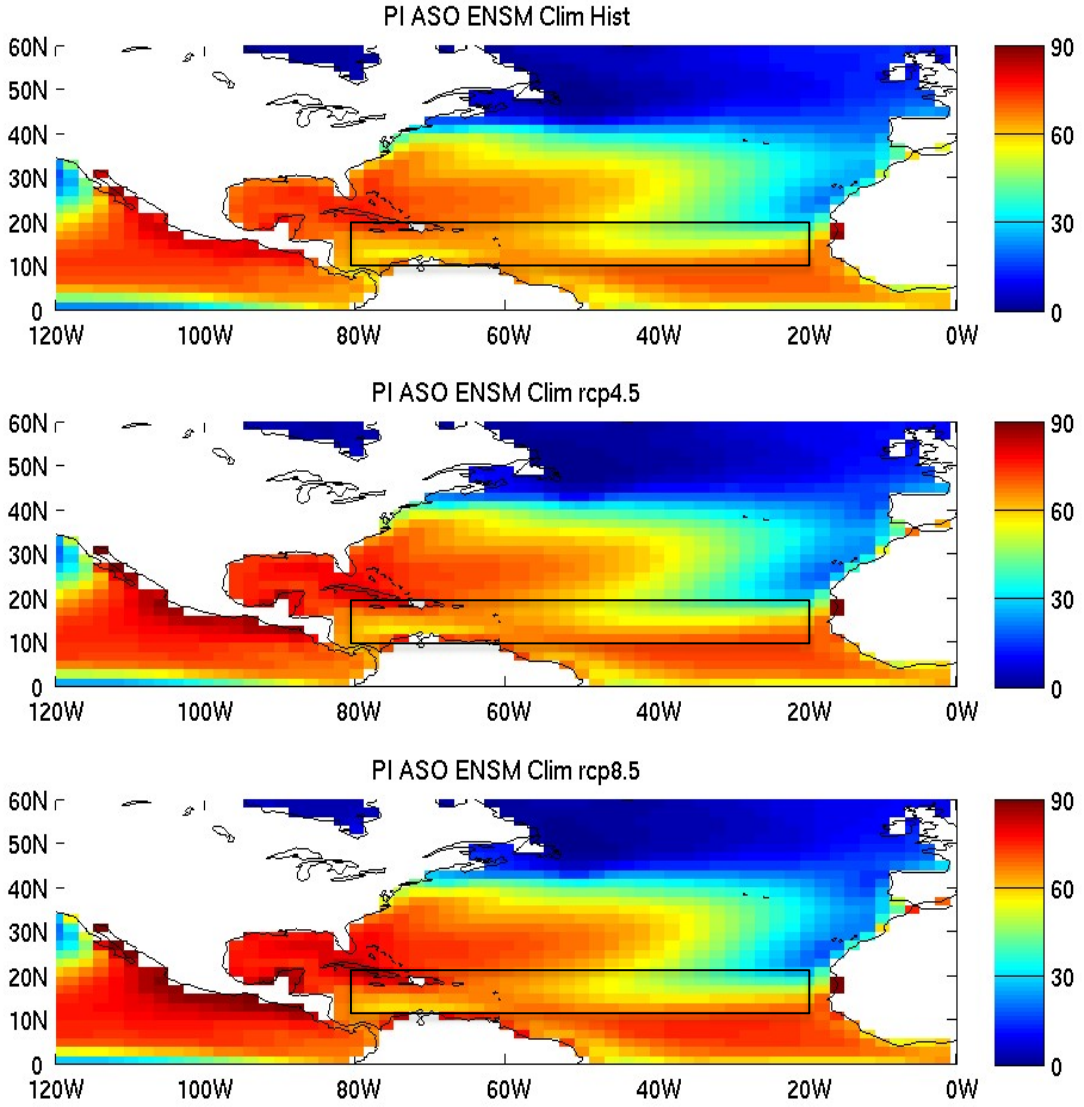
- Late 20th Century PI changes in the Atlantic MDR is dominated by AMV (~2m/s), and the climate change signal is rather weak, about .5 m/s increase over the past Century.
- Given that AMV is local to the Atlantic, local SST (TAGA) depicts well the PI changes due to AMV. But for Climate Change signal, local SST (TAGA) tends to exaggerate the PI changes (approximately doubling the amplitude) compared to that with global SST (GOGA), consistent with previous studies using PDI (e.g., Vecchi et al., 2008).
- How hurricane PI may change in the 21st century, when anthropogenic influence increases in amplitude while the AMV continue to slowly swing between negative and positive phases with presumably the same amplitude as during the 20th Century?

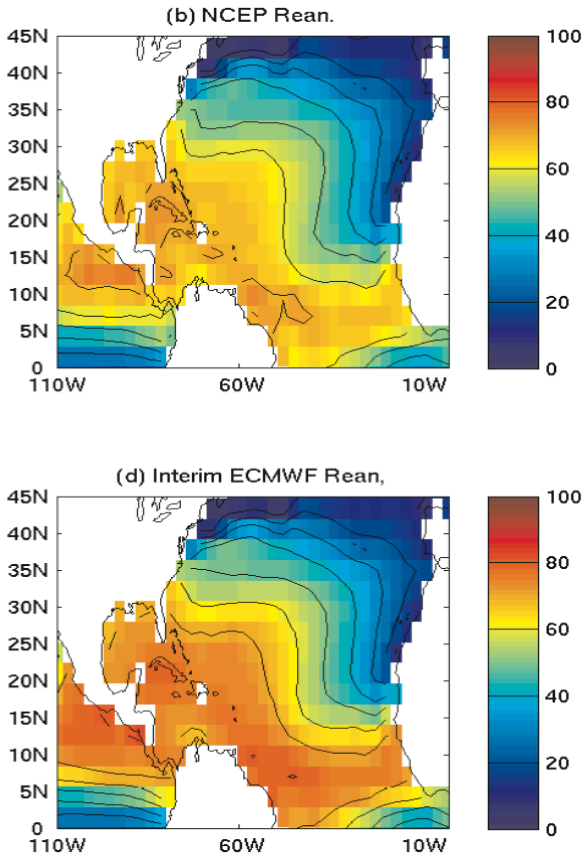
CMIP5 Models and Ensembles

	Model	Hist.	rcp4.5	rcp8.5		Model	Hist.	rcp4.5	rcp8.5
M1	ACCESS1-0	1	1	1	M13	HadGEM2-CC	1	1	1
M2	ACCESS1-3	1	1	1	M14	HadGEM2-ES	4	1	4
M3	bcc-csm1-1	3	1	1	M15	inmcm4	1	1	1
M4	CanESM2	5	5	5	M16	IPSL-CM5A-LR	5	3	4
M5	CCSM4	6	6	3	M17	IPSL-CM5B-LR	1	1	1
M6	CNRM-CM5	9	1	5	M18	IPSL-CM5A-MR	1	1	1
M7	CSIRO-Mk3-6-0	10	5	5	M19	MIROC5	4	1	3
M8	FGOALS-g2	5	1	1	M20	MIROC-ESM-LR	3	1	1
M9	FIO-ESM	3	3	3	M21	MIROC-ESM-CHEM	1	1	1
M10	GFDL-CM3	5	1	1	M22	MPI-ESM-LR	3	3	3
M11	GFDL-ESM2	1	1	1	M23	MRI-CGCM3	4	1	1
M12	GISSE2-R	5	5	1	M24	NorESM1-M	3	1	1

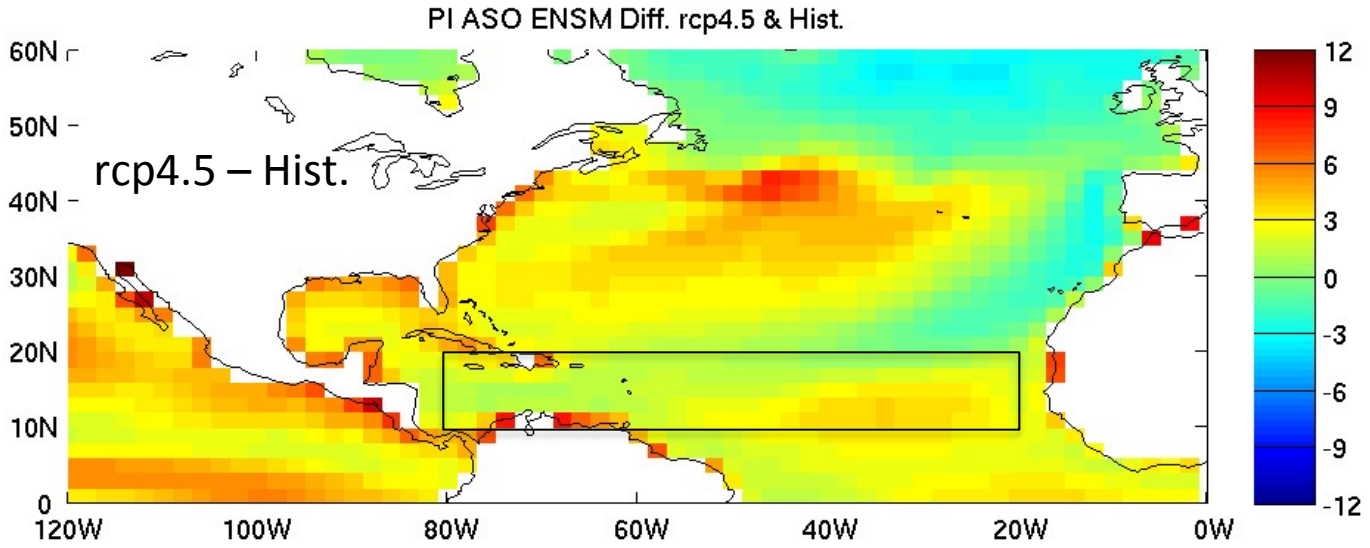
24 models, 85 ensemble members for historical, 47 members for rcp4.5 and 50 members for rcp8.5

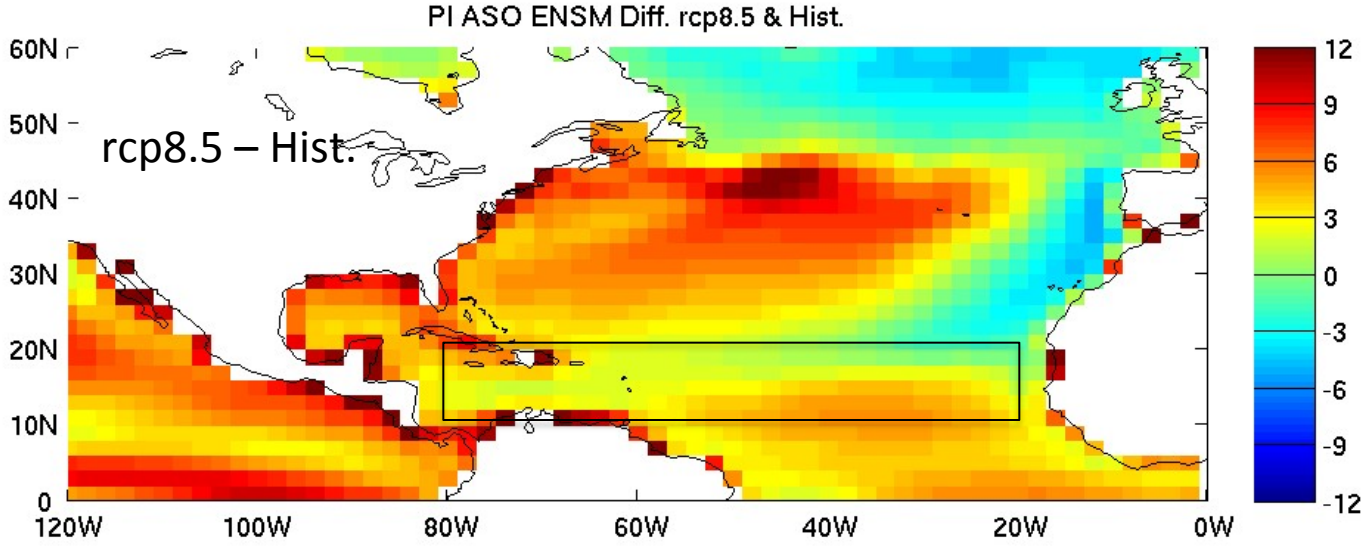
Atlantic PI Climatology ASO – Multi-model mean



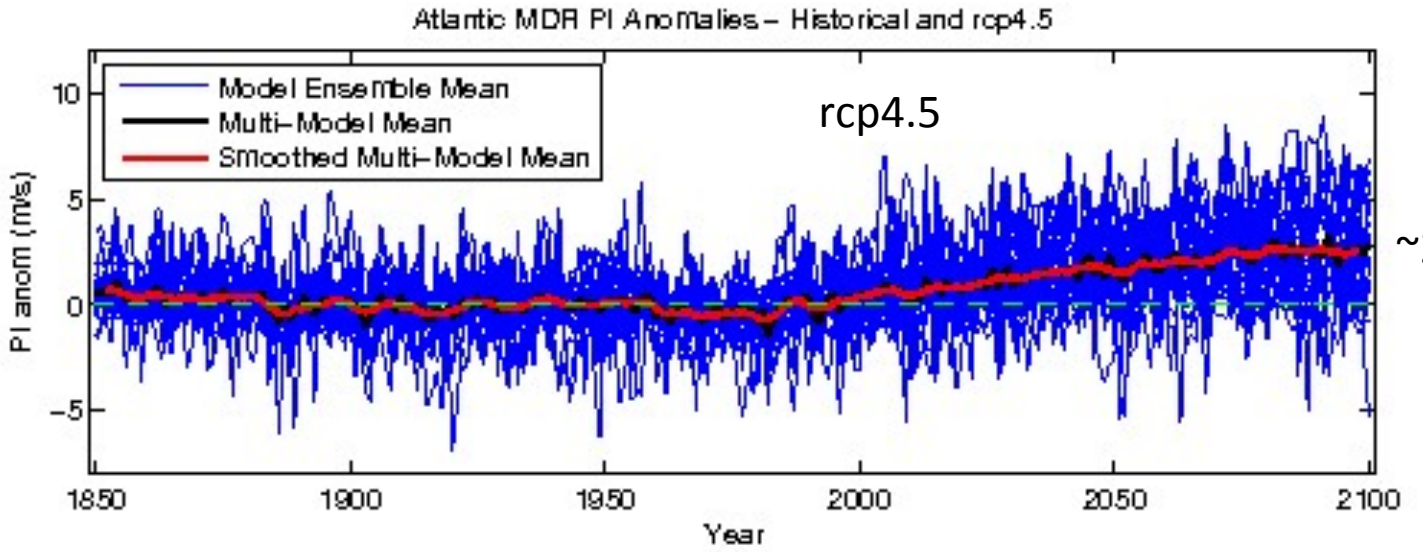


Atlantic PI ASO 21C and 20C – Multi-Model Mean

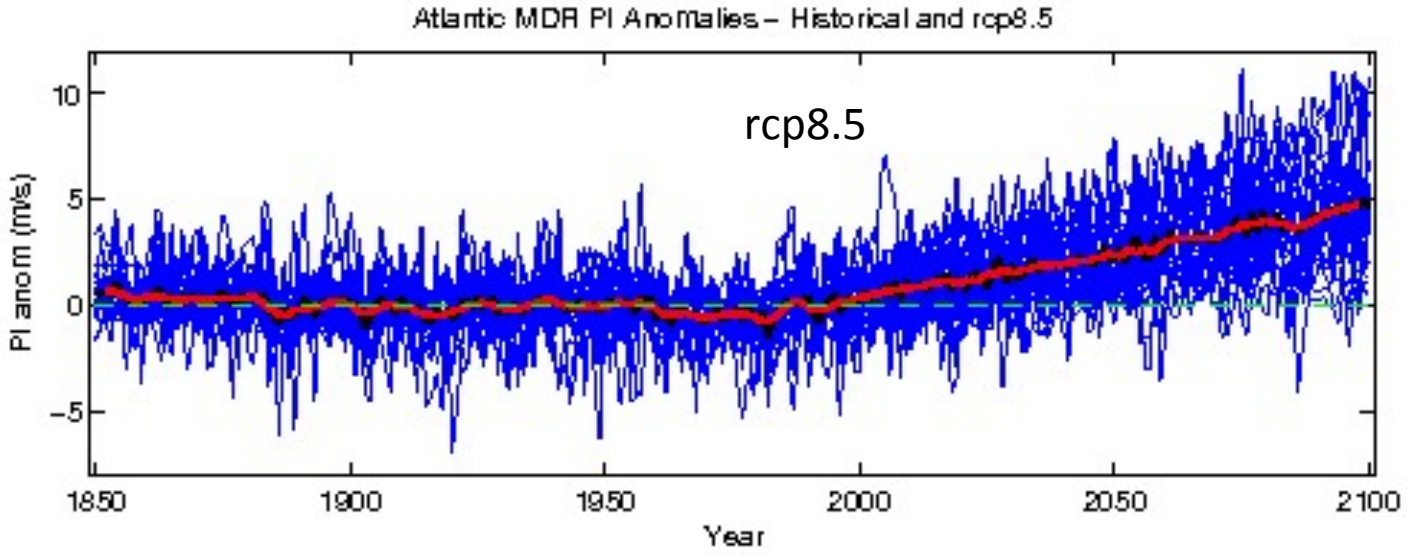




Atlantic MDR PI ASO Anomalies



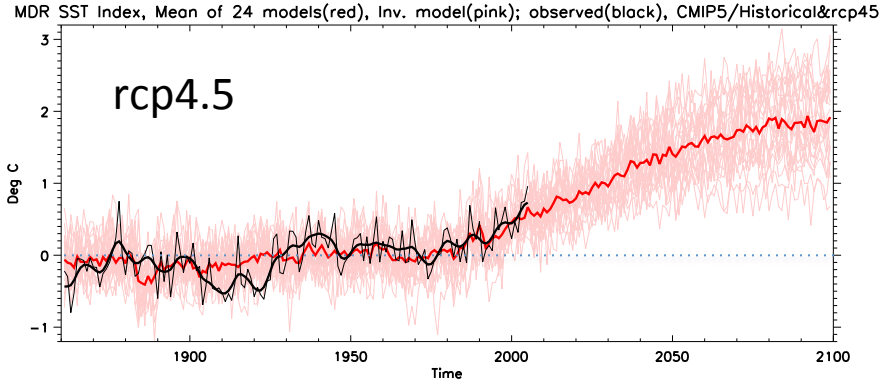
~2.5 m/s

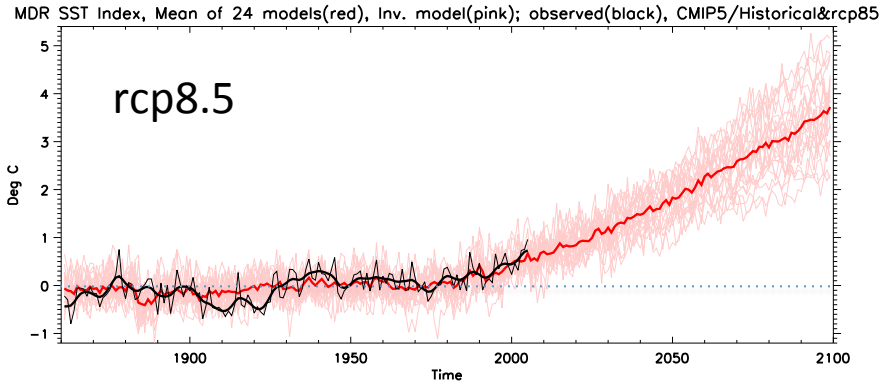


~5 m/s

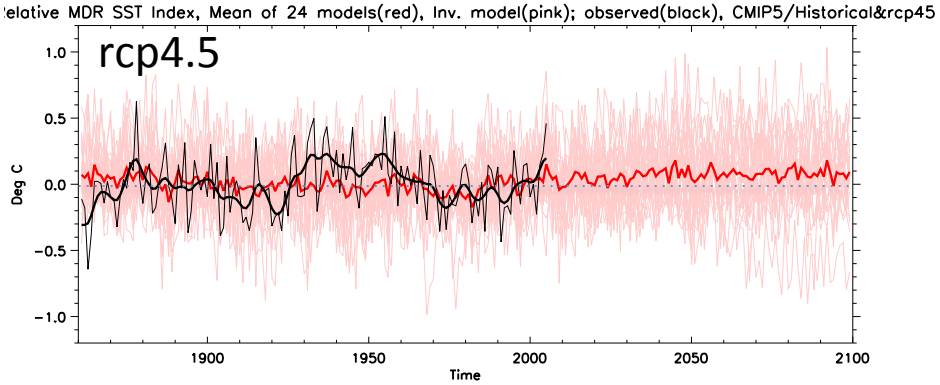
MDR Absolute vs. Relative SST in CMIP5 Models

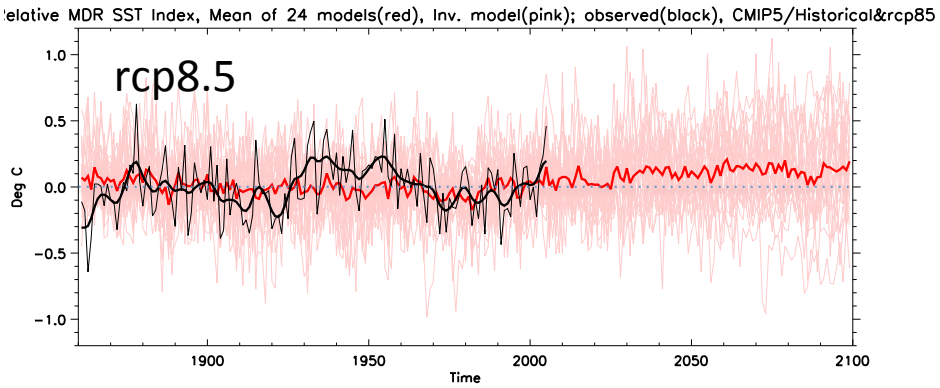
Absolute SST Anomalies





Relative SST Anomalies

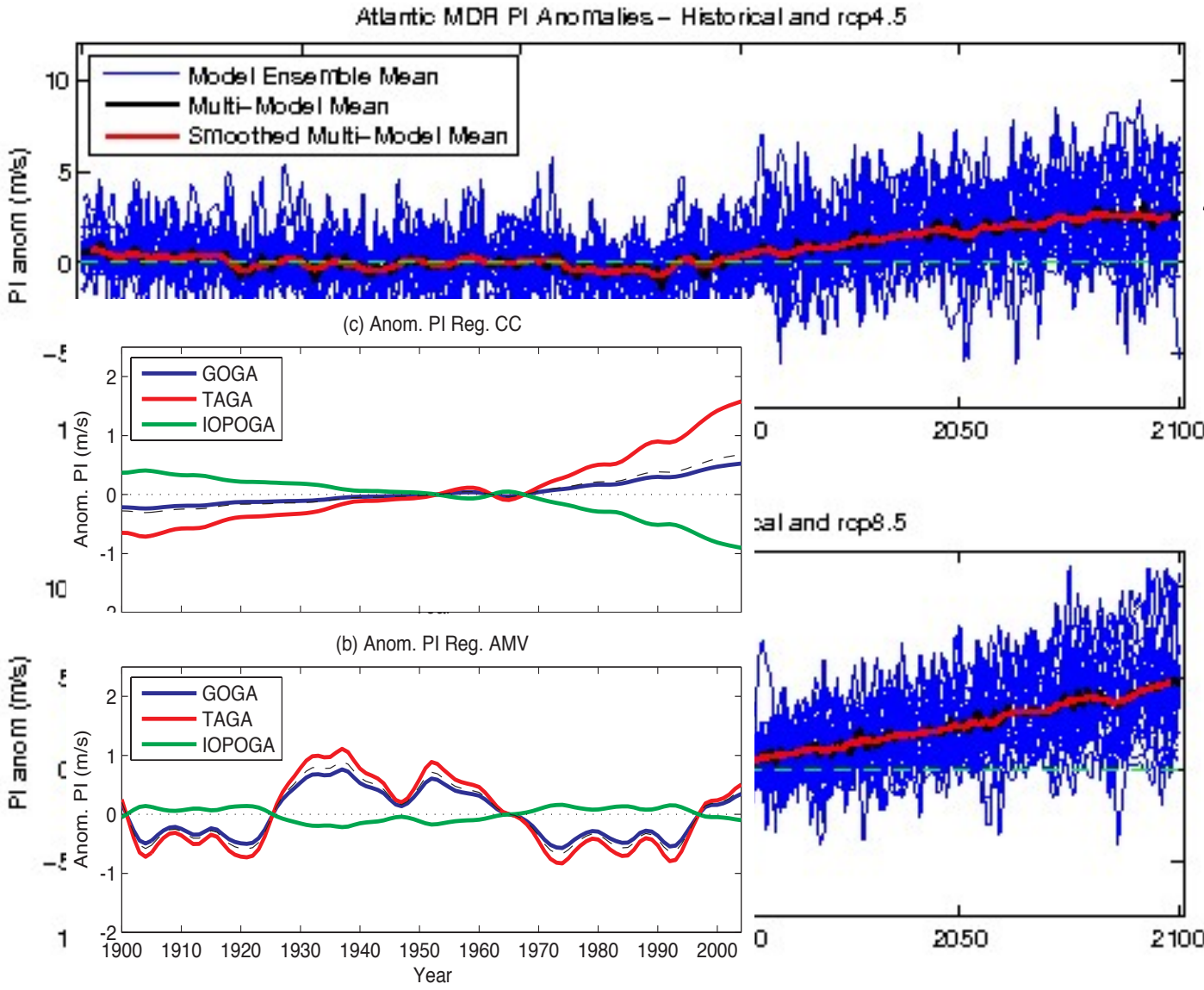




Black: Observations; Think pink: individual models; Thick pink: multi-model mean

By the end of this century, absolute MDR SST increases reach about 2^{o}C for rcp4.5, and 3.8^{o}C for rcp8.5, while relative SST barely changed

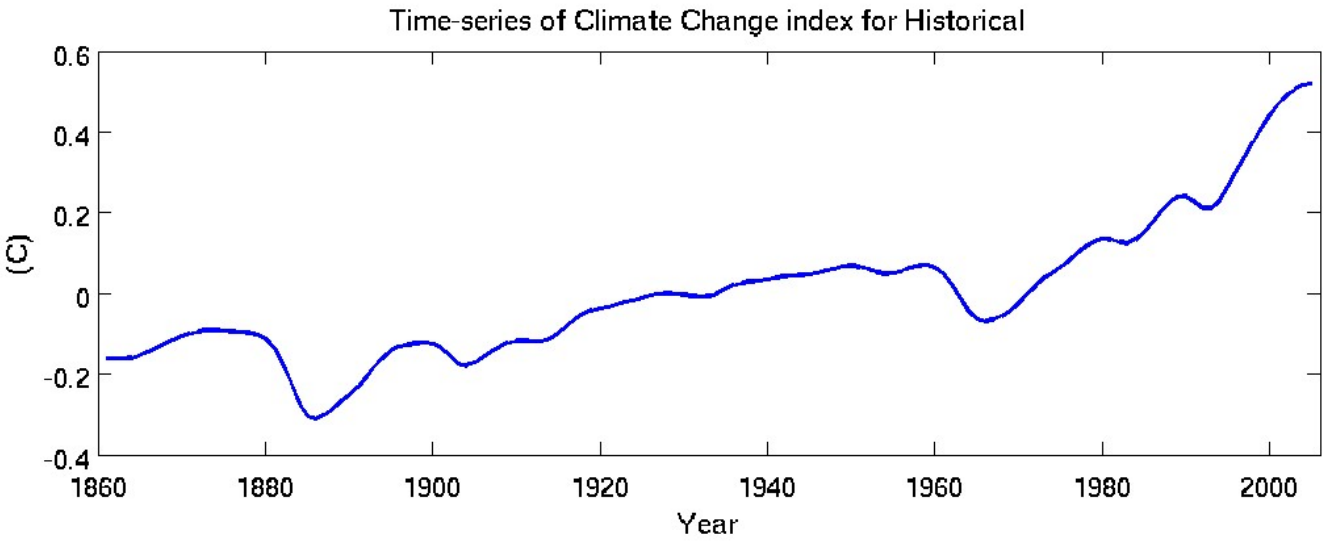
Atlantic MDR PI ASO Anomalies

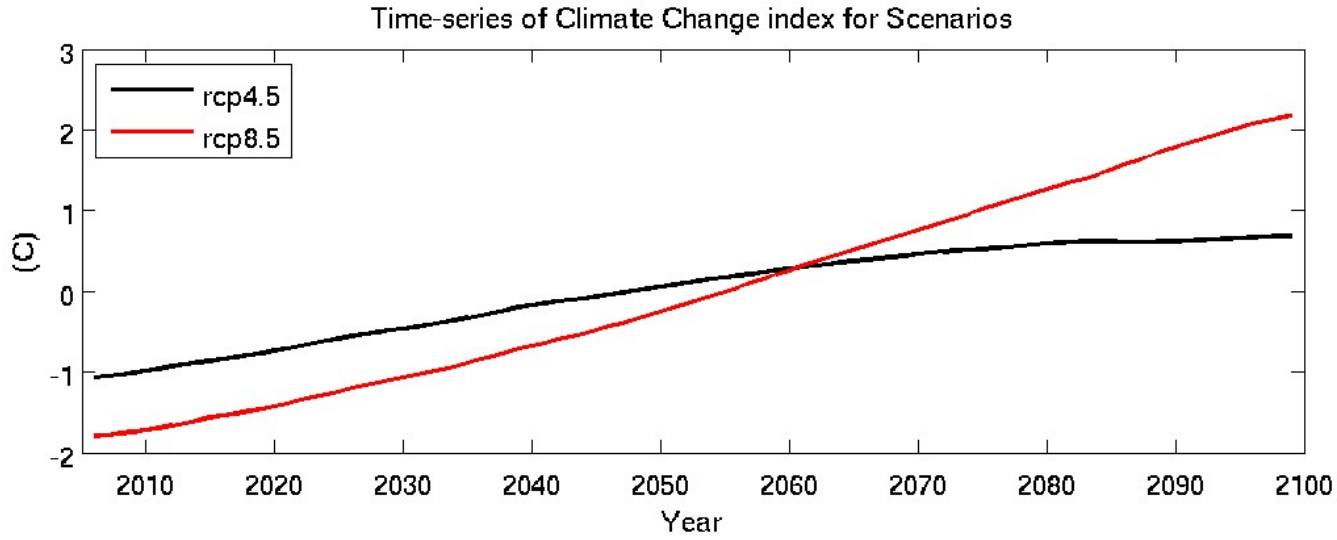


~2.5 m/s

~5 m/s

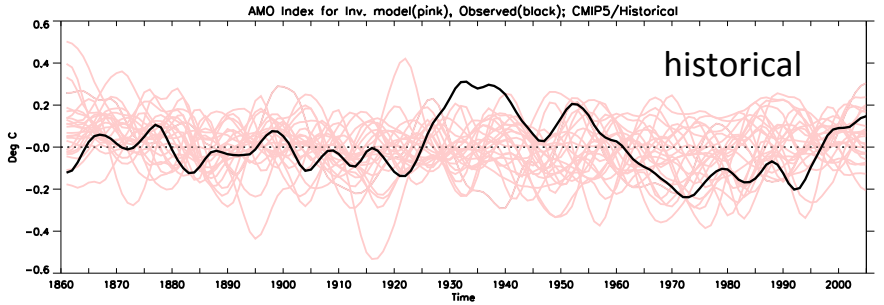
Climate Change indices

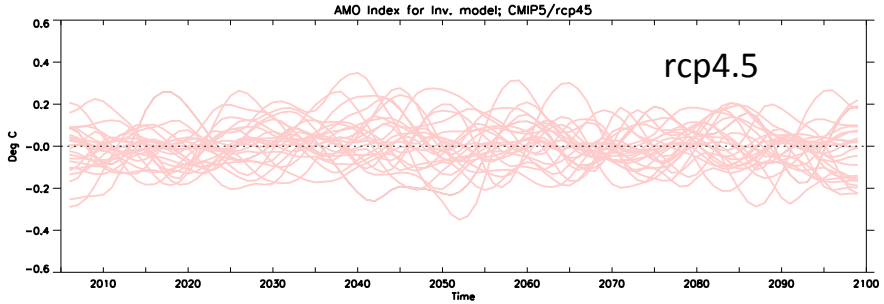


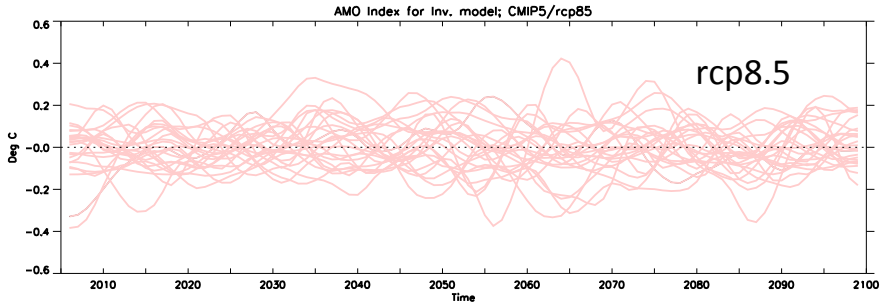


AMV in CMIP5 models (historical, rcp4.5 and rcp8.5)

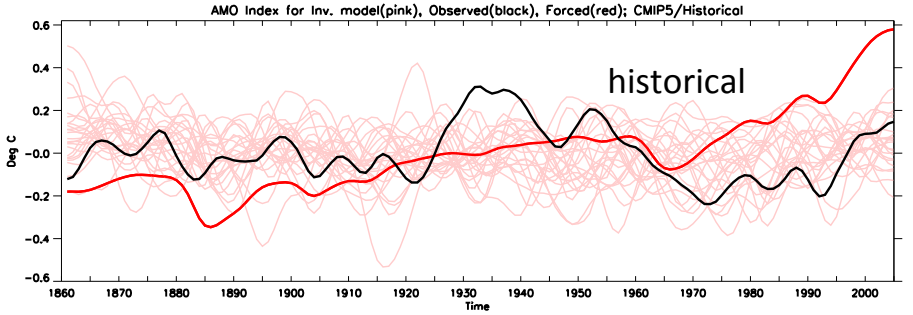
AMV indices

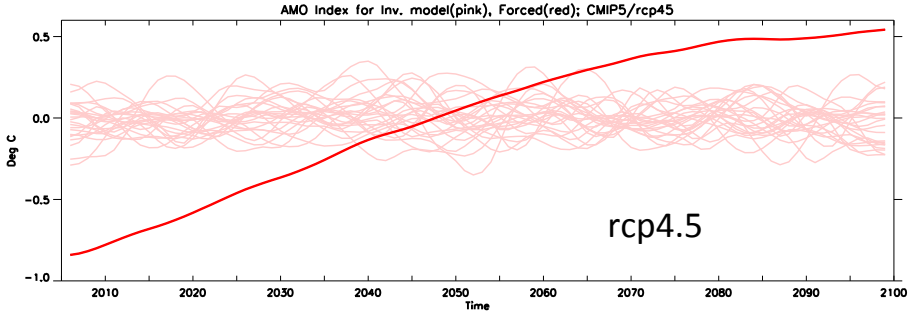


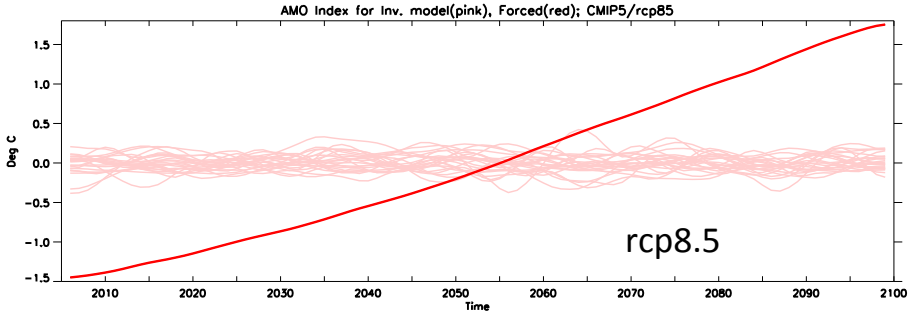




AMV and CC (thick red) indices

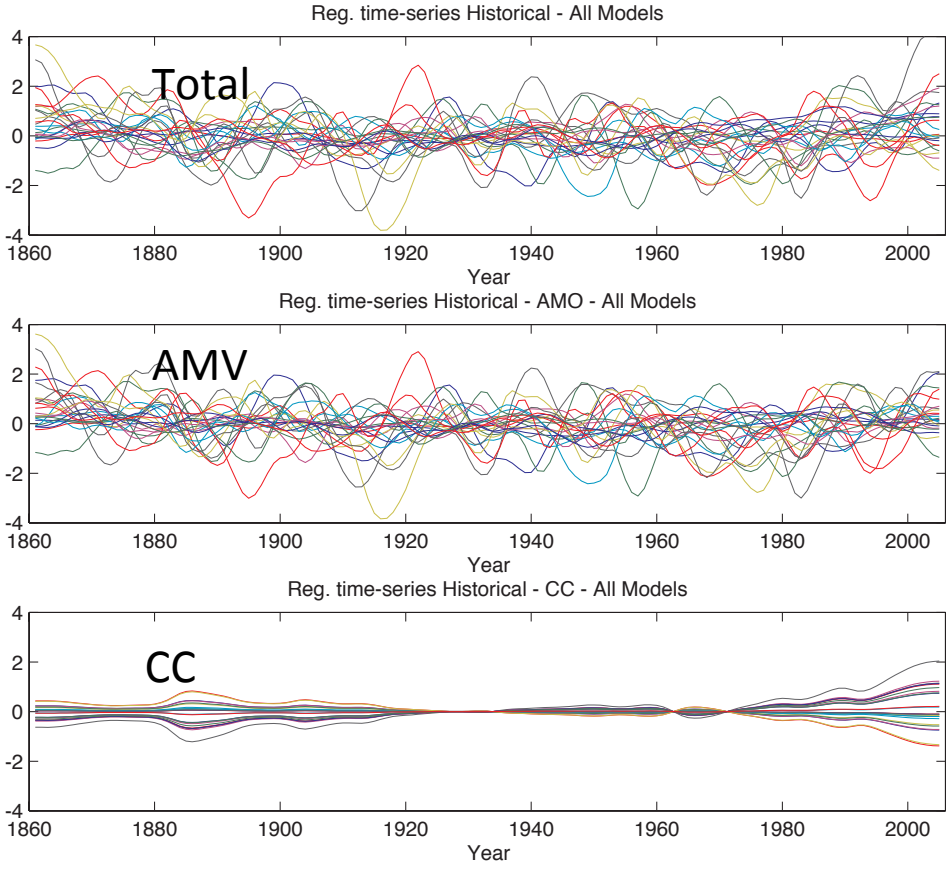




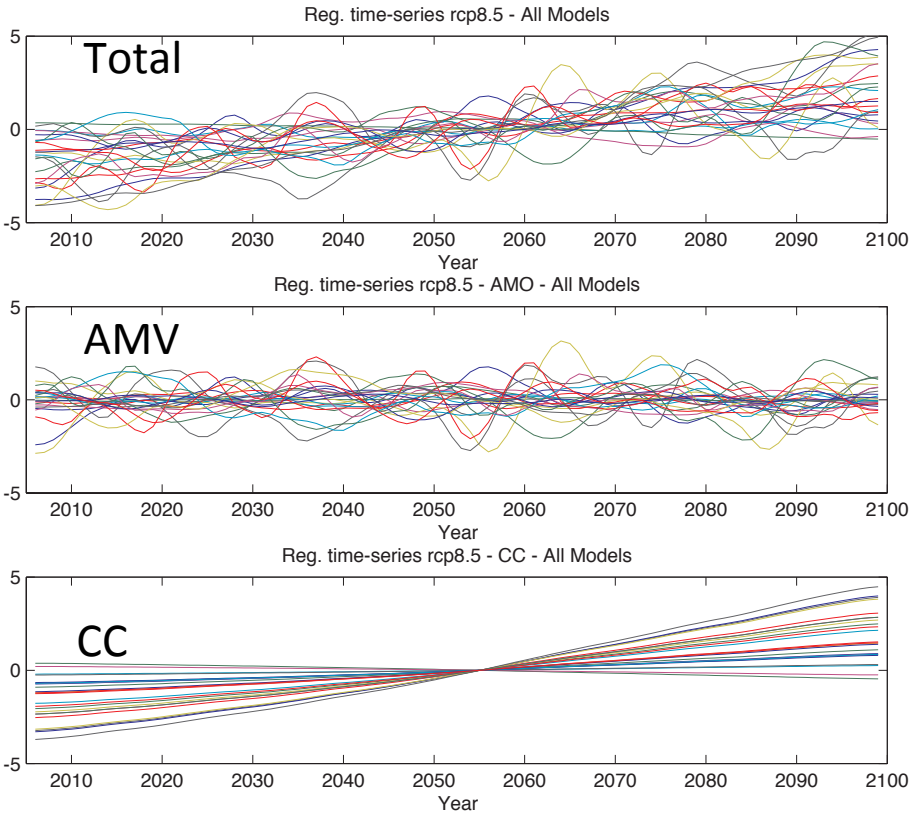


PI Anomaly - AMV vs. Climate Change

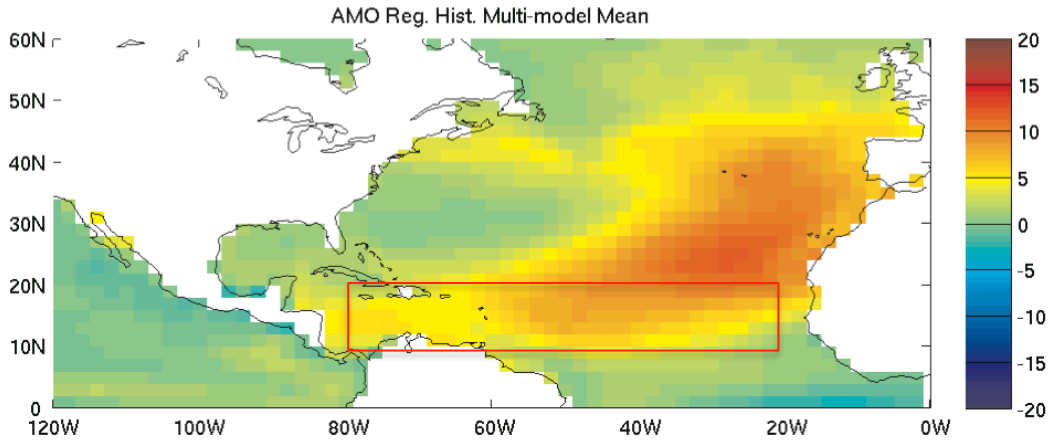
Historical

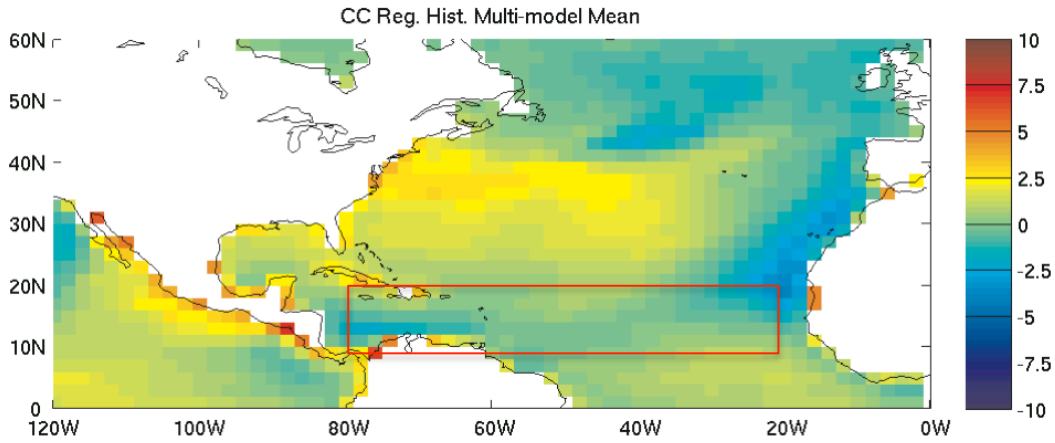


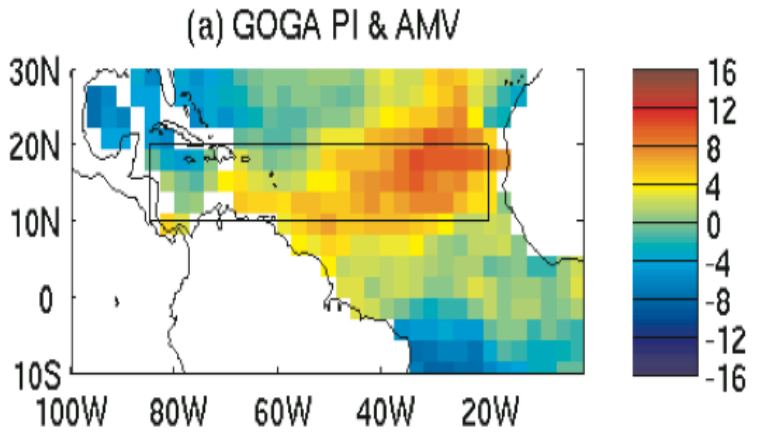
rcp8.5

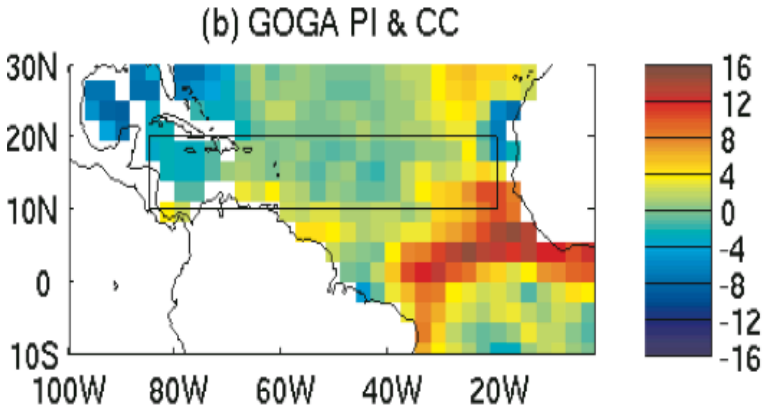


PI Regression Patterns – Historical Multi-Model Mean

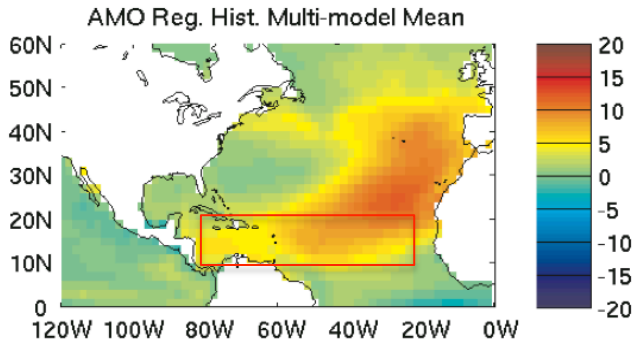


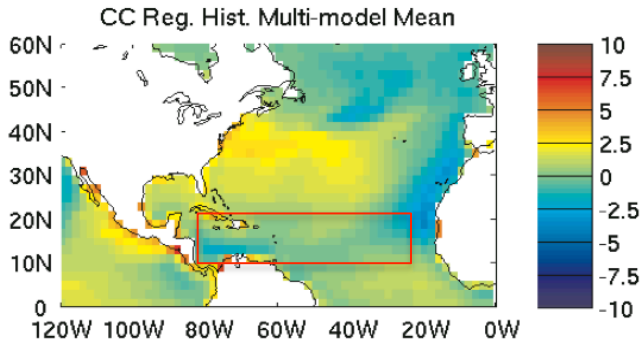


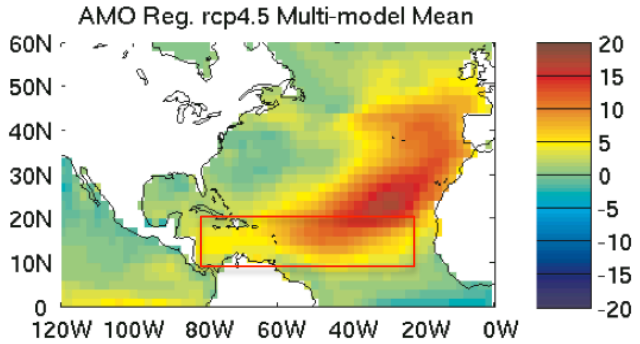


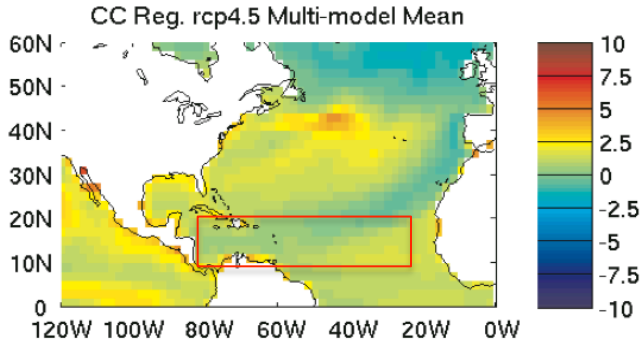


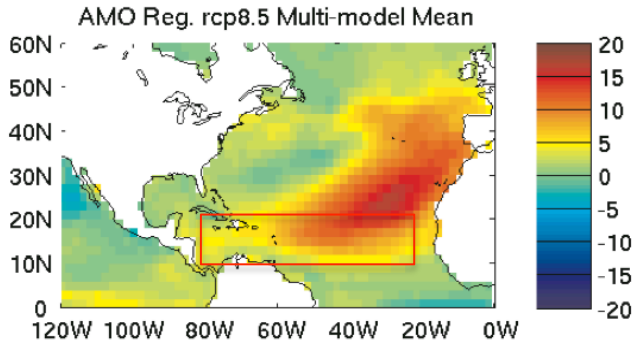
PI Regression patterns (Multi-model mean)

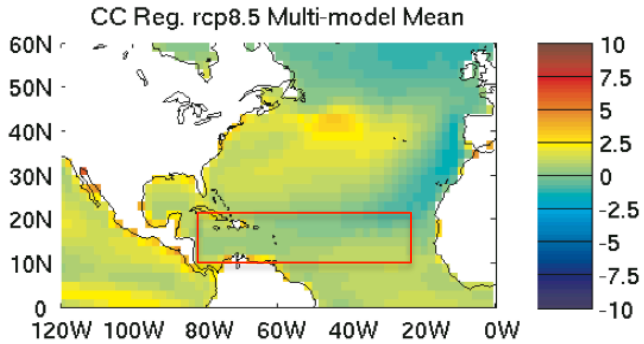




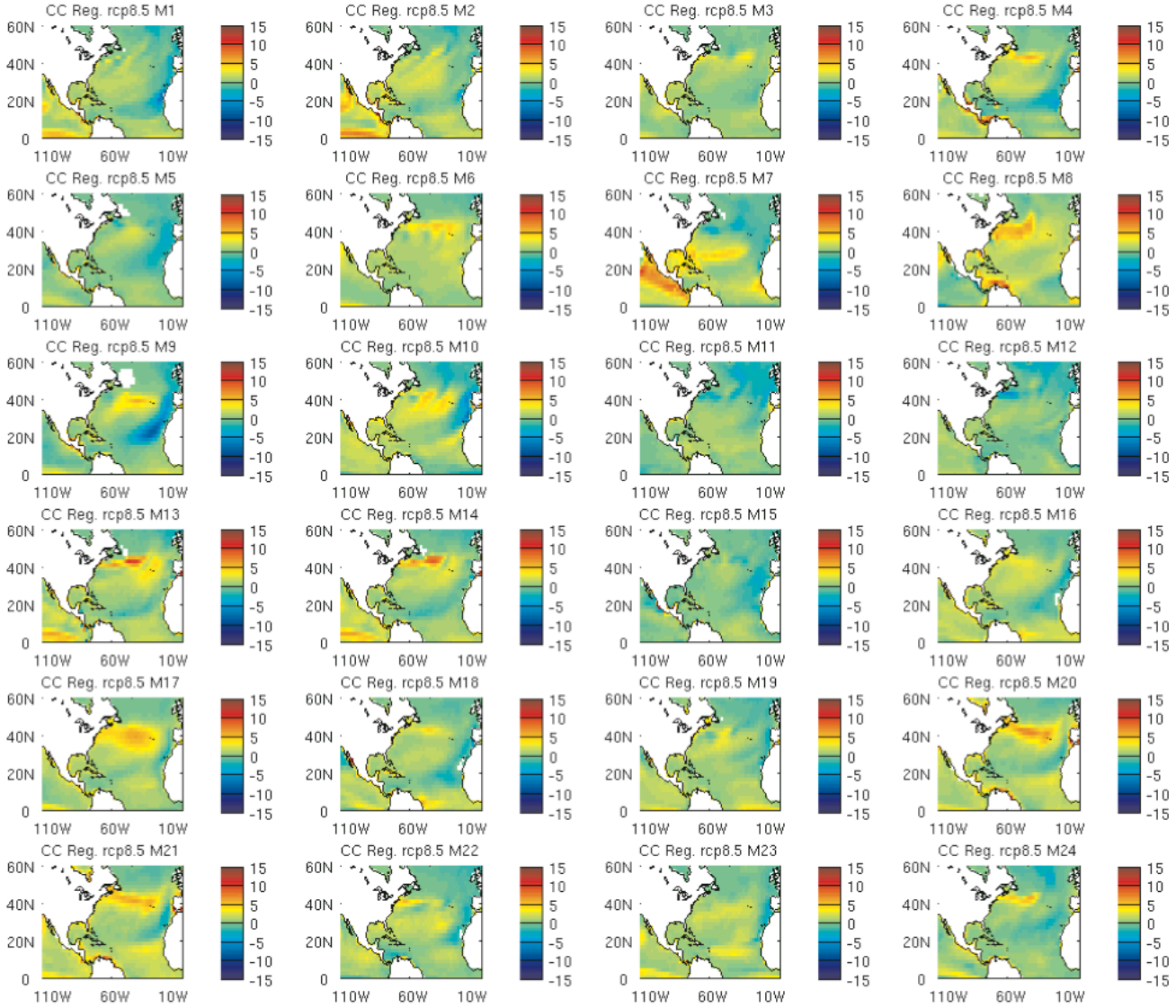




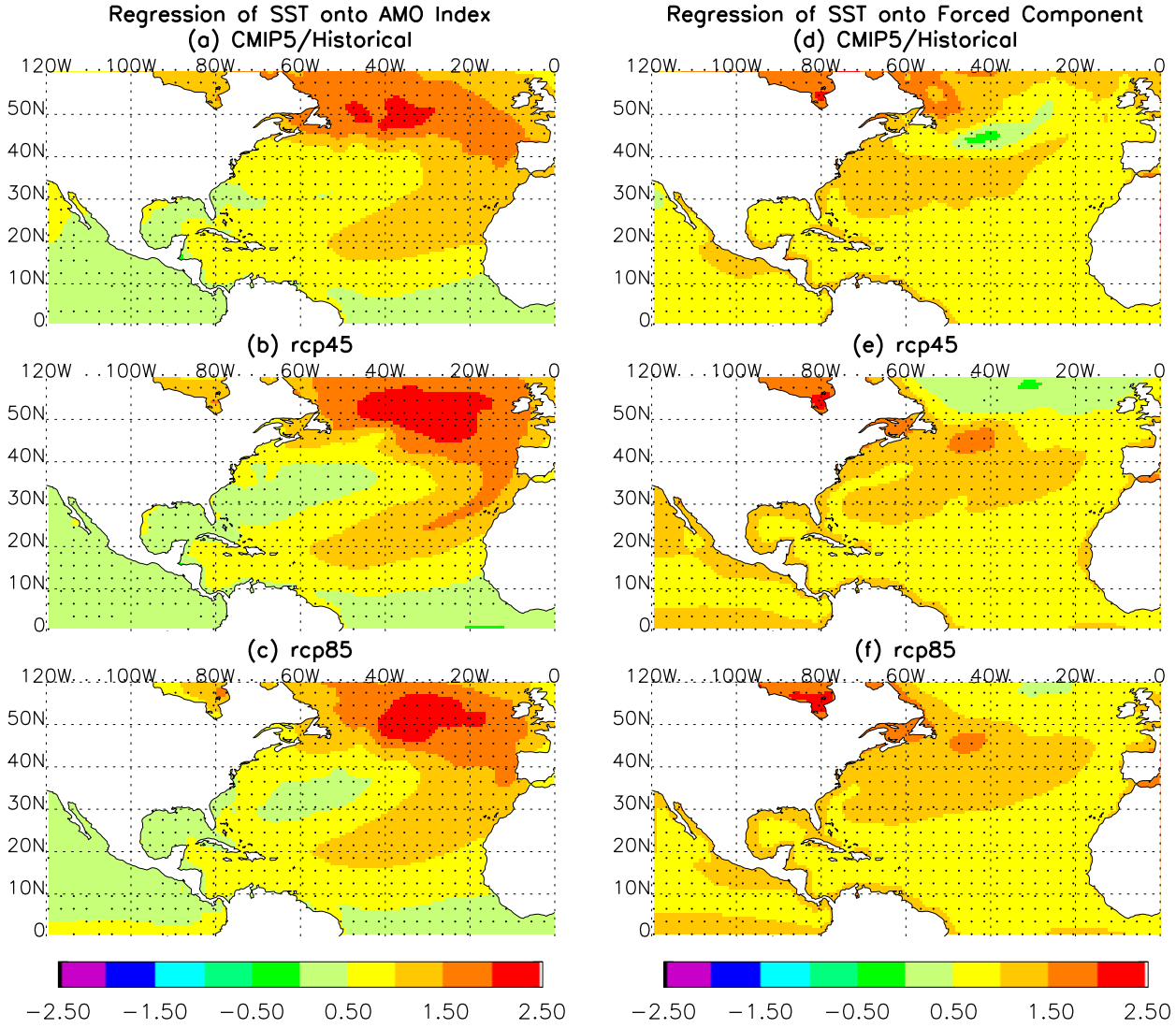




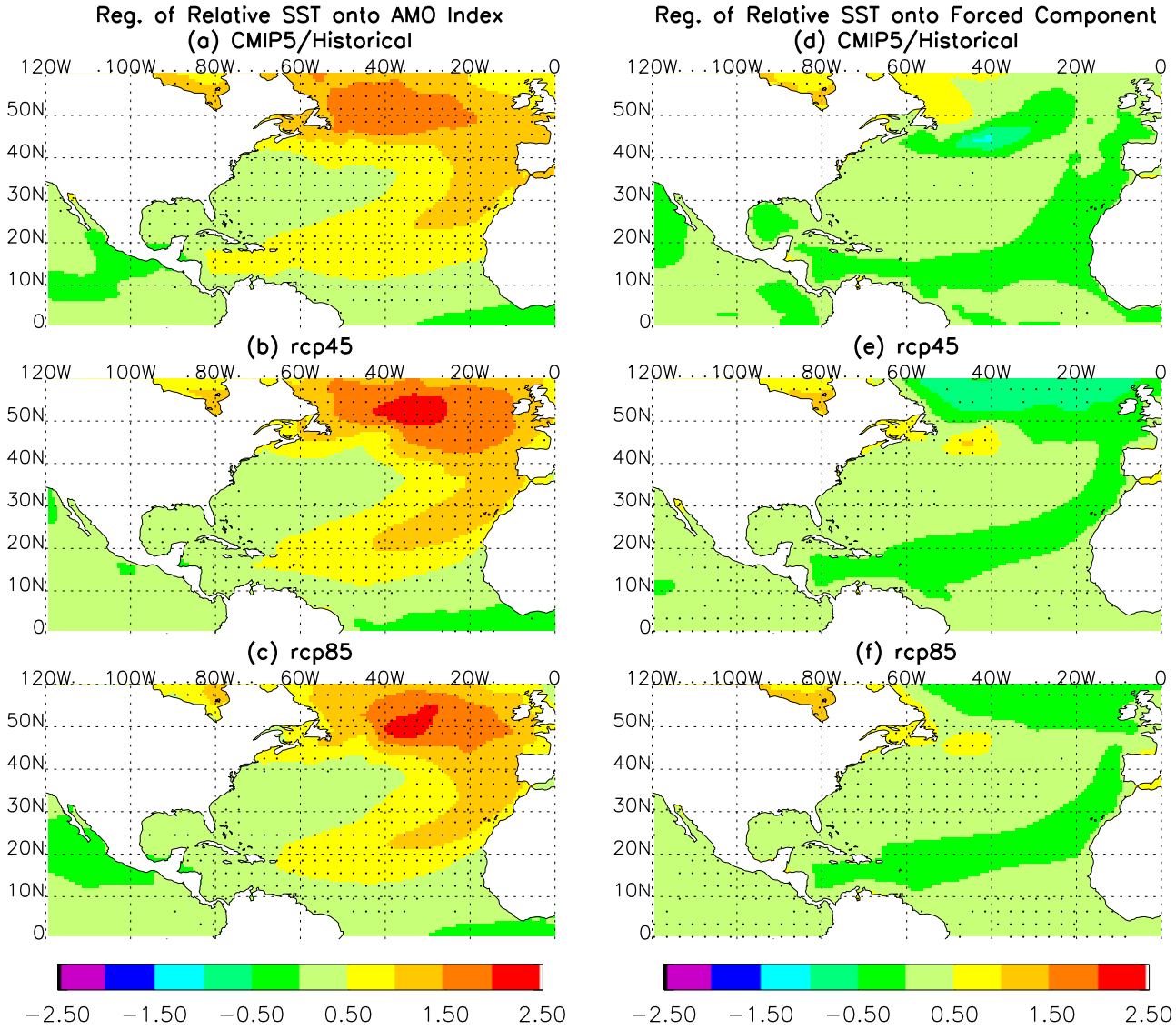
PI Regression Patterns – CC rcp8.5



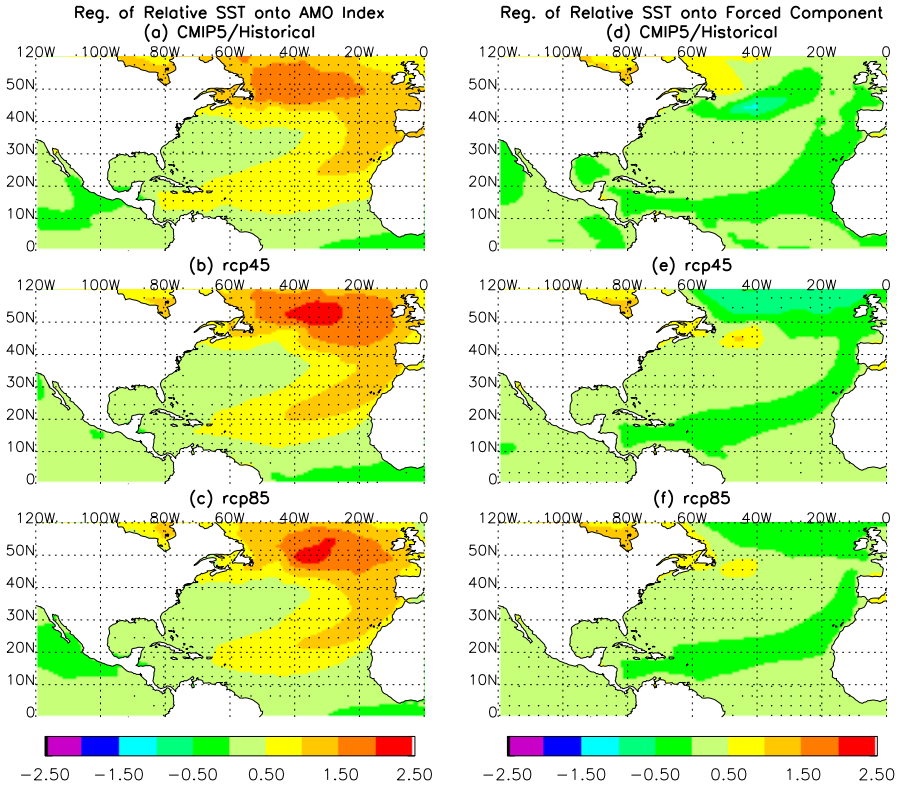
SST regression onto Climate Change and AMO indices

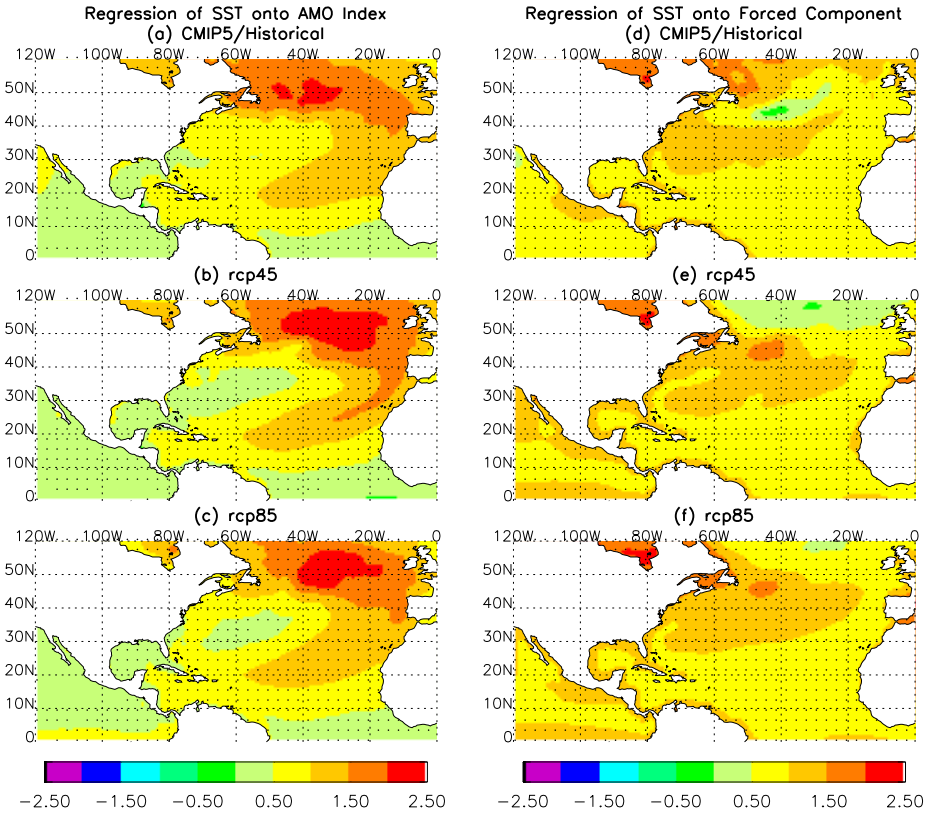


Relative SST regression onto Climate Change and AMO indices

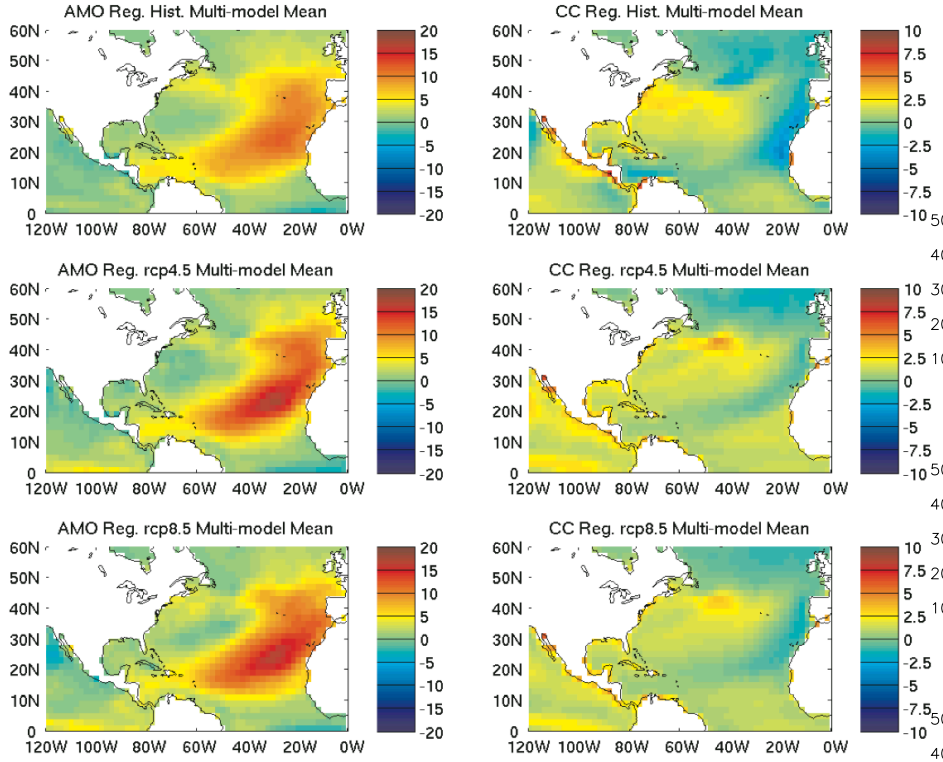


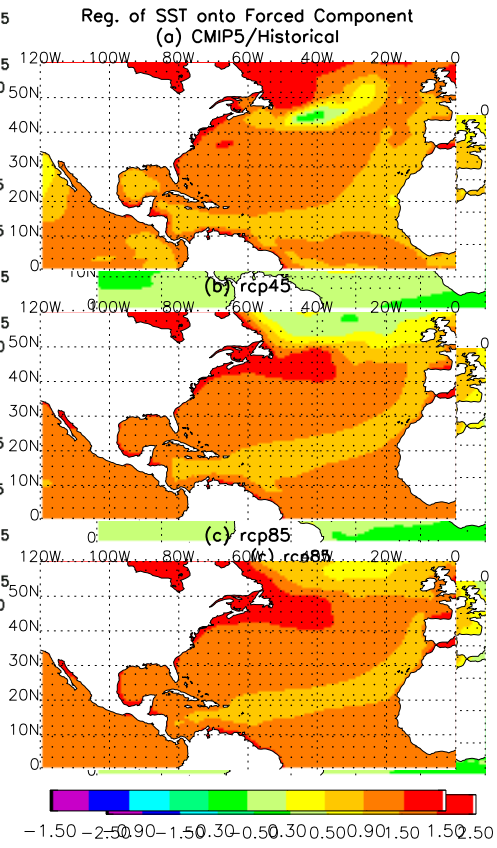
Relative vs. Absolute SST regression onto Climate Change and AMO indices

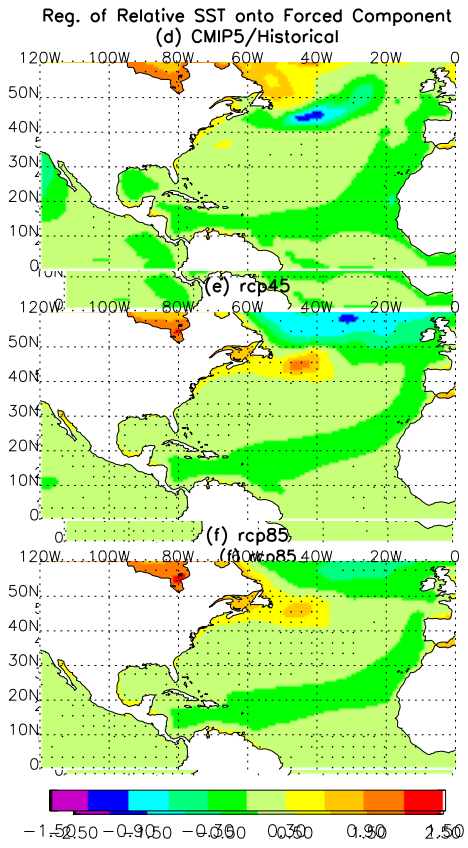




PI vs. Relative SST Regression patterns (Multi-model mean)







- There is a clear resemblance between spatial patterns of PI and the relative (and absolute) SST for both the Climate Change and the AMO related patterns

Summary

- Hurricane potential intensity (PI) changes in the tropical Atlantic main development region in the past few decades are dominated by natural SST variability known as the Atlantic Multidecadal Variability (Camargo et al., 2012)
- PI increases due to forced climate change signal by the end of the 21st Century will surpass the amplitude of the natural variability in both rcp4.5 (~2.5m/s) and rcp8.5 (~5m/s) scenarios based on CMIP5 multi-model means
- While the spatial pattern of the PI associated with climate change resembles both the absolute and the relative SST patterns, neither the absolute SST nor the relative SST change associated with climate change signal is a good indicator of the amplitude change of the hurricane potential intensity
- The PI changes associated with AMV does not change substantially as the radiative forcing amplitude changes (historical vs. rcp4.5 vs. rcp8.5)