Low-Frequency SST variability CMIP5 Historical Integrations

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Objective

Problem:

Anthropogenic-driven change in hurricane activity is obscured, among other things, by low-frequency natural SST variability.

Our goal

Set up a modeling system to estimate changes in Atlantic hurricane frequency in response to changing climate, separating the anthropogenic from the natural-variability components of the projected SST warming.

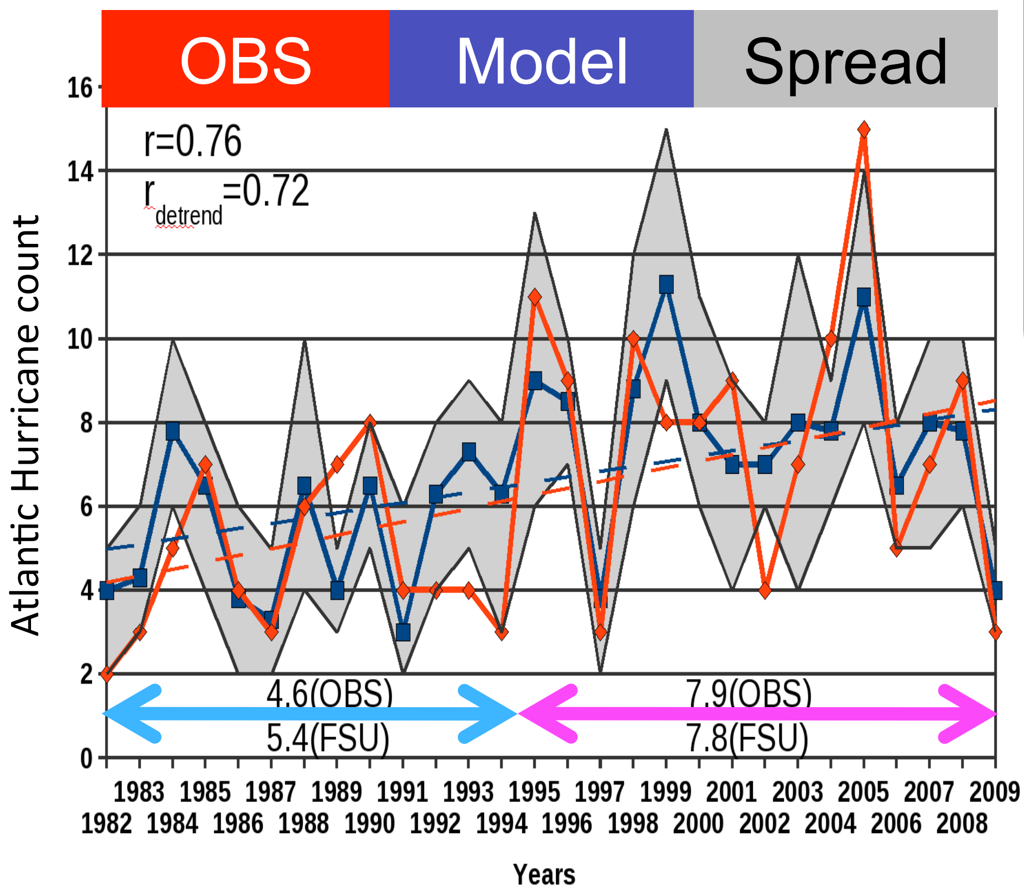
Prerequisites

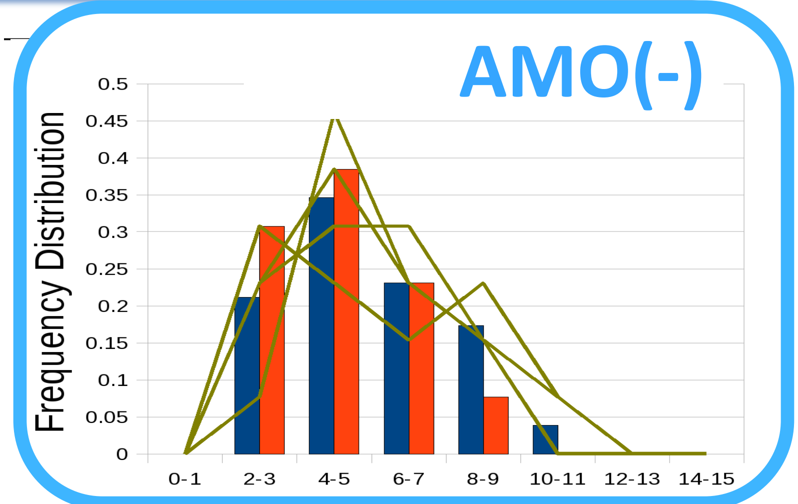
☐ A hurricane frequency model with demonstrated historical skill; and

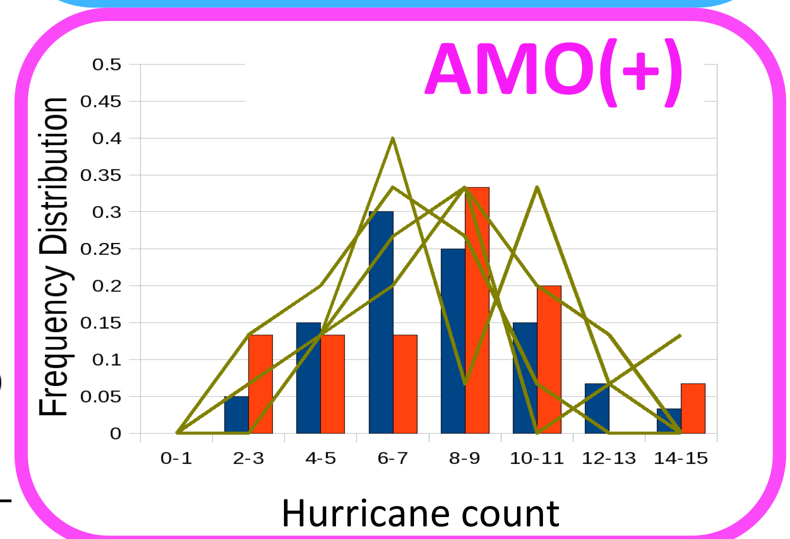
☐ SST projections from a global model with a degree of realism in its representation of the physical mechanisms for low-frequency variability.

Atlantic Hurricanes: FSU/COAPS Model

1982-2009; model forced with CFS seasonal SST fcst

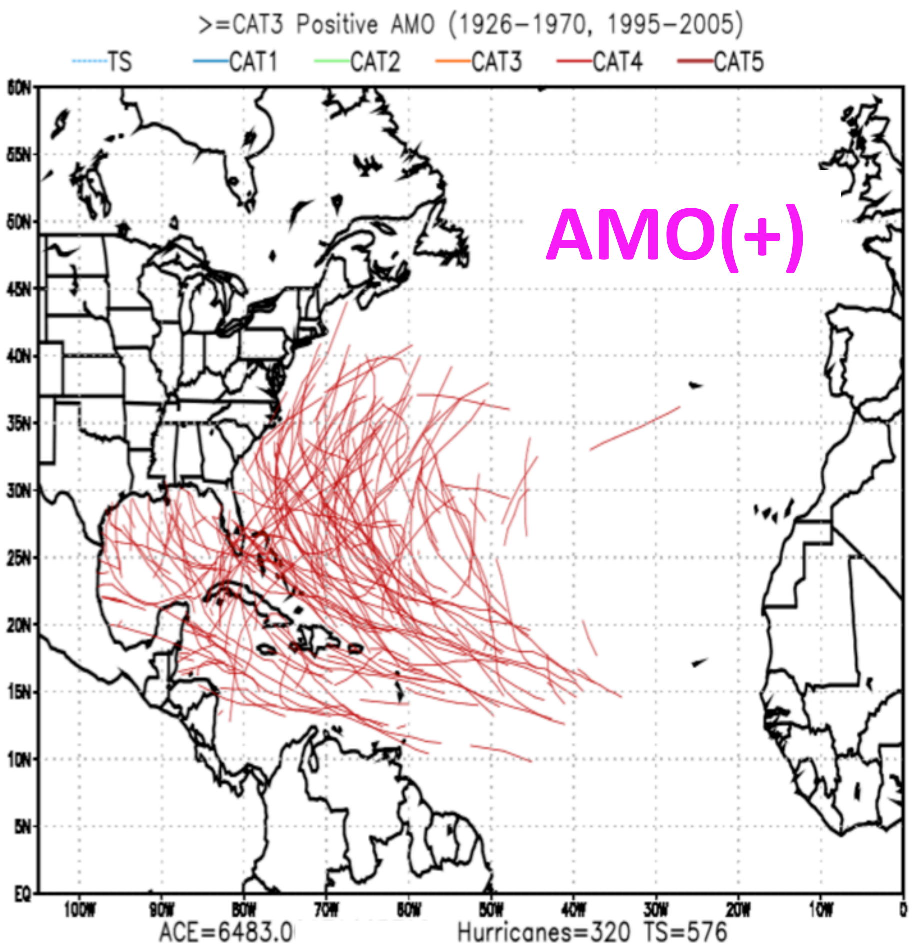


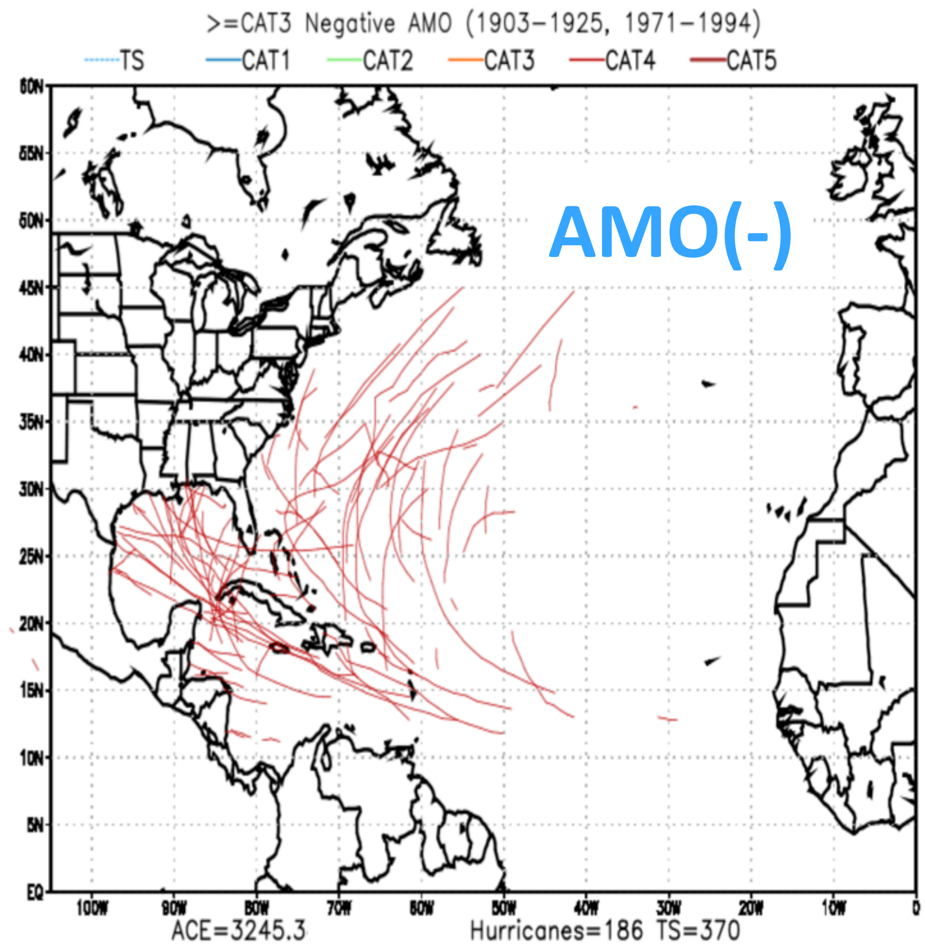




☑ A dynamical model with demonstrated Atlantic hurricane frequency skill in response to SST forcing

Multi-decadal SST variability and Atlantic Hurricanes





Hurricanes and North Atlantic SSTs

North Atlantic hurricane activity in the mid to late 21st century is projected to decrease in frequency but increase in intensity (Knutson *et al.* 2010).

However, climate model estimates have large uncertainties; one source for the uncertainty is changes in low frequency (multidecadal) sea surface temperatures (SSTs) variability. This multidecadal variability has been shown to have a pronounced impact on North Atlantic hurricane activity (eg. Goldenberg *et al.* 2001).

However,

This talk is NOT about hurricanes.

‘All models are wrong, but some are useful’ (Box 1979 via Knutti 2008)

We want to use SST projections from the “best” IPCC AR5 CMIP5 as forcing for the FSU/COAPS atmospheric model.

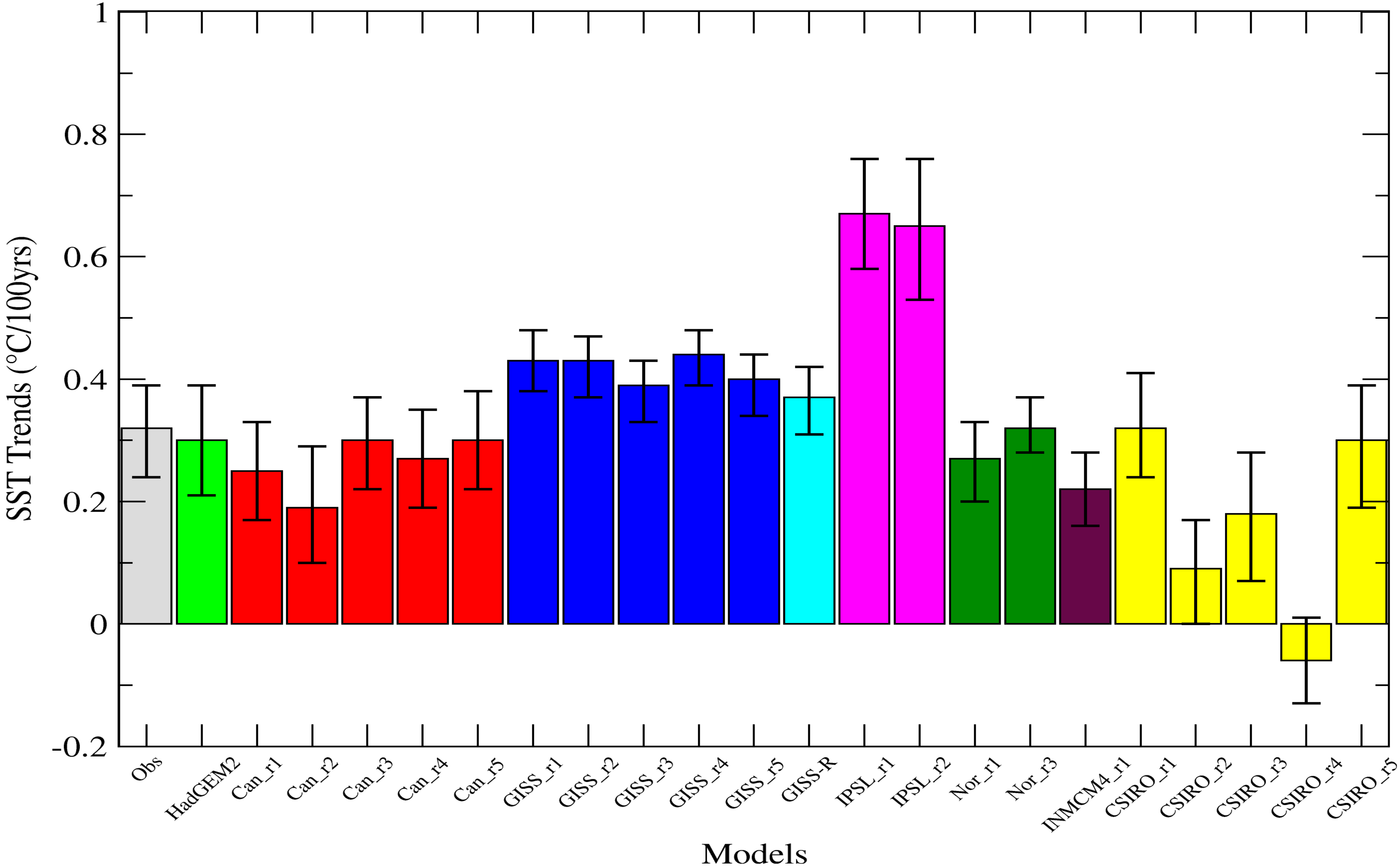
To identify the “best” models, we evaluate CMIP5 historical baseline (1850-2005) simulations. Our assessment focuses on the models’ 20th century SST trend and ENSO-, and AMO-related variability.

Past performance does not guarantee future results (Reifen and Toumi 2009) versus ***Signal loss from multi-model averaging*** (Knutti et al 2010)

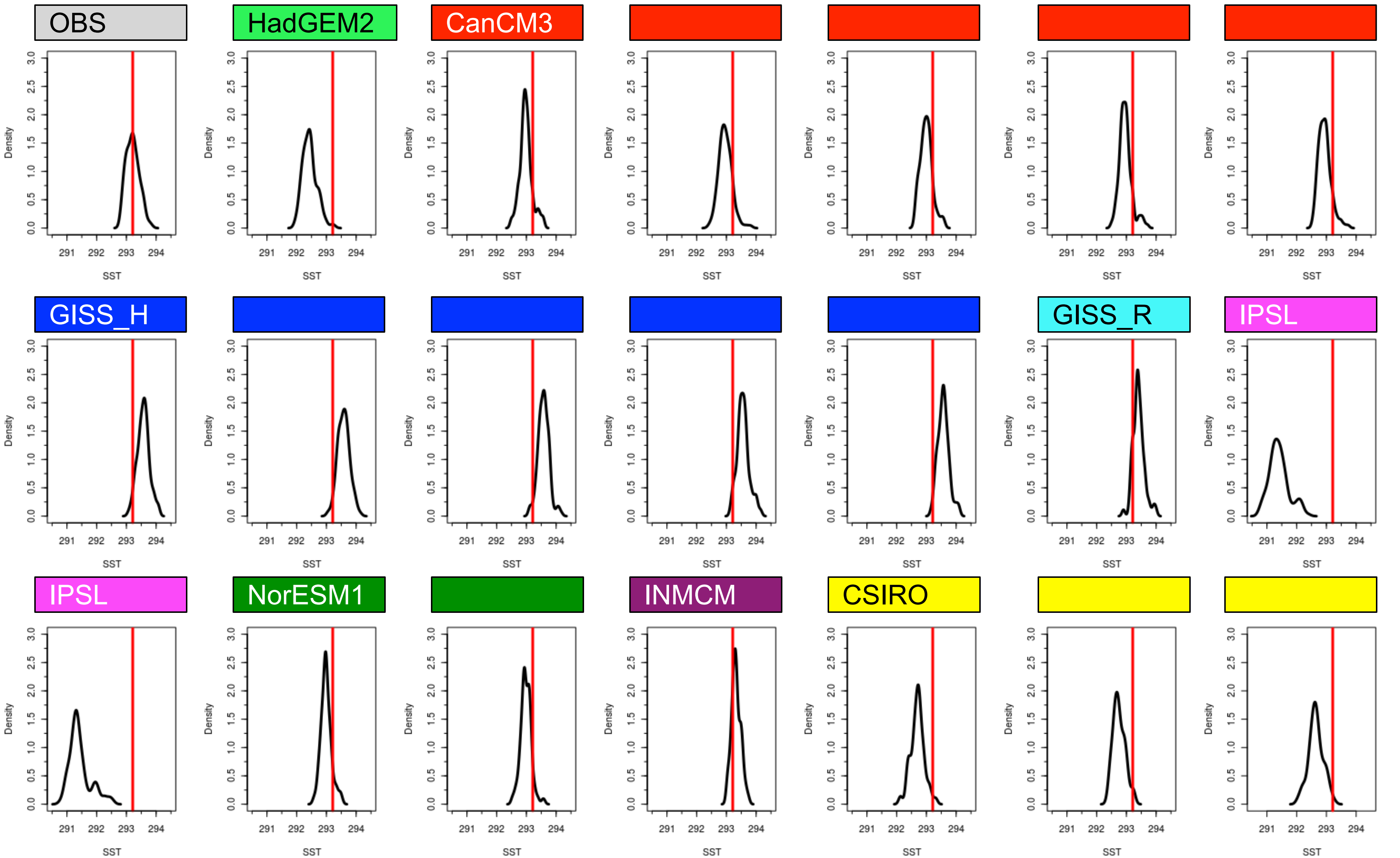
Available CMIP5 simulations @PCMDI (Sep 20)

Center	Model	Resolution	Ensemble size
Met Office Hadley Centre	HadGEM2	360x216	1
Canadian Centre for Climate Modeling and Analysis	CanESM2	256x192	5
Norwegian Climate Centre	NorESM1-M	320x384	2
NASA Goddard Institute for Space Studies	GISS-E2-H	144x90	5
NASA Goddard Institute for Space Studies	GISS-E2-R	144x90	1
Institute for Numerical Mathematics (Russia)	INMCM4	360x340	1
Institut Pierre-Simon Laplace (France)	IPSL-CM5A-LR	182x149	2
Australian Commonwealth Scientific and Industrial Research Organization	CSIRO-Mk-3-6.0	189x192	10

20th Century Trends of Atlantic SSTs

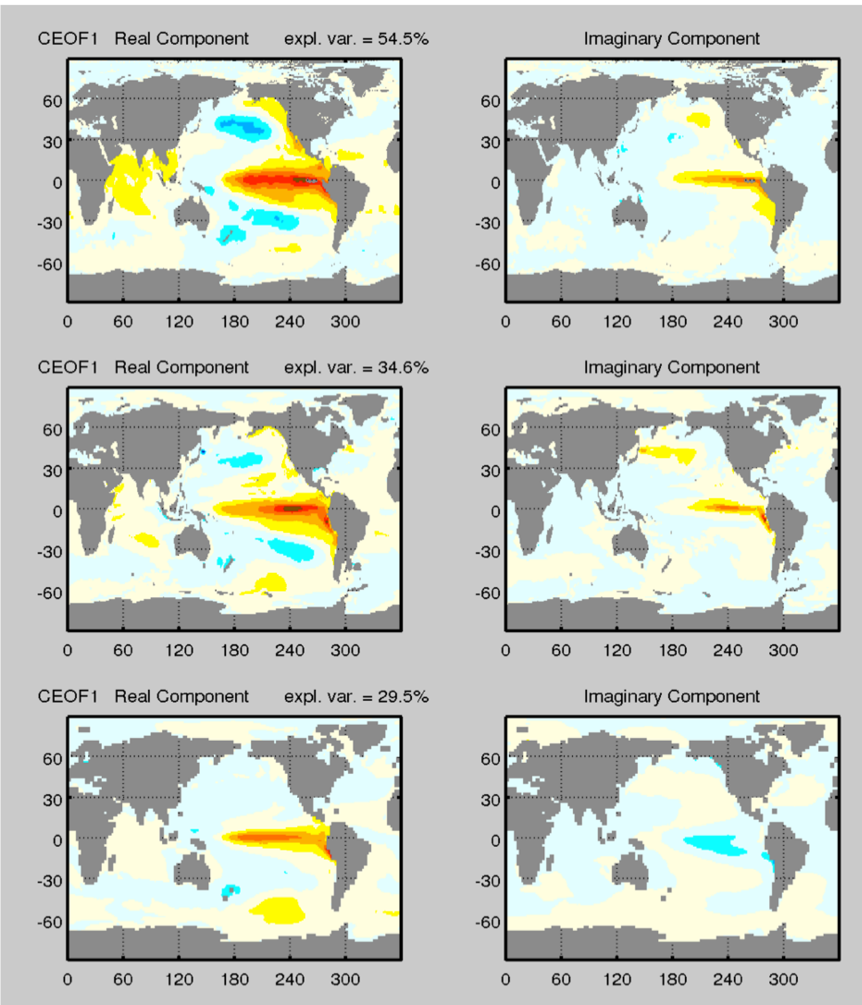


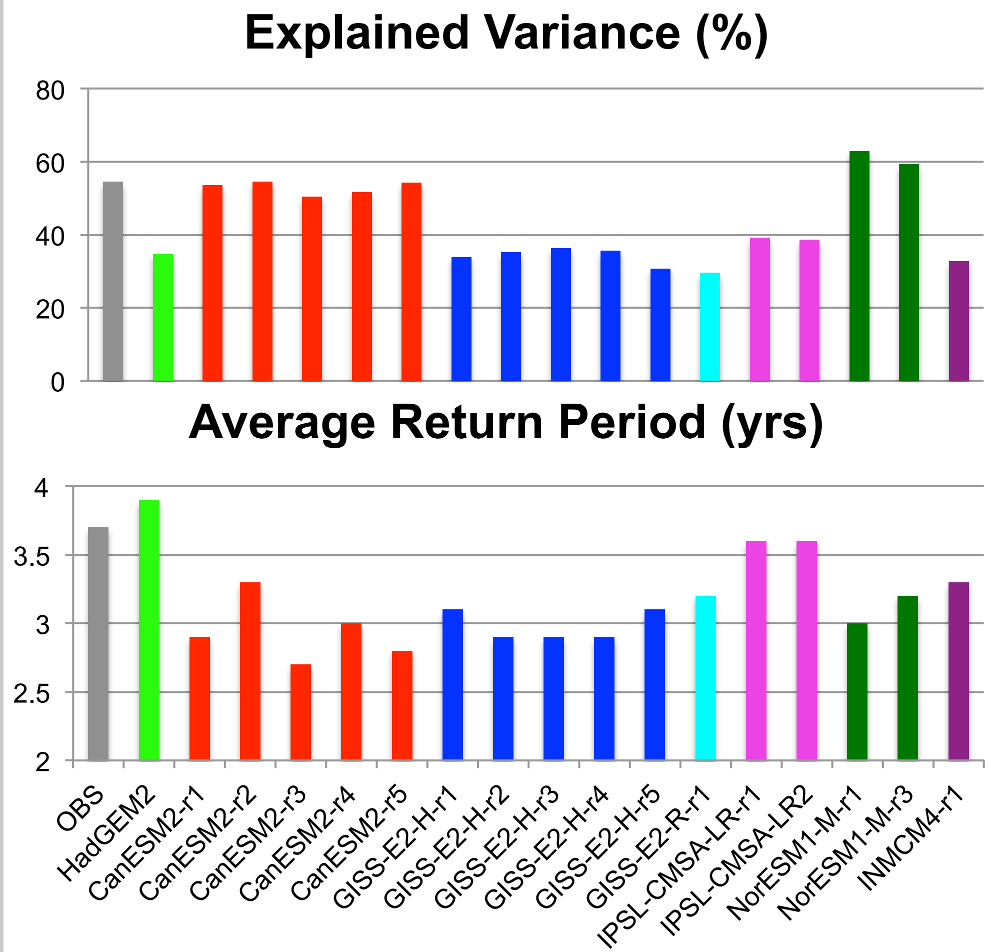
North Atlantic, annual mean PDFs



ENSO in CMIP5

➢ first complex EOF of the de-trended, annual-cycle-removed band-pass (1.5-8yrs) filtered SST (Enfield and Mestas-Nunez, 1999)





ENSO in CMIP5: findings

All models have a strong tropical Pacific signal in the 1.5-8 year band.

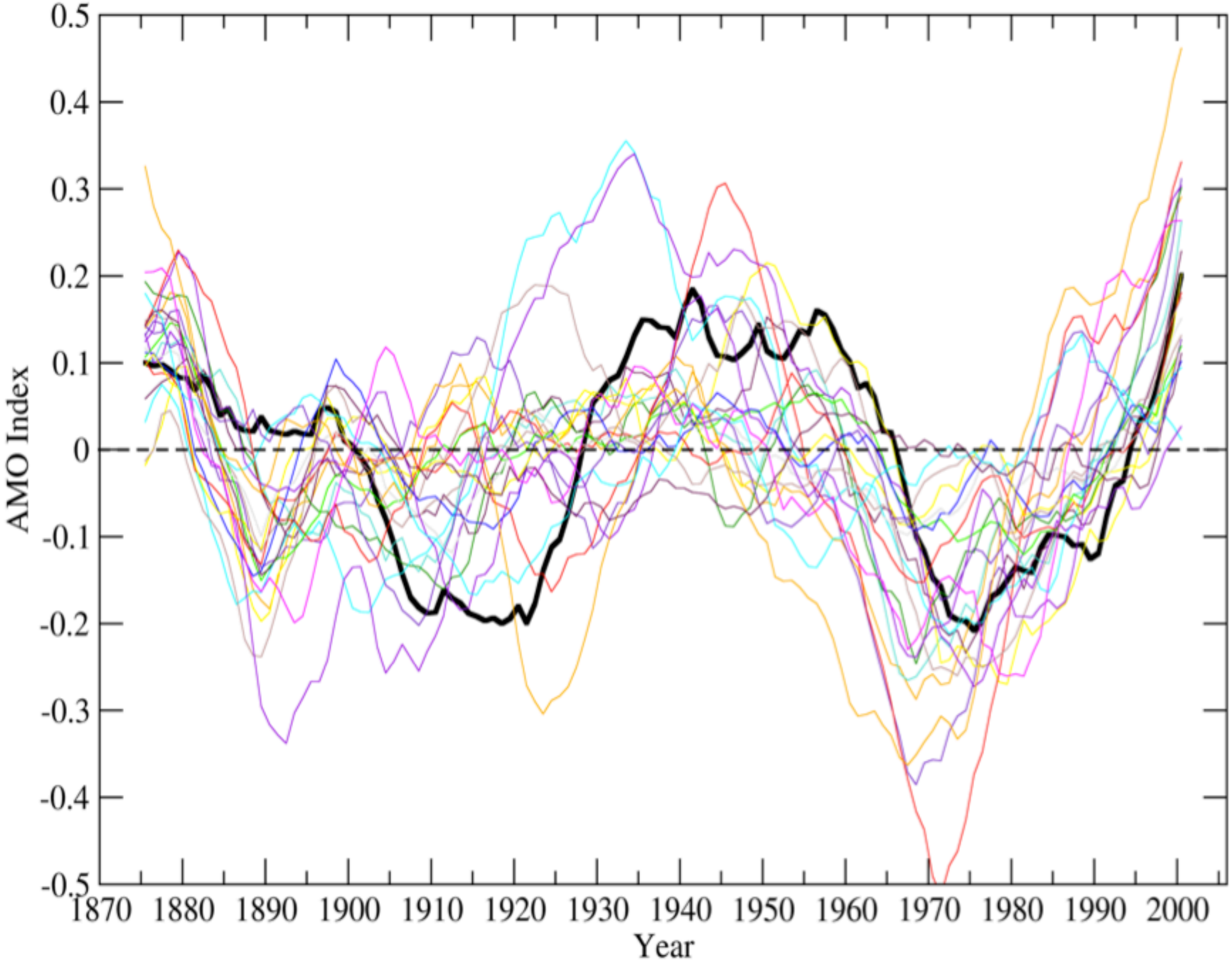
In the observations, the first complex EOF accounts for 54.5% of the total variance for this frequency band. Amongst the CMIP5 model runs, this percentage ranges from 30.7% (INMCM4-r1) to 62.9 (NorESM1-M-r1).

The variance explained by CEOF1 differs among the individual realizations of a given model by up to 5.6 percentage points.

The mean observational ENSO period is 3.7 years. The model ENSO period is generally underestimated, varying from a rapid return period of 2.7 years (CanESM2-r3) to 3.9 years (HadGEM2).

Individual realizations differ in their estimate of the average return frequency of ENSO by up to 0.5 years.

Atlantic Multi-decadal Oscillation (AMO)



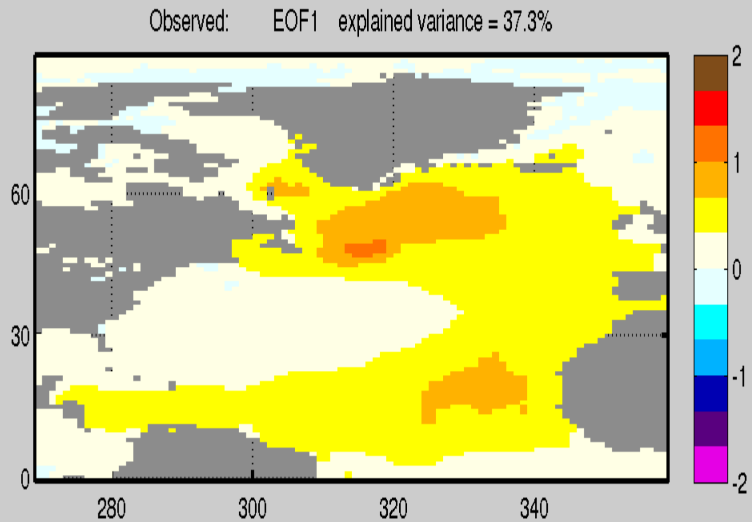
AMO signal: EOFs

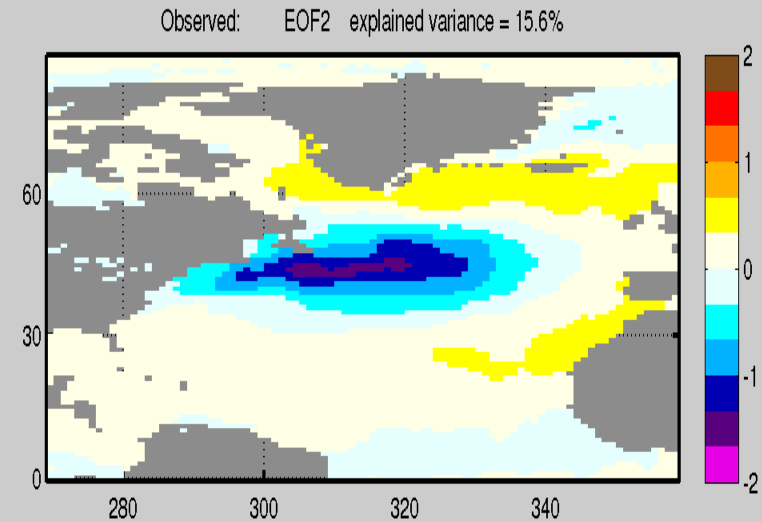
Initially, we intended to use rotated principal components analysis for the global SST anomalies to diagnose the AMO signal, however, the data revealed a great amount of variance in high latitudes, particularly in the southern hemisphere. This spurious signal was found to skew the principal component decomposition of the residuals making a global approach untenable.

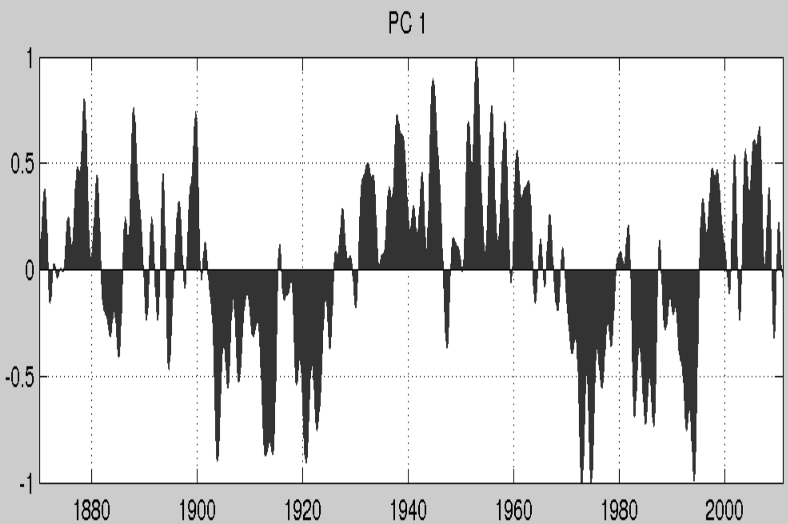
We therefore diagnose the AMO signal through a principal component analysis of the de-trended and ENSO-removed data set limited to the Atlantic basin.

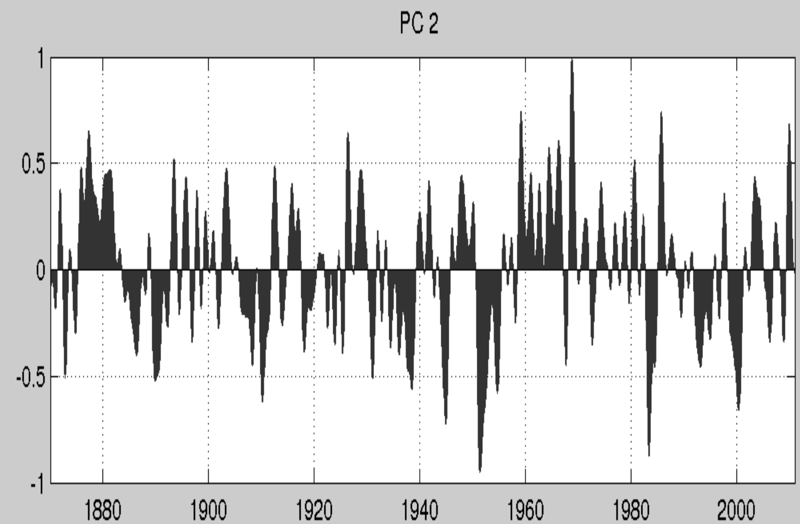
We compare the first two EOFs of the observations and two models (illustrating the range in the AMO simulation and the power spectra of the corresponding PCs

Observations, Atlantic EOFs 1 and 2

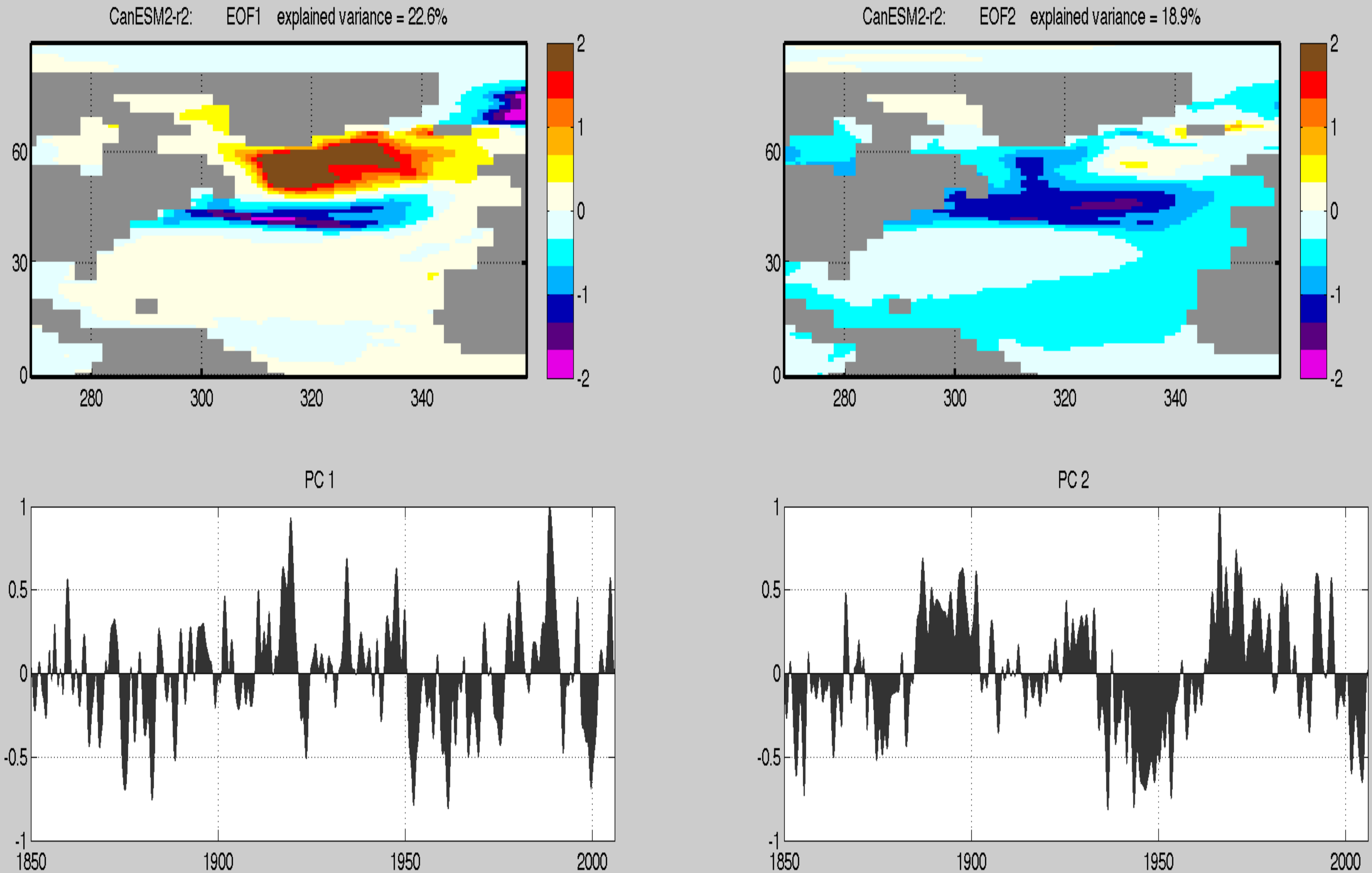




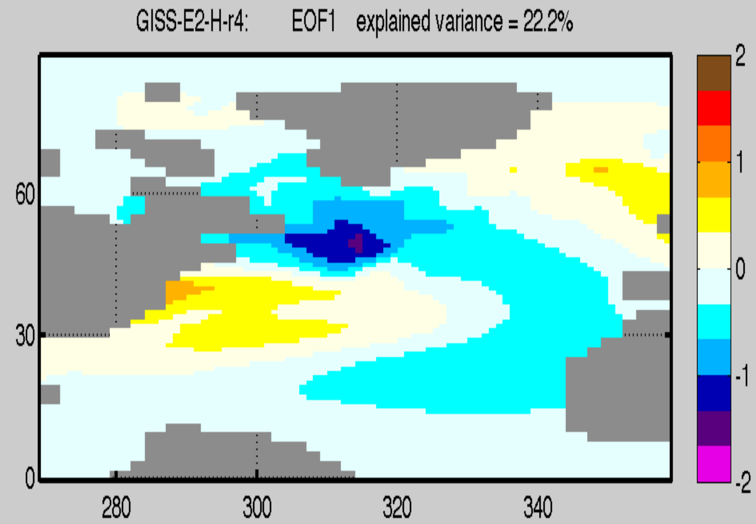


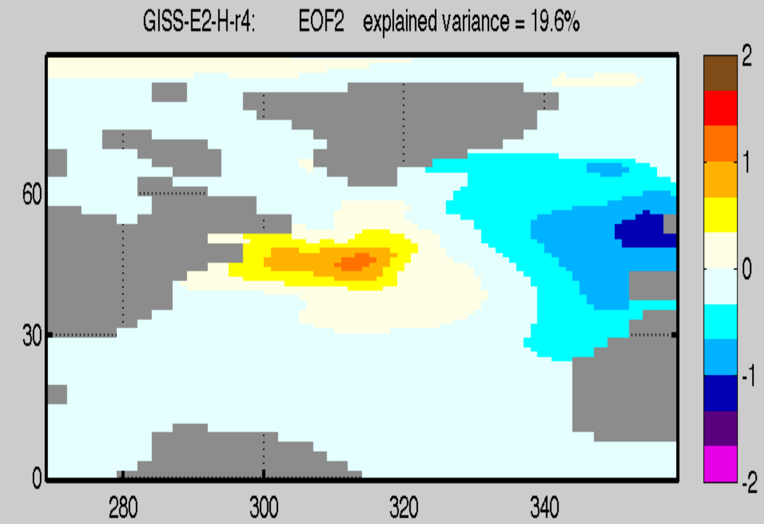


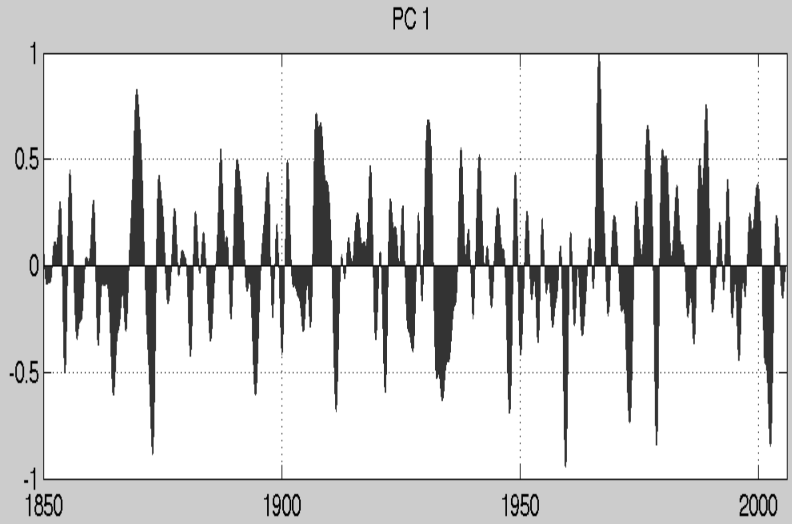
CanESM2, Atlantic EOFs 1 and 2

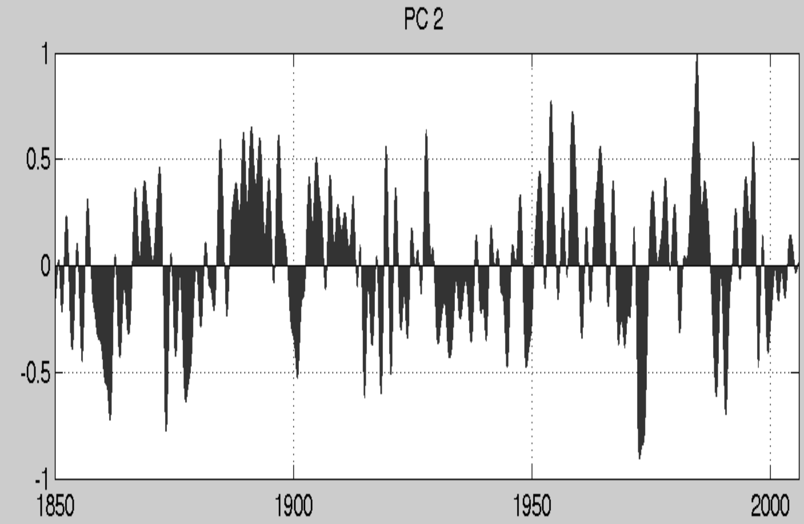


GISS-H, EOFs 1 and 2

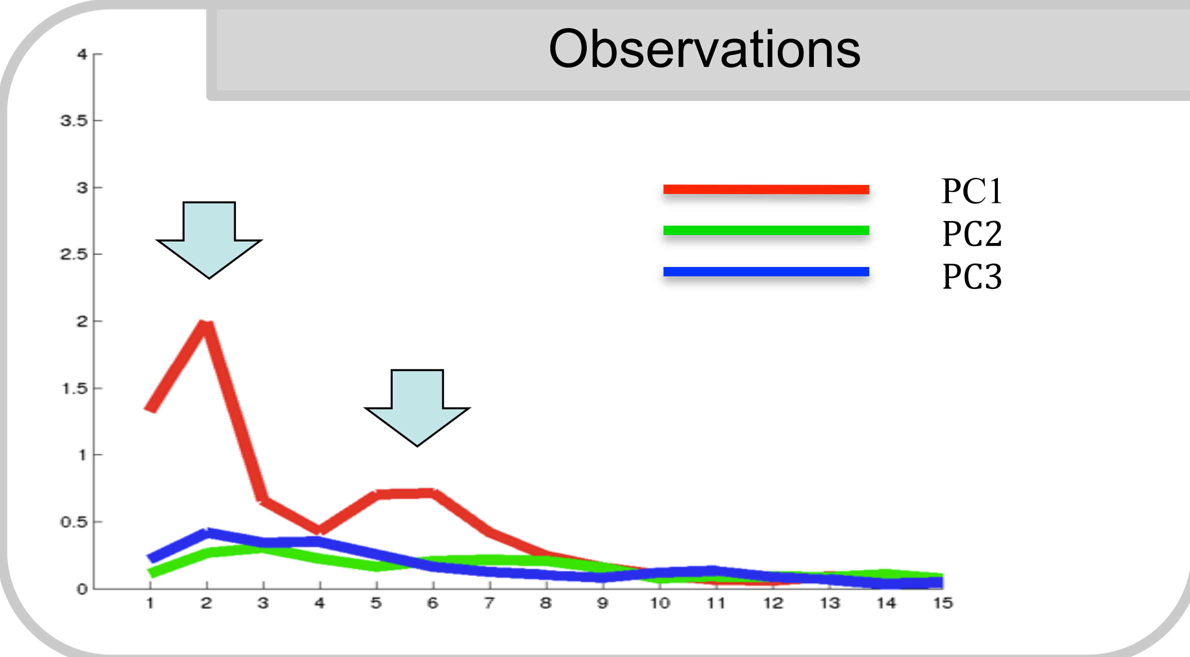


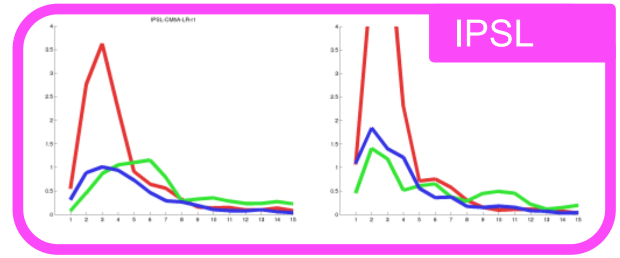


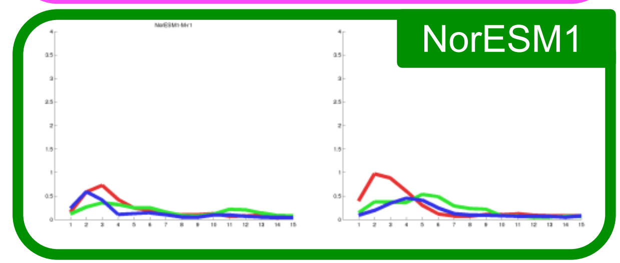


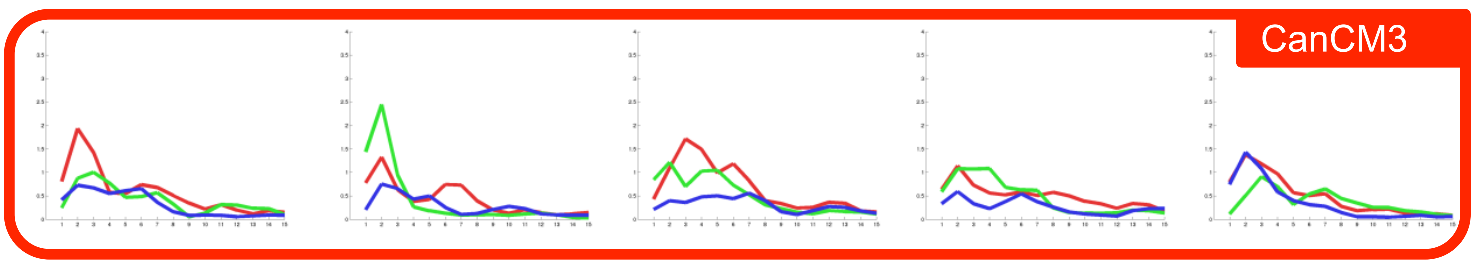


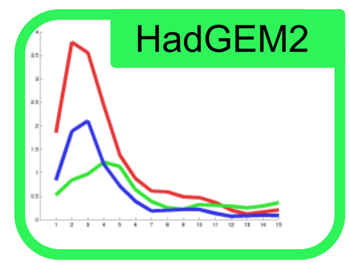
Power Spectra of Atlantic PC 1, 2 & 3

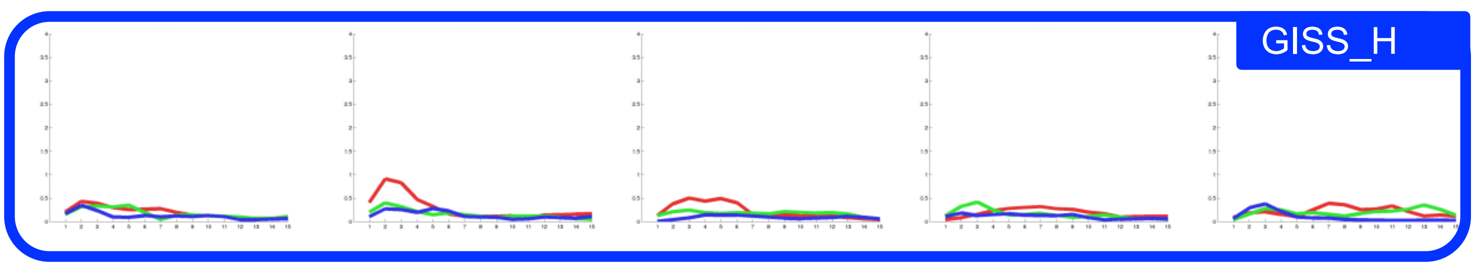


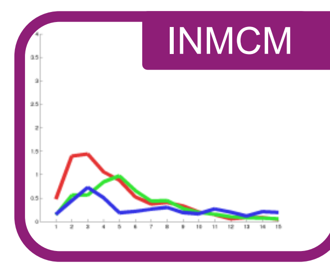












Atlantic Multi-decadal Variability in CMIP5

- Most (but not all) models have a pronounced AMO signal in two dominant frequency bands ~70 years and ~25 years.
- In the observed data, both frequencies are found in PC1, while in the model data they tend to be distributed between PC1-2.
- The two GISS (R and H) models and the Norwegian model have very weak multi-decadal signal in the Atlantic.
- IPSL and HadGEM2 overestimate the power spectrum
- The rest of the models are more or less comparable to observations.

Summary: Trends

- All available models capture the observed increase in SSTs in both the North Atlantic and tropical Pacific.
- Models show marked increase in warming (~4x) in the RCP4.5 simulated 21st Century compared to the 20th Century Historical simulations in the North Atlantic and tropical Pacific Oceans.
- The largest difference between the models' trends during the 21st Century is in the tropical Pacific.

Summary: ENSO and AMO

- All models have strong tropical Pacific SST variability in the 1.5-8 year range.
- Average model ENSO return period ranges from 2.7 to 3.9 years, compared to the observed 3.7 years.
- Best model ENSO: CanESM2 and HadGEM2.

- Most models have pronounced multi-decadal Atlantic variability with dominant modes ~70 and ~25 years.
- In the observations, both modes are contained in EOF/PC1; in the models, they are spread between EOF/PC1,2 and 3.
- Best model AMO: CanESM2.

Summary: Residuals

- Some models have spurious signal in the high latitudes of the southern hemisphere.
- Most models have pronounced multidecadal Pacific variability that we have not analyzed in detail.

Final Word

- As historical simulations from additional CMIP5 models become available, we will update the above evaluation.

- Our preliminary conclusion is that of the models available so far, CanESM2 has the winning combination of trend, ENSO and AMO variability and its SSTs would be the most suitable for addressing Atlantic basin hurricane projections.