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Low-Frequency SST variability in CMIP5 Historical Integrations

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1.Introduction

Anthropogenic-driven change in hurricane frequency is obscured, among other things, by low-frequency natural sea surface temperature (SST) variability. Our goal is to set up a modeling system to estimate changes in North Atlantic hurricane frequency in response to changing climate, separating the anthropogenic from the natural-variability components of the projected SST warming. Prerequisites for this undertaking are: an atmospheric general circulation model with demonstrated skill in reproducing the observed North Atlantic hurricane frequency and trend, and SST projections from a global model with a degree of realism in its representation of the physical mechanisms for low-frequency variability.

The FSU/COAPS AGCM satisfies the first of these prerequisites. LaRow *et al.* (2008, 2010) have documented the skill of the FSU/COAPS AGCM in simulating the observed historical hurricane frequency when driven with either observed or model-produced (namely, CFS) SSTs. The FSU model accurately simulates the interannual variability in response to time varying SSTs, and is also able to reproduce the trend in Atlantic hurricane counts since 1982.

One theory suggests that the North Atlantic hurricane activity is strongly modulated by the phase of the Atlantic Multidecadal Oscillation (AMO) (Goldenberg *et al.* 2001). However, climate model estimates of future hurricane activity have large uncertainties; one source for the uncertainty is changes in low frequency (multidecadal) SST variability. In addition, the low frequency SST variability is difficult for many climate models to correctly simulate.

In order to address the low-frequency modulation of hurricane variability in a future climate, we need SST projections from the "best" IPCC AR5 CMIP5 model simulations to use as boundary forcing in 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.

2. Data and methodology

Table 1 shows the models that are currently available (as of October 2011) from the IPCC CMIP5 historical experiment (obtained from http://pcmdi3.llnl.gov/esgcet/home.htm). Also shown in the table are the models' native horizontal resolutions and the number of ensemble members. Before conducting the analysis on the models' sea surface temperatures, the horizontal resolution of each model was re-mapped to a 360x180 uniform resolution. We analyze the low-frequency component of

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

Table 1 List of the CMIP5 models used in this assessment and their native resolution and ensemble size.

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SSTs in the CMIP5 historical simulations by comparing the 20th Century trend, the Atlantic Multidecadal Oscillation (AMO) and the ENSO characteristics (spatial distribution, frequency and magnitude) of the member models' SSTs to the corresponding observed characteristics during the period.

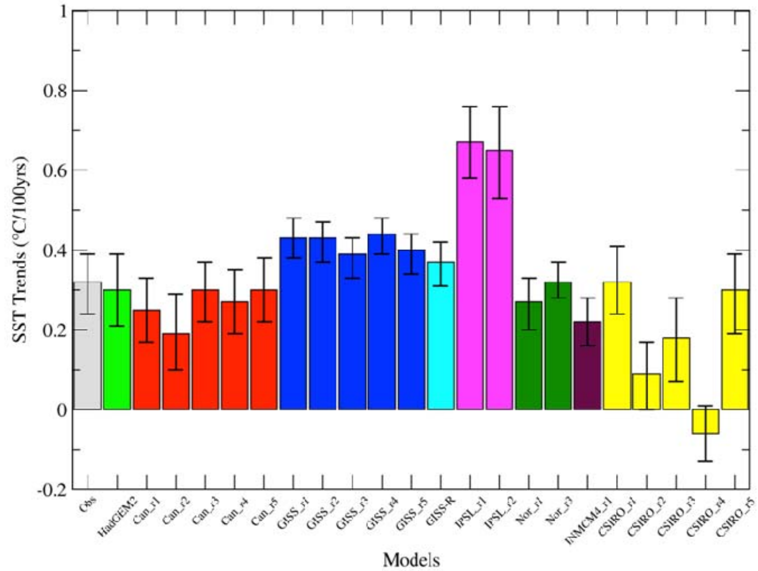

Fig. 1 North Atlantic SST trends in observations (grey bar) and CMIP5 models (colored bars; color coding as in Table 1

3. Results

3.1 Trend

All available models reproduce the observed increase in SSTs in both the North Atlantic (Fig. 1) and tropical Pacific (not shown). Models show marked increase in warming (~4x) in the simulated (RCP4.5) 21st Century compared to the 20th Century Historical simulations in the North Atlantic and tropical Pacific Oceans (not shown). The largest difference between the models' trends during the 21st Century is in the tropical Pacific.

3.2 ENSO

All models have a strong tropical Pacific signal in the 1.5-8 year band (Fig. 2). In the observations, the first complex EOF (CEOF1) 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 AR5 models' ENSO period is generally underestimated, varying from a rapid return period of 2.7 years (CanESM2-r3) to 3.9 years

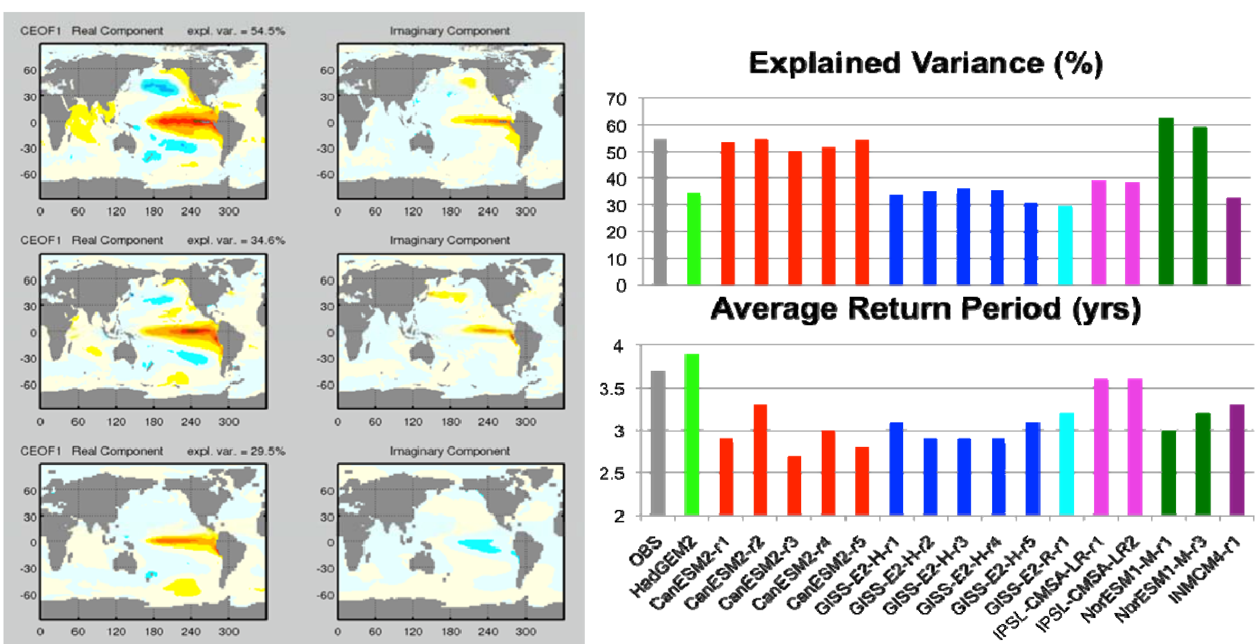

Fig. 2 Left: Real and imaginary components of the leading Complex EOF for the observed (top), best model (center) and worst model (bottom) historical period SSTs. Right: Explained variance and average return period of ENSO.

(HadGEM2). Individual realizations differ in their estimate of the average return frequency of ENSO by up to 0.5 years.

3.3 AMO

Most (but not all) of the analyzed models have a pronounced AMO signal in two dominant frequency bands ~70 years and ~25 years. In the observed data (HadISSTv1.1, Rayner *et al.* 2003), both frequencies are found in PC1 of the de-trended North Atlantic SSTs, while in the model data they tend to be distributed between PC1-3 (Fig. 3).

Some models (*e.g.*, GISS (R and H) models and NorESM1) have a very weak multi-decadal signal in the North Atlantic. Others (e.g. IPSL and HadGEM2) overestimate the power spectrum. The rest of the models are more or less comparable to observations.

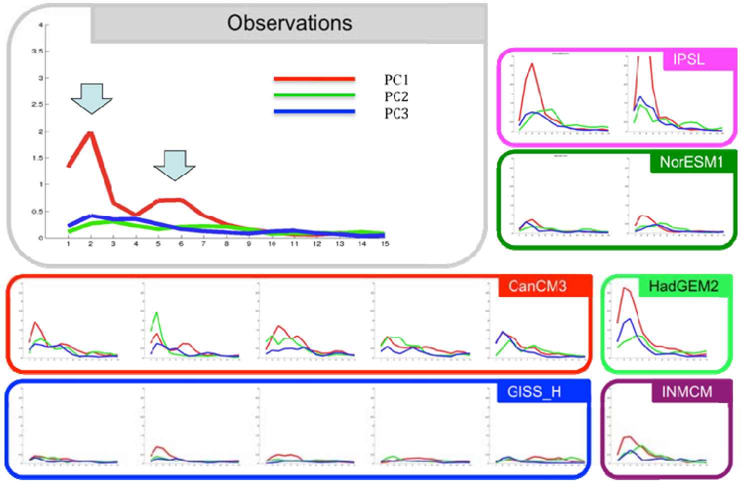

Fig. 3 Power spectra of the first three principal components of North Atlantic SSTs for observations and historical simulations. The abscissa denotes number of cycles per 140 years. Blue arrows indicate the observed spectral peaks at ~70 and ~25 years.

4. Summary and conclusions

All models have strong tropical Pacific SST variability in the 1.5-8 year range. The average model ENSO return period ranges from 2.7 to 3.9 years, compared to the observed 3.7 years. The models with most realistic ENSO representation are the 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 the Atlantic EOF/PC1; in the models, they are spread between EOF/PC1, 2 and 3. The best AMO representation amongst the models analyzed thus far is that of the CanESM2.

In addition, some models have spurious signal in the high latitudes of the southern hemisphere. Most models have pronounced multidecadal Pacific variability that we have not yet analyzed in detail.

As historical simulations from additional CMIP5 models become available, we will update the above evaluation. Our preliminary conclusion is that of the models available thus 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 for the mid- to late-21st century.

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