UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

Variable external forcing obscures the weak relationship between the NAO and north Atlantic multi-decadal SST variability

Introduction and background

North Atlantic SST exhibits a lagged response to the NAO in both models and observations, which has previously been attributed to changes in ocean heat transport (e.g. AMOC). However, variable ocean heat transport is not necessary to reproduce the pattern and statistics of the AMO, in climate models. We examine the magnitude and contribution of the ocean heat transport mechanism to the AMO in pre-industrial control runs, historically-forced runs, and observations in order to better understand these seemingly opposite conclusions.

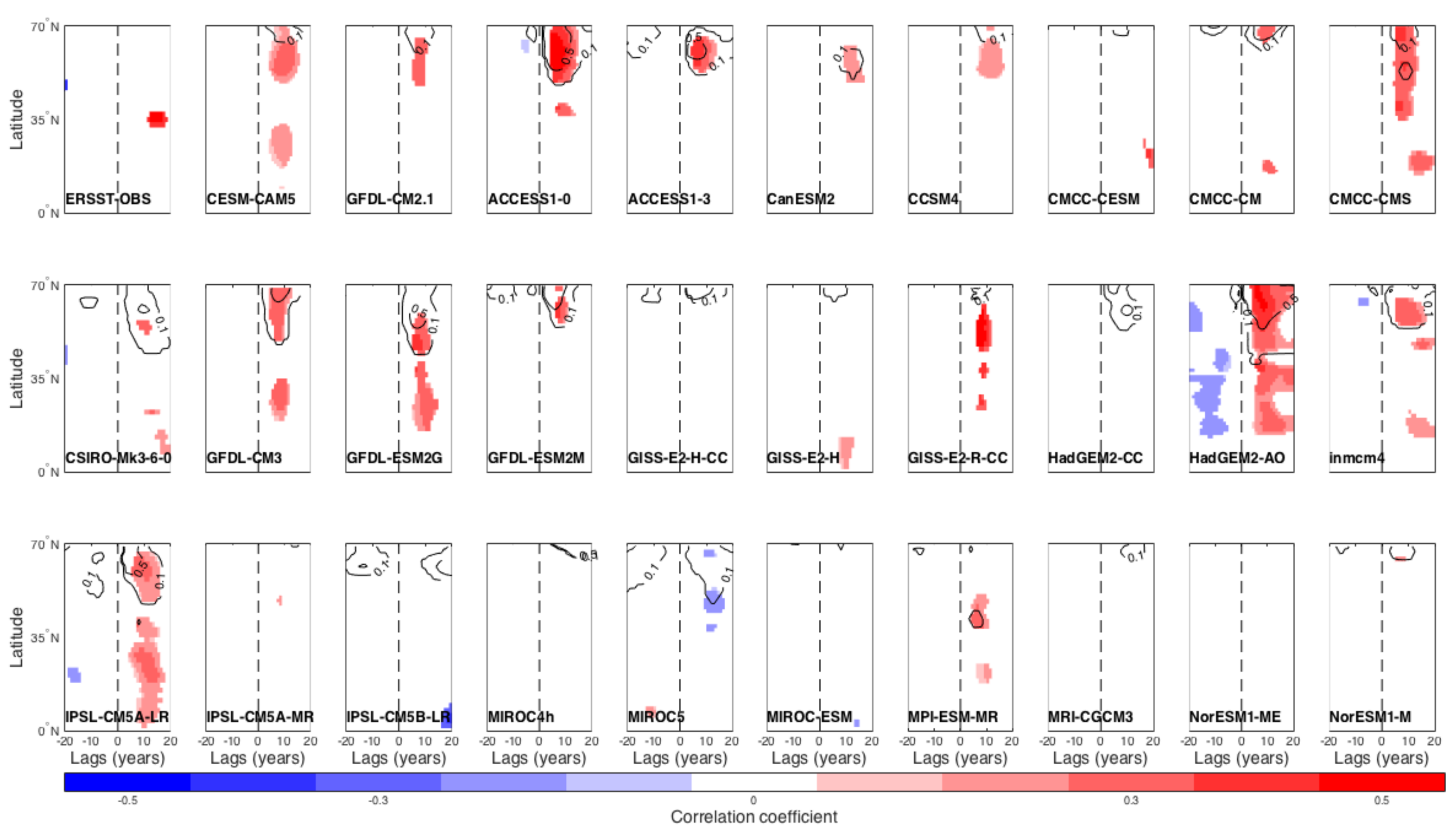


Figure 1: The zonal mean correlation (colors) and regression (contours) between the low-pass filtered NAO index and low-passed filtered annual average SST for a selection of CMIP5 pre-industrial model runs at lags -20 through 20 (following the methodology of Delworth et al. 2017). Pixels that did not pass a statistical test based on the auto-correlation of the filter are colored white. Note the variability in the lag of maximum correlation across models as well as the discrepancy between models and observations.

We cannot reject the null hypothesis that positive lagged correlations in the subtropics are an artifact of filtering. The mechanism responsible for the lagged response to the NAO may be limited to the subpolar gyre.

Results: NAO adds little predictive skill

The distribution of the AMO index conditional on a prior NAO+ event is statistically significantly different from climatology. However, the climatological probability of an AMO warm event (± 0.15 °C anomaly) is 23% and the probability conditional on a prior NAO+ event is 26%, in observations.

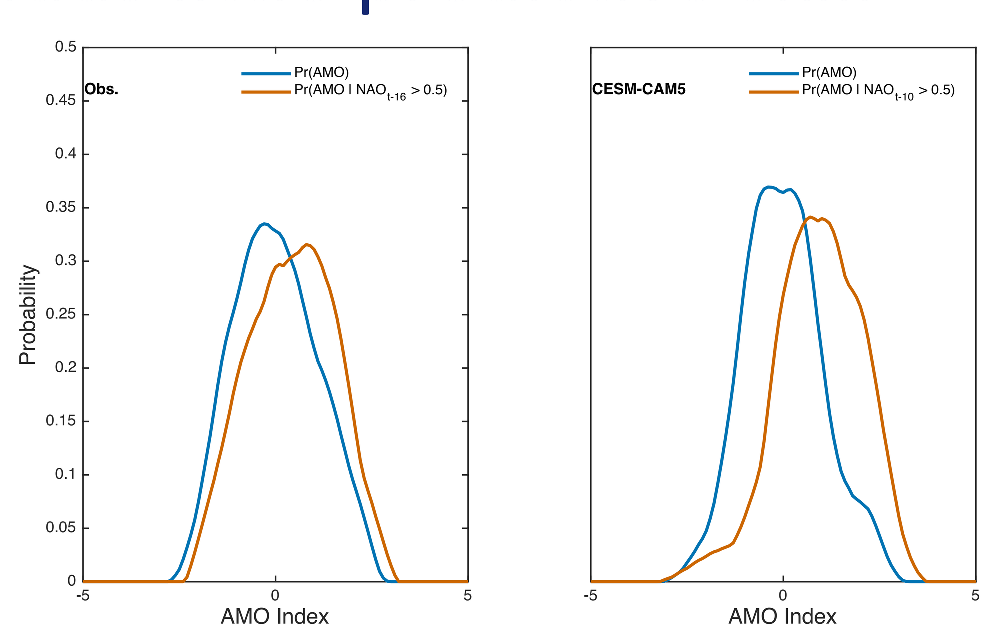


Figure 2: Probability density functions of the climatological AMO index and the AMO index conditional on an NAO+ event preceding it, for observations (*left*) and a model (*right*). The lag is determined by the maximum of the cross-correlation function between the AMO and NAO.

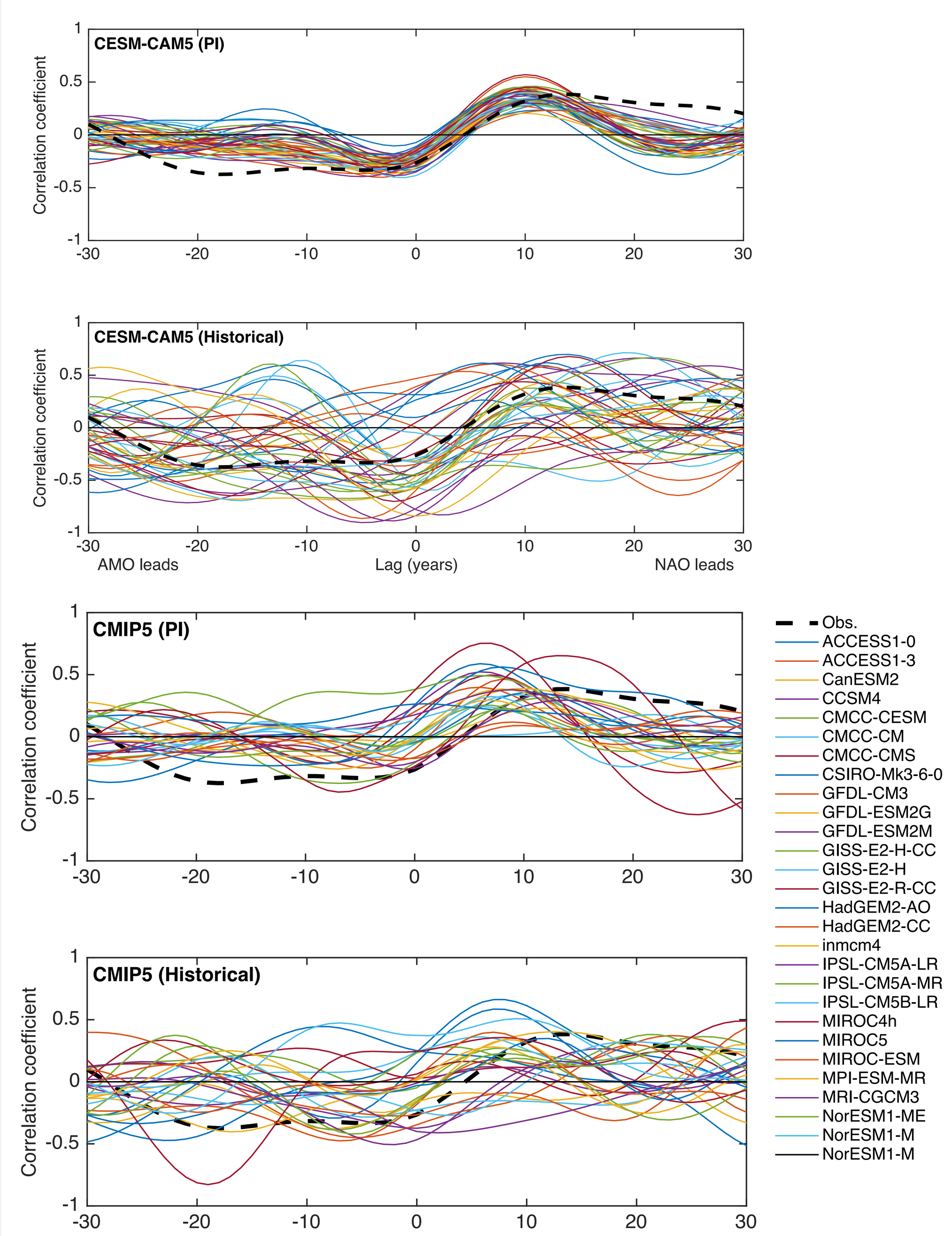
Results: NAO explains a small portion of AMO variance

The linear lagged SST response to the NAO only accounts for between 1% and 12% of the variance in the AMO index in control runs of CMIP5 models (4% on average), and 19% in observations.
On average, the unlagged, low-pass filtered NAO index explains only ~5% and ~7% of the variability in the AMO index in control runs of CMIP5 models and observations, respectively.

	Years	Lag of maximum correlation (years)	% AMO_{MID} variance explained by $NAO_{t=0}$	% AMO variance explained by $NAO_{t=0}$	% AMO_{MID} variance explained by lagged response	% AMO variance explained by lagged response
Observations						
ERSST/NAO	153	15	20%	7%	31%	19%
Models						
CESM1-CAM5	899	10	10%	0%	6%	4%
CESM1-SOM	899	-	44%	20%	-	-
GFDL-CM2.1	499	7	3%	0%	7%	8%
CMIP5 models						
ACCESS1-0	499	6	0%	3%	7%	7%
ACCESS1-3	499	6	0%	0%	5%	3%
CanESM2	995	12	8%	2%	2%	3%
CCSM4	1050	12	3%	2%	4%	3%
CMCC-CESM	276	13	24%	16%	4%	8%
CMCC-CM	329	9	13%	5%	0%	2%
CMCC-CMS	499	7	1%	1%	8%	12%
CSIRO-Mk3-6-0	499	11	3%	1%	1%	3%
GFDL-CM3	499	8	0%	0%	8%	9%
GFDL-ESM2G	499	8	2%	0%	1%	1%
GFDL-ESM2M	499	6	3%	2%	5%	5%
GISS-E2-H-CC	250	6	1%	0%	0%	1%
GISS-E2-H	779	6	18%	15%	4%	3%
GISS-E2-R-CC	250	7	8%	11%	11%	11%
HadGEM2-AO	699	8	1%	0%	7%	6%
HadGEM2-CC	239	9	36%	32%	3%	4%
inmcm4	499	10	7%	3%	1%	1%
IPSL-CM5A-LR	999	9	6%	1%	3%	4%
IPSL-CM5A-MR	299	7	12%	1%	1%	6%
IPSL-CM5B-LR	299	22	4%	0%	3%	1%
MIROC4h	99	13	11%	23%	1%	1%
MIROC5	999	1	0%	0%	1%	1%
MIROC-ESM	629	23	22%	8%	1%	1%
MPI-ESM-MR	999	7	3%	0%	3%	5%
MRI-CGCM3	499	14	5%	0%	3%	5%
NorESM1-ME	251	8	6%	2%	2%	4%
NorESM1-M	500	7	10%	0%	1%	1%
CMIP5 Average		9.4	8%	5%	3%	4%

Table 1: Estimates of the influence of the low-pass filtered NAO on multidecadal SST variability in the Atlantic. Note that, by our definition, the lag of maximum correlation for observations is lower than other estimates in the literature.

Results: Variable external forcing obscures NAO-AMO relationship



In pre-industrial control runs, most models exhibit a lagged warm response to the NAO. However, when model runs account for variations in external forcing, the NAO-AMO relationship is obscured. The influence of external forcing is noted in both an ensemble of a single model (CESM-LENS) and a multi-model ensemble (CMIP5).

Figure 3: Cross-correlation functions between the low-pass filtered NAO index and the low-pass filtered AMO index. The dashed black line is observations and is the same in each panel. Note that the top panel is created by sub-sampling a single long PI run of CESM1 into 85-year segments to allow for direct comparison to CESM-LENS.

Discussion: Is the observed NAO-AMO relationship due to chance alone?

$$AMO_{LP} = \beta_1 NAO_{LP,t=0} + \beta_2 NAO_{LP,t=10} + \beta_3 \cos \omega t$$

In the stochastic, statistical model above, we prescribe the NAO-AMO relationship as well as the influence of variable external forcing. Coefficients are calculated via independent linear regressions, yielding values of -0.05 C/std. dev., 0.1 C/std. dev., and -0.68 C/unit forcing. Inclusion of the β_3 term interrupts or obscures the prescribed lagged relationship between the NAO and AMO.

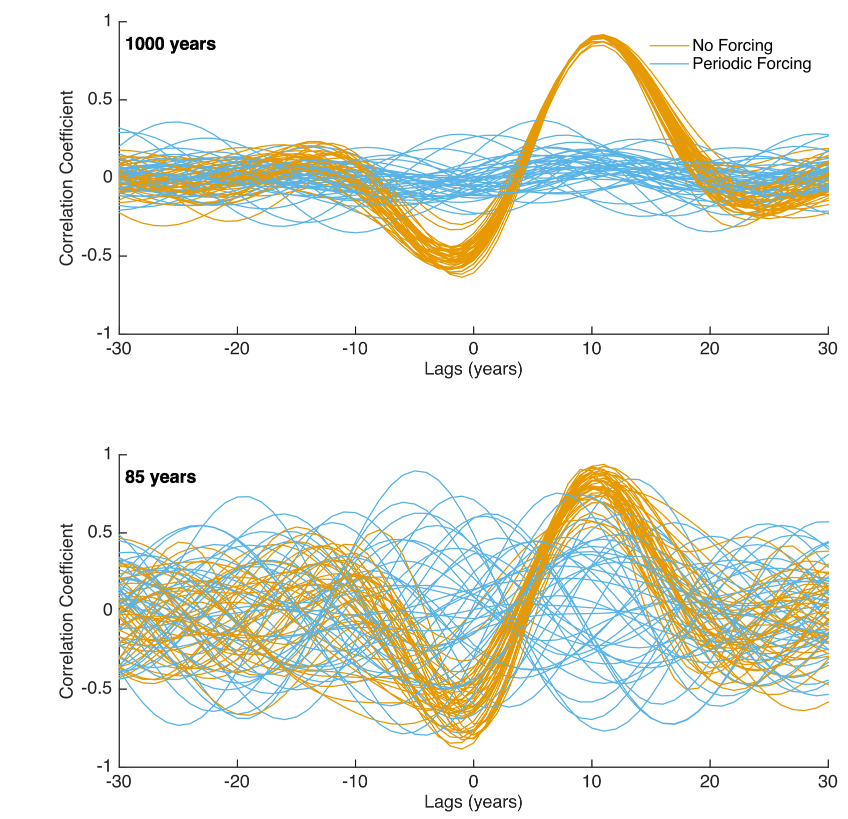


Figure 4: Ensembles of a statistical model designed to illustrate the influence of external forcing on the lagged relationship between the NAO and AMO. The forcing in this simple model is a cosine function with a 30-year period. Top: Ensemble of 1000 year runs of the statistical model with and without the β3 term. Bottom: Ensemble of 85 year runs of the statistical model with and without the β_3 term.

Summary

We find evidence to support the hypothesis that ocean dynamics play a role in multidecadal SST variability; however, its contribution to overall variability and predictability in the region is small. When climate models include variable external forcing, the NAO-AMO relationship is obscured. Historical runs of climate models as well as a statistical model allow for the possibility that the observed relationship between the NAO and AMO is due to chance alone.

Outstanding questions

- What (if any) is the role of ocean heat transport in setting the timing of AMO transitions?
- Through what mechanism does external forcing change AMO variance?
- What induces non-stationarity in the AMO index?
- When did variable external forcing become a key influence on AMO variability
- What details of external forcing are valuable for prediction of the AMO?

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