Is AMOC More Predictable than North Atlantic Heat Content?

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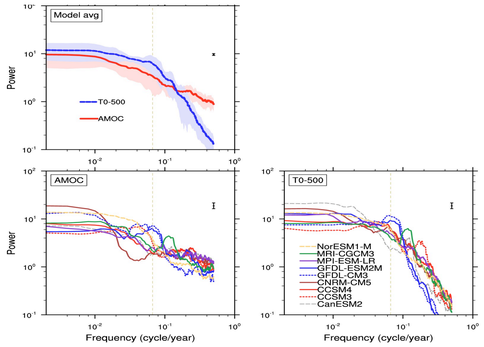
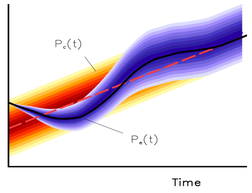
Introduction

The Atlantic Meridional Overturning Circulation (AMOC) is often assumed to be an especially predictable component of the climate system. We test this hypothesis by comparing its predictability to that of North Atlantic upper 500m heat content, which is a climate component that can directly impact the atmosphere via SST. We have reasoned that if AMOC predictability is greater than heat content predictability, then there is the potential for improving initial value predictions of near surface conditions by improving predictions of AMOC.

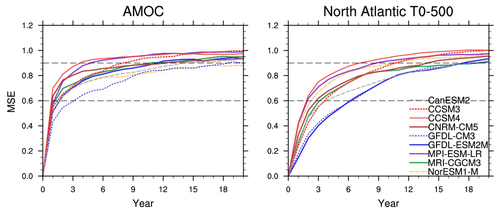


We have made this comparison for 9 climate models, 8 of which participated in CMIP5. When we plot averaged spectra of AMOC and heat content (T0-500) of these models, we find the heat content spectrum is redder than that of AMOC except at low frequencies, and a redder spectrum is often used as an indicator of higher predictability.

Generic predictability properties



Predictability has to do with the time it takes for trajectories starting from very similar conditions to become as dissimilar as random states. In this schematic predictability vanishes when the collection of initially similar states in the blue distribution become indistinguishable from the (red) climatological distribution – which may be changing in reaction to changing external conditions. We measure predictability by the ratio (denoted MSE) of the variance of the blue distribution to the variance of the red distribution.

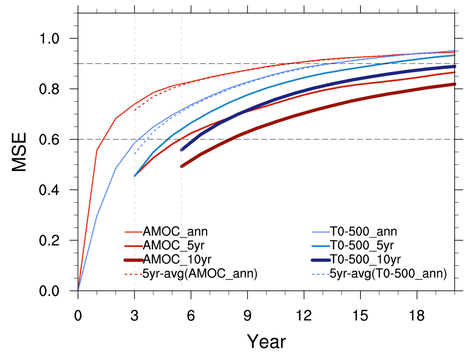


Mean square error (MSE) for AMOC (left) and North Atlantic upper 500m heat content (right) based on 10 PCs. The two horizontal reference lines correspond to MSE=0.60 and 0.90, respectively, and the latter value is here used as the threshold of the limit of predictability.

We have found the predictability of 9 CMIP5 models through a technique by which predictability can be estimated from control run behavior. (Branstator et al. 2012). For annual means the spread of initially similar states approaches the spread of the climatological distribution much faster for AMOC than heat content in 8 of the 9 models indicating AMOC is less predictable.

Temporal averaging

Because at the low frequency end, AMOC spectra tend to be redder than heat content spectra, time averaging will emphasize the frequencies for which AMOC is likely to be more predictable. To quantify this effect, we have repeated our calculations for multi-year averages."



For both 5-year and 10-year means predictability is much higher than for annual means. Furthermore, for these averages, AMOC is much more predictable than heat content.

Summary

The results of our predictability comparison were mixed. On the one hand, when considering generic fluctuations of annual means we found that AMOC is less predictable than heat content, that is, it is more sensitive to initial state uncertainty.

On the other hand we found that there are components of AMOC variability that are much more predictable than are its generic variations. These components tend to be more predictable than generic components of North Atlantic heat content. We were able to isolate these components using two methods.

Most encouraging is our finding that there are components of AMOC, and heat content, that are predictable for much more than a decade and these components represent a substantial fraction of variability.

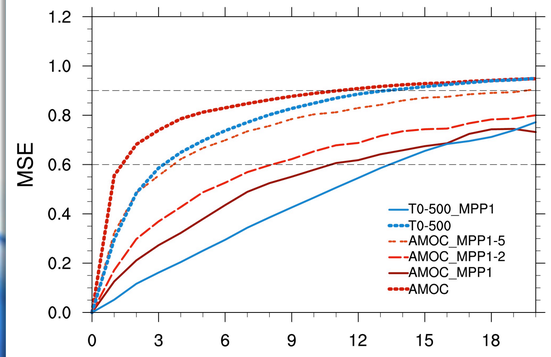
References

Branstator, G., H. Teng, G. A. Meehl, M. Kimoto, J.R. Knight, M. Latif, and A. Rosati, 2012: Systematic estimates of initial-value decadal predictability for six AOGCMs. *J. Climate*, 25, 1827-1846.

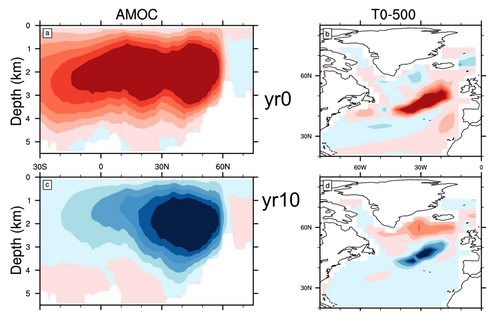
Branstator, G. and H. Teng, 2014: Is AMOC more predictable than North Atlantic heat content? *J. Climate*, in press.

Most predictable patterns (MPPs)

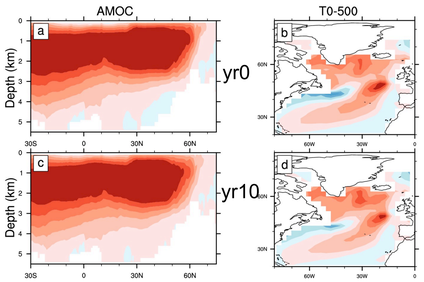
We have also determined whether there are particular components of AMOC variability that may have above average predictability using a method based on canonical correlation analysis (Branstator and Teng 2014). As shown in this diagram there are patterns that are predictable for as much as two decades, which is much longer than the predictability of typical heat content.



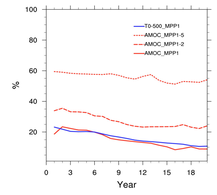
Multi-model averaged MSE for AMOC (red) and North Atlantic upper 500m heat content (blue) based on 10 PCs and MSE for AMOC most predictable pattern 1 (solid dark red), 1-2 (long dash) and 1-5 (short dash) and the heat content most predictable pattern 1 (blue solid).



The most predictable patterns have very different structures in the various CMIP5 models. In CCSM3 (left) the pattern consists of an oscillating AMOC feature that is accompanied by a counterclockwise propagating heat content feature in the subpolar gyre. By contrast, for CNRM-CM5 (below), the most predictable AMOC pattern is stationary, as is the heat content anomaly that accompanies it.



AMOC MPP1 in the initial condition (top left) and 10-year prediction (bottom left) and the associated heat content patterns.



Fraction of variance of control integration variability explained by MPP1 of AMOC and of heat content, and by MPP1-2 and MPP1-5 of AMOC. The fraction has been calculated for each model and the average is displayed.