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Resolution-dependent interannual Gulf Stream, heat content, and overturning variability in the CMIP5

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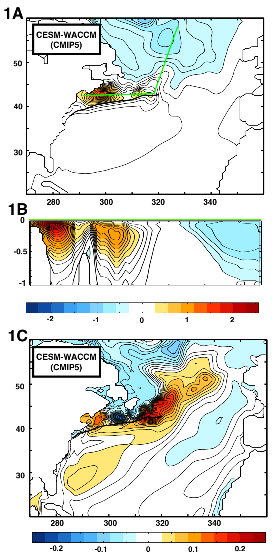
1. Background/Motivation



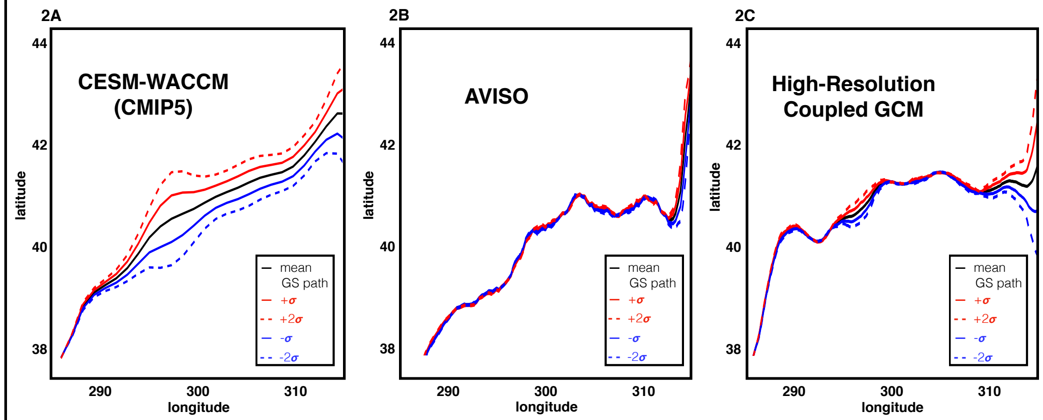
The principal mode of North Atlantic temperature/heat content variability within the CESM (and much of the CMIP5) has a spatial pattern resembling Figure 1A. It is defined by a high in the Eastern nearshore and along the shelf, as well as a low within the subpolar gyre. A transect taken along the principal axis of this dipole (green segments in Fig. 1A) shows that this mode intensifies at depth (Fig. 1B) and has a long decorrelation timescale.

To help elucidate the mechanisms underlying this mode, we take a complex EOF. This shows the intermediate state between negative and positive phases of the EOF, accessible with a Hilbert transform. Fig. 1C shows the imaginary part of the complex EOF. This pattern carries the signature of the offshore advective transport of the coastal high and implicates Gulf Stream (GS) variability in its maintenance.

This dominant mode of temperature variability is driven by large-scale meridional GS position variance (Frankignoul 2015). Here we show that this is the result of at the amplified variability found in CMIP5 members, and is not found either in altimetric observations or in comparable high-resolution coupled GCM's.

Given its influence on temperature and SSHa, a complete understanding of the mechanisms underlying this temperature variability in essential to evaluating the representation of North Atlantic climate within the CMIP5.

2. Gulf Stream Position variability in the CMIP5



We use a simple algorithm for determining both the position and strength of the Gulf Stream within model output. For each line of longitude we make a meridional profile of RMS velocity and locate the maximum, as well as all other points within 80% of this maximum. The mean value of these points we consider the strength, and their mean latitudinal location we take as the position. We employ the first principal components of along-track GS strength and position as convenient 1-D time indices.

Figure 2A shows both the mean position of the GS as well as the leading mode of position variability from a representative member of the CMIP5. This shows the large-scale monotonic position variability that dominates North Atlantic temperature variability in the relevant members of the CMIP5. There is a noticeable amount of monotonic variance, indicating that the low-resolution modeled GS swings meridionally on interannual time scales.

Figure 2B shows the corresponding mean and large-scale variability in AVISO altimetric observations. Position was determined by a alternate method more appropriate for observed SSH. Here an error function is fitted to the GS SSH front. There is much less large-scale position variability in observations - GS position is dominated by Rossby waves, mesoscale eddies, and other high-wavenumber phenomena.

Figure 2C was derived from the output of a high-resolution (0.1 degree horizontal; 62 vertical layers) coupled GCM (using the maximum-RMS speed method described above). This model, described in Small et al. [2014], evinces little large-scale GS position variance as in observations. While the mean position is further inshore, the pattern of variability is similar to that derived from AVISO.

This indicates that the heightened interannual GS variability seen in many of the members of the CMIP5 is resolution-dependent, and that its dominance of North Atlantic heat exchanges cannot be expected at higher resolutions.

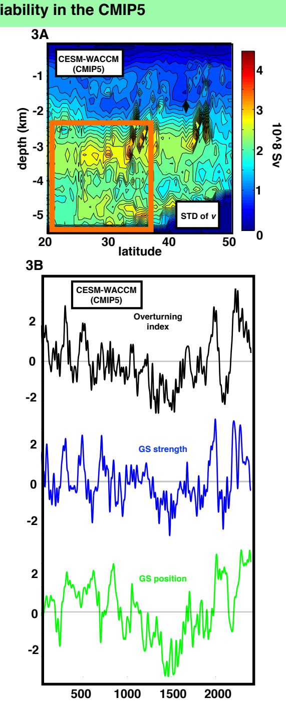
3. North Atlantic Interannual Variability in the CMIP5

The elevated GS position variability found across the CMIP5 drives SST and heat content variability across the North Atlantic. Here we examine the mechanism by which this mode is maintained in a CESM-WACCM control simulation.

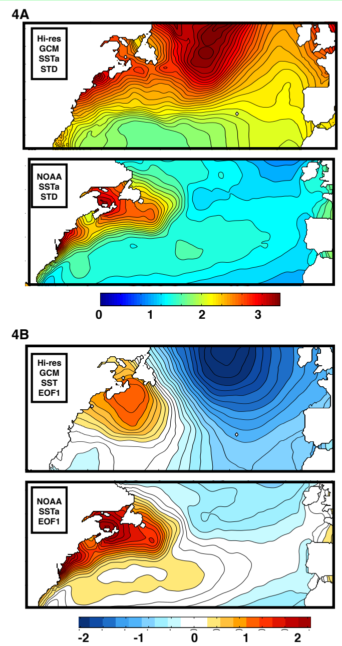
There is a well-established relationship in models and observations between GS strength and overturning variability (Cunningham et al. 2007). Here we make an index of overturning by taking a spatial mean in its area of greatest variance (Figure 3A). This time series (lowpassed and normalized to highlight interannual variance) is shown in Figure 3B. This index leads our index of GS strength (described in Section 2) by 3 months with a correlation of 0.7

This amplified GS strength tends to bring shelf water offshore (Forsyth et al 2015) and to drive a local SST high (Figure 1A). This high geostrophically displaces the GS front and alters its position. The strength index leads the position index by 7 years with a correlation of 0.7.

The altered GS position then drives North Atlantic heat content variability, altering the background for overturning (Joyce and Zhang 2010).



4. High-resolution coupled simulation results



Large-scale nonseasonal SST variance in the high-resolution simulation has a spatial pattern similar to observations at the midlatitudes (Fig. 4A).

The leading mode of SST variability in the high-resolution model is similar as well, showing an NAO precursor pattern.This is in contrast to the leading mode of heat content variance in much of the CMIP5 (Figure 1A), which is (as shown in section 3) largely the result of elevated GS variance. With a more meridionally stable GS (as in observations), the high resolution simulation is largely defined by an integrated response to atmospheric forcing.

5. Conclusions

- North Atlantic temperature variability in the much of the CMIP5 is driven ultimately by heightened Gulf Stream position variability and meridional overturning.
- Within representative CMIP5 members, this variability operates by the following mechanism. Overturning drives the strength of the Florida Current/Gulf Stream. Gulf Stream strength drives temperature anomalies within the shelf. These temperature anomalies displace the front and alter the downstream position of the Gulf Stream.
- The output of an eddy-permitting coupled GCM shows very little large-scale GS position variability (as in altimetric observations), and lacks the attendant mode of temperature variability. Its dominant mode of SST variability resembles the pattern derived observations.
- This work highlights the importance of model resolution in simulating even large-scale variability and provides a more holistic view of North Atlantic variability on time scales interannual and longer, uniting overturning, temperature, and Gulf Stream variability. It also allows for diagnostics of this variability in the CMIP5 derived from observables.

6. References

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7. Acknowledgements

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