Identifying Mechanisms of AMOC Variability in ECCO State Estimates and CMIP5 Models

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Over the past year, our project has focused on two main science questions: (1) determining the relative roles of atmospheric forcing and ocean dynamics (e.g., Rossby waves, changes in the gyre circulations and/or AMOC) in setting upper-ocean heat content (UOHC) variability in the North Atlantic and (2) exploring mechanisms of decadal AMOC variability originating from the North Atlantic basin. Thus far, our main tool has been data-constrained, dynamically and kinematically consistent estimates of the global circulation produced by Estimating the Circulation and Climate of the Ocean (ECCO).

Relationship between AMOC and UOHC variability

Our goal is to determine the portion of North Atlantic UOHC variability that is due to active ocean dynamics, such as the AMOC. To explore this question, we utilize the ECCO state estimate (1992-2011) to quantify the upper ocean heat budget in the North Atlantic on monthly to interannual timescales (seasonal cycle removed). Three novel techniques are introduced: (1) the heat budget is integrated over the maximum climatological mixed layer depth (integral denoted as H), which gives results that are relevant for explaining SST while avoiding strong contributions from vertical diffusion and entrainment; (2) advective convergences are separated into Ekman and geostrophic parts; and (3) air-sea heat fluxes and Ekman advection are combined into one "local forcing" term. In the interior of the subtropical gyre, the sum of air-sea heat fluxes and Ekman heat transport convergences is a reasonable measure of local atmospheric forcing, and such forcing explains the majority of H variability on all timescales resolved by ECCO. In contrast, the Gulf Stream region and subpolar gyre have ocean dynamics that are found to be important in setting H on interannual timescales. Air-sea heat fluxes damp anomalies created by the ocean and thus are not set by local atmospheric variability.

These results suggest that the AMOC does not play an active role in setting UOHC anomalies in the subtropical gyre on the timescales resolved by the ECCO estimate. In contrast, ocean dynamics, perhaps including ocean heat transport (OHT) convergence variability due to AMOC variability, play a role in setting UOHC in the Gulf Stream region and the subpolar gyre. Whether these results hold at longer timescales is a subject of our present work using CMIP5 models.

Mechanisms of decadal AMOC variability

Currently there is no accepted mechanism for decadal AMOC variability and little background theory on which the community agrees. Insights about mechanism have largely come from models, but the magnitude and time scale of AMOC variability varies markedly across models and model formulations. Despite this, there are three robust features of AMOC variability that may inform mechanisms of decadal variability. (1) Observations and models suggest that buoyancy anomalies on the western boundary are key to understanding low-frequency AMOC variability. (2) A pacemaker region for decadal AMOC variability appears to be located along the boundary between the subtropical and subpolar gyres. (3) Meridionally coherent decadal AMOC anomalies are communicated southward from this pacemaker region. We use these three robust features to argue that the region near the Grand Banks where the Gulf Stream/North Atlantic Current and the deep western boundary current cross over, henceforth called the transition zone (TZ). The TZ is a key region influencing large-scale decadal AMOC variability. Processes that are important in creating buoyancy anomalies in the TZ are expected to play an important role in AMOC variability. Such processes include local atmospheric forcing, advection of anomalies by mean currents, westward propagating baroclinic Rossby waves, anomalies resulting from large-scale ocean circulation changes (such as shifts of the Gulf Stream path), and anomalies advected/propagated from high latitudes. The complex ocean dynamics in the TZ likely explain why AMOC variability is so sensitive to model formulation, both between models and in the same model when changes are made to its resolution, overflow parameterizations, etc.

We are currently investigating decadal variability of the AMOC in the ECCO v4 model, and relating it to variability in the TZ region. Furthermore, we have conducted an UOHC budget over the TZ in order to assess the processes that are important in setting UOHC variability in this key region (see Figure 1). We find that geostrophic currents (eddy and mean) dominate temperature variability on interannual timescales, while local air-sea heat flux and Ekman mass transport variability dominate on intra-annual timescales.

Bibliography

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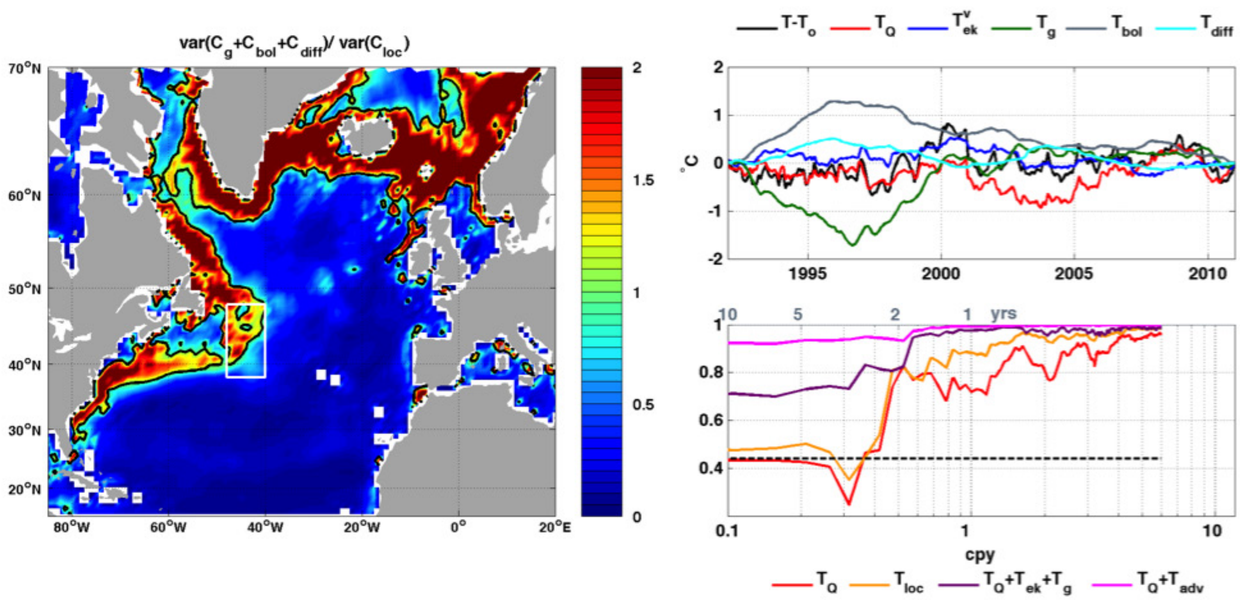

Figure 1. A heat budget analysis over the maximum climatological MLD using ECCO v4. (left) Map shows the ratio of the variance of convergences due to ocean dynamics (Cg+Cbol+Cdiff, geostrophic, bolus, and diffusive convergences, respectively) to convergences due to local forcing (Cloc). The ratio is small over the gyre interiors, but large over boundary currents and the TZ region. (right) The temporally integrated heat budget over the TZ (white box in left panel). (top right) Time series of temperature (T-To), air-sea heat fluxes (TQ), convergence due to Ekman mass transport variability (Tek^v), geostrophic convergences (Tg), bolus convergences (Tbol), and diffusive convergences (Tdiff). The advective convergence (Tadv) is separated into the linear advective convergence (Tlin) and Tbol and Tek+Tg ≈Tlin. (bottom right) Magnitude of the coherence between T-To and various sums of terms in the T budget.