A Linear Stochastic Analysis of Model Diversity in AMOC Dynamics

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The variability of the Atlantic Meridional Overturning Circulation (AMOC) differs greatly among the separate coupled General Circulation Models (GCMs). Even within the same model, AMOC variability can be considerably different, depending on the CO2 scenario. Statistical techniques explicitly employing linear assumptions were used to document and characterize these differences in parallel investigations, results of which were recently presented at the 2014 AMOC meeting held 9-11 September in Seattle, WA.

In the first project, we used Linear Inverse Modeling (LIM) to weigh the relative importance of heat flux (HF) and freshwater flux (FW) to the AMOC as represented in two coupled GCMs, the GFDL ESM2M and the NCAR CCSM4. These models were chosen as examples of the contrast between strongly periodic and highly chaotic representations of AMOC in coupled GCMs. We found that the strongly periodic AMOC in ESM2M (not shown) is an internal oscillation that, once set off, is little affected by variations in HF and FW. In contrast, the CCSM4 relies heavily on these fields in order to maintain AMOC variability.

We represent AMOC variability by the annually averaged, zonally averaged stream function anomalies from which not only the climatology, but also the Ekman component, has been subtracted. Augmenting this field, hereafter ψ_{NoEck}, with HF and FW, we used a combination of lagged and contemporaneous covariance statistics to estimate the propagator matrix $\mathbf{G}(\tau)$ for the three-variable system over a time τ. The right singular vector ϕ of $\mathbf{G}(\tau)$, suitably normed, is the initial condition giving rise to the maximum amplification of ψ_{NoEck}, i.e., the optimal initial condition for growth. We normalized ϕ to unity and estimated the importance of HF and FW to the propagation of ψ_{NoEck} by operating $\mathbf{G}(\tau)$ and modifications thereof on ϕ.

In Figure 1, the red curve is the Euclidean norm of ψ_{NoEck} as a function of lead time for ESM2M and CCSM4 using the (ψ_{NoEck}, FW, HF) field. We repeated estimation of ψ_{NoEck}, successively suppressing interactions of 1) HF with ψ_{NoEck} (blue curve in Figure 1a,b), 2) FW with ψ_{NoEck} (green curve) and 3) both FW and HF with ψ_{NoEck} (purple curve) in $\mathbf{G}(\tau)$. For the ESM2M, the variance amplification is maximized at three years (Figure 1a), consistent with a period of about 12 years. The amplification is only slightly dependent on whether or not HF and FW are allowed to interact with ψ_{NoEck}. Further, the contribution to the variance of ϕ by ψ_{NoEck} is very close to unity, indicating that FW and HF contribute very little to the optimal initial condition for growth. In contrast, ψ_{NoEck} contributes less than two-thirds of the variance of ϕ in CCSM4 (Figure 1b). Interactions of HF and FW with ψ_{NoEck} strongly affect the amplification of ψ_{NoEck}, and this amplification occurs at smaller timescale than that in the ESM2M.

These results immediately present two questions, which are subjects of present work: 1) how can we decide which scenario is closer to the truth, and 2) how do dynamics operating on sub-annual timescales affect our results? We shall approach the first question by projecting Mercator reanalysis data onto basis patterns appropriate to each model and, using the LIM dynamical description of each model as a simulator, compare hindcasts with verification. The second question requires analysis of monthly model output to estimate sub-