Low Pass Filtering, Heat Flux and the AMO

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Abstract

Clement et al (2015) showed that in the absence of external forcing the Atlantic Multi-Decadal Oscillation (AMO) in atmospheric general circulation models (AGCMs) coupled to slab oceans has the same temporal and spatial characteristics as one produced by AGCMs coupled to a dynamically active ocean. This indicates that ocean circulation is not needed for the AMO, and that the AMO may be driven by white noise forcing from the atmosphere.

Here we augment these results on the mechanisms of the AMO in complex models by comparing with the one dimensional noise driven model, $\mathrm{d}T/\mathrm{d}t = -\alpha T + q_a + q_o$, where the first term on the right damps temperature anomalies and the last two terms represent white noise forcing by the atmosphere and by the ocean. We obtain general analytic expressions for both the unfiltered and low pass filtered lead-lag correlations of this model. We show that this simple model reproduces many of the simulated lead-lag relationships among temperature, rate of change of temperature, surface heat flux, and ocean heat flux. We conclude that some features that have been previously interpreted in the literature as showing that the ocean circulation is necessary for the AMO are in fact consistent with the hypothesis that the AMO is driven by white noise heat fluxes from the ocean and atmosphere. We show that some results in the literature are artifacts of low pass filtering, which creates low frequency signals when the underlying data is white or red noise.

A principal challenge to the view that ocean circulation is not essential for the AMO is based on the finding in models (Zhang et al, 2016; O'Reilly et al 2016) and observational data (Gulev et al, 2013) that at multidecadal periods the surface heat flux is out of the ocean when temperatures are warm. This finding been interpreted as proof that the ocean must be the driver of the AMO. Here we show that this relation between temperature and surface heat flux is a necessary consequence of the fact that at long periods the net heat flux (ocean plus atmosphere) is zero to a good approximation. Zero net heat flux is achieved by the damping associated with turbulent surface fluxes balancing ocean heat convergence and other atmospheric fluxes (e.g. radiation). This balance implies that the correlation of temperature and surface heat flux out of the ocean must be negative no matter how strong the atmospheric forcing is; it goes to zero only if there is no influence from the ocean whatsoever. The negative relation of temperature and surface heating is a signature of the near-equilibrium state and cannot tell us whether the heat source for the AMO is in the ocean or the atmosphere. We discuss some alternative methods for diagnosing the role of the ocean in the AMO, and other low-frequency surface temperature variations.