The fingerprint of ocean influence on seasonal and interannual temperature change

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Abstract

Land temperatures are not warming uniformly. The spatial pattern of warming is influenced by local feedbacks, differences in radiative forcing, and stochastic sources of variability; here, we explore the degree of the structure that can be explained by the damping effect of ocean heat capacity. We use GFDL AM2.1 as a controlled laboratory to evaluate the importance of the effect, with an eye towards the application to the instrumental record. We focus first on the seasonal cycle in temperature to evaluate oceanic influence, because it has been repeatedly observed in the instrumental record. We calculate a spatially-varying mixing ratio between oceanic and continental end members that captures almost all of the structure of the seasonal cycle in the extratropics, providing a global map of the magnitude of oceanic influence. Oceanic influence is present on land masses, decreasing from west to east, due to the balance between the radiative relaxation and synoptic timescales of the atmosphere, leading to limited atmospheric memory of ocean while over land. To test if a similar relationship occurs on interannual timescales, we analyze output from an AM2.1 simulation with fixed SSTs and sea ice forced by a doubling of CO_2. In this controlled simulation, long-term feedbacks are absent, so the resulting pattern of temperature change primarily reflects the damping effects of the ocean. We calculate the interannual mixing ratio as a linear function of equilibrium temperature change. Within the AM2.1 model, there is a nearly one-to-one relationship between the mixing ratio calculated from the seasonal cycle and that from the equilibrium response to increased CO_2, with the greatest agreement in the Northern mid-latitudes ($R > 0.9$ between 30 and 55 N). Based on the result that interannual temperature responses to perturbative radiative forcing are related to the ocean-land mixing ratio in AM2.1, we apply the same methods to the Hadley Climate Research Unit instrumental temperature record in the Northern Hemisphere mid-latitudes. The mixing ratio from the climatological seasonal cycle correlates with centennial-scale temperature change in the instrumental record with an R value of 0.61 on a gridbox-by-gridbox basis, and $R = 0.75$ averaged across latitude. The use of a seasonal cycle-based predictor does not account for long (>1 year) timescale feedbacks, changes in heat transport and circulation, zero-mean natural variability, or the larger effective oceanic heat capacity for longer timescales. Nevertheless, the oceanic influence diagnosed from the seasonal cycle can explain a signifiant fraction of the spatial pattern of warming observed over the twentieth century.