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# *HEAT CAPACITY, TIME CONSTANT, AND SENSITIVITY OF EARTH'S CLIMATE SYSTEM*

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**ABSTRACT**

Earth's climate system responds to perturbations on numerous time scales from short -- diurnal, annual -- to long -- multiple centuries (warming of the deep oceans) to millions of years (Kelvin and "the age of the Earth"). Here I argue that the time scale pertinent to climate system response to forcings over decadal scales is that associated with change in global mean surface temperature GMST. On such time scales GMST is tightly coupled to the ocean mixed layer, which provides virtually all the heat capacity of the system, global mean areal heat capacity 9.4 W yr $m^{-2}$ $K^{-1}$ (100 m depth; fractional ocean area 0.71). Recent compilations of the rate of increase in the heat content of the oceans over 1960-2000 together with the observed rate of increase of GMST over this time period permit determination of the heat capacity pertinent to climate change as 9 W yr $m^{-2}$ $K^{-1}$, uncertain to 50%, comparable to that of the ocean mixed layer. From energy balance considerations such a global heat capacity yields for the time constant of climate system response (time for e-fold decay of a perturbation) a value of 2.5 years in the absence of feedbacks; inclusion of a feedback factor of up to several fold yields a time constant of up to a decade or so. Similarly short values of the time constant are obtained from analysis of autocorrelation of time series of GMST and ocean heat content. Such a short time constant implies that most of the change in GMST due to radiative forcing on the decadal time scale has been realized and hence that climate sensitivity might in principle be inferred from observed change in GMST if forcing were known with sufficient accuracy, but the present uncertainty in aerosol forcing does not usefully bound that sensitivity. For reasonable estimates of aerosol forcing (corresponding to aerosol forcing over the industrial period of -0.5 to -1.5 W $m^{-2}$) climate sensitivity is estimated as 0.63 to 1.4 K/(W $m^{-2}$), equivalent to a temperature increase for doubled $CO_2$ of 2.5 to 5.8 K. The corresponding range of present temperature increase due to increased $CO_2$ alone is 1.0 to 2.3 K, the difference relative to the observed temperature increase (~0.6 K) being due mainly to cooling by anthropogenic aerosols. Relaxation of the perturbation to GMST due to enhanced greenhouse gases requires a much longer time, being governed mainly by the decay of excess $CO_2$, which occurs on the time scale of centuries.

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