Macroweather forecasts and Climate Projections: linear but stochastic challenges

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Beyond their 10 day deterministic predictability limit, Numerical Weather Prediction (NWP) and Global Circulation Models (GCMs) effectively become stochastic. In addition, for both macroweather forecasts (10 days to $\approx 10$ years) and climate projections ($\approx 10$ years to 2100 or more), the forcings are sufficiently small, so that the responses are nearly linear. By analyzing the projections used in the latest IPCC report, I show that each one has a nearly linear response to the forcing scenarios. However, each model has a significantly different climate, so that the overall “multimodel ensemble” has a wide dispersion, implying large projection uncertainties. The challenge is thus to construct linear stochastic models valid above the weather-macroweather transition scale of about 10 days. Such models have already been used successfully for both monthly and seasonal forecasting as well as projecting temperatures to 2100. When compared GCMs, they have the advantage of being based on the real world rather than model climates. To date, stochastic macroweather models have been phenomenological with the more successful ones mentioned above, being based on the physical principle of scale invariance, but it is important to put the models on a strong physical basis. We show how the principle of energy balance allows this to be done. The conventional energy balance equation (EBE) is a linear differential equation of first order implying exponential relaxation of the temperature to equilibrium. It turns out that the actual relaxation process is a qualitatively different long memory, power law process with only a small fraction of the return to equilibrium occurring within the analogous (power law) relaxation time due to the hierarchy of ocean gyres and eddies each transferring heat at a rate that depends on their size and depth. Heat transfer over land also occurs in a hierarchy manner. Power laws are obtained via a seemingly trivial change in the EBE; making the differential (storage) term of fractional order:

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the Fractional EBE (FEBE). However, this introduces a long memory so that mathematically the problem becomes a past value problem (rather than an initial value problem) where all the past forcings contribute to the present response. By solving the FEBE we show that the (fractional) relaxation time represents a transition between two power laws; between two regimes with strong but different memories characterized by theoretically related exponents: $HE = -(1/2+ HI)$. The (internal) exponent $HI \approx -0.1$, allows one to make accurate forecasts from weeks to years (macroweather), whereas the (external) exponent $HE = -(1/2+ HI) \approx 0.4$, leads to accurate decadal, centennial climate projections. The former was evaluated using hindcasts, the latter by comparisons with CMIP5 GCM integrations and on hindprojections that include the pause/slowdown/hiatus in the warming that we accurately hindproject a century earlier.