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Spatiotemporal correlations in Earth's temperature field from fractional stochastic-diffusive energy balance models

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In the Earth temperature field, spatiotemporal long-range dependence is usually explained as a result of nonlinear cross-scale coupling and cascading. In this contribution we challenge that paradigm, demonstrating that the observed correlation structure can arise from simple, linear, conceptual models. A two-dimensional stochastic-diffusive energy balance model (EBM) formulated on a sphere by G. R. North et al., J. Climate, 24:5850-5862, 2011, is explored and generalized. We compute instantaneous and frequency-dependent spatial autocorrelation functions, and local temporal power spectral densities for local sites and for spatially averaged signal up to the global scale. On time scales up to the relaxation time scale given by the effective heat capacities of the ocean mixed layer and land surface, respectively, we obtain scaling features reminiscent of what can be derived from the observed temperature field. On longer time scales, however, the EBM predicts a transition to a white-noise scaling, which is not reflected in the observed records. We propose and explore a fractional generalization (FEBM), which can be considered as a spatiotemporal version of the zero-dimensional, long-memory EBM of M. Rypdal and K. Rypdal, J. Climate, 27:5240-5258, 2014. The fractional equation introduces a power-law (rather than exponential) impulse response representing the delayed action due to the slow heat exchange between the mixed layer and the deep ocean. It is demonstrated that this generalized model describes qualitatively the main spatiotemporal correlation characteristics of the temperature field derived from instrumental data and from a 500 yr control run of the Nor-ESM model. For instance, the FEBM implies temporal power-law spectra where the spectral exponent for globally averaged temperature is twice that of local temperatures, and spatial autocorrelation lengths increases with time scale, in good agreement with the Nor-ESM simulations. It also reproduces the long-time response to a step-function forcing in the Nor-ESM model.