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Spatiotemporal correlation structure of the Earth's surface temperature

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We investigate the spatiotemporal temperature variability for several gridded instrumental and climate model data sets. The temporal variability is analysed by estimating the power spectral density and studying the differences between local and global temperatures, land and sea, and among local temperature records at different locations. The spatiotemporal correlation structure is analysed through cross-spectra that allow us to compute frequency-dependent spatial autocorrelation functions (ACFs). Our results are then compared to theoretical spectra and frequency-dependent spatial ACFs derived from a fractional stochastic-diffusive energy balance model (FEBM). From the FEBM we expect both local and global temperatures to have a long-range persistent temporal behaviour, and the spectral exponent (β) is expected to increase by a factor of two when going from local to global scales. Our comparison of the average local spectrum and the global spectrum shows good agreement with this model, although the FEBM has so far only been studied for a pure land planet and a pure ocean planet, respectively, with no seasonal forcing. Hence it cannot capture the substantial variability among the local spectra, in particular between the spectra for land and sea, and for equatorial and non-equatorial temperatures. Both models and observation data show that land temperatures in general have a low persistence, while sea surface temperatures show a higher, and also more variable degree of persistence. Near the equator the spectra deviate from the power-law shape expected from the FEBM. Instead we observe large variability at time scales of a few years due to ENSO, and a flat spectrum at longer time scales, making the spectrum more reminiscent of that of a red noise process. From the frequency-dependent spatial ACFs we observe that the spatial correlation length increases with increasing time scale, which is also consistent with the FEBM. One consequence of this is that longer-lasting structures must also be wider in space. The spatial correlation length is also observed to be longer for land than for sea. The climate model simulations studied are mainly CMIP5 control runs of length 500-1000 yr. On time scales up to several centuries we do not observe that the difference between the local and global spectral exponents vanish. This also follows from the FEBM and shows that the dynamics is spatiotemporal (not just temporal) even on these time scales.