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Time-scale dependent estimation of spatial degrees of freedom

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Effective spatial degrees of freedom (ESDOF) provide a simple metric to characterize the spatial structure of a time-varying field. Methods to estimate the ESDOF from global fields of climate variables are useful in a variety of cases. For example, variance estimation of global averages or field reconstruction, from a limited number of observations, always require some knowledge about such basic statistical properties of the underlying processes. However, in many applications the ESDOF estimate depends on the time-scale under consideration. This becomes particularly important in the field of paleo-climate reconstruction, (i) because of the wide range of scales involved in the analysis, and (ii) because the sparsity of climate proxy data increases with time-scale.

Here we show how some simple ESDOF measures can be reformulated as a function of frequency. Their properties and interrelations are then illustrated by their application to (a) the Holocene episode of the TraCE-21ka paleo-climate model simulation, and (b) to a simple stochastic-diffusive energy balance model. These model systems indicate a distinct ESDOF reduction with increasing time-scale and, thus, serve as suitable test cases for frequency-dependent ESDOF measures. They also illustrate how additional conclusions, beyond the ESDOF estimate itself, can be drawn from comparison of different measures built on different metrics of the spatio-temporal covariance structure.