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The space-time variability and scaling of climate data, climate models and their converge as functions of space-time scale

Shaun Lovejoy and Lydia Elias
McGill University, Department of Physics, Montreal, Canada (lovejoy@physics.mcgill.ca, +1-(0)514-3988434)

Climate models are evaluated by comparing them with other models and (when possible), with climate data: one attempts to match the data and numerics as closely as possible pixel by pixel, time step by time step- i.e. deterministically. As a consequence very little attention has been paid to understanding the space-time statistical properties of the models and data. There is little understanding of the convergence of the model and data to their “climates” and to each other. In the time domain, there is no objective definition of the distinction between weather and climate in the spatial domain, there is corresponding lack of understanding of climate regions.

In order to overcome this, we systematically study the statistics of fluctuations (primarily of temperature but also precipitation and pressure) as function of space and time. For both data and models, we find that in space, that fluctuations increase up to about 5000 km before starting to decrease; this quantitatively defines the typical size of regional climates. In time, we find that fluctuations decrease out to about 10-30 years in the industrial epoch, out to 50 -100 years in the pre-industrial epoch and then starts to increase; this defines the difference between “macroweather” and the climate.

Applying fluctuation analysis to longer time scales, we examine last millennium simulations from four GCMs, we show that control runs only reproduce macroweather. When various (reconstructed) climate forcings are included, in the recent (industrial) period they show global fluctuations strongly increasing at scales >_10–30 yr, which is quite close to the observations. However, in the preindustrial period we find that the multicentennial variabilities are too weak and by analysing the scale dependence of solar and volcanic forcings, we argue that these forcings are unlikely to be sufficiently strong to account for the multicentennial and longer-scale temperature variability. A likely explanation is that the models lack important slow “climate” processes such as land ice or various biogeochemical processes.

This technique can be used to show that the error in estimating the global temperature is about ±0.03K, and this – surprisingly - at any time scale out to over 100 years. Similarly, in space the different surface temperature only start to converge (i.e. to agree with each other) at scales larger than $\approx$ 2000 km.

The same fluctuation analysis technique can be used to quantify the convergence of the models to the model climates and to the real climate. By comparing different realizations of the NASA GISS model historical simulations (from 1850), we show that in time, they converge to each other (i.e. to the model climate) at the slow rate $\Delta t^{-0.3}$; however in space, they *diverge* up to about 5000km ($\approx \Delta t^{0.4}$) only converging to their climate at larger scales, this “continental scale” is thus the smallest scale that can be attained by climate models and this likely imposes a fundamental limit on regional skill. By comparing the model to the data (20C reanalysis), we find that the two differ by between ±1 and ±2K at all space and time scales – beyond about 8 months, temporal averaging does not improve agreement, nor does spatial averaging help much. However, if the long tem averages are know and removed - so that one considers anomalies – space-time statistics of the model and the data are remarkably similar. This indicates that the model produces space-time fields of similar type to the data, but that the model and real climates are significantly different.