Long-range memory in Earth surface temperatures: spatial scale dependence and land-sea differences

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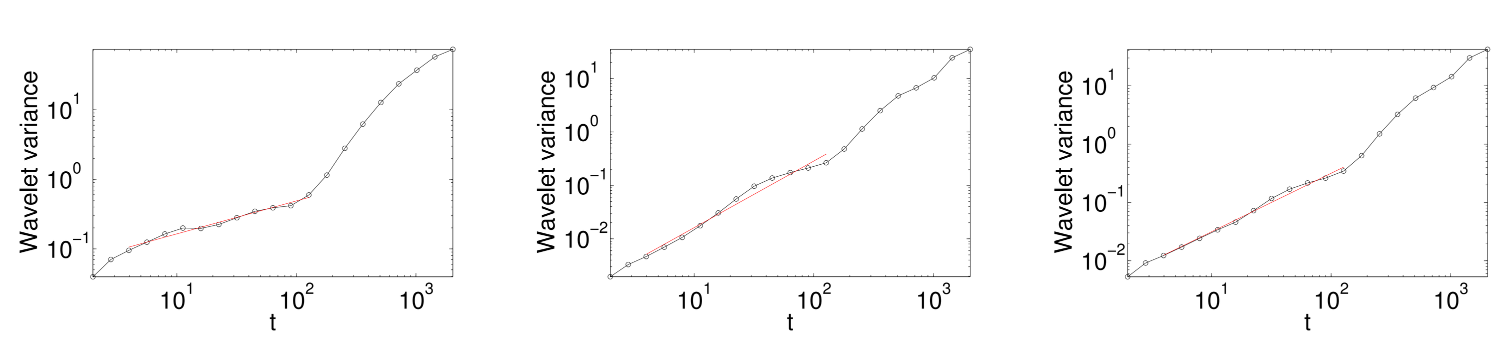
Introduction

This study investigates how the long-range memory in temperature time series on scales from months to decades varies between land and sea, and with different degrees of spatial averaging. Earlier analyses suggest that sea temperatures are more persistent than land temperatures, and that global temperatures are more persistent than regional temperatures. As a measure of the long-range memory we estimate the Hurst exponent H, and by performing spatial averaging of global gridded temperatures we make a systematic investigation of how the Hurst exponent varies on different spatial scales and between ocean/coastal and continental interior data records.

Long-range memory

For the temperature records the covariances seem to have a power law dependence on time for time scales from months to decades, with strong correlations on short time scales and weaker correlations on longer time scales. Then it can be modelled as a long-range memory process, which is defined as a process where the autocovariance function sums to infinity. One class of models that has this property is fractional Gaussian noises and fractional Brownian motions.

In a double logarithmic plot a power law becomes a straight line, and the slope of that line in a plot of the autocovariance is determined by the Hurst exponent. The Hurst exponent can also be estimated in other ways that measure the strength of the variance on different time scales, in the frequency domain (e.g. by periodogram), or the time domain (e.g. by fluctuation analysis, wavelet variance or rescaled range).



(a) Land (b) Sea (c) Combined

Figure 1: Wavelet variances of global land temperature, sea surface temperature, and combined land and sea surface temperature. The time scale t is measured in months, and the slopes of the red lines give us estimates of the Hurst exponents.

Results

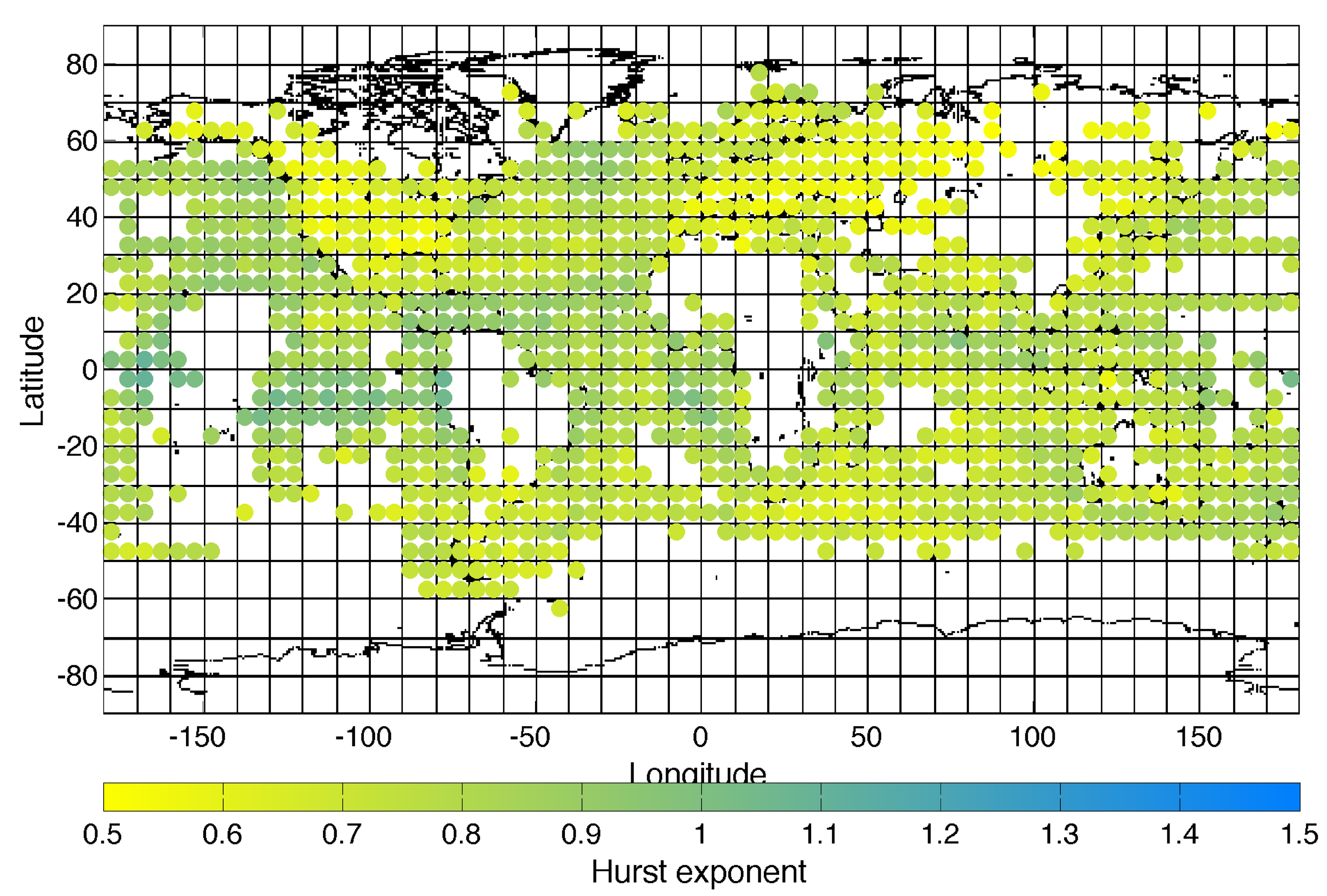
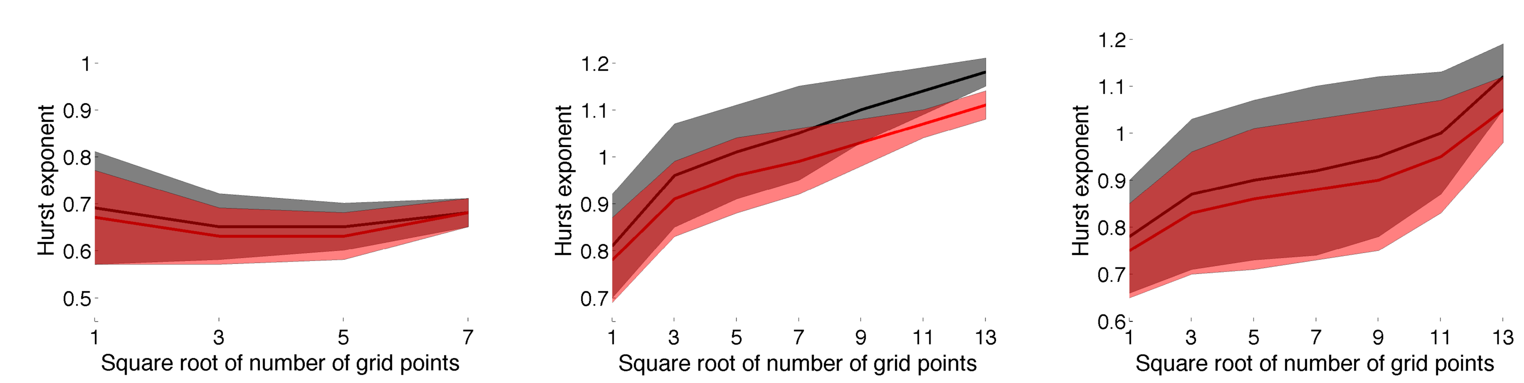


Figure 2: This figure shows the Hurst exponent estimated using wavelet variance of the $5^\circ \times 5^\circ$ gridded dataset HadCRUT4 on time scales from 3 to 128 months. The white areas are where we don't have enough data to get good estimates.

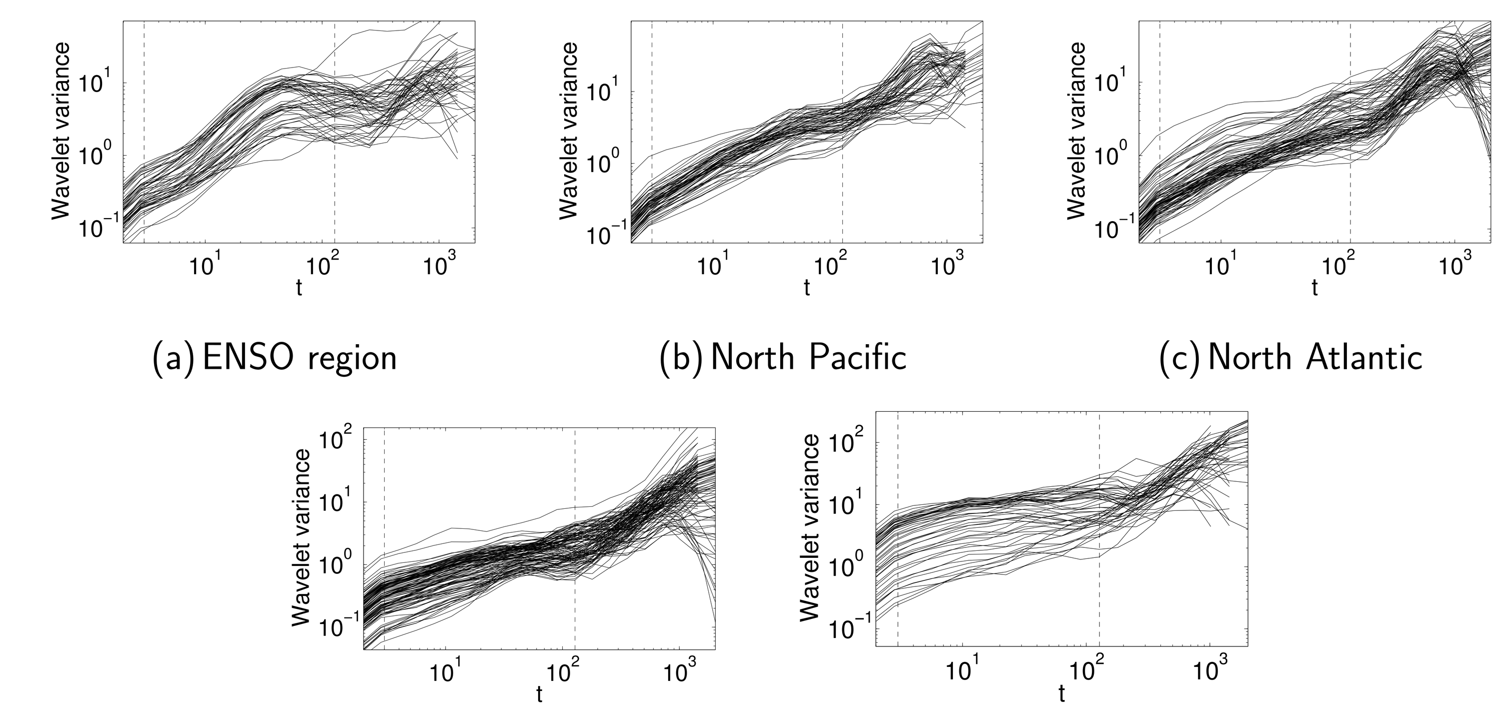


(a) Land (b) Sea (c) Combined

Figure 3: These figures show the Hurst exponents we get as a function of the size of the area the temperature is averaged over, where the black curves show the result when we use the periodogram as an estimator, and the red curves when we use wavelet variance. The shaded areas are one standard deviation on each side of the mean, and by one grid point I mean a grid of size $5^\circ \times 5^\circ$. The high Hurst exponents for the smallest scale land temperatures is a result of the influence of the sea on coastal land temperatures.

	Only land			Only sea			Combined		
	Global	NH	SH	Global	NH	SH	Global	NH	SH
Wavelet variance	0.75	0.71	0.86	1.12	1.04	1.01	1.00	0.87	1.02
Periodogram	0.76	0.73	0.84	1.22	1.15	1.05	1.08	0.93	1.07

Table 1: This table shows the global and hemispheric Hurst exponents.



(a) ENSO region (b) North Pacific (c) North Atlantic

(d) Indian Ocean (e) Some land temperatures

Figure 4: Wavelet variances from $5^\circ \times 5^\circ$ grids in the the Pacific ocean on latitudes between -10° and 10° and longitudes between -180° and -75° where ENSO has a large effect (a), North Pacific ocean on latitudes between 20° and 55° and longitudes between -180° and -125° (b), North Atlantic ocean on latitudes between 10° and 60° and longitudes between -60° and -15° (c), and Indian ocean on latitudes between -50° and 10° and longitudes between 50° and 110° (d), and some land temperatures (e). The region between the dashed lines is where I fit the straight line when estimating the Hurst exponent, and the time scale t is measured in months.

Conclusions

- Hurst exponents for interior land temperatures are smaller than Hurst exponents for sea surface temperatures.
- Hurst exponents increase with increasing spatial scale, at least for sea surface temperatures. For land temperatures it is not very significant, much due to the large influence of the sea surface temperature on the coastal land areas, which contribute more to the statistics on the smallest scales.
- Not all temperature variations follow perfect power laws. The largest deviations we find in the regions where ENSO is dominant, as we can see in figure 4. This process is so strong that it also influences the wavelet variance for global temperature seen in figure 1.
- The trend in the temperature is affecting the temperature variations only on the largest time scales, and is seen more clearly for land temperatures than for sea surface temperatures in these studies.