Unveiling signatures of interdecadal climate changes by Hilbert analysis

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A recent study demonstrated that, in a class of networks of oscillators, the optimal network reconstruction from dynamics is obtained when the similarity analysis is performed not on the original dynamical time series, but on transformed series obtained by Hilbert transform. [1] That motivated us to use Hilbert transform to study another kind of (in a broad sense) "oscillating" series, such as the series of temperature. Actually, we found that Hilbert analysis of SAT (Surface Air Temperature) time series uncovers meaningful information about climate and is therefore a promising tool for the study of other climatological variables. [2]

In this work we analysed a large dataset of SAT series, performing Hilbert transform and further analysis with the goal of finding signs of climate change during the analysed period. We used the publicly available ERA-Interim dataset, containing reanalysis data. [3] In particular, we worked on daily SAT time series, from year 1979 to 2015, in 16380 points arranged over a regular grid on the Earth surface. From each SAT time series we calculate the anomaly series and also, by using the Hilbert transform, we calculate the instantaneous amplitude and instantaneous frequency series.

Our first approach is to calculate the relative variation: the difference between the average value on the last 10 years and the average value on the first 10 years, divided by the average value over all the analysed period. We did this calculations on our transformed series: frequency and amplitude, both with average values and standard deviation values. Furthermore, to have a comparison with an already known analysis methods, we did these same calculations on the anomaly series. We plotted these results as maps, where the colour of each site indicates the value of its relative variation. To give some examples, in Fig. 1 we report the map of average frequency during the first 10 years, in Fig. 2 the same map but during the last 10 years and in Fig. 3 the map of relative variation of frequency average between the two cases.

Finally, to gain insight in the interpretation of our results over real SAT data, we generated synthetic sinusoidal series with various levels of additive noise. By applying Hilbert analysis to the synthetic data, we uncovered a clear trend between mean amplitude and mean frequency: as the noise level grows, the amplitude increases while the frequency decreases.

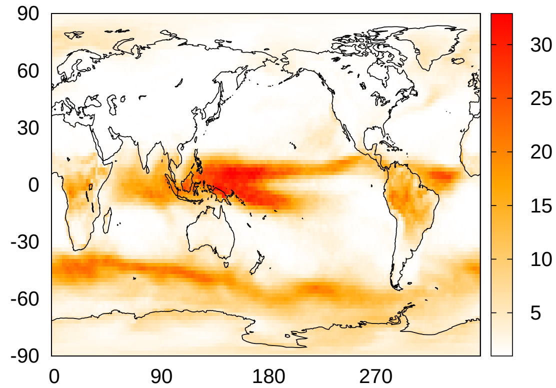

Figure 1: Average frequency during the first 10 years.

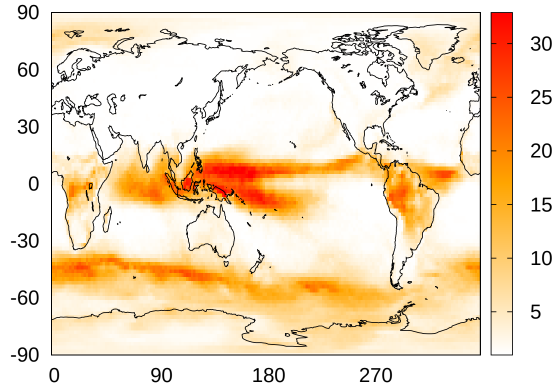

Figure 2: Average frequency during the last 10 years.

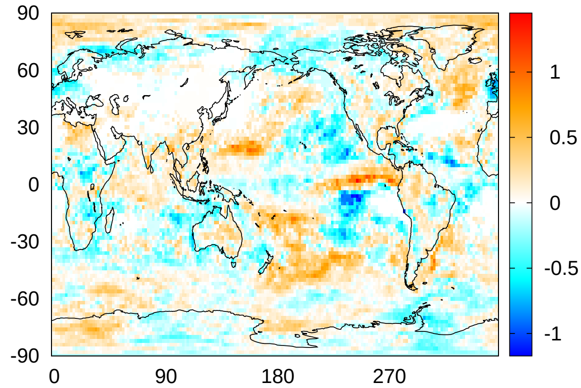

Figure 3: Relative variation of frequency average over the analysed period.

[1] G. Tirabassi, R. Sevilla-Escoboza, J. M. Buldú and C. Masoller, *Inferring the connectivity of coupled oscillators from time-series statistical similarity analysis*. Sci. Rep. **5**, 10829 (2015).

[2] D. A. Zappalà, M. Barreiro and C. Masoller, *Global Atmospheric Dynamics Investigated by Using Hilbert Frequency Analysis*. Entropy **18**(11), 408 (2016).

[3] D. P. Dee et al. *The ERA-Interim reanalysis: configuration and performance of the data assimilation system*. Q.J.R. Meteorol. Soc. **137**, 553-597 (2011).