Evolving complex networks from global climatological fields

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Motivation

Aim of our analysis is the investigation of the numerous and manifold interactions between components in the climate system of the earth. For this purpose we create the network of statistical interdependencies between time series covering the whole globus and study its properties. The temporal and spatial resolution of the network's evolution allows further interpretation of our network representation by relating it to impacts of events known as climatological relevant.

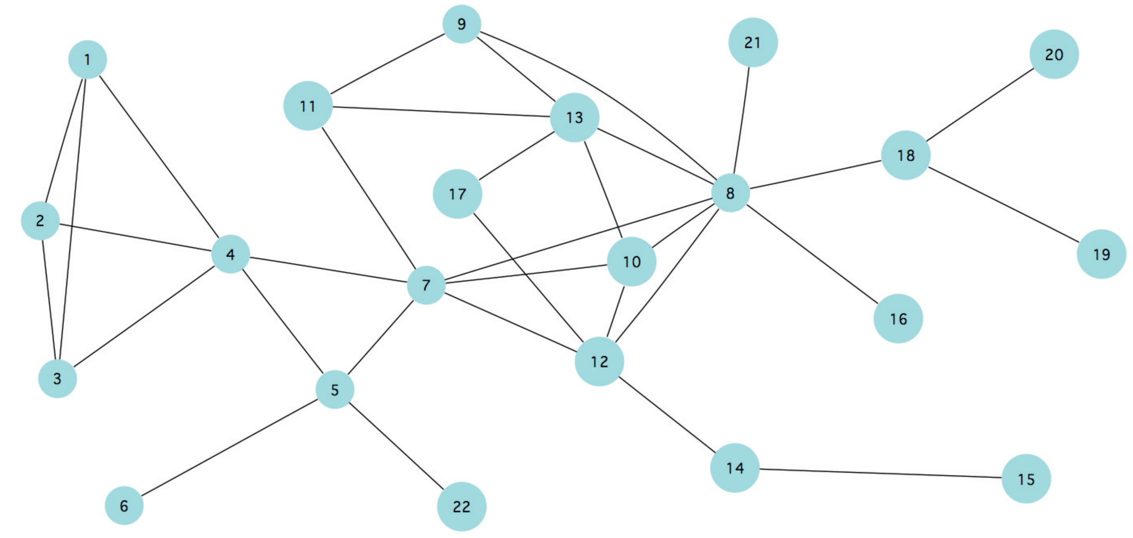
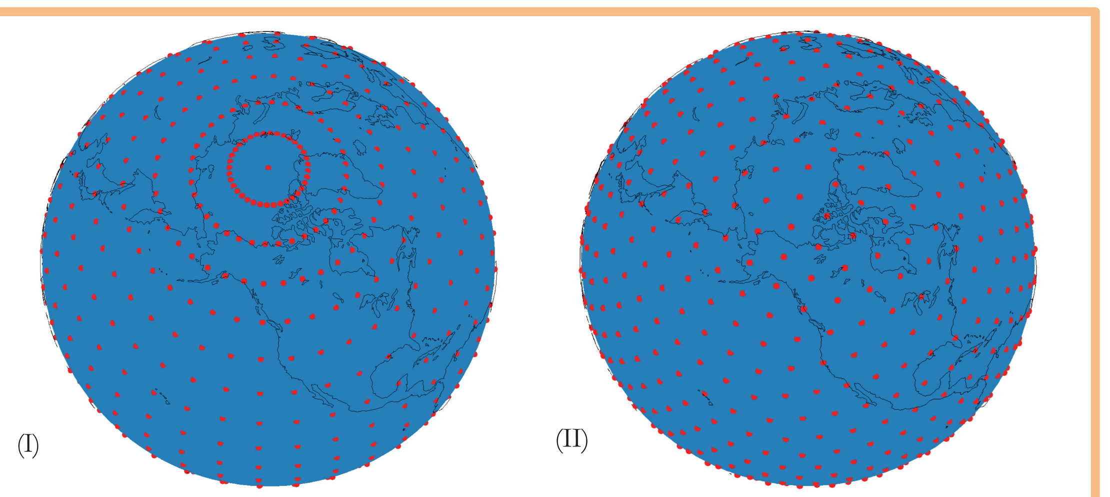


Figure 1: Illustrating example of a simple network. Note the nontrivial observation: Even if node 7 has a smaller degree centrality than node 8 (6 compared to 8) its geodesic betweenness centrality is higher (103.5 compared to 98.2), indicating its important role as a bottle neck. Node 8 has the smallest nonzero clustering coefficient of 0.18, the global clustering coefficitent is 0.29. Node 15 is the one with lowest closeness (0.26), quantifying that it is the most "far away" from all others. The average (shortest) path length is 2.84, while the diameter (longest shortest path) is 5. For the technical definition of those measures refer to [1].

Construction of the network

First, we identify 10512 globally distributed time series of the NCEP/NCAR Reanalysis SAT field as nodes of our network. Links are founded by strong interrelations (quantified by measures of association as Pearson correlation, mutual information, ...) between pairs of time series. Beforehand, the data sets are interpolated onto an icosahedral grid. Having almost everywhere the same number of nearest neighbours and an approximately constant nearest neighbour distance it fulfills the essential requirement of maximal spatial homogeneity. Any structural asymmetry within the grid would directly lead to artefacts in the link construction and hence the entire network, since the grid represents a discrete sampling of the underlying continuous physics.

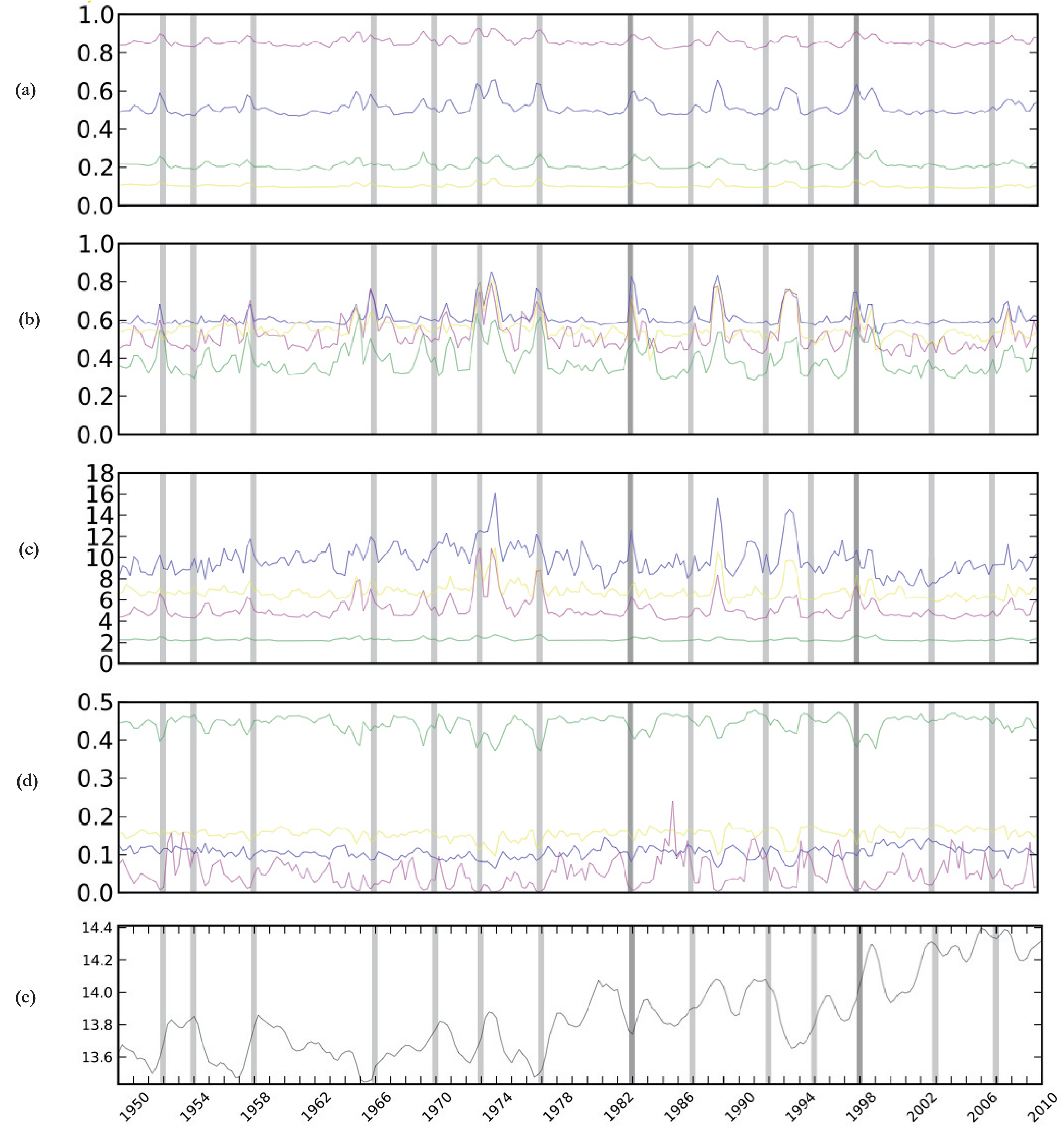
Figure 2: (I) The classical Gaussian grid. Homogeneous density in the latitude-longitude-space. But embedded on the sphere the spatial density increases towards the poles. The poles are singular by having a much higher number of nearest neighbours. (II) The icosahedral grid with 642 points. Created by succesive subdivision of the 20 corners of an icosahedron projected onto the sphere. The fraction of smallest and largest nearest neighbour distance is 0.8. Except the 20 initial grid points every node has 6 neighbours (the former have 5 of them).



Comparison by network measures

After we determined for which interdependencies to create links we end with a complex network, which cannot be examined by visual inspection. To grab its strucure we calculate the following properties: the fields of degree centrality, local clustering coefficient and betweenness centrality (shown on the right), the global clustering coefficient (b), the average shortest path length (c) and the spatial average of the closeness centrality field (d). The correlation is calculated within windows of one year. Plot (a) shows the threshold we have chosen to hold the link density constant for each time step. Plot (e) shows the spatial average of the original variable (SAT). Horizontal bars indicate El Nino events.

COLOR	ORIGINAL TEMPORAL RESOLUTION	MEASURE OF ASSOCIATION	LINK DENSITY
blue	6 hours	Pearson correlation	0.005
green	6 hours	Pearson correlation	0.050
purple	1 month	Pearson correlation	0.005
yellow	6 hours	mutual information	0.005



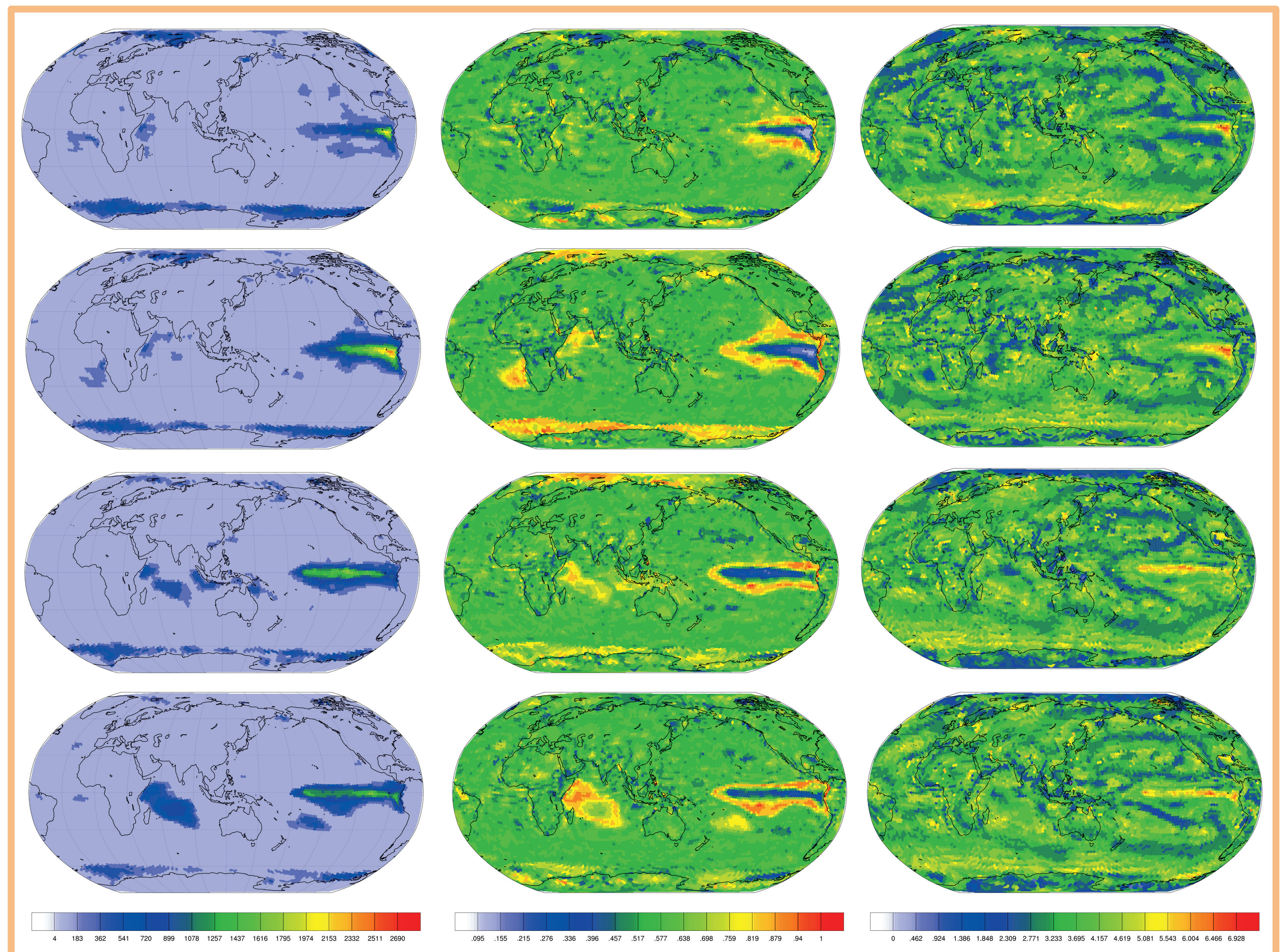
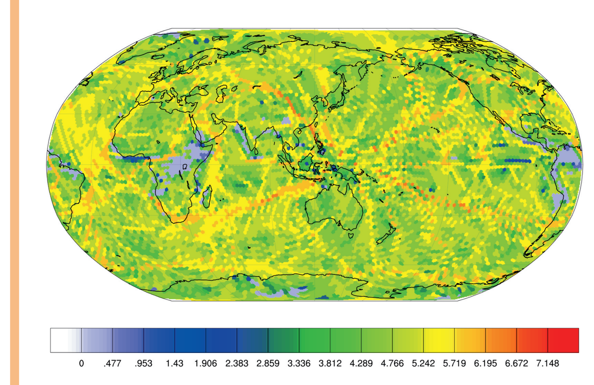


Figure 3: Above, from the left to the right the fields of degree centrality, local clustering coefficient and betweenness centrality. The vertical order follows the time direction (end of the correlation intervals are: July '97, October '97, October '98, January '99). El Nino (as its name is derived from the Christ Child) reaches its maximum in winter. However, the network indicates the upcoming 1997/98 event already by the window ending in summer of '97. The higher degree in the interiour of the ENSO region obviously carries teleconnections as it has high betweenness and small clustering coefficient (since the ends of teleconnections have a higher degree of spatial freedom and hereby a smaller probability to be connected among each other). All plots refer to the yellow-labeled results on the left, except a higher link density of 0.01. // In the right box we show the betweenness field of the same analyis, this time for a link density of 0.001 and the window ending October '93. It is the last frame of a series of remarkable spatial patterns, which remain for about one year. It probably is induced by the eruption of Pinatubo vulcano, which triggered synchronization of time series by the cooling effect of into the atmosphere ejected aerosols.



Conclusions & Outlook

The network approach offers an intuitve way of observation of spatiotemporal interdependencies within the climate system. To keep its promise of a new perspective on data driven analysis of real systems' coupled dynamics a stronger separation of noise and coupling effects by reiterating the mechanism of link creation has to be achieved.

References

[1] J. F. Donges, Y. Zou, N. Marwan, J. Kurths, Eur. Phys. J. 174 Special Topics, (2009) 157-179

[2] J. F. Donges, Y. Zou, N. Marwan, J. Kurths, Eur. Phys. L. 87(4), (2009)

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