Regional and inter-regional effects in evolving climate network

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Evolving networks and temporal variability of SAT

» study of time evolution of complex networks in climate

» technique using sliding window in time

» recently used to analyse the temporal variability of surface air temperature (SAT) correlation structures by Radebach et al. [1]

» authors analysed the evolving network for 62 years of SAT and provided insights into the global response of the climate system to events such as volcanic eruptions or different phases of the El Niño - Southern Oscillation (ENSO)

» varimax-rotated PCA to define climate components

» motivation: whether, how and to what extent the temporal evolution of the grid-based climate network is already reflected in the dynamics of the higher level inter-component network and the role of local (within-component) and distant (between-component) links in the global network evolution

[1] Radebach et al. 2013. *Phys. Rev. E*, **88**.

Network characteristics - data and components

» SAT field from NCEP/NCAR Reanalysis 1 [2]
» 1 Jan 1948 - 31 Dec 2009 = 62 years
» daily data - network evolution analysis
» monthly data - identification of the key components
» angularly regular 2.5° x 2.5° grid remapped to quasi-isotropic icosahedral grid - homogeneous in number of neighbours and nearest-neighbour distance
» removed long-term mean annual cycle and seasonality in variance, detrending to remove slow linear trends
» cosine reweighting

» components - data-driven dimensionality reduction
» varimax-rotated PCA yields the spatial distribution and representative time series of a set of components of SAT variability [3]
» components transformed into clusters with maximum loading criterion

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[2] Kalnay et al. 1996. *Bull. Amer. Meteor. Soc.*, **77**.
[3] Vejmelka et al. 2014. *Clim. Dyn.*, in review

Network characteristics - network construction

» vertices - grid points or components - *n*

» edges - determined by Pearson correlation - $r(x_i, x_j)$

» *n* x *n* weighted connectivity matrix $\mathbf{W}_{i,j} = r(x_i, x_j)$

» unweighted network: $A_{i,j} = 1$ if $W_{i,j} > W^*$ and $A_{i,j} = 0$ otherwise

» unweighted to weighted network - apply threshold W^*

» other characteristics of graph *G*: node degree *k*, clustering co-efficient *C*, transitivity *T* and average path length *L*

» applying thresholding on several graphs, it is convenient to determine thresholding based on predefined density of the graphs

» evolution characteristics: window length *w* = 365 days and offset *δ* = 30 days

» in evolution, 62 years correspond to 742 time points

» N.B.: consecutive windows are partially overlapping and thus they are dependent

Grid-based vs. RPCA network evolution

» evolution of the threshold W^* - Fig. 1 - most of the significant peaks from grid-based network are well reproduced in the component network

» the correlation is stronger for lower densities of the component network (Fig. 2), this suggests that the evolution of the core backbone of the inter-regional network is most relevant

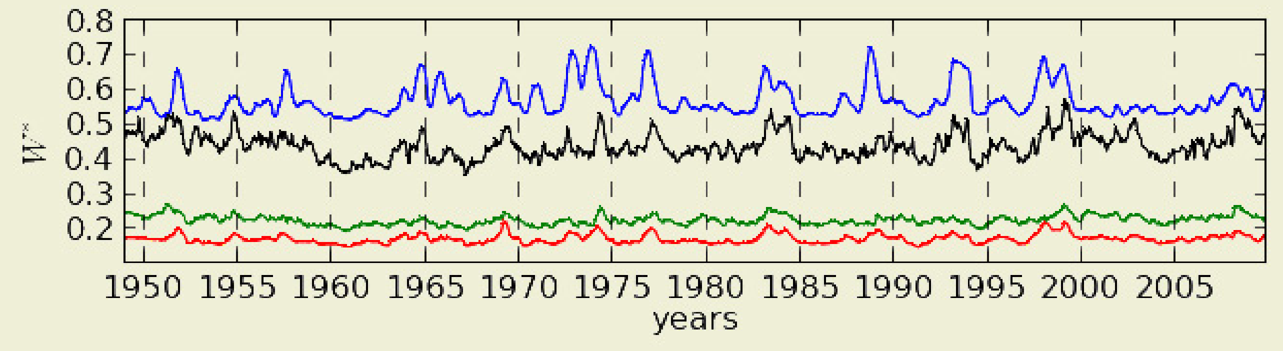

Fig. 1: comparison of the evolution of W^*-
blue / black - grid-based / RPCA, $\rho = 0.005$
red / green - grid-based / RPCA, $\rho = 0.142$

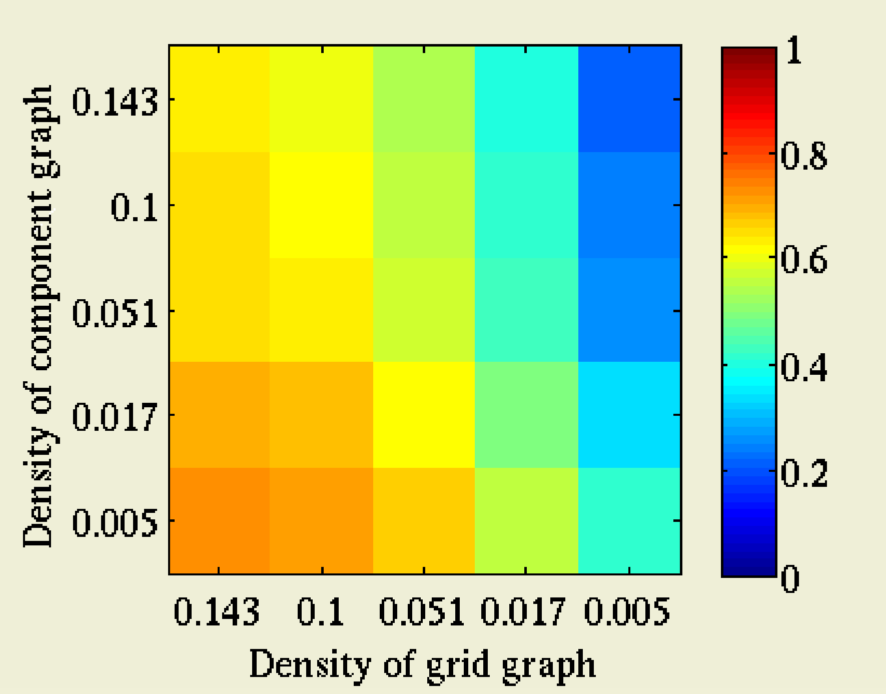

Fig. 2: correlation coefficients - grid-based graph vs. RPCA graph

Intra-regional contributions to evolution

» evolution in subgraphs: within parcel or between two parcels - bipartite graph

» its density $k \sim \alpha \log n$, $\alpha \sim 1.6$

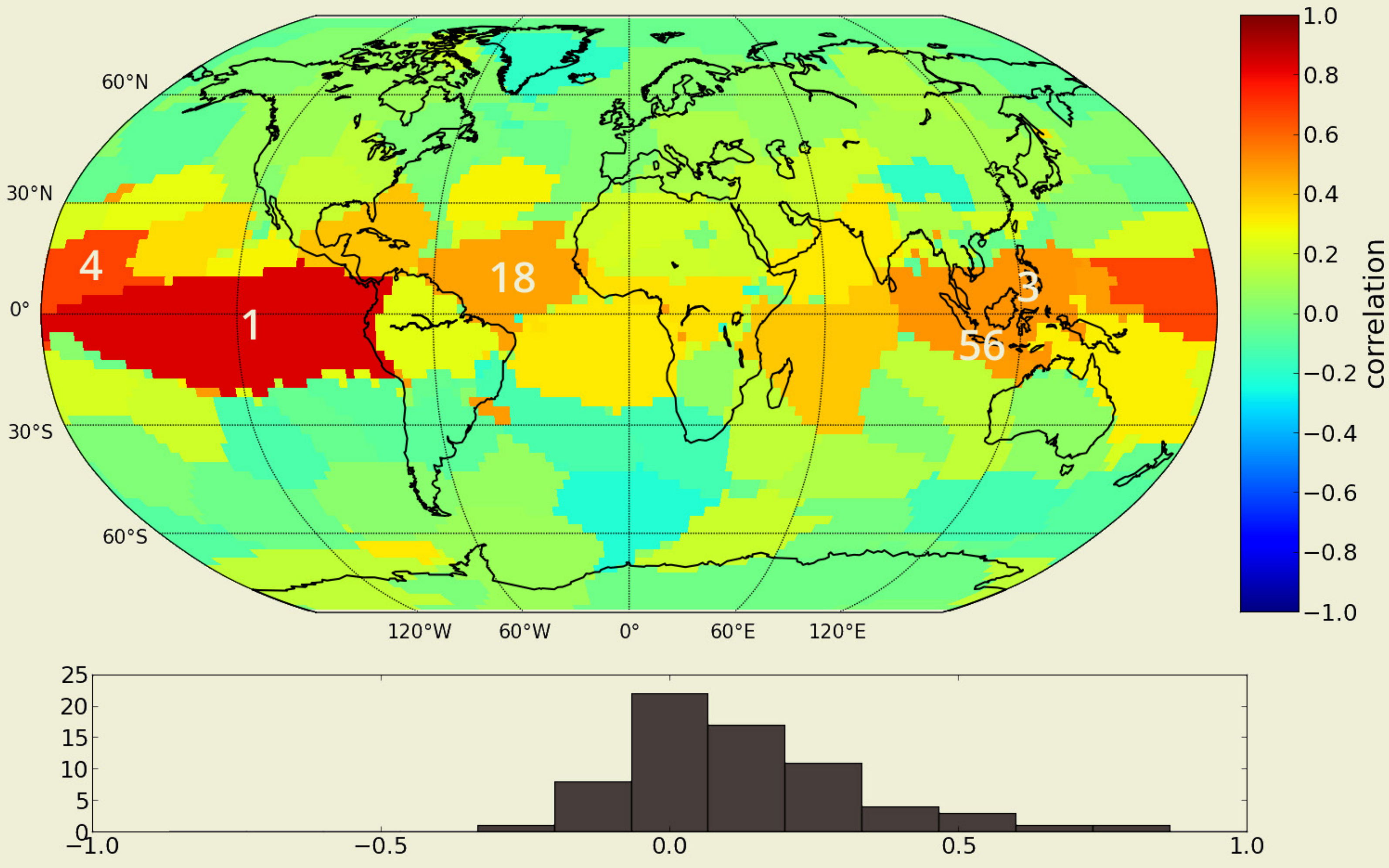

Fig. 3: Regions with high relevance for the global graph evolution. Shown are correlation of the intra-regional threshold evolution with the global 2562-node network. Correlations as follows: comp. 1 - 0.841, comp. 4 - 0.672, comp. 3 - 0.503, comp. 56 - 0.485, comp. 18 - 0.476

Inter-regional contributions to evolution

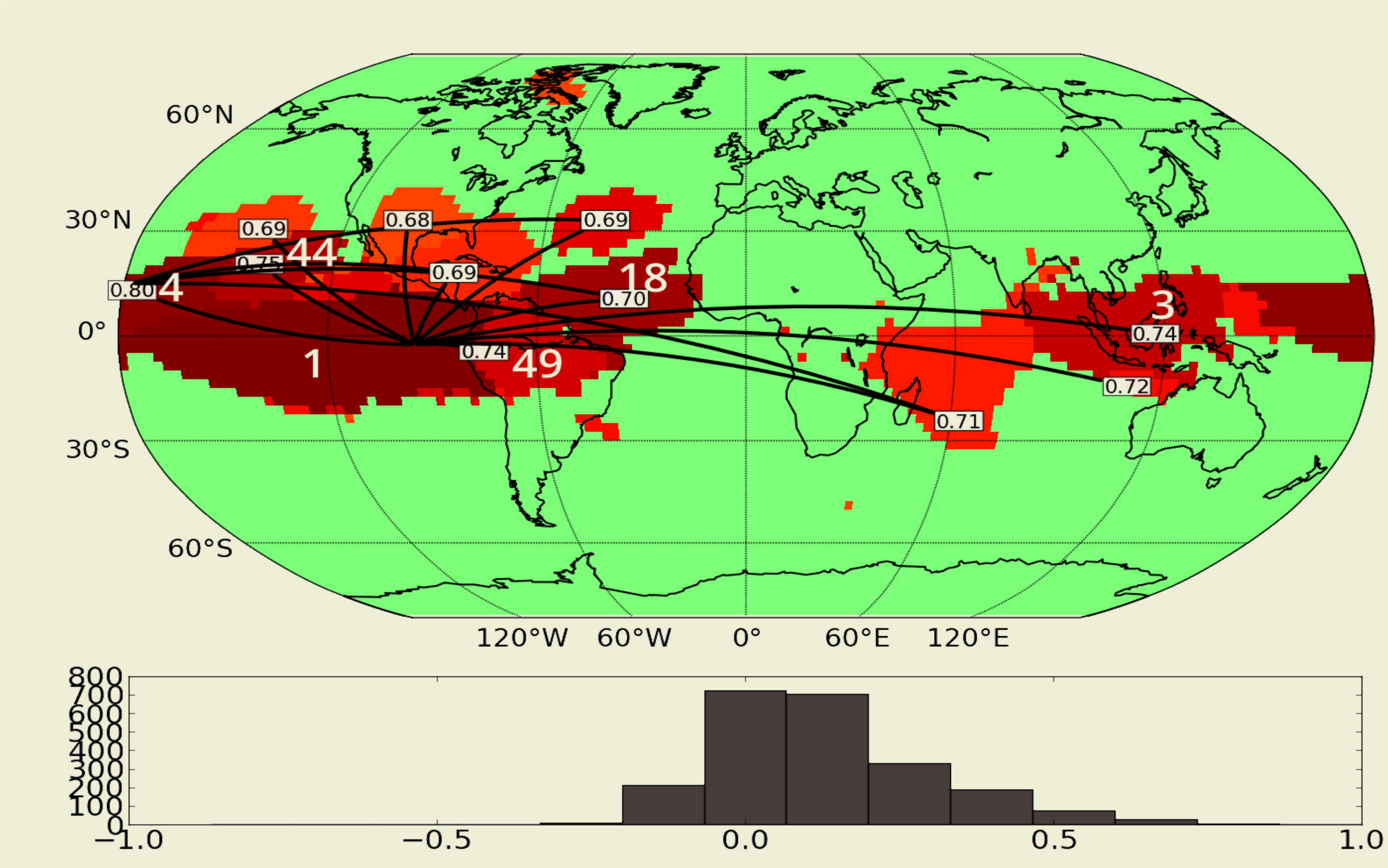

Fig. 4: Pairs of regions with high relevance for the global graph evolution. Shown are 15 region pairs with strongest correlation of inter-regional connectivity evolution with the global 2562-node network. Five strongest pairs as follows: 1+4 - 0.800, 1+18 - 0.768, 1+44 - 0.749, 1+3 - 0.744, 1+49 - 0.739

» Eastern to Central Pacific plays a central role in both dominant interactions

» global graph evolution is reflected in the interactions between ENSO and other tropical regions

Splitting the network

» global grid-based graph was split into two parts: the ENSO (or tropics in general) and the extra-ENSO (or extra-tropics)

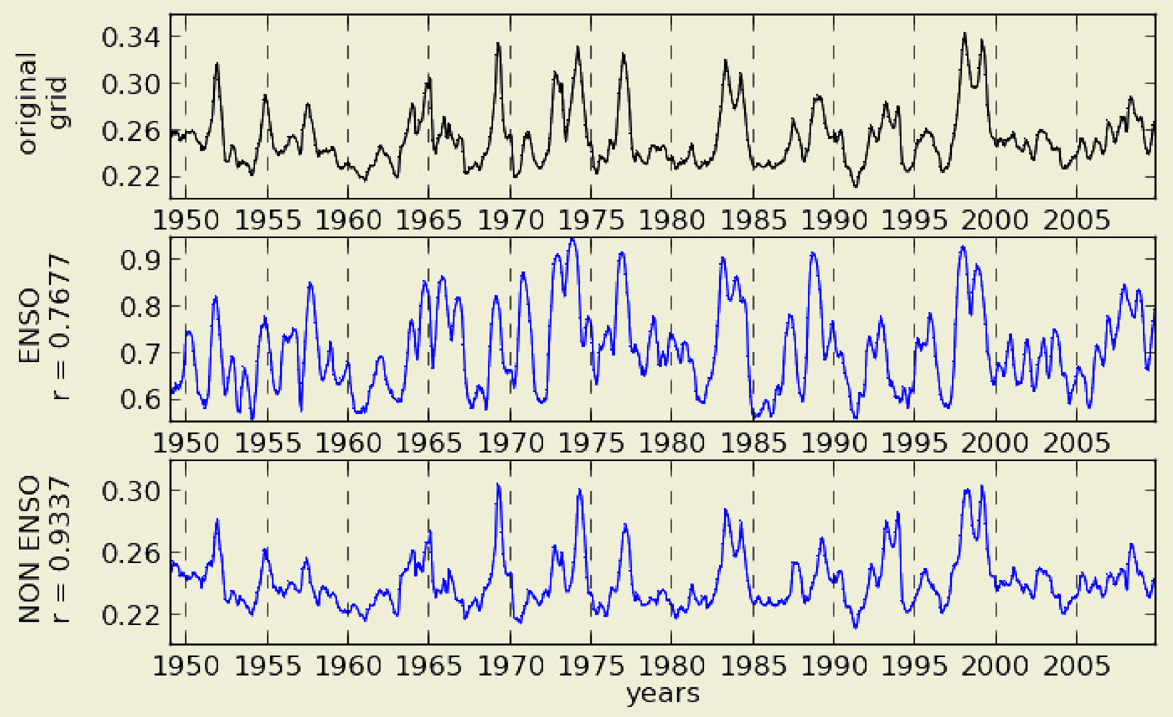

Fig. 5: temporal evolution of the ENSO and extra-ENSO subgraph. Correlations as follows: ENSO - 0.768, extra-ENSO - 0.934

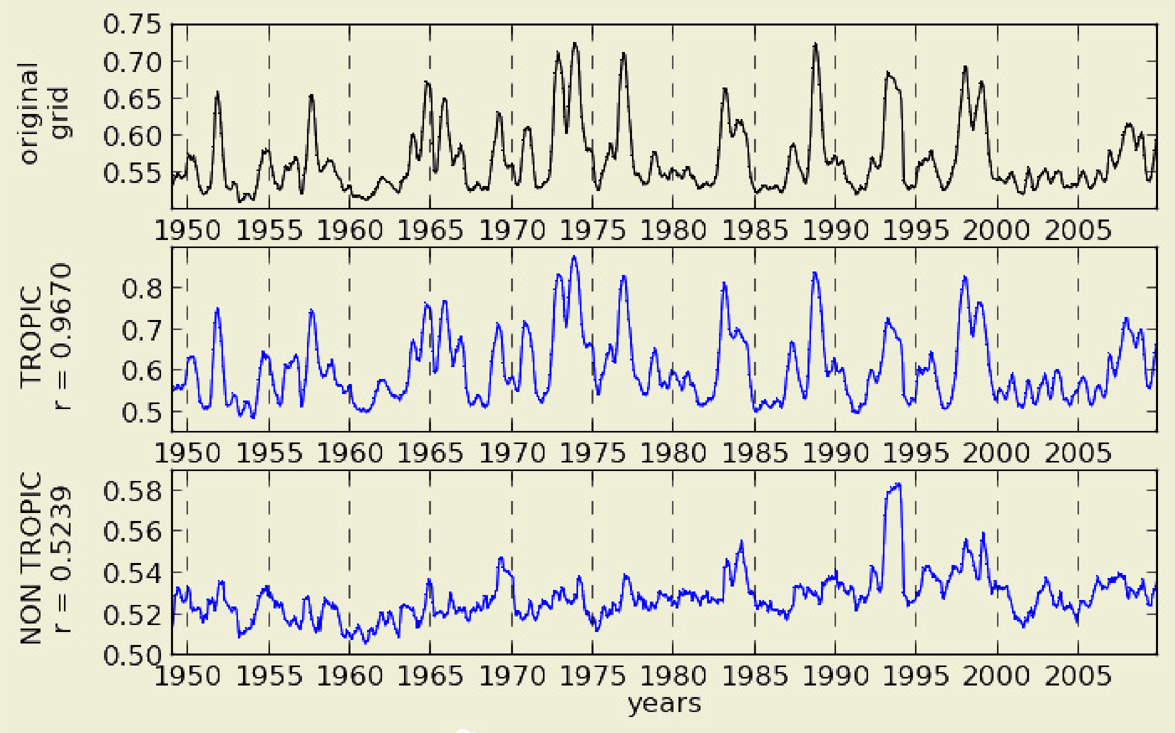

Fig. 6: temporal evolution of the tropical and extra-tropical subgraph. Correlations as follows: tropics - 0.967, extra-tropics - 0.524

» evolution within ENSO resembles the global graph evolution, but to a higher extent it is true in extra-ENSO

» tropical subgraph is almost perfectly correlated with the global graph evolution, while extra-tropics are much less correlated

Alternative grid size

» since global graph evolution reflects the dynamics of long-range links, it should not be affected by spatial sub-sampling

» use of sparser spatial grids with 642, 162 and 42 grid points

» compare also with RPCA-based network

» component-based network shows qulitatively different behaviour, it shows highest correlations when thresholded at very low densities, irrespective of the density used for full graph

» dimensionality reduction by RPCA is qualitatively different from coarse-graining of the network

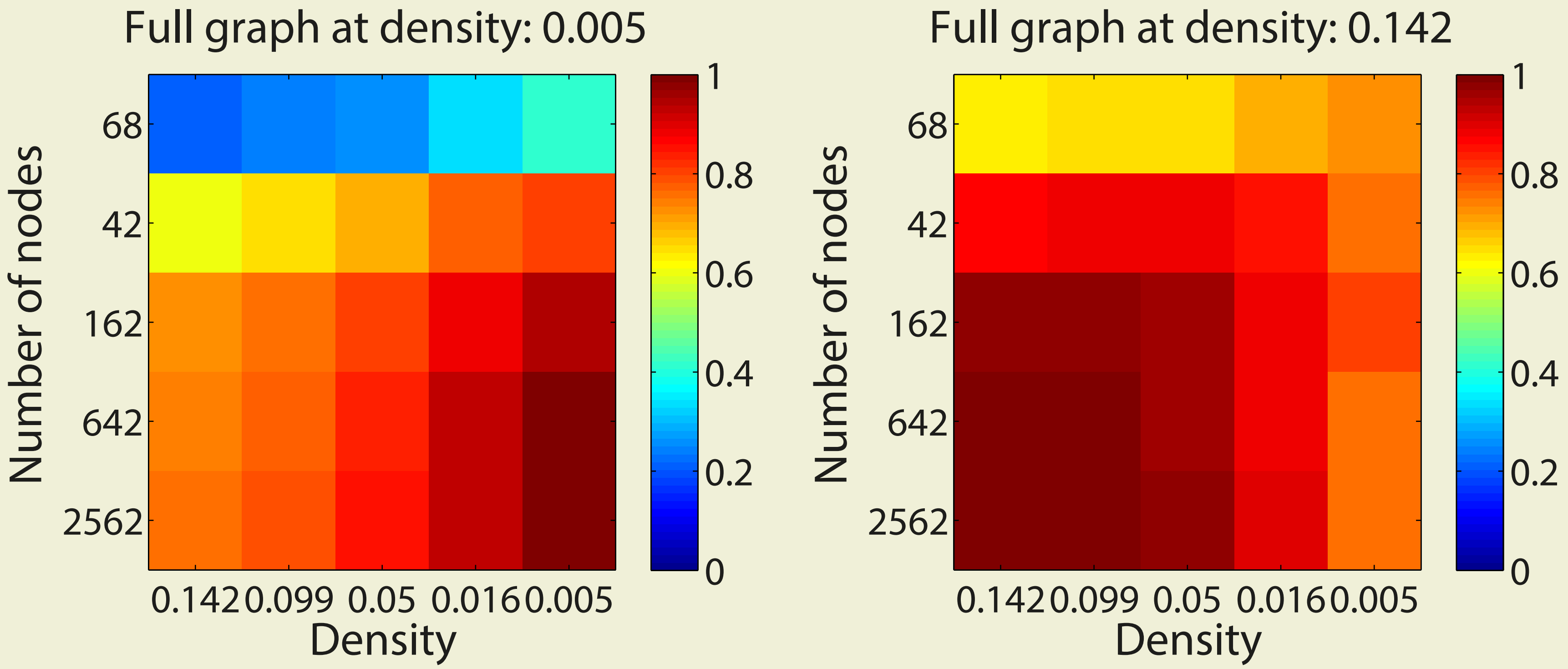

Fig. 7: similarity for varying grid size and density of graphs

Alternative thresholding for subgraphs

- before the subnetworks were thresholded to fixed pre-defined density, so the edges present do not necessarily correspond to those in the global graph in the same time window
- now - threshold for the global graph is used for all subgraphs
- the time-dependent variable is now density and they are mutually dependent, i.e. increase in connectivity must be compensated by a decrease

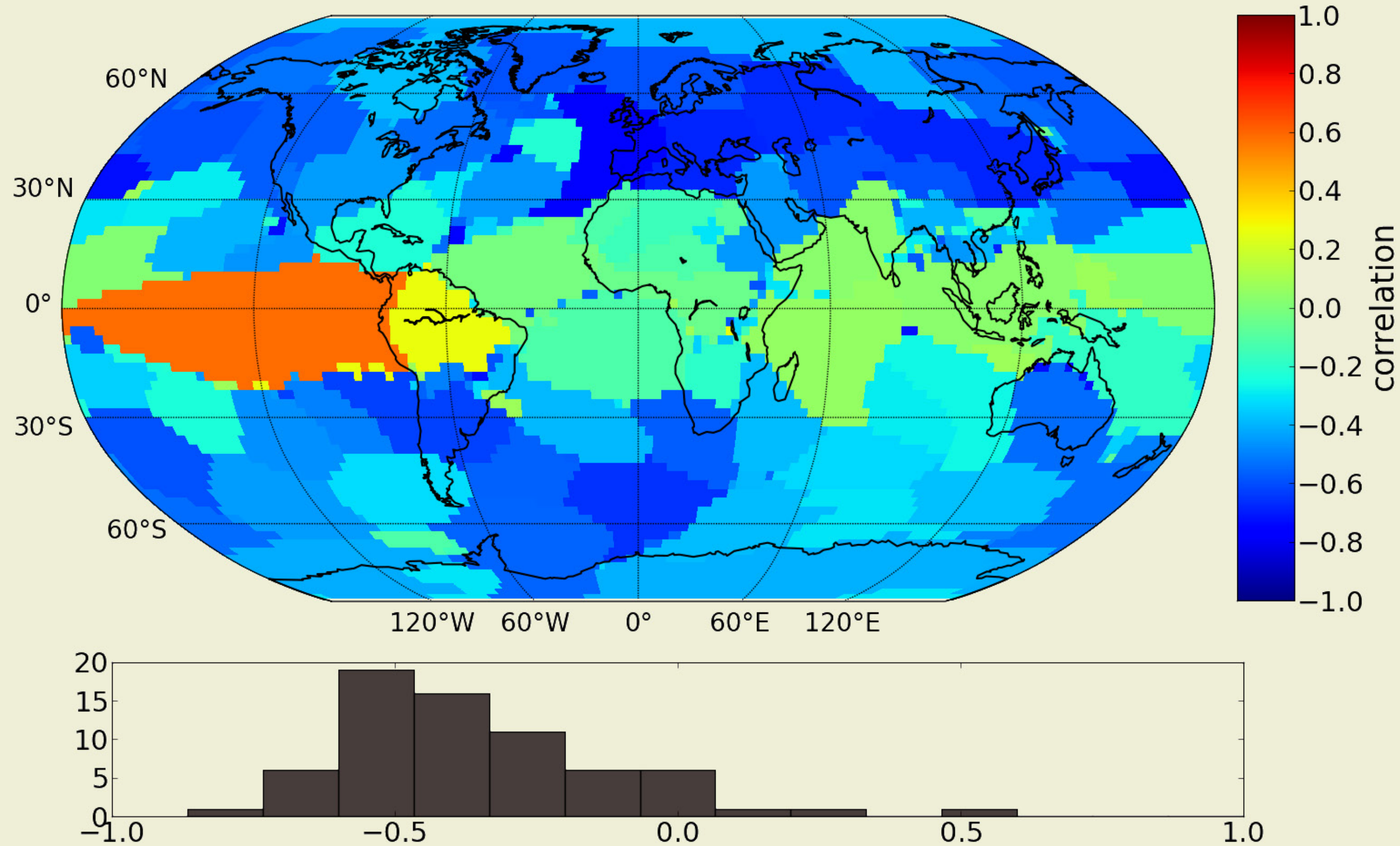

Fig. 8: Regions with high relevance for the graph global evolution with alternative thresholding.

Conclusions

» temporal changes of localised and inter-regional connectivity are reflected in the global graph evolution

» important role of ENSO and other tropical regions

» the evolution of the component graph was most similar to the evolution of the full grid-based graph for low component graph density and high grid-graph density

» particularly for higher densities the global grid graph is more strongly determined by long-range connections and therefore more related to the component graph

» this suggustes that the character of networks constructed using the RPCA dimension reduction scheme differs significantly from networks obtained by a simple down-sampling

Thanks for your attention!

full paper: Hlinka et al.: Regional and inter-regional effects in evolving climate networks, *Nonlinear Processes in Geophysics*, **21**, 451-462, 2014.

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