Network studies of large-scale weather and climate variability patterns on intraseasonal and interannual time scales

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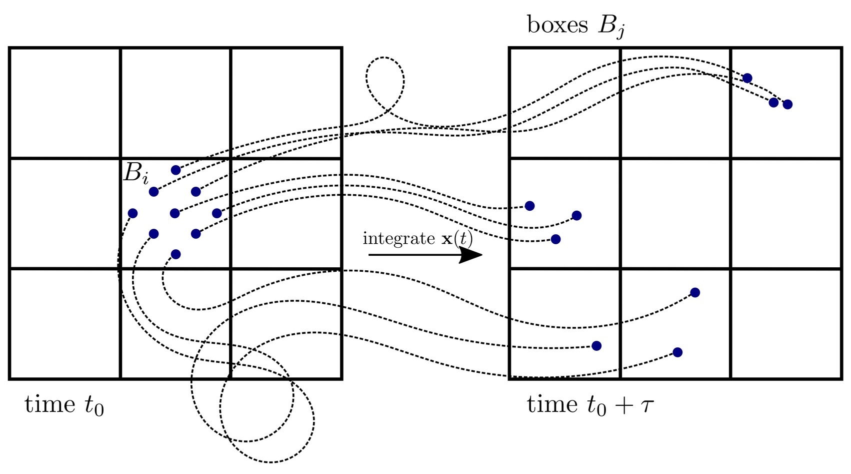
CAFE Climate Advanced Forecasting of sub-seasonal Extremes

1. Detection and tracking of atmospheric blocks: a structural network approach

We utilize a ***Lagrangian flow network*** representation of the atmospheric circulation to study blocking situations during Northern hemisphere summer.

Network ***nodes*** → ***spatial locations***
Network ***links*** → ***material transport***

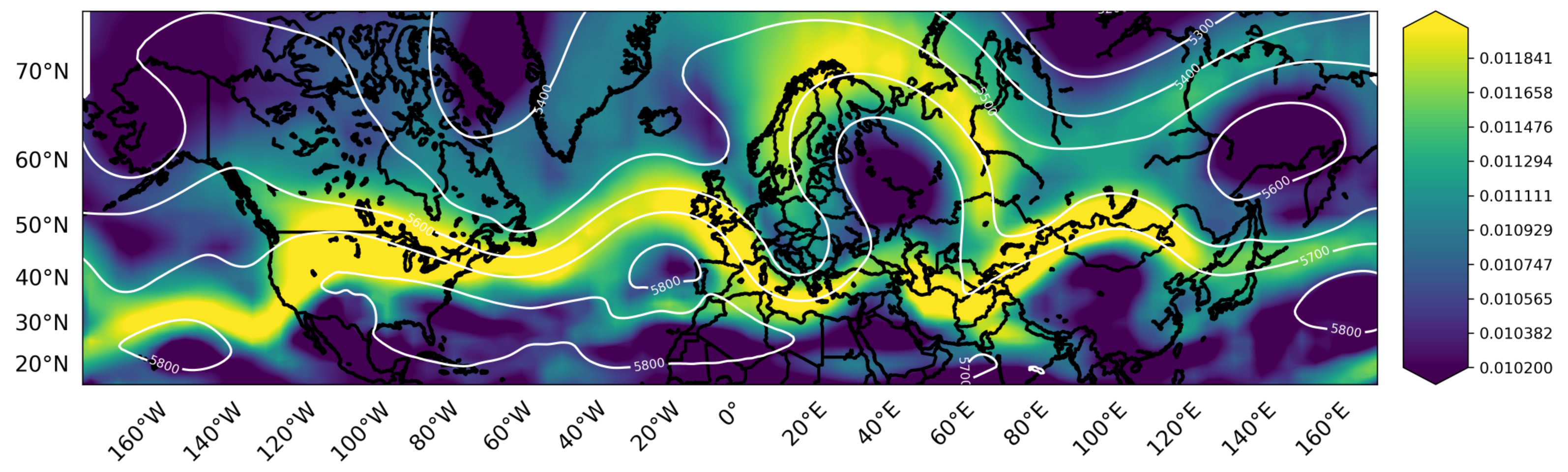


The network describes the atmospheric connectivity in terms of mass flow.

The network's (weighted) harmonic out-closeness centrality is defined as

$$C_i(t_0,\tau) = \left(\frac{1}{N-1}\right)\sum_{j\neq i}\frac{1}{d_{ij}}$$

where d_{ij} is inversely proportional to the mass transported between *i* and *j*



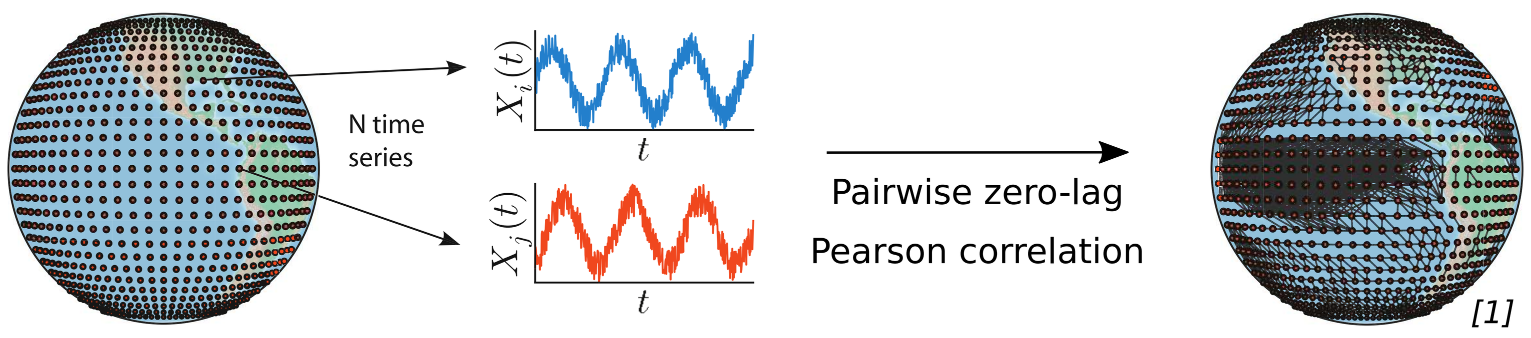
Closeness field (colour) during a blocking event - blocking anticyclone centered at 43ºE. Tracers were released at 300 hPa. The geopotential height contours at 500 hPa are shown as reference. The fields are averaged over the 4-days period : 25-29/07/2010.

Highlights: The network's closeness centrality (but also the degree and entropy - not shown) trace important spatio-temporal characteristics of atmospheric blocking events, including the isolated character of the pressure cell forming the blocking high and the deviation of the main atmospheric currents around it. *Chaos 31, 093128 (2021).*

2. Anticipating sudden shifts in irregular (climate) oscillations: a functional network approach

We study the potential of percolation measures from ***correlation networks*** to anticipate sudden shifts in the state of coupled irregularly-oscillating systems.

Network ***nodes*** → ***spatial locations***
Network ***links*** → ***similarity of the variability***



The network describes the correlation of the variability between the spatial sites of the system.

... but what processes trigger the percolation in the correlation network ?

- a gloal trend: a large and coherent change in all spatial units
- critical slowing down of the dynamics

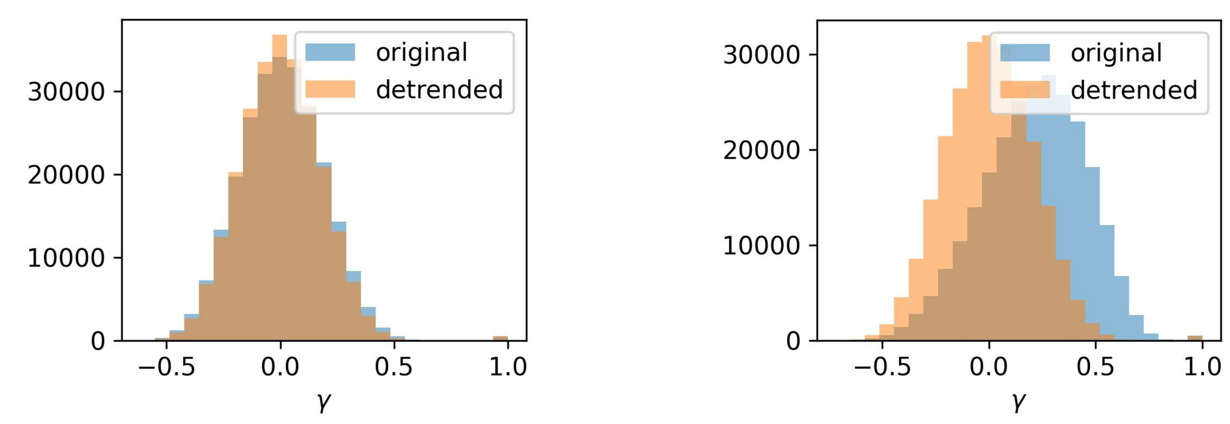
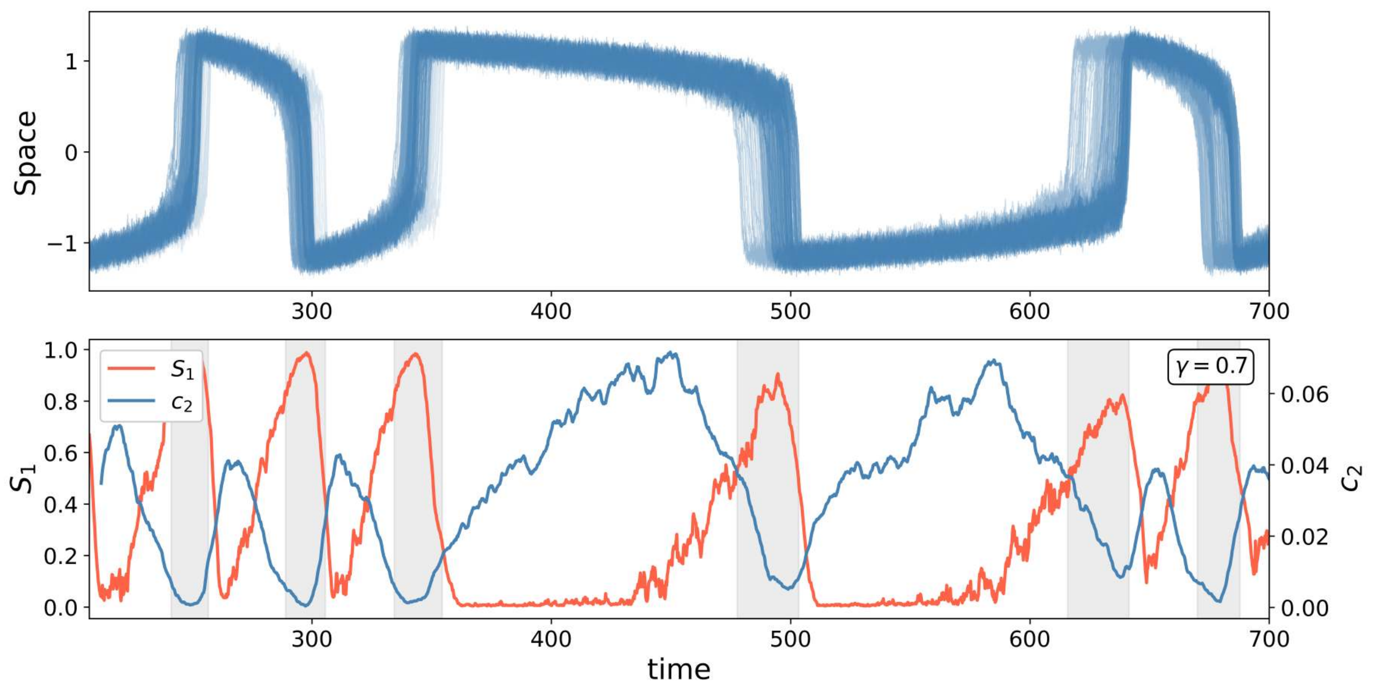


Illustration of the differences in correlation distributions, far away (left) and close to (right) a "jump" in *u*, when the time series used for the network's construction are detrended and when they are not.

2.1 Application to a ring of stochastic, non-periodic, diffusively coupled Fitzhugh-Nagumo oscillators

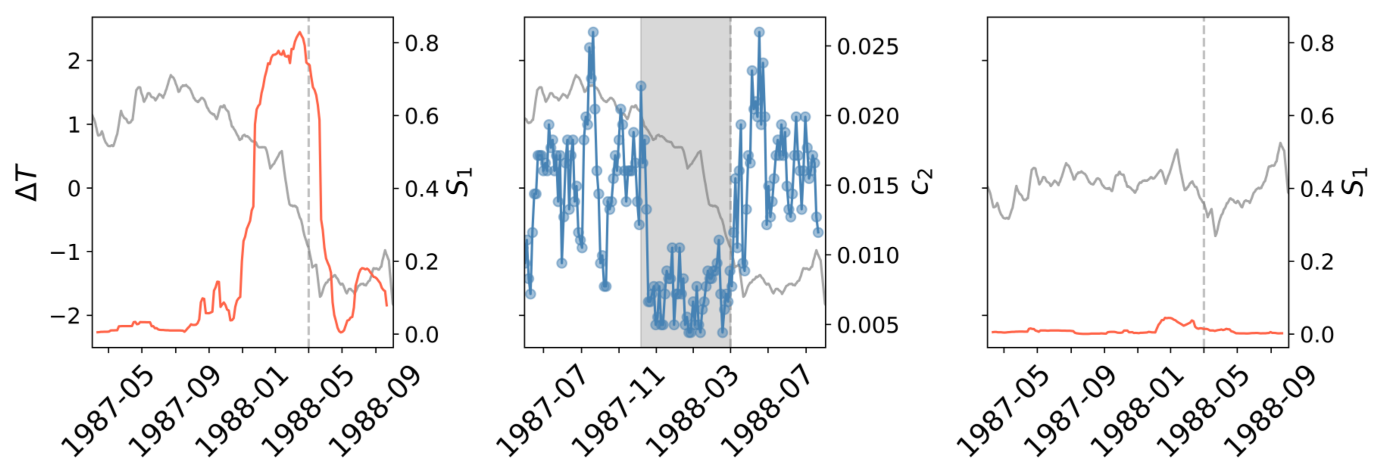
$$\epsilon \dot{u_k} = f(u_k) - v_k + I + (\Delta u)_k + \sqrt{2D^{(u)}}\eta_k^{(u)},$$
$$\dot{v_k} = u_k - bv_k + c + (\Delta v)_k + \sqrt{2D^{(v)}}\eta_k^{(v)}$$
$$(\Delta u)_k = u_{k+1} + u_{k-1} - 2u_k$$
$$(\Delta v)_k = v_{k+1} + v_{k-1} - 2v_k$$



Top: Time series of the fast variable of the system, *u*, (each line corresponds to a different node). *Bottom:* Relative size S_1 of the largest connected component in the network constructed from the the variable *u*. Probability c_2 that a randomly chosen node belongs to a component of size 2.

Both S_1 and c_2 anticipate the abrupt "jumps" in *u*...

2.2 Application to El Niño-Southern Oscillation



Gray: average Sea Surface Temperature anomaly over the Niño3.4 region (detrended in the third panel). *Dashed lines:* La Niña event. *Left and center:* relative size of the largest connected component (S_1) and probability that a randomly chosen node belongs to a component of size 2 (c_2) in the correlation network of non-detrended SSTs. Reproducing results from [2]. *Right:* S_1 in the network computed from detrended SSTs.

Highlights: We find that the percolation properties of correlation networks successfully anticipate the rapid shifts in the state of the oscillating Fitzhugh-Nagumo system. Characterizing the processes causing percolation transitions in this system leads to a better understanding and interpretation of the outcomes of percolation methods when applied to El Niño-Southern Oscillation. *Manuscript in preparation.*

[1]R. V. Donner, M. Wiedermann, and J. F. Donges, Nonlinear and Stochastic Climate Dynamics 159 (2016). *[2] V. Rodríguez-Méndez, V. M. Eguíluz, E. Hernández-García, and J. J. Ramasco, Sci Rep 6, (2016).*

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