Inferring link directionality in climate networks via nonlinear time-series analysis

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**Dynamic Days Europe,
Bayreuth, Germany,
September 2014**

*i*crea

"LINC" ITN
Learning about Interacting Networks in Climate

# A complex system of interacting sub-systems

The Climate System

Courtesy of Henk Dijkstra (Ultrech University)

Correlation Matrix

Thresholded Matrix

Network Extracted

After Eguiluz et al, PRL 2005

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Regular grid
2.5º x 2.5º
$\Rightarrow$ 10226 nodes

2.5º

2.5º

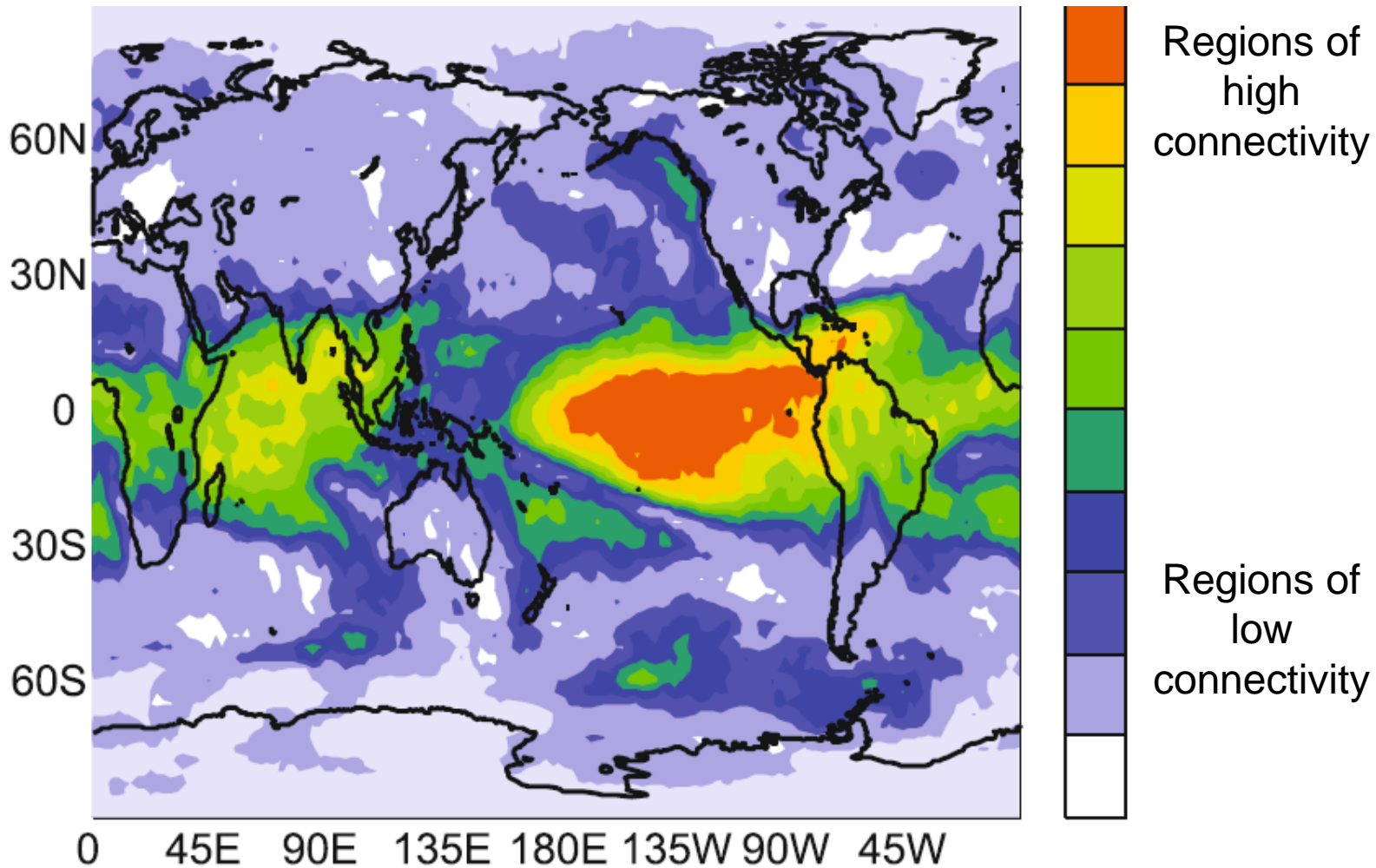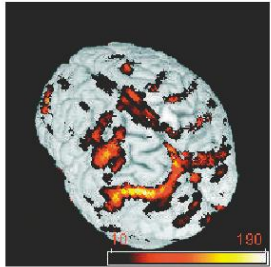70 years time series in each point

$X_i(t)$

$X_j(t)$
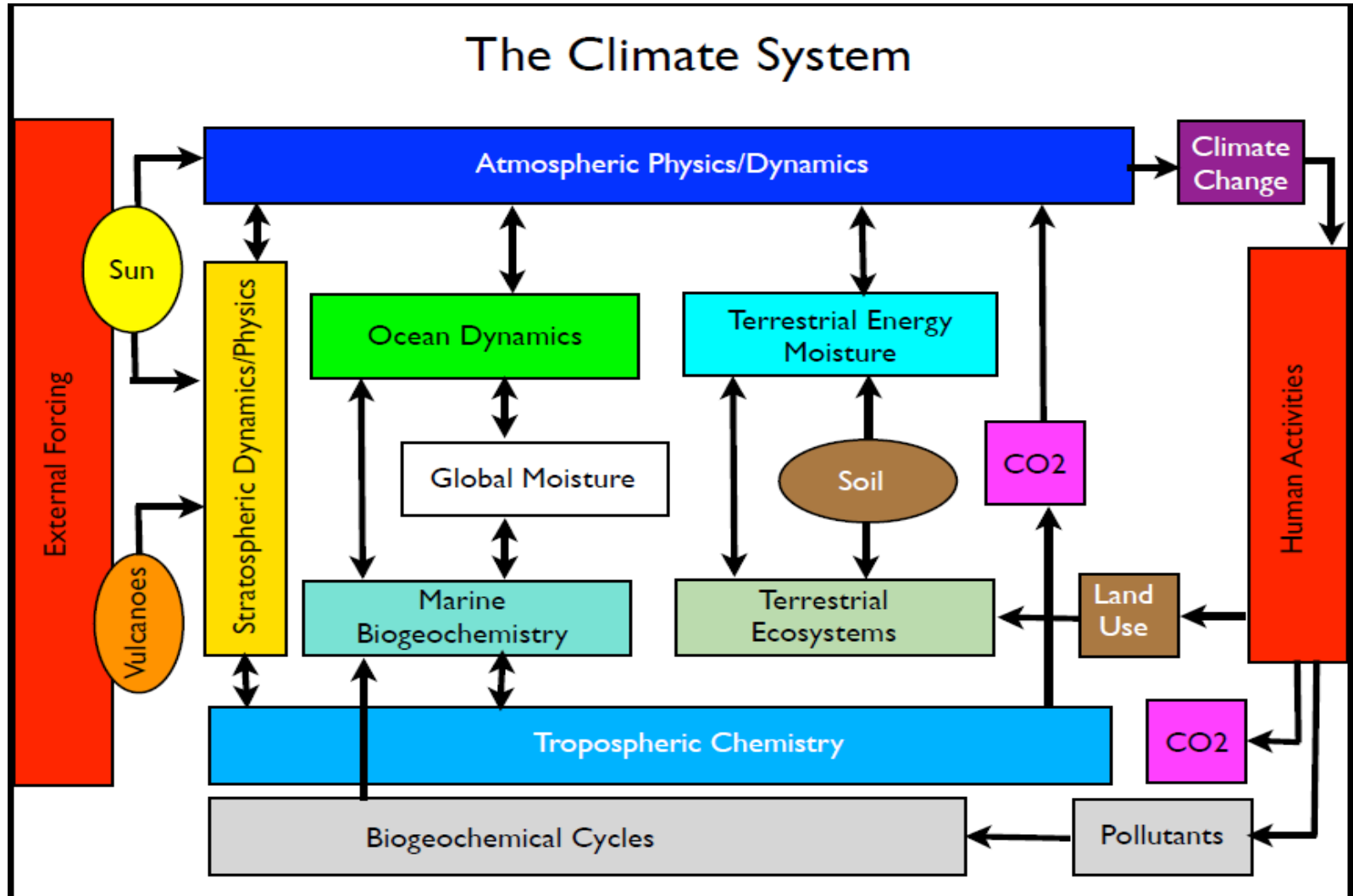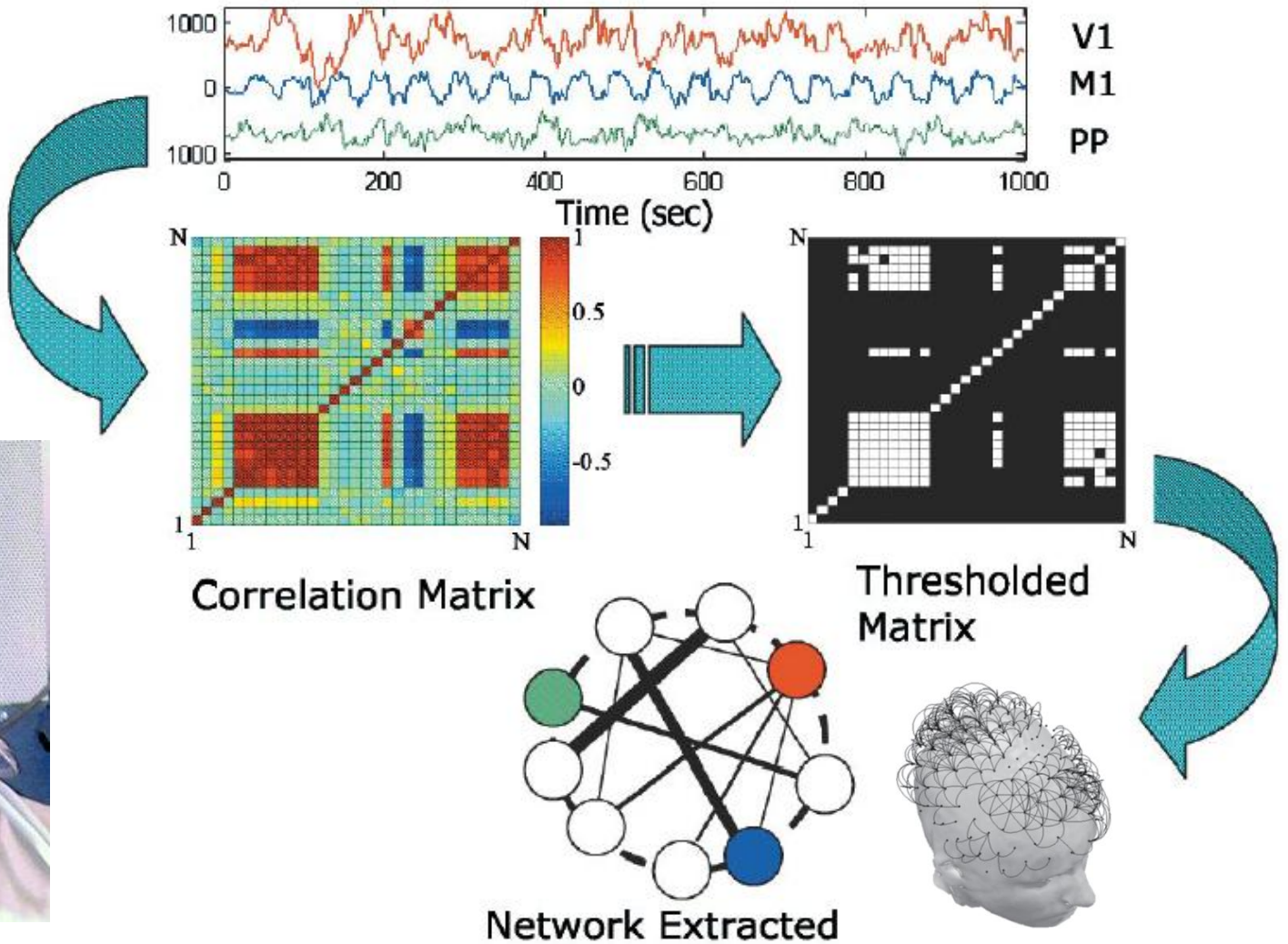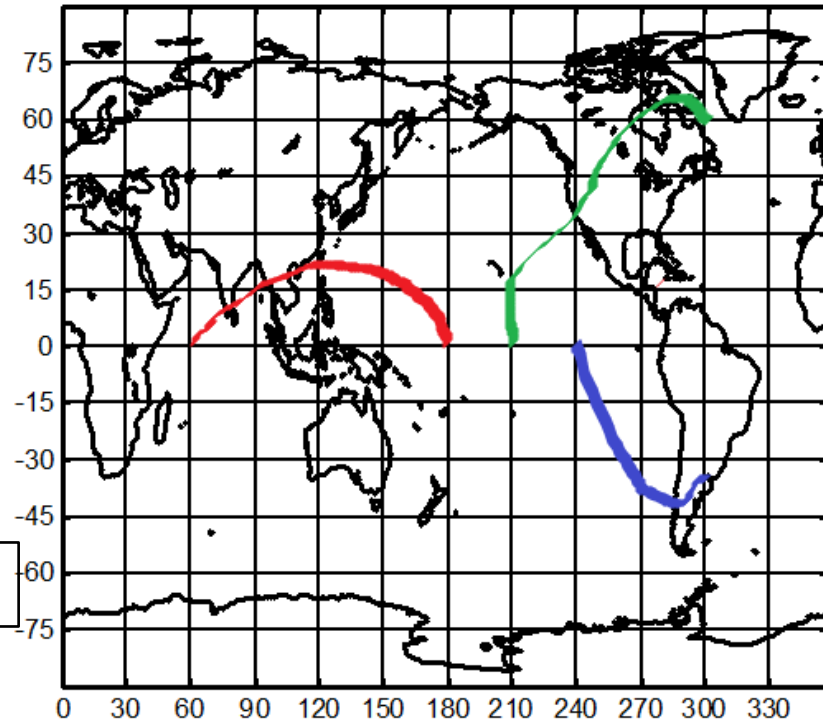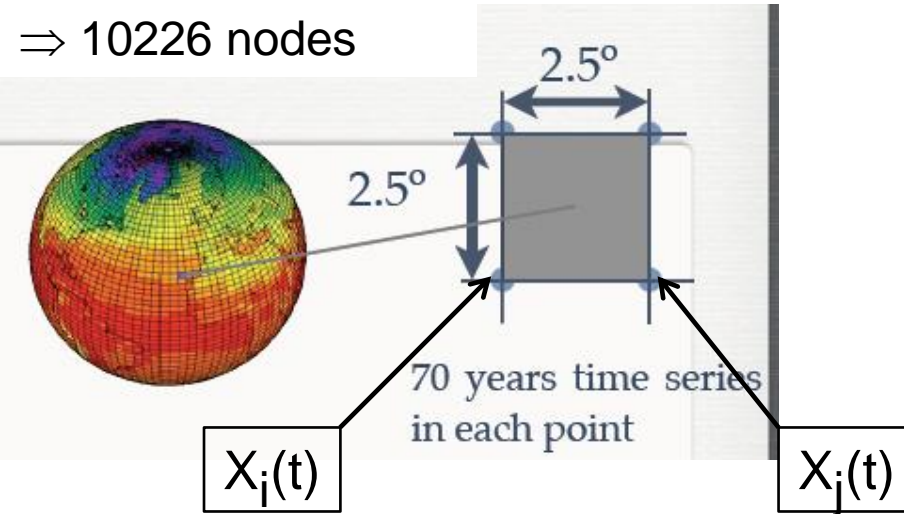
CNs constructed from an **interdependency** analysis of a climate variable.

In our case: **surface air temperature.**

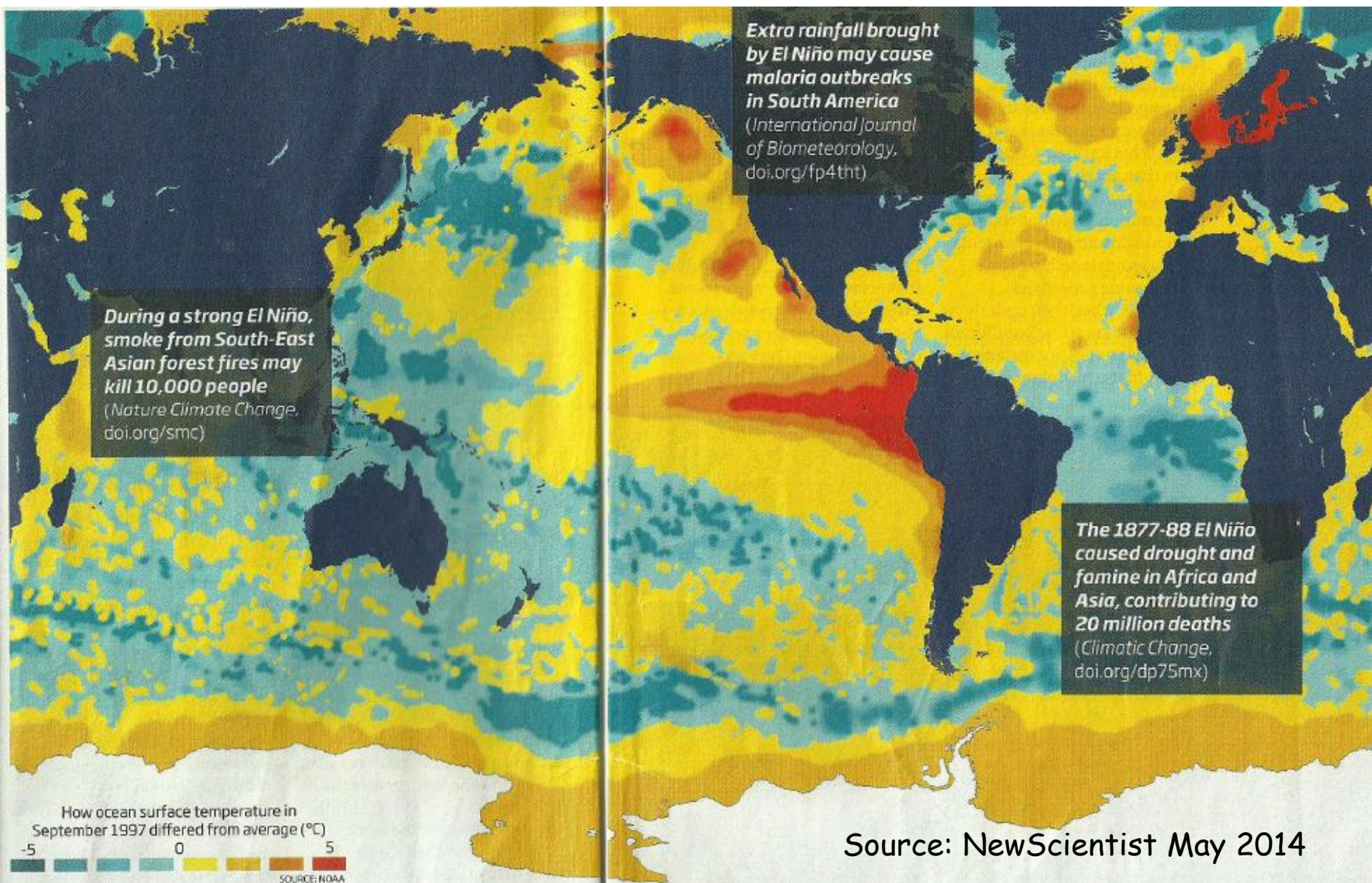Interdependency measure: **mutual information**

12/09/2014

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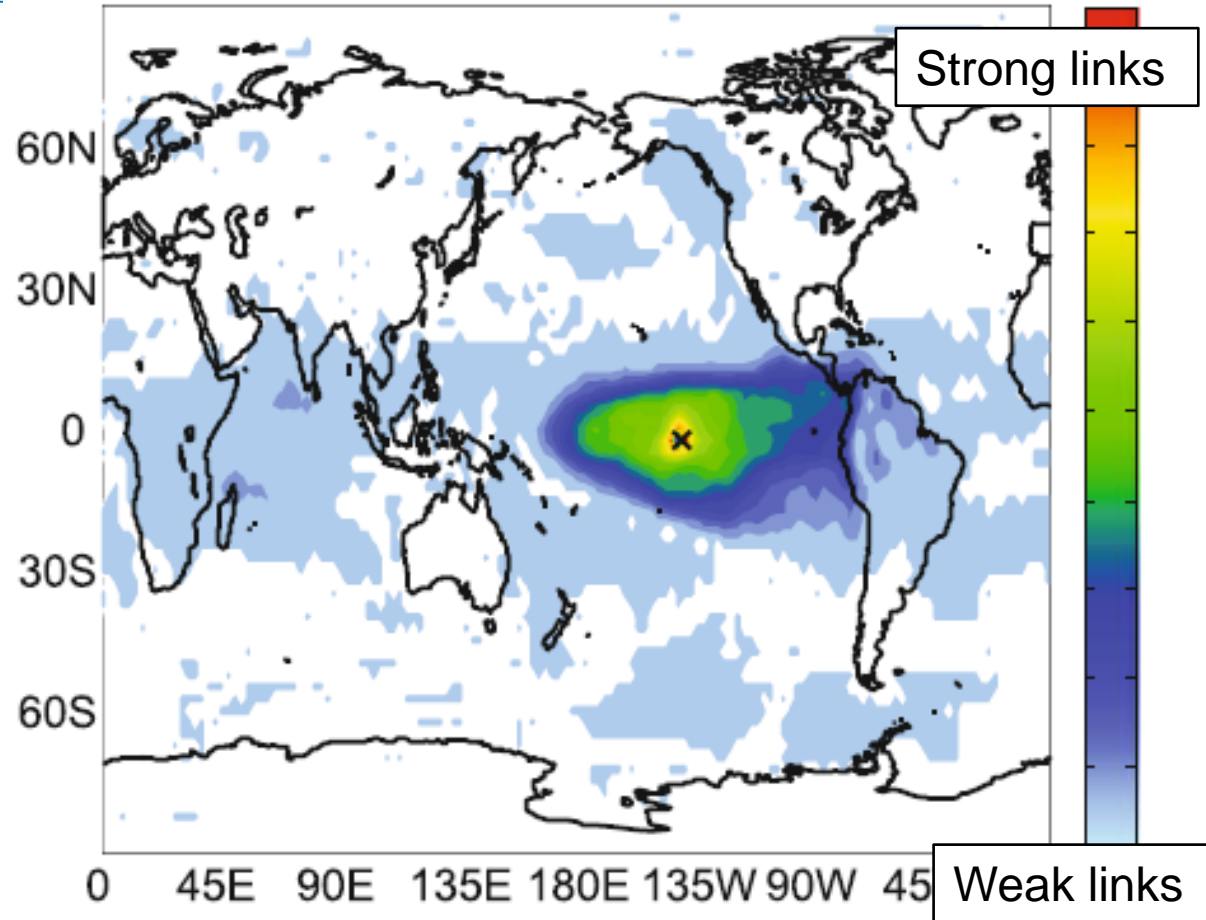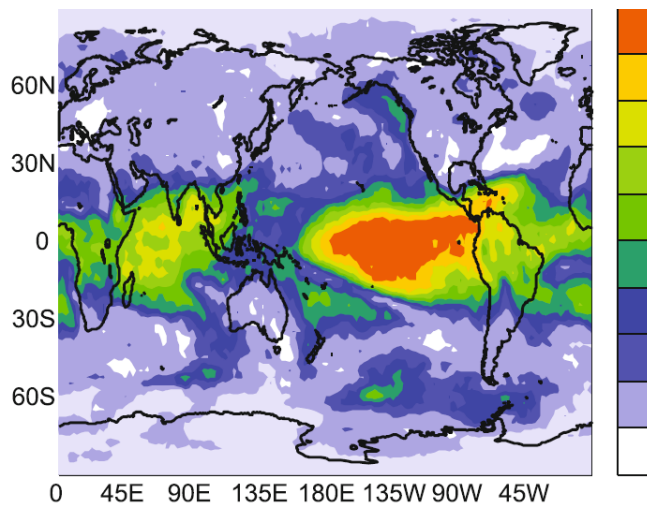# Graphical representation: area weighted connectivity (weighted degree)

Regions of high connectivity

Regions of low connectivity

J. I. Deza, M. Barreiro and C. Masoller, Eur. Phys. J. Special Topics 222, 511 (2013)

**In September 1997: El Niño
How ocean surface temperature in differed from average**

Extra rainfall brought
by El Niño may cause
malaria outbreaks
in South America
(*International Journal
of Biometeorology,*
doi.org/fp4tht)

During a strong El Niño,
smoke from South-East
Asian forest fires may
kill 10,000 people
(*Nature Climate Change,*
doi.org/smc)

The 1877-88 El Niño
caused drought and
famine in Africa and
Asia, contributing to
20 million deaths
(*Climatic Change,*
doi.org/dp75mx)

How ocean surface temperature in
September 1997 differed from average (°C)

-5   0   5

SOURCE: NOAA

Source: NewScientist May 2014

Strong links

Weak links

The color-code indicates the value of the mutual information.
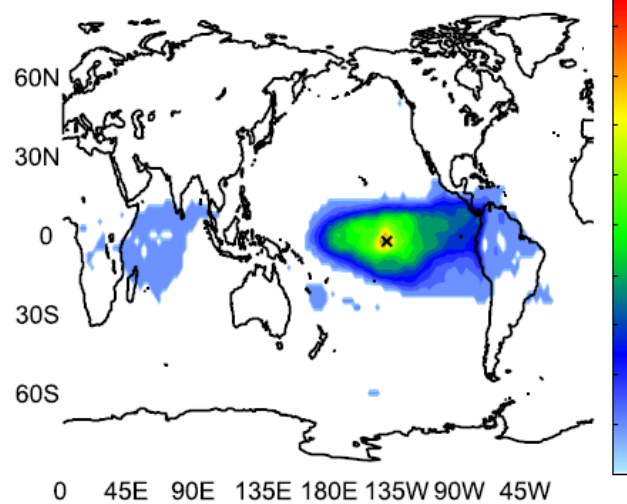Only the "significant" links are shown.

J. I. Deza, M. Barreiro, and C. Masoller, Eur. Phys. J. Special Topics 222, 511 (2013)

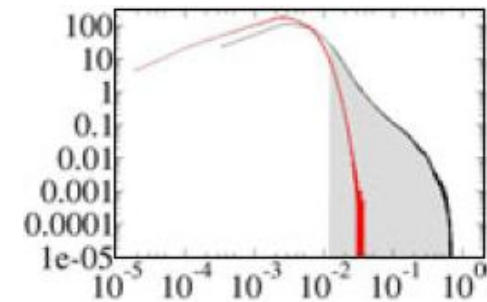# The network depends on the significance criterion

Low threshold
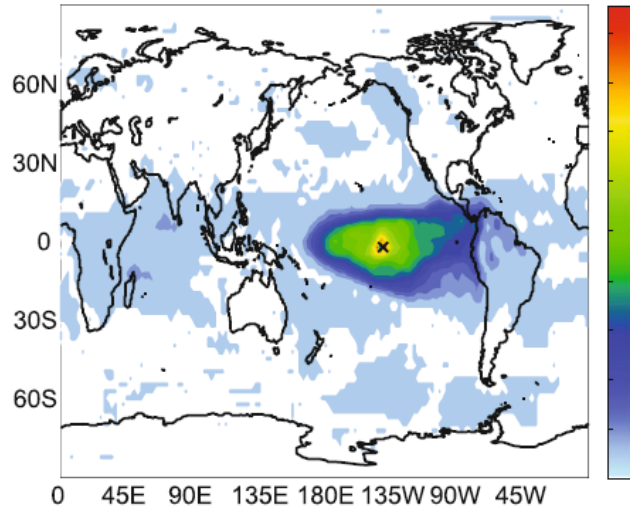
Higher threshold

PDF MI values
Surrogated
Original data

$$M_{ij} = \sum_{m,n} p_{ij}(m,n) \log \frac{p_{ij}(m,n)}{p_i(m)p_j(n)}$$
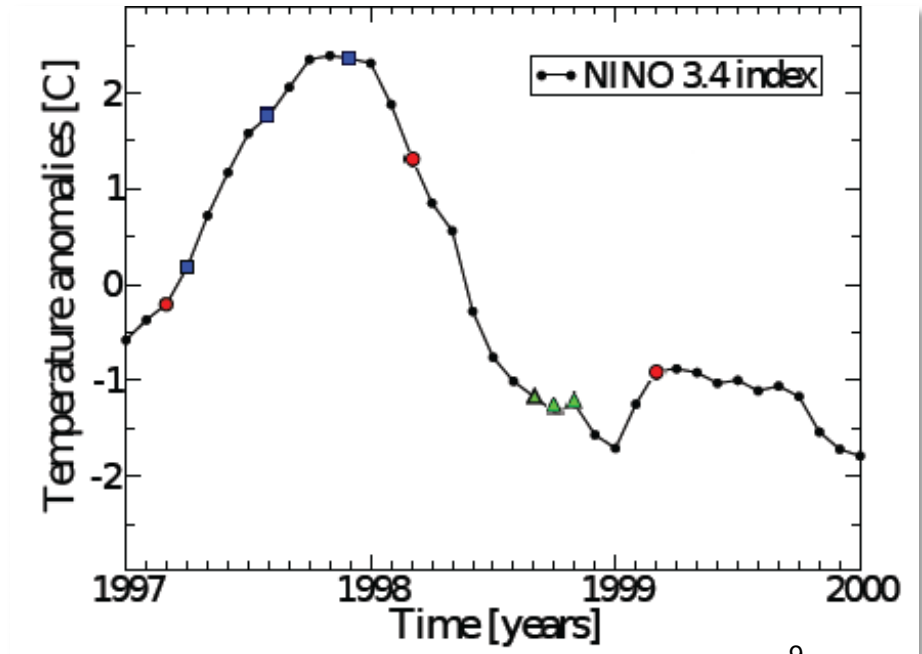
$$p_{ij}(m,n) = p_i(m)p_j(n) \iff M_{ij} = 0$$

Ordinal Pattern Analysis

- "Words" of **D letters** can be formed by considering the **order relation** between sets of D values $\{…x_i, x_{i+1}, x_{i+2}, …\}$.
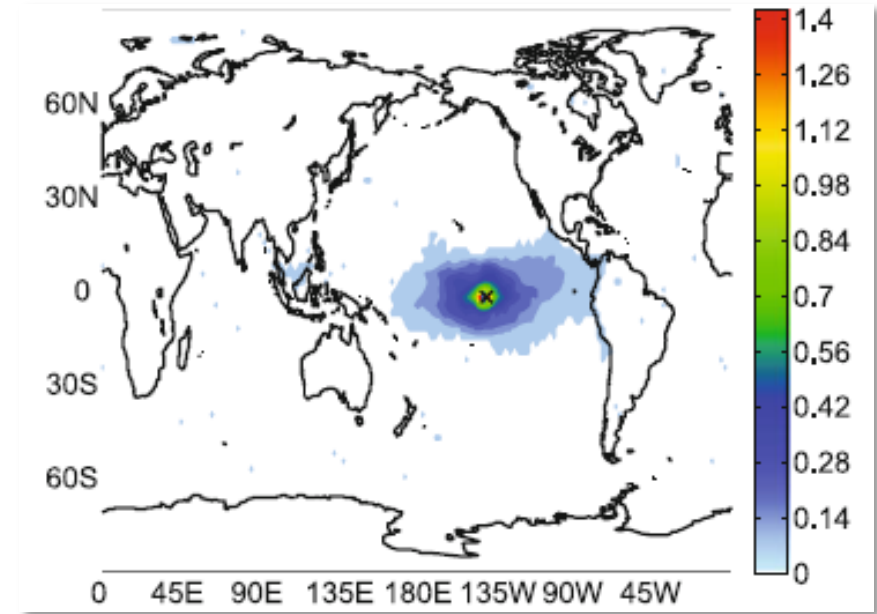
- For **D=3**

012   021   102   120   201   210

- Advantage: allows selecting time-scales.

- Drawback: does not take into account the values.

Brandt & Pompe PRL 88, 174102 (2002)

Masoller

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Area weighted connectivity (weighted degree)
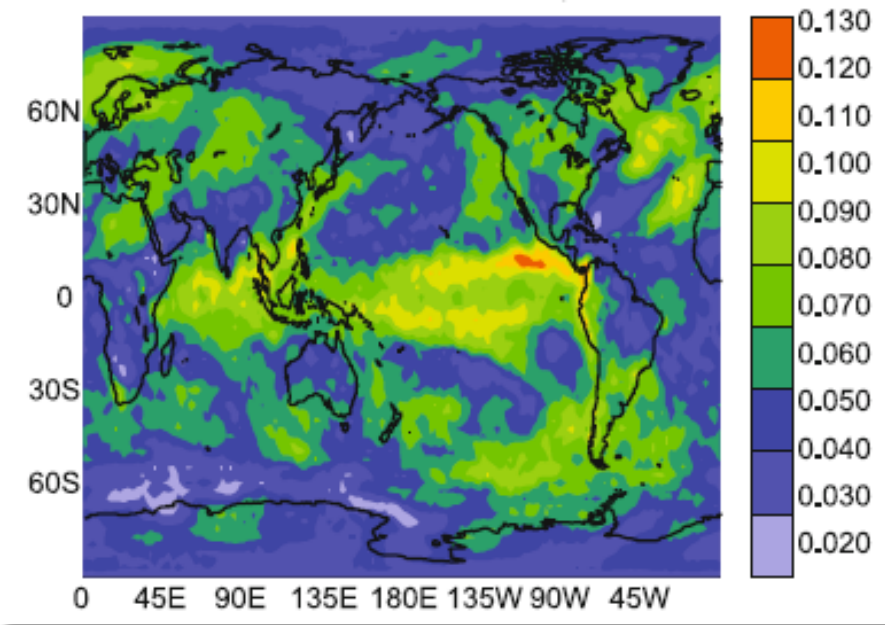
Links of a node in Central Pacific

Drawback of Mutual Information

symmetric
measure of inter-dependency

$\Rightarrow$

provides no information
about the direction of the
interaction

$$D_{XY}(\tau) = \frac{I_{XY}(\tau) - I_{YX}(\tau)}{I_{XY}(\tau) + I_{YX}(\tau)}$$

- $I_{xy}(\tau)$ is the *conditional* mutual information, it estimates the net information about the τ-future of *Y(t)* contained in *X(t).*

- $D_{xy} > 0$ if the **net** information flow is $X \rightarrow Y$
- $D_{xy} < 0$ if the **net** information flow is $Y \rightarrow X$

M. Rosenblum and A. Pikovsky. *Detecting direction of coupling in interacting oscillators*, PRE 64, 045202 (2001).

Central Pacific
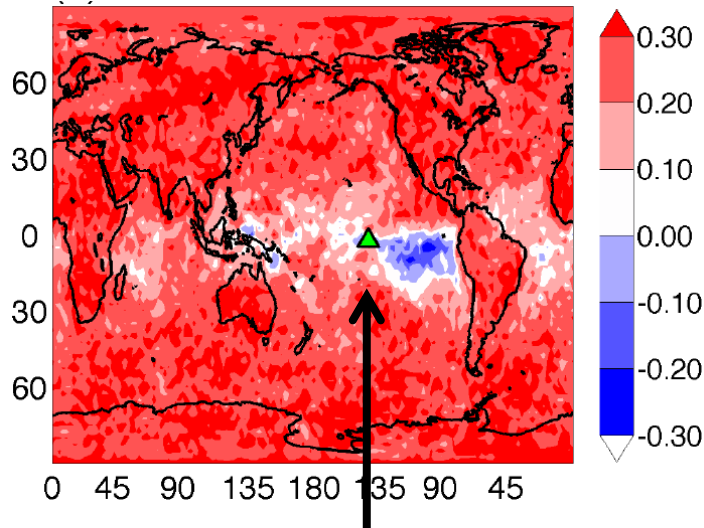
Indian Ocean
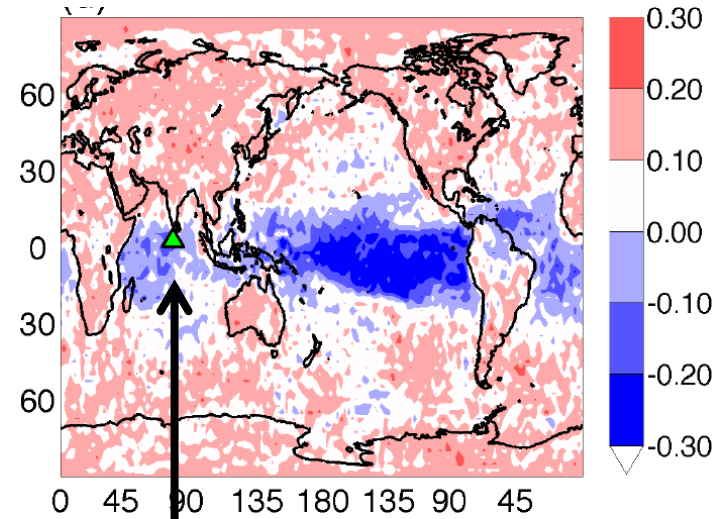
Drawback: DI does not distinguish between direct/indirect links

X → Y

X → Z

- Y → Z?
- Z → Y?
- or no link between Y and Z?

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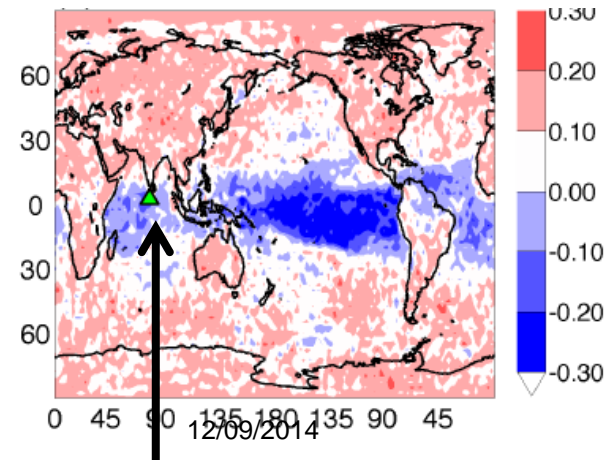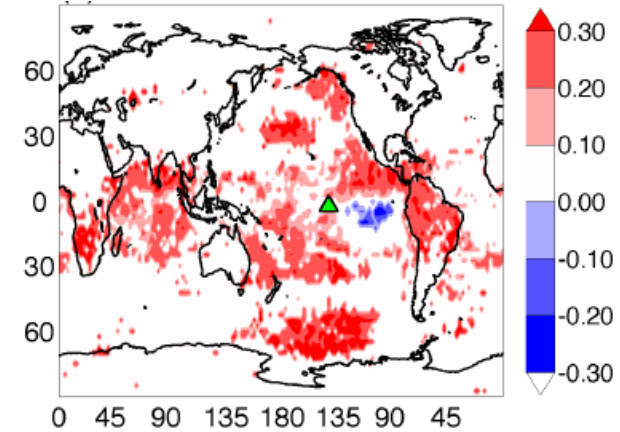DE CATALUNYA
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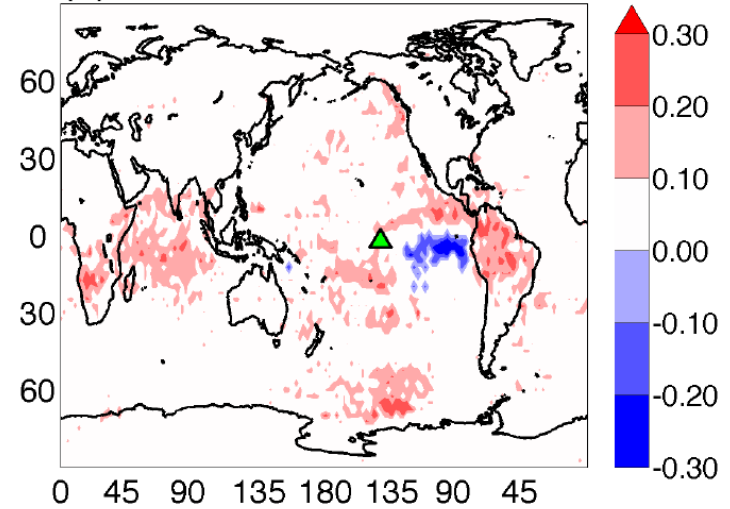
DI
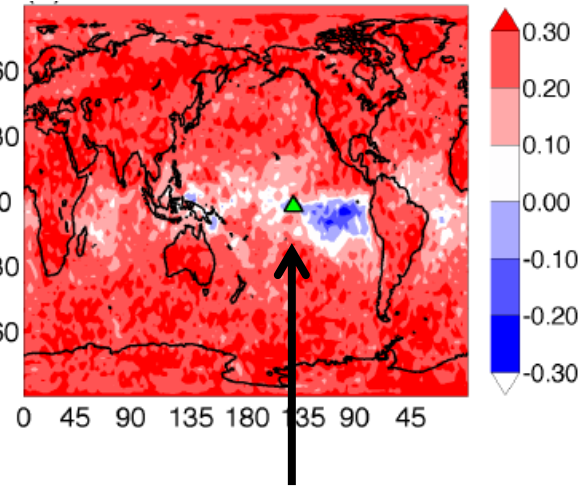
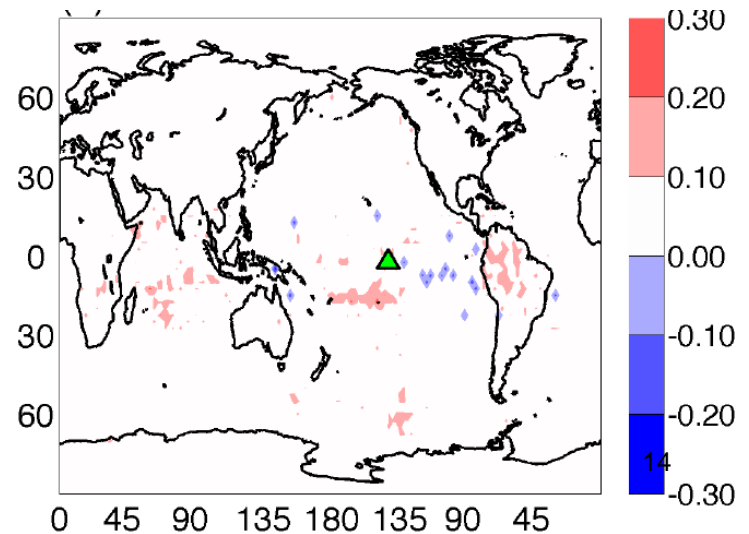## Significant MI
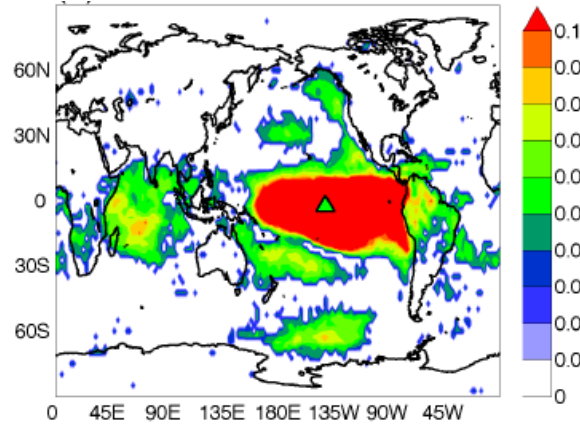
DI –selected links
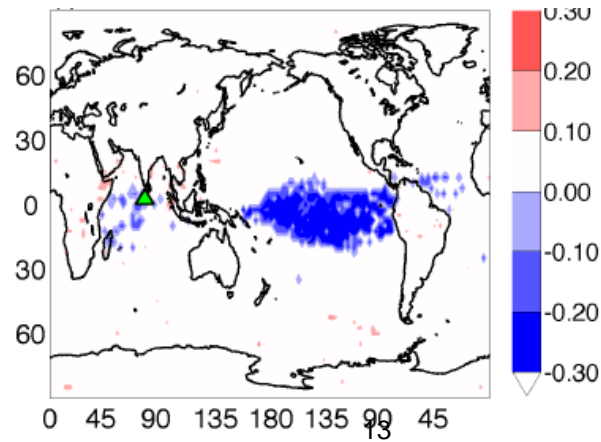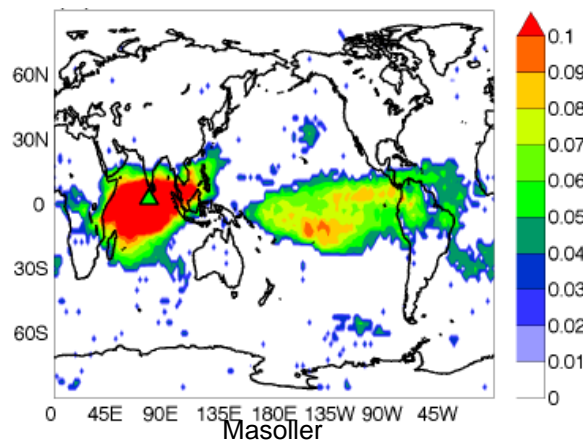
Influence of τ
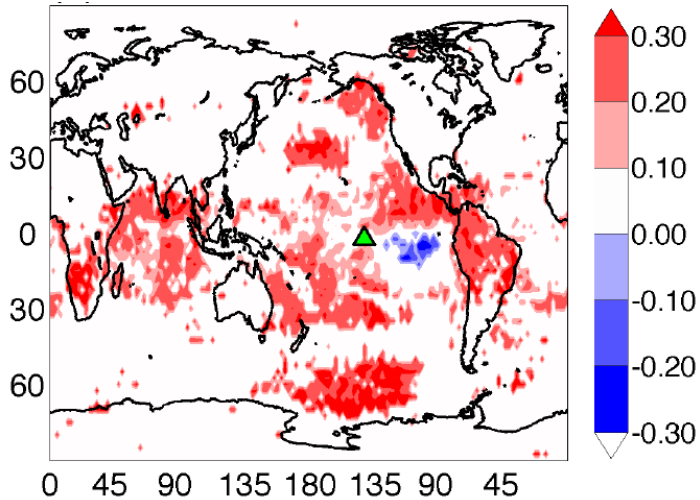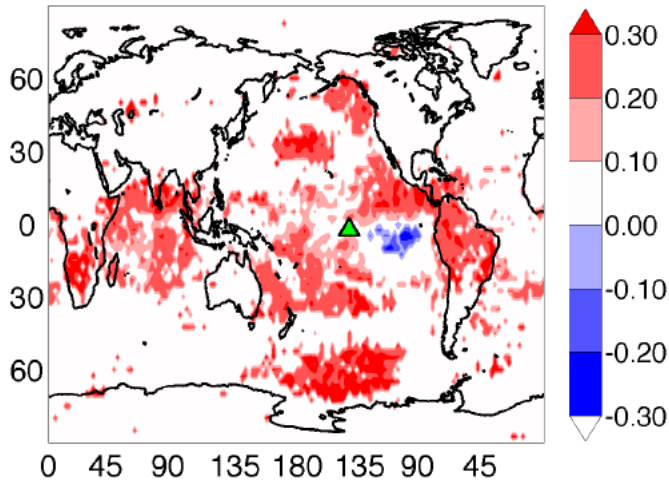
τ = 1 month

τ = 3 months

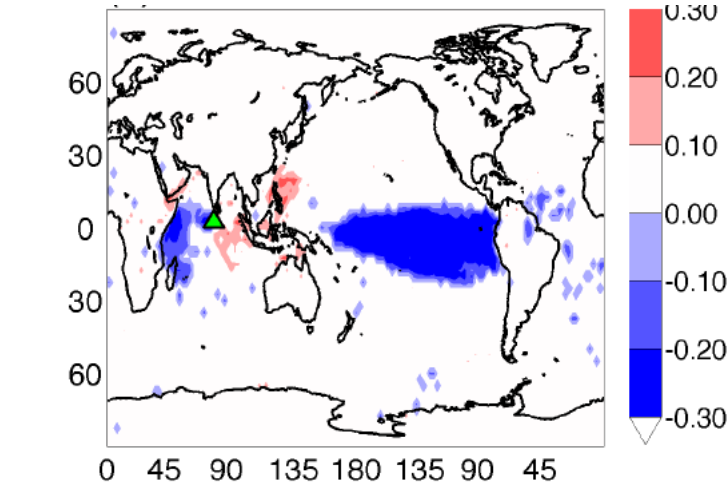**τ = 6 months**

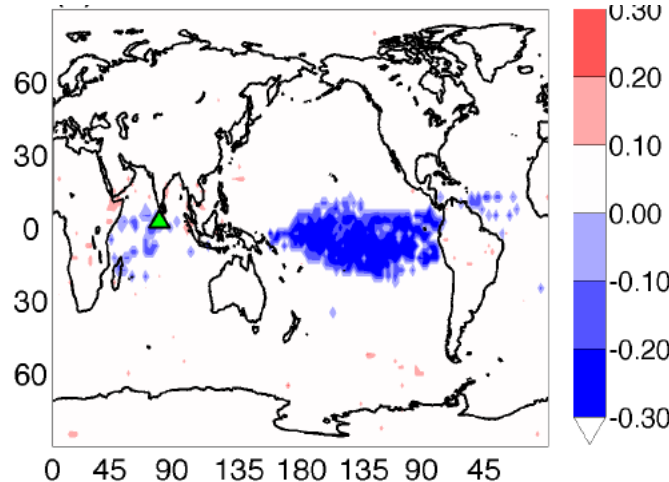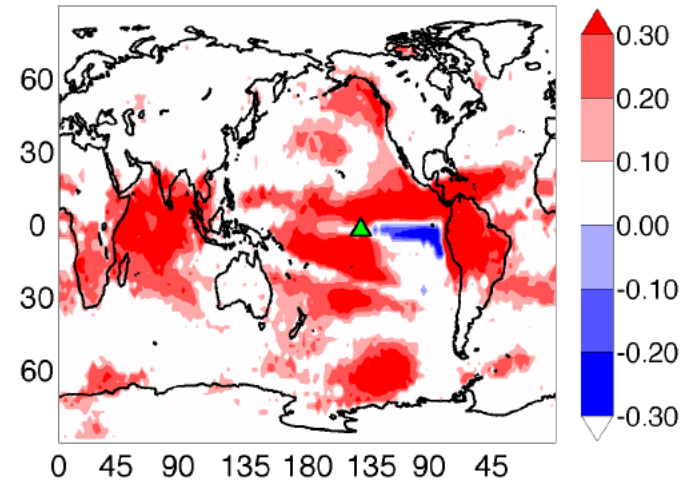January 1949 to December 2013: in each node we have a time series of **780** data points.
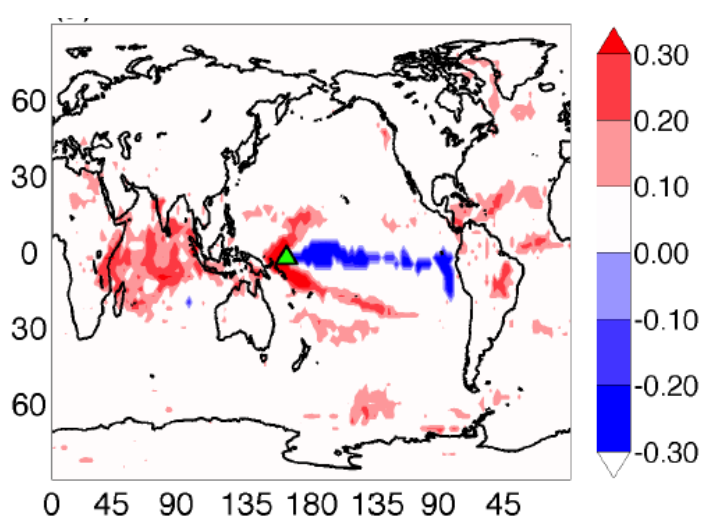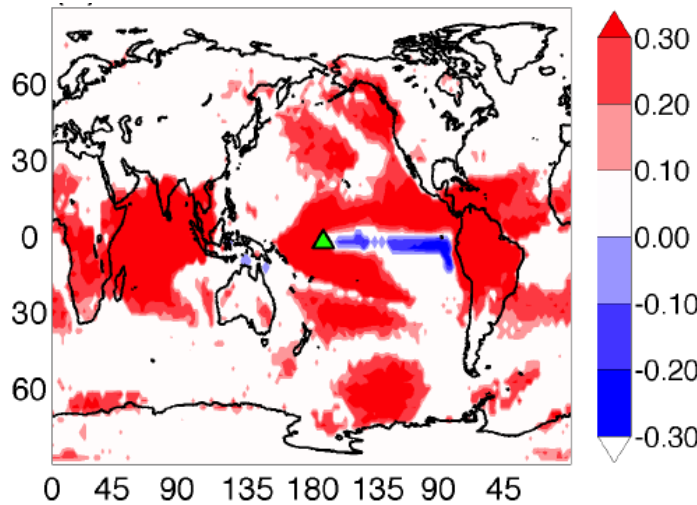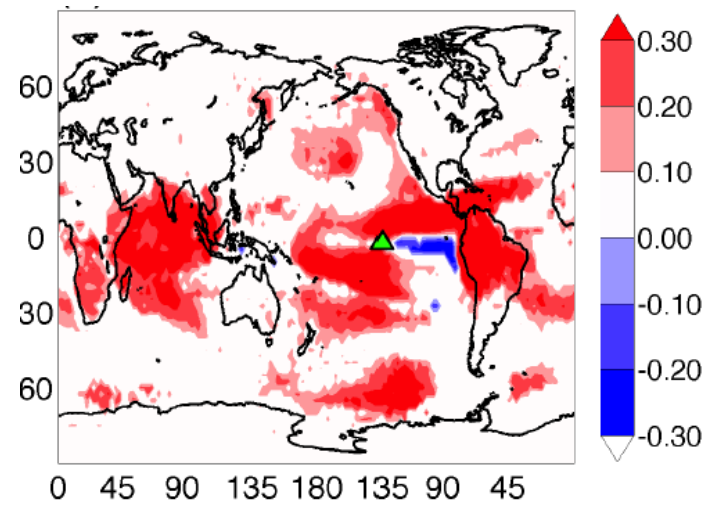
With higher time-resolution

Monthly data, τ = 1 month
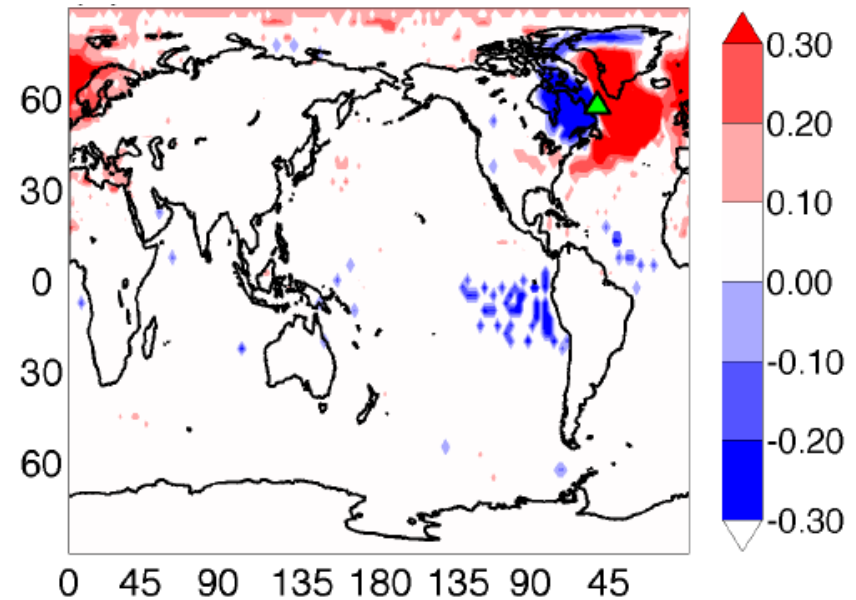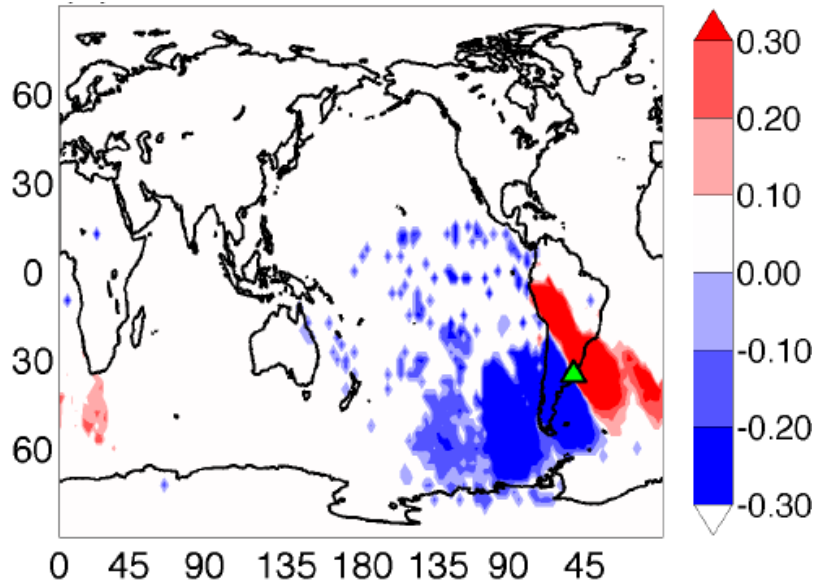
Daily data, τ = 30 days

video
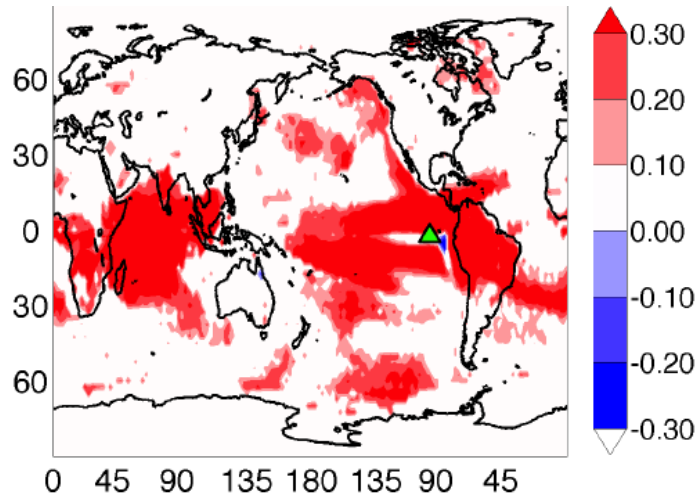
DI –selected links τ=1 day

- The directionality index is a measure that adequately captures the direction of the links of climate networks.

- After significance test + tuning τ: well-defined atmospheric patterns are uncovered.

- Ongoing and future work: how the network changes in the different seasons? Comparison with other methods (e.g. Granger causality)? How to distinguish direct/indirect connections?

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THANK YOU FOR YOUR ATTENTION !

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http://www.fisica.edu.uy/~cris/

M. Barreiro, A. C. Marti, and C. Masoller,
Inferring long memory processes in the climate network via ordinal pattern analysis, Chaos 21, 013101 (2011)

J. I. Deza, M. Barreiro, and C. Masoller,
Inferring interdependencies in climate networks constructed at inter-annual, intra-season and longer time scales, Eur. Phys. J. Special Topics 222, 511 (2013)