Complex networks tools for investigating large-scale atmospheric phenomena

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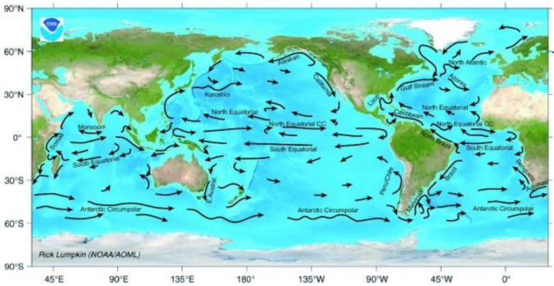
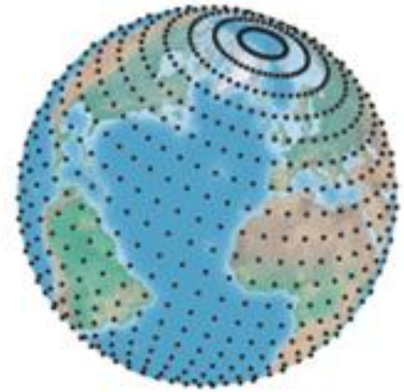
Mapping Complexity Foundations and Applications of Network Geometry
MACFANG, Barcelona 2017

Complex network representation of the climate system

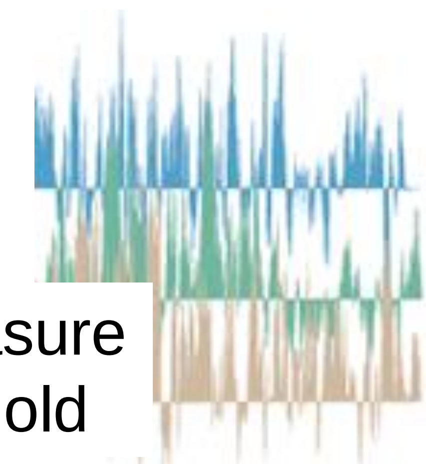




More than 10000 nodes.

Back to the climate system: interpretation (currents, winds, etc.)

Sim. measure + threshold

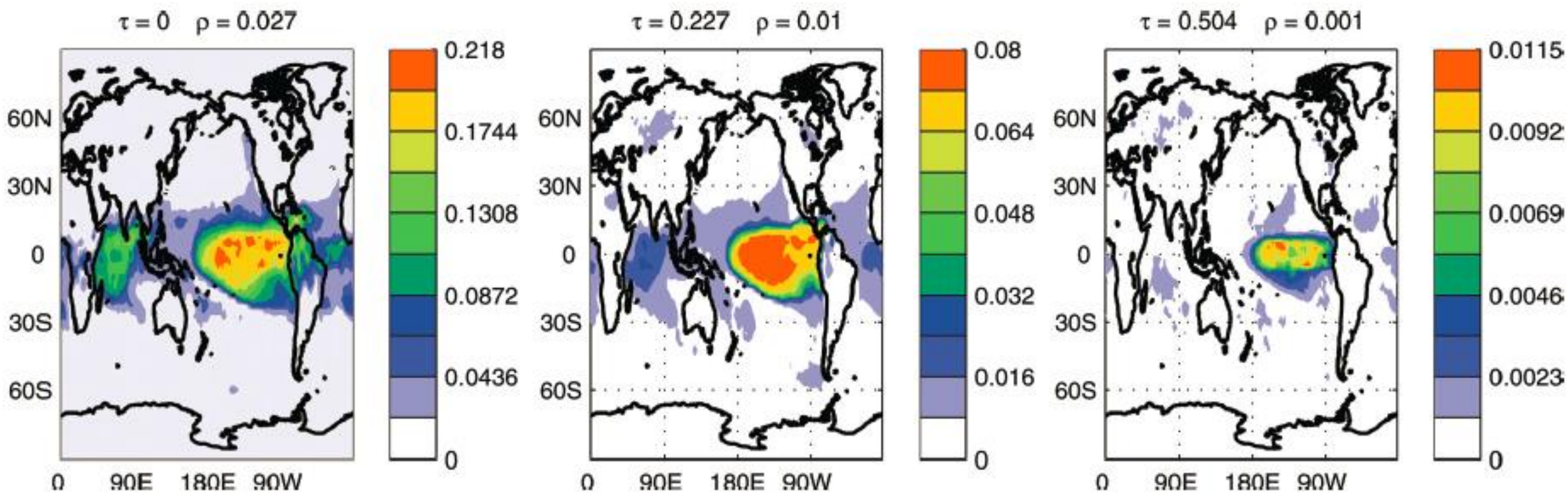


Daily resolution: more than 13000 data points in each TS

Donges et al, Chaos 2015

Surface Air Temperature <u>Anomalies</u> (solar cycle removed)

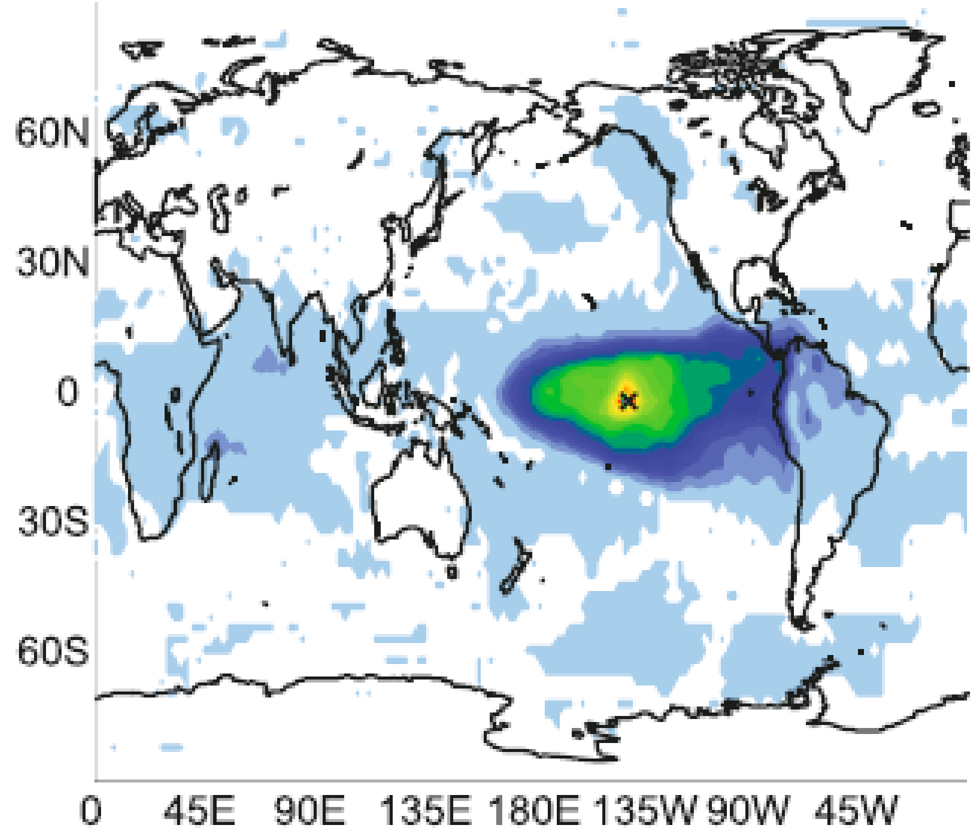
Graphical representation: area weighted connectivity (weighted degree)



Barreiro, Marti, and Masoller, Chaos 21, 013101 (2011)

Problem: the spatial embedding of the network

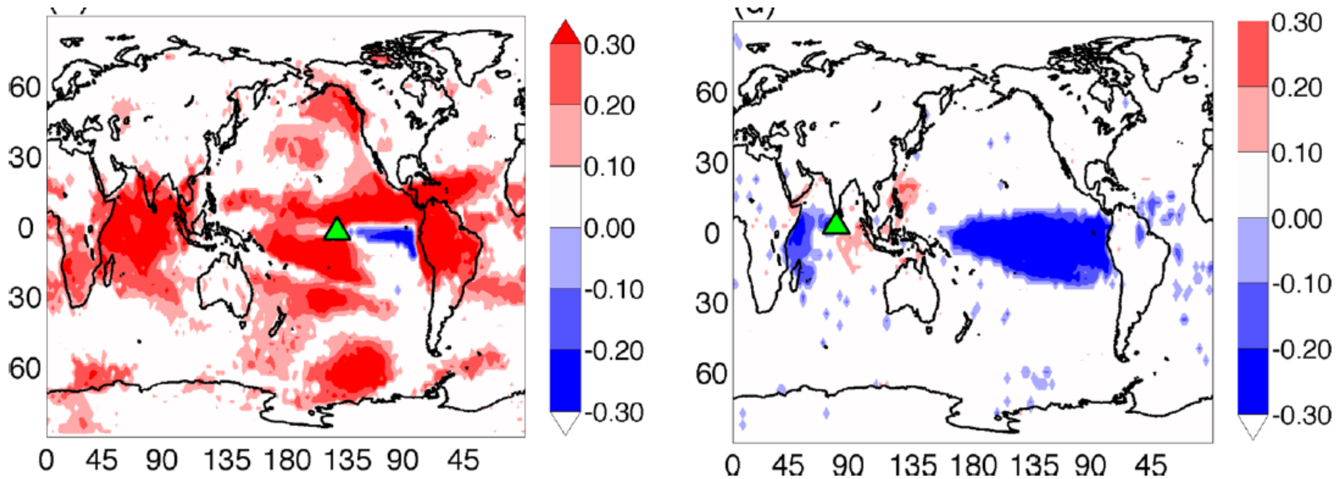
- Due to the **physical proximity**, the links (defined via thresholding similarity measure – cross correlation, mutual information) are mainly between neighboring nodes ⇒ **long distance links are scarce.**

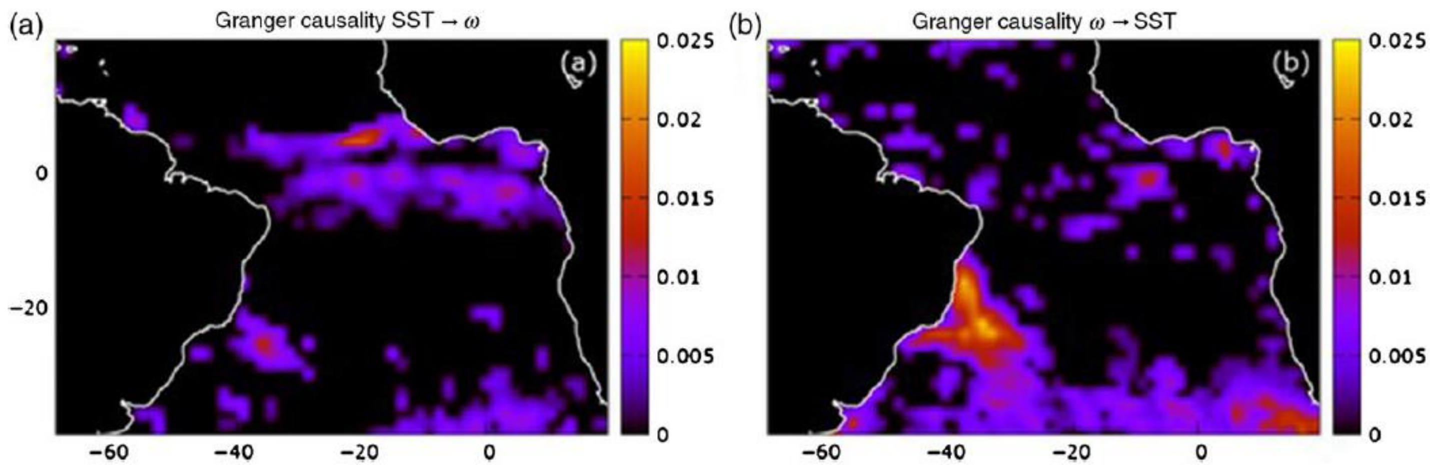


Cross correlation of surface air temperature anomalies (seasonal cycle removed)

- **No direct North – South links**.

Link directionality (information transfer, Granger causality)



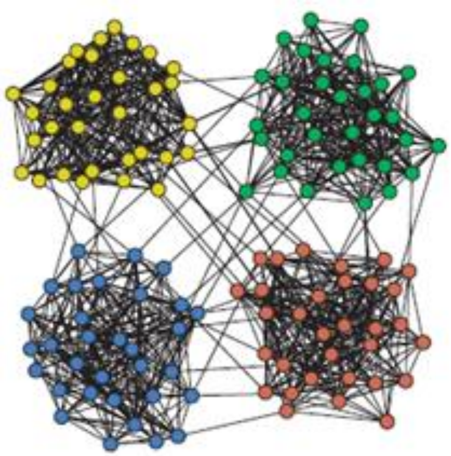


Deza, Barreiro, and Masoller, Chaos 25, 033105 (2015)
Tirabassi, Masoller and Barreiro, Int. J. Climatol. (2014)

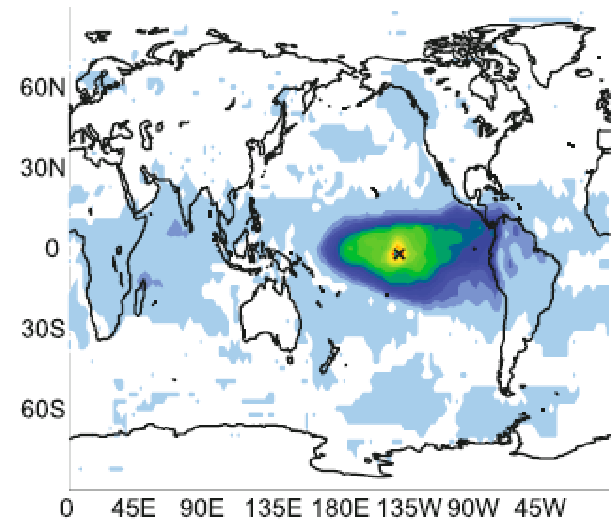
How to identify geographical regions with similar climate?

- Construct the climate network identify the communities.

- Regions with similar climate (rainforests, dry and arid regions, maritime regions, etc.) should belong to the same "community".



- Problem: with "usual" network analysis the north and south hemispheres are only indirectly connected.



How to identify geographical regions with similar climate?

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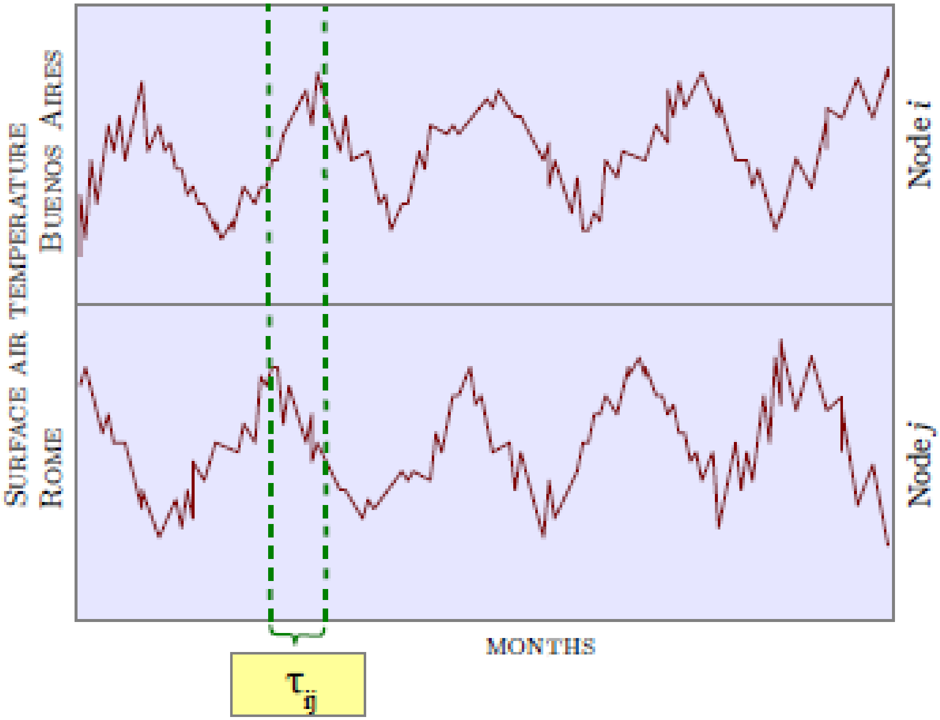
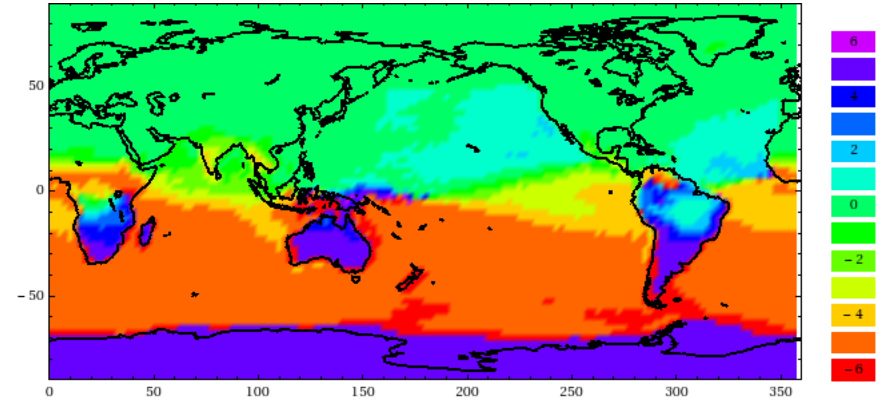
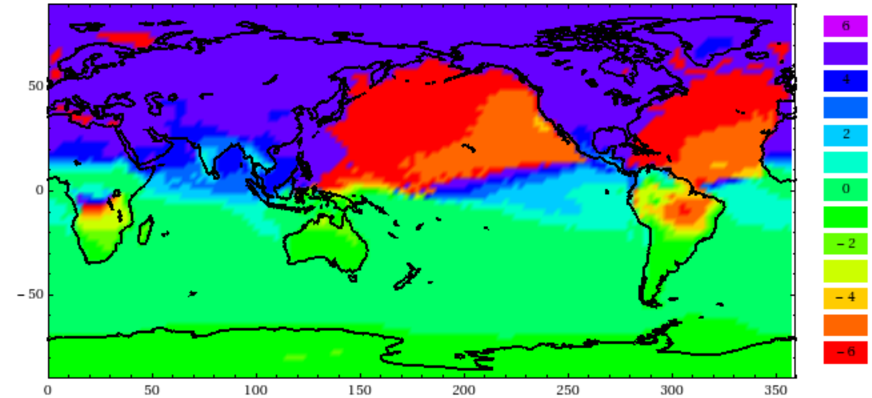
- Our first approach: lag-times between seasonal cycles (correlation analysis of Surface Air Temperature)



Rome

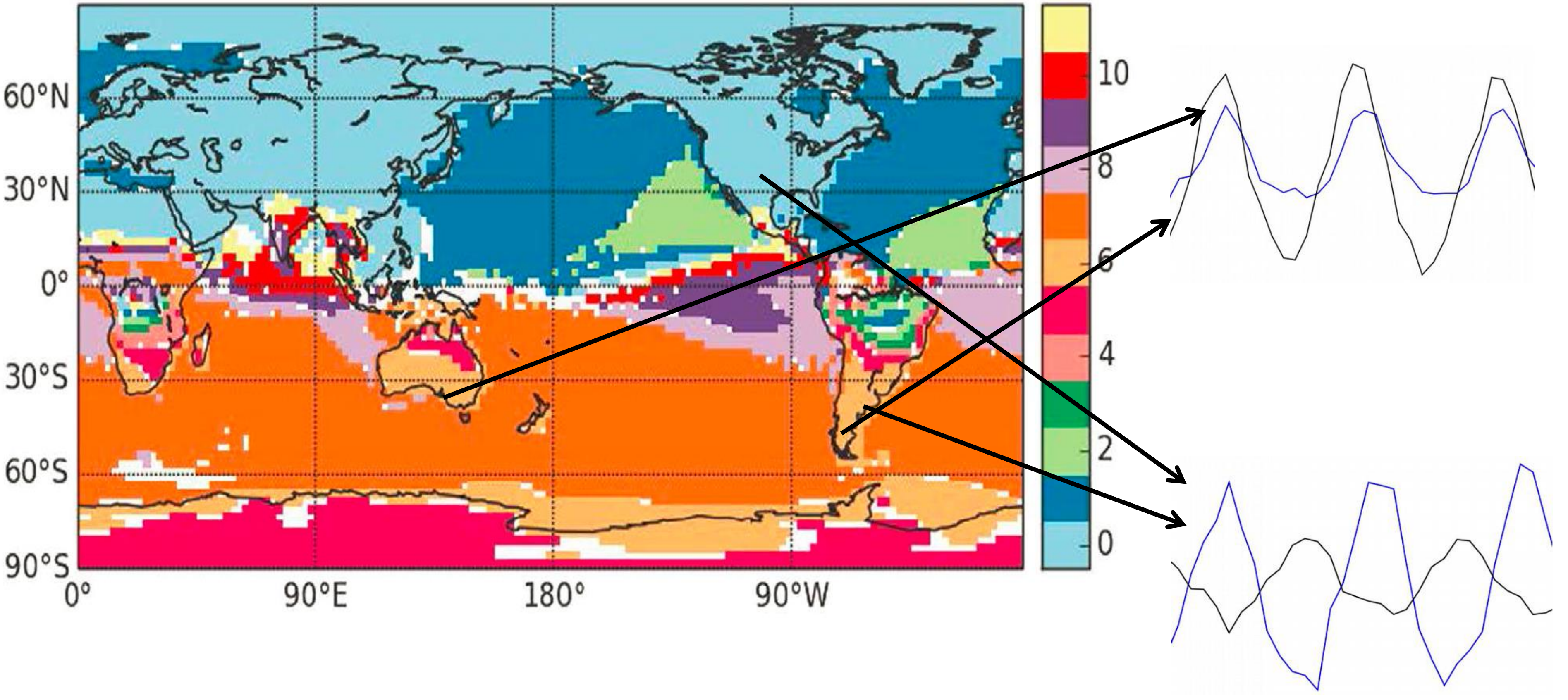


Buenos Aires



G. Tirabassi and C. Masoller, Sci. Rep. 6:29804 (2016)

Geographical regions with synchronous (inphase) seasonal cycles



- Six-month lag between the two hemispheres.
- Oceans have a one-month lag with respect to the landmasses

G. Tirabassi and C. Masoller, Sci. Rep. 6:29804 (2016)

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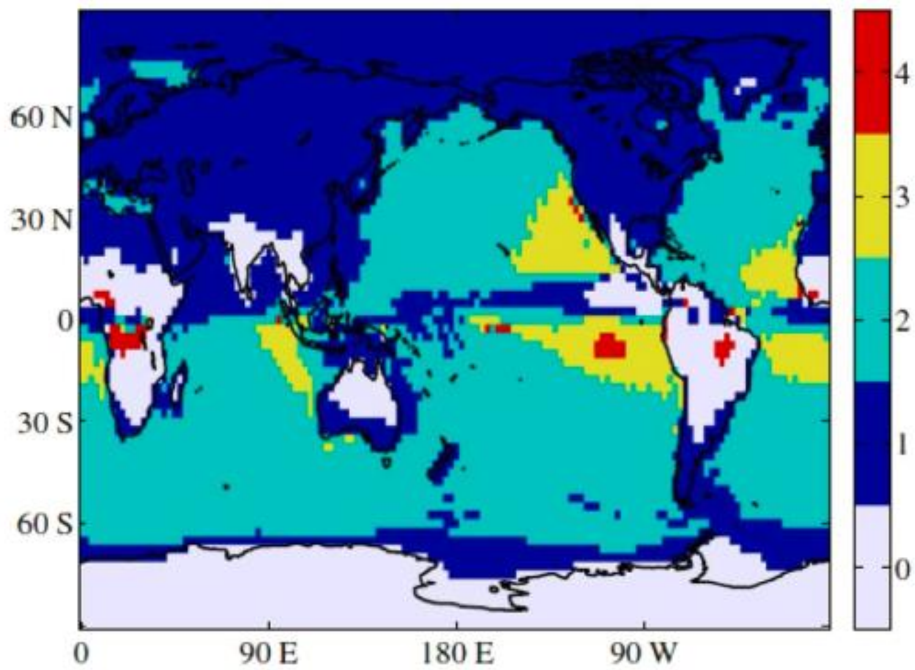
Second approach

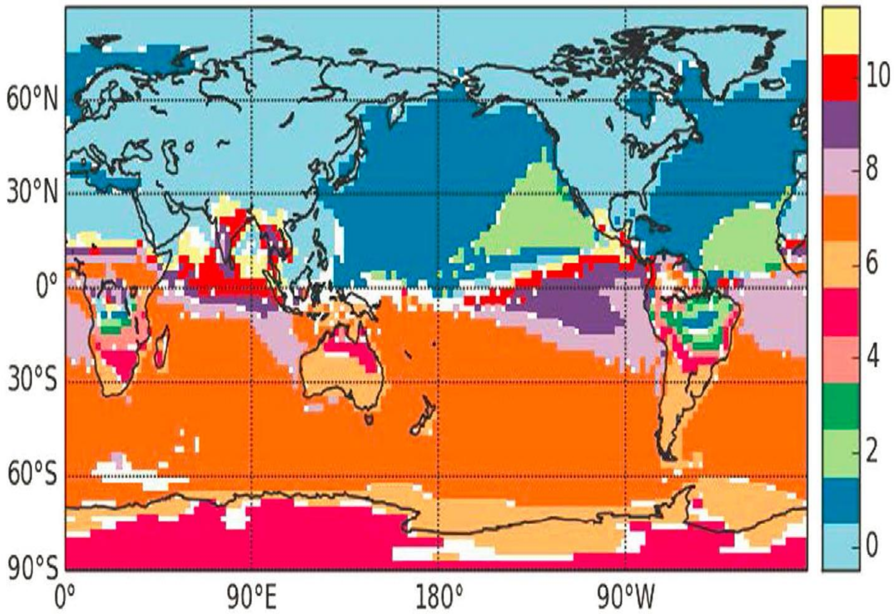
- Lag-time between surface air temperature and the <u>isolation</u> (local top-of-atmosphere incoming solar radiation)
- computed by minimizing the distance between the time-series.



F. Arismendi, M. Barreiro and C. Masoller, Sci. Rep. 7, 45676 (2017)

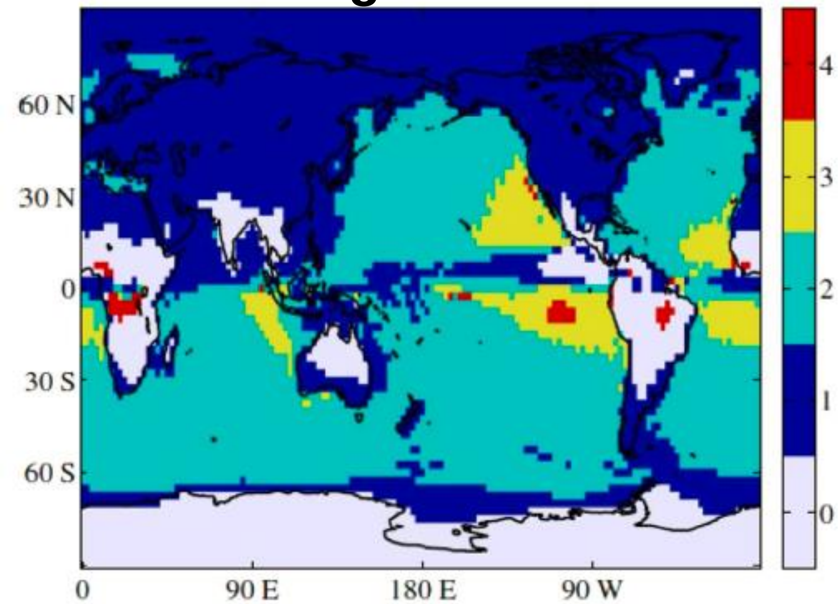
Comparison

Regions with inphase (synchronized) surface air temperature seasonal cycle



G. Tirabassi and C. Masoller, Sci. Rep. 6:29804 (2016)

Lag between surface air temperature seasonal cycle and incoming solar radiation



F. Arismendi, M. Barreiro and C. Masoller, Sci. Rep. 7, 45676 (2017)

Third method: network based on similar symbolic dynamics

- Step 1: transform SAT anomalies in each node in a sequence of symbols (we use ordinal patterns)

  s_i = {012, 102, 210, 012…} s_j = {201, 210, 210, 012, …}

- Step 2: in each node compute the transition probabilities

  $TP^{i}_{\alpha\beta} = \#(\alpha \rightarrow \beta)/N$

- Step 3: define the weights $$w_{ij} = \frac{1}{\sum_{\alpha\beta}\left(TP^{i}_{\alpha\beta} - TP^{j}_{\alpha\beta}\right)^2}$$

  High weight if similar symbolic "language"

- Step 4: threshold w_{ij} to obtain the adjacency matrix.

- Step 5: run a community detection algorithm (Infomap).

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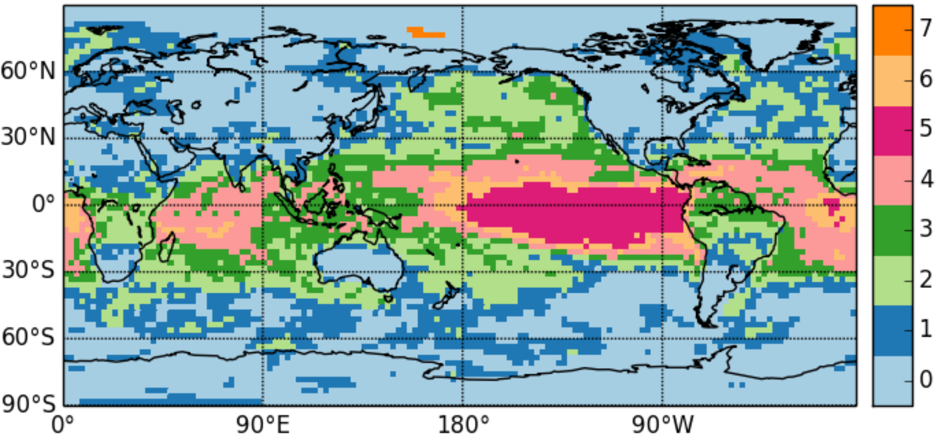
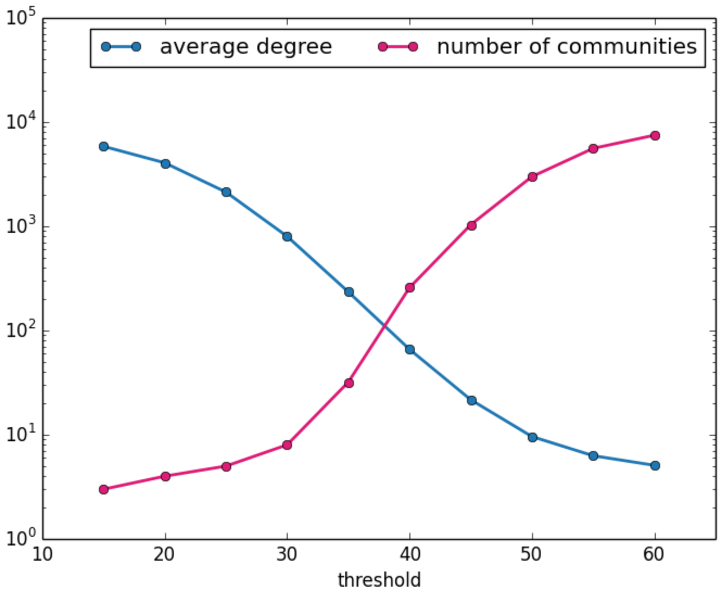
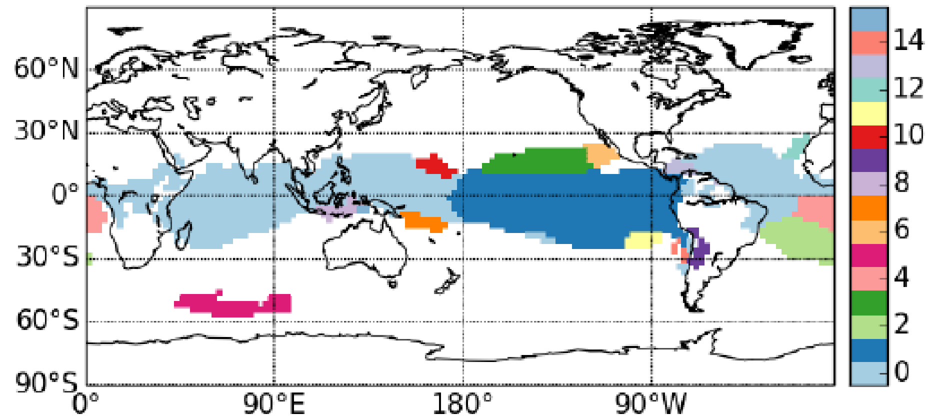
Results

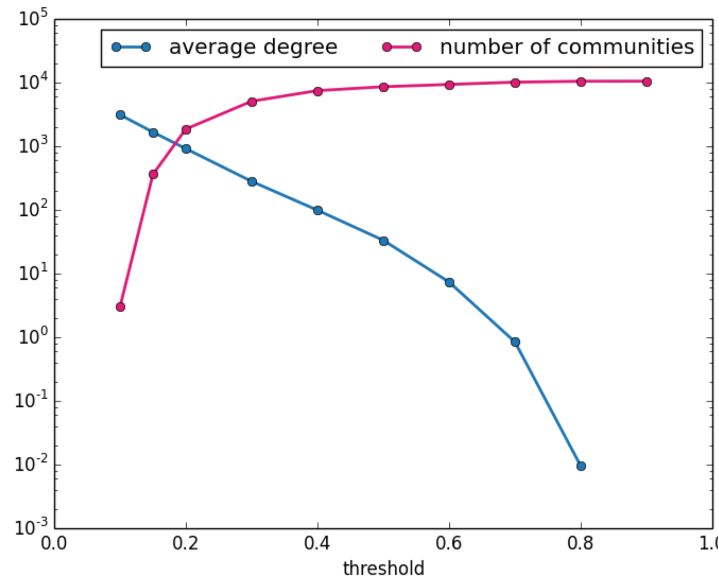
TP Network





CC Network (only the largest 16)





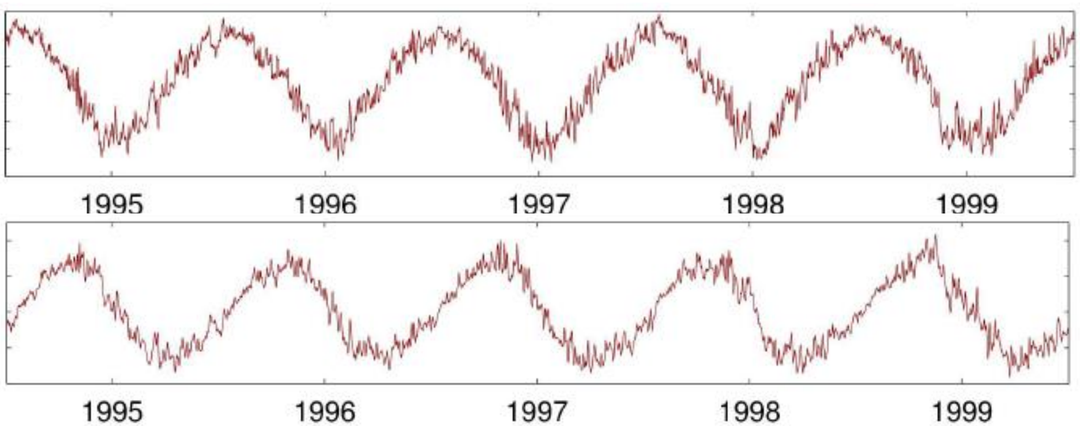
Fourth method: synchronized phase dynamics

- Hilbert Transform of a real **oscillatory** signal.
- Allows to calculate, **for each data point** in the time series, the instantaneous

  Amplitude **$a(t)$**   Phase **$\varphi(t)$**   Frequency **$\omega(t)=d\varphi(t)/dt$**

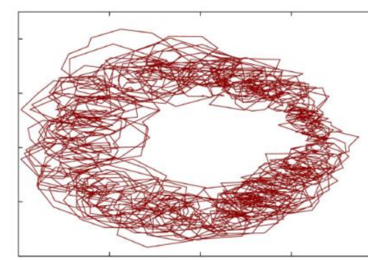
- $HT[\sin(\omega t)]=\cos(\omega t)$

x



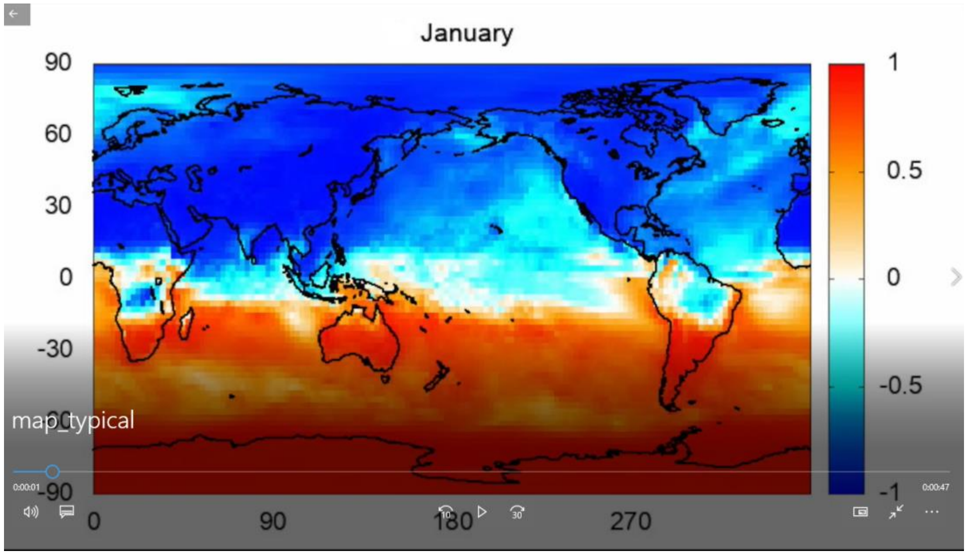
HT[x]

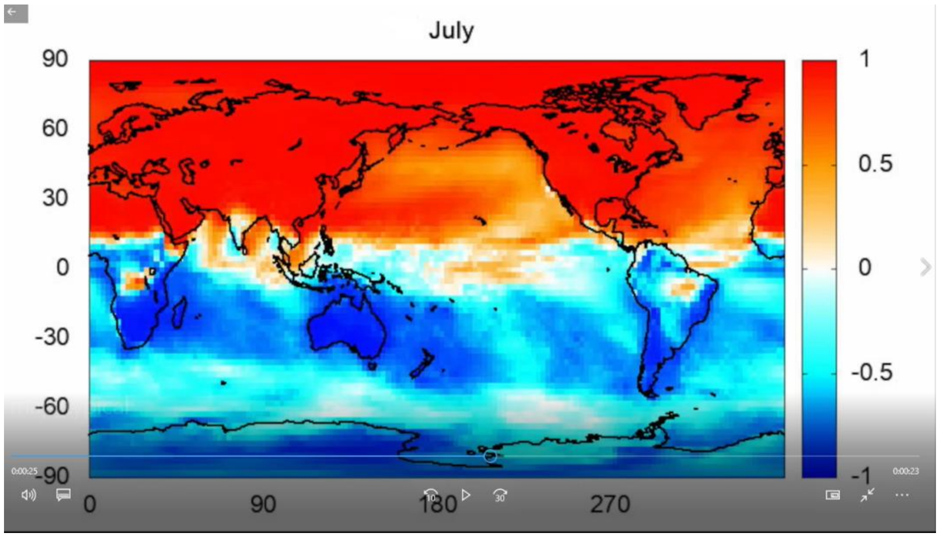
Y=HT[x]



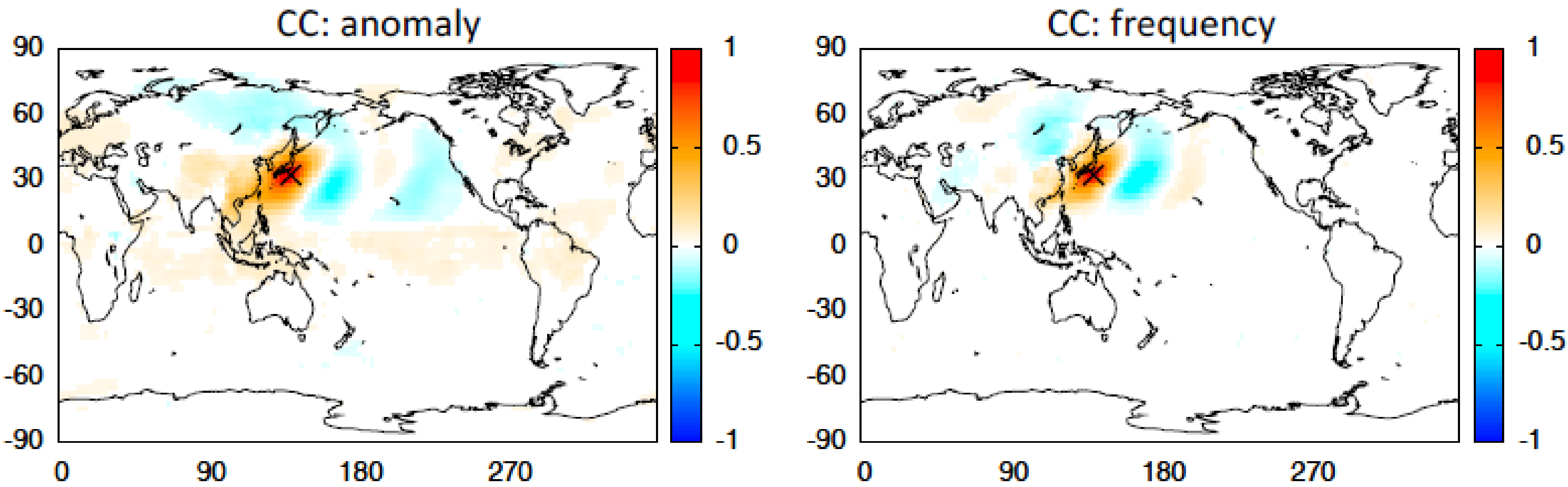
x

Phase dynamics: cos(phase)

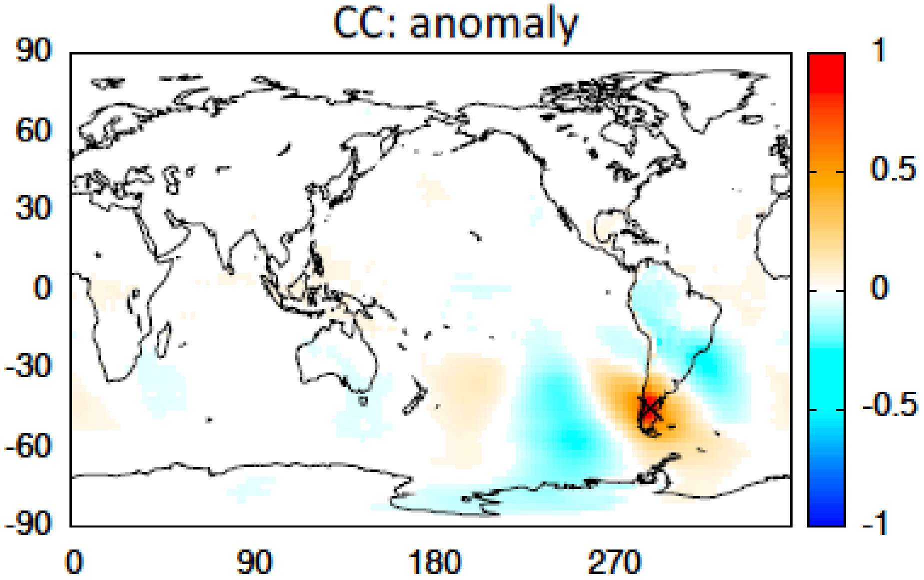


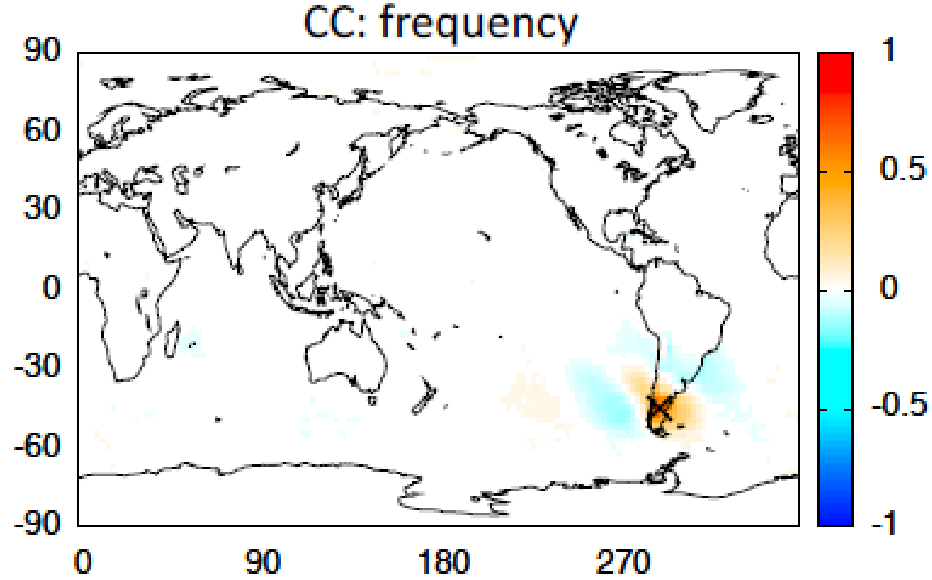


Comparison in the extra-tropics



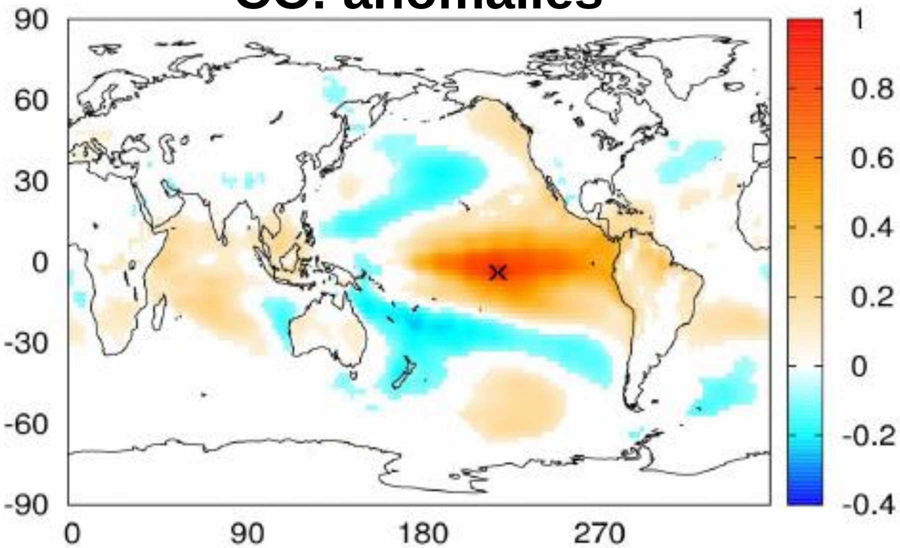
Significance: 100 surrogates (anomaly TS or Hilbert TS), then use 3σ confidence level


CC: anomaly
90
60
30
0
-30
-60
-90
0
90
180
270
1
0.5
0
-0.5
-1

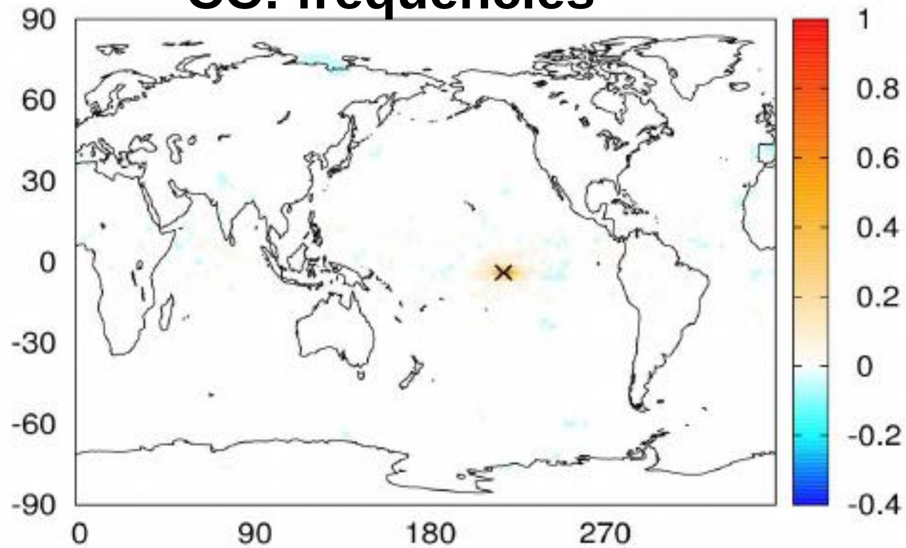

CC: frequency
90
60
30
0
-30
-60
-90
0
90
180
270
1
0.5
0
-0.5
-1

Comparison in the El Niño region

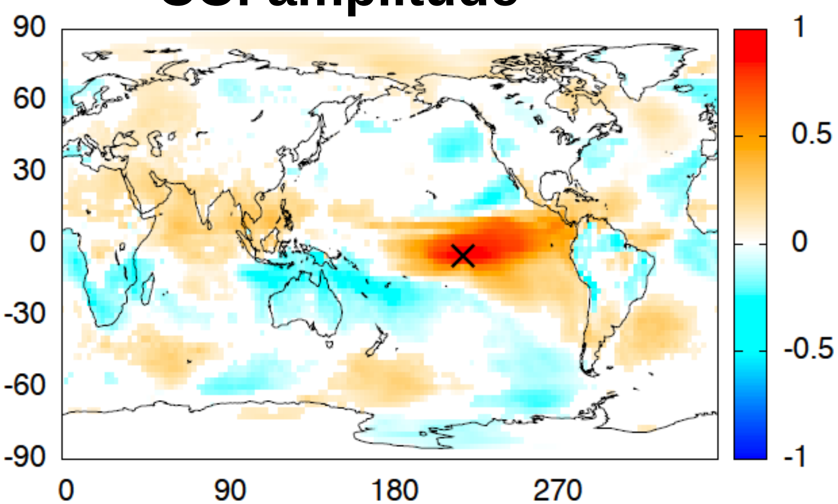
CC: anomalies



CC: frequencies



CC: amplitude



$\Rightarrow$ Frequency dynamics in the tropics not synchronized with the extra-tropics

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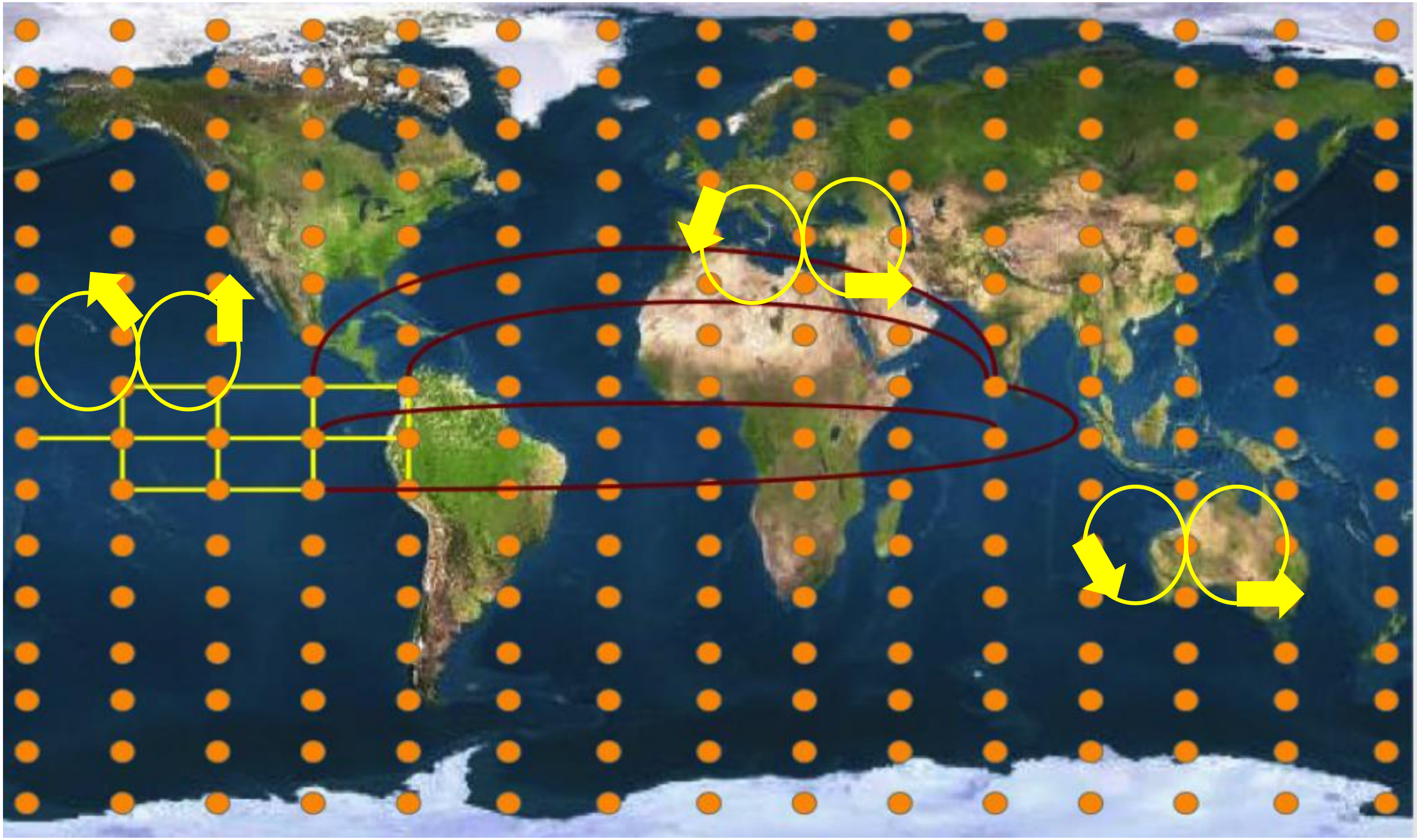
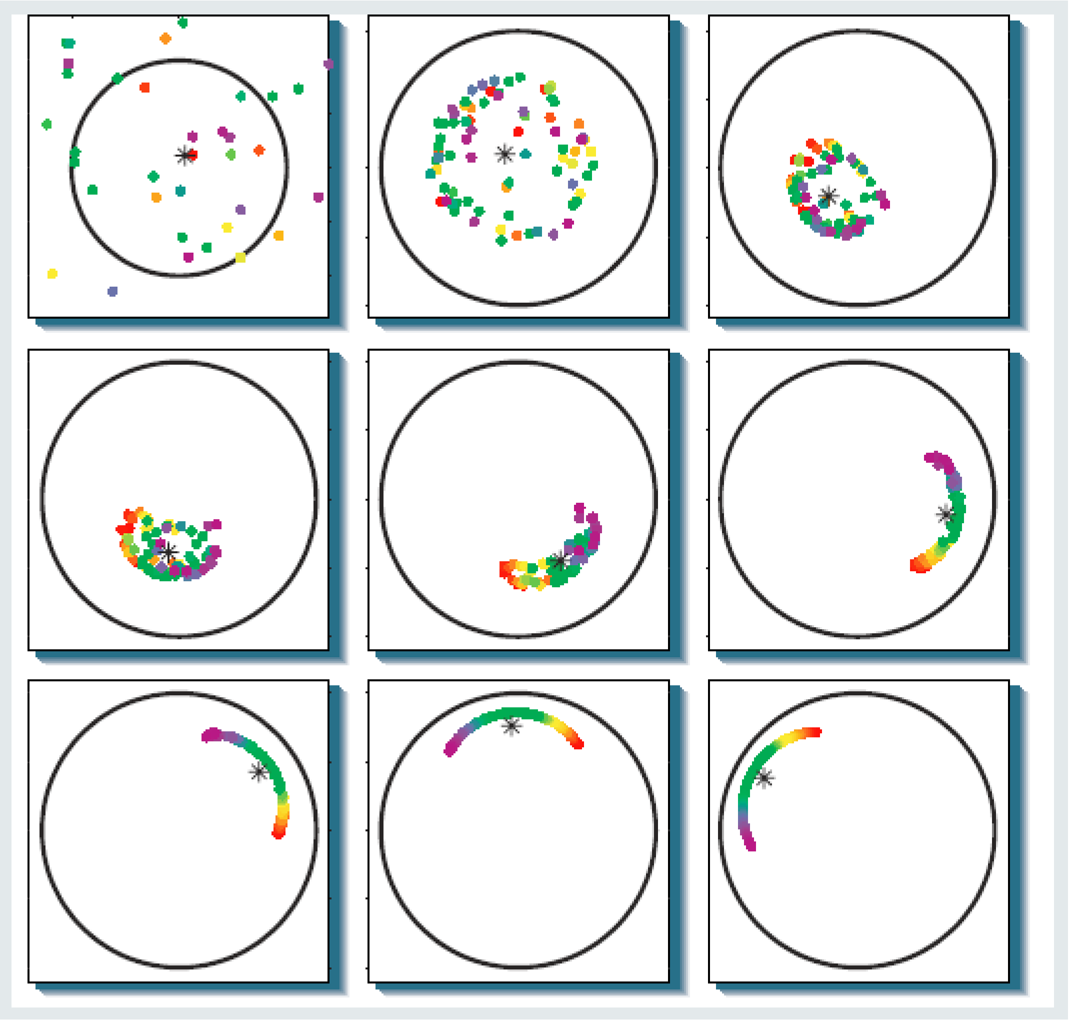
Network of individual oscillators



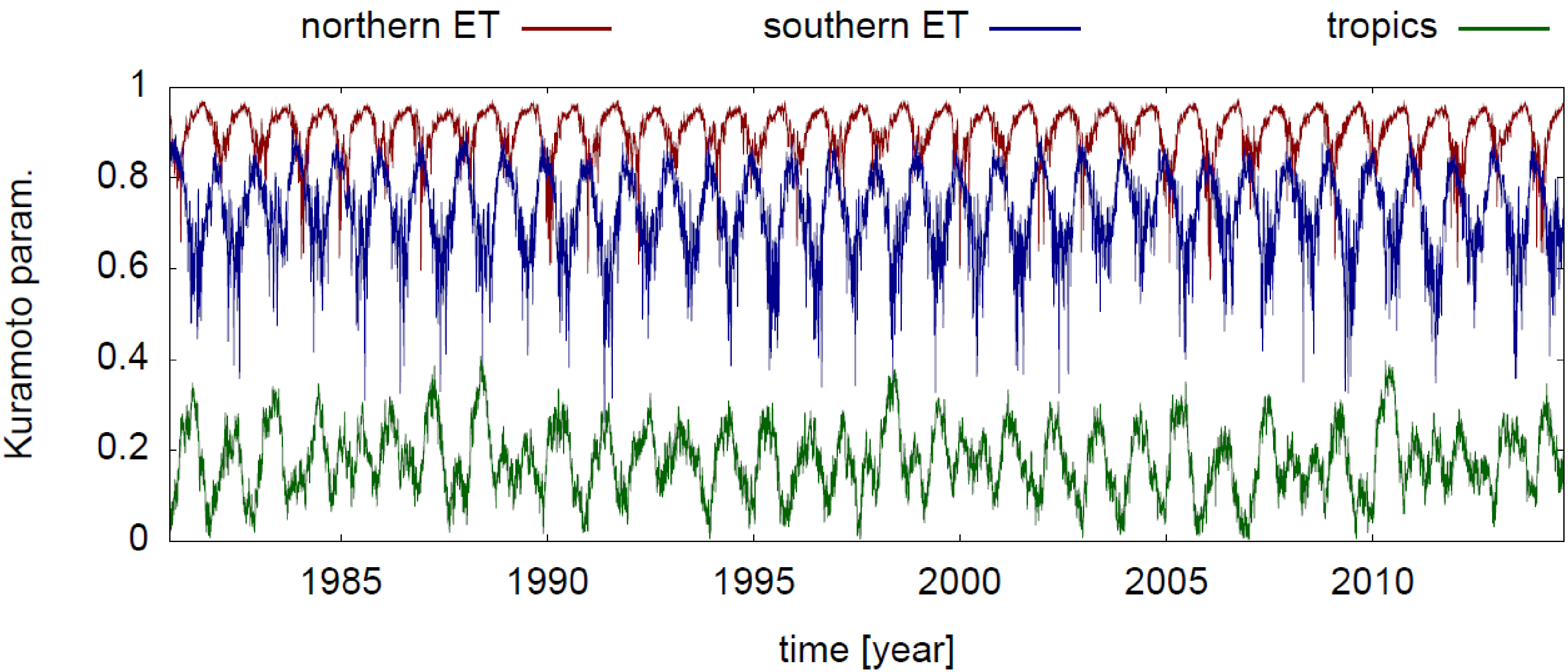
Quantifying phase synchronization

- Kuramoto order parameter

$$r(t)=\left|\frac{1}{N}\sum_{j=1}^{N}e^{i\theta_j(t)}\right|$$



Steven H. Strogatz, Nature 2001

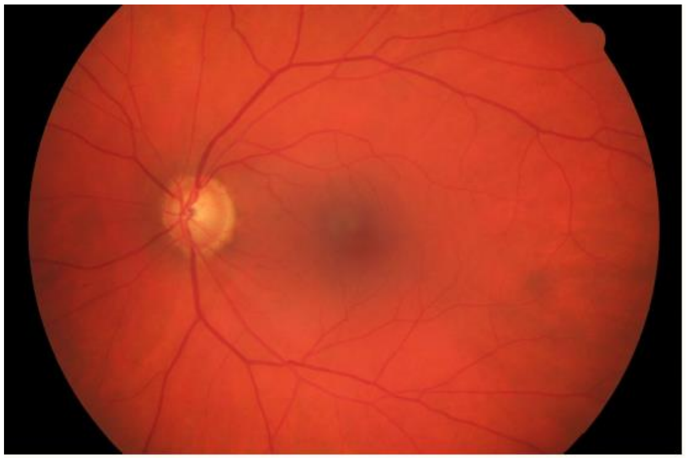

northern ET
southern ET
tropics
Kuramoto param.
1
0.8
0.6
0.4
0.2
0
1985
1990
1995
2000
2005
2010
time [year]

Conclusions

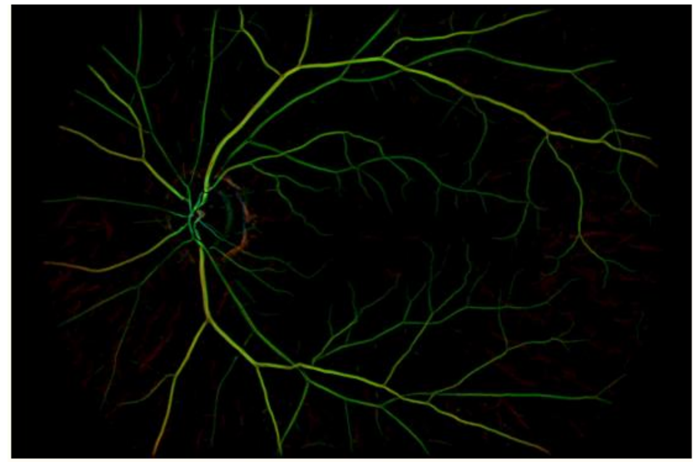
What did we learn?

- Different methods have been used to identify regions with similar climatic properties (climate communities).
- Hilbert analysis applied to **raw** data yielded light into phase dynamics and synchronization.
- High synchronization in the NH, lower in the SH, and no synchronization in the tropics.
- Ongoing work: predictive power?

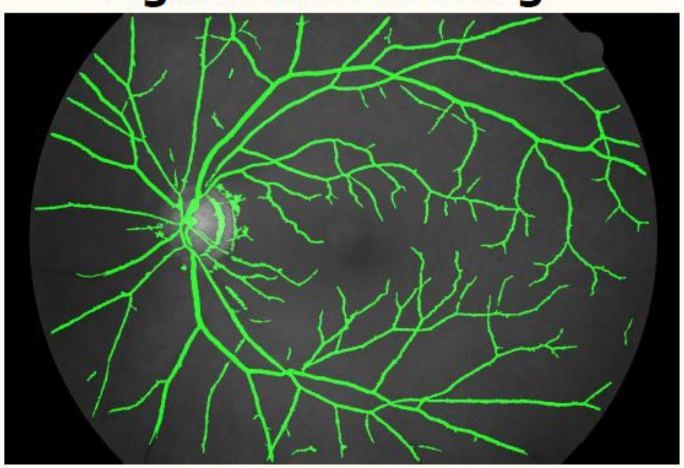
Flash “extra bonus”



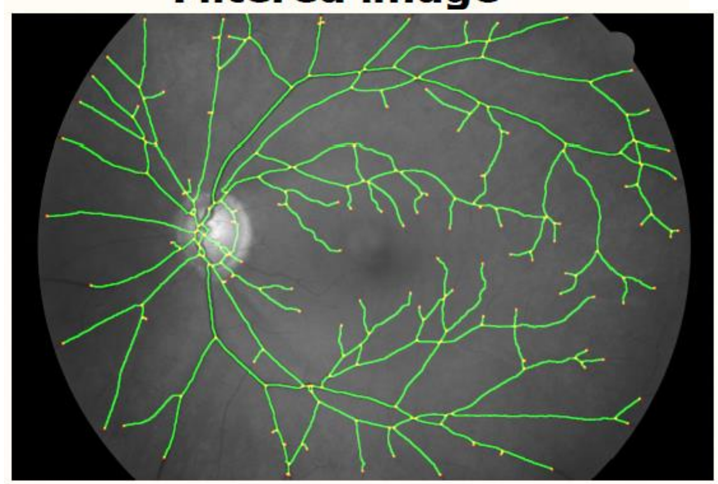
Original fundus image



Filtered image



Segmentation result



Network identification

Advertising

- School on "***Nonlinear Time Series Analysis and Complex Networks in the Big Data Era***", co-organized with Jesus Gomez-Gardenes and Hilda Cerdeira

  ICTP-SAIFR (Sao Paulo): February 19 – March 2, 2018

- Workshop on "***Predicting transitions in complex systems***", co-organized with K. Lehnertz and J. Hlinka

  Max Planck Institute for Physics of Complex Systems (Dresden): 23 – 27 April 2018

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

G. Tirabassi and C. Masoller, "*Unravelling the community structure of the climate system by using lags and symbolic time-series analysis*", Sci. Rep. 6, 29804 (2016).

F. Arizmendi, M. Barreiro, C. Masoller, "*Identifying large-scale patterns of unpredictability and response to insolation in atmospheric data*", Sci. Rep. 7, 45676 (2017).

D. A. Zappala, M. Barreiro, and C. Masoller, "*Global atmospheric dynamics investigated by using Hilbert frequency analysis*", Entropy 18, 408 (2016).

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