Complex networks in climate and sustainability science

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Outline

Motivation

Envision earth system and its subcomponents (climate system, world economy, ...) as hierarchical complex networks of dynamical systems.

Idea

Apply recent theory of complex networks to the earth system.

Goals

- Systematize earth system analysis and modeling
- Gain novel insights into relation of structure and dynamics (global change)
- Develop new tools for data analysis

Example in climate science

K. Yamasaki, A. Gozolchiani and S. Havlin, *Climate Networks around the Globe are Significantly Effected by El Nino*. Unpublished 2008. [3]

Objective

Detect El Nino signals in the dynamics of climate networks generated from various observables.

Construction of a climate network

Data processing

- Obtain daily records of observable of interest on a grid $\hat{T}_l^y(d)$
- Remove seasonal trends. Filtered signal: $T_l^y(d) = \hat{T}_l^y(d) - \frac{1}{N}\sum_y \hat{T}_l^y(d)$

Construction of a climate network

Calculate correlation strength matrix

- Compute cross correlation function $X^{y}_{l,r}(\tau > 0) = \langle T^{y}_{l}(d) T^{y}_{r}(d+\tau)\rangle_{d}$ for $\tau \in [-\tau_{max}, \tau_{max}]$
- Choose correlation strength $W^{y}_{l,r} = \frac{MAX(X^{y}_{l,r})}{STD(X^{y}_{l,r})}$

Construction of a climate network

Generate time-dependent connectivity matrix

Set physical threshold Q so that $\rho^{y}_{l,r} = \Theta(W^{y}_{l,r} - Q)$

Derived network measures

Blinking links

Count number of times a link appeared before continously:
$M_{l,r}^{y} = \sum_{n=0}^{y-1} \prod_{m=y-n}^{y} \rho_{l,r}^{m}$

Count number of stable links

Number of links that existed for k days or longer:
$n_k(y) = \sum_{l=0}^{N} \sum_{r=l+1}^{N} \Theta(M_{l,r}^{y} - (k-1))$

Geographical Regions

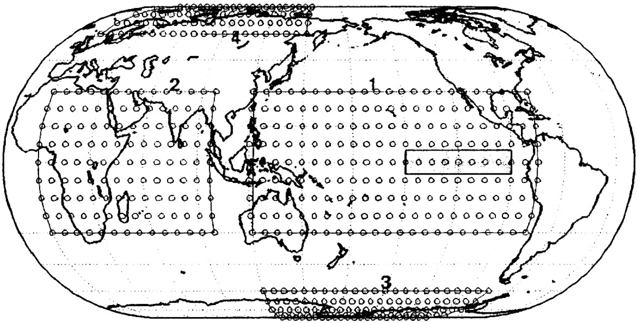


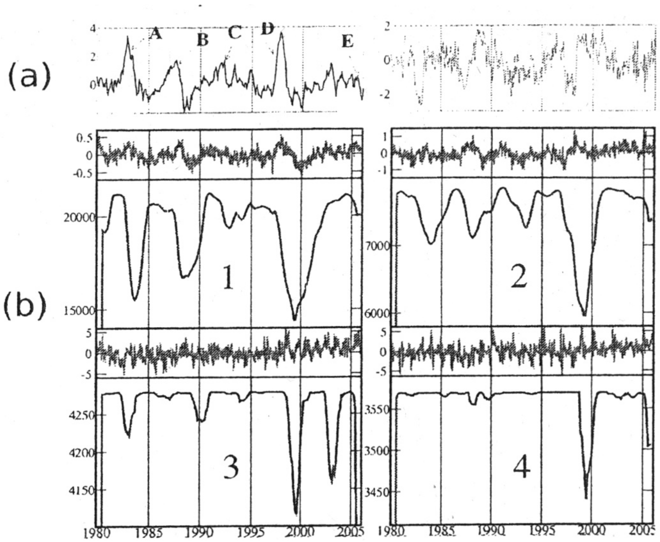
Figure: Four geographical zones used for constructing climate networks

Observables

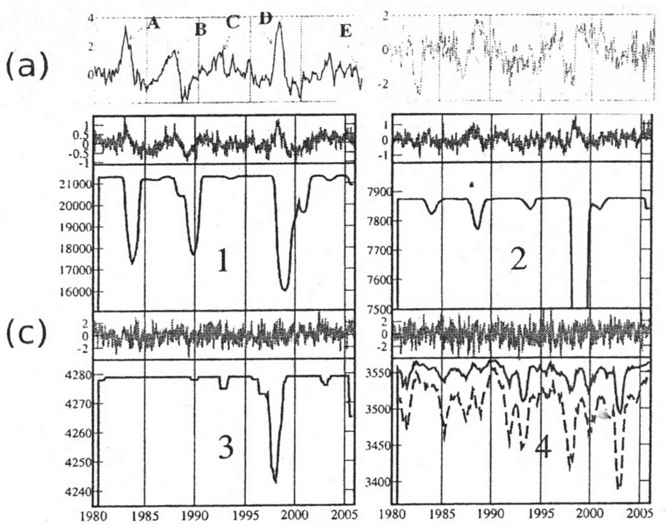
Chosen observables

- Temperature close to sea level (Networks A_j)
- Temperature on a $500mb$ pressure level (Networks B_j)
- Time span: 1979-2006 (8 El Nino events)
- Grid resolution: 7.5 degrees

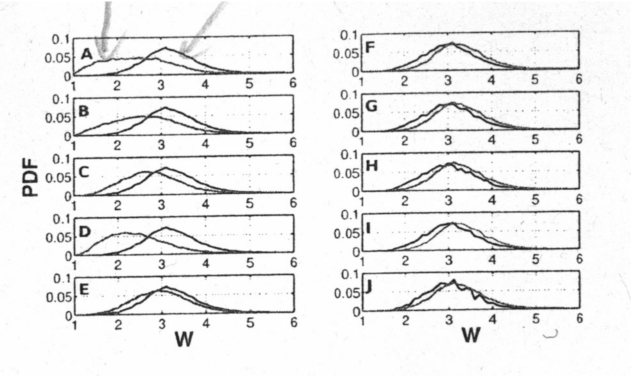
$n_k(y)$ vs. NINO3, SOI and regional temperture anomalies, A_j



$n_k(y)$ vs. NINO3, SOI and regional temperture anomalies, B_j



Distributions of correlation strength $W_{l,r}^{y}$



Distributions of time delay

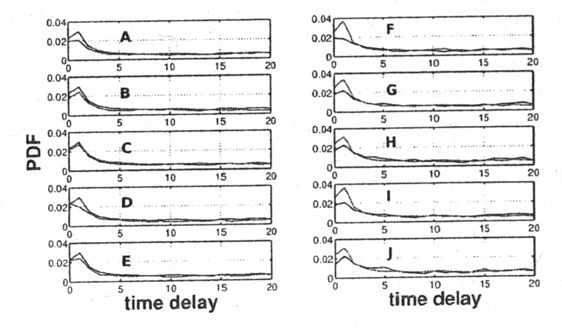


Figure: Time delay: delay at maximum cross correlation

Conclusions

- $n_k(y)$ responds significantly to El Nino, even where mean temperature level is not affected (Arctic, Antarctica)
- Physical threshold Q can be selected from correlation strength distribution
- Links that break during El Nino tend to have larger time delay
- In some sense, El Nino introduces disorder into the temperature field [1] [2]

Observables

- Precipitation
- Pressure
- Salinity
- Data from model simulations
- ...

Network measures

- Clustering coefficient
- Area weighted connectivity (related to vertex degree) [1] [2]
- Power law exponents
- ...

Nonlinear measures of synchronization

- Mutual information
- ...

Theoretical understanding of underlying mechanisms

- How do changes in (climate) network structure arise physically?
- Apply theory of synchronization in complex networks.
- Build models to study those changes.
- Exploit some deep connection of theory of PDE's and complex networks.
- ...

Discussion

Questions?

References

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