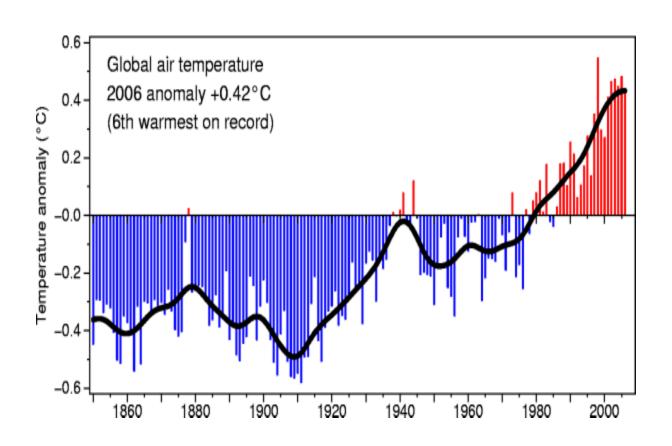
Synchronization and coupling in climate networks

A new dynamical mechanism for major climate shifts

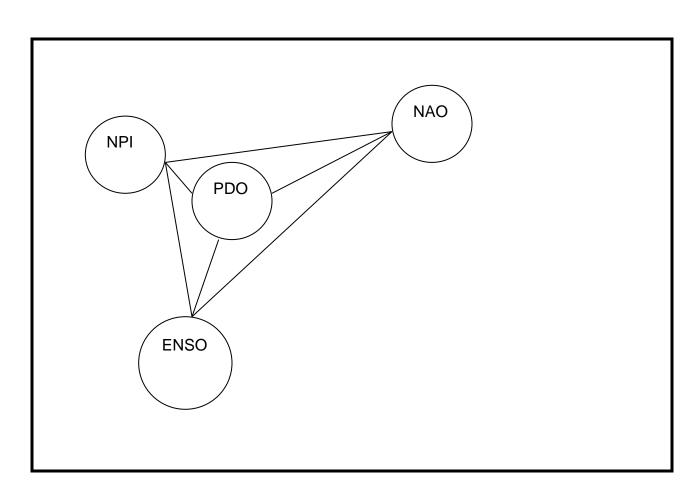
Anastasios A. Tsonis

Global Temperature record



The network used

a



Definition of Distance

Mean distance:

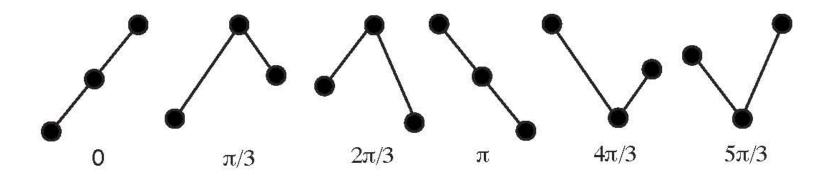
$$d(t) = \frac{1}{N(N-1)/2} \sum_{\substack{dt \in Dt \\ ij}} d_{ij}^t$$

where

$$d_{ij}^t = \sqrt{2(1 - \left| \rho_{ij}^t \right|)}$$

where ρ_{ij}^t is the correlation coefficient between nodes i and j in a window centered at t.

Symbolic phases



Measure of coupling

The symbolic phase ϕ^j_n is constructed separately for the four climate indices, where j denotes the index and n the year. The phases for a given year n are represented by the complex phase vector \vec{Z}_n with elements $Z_n^{\ j} = exp(i \ \phi^j_n)$. The predictability of this phase vector from year to year provides a measure of the coupling and is determined using the least squares estimator

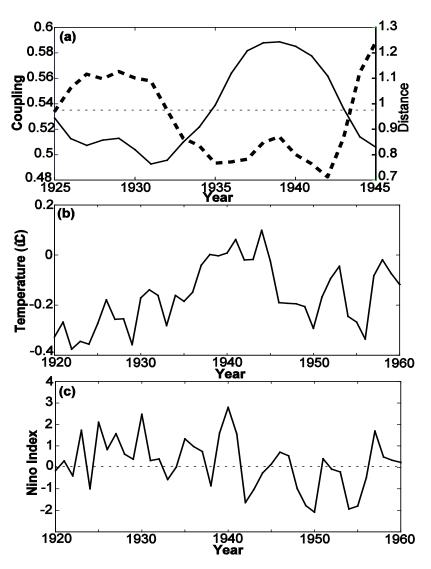
$$\vec{Z}_{\scriptscriptstyle n+1}^{\scriptscriptstyle est} = \mathbf{M} \vec{Z}_{\scriptscriptstyle n}$$

where $\mathbf{M} = [\mathbf{Z}_+ \ \mathbf{Z}^T] \ [\mathbf{Z} \ \mathbf{Z}^T]^{-1}$ is the least squares predictor. Here \mathbf{Z} and \mathbf{Z}_+ are

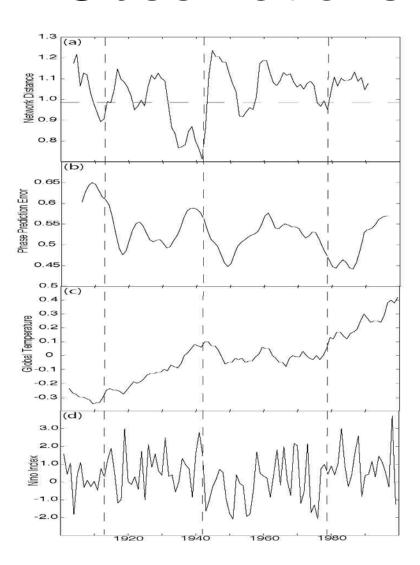
the matrices whose columns are the vectors \vec{Z}_{n} and \vec{Z}_{n+1} , respectively, constructed

using all years. A measure of the coupling then is simply $\left\| \vec{Z}_{n+1}^{est} - \vec{Z}_{n+1} \right\|^2$, where strong coupling is associated with small values of this quantity, i.e., good phase prediction.

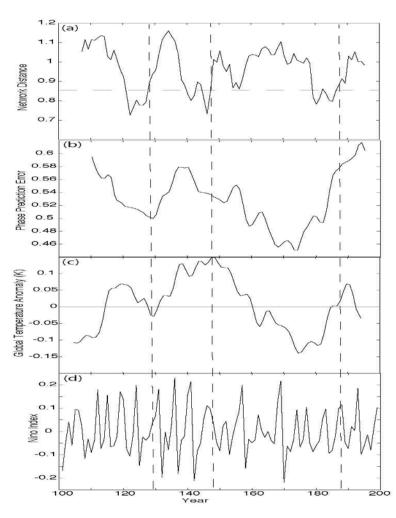
The shift in the 40s



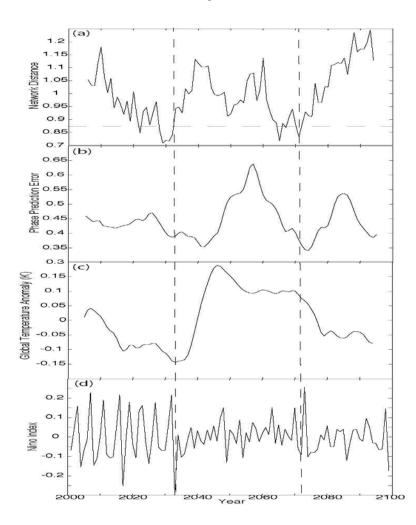
Observations



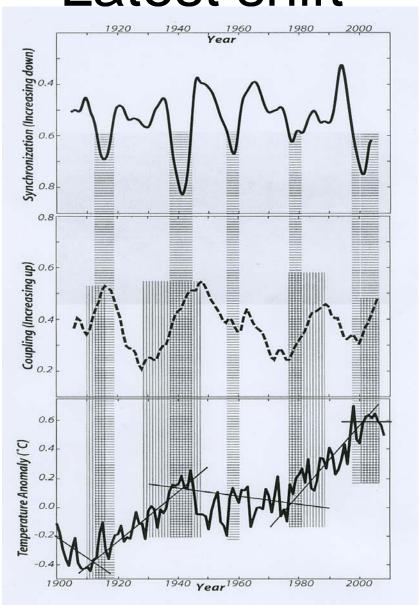
Control (GFDL CM2.1)



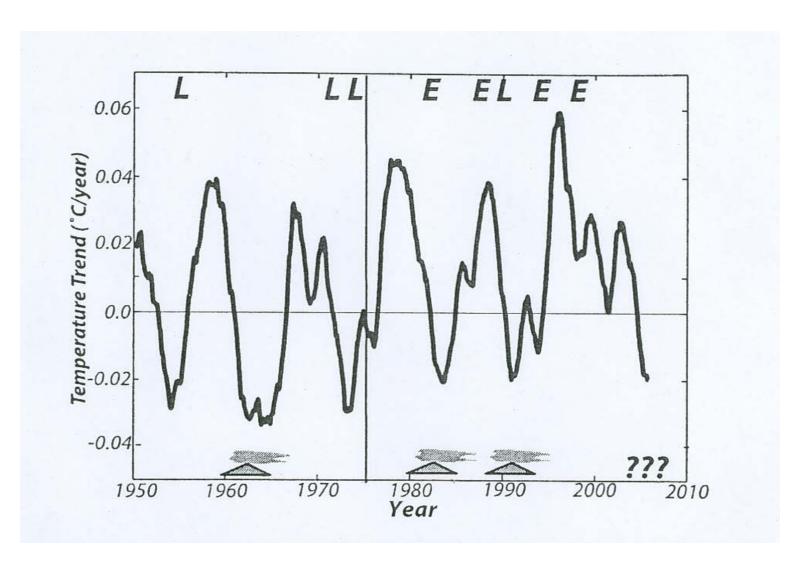
21st century (SRESA1B)



Latest shift



7-Year linear trend



Conclusions

- The above observational and modeling results suggest the following intrinsic mechanism of the climate system leading to major climate shifts. First, the major climate modes tend to synchronize at some coupling strength. When this synchronous state is followed by an increase in the coupling strength, the network's synchronous state is destroyed and after that climate emerges in a new state. The whole event marks a significant shift in climate, which is evident in the global temperature trend changes and in ENSO variability changes.
- The collective behavior of the four modes captures the essence of decadal variability and climate shifts.
- Climate appears to have shifted lately suggesting a 20-30 year cooling period which would in turn imply more La Nina than El Nino conditions.