TSONIS FINAL PROJECT REPORT

DOE grant DE-0005305 “Collaborative research: An Interactive Multi-Model for Consensus on Climate Change”

Reporting period: 9/1/2010-9/14/14

PI/C0-PI information:

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Project synopsis

This collaboration has several components but the main idea is that when imperfect copies of a given nonlinear dynamical system are coupled, they may synchronize for some set of coupling parameters. This idea is to be tested for several IPCC-like models each one with its own formulation and representing an “imperfect” copy of the true climate system. By computing the coupling parameters, which will lead the models to a synchronized state, a consensus on climate change simulations may be achieved.

Tsonis’ research and results

Another aspect of synchronization in climate (and my part of the project) is the synchronization of climate modes. These modes represent low-order subsystems in climate and it has been shown that they often synchronize. An important element in the theory of synchronization between coupled nonlinear oscillators is coupling strength. The theory of synchronized chaos [1, 2] predicts that in many cases when such systems synchronize, an increase in coupling strength between the oscillators may destroy the synchronous state and alter the system’s behavior. These ideas were initially explored in a network of four climate oscillators, namely El Nino-Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), the North Pacific Index (NPI), and the Pacific Decadal Oscillation (PDO) [3, 4, 5]. The results indicate that this network in the 20th century synchronized several times. It was then found that in those cases where the synchronous state was followed by a steady increase in the coupling strength between the indices, the synchronous state was destroyed, after which a new climate state emerged. These shifts are associated with significant changes in global temperature trend over decadal time scales. We also find the evidence for such type of behavior in three climate simulations (control and CO_2 forced) using simulation from state-of-the-art models.

Part of my work was to understand relationships between regime shifts and synchronization in a set of ordinary differential equations (ODE's) representing climate modes. To this end we further studied synchronizations by extending the previous analysis to include more indices. Some results are shown in figure 1. On the x-axis are the different modes and on the y-axis is time. This figure may be interpreted as follows. Horizontal orange or yellow lines indicate synchronization events and the modes involved in each synchronization event. The main conclusion here is that de-synchronization does not always mean a regime shift. For example, while in the early 1940s a climate shift took place, no shift occurred in the 1920s or early 1930s. In accordance with the previous results only in those times when increase in coupling is involved de-synchronization is associated with a climate regime. In relation to the goals of the complete proposal it is important to establish the mechanism via which synchronization and coupling increase occur. Our results also indicate that in the four mode network the direction of influences (figure 2) begins with North Atlantic coupling to North Pacific which then couples to tropical Pacific which in turn couples back to North Atlantic [5, 6].

The bulk of our knowledge about causes of twentieth century climate change comes from simulations using numerical models. A strong component in my research was the ability of models to simulate realistically the observations. In particular, these models seemingly reproduce the observed nonuniform global warming, with periods of faster warming in 1910–1940 and 1970–2000, and a pause in between. More research into to this issue [7] reveals some differences between the observations and model simulations. We showed that observed multidecadal variations of surface climate exhibited a coherent global-scale signal characterized by a pair of patterns, one of which evolved in sync with multidecadal swings of the global temperature, and the other in quadrature with them. In contrast, model simulations are dominated by the stationary—single pattern—forced signal somewhat reminiscent of the observed “in-sync” pattern most pronounced in the Pacific. While simulating well the amplitude of the largest-scale—Pacific and hemispheric—multidecadal variability in surface temperature, the model underestimates variability in the North Atlantic and atmospheric indices. We also show that there exist further significant differences in the dynamics between the different models [8; figure 3] especially for the surface temperature and precipitation fields; two fields of great interest in climate projections under increasing amounts of CO_2. This imposes a problem when synchronization between models is desirable.

References

[1] L.M. Pecora, T. L. Carroll, G. A. Johnson, and D. J. Mar, “Fundamentals of synchronization in chaotic systems, concepts, and applications”, *Chaos* 7, 520 (1997).
[2] S. Boccaletti, J. Kurths, G. Osipov, D. J. Valladares, and C. S. Zhou, “The synchronization of chaotic systems”, *Phys. Rep.* 366, 1 (2002).
[3] A.A. Tsonis, K. Swanson, and S. Kravtsov, “A new dynamical mechanism for major climate shifts”, *Geophys. Res. Lett.* 34, L13705 (2007).
[4] K.L. Swanson and A.A. Tsonis, “Has the climate recently shifted?”, *Geophys. Res. Lett.* 36, L06711 (2009).
[5] G. Wang, K.L. Swanson, and A.A. Tsonis,“The pacemaker of major climate shifts”, *Geophys. Res. Lett.* 36, L07708 (2009).
[6] S. Ineson, and A. A. Scaife, The role of the stratosphere in the European climate response to El Nino, Nat. Geosci., 2, 32–36 (2009).
[7] Kravtsov, S., M. G. Wyatt, J. A. Curry, and A. A. Tsonis (2014), Two contrasting views of multidecadal climate variability in the twentieth century, Geophys. Res. Lett., 41, doi:10.1002/2014GL061416.

[8] K. Steinhaeuser and A.A. Tsonis (2013), A climate model intercomparison at the dynamics level, Clim. Dyn. Doi:10.1007/s00382-013-1761-5

Publications from this research

1) G. Wang, P. Yang, X. Zhou, K.L. Swanson, and A.A. Tsonis (2012), Directional Influences on Global Temperature Prediction. Geophys. Res. Lett., 39, L13704, doi:10.1029/2012GL052149.
2) A.A. Tsonis and K.L. Swanson (2012), On the origins of decadal climate variability. Nonlinear Process in Geophysics., 19,559-568, doi:10.5194/npg-19-559-2012
3) K. Steinhaeuser and A.A. Tsonis (2013), A climate model intercomparison at the dynamics level, Clim. Dyn. Doi:10.1007/s00382-013-1761-5
4) Kravtsov, S., M. G. Wyatt, J. A. Curry, and A. A. Tsonis (2014), Two contrasting views of multidecadal climate variability in the twentieth century, Geophys. Res. Lett., 41, doi:10.1002/2014GL061416.

Presentations

1) A.A. Tsonis: A new dynamical mechanism for major climate shifts. Third Santa Fe Conference on Global and Regional Climate Change Oct. 30-Nov. 4, 2011 (Invited speaker).
2) A.A. Tsonis: Atlantic Multidecadal Oscillation and Northern Hemisphere's climate Variability Poster presentation in DOE climate modeling PI meeting, 19-22 Sept., 2011.

3) A.A. Tsonis: A climate model intercomparison at the dynamics level, Presentd at:

a) AGU fall 2012 meeting (Invited speaker).

b) 12 Int. Meeting on Statistical Climatology, 24-28 June 2012, Jeju, Korea (Invited speaker).

c) Facets of Uncertainty, 5^{th} EGU Leonardo Conference, 17-19 October 2013, Kos, Greece (Invited speaker).

d) EGU, April 2013, Vienna, Austria (Invited speaker).

e) European Conference on complex networks, 22-26 September 2014, Lucca, Italy.

Travel

Travel to the above seven presentations and to DOE BER climate modeling proposal review panel, 16-18 May, 2011.

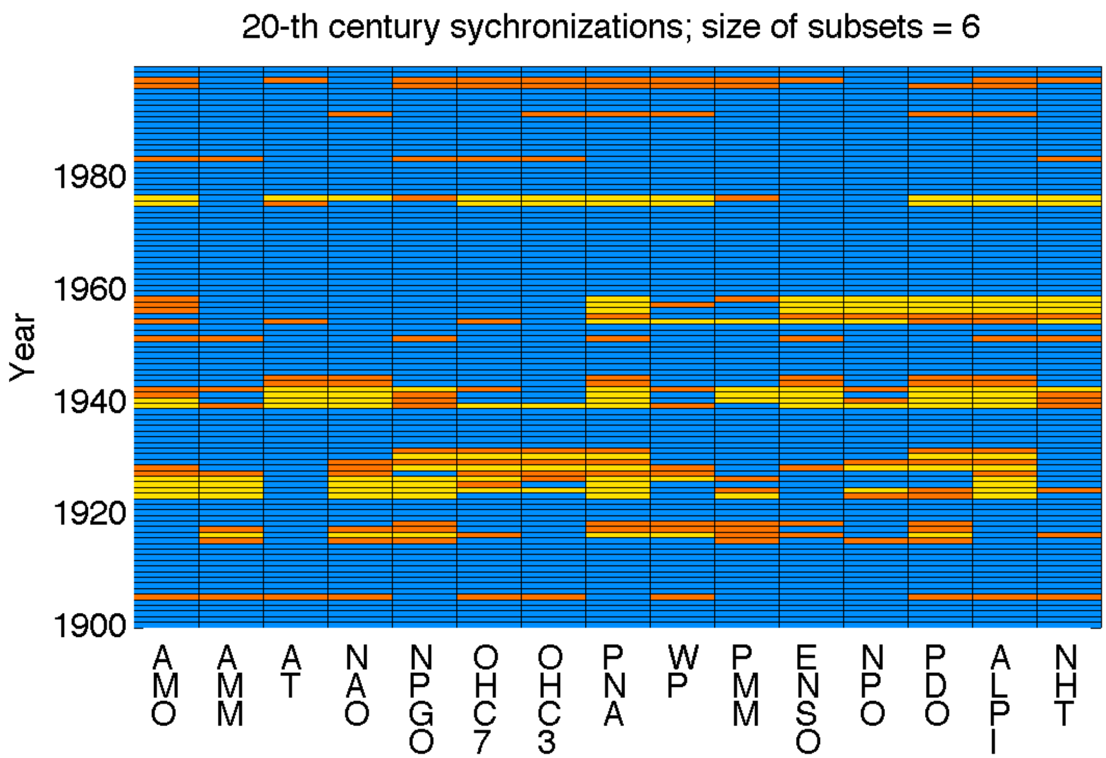


Figure 1: (see text for explanation)

AMO: Atlantic Multi-decadal Oscillation, AMM: Atlantic Meridional Mode

AT: Atmospheric-mass Transfer anomalies index, NAO: North Atlantic Oscillation

NPGO: North Pacific Gyre Oscillation, OHC7: Ocean Heat Content at 700 meters index

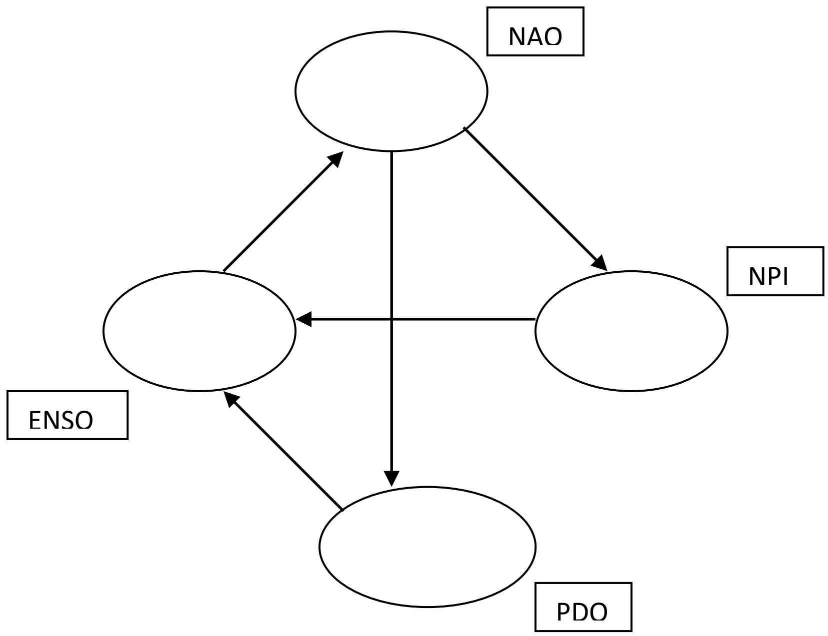
OHC3: Ocean Heat Content at 300 meters index, PNA: Pacific North America index

WP: Western Pacific Pattern index, PMM: Pacific Meridional Mode

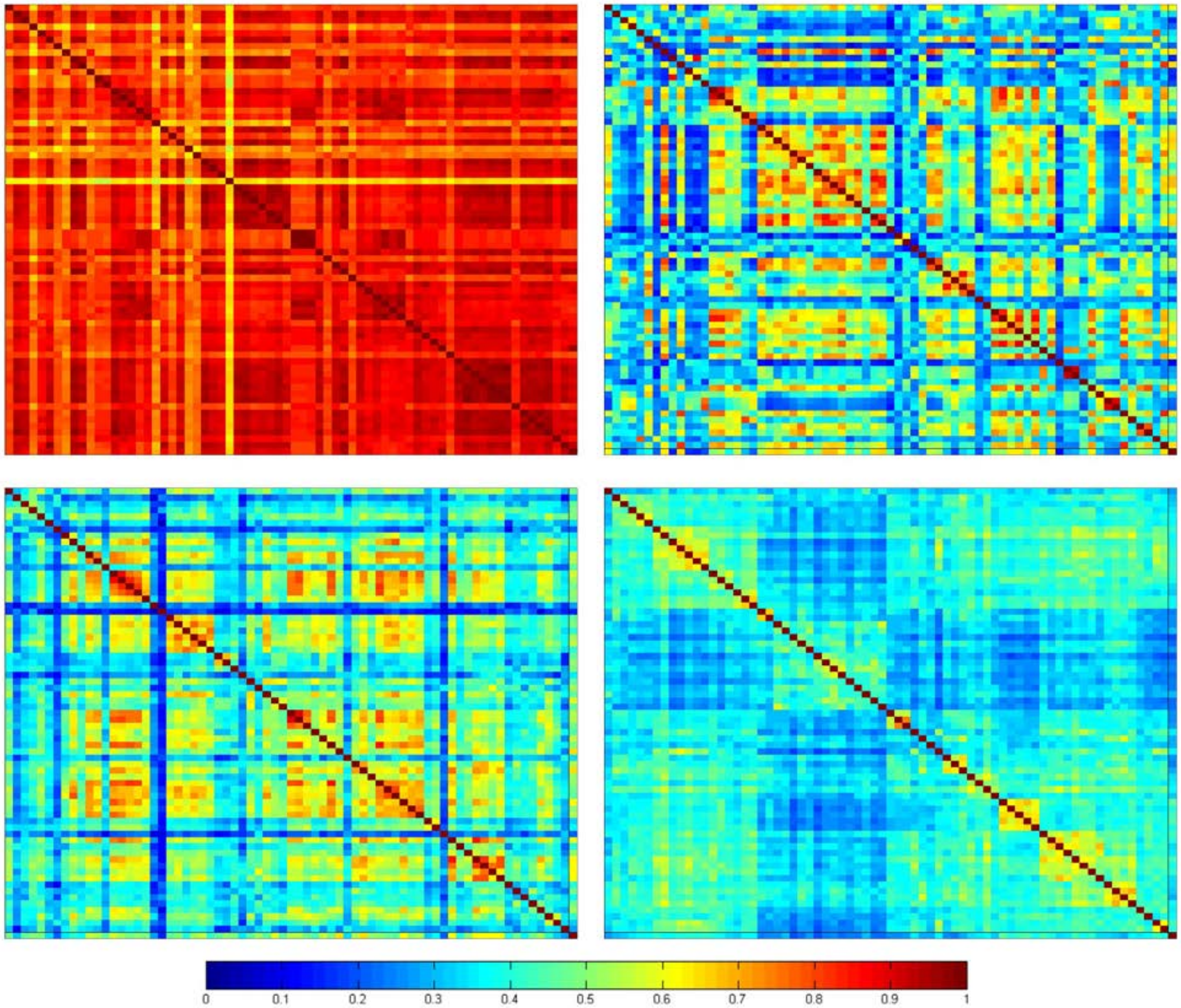
ENSO: El Nino/Southern Oscillation 3.4, NPO: North Pacific Oscillation

PDO: Pacific Decadal Oscillation, ALPI: Aleutian Low Pressure index

NHT: Northern Hemisphere Temperature



<u>Figure 2</u>: Directional influences in the network of four modes.



<u>Figure 3.</u> We considered 70 20-century forced runs from 23 different CMIP3 climate models. For each run we considered four fields: (A) the 500 hPa field, (B) the Sea Level Pressure (SLP) field, (C) the Surface Air Temperature (SAT), and (D) the precipitation field. For each run and each field we constructed the network and delineated its communities. We then estimated the Adjusted Rand Index (ARI) between a model run and all other available model runs The top left panel corresponds to the 500 hPa field, the top right to the SLP field, the bottom left to the SAT

field, and the bottom right to the precipitation field. The top row is the comparison of run 1 with all other runs and the bottom row is the comparison of run 70 with all other runs. The ARI between a run with itself is equal to one (red diagonal). Here NCEP (reality) is also included as number 71 (last row/column) separated from the runs by a thin black. Most models do well in simulating the features of the upper atmospheric flow, but not well in simulating the SLP, SAT, or precipitation fields. This is an issue especially for SAT and precipitation, as those are the fields that are predicted to get projections of regional temperature and precipitation changes under CO_2 forced scenarios. Even if the models manage to agree on global averages they surely don't agree on regional changes.