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AGU BOOKSHELF

Climate Dynamics: Why Does Climate Vary?

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In recent years, climate change has become a major focus of public and political discussion. Ongoing scientific inquiry, revolving predominantly around understanding the anthropogenic effects of rising greenhouse gas levels, coupled with how successfully findings are communicated to the public, has made climate science both contentious and exigent. In the AGU monograph Climate Dynamics: Why Does Climate Vary?, *editors De-Zheng Sun and Frank Bryan reinforce the importance of investigating the complex dynamics that underlie the natural variability of the climate system. Understanding this complexity—particularly how the natural variability of climate may enhance or mask anthropogenic warming—could have important consequences for the future. In this interview,* Eos *talks to De-Zheng Sun.*

Eos: *What are examples of strong climate forces other than an augmented greenhouse effect?*

Sun: We live in air and water. The force that underlies all other climate forces is buoyancy, which is in turn linked to Earth's gravity field. Air and water move because the atmosphere is heated unevenly in both the vertical and horizontal directions. The greenhouse effect is a contributor to this differential heating. The motion has a wide range of spatial and temporal scales and can be very nonlinear. The differences in density and heat capacity between air and water, and the phase changes of water, all add to the complexity of the motion in the atmosphere and ocean and thereby to the complexity of the climate system. Because of this complexity, even without any external forcing from human activity, the state of the climate system varies substantially.

The book covers such variability over several time scales. For example, on the intraseasonal time scale the Madden-Julian Oscillation (MJO) occurs due to the self-organization of deep convection over the warmest parts of tropical oceans. Deep convection is a form of motion in the atmosphere in response to vertical differential heating amplified by the presence of moisture. On the seasonal time scale, monsoons bring the essential water for crops to grow in many regions of the world, particularly in South Asia and Southeast Asia. The monsoon system is a showcase of the effect of differential heating in the horizontal direction—the difference in the heating over land and the ocean—on climate.

Next on the time scale ladder is the El Niño–Southern Oscillation (ENSO). Every 2–7 years the western Pacific warm pool extends to the east, resulting in anomalous warming in the central and eastern Pacific Ocean. The warming in turn causes changes in the large-scale circulation in the atmosphere and ocean and thereby affects climate worldwide, including that of the United States. The ENSO phenomenon owes itself to the coupling between the atmosphere and the ocean and, in my view, is also a good example of the power of heating and nonlinearity in the presence of two fluids with different heat capacity and density. On the decadal time scale the book has a chapter on the Pacific Decadal Oscillation, whose causes are still being fully unraveled.

These are only a few examples, but one thing this book emphasizes is that, at least for interannual and decadal time scales, the climate is capable of varying in a substantial way in the complete absence of any external forces.

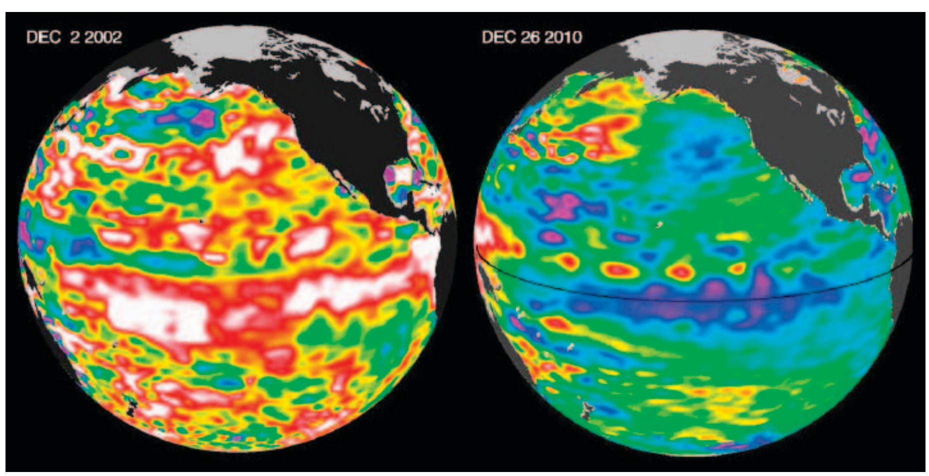
Eos: *Many studies seek to distinguish the natural climate variability you just mentioned from anthropogenic effects. Is such a distinction clear-cut?*

Sun: No. As I've already mentioned, the greenhouse effect is a contributor to the differential heating in the atmosphere that sets air and water in motion. When we enhance the greenhouse effect in the atmosphere by adding carbon dioxide (CO_2), what the dynamics of the atmosphere feels is its heating effect. To the degree that climate variability is linked to the motions in the atmosphere and ocean, and to the degree the latter is due to the differential heating to which the greenhouse effect contributes, changes in variability are expected to be the norm of the effect of anthropogenic forcing.

However, the anthropogenic effect was initially studied in a way that gave focus to its effect on the globally averaged energy balance. One-dimensional models were the early tools used to study the anthropogenic effect. While these models illustrated the importance of various radiative feedbacks in the context of global energy balance perturbed by an increase in CO_2, they did not have the MJO, monsoons, ENSO, or the Pacific Decadal Oscillation, all of which may change in behavior as more greenhouse gases are released. All you can get from these one-dimensional models is a monotonic increase in global mean temperature as you increase CO_2 in the atmosphere.

Although three-dimensional models have now been developed, the conceptual picture about the effect of an increase in CO_2 is still largely underpinned by the results from those one-dimensional models, as is evident in the notion that a significant linear trend in temperature will be the defining feature of global warming caused by anthropogenic enhancement of the greenhouse effect. The continuing influence from these early models over the way people conceptualize the anthropogenic effect is also because the state-of-the-art three-dimensional models still do not properly simulate natural variability such as MJO and ENSO. As a result, models are not yet able to capture the anthropogenic effect that takes place in the form of climate variability. In other words, our models may be underestimating the effect from anthropogenic forcing on natural variability. It is time to look seriously at an alternative hypothesis, which is that the defining feature of global warming will be changes in the magnitude of climate variability, as I note in chapter 6.

I also wanted to use this book to urge caution with regard to another traditional idea: that even if we don't simulate natural



Dramatic variations in sea surface temperature between (left) El Niño and (right) La Niña play a large role in the dynamic nature of Earth's climate. Red indicates surface temperatures warmer than average, and blue indicates surface temperatures cooler than average. Improving scientific understanding of the El Niño–Southern Oscillation, which cycles through El Niño and La Niña states every 2–7 years, could help unmask the effects of global climate change. Image courtesy of NASA Jet Propulsion Laboratory.

variability very well, we may still get anthropogenic global warming right. Such an assertion is probably too optimistic. One of the key questions is whether the simulated climate system is in the correct dynamic regime, because a system near a critical point can respond very differently than a system that is in a very stable regime. A poor simulation of a natural mode of variability such as MJO or ENSO suggests that the involved system is not in the correct dynamic regime. Also, those feedbacks that affect global energy balance, such as cloud and water vapor feedbacks, may depend on the natural variability—MJO, ENSO, etc. However successful state-of-the-art climate models may be in simulating some key features of the climate system, the question of whether these models capture fully the complexity of the dynamics—in particular, whether or not these models are in the same dynamic regime as the observed climate—has yet to be answered.

Eos: *How should we seek to quantify climate changes stemming from anthropogenic release of greenhouse gases? How can we separate the impacts of climate variability from anthropogenic effects?*

Sun: The prevailing conceptual framework that has been used to quantify climate changes stemming from anthropogenic forcing is that increasing CO_2 concentration will create a linear trend in temperature and other state variables that define the mean climate. I would suggest that the focus may need to shift from looking for trends in mean temperature to statistical changes in the magnitude and other attributes of natural variability. The effect of anthropogenic forcing is likely to manifest in climate phenomena at all time scales so long as these climate phenomena derive energy from differential heating. This shift in paradigm may further highlight the need for a better understanding of the mechanisms behind natural variability, in particular, their thermal and nonlinear aspects.

Such a shift in paradigm will also highlight the need for more data with finer spatial and temporal resolution. Motions with smaller spatial scale and on the faster side of the spectrum of motions in the climate system may indeed be those on the front line responding to the additional thermal stress exerted on the climate system from manmade greenhouse gases. In this connection, it is worth noting that it is the fast and small-scale motions that climate models are not yet able to fully resolve, and thus they underestimate variability. This in turn speaks of the need for more powerful computers in climate change research.

Eos: *A large portion of the monograph is dedicated to ENSO. Why is this system so important when discussing climate change?*

Sun: ENSO is indeed special in many ways. It is a natural climate variability mode that involves both the atmosphere and the ocean. The signal is large and global in scale. We also have a relative abundance of data describing this phenomenon in the real world. It bears particular importance in discussing climate change because a deeper understanding of its causes, in particular, its relationship with the heat budget in the tropical Pacific and beyond, may hold the key to understanding how the greenhouse effect influences natural variability.

Studies have suggested that the very existence of ENSO may be linked to the intensity of the heat flux into the equatorial ocean and that ENSO events collectively may regulate the tropical maximum sea surface temperatures, which in turn can affect other climate modes. These findings have obvious implications about how the anthropogenic effect may influence ENSO variability and how ENSO variability may in turn influence the anthropogenic effect on the Earth's temperature.

Eos: *Rising temperatures supposedly increase the strength of monsoons, with the potential for drastic effects on human health and quality of life. One chapter of the book deals with monsoon variability in a changing climate. How does increased warming interact with the monsoon system?*

Sun: In the simplest terms, monsoons are driven by a thermal land-sea contrast. As the summer Sun arrives, the land is heated more quickly than the ocean, creating a temperature gradient that causes storms. So if you increase CO_2, you add more heating, and assuming all other things are fixed, that will tend to heat the land more quickly than the ocean, leading to a strong monsoon.

That's the zero-order picture, however. In one chapter of the monograph, one of the contributors, Tim Li from the University of Hawai`i, showed that ENSO events can affect the Asian monsoons and that ocean-atmosphere interaction over the Indo-Pacific warm pool can cause biannual oscillations in the rainfall in monsoon regions. He also shows that these monsoon systems are capable of strong intraseasonal variability owing to dynamical processes. This means that interpretations of the changes in the monsoon need to be a little more cautious. Both local and remote dynamical processes need to be assessed.

Eos: *In the book you seem to be concerned about the approach some scientists take when talking to the public about climate change. What is it you are worried about?*

Sun: Climate scientists are subject to pressure and difficulty in communicating to the public about global warming science. Overall, I think we have done a good job, but I also sense that the complexity of the dynamic processes seems to be either overlooked or oversimplified in many communications to the public. I suspect that could cause problems down the road, because we know climate can vary strongly on a range of time scales in the complete absence of any external forcing. If you overlook the complex dynamics of the climate system, and you don't explain those processes up-front to the public, then you can cause confusion down the road.

For example, this past winter was pretty cold—we got lots of snow in North America and strong winter storms in Europe. Some climate scientists and the media, who have been more inclined to equate climate change to a monotonic warming, appeared to experience some trouble in explaining this harsh winter to the public. If one feels difficulty and potential embarrassment in explaining away a cold winter, what happens if we witness that the coming decade is cooler than the decade we have just lived through, something we know is possible within the realm of natural variability? If what is conveyed to the public is essentially a monotonic warming, how do we explain a halting or a reversal in the global temperature trend? I think it is better to be as forthright as possible, risking a little bit of confusion up-front, rather than losing credibility later on.

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—Colin Schultz, Staff Writer