DO THE TROPICS RULE?

Assessing the State of Tropical Climate Science

BY RICHARD SEAGER, JOHN C. H. CHIANG, AND JEFFREY SHAMAN

The tropics are now thought of as the dominant player in the global climate system. This is remarkable given that just a few decades ago dynamical meteorology was focused largely on mid-latitude circulations, with the tropics receiving far less attention. However, intensive research into tropical climate, in particular El Niño–Southern Oscillation (ENSO), fundamentally altered our view of global climate. Advances in equatorial oceanographic and atmospheric dynamics in the 1960s and 1970s paved the way for understanding ENSO as a coupled ocean–atmosphere system in which two-way interaction produced an entirely new regime of behavior. In the 1980s it was shown that ENSO is the largest coherent single source of global climate variability on interannual-to-decadal time scales with the tropics and extratropics communicating via atmospheric planetary waves. Because ENSO events are predictable with skill up to a year in advance, this translated into an ability to make seasonal forecasts of regional climate. These forecasts have tremendous societal benefit as they afford climate-vulnerable regions time to prepare for adverse environmental conditions. Finally, studies of the recent and long-term past indicate that the tropics played a key role in past climate changes, including the mid-1970s decadal climate shift, changes in the West African and Asian monsoons, and north–south shifts of tropical rainbands. These provide motivation for determining how the tropics will change in the future, both on their own and as a response to increased radiative forcing.

The career of Professor Mark Cane of Columbia University's Lamont-Doherty Earth Observatory both shaped and spanned this important scientific history; indeed, he has arguably had the greatest influence of any individual on this shift in our understanding of the global climate systems. Cane's research has led to fundamental advances, specifically tropical ocean dynamics and ocean–atmosphere interactions, seasonal forecasting, applications of climate science to society, data analysis techniques, and paleoclimate dynamics. Along with Steve Zebiak

THE TROPICS RULE: A SYMPOSIUM HONORING MARK CANE'S CONTRIBUTIONS TO CLIMATE SCIENCE

WHAT: Over 150 climate scientists from the United States and abroad participated in two days of talks and discussion on the progress made in tropical climate science over the last few decades, in particular on topics that Columbia University's Mark Cane has helped bring to the fore of climate science: ENSO and equatorial dynamics, climate prediction, climate impacts, and the tropics in past and future climate.
WHEN: 20–21 October 2014
WHERE: Palisades, New York

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(Columbia University), he developed the first self-consistent dynamical model of ENSO and in 1986 produced the first dynamical prediction of ENSO that successfully forecast the 1986/87 El Niño event a half year in advance (Cane et al. 1986). This and subsequent work paved the way for routine predictions of ENSO and the development of operational seasonal-to-interannual predictions of global climate variability. He also led the way in the application of climate information and was the driving force in the creation of the International Research Institute for Climate and Society (IRI), an organization now considered a world leader in using predictive climate information for the betterment of society. Cane also developed new methodologies for the global reconstruction of climate fields over the instrumental era, in particular sea surface temperature (Kaplan et al. 1997). More recently, he has focused on the role of the tropics in past and future climate changes, championing the importance of the tropics, and in particular the ENSO system, in determining global climate changes of the Holocene, glacial period, and the Pliocene (e.g., Clement et al. 1999). Much of the community's work in recent years on tropical paleoclimate and its global implications can be directly traced back to Cane's pioneering efforts.

SYMPOSIUM. A symposium honoring Mark Cane and his role in the advancement of climate science was held at the Lamont-Doherty Earth Observatory of Columbia University in October 2014. The event brought together colleagues and students in climate-related research, as well as Cane's current and former students and postdocs. Two days of talks focused on subject areas that Cane has helped bring to the fore: ENSO and equatorial dynamics, climate prediction, climate impacts, and the tropics in past and future climate. The symposium was primarily prospective and focused on unresolved questions and ongoing issues. Indeed, a number of challenges were put forth to the broader community, including improvement of decadal prediction, better integration of climate science and its impacts in decision-making, and the need for greater rigor and inclusion of dynamics in global climate change science.

Day 1 of the symposium began with a retrospective session on the development of tropical ocean–atmosphere interactions, equatorial wave dynamics, and a theory for ENSO. The aforementioned Steve Zebiak, David Halpern (NASA JPL), and Ed Sarachik (University of Washington) each provided historical context on the advances during the 1960s to 1980s that led to ENSO prediction. Cane's role in these developments, as well as the seminal work of his colleagues and predecessors, was highlighted. However, many aspects of the tropical ocean–atmosphere system remain poorly understood, as the second session, which focused on outstanding issues in tropical ocean–atmosphere interactions, underscored. Amy Clement (University of Miami) discussed our limited understanding of multidecadal climate variability, and Christina Karamperidou (University of Hawai'i at Mānoa) and Eli Tziperman (Harvard University) both explored the new problems posed by how climate and weather variability respond to and interact with warming trends. Fei-Fei Jin (University of Hawai'i at Mānoa) presented recent advances in understanding the dynamics of ENSO complexity.

The first afternoon session focused on the development and status of seasonal-to-decadal climate prediction. Lisa Goddard (IRI) discussed the practical limits to seasonal-to-interannual predictability, identifying key sources of uncertainty and how those uncertainties limit the use of such predictions. Sulochala Gadgil (Indian Institute of Science) spoke on the South Asian monsoon prediction problem and highlighted the emerging awareness of the critical role of the Indian Ocean dipole mode. Tony Rosati (University of Maryland) argued for the role of the tropical Pacific in the recent global warming hiatus. Jeffrey Shaman (Columbia University) presented the recent development of prediction systems for infectious diseases, including influenza and Ebola.

The final session of day 1 explored the impact of climate on society. Heidi Cullen (Climate Central) spoke on the role for climate scientists in communicating climate science information to the general public. Sam White (The Ohio State University) presented evidence of an impact of climate on societal vitality from the historical record, in particular on the first American colonies. Eugenia Kalnay (University of Maryland) introduced a new conceptual model for understanding the interaction between society and the environment. Gidon Eshel (Bard College) discussed the impact that the American diet has on the geophysical environment via land and water use, biodiversity, reactive nitrogen discharge, and greenhouse gas emissions.

Day 2 of the symposium focused on the tropics in climate change, from paleoclimate time scales to the present and future. The first session of the morning was devoted to outstanding issues in paleoclimate dynamics. David Battisti (University of Washington) revisited the question of why the ocean overturning circulation was situated in the Atlantic and not the Pacific, reviewing various hypotheses for why the

Atlantic is the saltier ocean. Peter Molnar proposed that the saltier Atlantic is a result of the emergence of the eastern equatorial Pacific cold tongue since the Pliocene. Jeffrey Severinghaus (University of California, San Diego) introduced some exciting new results from the West Antarctic Ice Sheet (WAIS) Divide ice core record, in particular showing that abrupt Dansgaard–Oeschger warming recorded in Greenland ice cores led the onset of cooling seen in WAIS Divide core by ~200 years, demonstrating convincingly that the northern high latitudes lead the southern high latitudes during these events and that the influence is mediated through ocean circulation (WAIS Divide Project Members 2015). Finally, John Chiang (University of California, Berkeley) spoke on a new hypothesis for East Asian paleomonsoon changes, focusing on the role of the westerlies impinging on the Tibetan Plateau.

The paleoclimate theme continued into session 2 with two talks discussing the state of the tropical Pacific during the Pleistocene. David Lea (University of California, Santa Barbara) showed that the current observational evidence for equatorial Pacific variability is in concert with glacial–interglacial variations and argued that it is primarily a response to CO_2 variations. Tom Koutavas (City University of New York, Staten Island) presented exciting new data that suggest ENSO variations increased during the last glacial maximum but were reduced during the mid-Holocene. Julien Emile-Geay (University of Southern California) discussed the evolution of the tropical Pacific during the Holocene from a data–model synthesis. Finally, Gerald Meehl (National Center for Atmospheric Research) brought the discussion to the present by focusing on the role of the tropical Pacific on interannual through decadal time scales and its likely role in the recent global warming "hiatus."

The first afternoon session focused on the tropics in future climate. Richard Seager (Columbia University) discussed the response of tropical SST changes in both twentieth-century observations and Coupled Model Intercomparison Project phase 5 (CMIP5) simulations, arguing that model simulations underestimate the spatial contrast of the SST response. Mojib Latif (University of Kiel) highlighted uncertainty in our understanding of tropical Pacific climate and ENSO, as well as the importance of the mean state for simulating variability. David Neelin (University of California, Los Angeles) presented recent advances in the physics of convection with implications for understanding future precipitation changes. Last, Shang-Ping Xie (University of California, San Diego) discussed whether patterns of rainfall change could be understood and predicted for the future.

The final session of the symposium highlighted the perspectives of climate dynamics from some key contributors to the field. Tim Palmer (University of Oxford) discussed nonlinear dynamics and regime shifts as a paradigm for understanding climate changes. George Philander (Princeton University) argued for a marriage of reductionist and holistic approaches to climate science, similar to what happened in weather forecasting. John Marshall [Massachusetts Institute of Technology (MIT)] argued that the ocean is key to transient climate change, setting the time scale of the response through the ocean's heat capacity and also producing spatial patterns of SST response. Finally, Isaac Held (NOAA/GFDL) discussed advances in our fundamental understanding of tropical cyclones through idealized modeling; for example, a recent study by Merlis et al. (2013) showed that the number of tropical cyclones simulated in an aquaplanet is highly sensitive to the poleward positioning of the intertropical convergence zone. As such, he argued that advances similar to those made in understanding extratropical cyclones since the mid-1970s are under way.

CANE'S CLOSING REMARKS. The symposium stands as a testament to Mark Cane's tremendous impact on the field, and it was fitting that the proceedings ended with him. He discussed the emergence of ENSO science and remarked on his fortune to have stumbled into a field of "such profound ignorance" whereupon he could participate in its creation. Cane attributed the successful development of ENSO science to the gathering and synthesis of data (Jacob Bjerknes, Klaus Wyrtki, Eugene Rasmussen, and Thomas Carpenter) that gave the theorists "something to shoot for" and the availability of simple wave theory (initially from James Lighthill, Taroh Matsuno, and Andrew Moore) that was enormously effective at understanding the features that matter to ENSO. It also helped that the research community was able to focus on the right questions—namely, ocean–atmosphere interactions—rather than being distracted by elegant but ultimately irrelevant features like the theory of the equatorial undercurrent.

Cane also reflected on the state of paleoclimate science, which today exhibits the same features that made ENSO such an attractive research proposition at the beginning of his career. Like ENSO at the time, there remains a profound ignorance so

that "everything is in play"; however, the amount of paleoclimate data collected over the last decade rivals all the data collected prior to the last decade, and climate models now can be used as effective tools for exploration. According to Cane, among our scariest ignorances is our lack of understanding of what drove the abrupt climate events during the recent glacial period: how is it possible that the climate system could reorganize so profoundly in a decade? He cautioned this lack of understanding should make us all circumspect of what we can predict for the future.

Cane closed with some advice for those starting off in the field. He related his philosophy of research that was instilled in him by his advisor Jule Charney, and reinforced through interactions with Wally Broecker: that *we should all work on what matters*. Given that there is still a vast amount of ignorance in our understanding of the climate system, those starting their careers should find plenty of opportunity.

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