

ENSO EXTREMES AND DIVERSITY

Dynamics, Teleconnections, and Impacts

BY AGUS SANTOSO, WENJU CAI, MAT COLLINS, MIKE MCPHADEN, FEI-FEI JIN, ERIC GUILYARDI, GABRIEL VECCHI, DIETMAR DOMMENGET, AND GUOJIAN WANG

Underlying a predictive capability of the El Niño–Southern Oscillation (ENSO) is a grounded understanding of its dynamics. The 1982/83 and 1997/98 “super–El Niño” events pose a challenge to this understanding. The 1997/98 event was dubbed “the climate event of the twentieth century” for its extraordinary magnitude and global-scale destructive effects. Modeling studies over the last 2 years have led to further insights into extreme El Niños and have found that their frequency is projected to increase significantly under greenhouse warming.

ENSO EXTREMES AND DIVERSITY: DYNAMICS, TELECONNECTIONS, AND IMPACTS

WHAT: Sixty leading ENSO experts met to review recent progress in ENSO research and determine the present state of understanding of ENSO in terms of its extreme and diverse behavior and its overarching physical implications.

WHEN: 4–6 February 2015

WHERE: Sydney, New South Wales, Australia

AFFILIATIONS: SANTOSO—ARC Centre of Excellence for Climate System Science and Climate Change Research Centre, University of New South Wales, Sydney, Australia; CAI AND WANG—CSIRO Marine and Atmospheric Research, Aspendale, Victoria, Australia; COLLINS—College of Engineering Mathematics and Physical Sciences, University of Exeter, Exeter, United Kingdom; MCPHADEN—NOAA/Pacific Marine Environmental Laboratory, Seattle, Washington; JIN—Department of Meteorology, SOEST, University of Hawai‘i at Manoa, Honolulu, Hawaii; GUILYARDI—NCAS–Climate, University of Reading, Reading, United Kingdom, and Laboratoire d’Océanographie et du Climat: Expérimentation et Approches Numériques (LOCEAN), IRD/UPMC/CNRS/MNHN, Paris, France; VECCHI—NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey; DOMMENGET—ARC Centre of Excellence for Climate System Science and School of Earth, Atmosphere and Environment, Monash University, Clayton, Victoria, Australia

* Pacific Marine Environmental Laboratory Contribution No. 4328

CORRESPONDING AUTHOR: Dr. Agus Santoso, Climate Change Research Centre, L4 Mathews Bldg., University of New South Wales, Sydney, NSW 2052, Australia
E-mail: a.santoso@unsw.edu.au

DOI:10.1175/BAMS-D-15-00141.1

In final form 11 May 2015
©2015 American Meteorological Society

In boreal spring of 2014, the tropical Pacific was primed for an El Niño, when most forecast agencies such as the National Oceanic and Atmospheric Administration (NOAA) and the Australian Bureau of Meteorology elevated their El Niño probability to more than 60%. A remarkable increase in warm water volume with a series of westerly wind bursts in boreal spring alerted ENSO experts to the possibility of a strong event, one which some thought could be the first extreme El Niño since 1997, generating news headlines worldwide. However, while the equatorial Pacific remained anomalously warm, the expected super–El Niño did not materialize. That failed expectation may, in part, be a reflection of our incomplete knowledge of extreme El Niño and its predictability or perhaps the very nature of the ENSO system itself.

Against this backdrop of progress, uncertainties, and ensuing greenhouse warming, it is timely to ask—what is the current state of understanding of ENSO diversity, extremes, impacts, and teleconnections? It is for this reason that ENSO researchers gathered in Sydney, Australia, earlier this year for a 3-day workshop at the University of New South Wales. The 60 participants consisted of leading ENSO experts,

including 20 postdoctorates and graduate students, who delivered 39 oral and 24 poster presentations, highlighting recent advances and ongoing research to facilitate the discussions of ENSO extremes and diversity. The science presented covered the use of modeling, observations, theories, and paleoreconstructions.

The workshop was opened by a stimulating presentation called “Who Killed the Big 2014 El Niño,” which outlined the possible factors that may hold the key to understanding this elusive event. The general perception is that the atmospheric feedback failed to occur, despite the significant ocean subsurface warming, and this appears to be due to various factors such as the cold phase of the interdecadal Pacific oscillation (IPO) or the Pacific decadal oscillation (PDO), an anomalously warm Indian Ocean, and muted westerly wind bursts, among other possibilities. All of these factors reflect the main complexities of ENSO dynamics, which remain today an active topic of investigation. These are outlined below as discussed by several presenters.

ROLE OF THE BACKGROUND STATE ON ENSO VARIABILITY. The mean climate, upon which ENSO evolves, varies on multidecadal time scales, manifesting itself as a global-scale phenomenon in what is commonly known as the IPO or PDO. Disentangling the link between ENSO and IPO has been one challenging research topic as the two are intertwined. Is the IPO an ENSO rectification effect on the mean climate, for instance through ENSO skewness as discussed by a presenter? Or is the IPO an independent mode of low-frequency variability that impacts ENSO? A clear example of this was demonstrated in a presentation that ENSO predictability was weaker during the recent negative IPO phase than during the preceding positive IPO phase. Our current theoretical understanding, as mentioned by a keynote speaker, is that modest changes in the basic state can lead to different types of El Niño emerging during certain epochs. As such, the presence of the IPO would complicate the detection of greenhouse warming effects, as well as other external forcing, on ENSO changes.

PRECURSORS. A positive warm water volume anomaly was mentioned to be a necessary condition for a strong El Niño, as are strong westerly wind anomalies in boreal spring/summer. Warm water volume increase is achieved through downwelling Kelvin waves, often initiated by westerly wind bursts. However, it was shown that the different spatial and

temporal characteristics of the wind bursts mean that the effect of the generated waves on El Niño development can be very different. A potential link between variations in the warm pool spatial structure and development of strong El Niño was also suggested. Other precursors of extreme El Niño include specific vacillations in surface pressure in the Southern and Northern Hemispheres, respectively, referred to as the “Southern Hemisphere booster” and the “Pacific meridional mode.” Such insights have direct implications for the seasonal prediction of El Niño.

INTERBASIN INTERACTIONS. While ENSO influences air–sea processes outside of the tropical Pacific, those processes in turn affect ENSO evolution. The interactions between climate variability in the Indian (e.g., Indian Ocean dipole), Atlantic, and extratropics (e.g., North Pacific Oscillation) were presented, with apparent impacts on ENSO evolution. The results, which can be model dependent, suggest that understanding ENSO evolution should be approached from a global perspective rather than focusing solely on the tropical Pacific.

COUPLED FEEDBACK PROCESSES. Representing ENSO feedbacks in climate models remains challenging, with biases attributed significantly to inaccuracies in cloud simulation. A presentation showed cloud feedback accounts for a substantial portion of ENSO variability in a climate model. This issue needs to be resolved, not least because the growth of extreme El Niños was suggested to involve convectively nonlinear Bjerknes feedbacks. On a closely related topic, the characteristics of coupled feedback processes were shown to be notably different between eastern and central Pacific ENSO events, contributing to the debate as to whether ENSO exhibits a number of independent modes of variability or whether these are part of an ENSO continuum.

SEASONAL PHASE LOCKING. The explanation for why ENSO amplitude tends to peak in boreal winter is not complete. Yet seasonal phase locking contributes to the nonlinear behavior of ENSO, such as the southward wind shift at the peak of a strong El Niño that leads to the demise of the event and preconditioning for La Niña in the following year. Seasonal feedback between clouds and sea surface temperature (SST) was suggested to be a mechanism for ENSO seasonal phase locking. Other potential contributors include the annual cycle of the warm pool, as well as feedback from Atlantic and Indian Ocean variabilities.

ENSO ASYMMETRY. El Niño and La Niña are not mirror images of one other. El Niño events tend to be of shorter duration and can attain a much larger magnitude than La Niña. Asymmetry underpins the notion of ENSO extremes whose many aspects were extensively discussed, from the characteristics of SST anomaly patterns and the ocean mixed-layer heat budget to the nonlinear response of rainfall to SST anomalies. The role of reversing equatorial Pacific zonal currents coupled with an eastward shift of atmospheric convection in pushing El Niño to extreme amplitudes was also highlighted. This mechanism was also proposed as a possible explanation for the differing skewness of ENSO SST anomalies across models.

The aforementioned factors are an integral component of ENSO dynamics. A better understanding in one will lead to further insights into another. Rapid gain of knowledge has been facilitated by the breadth of data from the latest generation of climate models as part of the Coupled Model Intercomparison Project (CMIP) initiative. Data from the fifth phase of CMIP (CMIP5) were utilized by several presenters. It was shown that although CMIP5 models still have issues in simulating many aspects of ENSO including its extremity, they have some success in seasonal predictions of the 1997/98 event. This is in part because of the good quality observational data used to initialize the models, but the predictive skill is hampered by numerical drifts and model biases.

The challenge in simulating ENSO was highlighted. One presentation showed that atmosphere–ocean dynamics can be very different in an ocean-only model forced by air–sea fluxes than when it is coupled to an atmospheric model, illustrating the complex coupled nature of ENSO. In earlier generations of models, “flux adjustments” were used to more realistically capture the seasonal cycle and minimize drifts. However, flux adjustments are a rather artificial fix to a problem that is inherently complex. A finer model resolution has been generally thought to be the most appropriate solution. A speaker, however, put forth a compelling argument for the use of flux adjustment, which appears to actually have overarching benefits along with increasing resolution. Regardless of these issues, the large diversity, accessibility, and economy of running CMIP models make them desirable for understanding future projections of ENSO. In light of the relatively short instrumental record, paleo-reconstructions are also a useful tool. Here, a speaker provided paleo-based evidence that an increase in ENSO variance since the mid-Holocene is outside the range of internal variability, indicating the role of external forcing.

How ENSO responds to greenhouse warming has long been a contentious issue, with disagreement among the models in projecting ENSO’s amplitude, typically defined as the magnitude of eastern equatorial Pacific SST anomalies. However, as one speaker showed, CMIP5 models with more realistic balance among the coupled feedback components exhibit a time-varying response in amplitude, in contrast to the less realistic group of models exhibiting a static increase into the future. The time-varying response appears to be driven by surface warming differences between the Indian and Pacific Oceans, which in itself is an interesting feature requiring further investigation. As discussed in other presentations, several recent projection studies have instead utilized more process-based indicators. These include the propagation direction of the SST anomalies and rainfall response to ENSO SST patterns superimposed on the background warming. These studies found an increase in the frequency of events, with unique features seen in the 1982/83 and 1997/98 extreme El Niños, as well as extreme La Niña events.

The workshop featured many presentations on ENSO teleconnections and their impacts, including effects on regional rainfall and interannual variability of atmospheric CO₂ concentrations. Presentations on the atmospheric teleconnections of ENSO include the effect on East Asian rainfall, the effect on Arctic Oscillation via the stratosphere, and the influence of La Niña on the 2010 eastern Australian extreme rainfall via an SST warming trend and interactions with the southern annular mode. There were also presentations on oceanic teleconnections, including the impact of ENSO on Southern Ocean circulation. A paleo-based presentation linked La Niña with ocean heat-wave events off of western Australia, dubbed the Ningaloo Niño, via ocean advection through the Indonesian Throughflow. A marked increase in the occurrence of Ningaloo Niño since the late 1990s was suggested by a speaker as related to the negative IPO, with a possible feedback on ENSO. Another highlight was a talk on the influence of El Niño heat discharge on eastern Pacific tropical cyclones, underscoring the importance of ENSO ocean teleconnections on extreme weather.

The workshop concluded with a discussion on coordinated multimodel experiments proposed for the sixth phase of CMIP (CMIP6) and the opportunities they present for understanding ENSO dynamics. It was agreed that, in addition to all the analysis that will be performed on the many CMIP6 multimodel experiments, some more targeted experiments should be conducted to investigate aspects such as the role of

the pattern of mean SST change in driving uncertainties in rainfall response to ENSO events in the future. Further discussions of the details will be scheduled for future meetings.

This workshop highlighted current issues in ENSO research that are also under the broader research focus of the Climate and Ocean: Variability, Predictability and Change (CLIVAR; www.clivar.org/research-foci/enso) project: robustness of ENSO projections amid model uncertainties and relatively short instrumental records; proper simulation of underlying physical processes (getting ENSO right for the right reasons); ENSO linkage with the background climate (e.g., IPO); characteristics, predictability, and teleconnections of extreme ENSO; mechanisms behind seasonal phase locking, ENSO diversity, and interbasin feedback interactions; and the use of paleoproxies for studying the spatial evolution of ENSO. With the increasing availability of observations, improved models, more elaborate experiments, and more paleoreconstructions, some of these issues will eventually be resolved. The workshop has further highlighted the need to bring together theories, models, observations, and

paleoreconstructions to make significant progress and demonstrated that the ENSO research community has the breadth of expertise and enthusiasm to address the challenges that lie ahead.

ACKNOWLEDGMENTS. This workshop was financially supported by CSIRO and the Australian Research Council (ARC) Centre of Excellence for Climate System Science. Logistic support provided by the Climate Change Research Centre and the University of New South Wales is gratefully acknowledged. The authors thank Sarah Ineson, Harry Hendon, Neil Holbrook, and WonMoo Kim for proofreading this article and all participants for contributing to the workshop. Workshop program, abstracts, full report, participants list, and most presentations can be found at www.climatescience.org.au/content/806-enso-workshop-australia-2015. This workshop contributes to the objectives of CLIVAR of the World Climate Research Programme (WCRP) and to the interests of the International Commission on Climate (ICCL) of International Association of Meteorology and Atmospheric Sciences (IAMAS)/International Union of Geodesy and Geophysics (IUGG).

BEST SELLER!

"Here before you is the complete guide to writing a good scientific paper... Prepare to absorb what may prove the most valuable advice you will receive as a scientist."

— from the Foreword by Prof. Kerry Emanuel, Massachusetts Institute of Technology

Eloquent Science: A Practical Guide to Becoming a Better Writer, Speaker, and Atmospheric Scientist

DAVID M. SCHULTZ

What started out as a communications workshop for undergrads in atmospheric science evolved into a book that would benefit scientists at any stage in their careers. Drawing on Schultz's experience as a journal editor and prolific writer, the insights of his colleagues, and the best advice from hundreds of sources, this must-have reference includes:

- Tips for writing and reviewing scientific papers and a peek into the operations of the publishers of scientific journals
- Guidance on creating and delivering effective scientific presentations
- Experts' advice on citing others' work, critiquing scientific papers, communicating with the media, and more

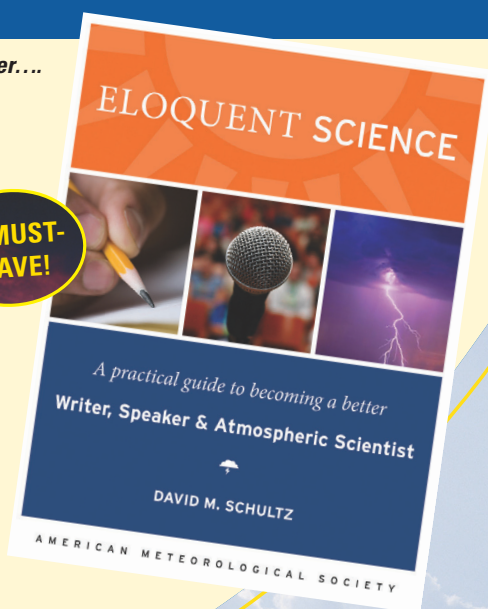
LIST \$45 MEMBER \$30 © 2009, PAPERBACK, 440 PAGES, ISBN 13: 978-1-878220-91-2, AMS CODE: ESCI

ORDER TODAY!

ONLINE AMS BOOKSTORE www.ametsoc.org/amsbookstore

OR use the order form in this magazine

A MUST-HAVE!



AMS BOOKS

RESEARCH APPLICATIONS HISTORY