MEETING SUMMARIES

NEW STRATEGIES FOR EVALUATING ENSO PROCESSES IN CLIMATE MODELS

by Eric Guilyardi, Wenju Cai, Mat Collins, Alexey Fedorov, Fei-Fei Jin, Arun Kumar, De-Zheng Sun, and Andrew Wittenberg

The El Niño–Southern Oscillation (ENSO) is a naturally occurring fluctuation that originates in the tropical Pacific region and affects ecosystems, agriculture, freshwater supplies, hurricanes, and other severe weather events worldwide. Ocean–atmosphere coupled general circulation models (CGCMs) are routinely used to analyze ENSO mechanisms and teleconnections and to predict and project ENSO's evolution on a broad range of time scales, from seasonal to centennial. The ability of CGCMs to simulate El Niño has largely improved over the last few years. Nevertheless, the diversity of model simulations of present-day El Niño characteristics indicate current limitations in our ability to model this climate phenomenon and anticipate changes in its properties on short and long time scales. For instance, and

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WHAT: Fifty ENSO experts, including 15 graduate students and early-career postdoctoral fellows, met to discuss existing approaches to assess ENSO in coupled GCMs, review the recent progress, and propose recommendations for future research (www.clivar.org)

WHEN: 17–19 November 2010

WHERE: Paris, France

despite considerable progress in our understanding of the impact of climate change on many of the processes that contribute to ENSO variability, it is not yet possible to say whether ENSO activity will be enhanced or damped, or if the frequency of events will change under the influence of anthropogenic climate change. As ENSO involves a complex interplay of numerous ocean and atmospheric processes, accurately modeling this climate phenomenon with CGCMs and understanding, anticipating, and predicting its behavior on seasonal to decadal and longer time scales still pose formidable challenges.

Major progress in ENSO research has been made over the last 30 years since the establishment of the basic physical mechanisms. New theoretical insights, together with better observations, increased computer power, and improved physical parameterizations of subgrid-scale processes, have resulted in better simulations of ENSO in CGCMs. Although the

AFFILIATIONS: GUILYARDI—LOCEAN/IPSL, Paris, France and NCAS-Climate, University of Reading, Reading, United Kingdom; CAI—CSIRO, Aspendale, Victoria, Australia; COLLINS—University of Exeter, Exeter, United Kingdom; FEDOROV—Yale University, New Haven, Connecticut; JIN—University of Hawaii at Manoa, Honolulu, Hawaii; KUMAR AND SUN—NOAA/ESRL, Boulder, Colorado; WITTENBERG—NOAA/GFDL, Princeton, New Jersey

CORRESPONDING AUTHOR: Eric Guilyardi, LOCEAN/IPSL, UPMC, 4 Place Jussieu, 75252 Paris CEDEX 05, France
E-mail: eric.guilyardi@locean-ipsl.upmc.fr

basic properties of ENSO are now well simulated, the community is nevertheless now faced with the much harder problem of getting its detailed properties right (e.g., skewness, diversity of events, physical feedbacks). Further progress will require a coordination of diverse research communities, a process recently undertaken through the intercomparison of state-of-the-art CGCMs [Coupled Model Intercomparison Project phase 3 (CMIP3) and the upcoming CMIP5].

Over the past few years, new promising methods have emerged that can improve ENSO simulations, for example, by bridging ENSO theoretical frameworks and CGCM modeling. Examples include the development of indices that can be used to assess the stability of ENSO in CGCMs and intermediate models that can be used to predict ENSO characteristics from aspects of the mean state. By focusing on the key processes affecting ENSO dynamics (e.g., the thermocline feedbacks or the wind stress response to SST anomalies), these new approaches have a strong potential to accelerate progress and improve the representation of ENSO in complex climate models. Not only can these new methods help address the question of whether the characteristics of ENSO are changing in a changing climate but also potentially improve the reliability of centennial-scale climate projections and predictions on seasonal time scales.

In that context, this Climate Variability and Predictability (CLIVAR, www.clivar.org) workshop's aim was to present and discuss emerging new methods for the process-based evaluation of ENSO in CGCMs, and their use in multimodel assessments (e.g. CMIP5), and to identify future directions and challenges. The goals of the workshop include the following:

- To survey existing methods of evaluating ENSO processes in CGCMs
- To identify methods of bridging ENSO theory and CGCM modeling
- To review the observing system and reanalysis data available for evaluating ENSO in CGCMs
- To propose community recommendations and actions (including CMIP5 analysis)

The 3-day workshop was held at the Institut Pierre-Simon Laplace (IPSL) and the Laboratoire d'Océanographie et du Climat: Expérimentations et Approches Numériques (LOCEAN) on the Jussieu campus of the Université Pierre and Marie Curie in Paris, and was sponsored by CLIVAR, the World Climate Research Programme (WCRP), IPSL, and the French Centre National de la Recherche Scientifique (CNRS). Invited speakers consisted of 35 ENSO experts, including representatives from the main groups involved in CMIP5 analysis and developing CGCMs around the world. Fifteen students and early-career postdoctoral fellows successfully applied to attend the workshop and present their work in a well-attended poster session. This provided a unique opportunity for networking and sharing of ideas in an informal, yet focused, atmosphere. Expertise on ENSO and related areas included theory, observations, modeling, seasonal forecasting, statistics, teleconnections, paleoclimate, and climate change (http://wcrp.ipsl.jussieu.fr/Workshops/CLIVAR/index.html).

The initial session presented review lectures on all major aspects of ENSO research. An ENSO theory and research review ("What is new since 2000 and what is achievable by 2020?") provided a basis for insightful discussions and debates. Some points of progress included improved availability of observational data for forcing and evaluating the component of CGCMs and for illuminating the essential dynamics and thermodynamics of ENSO; further recognition of the sources and importance of nonnormal transient growth and nonlinearity for ENSO; better understanding of how errors in the climatological mean state of the high-end models interact with ENSO; evidence from CGCMs that substantial multidecadal shifts in ENSO statistics can arise stochastically, independent of changes in the climatological state, consistent with expectations from linear stochastic theory and intermediate-complexity models; and improvements in the seasonal prediction skill of ENSO based on dynamical models but inconclusive evidence that full potential predictability has been reached. A summary of challenges and outstanding issues for the next 10 years included improving CGCMs, especially those with gross biases in their mean states and ENSO behavior; better assessing and understanding the diversity of ENSO behavior, and implications of intrinsic modulation of ENSO for detection and attribution of past and future changes in ENSO; and better defining the limits of potential predictability and forecast skill for ENSO. Speakers also presented insights gained from studies of paleoclimate, decadal variability, observational networks, and climate change. A paper is being prepared to present this review in more detail to a wider audience.

The bulk of the workshop was dedicated to the presentation and discussion of existing approaches to evaluate ENSO processes in CGCMs and a large

fraction of the current experts were present. These approaches ranged from process-based diagnostic methods to the use of ENSO models of intermediate complexity (ENMICs). In the latter case, the CGCMs mean state is used to define a simpler model of ENSO; if this simpler model is able to reproduce the ENSO characteristics of the CGCM (as shown by several studies), then unraveling the mechanisms behind the ENSO success or errors in the CGCM potentially becomes possible. The current generation of ENMICs capture the leading-order ENSO processes and feedbacks; however, more work is required to include other processes, for example, nonlinearities and the effects of processes such as tropical instability waves which are beginning to be resolved in the current generation of CGCMs. The remaining challenge is then to use insights gained from ENMICs to understand and improve CGCMs.

Several presentations emphasized that ENSO in CGCMs is extremely sensitive to the representation of atmospheric convection and clouds in the CGCM. This sensitivity demands attention, not only to the parameterization of subgrid-scale processes in the atmospheric model, but also in the ocean model because the simulated climatological SST, which strongly controls both the climatological convection and its sensitivity to SST fluctuations, is itself a product of the interaction between both components. The standard conceptual way of thinking about the role of atmospheric processes in ENSO is in the response of the wind stress to SST anomalies and in the damping of those SST anomalies by surface fluxes, both usually taken as constants in ENSO theory. As it is clear that atmospheric processes in CGCMs are important in determining modeled ENSO characteristics, this current simplified conceptual thinking may require some revision.

The impacts on ENSO from weather and climate fluctuations in regions outside the tropical Pacific (e.g., the Indian Ocean and midlatitudes) were also discussed in several presentations, highlighting a likely area of intense research over the coming years. A prominent example is the possible role of boreal winter midlatitude atmospheric variability in triggering ENSO events, by imparting a thermal "footprint" in the oceanic mixed layer of the North Pacific, whose tropical signature can generate westerly wind stress anomalies in the equatorial Pacific that trigger or otherwise alter ENSO events. While several forcings external to the tropical Pacific—ranging from synoptic weather systems to interannual variability—were identified that could affect ENSO, it was agreed that their relative importance is not yet clear.

The ability of CGCMs to reproduce different types of El Niño (the warm phase of ENSO) situations was also addressed in several presentations. Recent studies have highlighted El Niño situations in which SST anomalies are confined to the central Pacific and do

OVERALL FINDINGS AND RECOMMENDATIONS

Findings

- The basic physical properties of ENSO are now well simulated by a growing number of CGCMs.
- The detailed properties of individual events (El Niño, La Niña) and their subtle differences still present a challenge for CGCMs.
- The parameterization of the atmospheric convection (and its interaction with the resolved flow and other parameterized processes) plays a critical role in the ENSO performance of CGCMs.
- Model diagnostics of ENSO behavior and the underlying mechanisms are improving, guided by theory and the availability of quality decade-and-longer-duration datasets.
- Mature approaches to bridging ENSO theoretical frameworks and CGCM results are now available.
- ENSO prediction and simulation are far from being solved.

Recommendations and research priorities

- Reduce mean state biases in CGCMs (e.g., equatorial cold tongue extension, intensity of trade winds, double ITCZ, properties and extent of tropical clouds) and develop pathways to understand and reduce modeled ENSO biases.
- Understand causes for El Niño and La Niña interevent diversity.
- Understand causes for low-frequency modulation of ENSO.
- Understand how weather and climate of the midlatitudes and other tropical regions may influence ENSO.
- Understand how ENSO may change in response to global warming, including quantifying and reducing uncertainty in projections.
- Coordinate CMIP5 ENSO analysis.
- Continue to develop process-based ENSO metrics as methods to understand ENSO in CGCMs; document as part of a dedicated website.
- Continue to bring together the different communities of experts needed to collectively make significant progress in the representation of ENSO in CGCMs and in the use of CGCMs in addressing open questions in ENSO science.

not extend all the way to the coast of South America. There are suggestions that these warm pool central Pacific or Modoki El Niño situations, as they have variously been termed, have a subtly different balance of feedbacks in comparison with the canonical or east Pacific El Niño situation with a greater role for the zonal advection of warm pool SSTs. In addition, the teleconnection patterns are altered in comparison to the standard picture. There was much interest as well as controversy regarding the nature of these central Pacific El Niños—it is unclear whether they are statiscally different from the canonical El Niños and if an increased occurrence over the past few decades, as suggested by some studies, is simply an expression of ENSO's large intrinsic variability or a fundamental change in ENSO that might continue into the future.

The use of seasonal forecasting to understand the development of ENSO errors in CGCMs was also presented as a powerful approach to identify possible causes for model bias that are often challenging to analyze in highly complex coupled models and in long simulations.

The success of this workshop clearly calls for a sustained activity to coordinate research to understand and improve ENSO in CGCMs, both within CLIVAR (and the several panels concerned) and WCRP (CMIP model evaluation). The chairs or cochairs of the CLIVAR Pacific panel, the CLIVAR Work Group on Seasonal to Interannual Prediction (WGSIP), and the CLIVAR Madden–Julian Oscillation (MJO) Work Group were present.