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New strategies for evaluating ENSO processes in climate models

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- What: 50 ENSO experts, including 15 graduate students and early career postdocs met to discuss existing approaches to assess ENSO in coupled GCMs, review the recent progress and propose recommendations for future research.
- When: 17-19 November 2010
- Where: IPSL/LOCEAN, Paris, France

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 both to analyze El Niño mechanisms and teleconnections and to predict and project its evolution on a broad range of timescales, 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 despite considerable progress in our understanding of the impact of climate change on many of the processes that contribute to El Niño 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. If the 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 coordination of diverse research communities, a process recently undertaken through intercomparison of state-of-the-art CGCMs (CMIP3 and the upcoming CMIP5).

Over the past few years, new promising methods have emerged, which can improve

ENSO simulations, for example by bridging ENSO theoretical frameworks and CGCM modelling. 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 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 potentially they can also improve reliability of centennial-scale climate projections and predictions on seasonal time scales.

In that context, this CLIVAR workshop aimed to present and discuss emerging new methods for the process-based evaluation of ENSO in CGCMs, their use in multi-model assessments (e.g. CMIP5) and to identify future directions and challenges. The goals of the workshop were :

- 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 IPSL/LOCEAN on the Jussieu campus of the Université Pierre and Marie Curie in Paris, and was sponsored by CLIVAR, WCRP, IPSL and CNRS. Invited speakers consisted of 35 ENSO experts, including representatives from the main groups involved in CMIP5 analysis and developing CGCMs around the world. 15 students and early-career postdocs 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.

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?”) was presented by David Battisti and Mark Cane, and 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 non-normal transient growth and nonlinearity for ENSO; better understanding of how errors in the climatological mean state of the high end models interacts 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; improvements in 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 GCMs, with a large fraction of the current experts 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 but more work is required to include other processes e.g. non-linearities and the effects of processes like tropical instability waves that 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 was 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 - since 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 modelled ENSO characteristics, this current simplified conceptual thinking may require some revision.

The impacts on ENSO of 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 mid-latitude 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 the observed diversity of El Niño events was also addressed in several presentations. Recent studies have highlighted ENSO events in which SST anomalies are confined to the central Pacific and do not extend all the way to the coast of South America. It is suggested that these warm-pool, central Pacific or Modoki El Niños, as they have variously been termed, have a subtly different balance of feedbacks in comparison with the canonical or east Pacific El Niño 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 central Pacific El Niño's in recent decades - it is unclear whether their increased occurrence over the past few decades 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 GCM, both within CLIVAR (and the several Panels concerned) and WCRP (CMIP model evaluation). The chairs or co-chairs of the CLIVAR Pacific Panel, the CLIVAR Work Group on Seasonal to Interannual Prediction (WGSIP), and the CLIVAR MJO Work Group were present.

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Box 1: 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 flavors 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 behaviour and the underlying mechanisms are improving, guided by theory and availability of quality decade and longer-duration data sets;
- Mature approaches to bridging ENSO theoretical frameworks and CGCM results are now available;

- ENSO prediction and simulation is far from being solved or a well understood problem

Recommendations and research priorities:

- Reducing mean state biases in CGCMs (e.g. equatorial cold tongue extension, intensity of trade winds, double ITCZ, properties and extent of tropical clouds) and developing pathways to understand and reduce modeled ENSO biases;
- Understanding causes for El Niño and La Niña inter-event diversity;
- Understanding causes for low-frequency modulation of ENSO;
- Understanding how mid-latitudes and other tropical regions may influence ENSO;
- Understanding how ENSO may change under 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 web site;
- 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.