

ENSO in a changing climate

Eric Guilyardi, Andrew T. Wittenberg, Mike McPhaden, Wenju Cai, Mat Collins,
Tony Lee, Ben Kirtman

Version 10 Sept. 2013

1. Description

The El Niño–Southern Oscillation (ENSO) phenomenon is a naturally occurring climate fluctuation, which originates in the tropical Pacific region and affects ecosystems, agriculture, freshwater supplies, hurricanes and other severe weather events worldwide (Goddard and Dilley 2005; McPhaden et al. 2006). Despite considerable progress in our understanding of the impact of climate change on many of the processes that contribute to ENSO variability (e.g., Collins et al. 2010), it is not yet possible to say whether ENSO activity will be enhanced or damped, or if the frequency or character of events will change in the coming decades (Vecchi and Wittenberg 2010). As changes in ENSO have the potential to be one of the largest manifestations of anthropogenic climate change, this status has profound impacts on the reliability of regional attribution of climate variability and change. Two main reasons can be invoked for these shortcomings. First there is a lack of long and comprehensive enough observations of the various ENSO processes to be able to detect past changes. It may be that we need to observe ENSO for another several decades to detect and attribute significant ENSO changes (Wittenberg 2009; Stevenson et al. 2012). Second, 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 behaviour on seasonal to decadal and longer time scales still pose formidable challenges (Guilyardi et al. 2009). Even though the ability of CGCMs to simulate El Niño has largely improved over the last few years, 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.

Since the establishment of the basic physical mechanisms 30 years ago, major progress in ENSO research has been made (Sarachik and Cane 2010, Wang and Picaut 2004). New theoretical insights, together with longer and more comprehensive observations, increased computer power, and improved physical parameterizations of subgrid-scale processes, have resulted in better understanding of ENSO dynamics and much improved simulations of ENSO statistics in CGCMs (Guilyardi et al. 2009, Delworth et al. 2012, Bellenger et al. 2013). Although forecast models, assimilation systems, and data availability have all improved in past decades, ENSO forecast skill has declined in the last decade because of reduced predictability (Barnston et al, 2012). If the basic properties of ENSO are now better understood and simulated, the community is nevertheless now faced with the much harder problem of addressing its detailed properties (e.g. skewness, diversity of events, physical feedbacks, asymmetries between El Niño and La Niña, etc.) and how these interact with the slowly (decadally to centennially) varying background (An et al. 2005; Power et al. 2006; DiNezio et al. 2012; Watanabe and Wittenberg 2012; Watanabe et al. 2012; Ogata et al. 2013; U.S. CLIVAR 2013ab). Further progress will require coordination of diverse research communities, a process recently undertaken through intercomparison of state-of-

the-art CGCMs (Coupled Model Intercomparison Project - CMIP3 and 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 simulations. 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 strong potential to accelerate progress and improve representation of ENSO in complex climate models (Dewitte et al. 2007, Kim and Jin 2010, Philip and van Oldenborgh 2010, Roberts and Battisti 2011, Bellenger et al. 2013, Choi et al. 2013). The relative role of the ocean and the atmosphere in shaping ENSO is being significantly revisited (Kitoh et al. 1999, Guilyardi et al. 2004, Dommenges et al. 2010, Clement et al. 2011, Lloyd et al. 2011). A number of studies suggest that regions outside the tropical Pacific have a role in triggering El Niño (Vimont et al. 2003, Zhang 2005, Izumo et al. 2010, Terray 2011, Wang et al. 2011), for instance via zonal or meridional atmosphere or oceanic teleconnections, such as the Madden-Julian Oscillation, the proposed seasonal footprinting mechanism (Alexander et al. 2010) or the meridional mode (Chang et al. 2007). Not only can these new methods and research areas help address the question of whether the characteristics of ENSO are changing in a changing climate (e.g. Yeh et al. 2009, Collins et al. 2010, McPhaden et al. 2011), but potentially they can also improve reliability of decadal and centennial-scale climate projections and predictions on seasonal time scales.

Two CLIVAR-sponsored workshops held in 2010 in Paris, France (Guilyardi et al. 2012) and in 2013 in Hobart, Australia¹ reviewed “new strategies for evaluating ENSO processes in climate models”. A main recommendation was to continue to “bring together the different communities of experts 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.”

2. Major Themes

This Research Opportunity will bring experts together towards three main goals: 1) better understand processes that control ENSO characteristics in nature and in the models, namely diversity of El Niño events and decadal variations, 2) propose a standard ENSO evaluation protocol for CGCMs and 3) understand how ENSO characteristics might be modified in the next decades, namely under the influence of anthropogenic climate change. Working towards these ambitious goals requires a synthesis of existing ENSO evaluation methods for CGCMs, including metrics, process based evaluation methods and El Niño Models of Intermediate Complexity (ENMICs). Another step is to identify gaps and duplication in these methods, which observations are essential, and how they can be better used. In particular paleo and last millennium observations (e.g. Emile-Geay et al. 2013ab; McGregor et al. 2013) have a large mostly untapped potential. A next step is to use the proposed rich and coordinated multi-model evaluation in innovative ways to inform society and other stakeholders how ENSO may, or may not, evolve in the next decades. Last but not least, a capacity building component will bring

¹ <http://www.clivar.org/organization/pacific/activities/third-workshop-evaluation-enso-processes-climate-models>

together an interdisciplinary group and train young scientists. The protocol and methods proposed will be used to document ENSO performance of existing multi-model databases (e.g. CMIP) and contribute to the Metrics Panel set up under WGCM guidance. CLIVAR is the natural place to formalise this cross-cutting Research Opportunity, as many of its Panels and topical groups should be involved (Pacific and Indian Ocean Panels, WGOMD), Links with WGCM, WGSIP, WGNE, SOLAS and PAGES will also be central. This Research Opportunity will also make strong contributions to both the model development process (CMIP6 protocol) and the IPCC assessment.

3. The Way Forward

- Better understand the role of different physical processes that influence ENSO characteristics and the diversity of El Niño events on decadal time scales.
- Provide a synthesis of existing ENSO evaluation methods in GCMs.
- Propose ENSO evaluation protocols and develop a strategy for coordinated ENSO analysis of CMIP models, including development and maintenance of an interactive website, in coordination with the WGCM Metrics Panel.
- Propose ENSO specific simulations for consideration by CMIP6 (“ENSOMIP”).
- Identify new observations needed to better constrain ENSO processes, both for the current climate and for past climates (via paleo proxies).
- Provide a better understanding of how ENSO might change in the future.
- Promote and coordinate international collaboration between observationalists and modelers for studies of ENSO
- Build research capacity by contributing to the development of the next generation of talent dealing with ENSO science.

a. Strategy and timeline

a.1. Processes responsible for ENSO characteristics

Approach: convene a workshop to bring together an interdisciplinary group of experts (ENSO processes, atmosphere and ocean physics, ...). This workshop will build on the previous such CLIVAR meeting and initiatives, including the recent US CLIVAR work group on ENSO diversity (U.S. CLIVAR Project Office 2013b).

Deliverables: a workshop report and a review paper about physical mechanisms responsible for ENSO characteristics (origin, amplitude, diversity,...).

a.2. Model ENSO evaluation protocol

Approach: from material from the Paris 2010 and Hobart 2013 CLIVAR workshops and recent CMIP analysis, establish a list of existing ENSO evaluation methods in CGCMS. Convene focused experts workshop (followed by a series of video/telephone conferences of a core group) to 1) define steps to compare methods and identify potential gaps, 2) propose an ENSO evaluation protocol for CGCMS, 3) review observations available and those missing and 4) apply protocol to CMIP3+5. The protocol will require standard CMIP simulations but may also involve specific simulations (e.g. seasonal hindcasts). Work for this phase will require a full time postdoctoral fellow for 2 years. CSIRO and IPSL have tentatively committed to jointly fund it.

This will contribute to the on-going CMIP metrics panel and activities within WGCM.

Deliverables: a report/paper on the proposed ENSO evaluation protocol and a web site, including web services to compute the metrics/analysis required for the protocol.

a.3. ENSO in a changing climate

Approach: Based on improved understanding of ENSO characteristics and ENSO evaluation protocols, analyse CMIP scenarios to better understand for ENSO changes in the future. Will use innovative approaches such as Bayesian methods and the use of ENMICS to emulate possible ENSO changes. Also, we will explore the possibility of a coordinated set of model experiments and/or coordinated set of model diagnostics to test hypotheses about future changes in ENSO. If preliminary experiments/diagnostics prove useful, we would propose their inclusion in CMIP6.

Deliverable: peer review paper on ENSO in a changing climate providing latest estimates of likely ENSO changes over the next few decades.

4. Research capacity and community building

There is a need for a strong capacity building component to support young scientists training. This will be done by inviting a selection of young scientist to workshops held and by organising an ENSO summer school for graduate students, (following the successful 2009 Pacific Panel ENSO summer school). Also, it is important to enhance general public information on basic knowledge of ENSO and analysis of ENSO in models, and this could be done via web site and blogs.

References

- Alexander, Michael A., Daniel J. Vimont, Ping Chang, James D. Scott, 2010: The Impact of Extratropical Atmospheric Variability on ENSO: Testing the Seasonal Footprinting Mechanism Using Coupled Model Experiments. *J. Climate*, **23**, 2885–2901. doi: 10.1175/2010JCLI3205.1
- Barnston, A. G., M. K. Tippett, M. L. L'Heureux, S. Li, D. G. DeWitt, 2012: Skill of Real-Time Seasonal ENSO Model Predictions during 2002-11: Is Our Capability Increasing?. *Bull. Amer. Meteor. Soc.*, **93**, 631-651.
- Bellenger H., E. Guilyardi, J. Leloup, M. Lengaigne, J. Vialard, 2013: ENSO representation in climate models: from CMIP3 to CMIP5. *Clim. Dyn.*, revised
- Chang P., L. Zhang, R. Saravanan, D. J. Vimont, J. C. H. Chiang, L. Ji, H. Seidel, and M. K. Tippett, 2007: Pacific meridional mode and El Niño–Southern Oscillation. *Geophys. Res. Lett.*, **34**, L16608, doi:10.1029/2007GL030302.
- Choi, K., G. A. Vecchi, and A. T. Wittenberg, 2013: ENSO transition, duration and amplitude asymmetries: Role of the nonlinear wind stress coupling in a conceptual model. *J. Climate*, published online, doi: 10.1175/JCLI-D-13-00045.1
- Clement, A, P. DiNezio, C. Deser, 2011: Rethinking the Ocean's Role in the Southern Oscillation. *J. Climate*, **24**, 4056–4072. doi: 10.1175/2011JCLI3973.1
- Collins, M., et al., 2010: The impact of global warming on the tropical Pacific Ocean and El Niño. *Nature Geosci.*, **3** (6), 391–397, URL <http://dx.doi.org/10.1038/ngeo868>.
- Delworth, Thomas L., and Coauthors, 2012: Simulated Climate and Climate Change in the GFDL CM2.5 High-Resolution Coupled Climate Model. *J. Climate*, **25**, 2755–2781.
- Dewitte, B., C. Cibot, C. Périgaud, S.-I. An, and L. Terray, 2007: Interaction between near-annual and ENSO modes in a CGCM simulation: Role of equatorial background mean state. *J. Climate*, **20**, 1035–1052.
- DiNezio, P. N., B. P. Kirtman, A. C. Clement, S.-K. Lee, G. A. Vecchi, and A. Wittenberg, 2012: Mean climate controls on the simulated response of ENSO to increasing greenhouse gases. *J. Climate*, **25**, 7399-7420. doi: 10.1175/JCLI-D-11-00494.1.
- Dommenget D. (2010), The slab ocean El Niño, *Geophys. Res. Lett.*, **37**, L20701, doi:10.1029/2010GL044888.

- Emile-Geay, J., K. Cobb, M. Mann, and A. T. Wittenberg, 2013a: Estimating central equatorial Pacific SST variability over the past millennium. Part 1: Methodology and validation. *J. Climate*, **26**, 2302-2328. doi: 10.1175/JCLI-D-11-00510.1.
- Emile-Geay, J., K. Cobb, M. Mann, and A. T. Wittenberg, 2013b: Estimating central equatorial Pacific SST variability over the past millennium. Part 2: Reconstructions and implications. *J. Climate*, **26**, 2329-2352. doi: 10.1175/JCLI-D-11-00511.1.
- Goddard, L. and M. Dilley, 2005: El Niño: Catastrophe or Opportunity. *J. Climate*, **18**, 651–665.
- Guilyardi, E.; Gualdi, S.; Slingo, J. M.; Navarra, A.; Delecluse, P.; Cole, J.; Madec, G.; Roberts, M.; Latif, M. & Terray, L. (2004). Representing El Niño in coupled ocean-atmosphere GCMs: the dominant role of the atmospheric component. *J. Climate*, **17**, 4623-4629
- Guilyardi, E., A. Wittenberg, A. Fedorov, M. Collins, C.Z. Wang, A. Capotondi, G.J. van Oldenborgh, and T. Stockdale, 2009: Understanding El Niño in ocean-atmosphere General Circulation Models: Progress and challenges. *Bull. Amer. Met. Soc.*, **90**, 325–340
- Guilyardi, E., W. Cai, M. Collins, A. Fedorov, F.-F. Jin, A. Kumar, D.-Z. Sun, A. Wittenberg (2012). CLIVAR workshop summary: New strategies for evaluating ENSO processes in climate models. *Bull. Amer. Met. Soc.*, **93**, 235-238
- Izumo T., Vialard J., Lengaigne M., De Boyer Montegut C., Behera S. K., Luo J.-J., Cravatte S., Masson S., Yamagata T. (2010). Influence of the state of the Indian Ocean Dipole on the following year's El Niño. *Nature Geoscience*, **3**, 168-172
- Kim S. T. and F-F Jin 2010: An ENSO stability analysis. Part II: results from the twentieth and twenty-first century simulations of the CMIP3 models. *Clim. Dyn.*, **36**, 1609-1627, DOI: 10.1007/s00382-010-0872-5
- Kitoh, Akio, Tatsuo Motoi, Hiroshi Koide, 1999: SST variability and its mechanism in a coupled atmosphere–mixed layer ocean model. *J. Climate*, **12**, 1221–1239. doi: 10.1175/1520-0442
- Lloyd, J., E. Guilyardi and H. Weller (2011), The role of atmosphere feedbacks during ENSO in the CMIP3 models, Part II: using AMIP runs to understand the heat flux feedback mechanisms, *Clim. Dyn.* **37**, 1271-1292, DOI: 10.1007/s00382-010-0895
- McGregor, S., A. Timmermann, M. H. England, O. Elison Timm, and A. T. Wittenberg, 2013: Inferred changes in El Niño-Southern Oscillation variance over the past six centuries. *Clim. Past Discuss.*, **9**, 2929-2966. doi: 10.5194/cpd-9-2929-2013.
- McPhaden, M.J., S.E. Zebiak, and M.H. Glantz, 2006: ENSO as an integrating concept in Earth science. *Science*, **314**, 1740-1745.
- McPhaden, M. J., T. Lee, and D. McClurg (2011), El Niño and its relationship to changing background conditions in the tropical Pacific Ocean, *Geophys. Res. Lett.*, **38**, L15709, doi:10.1029/2011GL048275.
- Philip, S. Y., and G. J. van Oldenborgh, 2010: Atmospheric properties of ENSO: Models versus observations. *Clim. Dyn.*, **34**, 1073–1091. doi:10.1007/s00382-009-0579-7
- Ogata, T., S.-P. Xie, A. Wittenberg, and D.-Z. Sun, 2013: Interdecadal amplitude modulation of El Niño/Southern Oscillation and its impacts on tropical Pacific decadal variability. *J. Climate*, **26**, 7280-7297. doi: 10.1175/JCLI-D-12-00415.1.
- Power, S., Haylock, M., Colman, R., (2006) The Predictability of Interdecadal Changes in ENSO Activity and ENSO Teleconnections, *J. Clim.*, **19**, 4755-4771
- Roberts, W.H.G. and Battisti, D.S.A (2011) new tool for evaluating the physics of coupled atmosphere-ocean variability in nature and in general circulation models. *Clim Dyn.* **36**, 907-923, DOI: 10.1007/s00382-010-0762
- Sarachick E. and Cane, M.A., 2010: The El Niño-Southern Oscillation Phenomenon. *Cambridge University Press*, London, 384p.
- Stevenson, S., B. Fox-Kemper, M. Jochum, R. Neale, C. Deser, and G. Meehl, 2012: Will there be a significant change to El Niño in the twenty-first century? *J. Climate*, **25**, 2129-2145.
- Terray, P. (2011). Southern Hemisphere extra-tropical forcing: a new paradigm for El Niño-Southern Oscillation, *Clim Dyn.* **36**, 2171–2199 DOI 10.1007/s00382-010-0825-z
- U.S. CLIVAR, 2013a: ENSO diversity. *U.S. CLIVAR Variations*, **11** (2), 28pp. Available from http://www.usclivar.org/sites/default/files/USCLIVAR_VARIATIONS_11_2_Summer2013.pdf
- U.S. CLIVAR, 2013b: U.S. CLIVAR ENSO Diversity Workshop Report. Report 2013-1, U.S. CLIVAR Project Office, Washington, DC, 20006, 20pp. Available from http://www.gfdl.noaa.gov/~atw/yr/2013/ENSO_Diversity_Workshop_Report2013.pdf
- van Oldenborgh, G.J., S. Philip, and M. Collins, 2005: El Niño in a changing climate: a multi-model study. *Ocean Science*, **1**, 267-298

- Vecchi, G. A., and A. T. Wittenberg, 2010: El Niño and our future climate: Where do we stand? *Wiley Interdisciplinary Reviews: Climate Change*, **1**, 260-270, doi:10.1002/wcc.33
- Vimont, D. J., J. M. Wallace, and D. S. Battisti, 2003: The seasonal footprinting mechanism in the Pacific: Implications for ENSO. *J. Climate*, **16**, 2668–2675
- Wang, C. and J. Picaut, 2004: Understanding ENSO Physics - A Review. *In: Earth's climate: the ocean-atmosphere interaction. AGU, Washington D.C., C. Wang, S.-P. Xie and J.A. Carton Eds.*, 21-48.
- Wang et al. (2011). Teleconnected influence of North Atlantic sea surface temperature on the El Niño onset. *Clim Dyn.*, **37**, 663-676, DOI: 10.1007/s00382-010-0833-z
- Watanabe, M., and A. T. Wittenberg, 2012: A method for disentangling El Niño-mean state interaction. *Geophys. Res. Lett.*, **39**, L14702. doi: 10.1029/2012GL052013.
- Watanabe, M., J.-S. Kug, F.-F. Jin, M. Collins, M. Ohba, and A. T. Wittenberg, 2012: Uncertainty in the ENSO amplitude change from the past to the future. *Geophys. Res. Lett.*, **39**, L20703. doi: 10.1029/2012GL053305.
- Wittenberg, A. T. (2009), Are historical records sufficient to constrain ENSO simulations?, *Geophys. Res. Lett.*, **36**, L12702, doi:10.1029/2009GL038710.
- Yeh, S.-W., et al. (2009), El Niño in a changing climate, *Nature*, **461**, 511–514, doi:10.1038/nature08316.
- Zhang, C. (2005), Madden - Julian Oscillation, *Rev. Geophys.*, **43**, RG2003, doi:10.1029/2004RG000158.