A Prospectus for a US-CLIVAR Working Group on ENSO diversity

1. Motivation

El Niño-Southern Oscillation (ENSO) is a fundamental component of the climate system due to its profound impact upon the global climate. Over the last few years extensive literature has developed to describe a type of El Niño in which the maximum sea surface temperature (SST) anomalies are located in the central equatorial Pacific rather than in the eastern Pacific, as in the canonical event. This central equatorial Pacific warming has been referred to as “Central Pacific El Niño” (CP- El Niño, e.g. Kao and Yu 2009), “warm-pool El Niño” (Kug et al. 2009), “dateline El Niño” (Larkin and Harrison 2005), and “El Niño Modoki” (“Pseudo El Niño”, Ashok et al. 2007) in an attempt to distinguish it from the classical Eastern Pacific (EP) El Niño. However, it is not clear whether there is a clear dichotomy between eastern vs. central Pacific warming events, or whether the location of maximum warming ranges over a continuum of longitudes resulting in events that could be defined as “central”, “central-eastern” or “eastern”. The SODA ocean analysis, as well as a long control integration of the National Center for Atmospheric Research (NCAR) Community Climate System Model version 4 (CCSM4) support the view of El Niño events occurring over a continuum of longitudes (Capotondi 2011). These different ENSO “flavors”, defined here as the individual manifestations of this continuum, can be represented, for example, by secondary ENSO indices corresponding to east-west differences in SST (Trenberth and Stepaniak 2001; Ashok et al. 2007; Kim et al. 2009; Yeh et al. 2009).

Different locations of maximum warming can lead to different patterns of extra-tropical teleconnections. In particular, warming in the central Pacific may be especially efficient in forcing a PNA-like atmospheric response (Alexander et al. 2002; Barsugli and Sardeshmukh 2002; Goddard et al. 2006) and also appears to force the southernmost lobe of the North Pacific Oscillation (Di Lorenzo et al. 2010), that in turn provides the atmospheric forcing for the North Pacific Gyre Oscillation (NPGO). The NPGO is the second mode of SST and Sea Surface Height (SSH) variability over the North Pacific, and is strongly connected to coastal upwelling and variations of quantities relevant to ecosystem dynamics (Di Lorenzo et al. 2008). North Pacific SST decadal variability likewise appears more related to central Pacific than eastern Pacific tropical SST anomalies (e.g., Zhang et al. 1997; Newman 2007; Yeh and Kirtman 2008). The dominance of CP- vs. EP- El Niño over decadal long periods appears to produce a decadal modulation of the influence of ENSO upon temperature and precipitation over the United States (e.g., Ashok et al. 2007, Mo 2010), and North Atlantic tropical cyclones (Kim et al. 2009). Central-Pacific warming was also linked to the warming in Antarctica (Lee et al. 2010; Ding et al. 2011). Robust differences among warming patterns may have implications for predictability and prediction both at seasonal-to-interannual, and decadal timescales. Tropical Pacific variability is hard to predict, partly due to the coupled models inability to simulate ENSO with sufficient fidelity. Exploring
the dynamics of ENSO flavors promises to be a new approach to this problem, with a potentially large payoff in the exploration of low-frequency predictability.

The more frequent occurrence of central Pacific warming in recent decades has led some researchers to interpret it as an indication of ENSO changes due to global warming (e.g. Yeh et al. 2009). Observations in the past three decades also seem to indicate an increasing intensity of El Niño events in the CP region (Lee and McPhaden 2010). However, the observational record is relatively short, and modeling studies of millennia long integrations suggest that ENSO characteristics, including amplitude and frequency, may vary considerably during different epochs (Wittenberg 2009). The preferred occurrence of ENSO over a given longitude range may just be part of natural climate variations (Newman et al. 2011), and be viewed as ENSO longitude modulation. The role of climate change vs. natural variability upon the longitudinal location of maximum warming, as well as spatial scale and duration, needs to be clarified. This distinction is in line with the activities of the Decadal Predictability Working Group, since one of the objectives of that working group is the development of a framework to separate natural from anthropogenically-forced variability at decadal timescales. Although the Decadal Predictability Working Group is ending next year, decadal predictability activities will continue, and a better understanding of ENSO diversity will be beneficial. Whether some ENSO flavors may be potentially predicted at longer lead times and/or have different characteristic event duration is also an open question that impacts the decadal predictability problem.

In preparation for the Intergovernmental Panel for Climate Change Assessment Report 5 (IPCC-AR5) an evaluation of the CMIP5 archive will be carried out. In depth diagnostics and process-guided strategies to evaluate ENSO in climate models need to be considered (International CLIVAR workshop, Paris November 2010). A better understanding of the processes/trend responsible for the longitudinal position of the maximum warming, and the associated large-scale impacts, is necessary for a more comprehensive model evaluation, and for the identification of models more reliable for decadal predictions.

2. Objectives

The primary objective of this working group is to clarify, coordinate and synthesize research devoted to achieve a better understanding of ENSO diversity, including: 1) surface and sub-surface characteristics, 2) tropical-extratropical teleconnections, 3) physical mechanisms, 4) predictability, and 5) relationship with climate change. The increased understanding of the various flavors of ENSO, and their origin, will support seasonal, interannual, and decadal predictability activities, and will provide a broader set of metrics in the evaluation of ENSO in climate models. Since central Pacific warming may influence North Atlantic tropical cyclones, and possibly force the NPGO oceanic mode of variability, the activities of this Working Group can dovetail with those of the hurricane Working Group, as well as North Pacific biological studies. Because of the influence of the different ENSO flavors upon high-latitude processes through atmospheric teleconnections, findings within this Working Group can leverage the high-
latitude physics studies. In addition, the intercomparison of different ocean reanalyses and observational data sets can benefit the ocean reanalysis activities.

The Working Group will have two specific objectives:

1) Examine the range of ENSO flavors with focus upon longitudinal variations of warming, identify basic surface and subsurface characteristics that are robust among different datasets, assess the existence of possible, and distinct, “precursors” to the different flavors and create a framework that will allow the community to use these results to better understand how the interplay of different oceanic, atmospheric, and coupled processes drive different ENSO flavors and impact their predictability.

The definitions of CP-El Niño proposed in the recent literature are based on different locations of maximum SSTs and different phases of El Niño events. The reason for these differences is likely associated with the large diversity of ENSO events, and with the possibility that ENSO properties vary in a more continuous fashion than implied by the recent literature. The first objective of the Working Group will be to document this range of variations and the associated surface and subsurface characteristics. A more precise characterization of the different flavors of ENSO will provide guidance in understanding the underlying physical processes. Available observational data sets, as well as ocean analysis, have limitations, and may disagree in the representation of ENSO events. Intercomparison and evaluation of the different data sets will be a central objective of the working group. This task will be undertaken with full consideration of the “null hypothesis”: the limited data record may not allow for predictable differences in ENSO events to be determined.

Climate models will also be included in the study. Preliminary analyses of the Climate Model Intercomparison Project 5 (CMIP5) indicate a larger degree of realism in the representation of ENSO by the new generation of models relative to the CMIP3 archive (see, for example, Deser et al. 2011 for a description of ENSO in CCSM4). The longer duration of the model simulations, especially their control simulations, relative to observations, as well as the spatial and temporal completeness of their oceanic and atmospheric fields, may be useful for identifying relationships among dynamical quantities and clarifying the underlying mechanisms. On the other hand, one question that must also be addressed is the extent to which the newer generation of models is capable of generating realistic ENSO flavors. The dynamical processes associated to different ENSO flavors should be part of the “metrics” to evaluate the performance of climate models in simulating ENSO.

Tasks:

I. Examine the consistency of SST and ocean analysis datasets in characterizing ENSO diversity. There are many SST data products available for climate studies, including, for example, the various versions of Reynolds OI SST, NASA/NOAA Pathfinder SST, Extended Reconstructed SST (ERSST), Hadley Centre sea ice and SST
(HadISST), Kaplan Extended SST, differing in their spatial/temporal resolution, reconstruction techniques, as well as type of data acquisition (for example, in situ vs. remote sensing). Similarly, ocean analyses differ in their dynamical models, assimilation schemes, surface forcing, as well as technical choices in implementing those schemes. Thus, some level of disagreement may be expected in the representation of ENSO events and ENSO flavors by the different products (Deser et al. 2010; Giese et al. 2010). For example, CP-El Nino (at least as defined by Yeh et al. 2009) is not present within the NOAA datasets in the first half of the 20th century, whereas it is (albeit less frequent than in the latter half of the record) in the HadISST dataset (Newman et al. 2011). Gauging the changing level of uncertainty in the representation of ENSO diversity over time, such as may be done with new analyses that are output as ensembles (20th century reanalysis, upcoming Hadley SST product), will thus be a key aspect of the analysis. Un-interpolated SST data sets, for example Hadley Centre SST Version 2 (HadSST2), and Minobe/Maeda, as well as data sets of related quantities, such as cloudiness and sea level pressure (SLP) are available for comparison and validation, an approach similar to that used in Deser et al. (2011) for examining SST trends over the 20th century, which can yield indices of ENSO flavors analogous to the Optimal Tropical Index (Deser et al. 2004).

The comparison of the observational and analysis products will include statistical approaches such as the center of heat index (CHI, Giese and Ray 2011), which provides a concise description of longitude, amplitude, and spatial extension of warm (or cold) events. A complementary approach to the identification of different ENSO flavors is Linear Inverse Modeling (LIM), whose application to ENSO diversity is described in Newman et al. (2011). CP- and EP-ENSOs (both positive and negative phases) emerge from the LIM approach as the mature phase of the two leading optimal structures. A continuum of ENSO flavors can result from some linear combination, plus additional noise subsequent to the initial time, of the two structures.

It has been suggested (Kug et al. 2009) that the dynamical processes controlling CP-El Niño events are different than those associated with EP events. These results, based on a handful of events of both types need to be revisited in the context of a broader range of data sets. Composites at different lags will be used to outline patterns of atmospheric forcing/oceanic preconditioning, as possible precursors of the different ENSO events. Observations and atmospheric analyses will be used to examine the dependency of tropical-extratropical teleconnections upon the location of ENSO SST anomalies.

Coral data are available at several locations, and they have proved useful for isolating different timescales of tropical Pacific variability (Ault et al. 2009). Problems in the use of coral and other proxy data for reconstructions of spatial patterns of SST variations arise as a result on the non-stationarity of the climate record (Furtado et al. 2006). Thus, the ability of corals, and proxy records in general to provide insights on the full spectrum of ENSO expressions may be uncertain. This is a large area of research, and somewhat beyond the resources available to a Working Group. However, through the expertise of some of our members, we will work with the paleoclimate community to promote the use of proxy data for improving the understanding of ENSO diversity.
The CMIP5 climate models will also be analyzed, and those models that show skill in the simulation of ENSO diversity will be used to complement the observational record, and help assess the robustness of certain aspects of that diversity based on dynamical consistency and a higher degree of statistical significance.

II. **Establish a set of metrics to characterize ENSO diversity.** Such metrics should highlight the range, implications and effects of the continuum of ENSO flavors. These metrics will be based on the aspects of ENSO diversity that have emerged as robust among the observational and analysis data sets, as well as climate models (Task I). This may include indices that are more appropriate to identify event types with distinct dynamical processes. The metrics should also include measures of the relative importance of different dynamical feedbacks (e.g. zonal vs. vertical advection), indications of possible atmospheric and oceanic conditions that may act as precursors/preconditioning of the continuum of ENSO flavors, and aspects of atmospheric teleconnections that characterize the global impact of different longitudinal locations of anomalous warming or cooling.

**Role for U.S. CLIVAR in achieving this objective.** Through the achievement of this objective and the establishment of a broader characterization of ENSO, U.S. CLIVAR will play a central role in clarifying and coordinating ENSO research in its different flavors, and in providing a comparison and evaluation of different SST datasets and ocean analyses in the tropical Pacific.

**Expected Deliverables:** The Working Group will start with a synthesis of the results already available in the literature along the lines described above, and use teleconferences for coordinating further activities. Recommendations for a more unified set of metrics to characterize the continuum of ENSO flavors will be an outcome of the Working Group activities. Results from the above tasks will be described in a white paper entitled: “ENSO diversity: Basic characteristics and remote influences” to be submitted to BAMS. A special session at the Fall AGU meeting in San Francisco will be organized.

2) **Examine the performance of the CMIP5 archive in reproducing the best observational estimate of ENSO diversity, and assess its projected changes.**

Climate models are the primary tool available for climate prediction and projection. Several of the simulations planned for CMIP5 include decadal prediction experiments. The evolution of ENSO in its different flavors can be expected to influence decadal predictions, and needs to be evaluated in the CMIP5 archive. For example, can the models reproduce the full range of ENSO diversity, or do some models tend to be locked in some specific aspect of it? Are the dynamical processes associated with the spectrum of ENSO flavors “realistically” reproduced by the models? Studies that have examined ENSO diversity in the CMIP3 archive seem to indicate that only a few models show a broad range of longitudes where warming occurs (Ham and Kug 2011). However, other models participating in the CMIP5 project (GFDL_CM2.1 and CCSM4, see Kug et al. 2010, and Capotondi 2011 for analyses of the two models, respectively) show aspects of
ENSO diversity that are consistent with observations. The performance of the rest of the CMIP5 archive remains to be assessed. The metrics developed under Task II of Objective 1 can be used for model evaluation. Those models that exhibit a more realistic behavior can then be used to examine future projections of ENSO diversity. There is some evidence based on the CMIP3 models of an increasing frequency of central Pacific warming in some of the scenario simulations of the 21st century, which may be interpreted as indicative of a global warming influence, but a nontrivial fraction of the models showed the opposite signal. Also, some recent results suggest that more frequent central Pacific events could occur naturally (Yeh et al. 2010; Newman et al. 2011). Further studies based on long control integrations and large ensembles of 21st century integrations are needed to clarify whether the increasing frequency of central Pacific warming described in the recent literature is associated with climate change.

Task:

1. **We propose the creation of a CLIVAR web page as a platform for sharing the analyses of ENSO flavors in the CMIP5 archive.** A similar, albeit more informal, network for the CMIP3 ENSO analyses has proved very useful to share ideas and coordinate ENSO research, and has led to a BAMS paper (Guilyardi et al. 2008). In view of the large spectrum of ENSO flavors, the set of metrics used for evaluating ENSO in climate models needs to be broadened to include measures of the range of surface variations, as well as measures of the dynamical processes associated with the different flavors. Coordination of ENSO research through the website can help the establishment of an ongoing discussion on possible metrics. Coordination and discussion will also be needed for determining the choice of models and ensembles to be used for examining projections on ENSO flavors in the next century, according to different scenarios. The website can provide a resource for the IPCC-AR5, while supporting tropical Pacific research and prediction activities at large.

*Role for U.S. CLIVAR in achieving this objective.* U.S. CLIVAR will be a central player in coordinating research activities to validate the CMIP5 archive, identify models whose representation of ENSO diversity is more realistic, and define the requirements (simulation duration, ensemble size) for isolating the influence of global warming upon the occurrence of specific flavors.

*Deliverables:* A workshop will be held toward the end of the Working Group lifetime to synthesize results and ideas discussed through the web site. A synthesis paper on ENSO flavors in the CMIP5 archive and their connection with global warming will be prepared.

3. **Membership:**

Antonietta Capotondi (University of Colorado, co-chair)
Julia Cole (University of Arizona)
Emanuele Di Lorenzo (Georgia Tech)
Ben Giese (Texas A&M)
Fei-Fei Jin (University of Hawaii)
Ben Kirtman (University of Miami, co-chair)
Tong (Tony) Lee (JPL)
Matthew Newman (University of Colorado)
Niklas Schneider (University of Hawaii)
Andrew Wittenberg (GFDL)
Yan Xue (NCEP)
Jin-Yi Yu (University of California Irvine)

(Potential) International members (unsupported by U.S. CLIVAR):

Boris Dewitte
Sang-Wook Yeh
Eric Guilyardi

4. Resources

Teleconference support
Web page creation support
2 WG meeting (coincident with US CLIVAR summit)
1 workshop
1 article
1 article/workshop report
References


Kug, J.-S., and co-authors, 2010: Warm Pool and Cold Tongue El Niño events as simulated by the GFDL 2.1 coupled GCM. *J. Climate*, 23, 1226-1239.


