Challenges in understanding and modeling ENSO

Antonietta Capotondi[1], E. Guilyardi[2] and B. Kirtman[3]

[1]CIRES, University of Colorado, Boulder, USA; antonietta.capotondi@noaa.gov
[2]LOCEAN, Institut Pierre Simon Laplace, Paris, France; [3]RSMAS/MPO, University of Miami, USA

Some new exciting directions in ENSO research explore inter-event differences in spatial patterns, teleconnections and impacts, asymmetries between warm and cold phases, and the role of extra-tropical regions in triggering ENSO events. However, large uncertainties remain regarding ENSO projections.

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. Over the last thirty years significant progress has been made in improving our understanding of the dynamic processes underlying ENSO, including the ocean-atmosphere feedbacks that are essential to this coupled phenomenon.

The oscillatory nature of ENSO, alternating between El Niño and La Niña events, can be described in terms of the recharge and discharge of warm water to and from the equatorial thermocline ("recharge oscillator"; Jin 1997) or in terms of thermocline depth changes associated with wave propagation ("delayed oscillator", e.g. Suarez and Schopf 1988). These simple paradigms of ENSO as a linear oscillator capture basic dynamical processes; however, they fail to explain differences among events and asymmetries between warm and cold episodes. Moreover, they ignore the important role of stochastic atmospheric phenomena (e.g. westerly wind bursts) and other non-linear effects.

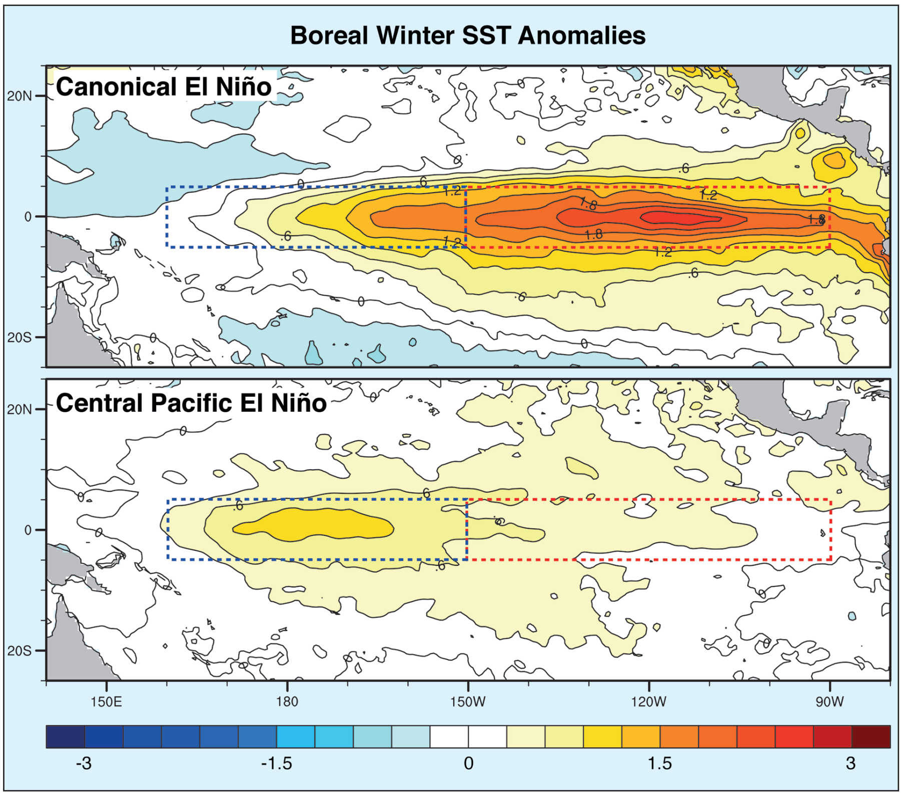

Figure 1: Composite spatial pattern of SST anomalies for the "canonical" ***(top)*** *and "Central Pacific"* ***(bottom)*** *El Niño types (SODA 2.0.2/3) from 1958 to 2007 computed with the approach of Kug et al. (2009). Canonical El Niños are characterized by a boreal winter (DJF) Niño3 index larger than 0.5°C and larger than the Niño4 index (red and blue dashed boxes, respectively), and vice versa for the Central Pacific El Niño (from Capotondi, in press). Observed El Niño events can be described as blends of these two end-member types.*

Understanding and predicting the diverse characteristics of El Niño and La Niña events is important since their regional climatic impact can vary heavily depending on the longitudinal location of the SST anomalies. Also, understanding how teleconnections vary depending on the event type is crucial when proxy records are used to reconstruct past ENSO. Hence, exciting new research developments have emerged to address this observed ENSO diversity.

Understanding ENSO dynamics

The first development is a renewed interest in inter-event differences and the related "El Niño Modoki" debate. Based on a statistical analysis of SST in the tropical Pacific, Ashok et al. (2007) suggested the existence of another type of El Niño, called Central Pacific El Niño (or Date Line El Niño or El Niño Modoki by various authors). They argued that this type of El Niño is not the same as the "canonical" El Niño because its center of action is in the central Pacific instead of the eastern Pacific, as illustrated in Figure 1. It was also suggested that Central Pacific El Niños have become more frequent in recent decades, and their frequency may increase further with global warming (Yeh et al. 2009). Subsequent observational and modeling studies have tried to define the Central Pacific El Niño more precisely or differently (Kug et al. 2009; Kao and Yu 2009). However, as yet no agreement has been reached on the best way to characterize the new Central Pacific-type of El Niño. Some studies have tried to distinguish the central Pacific and eastern Pacific (canonical) warm events based on their underlying dynamical processes, and their relationship with the oceanic mean state (e.g. Choi et al. 2011; McPhaden et al. 2011). A number of other studies dispute the statistical significance of the distinction between the two El Niño types or at least of the increasing occurrence of the Central Pacific variety. They argue either that the reliable observational record is too short to detect such a distinction (Nicholls 2008; McPhaden et al. 2011), or that they have found no trend using other approaches (Giese and Ray 2011; Newman et al. 2011; Yeh et al. 2011). Other authors alternatively suggest to distinguish between other types of El Niño, such as standard and extreme El Niños (Lengaigne and Vecchi 2010; Takahashi et al. 2011). Due to the asymmetric nature of the warm and cold phases of ENSO, Kug and Ham (2011) could not identify analogous distinctions for La Niña, neither in observations nor in the simulations of the Climate

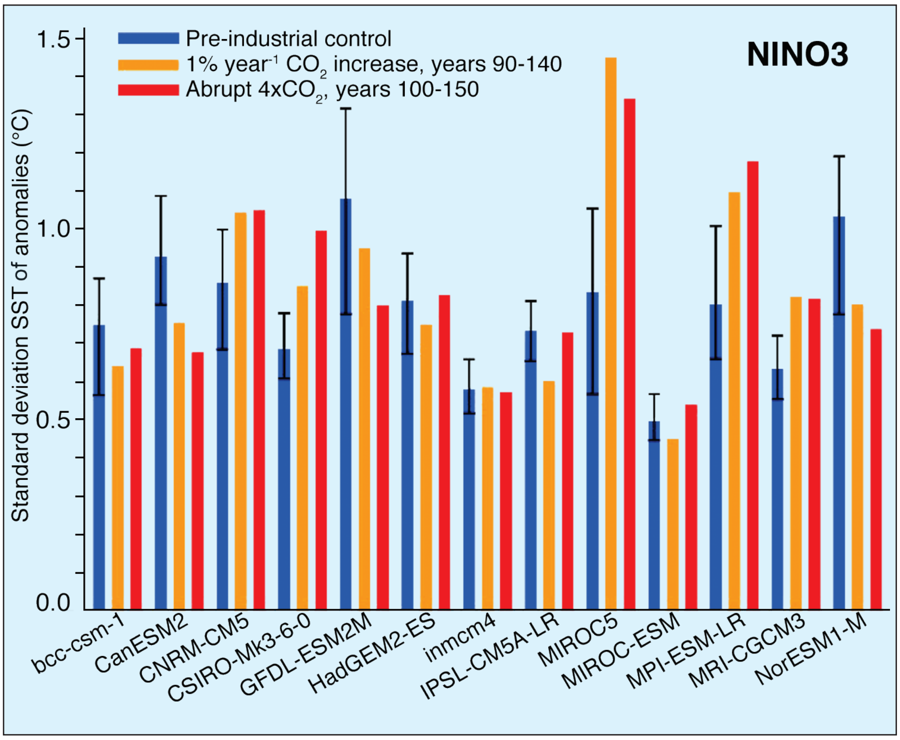

Figure 2: Standard deviation of Niño3 SST anomalies for thirteen CMIP5 model experiments. Blue bars, pre-industrial control experiments; orange bars, years 90-140 from the 1% year^{-1} CO$_2$ increase experiments; red bars, years 50-150 after an abrupt four-fold CO$_2$ increase. Model names are given on the x-axis. Error bars indicate the standard deviations over 50-year windows of Niño3 anomalies in the multi-century control experiments. Thus, when the Niño3 standard deviation in one of the CO$_2$ runs falls outside the error bar, the changes are deemed significant (modified from Guilyardi et al. 2012b). As in CMIP3, this new set of model simulations does not provide a clear trend for ENSO strength in a warming climate.

Model Intercomparison Project version 3 (CMIP3). Due to the large societal relevance of the impacts of ENSO, it is important to predict not only whether an El Niño (or La Niña) event is expected, but if possible which expression the anomaly will take. Fueled by these early studies, new questions are now emerging asking, for instance, if discrete classes of ENSO events emerge from observations, paleoclimate records and model simulations, or if ENSO diversity is better described as a continuum with a few characteristic extremes (e.g. Wu and Kirtman 2005).

Other new lines of research in ENSO diversity include revisiting the relative roles of the ocean and the atmosphere in shaping ENSO (Kitoh et al. 1999; Guilyardi et al. 2004; Dommenget 2010; Clement et al 2011; Lloyd et al. 2011) and exploring the role of regions outside the tropical Pacific in triggering ENSO events (Vimont et al. 2003; Izumo et al. 2010; Terray 2011; Wang et al. 2011). An example of remote influence is the seasonal footprinting mechanism (Vimont et al. 2003): Atmospheric variability originating in the North Pacific can impact the subtropical ocean during winter, and the resulting springtime SST anomalies alter the atmosphere-ocean system in the tropics during the following summer, fall and winter. The diversity of geographical sources and mechanisms proposed may explain the diversity of El Niño events, both in observations and in models.

ENSO in climate models and future projections

Most of our understanding of the representation of ENSO in climate models has been derived from the analysis of the model simulations of the Climate Model Intercomparison Project versions 3 (CMIP3) and 5 (CMIP5). While the models appear to reproduce some of the basic processes and feedbacks associated with ENSO, the details of the SST anomaly patterns as well as the temporal evolution of the anomalies often differ from the observed, and reflect model biases or erroneous atmosphere-ocean interactions (Capotondi et al. 2006, Guilyardi et al. 2009; Guilyardi et al. 2012a). For example, in most of the CMIP3 models, the largest anomalies are located further west along the equator than in observations. Furthermore, in many models ENSO events tend to occur more frequently and regularly than in the real world. While the models keep improving in their simulation of ENSO, no quantum leap was seen in CMIP5 compared against CMIP3 (Guilyardi et al. 2012b).

Over the past few years, new promising methods have emerged, which could improve ENSO simulations, for example by bridging ENSO theoretical frameworks and climate modeling. Resulting innovations include the development of indices that can be used to assess the stability of ENSO in Coupled General Circulation Models (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 much 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 potentially they can also improve the reliability of centennial-scale climate projections and predictions on seasonal time scales.

Looking forward

At present, we don't know enough about how ENSO has changed in the past (the detection problem) and what caused the changes i.e. the contribution from external forcing vs. that due to internal variability (the attribution problem). Given the much too short reliable observational record (both for ENSO and for the external forcing fields, Wittenberg 2009), the complexity and diversity of the paradigms and processes involved, and the shortcomings of current state-of-the-art models, understanding the causes of ENSO property changes, both in the past and in the future, remains a considerable challenge. For instance Collins et al. (2010) concluded that it is not yet possible to say whether ENSO activity will be enhanced or damped in future climate scenarios, or if the frequency of events will change (Fig. 2). Paleoclimatic and paleoceanographic reconstructions have the potential to initiate the next quantum leap.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2013_2.pdf

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