EDITORIAL
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Editorial: ENSO Nonlinearity and Complexity: Features, Mechanisms, Impacts and Prediction

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Editorial on the Research Topic

ENSO Nonlinearity and Complexity: Features, Mechanisms, Impacts and Prediction

El Niño-Southern Oscillation (ENSO) phenomenon is the most important tropical climate variability on the interannual timescale, but its impacts are not limited in the tropics, affecting weather and climate worldwide through far-field teleconnections. Over the past 4 decades, great progress has been made in understanding features, mechanisms, impacts, and prediction of ENSO (see reviews by McPhaden et al., 2020). However, with the increasing availability of observations, as well as the improvements of climate models, the ENSO complexity, which has received widespread attention in recent 2 decades because of the recognizing of ENSO spatial diversity, namely the distinction between the two main ENSO types, the eastern-Pacific (EP) and central-Pacific (CP) types, has become a hot topic and a challenge to the classical ENSO theory and dynamics (see reviews by Capotondi et al., 2015, 2020; Timmermann et al., 2018; Taschetto et al., 2020), e.g., the observed ENSO spatiotemporal diversity might be connected with a combination of two ENSO interannual modes (Timmermann et al., 2018; Wang and Ren 2020).

The ENSO complexity, essentially originating from the nonlinearity of ENSO itself and its interactions with other climate modes, makes it more difficult to do ENSO prediction and thus the prevention and mitigation of ENSO-related disasters. Better understanding towards the ENSO nonlinearity and complexity, as well as the development of corresponding predictability theory and prediction methodology of complex ENSO behaviors, is essential to enhance capabilities for the subseasonal-interannual climate prediction. Here, as one of the leading experts in the ENSO field, Jin summarized the recent active research on the dynamics of ENSO spatiotemporal pattern diversity (STPD) within a synthesized theoretical framework, and discussed challenges and outlooks for theoretical, diagnostic, and numerical modeling approaches to advance our understanding and modeling of ENSO, its STPD, and their broad impacts.

As a matter of fact, the observed key features of ENSO STPD are still inadequately captured by state-of-the-art climate models, though the physical process simulations and model resolutions are improving. Considering that hierarchical modeling approaches, comprising conceptual models, intermediate complexity models, and comprehensive climate models, are fundamental and constructive for ENSO-related research, the assessment and improvement of models are necessary for better simulating ENSO. Same in this Research Topic, Geng and Jin established a revised Cane-Zebiak (RCZ) model, which consists of revised model formulations and well-tuned parameterization schemes. The simulated atmospheric and oceanic responses, as well as characteristics of ENSO in the RCZ model are much better than the original CZ model, making the RCZ model can be a useful tool in studying the dynamics of ENSO STPD. Ineson et al. explored the lack of ENSO amplitude asymmetry between El Niño and La Niña phases in HadGEM-GC3.1. They found that the underestimated subsurface zonal nonlinear dynamic warming due to the inadequate ocean circulation response to ENSO in the model probably be a major cause, which showed us a focus for future model development.

At present, accurately predicting the ENSO events at leads of 6–12 months is still a serious challenge, which is usually subject to the inherent spring predictability barrier of ENSO. The recent 2020/21 La Niña event was not well predicted by most climate models. Cao et al. detected that the predominance of anomalous southeasterly winds over the central equatorial Pacific in spring 2020 is critical for initiating this event by using a pattern clustering approach to compare the best and worst prediction members in an ENSO ensemble prediction system.

Meanwhile, a better simulated mean state in climate models is still an important factor for improving model simulations and predictions. Song et al. assessed the ENSO prediction skill of the recently updated seasonal prediction system FIO-CPS v2.0 from version 1.0 and found that FIO-CPS v2.0 had a better simulated mean state and thus had a higher skill for predicting ENSO compared with v1.0. In addition, due to the insufficient length of modern observational data, evaluating current models' performances in simulating past climate changes by using proxy datasets is a potential way to validate model simulations. Song and Chen examined tropical climate changes, including both basic state and interannual variability, using recently released Paleoclimate Model Inter-comparison Project phase 4 (PMIP4) outputs along with PMIP3 archives.

In the ENSO cycle, the warming and cooling of sea surface temperatures (SSTs) in the tropical Pacific are coupled with large-scale atmospheric circulation anomalies, interact with multiscale variability both within and outside the tropical Pacific. The diversity of ENSO triggers is an important factor for ENSO complexity (see reviews by Amaya, 2019; Cai et al., 2019; Wang 2019). Fu et al. revealed a significant leading role of Siberian High (SH) in the boreal winter on the ENSO development in the following year, and the evolution of the SH-associated response over the North Pacific plays a crucial role in linking SH with ENSO. Li et al. investigated that the reversal of winter surface air temperature anomalies over Central Asia between December and January is closely related to the SST anomalies over the central tropical Pacific. Gao et al. demonstrated that the medium-range predictability of western North Pacific subtropical high (WNPSH) mainly originates from ENSO, and its significant lagged effects on WNPSH well revealed in observation can be realistically reproduced by the National Centers for Environmental Prediction-Global Ensemble Forecast System within the effective prediction lengths. ENSO nonlinearity and complexity also lead to diverse impacts and teleconnections. Several La Niña events featuring relatively long duration and bimodal evolution recently have drawn much attention, showing different climate impacts and teleconnections compared with the canonical single-peak La Niña. Huang et al. systematically examined the multiyear La Niña and found that this type of La Niña could lead to long-lasting impacts on the precipitation in southern China alternately contributed by various mechanisms.

More than that, the global teleconnections of ENSO also have decadal changes, which might be modulated by interdecadal natural variabilities. Chen et al. suggested that the Pacific Decadal Oscillation (PDO) has a strong modulation on the linkage between the spring Arctic Oscillation (AO) and the following winter ENSO. Zhao et al. emphasized that the Atlantic Multidecadal Oscillation (AMO) modulates the relation of ENSO with the central-western Indian Ocean precipitation during the boreal winter.

Understanding broad aspects of ENSO nonlinearity and complexity gives rise to potential skills for seasonal predictions and future projections of ENSO and its global impacts, though properly simulating ENSO complexity in climate models remains a challenge. To provide better predictions and projections of worldwide climate, climate models need to be assessed and further improved from viewpoints of various components of ENSO complexity entangling with each other.

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All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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