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El Niño and the related phenomenon Southern Oscillation (ENSO): The largest signal in interannual climate variation

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ABSTRACT El Niño and the related phenomenon Southern Oscillation (ENSO) is the strongest signal in the interannual variation of ocean-atmosphere system. It is mainly a tropical event but its impact is global. ENSO has been drawing great scientific attention in many international research programs. There has been an observational system for the tropical ocean, and scientists have known the climatologies of the upper ocean, developed some theories about the ENSO cycle, and established coupled ocean-atmosphere models to give encouraging predictions of ENSO for a 1-year lead. However, questions remain about the physical mechanisms for the ENSO cycle and its irregularity, ENSO-monsoon interactions, long-term variation of ENSO, and increasing the predictive skill of ENSO and its related climate variations.

El Niño is an extensive warming of the upper ocean in the tropical eastern Pacific lasting more than 5 months. Usually the NINO3 index is defined as the mean sea surface temperature (SST) anomaly to climatology over the region 5°N-5°S, 150°W-90°W to identify El Niño events. Quantitative definition of an El Niño needs a NINO3 index to be larger than +0.50°C for 5 months at least. The Southern Oscillation is a widespread interannual oscillation in sea-level pressure between one region near northern Australia and one in the central Pacific. We call these related phenomena together ENSO. Hence the warm phase of ENSO is related with El Niño and the cold phase of ENSO is related with La Niña.

Because ENSO is the largest signal in the interannual variation of the atmosphere-ocean system and it has global climatic impact, studies on ENSO cycle and the related climate variability are among the most important frontiers in the atmospheric and oceanic sciences.

Through studies on observed SST data and dynamic theory and modeling of the coupled ocean-atmosphere system, achievements have been made about the general features of ENSO, ENSO's impact on world climate, modeling and forecasting of ENSO, and so on.

What We Know

Since the 1980s, four warm phases of ENSO (1982–83, 1986–87, 1991–92, and 1997–98), plus one prolonged warmth in the Pacific during 1990–1994, have been observed. We have obtained climatologies of the key quantity SST from history records of *in situ* data or by accumulating statistics from operational analyses (1). We've also obtained wind climatologies from historical records. From the climatologies of the oceanic subsurface thermal structure and circulation, it is clear that the main processes to change SST are the surface fluxes and the surface advection, affecting the mixing processes that determine the mixed layer depth of the ocean.

We now know that there is irregularity in the ENSO occurrence, the warming during 1990–1994 is an example. This warming is unprecedented in the instrumental record. The Southern Oscillation index was negative during the 5 years, the western Pacific around the date line was anomalously warm for most of the period, and there were two warm phases of ENSO very close to each other and another one well developed at the end of 1994. The predictions of NINO3 SST anomaly were poor during this period, with some notable misses by all dynamic and statistical models. We experienced the strongest El Niño in instrumental record during 1997–98 (1).

It is known that ENSO has global climatic impact (2). In the tropics, SST anomaly in the Pacific relates the same sign anomalies in the Indian Ocean and opposite sign anomalies in the Atlantic. The role of air-sea interactions in the tropical Indian and Atlantic oceans is mainly that of an amplifier by which the ENSO-induced signals are enhanced in the ocean and atmosphere. In middle latitudes, the atmosphere responds to ENSO through some teleconnection patterns, although the internally generated variations may overwhelm the signal of ENSO influence. The Asian and Australian monsoon circulations are reduced during warm phase of ENSO and vice versa. However, there are periods of low ENSO variance when there appears to be little connection between ENSO and monsoon, and periods when the variability of monsoon seems to lead ENSO variability (1).

Presently the theory for ENSO events that best fits the observations is the delayed-oscillator theory (3–4). We have a series of coupled ocean-atmosphere models to use to predict ENSO around the world. The first such system was designed to give successful forecasts of the 1986–87 warm event (5). Fortunately, the 1997–98 warm event was predicted by many coupled systems several months in advance (6).

What We Do Not Know

We do not know the climatologies for quantities of ENSO other than SST, such as thermal depth, surface current, subsurface current, and subsurface temperature. These quantities are very important for the verification of ENSO theories and the validation of the coupled ocean-atmosphere models for use in ENSO predictions.

We need to know the long-term variability of ENSO to study the multiscale variation of ENSO. Because the instrumental record is short, the decadal scale variation of ENSO is not yet physically understood or even well observed. This decadal pattern of change in the tropical Pacific essentially imposes a slowly varying background change over the more rapid interannual ENSO fluctuations and appears to make interannual prediction more challenging. Although several mechanisms

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have been proposed to explain decadal ENSO-like variability, its physical cause remains unclear.

Evidence has shown that interactions between monsoon and ENSO may change in long-term scales. The effects of ENSO in neutral phase to monsoon remains unknown. Also, the effects of SST anomaly on more regional quantities, such as countrywide seasonal mean precipitation, are largely unclear. These issues are most important for practical forecasting. We need to know how the anomalies of monsoon system change the ocean-atmosphere circulation under some circumstances to understand the physical relations of ENSO and monsoon.

So far, most coupled ocean-atmosphere models tend to underestimate the amplitude of the interannual variability of SST, and the skill of seasonal and interannual prediction of ENSO needs to be increased. This would depend mostly on the improvement of coupled ocean-atmosphere models and the methods of initialization. In this regard, the ongoing international programs for model intercomparisons [Atmospheric Model Intercomparison Project (AMIP) and Coupled Model Intercomparison Project (CMIP)] and the research projects on data assimilation around the world will provide major contributions.

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