PERSPECTIVES

GEOSCIENCES

Special Topic: Advances in El Niño Research

The evolving ENSO observing system

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El Niño–Southern Oscillation (ENSO) is by far the most energetic and influential short-term climate variability on our planet, originating from an instability of the large-scale ocean-atmosphere interaction in the tropical Pacific. ENSO influences climate worldwide because it brings about large changes in the heating of tropical atmosphere that greatly alter the global atmospheric circulation. Since societies and ecosystems are profoundly affected, monitoring and predicting ENSO are of great importance for our wellbeing and sustainability. Therefore, tremendous resources and efforts have been devoted to ENSO research over the last three decades. Of particular interest is the construction and maintenance of an ENSO observing network that covers the tropical Pacific ocean-atmosphere coupled system, providing real-time data for ENSO state monitoring and forecast initialization. Such an observing system was first established during the 10-year (1985–94) international Tropical Ocean-Global Atmosphere (TOGA) program [1]. It has evolved over the years, and will continue to provide invaluable and irreplaceable service to the ENSO research and prediction community.

TOGA was largely motivated by the strong 1982–83 El Niño event, which came as a total surprise because of the lack of real-time observation and prediction. With a focus on ENSO, the goals of TOGA were to 1) gain a description of the tropical oceans and the global atmosphere as a time-dependent system in order to determine the extent to which the system is predictable on time scales of months to years and to understand the mechanisms and processes underlying its predictability; 2) study the feasibility of modeling the couple ocean-atmosphere system for the purpose of predicting its variation on time scales of months to years; and 3) provide the scientific background for designing an observing and data dissemination system to support operational ENSO predication by coupled ocean-atmosphere models. These goals were generally achieved [2], making TOGA one of the most successful international programs in ocean and climate research. A great legacy of TOGA is its Tropical Atmosphere Ocean (TAO) array completed in 1994, which consists of nearly 70 moored buoys in the tropical Pacific with both oceanic and atmospheric data available in real-time. In 2000, with the Triangle Trans-Ocean Buoy Network (TRITON) supported by Japan, TAO was extended westward to become the TAO/TRITON array, and it has been in service ever since.

Aside from the TAO/TRITON array, there are also other observational platforms and technologies used for ENSO research, including surface drifters, Argo profiling floats, tide gauges, ships of opportunity lines of expendable bathythermograph (XBT), as well as satellite remote sensing. Collectively they are now called the Tropical Pacific Observing System (TPOS, Fig. 1). It has been demonstrated over and over again that the TPOS is indispensable for our understanding, monitoring and forecasting of ENSO [3], and to a large extent it has been the observational basis for ENSO research over the last 30 years. Nevertheless, the current TPOS has its limitations, and it is time to redesign and enhance the system for both scientific and logistic reasons. Scientifically, some important aspects of ENSO, such as its diversity and predictability, are still not well understood and were not emphasized when the TPOS was originally designed. Thus the new design should take into account of the recent scientific understanding of ENSO and support new process studies in addition to broad-scale observations. Logistically, the sustainability of the TPOS has been a concern in recent years, with the deterioration of the TRITON array in the western Pacific being particularly alarming. At the same time, advances in new technologies of ocean observation, such as satellite salinity, altimetry and scattorometry, and autonomous platforms including Argo and gliders, have begun to provide additional sources of information. Thus the new design should take advantage of all these platforms and optimize their integrated implementation.

It is for these reasons that the international TPOS 2020 project [4] was launched in 2014 to promote the transition of the TPOS into a more robust and sustainable system by the year of 2020. The objectives of the project are to redesign and refine the TPOS to observe ENSO and advance scientific understanding of its causes; to determine

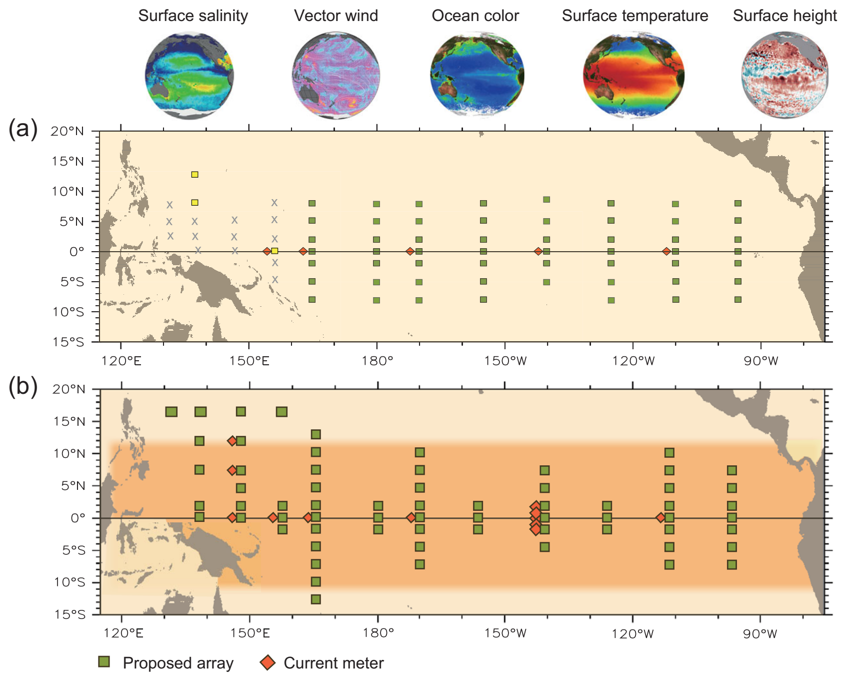

Figure 1. Schematic of the TPOS 'Backbone' configuration. (a) The current TAO (green boxes) and TRITON (yellow boxes) mooring locations. Current meter locations are shown as red diamonds. Vacant TRITON sites are marked with (x). (b) The TPOS 2020 proposed array (large green boxes). Current meter locations are shown as red diamonds and double Argo in dark orange. In both cases satellites (top row) and other *in situ* systems also contribute.

the most efficient and effective observational solutions to support prediction systems for ocean, weather and climate services; and to advance understanding of tropical Pacific physical and biogeochemical/ecosystem variability and predictability [5]. While the TPOS 2020 calls for further investment in both sustained and experimental observations, its primary focus is on the former. The sustained observing system, or the backbone of the TPOS, has its core evolving from the TAO/TRITON array and the Argo network. As illustrated in Fig. 1, the backbone mainly consists of a tropical moored buoy array (TMA) with moorings along the equator and along several strategically placed cross-equatorial sections, and an enhanced deployment of Argo floats within 10°S-10°N. As compared to the current TPOS, the TMA will be optimally rearranged and the number of Argo floats will be doubled in the tropical band. It is worth noting that a regional observation program has recently been proposed by China as a contribution to the TPOS (the western Pacific additions in Fig. 1). It will not only fill the gaps left by the withdrawal of the TRITON buoys, but also extend the TPOS to cover the low-latitude western boundary currents, Asian Monsoon and typhoons, which may have significant impact on ENSO [6, 7] aside from being scientifically important on their own right.

The ENSO observing system, mostly embedded in the TPOS, will be continuously evolving to meet new scientific challenges and to make use of new technologies [8–10]. Further refinement of the system may benefit from optimization methods such as target observation analysis [11, 12]. As stated in the TPOS 2020 First Report [5], the system should always have five key functions: 1) to provide data in support of ENSO prediction and other forecasting systems and to foster their advancement; 2) to provide observations to quantify the evolving state of the surface and subsurface ocean; 3) to support integration of satellite and *in situ* approaches including calibration and validation; 4) to advance understanding and modeling of the climate system in the tropical Pacific, including through the provision of observing system infrastructure for process studies; and 5) to maintain and extend the tropical pacific climate record. The TPOS 2020 recognizes the difficulties of sustaining an observing system with the precision to detect small changes over decades, not only for climate change but also for the climatology that underpins ENSO forecasts. As the first step toward redesigning and enhancing the current system, the TPOS 2020 team has made 22 recommendations with 15 near-term actions [5], which are presently being deliberated by the scientific community as well as the stakeholders. There is no doubt that the future evolution and sustainability of the ENSO observing system will depend critically on a close, long-lasting international collaboration among scientists and funding agencies from both sides of the Pacific Ocean.

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