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CLIVAR Ocean and Climate: Variability, Predictability and Change is the World Climate Research Programme's (WCRP) core project on the Ocean-Atmosphere System

The Tropical Pacific Observing System 2020 Project: The Role of Research and Innovation

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Introduction

In January 2014, NOAA and JAMSTEC, in collaboration with the Ocean Observations Panel for Climate (OOPC) convened a Review of the Tropical Pacific Observing System (TPOS), through a Workshop and associated White Papers (TPOS 2020, 2014). The Review was in direct response to the deterioration of the mooring array elements (TAO) of the network during 2012-2014 (Figure 1) and consecutive decreasing number of deployed buoy of TRITON since 2011 (fifteen buoys to eight buoys in the western Pacific), and highlighted the risks to a system that underpins the capability for seasonal forecasting around the globe. The Review considered immediate actions to address the deterioration in the observing system, but more importantly proposed a number of activities and provided recommendations to change to a more robust and sustainable system.The major outcome was initiation of a TPOS 2020 Project to achieve this change (Smith et al, 2015).

The TPOS 2020 Project will evaluate, and where necessary change, all elements that contribute to the Tropical Pacific Ob serving System based on the current understanding of tropical Pacific science (see McPhaden et al 1998 for a description of the original TOGA observing system). The project aims for enhanced effectiveness for all stakeholders, including research, and requirements of the operational climate prediction systems that are primary users of TPOS data. TPOS 2020 embraces the integration of diverse sampling technologies, with a deliberate focus on robustness and sustainability. TPOS 2020 is a focused, finite term project, beginning in 2014 and completing in 2020, with its primary outcome being an internationally-coordinated and supported sustainable observing system for the Tropical Pacific Ocean.

This note focuses on the role of research and innovation in the evolution of the TPOS. To achieve change, the Project will draw on the scientific evidence available today and, as appropriate, facilitate research and technical development to guide the redesign of the TPOS to meet the requirements of 2020 and beyond.

Initial themes of work

Under the guidance of the TPOS 2020 Project Steering Committee (see http://TPOS2020.org/), a number of initial tasks were agreed, some with relatively short time horizons, others with longer. Given that TPOS 2020 has a finite lifetime and that some of these tasks may endure beyond 2020, it is important that TPOS 2020 engages early with international research groups and intergovernmental organizations that have enduring mandates.

The specific areas for action include:

i. Re-evaluation of the backbone of the TPOS, including broad-scale aspects. The backbone of the TPOS is a legacy of the Tropical Oceans-Global Atmosphere Experiment (TOGA, the forerunner of CLIVAR; McPhaden et al 1998) and the following TAO/TRITON array with salinity time series in the western Pacific region, but a number of different remote and in situ platforms have emerged over the last two decades and it is timely to revisit and, as appropriate, adjust the design.

ii. Elaboration of the scientific need and feasibility of observing the planetary atmosphere-ocean boundary layer. TPOS 2020 sees this as a potential area for innovation. Coupling between the atmosphere and ocean occurs on a range of scales. Research is showing that inclusion of near-surface processes on diurnal time scales may lead to improvements in weather and climate models (Tseng et al., 2015, Woolnough et al. 2007). Thus for example, capturing the diurnal cycle associated with the Madden Julian Oscillation may help improve intermediate time scale forecasts.

iii. Evaluation of observational approaches for the eastern and western boundary regions. Despite the many scientific advances over the last 30 years, these regions continue to represent knowledge gaps and sources of errors on time-scales of weather prediction to climate change.

iv. Development of rationales, requirements and strategy for biogeochemical observations. The ENSO Observing System and its modern manifestation TPOS were focused on physical climate. It is timely and appropriate to extend the design to biogeochemical requirements and, in time, to biological observations.

v.Consideration of approaches to improve modelling, data assimilation and synthesis, and use of models and their requirements for informing the design and evolution of TPOS. One of the barriers to success for TPOS is the inefficient use of ocean data by models. Model bias (see Figure 2) reduces the efficiency of the observed data during assimilation, and therefore, limits the effectiveness of the

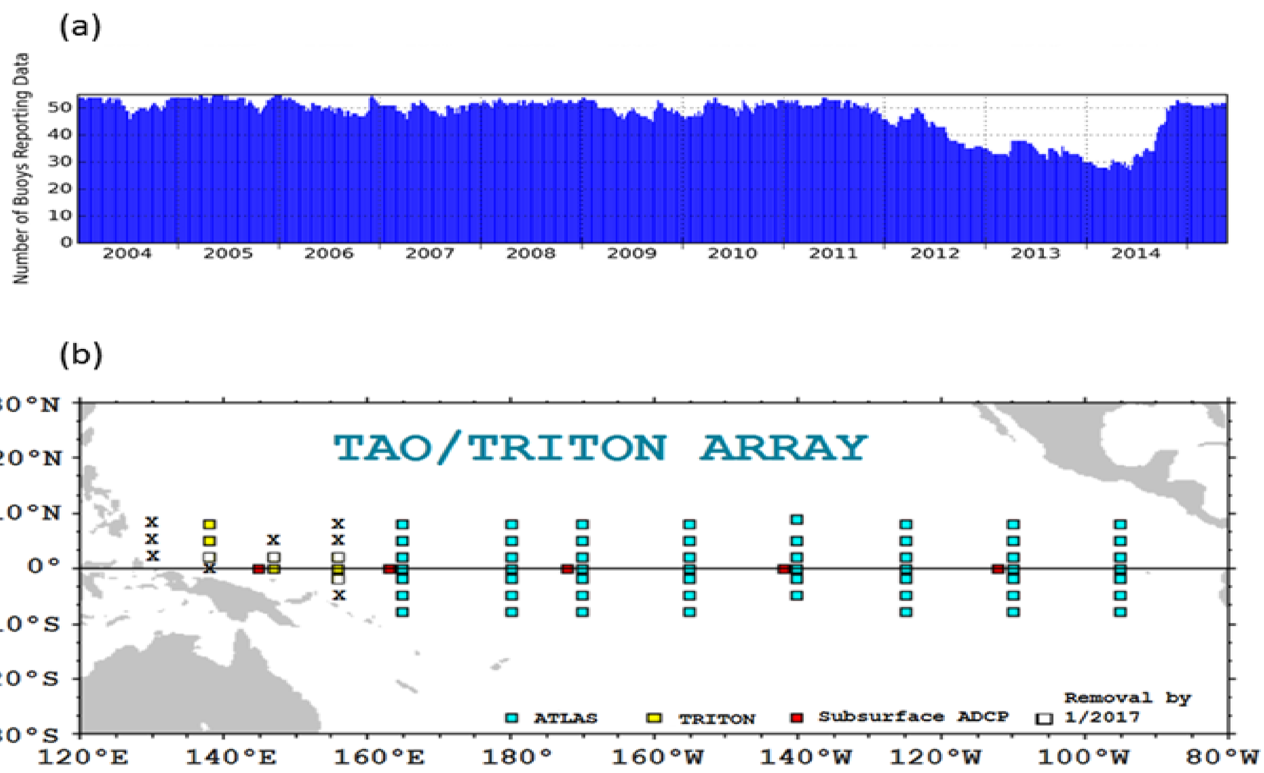

Figure 1: (a) Number of TAO moorings returning data 2003-2015 (courtesy PMEL). (b) The TAO/TRITON array in the western Pacific. Sites where operation has ceased are marked with a cross. Locations that are planned to cease in early 2017 are shown in yellow (latest information provided by JAMSTEC).

observing system for monitoring and predicting climate variability.While the next section will provide further elaboration, a number of other aspects are worth noting:

- The observing system should be considered as an integrated whole, including satellites, modeling, data management and the range of modern and robust in situ technologies. Thus the project will articulate the strengths of a multi-platform approach appropriate to the multi-scale variability of the tropical Pacific.
- There should be the explicit assessment of risks to the observing system as part of TPOS 2020, taking into account system requirements such as necessary redundancy, sensor diversity, etc. Identifying and managing risks to the long-term climate records will be a priority.
- It is critical that the TPOS 2020 re-energize the associated research community. In the past two decades, models have continued to improve but the improvement has slowed (see for example, FAQ 9.1, in Flato et al, 2013) and the research community dedicated to climate model prediction improvements has seemingly plateaued, perhaps even shrunk. In the meantime, more questions about the diversity of ENSO and its hiatus have been raised.
- Initiate discussions with interested organizations to broaden support for the TPOS, including all-important research vessel/ship support and participation in coordinated joint process and modelling studies. For example, WCRP and CLIVAR support a number of Panels and Working Groups that either coordinate specific aspects of model development and modeling activities (e.g. the CLIVAR Ocean Model Development Panel (OMDP)) or include modelling in their mandate (e.g. the CLIVAR regional basin panels). Relevant activities include the Coordinated Ocean-ice Reference Experiments, particularly CORE-II, a suite of hindcast experiments coordinated by OMDP, and a new project being developed within the WCRP Working Group on Seasonal to Interannual Prediction (WGSIP) on assessing the impact of model drift/initial shock on performance within the first month of forecasts. Likewise, while the U.S. and Japan have been the primary sponsors for the existing TPOS, in the future, other nations may play increasingly important roles.

Elaboration of research requirements

Backbone Observing System

TPOS 2020 refers to the basic sustained sampling network as the "backbone" (formerly called "broadscale") of the system. This terminology emphasizes that the backbone anchors and underlies all other pieces of the observing system, some of which may be experimental or implemented for a limited time. The backbone will be designed to maintain consistent and well-understood sampling rates and scales that allow for the detection of climate variability and climate trends and maintenance and extension of the climate record. The backbone observing system will observe and quantify the state of the ocean, on time scales from weekly to interannual/decadal, and provide data for forecasting systems. It will also support integration of satellite measurements into the system, including for calibration and validation.

Scientific evidence and research will elucidate the unique capabilities of the 'legacy' (eg, McPhaden et al 1998) and existing observing system elements (Roemmich and Cravatte, 2014) as a contribution to the backbone of TPOS beyond 2020, including consideration of efficiency, effectiveness and scientific utility. Based on current requirements for essential ocean and climate variables, enhancements and/or modifications to these efforts will be studied, taking account of available synthesis approaches. The use of models and data assimilation tools to aid the objective design of the future backbone of TPOS and for the assessment of an integrated ocean observing system is the more straightforward approach. However, given the presence of systematic errors

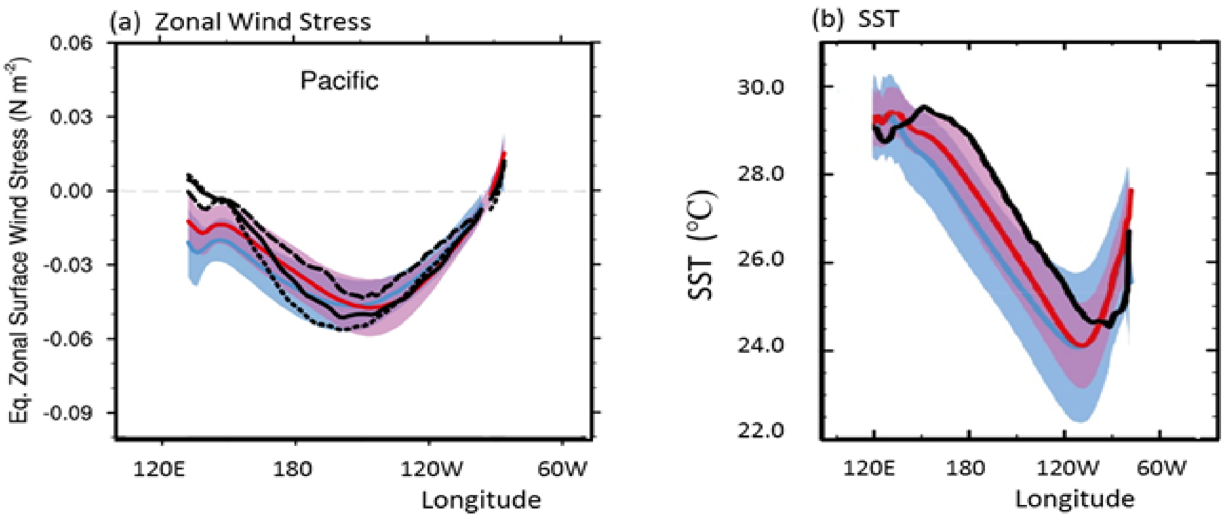

Figure 2: [Adapted from Flato et al 2013] (a) Equatorial (2°S to 2°N averaged) zonal wind stress for the Pacific in multi-model mean comparison with CMIP3. Shown is the time-mean of the period 1970-1999 from the historical simulations. The black solid, dashed, and dotted curves represent ERA-Interim (Dee et al., 2011), National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis I (Kalnay et al., 1996) and QuikSCAT satellite measurements (Risien and Chelton, 2008), respectively. Shading indicates the inter-model standard deviation. (b) Equatorial multi-model mean SST in CMIP5 (red curve), CMIP3 (blue curve) together with inter-model standard deviation (shading) and observations (black). Model climatologies are derived from the 1979-1999 mean of the historical simulations. The Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) (Rayner et al., 2003) for observations.

in the modelling and assimilating tools, such guidance needs to be used with caution. Specific studies will assess the strengths and weaknesses of individual components of the observing system, their capabilities to represent specific individual components of the observing system, their capabilities to represent specific physical processes, and explore different sampling strategies (e.g. Gasparin et al. 2015, submitted). As stated above, the observing system should be considered as an integrated whole, and studies will also be carried out to combine the different components of the observing system (satellite data, in situ Lagrangian and in situ Eulerian data platforms) in the most efficient way. Tools such as ARMOR-3D (Guinehut et al., 2012) and DFS (Oke et al., 2009) may help in assessing the contribution, redundancy and content of information of each part of the observing system. As these tools rely on the assumed decorrelation scales, results will depend on the processes we aim at resolving, and experiments should be performed to cover the different space/time scales of phenomena that are to be resolved by the backbone observing system.

We need to anticipate the future evolution of prediction systems and draw on research advice, for example to determine the initial strategy for backbone biogeochemical observations.

Western Pacific and Eastern Pacific Boundary Regions

The boundary regions of the Western and Eastern Pacific remain regions of high scientific interest due to their fundamental role in variability and predictability of the coupled climate system as well as their direct socio-economic benefits (for example, Harrison et al 2014; Takahashi et al 2014). Several large regional observing activities or finite-lifetime process studies already exist or are planned in the Western Pacific (eg, Ganachaud 2013; Ganachaud et al 2008; Hu et al 2011), and TPOS 2020 has compiled a report on these activities of operational and research agencies in a relevant region. (Ando, K., in preparation).

A number of NE Asian agencies are contemplating significant research in the western Pacific, motivated by interest in the Western Pacific ocean circulation including Indonesian Through Flow, the East Asia monsoon, typhoons and ENSO. The CLIVAR Pacific Region Panel can foster coordination so that the whole can be more than the sum of the individual pieces; there would be benefit to all by joining these activities together as an integrated research initiative, including connecting up the science rationale. Such integration may raise opportunities for greater research collaboration, and lead to discussions about what a sustained regional observing system for the Western Pacific could look like post 2020.

For the Eastern Pacific, there is strong potential to strengthen regional collaboration by bringing together a core group of researchers across regional agencies. Persistent serious errors in climate models are particularly obvious in the eastern tropical Pacific, including a warm bias off South America; a double Inter-Tropical Convergence Zone (ITCZ) with excessive precipitation in the Southern Hemisphere; an excessively strong seasonal cycle in SST and winds and a spurious semi-annual cycle; and weak cloudiness in the marine boundary layer (Flato et al. 2013). Additionally, climate forecasts at up to three months lead time in advance for western South America depend critically on the propagation of equatorial Kelvin waves (Takahashi et al., 2014; Figure 3), which can interact strongly with the mean thermocline structure in the eastern Pacific (e.g. Mosquera-Vásquez et al., 2014), while long-range forecast skill is low in this region, particularly during strong El Niño events (Takahashi et al., 2014). This makes the region an obvious focus for TPOS 2020. Although mooring arrays in the region have typically had low data returns due to high levels of vandalism, Argo floats and new technologies such as gliders and wave-gliders may make observing the ocean in this region more achievable in future.

Additionally, regional observational and data exchange initiatives exist, such as the CPPS Regional Cruise and the GOOS Regional Alliance for the South-East Pacific region (GRASP), respectively, that can serve as a basis and provide important input to the TPOS in this region. As with other regional activities, any focused regional work around the far eastern Pacific boundary will inform requirements and options for the backbone TPOS. Priority is being attached to engaging regional experts and institutions and capacity building to improve sustained observing capability; the development of a regional research project may facilitate improved guidance for a sustained observing system.

Modelling and data assimilation

Much of the use and benefit of TPOS observations will be realized through their use in model assimilation systems that provide initial conditions for coupled model climate forecasts and are used for process studies. However, model biases degrade the value of the observations because models rapidly drift towards their own climate once a forecast commences (see for example Figure 2). The model and data assimilation development community and operational prediction centers are key research partners in the success of TPOS. TPOS 2020 efforts, including embedded process studies, will be designed to address phenomena that are leading candidates for causes of systematic errors in models, and where detailed observations are needed to guide diagnostics of model errors (Fujii et al, 2015; Guilyardi 2009; Guilyardi, 2015). Examples of potential studies include those geared toward a greater understanding of the relationship of ocean near-surface conditions and convective rainfall in the tropics, and the mechanisms that communicate surface fluxes into the subsurface ocean (see following sub-section).

The initial focus is on identifying research pathways that will contribute to improved understanding of systematic errors and, hopefully, to subsequent model improvements, especially through promotion of joint activities with other bodies such as WCRP and CLIVAR that have mandates to improve models. In an ideal world, observational system studies using assimilation systems would be central to designing and planning the future TPOS observing systems, but the aforementioned systematic errors limit their efficacy and conclusions have to be used with caution (Fujii et al 2015). Another avenue for advancing the outcome of TPOS is development of data assimilation systems that can take advantage of the full suite of TPOS observations (e.g., salinity, ocean currents).

There are numerous possible pathways into the research modelling community, and TPOS 2020 does need to be judicious and efficient in such engagements. The WCRP/GEWEX Grand Challenge on Clouds, Circulation and Climate Sensitivity (Bony et al 2015), the various WCRP and CLIVAR groups (e.g., on seasonal prediction, ocean and coupled model development, global synthesis and observations), the emerging Year of the Maritime Continent initiative, and the various Task Teams under GODAE/OceanView are some of the avenues to be explored. Improved understanding and prediction of sub-seasonal climate variability has also been identified as a priority.

Surface Boundary Layers

The ocean and atmospheric boundary layers represent one of the main knowledge gaps for the tropical Pacific Ocean and dependent forecast systems (Cronin et al 2014; Josey et al 2014). TPOS 2020 aims to formulate a practical observing strategy and technical sampling requirement for oceanic and atmospheric boundary layer measurements. There is increasing appreciation of the role of diurnal variability of air-sea fluxes and boundary-layer properties in affecting large-scale, lower-frequency variability such as the Madden-Julian Oscillation (Zhang, 2005; Woolnough et al., 2007), and TPOS 2020 aims to identify a set of key ocean and climate regimes for which high-frequency measurements (hourly or better resolution) of the air-sea fluxes of heat, moisture, and momentum are needed. Likewise, because these ocean and atmosphere exchanges are moderated by and impact the planetary boundary layer, observations within the planetary boundary layer need to be made at a significantly higher resolution than needed for observations of thermocline variability associated with equatorial waves. TPOS may thus refocus surface mooring platforms for observing the planetary boundary layer variability, and rely upon other platforms for monitoring slower ocean deeper ocean variability.

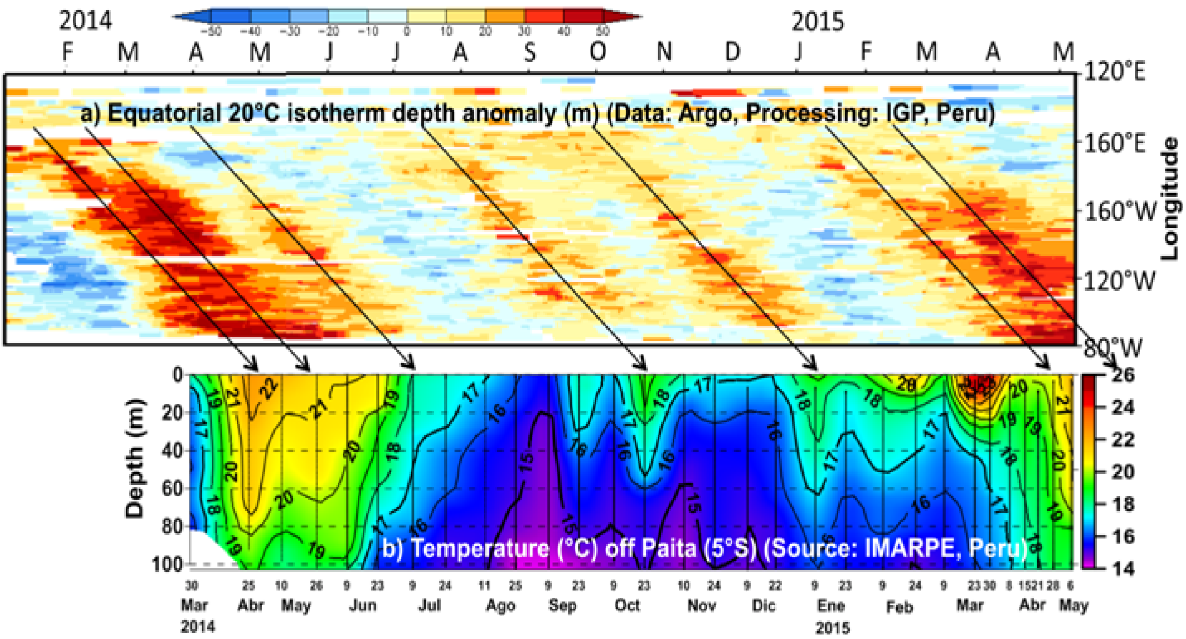

Figure 3: Example of propagation of Kelvin waves (with Argo data) and their impact on ocean temperature at the Peruvian coast (Peruvian data).

The mix of sustained versus campaign network elements is to be determined. Further studies are required on the most efficient way to meet existing and developing ocean satellite and modelling requirements. One consideration for possible innovation is a subset of regimes where direct eddy-correlation approaches might be tested for feasibility and scientific value. This area provides research opportunities with the biogeochemical and ecosystem community to ensure the needs of key gas exchange calculations are met as well as to improve the all-important mixed layer representation.

New technology

The community is demanding ever more sophisticated services derived in whole or in part from the TPOS (for example, as manifested in the Global Framework for Climate Services; http://www.wmo.int/gfcs/), but the basis of such services has a number of risks. The underlying observations are under resource pressures and the evolution of the prediction systems is not keeping pace with expectation in terms of accuracy and reliability. This represents an opportunity for scientists, technologists/engineers, and operational climate services to re-engage to achieve major change, change that will have profound benefits for future generations.

We believe technology has much to contribute to this change, through improved and more efficient observations and models, and through novel approaches to the challenges of observing ENSO. The recent two pilot satellite missions dedicated to sea surface salinity measurements (Halpern et al., 2015) and the glider application in monitoring the South-western Pacific boundary current (Davis et al., 2012) are excellent demonstrations of the promise and value of new technology. In the next decade there will be some exciting advancement in technology, autonomy and platforms that the observing and prediction community can take advantage of (Figure 4).

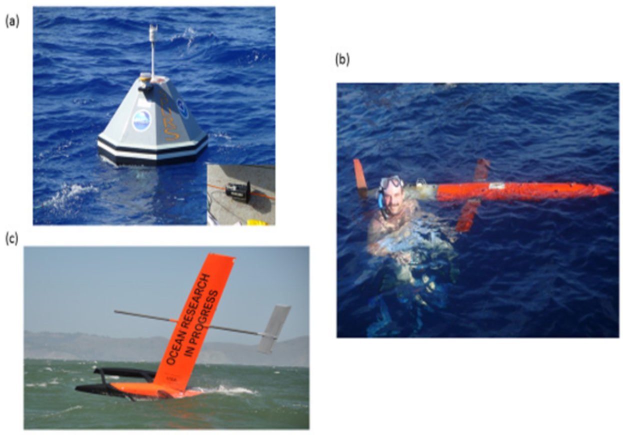

Figure 4: Examples of new technology. (a) Wave-powered moored ocean profilers and PRAWLER (inset; courtesy John Shanley (@ NOAA, (b) sea gliders that can be directed to undertake observations in a certain pattern or for a specific region (photo by Lionel Gourdeau, LEGOS), and (c) observing platforms that are deployed and recovered from shore [courtesy C Meinig, PMEL]

Conclusions

The TPOS 2020 Project was initiated by research and operational agencies to develop a more robust sustained observing system for beyond 2020. At its heart, it is a Project of change and will be informed by accumulated scientific knowledge and, as appropriate, specific studies and projects where knowledge gaps exist. TPOS 2020 will deliver a refreshed and more effective design for the TPOS, promoting sustainability, and making full and appropriate use of new and emerging technologies.

TPOS 2020 will endeavour to enhance cooperation and coordination among the TPOS international sponsors and contributors, including research, to deliver improved efficiency, reduced risk and greater robustness. Facilitation of experiments and studies in process parameterisation and modelling will guide improvements in climate prediction and associated applications, a core interest of CLIVAR. There will be a comprehensive assessment of climate scales and signatures and their dependency on the backbone observing system in order to safeguard and enhance the climate record. Innovations include the integration of biogeochemical and biological sampling into the TPOS design and implementation and potentially new approaches to sampling at diurnal and subseasonal scales and in the ocean boundary layers.

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