BAMS
Meeting Summary

Focused Observations for Expanded Comprehension

Advancing Tropical Pacific Coupled Modeling and Process Understanding

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Tropical Pacific Observing Needs to Advance Process Understanding and Representation in Models

What: Two hundred observers, modelers, and data assimilation experts met to identify tropical Pacific ocean and atmosphere observing needs to advance process understanding and model representation of ocean–atmosphere coupled interactions.

When: 24–26 May 2021

Where: Online

KEYWORDS: Atmosphere-ocean interaction; Marine boundary layer; Oceanic mixed layer; Cumulus clouds; Mixing; Tropical variability

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Multiscale tropical ocean–atmosphere coupled feedbacks regulate tropical–extratropical interactions and weather across the globe. Sustained in situ and satellite observations of the ocean and lower atmosphere have provided key observations for evaluating cross-scale coupled feedbacks and their representation in climate and forecast models, while high-resolution targeted measurements collected during field campaigns have provided critically needed observations of fundamental oceanic and atmospheric processes that cannot be resolved by climate and forecast models. The 2020 redesign recommendations for the Tropical Pacific Observing System (TPOS; Kessler et al. 2021) motivated the 2019 U.S. CLIVAR Workshop on Atmospheric Convection and Air–Sea Interactions Over the Tropical Oceans (Hagos et al. 2021), where the community gathered to assess the state of knowledge of tropical Pacific ocean–atmosphere feedbacks and to initiate discussions of needed process study observations to fill spatiotemporal gaps in the TPOS. The 2021 U.S. CLIVAR Tropical Pacific Observing Needs to Advance Process Understanding and Representation in Models Workshop (TPON Workshop) furthered this discussion of observing needs. The 3-day TPON Workshop was attended by over 200 observers, modelers, and data assimilation practitioners who outlined needs for both coordinated sustained observations as well as process studies in specific locations.

Key topics and results

Plenary speakers, breakout session panelists, and poster presenters introduced advances in Earth system prediction and data assimilation, understanding ocean–atmosphere coupled processes, and current and emerging ocean and atmosphere observing strategies. Workshop participants incorporated this information into open discussions whose outcomes are summarized here.

Tropical climate variability is governed by coupled cross-scale interactions, where variability on one scale in the atmosphere can force a response in the ocean on another scale, which may then feed back to the atmosphere on yet another scale. The multiscale exchanges, which are themselves regulated by small-scale, high-frequency processes such as vertical turbulent mixing in the ocean; surface fluxes of heat, freshwater, and momentum; and the initiation of atmospheric convection, are not always well represented in climate and forecast models. Workshop participants noted that these process biases have particularly concerning consequences for predicting MJO teleconnection patterns and ENSO variability, especially in regard to 1) warm pool eastward expansion (WPEE) events and their relationship to atmospheric convection, teleconnections to the extratropics, and ENSO cycles (Wang et al. 2019; Lee et al. 2019; Kessler 2005) and 2) the eastern Pacific equatorial upwelling (PUMP) region, its influence on seasonal-to-interannual climate variability, and its links to ocean biological productivity through regulation of oxygen

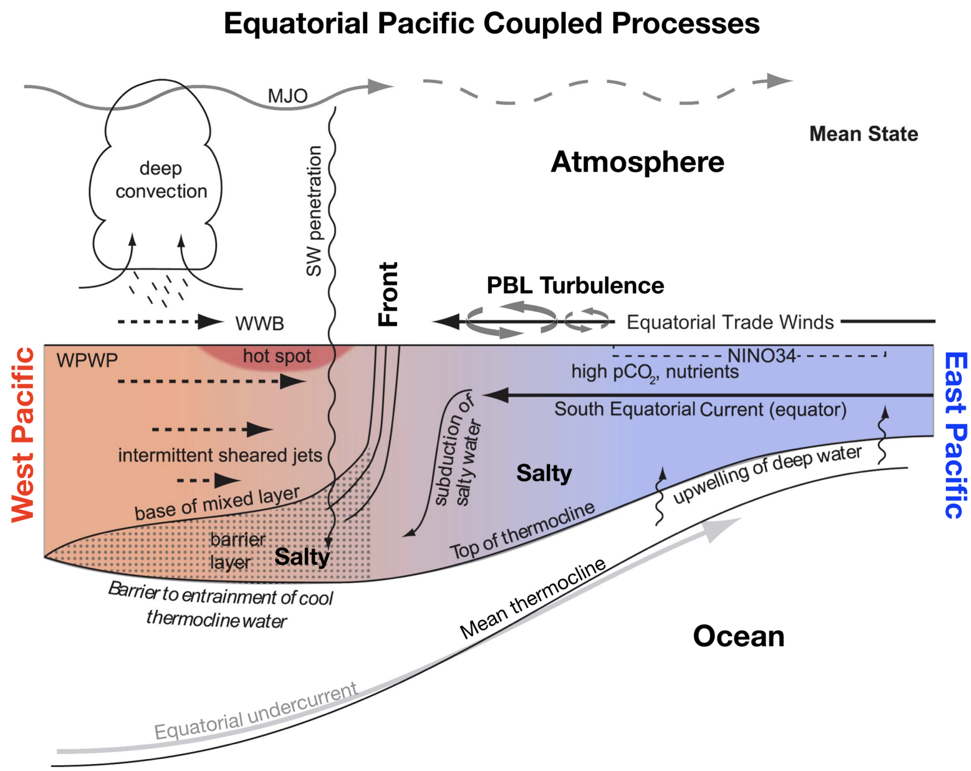

Fig. 1. Schematic illustration of tropical Pacific ocean and atmosphere processes [adapted from Brown et al. (2015) with input from W. Kessler].

minimum zones and carbon chemistry (Cravatte et al. 2016). Figure 1 illustrates some of the processes that characterize the two regions. The ocean stratification at the eastern edge of the west Pacific warm pool plays a key role in maintaining the warm SSTs in the region and in modulating the local air–sea interactions on intraseasonal time scales. These interactions have cascading effects on ENSO evolution and global teleconnections. Hence, understanding the role of the upper-ocean salinity stratification (barrier layer) and its drivers in this region is important for improving our models and forecasts. Similarly, the ocean–atmosphere dynamics in the Pacific Ocean is critically regulated by upwelling and mixing processes in the east-central Pacific Ocean that influence global circulation patterns, ocean biogeochemistry, and the global carbon cycle. Hence, better observations of the spatiotemporal variability of these processes in the east Pacific are needed to constrain our current climate models and to better understand how they influence local and regional drivers of ocean biogeochemical cycles.

Participants discussed that these biases are rooted in gaps in understanding the large-scale drivers of small-scale process variability and their cross-scale interactions, especially within the upper-ocean mixed layer and lower atmospheric boundary layer. Processes that regulate the coupled boundary layers are not limited to surface fluxes, but include transports across the top of the marine boundary layer, across the base of the ocean mixed layer, and extending as deep as the ocean thermocline. Modern atmospheric reanalysis products generally well represent thermodynamic variability for vertical levels above about 600 hPa, but exhibit distinct biases below this level when compared to in situ measurements (Wolding et al. 2022). As a result, improved observation of processes above the atmospheric marine boundary layer, such as convective moistening of the lower atmosphere, and below the ocean mixed layer, such as vertical turbulent mixing, are needed to elucidate key scales of ocean–atmosphere energy and mass transfers.

Participants concluded that reducing model biases and gaps in understanding will require sustained, high-frequency, vertically and horizontally resolved, and collocated observations of the upper-ocean and lower atmosphere to adequately sample the spatiotemporal scales of covariance across the ocean–atmosphere interface over a broad spectrum of background states. Such measurements should include ocean vertical temperature and salinity profiles and their local horizontal gradients; atmospheric boundary layer temperature, humidity, and wind profiles; and cloud populations, as well as their variability across a range of scales. Participants also argued persuasively for collecting measurements of ocean chemical tracers and biological species and atmospheric water vapor isotopes as these can help constrain key components of large-scale processes that are otherwise difficult to observe.

The overarching conclusion from the workshop is that, while there is a clear need from the data assimilation and process study communities for enhanced and sustained coupled ocean–atmosphere observations at one or more locations throughout the tropical Pacific, efforts to develop these platforms are in their early stages (e.g., Clayson et al. 2021) and will not be realized for several years. In the meantime, ongoing development of coupled data assimilation methods combined with increases in computing power and model resolution have advanced the state of coupled forecast models to the point that they are ready to make use of new observational guidance. At the same time, recent advances in autonomous surface and subsurface vehicles (e.g., Saildrones, gliders) and atmospheric profiling systems (e.g., high-resolution Doppler lidars; sensor-equipped drones) have greatly expanded the ability to measure the local three-dimensional structure of the ocean and atmosphere at resolutions needed for model development and validation. The alignment of emerging observational needs with new observational capabilities provides strong rationale for conducting process studies in the tropical Pacific to meet the diverse needs of the modeling community and to test observing strategies that could enhance the sustained ocean–atmosphere coupled observing system.

Recommendations

In light of the need for integrated ocean–atmosphere column sampling, basinwide horizontal sampling, and the latest advances in atmospheric and oceanic measuring capabilities, workshop participants put forth the following recommendations.

1) *Convene a community-wide forum to broadly disseminate information regarding modern in situ and remote sampling capabilities*. While model developers and process study experts can identify model parameters or processes that are poorly constrained by observations, they may be less aware of observational capabilities that could help reduce those uncertainties, and the logistical considerations that affect when, where, and for how long these assets can be deployed. Rapid advances in satellite and in situ observing technology can make it difficult for model developers to stay informed of the evolving observing landscape. Similarly, observers may not be attuned to sampling strategies that best enable model–observation comparisons. Such a forum could help bridge these conceptual gaps and facilitate effective planning for process studies.
2) *Form a Task Team to design process studies in the tropical Pacific WPEE and PUMP regions*. Following the recommendations of Sprintall et al. (2020), process study observing strategies should be designed as a collaborative effort between observers, process study experts, and modelers to address model shortcomings unique to the WPEE and PUMP regions. Furthermore, given the importance of tropical Pacific ocean–atmosphere coupling to global weather prediction (e.g., Hong et al. 2017), input from data assimilation experts should be sought when designing sampling strategies. Additional expertise in the areas of process understanding, process diagnostics, forecasting, theory, parameterization development, and satellite retrieval algorithms is also recommended. Observing and modeling teams should include scientists from all career stages so that experienced observers and modelers can share their accumulated wisdom with students and early

career scientists who will assume these leadership roles in future campaigns. Finally, the Task Team should include international members, or their U.S. liaisons, to facilitate coordination with multinational process study efforts, such as those aligned with objectives of the UN Decade of Ocean Science for Sustainable Development, the Global Ocean Observing System (GOOS) Ocean Observing Co-Design, and OASIS.

3) *Conduct process studies in the WPEE and PUMP regions*. Sampling strategies should target processes that are poorly understood and underconstrained in models. Observing strategies should incorporate traditional measuring platforms (i.e., ships, aircraft) as well as unpiloted vehicles to fulfill the identified needs for collocated, coincident, and vertically and horizontally resolved measurements of state variables, biogeochemistry, and water isotopes within the ocean–atmosphere transition zone (i.e., from the ocean thermocline to the atmospheric boundary layer top). Echoing an outcome from the 2019 U.S. CLIVAR Workshop on Atmospheric Convection and Air–Sea Interactions Over the Tropical Oceans, participants advocated for the inclusion of novel deployment strategies of unpiloted observing systems to extend the spatial and temporal scales sampled during the process study.

4) *Coordinate with GOOS, WMO/WIGOS, and GCOS to establish an international TPOS committee*. This recommendation arises from the need for ongoing and sustained monitoring and maintenance of the TPOS. Formation of this committee is also aligned with the Action 15 recommendation from the TPOS2020 committee that is just sunsetting. The recommendation for the development of Super Site observing systems, put forth by the 2019 U.S. CLIVAR Workshop on Atmospheric Convection and Air–Sea Interactions Over the Tropical Oceans and supported by participants of this workshop, could fall under the purview of an international TPOS committee.

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