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Climate Variability & Predictability

2016 US CLIVAR PROCESS STUDY MODEL IMPROVEMENT PANEL REPORT

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COVER IMAGE

Sunset over Eel Pond, Woods Hole, MA., Credit: Slack12, CC BY-NC-DC 2.0.

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1 EXECUTIVE SUMMARY

The 2016 Process Study Model Improvement Panel (PSMIP) Meeting focused on several scientific and programmatic topics including high-latitude and cryospheric processes, coastal and marginal sea processes, biophysical interactions, the next-generation Tropical Pacific Observing System (TPOS-2020), and data management strategies for process studies. Common issues arising amid the scientific sessions included sources of model biases, limitations in our mechanistic understanding and/or ability to predict owing to limited parameterizations and spatial resolution, challenges in observing interactions between realms such as physics and biology, and the need for deeper interaction between observationalists and modelers/modeling centers. To put it plainly, a great deal of observational and process study work needs to be done in order to identify what processes are important in tandem with improving model parameterizations and increasing computational capacity, such that models are naturally able to resolve smaller scales globally through higher resolution.

Presentations on high-latitude and cryospheric processes covered a wide range of polar climatic processes including glacier dynamics, physical-biogeochemical interaction, ice-atmosphere interaction, and sea-ice modeling and contrasting Arctic and Antarctic sea-ice changes. Ocean stability changes and feedbacks influenced by mesoscale eddies, dense water formation, and upwelling are important, but there are insufficient upper ocean measurements at high latitudes to evaluate such processes in models. Panel discussion distilled a set of priority processes – snow accumulation on sea ice, cloud radiative forcing in the Southern Ocean, and atmospheric forcing on ice sheets – for making near-term progress on addressing model biases.

The coastal and marginal sea processes session identified and discussed key areas where improvements in current climate models are needed. This included recommendations for improved parameterization of mixing in estuaries, barrier layer dynamics, and cloud microphysics; for systematic multi-scale modeling to capture estuary mixing, coastal-open ocean exchange in the western boundary current regions, ocean-tropical cyclone interactions, and low-level wind stress structure in the coastal upwelling regions; and to develop adjoint and related methods to study model sensitivities and diagnose the coastal and marginal sea processes' influence on regional and large-scale climate. To strengthen the observational basis, the panel recommends improving the resolution, calibration/validation algorithms, and atmospheric corrections for satellite data for application to the coastal seas. In general, the panel agreed that the topic of biophysical interactions is one in which there remains a wide gap between important processes identified through observations

and what numerical models are presently able to resolve. Integrating observations with modeling early and often can lead to the identification and mechanistic understanding of important processes and ultimately contribute to societal applications, such as quantitative ecosystem predictions. The current capability to observe physics exceeds that of biology, with interactions between physics and biology being even more difficult to observe in situ. Presenters and panelists identified several upcoming process studies related to biophysical interactions that PSMIP will follow closely and potentially interact with, including CANON, NASA Exports, and NAAMES, and observational programs such as the Ocean Observatory Initiative and Biogeochemistry-Argo.

During the TPOS2020 session, the importance of measuring equatorial turbulence and the equatorial deep jets within the TPOS framework was discussed, especially given their potential impact on equatorial mixing and sea surface temperature (SST). The panel also noted that barrier layer development and its role in phenomena ranging from tropical cyclones to the Madden-Julian Oscillation (MJO) would be a useful process study.

Finally, the session on data management highlighted the importance of data management planning for successful exchange between observational and modeling efforts, and provided an overview of lessons learned from data management practices in exemplary process studies and data portals. Careful deliberation of data management requirements in consultation with intermediate data centers at the proposal writing, planning, and budgeting stages is advised. Agency mandates and enforcement of data policies are found to be important to achieving success in timely delivery of publically available data.

The panel reflected upon the status of action items identified at the 2015 US CLIVAR Summit in Tucson, Arizona, while looking forward to a range of new action items for the upcoming year. Several activities from 2015 will continue — such as engagement with TPOS2020, the bio-physical interactions community, and process study feedback webinars — while new directions will include a focus on reports and useful articles, topical webinars, and the proposition of workshops on biophysical interactions and coastal and marginal sea processes.

2 INTRODUCTION

The PSMIP meeting took place at the Woods Hole Oceanographic Institution (WHOI) from Tuesday, June 14 through Thursday, June 16. The meeting was organized around a series of four topical sessions, with each session organized by one or more panel members. The topical sessions were attended by panel members and invited speakers, including WHOI-based scientists participating locally and with presentations via videoconference from remote speakers. All presentations are available via the PSMI Panel Meeting page at the US CLIVAR website.

Session I: High-Latitude and Cryospheric Processes

Convener: Taka Ito
Speakers: Luke Trusel, Igor Kamenkovich, Judah Cohen, Jennifer Kay, and Ian Eisenman

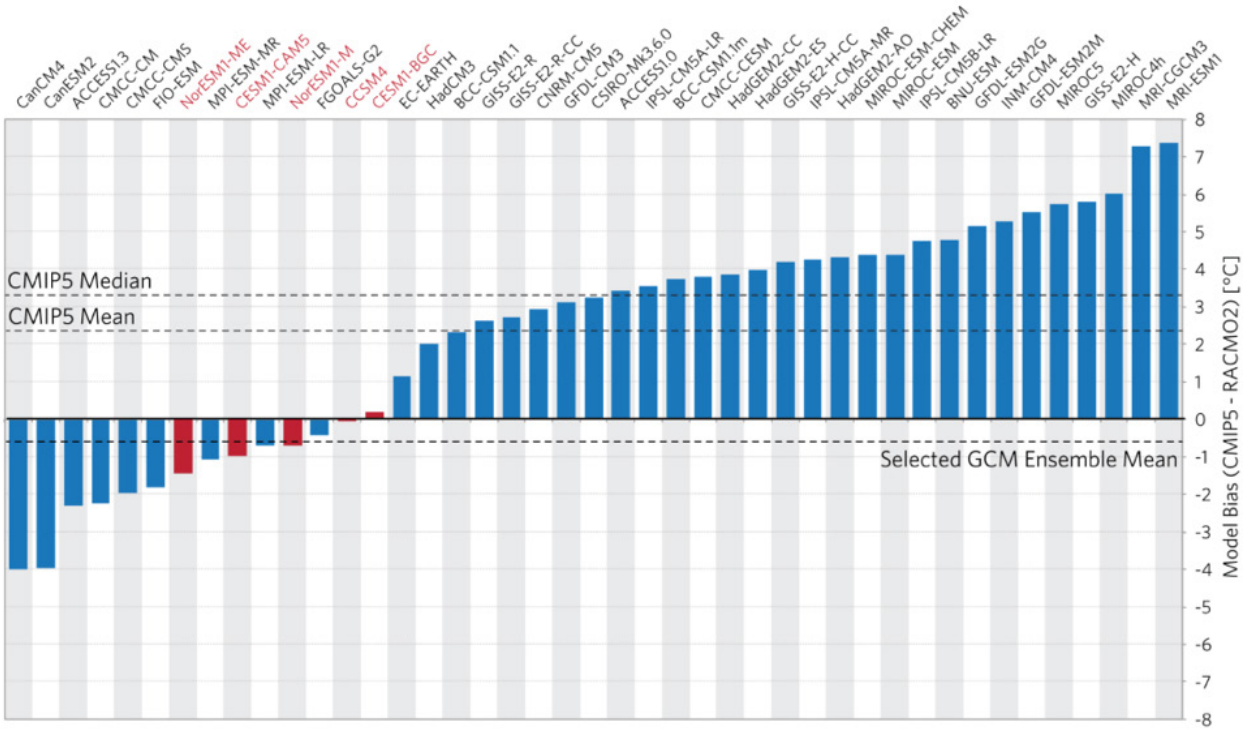
The objective of the high-latitude and cryospheric session was to discuss issues on the polar climate in the current generation of climate models. In particular, the speakers were asked to address the following overarching questions were addressed by the five invited speakers:

- What are the major biases in climate models' representation of polar climate?
- What are the key processes/interactions of processes that contribute to the biases?
- What new ideas/datasets are available which could be translated to model improvements?

The presentations included a wide range of polar climatic processes, including glacier dynamics, physical-biogeochemical interaction, ice-atmosphere interaction, and sea-ice modeling, and contrasting Arctic and Antarctic sea-ice changes. The main points of the presentations are briefly summarized blow.

Luke Trusel presented an overview of the surface melting of Antarctic glaciers in the Coupled Model Intercomparison Project version 5 (CMIP5) models. Under a warming climate, a glacier melts both at the surface (surface melting) and at the coasts where it meets the ocean (basal melting). In the present climate, basal melting plays a dominant role, but surface melting can rapidly increase and exceed basal melting under the rapidly increasing polar atmospheric temperature. Fewer than half of the CMIP5 models represent surface melting. Surface

melting is expected to increase exponentially with increasing temperatures. Thus relatively small differences in the mean state can develop major differences after the exponential growth. Air temperature can be used as a metric for the surface melting, and the CMIP5 models show a wide range of biases in the polar air temperature. Similarly, many models do not represent ice shelves, and their rate of melting depends on the ocean temperature.



Evaluation of model bias in the Antarctic air temperature, a metric for the surface melt. The CMIP5 models are compared against (reanalysis-forced) RACMO2. Figure credit: L. Trusel.

Igor Kamenkovich discussed the physical biogeochemical interaction in the context of the Southern Ocean. In the Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) project, observations from the autonomous biogeochemical sensors are assimilated into a Southern Ocean State Estimation model. In turn the model outputs are used to interpret the observational data and to develop new analysis techniques. Ocean system simulation experiments (OSSE) are also designed to provide guidance on the optimal design of an observing system.

Judah Cohen, co-chair of US CLIVAR's Arctic Mid-latitude Working Group, discussed the interaction between the Arctic climate change and its potential influences on mid-latitude weather and climate. Climate models fail to represent the observed, warm Arctic–cold continents pattern, which can be an indication of poorly represented processes, including sea ice-atmosphere interaction, snow-atmosphere interaction, and troposphere-stratosphere interaction.

Jennifer Kay discussed the importance of observations that can discriminate between natural variability and model bias. Observations with relatively short record length may

have a large component of natural climate variability. Major mean state biases found in modeled polar climate include sea ice thickness, snow on sea ice, cloud opacity, ocean/atmosphere stratification, precipitation, and summer temperatures over ice sheets. Phase changes are key for polar processes in the ocean and atmosphere and have profound impacts on forcing and feedbacks. Kay highlighted the importance of bringing together different expertise in settings that inspire collaboration and develop a common language from definitions to data formats.

Ian Eisenman discussed the representation of Arctic sea-ice loss and Antarctic sea-ice expansion from CMIP3 and CMIP5 models. Although the ensemble-mean model response has too much ice retreat in the Antarctic and too little in the Arctic, the models are at least marginally consistent with the observations given the spread of simulated natural variability. However, the models seem to be getting the right sea-ice trends for the wrong reasons: they only simulate accurate sea-ice trends in runs with substantial biases in global warming. A recurring topic is the importance of mean state model biases that can affect the trends, especially when there is an accelerating change (e.g., surface ice melting), and a relatively small offset in the mean state could amplify with time. There are striking large-scale differences in climate change responses between the Arctic and Antarctic regions.

The panel engaged the presenters to further identify and discuss processes that contribute to model biases in simulating polar climate and the observational needs to address them. Additional features and processes that present challenges include polynyas, icebergs, cross-shelf transports, melting of Antarctic ice shelves, Arctic stratification, and eddy mixing. For the ocean, stability changes and feedbacks (influenced by mesoscale eddies, dense water formation, and upwelling) are important, but we do not have sufficient upper ocean measurements at high latitudes to evaluate such processes in models. Priority processes identified within the community for making near-term progress on addressing model biases include: snow on sea ice, cloud phase (shortwave radiation bias) in Southern Ocean, and atmospheric forcing on ice sheets.

Session II: Coastal and Marginal Sea Processes

Convener: Hyodae Seo and Aneesh Subramanian
Speakers: Ruby Leung, Ichiro Fukumori, Sarah Giddings, Andrew Thomas, Glen Gawarkiewicz, Sang-Ki Lee, Jiayan Yang, and Christina Patricola

This session evaluated the current level of understanding of processes related to coastal and marginal seas and their influence on regional and large-scale climate. Presentations were invited to address the following specific questions:

- What is the current understanding of processes related to coastal/marginal seas that influence large-scale and regional climate?
- Which of these process representations can be improved in current climate models?
- How to improve observations and data assimilation for the relevant regions to help improve our understanding further?

Eight invited speakers covered a broad range of outstanding issues related to the coastal and marginal seas. They helped inform the panel discussion of key areas, where improvement of observations, data assimilation, and process representations in current climate models are needed.

Ruby Leung discussed the role of the subsurface ocean thermal structure and barrier layer dynamics in the simulation and prediction of the tropical cyclone intensity. She proposed a new dynamic potential tropical cyclone intensity metric to aid the statistical and dynamical intensity prediction for the landfalling tropical cyclones.

Ichiro Fukumori demonstrated the merit of the adjoint sensitivity approach for the study of sea level and ocean bottom pressure in the high-latitude marginal seas. The adjoint-based approach will provide a useful diagnostic method for the response, as well as for the detection and attribution of the natural and climate change-related sea level rise.

Sarah Giddings reviewed the multi-scale nature of the complex estuarine dynamics and their impact on the dynamics and biogeochemistry of the coastal oceans. Key features and processes to be modeled include mixing within estuaries, frontal strength, impacts of waves, remote internal waves, ice/plume interactions, under-ice estuaries, and multiple small estuaries. Giddings also showed the beneficial effects of parameterizing estuaries in a global climate model.

Andrew Thomas reviewed the challenges in using the satellite data for the coastal and marginal sea applications. The algorithms for calibration and validation are often not suitable for coastal studies, since the accuracy and resolution of the satellite data near the coasts are poor. Efforts are needed to improve the correction algorithms, including the coastal tide gauge data merged with the simulation models, and the improved atmospheric forcing functions.

Glen Gawarkiewicz presented observational evidence of decadal changes in water mass properties over the shelf break in the US Eastern seaboard. He suggested that these decadal changes are important for the stratification and contribution to deep convection in the open ocean. An improved eddy parameterization of the mixing of the water mass between the shelf break and large-scale circulation is needed to better simulate the coastal/open ocean exchange.

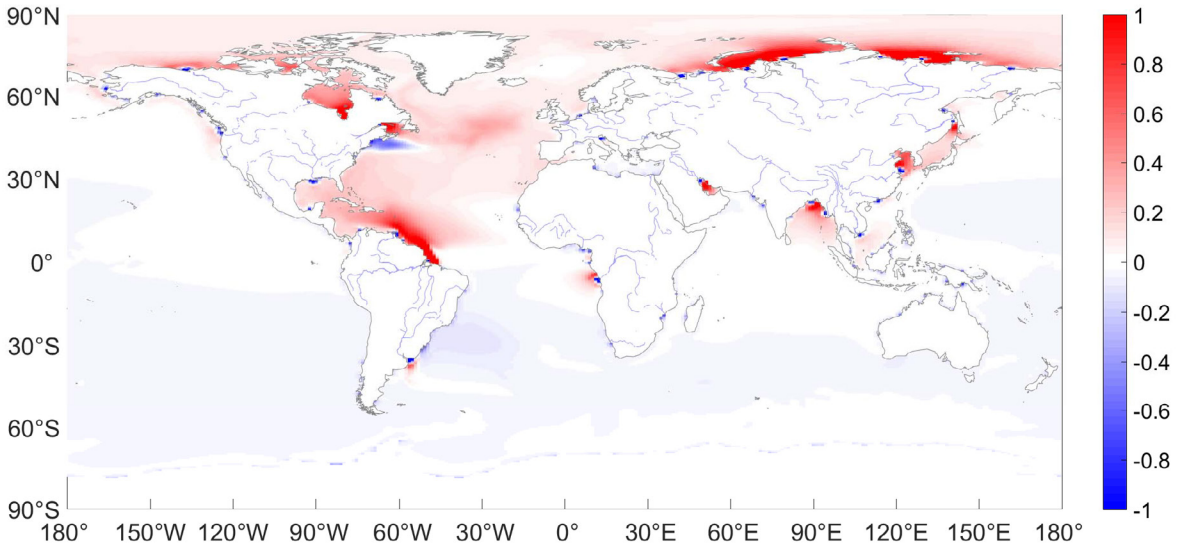


Figure highlights an effort to improve the representation of the estuary-shelf freshwater exchange in a climate model. It shows the difference in sea surface salinity between two simulations, one with and one without a coupled estuary box model. Red (blue) shading indicates higher (lower) salinity for the case with an estuary box model relative to the control. This particularly emphasizes the far-reaching effect of riverine freshwater input as represented through an estuary box model. Figure credit: Sun et al. 2017, *Ocean Modelling*.

Sang-Ki Lee reviewed the current state of understanding of variability and predictability of the Atlantic warm pool and its impacts on regional climate, including summer precipitation over the central and southern US (related to the size of the warm pool and its influence on the strength of the North American low level jet) and tropical cyclone formation (influenced by vertical wind shear response to warm pool heating). CMIP models show a cold/dry biases in the warm pool. Lee noted that the Intra-Americas Seas warm pool region is as poorly observed as the Polar regions.

Jiayan Yang discussed the physical oceanographic features in the East Asian marginal seas and stressed the open ocean control of the marginal sea boundary currents through the large-scale pressure gradient setup. Large-scale models are unable to represent the key ageostrophic processes, calling for systemic modeling studies for two-way interaction between basin-scale, shelf-scale, and local-scale. Sustained monitoring of the Asian marginal seas is needed, perhaps through a stripped down version of the Pioneer array at the shelfbreak in the main areas of the western boundary current.

Christina Patricola discussed the coupled model SST bias in the Benguela coastal upwelling region. The source of bias is traced back to errors in wind stress associated with the formation of the low-level jet. Since the low-level jet is a result of complex interaction among the SST, land-sea thermal contrast, steep terrain, and shape of the coastline, the alleviation of the SST bias in the eastern boundary upwelling regions would be possible through high-resolution modeling.

Recommendations resulting from this session:

- Improve the physical parameterization (e.g., mixing in the estuaries, barrier layer dynamics, cloud microphysics) and data assimilation techniques in climate models for representation of the coastal and marginal sea processes.
- Conduct systematic multi-scale modeling to capture regional and marginal sea processes, including estuary mixing, coastal-open ocean exchange in the western boundary current regions, ocean-tropical cyclone interactions, and low-level wind stress structure in the coastal upwelling regions.
- Develop adjoint and similar methods to study model sensitivities and diagnose the coastal and marginal sea processes' influence on the regional and large-scale.
- Improve the satellite data for the application of the coastal seas, by improving the resolution and calibration/validation algorithms, and atmospheric corrections

Session III: Biophysical Interactions

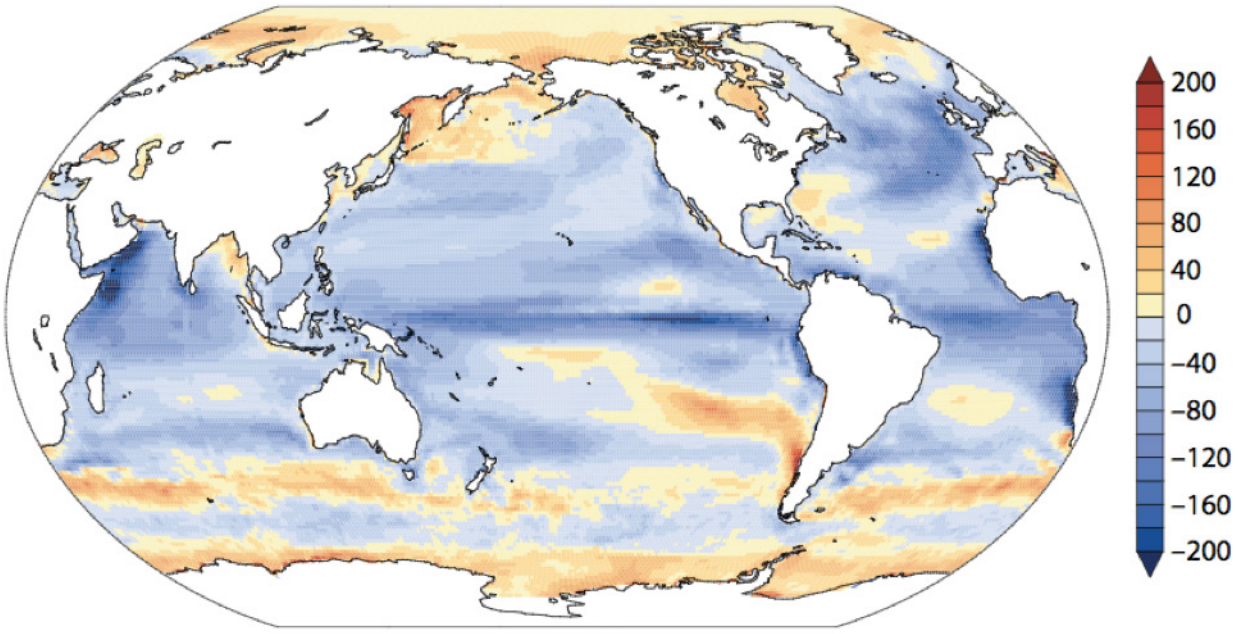
Convener: Kris Karnauskas
Speakers: Scott Doney, Dennis McGillicuddy, Art Miller, and Monique Messié

The third session, Biophysical Interactions, was convened to survey the state of the science surrounding our ability to observe, model, understand, and predict interactions between the physics and biology of the ocean, and to discuss areas ripe for new process studies and interactions between observationalists and modelers.

The presentations and discussions were held with five specific questions in mind:

- How is the community addressing the challenge of systematically forecasting marine ecosystem responses to individual climatic (e.g., El Niño-Southern Oscillation; ENSO) events?
- What is the state-of-the-art in representing the coupling between ocean biogeochemistry and physics in global climate models, and what new observations or process studies are needed?
- How deep is our understanding of physical-biological interactions at the oceanic mesoscale, how well are they represented in current models, and what new observations or process studies are needed?
- What are the current capabilities to observe interactions between ocean physical and biological processes (including the response of one to the other), and what *in situ* observations and process studies do the satellite development community need?
- What can PSMIP do to catalyze the progress on challenges identified?

Scott Doney provided an overview of recent progress and remaining challenges surrounding ocean biogeochemistry and carbon cycle science in the context of global coupled climate models. The underlying problem, rooted in anthropogenic CO_2 emissions to the atmosphere, is the fate of those emissions in the ocean, their effects on marine productivity, and feedbacks with the climate forcing. Doney identified the Global Carbon Project as a successful example at the international level of putting carbon fluxes in the context of climate variability. The partitioning of fluxes between reservoirs has reduced error bars from 50% to 20%, and comparison with models demonstrates useful divergence with respect



Spatial map of the change in marine net primary productivity (g C m^{-2} yr^{-1}; end of twenty-first century minus current conditions) based on the mean of an ensemble of 10 different CMIP5 models integrated in time following the RCP8.5 scenario. From Doney et al. 2014, *Oceanography*.

to interannual variability. CMIP5 model simulations of a warmer climate indicate increased ocean stratification and slowing of overturning and uptake of CO_2. Such carbon-climate feedbacks represent perturbations roughly on the order of magnitude of 10% of the total annual cycle. Globally, a corresponding reduction in biology is compensated by reduced advection of carbon from the deep. The near-cancellation of two terms explains why the carbon-climate feedback may be relatively small. Thus, Doney emphasized the need to focus not only on productivity, but how much of the carbon gets exported to depth. Specifically, we need to know about the different types of phytoplankton, zooplankton dynamics (major consumers of phytoplankton), and vertical transport terms, including resolved advection, diapycnal mixing, eddy advection, and export from upper mixed layer to depth. The NASA EXPORTS program is intended to help address some of these issues, with modeling being a significant part of the program early on. Also, Bio-Argo with oxygen, nitrate, pH, and bio-optics will provide much needed data, despite initially being very sparse (relative to the full Argo float array). The panel discussion focused on the causes of model biases—particularly whether the underlying issues stem from physical biases or the biogeochemistry in models. Doney argued that results point to the primary role of physical biases and inadequate representation of some biological processes such as net primary productivity.

Dennis McGillicuddy presented recent observational and modeling work aimed at understanding the mechanisms governing productivity and, more generally, the biological pump. McGillicuddy emphasized that the mechanisms controlling the biological pump are taking place at the oceanic mesoscale. He demonstrated that sea surface height (SSH) observations (e.g., Dudley Chelton's eddy tracking database) and surface chlorophyll observations (from satellite) provide the ability to identify the fingerprint of various mechanisms controlling productivity in the presence of mesoscale variability, such as cyclonic and anticyclonic eddies. Mechanisms identified include stirring, trapping, formation/intensification, Ekman pumping, and mixed layer depth modulation, which can be evaluated using the spatial and temporal structure of the SSH-chlorophyll correlation. In terms of modeling, recent work (including that of John Marshall, MIT) suggests that models have some skill at reproducing the global distribution of the balance of mechanisms. McGillicuddy suggested the need for detailed process studies to ensure that the different mechanisms identified through fingerprinting are well represented in large-scale models. For example, we can observe relatively straightforward feedbacks within eddies; anticyclonic eddies have warm SST anomalies and if chlorophyll increases, is there a positive feedback? This is observable but entirely absent in global models due to their resolution. Process studies will be needed to study processes underlying mesoscale interactions before model resolution becomes sufficient. In addition, *in situ* measurements for regions of deep productivity, at depths beyond the view of satellite retrievals, will be helpful (e.g., NASA EXPORTS).

Art Miller presented the case for marine ecosystem prediction using persistence in physical and biological systems as a baseline for skill. Miller emphasized the need to understand physical forcing that can lead to biological responses as distinct from intrinsic biological variability. Processes that have the potential to be predictable include deterministic forcing (shifts in means) and natural variations associated with natural oscillations such as ENSO, MJO, as well as more chaotic forcing such as eddies, synoptic weather events, and upwelling events. We do not yet understand the dynamical basis for predictability at tropic levels—how much skill for such predictions is possible from the physical forcing? Are their nonlinearities that will lead to exponential growth up through tropic levels? During the discussion, it was suggested that process studies have played a vital role for understanding

processes, but not for determining which processes may be more important over time for improving predictability. The gap between the environmental information available and what is incorporated into stock assessments in many regions remains a multifaceted challenge but also a critical opportunity. The US CLIVAR-sponsored workshop on ENSO-based predictions of US West Coast ecosystems provides an important forum for further discussion of this topic.

Monique Messié provided an overview of strategies (observational platforms and analysis methods) currently utilized for observing and studying *in situ* biophysical interactions. Observational tools currently used range from large (satellites) to regional (Argo, time series stations, and surveys) to local process study scales (e.g., gliders, wave gliders). As an example, the Controlled, Agile, and Novel Observing Network (CANON) process study in the Monterrey Bay uses a wide variety of techniques to track fronts, chlorophyll patches, and isotherms, and to follow a water mass in four dimensions. This proves extremely challenging when trying to track both physical and biological properties over space and time with finite time windows in which to work. Importantly, Messié presented the case that we as a community are currently much better and more capable of observing physics than biology — interactions between physics and biology are even more difficult to observe *in situ*. Increasing the number of Bio-Argo floats and chemistry-equipped floats will be helpful. In the example of CANON, the path to direct model improvement is not yet entirely clear, but collaborations with modelers at UCLA and the University of Maine are diagnosing biases of high-resolution simulations of Monterrey Bay.

Throughout the presentations and subsequent discussions, an attempt was made to focus on how integrating observations with modeling early and often can lead to the identification and mechanistic understanding of important processes, and ultimately contribute to societal applications such as quantitative ecosystem predictions. In general, for biophysical interactions, the notion was formed that there remains a relatively wide gap between processes identified through observations and what numerical models are presently able to resolve. There is also a wide but closing gap (in some regions) between the application and the related observations, modeling, and mechanistic studies—with fish stock assessments an important example. Presenters and panelists identified several upcoming process studies related to biophysical interactions that PSMIP would like to follow closely and potentially interact with, including CANON, NASA EXPORTS, NAAMES, as well as observational programs such as the Ocean Observatory Initiative and Biogeochemistry-Argo.

Session IV: Tropical Pacific Observing System (TPOS) 2020

Conveners: Janet Sprintall and Greg Foltz
Speakers: Billy Kessler, Meghan Cronin, Eric Guilyardi, Lisan Yu, and Adrienne Sutton

The TPOS 2020 project will evaluate the design of the Tropical Pacific Observing System (TPOS) to achieve enhanced effectiveness for all stakeholders, including operational monitoring and prediction centers as well as the research community. This session aimed at understanding the key functions of TPOS 2020 and providing an update on the scientific rationale for the initial set of recommended changes to the TPOS.

Presentations and discussion centered on the following set of questions:

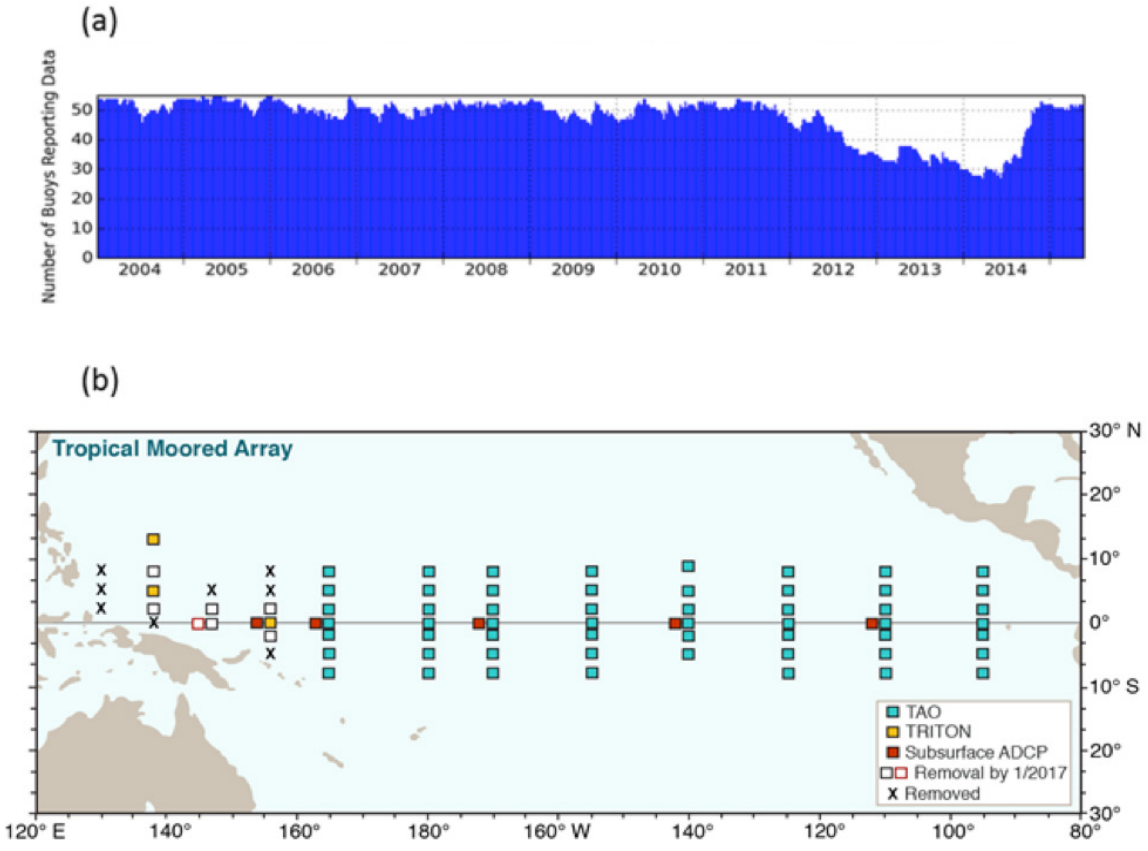
- What observations are needed for improved understanding and optimal data assimilation, modeling, and prediction of ENSO and other Pacific climate phenomena?
- What are the areas of large uncertainty where model/reanalyses diverge? What are the related processes that are poorly represented in models/reanalyses, inhibiting improvements in prediction and understanding? How might model biases improve through implementation of TPOS 2020?
- What process studies are needed to improve the relevant model components? How do these fit in with, and how easily might they build upon, the current and planned TPOS?
- What coordinated observing system and process study experiments will be required for the design of an observing system beyond TPOS 2020?

Billy Kessler, co-chair of the TPOS 2020 Steering Committee, provided motivation for TPOS 2020, noting the advances in new technology (e.g., satellites, Argo) and new scientific understanding (e.g., importance of diurnal cycle and coupled boundary layer) since the original TPOS was developed in the 1980s. A re-examination of the TPOS is therefore timely, with a focus on observations that can lead to model improvement and more skillful weather and climate prediction. A draft TPOS 2020 interim report was finished recently. The key changes to the current observing system would be to improve the ability to observe the upper ocean and more fully resolve the surface heat and moisture fluxes of the planetary boundary layer. Mooring lines with full air-sea flux measurements would be expanded into high rainfall regimes, such as the warm pool, Intertropical Convergence Zone (ITCZ), and South Pacific Convergence Zone (SPCZ), where satellites most need validation and calibration. Additional moorings would be added to the near-equatorial region, where spatial scales of variability are much smaller, with higher vertical resolution in the near-surface layer. The interim report also recommends doubling the number of Argo floats in the tropical Pacific to provide fine vertical structure of temperature and salinity in the mixed layer. There may be some loss of moorings in the central Pacific off-equatorial region, and the risks of this were discussed. Kessler posed several questions to the PSMI Panel related to the proposed changes to the TPOS and suggestions for process studies, as discussed below.

Meghan Cronin, co-chair of the TPOS 2020 Planetary Boundary Layer Task Team, emphasized the importance of resolving the diurnal cycle of near-surface winds and upper-ocean temperature, salinity, and currents from TPOS moorings. The current mooring array is too sparse, especially near the equator, and most sites do not resolve the mixed layer depth nor provide measurements of radiation and precipitation. Based on responses from the broader scientific community, there is a desire for more heavily instrumented sites on a coherent grid that can also serve as good “hub sites” for process studies, such as the Year of the Maritime Continent, Pacific Upwelling and Mixing Process Study, and Double ITCZ Process Study. Two technology proposals were recently funded by NOAA’s Climate Program Office: the Saildrone, for autonomous measurements of the oceanic and atmospheric boundary layers and biogeochemistry, and enhancements to near-surface current profiling on the existing mooring array.

Eric Guilyardi, co-chair of the TPOS 2020 Modeling and Data Assimilation Task Team, discussed the importance of observations for improving models, data assimilation, and

predictions. Forecasts of ENSO have improved, but models still have large biases. Coupled models have parameterizations and tuning that rely on observations, and co-located oceanic and atmospheric measurements could be very important for future data assimilation systems. Some pilot studies are proposed that could help to reduce specific model biases, including enhanced measurements in the ITCZ and SPCZ, a TOGA-COARE type campaign in the eastern Pacific, and examination of wind stress, which is the most important forcing parameter for the ocean and therefore capable of producing large model biases.



(a) Number of TAO moorings returning data during 2003-2015 (courtesy of NOAA/PMEL). Note the decline during 2012-14. (b) The TAO/TRITON array; sites in the western Pacific Ocean, where operation has ceased, are marked by a cross. Locations that are planned to cease in 2017 are shown in yellow (information provided by JAMSTEC). Figure from the TPOS 2020 Interim Report courtesy of W. Kessler.

Lisan Yu, member of the TPOS 2020 Backbone Task Team, focused on the role of observations for calibrating and validating satellite retrievals of near-surface winds and for improving ocean data assimilation. Models often have difficulty assimilating mooring observations because they are not on a regular grid and have gaps in the time series. The need for moorings in different meteorological regimes (e.g., eastern Pacific stratus cloud region, western Pacific warm pool with deep convection) was emphasized. Differences in satellite wind products are mostly a function of the retrieval algorithms used, highlighting the need for moorings to fine-tune these algorithms under different conditions and regimes.

Adrienne Sutton, co-chair of the TPOS 2020 Biogeochemistry Task Team, noted that the Pacific is the largest natural source of CO_2 for the atmosphere, and the first mode of global CO_2 variability is ENSO. The main motivation for sustained observations of biogeochemistry in the tropical Pacific is therefore a better understanding of long-term changes and natural variability of carbon, oxygen, nutrients, and primary productivity. Process studies are needed to identify source waters (e.g., pathways of upwelling in the cold tongue), which affect nutrient availability and primary productivity, and to trace ecosystem impacts up trophic levels. The development of new technology, such as the Saildrone (instrumented with CO_2 and pH sensors originally tested on gliders) and Biogeochemistry Argo floats (providing profiles from the surface to 2 km) will also help to simultaneously measure the air-sea fluxes of heat and carbon and upper-ocean physics and biogeochemistry.

Panel discussion included the rationale for reducing the number of moorings and thereby ending some of the long time series of measurements. The TPOS 2020 philosophy is to be proactive in providing scientific reasons for the proposed new design. This is especially true in the face of international funding pressures.

The choice to focus on planetary boundary layer and near-equator as targets for advancement seems appropriate, as these regions are where variability is strongest and makes the most difference. The importance of measuring equatorial turbulence and the equatorial deep jets within the TPOS is emphasized, given their potential impact on equatorial mixing, stratification, and SST. Downward looking Acoustic Doppler Current Profilers are being considered. A process study may be required to establish whether such observations should be sustained.

The panel welcomed the plans to enhance moorings to measure the full suite of surface fluxes along lines, enabling the ability to study a range of phenomena the zonal and meridional directions. A process study could address whether surface fluxes measurements *in situ* plus satellite-based observations provide adequate estimates of fluxes in regions where we do not have moorings — thereby evaluating the risk of losing surface meteorology in the trade wind region. The panel also noted that barrier layer development and its role in stratification and air-sea fluxes impacting phenomena ranging from tropical cyclones to MJO variability would be a useful process study.

With the widening of the tropical belt, the assumption of stationarity of the trades may not hold. The panel suggests using the 2050 map of CMIP5 projections to overlay the future backbone system to examine if it captures projected changes in phenomena.

There may be additional predictability from the tropical Pacific. TPOS 2020 should consider examining predictability using a twin experiment framework and data deprivation experiments. Trying to determine additional predictability from forecast experiments could be difficult. Prediction of MJO propagation is another target. Capturing the atmospheric boundary layer is important elucidating convection processes. Western Pacific moorings in the northwest ITCZ/warm pool region and the corresponding site in the South Pacific could be important for the MJO. Improved data assimilation could enhance predictive skills. Current data assimilation efforts do not use all of the data collected, e.g., daily averages vs. hourly data ingest. Employing coupled data assimilation can also improve prediction.

Data Management Session

Convener: Caroline Ummenhofer
Speakers: Chidong Zhang, Cyndy Chandler, and Steve Diggs

The data management session had two aims: (i) to highlight the importance of data management for successful exchange between observational and modeling efforts, and (ii) provide an overview of lessons learned from data management practices in exemplary process studies and data portals. Speakers were sourced both from recent/ongoing process studies that had an extensive data management component and from coordinators of key data portals that are storing, curating, and coordinating oceanographic observational datasets.

Chidong Zhang described data management efforts undertaken as part of the DYNAMO field campaign, which is guided by the aim to make observational data available to the modeling community to be used for evaluation and improvement. The US DYNAMO principal investigators adopted a data policy, based on the World Meteorological Organization Resolution 40, agreeing to submit all data to the field program archive center at NCAR Environmental Observing Laboratory (EOL) within six months of the field campaign for use by DYNAMO PIs. Quality controlled data sets were to be furnished to EOL within twelve months and made publically available. With agency-encouraged compliance of the data policy, 90% of the data were released on schedule, with some delays for completing quality control, PI field schedules, and student theses/dissertations. Agency mandates and enforcement of data policies were important to achieving success in timely delivery of publically available data. Problems encountered in data archiving included inconsistent and inconvenient data formats, data being grouped by instrument or dates, lack of standardized calibration and quality control, and redundancies in generating data products. To make the data available in a format more amenable to model-data comparison, DYNAMO legacy products are being developed that standardize the format and consolidate data into mega files.

Cyndy Chandler, with the Biological and Chemical Oceanography Data Management Office (BCO-DMO), addressed recent changes in the research community that included greater expectations for open data and machine access, as well as promoting interoperability. Challenges in this new paradigm of open access data are: (i) the need for documentation and metadata that is standards-compliant, includes quality control and provenance information, and supports access by machine clients; and (ii) the promotion of data access by other science domains, educators, and policy-makers (requiring additional work than for data access within a disciplinary community), and (iii) the emphasis on web-based access to data so that they are discoverable. Her recommendation for process studies in the planning stages were to consider the benefit of intermediate data management facilities, employ comprehensive community engagement, share the data in the research process (allowing for crowd sourcing the quality control), ensure a persistent archive, formally publish data with a direct object identifier (doi), and encourage citation of data sources in papers.

Steve Diggs, with the CLIVAR & Carbon Hydrographic Data Office (CCHDO), emphasized the need for intermediate and long-term archives to align. Focusing on involvement with new microstructure and turbulence measurements obtained as part of the ocean mixing climate process team (CPT), an updated web architecture had to be created for improved

efficiency, making use of browser technology. He suggested that data format would become less important in the future with an increasing move toward machine-to-machine communication.

In the panel discussion, all speakers stressed the importance of carefully deliberating data management requirements at the proposal writing, planning, and budgeting stages. National data centers cannot be expected to keep up with all of the specialized and new data sets that are being collected. Intermediate data centers (such as NCAR EOL, BCO-DMO, and CCHDO) are particularly helpful in this regard and should be consulted at the proposal-writing stage to determine data management plans and associated costs.

3 SUMMARY OF ACTION ITEMS FROM 2015

1. TPOS 2020 engagement:

   Status: Ongoing. PSMIP has opened dialog with TPOS 2020 by holding a science session at the 2016 PSMIP Annual Meeting in which the TPOS leads (Billy Kessler, and others) were invited to present and discuss TPOS status, outstanding issues, and potential for TPOS to contribute to (and be informed by) process studies. PSMIP has the opportunity to provide coordinated feedback on the TPOS First Report (2nd draft), in which we will continue to encourage engagement with modeling centers and consideration of data assimilation experiments — both of which may assist in the optimal design of TPOS 2020. Two members of PSMIP remain members of TPOS 2020 task teams (Sprintall and Karnauskas).

2. Process study webinars:

   Status: Completed a series of eight process study webinars during the winter/spring 2015/2016. The following process studies gave webinar presentations: DIMES, Calwater-2, LASIC, ORACLES, AWARE, MAGIC, ACAPEX, SPICE. Webinars were open to the public and were advertised amongst the US CLIVAR panels, SSC, and the broader community through the US CLIVAR Newsgram. A series of templates were developed to streamline the reporting and feedback process, both on the side of the process study presenters and on the panel providing feedback to the presenters. Process study presenters were provided with feedback by the PSMI panel and 'lessons learned' that could be of benefit to other process studies have been collected by the PSMI panel. For a full list of the process study webinars and their associated feedback, see Appendix C.

3. Facilitate interaction and cross-fertilization of process studies and modeling centers:

   Status: Completed the US CLIVAR Workshop on "Translating Process Understanding to Improve Climate Models," held at the Geophysical Fluid Dynamics Laboratory in Princeton in October 2015, which brought together observationalists, modelers, and theoreticians to address means of enhancing exchange between the observational community and modeling centers. A workshop summary was provided to the IAG and a white paper was published as a US CLIVAR Report. Results from the community survey conducted prior to the workshop by PSMIP and outcomes from the workshop

discussion are provided online. A list of modeling center contacts will be invited to upcoming process study webinars (see new action items below).

4. Encourage more interaction between physical and ecosystem scientists, especially in context of process studies, possibly using ENSO as a natural laboratory:

Status: Ongoing. PSMIP members Subramanian and Karnauskas served as members of the scientific organizing committee for the recently concluded workshop, "Forecasting ENSO Impacts on Marine Ecosystems of the US West Coast." Karnauskas and Subramanian facilitated an afternoon-long session on "Impacts of ENSO Diversity on ecosystem drivers" with presentations by both physical scientists (e.g. Antonietta Capotondi, NOAA) and ecosystem scientists (e.g., Mark Ohman, SIO).

5. US CLIVAR to provide a concise summary of Hiatus discussion (cf. Summit special science session and recent issue of Variations) for scientists (e.g., bulleted list of points from Hiatus session)

Status: Done. Simon Wang has published a video explanation of the hiatus, and Janet Sprintall, Dimitris Menemenlis, and Simon Wang produced a concise summary of the special session, "Understanding the Earth's climate warming hiatus," included in the 2015 US CLIVAR Summit Report (section 2.6).

6. Facilitate organization of science workshops to address gaps in process understanding

Status: Ongoing. Several of the science-themed sessions at the US CLIVAR PSMIP meeting this year were formed around topics considered suitable for potential workshops. See new action items for a list of potential science workshop topics that the discussions at the panel meeting have stimulated.

4 NEW ACTION ITEMS

Building on the actions from the previous year and the meeting discussions, the PSMI Panel generated a list of action items to continue progress in advancing the goals of the US CLIVAR program. Below is the list of action items, along with panel members assigned to taking the lead in implementing them over the next year.

Publications

- Produce a report of the annual panel meeting (Ummenhofer, Karnauskas) from summaries of topical sessions (Foltz, Ito, Karnauskas, Seo, Sprintall, Subramanian, Ummenhofer)
- Write EOS article summarizing the emerging themes from annual meeting (Karnauskas)
- Encourage a US CLIVAR Variations issue about Antarctic sea ice gain (Legg)

Fall 2016 process study feedback webinars

- Update complete list of process studies and stratify list by stage in life cycle (Ummenhofer)
- Organize and schedule the webinar series for the 8-10 process studies that were agreed upon (Uhlenbrock, Ummenhofer)
- For the input documentation on a process study by the reporting PI (Document A), add a question on which community they lack a strong connection to and would like to engage (modelers vs. observationalists, atmospheric scientists vs. oceanographers, etc.); provide that prior to webinars and facilitate communication afterward (Karnauskas)
- Produce a contact list for modeling centers and directly invite modeling center contacts to attend relevant webinars (Subramanian)
- Obtain feedback via email survey from PIs that were recently part of the Process Study webinar series (Karnauskas, Ummenhofer)

Topical webinars (as distinct from process study feedback webinars)

- Organize a webinar on barrier layers including feedbacks to hurricanes (Flatau, Foltz, Reed, Sprintall)

- Organize a webinar on biogeochemical data assimilation (Legg, Penny)
  - Include SOCCOM
  - Host after the WMO coupled data assimilation workshop in October 2016

Workshops

- Encourage a workshop (virtual?) proposal on biophysical interactions (Ito)
- Organize a workshop on coastal/marginal seas around the world (Seo, Subramanian)
  - Submit workshop proposals by October
  - This could lead to the planning of future coordinated/dedicated experiments
  - Consider working group proposal afterward

APPENDIX A: PARTICIPANTS

PSMI Panel Members

Maria Flatau, Naval Research Laboratory
Gregory Foltz, NOAA Atlantic Oceanographic and Meteorological Laboratory
Taka Ito, Georgia Institute of Technology
Kris Karnauskas (Co-Chair), University of Colorado
Sonya Legg (SSC Executive Committee), Princeton University
Gad Levy, Northwest Research Associates
Steve Penny, University of Maryland/NOAA National Centers for Environmental Prediction
Kevin Reed, Stony Brook University
Hyodae Seo, Woods Hole Oceanographic Institution
Janet Sprintall, Scripps Institution of Oceanography
Aneesh Subramanian, Scripps Institution of Oceanography
Caroline Ummenhofer (Co-Chair), Woods Hole Oceanographic Institution

Guest Speakers

Judah Cohen, Atmospheric and Envrionmental Research/MIT
Cyndy Chandler, Woods Hole Oceanographic Institution
Meghan Cronin, NOAA Pacific Marine Environmental Laboratory
Steve Diggs, Scripps Institution of Oceanography
Scott Doney, Woods Hole Oceanographic Institution
Ian Eisenman, University of California, San Diego
Ichiro Fukumori, NASA Jet Propulsion Laboratory
Glen Gawarkiewicz, Woods Hole Oceanographic Institution
Sarah Giddings, Scripps Institution of Oceanography
Eric Guilyardi, Institute Pierre Simon Laplace
Sang-Ki Lee, University of Miami
Ruby Leung, Pacific Northwest National Laboratory
Igor Kamenkovich, University of Miami
Jennifer Kay, University of Colorado
Billy Kessler, NOAA Pacific Marine Environmental Laboratory
Monique Messie, Monterey Bay Aquarium Research Institute
Art Miller, Scripps Institution of Oceanography
Dennis McGillicuddy, Woods Hole Oceanographic Institution
Christina Patricola, Texas A&M University
Adrienne Sutton, NOAA Pacific Marine Environmental Laboratory
Andrew Thomas, University of Maine
Lisa Yu, Woods Hole Oceanographic Institution
Luke Trusel, Woods Hole Oceanographic Institution
Jiayan Yang, Woods Hole Oceanographic Institution
Chidong Zhang, University of Miami

Project Office

Mike Patterson
Kristan Uhlenbrock

APPENDIX B: AGENDA

TUESDAY, JUNE 14

Session I. High–latitude and cryospheric processes

Specific themes or questions:

- What are the major biases in climate models' representation of polar climate?
- What are the key processes/interactions of processes that contribute to the biases?
- What new ideas/datasets are available which could be translated to model improvements?

9:15am	Introduction (Taka Ito)
9:20am	Luke Trusel (WHOI) – CMIP5 analysis
9:45am	Igor Kamenkovich (U Miami) – linking data assimilation & model improvement in SOCCOM
10:10am	Judah Cohen (AER/MIT) – Arctic Mid-latitude WG
10:35am	Coffee break
10:50am	Jennifer Kay (UC Boulder) – polar climate feedbacks, a summary from the PCPI workshop
11:15am	Ian Eisenman (UCSD) – sea-ice
11:45am	Final synthesis discussion

Session II. Coastal and marginal seas processes

Specific themes or questions:

- What is the current understanding of processes related to coastal/marginal seas that influence large-scale and regional climate?
- Which of these process representations can be improved in current climate models?
- How to improve observations and data assimilation for the relevant regions to help improve our understanding further?

1:30pm Ruby Leung (PNNL) – Regional/coastal climate modeling

1:45pm Ichiro Fukumori (JPL) – Data Assimilation, Adjoint modeling and satellite remote sensing in marginal/coastal seas

2:00pm Sarah Giddings (UCSD) – Estuary processes

2:15pm Andrew Thomas (U Maine) – Coastal, ecosystem satellite study

2:30pm Glen Gawarkiewicz (WHOI) – Coastal shelf-open ocean exchange

2:45pm Sang-Ki Lee (RSMAS) – Atmosphere-ocean processes in the Intra-Americas Sea their impacts on regional climate variability

3:00pm Coffee break

3:15pm Christina Patricola (Texas A&M) – EBUS air-sea processes, modeling, bias

3:30pm Jiayan Yang (WHOI) – Asian marginal seas

3:45pm General Discussion

4:45pm Daily Wrap-up

6:00pm Panel meeting Dinner

WEDNESDAY, JUNE 15, 2016

Session III. Biophysical interactions

Specific themes or questions:

- How is the community addressing the challenge of systematically forecasting marine ecosystem responses to individual climatic (e.g., ENSO) events?
- What is the state-of-the-art in representing the coupling between ocean biogeochemistry and physics in global climate models, and what new observations or process studies are needed?
- How deep is our understanding of physical-biological interactions at the oceanic mesoscale, how well are they represented in current models, and what new observations or process studies are needed?
- What are the current capabilities to observe interactions between ocean physical and biological processes (including the response of one to the other), and what *in situ* observations and process studies are needed by the satellite development community?
- What can PSMIP do to catalyze the progress on challenges identified?

9:15am Scott Doney (WHOI) – Ocean biogeochemistry and global climate modeling

9:45am Dennis McGillicuddy (WHOI) – Mechanisms of physical-biological interaction at the oceanic mesoscale

10:15am Art Miller (UCSD) – Marine ecosystem prediction

10:45am Coffee break

11:00am Monique Messie (MBARI) – Observing biophysical interactions

11:30am General Discussion

IV. Tropical Pacific Observing System (TPOS)–2020

Specific themes or questions:

- What observations are needed for improved understanding and optimal data assimilation, modeling, and prediction of ENSO and other Pacific climate phenomena?
- What are the areas of large uncertainty where model/reanalyses diverge? What are the related processes that are poorly represented in models/reanalyses, inhibiting improvements in prediction and understanding? How might model biases improve through implementation of TPOS2020?
- What process studies are needed to improve the relevant model components? How do these fit in with, and how easily might they build upon, the current and planned TPOS?
- What coordinated observing system and process study experiments will be required for the design of an observing system beyond TPOS2020?

1:30pm Introduction to Session (Greg and Janet)

1:35pm Billy Kessler (NOAA/PMEL) – SC

2:05pm Meghan Cronin (UW) – PBL-TT

2:35pm Eric Guilyardi (IPSL) – M&DA-TT

3:05pm Coffee break

3:20pm Lisan Yu (WHOI) – BB-TT

3:50pm Adrienne Sutton (PMEL) – BGC-TT

4:20pm Wrap-up and Discussion

Data Management

Specific themes or questions:

- Importance of data management for successful exchange between observational and modeling efforts
- Lessons learned from data management practices in exemplary process studies and data portals

4:45pm Chidong Zhang (RSMAS) – DYNAMO

5:00pm Cyndy Chandler (WHOI) – BCO-DMO

5:15pm Steve Diggs (UCSD) – CCDHO, mixing-CPT

5:45pm General discussion

6:15pm Daily Wrap-up

THURSDAY, JUNE 16, 2016

Panel business

9:15am Caroline Ummenhofer and Kris Karnauskas

12:30pm Adjourn

APPENDIX C: PROCESS STUDY WEBINAR FEEDBACK

In 2015/16, the PSMI Panel organized a series of eight webinars to provide feedback to active process studies with linkages to US CLIVAR research activities. The goals of the webinar series were to i) provide feedback on the plans and challenges for individual process studies, and ii) distill programmatic lessons to help current and future observational programs effectively meet the broader goals of improving the understanding of physical processes in the ocean and the atmosphere and to translate this understanding into improved observational and modeling capabilities. Below are the schedule and feedback summaries that were provided to the presenting PI. The feedback was intended to share information about best practices within the community and provide considerations on coordination, data management, and synergistic activities.

2015/16 Process Study Webinar Series Schedule

Thursday, November 19, 2015

- Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES), Sarah Gille, Scripps (Video | PDF)
- CalWater-2, Marty Ralph, UC San Diego (Video | PDF)

Friday, February 19, 2016

- Layered Atlantic Smoke Interactions with Clouds (LASIC), Paquita Zuidema, U. Miami (Video | PDF)
- ObseRvations of Aerosols Above Clouds and Their IntEractionS (ORACLES), Jens Redemann, NASA-Ames (Video | PDF)

Wednesday, March 2, 2016

- ARMWest Antarctic Radiation Experiment (AWARE), Dan Lubin, Scripps (Video | PDF)
- Marine ARM GPCI Investigations of Clouds (MAGIC), Ernie Lewis, Brookhaven National Lab. (Video | PDF)

Wednesday, March 23, 2016

- ARM Cloud Aerosol and Precipitation Experiment (ACAPEX), Ruby Leung, Pacific Northwest National Lab. (Video | PDF)
- Southwest Pacific Ocean Circulation and Climate Experiment (SPICE), Janet Sprintall, Scripps (Video | PDF)

PROJECT: DIMES

1. Comments on progress towards scientific objectives:
   - The observational campaign and integration/synthesis of data sets are complete.Analysis and modeling efforts are underway.
   - DIMES has already proven an extremely productive process study. The research output of the program is viewed as superior by the panel, as evident by the publications on the program's website.The papers listed show evidence of meeting (and surpassing) objectives including observations, modeling, and model-assisted interpretation of data.
   - DIMES is viewed by the panel as a superb project—important and valiantly carried out in the face of hostile seas and harrowing mishaps for which there are no templates for avoiding in the future.
   - The Special JPO Collection on DIMES provides a growing set of PI papers on the analysis of new datasets, expanded theory, and numerical simulations to quantify the role of small- and large-scale turbulent mixing in the ACC. The panel recommends the PIs consider publishing a state of science synthesis paper(s) near the completion of the synthesis phase to summarize the objectives, execution, new scientific understanding gained, remaining questions to be tackled, and legacy data and follow-on activities.

2. Comments on coordination among experiments or agencies:
   - The US and UK PI coordination of proposals at the outset and simultaneous review and award of proposals by US NSF and UK NERC has helped ensure the ability for the scientists to effectively coordinate their plans and meet established timelines for fieldwork and data synthesis.
   - The alternating of research cruises supported by NERC (UK) and NSF (US) appears to have run smoothly and serves as a model to emulate.

3. Comments on data management:
   - A nice website for posting publications and sharing data hosted by Scripps is set up, requiring registration. The panel suggests improving the clarity on guidance for registration and gaining access to the data for the broader scientific community and public beyond just the DIMES funded PIs. Also, the panel strongly recommends posting PDFs of all papers listed—even just the accepted manuscripts in the case that a publisher does not allow posting the published, typeset articles.
   - The panel recommends continuing to work with data management specialists to ensure access and readability of all data including those initially stored in nonconventional formats.
   - The dedicated NetCDF implementation will be of value for broad community use.
   - It should also be noted that the program website (http://dimes.ucsd.edu/en/) is beautiful and well organized, which likely assists those looking for information and data resulting from the program.

4. Comments on synergy between observations and modeling:
   - It is clear that models and observations played very well together during and in the wake of DIMES fieldwork. Annual meetings supported by the funding agencies enabled the interaction among observational and modeling activities.
   - DIMES should be viewed as a model for such cross-pollination in future field campaigns.

PROJECT: CALWATER2

1. Comments on progress towards scientific objectives:
    - Timeline: The CalWater2 experiment got underway in 2014 and will run through 2018, with a primary field season in January-March 2015. Planning initiated in 2012, following the series of field campaigns for CalWater1 during winters of 2009-2011. A white paper outlining the scientific gaps, program objectives, experimental design, and expected outcomes was issued in 2013.
    - A recent BAMS review article, authored by the scientific working group members, communicates to the broader community select findings from CalWater1 and the expanded goals of CalWater2.
    - CalWater2 extended the domain of observations (confined inland in CalWater1) offshore of California into the eastern Pacific. The observational projects were successfully deployed and captured several strong atmospheric rivers. Principal observational targets included winds, water vapor, aerosols, clouds, precipitation (rain and snow) with supplementary air-sea fluxes and subsurface ocean conditions.
    - Ocean's role and ocean observations? This was mostly done via a 2015 project with Ron Brown and AXBTs. There is no additional ocean component planned going further. Understanding the source region for water vapor looks to be beyond the scope of the experiment.
    - It is too early to assess the impact of CalWater2 vis-à-vis the stated scientific objectives.

2. Comments on coordination among experiments or agencies:
    - What worked or not with various agencies? While CalWater1 was undertaken with mostly NOAA and California State support, CalWater2 reflected an expanded investment by additional agencies – DOE, NSF, NASA, and ONR, including critical deployment and coordination of multiple facilities – aircraft from DOE, NOAA (2), and NASA, the NOAA ship, DOE ARM Mobile Facility, and NSF and California Department of Water Resources networks on land.
    - An international version of this study may be undertaken in the future, but the PIs are concerned that the funding cycle and scheduling mismatches, while challenging among US agencies, could be even more daunting internationally.

3. Comments on data management:
    - A data management team is established to coordinate data issues. Currently, there is no accepted timeframe for data release. Individual PIs are responsible for quality control and release of the data collected under their funded projects in accordance with their projects' data management plans The BAMS article gives POCs for data sets.
    - The panel recommends that the data management team establish and advertise timeframes for delivery of quality controlled data.
    - We further suggest that the team coordinate a one-stop online resource for dissemination of CalWater# data. This may require a proposal to funding agencies.
    - Exploring the approach of the ACAPEX project may be helpful to informing the approach. The NCAR Earth Observing Laboratory offers other examples of data cataloguing and archiving for field campaigns.
    - The panel suggests moving forward with streamlining a policy for disseminating data to the community.

4. Comments on synergy between observations and modeling:
    - There is merit in considering approaches to incorporate understanding of AR processes into climate models.
    - The panel encourages collaboration with modeling centers to examine, for example, whether ARs are represented properly in models, the roles of ocean and storm tracks.

PROJECT: LASIC AND ORACLES

1. Comments on progress towards scientific objectives:
    - The panel commends the PIs for developing the exciting projects. As the projects move forward it may be helpful to consider adaptability: willingness to revise plans midway based on interaction with collaborating modelers and data users are very promising in this regard.

2. Comments on coordination among experiments or agencies:
    - Multiple projects appear to be well connected through the PIs. International coordination: there is unfortunately no longer an African CLIVAR panel, but the Southeast Atlantic hosts an important upwelling region, aligned with one of the new research foci of CLIVAR. Interaction with the upwelling study group could bring fruitful collaboration. It is recognized that the PIs will be involved in this effort.

3. Comments on data management:
    - It is important to design and set up early on a centralized data distribution system that includes quality control, formatting, archiving and access. Receiving input from data users could be helpful in designing a data system that maximizes its potential use. Previous efforts that employed this successfully include VOCALS, SPURS, and DYNAMO, which could provide feedback to the PIs on useful best practices.

4. Comments on synergy between observations and modeling:
    - Engaging the climate modeling community: there may be an opportunity to engage major modeling centers early on, for example, to plan/arrange a model inter-comparison project. How about engaging operational centers, such as NCEP or ECMWF, to open opportunities for assimilating the observation data into their systems and produce a reanalysis product for this field campaign? A similar product was produced for the DYNAMO project.

PROJECT: AWARE

1. Comments on progress towards scientific objectives:
    - AWARE has made excellent progress toward their objectives. It is now three months into a 13-month deployment, with everything working well.

2. Comments on coordination among experiments or agencies:
    - Coordination between experiments and agencies is very good. The project has done well with a diverse and unique set of challenges in coordinating experiments and managing interagency collaborations. The fruitful collaboration with Australian colleagues has been noted in particular.

3. Comments on data management:
    - ARM is responsible for data management and sharing, freeing up time for the PIs to work on the science. This seems like a very good setup. The project is making all quality-controlled data available to the public with minimal delay. Prompt data archiving and sharing to scientific community has been excellent, but comments were made about the need for higher level data to fit the modelers' specific needs for model validation and process modeling.

4. Comments on synergy between observations and modeling:
    - The campaign was clearly planned with the goal of collecting data to improve numerical models. Because the project proposals did not include a clear set of hypotheses or scientific questions, for future ARM projects it may be useful to involve modelers and US CLIVAR PSMI Panel at an early stage of setting up the experiments to develop/refine science plans, so as to ensure that no important measurements are missing. At this point, US CLIVAR could keep helping to connect the AWARE investigators with modeling centers and groups to discuss obs-modeling evaluation. In terms of encouraging modelers to use the data collected by ARM projects, US CLIVAR can help by advertising the data sets more broadly to modeling centers, e.g., through creating a database of modelers and the specific parameterizations they are working on, and inviting modelers with relevant interest(s) to join future process study webinars. The US CLIVAR Project Office can also help promote the availability of the AWARE data via their monthly newsgram.

PROJECT: MAGIC

1. Comments on progress towards scientific objectives:
    - MAGIC completed its field campaign, has made the data available to the public, and has several publications to date using the data.

2. Comments on coordination among experiments or agencies:
    - Coordination between experiments and agencies is very good. The project has done well with a diverse and unique set of challenges in coordinating experiments and managing interagency collaborations.

3. Comments on data management:
    - ARM is responsible for data management and sharing, freeing up time for the PIs to work on the science. This seems like a very good setup. The project is making all quality-controlled data available to the public with minimal delay. Prompt data archiving and sharing with the scientific community has been excellent, but comments were made about the need for higher-level data to fit the modelers' specific needs for model validation and process modeling.

4. Comments on synergy between observations and modeling:
    - The campaign was clearly planned with the goal of collecting data to improve numerical models. Because the project proposals did not include a clear set of hypotheses or scientific questions, for future ARM projects it may be useful to involve modelers and US CLIVAR PSMI Panel at an early stage of setting up the experiments to develop/refine science plans, so as to ensure that no important measurements are missing. At this point, US CLIVAR could keep helping to connect the MAGIC investigators with modeling centers and groups to discuss obs-modeling evaluation. In terms of encouraging modelers to use the data collected by ARM projects, US CLIVAR can help by advertising the data sets more broadly to modeling centers, e.g., through creating a database of modelers and the specific parameterizations they are working on, and inviting modelers with relevant interest(s) to join future process study webinars. The US CLIVAR Project Office can also help promote the availability of the MAGIC data via their monthly newsgram.

PROJECT: ACAPEX

1. Comments on progress towards scientific objectives:
   - The ACAPEX field campaign, part of the CalWater2 project, has been successfully completed.
   - Successful completion required overcoming formidable challenges involving coordination across several agencies and observational platforms.
   - Several presentations were given at the 2015 AGU Fall meeting in an oral and a poster session.
   - Measurements collected during ACAPEX are now being used to evaluate operational weather forecast and climate models and study aerosol impacts on clouds and precipitation.

2. Comments on coordination among experiments or agencies:
   - The building of long lead times and solidification of a common goal among PIs, agencies, etc., appears to have been essential for success in such a cross-platform and cross-agency field campaign.
   - ACAPEX is a model of success on this challenge, despite PI suggestion that some luck is needed.

3. Comments on data management:
   - ACAPEX is relatively unique among other field campaigns in that DOE-ARM automatically curates and archives the measurement data.
   - Data have been uploaded to the ARM data repository 6 months after the field campaign and made available to the community.
   - Summaries and data somewhat scattered between arm.gov and UCSD; suggest integration between the two sites.
   - Integration of ACAPEX data into the broader CalWater2 project's data management plan should be considered.

4. Comments on synergy between observations and modeling:
   - It is clearly not ideal that it is relatively difficult for PIs to do both the field campaign and the analysis/modeling afterward.
   - It is a formidable challenge that PIs must therefore submit different proposals to use the resulting data sets, given the uncertainty related to the long lead times involved in funding and coordinating field experiments as well as the follow-on analysis work.
   - Field campaigns that are part of a broader project (ACAPEX and CalWater2, in this case) may have a better chance of success in achieving observation-model synergy.

PROJECT: SPICE

1. Comments on progress towards scientific objectives:
   - • The engagement of the PSMI Panel focused on the US participation in the international CLIVAR-endorsed SPICE project, specifically the Solomon Sea experiment. The multi-year observational component is ongoing, with the PIs already undertaking the data q/c, analysis, and synthesis phase.
   - Some results of the project are described in the JGR, 2014 Special Issue and as overview article (Ganachaud et al.) in progress. The panel applauds these early efforts to share findings with the broader community.
   - The project appears to provide a great data set for the analysis work for graduate students.
   - The project has provided the improved understanding of the circulation features in the EUC, and some new features (e.g., the deep extension of the New Caledonia Jet) have been discovered. Plans for synthesis of observational data to explore transport, storage, and water mass transformations are expected to further advance scientific understanding of the WBC system.
   - It appears the biggest challenge has been the lack of collaboration with the atmospheric science community, and that can impact the understanding of the SPCZ dynamics and the influence of the SPICE area variability on climate. US and International CLIVAR should follow-up with the science working group and help promote the engagement across different communities during the analysis and synthesis phase.

2. Comments on coordination among experiments or agencies:
   - The "umbrella" character of SPICE, under which sub-basin focused experiments in the Solomon, Coral, and Tasman Seas, appears to have worked well in such large, international project. Notably, the international CLIVAR endorsement and sponsorship of planning meetings helped facilitate the multi-country buy-in for the project. Early entrainment of local scientists and students in planning and implementing the experiments has been critical to project successes to date, particularly in the scheduling of ship time, sharing of instruments, and engagement of students. This effort to accommodate complex platforms/international contributions could be the start of a framework to be emulated for encouraging synergies between observational and modeling components of process studies.
   - The individual sub-basin experiments, while interconnected, also remained sufficiently self-contained and independent, such that the lack of funding in one did not critically influence the others.
   - Testing of large-scale monitoring of key climate quantities (e.g., thermocline inflows, outflows, air-sea fluxes) are valuable for informing future ocean observing requirements, as are being explored in connection with TPOS2020 West Pacific Task Team. The panel understands that a multi-component time series approach would be needed to adequately sample the structure of the low latitude western boundary current at suggested high resolution and for sufficient duration to resolve interannual and longer variability.

3. Comments on data management:
   - Data management planning appears to have been comprehensive. The panel commends the reported adherence to the international CLIVAR open data policy for free and unrestricted access.
   - Timely public data access is emphasized. Hydrographic data are quality controlled and shared via NCEI; mooring data are undergoing q/c and will be made public through Ocean Sites. Enhanced VOS and Argo deployments, while not discussed, are similarly anticipated to be available through their respective data servers. The fate of glider data, while similarly not discussed with the panel, should also be clarified on the project webste.

- The plan to include computed data products (e.g., transports) is especially interesting.
- To help facilitate community engagement of the observational and modeling data sets, consideration should be given to a one-stop data portal for the SPICE project and component experiments, with links to the various data repositories. Such an effort can indicate the expected timeframe for access to any outstanding data sets.

4. Comments on synergy between observations and modeling:
   - The plans for modeling are quite impressive.
   - The modeling, especially the high-resolution models in the marginal seas, has been an integral part of the project from the start (planning phase). Future modeling work utilizing the observational data to improve mixing parameterizations and sub-mesoscale variability is expected.
   - This multi-prong simultaneous observational-modeling approach is worth sharing among CLIVAR process studies as an outstanding example.

For more information visit:
https://usclivar.org/panels/psmi

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