WCRP REPORT

World Climate Research Programme

Project report

Report of the 10th Session of the CLIVAR Pacific Region Panel

10 – 11 October, 2015 Santiago, Chile

January 2016

WCRP Informal/Series Report No. 4/2016

ICPO Informal Report 207/16

Content

ACTION ITEMS

ACTION: Organize a small workshop on these Indo-Pacific connections to initiate the work **(Dongliang Yuan/Wenju Cai/ Michael McPhaden / Matthieu Lengaigne)**

ACTION: Propose a review paper on the Indo-Pacific connections with IOP and ENSO RF (including oceanic/atmospheric bridges, intraseasonal to multidecadal) **(Matthieu Lengaigne)**

ACTION: Feasibility of creating a CLIVAR website dedicated to ENSO extreme **(Agus Santoso)**

ACTION: Contact Climate Dynamics panel to investigate possible collaboration on this topic and avoid overlapping **(Matthieu Lengaigne)**

ACTION: Provide a first assessment of the PDV as simulated by CMIP models and related mechanisms **(Matthieu Lengaigne)**

ACTION: Investigate the possibility of the session on this specific topic at CLIVAR meeting in Qingdao **(Matthieu Lengaigne)**

ACTION: Contact Sea Level RF to investigate possible collaboration on this topic and avoid overlapping **(Tatsuo Suzuki)**, and **Lei Han** will help to contact CLIVAR Sea Level RF.

ACTION: Contact OOPC/GOOS **(Tatsuo Suzuki)**

ACTION: Investigate effectiveness of downscaling methods **(Tatsuo Suzuki)**

ACTION: To seek coordination for data availability and analysis with NPOCE, ITF and TPOS-2020, propose a WBC coordination group structure to both TPOS-2020 and CLIVAR SSG (done as of Jan 2016; starting co-chairs are K. Ando and A. Ganachaud, then replaced by J. Sprintall for ITF-TT legacy). **(J Sprintall)**

ACTION: NPOCE to report to PP about NPOCE data management: long term storage, processing, formats (ref to GO-SHIP and OceanSites) as well as distribution and sharing (internal to NPOCE and public). (**Xiaopei Lin**

ACTION: After the NPOCE data issue is resolved, write a proposal to be submitted to CLIVAR to formalize the PGI project **(Dongliang Yuan)**

ACTION: Report to PP after TPOS SSG Oct 13-15 2015; solicit PP and ENSO RF for feedback **(Billy Kessler)**

ACTION: Contact Indonesian scientists to foster collaboration (invite to next panel meeting) **(Dongliang Yuan)**

1. Charges to the meeting

The CLIVAR Pacific Region Panel (PRP) held its 10th Session in Santiago, Chile during 10th-11th, October 2015, back to back with the ICSHMO-11 (International Conference on Southern Hemisphere Meteorology and Oceanography). This meeting was kindly hosted by Millennium Institute of Oceanography(IMO), Chile and locally organized by Dr. Wolfgang Schneider and his colleague, Ms. Monica Sorondo.

A full attendence with all of the 13 panel members was achieved in this session, as well as some invitees from US, Australia, China and Chile (see Appendix B the list of attendees).

Alexandre Ganachaud and Matthieu Lengaigne, PRP co-chairs, drafted the agenda (see Appendix A the agenda) and hosted the panel meeting. Each PRP member and some invitees reported recent progress and major science challenges on the climate and ocean research in the Pacific region, including ENSO, Pacific Decadal Variability, Reginal Sea Level changes, TPOS-2020 planning, Western Boundary Current and Indonesian Through Flow. Through discussions were conducted on these issues (See the following part of the report for the discussions and conclusions).

The panel reviewed the membership renewal issue. Alexandre Ganachaud and Wenju Cai will rotate off when their terms are due next year. Xiaopei Lin will be the new co-chair replacing Alexandre. Two new members will join the panel after being approved by CLIVAR SSG. Lei Han on behalf of the International CLIVAR Project Office, and the two co-chairs on behalf of the panel thanked the tremendous contributions from Alexandre Ganachaud and Wenju Cai to PRP during all the past years they served, and wished them to keep following up PRP activities in their future work.

The panel also discussed the PRP inputs to the CLIVAR Science Plan. Lei Han publicized the CLIVAR Open Science Conference to be held in September 2016 in Qingdao, China, whose abstract submission call will be announced soon. All the CLIVAR panels will be encouraged to meet there.

2. ENSO science

Within the new CLIVAR architecture, a research focus group has been build on “ENSO in a changing climate”. The main task of this group is to propose a standard ENSO evaluation protocol for CMIP models as a resource for model developers and impact studies and to provide a better understanding of whether ENSO might change in the future. In addition, a US CLIVAR “ENSO Diversity” working group was formed in 2012 to clarify, coordinate and synthesize research to achieve a better understanding of ENSO diversity. This group led to a better understanding of ENSO flavours in relationship with their surface and sub-surface characteristics, tropical-extra-tropical teleconnections, physical mechanisms and climate change impact recently summarized in a review paper in BAMS (Capotondi et al. 2015) and a special issue to appear soon in Climate Dynamics. The Pacific Panel hence decided to focus his ENSO research on three main topics not covered by these groups, namely (1) the understanding of ENSO basic mechanisms, (2) the specific dynamics and predictability of extreme ENSO events and (3) the remote influence of regions outside the tropical Pacific on ENSO. These three topics are detailed below.

2.1. Main science questions:

2.1.1. What are the major gaps in our understanding of ENSO basic mechanisms?

The predictability of ENSO is grounded on our current understanding of its mechanisms. It is now well accepted that ENSO anomalies develop under the influence of the Bjerknes air-sea coupled feedback, offset by several negative feedbacks. Amongst them, the recharge oscillator is now a widely accepted paradigm to explain the delayed negative feedback due to oceanic processes, which eventually terminates the ENSO event. ENSO predictability is largely provided by this ocean subsurface memory, the equatorial Pacific heat content leading ENSO SST evolution by ~8 months. Even if tremendous progress have been made in understanding basic ENSO dynamics, the real-time ENSO prediction skills are generally lower during the last decade compared to the 1990's, with for instance a weaker predictive skill of the WWV since 2002. Understanding ENSO basic mechanisms is therefore a very important area of research that must continue in the future.

- **Interactions between the seasonal cycle and ENSO:** The interactions between ENSO and the seasonal cycle is far from being completely understood. CMIP models analysis suggests a strong inverse relationship between the amplitude of the seasonal cycle and ENSO while recent analysis of Holocene proxy data suggest that ENSO is more energetic when the seasonal cycle is larger. This disagreement points towards the existing deficiencies in our current understanding of ENSO interactions with the seasonal cycle. Similarly, although several mechanisms have been proposed to explain the ENSO tendency to peak in boreal winter (seasonal modulation of air-sea coupling, southward shift of the wind, cloud feedbacks), no consensus on the dominant process has been found so far. Further work has therefore to be undertaken to better understand the underlying mechanisms linking the seasonal cycle in the equatorial Pacific and ENSO.
- **Role of background state on ENSO variability:** The mean climate upon which ENSO evolves varies on decadal to multi-decadal time scales, manifesting itself in a Pacific-scale phenomenon that is in what commonly known as the Interdecadal Pacific Oscillation. Disentangling the link between ENSO and IPO has been one challenging research topic as the two are closely intertwined. ENSO predictability appears for instance to be weaker during negative phase of the IPO than during positive IPO. Modest changes in the basic state has been suggested to lead to different types of El Niño but more studies on this topic are needed to better understand the mean state control on ENSO characteristics.

2.1.2. What are the specific dynamics and predictability of extreme ENSO events?

The series of recent Nature paper led by PP members on the evolution of ENSO extreme in a future climate (Cai et al. 2012, 2014, 2015ab, Santoso et al. 2013) along the lines of the 1982 and 1997 super El Nino events and the ongoing 2015 strong El Niño event reinvigorated the interest of the scientific community on the dynamics of these peculiar events. Recent ENSO workshops in Sydney and Paris organised under the auspices of CLIVAR discussed specifically these events and how they might change in the future. CLIVAR PP should encourage coordinated work on the following aspects of extreme El Niño events:

- **Definition and characteristics:** There is to date no consensus on the definition of extreme ENSO events, which could either be defined based on the usual SST indices (e.g. Niño3), atmospheric indices such as development of convective precipitation in the eastern Pacific (Cai et al. 2014) or regional indices of their related impacts. A revision of the El Niño definition following Trenberth et al. (1997) that includes these extreme events should be considered. Related to the above issue, the short observational record does not allow to well constrain the properties of these extreme events, even if the 2015/16 El Nino could add to the actual record. An assessment of the feasibility of using paleo-proxies to identify extreme ENSO events for past climate should be carefully considered. This would require to first separate the effect of temperature and hydrology in oxygen isotopes for a more accurate coral proxy estimates of ENSO SST/precipitation signals in equatorial Pacific and to better understand the salinity budget at interannual and decadal timescales.
- **Mechanisms and precursors:** The oceanic mechanisms behind the SST evolution during ENSO extremes are getting better understood through the analysis of climate models and the limited observations. There is however a clear need to better understand the role of atmospheric and air-sea coupled processes in the development of these extreme events, including the role of Westerly Wind Events, the non-linearites in wind and cloud or specific vacillations in surface pressure in the southern or northern hemisphere (the 'Southern Hemisphere Booster' and the 'Pacific Meridional Modes'). In addition, the prediction of ENSO intensity remains a major issue even after the spring barrier. The prediction of "strong" 2015 El Nino and the failure of the prediction of aborted 2014 El Nino is an opportunity to further discuss and revise our knowledge of the predictability of extreme ENSO events. It is still currently unknown if specific ENSO precursors exist for extreme El Nino events.
- **Model representation and predictability:** Climate models remain the main avenue to assess the potential impact of climate change on the future of extreme ENSO events. These models have been used to suggest an increase in extreme ENSO frequency in the coming decades. There are, however, known uncertainties that keep the confidence in these projections at the 'medium' level, following the IPCC definition. It is indeed currently not clear to which extent these climate models as well as ENSO dynamical prediction systems are able to simulate the characteristics and specific mechanisms of extreme ENSO events. Amongst the current limitation in simulating such events, the underestimated ENSO nonlinearity/asymmetry and the persisting cold tongue and double ITCZ biases in these models remain a major issue. A careful assessment of the ability of these models to simulate the characteristics and specific mechanisms of extreme ENSO events and impact of model common biases in simulating these specific events should be encouraged.

2.1.3. How do regions outside the tropical Pacific influence ENSO?

While ENSO influences air-sea processes and SST variability outside the tropical Pacific, these remote forcing also affects ENSO evolution. A large body of literature has emerged during the past decade discussing the potential impact of regions outside the tropical Pacific on ENSO events initiation and development, including Pacific mid-latitudes (e.g., North Pacific Oscillation), the Indian Ocean (e.g., Indian Ocean Dipole) and the Atlantic. The relative importance of each basin on ENSO dynamics and predictability needs to be further refined:

- **Global assessment:** While many studies suggest that various regions outside the tropical Pacific may influence ENSO, these results can be model dependent and generally focuses on a single region with different numerical and/or statistical strategies. It is presently unclear which regions outside the tropical Pacific are most influencial on ENSO dynamics and which regions bring added predictive skills to tropical Pacific intrinsic predictability. Indeed, most statistical hindcast models of ENSO do not use predictors from outside the tropical Pacific. There is hence a need to promote standard and global modelling strategies to allow a fair comparison of the respective influence of each region on ENSO dynamics and predictability (relate to ENSO precursor in 1 and 2). In addition, assessing the influence of other basin on the tropical Pacific in the CMIP database should be encouraged.
- **The specific case of the Indian Ocean:** Amongst these regions, the Indian Ocean has been recently proposed as credible candidate for influencing ENSO evolution. Enhanced predictability of ENSO at the lead-time of one year across the spring persistence barrier has been identified if anomalies over the tropical Indian Ocean are used as a predictor. Both the basin wide warming and the Dipole of the Indian Ocean have been suggested to influence ENSO evolution and/or predictability. More studies are however needed to assess the mechanisms by which the Indian Ocean may influence ENSO (e.g. the oceanic vs atmospheric bridge) and the expected ENSO predictability increase from the inclusion of Indian Ocean predictors.

2.2. Proposed action items:

(1) Organize a small workshop on these Indo-Pacific connections to initiate the work (Dongliang/Wenju/Mike/Mat)
(2) Propose a review paper on the Indo-Pacific connections with IOP and ENSO RF (including oceanic/atmospheric bridges, intraseasonal to multidecadal) (Mat)
(3) Feasibility of creating a CLIVAR website dedicated to ENSO extreme (Agus)

3. Pacific Decadal Variability

The Interdecadal Pacific Oscillation (IPO) manifests as a low-frequency El Niño-like pattern of climate variability, with a warm tropical Pacific and weakened trade winds during its positive phase, and a cool tropical Pacific and strengthened winds during its negative phase. Recent papers suggested that the recent global surface warming slowdown during the last decade (referred to as « hiatus ») could be related to the negative phases of the IPO. These findings reinvigorated the interest of the climate community on natural decadal variability in the Pacific Ocean. The Pacific Panel strongly encourage these efforts, especially regarding (1) the mechanisms responsible for the Pacific Decadal Variability, (2) the regional imprints of the Pacific Decadal Variability and (3) their representation in CMIP models.

3.1. Main science questions:

3.1.1. What are the main mechanisms driving the Pacific Decadal Variability?

Low-frequency fluctuations of the ocean and atmosphere over the North Pacific Ocean on interannual to decadal timescales significantly impact the weather and climate of North America and Eurasia and drive important state transitions observed in marine ecosystems. Besides decadal ENSO variations, the modes of the North Pacific Decadal Variability include the Pacific Decadal Oscillation (PDO) as well as the recently discovered North Pacific Gyre Oscillation (NPGO). Understanding the mechanisms driving these natural climate fluctuations is therefore of broad scientific and socioeconomic interest.

- **Role of ENSO forcing on the PDV:** To first order, the PDO is a forced response of the North Pacific ocean to atmospheric forcing by variability of the Aleutian Low while the NPGO is forced by the North Pacific Oscillation. These two modes are connected to ENSO forcing via an atmospheric bridge that modulates the atmospheric variability in the North Pacific. At interannual timescales, the variability originating from the tropics (ENSO or ENSO-like) has been identified as a major driver of these patterns of variability. However, it is currently debated whether the variability in the tropics influences the variability in the mid-latitudes at decadal and/or multi-decadal timescales, or if the variability in the tropics results from variability outside the tropical region. The limited number of degree of freedom of the observational record makes coordinated model experiments the best hope to identify the causal relationship between the tropical and extra-tropical variability at decadal timescales and their related mechanisms (oceanic vs. atmospheric bridge).
- **Other mechanisms: ocean gyre dynamics and air-sea coupled feedbacks:** ENSO has not been suggested as the only driver of the PDV. While most of the North Pacific decadal variability is driven by atmospheric forcing, decadal changes in the Kuroshio-Oyashio current system is forced, for instance, by winds over the North Pacific driving westward propagating oceanic Rossby waves that manifest as SST variability along the subarctic front in the western Pacific ocean. Recent studies suggest that the atmospheric response to decadal SST variability in the Kuroshio Extension region could induce an atmospheric response in the anomalous Aleutian low, which may enhance variability at decadal periods. The nature of the ocean gyre dynamics and coupled ocean-atmosphere dynamical response to Pacific Decadal Variability is not yet very clear and more studies are needed to ascertain their characteristics and their importance to the overall decadal/multidecadal variability in the Pacific as a function of the timescale considered.
- **PDV representation in CMIP models:** Projections of the climate system response to anthropogenic forcing are generally derived from the analysis of simulations from the Coupled Model Intercomparison Project database. The aforementioned importance of Pacific decadal variability for hiatus periods in observations stresses the need to evaluate how these models capture internal decadal climate variability. Although some studies have already been dedicated to this task, there is an urgent need to more thoroughly assess the ability of CMIP models to capture the main PDV characteristics and their related mechanisms, owing to the emerging importance of decadal prediction.

3.1.2. What is the imprint of the Pacific Decadal Variability in the coastal regions of the Pacific and in other basins?

- **Pacific Decadal Variability signature on coastal regions:** If large-scale SST patterns related to the PDV are relatively well constrained by the available observational products, the contribution of these decadal modes of variability near the coast is not yet unambiguously assessed. For instance, the relative role changes in the IPO related equatorial variability and changes in the South Pacific Anticyclone on the Peru upwelling system is not well understood. Similar issues arise from other coastal regions around the Pacific rim. There is therefore a need to better understand understand the respective influence of local/regional processes and large-scale Pacific Decadal Variability in driving the coastal dynamical features through dedicated observational analysis and regional model experiments
- **Pacific Decadal Variability signature outside the Pacific region:** It is well known that ENSO decadal variability influences the Indian Ocean SST through zonal shifts of the Walker circulation, resulting in a tropical Indian Ocean basin-wide warming until the end of spring. How this influence translates at decadal timescales, or whether an independent mode of Indian Ocean variability exists at this timescale, however, remains largely unexplored. Although presumably weaker, the signature of Pacific decadal variability over the Atlantic region should also be analysed.

3.2. Proposed action items:

(1) Contact Climate Dynamics panel to investigate possible collaboration on this topic and avoid overlapping (ML)
(2) Provide a first assessment of the PDV as simulated by CMIP models and related mechanisms (ML)
(3) Investigate the possibility of the session on this specific topic at CLIVAR meeting in Qingdao (ML)

4. Pacific regional sea level changes

Addressing and mitigating the effects of sea level changes involves accurately determining the contributing factors and associated impacts to past, present and future sea-level rise and variability. Within the new CLIVAR architecture, a research foci group “Sea level rise and regional Impacts” has been build. The overarching goal of this group is to establish (1) a quantitative understanding of the natural and anthropogenic mechanisms of regional to local sea level variability, (2) to promote advances in observing systems required for an integrated sea level monitoring and (3) to foster the development of sea level predictions and projections that are of increasing benefit for coastal zone management. To support this effort, the CLIVAR Pacific Panel decided to contribute to a regional assessment of some of these issues for the case of the Pacific in relationship with the research foci group, namely (1) identify the robust regional sea-level signals in the Pacific at large and local scale and attribute these changes to natural modes of variability or anthropogenic forcing, (2) identify the mechanisms at stake in driving these changes and (3) the robust regional sea level changes expected in the future and their related uncertainties.

4.1. Main science questions

4.1.1. What are the robust regional sea level signals in the Pacific?

Sea level rise is far from being uniform and exhibits significant spatial variations regionally. Recent studies have indeed investigated the regional sea level evolution in the Pacific, demonstrating that the sea-level rise in the western tropical Pacific during the past two decades was three time larger than the global mean sea level rise while sea level rise was weaker in other regions, like in the eastern tropical Pacific or along the western coast of North America. Long-term historical hydrographic observations have also shown the decadal to interdecadal sea level variability in the mid-latitudes. These regional differences are partly due to the natural climate variability, with a non-negligible contribution from anthropogenic forcing in some places. Separating the respective contribution of Pacific climate variability, anthropogenic forcing as well as natural forcing (such as volcanic eruptions or solar variability) to the Pacific regional sea-level variations is however highly challenging because the internal climate variability introduces strong decadal changes in regional sea level, resulting in a very unfavorable signal to noise ratio for detecting the forced sea level response. In addition, the temporal and/or spatial limitations of sea-level observations complicate the attribution of the observed changes. Further studies are therefore needed to ascertain these contributions and their relationship with observed coastal sea level signals.

- **Detection and attribution of large-scale sea-level signals:** Given the available observations of sea level, it is still very challenging to separate out the anthropogenic secular signals and signals from internal climate variability. The modern satellite altimetry record offers a nearly global coverage but only spans twenty years. Tide gauge have much longer records but have a very poor spatial coverage and need suitable corrections for both large-scale signal and more local processes. Other alternative sea level products include ocean reanalysis and sea level reconstructions that provide global coverage over several decades and allow separating the effect of natural decadal climate variability and anthropogenic sea-level trends. The robust signals and related uncertainties associated with these various available products however need to be further ascertained.
- **Coastal sea-level signals:** In addition to this large-scale assessment, there is a need to understand how these large-scale regional sea-level changes (whether natural or anthropogenic) combine with more local signals (local circulation, ground motion, tectonic/volcanic activity) to produce sea level variations observed in coastal regions. Providing this information is particularly important for the Pacific islands countries, where national and international agencies require inputs for risk assessments, in order to decide upon climate adaptation measures. The sea-level rise is indeed one of the most threatening consequences for these low-lying coastal environment that could become more vulnerable to flooding and land loss. Amongst other solutions, there is need to propose downscaling methodologies to address these key issues.
- **Improving the existing observing system:** Long-term measurements are required to understand the ongoing and future sea level changes and attribute them to natural variability or anthropogenic effects. Widespread deployment of tide gage system is indispensable to provide valuable information about coastal sea level changes. Furthermore, combination of the tide gauge, satellite and hydrographic

observations is helpful to understand the connection between sea level change in the open ocean and the consequence coastal sea level changes and improve the downscaling method. A proper assessment of the current observing system and coordinated plans regarding its future evolution is therefore required.

4.1.2. What are the main processes driving regional sea level variations in the Pacific?

Regional deviations from global mean sea level rise are primarily caused by movements of the sea floor, changes in gravity due to water mass redistribution (land ice and other terrestrial water storage) as well as by dynamical processes related to redistribution of water masses and change of water masses properties caused by changes in winds, aire pressure, air-sea fluxes and ocean currents associated with both natural or anthropogenic climate modes.

- **Wind-driven contribution:** Wind stress forcing has been shown to strongly contribute to regional sea-level variations in the Pacific, through Ekman pumping signals and planetary waves generation that imply massive zonal and meridional thermal stratification changes. It is however not fully understood how wind changes related to either low-frequency climate fluctuations or anthropogenic forcing translate into the observed low-frequency sea-level patterns. In addition, there is a clear need to better ascertain the robust features and uncertainties in wind changes available from the numerous available long-term wind products.
- **Assess contribution from subsurface water mass modification:** In addition to dynamical wind driven isopycnal movement, substantial water mass density change can also affects regional steric sea level change. Hydrological observation shows that the secular modification of subtropical mode waters in the North Pacific could contribute to the observed secular sea level changes. These signals project onto the higher baroclinic modes rather than the first baroclinic mode. Further studies are required to be better assess the contribution from deep water masses characteristics to the observed sea level changes.

4.1.3. What are the regional sea level changes expected in the future?

Projections of the climate system response to anthropogenic forcing are generally derived from the analysis of simulations from the Coupled Model Intercomparison Project database. CMIP projections of regional sea level provide information primarly about dynamical sea level changes resulting form increased heat uptake and changes in the wind forcing. Natural climate variability will strongly contribute to Regional relative sea level changes over the next upcoming decades but all other contributions will become important at the end of the 21st century, to eventually dominate over the natural variability.

- **CMIP models assessment:** Owing to the strong interplay between sea level signals driven by natural variability and anthropogenic signals, there is a need to thoroughly assess the CMIP models ability to capture the main sea level patterns driven by driven by the Pacific Decadal variability in the Pacific and understand better the reasons behind models differences. It is also a must to better understand how the models biases in representing the natural sea-level variability will impact sea level changes assessment.

- **Expected future changes:** Future greenhouse warming pattern of SST in the tropical Pacific generates a robust wind response in the tropical South Pacific, which will act to decrease of sea level relative to the global mean signal in many areas in the South Pacific. Although these projected changes appear to be robust, a similar assessment of the effects of long-term wind changes on the regional characteristics of future sea level trends in other Pacific regions needs to be carried out along with a proper estimation of the effect of the models biases (cold tongue and SPCZ biases) on the spatial characteristics of the anthropogenic sea level signals.

4.2. Proposed action items

(1) Contact Sea Level RF to investigate possible collaboration on this topic and avoid overlapping (TS), and Lei Han will help to contact CLIVAR Sea Level RF.
(2) Contact OOPC/GOOS (TS)
(3) Investigate effectiveness of downscaling methods (TS)

5. The tropical Pacific Ocean Observing System: TPOS-2020

Main points:

The TAO/TRITON crisis has become an opportunity to formulate future plans to observed the tropical Pacific in a consistent manner. The TPOS2020 project was established in 2014 for the purpose to re-design Tropical Pacific Ocean Observing System as integrated system to meet scientific and societal needs and to be robust and sustained. TPOS-2020 will put together all tools into a complete design system, and its scope extends beyond ENSO, including the boundary layers (e.g., diurnal cycle, Ekman divergence and upwelling, barrier layers and cold tongue front).

Proposed changes to the existing systems consider the fact that we need to continue having TAO in some form, with increasing the density of moorings along the equator from 7S to 7N, and increasing latitudinal array to capture ITCZ and SPCZ. Argo (a part of TPOS-2020) is improving and complementing TAO subsurface sampling, but cannot capture diurnal mixed layer and surface meteorological observations. There is also a need to explore other new autonomous platform and fully integrate satellite observations.

TPOS-2020 will produce a compelling plan that:

- May need to re-prioritize to cut costs
- Needs care and risk assessment if necessity to dismantle sites because they are part of a whole, and taking out certain components may risk having the entire system being invalid

- Do not repeat the mistake of changing observing systems without adequate overlap and evaluation.

TPOS-2020 involves CLIVAR PP members and will seek feedback from the PP as the observation plan progresses (due June 2016)

6. Western Boundary Currents (WBCs) and Indonesian Throughflow

Due to their energetic dynamics and ability to transport quickly large water volumes across latitude bands, the WBC have an important role within the climate system, inducing ENSO and subtropical/high latitudes. Over the past 10 years, regional CLIVAR coordinated programs allowed a great progress in their measurements and understanding, e.g. SPICE, NPOCE and ITF programs.

6.1. Main science questions:

6.1.1. What is the role of WBCs in the climate system

The three aforementioned programs were driven by the following science question: what role does the western boundary currents have on the climate system? Specifically, the following questions arose:

1. How much water and heat is transported towards the equator and the high latitudes?
2. How is the connection done, e.g. through the different WBC pathways?
3. How do model reproduce the transports and pathways?
4. How does this influence the background oceanic conditions and ENSO?
5. How does the WBC system control the warm pool and the warm water volume?
6. How are the water characteristics altered during the transit via the WBC pathways? What is the effect of the highly energetic mesoscale and submesoscale eddies?
7. How do the WBCs interact with the atmosphere and surrounding oceanic regions?
8. How do the low-latitude WBCs influence ENSO; how will they influence ENSO in the context of global warming? This can be declined into the role of the ITF, the MC and the NGCU that all supply the Warm Water Volume.

SPICE and NPOCE reported to the panel:

SPICE:

Accomplishments, ongoing and future activities were reported in a review paper by Ganachaud et al. (2014). Those include:

- A refined description of LLWBC pathways to the equator; the jets; EUC origins; seasonal and interannual variations; damping of spiciness anomalies and Solomon Sea circulation/inflows/outflows/partition
- The discovery of the TF/EAC interplay on the poleward pathways; improved TF/EAUC circulation; improved undertanding of the EAC extension behavior and impacts on ocean conditions
- Improved understanding of the southeastward tilt of the SPCZ in relation with SST, wind and rainfall

Main in situ operations finished; ongoing monitoring with moored array, gliders and XBTs

NPOCE

- in situ program continues and expands, including 19 deep ocean moorings deployed in 2014 in the West Pac
- MC and Kuroshio observations published (see Chen and Wu 2015)
- However, the Big Cross plan was not funded

Concerns were again raised about NPOCE data storage and distribution: little progress has been made besides repeated requests from CLIVAR; recent availability of specific time series on the NPOCE website remains far below expectations in terms of data management, secure long term storage and availability according to CLIVAR data policy.

6.1.2. What are the key dynamics that controls the variability in the Western Boundary Currents on eddy-to-basin scales?

Important gaps in our understanding of the dynamics themselves need to be addressed. Notably, we do not know what are the key dynamics that controls the multi-scale variability, including eddies. The deficiency of the Sverdrup theory to explain LLWBC dynamics (Yuan 2014) also needs to be elucidated.

6.1.3. What are the main drivers of the Indonesian Throughflow variability?

The Indonesian seas represent the only pathway that connects different ocean basins in the tropics, and therefore play a pivotal role in the coupled ocean and climate system. Here, water flows from the Pacific to the Indian Ocean through a series of narrow straits. Temperature, salinity and velocity depth profiles of the ITF are determined by intense vertical mixing within the Indonesian seas. This mixing results in the net upwelling of thermocline water in the Indonesian seas, which in turn lowers sea surface temperatures in this region by about 0.5 °C, with implications for precipitation and air–sea heat flux. Moreover, the depth and velocity of the core of the ITF has varied with the El Niño/Southern Oscillation and Indian Ocean Dipole on interannual to decadal timescales. Specifically, the ITF slows and shoals during El Niño events. Changes in the ITF alter surface and subsurface heat content and sea level in the Indian Ocean between 10 and 15°S. Inter-ocean exchange through the Indonesian seas serves as a feedback modulating the regional precipitation and wind patterns.

6.1.4. How to improve and sustain the monitoring of these currents?

ITF-TT: From 2012 to 2014, a CLIVAR task team was created to identify the scientific gaps of ITF knowledge and develop an integrated strategy towards an internationally sustained ITF Observing System. Two meetings took place, one in March 2012; then a capacity building workshop in Indonesia in January 2014; both were reported to the CLIVAR Pacific Panel and SSG. The ITF-TT and related programs include partners from LIPI, IPB, MGI, IOCAS, RCO, IRD-LEGOS, SIO, Japan. The ITF-TT provided a synthesis of past and ongoing mooring operations.

A component of ITF monitoring systems for the west Pacific and east entrance pathways to the Indonesian seas, the Pacific Gateway into Indonesia (PGI) is a NPOCE-driven program that has started. IOCAS engaged collaboration with Indonesian LIPI (Agreement 2014-2018) with cruises in 2014, 2015 and plans for 2016. The PGI leader D. Yuan expressed concerns with data management and sharing given the reluctance from LIPI to make data available (data has to be publicly available "in a timely manner" an QC and stored for future generations to ensure true progress). While an endorsement from CLIVAR would be helpful, given the lack of data management plan and data availability currently occurring with NPOCE, it is too early to submit endorsement such a new, NPOCE driven program.

Coordination amongst the different WBC/ITF ongoing programs:

SPICE, NPOCE and ITF occurred as process studies under the umbrella of CLIVAR and are now oriented towards monitoring. A Pacific WBCs nature review article was published, as well as SPICE and ITF review articles, but as of today, data is not yet available to start comprehensive studies allying all WBC components. The CLIVAR PP has been promoting coordination of those for the past 5 years.

In parallel, TPOS-2020 started a Western Boundary Current coordination group that includes PP members (A. Ganachaud, D. Yuan), past members (K. Ando) and ITF-TT leader (J. Sprintall). The TPOS-2020 experiments consider that LLWBC measurements are part of their scope. It was propose to create a single WBC group that includes PP and TPOS members to optimize efforts, benefit of overlap and avoid duplications of advisory groups. This group will provide expert feedback on both TPOS-2020 and CLIVAR PP (+IOP). While TPOS-2020 scope is limited to LLWBCs, CLIVAR scope will include higher latitudes, but restricted to the west Pacific (East Pacific is a different context, tackled by the TPOS-2020 East Pacific Task Team). This group will also benefit from the constrained TPOS-2020 deadlines to provide timely input the TPOS science plan. See "action items" below.

6.2. Main questions for the next 5 years:

- What are the three-dimensional structure and variability of the Pacific low latitude western boundary currents?
- How does WBC water connects with the equator? How does this modulate ENSO?
- How does the western Pacific Ocean circulation interacts with the ambient current systems (ITF, SCSTF, tropical-extratropical exchange, etc.)?
- How are the warm pool and the Asian monsoon system affected by the variability of the western Pacific Ocean circulation?
- How much vertical and horizontal mixing occurs on the way ?
- What are the characteristics and impact of submesoscale is these highly energetic regions?

6.3. Proposed action items and recommendations:

- (A. Ganachaud): to seek coordination for data availability and analysis with NPOCE, ITF and TPOS-2020, propose a WBC coordination group structure to both TPOS-2020 and CLIVAR SSG (done as of Jan 2016; starting co-chairs are K. Ando and A. Ganachaud, then replaced by J. Sprintall for ITF-TT legacy).
- NPOCE to report to PP about NPOCE data management: long term storage, processing, formats (ref to GO-SHIP and OceanSites) as well as distribution and sharing (internal to NPOCE and public). (Xiaopei Lin)
- After the NPOCE data issue is resolved, write a proposal to be submitted to CLIVAR to formalize the PGI project (DY)
- (B. Kessler): report to PP after TPOS SSG Oct 13-15 2015; solicit PP and ENSO RF for feedback
- (D. Yuan) Contact Indonesian scientists to foster collaboration (invite to next panel meeting)

Appendix A: Agenda and Rapporteur

Day 1 Saturday, Oct 10th

9:00---9:10 Welcome/organization/scope (*Alex/Matt*)

Remind main past actions:

- Review papers (Cai etc)
- Main science topics
  - WBC
  - SPCZ
  - ENSO
- Ocean observations: SPICE, NPOCE, OKMC, ITF via ITF-TT (?KIOST projects)
- Platform for coordination and data sharing

New questions and focus (Implementation of grand challenges)

- Low frequency variability forced versus internal variability
- Regional sea level
- And more !

Objective of each discussion (rapporteurs):

1. identify big science questions for the next 3-5 years
2. identify actions that can be done as a community
3. foster collaboration, information and data exchange

Session 1: Opportunity for new challenges within PP

09:10---09---30: Pacific Decadal Variability/Hiatus (*Mat, Boris*) (rapporteur: Antonietta)

What are the main characteristics of decadal natural variability in the Pacific?
What are their related mechanisms ?
How do these natural variations relate to the recent hiatus ?

09:30---09:50: Pacific regional sea---level changes: Insights from observations (*Tatsuo*) (rapporteur: Alex)

What are the available observational tools regarding Pacific sea level variability?
What are the major natural decadal sea-level patterns in the Pacific ?
What are the major uncertainties ?
How do they alias the sea-level anthropogenic pattern?
Could the sea level observing system in the Pacific be improved ?

09:50---10:10: Pacific regional sea---level changes: Model projections (*Mat/Mat*)
(rapporteur: Alex)

What are the predicted regional sea level changes in the Pacific for the 21st century?
What are the major CMIP model biases in terms of sea level variability ?
What are the impact of the CMIP models biases on these predictions ?

10:10-- - 10:30: Vulnerability and training (*Awnesh*) (rapporteur: Billy)

10.30-- - 11.00: Coffee Break (30min)

11:00---11:20 First general discussion on new challenges to include in PP agenda (*Xiaopei /Matt, Alex*) (rapporteur: Wang Jin)

Amongst all the topics discussed above and given our limited availability, what shoudl the PP priorities regarding new PP research challenges (aside Pacific observing system design, ENSO research and WBC dynamics) in the coming years?

Session 2: Observation programs: status and future plans

11.20---11.40: West: SPICE (*Alex*) (rapporteur: Xiaopei)

How does water connects with the equator?
How does this modulate ENSO?
How much vertical on horizontal mixing on the way ?

11.40---12:00: West: NPOCE (Dr. Wang Jing -- Dongliang) (rapporteur: Tatsuo)

What are the three-dimensional structure and variability of the Pacific low latitude western boundary currents?
How does the western Pacific Ocean circulation interacts with the ambient current systems (ITF, SCSTF, tropical-extratropical exchange, etc.)?
How are the warm pool and the Asian monsoon system affected by the variability of the western Pacific Ocean circulation?

12:00---12.20: WBC dynamics (*Xiaopei*) (rapporteur: Dongliang)

What is the key dynamics that controls the multi-scale variability in the WBCs?
What is the role of WBCs in the open ocean-marginal sea exchange and air-sea interaction?
How do the WBCs response and affect global climate change?

12:20---14:00 Lunch

Session 2: Observation programs: status and future plans (cont')

14.00---14.20: Basin scale: Paleo records (*Kim*) (rapporteur: Mat)

What are the currently available proxy data in the Pacific for climate studies?
To which extend can they be considered as representative of a climate mode such as ENSO?
What paleo proxies can be used to study the spatial evolution of ENSO?

14.20---14:40: Basin scale: TPOS---2020 (*Billy*) (rapporteur: Agus)

What is the current status of TPOS?
What are the next milestones?
What are TPOS expectations from PP?

14:40---15.00: East: Peru including TPOS---eastern TT (*Ken/Boris*) (rapporteur: Lei)

What are the main discussions within TPOS-eastern TT ?
What are the major observing programs at IMARPE and at InstitutoGeophysico del Peru ?

15.00--15:20: East: Chile (Wolfgang) (rapporteur: Lei)

What are the major observing programs at IMO and at Univ. Of Concepcion ?
What are the major science challenges that can benefit from CLIVAR synergies?

15.30---16.00: Coffee Break

Session 3: Opportunity for new challenges within PP

16:00---16:20: ITF plans (Alex/Dongliang) (rapporteur: Ken)

ITF TT: follow-ups and plans (*Alex for Janet Sprintall & Ariane Koch-Larrouy)*
PGI (*Dongliang/Dr. Wang Jing*)

16:20---16---40: Southeast Pacific variability(*Boris/Wolfgang*) (rapporteur: Mat)

What are the major science challenges that can benefit from CLIVAR synergies?
What are the observations planned and needed?

16.40-17.00: West: Coordination including TPOS WBCs (*Alex/ Xiaopei/ Dongliang*) (rapporteur: Billy)
How do we coordinate science and data between SPICE, NPOCE, etc
How and when do we make data available to the community
After SPICE and NPOCE: a WBC observing system including ITF?

17---00---17---30: PP feedback on CLIVAR Science Plan (Boris) (rapporteur: Xiaopei)
19.30-- - 22.00: PP diner (no host)

Day 2: Sunday, Oct 11th

Session 4: ENSO

09:00---09:10: Recap day 1 and aim of ENSO session (Alex/Mat)

09:10---09:30: ENSO PP: Relation with ENSO RF and IOP (*Mat*) (rapporteur: Cai)
Presentation on ENSO related work in ENSO RF and IOP

09:30---09---50: ENSO extreme (*Agus/Cai*) (rapporteur: Awnesh)
What are the characteristics of ENSO extreme events ?
How should they be defined ?
Do they display specific mechanisms ?
How predicatable are extreme ENSO events ?
What are the oceanic and atmospheric teleconnections of extreme ENSO?
How are these peculiar events represented in CMIP models ?

09:50---10---10: ENSO diversity (*Antonietta*) (rapporteur: Ken)
What are the characteristics of ENSO CP/EP events ?
How should they be defined ?
What are the EP/CP specific mechanisms ?
Is ENSO Modoki a truly independent mode of variability?
How predicatable are these two types of events ?
What are the oceanic and atmospheric teleconnection of CP/EP ENSO?
How are these two types events represented in CMIP models ?

10:10---10---30: Interbasin interactions (*Mat/Dongliang*) (rapporteur: Kim)
What is the impact of the extra-tropical Pacific on ENSO?
What is the impact of Indian Ocean variability on ENSO?
What is the impact of Atlantic variability on ENSO?
If any, does it occur through an oceanic or atmospheric pathway ?
How these interbasin interactions are simulated in CMIP models ?
What is the best modelling strategy to further progress on this question ?

10.30---11.00: Coffee Break (30mn)

Session 4: ENSO (cont')

11:00---11---20: ENSO variability at paleo timescales? (*Kim*) (rapporteur: Mike)
What do we know about ENSO variations on paleo timescales?
What are the related uncertainties?
Does models agree with proxy data for the different climate ?

11:20---11---40: ENSO predictability (*Ken*) (rapporteur: Agus)

What is the current accuracy of ENSO prediction from statistical/coupled models ?
What are the impact of dynamical model drift/biases on ENSO prediction?Can a better data management allow to initialize more efficiently ENSO dynamical forecasts?
Could we estimate the credibility of ENSO forecasts in real-time using a mechanistic approach?

11:40---12:00: Main ENSO topics to be addressed by PP (*Cai*) (rapporteur: Antonietta)

Amongst all the topics discussed above and given our limited availability, what should the PP priorities regarding ENSO research in the coming years?

12:00---13:00: Business as usual (next meeting, membership, etc…) (Lei,Mat/Alex)
(rapporteur: Lei)

13:00: Excursion

20:00: direct return to airport

Appendix B: List of attendess

Panel members	Role	Term	Institution	Country
Alexandre Ganachaud	Co-Chair	2015	LEGOS	France
Matthieu Lengaigne	Co-Chair	2017	LOCEAN	France
Kim Cobb	Member	2016	Georgia Institute of Technology	USA
Wenju Cai	Member	2015	CSIRO	Australia
Billy Kessler	Member	2016	NOAA/PMEL	USA
Xiaopei Lin	Member	2016	Ocean University of China	China
Dongliang Yuan	Member	2016	IOCAS	China
Agus Santoso	Member	2017	University of New South Wales	Australia
Ken Takahashi	Member	2017	Instituto Geofisco del Peru	Peru
Awnesh Singh	Member	2017	University of the South Pacific	Fiji
Tatsuo Suzuki	Member	2017	JAMSTEC	Japan
Wolfgang Schneider	Member	2017	Millennium Institute of Oceanography	Chile
Michael McPhaden	Ex officio		NOAA/PMEL	USA
Lei Han	ICPO staff		First Institute of Oceanography	China
Guest attendees				
Guojiang Wang	with Wenju		CSIRO	Australia
Jing Wang	with Dongliang		IOCAS	China
Antonietta Capotondi			University of Colorado	USA
Ali Belmadani			University of Concepcion	Chile
Boris Dewitt	CLIVAR SSG co-chair		LEGOS	France

Group Photo of attendees