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Pacific Region Panel Report

CLIVAR SSG 21

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Table of Contents

1. Highlights

Highlight your Panel/WG's achievements over the last 10 years in terms of advances in understanding, climate model development, observing system development, data sets, analyses, etc., with summary text, key figures and references. This material will contribute to a comprehensive review of CLIVAR achievements that will be produced in 2014, the first draft of which will be presented at the pan-CLIVAR meeting.

Highlights are tentatively presented according to scales: climate models – ENSO (teleconnections) – hiatus – process studies – observing systems and coordination

1.1. Benchmarking climate models for Indo-Pacific variability

(WC) The Indo-Pacific is home to major modes of climate variability, the El Niño-Southern Oscillation, and the Indian Ocean Dipole. Extreme El Niño events, as occurred in 1982/83 and 1997/98, cause global disruption of weather patterns and affect ecosystems and agriculture through changes in rainfall. The issue of how the frequency of extreme El Niño will change under global warming has challenged scientists worldwide. Extreme El Niños is associated with a dramatic shift of atmospheric convective zone to the eastern equatorial Pacific, leading to large rainfall anomalies. In association, the response of rainfall to sea surface temperature anomalies is nonlinear such that there is positive rainfall skewness in the eastern equatorial Pacific. Thus, these characteristics may be used to benchmark climate models: (1) skewness and (2) ability to produce extreme rainfall response in the eastern equatorial Pacific (Cai et al. 2014a). Similarly, extreme positive Indian Ocean Dipole, as occurred in 1961, 1994 and 1997, causes devastating floods in eastern African but severe drought an bushfires in countries surrounding the eastern Indian Ocean (Cai et al. 2014b, Cai et al. 2013). In the eastern Indian Ocean, cold SST anomalies attain a greater amplitude than the warm ones, indicating that positive Indian Ocean Dipole events tend to be greater than negative Indian Ocean Dipole events. During such positive events, the cool anomalies and the associated subsidence in the eastern Indian Ocean extend westward along the equator, pushing the convergence downstream further west toward the eastern Africa, leading to floods in east African countries. This westward extension is additional to that represented by the conventional Indian Ocean Dipole index. The negative SST skewness in the eastern Indian Ocean and the westward extension of cool and dry anomalies along the equator are features that can be used to select models for studying the response of extreme positive Indian Ocean Dipole events, which is characterized by an increase of a factor of three in the frequency of extreme Indian Ocean Dipole events (Cai et al. 2014b).

1.2. Southwest Pacific climate change, ocean circulation and food security

(AG) The fish and invertebrates harvested from the tropical Pacific Ocean and the coastal waters of the region, and the ecosystems that support these species intimately on the oceanic environment. Large- and small-scale circulation patterns influence larval dispersal and the migration of species; water temperature, salinity, nutrient availability, dissolved oxygen concentration and pH affect biological activity; and oceanic currents, waves and sea level shape coastal habitats. Together, these properties of the tropical Pacific Ocean have a profound effect on the productivity of oceanic and coastal fisheries, and coastal aquaculture. Understanding how these features of the ocean vary on different timescales is one of the primary keys to managing and forecasting production from the fisheries sector. To respond to the demand of Pacific Island governments and provide a scientific basis for adaptation and planning, the Secretariat of the Pacific Community (SPC) edited a comprehensive scientific review, involving CLIVAR scientists (Bell et al, 2011a). The 922-page book included 13 chapters, each reviewing the state of knowledge on the past, present, and projected changes of different aspects, from basic physical climate changes to ocean food webs, freshwater fish, corals, and societal responses. A Nature article summarizes the book results (Bell et al, 2013). An additional country-per-country report was written to facilitate usage by governments (Bell et al, 2011b). Two chapters address physical atmosphere and ocean of the Southwest Pacific (Lough et al. 2011, Ganachaud et al. 2011); the corresponding analysis CMIP3 was published separately (Ganachaud et al 2012, Sen Gupta et al 2012, Brown et al 2012); several workshops were organized with Pacific Island country governments and fisheries to promote communication between scientists and decision makers.

1.3. SPCZ

(ML) The South Pacific Convergence Zone (SPCZ), which extends more than 8000km from Papua New Guinea to Tahiti, represents the largest perennial rainfall feature in the Southern Hemisphere. Owing to its strong rainfall gradient, a small displacement in the position of the SPCZ causes drastic changes to hydroclimatic conditions and the frequency of extreme weather events experienced by vulnerable island countries in the region. Owing to its climatic relevance, substantial efforts have been devoted to improve the SPCZ description and understanding over the past four years within our Panel-related activities. The interannual SPCZ displacements has first been shown to strongly differ depending on the characteristics of El Nino events: while it moves a few degrees in latitude during moderate El Niño events, the SPCZ undergoes an extreme swing and collapses to a more zonally oriented structure during strong El Niño events (Vincent et al. 2009). Aside from its severe weather impact across the Pacific island nations, this commensurable SPCZ shift may also drive the abrupt termination of strong El Niño events (McGregor et al. 2012, 2013). Identification of the SCPZ response to global warming usually rely on the analysis of CMIP models that generally display overly zonal SPCZ (Brown et al. 2012). These simulations along with unbiased experiments indicate a very robust increase in the frequency of these extreme SPCZ displacements during the XXI century (Cai et al. 2012). But CMIP model uncertainties in rainfall are usually greater in the mean state than in anomalies in the tropical Southwest Pacific (Brown et al. 2012, Widlansky et al. 2013). Removing mean biases however results in an overall northeastward shift of the SPCZ for the late 21st century which leads to a summer drying in vast areas of the South Pacific (Widlansky et al. 2013).

1.4. ENSO

1.4.1. Major advances in ENSO research (CP/EP El Ninos):

(SWY-MM) The diversity of El Niño has received increasing attention over the last decade because of the frequent emergence of a different type of El Niño, named "Dateline El Niño," "El Niño Modoki," "Warm Pool El Niño," and "Central Pacific El Niño" (Larkin and Harrison, 2005; Ashok et al. 2007; Kao and Yu, 2009; Kug et al. 2009). These El Ninos have different characteristics compared to "conventional" El Nino. This is very important in terms of atmospheric teleconnections from the tropics to the midlatitudes in both Hemispheres (Weng et al., 2007, Di Lorenzo et al., 2010, Graf and Zanchettin 2012), and can thus lead to large differences in ENSO impacts in the high latitudes (Kim et al., 2009, Lee et al., 2010, Yu et al., 2012). So far, investigations of observations, ocean reanalysis, and climate models has some agreement to some extent that different dynamical terms such as thermocline feedback, zonal advective feedback, and surface heat flux damping may be more effective at different locations along the equator and their relative role may vary in each El Nino event. Thus, differences among events can be viewed as the diverse expressions of the complex, multi-faceted, and evolving ENSO phenomenon (Capotondi et al., 2014).

1.4.2. Effects of greenhouse gas forcing on ENSO (See also ENSO in a warming world RF)

(MC) The IPCC AR5 concluded that "El Niño-Southern Oscillation very likely remains as the dominant mode of interannual variability in the future and due to increased moisture availability, the associated precipitation variability on regional scales likely intensifies….. natural modulations of the variance and spatial pattern of El Niño-Southern Oscillation are so large in models that confidence in any specific projected change in its variability in the 21st century remains low." This statement builds on a number of Panel-related activities including the review of Collins et al. (2010) which, in turn, builds on a large number of theoretical and modelling studies (see references in that paper). One notable advance has been in the definition of a number of standard metrics that may be used to evaluate climate models (e.g. Guilyardi et al., 2009). These have been developed, in part, during a series of ENSO workshops spearheaded by Eric Guilyardi discussing ENSO in climate models. Even in the short time since AR5 there have been a number of new studies that point to more robust findings about future changes in ENSO. Santoso et al (2013) and Cai et al (2014a) find a tendency for larger ENSO events in the future when examining the east-west propagation characteristics of ENSO events and when re-casting an ENSO event in terms of a massive reorganisation of tropical Pacific precipitation respectively. Power et al. (2013) and Chung et al. (2013) also find an emerging robust signal of ENSO precipitation teleconnections moving eastward across the topical regions and intensifying. Verifying such projections against observations remains a challenge due to signal-to-noise issues but further work in the physical understanding of model results is underway in order to test robustness.

Finally, the ratio of central Pacific El Nino to Eastern Pacific El Nino type events is increased in both the CMIP3 and CMIP5 model simulations under global warming scenarios (Yeh et al. 2009, Kim and Yu 2012). However, it is difficult to evaluate the mechanisms to lead this change under global warming.

1.4.3. Role of the tropical Pacific in sequestering heat associated with the hiatus in global warming

(MC, WC, XL) Scientists have yet to fully explain the recent slowdown in air-temperature increases. Although cool surface waters in the eastern and central Pacific Ocean have been identified as a key component of this feature, it has so far been unclear how this occurs. England et al. (2014) investigates how strengthened Pacific trade winds can account for 0.1–0.2°C cooling — much of the temperature slowdown — through increased subsurface ocean heat uptake. They show that when the model is forced by the strengthening winds, the sea surface response matches observed trends. The study backs up the results of Kosaka and Xie (2013) in which SSTs in the tropical Pacific were relaxed to observed SSTs in a coupled model. The shallow overturning circulation loops are sped up by the intensified winds, causing increased equatorial upwelling of cool waters and the subduction of warm water, or heat drawdown, to the subsurface layer. England et al. (2014) find that around 80% of the surface temperature cooling occurred after 2000, indicating that wind acceleration is a key contributor to the slowdown in warming. These findings suggest that if the stronger trade winds continue, the slowdown in warming will persist, but if they lessen there will be a return to rapid warming. The strengthening of the wind along the equatorial Pacific is amplified by warming in the Atlantic (McGregor et al, 2014). The differential warming among the Indian and Pacific basin could also contribute to strengthen the Pacific trade winds (Kim et al. 2014). Recent works also show the importance of heat intake in deep Atlantic and Southern Ocean layers (Chen and Tung, 2014).

1.4.4. ENSO-IOD relationship

(DY, WC, ML) The Indian Ocean Dipole (IOD) events, characterized by anomalous cooling in the southeastern tropical Indian Ocean and warming in the west, is believed to be forced by the atmospheric Walker Circulation variations associated with ENSO. However, some of the IOD events are found not to be accompanied by ENSO events, suggesting independent Bjerknes-type ocean-atmosphere coupling in the tropical Indian Ocean (Yamagata et al. 2003). Yuan and Liu (2009) have shown that the western and eastern boundary reflections play an important role in the termination of the IOD events. Nagura and McPhaden (2013) suggest that the IOD evolution is partly in agreement with the discharge-recharge paradigm of ENSO. Cai et al. (2013) project that the overall frequency of the IOD events is not to change under global warming, but a reduction in the difference in amplitude between positive and negative dipole events is expected. More studies are needed to understand the coupled dynamics of the IOD either influenced by ENSO or not. 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. Lag correlation analyses have suggested that about half of the cold tongue SSTA variability can be predicted at the one-year lead when the Indian Ocean Dipole Mode Index and the warm water volume in the western equatorial Pacific Ocean are used as precursors (Izumo et al. 2010, 2014). The dynamics have been suggested to be through the Walker Circulation variations over the Indo-Pacific Ocean. Analyses of both observational and numerical experiment data have suggested that IOD can be used as a precursor for ENSO prediction across the "Spring Barrier" at the one-year lead time (Izumo, et a., 2010, 2014; Yuan et al., 2011). Lag correlation analyses by Izumo et al. (2010, 2014) suggest that about half of the cold tongue SSTA variability can be predicted at the one-year time lead when using surface IOD and subsurface ENSO indices as precursors. The Indonesian Throughflow, under strong influence of the Indian Ocean Dipole, was also found to provide significant ENSO predictability (Yuan et al., 2011), with SSTA in the southeastern tropical Indian Ocean predicting ENSO at one-year lead (Yuan et al., 2013; Xu et al., 2013).

1.5. WBC and SST warming pattern

(XL, WC) The long term SST warming is uneven, both in regions and seasons. In the Ocean, outside of polar regions, accelerated warming is found along two latitudinal bands, roughly 25-40 degree, and peaks in the western boundary current (WBC) regions (Deser et al. 2010, Wu et al. 2012). The post-1900 SST warming rate over the path of WBC is two to three times faster than the global mean surface ocean warming rate and enhanced during winter, suggesting a major role of ocean dynamics in shaping SST warming patterns along WBC, while atmospheric processes make some contributions (Zhang et al. 2010, Yeh and Kim 2010). The accelerated warming is associated with a synchronous poleward shift and/or intensification of global subtropical western boundary currents in conjunction with a systematic change in winds over both hemispheres (Cai et al. 2010, Wu et al. 2012). A dynamical framework that links the western boundary current to global warming has been explored in both hemispheres (Cai et al. 2005, Yang et al. 2013, Sun et al. 2013).

1.6. Process studies

1.6.1. SPICE

(AG) The Southwest Pacific Ocean Circulation and Climate Experiment (SPICE) objective was to understand the southwest Pacific Ocean circulation and the SPCZ, as well as their influence on regional and basin-scale climate. South Pacific thermocline waters are transported in the westward flowing South Equatorial Current (SEC), from the subtropical gyre centre toward the southwest Pacific Ocean, creating a major circulation pathway that redistributes water from the subtropics to the equator and to the Southern Ocean. A major part of SEC waters enters the Southwest Pacific area, with its numerous Islands and straits. This transit in the Coral, Solomon and Tasman Seas is potentially of great importance to the climate system. Changes in either the temperature or the amount of water arriving at the equator have the capability to modulate ENSO, while the southward pathways influence climate and biodiversity in the Tasman Sea. The concept of a coordinated experiment in the Southwest Pacific started during a workshop in 2005 (Cairns, Australia), which led to the development of a science plan and endorsement by CLIVAR in 2008 (on clivar.org). Over the past six years, substantial efforts have been devoted to improve understanding of this region, through in situ oceanic observations, modeling, as well as remote sensing and comprehensive analyses of historical data. Many aspects have been addressed through SPICE-coordinated projects: heat and mass transports; properties and dynamics of the strong boundary currents and jets; water mass transformations and SPCZ behavior. More information and references are on http://spiceclivar.org and in two recent review papers: Ganachaud et al. (2013, 2014). Two hydrographic cruises – Pandora (July 2012) and MoorSPICE (March 2014) – have been undertaken as part of SPICE, that included mooring deployments designed to directly capture the various streams of the WBC that flow through the Solomon Sea toward the equator. A capacity-building workshop focused on practical hands-on training of students was held in Port Moresby, Papua New Guinea, November 2013.

1.6.2. NPOCE

(DY) The Northwestern Pacific Ocean circulation and climate (NPOCE) aims at better understanding the WBCs and their relations and impact with the ocean-atmosphere system in this area. After the successful Open Science Symposium on Western Pacific Ocean Circulation and Climate in October 2012 in Qingdao, China, two new 973 projects were approved by the Chinese MOST to study "Processes and mechanisms of multi-scale marine variability in the Northwest Pacific and its predictability" (led by Lixin Wu, 2013-2017) and "Mechanisms of upper ocean response to and modulation on typhoon" (led by Dake Chen, 2013-2017). In 2013, a new project called the Strategic Priority Project of the Chinese Academy of Science was established to study the northwestern Pacific Ocean circulation and climate.

The project will deploy scores of subsurface moorings in the key strategic sections of the western boundary currents and the main equatorial currents to measure the seasonal to interannual variations of these currents for better climate predictions. The project has been funded for the period of 2013-2017. The mooring arrays will be deployed in the summer of 2014 to cover the strategic key sections in the western Pacific Ocean and the Indonesian seas. In 2013, the Korean *Poseidon* project has replaced the moorings in the North Equatorial Current. The Korean *GAIA* project has deployed subsurface ADCPs on the TAO moorings along the 165°E section at 2° N, 5°N, and 8°N to monitor the subsurface currents. Japan has carried out a cruise in the west Pacific Ocean in early 2013 to conduct measurements along 8°N, and 130°E on its way to maintain the TRITON arrays near the equator. Given the fast progress, the NPOCE SSC met in August in Lijiang to summary the progress and to discuss adding two working groups of biogeochemical study and numerical modeling under NPOCE SSC (NPOCE SSC meeting minutes, available on http://npoce.qdio.ac.cn)

1.6.3. ITF programs (CLIVAR Indonesian Throughflow Task Team)

(JS) Sustained observational and modeling efforts are needed in the marginal Indonesian Seas to provide insight into the long-term behavior and the response of this complex region to future climate change. Under joint recommendation from the CLIVAR Pacific and the Indian Panels, and the Asian-Australian Monsoon Panel, an Indonesian Throughflow (ITF) Task Team was formed in 2011. The overarching objective of the ITF Task Team is to identify the scientific gaps in our knowledge of the ITF and develop an integrated strategy towards an internationally sustained ITF observing system. Achievements of the Task-Team to date include an international workshop held March 2012 in Jakarta leading to the co-ordination of many international science and implementation plans for ITF studies; A Progress Article in Nature Geosciences that has been recommended for publication after some minor revision (Sprintall et al., 2014); and a capacity building workshop held January 2014 in Bandung, Indonesia to train regional scientists and students with interests in the ITF and directly engage them in the use of data and tools for monitoring the ITF. The ITF-TT is continuing to engage the international observational community to integrate at least some elements of an ITF observing system into TPOS-2020 (see below).

In the ITF region, sustained measurements are presently maintained by individual researchers in the Makassar inflow and the Lesser Sunda Island outflow passages of Ombai Strait and Timor Passage. Other discrete moorings in individual passage are planned for deployment by the Chinese Academy of Sciences (2013-2018). An observational measurement system to understand what controls the Pacific inflow into the Indonesia seas is the primary missing element of the present ITF monitoring array, and the proposed international Gateway program has targeted three key regions for study: 1. the Mindanao Current; 2. the Mindanao/Halmahera eddies/retroflection and 3. the Northeast Seas of Indonesia. International participants are from China, Japan, Korea, Indonesia and the USA. Components of Gateway include mooring deployments as well as hydrographic surveys with a focus of understanding the role of mixing in water mass formation and transformation within the Indonesian seas.

1.6.4. OKMC

(BQ) The objectives of the Origins of the Kuroshio and Mindanao Currents (OKMC) program are to clarify the time-varying dynamic state of the NEC-Kuroshio-Mindanao Current system, to quantify the temporal evolution of the upper ocean temperature and salinity fields, the seasonal mixed layer above the pycnocline, and the deeper mode and intermediate waters, and to improve the predictability of the oceanic circulation variability on various timescales in the western North Pacific Ocean. The program in-situ measurements have included gliders, surface drifters, surface moorings, profiling floats (SOLO-II and EM-APEX) and other R/V-based measurements. Complementary tools included satellite altimetry product, eddy-resolving OGCMs, and data assimilating experiments. At present, all field observations have concluded, with the exception that 37 SOLO-II profiling floats are still returning temperature-salinity-pressure data and functioning as part of the International Argo Program. Several studies based on the OKMC data have been published and/or under review, with topics ranging from NEC bifurcation variability, sub-surface multiple eastward jets beneath the NEC, Kuroshio variability inside the Luzon Strait, to Kuroshio-mesoscale eddy interactions along the Pacific western boundary. The program is proposing to organize a special issue summarizing the OKMC science results in JGR-Oceans.

1.6.5. POSEIDON/GAIA/TIPEX

(SWY) The Korea Institute of Ocean Science and Technology (KIOST) ship observation is currently going on understanding the mixing parameterization around the thermocline depth in the western tropical Pacific in the GAIA project. In addition, the zonal currents are monitored by the ADCP at TAO buoy site (165°E line, 2°N, 5°N, 7°N). This ADCP monitoring will be extended to 2°S in the near future in the GAIA project. The POSEIDON project will be finished in this year (2014) and it is found that the North Pacific subtropical Counter Current exits in the observation systems in the POSEIDON project. The TIPEX project is about to start in the next year (2015) and will focus on observing the ITF along with the ITF Gateway program.

1.7. Observing Systems

1.7.1. TPOS-2020

(BK, KA) A Tropical Pacific Observation System (TPOS) conference was held in Scripps Institution of Oceanography during January 27-30, in response to TAO defection and a white paper initiated by the Pacific Panel. The conference was sponsored by OOPC, NOAA, JAMSTEC, KIOST and SOA. The fourteen White Papers discussed and reviewed requirements, operational forecasting and scientific issues, implementation, and logistics (www.ioc-goos.org/tpos2020). Nine organizations interested in TPOS were represented. In the workshop, we discussed new scientific requirements for observation, and heard enthusiastic opinions. The workshop concluded by creating the TPOS-2020 project, loosely under GOOS, described in the Workshop Report as "The review recommends the creation of a TPOS 2020 Project to achieve the major change from a loosely coordinated set of ocean observing activities in the tropical Pacific to a systematic, sustained TPOS by 2020."

The goals of the project is to,

1) monitor, observe, define the state of ENSO and advance scientific understanding of its causes,

2) support observation and prediction systems for ocean and weather and climate services of high societal and economic utility,
3) advance and refine the degree to which the tropical Pacific (physical and biogeochemical) and its climate impacts are predictable
4) determine how inter-annual to multi-decadal variability and human activities impact the relation between marine biogeochemistry and biology to carbon budgets, food security and biodiversity.

1.7.2. Monitoring LLWBCs with gliders

(BK) The low-latitude western boundary current (LLWBC) in the South Pacific, precisely the New Guinea Coastal Undercurrent (NGCU) is a key element of the inflow that brings extratropical water to the equator. Estimates from water properties and models suggest that more than half the water of the equatorial thermocline comes through the Solomon Sea LLWBC system, but direct measurements of the NGCU have been difficult to obtain. The current is narrow, close to the coast, remote from transport and without nearby infrastructure. Since 2007, collaborators from Scripps and PMEL have implemented regular ocean glider sections across the NGCU, although typical current speeds are larger than the glider's speed. Initially about 4 sections/year were obtained; with experience and technical improvements to the Spray gliders, 10-12 coast-to-coast sections/year are now made. Annual and interannual variability can be clearly defined, each with fluctuations of about ±8Sv on a mean of about 20Sv. Maximum annual transport is in July, and interannual fluctuations lag central Pacific ENSO indices by about 3 months, with larger transport following El Nino events. Most of this low-frequency variability occurs in the central Solomon Sea as a direct inflow from the South Equatorial Current, rather than in the narrow, subsurface western boundary current.

1.8. Coordination

1.8.1. Meetings involving or co-organized by the PP

- **10ICSHMO, New Caledonia, 2012**. Since its advent in 1983, the International Conference on Southern Hemisphere Meteorology and Oceanography (ICSHMO) conferences have provided a unique contribution to ocean and atmosphere sciences that are specific to the Southern Hemisphere. The objective of the 10th ICSHMO (http://www.colloque.ird.fr/icshmo-2012/) was to provide an interdisciplinary forum for presentations of our current state of knowledge, as well as motivating new research and applications within the variety of disciplines related to weather and climate of the ocean and atmosphere. This was also the first ICSHMO conference conducted in a Pacific Island state. 10ICSHMO was a great success; with over 325 attendees from countries across the southern hemisphere, as well as many key attendees from the boreal half of the planet, the 10ICSHMO held a total of 17 sessions covering the breadth of oceanic and atmospheric science with paper and poster presentations ranging from tropical cyclones, ocean observations, climate variability and the South Pacific Convergence Zone; to special sessions on data rescue and management, and climate change and related science work in developing nations in the Pacific Islands region. The conference benefitted from an extremely diverse set of attendees that including academics, scientists from large national agencies, and most encouraging young scientists and students, and up and coming scientists from developing nations. The papers and posters were of extremely high quality, but even more vital was the great exchange of information that took place in the hallways, buses to and from the hotels, and social events. Attendees are already looking forward to the 11th ICSHMO (Santiagao, Chile, Nov 2015).

- **OSS, Qingdao, 2012**: To highlight recent advances and to enhance scientific coordination of SPICE and NPOCE (see above) and other related activities, an Open Science Symposium on Western Pacific Ocean Circulation and Climate (OSS) organized under the auspices of CLIVAR/WCRP was held on October 15-17, 2012 in Qingdao, China, and was attended by about 200 participants from 13 countries with about 120 papers presented (50 oral, and 70 poster). New findings in understanding ocean circulation and climate in the western Pacific Ocean were presented, covering a wide-range of areas including the bifurcation dynamics, decadal fluctuations of the circulation system, climatic impacts, implications for climate change, and needs for sustainable observations and model improvements. The OSS also identified knowledge gaps and scientific issues for future studies.

- **International Symposium on Boundary Current Dynamics**
  First symposium, Qingdao, China, May 31-June 2, 2010
  Second symposium, Lijiang, China, July 8-9, 2013:
  To synthesize understanding and discuss future research forefronts in boundary currents and coastal processes within the context of global climate changes, this symposium series was organized by Physical Oceanography Laboratory, Ocean University of China. The first symposium (2010) was about "boundary current: its connection with open-ocean and coastal processes and responses to global climate" and gathered more than 100 scientists and students. The second symposium (2013) was about "boundary currents: connection with open-ocean, coastal processes, biophysical interactions and responses to global climate change" and gathered more than 200 scientists and students from 18 countries and regions. A new Joint CLIVAR/PICES Session of 'Biophysical interactions' was added in the second symposium. Three scientific questions were addressed in these symposiums:
  1- What are key processes that determine variability of boundary currents in the tropical-subtropical ocean basins? How do climate changes affect these processes? How does boundary current variability affect climate?
  2- What are the main dynamic processes that govern interactions of the marginal sea system with boundary currents and open ocean? How does climate variability affect such interactions and how physical and biological states in coastal seas respond?
  3- How does ocean respond to and feed back onto climate change? How to improve the decadal and longer timescale predictability of the climate system?

1.8.2. JGR SPECIAL ISSUE on Western Pacific Ocean Circulation and Climate

A JGR SPECIAL ISSUE on Western Pacific Ocean Circulation and Climate will be finalized this year (Guest editors: D. Hu, A. Ganachaud, W. Kessler, J. Sprintall and W. Cai). The issue stimulated the coordinated publication of results from NPOCE, SPICE and ITF programs, and more. Since the end of TOGA-COARE in early 1990s, there had been no large scale field observations in the western Pacific Ocean including the low-latitude western Pacific until 2008, when SPICE was endorsed by CLIVAR, soon followed by NPOCE (2010). With the two programs, out of which many new results have emerged from observations, modeling, and data analysis, a new era of ocean circulation and climate study in the western Pacific Ocean has arrived. This special issue entitled "Western Pacific Ocean Circulation and Climate" is mainly sourced from papers presented at the OSS. At present, we have 52 intended papers (see attached a tentative list) for the special issue consisting of approximately 40 papers on ocean circulation, 10 on climate, and several on marine biogeochemistry. This special issue will provide latest scientific results and well-thought out strategic direction for future studies of ocean circulation and climate in the western Pacific Ocean.

2. Future plans and issues

b) Propose future plans and issues including those discussed at the pan-meeting, such as priority areas that will be addressed by your Panel/WG in the coming 5 years.

We present here the future plan and issues referring to the different highlights of Section 1

2.1. Challenges

2.1.1. SPCZ

(ML) We identified SPCZ research priorities as follows:

1. Interannual variability and relationship with ENSO,
1. Response to background changes (Past and future)
2. Representation in climate models,
3. Natural Decadal/multidecadal variations
4. Local impact on island countries (precipitation, sea level, extreme events)

2.1.2. Natural decadal variability in the Pacific region (IPO, IPV, PDO…) and hiatus

(ML) In addition to interannual ENSO fluctuations, the Pacific exhibits decadal and multidecadal climate variability. The most prominent low-frequency climate variability in the North Pacific has been termed the ''Pacific decadal oscillation'' (PDO). The PDO is also known as the interdecadal Pacific oscillation (IPO) in recognition of its extension to the equatorial and South Pacific. Given the relatively short observational record, it is difficult to ascertain whether there is a robust spectral peak in the observed PDO time series and coupled mechanisms that may be at stake in driving this variability is still the matter of intense debate. Given the intensive of use CMIP models for decadal prediction, there is a need to assess the models performance in reproducing the observed PDO/IPO characteristics. The availability of longer time series will also allow to investigate their relationship with ENSO forcing and the spectral characteristics of this decadal variability in the model to see if these models do exhibit robust spectral peaks. This decadal variability is also known to drive decadal variations in precipitations (SPCZ) and sea-level. These signals complicate the detection of regional anthropogenic trends. It is therefore necessary to better identify the sea-level and precipitation signature of the PDO/IPO to be able to more confidently attribute the observed/modeled change to natural and forced variability.

The following research priorities were identified:

1. What is the role of the Pacific in the hiatus?
2. What are the mechanisms of Pacific decadal variability? Does it originate in the tropics ?
3. How do natural decadal modes of variability interact with the forced global warming signal and with other forcing factors (e.g. aerosols)?
4. How can we validate the relationship of PDO and ENSO variability in CMIP model?
    4.1.1. This relates with decadal/multi-decadal variations in precipitations (SPCZ) and sea-level along with its potential aliasing on the regional anthropogenic trends such as sea-level and precipitations.
5. How can decadal prediction be used and applied in the Pacific region?

Action items
• (MC, ML, WC) Develop PP contribution to the science plan on decadal variability in relation with the decadal RF; get expertise in the panel (new members) • (ML) Validate PDO and relationship with tropical variability in CMIP models • (AG) Evaluate decadal predictions in the Pacific

2.1.3. ENSO in a Changing Climate

(MC, WC) Several members of the PP are heavily involved in this topic, and we should refer to the corresponding Research Focus.
Sang-Wook Yeh will convene the session entitled as "Dynamics of ENSO and tropical climate variability" at AOGS, will be held at 28 Jul to 01 Aug., 2014. and "ENSO, its precursor, and their change under global warming" at AGU, will be held at 15-19 Dec. 2014. The goal of both sessions are as follows: how ENSO will or will not change due to increasing greenhouse gasses, what processes drive two-types of El Niños, what the role of inter-basin coupling is in the ENSO dynamics and predictability, how ENSO interacts with lower frequency decadal variability as well as higher frequency weather disturbances, how we can improve ENSO simulation in general circulation models, assemble physical evidence of, and address mechanisms for, any changes in the ENSO precursor pattern and how such changes affect the future development of ENSO.

Action items
• (SWY) Report on special session at AOGS

2.1.4. ENSO-IOD relationship

(DY, ML) Further work is still needed to understand whether this influence of the IOD on ENSO occurs through an atmospheric bridge modifying the equatorial Pacific wind (Izumo et al. 2010) or through oceanic Kelvin wave propagation from the eastern Equatorial Indian Ocean into the Indonesian seas (Yuan et al., 2011, 2013; Xu et al., 2013). The IOD-ENSO teleconnection is found to have decadal variations, the dynamics of which not clear at present.

2.1.5. ENSO teleconnections and how they might change under climate change

(SWY, MC,KC) Teleconnections from ENSO, how they can vary naturally and how they might change in the future remains an understudied area. The ability of models to simulate teleconnections is hampered by biases in the model mean climates. Recent studies by Power et al. (2013) and Chung et al (2013) provide an experimental protocol to understand ENSO teleconnections with different baseline climate states. The protocol could be extended to other time periods, to look at different flavors of ENSO events and to assess uncertainties coming from different models and different possibilities for the mean-state changes. Integration with CMIP6 would be desirable. Discussion amongst the community is required before undertaking such a coordinated set of experiments.
The following research priorities were identified:

1. Continue discussion about current status of ENSO and its diversity (EP/CP etc.)
2. Study the regional differences of ENSO teleconnections due to linear versus non-linear processes

3. How the climate models properly simulate the ENSO teleconnections in the present climate ?
4. How such teleconnections might change under global warming
5. What are the influences from other basins on teleconnections

Action items:

- (MC, BK, ML) Organize a discussion of coordinated experiment for CMIP6 on changes in ENSO; help designing the experiments and proposing metrics for evaluation of ENSO properties and teleconnections
- (SW Y) Write review paper on ENSO teleconnections in models and in the real world

2.1.6. SPICE

(AG) Our understanding of the Southwest Pacific ocean has much improved over the past 10 years. Nevertheless, several areas still remain unexplored, e.g. southeast of the Solomon Islands or inside the Gulf of Papua (Ganachaud et al. 2014). Monitoring of key currents and transports is ongoing: the transport into the Coral Sea and Tasman Sea through high resolution XBT lines. The WBC transports through the Solomon Sea are monitored through moorings and repeat gliders, as well as the WBC off the Great Barrier Reef; the EAC current-meter array measurements are being pursued. Beside the permanent challenge of maintaining such key observing systems, new research challenges for the southwest Pacific CLIVAR science include (Ganachaud et al. 2014):

1. Ocean vertical mixing (remains quasi unexplored in the area)
2. Submesoscale activity is a new arising field (Gourdeau et al. 2014).
3. Document undocumented aspects: SICU, SCJ and GPC (existence for SICU?);
4. revise the pathways to the equator and their variability: influence on ENSO and climate variations?
5. Is monitoring of this area important? Similar questions regarding the TO/poleward pathways.
6. Develop studies on climate change projections / decadal variability and impact on the southwest Pacific ocean and islands in coordination with local communities (i.e., SPC).

Action items:

- (AG) Maintain SPICE coordination and continue developing data information and exchange between the different groups
- (AG) Develop and/or stimulate programs to address the remaining questions
- (AG JS) Carry on Solomon Sea analysis and diagnostics
- (BK) Ensure continued glider monitoring across the NGCU with SIO

2.1.7. WBC dynamic role on climate changes

(XL, WC) The IPO/PDO mechanisms are still under debate, and we do not fully understand the ocean response to global climate change, such as the fast warming before 2000s and the following hiatus. WBC should be a key role in the future study. Continuous and enhanced observations are needed in Pacific WBC regions that should be integrated to include contributions to the ITF, like RAPID Line and Line W in the Atlantic Ocean. The following research priorities were identified:

1. Describe the 3-d structure (surface, subsurface, and deep WBCs) and variability of the western Pacific Ocean circulation (including those of the WBCs)
2. Understand the interactions of WBCs with ambient current systems
3. Understand the role of WBCs in climate variability
4. Evaluate the predictability of the warm pool and climate
5. Understand how the South Pacific waters reaches the ITF

Action items:
• (WC) Write a review on the WBCs of the Pacific

2.1.8. TPOS-2020

(KA, BK) The following challenges were identified, as reinforcing key priorities:

1. Sustain long climate records as a priority
2. Maintain and improve broad scale sampling, taking into account all observing networks.
3. Encourage integration of BioGeoChemistry and Biology

New requirements for TPOS 2020 are,
1) Resolving the Atmosphere/Ocean Boundary Layer, which includes higher vertical resolution of temperature, salinity, velocity resolving the diurnal cycle across regimes, hourly state variables in the atmosphere, and improved observations at air-sea interface,
2) Boundary regions measurements, which include definition of requirements for sustained observations of Equatorial boundary region, eastern boundary, western boundary, and also task NPOCE, SPICE, ITF TT, Eastern Boundary regional nations/alliances to assess requirements for observations in sustained mode (e.g. Sustained array for ITF based on INSTANT)
3) Deep Ocean to extend observations to the deep ocean to resolve seasonal cycle.

The Workshop recommends strengthening connections:
1) Biogeochemical/Biology: to advance the measurements of the drivers of oxygen, carbon dioxide, inorganic nitrogen, biological productivity, and the abundance and distribution of living marine resources across the tropical Pacific Ocean, and at sufficient resolution to resolve inter-annual to multi-decadal variations, and to pursue integration with physics observations, leveraging platforms (in relation with Upwelling RF)
2) Modeling and data assimilation: to exploit multisystem analysis activities for observing system evaluations, to develop project plan, including straw men of potential future TPOS configurations, and to identify requirements for targeted process studies to reduce model error.

All documents from the TPOS Workshop, including the White Papers, the presentations given, and the Report, are available at: http://www.ioc-goos.org/tpos2020

Action Items
• (BK): keep the PP informed on TPOS-2020 progresses

2.1.1. ITF

(JS/AG) In section 1 we pointed to the importance of maintaining and ensuring sustainability of ITF measurements. This is done by the ITF Task Team

(DY) Existing observations suggest that the confluence of the Mindanao Current (MC) and the New Guinea Coastal Current/UnderCurrent (NGCC/NGCU) presents bimodal structure, with a branch of MC penetrating into the Sulawesi Sea (ITF) or choked at the entrance of the Indonesian seas. The dynamics of this current system have been shown to be due to the nonlinear bifurcation and hysteresis of the colliding western boundary currents (Wang and Yuan, 2012 JPO). In addition, the circulation of the Mindanao Dome is found to have complicated surface-subsurface current interleaving, the meridional transports of which are significantly different from the classical Sverdrup theory (Yuan et al., 2014, JPO). These issues bare consideration in the understanding of the ITF gateway processes.

The Maritime Continent (MC) of Indonesia is at the center of global multiscale interaction involving the global mean circulation and variability on a wide range of timescales. It hosts one of the major equatorial atmospheric convection centers associated with the ascending branch of the Walker Cell. Patterns of SST and rainfall are influenced by the ITF heat and freshwater transports and the strong mixing that takes place within the internal seas of the MC. The MC is also a known barrier for the eastward propagation of the *intraseasonal* MJO. Current state-of-the-art global GCMs and NWP models suffer from persistent systematic errors over the MC. They cannot reproduce the observed diurnal cycle of precipitation and show systematic dry biases in precipitation over the ocean and wet biases over land. In NWP models, this leads to an MC prediction barrier for the MJO. Given the role of the MC in the global weather-climate continuum and our inability of simulating and predicting the atmospheric-oceanic variability in the MC region, an international "Year of the Maritime Continent (**YMC, 2017-2018**)" is proposed so as to make expedited progress in the study of the MC role in the weather-climate continuum. It is envisioned that a sequence of intensive field campaigns will take place in the MC region during the YMC, including the diurnal cycle in cloud and precipitation, evolution of the cloud population through the local life cycle of the MJO, ITF, ocean mixing and dynamics, air-sea interaction of the marginal seas, and troposphere-stratosphere interaction, among others. Advocating some potential international resources might also help evolve the process-oriented boundary measurements associated with YMC towards a sustained system that is co-ordinated with other ITF measurements.

Action items:

- (JS): Apply to SSG for at 2-year renewal of the ITF Task-Team
- (JS, AG, WC): Look towards integration of ITF-TT into the PP in the future
- (JS): Ensure coordination of ITF operations with YMC
- (DY): Deploy ITF Gateway moorings; ensure data storage and availability

2.1.2. Coordination in the western Pacific.

(AG) The SPICE/NPOCE/ITF programs generated a large amount of data. All program/area supply the warm pool and the EUC, and provide an unprecedented opportunity to create budgets of the warm pool (see the recent workshop by Brown et al. 2013) and EUC waters. CLIVAR coordination and data sharing will be crucial in this regard.

(XL) **OUC data center:** A new Chinese data center was set up, consisting of three servers and a super computer with more than 300T storage to support climate change research. It contains the most common used remote sensing data and reanalysis data as well as nearly all the CMIP5 Ocean and Atmosphere data with automatic update. The OUC data center also aims at storing data produced by OUC scientists, including the NPOCE program. It presently contains all in situ observations by R/V 'Dongfanghong 2' since 2000, and provides high resolution global ocean hindcast, high resolution regional coupled model outputs, high resolution regional reanalysis ocean and atmosphere data. A Northwestern Pacific Ocean Operational System is running in this data center for short-term prediction.

Action items:

- (AG, XL, WC, JS): design a plan to analyze jointly the NPOCE-SPICE-ITF data and WP budget
- (XL, DY): ensure NPOCE data quality and public availability within CLIVAR policy

2.2. new Millennium Institute of Oceanography (IMO)

(CM, WS) Climate variability in the region of the Eastern South Pacific (ESP) remains as an issue of the highest scientific interest because this region includes a set of unique conditions (e.g. areas of very low oxygen - low pH, high pCO_2, extreme changes in topography (Atacama trench, ridges and numerous seamounts), high productivity in the coastal upwelling zone and associated strong fishing activity, extensive coastal-ocean exchanges through mesoscale activity, and the influence of deep water formation in the Antarctic). In the next 5 to 10 years, the newly created Millennium Institute of Oceanography (IMO), based in Chile, will tackle climate-related issues in the ESP open and deep water systems, including: i) the dynamics and variability in regional circulation and mesoscale activity, ii) their effects on water chemistry, biogeochemical cycles and populations/ecosystems, iii) adaptations of functional plankton groups to changing ocean chemistry and their impact on biogeochemical cycling, and iv) the exploration of ecosystems in abyssal waters of the ESP. Three research questions of IMO were identified to be in the context of the CLIVAR Foci:

1. What is the role of mesoscale activity in governing energy and matter transfer in the ESP from the coast to the open ocean?
2. How do large-scale perturbations impact the dynamics of the ESP?
3. How do key functional plankton groups adapt to changing ocean?

For instance, the COPAS/University of Concepcion Biophysical Time Series coastal station off Concepcion (Station 18, ~36.5°S), which started in 2002, will be maintained. A new time series will be started with an offshore mooring (within 1000m depth) off Juan Fernandez Archipelago (~33°S, ~80°W).

Action items:

- (WS and co-chairs) Next CLIVAR PP meeting could be hosted by the Millenium Institute, during 11ICSHMO conference (to be coordinated, contact is Rene Garreaud <rgarreau@dgf.uchile.cl>)
- (WS) Seek CLIVAR endorsement application for the Millenium Institute
- (WS, CM) Inform the Panel about IMO progresses; seek possible coordination with through the Pacific Panel.

3. Relevance to CLIVAR

c) Address in particular your Panel/WG's implementation activities that will contribute to the CLIVAR Research Foci and/or WCRP Grand Science Challenges.

The different highlights and challenges address most of the CLIVAR RF in different and sometimes obvious ways. For instance:

- (ML) Understanding the natural decadal variability is of great importance for South Pacific island countries (not only) and gather three research foci below, for the Pacific region (point 2, 3 and 5).
- (DY, AG) The primary purpose of the NPOCE, SPICE, ITF and TPOS observations is to understand the roles of the (western) Pacific Ocean circulation in the warm pool variability and in climate variations. This was in great part motivated by understanding *decadal climate modulation* through WBCs transports in the southwest Pacific towards the equator and high latitudes. Measurements of the WBCs and the ITF are essential for the fulfillment of the scientific objectives. Arrays of moorings in the WBCs, in the South China Sea, and in the Indonesian seas have been designed to measure the ocean circulation (See the respective implementation plans from NPOCE and SPICE websites: Ganachaud et al 2007, 2008; Hu et al., 2010; Sprintall et al 2013). The foci are on the interannual to decadal time scale variations of the ocean circulation and climate, with biogeochemical aspect of the circulation also considered. A better knowledge of the ocean transports, circulation and variability will also help understanding *regional aspects of sea level* and climate. SPICE was also related with ecosystem dynamics and food security in the Southwest Pacific (Ganachaud et al. 2011, 2012; Bell et al. 2013).
- (CM) The Millenium Institute of Oceanography, (IMO, Chile) will seek international collaboration through CLIVAR and other related global programs in the framework of CLIVAR Research Foci 2,4,5 and 7.

CLIVAR Research Foci (http://www.clivar.org/science/clivar-research-foci)

1. Intraseasonal, seasonal and interannual variability and predictability of monsoon systems
2. Decadal variability and predictability of ocean and climate variability
3. Trends, nonlinearities and extreme events
4. Marine biophysical interactions and dynamics of upwelling systems
5. Dynamics of regional sea level variability
6. Consistency between planetary heat balance and ocean heat storage
7. ENSO in a changing climate

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