

CLIVAR PACIFIC REGIONAL PANEL

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Panel overview

The PRP general objectives cover a wide range of science issues. This includes efforts to develop a coordinated international strategy for a sustainable Pacific observing system (such as in support of the TPOS2020 steering committee) and a better understanding of (1) the internal dynamics of the Pacific variability (including ENSO and Decadal Variability), (2) the impact of external forcing on the Pacific (including greenhouse gases, aerosols, volcanic eruptions and solar insolation), (3) how Pacific climate variability generates remote impacts through teleconnections and interacts with climate variations external to the Pacific, (4) the dynamics that control the multi-scale variability in Western Boundary Currents WBCs, the influence of WBCs on the Pacific climate and their oceanic connection to the Indian Ocean through the Maritime Continent and (5) the predictability of Pacific climate. Due to time constraints of all panel members and the breadth of topics in scope, the PRP is currently focussing most of its attention on three main activities: decadal variability in the tropical Pacific, activities on ENSO in a changing climate, and interaction with the TPOS2020 Backbone Task Team (BBTT) to convey the PRP's concerns in setting priorities for the Pacific observing system.

Achievements for 2018-19

- **Conferences/Workshops/Meetings**

A large number of sessions in international conferences and workshops have been chaired and/or organized by PRP members as individuals (e.g. AGU Ocean Sciences, EGU, etc.). In the following, we only focus on the achievements involving the PRP members as a community:

- **Decadal variability workshop (Paris, April 2019)**: Decadal Sea Surface Temperature variations in the tropical Pacific are a major pacemaker of low-frequency climate variations worldwide and have been identified as the major cause of the recent slowdown, or “hiatus”, in global surface warming. While this phenomenon is partly driven by decadal ENSO modulations, the mechanisms underpinning Tropical Pacific Decadal Variability (TPDV) are not fully understood. To discuss and review our current understanding of TPDV and its predictability, the PRP organised a first workshop back-to-back with the annual IVth international ENSO conference in San Pedro de Manglaralto (Ecuador) on the 13th and 14th of October 2018. To further pursue this effort and make progress on the writing of a review paper on this topic, the PRP organised a second workshop the first week of April 2019 with most of the participants from the first workshop and a few additional experts. This workshop allowed us to make considerable progress on a paper that reviews our current knowledge of TPDV, whose proposal for publication has been accepted by *Science*. This workshop gathered a total of approximately 25 climate scientists from CLIVAR PRP and ENSO Research Focus group, as well as other targeted scientists. The review article is now close to completion, with a submission date planned for late December.

- **Workshop on “Atmospheric convection and air-sea interactions in the Tropical Oceans”** held in Boulder (Colorado, USA) on 7-9 May 2019. This workshop, which was co-organised by

PRP (through A. Capotondi who joined the organising committee), IORP, ARP and US CLIVAR. reviewed the progress in the field over the past 30 years and identified key scientific problems that could benefit from coordinated modelling and observational process studies involving the tropical convection and air-sea interaction communities. This topic is particularly important for CLIVAR PRP as the non-linear response of tropical convection to SST is poorly understood and very important to make progress in our understanding of ENSO, intraseasonal variability, atmospheric teleconnections and interbasin interactions.

- **PRP panel meeting:** The 14th Session of CLIVAR Pacific Region Panel (PRP) took place on 19 October 2019, in Victoria, Canada, alongside the 2019 PICES Annual Meeting. During the meeting, updates on the 2018-2019 panel activities have been summarized, including progresses on ENSO conceptual models and ENSO Metrics working groups, update on Wiley book on ENSO in a changing climate, preparation of 2020 ENSO Summer School in Trieste, Western Boundary Current and Indonesia Throughflow activities, Tropical Pacific Decadal Variability science paper, etc. The work plan for 2020 and onwards has also been discussed by all members during the meeting, including the potential cross-activities with US CLIVAR on ocean isotopes, the way forward with TPOS2020, possible panel activities including marine biogeochemistry and cooperation with PICES WG-40, potential interactions with other core projects of WCRP and the Southern/Northern Region Panel of CLIVAR, as well as the way forward after the completion of the TPDV Science paper. Panel membership and next panel meeting were also discussed at the end of the day.

- **PRP/PICES meeting:** The PRP met with the PICES working group on “Climate and ecosystem predictability” (WG-40) on October 20, 2019 in Victoria, Canada. The aim of the meeting was to share expertise to synthesize our current state of knowledge on the sources of marine ecosystem predictability arising from the large-scale climate. During the meeting, sources of predictability on the eastern and western sides of the North Pacific, the region of primary interest for PICES, were compared and contrasted using both statistical and dynamical approaches. Since ENSO is a large source of predictability in the northeast Pacific, the mechanisms by which ENSO precursors in the North Pacific can lead to ENSO development were discussed. Examples of the influence of climate on ocean primary productivity and extreme temperature conditions in other parts of the world (Tasman Sea and Arabian Sea) were also presented. The meeting promoted fruitful interactions and discussions among the members of the two communities and identified possible research topics that the PRP may pursue during the coming years, one of which is Marine Heat Waves, extreme ocean warming events that have recently occurred over several areas of the North Pacific (West Australia, Tasman Sea, Northeast Pacific) with dramatic ecosystem and economic impacts, and may deserve a systematic examination basin-wide.

- **ENSO Science Symposium:** The symposium “Understanding ENSO in a Changing Climate” was held in Hobart, Tasmania, Australia 29 – 31 January 2019. Convenors were M. McPhaden, A. Santoso and W. Cai. Sixty scientists from around the world gathered to discuss questions about whether anthropogenic greenhouse forcing has affected ENSO already or whether it will in the future. These questions have been debated for nearly 30 years, but they take on greater urgency now as the manifestations of climate change become ever more apparent and as greenhouse gas concentrations continue rise in the atmosphere. The symposium was followed by a 2-day coordination workshop on the AGU Monograph entitled “ENSO in a Changing Climate,” which will cover the latest science on ENSO dynamics, impacts, prediction, and future projections. More on the workshop can be found at <https://cshor.csiro.au/news/cshor-enso-science-symposium/> and in a meeting report published in Eos (<https://doi.org/10.1029/2019EO124159>).

- **Activities on the Pacific observing system**

TPOS2020 interactions: The PRP also provided feedback on the first and second reports of TPOS2020 that we believe has improved its scientific capacity. The overall goal of TPOS2020 is to build a robust observing system of the Tropical Pacific that can detect and diagnose expected and unexpected changes, both due to ENSO and anthropogenic climate change. The feedback provided by the PRP revolved around ensuring the project did not sacrifice continuous long temporal coverage from the pre-existing moored array for improvements in spatial resolution from increase in Argo density and remotely sensed winds, as both aspects are fundamental to detection of both natural or anthropogenically driven changes. In particular, there was consensus within the PRP that TPOS2020 did not sufficiently prioritize sustaining decades-long moored time series, and did not convincingly justify the removal of so many long mooring records. Our feedback led to changes in the proposed TPOS observational network, such that it now provides a better balance between long continuous records and improved spatial coverage. Xiaopei Lin represented the PRP at the 6th Steering Committee Meeting of TPOS2020, which was organized from 5 to 7 November 2019 in Hangzhou, China. He re-illustrated the points from the PRP to TPOS2020 as mentioned above and expressed the willingness of the PRP to contribute to the implementation plan of TPOS2020.

- **NPOCE-ITF observation platform:** The PRP and the NPOCE have helped to develop a strategy for an observational sampling of the Pacific Lower Latitude Western Boundary Currents (LLWBCs) and their connection with the Indonesian Throughflow. This has included the development of new technologies, such as real-time subsurface mooring reporting and drifting floats. Some PRP members contributed to white papers related to the LLWBCs and ITF observations that were presented at the 2019 Ocean Obs' Meeting (see list at end of this document).

- **Scientific results from activities**

All panel members contributed individually to a large number of papers relevant for the PRP activity. In the following discussion, however, we only summarize achievements arising from a PRP community effort. In this regard, three major themes (ENSO, tropical pacific decadal variability and reviews on the observing system) have been tackled during the past year:

- **Chapters on AGU Book on ENSO in a changing climate:** The PRP strongly contributed to different chapters of an AGU monograph written for the AGU Centennial titled *ENSO in a Changing Climate*. This book, edited by A. Santoso (former PRP member), W. Cai (SSG co-chair and former PRP co-chair and ENSO RF member) and M. McPhaden (PRP ex-officio), provides a comprehensive review of ENSO and the effect of climate change on its dynamics, predictability, and impacts. Section 1 introduces what ENSO is, the basic characteristics and processes, including the climatology of the tropical Pacific and pertinent issues in ENSO research. The basic dynamics of ENSO is firstly covered in three chapters in section 2 largely using conceptual models with some mathematical equations. For the rest of the book, each chapter includes a perspective on climate change. Section 3 describes the three main tools to conduct ENSO research: observations, paleo-reconstructions, and models. This sets up the readers to understand the next sections, which will utilize models, observations, and paleo records. Section 4 discusses external and remote forcing of the tropical Pacific, followed by Section 5 on predictions and Section 6 on

teleconnection and impacts. Among the 20 chapters contained in this book, six of them were led by PRP members and ten members contributed to ten of these chapters.

- **Tropical Pacific Decadal Variability draft for *Science*:** One major achievement arose from the PRP's contribution to a new review paper on Tropical Pacific Decadal Variability (TPDV) to be submitted soon to *Science* (Power et al. in prep.) as a result of two workshops held on this topic this year (see above). This paper provides a comprehensive review of our current state-of-knowledge of TPDV, its spatial and temporal characteristics, its many proposed mechanisms, and the current ability of state-of-the-art modeling and prediction systems to simulate and predict TPDV. The review is based on analyses of a wide, diverse, and in some cases contradictory array of evidence from historical records, instrumental and paleoclimate data, theory, mathematical models of Earth's climate, and decadal prediction systems. From the critical synthesis of this information, the review concludes with a novel and informed set of recommendations to advance our understanding of TPDV and our ability to predict it. The review provides, in particular, a comprehensive and holistic synthesis of the natural (e.g., internal variability in the tropical and extra-tropical Pacific, influences from other oceans; explosive volcanic eruptions) and anthropogenic (e.g., emissions of greenhouse gases and sulfate aerosols) processes posited to cause or strongly influence TPDV, and the interactions between them. This review also provides the degree of confidence our world-class team of experts has in the proposed mechanisms and the extent to which oceanic processes may provide some degree of predictability.

- **Community White papers for OceanObs'19:** The OceanObs'19 Research Topic in Frontiers in Marine Science was intended to provide a forum for community recommendations to the OceanObs'19 conference, and to guide post-conference activities. PRP members have been involved in the writing of several Community White Papers (see list at the end of this document). These papers promote international collaborations, describe the status of a truly large-scale sustained ocean observing effort, and collectively help shape a vision for the future. They gather the collective knowledge of the community to evaluate and enhance the efficacy of our global and regional ocean observing networks. They also identify substantial challenges that we need to overcome as a community and offer suggestions for solutions.

- **Report on Atmospheric Convection and Air-Sea Interaction workshop:** A workshop report summarizing the key outcomes of the workshop was prepared for BAMS, and has just been accepted.

- **Scientific capacity building and career support**

- During the last three years, A. Capotondi and J. Sprintall have served as mentors for the US program "Mentoring Physical Oceanography Women to Increase Retention" (MPWIR). This program involves one conference call per month to support young women at the PhD and Post-Graduate level in successfully navigating the field of Physical Oceanography and finding appropriate and fulfilling roles.
- From 2013, Xiaopei Lin has sent several Ph. D students to visit the top institutions (WHOI, Scripps, CSIRO, AWI), from short term study to joint degree program. Some of them now graduated and worked as individual scientists and contributed to PRP related activities (NPOCE or others).
- Yann Planton, one of the major contributor to the development of ENSO Metrics will move to PMEL to work with Mike McPhaden for one year to further explore the ENSO metrics implementation and their application to the analysis of CMIP5/6.

Plans for 2019 and beyond

As an outcome of the discussions PRP members had during the last PRP meeting in Canada, the panel proposes the following action items for the upcoming year:

1- CLIVAR recommendations on TPOS2020 implementation plan: The PRP was invited to provide input on the implementation plan and PRP members are willing to interact with TPO2020 on this topic if given more details on the current implementation plan.

2- Integration of low-latitude western boundary current and maritime continent observations into a unified multi-platform observing system: Numerous observations have been deployed over the past decade in the course of two projects endorsed by CLIVAR PRP, the North Pacific Ocean Circulation Experiment (NPOCE) and the Southwest Pacific Ocean and Climate Experiment (SPICE). Similarly, several years ago the activities of the former ITF Task Team around the oceanic connection between the Pacific and Indian Oceans through the Maritime continent were formerly integrated in the PRP scope. Because of other PRP foci and the lack of a formalised link with previous ITF TT members, the PRP did not manage to sufficiently develop activities around this central scientific theme. However, the maritime continent remains in the PRP terms of reference (4), and is also the focus of new international interest through the Years of the Maritime Continent effort. Janet Sprintall and Xiaopei Lin both investigated the best way to move forward and this issue and proposed the following actions: (1) Identify the key stations and transects that have been historically occupied in the LLWBC regions, (2) Coordinate observations among major countries to produce a coherent atlas of velocity measurements to enhance understanding of the flow in the boundary regions and help inform the development of an observational strategy, (3) Extend the research area of NPOCE and work with other projects in this region to better coordinate the observations (4) Potentially link to other operational systems, such as TPOS2020, for the forecast and prediction.

3- Continuing work on ENSO metrics, formerly the CLIVAR Research Focus on ENSO in a Changing Climate (ENSO RF): The ENSO metrics effort, which merged into the PRP last year, continues to make excellent progress. It has already generated a Python package to diagnose and explore ENSO characteristics in the CMIP5 and CMIP6 models, and the interactive capabilities of this package were demonstrated at the PRP meeting. The planned ENSO metrics activities will greatly assist in evaluating and comparing model simulations, understanding ENSO dynamics, and projecting possible future changes in ENSO. Community metrics remain a high priority to help integrate observations, models, and theory to better understand, predict, and project future ENSO behavior. To support model developers and users, the package is designed to plug into widely-used community diagnostic tools, including ESMValTool and the PCMDI Metrics Package, and the ENSO metrics team maintains active dialogues with the developers of those tools. Further support for ENSO metrics development is strongly encouraged and endorsed by the PRP.

4- Working group on ENSO conceptual models: This new activity has been proposed by J. Vialard and echoes the above will to integrate ENSO RF activities into PRP activities. Conceptual models of ENSO such as the recharged or delayed oscillators are very important in the way the community pictures the key mechanisms responsible for ENSO properties. The recharge oscillator is in many ways very successful in representing ENSO observed properties, or how they are represented in CMIP models. Yet, some physical interpretations of e.g., the lead relation between equatorial Pacific oceanic heat content and ENSO (which is at the heart of this conceptual model) have recently been challenged. This conceptual model furthermore cannot represent ENSO flavors

or does not represent important nonlinearities such as the absolute SST threshold for triggering deep atmospheric convection, which are thought to play an important role in shaping up extreme El Niño events. The last published review on ENSO conceptual models by Wang and Picaut also dates from 2004. Due to time constraints from the PRP organiser (J. Vialard), not much progress has been done this year but some key researchers have been contacted and agreed to join that team (FF. Jin, A. Wittenberg, A. Fedorov, M. Lengaigne, A. Capotondi, S. McGregor). We are expecting an answer from other identified researchers. The idea is to build a team selected from PRP, ENSO RF members & invited experts, gathering theorists, modellers and specialists of observations, to work on the following questions: What fundamental ENSO properties should a conceptual model represent? What key physical processes are needed to account for these properties? What are the strengths and weaknesses of various existing conceptual models? What is the relevance of these conceptual models for identifying main ENSO biases in state-of-the-art coupled general circulation models? What is the way forward to build improved conceptual models? The final outcome of this activity would be to promote new developments on ENSO conceptual models and a review paper summarizing our current knowledge. A formal working group proposal, with identified members, terms of reference and a precise goal (review paper on ENSO conceptual models, including a strategy for moving forward) will be sent to the CLIVAR SSG in early 2020.

5- Role of oceanic processes in TPDV: The review paper on TPDV outlines several possible mechanisms that can give rise to potentially predictable decadal variations. These mechanisms include, for instance, variations in the strength of the upper-ocean overturning circulation in the form of the Subtropical-Tropical Cells, advection of temperature anomalies along isopycnal surfaces from the subtropical to the equatorial regions, etc. While these mechanisms have been shown to contribute to equatorial SST anomalies, their interplay and effectiveness in the presence of climate noise is not clear. Other aspects that are unclear include the role of western Pacific off-equatorial heat content, Low-Latitude Western Boundary Currents (LLWBCs) and Pacific-Indian Oceans connections via the Throughflow in regulating the variations of equatorial Pacific heat content at decadal timescales. After the completion the TPDV paper, the PRP will gather the panel expertise to identify avenues for making progress on these open questions.

6- Mechanisms of formation of Marine Heat Waves in the Pacific basin: Marine Heat Waves are a topic of increasing relevance in the Pacific Ocean given their occurrence in several parts of the basin (Western Australia, Tasman Sea, Kuroshio region, Baja California, and northeast Pacific), and their projected increase in frequency. These extreme warm events have dramatic consequences on marine ecosystems, and devastating economic impacts. They also open the very interesting scientific questions of preferred “hot spots”, and heat content re-distribution within the basin. Given the close link of marine heat waves with ocean biogeochemistry, and the presence of expertise in the panel, we will examine during the coming year the possibility of creating a study group on this topic.

7- ENSO summer school (Trieste, August 2020): The PRP is currently involved in the organisation of a summer school on ENSO. This school will take place at the International Center for Theoretical Physics (ICTP) in Trieste, Italy, August 3-14, and is expected to gather ~50 students. The first week of the school will be entirely devoted to different aspects of ENSO, including phenomenology, theory, modelling, and prediction. We will build on the content of the comprehensive AGU Monograph “El Niño Southern Oscillation in a Changing Climate”, as well as on the PRP activities on ENSO conceptual models to provide the most up-to-date ENSO

curriculum. We also plan to use concepts and tools from the work on ENSO metrics and the output of the CMIP6 models to design appropriate practical activities for the students. The second week will explore teleconnections from the tropical oceans to the extra-tropics, decadal variations of ENSO teleconnections, and inter-basin teleconnections. ICTP will provide the facility for the workshop, lodging for students and lecturers, as well as some funding for student travel costs, especially students from developing countries. Additional funding is needed to cover the travel expenses of other students and lecturers. It will thus require funding sponsors such as US CLIVAR, WCRP/International CLIVAR, and IRD in 2020. Further support is welcome.

8- AGU Fall meeting 2019: To further strengthen our efforts to promote work on the TPDV, members (Shayne McGregor, Yu Kosaka) of the PRP have organised a session at the AGU fall meeting on “Drivers of Tropical Pacific Decadal Variability”. This session will aim at clarifying the dominant drivers of tropical Pacific decadal variations, and the relationship of TPDV with ENSO. As the CLIVAR Research Focus on “Decadal Climate Variability and Predictability” is ending, members of that working group aim to transmit their legacy to CLIVAR panels. To that end, a PRP member (A. Capotondi) has participated in the organization of a WCRP-sponsored session on “Decadal to Multidecadal Climate Variability: Mechanisms, Predictability and Impacts” at the AGU Fall Meeting.

9- Potential interactions with ANDEX: The PRP discussed the possibility of interacting with one of the WCRP crosscutting projects (Greenland melt, ANDEX, and TPI). There is interest within the PRP to interact with the ANDEX initiative, since ENSO provides a strong forcing for the atmospheric circulation over the Andes. An initial contact was established with one of the co-Chairs, Dr. German Poveda. A contact person for the PRP on this topic is Mike McPhaden.

Budget and other needs for 2019-2020

1- Next PRP meeting (August 1-2, 2020, Trieste): The PRP requested a 4k CHF funding to support the travel of two PRP members that cannot use their own funds).

2- ENSO summer school (August 3-14, 2020, Trieste): The PRP requested a 4k CHF funding to support the travel of two PRP members that cannot use their own funds).

Articles published in 2018/19 as part of panel activities (PRP members in bold)

- [1] Cai W., L. Wu, **M. Lengaigne**, T. Li, **S. McGregor**, **J.S. Kug**, J.Y. Yu, M.F. Stuecker, A. Santoso, X. Li, Y.G. Ham, Y. Chikamoto, B. Ng, **M.J. McPhaden**, Y. Du, D. Dommenges, F. Jia, J.B. Kajtar, N. Keenlyside, **X. Lin**, et al., 2019: Pantropical climate interactions, *Science*, 363, 944.
- [2] Todd R.E. et al.: Global Perspectives on Observing Ocean Boundary Current Systems, *Frontiers in Marine Science*, accepted.
- [3] Stammer D. et al.: Ocean climate observing requirements in support of Climate Research and Climate Information, *Frontiers in Marine Science*, accepted.
- [4] Hermes J. et al.: A sustained ocean observing system in the Indian Ocean for climate related scientific knowledge and societal needs, *Frontiers in Marine Science*, accepted.
- [5] **Capotondi, A.**, et al., 2019: Observational needs supporting marine ecosystems modeling and forecasting: From the global oceans to regional and coastal systems. *Frontiers in Marine Science*, <https://doi.org/10.3389/fmars.2019.00623>.

- [6] Fedorov, A., S. Hu, **A. T. Wittenberg**, A. Levine, and C. Deser: ENSO low-frequency modulations and mean state interactions. AGU monograph, accepted.
- [7] Guilyardi E., **A. Capotondi**, **M. Lengaigne**, S. Thual, and **A. Wittenberg**: ENSO modelling: history, progress and challenges, AGU monograph, accepted.
- [8] Kessler, W. S., et al., 2019: Second Report of TPOS 2020. GOOS-234, 265 pp. Available online at <http://tpos2020.org/project-reports/second-report>.
- [9] **Kug J.-S.**, **J. Vialard**, J.-Y. Yu, Y.-G. Ham, **M. Lengaigne**: Remote forcing: Influence of climate variability outside the tropical Pacific, AGU monograph, submitted.
- [10] Cai W., G. Wang, L. Wu, M. Collins, A. Timmermann, **S. Power**, **M. Lengaigne**: ENSO response to greenhouse forcing, AGU monograph, submitted.
- [11] **Capotondi**, **A.**, **A. Wittenberg**, **J.-S. Kug**, K. Takahashi, and **M. McPhaden**, 2019: ENSO Diversity, AGU Monograph, accepted.
- [12] **McPhaden**, **M. J.**, A. Santoso, and W. Cai, 2019: Introduction to El Niño Southern Oscillation in a Changing Climate, AGU Monograph, accepted.
- [13] **McPhaden**, **M. J.**, T. Lee, S. Fournier and M. A. Balmaseda, 2019: ENSO Observations, AGU Monograph, accepted.
- [14] Karamperidou, C., M. F. Stuecker, A. Timmermann, K.-S. Yun, S.-S. Lee, F.-F. Jin, A. Santoso, W. Cai, and **M. J. McPhaden**, 2019: ENSO in a changing climate: Challenges, paleo-perspectives, and outlook. AGU Monograph, accepted
- [15] **Shayne McGregor**, Myriam Khodri, Nicola Maher, Masamichi Ohba, Francesco S. R. Pausata, and Samantha Stevenson (2020). The Effect of Strong Volcanic Eruptions on ENSO. AGU monograph - *In El Niño Southern Oscillation in a Changing Climate*, Michael J. McPhaden, Agus Santoso, and Wenju Cai (Eds.). Wiley.
- [16] **McPhaden**, **M.J.**, A. Santoso, and W. Cai, 2019: Understanding ENSO in a Changing Climate. *Eos*, Trans. Am. Geophys. Union., 100, <https://doi.org/10.1029/2019EO124159>.
- [17] Hagos, S., G.R. Foltz, C. Zhang, E. Thompson, H. Seo, S. Chen, **A. Capotondi**, K. Reed, C. DeMott, A. Protat, 2019: Atmospheric Convection and air-sea interactions over the tropical oceans: Progress, challenges, and opportunities. *Bull. Amer. Meteor. Soc.*, accepted.

Proforma for CLIVAR Panel requests for SSG approval for meetings

1. **Panel or Working Group:** Pacific Region Panel
2. **Title of meeting or workshop:** 3rd Summer School on Theory, Mechanisms and Hierarchical Modeling of Climate Dynamics: Tropical Oceans, ENSO and their Teleconnections
3. **Proposed venue:** Trieste, Italy at the Abdus Salam International Centre for Theoretical Physics (ICTP)
4. **Proposed dates:** 3-14 August 2020
5. **Proposed attendees, including likely number:** Approximately 50 participants (mainly early career scientists) from around the world and 18 lecturers (senior scientists, with expertise on ENSO and its global teleconnections). The summer school will be advertised using multiple channels, and a selection committee will be established to select the participants who will get financial support to attend the Summer School, while other participants will be invited to attend the course at their own cost.
6. **Rationale, motivation and justification, including: relevance to CLIVAR science & WCRP Grand Challenges, and any cross-panel/research foci links and interactions involved:** ENSO understanding, modeling and forecasting have been major foci of research within International CLIVAR, given the impacts of ENSO in many areas very important for society. The proposed Summer School will build on the achievements of the ENSO Diversity Working Group, and extend its legacy with the inclusion of new advances in inter-basin interactions and tropical teleconnections. These recent advances will allow us to broaden the discussion on the topics that were identified as outstanding issues and key research priorities: Causes of ENSO diversity regime changes; Precursors and Triggers; Sustained and enhanced ocean observations for ENSO; Teleconnections and impacts; Assessment of climate model performance in simulating and predicting ENSO diversity. Thus, the goals of the proposed Summer School are fundamentally aligned with and support those of CLIVAR PRP research, including the PRP's planned activities on ENSO metrics, ENSO conceptual models, and the tropical Pacific observing system.
The proposed summer school will contribute to CLIVAR science: this topic is very relevant to the tropical climate dynamics and predictability, a core science topic in the new CLIVAR science plan. It is also relevant to WCRP Grand Challenge on "Near-term Climate prediction".
7. **Specific objectives and key agenda items:** The El Niño Southern Oscillation (ENSO) is a naturally occurring phenomenon in the tropical Pacific, and it is a strong driver of significant weather and climate anomalies across the globe. The global teleconnections related to ENSO and its diverse expressions continue to be an area of very active research, and include not only effects on the circulation over the mid-latitudes (Europe, Asia and North America), but also the strong influence on the Indian Monsoon. The Indian Monsoon (as well as other monsoons) also have their own set of teleconnections, not all of which are related to ENSO. In recent years, there have been significant advances in the understanding of the regions that affect the monsoon and of the regions the monsoon interact with, including the tropical ocean

basins, the adjoining land masses, mid-latitudes and the stratosphere. Recent research developments also include inter-basin interactions, and their influence on ENSO, its decadal modulation, and global teleconnections.

The proposed summer school on Tropical Oceans, ENSO and their teleconnections, is aimed to share the latest advances in the understanding of ENSO dynamics, diversity, modeling, predictability, and decadal modulation, as well as its associated broad range of teleconnections. The summer school is extremely relevant to scientists (particularly for early career scientists and students) from developing countries, because many economies (in particular in monsoon affected countries) depend on the accuracy of seasonal to longer-term prediction of agricultural production.

The lead organizers and many invited speakers for the summer school have participated in the organization of relevant activities led and coordinated by the CLIVAR Pacific Region Panel and former Research Focus on ENSO in a Changing Climate (2015-2018) in the past years, including:

- ENSO Complexity Workshop (Busan, Korea, 2017), which produced a paper entitled ‘El Niño–Southern Oscillation complexity’ published in Nature in 2018;
- IV International Conference on El Niño Southern Oscillation: ENSO in a warmer Climate (Ecuador, 16-18 October 2018);
- Two workshops on Tropical Pacific Decadal Variability (Ecuador, 2018 & Paris, France 2019), whose outcomes are being summarized in a paper to be submitted shortly to Science;
- A paper on ‘Pantropical climate interactions’ published in Science (2019).
- A standard ENSO evaluation protocol of CMIP models (ENSO Metrics)

Several of the organizers and speakers have also been involved as contributors to the new Wiley book entitled "El Niño Southern Oscillation in a Changing Climate" (McPhaden, Santoso, Cai, Eds.) that is in production now and will be published early next year. That book will be available to students as part of the summer school and will be a major source of material for the curriculum.

8. **Anticipated outcomes (deliverables):** A summary report of the summer school will be prepared. Key highlights from the school will be summarized in a report for BAMS.

We are also planning to publish a special edition of “CLIVAR Exchanges” providing a summer school summary and showcasing selected research presented.

Apart from these short-term deliverables, experience from previous summer schools that some of the organizers/lecturers participated in has shown the profound impact these schools have had on the early career scientists who attended them, by exposing them to cutting-edge research, instilling in them the curiosity and passion for science, thus fostering the development of a new generation of talented climate researchers.

9. **Format:** The summer school will be organized over a two-week period (10 working days plus one Saturday). The school will include not only lectures on the current state of knowledge on ENSO and the associated broad range of teleconnections, but also practical sessions and the development of student projects to provide a hands-on approach to the understanding of the material presented in the lectures.

The school will cover the following topics

Week 1: ENSO dynamics

- ENSO phenomenology
- ENSO theory
- ENSO modeling

- ENSO decadal modulation
- ENSO prediction

Week 2: ENSO teleconnections

- Pathways for tropical influence on the extra-tropics
- Remote impacts of the Indo-Pacific on Europe
- Global teleconnections with the Asian monsoon
- Decadal variations of interannual ENSO teleconnections
- Inter-basin teleconnections

Poster sessions will be organized during the summer school to give more opportunities for early career scientists and students to share their works among peers.

Sessions will also be planned to introduce the participants to the relevant activities and research interests of both US and International CLIVAR, which will provide opportunities for networking, as well as help identify possible pathways by which US and International CLIVAR can support early career scientists.

- 10. Science Organizing Committee (if relevant):** Antonietta Capotondi (University of Colorado and NOAA/ESRL, USA), co-chair of the International CLIVAR Pacific Region Panel; David Straus (George Mason University, USA); Jagadish Shukla (George Mason University, USA); Fred Kucharski (ICTP, Italy); Mike McPhaden (NOAA/PMEL, USUSA); Eric Guilyardi (IPSL/LOCEAN, Paris, France); Andrew Wittenberg (NOAA/GFDL, USA)
- 11. Local Organizing Committee (if relevant)**
- 12. Proposed funding sources and anticipated funding requested from WCRP:**

ICTP:	32,000 US\$ (including venue, facilities, lodging and meals for 68 attendees)
US CLIVAR:	30,000 US\$ (including travel for US lecturers and students)
WCRP:	4,000 CHF (travel support for non-US lecturers and students).

**Proforma for CLIVAR Panel requests
for SSG approval for meetings**

1. **Panel or Working Group:** Pacific Region Panel
2. **Title of meeting or workshop:** 15th session of the PRP meeting
3. **Proposed venue:** Trieste, Italy at the Abdus Salam International Centre for Theoretical Physics (ICTP)
4. **Proposed dates:** 1 or 2 August 2020
5. **Proposed attendees, including likely number:** PRP members + 5 invitees (~20 people)
6. **Rationale, motivation and justification, including: relevance to CLIVAR science & WCRP Grand Challenges, and any cross-panel/research foci links and interactions involved:** Opportunity to hold our meeting back to back with the ENSO summer school, to foster our collaboration with US CLIVAR, reduce carbon footprint and travel costs for the several PRP members participating in the summer school, and share the cost of the venue
7. **Specific objectives and key agenda items:** ENSO conceptual models, ENSO decadal variations
8. **Anticipated outcomes (deliverables):**
9. **Format:**
10. **Science Organizing Committee (if relevant)**
11. **Local Organizing Committee (if relevant)**
12. **Proposed funding sources and anticipated funding requested from WCRP:**
4k CHF (travel expenses for 2 PRP members)