

2009 Mechanism of North Pacific Low Frequency Variability Workshop

by Emanuele Di Lorenzo and Shoshiro Minobe

A 2-day workshop on “*Exploring the predictability and mechanisms of Pacific low frequency variability beyond inter-annual time scales*”, co-convened by the authors of this article, was held on October 24–25 at the 2009 PICES Annual Meeting in Jeju, Korea. The workshop was well attended with over 25 contributors, and was divided into four sections: (1) *Ocean and atmosphere variability in the North Pacific*, (2) *Coupling between tropics and extra-tropics*, (3) *North Pacific western boundary variability and feedbacks*, and (4) *Discussion and synthesis*. Thanks to the support of PICES, we were able to accommodate eight invited speakers, who covered each of the focus areas: Suman Nigam (University of Maryland, U.S.A.), Curtis Deutsch (University of California Los Angeles, U.S.A.), Lixin Wu (Open University of China) Michael Alexander (NOAA, U.S.A.), Dan Vimont (University of Wisconsin-Madison, U.S.A.), Bo Qiu (University of Hawaii, U.S.A.), Masami Nonaka and Bunmei Taguchi (Earth Simulator, JAMSTEC, Japan). The overall goal of this workshop was to review our current understanding of the dynamics underlying low-frequency fluctuations of the Pacific and to isolate potential mechanisms and linkages (*e.g.*, tropics/extratropics coupling, ocean/atmosphere coupling/feedbacks in the western boundary current system) that can provide the basis for low-frequency predictability.

Ocean and atmosphere variability in the North Pacific

(Invited speakers: S. Nigam and C. Deutsch)

The first section of the workshop was devoted to review of our current understanding of the modes of ocean low-frequency variability that act on timescales beyond interannual, and of the relationship between modes of variability in the ocean and atmosphere (S. Nigam). Several talks focused on the importance of the first two dominant modes of sea surface temperature (SST) and sea surface height (SSH) variability of the North Pacific, namely the Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO). Strong climate transitions of the North Pacific are likely better understood by considering both modes. For example, while the PDO has played a dominant role in the 1976–77 climate transition, the NPGO dominated the 1988–89 climate transition (S. Yeh). These transitions are a prominent signal in marine ecosystems and in biogeochemical tracers (*e.g.*, oxygen), although the dynamics connecting physics to ecosystems and biogeochemistry was not explored and to large extent remains unclear (C. Deutsch). While it was suggested that part of the Pacific low-frequency variability may be forced by the Lunar and Solar cycle (*e.g.*, PDO, S. McKinnell), it was generally recognized that the dynamics of the oceanic modes can be understood in the context of their

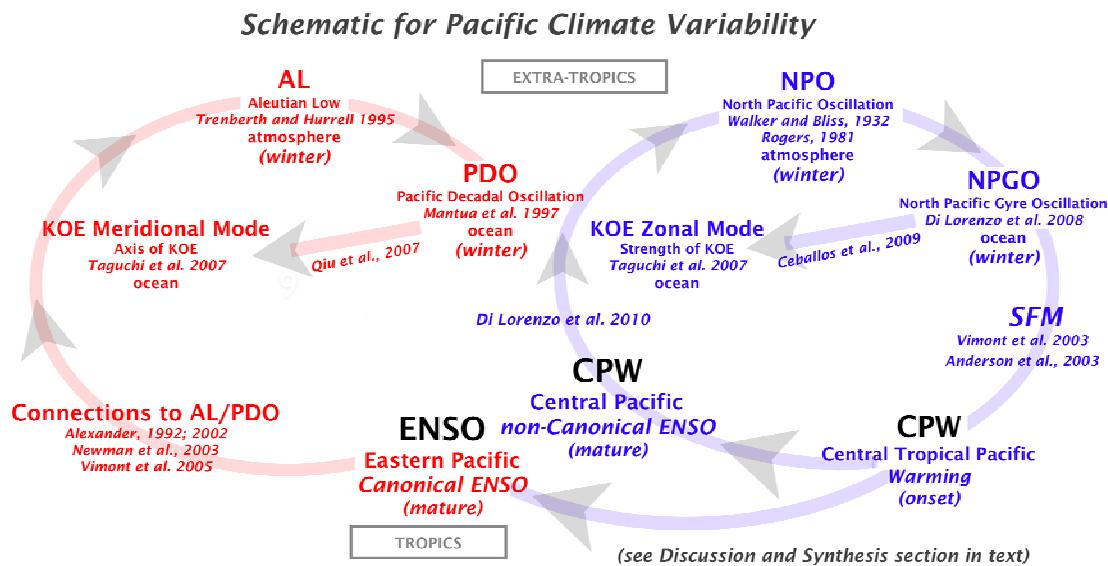
atmospheric drivers. While the PDO responds to variability of the Aleutian Low (AL) (S. Nigam), the NPGO appears to be forced by the North Pacific Oscillation (NPO) (E. Di Lorenzo), which emerges as the second dominant pattern of North Pacific sea level pressure after the AL. The AL and NPO are the surface expressions of atmospheric variability associated with the Pacific North American (PNA) and Western Pacific (WP) teleconnection patterns. Statistical analysis of SST (S. Nigam) also isolated a Pan-Pacific decadal variability mode that is related to the Atlantic Multidecadal Oscillation (AMO), which needs further investigation in terms of ecosystem impacts and may provide means to synchronize ecosystem variations between oceanic basins (*e.g.*, Atlantic and Pacific). Understanding how modes of ocean and atmospheric variability such as the PNA/AL/PDO and WP/NPO/NPGO respond to anthropogenic climate forcing was also discussed and remains an outstanding issue (M. Wang).

Coupling between tropics and extra-tropics

(Invited speakers: L. Wu, M. Alexander and D. Vimont)

This section of the workshop explored the mechanisms and dynamics by which tropics and extra-tropics interact. While we have known for a while that tropical activity associated with the canonical El Niño Southern Oscillation (ENSO) excites atmospheric variability of the PNA/AL/PDO, recent studies (D. Vimont, M. Alexander) also suggest that the extra-tropical variability of the NPO/NPGO – the second dominant pattern of atmospheric/ocean variability in the North Pacific – can affect ENSO. Coupled ocean/atmosphere model experiments shown by D. Vimont suggest that the NPO variability in the North Pacific excites a mode of variability that is independent of ENSO. This mode – referred to as the Meridional Mode because of its north-south spatial and temporal structure – generates warm temperature anomalies in the central tropical Pacific that lead to an ENSO response about one year later. Support for this hypothesis was presented using coupled climate models (M. Alexander). In addition to the NPO/NPGO to ENSO connection, other studies that used partial coupling of a coupled climate model suggested that the PNA/AL/PDO North Pacific expression may exert an even stronger control on tropical variability (L. Wu).

There was also discussion on a new flavor of a non-canonical ENSO characterized by a central Pacific warming (CPW) pattern which drives a teleconnection to the North Pacific that affects the variability of the NPO/NPGO (E. Di Lorenzo). This link may provide a positive feedback between tropics and extra-tropics.



Further understanding and quantifying of these coupling dynamics is necessary to establish the physical basis for exploring the predictability of North Pacific climate.

North Pacific western boundary variability and feedbacks

(Invited speakers: B. Qiu, M. Nonaka and B. Taguchi)

In this section we discussed how the large-scale modes of North Pacific variability (*e.g.*, PDO and NPGO) have a significant delayed impact on the low-frequency dynamics of the North Pacific western boundary, and explored mechanisms by which the western boundary SST variability can feedback onto large-scale atmospheric variability. The two dominant modes of oceanic variability in the Kuroshio-Oyashio Extension (KOE) region were viewed in terms of a lagged response to large-scale atmospheric variability of the AL/PDO and NPO/NPGO, respectively. Satellite SSH and SST analyses show that the first dominant mode in the KOE, which corresponds to a change in mean location of the jet's axis and a switch between a stable and unstable state (*B. Qiu*), is forced by the arrival of Rossby waves excited by the AL/PDO in the central North Pacific. From long-term *in situ* observations, the second mode of the KOE corresponding to an acceleration of the jet forced by the NPO/NPGO was reconstructed (*S. Minobe*). Effects of the NPO/NPGO modes were also reported in regional seas (*e.g.*, Okhotsk Sea, *E. Ustinova*). In addition, multi-decadal eddy-resolving ocean simulations elucidated some important non-linear dynamics and feedbacks in the KOE. It was shown that upon the arrival of these Rossby waves in the KOE region, adjustment of Kuroshio Extension's recirculation gyres organizes the incoming signals into narrow oceanic frontal zones, causing low-frequency variability in SST and surface heat fluxes (SHF), with large amplitudes along the fronts (*M. Nonaka*). The differential SHF across the oceanic fronts can potentially force the overlying atmosphere on a large scale. This feedback was

investigated using atmospheric regional model experiments (*B. Taguchi*) that confirmed the importance of the near-surface air-sea temperature gradients in shaping the seasonal (winter–spring) mean atmospheric storm-track along the oceanic frontal zones, as observed. A more direct coupling via atmospheric Ekman pumping was also suggested as a key process to couple the ocean mesoscale and atmospheric circulation in the KOE (*N. Schneider*).

It has been shown that there is predictability with a lead-time of several years associated with the propagation and arrival of the Rossby waves excited by the AL and NPO. If air-sea feedbacks from the KOE SST to the large-scale atmosphere are confirmed, they may provide an alternative pathway to self-sustained modes of variability in the extra-tropics, which could enhance even more the predictability of North Pacific decadal climate.

Discussion and synthesis

(Coordinators: A. Miller, S. Minobe and E. Di Lorenzo)

The discussion section was opened with an attempt to summarize our current understanding of the Pacific climate dynamics and the linkages among the various modes of ocean and atmospheric variability, including the connections between tropics and extra-tropics. The schematic above (from *E. Di Lorenzo*) depicts a synthesis of the hypothesis and dynamics discussed during the workshop. In this schematic there are two sets of dominant dynamics in the Pacific: the ENSO/AL/PDO (red path) and CPW/NPO/NPGO (blue path). These are physically linked and connected through the ENSO system in the tropics. Both the PDO and NPGO are to first order the oceanic expressions of the atmospheric forcing associated with the AL and NPO variability, respectively, and therefore, integrate the low-frequency variations of the canonical and non-canonical ENSO through atmospheric teleconnections from

ENSO→AL→PDO and CPW→NPO→NPGO. In addition to the tropics driving the extra-tropical variability, a link also exists from the extra-tropics back to the tropics through the NPO→CPW/ENSO (*D. Vimont, M. Alexander*), giving rise to the potential for a feedback between tropics and extra-tropics along the path NPO→CPW→NPO (*E. Di Lorenzo*). A link from the PDO to the tropics has also been suggested (*L. Wu*) but the relationship to the ENSO system is still being investigated.

While the AL and NPO atmospheric variability have maximum loading in the central and eastern North Pacific, their forcing also drives prominent decadal variations in the western North Pacific. Specifically, the oceanic adjustment to the SSHa anomalies of the AL/PDO and NPO/NPGO radiate Rossby waves that propagate into the western boundary. The arrival of the AL/PDO SSHa is associated with changes in the axis of the KOE, while the arrival of the NPO/NPGO SSHa modulates variations in the speed of the KOE. These two modes of KOE variability – the KOE Meridional Mode (shift in axis) and the KOE Zonal Mode (change in speed) – have been shown to capture the first two dominant modes of variability in the KOE. In the KOE, the expression of these modes is characterized by frontal scale features in SST and SHF that may feedback

onto the modes of atmospheric variability (e.g., AL, NPO) (*M. Nonaka, B. Taguchi, N. Schneider*).

The discussion section emphasized the need to develop quantitative approaches to evaluate the role of these ocean/atmosphere modes, especially the more recently recognized CPW/NPO/NPGO system, in explaining North Pacific (SST, circulation), sea ice, climate over land and marine ecosystem indices. PICES provides an ideal opportunity to use such quantitative models with long-term observations in the North Pacific from Canada, China, Japan, Korea, Russia, and the United States of America.

We thank PICES and the Korean government for providing a great venue for the workshop. We thank the attendees and participants and, in particular, we appreciate the effort of many of the invited speakers who are new to the PICES community and who endured a long travel to contribute to the workshop. The organizers would also like to thank Alex Bychkov (PICES Executive Secretary) and Julia Yavzenko (PICES Database and Web Administrator) for helping with the organization and logistics, and a special thanks to James Overland (PMEL, NOAA, U.S.A.) who was one of the proposers and a strong supporter of this workshop.



Group photo of the workshop participants (workshop convenors and authors of this article, Manu and Shoshiro, are at the far right). A full-size version of this and other photos are available at http://www.sci.hokudai.ac.jp/~minobe/meeting/2009_PICES_WS8. (Courtesy of N. Schneider who took the picture and is absent in the photo!)

Dr. Emanuele (Manu) Di Lorenzo (edl@gatech.edu) is an Associate Professor at the School of Earth and Atmospheric Sciences, Georgia Institute of Technology, U.S.A. His research interests and experience span a wide range of topics from physical oceanography to ocean climate and marine ecosystems. More specific focus is on dynamics of basin and regional ocean circulation, inverse modeling, Pacific low-frequency variability, and impacts of large-scale climate variability on marine ecosystem dynamics. In PICES he is a member of the Working Group on Evaluations of Climate Change Projections and of the Advisory Panel on Climate Ocean Variability and Ecosystems (COVE-AP). He also serves on the U.S. Comparative Analysis of Marine Ecosystem (CAMEO) Science Steering Committee.

Dr. Shoshiro Minobe (minobe@mail.sci.hokudai.ac.jp) is a Professor at the Graduate School of Sciences, Hokkaido University, Japan. His research interests focus on decadal climate variability and air-sea interaction. Included in his publications is a widely-referenced article proposing 50-yr climate variability and an interpretation of climate regime shifts associated with 50-yr and 20-yr climate variability. His paper on the ocean-to-atmosphere influence over the Gulf Stream was featured as the cover article of the journal Nature in 2008. Shoshiro worked as a convenor for the PICES symposium and workshops (1999, 2006, 2007) for decadal climate variability and its relation to marine ecosystem, and as a guest editor of the Progress in Oceanography special issue on "North Pacific Climate Regime Shift" (2000). He also served as a member of the Implementation Plan Writing Team for the PICES scientific program, FUTURE.