International Pacific Research Center

October 1997–March 2000

School of Ocean and Earth Science and Technology
University of Hawai‘i at Mānoa
Honolulu, Hawai‘i

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Introduction

This first report of the International Pacific Research Center (IPRC) provides an overview of the Center's activities from its inception to March 2000. The collective activities of its researchers are the "heart" of the IPRC, and much of the report consists of statements from individual researchers outlining their own accomplishments. The report also includes lists of research publications and conference presentations by IPRC scientists, as well as the seminars, workshops, visitors, meetings, and conferences sponsored by the IPRC. The IPRC computing facilities, so necessary for cutting-edge climate research, are also briefly described.

The IPRC was founded in October 1997 within the School of Ocean and Earth Science and Technology (SOEST) at the University of Hawai'i's (UH) Mānoa campus. Establishment of the Center became possible through an agreement between the United States and Japan under the "U.S.-Japan Common Agenda for Cooperation in Global Perspective." Today much of the Center's financial support comes from the Frontier Research System for Global Change (Frontier Program or FRSGC) through a cooperative agreement among the University of Hawai'i, the Japan Marine Science and Technology Center (JAMSTEC), and the National Space Development Agency of Japan (NASDA). Funding comes also from U.S. federal agencies, such as the National Aeronautics and Space Administration and, for individual IPCR scientists, from the National Science Foundation (NSF) and the Office of Naval Research (ONR).

The IPRC Implementation Committee is responsible for the overall design of the IPRC and its implementation. Currently this committee consists of four Japanese representatives selected by the Science and Technology Agency (STA), NASDA, and JAMSTEC; of four U.S. representatives selected by NASA, NOAA, NSF, and DOE; and of one representative from UH.

Guidance on scientific matters comes from the Scientific Advisory Committee, which at present is composed of eight scientists who are internationally recognized for their expertise in climate research areas relevant to the IPRC.

The IPRC mission is the following:

> ***To provide an international, state-of-the-art research environment to improve understanding of the nature and predictability of climate variability in the Asia-Pacific sector, including regional aspects of global environmental change.***

At the present time, the IPRC is one of only a few research organizations focused on this important mission. The Center is thus a necessary component of a complete research strategy for global change, which must rely on a network of cooperating institutions throughout the world.

The word *international* in the mission statement, and in the name of our Center, has true significance. It reflects our belief that the most effective way to make progress in answering large-scale climate questions is through international cooperation. Toward this end, our current staff has people from Australia, China, Denmark, Germany, India, Japan, Korea, Russia, and the U.S. In future hires we hope to expand this list. Furthermore, we have a strong program for international visitors and are committed to hosting two major international meetings each year.

To achieve its mission, the current IPRC research strategy is to carry out diagnostic and modeling studies of the atmosphere, ocean, and coupled ocean-atmosphere-land system. These activities require intensive use of data sets that cover a wide variety of time and space scales. Data assimilation, which allows optimal incorporation of observed data into models, is an integral part of this effort. To ensure that the necessary data sets are easily available and usable, we are seeking to establish the Asia-Pacific Data Research

Center (APDRC) within the IPRC, and we include in this report a section outlining our plans in this regard.

The IPRC Science Plan, which can be found at the IPRC website, is a guidebook for the maintenance and development of IPRC research and operations. Among other things, it sets forth four broad IPRC research themes. These themes and corresponding goals are as follows:

Theme 1: Indo-Pacific Ocean Climate

To understand climate variations in the Pacific and Indian Oceans on interannual-to-interdecadal time scales

Theme 2: Regional Ocean Influences

To determine the influences on Asia-Pacific climate of western boundary currents, the Kuroshio/Oyashio Extension system, marginal seas, and the Indonesian Throughflow

Theme 3: Asian-Australian Monsoon System

To understand the processes responsible for climatic variability and predictability of the Asian-Australian Monsoon System and its hydrological cycle at intraseasonal through interdecadal time scales

Theme 4: Impacts of Global Environmental Change

To identify the relationship between global environmental change and Asia-Pacific climate

Several objectives are associated with each theme and goal. They outline projects we believe are achievable within a finite time interval and with well-defined resources. Currently, IPRC scientists are working on all the objectives listed in the Science Plan for Themes 1–3. As yet, however, no IPRC researchers are working on Theme-4 projects, a consequence of the IPRC having no researcher with expertise in this field—a lack we intend to alleviate.

A major aspect of IPRC activities has been, and continues to be, the recruitment of qualified scientific staff. The intent was to hire in two stages: a rapid initial stage in which about half of the envisioned IPRC staff would be hired, followed by a more gradual expansion to its full size. The first stage is nearly completed. The current staff consists of the following: four scientists with tenure-track positions at the University of Hawai‘i; nine research scientists with the Research Corporation of the University of Hawai‘i; five research scientists with Japan’s Frontier Program, one visiting scientist, and four postdoctoral fellows. A fifth tenure-track faculty member has been hired, and he will arrive at the IPRC in Fall 2000. The Center has also two data specialists, two scientific computer programmers, and a computer systems engineer.

The first two-and-a-half years of the IPRC have been exciting ones for us all, and Center scientists have already achieved considerable success, a success this report demonstrates. The next few years will surely be equally, if not more, exciting as the IPRC grows to its full size.

Julian P. McCreary, Jr.
Director
International Pacific Research Center

Research Activities and Accomplishments
Theme 1: Indo-Pacific Ocean Climate

Overview

Because of the large heat capacity of water, Earth's oceans exert great influence on global climate. Among other things, they provide a long-term memory for the climate system. Thus, understanding how the states of the Indian and Pacific Oceans vary on climatic time scales, and how these variations interact with atmospheric processes, is critical for improving understanding and prediction of Asia-Pacific climate. Theme 1 of the IPRC is devoted to this effort.

The first two objectives of Theme 1 are to identify the oceanic and atmospheric processes that cause decadal variability in the extratropical North Pacific and in the El Niño-Southern Oscillation (ENSO). Concerning these objectives, an intermediate, coupled ocean-atmosphere model has been developed to investigate North Pacific and ENSO decadal variability (McCreary, Solomon). The model is able to generate both interannual (4-year) and decadal (16-year) signals, and the interactions between the two signals are being studied. Research with an atmospheric global circulation model (GCM) indicates that asymmetric sea surface temperature (SST) anomaly patterns about the equator (such as the Atlantic dipole pattern) can be sustained by positive feedback from the atmosphere and that this interaction can lead to climatic oscillations (Xie). Finally, studies using a coupled model suggest that the nature of the asymmetry of the continents around the Pacific Ocean plays a role in displacing the Intertropical Convergence Zone (ITCZ) north of the equator (Xie).

Diagnostic studies have also been carried out on these objectives. Analysis of observational data and simple coupled models indicates that the changes in time-space structures of ENSO around the late 1970s are due to shifts in the background state of the equatorial Pacific Ocean (An, B. Wang). Lagged correlation analysis between SST and 850mb geopotential height anomalies in the equatorial and extratropical North Pacific reveals a number of interesting evolutionary features of the Pacific decadal variability (Tomita, B. Wang). In a related study, decadal SST anomalies in parts of the North Pacific and North Atlantic were found to be correlated strongly between boreal winter and summer, indicating that there are mechanisms by which SST anomalies generated in winter can persist through seasons (Zveryaev, Xie).

The third Theme-1 objective is to determine the basic processes that maintain the Pacific Ocean general circulation and that cause its climatic variability. Toward this objective, an ocean GCM has been used to study the subsurface branch of the Pacific Subtropical Cell, a branch that allows subtropical water to reach the equator (Nonaka, Xie, McCreary). Solutions suggest an explanation for why temperature anomalies, which are generated by subduction of SST variability in the subtropical North Pacific, cannot be carried to the equator by this branch with any significant amplitude. In addition, the same model has been used to study the processes that form various North Pacific mode waters (Nonaka, Xie). Changes in the circulation pathways of North Pacific Central Mode Water were shown to cause substantial subsurface temperature anomalies. In the same study, the Kuroshio Extension was found to be a key region for the surfacing of the thermocline variability that results from Pacific basin-wide decadal variations in wind patterns. The effects of current shear and Earth's rotation on upper ocean mixing processes have been studied (D. Wang), yielding results that are expected to be useful in improving mixing parameterizations in climate models. Finally, in collaboration with the Japan Fisheries Agency and Hokkaido University, the first-ever *in-situ* study of the ocean-atmosphere characteristics of tropical instability waves has been conducted (Xie). This work has revealed the vertical structure of the atmospheric response to these waves and leads to a better understanding of how the planetary boundary layer dynamics respond to SST anomalies over a *cold*, rather than a warm, ocean surface.

The fourth Theme-1 objective is to determine the nature and causes of Indian Ocean SST variability on interannual-to-decadal time scales. The Cross-Equatorial Cell is a shallow meridional overturning circulation in the Indian Ocean analogous to the Subtropical Cells in the Pacific and Atlantic Oceans. It is responsible for exporting out of the region the net annual-mean surface-heat input into the northern Indian Ocean. Its structure and annual cycle have been explored in detail using a variety of numerical models of varying dynamical complexity (Miyama, McCreary, Jensen, Loschnigg). In a related project, the Indian Ocean heat budget and interannual variations in the cross-equatorial meridional heat transport have been investigated (Loschnigg). A project to study vertically propagating equatorially trapped waves has begun (Miyama, McCreary). Finally, studies of the influences of the Indonesian Throughflow (ITF) on both Indian and Pacific Ocean circulations have been carried out. The ITF has been shown to have a large effect on the circulation of intermediate water in the Pacific Ocean (McCreary). Using an Indo-Pacific model of intermediate complexity, the complete circulation pathways associated with the ITF have been investigated, and processes that influence the vertical structure of the ITF identified (Miyama, McCreary).

Individual Report

Tommy Jensen

Associate Researcher

Tommy Jensen obtained his Ph.D. in physical oceanography at the University of Copenhagen, Denmark, in 1986. In 1989 he received a second Ph.D., in geophysical fluid dynamics, from The Florida State University. He was a research scientist at Colorado State University, Department of Atmospheric Science, before joining the IPRC in 1998. His research interests include numerical modeling of oceans, coupled ocean-atmosphere models, equatorial dynamics, geophysical fluid dynamics, air-sea interaction, and coastal oceanography.

Tommy Jensen has developed and used the Thermodynamic Ocean Modelling System (TOMS) to construct several models of the Pacific and Indian Oceans and to conduct a number of projects.

To investigate the interannual variability of the North Equatorial Current and the Kuroshio Extension region (Theme 2), he set up three models that simulate events in the Pacific Ocean from 40°S to 40°N: a 4.5-layer thermodynamically active model, and hydrodynamic 1.5-layer and 2.5-layer models. Forced with monthly mean ECMWF climatological data, the runs showed that high interannual variability occurred in the modeled Kuroshio region, even when the same monthly climatological wind forcing was applied year after year—a result of baroclinic instability (Jensen, TRIANGLE ’98 Conference, 1998). He confirmed these results by developing and carrying out runs with a global 4.5-layer model and with an Indo-Pacific model that included the ITF.

Constructing thermodynamic models of the Indian Ocean that range from medium (1/3º) to high horizontal resolution (1/8º) and include reduced-gravity and bottom-topography, Jensen investigated effects of bottom topography on the semiannual equatorial currents and found the following: (a) the second baroclinic mode dominates the semiannual equatorial zonal currents; (b) bottom topography has little influence on the currents in the upper ocean; and (c) although the large-scale structure of the deep flow is highly coherent with the flow above, large local modifications occur near ocean ridges and plateaus (Jensen, FRSGC Symposium 1999).

Jensen used his 1/3º Indian Ocean model also to study the exchange of salt between the Arabian Sea and the Bay of Bengal. Prognostic temperature, salinity, and passive tracers were included in the model equations. The solutions suggest the existence of subsurface currents of high-salinity water from the Arabian Sea into the Bay of Bengal, but there is surprisingly little low-salinity transport in the opposite direction; instead, low-salinity water leaves the Bay of Bengal along the eastern side of the basin. He confirmed these transports using two passive tracers—one introduced into the Arabian Sea and the other into the Bay of Bengal. Also surprising was that, closely tied to the annual cycle, Arabian Sea water is transported southward across the equator in the central part of the Indian Ocean, particularly during the transition from the southwest monsoon to the northeast monsoon in the section from 47-60ºE. In further simulations with this model, Jensen found that the source of low-salinity water for the Arabian Sea lies in the western Indian Ocean, just south of the equator: water is carried northward along the African coast in the Somali Current as was suggested by Jensen (1991) using potential vorticity as a tracer. He has confirmed these pathways with model drifters (Jensen, Frontier Workshop, 1999; IPRC Mini-Workshop on the Indian Ocean, 1999; and the Symposium on Indo-Pacific Climate, 2000). Jensen is now collaborating with Miyama, McCreary, Loschnigg, and Godfrey on a study aimed at determining the pathways of cross-equatorial flow and explaining the mechanisms by which the flow overcomes the sign reversal in background potential vorticity.

Jensen has also carried out two studies for improving computational techniques. First, using his 1/3º Indian Ocean model, he assessed the accuracy of a numerical technique, the Gravity Wave Retardation method, which speeds up computations for layered models (Jensen, 2000, *Mon. Wea. Rev.*, submitted). This method, which had not been checked before under realistic forcing and ocean conditions, was found to be accurate for speed-ups to a factor of about 8. Second, Jensen evaluated with the TOMS different open boundary conditions for a stratified ocean model and found that the Flow Relaxation Scheme was the best choice for most applications (Jensen, 1998, *JMS*).

Finally, Jensen has worked on several collaborative projects: with Jorge Capella, he has set up an Atlantic thermodynamic ocean model for the University of Puerto Rico; for Michael Kelly at Colorado State University he has developed a two-dimensional, equatorial 8.5-layer model, which will be coupled to a simple atmospheric model; and he has used a coupled atmospheric-ocean model in a project with David Randall and Donald Dazlich at Colorado State University and researchers at other institutions to study the influence of vegetation on a doubled-CO_2 climate-change scenario (Bounoua et al., 1999, *J. Clim.*). These co-workers have also coupled a thermodynamic Pacific Ocean model, constructed by Jensen, to the Colorado State University atmospheric GCM in order to analyze air-sea interactions in the Pacific basin.

Johannes Loschnigg

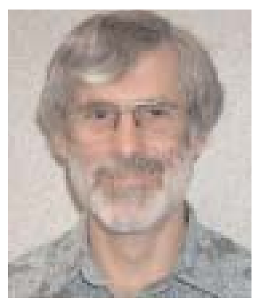
Postdoctoral Fellow

Johannes Loschnigg obtained his Ph.D. in atmospheric and oceanic sciences from the University of Colorado at Boulder in 1998. He came to the IPRC as a postdoctoral fellow in May 1999. His research interests include Indian Ocean climate dynamics; the relationship between the monsoon, the Tropospheric Biennial Oscillation, and SST anomalies in the Indian Ocean; intermediate coupled ocean-atmosphere modeling; and the impact of climate variability on human health and on other societal aspects.

Johannes Loschnigg's work at the IPRC has focused on the heat budget in the Indian Ocean in order to promote our understanding of the nature and causes of this ocean's SST variability. In a study by Loschnigg (with Peter Webster) on seasonal variations in the Indian Ocean heat balance and its relationship to the modulation of SST over the annual cycle, the major finding was the ability of meridional ocean heat transport to compensate for the large net surface heat flux into the northern Indian Ocean during boreal spring and early summer (Loschnigg and Webster, *J. Clim.*, in press).

Extending this work on the Indian Ocean heat balance to interannual time scales, Loschnigg is analyzing a 7-year run of a 2.5-layer Indian Ocean model for the years 1984–1990. The model shows a close relationship between the interannual variations in meridional heat transport (and thus in the heat balance of a large portion of the Indian Ocean basin) and the interannual variations in the strength of the Ekman-driven meridional circulation cell, which itself is driven by the surface winds of the monsoon. Loschnigg hypothesizes that this variation in heat transport may interact with the Asian monsoon system on interannual time scales and thereby enhance the biennial oscillation of the monsoon. He is preparing for publication a manuscript describing this work.

As a next step, Loschnigg intends to expand this work with the above Indian Ocean model to a 40-year run for the years 1958-98, hoping to isolate the modes of variability in the Indian Ocean and to analyze the key features in the Indian Ocean heat transport that affect SST. He plans to complement this study by analyzing the 300-year run of the NCAR Climate System Model to examine with this fully coupled model the influence of the Indian Ocean and SST anomalies on the variability of the South Asian monsoon and on the Tropospheric Biennial Oscillation (TBO). Dynamic features of the Indian Ocean relevant to the variability of the monsoon can then be isolated and further analyzed using the 2.5-layer model with which diagnostic studies are more readily conducted.



Julian P. McCreary, Jr.

Director, IPRC
Professor of Oceanography, SOEST
Theme 1 Co-Leader

Julian McCreary obtained his Ph.D. in physical oceanography in 1977 from Scripps Institution of Oceanography, University of California, San Diego. He was Dean of the Nova Southeastern University Oceanographic Center, Florida, for more than 15 years before joining the IPRC as Director in February 1999. His research interests include equatorial and coastal ocean dynamics, ocean circulation, coupled ocean-atmosphere modeling, and ecosystem modeling.

This past year, Jay McCreary has worked on projects dealing with the Pacific and Indian Oceans. Pacific Ocean projects include: (1) the development and analysis of an intermediate, coupled ocean-atmosphere model to study Pacific and ENSO decadal variability (with Amy Solomon), an extension of work reported by Kleeman et al. (1999, JGR); (2) investigation of the influences of the ITF on the Pacific Ocean general circulation (with Peng Lu and Zuojun Yu); and (3) an expansion of this second project that comprises both oceans and investigates the complete, three-dimensional pathways in the Pacific and Indian Oceans that are associated with the ITF (with Toru Miyama and Bo Qiu, University of Hawai‘i).

Two results of Project 2 are worth mentioning here. First, solutions suggest that the ITF is the reason why little North Pacific Intermediate Water (NPIW) recirculates in the northern tropics and Antarctic Intermediate Water flows into the far North Pacific (McCreary and Lu, 2000, *JPO*; in press), both properties resulting from the drainage of upper-layer water from the Pacific basin by the ITF. Second, solutions suggest also that the ITF is the primary driving force of the Tsuchiya Jets. These jets are eastward currents located on either side of the equator at depths of 200 to 500 meters along the poleward edges of thermostad water, and their transport is about 14 Sv. As such, they provide a major pathway for the circulation of sub-thermocline water throughout the tropical Pacific. If these results prove true, they provide a *remarkable* example of remote forcing by the ITF, with effects that are felt throughout the Pacific Ocean.

Indian Ocean projects include: (4) studying the causes of Indian Ocean SST anomalies on interannual time scales, including the Indian Ocean dipole mode (Murtugudde et al., 2000, *JGR*, in press); (5) isolating the influences of various salinity forcings in the Indian Ocean (Han et al., 2000a,b, *JGR*, submitted); (6) studying effects of diurnal and intraseasonal forcing on biological activity and mixed-layer variability in the Arabian Sea (McCreary et al., 2000, *JGR*, submitted); (7) simulating and understanding the dynamics of the Cross-equatorial Cell, a shallow, meridional overturning circulation in the Indian Ocean analogous to the subtropical cells in the Pacific Ocean (with T. Miyama, T. Jensen, and J. Loschnigg); (8) simulating and understanding vertically propagating, equatorially trapped waves at the annual and semiannual periods (with T. Miyama); and (9) writing a review paper on the dynamics of monsoon-related circulations in the Indian Ocean (Schott and McCreary, 2000, *Prog. Oceanogr.*, submitted).

Toru Miyama

Frontier Research Scientist

Toru Miyama obtained his Ph.D. in physical oceanography from Kyoto University in 1997. Upon receiving his degree, he came to the University of Hawai‘i at Mānoa as a visiting scientist with the Wyrtki Center before joining the IPRC as a Frontier research scientist. His research interests include dynamics of ITF variability and its role in the climate system, tropical and subtropical water exchange, and wavelet-optimized numerical ocean models.

Toru Miyama has worked on the following projects since coming to the IPRC: (1) a study of the influence of the ITF on the Pacific Ocean general circulation; (2) development of a wavelet analysis; (3) a Lagrangian analysis of the mass and heat budget of the warm water pool; and (4) a study of wave dynamics in the Indian Ocean.

The origins and vertical structure of the ITF are directly related to thermocline circulations and tropical-extratropical water exchanges between the Pacific and Indian Oceans. By using numerical models that include circulations in both the Pacific and Indian Oceans, factors in the thermocline circulations that govern the ITF can be identified. Thus, Miyama, in collaboration with Jay McCreary and Bo Qiu (University of Hawai‘i), developed a dynamic 4.5-layer model that includes both oceans in order to test hypotheses about essential dynamics of the circulation, especially the dynamics related to wind-driven circulation.

The model captured the thermocline circulations very well, yielding the following conclusions about the ITF: (a) the circulation corresponding to the intermediate waters is very sensitive to the parameterization of diapycnal mixing; (b) the total transport is 9 Sv and does not change with the mixing parameterizations, which suggests the validity of Godfrey’s Island Rule; (c) the vertical structure changes with the thermocline circulation in the Pacific Ocean; and (d) a deep core of the transport (2-3 Sv) corresponds to the

Antarctic Intermediate Water (AAIW) from the South Pacific; if this deep core is artificially blocked, the inflow corresponding to AAIW is greatly weakened in the North Pacific Ocean and comes mainly through the southern Indian Ocean.

In his second project, Miyama, in collaboration with Lee Jameson, developed a two-dimensional version of the numerical method known as the Wavelet Optimized Finite Difference Method (WOFD) for application to a model problem in oceanography. Such a wavelet analysis provides information on the energy present at various scales and locations throughout the computational domain. This method is a completely adaptive dynamic numerical approach, which has the ability to focus on small-scale physics.

In his third project, Miyama is using a Lagrangian method to examine the seasonal changes in the heat and mass balances of the warm water pool (WWP defined here as areas in the Pacific and Indian Oceans with water temperatures over 28˚C). The method tracks numerous particles in the velocity field of an ocean GCM, in which temperature values are tagged to particles at their instantaneous positions. This Lagrangian approach has the advantage over the Eulerian approach in that it shows clearly the origins of waters flowing into and out of the WWP and thus permits a more accurate evaluation of the large seasonal variability in the heat and mass budgets of the WWP. To identify the effect of air-sea heat flux, the temperature field was calculated using a diffusion equation with the same air-sea heat flux as in the ocean GCM. The results show, among other things, the following: The seasonal temperature change of water particles caused by air-sea heat exchange during their flow in and out of the WWP is most important for determining the seasonal temperatures of the WWP. The mass budget analysis reveals that the residence time of water particles in the WWP is about 1.3 years, implying that most particles leave after about one year and warm the adjacent regions. Thus, according to model calculations, vigorous water exchange between the WWP and the surrounding regions takes place (7% via the ITF). Major factors determining changes in the size and location of the WWP seem to be seasonal changes in the flow speeds of the currents and in the strength of the air-sea heat flux in and around the equator.

Finally, in the fourth project, with J. McCreary and W. Han (University of Colorado), Miyama is working on a study of the wave dynamics in the Indian Ocean in order to understand the mechanism and role of vertically propagating waves that are seen both in observations of the Indian Ocean and in general circulation models. (See figure 1 for a recent model run.) The numerical model that will be used is a linear, continuously stratified system. In this model, each variable is represented as an expansion in vertical modes. The merit of this method is that it can capture high vertical structure at small computational cost.

Masami Nonaka

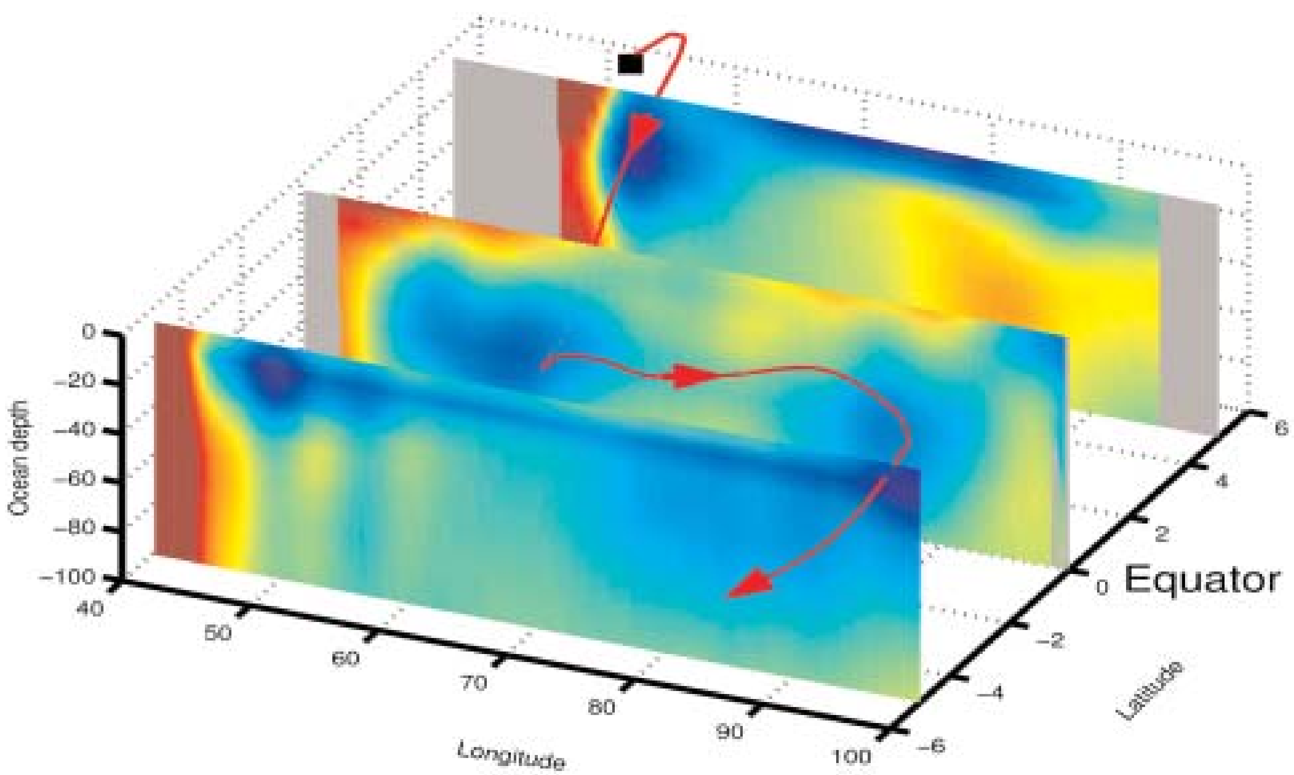
Frontier Research Scientist

Masami Nonaka obtained his Ph.D. in environmental earth science from Hokkaido University, Japan, in December 1998. He joined the IPRC as a Frontier research scientist in June 1999. His research interests include the ocean circulation connection between the subtropics and the tropics, and the role of the ocean in Pacific decadal climate variation.

Masami Nonaka's research focuses on the causes of decadal and interdecadal variations that appear in SST and subsurface temperature fields in the North Pacific and tropical Pacific. The propagation of temperature anomalies from the subtropics to the equator has been proposed to contribute to the tropical variations. Analysis of observed and simulated data, however, show that the southwestward-propagating signal does not reach the equator, and that temperature anomalies travel eastward in the northern Subtropical Gyre.

During this past year, Nonaka has used an ocean GCM to simulate the Pacific Ocean and to study how SST anomalies originating in the North Pacific are propagated in the subsurface layers of the ocean (see also section by Shang-Ping Xie). The simulation shows the pathway of temperature anomalies from the North Pacific and explains why it is difficult for these anomalies to cause equatorial temperature anomalies. This finding rules out one of the possibilities thought to contribute to equatorial temperature variations.

Figure 1. Annual mean northward current velocity in the equatorial Indian Ocean in a high-resolution ocean GCM (Ishida et al. 1998). Red (blue) denotes northward (southward) flow. The southward cross-equatorial flow occurs beneath the northward surface flow to form a shallow cross-equatorial roll. This is a local response to the cross-equatorial southerly winds that are a hallmark of the South Asia summer monsoon. The red line is the three-dimensional trajectory of a particle released off the Somalian coast at 10 m depth. Because of the equatorial roll, the particle stays near the equator for a long time, drifting toward the eastern boundary. There it eventually crosses the equator and then rides on the Ekman drift into the South Indian Ocean.



Amy Solomon

Assistant Researcher

Amy Solomon obtained her Ph.D. in climate dynamics from the Massachusetts Institute of Technology in 1997. She joined the IPRC in February 1998. Her research interests include coupled ocean-atmosphere interactions, and the role of baroclinic turbulence in the observed climate.

Amy Solomon's research emphasis at the IPRC has been to study the feedbacks that involve ocean-atmosphere interaction and tropical-extratropical interaction on interannual-to-decadal time scales in the Pacific sector. Her focus at this time is on understanding the dynamics of ENSO modulation by decadal extratropical ocean-atmosphere oscillations (with Jay McCreary). This research explores the decadal modulation of ENSO by studying changes in the circulation of the Northern Hemisphere Subtropical Cell. These changes are due to variations in Ekman transport at the northern edge of the tropics and affect equatorial upwelling.

This research uses a coupled model of the Pacific sector composed of a 3.5-layer ocean model (Lu et al.,1998), except that layer temperatures are allowed to vary, and an intermediate atmospheric model. The atmospheric model itself is composed of two parts: an empirical model that generates wind-stress anomalies from observed coupled patterns of wind stress and SST anomalies; and an atmospheric boundary layer model that generates heat-flux anomalies. Thus, the atmospheric model is driven by the ocean model's surface temperature, while the ocean model is driven by wind-stress and heat-flux anomalies produced by the atmospheric model.

Clearly, internal atmospheric processes can generate low-frequency variability with preferred spatial patterns similar to observed patterns of decadal variability, such as the Pacific North America atmospheric pattern (Horel and Wallace, 1981). What has proven difficult to ascertain from observations and GCM studies is whether there are also coupled extratropical ocean-atmosphere modes of variability that are fundamental in generating observed decadal variability. This research project is designed to study the decadal oscillations generated by these coupled modes and the influence of these oscillations on ENSO variability.

Solomon plans to continue research on the decadal modulation of ENSO. She will also investigate, using an idealized atmospheric GCM, the dynamical mechanisms that determine the atmospheric response to extratropical SST anomalies in the Pacific sector. This series of idealized studies is motivated by the complexity of the mechanisms that results from the sensitivity of the atmospheric response to the climatological mean state and from the location and intensity of the extratropical SST anomalies.

The research on the atmospheric response to extratropical SST anomalies will investigate several fundamental issues: the role of zonal asymmetry of equatorial SSTs in modifying the extratropical response, the sensitivity of the extratropical response to seasonality and location of extratropical SST anomalies, and the dynamics that control the growth and equilibration of the atmospheric response.

The model used for this study will be an idealized atmospheric GCM coupled to a fixed-thickness mixed-layer ocean model and an atmospheric boundary-layer model. This model explicitly resolves the intermediate-to-large-scale waves that transport heat and momentum while using simple parameterizations for atmospheric physics, such as convection and radiation. Due to the computational efficiency of the model, many runs can be done to test the sensitivity of the atmospheric response to the location of a SST anomaly. Simplified model physics, moreover, will allow the isolation of dynamical mechanisms that have been shown to play an important role in the extratropical atmospheric response to extratropical SST anomalies in studies with full atmospheric GCMs.

Dailin Wang

Associate Researcher

Dailin Wang received his Ph.D. in oceanography from the University of Hawaiʻi at Mānoa in 1993. He was a visiting scientist at the National Center for Atmospheric Research, Boulder, Colorado, before joining the IPRC in 1998. His research interests include ocean general circulation modeling and ocean turbulence.

Sea surface temperature, the single-most important ocean variable in air-sea interaction and climate change, is dependent upon ocean-mixing processes. Since climate models rely on parameterizations of these processes, the IPRC climate modeling effort must have state-of-the-art expertise and understanding of them. Dailin

Wang has been seeking to increase our knowledge of the ocean-mixing processes and has used the technique of large eddy simulations (LES) to study the effects of Equatorial Undercurrent (EUC) shear on equatorial upper ocean mixing and the effects of Earth's rotation on deep convection. On both topics, he has made significant progress.

One important finding is that the entire EUC shear, including the stable shear below the mixed layer, is crucial for the vertical transport of momentum and heat. Without either the unstable surface shear or the stable shear below the mixed layer, momentum and heat fluxes are dramatically reduced. The implication for tropical GCMs is that a correct parameterization of equatorial upper ocean mixing must take into account the whole EUC shear. If the EUC is incorrectly reproduced in a GCM, the vertical fluxes of momentum and heat will be suspect. In other words, if the flux simulations yield believable results but the EUC is not modeled correctly, the flux results will have been obtained for the wrong reason.

Wang also found that Earth's rotation exerts significant control on turbulent statistics only when the Rossby number is on the order of 0.1, not 0(1) as one would expect based on a scaling argument. Temperature, the most important variable of interest for climate variability, is only slightly affected by rotation, even when the mixed-layer depth is comparable to the depth of the ocean. Convection with or without rotation can be approximated well by convective adjustment, or non-penetrative convection. In fact, convective adjustment (or non-penetrative convection) is a better approximation of convection in the presence of rotation. This finding is significant because convection in most ocean GCMs is represented by convective adjustment, a choice that has been based on convenience rather than on an understanding of rotating convection.

To increase our understanding of ocean-mixing processes and to improve parameterizations for climate models, Dailin Wang (with B. Wang, Theme 3) has been analyzing a recent ocean stand-alone simulation that has been conducted at NCAR using 40-year NCAR/NCEP reanalysis winds and realistic surface-heat fluxes. The purpose of this reanalysis is to assess how well state-of-the-art GCMs can simulate tropical circulation. A comparison with the mean annual cycle (*World Ocean Atlas 1998*) showed the model reproduces the seasonal cycle very well, but yields a systematic bias in the annual mean state; for example, the equatorial Pacific cold tongue is too cold by about 1°C.

Shang-Ping Xie
Associate Professor of Meteorology, SOEST
Theme 1 Co-Leader

Shang-Ping Xie obtained his Doctorate of Science in geophysics from Tohoku University, Japan, in 1991. He was an associate professor in the Graduate School of Environmental Earth Science, Hokkaido University, Japan, before he joined the IPRC in August 1999. His research interests include large-scale ocean-atmosphere interaction, climate dynamics, and the general circulation of the atmosphere and oceans.

Shang-Ping Xie's research at the IPRC has focused on three major areas: tropical instability waves (TIWs), North Pacific Ocean climate, and tropical ocean-atmosphere interactions.

Tropical instability waves (TIWs) are highly visible from satellite infrared images as meanders of a sharp equatorial SST around 1–3°N. Since their discovery in 1975, TIWs are believed to be of oceanic origin. Recent studies, however, indicate that they also induce large variability in the atmosphere. The La Niña conditions and the launch of NASA's QuikSCAT/SeaWinds in 1999 offered an unprecedented opportunity for studying this coupled air-sea aspect of TIWs (Liu et al., *GRL*, in press). All available active and passive satellite microwave measurements for 1999 were used to describe TIWs and their atmospheric co-variability in the equatorial Pacific and Atlantic Oceans (Hashizume et al., *JGR*, submitted). This has revealed a number of interesting, new features of coupled TIWs: (a) Surface wind variability is driven by both vertical momentum mixing and SST-induced sea-level pressure changes. The former mechanism is dominant in the far eastern Pacific, while the two are comparable in their effect in the central Pacific. (b) The SST-wind coupling south of the equator is two-to-three times stronger than north of the equator. (c) Similar coupled TIWs are found in the tropical Atlantic. (d) The most interesting result is perhaps the detection of significant variability in column-integrated water vapor, cloud water, and precipitation in the southern portion of the ITCZ, suggesting that to the north, TIWs induce a remote response with a deep vertical structure (see figure 2).

From late September to early October 1999, Xie and others (Shiotani et al., 2000, *SPARC Newsletter*) collaborated with Japan Fisheries Agency and Hokkaido University in a study of TIWs. While on the research vessel *Shoyo Maru* in the eastern equatorial Pacific, they successfully conducted the first-ever atmosphere-ocean, *in-situ* survey of TIWs. The survey revealed the vertical structure of the atmospheric response to ocean TIWs. The data clearly show that the TIWs signals penetrate at least as deep as the planetary boundary layer (PBL), which is capped by a strong temperature inversion. Results from this in-situ survey can contribute to the design of a major United States field campaign that has been scheduled in the same region for Fall 2001.

The study of coupled TIWs leads to a better understanding of the PBL dynamics of the cold ocean surface that does not allow deep atmospheric convection and occupies most of the world ocean. This knowledge will, in turn, help us understand extratropical ocean-atmosphere interactions and climate variability.

Regarding the North Pacific Ocean climate, a 40-year integration of an ocean GCM forced by the NCEP reanalyzed wind-stress data from 1958 to 1997 has been com-

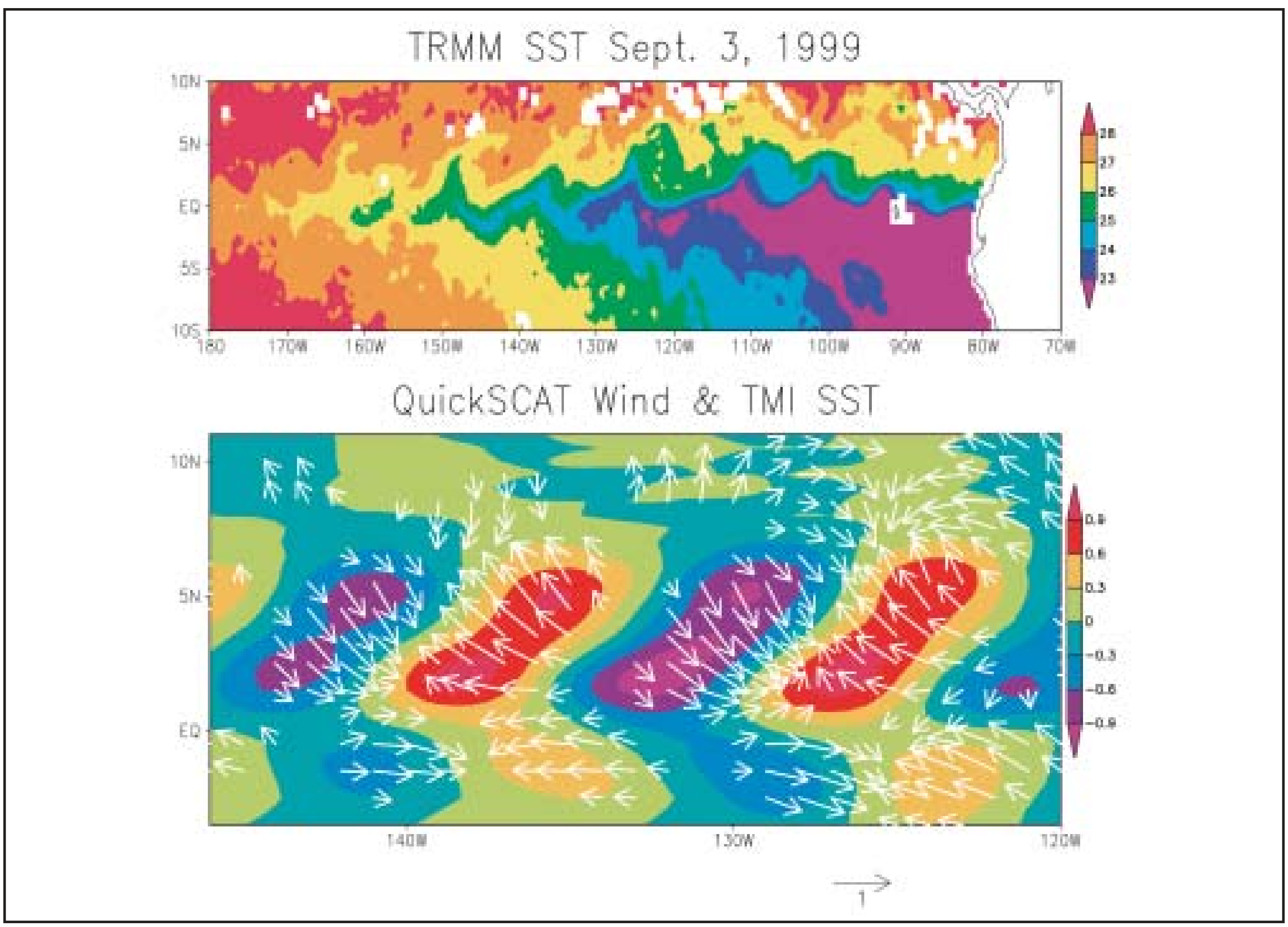


Figure 2. Spectacular meanders with wavelengths of about 1000 km develop along the equatorial front, which separates the cold upwelled water on the equator from the warmer water to the north beneath the Intertropical Convergence Zone (ITCZ). These meanders, or tropical instability waves (TIWs), have long been considered to be of oceanic origin. Recent observations show that they induce also a large response in the atmosphere. In a collaborative effort among IPRC, the Japan Fisheries Agency, and Hokkaido University, the Research Vessel *Shoyo Maru* sailed to the eastern Pacific in Fall 1999 and obtained the first-ever vertical soundings of these coupled ocean-atmosphere waves along 2°N.

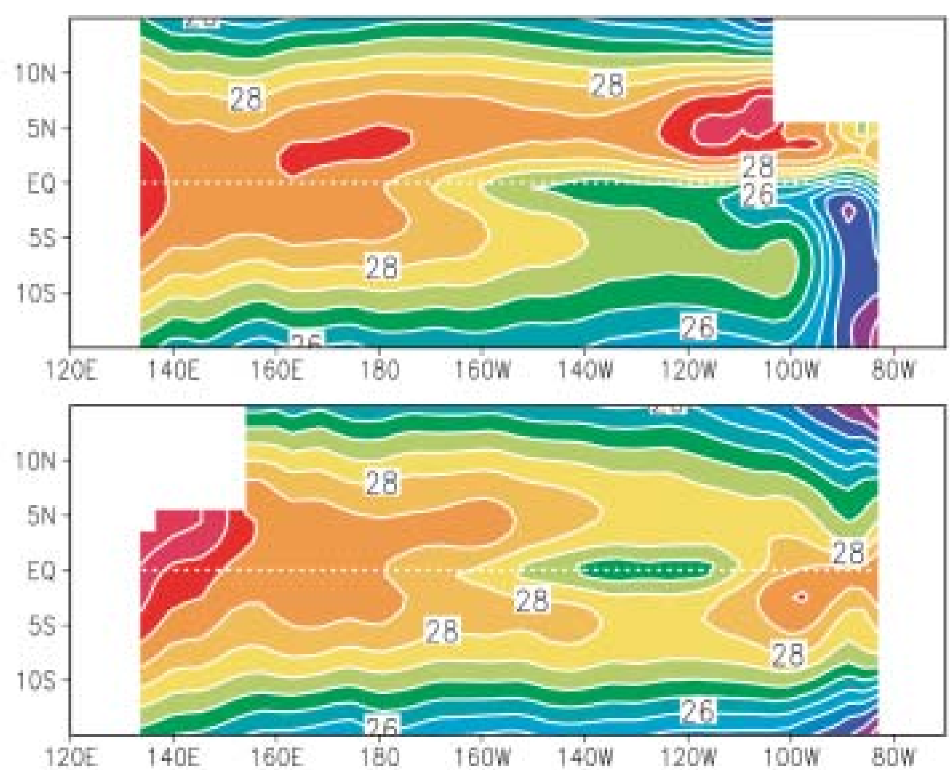
Upper panel: Sea surface temperatures (SSTs) observed by the Tropical Rain Measuring Mission (TRMM) satellite on September 2-4, 1999. Lower panel: TIW-induced surface wind anomalies (vectors) observed by the QuikSCAT satellite during the same period. Southeasterly trade winds intensify (weaken) over warmer (colder) sea surface. North of 7°N, where the SST perturbation vanishes, the TIWs induce a remote change in wind velocity that is associated with significant cloud and rainfall anomalies at the ITCZ.

pleted (Xie et al., *JPO*, in press). A decadal change was found in the path of North Pacific Central Mode water on the isopycnals and in the subsurface temperature signature that, in contrast to the usual first baroclinic mode response to wind-stress forcing, reaches a maximum where the vertical density stratification is weak. This type of wind-induced response by mode water can be understood using a multilayer ventilated thermocline model (Kubokawa and Xie, *JPO*, under revision). Changes in both the region where mode water forms and in the Sverdrup flow alter the path of the mode water in the interior ocean.

Even though the SST is restored to the monthly mean climatology in the above ocean GCM integration, substantial decadal SST variability is found in the Kuroshio Extension (KE) region. Xie and his collaborators noted that the KE is a key region where the ocean's memory of the past basin-scale wind changes is retrieved and surfaces. Their recent analysis of observational data yields evidence for these KE decadal SST variations that are induced by Rossby waves (with T. Tomita; see Tomita, Theme 3).

Because insolation is nearly symmetric about the equator, the northward shift of the ITCZ in the Pacific and Atlantic has been a long-standing puzzle of Earth's climate. To study how the asymmetric features of the continents interact with the ocean and atmosphere to shift the oceanic ITCZ north of the equator, Xie and colleagues are using an atmospheric GCM coupled with an intermediate ocean model. (See figure 3). Initial experiments confirm a westward control hypothesis and show that the ocean ITCZ is more sensitive to land asymmetries to the west than to the east (Xie and Saito, *J. Clim*., in press). The land asymmetries to the east force a coupled ocean-atmosphere wave

Figure 3. Sea surface temperature distribution in a coupled ocean-atmosphere model with deep atmospheric convection taking place over SSTs higher than 28°C. The model continents (white areas) are symmetric about the equator except for a northern bulge of landmass that breaks up the equatorial symmetry set by annual-mean solar radiation. Basin-wide climatic asymmetry develops in response to continental asymmetry in the east (upper panel) but remains largely symmetric about the equator when the same bulge is added to the western continent (lower panel). This suggests that climatic asymmetry in the Pacific results from continental asymmetries on the Americas. The east-west asymmetry in the modeled response arises from Earth's rotation—asymmetric information propagates only westward in the form of Rossby waves.



front that propagates westward and permanently displaces the ITCZ north of the equator. Xie is now looking at asymmetric elements of the American continents and studying how the coupled model responds to forcing by each of these separate elements (with Hideki Okajima).

Xie has studied also the role of the shallow Tropical-Subtropical Cell (STC) in decadal climate variability. Examination of the response of an ocean GCM to prescribed midlatitude SST anomalies (Nonaka and Xie, *GRL*, submitted) showed both southwestward and eastward propagation of the subducted temperature anomalies. The southwestward moving anomalies do not reach the equatorial ocean but are confined to the Subtropical Gyre (see section by Nonaka). A recent analysis of the wind-forced GCM run shows an interesting correlation on decadal time scales between the STC strength and equatorial SST anomalies (with Masami Nonaka and Jay McCreary).

The mechanisms that form various mode waters have been investigated in the same ocean GCM. The lateral induction from the deep, winter mixed-layer is the major mechanism for the western mode water, whereas the wide spacing of isolines of the winter surface-density is responsible for the eastern mode water (Xie et al., *JPO*, in press). Detailed analysis indicates that both temperature and salinity contribute to the formation of eastern mode water. The atmospheric high pressure system centered off California appears to play a key role in shaping the observed winter SST distribution that is favorable for mode water formation (Hosoda et al., *JGR,* submitted).

Given the limited record of ocean-atmosphere observations, studies that compare the Pacific and Atlantic are useful. In the tropical Atlantic, it is still controversial whether the SST dipole is an artifact or a physical phenomenon. The issue at the heart of this controversy is whether the atmospheric response to a SST dipole can provide positive feedbacks. Several long (80-year-long) atmospheric GCM integrations have been conducted to investigate this issue (Okumura et al., 2000, *AMS Proceedings*). The results show that the tropical atmosphere can exert positive feedback onto a prescribed SST dipole through wind-induced evaporation and shallow-cloud shielding against solar radiation. The extratropical response is highly significant over the Azores High and compares very favorably with observations. When the extratropical ocean is allowed to interact through a 50-meter-deep mixed layer, a tripole SST pattern—a well-known pattern of climate variation in actual observations—emerges in the North Atlantic, suggesting that an atmospheric teleconnection induced by the tropical SST dipole plays a significant role in North Atlantic climate variability.

Xie is analyzing also the ocean subsurface variability associated with the tropical SST dipole (with Y. Tanimoto). The vertical structure of this variability is rather complicated; sometimes the anomalies in the fixed layer and in the thermocline even have opposite signs.

By increasing our knowledge of the complex processes and mechanisms that control regional and global climate, the above studies contribute to a better understanding of Pacific climate and its variability. The comparative studies between the Pacific and the Atlantic, in particular, can lead to a general view of Earth's climate system.

Research Activities and Accomplishments

Theme 2: Regional Ocean Influences

Overview

Theme 2's overall goal is to investigate regional ocean phenomena that are known to affect the variability in the large Pacific Ocean gyres and in climate. These phenomena include eddy-mean current interactions in western boundary currents; cross-frontal exchange; formation of Subtropical Mode Water, North Pacific Intermediate Water, and other water mass types; and interactions with coastal and marginal seas. All of these processes play a role in the water exchange between gyres and between oceans, and also in the ITF. Our research on these processes will lead to better understanding of regional ocean circulations, such as the Kuroshio Meander, and also of the predictability of Pacific large-scale circulation.

The first objective under this theme is to understand the processes that maintain the Pacific western boundary currents and cause their climatic variability. Research in this area includes numerical modeling of the Kuroshio paths south of Japan and their predictability (Waseda and Mitsudera) and the analysis of current meter data in the Tokara Strait (Feng and Mitsudera). Observed short-term meander features of the Kuroshio paths were successfully simulated in these studies. In addition, studies using historical data (Qu) and ocean GCMs (Miyama, Jensen, Mitsudera) were conducted on low-latitude boundary currents, including the bifurcation of the North Equatorial Current into the Kuroshio and Mindanao currents off the Philippines.

Research under the second objective—"to determine the processes that maintain the Kuroshio-Oyashio Extension system and cause its climatic variability"—includes numerical modeling of the Kuroshio and Oyashio Current system using a regional model (Mitsudera and Waseda), analysis of historical hydrographic data prepared over isopycnal surfaces (Qu), analysis of field experimental data—such as Megapolygon '87—in the Subpolar-Front region (Maximenko and Yaremchuk), and a pilot study of the Kuroshio Extension using an acoustic tomography system (Yuan, Yaremchuk and Mitsudera). Reconstruction and analysis of the North Pacific circulation has also been conducted using a three-dimensional variational method (Yaremchuk).

The third objective is to determine the influence of the East-Asian marginal seas and the ITF on the Asian-Pacific climate system. Current research includes analysis of the surface heat content and circulation in the South China Sea based on historical hydrographic and expendable bathythermograph (XBT) data (Qu), and analysis of the ITF with a numerical diagnostic method (Lebedev and Yaremchuk). An ocean GCM study on this topic has started (Miyama, Jensen, and Mitsudera).

Konstantin Lebedev

Postdoctoral Fellow

Konstantin Lebedev obtained his Ph.D. in physical oceanography in 1995 from the P.P. Shirshov Institute of Oceanology, Moscow. He was a senior research scientist at the Shirshov Institute before joining the IPRC in November 1998. His research interests include numerical modeling of ocean dynamics and of the ocean response to non-stationary atmospheric forcing, variational data assimilation into numerical models, and variability of the ITF.

Konstantin Lebedev's work at the IPRC has focused on deriving estimates of the ITF climatology so that we can understand better the role played by the ITF in Asian-Pacific climate. In collaboration with Max Yaremchuk (see section by Yaremchuk), he has (a) used climatological data from temperature and salinity fields and surface wind stress to derive estimates of the mean seasonal variations in the amount of water transported from the Pacific to the Indian Ocean, and (b) performed a correlational analysis of ITF transport anomalies and sea surface height (SSH) difference anomalies obtained from remotely sensed TOPEX/Poseidon (T/P) altimetry observations (Lebedev and Yaremchuk, 2000, *JGR*; see also section by Yaremchuk).

Using a variable-grid, global GCM with 1/6º resolution in the Indonesian seas and configured with ETOP05 bottom topography, Lebedev and Yaremchuk diagnosed the three-dimensional velocity field in the region and conducted extensive sensitivity experiments to obtain error estimates. Computations show the ITF is maximum in boreal summer (13.9 Sv) and minimum in boreal winter (7.5 Sv). The annual-mean ITF transport amounts to 11.5 Sv (see figure 4). These values are within the range of various estimates from other studies of ITF transport and agree with seasonal maxima and minima. The largest seasonal transport variations (8 Sv) occur in the upper 175 meters of the water column. This results in substantial seasonal variability in heat transport from the Pacific into the Indian Ocean, ranging from 0.4 PW in January to 1.1 PW in August.

According to the model's simulation, water in the Luzon Strait contributes significantly to the ITF. During winter, the inflow of 6.3 Sv is distributed between the two outflows from the South China Sea, which follow the routes through the Karimata (4.4 Sv) and Mindoro (1.9 Sv) Straits. In summer, the Karimata pathway is blocked, and the net inflow of 4.7 Sv exits through the Mindoro Strait west of southern Luzon. The total contribution of the Luzon Strait inflow to the net ITF transport varies from 85% in boreal winter to 35% in summer, with an annual average value of about 50%.

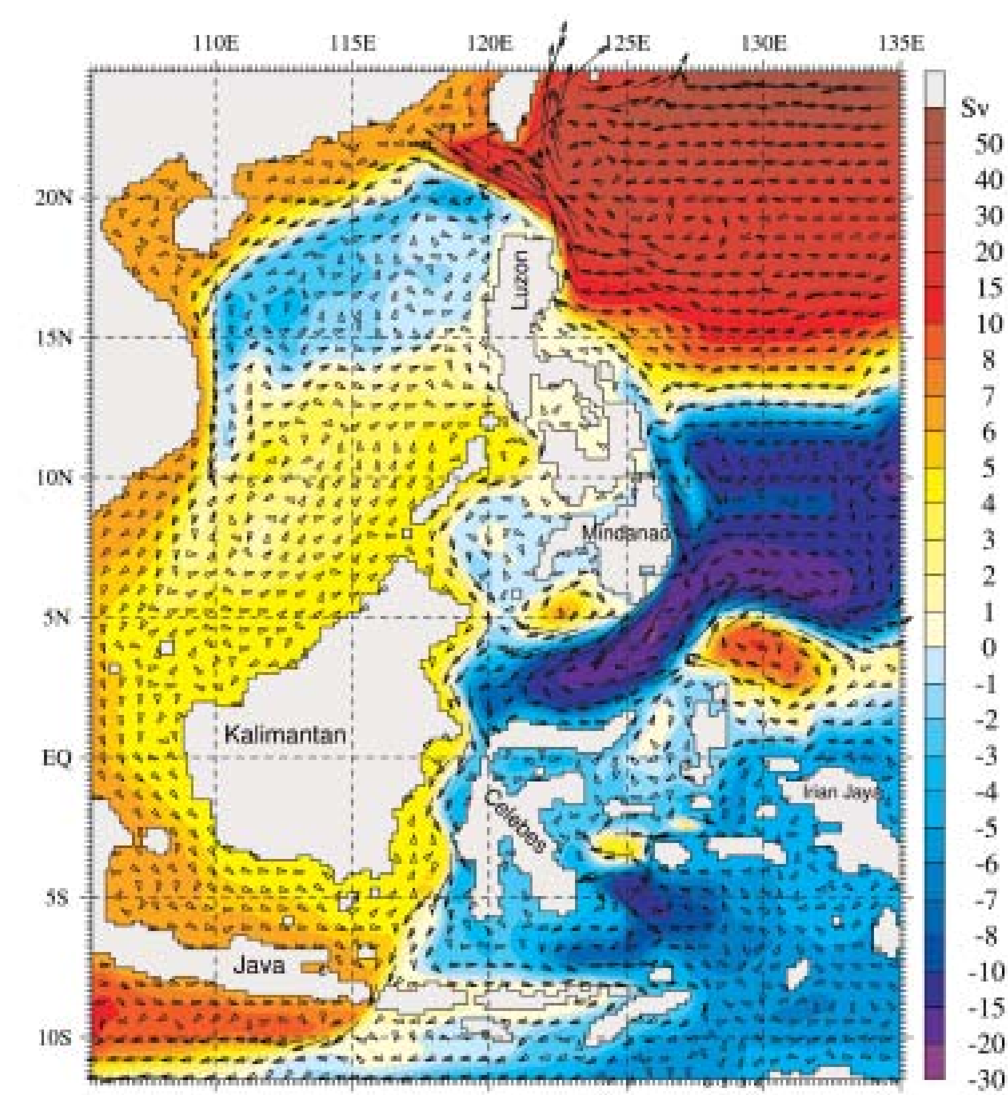
Cross-correlation analysis between the satellite T/P monthly mean SSH anomalies over 5 years (1993–97) and the diagnosed transport anomalies shows that the mean SSH difference between the western Banda Sea and the region north of Luzon correlates highly with the heat (0.96) and volume (0.91) transports. These strong correlations can be partly explained by the large contribution of the Luzon Strait transport to the ITF transport and also by the fact that seasonal ITF variability is confined to the upper layer and therefore caused mainly by SSH variations. The obtained correlations support the results of Metzger and Hurlburt (*JGR*, 1996), who suggested that seasonal variability of the Luzon Strait transport is controlled by the pressure head of the piled-up water created by the monsoon winds.

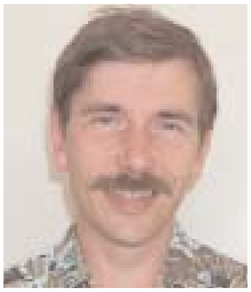
Seasonal variability of the ITF transport depends on many factors, such as friction in the numerous straits, Kelvin-wave statistics within the archipelago, and tidal effects. The diagnostic computations of Lebedev and Yaremchuk suggest, nevertheless, that the primary driving mechanism is monsoonal wind variability: the winds change SSH, which in turn causes the high inflow from the Luzon Straits. The strong correlation between the model's simulated SSH and T/P altimetry data confirms that the Luzon Strait *northern route* contributes considerably to the total ITF transport.

Recently, Lebedev has begun to study the climatological intra-annual variability of the thermohaline processes in the open region of the North Pacific Ocean in order to determine the processes that cause variability in the Pacific western boundary currents and in the Kuroshio Oyashio Extension. The study, which focuses on ocean-atmosphere interaction in midlatitudes and water-mass formation to a depth of 1000 meters, will give a better understanding of how seasonal variability in thermohaline forcing affects water-mass formation and the dynamics of the heat and freshwater content in the Kuroshio Extension region. It will also yield estimates of the mean production rates of the Subtropical Mode Water and Central Mode Water, which influence the thermohaline circulation of the North Pacific.

For this research, Lebedev will use variational assimilation of climatological data into a large-scale geostrophic model, controlled by initial and open boundary conditions. The data-assimilation technique allows data to be combined from different climatological sources (hydrology, satellite SST/SSH, drifters, heat/freshwater fluxes, wind stress) in a dynamically consistent manner. He is modifying the algorithm of the variational data assimilation scheme developed by Nechaev and Yaremchuk (1995, 1996). The revised scheme introduces a spherical coordinate system and the equation for seawater state; splits the density evolution equation into two separate equations, one for temperature and one for salinity; introduces the K-profile upper-layer parameterization (Large et al., 1994); and modifies the adjoint code and all associated routines.

Figure 4. Annual mean stream function of total transport (sverdrups) in the equatorial western Pacific, the Indonesian Archipelago, and the South China Sea. Contours are shown in sverdrups. Arrows are proportional to the total transport. The figure shows that substantial flow from the South China Sea joins the Indonesian Throughflow.





Nikolai A. Maximenko

Associate Researcher

Nikolai Maximenko obtained his Ph.D. in 1987 from the P.P. Shirshov Institute of Oceanology, Moscow, where he worked as a senior research scientist. He joined the IPRC in December 1999. His research interests include dynamics of large-scale fronts and mesoscale eddies, Lagrangian tracers, intra-thermocline lenses and submesoscale coherent vortices, and formation of North Pacific Intermediate Water.

Since joining the IPRC, Nikolai Maximenko has carried out a combined analysis of corrected current meter and CTD data from the Megapolygon-'87 experiment in the Pacific Subarctic Front. The experiment revealed a complex three-dimensional structure in the fronts, jets, and eddies of the region, and extremely intensive nonlinear interactions among them. The data show the following: the splitting and instabilities of fronts; the stretching, evolution, and decay of mesoscale eddies of different baroclinic structure; numerous submesoscale lenses and vortices; large-scale abyssal flows that compensate for near-surface ones; and ageostrophic currents in and around eddy cores.

Maximenko is now extending this work by using a variety of data sets (Megapolygon-'87, WOCE, historical, satellite, drifter and others) to study dynamic processes in the Subarctic Front-Kuroshio Extension region. He will investigate the interannual and decadal variability of main fronts, the role of mesoscale eddies in forming the frontal pattern and their ageostrophic dynamics, and the origin and persistence of deep compensative countercurrents.

In a second project, Maximenko will study the bimodality of the Kuroshio Current. Using time-lagged correlations, he will look at the relationship between the formation of the Kuroshio large meander south of Honshu and larger-scale phenomena such as the intensity of the North Pacific Subtropical Gyre and the El Niño. Specifically, he will investigate the local dynamics of the Kuroshio large meander and its relationship to (a) recirculation cells and instabilities up- and downstream, (b) the North Equatorial Current bifurcation east of Luzon, (c) the penetration of the Kuroshio into the South China Sea, (d) its meandering east of Taiwan and in the East China Sea, and (e) its split into the Tsuchima Warm Current. Findings should be useful for such projects as KESS, ARGO, Kuroshio Observation, and CLIVAR.

Humio Mitsudera

Frontier Group Leader and Theme 2 Co-Leader

Humio Mitsudera obtained his Ph.D. in physical oceanography in 1987 from Tohoku University, Japan. He began work as a research scientist with JAMSTEC in 1993. He joined the IPRC in 1997 as a Frontier group leader. His research interests include dynamics of ocean currents and ocean gyres, and coastal ocean processes.

Since joining the IPRC, Humio Mitsudera has focused on the mechanisms causing seasonal-to-interdecadal variability in the Kuroshio and Oyashio Currents and their extensions. Without doubt, variability in these currents has a strong influence on the climate of the region, which has been recognized as a key also for understanding the larger-scale decadal variations in the North Pacific. The Kuroshio and Oyashio are major exchange pathways between the Subtropical Gyre and the Subpolar Gyre in the western North Pacific. Known as the area with the largest heat release from the ocean to the atmosphere, this region shows large fluctuations in SST, surface heat content, and surface heat fluxes that can cause large climatic variations.

To study what determines climate variations in the Pacific western boundary currents, Mitsudera—in collaboration with Waseda (IPRC), Feng (IPRC, now with CSIRO Australia), Yoshikawa (JAMSTEC), and Taguchi (Mitsubishi R.I.)—has conducted numerical experiments using a high-resolution, primitive equation model of the Kuroshio and the Oyashio regions (the Kuroshio and Oyashio System Model or KOSM) and has performed data analysis of the current measurement in the Tokara Strait. This work has focused on path dynamics and predictability of the Kuroshio Current off the southern coast of Japan.

The model simulations and satellite observations both show that the interaction between the Kuroshio and anticyclonic eddies off the south coast of Japan is a key mechanism in the development of short-term meanders (Mitsudera et al., *GRL*, submitted; see section by Waseda and figures 5 and 6). These anticyclonic eddies are generated in the Kuroshio Extension region, propagate westward, and eventually impinge upon the Kuroshio off the southern coast of Kyushu. Moored current-meter measurements in the Tokara Strait south of Kyushu exhibit two principal flow patterns in the Strait that are associated with the incoming cyclonic and anticyclonic eddies (Feng et al., 2000, *JPO*; accepted). When an anticyclonic eddy encounters the Kuroshio there, it tends to generate a small meander downstream and then propagate eastward on the Kuroshio, forming a vortex pair. It is finally amplified to form the large meander-like structure. The numerical simulation using KOSM has successfully simulated such observed features.

Mitsudera has also conducted numerical experiments using KOSM to study the interaction between the Kuroshio and Oyashio (with Waseda, Yoshikawa, and Taguchi). Simulation with KOSM has realistically reproduced Oyashio's southward penetration along the Japanese coast, a feature that had been difficult to simulate. Analogous to observations, the numerical solutions develop a well-defined pathway from the Subpolar Gyre to the Subtropical Gyre within the layers of NPIW. Numerical experiments with and without the Okhotsk Sea outflow further prove that the Okhotsk Sea water has a striking impact on this pathway, completely changing the surface and subsurface temperature fields north of the Kuroshio Extension. Furthermore, the Oyashio water may influence the path of the Kuroshio Extension, which is destabilized due to the advection of anomalous potential vorticity through this pathway.

In parallel with this research, the climatology of the Kuroshio-Oyashio system has been developed from historical data. The hydrographic data was preprocessed carefully by averaging over isopycnal surfaces. The Subpolar Gyre was found to have a deep structure, and its extension southward beyond the wind-driven gyre boundary was confirmed (see section by Tangdong Qu). Using the data from the Kuroshio Extension pilot experiment of Summer 1997, Mitsudera collaborated with Gang Yuan to study how the recirculation gyre interacts with mesoscale eddies south of the Kuroshio Extension (see section by G. Yuan).

Finally, Mitsudera collaborated with Firing, Hacker, and Donohue (all at SOEST, University of Hawai‘i at Mānoa), and Ishida (JAMSTEC) and, using data from the high-resolution global ocean model developed by JAMSTEC, investigated the thermocline- and intermediate-layer circulation of the Pacific Ocean (work related to Theme 1). They successfully simulated for the first time the subsurface countercurrents known as the Tsuchiya Jets (see also the section by Jay McCreary).

Tangdong Qu

Associate Researcher

Tangdong Qu obtained his Ph.D. in physical oceanography in 1993 from the Institute of Oceanology, Chinese Academy of Sciences, Qingdao, China, where he served as a research scientist from 1987 to 1996. He was a visiting scientist with JAMSTEC, Japan, before he joined the IPRC in Summer 1998. His current research interests include upper-layer ocean dynamics and the thermal structure of the Pacific Ocean.

Since joining the IPRC, Tangdong Qu has used historical hydrographic data to study the circulation and water-mass distribution in the South China Sea. The main scientific findings of this research are the following:

- Water from the Pacific, both North Pacific Tropical Water and Intermediate Water, enters the South China Sea throughout the year through the Luzon Strait (Qu, Mitsudera, and Yamagata, 2000, *JGR*).
- Combined use of XBT and climatological temperature/salinity relationship data yields an annual transport through the Luzon Strait in the order of 3 to 4 Sv, with a maximum occurring in winter and a minimum in summer; this estimate is consistent with predictions using Godfrey's Island Rule (Qu, *JPO*, in press).
- On seasonal time scales, SST is negatively correlated with mixed-layer depth in most parts of the South China Sea, suggesting that SST tends to be higher (lower) when the mixed-layer depth is shallower (deeper). In addition to the surface heat flux, ocean dynamics also plays a role in generating the SST anomalies there (Qu, *JGR*, submitted).

These findings help to understand the interaction between the western Pacific and the South China Sea and the ocean processes important for Asia-Pacific climate.

Qu is planning a study on the circulation and water-mass distribution in the North Pacific. He will be using historical data combined with results from high-resolution GCMs and focus on (a) the confluence of the Kuroshio and Oyashio in the mixed water region east of Japan and (b) the eddy effects on the formation, distribution, and dissipation of the North Pacific mode waters. These studies will contribute to understanding climate variations in the Pacific and Indian Oceans and to determining the influences of the western boundary currents and the Kuroshio-Oyashio Extension on Asia-Pacific climate.

Figure 5. Sea Surface Height evolution of the eddy-Kuroshio interaction as simulated by numerical test with the Kurashiro and Oyashio System Model.

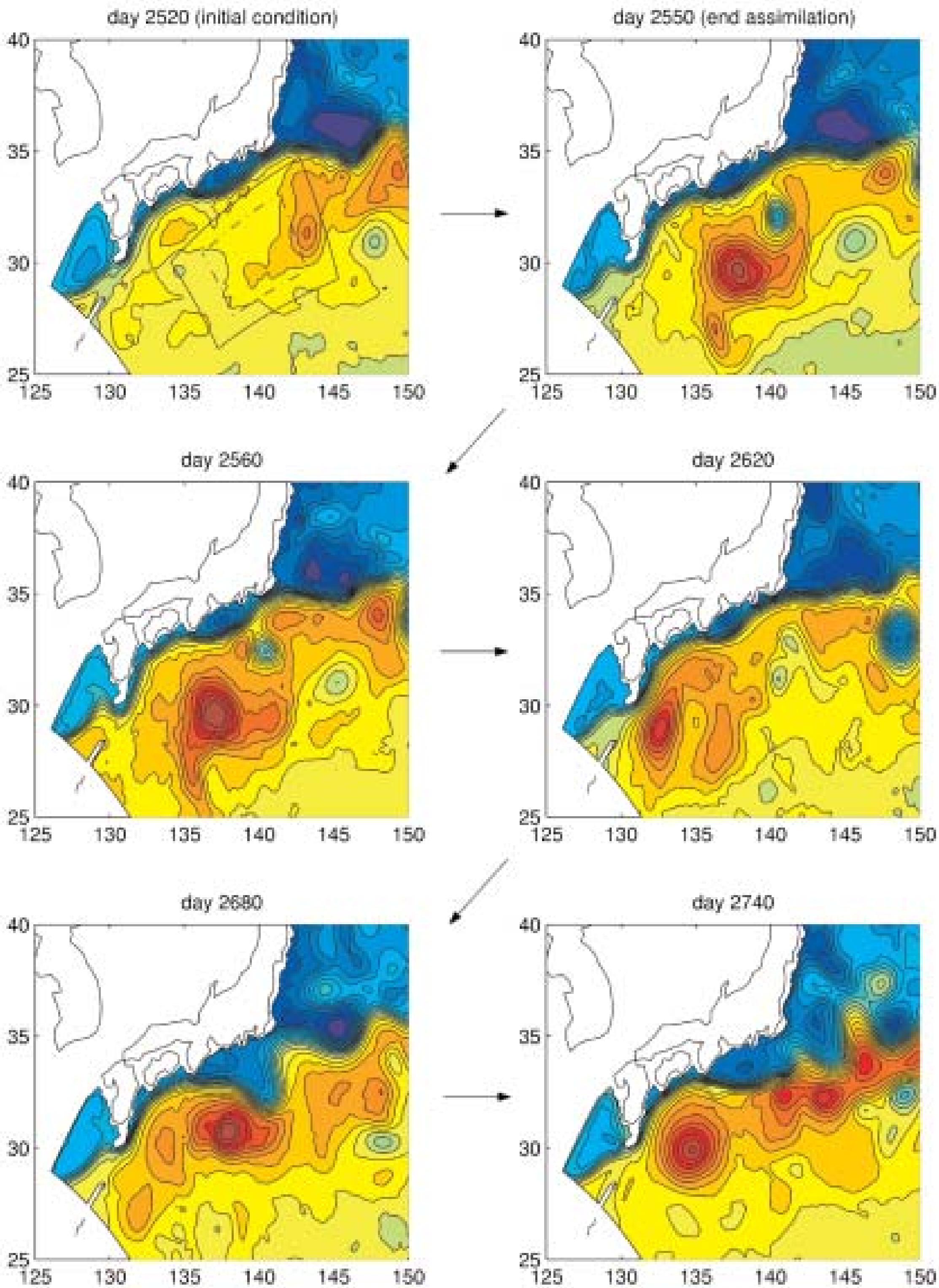
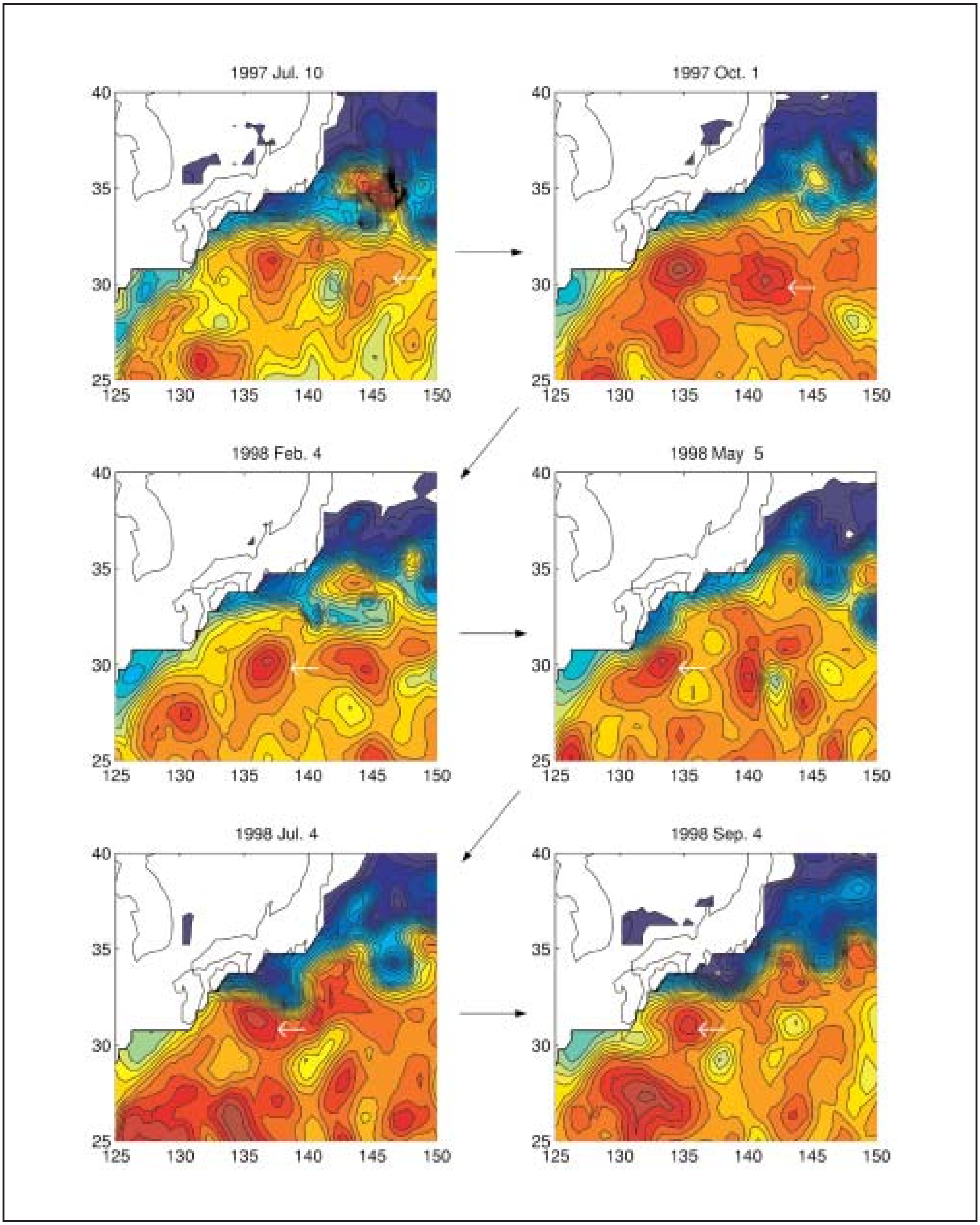


Figure 6. Sea Surface Height evolution of the eddy-Kuroshio interaction as shown by TOPEX/POSEIDON observations.



Takuji Waseda

Frontier Research Scientist

Takuji Waseda, a native of Japan, studied at the University of California, Santa Barbara, where he obtained his Ph.D. in ocean engineering in 1997. He joined the IPRC in October 1997 as a Frontier research scientist. His research interests include wind and water waves, satellite oceanography, the variability of the Kuroshio Current, and data assimilation.

Takuji Waseda's research relates to the Theme-2 objective "to determine the processes that maintain the Kuroshio-Oyashio Extension system and that cause its climatic variability." To study the ocean processes of the Kuroshio-Oyashio Extension system and the Kuroshio Current, Waseda synthesizes data from numerical models and observations using a high-resolution regional GCM. Because the particular assimilation scheme is important in such model-observation syntheses, Waseda (with L. Jameson, currently at Laurence Livermore National Laboratory, and H. Mitsudera) developed a wavelet diagnosis that estimates numerical errors and model variations and can be directly used to improve data assimilation.

An often-used assimilation scheme is the Kalman filter, which sequentially processes available observational data and discards them as soon as they are processed. This simplicity makes the scheme attractive, but in oceanographic applications, it places a large demand on computational resources as well as data management. The use of Kalman filtering in GCMs, therefore, requires substantial reduction of the model state, which is usually done by approximating the prediction-error covariance matrix with a matrix of a lower rank. This approach truncates the variability below a certain length scale and typically neglects error associated with the numerical schemes.

In contrast, wavelet analysis of the model fields allows estimation of the variability of different scales, where the smallest scale corresponds to the numerical error (Jameson and Waseda, *JAOT*, in press; Jameson et al., in preparation). Combination of all the wavelet coefficients allows estimation of model errors, including information of various scales. The new approach (EEWADAi & SUgOiWADAi) estimates the variance of the forecast error covariance matrix as a function of these wavelet coefficients. A twin experiment was conducted by reading the SSH field along the T/P satellite tracks from the output of the control run and then assimilating them into the simulation run. Waseda and his colleagues rated the ability of each scheme to minimize forecast error curves. From best to worst, the order was SUgOiWADAi, EEWADAi, and OI. To determine the forecast error, SUgOiWADAi uses the combination of the wavelet coefficients of three different scales; EEWADAi uses wavelet coefficients from the smallest scale, that is, the numerical error; and OI (optimal interpolation) uses fixed model variance.

Eddy processes are key to understanding the mesoscale variability in the Kuroshio and Kuroshio Extension (KE) regions. The isolated anticyclonic eddies originating from the KE region are thought to be responsible for triggering the short-term meander of the Kuroshio south of Japan. Because observational evidence is limited, numerical models are needed to substantiate this hypothesis. To study the interaction between eddies and the Kuroshio, Waseda has collaborated with H. Mitsudera, and with B. Taguchi and Y. Yoshikawa of JAMSTEC (see section by Mitsudera). Using KOSM, an anticyclonic eddy was initialized by assimilating data from the T/P Sea Level Anomaly observed in October 1992 (Waseda et al., in preparation; see figure 5). After intialization, the simulation shows that the westward propagating anticyclonic eddy collides with the Kuroshio southeast of Kyushu and is advected by the Kuroshio mean flow; then a meander develops, the eddy detaches from the Kuroshio, and finally migrates west again. A similar process repeats and causes the second meander, but not the third one. These sequences are similar to the Kuroshio-eddy interaction observed in 1997 (figure 6). This agreement supports the hypothesis that anticyclonic eddies trigger the short-term meander of Kuroshio. Four additional experiments with varying assimilation strengths were conducted. The two distinct evolution paths taken by the eddies in these experiments—one with a regular westward trajectory and the other with a sudden southward migration—are striking since the initialized eddies were similar in scale (Rossby number 0.012 to 0.014). Irregular eddy motions are well known, but this appears to be the first instance that such behavior has been simulated using a GCM with realistic eddy initialization. Indeed, in 1994 an observed eddy migrated far to the south, in striking agreement with the model results.

Max Yaremchuk

Associate Researcher

Max Yaremchuk obtained his Ph.D. in physical oceanography in 1984 from the P.P. Shirshov Institute of Oceanology in Moscow. He worked at the Shirshov Institute as a senior research scientist in the Ocean Dynamics Division before joining the IPRC in 1998. His primary research interest is in the field of inverse methods of data processing, including variational methods of data assimilation in finite-difference and finite-element numerical models.

Max Yaremchuk has been applying variational data assimilation methods to studies of midlatitude boundary currents and large-scale circulation. First, he has reconstructed a dynamically consistent steady-state circulation in the North Pacific Ocean. The fields describing the ocean state and the atmospheric forcing were computed by fitting a steady-state, large-scale ocean circulation model to the following data sets: WOCE hydrology (1.0 release), Da Silva atmospheric climatologies, T/P altimetry, and MEDS drifter data. The model inversion yielded estimates of the climatological means of heat, salt, and water mass transports for the major circulation features of the North Pacific. All estimates were supplied with error bars obtained with the approximate inversion of the Hessian matrix.

The optimized pattern shows that the North Pacific is heated at an average annual rate of 11 (±8) Wm^{-2} and loses 28 (±18) cm of fresh water from its surface per year. Zonal mean transport north of 20°N is characterized by an upwelling of 7 (±2) Sv in the intermediate layers (500 to 3000 m) within the latitudes 30° to 50°N. A weaker anticyclonic cell of 3 (±1) Sv contributes to the meridional circulation pattern north of 51°N. The net heat transport in midlatitudes is statistically indistinguishable from zero and amounts to 0.1 (±0.4 PW). Analysis of the water-mass transformation rates reveals that the major formation site for NPIW lies east of Hokkaido and the South Kuril Islands. A much weaker source is found in the Alaskan Gyre. These results provide an estimate of the North Pacific mean-state for the past decade (when most of the data were collected), thus giving a reference point for computation of interannual anomalies.

Yaremchuk has also conducted with Konstantin Lebedev (see section by Lebedev) a diagnostic analysis of the ITF and obtained estimates of the mean seasonal variations in the water properties transported from the Pacific to the Indian Ocean (Lebedev and Yaremchuk, 2000, *JGR*). The estimates are based on climatological data of temperature and salinity fields and of surface wind stress. The three-dimensional velocity field was diagnosed using a variable-grid global GCM that has 1/6° resolution in the Indonesian seas and is configured with ETOP05 bottom topography. A major result is that the flow into the Luzon Strait contributes significantly to the water in the Throughflow. In boreal winter the inflow of 6.3 (±1.5) Sv is distributed between the two outflows from the South China Sea, which follow the routes through the Karimata (4.4 ±0.5 Sv) and Mindoro (1.9 ±1.5 Sv) Straits. In summer the pathway around Borneo is blocked and the net inflow of 4.7 (±0.6) Sv exits through the Mindoro Strait west of southern Luzon. The contribution of the Luzon Strait inflow to the net ITF varies from 85% in boreal winter to 35% in summer, with an annual average value of about 50%. Cross-correlation analysis between the T/P monthly mean SSH anomalies and the diagnosed transport anomalies yields high correlations of the mean SSH difference between western Banda Sea and north of Luzon with the heat (0.96) and the volume (0.91) transports.

In another study, Yaremchuk constructed a dynamically consistent four-dimensional interpolation scheme capable of simultaneously processing data from multiple sources (such as satellite altimetry, acoustic tomography, drifting buoys, etc.). The nonlinear algorithm developed for inverting acoustic tomography data provides a better representation of acoustic tomography data in regions of strong currents, such as the Kuroshio and its extension, than existing schemes do. He has tested the algorithm with a three-dimensional variational inversion scheme by means of twin data experiments and against real data obtained in the course of a pilot Kuroshio Extension study during Fall 1997. The scheme will be useful in further work on the analysis of the dynamics and thermodynamics of the western boundary currents, marginal seas, and the Kuroshio-Oyashio Extension system. For instance, it should be helpful in processing the large variety of observations expected to come from the Kuroshio Extension region during a joint experiment between Japanese and U.S. oceanographic institutions, planned for 2001–05.

Finally, Yaremchuk has completed several Atlantic Ocean circulation studies, which he began before joining the IPRC. These studies describe variational estimates of the circulation on the Scotian Shelf and of the seasonal cycle in the North Atlantic Current. He also finished a theoretical study on the development of posterior variance estimators for variational data assimilation schemes.

Gang Yuan

Assistant Researcher

Gang Yuan obtained his Doctorate of Engineering (specializing in ocean acoustic tomography) in 1995 from Hiroshima University, Higashi-Hiroshima, Japan. He worked at JAMSTEC before coming to the IPRC in January 1999. His research interests include ocean acoustic tomography, inverse methods of data processing, and mesoscale ocean dynamics.

Guang Yuan has been studying SST and air-sea heat fluxes in the Kuroshio Extension region. Together with the JAMSTEC tomography team, he collected during Summer 1997 two months of acoustic travel-time data from an array of five acoustic tomography transceivers. The data covered a 1,000 km-scale domain in the Kuroshio-Extension region including its southern recirculation gyre (28°-36°N, 143°-154°E). These data were compared with T/P altimeter measurements. The acoustic data show that in the Kuroshio Extension region acoustic travel time varies consistently with SSH measurements obtained with the T/P altimeter. In the recirculation region, however, variations in acoustic travel time and SSH differ significantly from each other. The lack of correspondence between the two measurements in the recirculation gyre is thought to be due to the ability of acoustic tomography to measure the signals associated with changes in the seasonal thermocline (sea surface layer or mixed layer) as well as in the permanent thermocline (subsurface layer), whereas the altimeter mainly picks up signals associated with changes above the seasonal thermocline.

A new approach is being used for inverting the acoustic travel times in order to separate and quantify the seasonal and the permanent thermocline temperature variations. The inversions show that the temperature in the surface layer (0 to 100 m) increased by 1.2°C during the two months of the experiment, while temperatures in the subsurface layer (100 to 1500 m) decreased by about 0.2ºC. This increase in surface-layer temperature obtained from the acoustic data is consistent with the steric-height increase obtained from the NCEP net heat-flux data. A quantitative comparison of the surface temperature changes with the surface heat-flux changes made it possible to quantify the sources of heat in the Kuroshio recirculation region: the contribution of horizontal eddy advection to the heat budget was about 65%, and the remaining 35% of the heat budget resulted from thermal expansion or contraction (local surface buoyancy forcing) in a one-dimensional local mixed layer.

In the region of the recirculation gyre, the velocity of the horizontally and vertically averaged (barotropic), westward-flowing current determined from the reciprocal acoustic travel times is about 4 cm/s. This estimate compares well with the velocity of the horizontally averaged surface geostrophic current, which is 5 cm/s as determined from the SSH of the T/P measurements. This finding suggests that a barotropic rather than a baroclinic current dominates the Kuroshio recirculation region. Another result is that the more northward the Kuroshio Extension is shifted, the more it becomes a barotropic current with stronger recirculation at the surface. Yuan is preparing papers, together with H. Mitsudera and the JAMSTEC researchers, that report these findings.

Research Activities and Accomplishments

Theme 3: Asian-Australian Monsoon System

Overview

The Asian Australian monsoon system (A-AMS) is the most energetic component of Earth's climate system. This is not surprising as it covers the vast monsoon regions of South Asia, East Asia, Australia, East Africa, the tropical Indian and western Pacific Oceans, and the Asian marginal seas (e.g., South China Sea). The large variations from one year to the next in the monsoon greatly affect the economy and the people of the region. Moreover, evidence that the A-AMS has a powerful influence on global climate is growing: Fluctuations in monsoon rainfall alter the midlatitude jet stream of the winter hemisphere, and these changes ripple around the planet.

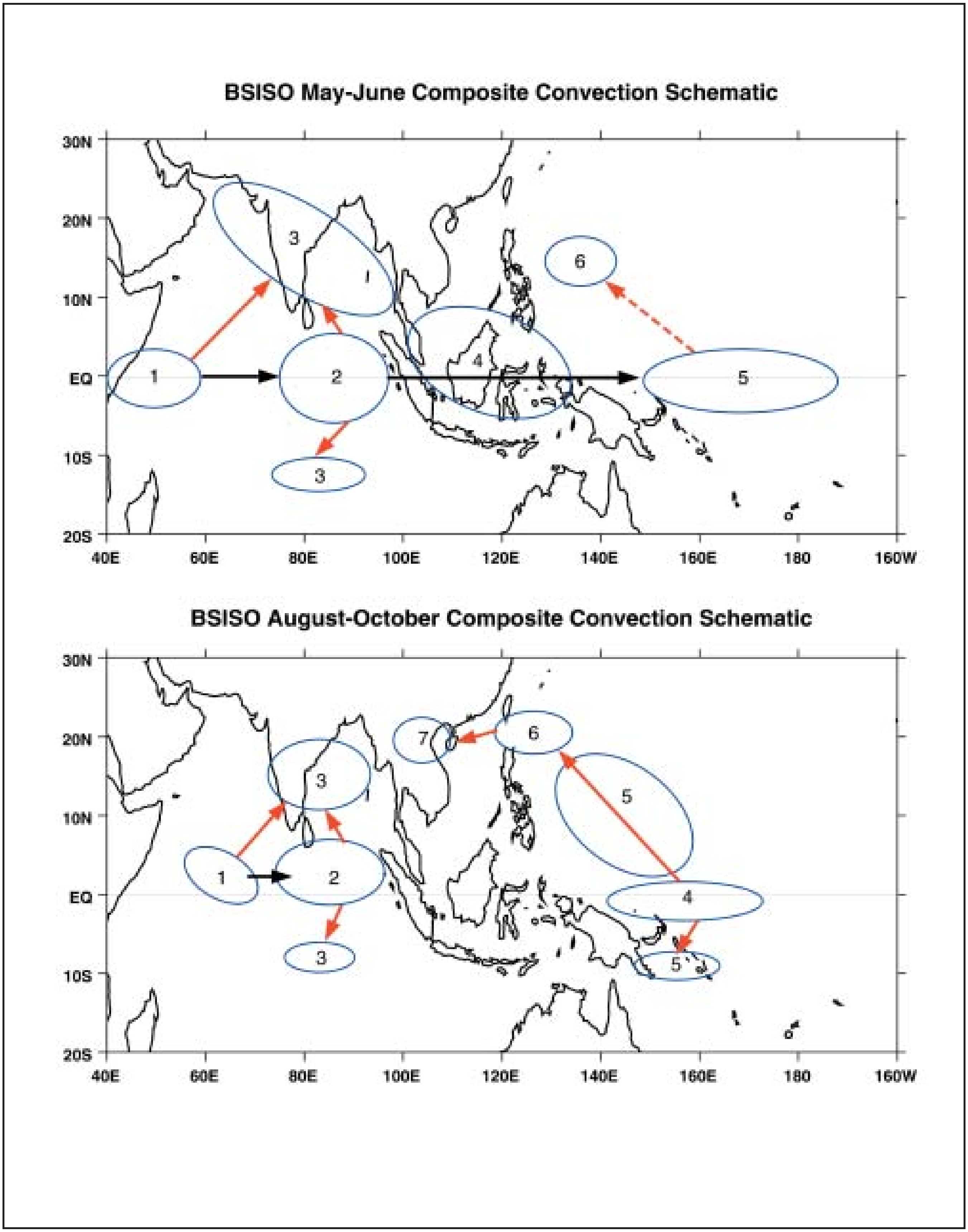
The overall goal of Theme 3 is to understand the physical mechanisms that govern the variability of the A-AMS. A recent observational study showed that the South Asian (Indian) monsoon, the East Asian monsoon, and the Northwestern Pacific monsoon have distinct progressive temporal and spatial structures (B.Wang and Lin). The distinctive climatological characteristics of onset and development of the Northwestern Pacific monsoon have been examined with observational data from the NCEP reanalysis and CMAP rainfall (Wu and B.Wang). The onset characteristics of the Asian monsoon over Indochina and its interannual variability have also been documented (Zhang et al.).

A number of studies have contributed to Theme 3's first objective, to understand the internal atmospheric variability in the monsoon region. The atmospheric and oceanic fields associated with the northward propagation of the boreal summer intraseasonal oscillation have been analyzed, and a possible mechanism responsible for this observed feature has been proposed (Kemball-Cook and B.Wang; see figure 7). Decadal variability of the intensity of the intraseasonal oscillations (ISOs) in the Asian summer monsoon region has been studied using precipitable-water data (Zveryaev and B.Wang). The active and break cycles of the Indian summer monsoon associated with ISOs have been investigated using observed OLR and ECMWF reanalysis data (Annamlai and Slingo). Interdecadal changes in the structure of ENSO and the relation between these changes to changes in ENSO frequency have been described (An and B.Wang).

The second objective is to determine the causes of interannual-to-interdecadal monsoon variability. An observational analysis showed that the physical mechanisms determining Indian monsoon rainfall variations are different on TBO (2–3-year) and ENSO (3–7-year) time scales (Li et al.). On TBO time scales, local low-level moisture transport associated with a warm SST anomaly in the Indian Ocean is critical. On ENSO time scales, land-ocean thermal contrast, convective activity along the monsoon trough in the western Pacific, and direct large-scale east-west circulation are all important. A simple analytical, coupled air-sea model has been advanced to understand the basic mechanisms of the TBO (Li et al.). Finally, the interannual variation of the Northwestern Pacific monsoon has been studied (Wu and Wang), and the spatial and temporal structure of decadal variability in global SST and lower-tropospheric circulation fields have been examined with a lag-correlation technique (Tomita et al.).

The third objective under Theme 3 is to understand the role of atmosphere-ocean-land interactions in monsoon predictability. To provide answers, coupled ocean-atmosphere-land models of both regional and global scales are required. A sophisticated atmospheric GCM, the ECHAM model (imported from the Max-Planck Institute), has been adapted and is being run extensively at the IPRC. This atmospheric GCM has been coupled to an intermediate ocean model (X. Fu). Furthermore, a regional climate model is being developed to simulate the fine structure of rain bands over the monsoon region (Y. Wang).

Figure 7: Life cycle of the Boreal Summer Intraseasonal Oscillation for early (May–June) and late (August–October) summer. Blue ovals indicate convection. Black arrows indicate eastward propagation along the equator. Red arrows indicate poleward propagation due to Rossby waves emanating from equatorial convection.



Soon-Il An

Postdoctoral Fellow

Soon-Il An obtained his Ph.D. in atmospheric sciences in 1996 from Seoul National University, Korea. He was a research associate at the Research Institute for Basic Science at Seoul National University before he joined the IPRC in 1998. His research interests include understanding the dynamics of intraseasonal-to-interdecadal climate variability, and intermediate and conceptual air-sea coupled modeling.

Soon-Il An's research at the IPRC has focused on the mechanisms that underlie ENSO. Using a simple air-sea model, he found that the transition to, and growth of, the El Niño phase can be explained by a basin-wide adjustment mechanism (An and Kang, 2000, *J. Clim.*, in press). Within a basin-wide adjustment process, two feedback mechanisms were shown to be important in ENSO evolution: thermocline feedback and the zonal advection feedback, which can contribute almost equally to the phase transition and growth of El Niño through their quasi-geostrophic balance (Jin and An, 1999, *GRL*; An et al., 1999, *J. Met. Soc. Jpn*; Kang et al., *J. Met. Soc. Jpn*, submitted). These findings suggest that an understanding of the El Niño must include both processes (An and Jin, to be submitted to *J. Clim.*).

Studying the interdecadal modulation of El Niño with the Cane-Zebiak (CZ) model, An showed that the decadal changes in the structure of ENSO are linked in a straightforward manner to decadal changes in the frequency of ENSO (An and B.Wang, 2000, *J. Clim.*). The dynamic interpretation is given through the eigenanalysis of a simple, coupled ocean-atmosphere model, in which the basic-state changes during the two decades are prescribed (An and Jin, *GRL*, in press). To explore this interpretation further, an experiment using a more sophisticated model is being conducted (Wang and An, to be submitted to *J. Clim.*).

Study of the seasonal phase-locking mechanism of ENSO with the CZ model verified that the phase locking of the La Niña to boreal summer, which had appeared in the CZ model run, is caused mainly by seasonal variations in the position of the ITCZ. The seasonal variations in the western Pacific surface wind and the mean thermocline depth are important to lock the mature La Niña to boreal winter. In addition, an eigenanalysis of the simple, air-sea coupled model showed that both frequency and instability of the slow mode are very sensitive to the zonal phase differences between the SST and atmospheric heating anomalies (An, *J. Met. Soc. Jpn.*, 2000; An and Kang, *Adv. in Atmos. Sc.*, submitted).

H. Annamalai

Visiting Assistant Researcher

H. Annamalai received his Ph.D. in atmospheric science in 1995 from the Indian Institute of Technology, Kharagpur, India. He was a post-doctoral research scientist with the Department of Meteorology, University of Reading, U.K., before joining the IPRC in December 1999. His research interests include diagnosis and modeling of the Asian summer monsoon system and its predictability, and an understanding of the dynamical and physical links between the monsoon and ENSO.

Since joining the IPRC, Annamalai has been finishing three manuscripts dealing with his research at the University of Reading. He has also conducted an extensive literature survey, from which he has identified two important research topics on specific aspects of intraseasonal-to-interannual variability in the East Asian monsoon, topics that he will research while at the IPRC. Specifically, he aims to document more fully the intraseasonal variability over the East Asian monsoon region and to increase our understanding of the processes involved in the intraseasonal and interannual variability of the entire Asian summer monsoon system.

Regarding the intraseasonal variability of the entire Asian summer monsoon, his research will focus on (a) the physical mechanisms that generate convection over the equatorial Indian Ocean, (b) teleconnections between the Asian summer monsoon and northwestern America and the eastern Mediterranean region, and (c) the relationship between intraseasonal and interannual variability over the West Pacific and East Asian monsoon domains. Regarding interannual variability, his focus will be on understanding the physical mechanisms that influence summer rainfall over North China during the developing phase of an El Niño and on understanding the regional modulations of the Walker circulation that result mainly from regional SST fluctuations over the Indian Ocean.

The processes that determine the overall behavior of the Asian summer monsoon are varied and interactive. Annamalai's proposed research will concentrate on the manner in which, during the developing phase of an El Niño, the tropical Indian Ocean SST and regional SST fluctuations affect the response of the entire Asian monsoon system with its three components: South Asian, East Asian, and West Pacific. To understand the role of SST and soil moisture on intraseasonal and interannual variability, he will design idealized numerical experiments.

Tim Li

Associate Professor of Meteorology, SOEST
Team 3 Co-Leader

Tim Li obtained his Ph.D. in meteorology from the University of Hawai'i at Mānoa in 1993. He was a research associate professor at the Naval Postgraduate School, Monterey, California, before joining the IPRC in April 1999. His research interests include climate dynamics and large-scale ocean-atmosphere interactions on seasonal-to-interdecadal time scales.

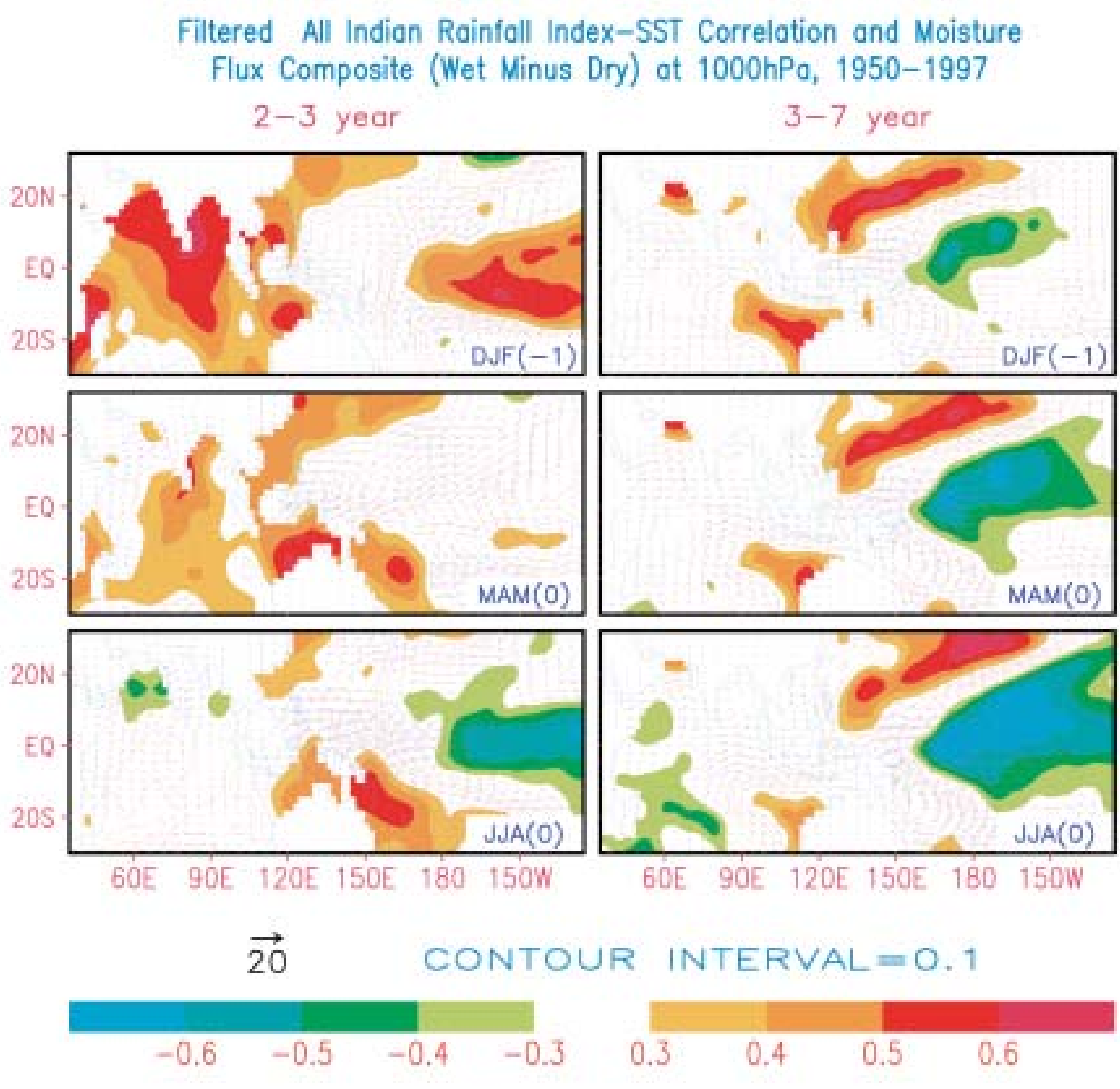
Tim Li's research at the IPRC has focused on understanding the TBO and the summer monsoon in South Asia and East Asia. In collaboration with C.-P. Chang (Naval Postgraduate School, Monterey), Tim Li has developed a theory of how the TBO maintains the same phase from northern summer in South Asia to southern summer in Australia and how the reversed phase can last through three locally inactive seasons to the next summer monsoon (Chang and Li, 2000, *J. Atmos. Sci.*). Using a simple coupled atmosphere-ocean model, they produced a TBO with SST and wind variations that resembled many aspects of observed TBOs (e.g., Lau and Yang, 1996, Webster et al., 1998). They propose the following sequence of events. A strong heating of the Indian monsoon induces a westerly wind anomaly, decreasing local SST through evaporation-wind feedback and intensifying a planetary-scale, east-west circulation that results in anomalous easterly winds over the western and central Pacific. This western Pacific anomaly opposes the seasonal mean westerlies, leading to reduced regional evaporation, warm SST anomalies, and a deepening of the western Pacific thermocline. This, in turn, increases the subsurface and surface temperatures, which overwhelm the effects of cold zonal advection and anomalous upwelling. The warm SST anomaly then persists in the western Pacific through northern fall, causing a stronger Australian monsoon and a stronger local Walker cell that produces a surface westerly anomaly over the Indian Ocean. This anomaly lets the cold SST Indian Ocean anomaly persist through the succeeding seasons and weakens the Asian monsoon in the following summer.

Li has also studied the relationship between the East Asian summer monsoon and tropical Pacific SST. (Chang et al., 2000, *J. Clim.*, in press). Observed rainfall in China, NCEP reanalysis data, and Reynolds SST data were analyzed for 1951–77 and 1978–96. During both decadal periods, wet summer monsoons were preceded by a warm equatorial eastern Pacific Ocean in the previous winter and followed by a cold equatorial eastern Pacific Ocean in the following fall. However, during 1951–77, the SST anomaly changed sign in northern spring, resembling a TBO pattern, while during 1978–96, the SST anomaly changed sign in northern fall, and the eastern Pacific TBO pattern disappeared. This interdecadal variation in the monsoon-SST relationship appears to result from the interdecadal change in the basic state of the coupled system.

In a third project, Li used a simple analytical coupled air-sea model (Li et al., *J. Clim.*, in press) to examine the fundamental cause of the TBO. The model simulated a regular TBO under the following conditions: (a) the amplification in opposite directions of the SST perturbations in the Indian and the western Pacific Oceans during the northern autumn, winter, and spring; and (b) the decay and change in sign of the SST anomaly in the western Pacific during the northern summer. Diagnosis of the model TBO revealed that the western Pacific SST and zonal wind anomalies have lagged correlations at two to three months, similar to observations. Such a phase-lag results from both remote and local ocean-atmosphere-land interactions. Oscillatory and non-oscillatory regimes of the model's solutions were analyzed. The model TBO was sensitive to both internal air-sea coupling coefficients and external basic state parameters. With a slight change in these parameters, the model may switch from a TBO regime to a chaotic regime or to an annual oscillation regime.

Finally, Li has examined the relationship between Indian Ocean SST and the Asian summer monsoon (Li et al. 2000,

Figure 8. Maps of lagged correlations between the India monsoon rainfall (time-filtered) and SST anomalies during December, January, February (DJF); March, April, May (MAM); and June, July, August (JJA) for the Tropospheric Biennial Oscillation (2–3-year) and El Niño-Southern Oscillation (3–7-year) scales (0 denotes the reference monsoon year, contour interval: 0.1). Regions where positive (negative) correlations exceed 0.3 are heavily (lightly) shaded. Taking into account the loss of the degree of freedom for each band-passed window, correlations = or > 0.4 are statistically significant at the .95 level or above. Plotted are also the "wet minus dry" composites of the moisture transport (units: ms-1gkg-1) at 1000hPa for the 10 wettest and 10 driest cases.



submitted to *GRL*). Indian Ocean SST has been thought to play a weaker role in Indian summer monsoon rainfall than equatorial eastern Pacific SST. This study showed that on TBO time scales, the Indian monsoon rainfall has significant positive correlations with Indian Ocean SST and with moisture flux transport in the preceding winter and spring (see figure 8). This SST effect is quite different from the remote forcing of Indian monsoon rainfall by eastern Pacific SST, which is more dominant on ENSO time scales. Based on a 48-year (1950–97) NCEP/NCAR reanalysis, surface temperature and all-India rainfall data, Li and his co-authors concluded that while both eastern Pacific SST and Eurasian land temperature may affect the monsoon on ENSO time scales, they are not important on TBO time scales. The biennial variability of the monsoon is largely influenced by Indian Ocean SST and tropical atmosphere-ocean-land interactions. (Chang and Li, 2000; Nichols, 1978, 1984). The lag relationship between Indian Ocean SST and the Indian monsoon, identified in the TBO time scales, is more useful for prediction than the simultaneous correlation between the monsoon and the eastern Pacific SST.

Tomohiko Tomita

Frontier Research Scientist

Tomohiko Tomita obtained his Ph.D. in geoscience from the University of Tsukuba, Ibaraki, Japan, in 1994. He was a research scientist with the NOAA Climate and Global Change Program, Department of Atmospheric Sciences, University of California at Los Angeles, before he joined the IPRC in 1997 as a Frontier research scientist. His research interests include the ENSO-monsoon system, global climate change, and intraseasonal-to-interdecadal climate variability.

While at the IPRC, Tomita has examined the spatial and temporal structures of decadal variability by obtaining lag-correlations between global SST and 850-hPa geopotential height observations for the last 50 years (Tomita et al., submitted to JGR). He distinguished three patterns of global decadal variability: a pattern associated with the decadal modulation of ENSO; an inherent decadal variability confined to the subarctic frontal zone of the midlatitude North Pacific; and a pattern associated with decadal variation in the North Atlantic. The patterns clearly showed decadal changes in the global SST and Z850 fields associated with the three regions. Among other things, this global analysis of observed decadal changes will be useful for validating solutions to GCMs being obtained at the IPRC and other climate research institutions.

Tomita has also investigated interannual SST variability across the equatorial oceans. An important finding is that in the equatorial central-eastern Pacific, the propagation direction of the anomalous SST and atmospheric divergence at 200 hPa height change as a function of their frequency. At periods of five years or longer, both anomalies propagate eastward, whereas at periods less than four years, they propagate westward. This observational finding corresponds to the theoretical model results of Hirst (1986), Neelin (1991), and Jin and Neelin (1993), and contributes to improving ocean, atmosphere, or coupled GCMs.

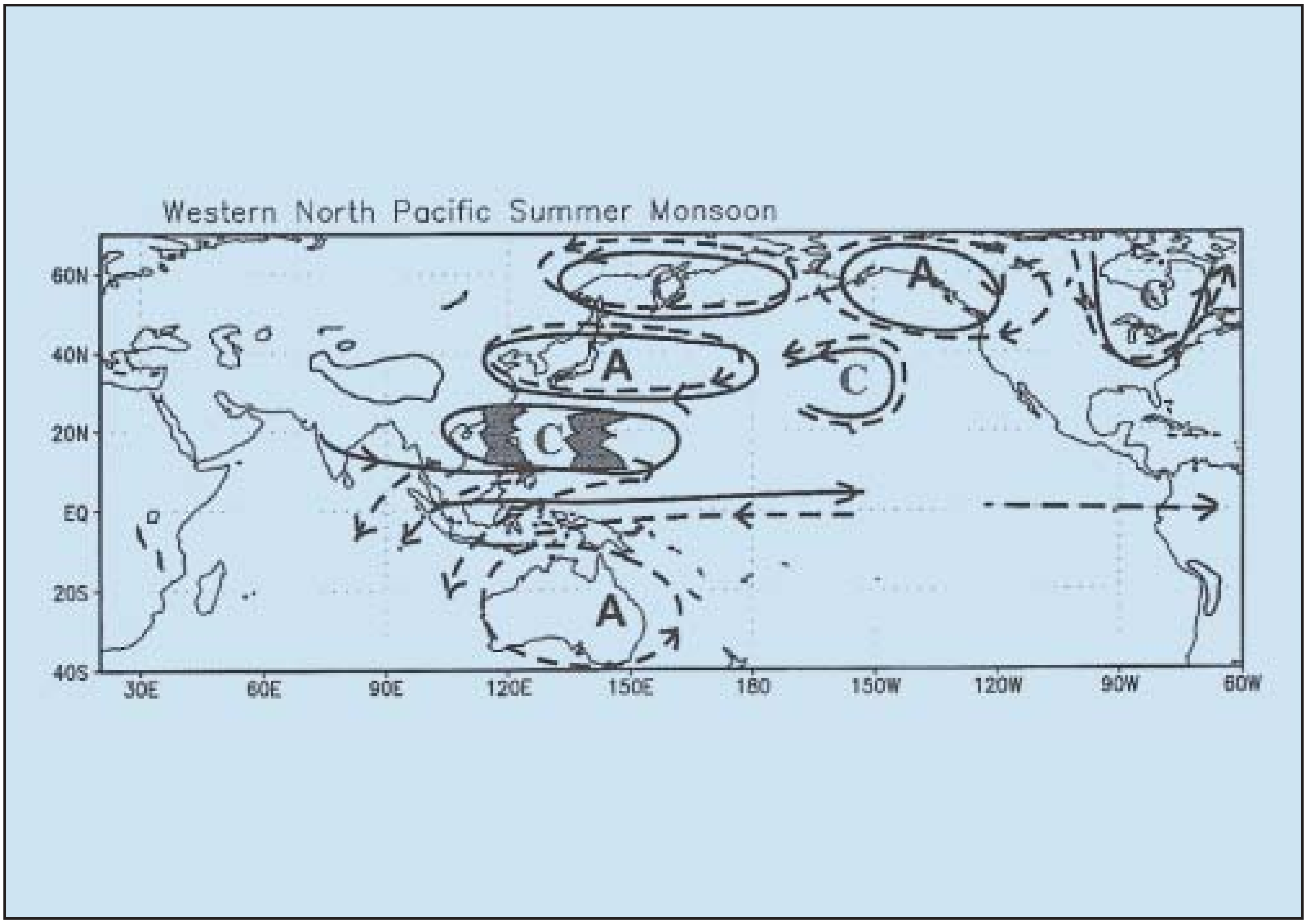
Bin Wang

Professor of Meteorology, SOEST
Team 3 Co-Leader

Bin Wang obtained his Ph.D. in geophysical fluid dynamics from The Florida State University in 1984. He came to the University of Hawai‘i at Mānoa as an assistant professor of meteorology in 1987 and received his promotion to full professor in 1992. He joined the IPRC in January 1999. His research interests include the variability and predictability of the A-AMS, interdecadal variability of the Asian-Pacific climate, TBOs, dynamics of ENSO and the ITCZ, large-scale ocean-atmosphere interaction, and the annual cycle in the coupled ocean-atmosphere-land system.

Bin Wang's research this past year has addressed, among others, the following three questions: (1) How does ENSO affect East Asian climate? (2) What is the dominant mode of interannual variability of the western North Pacific summer monsoon? How different is it from the Indian summer monsoon? (3) What caused the change in ENSO properties in the late 1970s? Research on the first two topics increases our understanding of the variability and predictability of the A-AMS (Theme 3), while the third seeks to understand interannual-to-interdecadal climate

Figure 9. Diagram of the major circulation anomalies associated with a strong western North Pacific summer monsoon (WNPSM). The upper-level and lower-level circulation anomalies are denoted by solid and dashed lines respectively. Letters A and C represent anticyclonic and cyclonic circulations.



variations in the Pacific and Indian Oceans by increasing our knowledge of ENSO dynamics (Theme 1). A brief summary of the major findings in these areas is presented below.

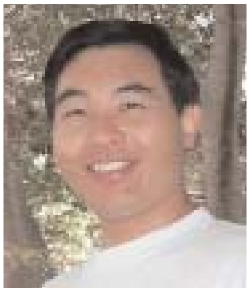
ENSO and East Asian climate: Using 50 years of NCEP/NCAR reanalysis data, Wang, in collaboration with Wu and Fu, showed that there is a teleconnection between the eastern-central Pacific and East Asia during the mature phase (often occurring during boreal winter) of the ENSO cycle. The key system that bridges the warm (cold) events in the eastern Pacific and the weak (strong) East Asian winter monsoon is an anomalous lower tropospheric anticyclone (cyclone) located over the Philippine Sea. It develops rapidly in late fall before the ENSO warm episode matures, and it persists until the next spring or early summer, causing unusual wet (dry) conditions along the East Asian monsoon front stretching from southern China northeastward to east of Japan (Kuroshio Extension). Given the chaotic nature of atmospheric motion, how can the anticyclone persist for two to three seasons and result in a delayed ENSO impact on the East Asian summer monsoon? Wang, Wu, and Fu (2000, *J. Clim.*) have proposed a theory that attributes the persistence of the teleconnection to positive thermodynamic feedback between the anticyclone and sea surface cooling in the presence of mean northeasterly trades.

Differences between the Indian summer and western North Pacific summer monsoons: Analysis of 50 years of the NCEP/NCAR reanalysis data by Wang and Wu (to be submitted to *J. Clim.*) revealed that the interannual variations of the two Asian monsoon subsystems—the Indian summer monsoon (ISM) and the western North Pacific summer monsoon (WNPSM)—are remarkably different from each other in terms of their spatial structures, dominant time scales, relationships to ENSO, and their teleconnections to midlatitudes and other tropical regions. The WNPSM is generally weak (strong) during the *decay* of an El Niño (La Niña), whereas the ISM tends to be weak (strong) during the *devel-*

opment of an El Niño (La Niña). Figure 9 shows the circulation anomalies associated with a strong WNPSM. Since the late 1970s, the WNPSM has become considerably more variable, but its relationship to ENSO has remained steady over the last 50 years. In contrast, the ISM has decreased in variability, but its association with ENSO has dramatically weakened. Possible causes of these differing changes and relationships are discussed in their paper.

Another discovery is a teleconnection between a suppressed (enhanced) WNPSM and lower (higher) than normal summer rainfall over the Central Plains of the United States (Wang and Wu; to be submitted to *J. Clim.*). This boreal summer teleconnection appears to be established through a wave-train pattern emanating from the Philippine Sea and extending to North America. The dynamics behind this teleconnection are under investigation.

Changes in El Niño properties in the late 1970s: The frequency and structure of the dominant ENSO mode evidently changed in the late 1970s. This change has been hypothesized to be due to changes in the background thermocline structure. Wang and An (to be submitted to J. Clim.) analyzed the available observations and found no clear-cut changes in thermocline from the pre-shift (1961–1975) to the post-shift (1981–1995) period: the most significant changes in the tropical Pacific were seen in SST and surface wind fields. Numerical experiments with the Cane-Zebiak (1987) model demonstrated that specified basic-state changes in surface winds and SST, similar to the observed changes during the pre- and post-shift periods, lead to changes in the oscillation period, amplitude, and structure of the coupled ENSO mode. These simulated changes also corresponded qualitatively to the observations. The critical factor that affected the ENSO behavior in the model was a change in the basic state of the equatorial winds and the associated equatorial upwelling. The change in background tropical winds and equatorial upwelling altered the structure of the coupled mode: in the post-shift period, the equatorial westerly anomalies shifted eastward during the mature phase of ENSO warming. This shift, in turn, prolonged the oscillation period and amplified the ENSO signal.



Yuqing Wang

Associate Researcher

Yuqing Wang obtained his Ph.D. in 1995 in applied mathematics at the Centre for Dynamical Meteorology and Oceanography, Monash University, Australia. He was senior professional officer at the Bureau of Meteorology Research Centre in Melbourne, Australia, before he joined the IPRC in February 2000. His research interests include atmospheric dynamics, tropical meteorology, tropical cyclones, air-sea interactions, low-frequency oscillations in the atmosphere and the ocean, the development of high-resolution regional atmospheric models, and numerical modeling of the atmosphere and the ocean.

Since his recent arrival at the IPRC, Yuqing Wang has surveyed the current status of regional climate modeling and has mapped out a strategy for developing an IPRC regional climate model based upon the tropical cyclone model he has developed previously. This model has now been installed on his workstation at the IPRC, and a simple radiation scheme has been implemented. To adapt his tropical cyclone model to a regional climate model, he will incorporate the best land-surface and radiation packages available, making the model appropriate for regional climate research. He also plans to introduce the regional climate model developed at the State University of New York at Albany to conduct comparison studies with the IPRC model.

Using the IPRC regional climate model, Wang will conduct research towards understanding A-AMS interactions on different time and space scales. His emphasis will first be on understanding the ISOs in the A-AMS and the annual march of the subtropical high and monsoon trough during the northern summer. His long-term goal is to increase our understanding of the nature of the A-AMS and its hydrological cycle through process studies based on numerical experiments.

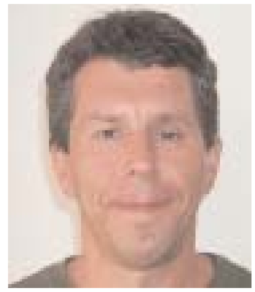
Yongsheng Zhang
Postdoctoral Fellow

Yongsheng Zhang obtained his Ph.D. in atmospheric science in 1995 from the Chinese Academy of Sciences, Beijing, China. He was a postdoctoral research associate with the Meteorology Department of the Naval Postgraduate School, Monterey, California, before coming to the IPRC in May 1999. His research interests include monsoon variability, monsoon and ENSO/TBO interactions, and satellite meteorology.

During this past year, Yongsheng Zhang has studied the relationship between the South Asian monsoon and the TBO (with Li and B.Wang). Using filter techniques on observed data, he investigated the possible processes that determine anomalies of Indian rainfall at interannual time scales. The results reveal that the mechanisms affecting the monsoon-rainfall anomaly differ significantly depending on their period. On the TBO time scale, the anomaly is mainly affected by local moisture convergence associated with SST changes in the Indian Ocean during the preceding winter and spring; on the ENSO time scale, it may result from anomalies in the large-scale, east-west overturning, convective activity along the monsoon trough and from land-ocean thermal contrast. Eastern Pacific SST and Eurasian land temperature may both affect the monsoon on the ENSO time scale, but they are not important on the TBO time scale (Li et al., submitted to *GRL; see section by Tim Li and figure 8*).

In another study, Zhang has used daily observed rainfall data and NCAR/NCEP reanalyses data to examine the onset of the Asian summer monsoon over Indochina and its interannual variability. In collaboration with Li and B. Wang, he documented (a) the variation in circulation and convection associated with monsoon onset, (b) ISO activity, and (c) precursors of early and late monsoon onset. Two components of the ISOs relevant to onset of the Asian monsoon were revealed: a 12-to-24-day mode (ISO1) originating in the South China Sea, and a quasi-30-day mode (ISO2) originating in the equatorial Indian Ocean. Mode ISO1 propagates westward, while ISO2 propagates northward. ENSO was found to have a strong effect on early or late monsoon onset (Zhang et al., to be submitted to *J. Clim.*).

Using station-observed snow-depth data over the Tibetan Plateau, Zhang investigated how the changes in Pacific and Indian Ocean SST during recent decades have affected snow-cover variations over the Eurasian continent. He found that the sudden increase in spring snow-depth and decrease in land surface temperature over the Tibetan Plateau since 1976-77 are linked to SST increases in the North Pacific and Indian Oceans.



Igor Zveryaev
Associate Researcher

Igor Zveryaev obtained his Ph.D. in physical oceanography in 1992 from the State Oceanographic Institute, Moscow. He worked as a senior research scientist in the Sea-Air Interaction and Climate Laboratory of the P.P. Shirshov Institute of Oceanology before joining the IPRC in 1998. His research interests include large-scale ocean-atmosphere interactions, seasonal-to-decadal climate variations, and tropical-extratropical climate interactions.

Igor Zveryaev's research at the IPRC has focused on studying aspects of decadal changes in the monsoon system (Theme 3) and on the seasonality of decadal variability in the North Pacific (Theme 1) and North Atlantic Oceans.

Zveryaev and B.Wang (manuscript in preparation) used 40 years of data on precipitable-water content (PWC) derived from the NCEP/NCAR reanalysis to study decadal-to-interdecadal changes in the intensity of ISOs and changes in the summer-mean atmospheric moisture of the Asian monsoon. The ISO intensity was defined in terms of the standard deviations of band-passed daily PWC. Decadal variation accounts for a substantial amount (30–50%) of the total variance in ISO intensity. The highest (75–85%) contribution of decadal variability in summer-mean PWC to its total variability is found over Southeast Asia and the South China Sea. In general, decadal changes are strong in the East Asian monsoon region, but relativity weak in the Indian monsoon region. An empirical orthogonal function (EOF) analysis revealed several centers of decadal variation within the East Asian monsoon region. The most important EOF mode for PWC consists of a prominent meridional dipole structure centered over northern China and the southern South China Sea. The first EOFs for PWC and ISO are strikingly similar in that they show the largest variations on decadal time scales, with a shift in the mid-1970s that occurs about the same time as the shift in North Pacific climate noted below.

Singular value decomposition (SVD) analysis has revealed strong correlations on decadal time scales among Indian and Pacific Ocean SSTs, summer-mean PWC, and summer ISO. The first SVD mode accounts for 64% of the total covariance, and the second SVD accounts for 20% of the total covariance. The first SVD mode has large centers of SST variability in the midlatitude North Pacific and in the tropical Indian and Pacific Oceans. The centers of largest variability in summer-mean PWC and ISO intensity are located over eastern China and the southern region of the South China Sea. All expansion coefficients of the first SVD mode show a regime shift in the mid-1970s. Coupling between monsoon variables and SST on decadal time scales, represented by the second SVD mode, is substantially weaker.

The pattern of ISO intensity changed over decades, with a prominent shift occurring also in the mid-1970s. While these interdecadal changes are most pronounced in the East Asian monsoon, the overall change in the pattern of ISO intensity is strongly linked to interdecadal variations in SST in the Pacific and Indian Oceans.

In a study of the climate characteristics of the seasonal cycle in the North Pacific and the North Atlantic Oceans, Zveryaev together with Yashayaev (Yashayaev and Zveryaev, *Int. J. Clim*., 2000, in press) examined (a) the contribution of the seasonal cycle to the total variance in SST, air temperature (AT), and sea level pressure (SLP); (b) the amplitudes and phases of the annual and semiannual harmonics of these fields; (c) their annual phase differences; (d) their semiannual-to-annual amplitude ratios; and (e) the differences in their contributions in various regions. They found that the seasonal cycle accounts for more than 80% of the total variance in SST and AT in mid- and high-latitudes, and for more than 95% of the variance in the centers of the Subtropical Gyres.

More specifically, they found that annual and semiannual harmonics together account for more than 95% of the seasonal variability in SST, AT, and SLP over the analysis domain. Seasonal variations in SST and AT are greatest in the western parts of the extratropical oceans. Annual phases of SST and AT increase in the eastern tropical oceans, indicating southeastern propagation over the oceans in the Northern Hemisphere. The annual cycle of AT leads the SST cycle by 1 to 3 weeks, with the largest phase differences observed in the western boundary regions of the North Pacific and North Atlantic Oceans. The SLP showed the greatest annual variation in three distinct areas of the North Pacific—off the Asian coast, around the Aleutian Islands, and off the California coast—and in one area in the North Atlantic, which was west of Iceland. Moreover, for the Northern Hemisphere, the largest semiannual variation in SLP is in the North Pacific.

Using these analyses, Zveryaev and Selemenov (2000, *Int. J. Clim.*, in press) studied long-term changes in SST annual variations in the North Pacific. Anomalies of the annual and seasonal means show definite climate regime shifts in 1976 and again in 1988. During the 1950s and 1960s, summer SST anomalies were larger than winter anomalies, and warm (cold) summer anomalies were associated with larger (smaller) amplitudes of annual cycle. Subsequently, the winter SST anomalies were larger, and the warm (cold) winter anomalies were associated with smaller (larger) amplitudes of annual cycle. An analysis that compared a wavelet transformation of the winter signal with the summer seasonal mean SST revealed that in the central North Pacific, summer SST varies much more over decades than winter SST.

Plans for the Asia-Pacific Data Research Center

The IPRC is seeking to establish a "data-research" center—the Asia-Pacific Data Research Center (APDRC)—in order to make data sets relevant to Asia-Pacific climate easily accessible to researchers. The Center is envisioned to be a powerful research resource, first for IPRC scientists and eventually for the national and international climate research community. The collection and distribution of data between the IPRC and other countries in the Asia-Pacific region (one of the APDRC functions) will provide a means for strengthening international collaboration.

A data committee was formed in June 1999 to develop a plan for establishing the APDRC. Its chairman is Humio Mitsudera, and members include IPRC researchers and computer staff.[1] A smaller sub-committee[2] was formed to identify the computational infrastructure needed for data-intensive research projects. The group identified two user-friendly software packages for data access, developed and used at the Pacific Marine Environmental Laboratory (PMEL) in Seattle, Washington: the Live Access Server (LAS) for gridded data sets, and EPIC for non-gridded *in-situ* data sets. To promote the group's knowledge of these products, computer systems engineer Ron Merrill and data specialists Yingshuo Shen and Xiaowei Sun visited PMEL in October 1999. The success of this visit led the IPRC to collaborate formally with the designers of LAS and EPIC, Steve Hankin, Nancy Soreide, and Don Denbo. They were invited to the IPRC in November 1999, and at that meeting a proposal was drafted to obtain financial support for the Center. That proposal is currently being considered by two U.S. funding agencies.

As stated in the proposal, the APDRC mission is to "increase understanding of climate variability in the Asia-Pacific region by developing the computational infrastructure necessary to make data resources readily accessible to, and usable by, researchers." Specific goals are to: (a) develop and implement a data server system (DSS); (b) establish efficient DSS communication in an international setting; (c) ensure the active participation of the international scientific community in the project; (d) undertake data-intensive research projects that will both advance scientific knowledge and lead to improvements in data collection and preparation; and (e) maintain a data archive focused on Asia-Pacific climate issues.

The DSS is to be built initially upon LAS and EPIC and is to have four distinct, but well-integrated functions: (a) location; (b) navigation and evaluation; (c) delivery; and (e) visualization and analysis. For the delivery part, the Distributed Ocean Data System (DODS), developed at the University of Rhode Island, is to be used. DODS is a software package that makes data transfer, data translation, and data sub-setting over the network a completely transparent process for users.

Linking data management (collection and preparation) with research is novel in a single center and an essential aspect of the APDRC. The combination is expected not only to lead to increased data usage, but also to feed back to the Center's data management branch, leading to improvements in the data processing itself.

The data committee has already started to implement aspects of the plan. The necessary computer equipment for the APDRC has been identified and, if not yet available at the IPRC, has been included in the procurement plans for IPRC computer hardware. LAS and DODS have already been installed on the IPRC server by Yingshuo Shen for the internal data library (http://rijicho.soest.hawaii.edu/las/main.html). Among other data sets, the LAS includes the SODA (Simple Ocean Data Assimilation) package of Carton et al. (1999a,b; *JPO*), an ocean reanalysis data product. It has also been extended to include meteorological data sets gridded over both ocean and land surfaces (e.g., NCEP reanalysis data).

1 Regular members are Humio Mitsudera (chair), Bohyun Bang, Tim Li, Nikolai Maximenko, Ronald Merrill, Tangdong Qu, Yingshuo Shen, Amy Solomon, Xiaowei Sun, Tomohiko Tomita, Takuji Waseda, Max Yaremchuk, Gang Yuan, Yongsheng Zhang, and Igor Zveryaev. Occasional participants are Tommy Jensen, Jay McCreary, Motoyasu Miyata, Bin Wang, and Shang-Ping Xie.

2 Data Server Committee members are Humio Mitsudera, Bohyun Bang, Ron Merrill, Yingshuo Shen, Xiaowei Sun, and Takuji Waseda.

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Wang, B., Nonlinear dynamics of ENSO. (Invited) IUGG 99, Birmingham, U.K., July 1999.

Wang, B., *WMO (World Meteorological Organization) International Workshop on Long-Range Weather Forecast '99*. (Invited) Nanjing, China.

Wang, B., *Climate variability and prediction.* (Invited) International Workshop on Frontiers of Science and NSFC Priority Setting, Beijing, China, October 1999.

Wang, B., *Climate variability: Theory and processes*. (Invited) US-China Symposium and Workshop on Seasonal-to-Interannual Climate Variability, Beijing, China, October 1999.

Wang, B., *East Asian monsoon: a distinctive subsystem of Asian monsoon.* (Invited) Monsoon Symposium, Honolulu, Hawai‘i, U.S.A., December 1999.

Wang, B., *Pacific–East Asian Teleconnection: How does ENSO affect East Asian Climate?* Eleventh Conference on Global Change, Long Beach, California, U.S.A., January 2000.

Wang, B., *Mechanism of monsoon-ENSO interaction during the mature-decay phase of ENSO cycle*. (Invited) Symposium on Indo-Pacific Climate, Tokyo, Japan, March 2000.

Wang, B., *Dynamics of Madden-Julian Oscillation.* (Invited) Workshop on MJO-ENSO relation sponsored by NSF and NOAA. GFDL, Princeton University, Princeton, New Jersey, U.S.A., March 2000.

Wang, B., *Mechanisms of ENSO impacts on East Asian monsoon.* (Invited) Fifth workshop on GCM simulation of East Asian Climate, Seoul, Korea, April 2000.

Wang, B., *Physical processes determining rapid establishment of the Pacific cold tongue and ITCZ complex.* Sixth International Conference on Southern Hemisphere Meteorology and Oceanography, Santiago, Chile, April 2000.

Wang, D., *Generation of internal waves in the equatorial undercurrent.* Internal Wave Modelling, Eleventh Aha Hulikoa Hawaiian Winter Workshop, Honolulu, Hawai‘i, U.S.A., January 1999.

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Waseda, T., *Experimental study of nonlinear water wave evolution including breaking.* (Invited) Evening Seminar of the Ocean Engineering Department, University of Tokyo, Tokyo; also at the Air-Sea Interface Symposium, The University of New South Wales, Sydney, Australia, January 1999.

Waseda, T., *Wavelet Analysis and data assimilation: Twin experiment using JAMSTEC Kuroshio Model-Comparison with optimal interpolation scheme.* Data Assimilation Summer School, Mutsu, Japan, August 1999.

Waseda, T., H. Mitsudera, B. Taguchi, and Y. Yoshikawa, *On the eddy-Kuroshio interaction: Initialization and evolution of the mesoscale eddy*. FRSGC Annual Symposium, Tokyo, Japan, March 2000.

Xie, S.-P., *Where is ocean memory located*? Fall Meeting, Oceanographic Society of Japan, Hakodate, Japan, September 1999.

Xie, S.-P., *Abrupt onset and slow seasonal evolution of summer monsoon in an idealized GCM simulation.* Monsoon Symposium, Honolulu, Hawai‘i, December 2000.

Xie, S.-P., *A dynamic mechanism for North Pacific interdecadal variability involving mode waters*. Ocean Science Meeting, San Antonio, Texas, U.S.A., January 2000.

Xie, S.-P., *Understanding summer monsoon by GCM experimentation.* Symposium on Indo-Pacific Climate, Tokyo, Japan, March 2000.

Xie, S.-P., *Northward displaced intertropical convergence zone in the Pacific and Atlantic: A result of ocean-atmosphere-land interaction*. Seminar, Department of Oceanography, University of Hawai‘i, Honolulu, U.S.A., March 2000.

Yaremchuk, M.I., *Circulation patterns in the Pacific Ocean derived by inversion of climatological and drifter data.*

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Yaremchuk, M.I., *A variational estimate of the mean North Pacific circulation during the last decade*. PACON '99, Moscow, Russia, June 1999.

Yaremchuk, M. I., *Water mass transformations in the North Pacific Ocean*. IUGG '99, Birmingham, U.K., July 1999.

Yaremchuk, M.I., and A. Senchev, *Surface velocity and tidal gauge data analysis using a finite element tidal model*. Third American Meteorological Conference on Coastal Atmospheric and Oceanic Prediction and Processes, New Orleans, Louisiana, U.S.A., 1999 (Proceedings, pp. 155–158).

Yuan, G., I. Nakano, H. Fujimori, T. Nakamura, T. Kamoshida, and A. Kaya, *Preliminary results from a 1000-km scale three-dimensional tomography experiment in the Kuroshio Extension region*. International Sym-posium on Acoustic Tomography and Acoustic Thermo-metry, Tokyo, Japan, February 1999.

Zveryaev I.I., *Long-term changes of the winter sea-level-pressure fields and related synoptic activity over the North Atlantic*. IUGG '99, Birmingham, U.K., July 1999.

Zveryaev I.I., and K.M. Selemenov, *Interpentadal changes in seasonal cycle of SST in the North Pacific*. TRIAN-GLE '98, Kyoto, Japan, September 1998.

Zveryaev I.I., and K.M. Selemenov, *Changes of seasonal cycle of SST and 500 hPa heights due to recent North Pacific climate shifts*. PACON '99, Moscow, June 1999.

Zveryaev I.I., and K.M. Selemenov, C*limatic changes of seasonal cycle of SST in the North Pacific*. IUGG '99, Birmingham, U.K., July 1999.

International Pacific Research Center Seminars

Date	Speaker	Affiliation	Title
4/21/99	Leland Jameson	International Pacific Research Center (IPRC)	*Adaptive Computational Methods—Wavelets*
4/28/98	Takuji Waseda	International Pacific Research Center (IPRC)	*Long Time Evolution of Gravity Wave Systems*
5/5/98	Amy Solomon	International Pacific Research Center (IPRC)	*A Study of the Role of Large-scale Eddies in a Multi-level Quasi-geostrophic Model*
5/12/98	Toru Miyama	International Pacific Research Center (IPRC)	*The Mindanao Current as a Source of the Indonesian Throughflow*
5/26/98	Soon-Il An	International Pacific Research Center (IPRC)	*Basin-wide Ocean Adjustment Processes of ENSO: A Model with the Zonal Mean and Eddy Separated*
6/2/98	Mike Kirby	Dept. of Mathematics, Colorado State University, Fort Collins, Colorado, U.S.A.	*Empirical Orthogonal Eigenfunctions*
6/9/98	Tommy Jensen	International Pacific Research Center (IPRC)	*TOMS—A (Fairly) General-purpose Thermodynamic Ocean Modeling System*
8/12/98	In-Sik Kang	Seoul National University, Seoul, Korea	*Advective Thermal Processes for the SST Oscillation of ENSO*
6/16/98	Ming Feng	International Pacific Research Center (IPRC)	*Upper Ocean Heat and Salt Balance in the Western Equatorial Pacific during TOGA COARE*
8/18/98	Zhengyu Liu	University of Wisconsin, Madison, Wisconsin, U.S.A.	*Modeling Long-Term Climate Change with 'Equilibrium' Asynchronous Coupling Scheme*
8/20/98	Max Yaremchuk	International Pacific Research Center (IPRC)	*Numerical Models as a Tool for Data Processing*
8/24/98	Dailin Wang	International Pacific Research Center (IPRC)	*Global Ocean Modeling and Large-Eddy Simulation of Equatorial-Ocean Boundary Layers*
9/2/98	Jonathan Overpeck	National Geophysical Data Center, Boulder, Colorado, U.S.A.	*The Role of Paleoclimatology in Understanding Climate System Dynamics*
9/8/98	Tangdong Qu	International Pacific Research Center (IPRC)	*Circulation and Water Mass Distribution of the Tropical Western Pacific Ocean*
9/18/98	Jim Potemra	International Pacific Research Center (IPRC)	*Seasonal Variations of the Pacific to Indian Ocean Throughflow*
10/14/98	Shoichi Kizu	Tohoku University, Sendai, Japan	*Measurement of Sea Surface Topography by Carrier-phase GPS*
11/10/98	Washington	National Center for Atmospheric Research (NCAR), Boulder, Colorado, U.S.A.	*The NCAR Parallel Climate Model*
12/2/98	Tom Rossby	University of Rhode Island, Kingston, Rhode Island, U.S.A.	*On the Structural Stiffness and Annual Migration of the Gulf Stream*
12/8/98	Tim Li	Naval Research Laboratory, Monterey, California, U.S.A.	*Monsoon and ENSO, Interactive System*
12/11/98	Jerry Meehl	National Center for Atmospheric Research (NCAR), Boulder, Colorado, U.S.A.	*Low Frequency Climate Variability and Climate Change in the Pacific Region*
12/15/98	Soon-Il An	International Pacific Research Center (IPRC)	*Transition and Instability Mechanisms of ENSO*
1/6/99	Claude Frankignoul	University of Paris, Paris, France	*On Decadal Variability and Air-Sea Coupling in the North Atlantic and the North Pacific in the ECHAM1/LSG Coupled Model*
1/7/99	Claude Frankignoul	University of Paris, Paris, France	*Variability of the Thermocline Due to a Sudden Change in Ekman Pumping*

Date	Speaker	Affiliation	Title
1/11/99	Jagadish Shukla	Center for Ocean-Land-Atmosphere Studies (COLA), Calverton, Maryland, U.S.A.	*Problems and Prospects for Regional Climate Prediction*
1/12/99	Lennart Bengtsson	Max-Planck Institut for Meteorology, Hamburg, Germany	*Numerical Modeling of the Hydrological Cycle on Global and Regional Scales*
1/26/99	Max Yaremchuk	International Pacific Research Center (IPRC)	*On the Mean State of the North Pacific Ocean in the Last Decade*
1/27/99	Steven Businger	Dept. of Meteorology, School of Ocean and Earth Science and Technology (SOEST), University of Hawai'i, Honolulu, Hawai'i, U.S.A.	*Observing and Photographing Geophysical Phenomena*
2/2/99	Hans von Storch	Meteorological Institute, University of Hamburg, Hamburg, Germany	*Empirical Modal Decomposition in Oceanography*
2/3/99	Rick Knabb	Dept. of Astronomy, University of Hawai'i, Honolulu, Hawai'i, U.S.A.	*The Mesoscale Structure of Eastern Tropical Plumes*
2/9/99	Jin Song von Storch	Meteorological Institute, University of Hamburg, Hamburg, Germany	Air-Sea Interaction in the Coupled GCM
2/10/99	Thomas Giambelluca	Dept. of Geography, University of Hawai'i, Honolulu, Hawai'i, U.S.A.	*Studying Land-Atmosphere Interaction: Field Research in Hawai'i, Brazil, Thailand and Vietnam*
2/16/99	Jurgen Sundermann	University of Hamburg, Hamburg, Germany	*Decadal Variability of Oceanic Processes on the Northwest European Shelf*
2/17/99	Bruce Cornuelle	Scripps Institute of Oceanography, University of California at San Diego, California, U.S.A.	*AMODE: An Example of Tomographic Data Assimilation*
2/22/99	Nikolai Maximenko	P.P. Shirshov Institute of Oceanology, Moscow, Russia	*Megapolygon-'87*
3/9/99	Michael Kelly	Colorado State University, Fort Collins, Colorado, U.S.A.	*A Simple Model of Ocean-Atmosphere Interactions in the Tropical Climate System*
3/16/99	T.N. Krishnamurti	The Florida State University, Tallahassee, Florida, U.S.A.	*Physical Initialization for Weather and Climate Forecasting*
3/17/99	Nikolai Maximenko	P.P. Shirshov Institute of Oceanology, Moscow, Russia	*Correction of Current Meter Data of Megapolygon-'87 Contaminated by Surface Wave Effect*
3/18/99	Akio Ishida	Japan Marine Science and Technology Center (JAMSTEC), Tokyo, Japan	*Introduction of the JAMSTEC Global High-Resolution Ocean GCM*
3/25/99	Peng Lu	NOVA Southeastern University, Fort Lauderdale, Florida, U.S.A.	*The Existence of Tsuchiya Jets*
3/25/99	Shang-Ping Xie	Hokkaido University, Hokkaido, Japan	*Decadal Variability in an Ocean GCM of the North Pacific Forced by the NCEP Re-Analysis Winds*
4/6/99	Tangdong Qu	International Pacific Research Center (IPRC)	*Circulation and Water Mass Distribution in the South China Sea and its Connection with the North Pacific Ocean*
4/16/99	Konstantin Lebedev & Max Yaremchuk	International Pacific Research Center (IPRC)	*A Diagnostic Study of the Indonesian Throughflow*
4/27/99	Kikuro Miyakoda	George Mason University, Fairfax, Virginia, U.S.A.	*Tropical-wide Teleconnection and Oscillation*
5/18/99	Dailin Wang	International Pacific Research Center (IPRC)	*Global Ocean Modeling Using POP (Parallel Ocean Program)*
5/27/99	Jim Potemra	International Pacific Research Center (IPRC)	*Forcing Mechanisms for Southern Tropical Indian Ocean Rossby Waves*
6/1/99	Thomas Stocker (IGCR Video Exchange)	University of Bern, Bern, Switzerland	*Abrupt Climate Change: Interpreting Ice-Core Results with Physical-biogeochemical Climate Models*
6/15/99	Gang Yuan	International Pacific Research Center (IPRC)	*Preliminary Results from a 1000-km Scale Three-dimensional Tomography Experiment in the Kuroshio Extension Region*

Date	Speaker	Affiliation	Title
6/22/99	Ming Feng	International Pacific Research Center (IPRC)	*Structure and Variability of Kuroshio Current at the Tokara Strait*
6/28/99	Kraig Winters	University of Western Australia, Nedlands, Australia	*Numerical Studies of Stratified Flow over Topography*
7/6/99	Masami Nonaka	International Pacific Research Center (IPRC)	*Tropical Subsurface Salinity and Tritium Distributions in a Pacific GCM: Their Differences and Formation Mechanisms*
8/5/99	Zhengyu Liu	University of Wisconsin, Madison, Wisconsin, U.S.A.	*Dynamics of Island Circulation*
8/9/99	Susan Kemball-Cook	L. Livermore National Laboratory, Livermore, California, U.S.A.	*The Onset of Convection in the Madden-Julian Oscillation*
8/10/99	Johannes Loschnigg	International Pacific Research Center (IPRC)	*The Heat Balance of the Indian Ocean in an Intermediate Ocean Model on Seasonal and Interannual Timescales*
8/11/99	Toshio Yamagata	Frontier Research System for Global Change (FRSGC), Tokyo, Japan	*Mysteries of the Kuroshio*
8/24/99	Lewis M. Rothstein	University of Rhode Island, Kingston, Rhode Island, U.S.A.	*Decadal-Interdecadal Thermocline Variability in the North Pacific Ocean*
11/9/99	Friedrich A. Schott	Institute for Oceanography, University of Kiel, Kiel, Germany	*Western Indian Ocean Circulation and its Interannual Variability*
11/23/99	Friedrich A. Schott	Institute for Oceanography, University of Kiel, Kiel, Germany	*How does the Conveyer Belt Cross the Equator?—Tropical Atlantic Watermass Pathways and Circulation Variability*
12/14/99	Lydia Dumenil-Gates	Max-Planck Institute for Meteorology, Hamburg, Germany	*Simulated Interannual Variability of the Indian Summer Monsoon—Present Day and at Doubled* CO_2
1/6/00	In-Sik Kang	Dept. of Atmospheric Sciences, Seoul National University, Seoul, Korea	*Physical Processes of the Intraseasonal Oscillation within a GCM*
1/10/00	Claude Frankignoul	University of Paris, Paris, France	*Influence of Atlantic Sea Surface Temperature Anomalies on the Atmospheric Circulation*
1/18/00	Tomohiko Tomita	International Pacific Research Center (IPRC)	*Spatiotemporal Structure of Decadal Scale Variability Observed in the Global SST and Lower-tropospheric Circulation Fields*
2/9/00	Brian Mapes	Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, Colorado, U.S.A.	*Momentum Fluxes by Deep Convection*
2/11/00	Chris Garrett	University of Victoria, Victoria, British Columbia, Canada	*Marginal Mixing Concepts*
2/24/00	Zuojun Yu	Pacific Marine Environmental Laboratory (PMEL), Seattle, Washington, U.S.A.	*On the Pacific North Equatorial Countercurrent: Part I: The influence of equatorial dynamics Part II: Validation of NSCAT winds*
2/25/00	Igor Zveryaev	International Pacific Research Center (IPRC)	*Interdecadal Changes in the Intensity of Intraseasonal Oscillations in the Asian Summer Monsoon System*
3/14/00	Akio Ishida	Japan Marine Science and Technology Center (JAMSTEC), Tokyo, Japan	*Global High-Resolution Ocean Modeling in JAMSTEC—Interannual Variation Experiment*
3/20/00	Kunio Kutsuwada	Tokai University, Japan	*Intraseasonal Variations in the Upper Equatorial Pacific Ocean during the 1997–98 El Niño*
3/21/00	Brian Mapes	Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, Colorado, U.S.A.	*Three Levels Plus a Boundary Layer: An Appropriate Technology Model for Tropical Troposphere*

Workshops and Conferences

THE INTERNATIONAL STRATEGY FORUM OF THE PROJECT FOR INTER-COMPARISON OF LAND-SURFACE PARAMETERIZATION SCHEMES (PILPS)

The IPRC hosted the International Strategy Forum for PILPS from February 23 to 26, 1999, at Tokai University, Honolulu. Sponsored partly by GEWEX, the forum was organized by Ann Henderson-Sellers, Director of the Environment at the Australian Nuclear Science and Technology Organisation. The purpose of the meeting was to summarize the scientific contributions by PILPS for the period 1992-98, convene an international group of scientists to identify new themes for PILPS 2000, and begin to delineate the process for new projects. The projects for 2000 were formulated around three themes: (a) the multi-criteria optimization technique for land-surface scheme comparisons, spearheaded by Hoshin Gupta and the hydrology and water resource group at the University of Arizona; (b) the Higher-order Land-Surface Schemes in coupled models developed by Ronni Avissar; and (c) the new Chameleon Surface Model developed by Carl Desborough.

THE EQUATORIAL THEORETICAL PANEL

The Equatorial Theoretical Panel met March 22–24, 1999, at the East-West Center in Honolulu to honor Professor Taroh Matsuno, Director-General of FRSGC, and to celebrate the 33rd anniversary of the publication of his groundbreaking and influential paper *Quasi-geostrophic motions in the equatorial area*. Michio Yanai of UCLA described in his opening speech, *Taroh Matsuno and the impact of his theory of equatorially trapped waves*, Professor Matsuno's significant contributions to the field of equatorial climate dynamics. Matsuno himself then spoke about his current research: *Dynamics of medium-scale wave disturbances trapped in midlatitude tropopause-waves due to the vertical Rossby effect.*

In addition to papers honoring Taroh Matsuno, papers were given on Equatorial Current Systems and on the El Niño-Southern Oscillation. In all, forty presentations were scheduled for the three-day meeting. As is the custom for the Equatorial Theoretical Panel meetings, this meeting provided a forum for informal exchange of ideas on a wide variety of equatorial climate issues.

Dennis Moore of PMEL organized the workshop; it was hosted by the IPRC and co-sponsored by the IPRC and JIMAR of Japan.

INDO-PACIFIC CLIMATE OBSERVATION WORKSHOP

The workshop on Indo-Pacific Climate Observation was held at the East-West Center in Honolulu from April 12 to 14, 1999. The purpose was to bring together Japanese and U.S. scientists who plan and/or conduct climate-related observational projects in the Indian and Pacific Oceans. Specifically, this meeting was designed for Japanese and U.S. scientists to review current plans and projects and to assess how various proposed and ongoing projects complement each other. The goal was to produce a list of various projects that were in the planning stage or had already been funded, make recommendations for collaboration between Japan and the United States, and set priorities and time tables for research activities. Another goal was to determine gaps in the existing and proposed activities, with a view toward trying to define a coordinated Indo-Pacific observing system for climate monitoring and prediction.

Dennis Moore of PMEL, Peter Niiler of Scripps Institution of Oceanography, and Kensuke Takeuchi of Hokkaido University organized the program. The IPRC hosted the workshop and sponsored it jointly with NOAA's Office of Global Programs.

The program consisted of presentations on the following projects:

ARGO project: Kensuke Takeuchi (Hokkaido University) and Russ Davis (SIO)

Western Boundary Currents and PBECS: Toshio Yamagata (University of Tokyo), Arata Kaneko (Hiroshima University), Roger Lukas (University of Hawai‘i), Russ Davis (Scripps Institution of Oceanography)

Eastern Pacific: PACS/EPIC: Meghan Cronin (PMEL); GLOBEC/Calcofi: Mark Huntley (University of Hawai‘i); CORC: P. Niiler (Scripps Institution of Oceanography)

Tropical Pacific: TOCS/TRITON: Yoshifumi Kuroda (JAMSTEC); TAO-TRITON Transition: Michael McPhaden (PMEL)

Kuroshio Extension: Humio Mitsudera (JAMSTEC); Bo Qiu (University of Hawai'i)

Tropical Western Pacific and Indian Ocean: Tetsuo Nakazawa (MRI); JASMIN: Peter Hacker (University of Hawai'i); Post-GAME: Tetsuzo Yasunari (Tsukuba University)

Indonesian Throughflow: Yuji Kashino (JAMSTEC)

Other Projects/Topics: NOPP: Michael McPhaden (PMEL); SAGE: Nobuo Suginohara (University of Tokyo); Acoustic Monitoring of the North Pacific Gyres: Peter Worcester (Scripps Institution of Oceanography); Decadal Variation: Kimio Hanawa (Tohoku University)

IPRC MINI-WORKSHOP ON THE INDIAN OCEAN

Julian P. McCreary and Tommy Jensen held a mini-workshop on the Indian Ocean November 29, 1999, at the University of Hawai'i in Honolulu. The workshop brought together visitors to the IPRC, IPRC researchers, and SOEST faculty, who shared with each other their research and knowledge on Indian Ocean climate dynamics. The speakers and topics were as follows:

Fritz Schott, University of Kiel, Germany: *Equatorial Indian Ocean circulation: Intraseasonal to interannual variability*

Peter Hacker, SOEST: *Recent Bay of Bengal sector observations: Comparison with climatologies and models, and modeling suggestions*

Roger Lukas, SOEST: *Preliminary upper ocean heat and salt budget estimates from JASMINE*

Julian P. McCreary, IPRC: *Indian Ocean Dynamics*

Weiqing Han, PAOS, University of Colorado: *Influence of salinity on dynamics, thermodynamics, and mixed-layer physics in the Indian Ocean*

Tommy Jensen, IPRC: *Cross-equatorial salt transport in the Indian Ocean: Model results*

Johannes Loschnigg, IPRC: *Cross-equatorial heat transport in the Indian Ocean*

Toru Miyama, IPRC: *Vertical structure of the Indonesian Throughflow: Potential impact to the thermocline circulation in the Indian and Pacific Ocean*

The workshop concluded with a general discussion about needs for further observations and modeling studies on the Indian Ocean.

MONSOON SCIENTIFIC CONFERENCE

The Monsoon Scientific Conference, co-sponsored by the IPRC, the CLIVAR Project, and the Climate System Science Center of Tokyo, was held December 6–10, 1999, at the East-West Center in Honolulu. The conference consisted of two parts, the Monsoon Symposium and the CLIVAR Monsoon Workshop. During the Monsoon Symposium, held December 6–7 and convened by Akimasa Sumi, the scientific accomplishments of atmospheric and oceanographic research on the Asian-Australian monsoon were reviewed. During the first part of the CLIVAR Monsoon Workshop, held from December 8– 9 and convened by In-Sik Kang and J. Stuart Godfrey, the atmospheric and ocean GCMs were compared with regard to the 1997–98 monsoon anomalies and monsoon-ENSO relationships. During the second part of the workshop, the CLIVAR Monsoon Implementation Plan met. Convened by William Lau and Stuart Godfrey, this working session served to present and discuss reports on such projects as GAME, SCSMEX, BOMEX, JASMINE, and others.

MEETING OF THE 12TH SCIENTIFIC STEERING SESSION OF THE GLOBAL ENERGY AND WATER CYCLE EXPERIMENT (GEWEX)

From January 31st to February 4th, the IPRC hosted the 12th session of the GEWEX Scientific Steering Group at the East-West Center in Honolulu. Reports at the meeting described the scientific accomplishments of the various research projects carried out under the GEWEX science plan: namely, to understand and predict global variations in the water cycle—particularly variations in continental rainfall and changes in water resources and soil moisture—and to understand radiation interactions and feedback among clouds, water vapor, and Earth's ocean and land surfaces. Discussion and strategic planning followed the reports.

Visitors

Name	Affiliation	Dates
In-Sik Kang	Dept. of Atmospheric Sciences, Seoul National University, Seoul, Korea	Jul.–Aug. 1998; Dec. 2, 1999–Jan. 31, 2000
Zhengyu Liu	University of Wisconsin, Madison, Wisconsin, U.S.A.	Oct. 1998; Aug. 13–17, 1999
Gerald Meehl	National Center for Atmospheric Research (NCAR), Boulder, Colorado, U.S.A.	Dec. 1998 Mar. 12–28, 1999 Jan. 29–Feb. 3, 2000
Lennart Bengtsson	Max-Planck Institute for Meteorology, Hamburg, Germany	Jan. 1999
Hans von Storch	Meteorological Institute, University of Hamburg, Hamburg, Germany	Jan. 1–Feb. 20, 1999
Jagadish Shukla	Institute of Global Environment and Society, Center for Ocean-Land-Atmosphere Studies (COLA), Calverton, Maryland, U.S.A.	Feb. 29–March 3, 1999
Ann Henderson-Sellers	Royal Melbourne Institute of Technology, Melbourne, Australia	Feb. 22–27 1999
Jurgen Sundermann	University of Hamburg, Hamburg, Germany	Feb. 5–17, 1999
Nikolai Maximenko	P.P. Shirshov Institute of Oceanology, Moscow, Russia	Jan.–Mar., 1999
Marla Meehl	National Center for Atmospheric Research (NCAR), Boulder, Colorado, U.S.A.	Mar. 12–28, 1999
T.N. Krishnamurti	The Florida State University, Tallahassee, Florida, U.S.A.	Mar. 14–17, 1999
Kikuro Miyakoda	Institute of Global Environment and Society, Center for Ocean-Land-Atmosphere Studies (COLA), Calverton, Maryland, U.S.A.	Mar. 22–May 14, 1999
Kraig Winters	University of Western Australia, Nedlands, Australia	Jun. 26–28, 1999
Susan Kemball-Cook	L. Livermore National Laboratory, Livermore, California, U.S.A.	Aug. 8–10, 1999
Lewis Rothstein	Graduate School of Oceanography, University of Rhode Island, Kingston, Rhode Island, U.S.A.	Aug.14–28, 1999
Friedrich Schott	University of Kiel, Kiel, Germany	Oct. 30.–Nov. 30, 1999
Weiqing Han	Program in Atmospheric and Oceanic Sciences (PAOS) University of Colorado, Boulder, Colorado, U.S.A.	Nov.–Dec., 1999
Nancy Soreide	NOAA-Pacific Marine Environmental Laboratory (PMEL), Seattle, Washington, U.S.A.	Nov. 29–Dec. 4, 1999
Don Denbo	NOAA-Pacific Marine Environmental Laboratory (PMEL), Seattle, Washington, U.S.A.	Nov. 29–Dec. 4, 1999
Steve Hankin	NOAA-Pacific Marine Environmental Laboratory (PMEL), Seattle, Washington, U.S.A.	Nov. 29–Dec. 4, 1999
Hiroshi Hashizame	Hokkaido University, Hokkaido, Japan	Nov.–Dec. 1999
Brian Mapes	NOAA-Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder, Colorado, U.S.A.	Dec. 2–March 3, 2000
Lin Ho	National Taiwan University, Taipei, Taiwan	Feb. 14–18, 2000
Shigeki Hosoda	Hokkaido University, Hokkaido, Japan	Feb., 2000
Zuojun Yu	NOAA-Pacific Marine Environmental Laboratory (PMEL), Seattle, Washington, U.S.A.	Feb. 21–26, 2000

Computing Facility

The IPRC computer systems have grown much over the brief history of this institution. Below the existing computer and network systems and the recently purchased upgrades are described.

The IPRC high-performance computing facility is equipped with one shared-memory vector-parallel machine and two distributed-shared-memory RISC-based parallel machines. The vector-parallel machine is a CRAY SV1 with 24 CPUs, 16.0 GB shared memory, and 156 GB local storage. It is capable of up to 28.8 GFLOPS (28.8 billion floating-point operations per second). A vector-parallel machine is most effectively used when the numerical code has both a high degree of vectorization and parallelization. For large applications, it outperforms most desktop workstations even when the code is run on a single SV1 CPU. The two RISC-based parallel machines are Origin 2000 systems. One system has 32 CPUs (250 MHz), 14.0 GB of logically shared memory, 180 GB of local disk storage, and a peak speed of 16 GFLOPS. The second system has 16 CPUs (195 MHz), 4.5 GB memory, 60 GB of local disk storage, and a peak performance of 6.2 GFLOPS. User-friendly, automatic parallel-code compilers allow easy generation of parallel executables from source codes. The degree of parallelism depends highly on the original code structure, and an appropriate code tuning improves performance.

These three systems are the main computational resources of the IPRC and have been used successfully for a number of scientific codes, including codes used widely in the oceanographic and meteorological community (POM, MOM, POP, CSM, etc.) and codes developed by IPRC researchers. Some of these codes were used as benchmarks to evaluate computers from various vendors, and the results were used to choose the computers for IPRC (see Jensen, 1999: IPRC/SOEST Technical Report 99-03).

Main storage is served by a 4-CPU Origin 2000 with a 900-GB SGI Clarion RAID (Redundant Array of Independent Disks) and an additional 10 TB provided by a tape library (StorageTek Timberwolf 9710 with 5 DLT drives and 252-tape capacity). Transfer of files between disks and tapes is automatic and transparent to the users, so the storage capacity of the local disks appears to be limited only by the maximum capacity of the tape library. The main compute servers and the data server are interconnected via a fast OC-12 link, provided by a Fore ASX-1000 ATM switch.

Each IPRC researcher is provided with a UNIX workstation and a PC. The IPRC currently owns 37 SUN workstations, 2 SGI workstations, and 54 PCs. The network connections of each machine to the servers as well as to the outside world is made through the LAN (Local Area Network), which is provided by the Research Computing Facility of SOEST.

The following upgrades were purchased by the end of March 2000 and are being integrated into the IPRC High-Performance Computing Facility:

- 8-CPU Origin 2400 (300 MHz), 4GB RAM (4.6 GFLOPS peak)
- 24-CPU Origin 3400 (400 MHz), 16 GB RAM (19.2 GFLOPS peak)
- 4-CPU SUN Enterprise 450 (450 MHz), 2 GB (3.6 GFLOPS peak)
- 2-CPU Aspen (750 MHZ Alpha-chip, 1GB (3.0 GFLOPS peak)
- Additional disk storage, SGI Clarion RAID array 10x36 GB
- Tape Library upgraded to a total of 6 DLT drives and 400 tapes (16 TB)
- A Brocade Fiberchannel switch to control a Storage Area Network (SAN)
- SUN workstations and PCs

These upgrades increase the CPU resources at the IPRC servers by 60%.

IPRC Staff[1]

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Lorenz Magaard
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Associate Dean and Professor of Oceanography, SOEST

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1 As of March 31, 2000
2 Frontier Research System for Global Change (FRSGC)

Implementation and Scientific Advisory Committees

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Acronyms

AAIW	Antarctic Intermediate Water
A-AMS	Asian-Australian Monsoon System
APDRC	Asia-Pacific Data Research Center
AT	Air Temperature
BOMEX	Barbados Oceanographic and Meteorologic Experiment
CLIVAR	Climate Variability and Predictability Project
CMAP	Centre de Mathématiques Appliquées
COLA	Center for Ocean-Land-Atmosphere Studies
CORC	Computational Optimization Research Center
CPU	Central Processing Unit
CSIRO	Commonwealth Scientific and Industrial Research Organization
CSM	Climate System Model
CTD	Conductivity, Temperature, and Depth
DODS	Distributed Ocean Data System
DLT	Digital Linear Tape
DSS	Data Server System
ECMWF	European Centre for Medium-Range Weather Forecasting
ENSO	El Niño-Southern Oscillation
EOF	Empirical Orthogonal Function
EUC	Equatorial Undercurrent
FRSGC	Frontier Research System for Global Change
GB	Gigabytes
GCM	General Circulation Model
GEWEX	Global Energy and Water Cycle Experiment
GFLOPS	Giga Floating Point Operations
GLOBEC	Global Ocean Ecosystems Dynamics
GSFC	Goddard Space Flight Center
ISM	Indian Summer Monsoon
ISO	Intraseasonal Oscillations
ITCZ	Intertropical Convergence Zone
ITF	Indonesian Throughflow
JAMSTEC	Japan Marine Science and Technology Center
JASMINE	Joint Air-Sea Monsoon Investigation
JIMAR	Joint Institute for Marine and Atmospheric Research
KE	Kuroshio Extension
KESS	Kuroshio Extension System Study
KOSM	Kuroshio and Oyashio System Model
LAN	Local Area Network
LAS	Live Access Server
LES	Large Eddy Simulations
MRI	Meteorological Research Institute
MOM	Modular Ocean Module
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NPIW	North Pacific Intermediate Water
OLR	Outgoing Long Wave Radiation
PACS	Pan American Climate Studies
PAOS	Program in Atmospheric and Oceanic Sciences
PBL	Planetary Boundary Layer
PILPS	Project for Intercomparison of Land-Surface Parameterization Schemes
PMEL	Pacific Marine Environmental Laboratory
POM	Princeton Ocean Model
POP	Parallel Ocean Program
PWC	Precipitable-Water Content
RAID	Redundant Array of Independent Disks
RISC	Reduced-Instruction-Set Computing
SAN	Storage Area Network
SCMEX	South China Sea Monsoon Experiment
SLP	Sea Level Pressure
SSH	Sea Surface Height
STC	Subtropical Cell
SST	Sea Surface Temperature
Sv	Sverdrup
SVD	Singular Value Decomposition
TAO	Tropical Atmosphere Ocean
TB	Tera Bytes
TBO	Tropospheric Biennial Oscillation
TIW	Tropical Instability Waves
TOCS	Tropical Ocean Climate Study
TOMS	Thermodynamic Ocean Modelling System
TRITON	Triangle Trans-Ocean Buoy Network
T/P	TOPEX/POSEIDON
WOCE	World Ocean Circulation Experiment
WOFD	Wavelet Optimized Finite Difference
WNPSM	Western North Pacific Summer Monsoon
WWP	Warm Water Pool
XBT	Expendable Bathothermograph