International Pacific Research Center

April 2000 – March 2001 Report

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

Editor:
Gisela E. Speidel, International Pacific Research Center

Designer:
Kym L. Miller, Kymaging

Printer:
Pacific Printing

International Pacific Research Center

April 2000 – March 2001 Report

School of Ocean and Earth Science and Technology
University of Hawaiʻi at Mānoa
Honolulu, Hawaiʻi

Table of Contents

About the International Pacific Research Center

The International Pacific Research Center (IPRC) is a research center for the study of climate in the Asia-Pacific region. It was founded in October 1997 within the School of Ocean and Earth Science and Technology (SOEST) at the Mānoa Campus of the University of Hawai‘i (UH). 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."

The IPRC mission is "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." 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.

A large part of the center's financial support comes from Japan's Frontier Research System for Global Change (Frontier 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). Institutional funding comes also from the U.S. National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Association (NOAA). Support for individual IPRC scientists comes from the National Science Foundation (NSF), Office of Naval Research (ONR), and NOAA.

The overall design of the IPRC and its implementation is the responsibility of the IPRC Implementation Committee. Currently this committee consists of four Japanese representatives selected by the Science and Technology Agency (STA), NASDA, and JAMSTEC, four U.S. representatives selected by NASA, NOAA, NSF, DOE, and one representative from UH. Guidance on scientific matters comes from the Scientific Advisory Committee, which is currently composed of eight scientists who are internationally recognized for their expertise in climate research areas relevant to the IPRC.

The word *international* in the mission statement and in the name of the IPRC has true significance. It reflects the belief of the IPRC leadership that the most effective way to make progress in answering large-scale climate questions is through international cooperation. Toward this end, the current staff is from Australia, Canada, China, Denmark, Germany, India, Japan, Korea, Russia, Turkey, and the United States. Furthermore, the IPRC has a strong program for international visitors and is committed to hosting two or more major international meetings each year.

To achieve its mission, the 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, an Asia-Pacific Data Research Center (APDRC) is being developed within the IPRC.

The IPRC Science Plan, which can be found at the IPRC website (http://iprc.soest.hawaii.edu), 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 timescales

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

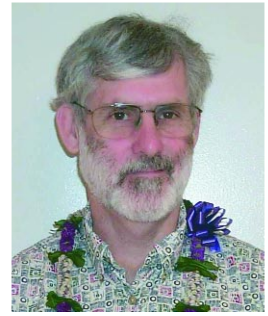
To understand the processes responsible for climatic variability and predictability of the Asia-Australian Monsoon System and its hydrological cycle at intraseasonal through interdecadal timescales

Theme 4: Impacts of Global Environmental Change

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

Each theme and goal has associated objectives that outline projects the IPRC believes are achievable within a finite time interval and with well-defined resources.

The Year's Highlights



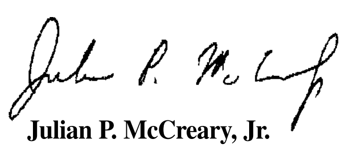
This second report of the International Pacific Research Center (IPRC) provides an overview of activities from April 1, 2000, through March 31, 2001. The heart of the IPRC is its researchers, and summaries of their individual accomplishments make up most of the report. Also included are lists of research publications and presentations by IPRC scientists as well as seminars, workshops, visitors, meetings, and conferences sponsored by the IPRC. In this brief introduction, I draw attention to several of the year's highlights.

Perhaps most noteworthy is the continued growth of the IPRC staff. In Fall 2000, Kevin Hamilton, who had been at the Geophysical Fluid Dynamics Laboratory and Princeton University, joined us as UH Professor of Meteorology. Recently selected as a Fellow of the American Meteorological Society and developer of the SKYHI general circulation model (GCM), he brings to his new position expertise in atmospheric global circulation, knowledge of stratospheric and mesospheric meteorology and chemistry, and a research interest in atmospheric and oceanic waves and tides. At the IPRC, he is continuing his research on climate modeling and climate change and is the team leader for Theme 4 research, which studies the relationship between Asia-Pacific climate and global environmental change. Zuojun Yu also joined our research staff. She is a physical oceanographer whose research focuses on the simulation of large-scale ocean circulations, mixed-layer dynamics, and eddy–mean flow interactions. Omer Sen came aboard as a postdoctoral research fellow, and he has incorporated a land-surface model, the biosphere-atmosphere transfer scheme (BATS), into the IPRC Regional Climate Model. Two other postdoctoral fellows, Axel Timmermann and Gang Huang, spent several productive months at the IPRC. Computer systems engineer Gary Tarver joined to help with planning, purchasing, and maintaining IPRC computer hardware and software, and Jan Hafner came as a scientific computer programmer for Theme-1 research.

There were also developments in the establishment of IPRC's Asia-Pacific Data Research Center (APDRC). Physical oceanographer Peter Hacker, senior research scientist at the Hawai‘i Institute of Geophysics and Planetology of the University of Hawai‘i, was appointed as the center's manager. The APDRC has received funding from NASA for a five-year project to support much of its research part, in particular, to conduct diagnostic and modeling studies that use existing and newly available NASA data to advance Asia-Pacific climate research. A proposal to NOAA to support the APDRC data-management part was submitted. (Notification that funding would be forthcoming was received July 1, 2001.)

An event of great excitement and relief for all was the long-awaited move into our new offices on the fourth floor of the Pacific Ocean Science and Technology Building on the UH Mānoa campus. UH President, Kenneth P. Mortimer, and SOEST Dean, C. Barry Raleigh, hosted the celebration, which was attended by over 70 guests. The offices were blessed by the Reverend Dr. James Fung in the Hawaiian tradition. President Mortimer and Japan's Senior Consul to Hawai‘i, Masae Kunou, symbolized the opening by untying the maile lei leading to the offices.

The coming year promises to be one of further excitement and continued growth. We are expecting to sponsor many visiting scholars again, and several workshops are on the drawing board already, among them the Global Ocean Data Assimilation Experiment (GODAE) workshop, a regional climate modeling workshop, and a climate and fisheries workshop. Most significantly, however, we plan to hire three more tenure-track faculty with joint appointments between the IPRC and the UH meteorology or oceanography department, three assistant or associate researchers, and eight new postdoctoral fellows. By the end of next year, then, the IPRC will be nearing the full strength envisioned by its original planners.



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

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

Overview

Earth's oceans exert great influence on global climate. The large heat capacity of water combined with the movement by the oceans of huge masses of warmer water toward the poles and colder waters toward the equator prevent huge swings in temperature and make Earth's climate livable. Changes in the oceans usually are slow and not readily detected; at times, though, they are quite swift with very noticeable climate consequences, as with the El Niño–Southern Oscillation (ENSO) phenomenon, where an altered pattern of sea surface temperature (SST) along the Pacific equator has far-reaching climatic effects. Thus, understanding how the Indian and Pacific Ocean climates vary from year to year, over decades and longer, and how these variations interact with atmospheric processes, is critical for better understanding and prediction of Asia-Pacific climate. Theme 1 is dedicated to this effort, and this year IPRC scientists have carried out research in the areas of Indo-Pacific ocean circulation, atmospheric response to SST changes, air-sea interaction, and coupled ocean-atmosphere modeling.

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 ENSO. Experiments with an ocean general circulation model (GCM) forced by observed wind stress indicate that equatorial Pacific SST variations are governed by different dynamics on interannual and decadal timescales (Nonaka, Xie, and McCreary). On decadal timescales, the heat transport by the shallow overturning circulations (subtropical cells), which link the subtropical and the equatorial oceans, contributes to equatorial SST anomalies, in addition to the equatorial dynamics that dominate the interannual timescale. This result is consistent with solutions of a coupled model consisting of an empirical atmosphere and a dynamic ocean (Solomon and McCreary). The coupled model produces both interannual and decadal variations resembling those in observations and other more complex models.

Diagnostic and modeling results suggest that decadal changes in the state of the Pacific ocean-atmosphere can modulate the temporal-spatial structure of ENSO (B. Wang and An, Theme 3). An alternative mechanism for these changes has also been proposed based on simple and intermediate coupled models. It involves nonlinear ocean dynamics within the tropics and the interaction of these ocean dynamics with the atmosphere (Timmermann and An). The slow decadal changes in the amplitude of ENSO might be predictable from such a nonlinear mechanism.

A number of Theme-1 studies have addressed the question of how the atmosphere responds to SST changes over an ocean surface not warm enough for atmospheric deep convection. This unanswered question has been a stumbling block for the study of extratropical air-sea interactions. A 20-member ensemble atmospheric GCM simulation has been completed in collaboration with Frontier's Institute for Global Change in Tokyo. Besides ENSO-induced changes in the North Pacific and North America, the ensemble-mean fields capture the North Atlantic Oscillation (NAO) in boreal spring (Huang and Xie). The response of the same atmospheric GCM to tropical Atlantic SST anomalies successfully reproduces many of the observed changes in the atmospheric circulation and in the stratus clouds (Okumura and Xie). A set of idealized atmospheric GCM experiments have been completed and analyzed to understand better how SST patterns affect zonal variations in the subtropical westerly jet and storm track (Xie).

Recent advances in satellite microwave remote-sensing technology open new opportunities to observe and study air-sea interaction. Analyses of scatterometer and other microwave measurements from space reveal that the Hawaiian Islands have far-reaching effects on the atmosphere and ocean (Xie and Nonaka). Due to positive feedback from the ocean, meridional variations in wind velocity west of Hawai‘i persist for 3,000 km, a distance one order of magnitude longer than observed anywhere else on Earth. The strong wind curl west of Hawai‘i generates an eastward current known as the Hawaiian Lee Countercurrent (HLCC) that advects warmer water from the west. This HLCC appears to be unstable and momentum transport by mesoscale eddies appears to affect the western extent of this current (Yu and Maximenko).

The third objective of Theme 1 is to determine the basic processes that maintain the Pacific Ocean general circulation and cause its climatic variability. Major progress has been made in determining the causes of the Tsuchiya Jets, a pair of strong subsurface eastward currents on either side of the equator; this task has eluded oceanographers since their discovery in the early 1970s. Theoretical analysis and model simulations show that such jets form along the arrested fronts where Rossby wave characteristics converge or intersect. Off-equatorial upwelling and the Pacific interocean circulation are important for generating these arrested fronts (McCreary and Yu).

Vertical mixing has a significant effect on ocean circulation and SST. Large-eddy simulations have been carried out under various surface conditions and with and without vertical shear. The results have been compared with several one-dimensional mixed-layer models (D. Wang). Such comparisons help to determine the values of key model parameters and to identify the strengths and weaknesses of various mixed-layer parameterizations.

An SST tendency equation was developed to diagnose the heat budget in the Kuroshio-Oyashio Extension (KOE) region where the mixed layer shows great seasonal variations. Analyses using an ocean GCM simulation and model-assimilated data indicate that geostrophic advection due to Rossby waves excited in the central North Pacific as well as local heat-flux forcing contribute to decadal SST variations in the KOE region (Tomita, Xie, and Nonaka).

The fourth Theme-1 objective is to determine the nature and causes of Indian Ocean SST variability on interannual-to-decadal timescales. A hierarchy of models was used to study the three-dimensional structure and mechanisms of the cross-equatorial circulation of the Indian Ocean (Miyama, McCreary, Jensen, and Loschnigg). Three-dimensional passive drifters and surface floats have been traced in the model, and differences in their trajectories explained. A related study on the mass and salinity transport from the Arabian Sea to the Bay of Bengal has been completed (Jensen). Progress, moreover, has been made in a joint project between Themes 1 and 2 to study the low-latitude western-boundary currents and the Indonesian Throughflow with a telescoped high-resolution model (see Theme 2, p. 34).

While the Pacific ENSO is known to affect Indian Ocean SST north of the equator, the large climate variability in the southern Indian Ocean remains largely unexplained. A synthesis of in-situ and satellite measurements and model-assimilated data shows that much of the variability in the southern Indian Ocean involves subsurface ocean dynamics (Xie, Annamalai, and McCreary; see Figure 1). In particular, an ocean Rossby wave forced by ENSO teleconnection leaves a clear signature in SST in the open-ocean upwelling zone in the tropical southern Indian Ocean and causes changes in tropical cyclone tracks.

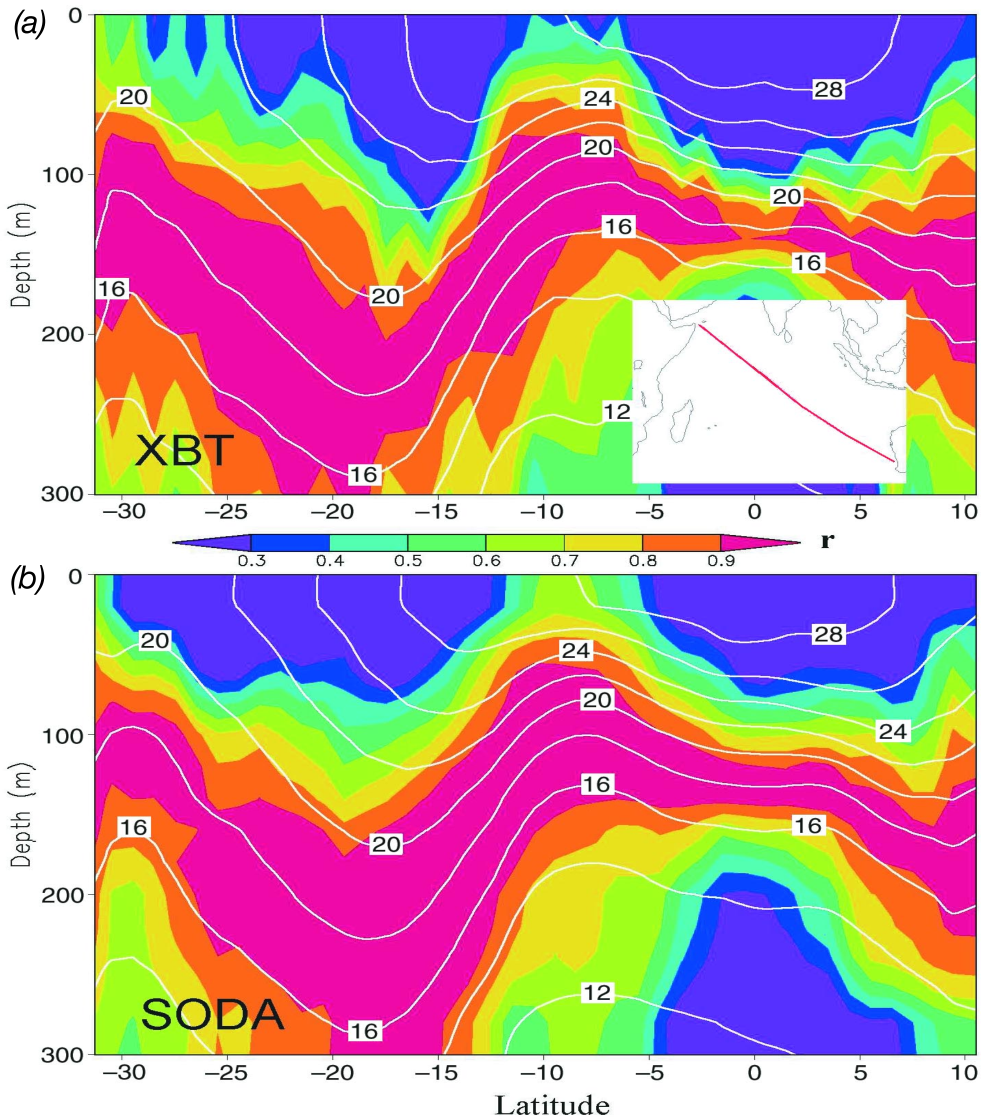


Figure 1. *Mean isothermals (white countours) and correlation coefficients (in color) between interannual variations in ocean temperatures and thermocline depth along an expendable bathythermograph section (red line in the insert) across the Indian Ocean derived from (a) in-situ observations and (b) a model assimilation product. Over most of the Indian Ocean, the effect of the thermocline-depth variability is trapped within the thermocline. However, an open ocean upwelling at 5ºS–12ºS, aided by a shallow thermocline, allows subsurface variability to affect SSTs, as shown by the high correlation that reaches to the surface in that region.*

Individual Reports

Gang Huang

Postdoctoral Fellow

Gang Huang obtained his Ph.D. in atmospheric science in 1999 from the Chinese Academy of Sciences, Beijing, China. Since then he has been working at the Academy as assistant researcher with the Institute of Atmospheric Physics. He was at the IPRC as a post-doctoral fellow from September 2000 through January 2001. His research interests include monsoon variability, monsoon and global climate change, model simulation analysis, and interannual-to-interdecadal climate variability.

While at the IPRC, Gang Huang analyzed a 20-member ensemble simulation with an atmospheric GCM developed by the University of Tokyo and the National Institute for Environmental Studies of Japan. The horizontal resolution is roughly equivalent to a 5.6º by 5.6º latitude/longitude grid; in the vertical, the model has 20 unevenly spaced levels. Simulations were run for 40 years, from January 1959 to November 1998, and were forced with observed SSTs taken from the geographic GISST3.0 data set. The 20 simulations differed only in their initial atmospheric conditions. Analysis of the 20-member ensemble model mean-field showed that winter and spring conditions were simulated reasonably well compared with NCEP reanalysis data.

SVD and EOF analyses of the 500 hPa geopotential height GCM ensemble-mean anomalies and NCEP reanalysis data were carried out. In the tropics, the GCM produces a realistic level of interannual variability, a variability that results mostly from the El Niño–Southern Oscillation (ENSO). In the North Pacific and North America (PNA), the interannual winter-spring variability due to the PNA teleconnection from the tropical Pacific is also reasonably well reproduced—albeit too weak by a factor of two. In the North Atlantic, the ensemble-mean variance is one order of magnitude smaller than the observed variance. From January to April, however, the GCM appears to produce a North Atlantic Oscillation (NAO) time-series similar to the observed one. The NAO simulated by the GCM, furthermore, is correlated with a tripole SST pattern as it is in observations.

These results confirm that ENSO is a dominant source of atmospheric variability. Other SST variations seem to have only modest effects on extratropical atmospheric variability; however, this latter conclusion may be subject to large model error and bias. The determination of whether and how SST variations over the cold ocean surface affect the atmosphere remains a challenge.

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.

Over the deep ocean, long surface waves propagate with a speed of a couple of hundred meters per second. This presents a technical problem for numerical ocean models, and special methods or models are usually used to eliminate these fast waves. In modeling tropical oceans, reduced-gravity models have been successfully used to circumvent the problem, but at the cost of losing the influence of bottom topography. A simple method, gravity-wave retardation (GWR), slows down surface waves and can include effects of bottom topography in layer models. Jensen applied this method, which is easy to implement, to a 5-layer Indian Ocean model with a resolution of 1/3º by 1/3º (Jensen 2001, *Mon. Wea. Rev.*). Compared to the control case, which allowed waves a realistic phase speed, his results showed that the baroclinic solutions were accurate, even when the waves were slowed down by a factor of 8, and they were more accurate than solutions to a 4.5-layer reduced-gravity model even when slowed down by a factor as large as 16.

In a second study (Jensen, *Global and Planetary Change*, submitted), Jensen showed that the barotropic solutions for the Indian Ocean model were more accurate using the GWR method and real bottom topography than using unmodified waves and a flat bottom, even when the waves were slowed down by a factor of 20. For best results, however, he recommends, on the basis of his analyses, applying a reduction in speed of only a factor of about 10. The accuracy of the method is of particular interest for ocean circulation models that are used to study climate change, because the computation of the oceanic barotropic mode is often done separately, and the GWR method can easily be applied and implemented on parallel computers.

Jensen has also been using the Indian Ocean model in a 4.5-layer configuration with prognostic temperature, salinity, and tracers in order to investigate the fluxes of salt between the Arabian Sea, the Bay of Bengal and the tropical Indian Ocean. The simulation provides the first direct evidence of transport of high-salinity water from the Arabian Sea into the Bay of Bengal, a process that was confirmed using a passive tracer (Jensen 2001, *AMS*). He determined the seasonal cycle in exchanges of high-salinity and low-salinity water in and out of the Arabian Sea and the Bay of Bengal, as well as the associated cross-equatorial transports. Intrusion of Arabian Sea water into the Bay of Bengal takes place from July to November between 83ºE and 90ºE. East of that longitude, low-salinity Bay of Bengal water is advected southward, eventually crossing the equator. The main source of low-salinity water for the Arabian Sea is the western tropical region, with northward flux during June through October, thus closing the clockwise circulation in the mixed layer.

Together with Bang, Miyama, Mitsudera, and Qu, Jensen has designed and constructed an Indo-Pacific model based on POM (Princeton Ocean Model), which is being applied to the Indonesian Throughflow and to investigations of low-latitude western boundary currents in the Pacific. Details are given under Theme 2, p. 34.

Johannes Loschnigg

Postdoctoral Fellow

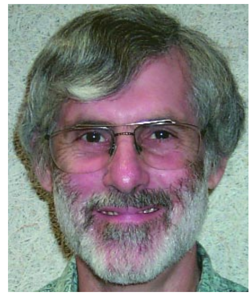
Johannes Loschnigg obtained his Ph.D. in atmospheric and oceanic sciences from the University of Colorado at Boulder in 1998. He came to the IPRC as a postdoctoral fellow in May 1999. His research interests include Indian Ocean climate dynamics; the relationship between the monsoon, the tropospheric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

In a 300-year baseline simulation, Johannes Loschnigg studied the ability of the NCAR Climate System Model to reproduce the Asian-Australian monsoon and the tropospheric biennial oscillation (TBO). He analyzed the climatological seasonal evolution of precipitation, SST, and surface winds from the boreal-summer monsoon to winter monsoon, and explored the ability of the model to reproduce the coupled interactions and the transitions from strong monsoon years to weak monsoon years. Composites of strong and weak monsoon years showed a strong relationship among monsoon variability, the Indian Ocean SST Dipole (Webster et al. 1999), the TBO, and variations in oceanic cross-equatorial meridional heat transport. Loschnigg also compared model output and observations of Indian summer-monsoon indices, which often disagree in their measurements of monsoon strength. This lack of agreement could be the result of several different monsoon circulation dynamics competing with one another on various temporal and spatial scales (Meehl and Arblaster 2001). Instead of using area-averaged indices, it is possible, using an SVD analysis, to relate the actual patterns of rainfall over the Indian monsoon region to certain processes that are active in the TBO, such as SST anomalies in the Indian and central Pacific Oceans and surface heating anomalies over Asia. The SVD analysis suggests that two mechanisms have a major role in the TBO's contribution to interannual variations in the South Asian monsoon: large-scale forcing from the tropical Pacific, and regional forcing associated with the meridional temperature gradient between the Asian continent and the Indian Ocean. Loschnigg is now preparing this work for publication.

Loschnigg also extended his previous work on the Indian Ocean heat balance (Loschnigg and Webster 2000) to interannual timescales by analyzing a simulation for the years 1984–1990 with the McCreary et al. (1993) 2.5-layer Indian Ocean model. He found that large interannual variations in oceanic cross-equatorial meridional heat transport are related to changes in the seasonal strength of the monsoon wind-forced Ekman transports. Interannual variability in the wind circulation of the South Asian monsoon may thus be linked to the basinwide heat balance in the Indian Ocean through coupled ocean-atmosphere processes. The boreal summer monsoon wind can modulate heat storage in the north and central Indian Ocean and produce temperature anomalies that persist through one or more seasons and affect monsoon variability the following year (Loschnigg, manuscript in preparation).

Loschnigg also collaborated on several other projects. He tracked imaginary floats released in the annual mean current fields of the McCreary et al. (1993) 2.5-layer Indian Ocean model to locate the sources and subsequent pathways of water upwelling in the north Indian Ocean, and to analyze the areas along the equator where water crosses between the Northern and Southern Hemispheres (see Miyama's report). He analyzed the role of Indian Ocean dynamics and meridional heat transport in the development of the large-scale Asian-Australian monsoon system and in the biennial cycle of the Indo-Pacific Ocean (Webster et al., 2001a; Webster et al., 2001b). He contributed to a study on the link between climate variations and outbreaks of malaria and cholera on the Indian subcontinent (Whitcombe et al., in preparation). The study is based on climate and health data of British India from 1860 to 1900. Finally, Loschnigg took part in the regional assessment of the consequences of climate variability and change in the Pacific Islands (part of the first U.S. National Assessment of the consequences of climate variability and change), which is scheduled for publication in Summer 2001.

Loschnigg has submitted a proposal to NOAA to study the impacts of climate variability and climate change on disease and human health in the island nations of the South Pacific. This will be a collaboration with scientists in the College of Arts and Science, University of Hawai'i, and at the East-West Center, Honolulu, and will form part of Loschnigg's research at the IPRC in the coming year.



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, the general ocean circulation, coupled ocean-atmosphere modeling, and ecosystem modeling.

During this year, Jay McCreary has continued to work on projects in 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; Solomon et al., *J. Clim.*, submitted); and (2) an investigation of the dynamics of the Pacific Subsurface Countercurrents, commonly referred to as Tsuchiya Jets (TJs) (with Zuojun Yu; McCreary et al., *JPO*, submitted). Indian Ocean projects include: (3) writing a review paper on the dynamics of monsoon-related circulations in the Indian Ocean (Schott and McCreary, *Prog. Oceanogr.*, in press); (4) simulating and understanding the dynamics of the Cross-equatorial Cell, a shallow, meridional overturning circulation in the Indian Ocean that is analogous to the Atlantic and Pacific Subtropical Cells (with T. Miyama, T. Jensen, and J. Loschnigg); and (5) determining the causes of biological activity in the Arabian Sea (McCreary et al., *JGR*, in press).

In Project 2, a hierarchy of models, varying from 2.5-layer to 4.5-layer systems, was used to explore TJ dynamics. The TJs are eastward currents located on either side of the equator at depths from 200 m to 500 m and at latitudes varying from about 2° to 7° north and south of the equator, and they carry about 14 Sv of lower-thermocline (upper-intermediate) water throughout the tropical Pacific (see Figure 2). Solutions were forced by winds and by a prescribed Pacific interocean circulation (IOC) of transport *M* (usually 10 Sv), the latter representing the outflow of water in the Indonesian passages and a compensating inflow from the Antarctic Circumpolar Current.

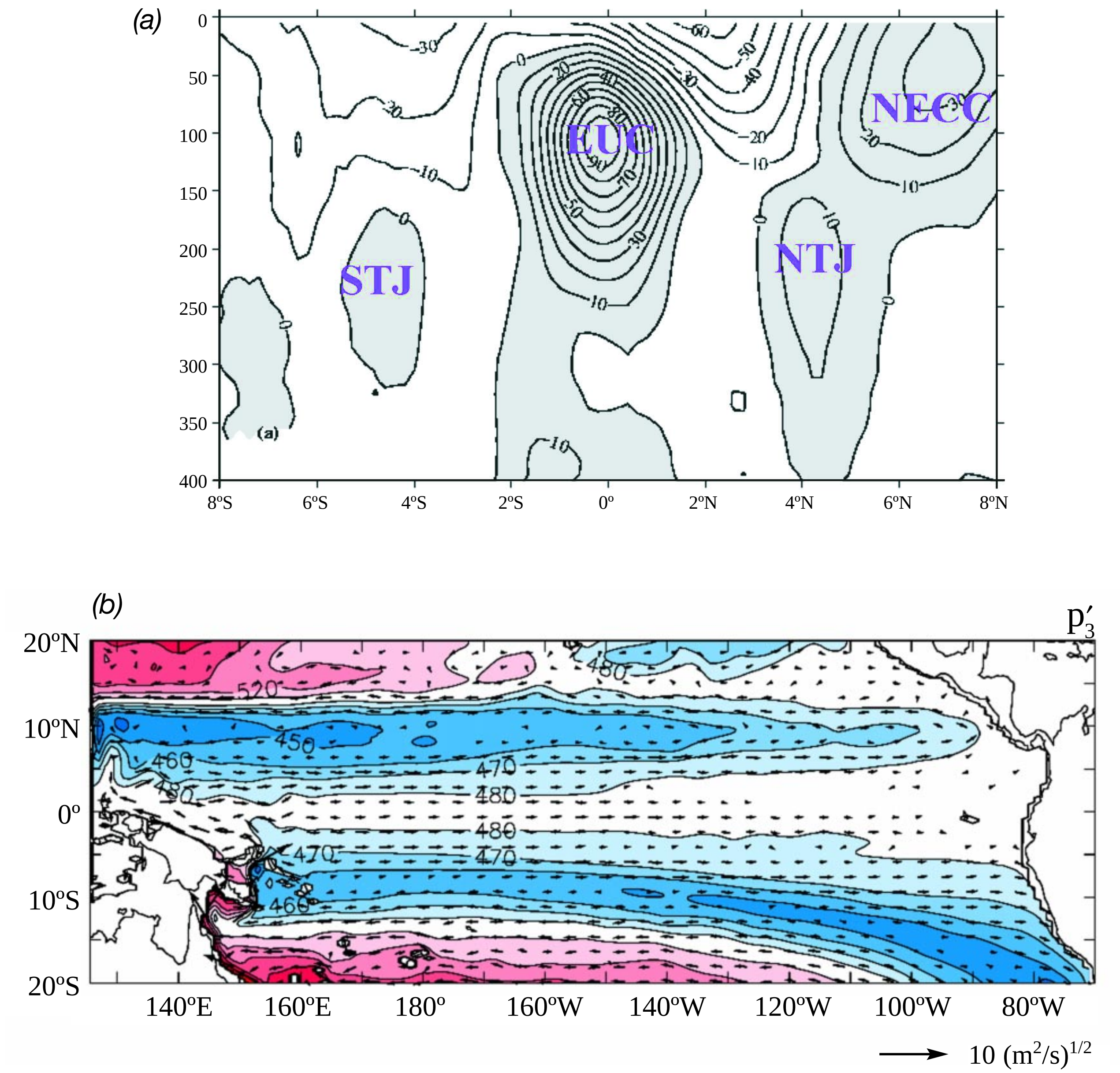


Figure 2. *Panel (a) shows the observed mean zonal flow along 135ºW with a contour interval of 10 cm/s. Shaded are the eastward Northern and Southern Tsuchiya Jets (TJs), the Equatorial Undercurrent (EUC), and the North Equatorial Countercurrent (NECC). The cores of the TJs are located near 250-m depth. (After Johnson et al. 2000.) Panel (b) represents the TJ layer (layer 3) from a solution to a 4.5-layer model. Shown are the horizontal distributions of momentum transport* $(h_3\mathbf{v}_3)'$ *(arrows) and geostrophic streamlines* p_3' *(contours). To emphasize weaker flow, momentum transport was rescaled to* $h_3\mathbf{v}_3/|h_3\mathbf{v}_3|^{1/2}$. *The geostrophic streamlines are defined by* $p_3' = p_3/g_{35}'$ *where* p_3 *is the layer-3 pressure and* g_{35}' *is a reduced-gravity coefficient. The contour interval is 20 m, except in blue regions where it is 10 m. (After McCreary et al. 2001.)*

Analytic solutions to the 2.5-layer model suggested that the TJs are geostrophic currents along arrested fronts. Such fronts are generated when Rossby-wave characteristics, carrying information about oceanic density structure away from boundaries, converge or intersect in the interior ocean. The solutions indicated that the southern and northern TJs are driven by upwelling along the South American coast and in the ITCZ band, respectively, that the northern TJ is strengthened by a recirculation gyre extending across the basin, and that TJ pathways are sensitive to stratification parameters. Numerical solutions to the 2.5-layer and 4.5-layer models confirmed these analytic results. They demonstrated that the northern TJ is strengthened considerably by unstable waves along the eastward branch of the recirculation gyre, showed that the TJs are important branches of the Pacific IOC, and illustrated the sensitivity of TJ pathways to vertical-mixing parameterizations and to the structure of the driving wind.

In a solution to the 2.5-layer model with $M = 0$, the southern TJ vanished but the northern one remained, being maintained by the unstable waves. In contrast, both TJs vanished in the $M = 0$ solution to the 4.5-layer model, apparently because wave energy can radiate into a deeper layer (layer 4). In the 4.5-model, then, the TJs are in fact driven by the Indonesian Throughflow, a remarkable example of remote forcing on a basinwide scale.

In Project 5, McCreary and mainland colleagues, Raleigh Hood, Kevin Kohler, and Sharon Smith, are developing and using a three-dimensional, physical-biological Indian Ocean model to study biological variability in the Arabian Sea. The physical model consists of four active layers overlying an inert deep ocean (a 4.5-layer model). The biological model consists of a set of advective-diffusive equations in each layer that determine nitrogen concentrations in four compartments: nutrients, phytoplankton, zooplankton, and detritus. In the first stage of the project, the influences of diurnal and intraseasonal forcing on mixed-layer and biological variability were examined and solutions were compared to data obtained from a mooring deployed and maintained from October 1994 to October 1995 in the central Arabian Sea by WHOI, as part of the Joint Global Ocean Flux Study (JGOFS). This research resulted in the publication noted above. In the second stage, the model-data comparison was expanded to include data taken during five JGOFS cruises, resulting in improvements to both the biological and mixed-layer models. In a planned third stage, data-assimilation techniques will be utilized to represent the state of the ocean better and to estimate biological model parameters objectively.

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 the variability of the Indonesian Throughflow and its role in the climate system, tropical and subtropical water exchange, and wavelet-optimized numerical ocean models.

The Cross-equatorial Cell (CEC) in the Indian Ocean is a shallow ($z \geq 500$ m) meridional overturning circulation, consisting of subduction at midlatitudes of the Southern Hemisphere, northward flow of thermocline water, upwelling in the Northern Hemisphere, and a southward return flow of surface water. This past year, Toru Miyama spear-headed a study that used several types of ocean models to investigate CEC structure and dynamics. The models varied in complexity from a linear, continuously stratified model (McCreary et al. 1996), to reduced-gravity models (McCreary et al. 1993; Jensen 1998), to a state-of-the-art general circulation model (JAMSTEC GCM; Ishida et al. 1998). The study focused on CEC pathways and dynamics, and integrated "equatorial rolls."

Pathways: The Lagrangian pathways of the Indian Ocean CEC are made visible by tracking model drifters from the upwelling regions in the Northern Hemisphere. The spin-up is done forwards in time to follow the surface pathways and backwards in time to follow the subsurface flows. In the subsurface branch, the cross-equatorial flow occurs via a western-boundary current because friction alters the sign of potential vorticity there. In the upwelling region, part of the upwelled water comes from the Indonesian Throughflow and part comes from the subduction region in the southern Indian Ocean. In contrast to the subsurface paths, surface paths (top 100 m) cross the equator at almost all longitudes in the interior ocean. In the layer models, particles in the surface path almost immediately cross the equator, whereas particles in the GCM stay near the equator, drifting toward the eastern boundary, where they eventually cross the equator, and then are advected by Ekman drift into the southern Indian Ocean.

Dynamics: In the surface branch, the annual-mean component of the zonal wind τ^x, which is predominantly asymmetric about the equator (that is, proportional to y), drives the cross-equatorial flow with westerly winds north of the equator, and with easterlies south of the equator. This wind drives a net southward Sverdrup flow across the equator. Interestingly, when τ^x varies proportionally to y, the Sverdrup transport equals the Ekman drift, which is well defined even at the equator. This is because there is no Ekman pump (and no mass convergence) due to this wind stress and therefore no change in layer thickness to produce a geostrophic current. The flow field sets up quite rapidly since there are no geostrophic currents. It should be emphasized that the condition in which the Sverdrup transport equals the Ekman drift holds best near the equator, where τ^x varies nearly linearly with y. Farther away from the equator, where the winds no longer grow linearly in y, the geostrophic component becomes noticeable.

Equatorial roll: In GCM solutions, the southward cross-equatorial flow occurs just below the surface, typically beneath the northward surface flow, creating a shallow, cross-equatorial roll. This feature is a direct (local) response to the southerly component of the winds. The basic dynamics of rolls are linear as evidenced by solutions to a linear, continuously stratified modal model that reproduce the roll very well. The strength of the roll depends closely on vertical mixing, and the roll does not exist without such mixing. Layer models do not show the roll because the surface layer is too thick for the vertical scale of the roll. Because of the equatorial rolls in GCM solutions, particles trapped in the surface level (say top 10 m) cannot cross the equator in the central ocean but rather cross near the eastern boundary where the rolls are weak. The existence of the equatorial roll is supported by drifter-buoy observations in the Indian Ocean, which show a similar pattern for the uppermost movement across the equator (Schott and McCreary, *Prog. Ocenaogr.*, in press).

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.

Variations in SST in the eastern equatorial Pacific are of central importance to global climate as shown by the far-reaching effects of El Niño events. Recent studies show that, in addition to very strong interannual SST variations, the region also displays significant decadal-to-interdecadal SST variations. The leading EOF of Pacific SST variability on decadal time scales resembles that of the interannual El Niño–Southern Oscillation (ENSO), but the equatorial center of action is weaker and has a broader meridional scale (Zhang et al. 1997).

Based on various coupled ocean-atmosphere models, several mechanisms have been proposed for these decadal SST variations in the equatorial Pacific. In some coupled models of the tropical Pacific, nonlinearity can give rise to chaotic modulation of ENSO on decadal and interdecadal time scales without contributions from the extratropics (see Timmermann's report). In other models, the source of decadal variability lies in the extratropics and then propagates into the equatorial region via the atmosphere (Pierce et al. 2000). In still other models (McCreary and Lu 1994; Liu 1994), the subtropical cells (STCs), which maintain the equatorial thermocline by carrying cold subtropical water into the tropics, play a central role in equatorial SST variations. They are hypothesized to do this by either of two mechanisms: (a) the STCs transmit SST anomalies formed in the subtropics into the equator through advection (Gu and Philander 1997; Nonaka and Xie 2000); or (b) variations in the strength of the STCs vary the amount of the cold water transported into the equator, leading to SST anomalies (Kleeman et al. 1999).

Nonaka has developed an ocean GCM, forced by reanalyzed wind stress, with which he has investigated the mechanism underlying decadal SST variability in the equatorial Pacific (in collaboration with Xie and McCreary). He asked two questions: Are the same ocean dynamics responsible for SST variability on both interannual and decadal timescales? How far away from the equator do we need to look in order to simulate the decadal variability at the equator? Answers to these questions will constrain the various hypotheses above.

Experiments with this ocean GCM showed that wind forcing occurring both within and beyond a 10º-wide equatorial band contributes equally to equatorial SST variability on decadal timescales, whereas midlatitude wind forcing north of 25ºN contributes very little. This finding contrasts with findings on interannual El Niño SST variability, which is mainly driven by equatorial winds. The results suggest that different ocean dynamics govern equatorial Pacific variations on these two timescales.

Solutions with Nonaka's model show that on decadal timescales, trade wind variations in the non-equatorial tropics cause variations in the strength of the STCs, and these variations are closely related to equatorial SST variations. By modulating the amount of subtropical cold water transported into the tropics, STC variations give rise to SST variations, a finding consistent with the mean-temperature velocity-anomaly mechanism proposed by Kleeman et al. (1999). McPhaden and Zhang's (2001) research also supports this mechanism. Using historical hydrographic data and geostrophic calculations, they found that the gradual increase in equatorial SST in recent decades is associated with a decrease in the STC transport into the equator across the boundaries of the subtropical gyres.

Conducting sensitivity experiments with his ocean GCM, Nonaka discovered that the STC-induced SST anomalies lag two years behind those in response to local equatorial winds. He suggests that this time lag can be explained by a tropic-wide change in the trade winds. A tropic-wide relaxation of the easterlies will lead to a flatter thermocline and an SST increase in the eastern equatorial Pacific through a rather fast equatorial wave adjustment. The reduced trade wind speed on the boundaries of the subtropical and equatorial oceans slows down the STCs due to reduced poleward Ekman transport. The weakened STCs will transport less cold water, thereby giving rise to delayed warming in the equatorial ocean. Thus, on decadal and longer timescales, the STCs act together with the ENSO-type equatorial wave adjustment to produce SST variability in the equatorial Pacific. This delayed effect of the STCs on SST also suggests that the STCs amplify ENSO-type SST variability rather than set the pace for switching from one decadal phase to another or causing a self-sustaining oscillation. If, indeed, the STCs are only amplifiers, then the mechanism that sets the timescale for equatorial decadal SST variability remains to be determined.

Amy Solomon

Assistant Researcher

Amy Solomon obtained her Ph.D. in atmospheric dynamics from the Massachusetts Institute of Technology in 1997. She joined the IPRC in February 1998. Her research interests include tropical-extratropical interaction in the Pacific Basin, the sensitivity of the free troposphere's climate to changes in SST, climate variability due to coupled ocean-atmosphere feedbacks, and the role of baroclinic turbulence in determining the observed climate.

Amy Solomon's research this past year was primarily devoted to studying decadal modulation of the El Niño–Southern Oscillation (ENSO) in a collaborative project with Jay McCreary. She explored the hypothesis that changes in the circulation of the Northern Hemisphere Subtropical Cell (STC) can modulate decadal ENSO variability. Solomon developed a coupled ocean-atmosphere model based upon the work of Kleeman et al. (1999): its ocean component is a variable-temperature, 3.5-layer model, in which fluid is allowed to transfer between layers in order to simulate the processes of upwelling and subduction; its atmospheric component is a perturbation model that generates wind-stress and heat-flux anomalies in response to SST anomalies. This latter component consists of two parts: an empirical model that generates wind stress from SST anomalies derived from correlations between observed fields; and a model of the planetary boundary layer that integrates an equation for surface air temperature and generates heat-flux anomalies.

For reasonable parameter choices, solutions had two dynamically distinct oscillations: an ENSO-like interannual signal (Figure 3a) and a decadal one (Figure 3b). The

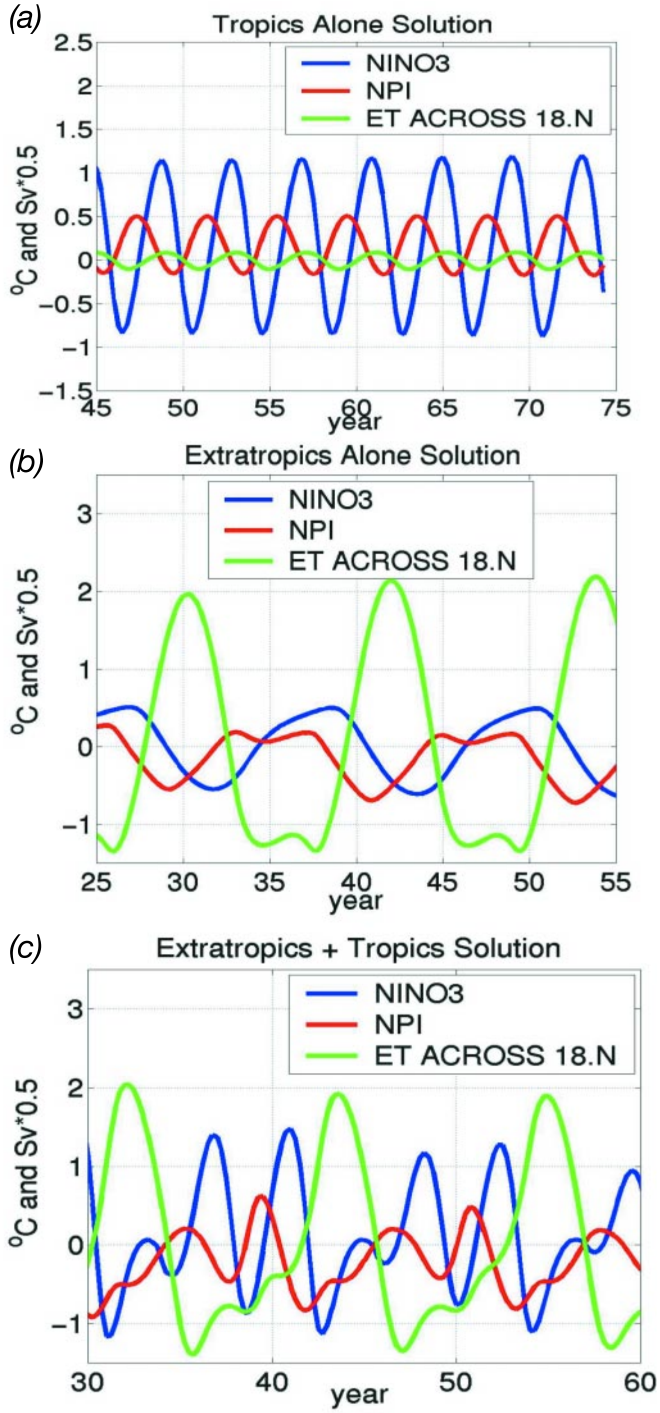


Figure 3. *A comparison of variations in SST anomalies averaged over the NINO3 and the North Pacific Index (NPI) regions and Ekman Transport (ET) across 18°N from solutions of the Solomon and McCreary model. The model produces two distinct oscillations: An interannual oscillation due to tropical ocean-atmosphere feedbacks (a), and a decadal oscillation due to ocean-atmosphere feedback in the extratropics (b). The modulation of the interannual oscillation by the decadal oscillation when feedbacks in both the tropics and extratropics are allowed is shown in (c).*

decadal oscillation extended throughout the extratropics and was similar in structure to observed and modeled variability. This oscillation affected the ocean's northern STC—the shallow, meridional overturning circulation in which water flows out of the tropics in the surface layer, subducts in the North Pacific subtropical gyre, returns to the tropics within the thermocline, and upwells in the eastern equatorial ocean.

The results of her numerical modeling study indicate that STC strength is determined by wind anomalies located near the equatorward edges of the subtropical subduction zones. In response to westerly wind anomalies along these edges, less warm surface water diverges from the tropical ocean, and, after a period of adjustment, less cool subsurface water flows into the region. The model showed that the thermocline deepens throughout the tropical ocean, less cool water upwells in the eastern Pacific, and the cold tongue extending westward off the coast of Peru weakens. Variations in the strength of the STC efficiently transmitted the subtropical decadal signal to the equatorial region, thereby modulating equatorial SSTs (Figure 3c). These solutions suggest a mechanism for ENSO modulation by transport anomalies rather than by temperature anomalies as hypothesized by Gu and Philander (1997).

Solomon presented the results of phases of this research at the IPRC Mini-Symposium on the Interaction of ENSO with Phenomena on Intraseasonal-to-Interdecadal Timescales, the NASA-IPRC-CLIVAR Workshop on Decadal Climate Variability, and the annual meeting of the European Geophysical Society. She is now preparing this research for publication.

As an extension of her previous research on how intermediate-scale waves maintain the climate of the midlatitude troposphere and how sensitive these waves are to changes in forcing (Solomon and Stone 2001, *J. Atmos. Sci.*; Solomon and Stone, *J. Atmos. Sci.*, in press), Solomon plans to use an idealized atmospheric GCM to investigate the dynamical mechanisms that determine the atmospheric response to extratropical Pacific SST anomalies.

Axel Timmermann

Postdoctoral Fellow

Axel Timmermann received his Ph. D. in Meteorology from the Max-Planck Institute of Meteorology, Hamburg, Germany, in 1998. He was with the Royal Dutch Meterological Institute before joining the IPRC for six months. He is now at the Institute for Marine Research, University of Kiel. His research interests include decadal-to-centennial North Atlantic climate variability, stochastic climate modeling, empirical derivation of nonlinear ENSO models, greenhouse warming, and thermohaline circulation stability.

During his stay at the IPRC, Timmermann collaborated with F.-F. Jin and S.-I. An in trying to answer the question, "What causes decadal changes in the activity of the El Niño–Southern Oscillation (ENSO) phenomenon?" The outcomes of his two primary projects are summarized below.

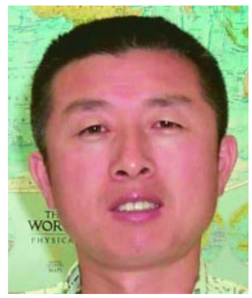
Dynamics of Decadal ENSO amplitude modulations: It is widely accepted that the amplitude of ENSO varies from decade to decade, but it is not understood why it does. ENSO decadal variations might be an expression of their being partly excited stochastically or the result of deterministic dynamical processes interacting with ENSO. In light of recent observational studies indicating that the amplitude of ENSO is modulated with a distinct timescale of 15 to 20 years, the latter appears likely. Timmermann's research has revealed that a low-order ENSO model, which captures the most important ENSO-relevant processes, can generate decadal amplitude modulations from internal advective nonlinearities. The mechanism is based on equatorial atmosphere-ocean dynamics alone and does not invoke extratropical forcing.

The generation of decadal tropical variability can be understood in terms of the dynamical systems concept of homoclinic chaos. This mathematical concept has implications for the simulation of the ENSO envelope period, as well as for ENSO irregularity. Timmermann's research showed that this nonlinear scenario, which is fundamentally different from the delayed dynamics perspective, is robust against the combined effect of annual cycle and stochastic forcing. Although the ENSO homoclinic chaos idea is less intuitive than hypotheses that account for the slow tropical background changes by remote extratropical dynamics, it seems to emerge as a natural consequence of nonlinear tropical atmosphere-ocean dynamics. The fundamentally new aspect is that this hypothesis does not deal with a "classical" memory timescale that is due to delayed ocean dynamics providing a memory on decadal timescales, but a nonlinear combination of different intrinsic timescales. Hence, this mechanism opens a completely new perspective on the decadal variability problem. This nonlinear scenario appears superior to previously suggested ENSO irregularity scenarios because the latter cannot generate decadal amplitude fluctuations of sufficient amplitude. These findings are supported by experiments with more complex models such as the Zebiak and Cane intermediate model and an empirical model derived from the Coupled General Circulation Model data.

Predictability of decadal ENSO amplitude modulations: In weather and climate prediction, we distinguish two kinds of predictions. The first kind, exemplified by conventional weather forecasting, characterizes initial value problems. The assumption is that a large part of the atmosphere's variability is "free", that is, independent of surface boundary conditions. This predictability measures how uncertainties in initial conditions evolve during the forecast. In weather and climate forecasting applications, initial condition errors are introduced by perturbing the initial state with the so-called singular vectors. These vectors represent the perturbations that have the strongest error growth with respect to an a *priori* chosen norm. They are obtained from the tangent model and its adjoint, linearized along a nonlinear model trajectory. Error-growth results from the non-normality of the linear propagator and its adjoint, rather than from the nonlinearity of the dynamical equations.

In predictions of the second kind, the attempt is to forecast how a system will respond to a prescribed change in one of its determining parameters, which Lorenz calls boundary-value dependent, "forced" variations. The response of climate to a doubling of atmospheric carbon dioxide concentrations is an important example.

Timmermann wishes to introduce a third kind of prediction, the nonlinear prediction of nonlinear systems, a prediction that is independent of initial-condition errors. The overall idea is that certain nonlinear systems exhibit amplitude modulations on long timescales while the dynamics on shorter timescales can be highly chaotic. The goal, in this case, is to assess the predictability of these slow amplitude modulations rather than to forecast the attractor as accurately as possible. Such a form of predictability deals with global properties of the attractor, which are independent of initial state errors. A paper is in preparation, which deals with this new predictability concept in the framework of decadal ENSO predictions.



Dailin Wang

Associate Researcher

Dailin Wang received his Ph.D. in oceanography from the University of Hawai'i 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.

Dailin Wang's research focuses on ocean mixing processes and their parameterizations in ocean GCMs. His goal is to improve our understanding of these processes and to improve their parameterizations in ocean GCMs and climate models.

Microstructure observations of the equatorial upper-ocean night-time convection often reveal internal waves with wavelengths of a few hundred meters. To understand how these waves are generated, Wang, in collaboration Peter Müller (Wang and Müller, *JPO*, in press) conducted a series of large-eddy simulations of the equatorial ocean boundary layer, using various velocity profiles. Figure 4 shows zonal sections of vertical velocity from their simulations. With full Equatorial Undercurrent (EUC) shear (Figure 4a), small-scale turbulent motions dominate above 40 m, and wave motions dominate below 50 m. The internal waves have wavelengths of about 300 m, consistent with observations and linear instability analysis. Without or with partial EUC shear, the waves have different characteristics: either the amplitudes are too weak (Figure 4d) or the wavelengths are too short (Figure 4c and e). The fact that neither wavelengths nor amplitudes were seriously affected by the magnitude of surface cooling demonstrates that the waves result from EUC shear instability. To our knowledge, this is the first three-dimensional numerical study that simultaneously resolves turbulence and internal waves in the EUC system.

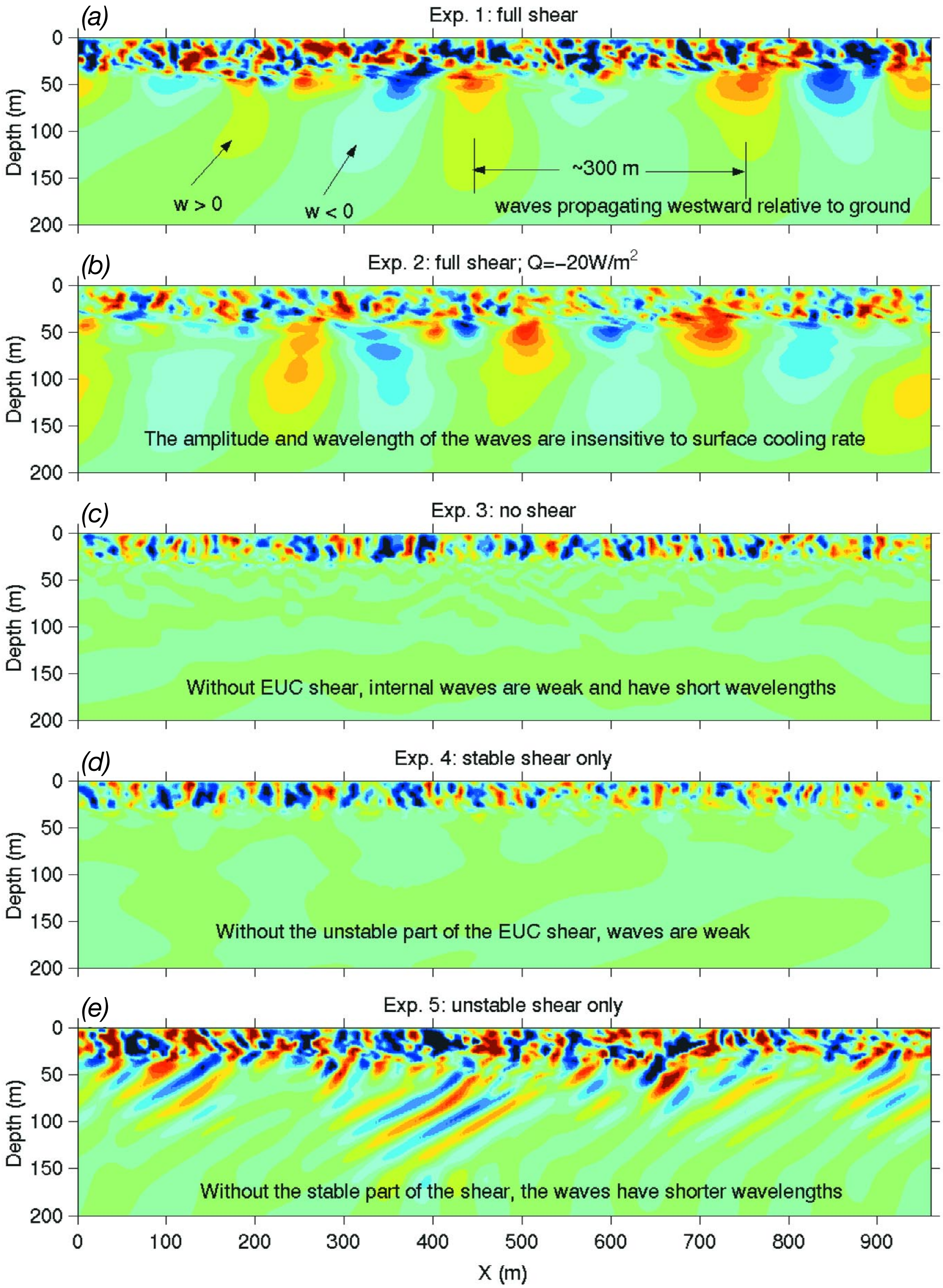


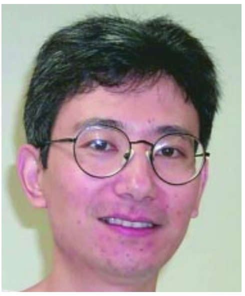
Figure 4. *Large-eddy simulations of the equatorial undercurrent (EUC) system. Zonal sections of vertical velocity for experiments with (a) full EUC shear; (b) same as (a) but the surface cooling rate is reduced by a factor or 10; (c) no shear (pure convection); (d) stable part of the EUC shear only (or portion of EUC profile that has Ri > 1/4); and (e) the unstable part of the EUC only (or portion of the EUC profile that has Ri <1/4). A surface cooling rate of 200 W/m^{-2} is employed for all experiments except for (b), in which surface cooling rate is a factor of 10 smaller, or 20 W/m^{-2}.*

To describe the ocean's surface mixed layer and to model it in ocean GCMs, modelers use a variety of one-dimensional (1-D) mixed-layer models varying from the simplest bulk models (or integrated models) to the sophisticated closure models. There is, however, no consensus as to which of these models is the best overall. Evaluation of individual 1-D mixed-layer models is difficult because accurate comparisons between 1-D models and observations are hampered by the difficulty, if not impossibility, of replicating observed ocean conditions in these models. Many horizontal processes such as internal waves, Ekman convergence/divergence, horizontal and vertical advection are either not well observed or are simply not present in many of the available data sets. Thus, the comparison between 1-D models and observations is not *clean.* Observed surface fluxes of momentum, heat, and salt are also subject to errors.

This past year, Dailin Wang began a systematic assessment of the strengths and weaknesses of the common 1-D mixed-layer models used in today's ocean GCMs. His approach is to compare 1-D models with large-eddy simulations (LES, or 3-D turbulence models). In an LES model, the largest eddies–those that contribute the most to turbulent fluxes of momentum and heat–are resolved, while turbulent fluxes due to unresolved subgrid-scale motions are parameterized. These subgrid fluxes, however, are only small fractions of the total fluxes. The LES models, therefore, depend less on parameterizations than traditional 1-D models, in which all turbulent processes are parameterized. The comparisons between 1-D models and LES are clean in the sense that exactly the same forcing or large-scale flow conditions can be imposed on both types of models.

More specifically, Wang is comparing 1-D models with LES models under a wide range of ocean conditions, from wind deepening, penetrative convection, to diurnal cycling with and without rotation (that is, equatorial or midlatitude) and with or without background shear. He has obtained a suite of high-resolution LES solutions under varying ocean conditions and has used them to test simple 1-D models. It is quite possible that a particular 1-D model can reproduce the mean properties of the ocean boundary layer reasonably well but for the wrong reason, that is, with wrong physics or incorrect balances in the turbulent kinetic energy (TKE). For example, Wang's preliminary comparison with the Kraus-Turner bulk mixed-layer model reveals that in this model very different combinations of the two coefficients related to shear production (m) and buoyancy production/destruction of TKE (n) can yield almost identical mixed-layer temperatures and mixed-layer depths. By adjusting one of the two parameters while setting the other parameter to zero, both penetrative convection and non-penetrative convection plus wind-deepening match almost equally well the LES results (subject to surface cooling alone or to both surface cooling and wind stress). This example illustrates that tuning 1-D models without understanding the physical processes is dangerous and can yield completely different conclusions. The correct values for these coefficients, however, can be determined from the TKE budget.

More realistic ocean and climate models will ultimately need more accurate parameterizations of mixing processes. Wang's work should provide guidelines for selecting mixed-layer models in those regimes in which they are advantageous and valid.



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.

This past year Shang-Ping Xie's research has consisted of three streams: application of satellite data to research on air-sea interaction; spatial and temporal variations in atmospheric circulation in relation to sea surface temperature (SST) distribution; and Pacific decadal variability.

Satellite study: Ocean islands modify surface winds on their lee sides. A 3,000-km-long wake, many times longer than any yet observed, has been detected lee of the Hawaiian Islands. Such a long wake cannot be explained with usual aerodynamic concepts. Using measurements obtained from several satellites of various ocean and atmospheric fields (wind divergence, cloud liquid water, Ekman pumping velocity, and SST) together with computer simulations, Xie et al. (2001) have shown an intricate chain of interactions between the winds and the ocean: As the broad, steady northeasterly trades impinge on Hawai‘i, a number of mechanical wakes form behind the individual islands. These individual wakes dissipate rather quickly and a broad wake takes their place 300 to 400 km leeward of the islands. The wind curl associated with this broader wake generates an eastward countercurrent. This eastward current advects warmer water from the west, giving rise to a sea-surface warm tongue pointing toward Hawai‘i (Figure 5b). This gradient in SST forces the north and south winds to converge, and a maximum in cloud liquid water forms in the region. The anomalous winds, in turn, weaken the northeasterly trades to the south of the warm tongue and strengthen them to the north, providing the means for the wake and the wind curl pattern to persist over the 3,000 km (Figure 5a).

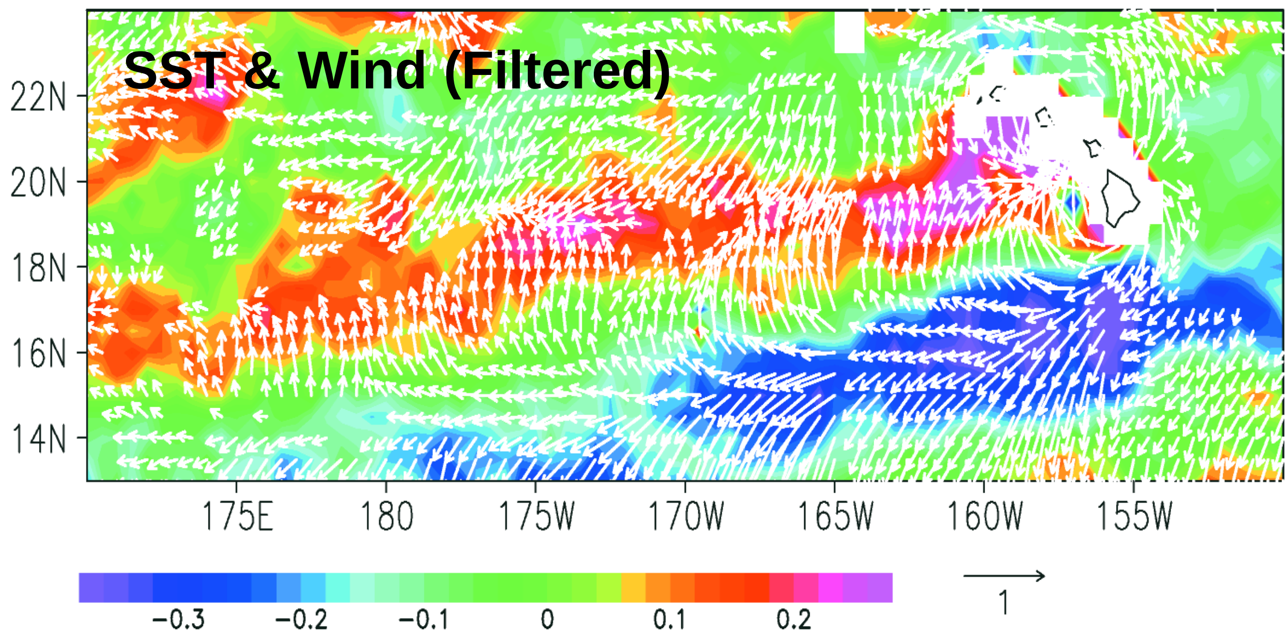
This study shows how tiny islands, barely visible on a world map, can affect a long stretch of Earth's largest ocean. Just how the atmosphere responds to extratropical SST anomalies is poorly understood, and this lack of understanding has been a stumbling block to further progress in the study of non-El Niño climate variability. The above results demonstrate that surface winds react to modest subtropical SST variations as small as a few tenths of a degree.

SST-induced atmospheric variations: Xie is collaborating with Hokkaido University, Japan, on a study to understand how SST distributions determine such important attributes of atmospheric circulation as stationary eddies and storm tracks (Inatsu et al., *JAS*, submitted). Analysis of a set of atmospheric GCM experiments shows that the extratropical land-sea distribution – a forcing long thought important – induces only modest stationary eddies in the upper troposphere that are confined to high latitudes. By contrast, the stationary-eddy response to zonal variations in tropical SST is strong in both the subtropics and midlatitudes, making it the major mechanism for forming the westerly jet cores in the upper troposphere. While changes in the midlatitude meridional SST gradient are not a major forcing for stationary eddies in the upper troposphere, these changes induce strong zonal variations in eddy activity or storm tracks. Given that sea surface momentum and heat flux is influenced by stationary and transient eddies, this result has important implications for air-sea interaction in the extratropics.

In a collaboration with G. Huang (Institute of Atmospheric Physics) and S. Matsumura (Frontier's Institute for Global Change), Xie is studying how temporal variations in SST affect the climate. They have conducted a 20-member ensemble atmospheric GCM simulation forced with the observed SST and sea ice for the past four decades (see Huang's report). Initial results indicate that most of the observed variance in geopotential height at 500 mb may be largely due to chaotic variability within the atmosphere. The best simulation of this ensemble was that of ENSO and its teleconnection into the extratropics, followed by the simulation of the North Atlantic Oscillation (NAO) from February to April.

Recent modeling results described in the literature suggest that cross-equatorial SST gradient (CESG) variability in the tropical Atlantic may be attributed to a coupled ocean-atmosphere mode, a notion currently under intense debate. To investigate the cause of CESG

(a)



(b)

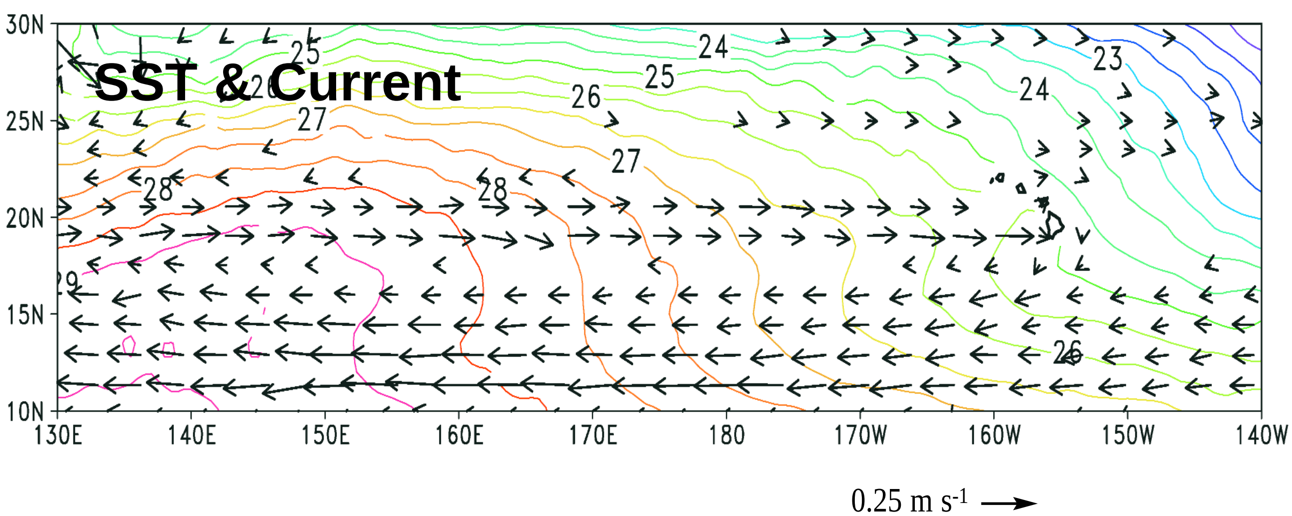
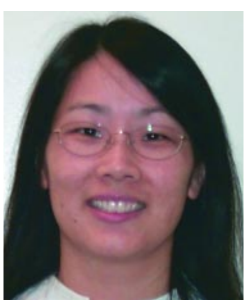


Figure 5. *The Hawaiian Islands affect the ocean and atmosphere, creating a 3,000-km-long wake—many times longer than any yet observed: (a) TRMM SSTs (high-pass filtered in the latitudinal direction to emphasize island effects; color scale in °C) and QuikSCAT wind vectors (m s^{-1}; the vector scale is changed to 3 m s^{-1} east of 165°W); (b) current vectors (in m s^{-1}) at 37.5 m averaged over 1992–98 in a high resolution ocean GCM, and annual mean SSTs (contours in °C) for 1999 TRMM satellite observations. East of the islands, the filtered SST field varies little, to the west greatly. In the shadow of the islands, a warm tongue in the ocean both causes the winds to converge and is the result of converging winds. The winds create an eastward countercurrent that generates the warm band via its warm advection. (Adapted with permission from Xie, Liu, Liu, Nonaka, 2001: Far-Reaching Effects of the Hawaiian Islands on the Pacific Ocean–Atmosphere System.* Science*, **292**, 2057–2060. Copyright 2001 American Association for the Advancement of Science.)*

variability and its teleconnection to the extratropics, Xie with Okumura and others (Okumura et al. 2001, *GRL*) has conducted an atmospheric GCM simulation that was forced with a prescribed SST dipole anomaly in the tropical Atlantic. The model response bears a striking resemblance to observations in both the tropics and extratropics. The simulated tropical response is robust and reinforces the prescribed SST anomalies through wind-induced evaporation. The researchers identified, both in the model and in observations, a new feedback mechanism involving low-level stratiform clouds in the subtropics. In addition, the tropical SST dipole forces a barotropic teleconnection into the extratropics that projects onto the NAO and significantly modulates cold surges during winter on the eastern seaboard of North America.

Pacific decadal variability: Three projects have been completed on the following topics: the cause of decadal variability in equatorial Pacific SST (Nonaka et al. 2001, *GRL*, to be submitted); mechanisms for SST variability in the Kuroshio-Oyashio Extension (KOE; Tomita et al., *J. of Clim.*, submitted); effects of mesoscale eddies in the KOE region on the subduction of subtropical mode waters (Qu et al., *JPO*, submitted). See the reports by the IPRC lead authors for details.



Zuojun Yu

Associate Researcher

Zuojun Yu obtained her Ph.D. in physical oceanography from Nova Southeastern University, Fort Lauderdale, Florida, in 1992. She was a research scientist with the Joint Institute for the Study of the Atmosphere and Ocean at the University of Washington in Seattle before joining the IPRC in Summer 2000. Her research interests include surface mixed-layer dynamics, simulation of large-scale ocean circulations, and eddy–mean flow interaction.

Since coming to the IPRC, Zuojun Yu has improved a 4.5-layer Pacific Ocean model. To keep the model's sea-surface salinity (SSS) field from drifting quickly from climatology, she introduced a "virtual runoff" scheme. This scheme enabled her to identify the importance of coastal runoff and to study the effect of $E - P$ (evaporation minus precipitation) over the interior Pacific Ocean without using the "sponge layers" (which exclude the effect of $E - P$). The model produces the best SSS fields when forced by satellite-based precipitation products, which is encouraging because only satellite observations can provide the needed spatial and temporal coverage. She is now working on simulating the structure of the mixed layer at mid- and high latitudes.

Yu has also been working with Jay McCreary on a modeling study of the Pacific Ocean subsurface countercurrents, called the Tsuchiya Jets (TJs; see McCreary's report). Applying a similar model to the tropical Atlantic Ocean Basin (30ºS–30ºN), Yu has begun to study the Atlantic's Northern and Southern Equatorial Undercurrents, which appear to be the counterparts of the Pacific's TJs. After a 30-year spin-up using the monthly climatology based on ECMWF winds from 1993 to 1999, the model was forced with monthly ECMWF winds from February 1989 onward; it was also forced with an inflow of 8 Sv of upper-intermediate water (layer 3) across the southern boundary and a compensating outflow in the surface and thermocline water (layers 1 and 2) across the northern boundary. These inflows and outflows represent the northward-flowing surface branch of the thermohaline overturning circulation (TOC). Her preliminary model results compare well with Schott et al.'s (1998) observations that were taken at, and west of, 35ºW. Yu was able to simulate the Schott et al.'s observations only when she included the TOC and used interannual ECMWF winds as forcings. She found that local recirculations tend to enhance the Northern and Southern Equatorial Undercurrents. Moreover, the dynamics of these currents appear to be very similar to those of the TJs in the Pacific Ocean. The seasonal variability of these Atlantic currents, however, is larger than that of the TJs, and considerably more observations are therefore needed to validate the modeling results.

In another project, Yu is using layer models of various complexities to resolve differences between observations and simulations in Xie et al.'s (see Xie's report) study on the Hawaiian Lee Countercurrent (HLCC, Flament et al. 1998). Her preliminary results suggest that baroclinic instabilities are important in setting up the mean structure of the observed HLCC, modifying the wind-driven Sverdrup balance considerably. She plans to compare her model results with drifter and altimeter data to determine whether the model has resolved these eddies adequately.

Research Activities and Accomplishments
Theme 2: Regional Ocean Influences

Overview

Huge amounts of water are transported every year in the large ocean gyres of the Pacific, the Kuroshio-Oyashio Currents, and the Indonesian Throughflow (ITF). The temperature and other aspects of these water masses vary from season to season, from year to year, and over decades and centuries, affecting the climate of the ocean and atmosphere, the Asian-Australian monsoon, and El Niño. Theme 2's overall goal is to determine the processes by which the western-boundary currents, the Kuroshio-Oyashio Extension (KOE) region, marginal seas, and the ITF influence Asia-Pacific climate. These processes include interactions between coastal and marginal seas and between eddies and the mean flow in western-boundary currents; water exchanges across fronts of water masses; and formation of Subtropical Mode Water, North Pacific Intermediate Water, and other water-mass types. Since all of these processes play an important role in the water exchange between gyres and oceans, this research will lead to a better understanding of variability in regional ocean circulations, such as the Kuroshio pathways, as well as global climate change and its effects. This greater understanding should result in a better ability to predict such changes. Toward this goal, IPRC Theme-2 research this past year has included simulations with high-resolution numerical models, the development of better techniques for assimilating data, and the diagnosis of processes using historical data.

The first objective under Theme 2 is to determine the processes that maintain the Kuroshio and Oyashio Currents and their extensions, and that cause their climatic variability. One piece of this research is to understand the mechanisms that cause meander formations in the Kuroshio south of Japan and, eventually, to be able to predict their formation. In a numerical simulation conducted in 1999–2000, Waseda and Mitsudera had shown that, contrary to traditional knowledge, *anticyclonic* eddies can contribute to such meander formation in the Kuroshio. This year, they conducted a detailed analysis of the numerical simulation, which revealed several dynamically relevant processes such as the eddy-shedding at sharp coastlines, meander-growth processes, and meander baroclinic structure during detachment of anticyclonic eddies from the Kuroshio. They also studied the chaotic advection of the coastal water that may be partly responsible for transporting fish eggs and larvae from the Japanese coast into the nutrient-rich Oyashio-Kuroshio confluence region (Waseda, Mitsudera). Furthermore, a new index for the Kuroshio path south of Japan has been introduced; the index is based on a bimodal decomposition of the temperature field at 400-m depth. A detailed analysis indicates the importance of deep circulation and upwelling in creating and maintaining the large meander state (Maximenko).

The study of the Kuroshio–Oyashio Extension (KOE) region and the Mixed Water Region, where the Kuroshio and the Oyashio meet, also falls under the first objective of this theme. A new climatology with a 0.5º by 0.5º resolution has been developed for the region by averaging all historical data along isopycnal surfaces in the Mixed Water Region east of Japan (Qu). This new climatology shows that water from the Oyashio overshoots the zero zonally integrated wind-stress-curl line by more than 5º and reaches as far south as 36º–38ºN along the western boundary. A high-resolution regional model succeeded in simulating various features of the KOE region (Mitsudera). The simulation reveals that Oyashio water, which is low-potential vorticity, has a striking influence on the stratification of water in the Mixed Water Region. The simulation further shows a well-defined pathway that goes from the subpolar gyre into the North Pacific Intermediate Water layer of the Subtropical Gyre. A study of the effects of eddies on the subduction process in this region with the JAMSTEC high-resolution ocean GCM indicates that mesoscale eddies enhance the subduction rate by up to 100 m yr^{-1} in the formation region of the Subtropical Mode Water (STMW) and Central Mode Water (CMW), accounting for 44% of the average regional formation (Qu, Xie, Mitsudera). Data from the Megapolygon '87 expedition in the Subpolar-Front region and acoustic tomography from the Kuroshio Extension Pilot Study were also analyzed and reveal the deep structures of eddies, fronts, and recirculation gyres in the KOE region (Maximenko, Yaremchuk, Yuan).

Data-assimilation techniques are being developed to examine further the processes in these regions. Thus, upper-ocean seasonal variability in the KOE region is being analyzed by means of four-dimensional variational assimilation with an ocean model that incorporates the K-Profile Parameterization scheme for the mixed layer. The optimized ocean state reveals two distinct sites of water-mass production, corresponding to STMW and CMW. Analysis of the heat and salt budgets in the region has shown that surface fluxes are counterbalanced by the horizontal divergence of the temperature and salinity advection in the ocean (Lebedev, Yaremchuk). A new technique, based on wavelet analysis, is being developed for error estimation and for determining the weights of observed data and computed values in assimilating data into various GCMs at the IPRC. In combination with the wavelet error diagnostic scheme developed in previous years, the SEEK filter (Singular Evolutive Extended Kalman filter) is now being implemented into Theme 2's regional modeling efforts (Waseda, Yaremchuk, Mitsudera).

The second objective of Theme 2 is to identify the processes that maintain the low-latitude western-boundary currents (LLWBCs) and cause their climatic variability. In the North Pacific, much of the water in the subsurface branch of the Subtropical Cell (STC), through which subtropical-tropical water exchange occurs, flows in a LLWBC, that is, the Mindanao Current. This current is fed by the North Equatorial Current, which bifurcates at the Philippine Coast into an equatorward flow (as a part of the STC) and a northward flow that returns to join the Kuroshio. Identification of the latitude of the bifurcation may provide a measure of the STC strength. This past year, a diagnostic study with historical hydrographic data (Qu) and numerical experiments with ocean GCMs (Miyama, Jensen, Mitsudera, Bang, and Qu) has begun to determine the bifurcation characteristics. Preliminary results are promising.

The third objective under Theme 2 is to determine the influence of marginal seas and the ITF on the Asia-Pacific climate system. Current research includes analysis of the surface-heat content and circulation in the South China Sea by using historical hydrographic and expendable bathothermograph (XBT) data (Qu). Ocean GCM experiments based on these analyses have already started.

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 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 the variability of the Indonesian Throughflow.

Konstantin Lebedev has worked this past year on the inversion of climatological, drifter, and sea surface height data in order to study seasonal variations in the Kuroshio Extension (KE) and the recirculation gyre to the south. The processed data sets include the NCEP surface fluxes of heat and salt, Hellerman wind stress, Levitus hydrology, TOPEX/POSEIDON altimetry, and drifter data. He used a variational data-assimilation technique to retrieve variability in the open ocean (18º–41ºN, 145ºE–150ºW) to a depth of 1,000 m. He made a special effort to represent accurately the upper mixed layer. The model has a refined vertical resolution (40 levels per km, with an average vertical spacing of 7 m in the upper 100 m) and uses the K-Profile Parameterization (KPP) scheme developed by Large et al. (1994) for mixed-layer thermodynamics. These features provide a reasonable degree of realism in simulating air-sea interactions and make it possible to analyze the mixed-layer dynamics as well as the formation and evolution of the North Pacific Mode waters. By optimizing the open boundary values of oceanic fields in combination with initial conditions and atmospheric forcing, he obtained a model solution consistent with climatological data within limits of observational errors. The optimized ocean state reveals two distinct sites of water-mass production, namely, Subtropical Mode Water (STMW) produced at an annual mean rate of 3.8 Sv around 145º–170ºE, 31º–35ºN, and Central Mode Water (CMW; shown in Figure 6) produced near 160ºE–175ºW, 37º–40ºN but at a slower rate (3.1 Sv).

The bulk of STMW is produced in February–March and then subducted southwest at an average vertical rate of 18 m/yr. The CMW, which is formed from February to April, follows eastward and southeastward subduction paths with typical vertical velocities of 28 m/yr. The KE annual-mean transport in the upper 1000 m is diagnosed at 68 Sv, with a maximum of 78 Sv in June–July and a minimum of 56 *Sv* in December–January. The assimilation experiments also gave an indication of seasonal changes in the structure of the upper 1000 m of the North Pacific Subtropical Gyre, its axis being displaced 0.8º north in summer (July–August). This displacement, however, cannot be stated with any confidence because of its sensitivity to variations in the assimilation algorithm parameters and low resolution of the data.

Analyses of the heat and salt budgets have shown that atmospheric forcing is balanced mainly by horizontal advection of heat and salt. In the annual mean, horizontal diffusion contributes less than 10% to the net heat and salt budgets. This balance also holds for the upper mixed layer. Results of this study (Yaremchuk and Lebedev) have been submitted to *JPO*.

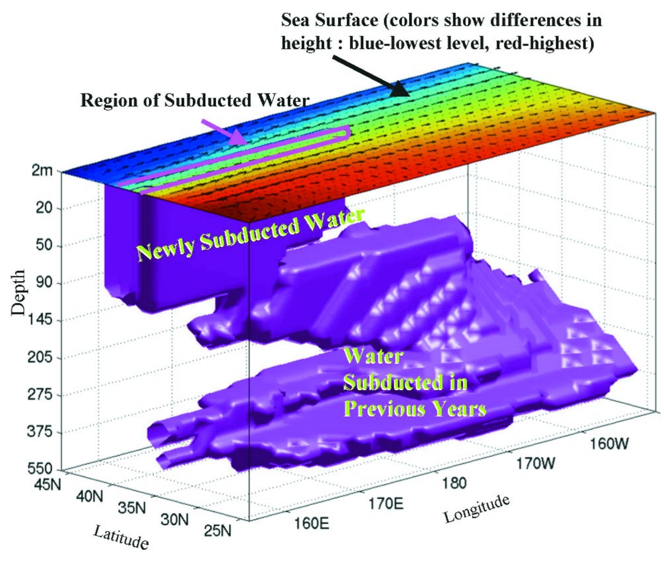
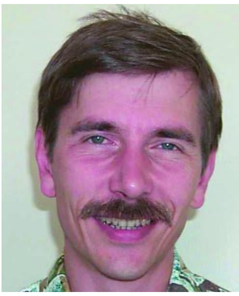


Figure 6. *During winter cold water forms in the upper ocean and then sinks, fueling the ocean circulation and thereby helping to maintain Earth's climate. This figure shows how new Central Mode Water (dark purple) is formed during January in the Pacific and replenishes the cold water mass below the surface formed during previous years (light purple). The image was generated by a simulation that assimilated sea surface height data from the TOPEX/POSEIDON satellite and climatological and drifter data into a mixed-layer model.*



Nikolai A. Maximenko

Associate Researcher

Nikolai Maximenko obtained his Ph.D. in physical oceanography from the P.P. Shirshov Institute of Oceanology, Moscow, in 1987. He continued at the Institute as a senior research scientist in the Marine Currents Laboratory of the Large-Scale Air-Sea Interaction Division. 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 the formation of North Pacific Intermediate Water.

Nikolai Maximenko studied the large meander of the Kuroshio this past year (Maximenko, *GRL*, submitted). To analyze the path of the Kuroshio south of Japan, he introduced an index derived from the bimodal decomposition of the temperature field at 400 m. He found that sorting historical data with this index, provided a better description than previous data analyses of the three-dimensional structure of the Kuroshio during both straight- and meander-path state, and of the differences between these states. A precise water-property analysis on isopycnal surfaces revealed that the water that filled the interior of the large meander had upwelled from below as the meander formed and was modified by increased vertical mixing in the upper ocean (see Figure 7). Estimates of available potential energy reveal that the energy is greater in the meander state, indicating that the meander cannot be formed by any kind of instability. (Decay of the meander, on the other hand, is likely due to baroclinic instability, a process confirmed by the higher variability of the temperature index in the offshore Kuroshio path.)

Vertical displacement of isopycnals during the meander formation is significant to very deep levels and is approximately a linear function of the distance from the ocean bottom. This observation supports the hypothesis that it is the time-varying deep circulation that causes the accumulation of deep water within a meander south of Honshu. Being pushed offshore by this water, the Kuroshio, itself, plays only a pas-

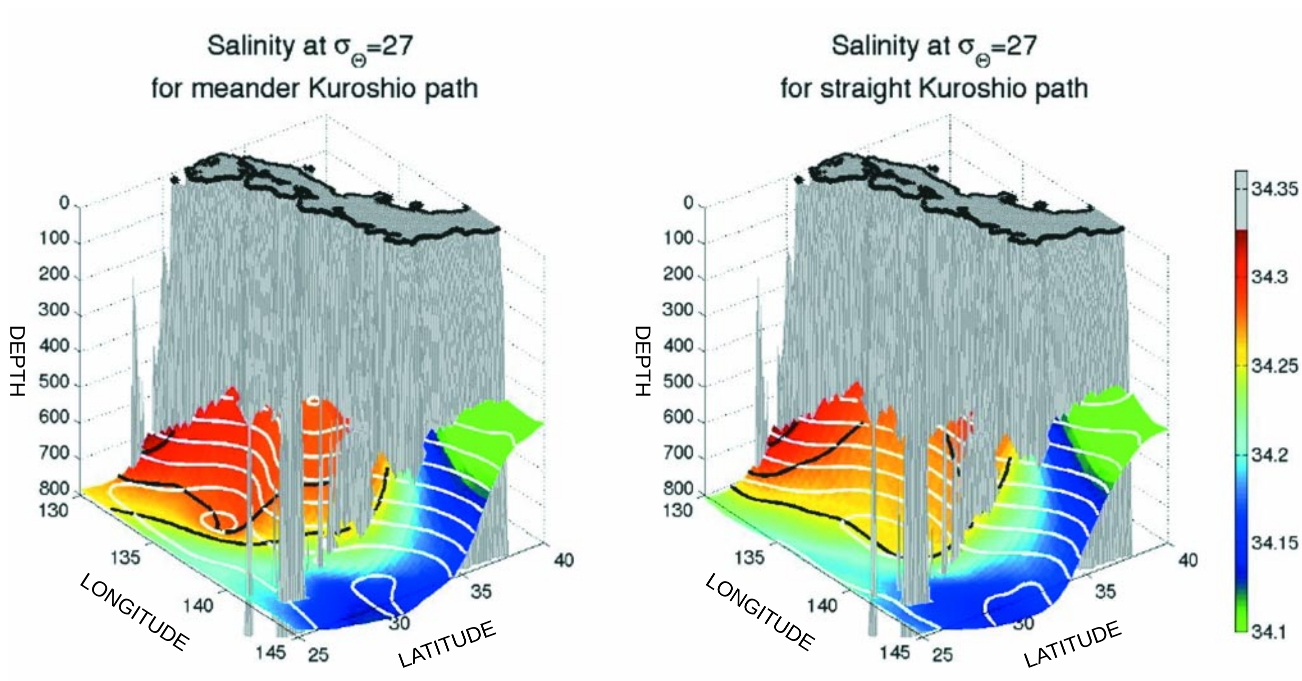


Figure 7. *Isopycnal surfaces and salinity distributions at σ_θ =27 for the meander and the straight Kuroshio paths south of Japan as revealed by a water-property analysis based on an index derived from historical data. Black lines represent 34.25, 34.28, and 34.31 isohalines; white lines, the depth of the isopycnal plotted at 50-meter intervals. Gray represents the sea floor relief and the Japanese coastline. Comparison of the figures shows that in the meander path, deep, saline Kuroshio water accumulates and lifts the isopycnal.*

sive role in its meander formation. This scenario also explains why previous explanations of meander formation have failed. Maximenko is now studying the extent to which the meander-related signal spreads horizontally and the physical mechanism underlying the meander formation process.

Maximenko has collaborated on the following research projects: With M. Yaremchuk and others, he has worked on the "Megapolygon-87" Project (see Yaremchuk's report; Maximenko, Koshlyakov, Ivanov, Yaremchuk, and G.G. Panteleev, *JGR*, in press). With Peter Niiler (Scripps Institution of Oceanography), he conducted a study using drifter and satellite altimetry data to analyze the mean-field surface velocities and their anomalies in the western North Pacific. In particular, they investigated peculiarities in the Lagrangian statistics, correspondence between *in-situ* and remote measurements, and statistical sufficiency of the dataset. Furthermore, they described the main jets, eddy distribution, and lack of horizontal cross-frontal water exchange in the Kuroshio Extension mixed layer west of the date line.

Maximenko has also completed negotiations with Nikolay Rykov and Yurii Volkov of the Regional Oceanographic Data Center, Far East Regional Hydrometeorological Research Institute (FERHRI), Vladivostok, Russia, to recover FERHRI data and transfer 48 (1980–1991) seasonal surveys of the Kuroshio and its extension southeast of Japan. Copies of the data will be submitted to IPRC's Asia-Pacific Data Research Center and the World Ocean Data Center–A (U.S.). This easily accessible data-set will significantly improve data coverage of the Kuroshio region.

Maximenko continues with Andrey Zatsepin (P.P. Shirshov Institute of Oceanology) as co-principle investigator of field observations of the Black Sea. Observations from 1999–2000 revealed a high correlation between surface-drifter trajectories and wind-stress curl, demonstrating that the mean Rim Current consists mainly of highly variable, instantaneous eddies. Mesoscale eddies are generated either by direct wind forcing or by baroclinic instability of the basin-scale gyre. (Motyzhev, Poulain, Zatsepin, Fayos, Kostyanoy, Maximenko, Poyarkov, Soloviev, Stanichny, 2000, *WMO Technical Report.*) Maximenko and his research team consider these findings important for understanding currents in all enclosed seas, and Maximenko plans to apply the findings in the coming year to data from the Japan Sea.

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 at the Japan Marine Science and Technology Center (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.

Humio Mitsudera has worked this past year on projects related to the modeling of the Kuroshio-Oyashio confluence, the dynamics of the Kuroshio along the southern coast of Japan, and the intermediate-layer circulation of the tropical ocean.

The Kuroshio and Oyashio Currents meet off the eastern coast of Japan where the Mixed Water Region forms. With Y. Yoshikawa (JAMSTEC) and B. Taguchi (University of Hawai'i), Mitsudera has conducted numerical experiments using a regional, high-resolution model to study the interaction between the Kuroshio and Oyashio. The model realistically simulated the Oyashio's southward penetration along the Japanese coast, a feature that previous models have found difficult to simulate. The successful simulation allowed study of the southward Oyashio pathways. Analogous to observations, the numerical solutions showed a well-defined pathway that extends from the Subpolar Gyre into the North Pacific Intermediate Water layer of the Subtropical Gyre. Cold but fresh (hence light) outflow water from the Okhotsk Sea is the key component of the pathway. The outflow becomes a density-driven current along the northeast coast of Japan, carrying cold water to the south, and then subducts across the Kuroshio Extension below the subtropical water. A comparison between numerical experiments with and without the Okhotsk Sea outflow reveals that the water from the Okhotsk Sea has a striking impact, changing the surface and subsurface temperature field completely in the Mixed Water Region north of the Kuroshio Extension.

Mitsudera has continued to work with T. Waseda on studying the Kuroshio path dynamics. When the Kuroshio Large Meander is formed, it tends to stay west of the Izu

Ridge, a noteworthy topographic feature off the southern coast of Japan. They have found that variations in the recirculation gyre due to mesoscale eddies strongly influence the variability of the Kuroshio path (see details in Waseda's report). In another study, in which the meander moves somewhat eastward and encounters the Izu Ridge, the ridge tends to prevent the meander from propagating further eastward. Many modeling simulations have assumed the ridge to be a vertical wall with a gate that channels the Kuroshio. In reality, however, the Izu Ridge is a submarine ridge rather than a vertical wall. Mitsudera has, therefore, investigated the combined effect of bottom topography and density stratification in blocking the meander and found that the combination can result in the following alternative blocking mechanism: when the large meander encounters the ridge, the joint effect of baroclinicity and relief (JEBAR) produces a cyclonic torque even though the Kuroshio flows up-slope over the western slope of the Izu Ridge. The torque forces the Kuroshio axis to rotate cyclonically over the ridge, blocking and amplifying the meander.

In collaboration with E. Firing (University of Hawai'i), K. Donohue (University of Rhode Island), and A. Ishida (JAMSTEC), Mitsudera has investigated the thermocline and intermediate-layer circulation of the Pacific Ocean. Comparing data from the JAMSTEC high-resolution global ocean model with historical ADCP (acoustic Doppler current profiler) and CTD (conductivity, temperature, and depth) observations, they found that the JAMSTEC simulation of the subsurface countercurrent, known as the Tsuchiya Jets (TJs; see reports by McCreary; Yu), was the best among high-resolution global ocean GCMs. The simulation showed that the northern TJ is probably associated with the intense recirculation gyre caused by potential vorticity homogenization. Upwelling off Peru and upwelling associated with the Costa Rica Dome probably also force the Tsuchiya Jets.

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 the Ocean Research Department of Japan Marine Science and Technology Center, Yokosuka, 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.

This past year, Tangdong Qu used historical data and results from a general circulation model to study (1) the circulation and water-mass distribution in the Mixed Water Region east of Japan, and (2) the subduction of mode waters in the North Pacific.

In project 1, Qu has developed a 0.5º by 0.5º climatology of the Kuroshio–Oyashio system by averaging all historical data along isopycnal surfaces in the Mixed Water Region east of Japan. This new climatology shows that water from the Oyashio overshoots the zero zonally integrated wind-stress-curl line by more than 5º, reaching as far south as 36º–38ºN along the western boundary; water from the Kuroshio Extension, on the other hand, tends to feed into the Oyashio Front in the ocean interior. The zero meridional transport integrated from the western boundary to 180º occurs at about 44ºN, coinciding reasonably well with the latitude predicted by Sverdrup theory (see Figure 8; Qu, Mitsudera, and Qiu, *JPO*, in press). An additional finding is that the Kuroshio–Oyashio system in the Mixed Water Region east of Japan is characterized by a double-front structure within the depth range of the thermocline, but it does not have a strong signature near the surface, where water density remains rather uniform across the Oyashio Front.

In project 2, using results from a general circulation model developed at JAMSTEC, Qu (Qu, Xie, Mitsudera, and Ishida, *JPO*, submitted) found two peaks in the subduction rate in the North Pacific, which correspond well to the observed mode-water distribution. He suggested that the double-front structure of the Kuroshio–Oyashio system described above is responsible for the occurrence of these subduction peaks. Although eddies do not markedly affect the general subduction pattern, they enhance the subduction rate by up to 100 m yr^{-1} in the formation region of the Subtropical Mode Water (STMW) and Central Mode Water (CMW), a 44% increase over the regional average. Most of the eddy-induced annual subduction rate in the STMW/CMW formation region is due to mesoscale eddies, the small-scale (less than 5 days) eddies generally having little effect.

The results of the project help to understand the interaction between the Subtropical and Subpolar Gyres in the Pacific. They provide useful information for further investigations of those oceanic processes that may be important for Pacific decadal climate variability.

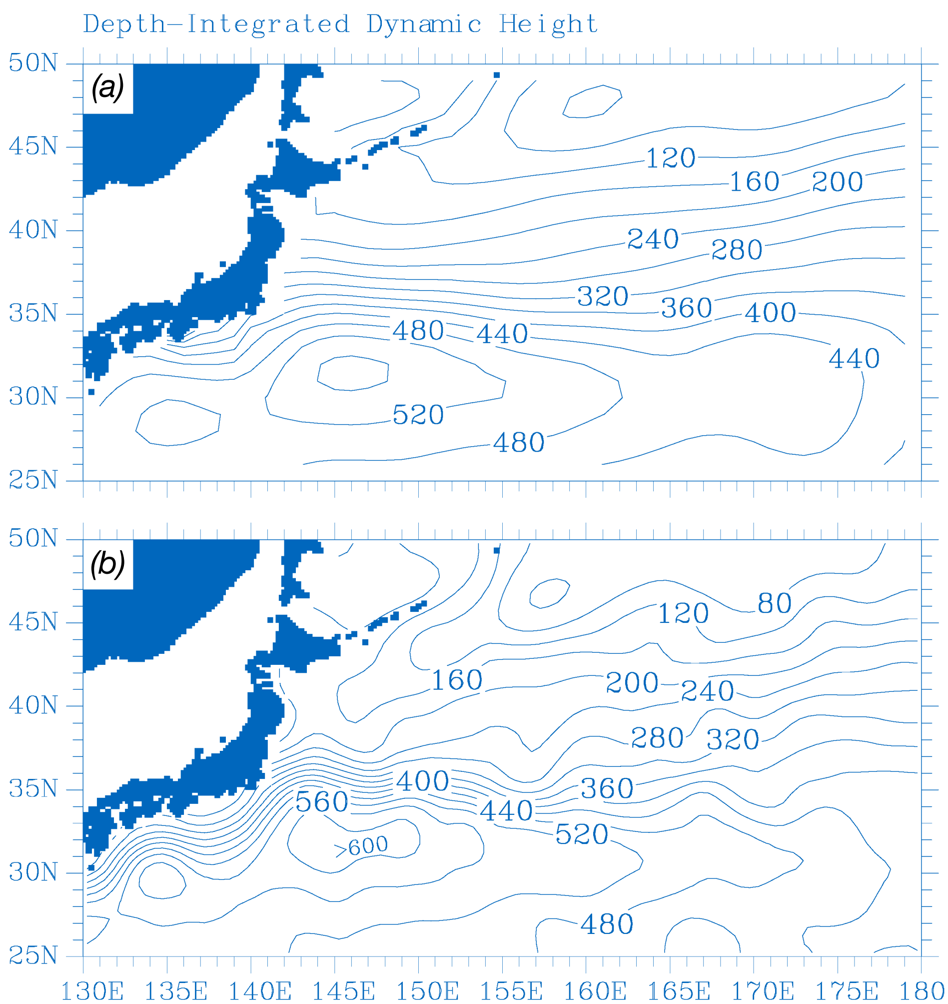


Figure 8. *Comparison of dynamic heights in (a) The World Ocean Atlas 1998, which has a 1°x 1° resolution and is averaged along pressure surfaces; and (b) the new Qu, Mitsudera, and Qiu climatology, which has a 0.5°x 0.5° resolution and is averaged along isopycnal surfaces with 100-km e-folding smoothing scales. The new climatology shows that the Oyashio water reaches as far south as 36–38ºN along the western boundary and Kuroshio Extension water feeds into the Oyashio front in the ocean interior. The zero meridional transport integrated from the western boundary to 180º occurs at about 44ºN, agreeing fairly well with Sverdrup theory predictions. [Represented is the depth-integrated (0–2000 m) dynamic height (m^2) relative to 2000 db. Contour intervals are 40 m^2. The value of 1220 m^2 has been subtracted before plotting.]*

Takuji Waseda

Frontier Research Scientist

Takuji Waseda received his Bachelor of Engineering in ocean engineering and naval architecture from the University of Tokyo, Japan, in 1990. He continued his education at the University of California, Santa Barbara, in the Ocean Engineering Department, from which he obtained his M.S. in 1992 and his Ph.D. in 1997. He joined the IPRC in October 1997 as a Frontier research scientist. His research interests include wind and water waves, satellite oceanography, data assimilation, and ocean processes in the Kuroshio Current.

Takuji Waseda's research focus is on the processes that maintain the Kuroshio-Oyashio Extension system and cause its climatic variability. For this purpose, he is using a regional GCM with a simple data- assimilation scheme to synthesize model and observational data. His research consists, therefore, of two parts: (1) process-study oriented numerical experiments, and (2) assimilation scheme development. For the former, he is collaborating with H. Mitsudera and for the latter with H. Mitsudera, M. Yaremchuk, and L. Jameson (Lawrence Livermore National Laboratory).

In the previous year, Waseda conducted a numerical experiment to simulate the observed interaction between an anticyclonic eddy and the Kuroshio Current, which led to the formation of a short-term Kuroshio Meander (Mitsudera, Waseda, Yoshikawa & Taguchi, *GRL* 2001; Waseda, Mitsudera, Taguchi & Yoshikawa, *JGR*, submitted). The simulation captured the essential processes of the short-term meander observed by the TOPEX altimeter: 1) collision between the westward propagating eddy and the Kuroshio near Kyushu; 2) advection of the eddy by the Kuroshio and meander formation; 3) detachment of the eddy from the Kuroshio; 4) westward propagation of the eddy; and 5) repetition of stages 1–4.

This year, he conducted a detailed analysis of this numerical simulation. The analysis revealed a number of dynamically relevant processes, such as eddy shedding at sharp coastlines, growth of the separation bubble, baroclinic structure dur-

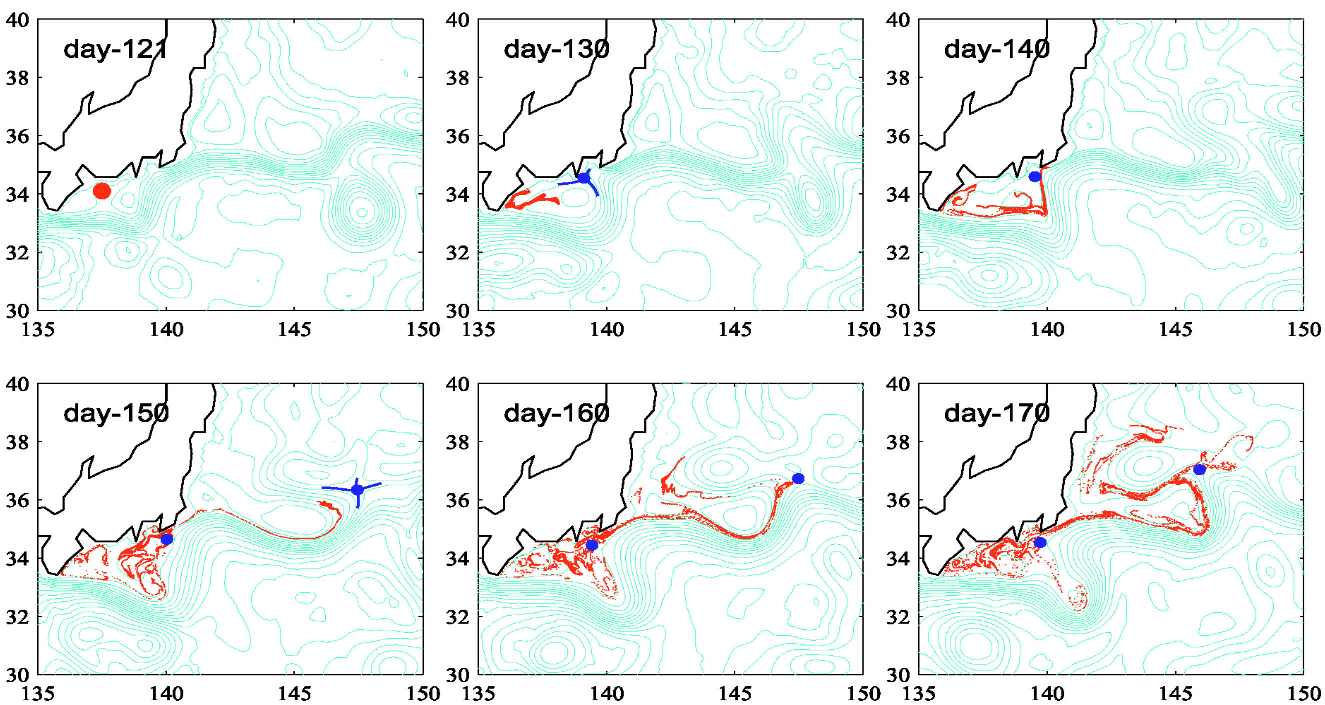


Figure 9. *Results from a numerical model in which ten thousand particles (in red) were released in the Enshu-nada Sea on day 121. They leak from the Enshu-nada Sea separation bubble and are transported northward into the Kuroshio/Oyashio confluence zone by day 170. Possible locations of perturbed hyperbolic points of the geostrophic currents (blue circles) are seen near the Izu Peninsula and at the Kuroshio Extension. As a result of chaotic transport, the particles eventually cross the possible stable and unstable manifolds (blue lines). Examples of manifolds are shown only for days 130 and 150. Sea surface height contours are shown in turquoise with contour intervals of 0.1 m.*

ing anticyclonic eddy-detachment from the Kuroshio, and so forth (see http://www.po.gso.uri.edu/wbc/). As part of the analysis of the dynamics of the short-term meander event, the kinematics of the water parcels were studied, particularly, the evolution of inshore Kuroshio coastal water in the Enshu-nada Sea. Because of the chaotic advection by geostrophic turbulence, Enshu-nada sea water can leak from the separation bubble and flow eastward into the Kuroshio Extension region (see Figure 9, p. 30).

The kinematics of fluid parcels in a turbulent flow can be characterized by a saddle point and its associated stable and unstable manifolds, which separate the flow into distinct regions of fluid motion. Replacing the Hamiltonian function with the stream function, various techniques used in dynamical systems theory can be applied to the analysis of turbulent flows. Similar analyses have recently been applied to oceanographic problems. In the Enshu-nada Sea Water example, Waseda and Mitsudera identified two saddle points in the flow: the first located between the Izu and the Boso Peninsula and the second at the Kuroshio Extension. When the water parcels approach the first saddle point, the parcels in a steady case remain within Enshu-nada Sea. In an unsteady case (the saddle point is perturbed), their direction of motion can shift dramatically and leak into the Kuroshio Extension along the northern edge of the Kuroshio Current. When these parcels later meet the second saddle point, some parcels are carried north into the Kuroshio–Oyashio confluence zone.

Waseda and Mitsudera have made a preliminary assessment of this chaotic transport mechanism as a vehicle for transporting fish eggs and larvae from the Japanese coast into the nutrient-rich Oyashio–Kuroshio confluence region; they are planning further study of this mechanism in collaboration with S. Kimura and T. Sugimoto at the Ocean Research Institute of the University of Tokyo. This chaotic advection mechanism should be significant for the cross-frontal exchange of water masses, as well as for water-mass bifurcation at the western boundary. Development of the necessary tools for such diagnoses is underway.

In order to use the Kuroshio–Oyashio ocean GCM for climate studies, Waseda is working with Jameson and researchers at IPRC to develop a data-assimilation system. They have started to investigate the implementation of the SEEK filter (Singular Evolutive Extended Kalman filter), combining it with the wavelet-error diagnostic scheme developed in previous years (Jameson & Waseda, *JAOT* 2000; Jameson, Waseda and Mitsudera, *JAOT*, submitted). The basic idea is to have the two schemes complement each other in a spectral sense. A preliminary study showed that the eigenmodes to be used in the SEEK filter are, to a good approximation, orthogonal to the wavelet bases of the first few scales (Jameson, Waseda, Mitsudera and Yaremchuk, in preparation). The intent of this assimilation scheme is to have a scheme that other GCMs at IPRC can readily use to assimilate data.

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, where he continued on 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.

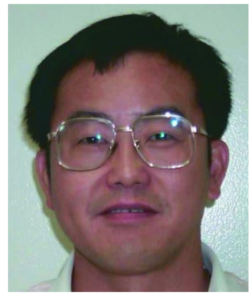
For a major project this year, Max Yaremchuk collaborated with D. Nechaev (Stennis Space Center) and J. Schröter (Alfred Wegener Institute, Germany) on a three-dimensional computation and optimization of a steady-state oceanic circulation. They developed a stabilized finite-element, nonlinear scheme for inverting climatological data. The code uses a residual-free bubble function stabilization technique to override limitations imposed by the Babushka-Brezzi condition on the structure of the functional spaces. They show that the code is highly efficient on parallel machines, flexible in handling variable resolution of the model domain, and suitable for variational assimilation of diverse types of climatological data. The inverse model has been successfully applied to the reconstruction of the steady-state circulation in the Antarctica. A manuscript describing the study has been submitted for publication and is available upon request.

In an inverse modeling project on intra-annual variability in the subtropical North Pacific Ocean, Yaremchuk's and Lebedev's objective was to analyze seasonal variability in the Kuroshio Extension area by means of a four-dimensional variational assimilation of climatological data into a large-scale circulation model controlled by initial and open boundary conditions. They estimated the pathways and production rates of Subtropical Mode Water and Central Mode Water and analyzed the seasonal cycle of the upper-ocean heat balance for the region (see Lebedev's report for details).

In a third study, Yaremchuk has been working with H. Mitsudera, T. Waseda, and L. Jameson (Lawrence Livermore National Laboratory) to improve the SEEK filter technique so that it can be applied to multivariate sequential data assimilation of observations. Yaremchuk has contributed to the modification of the algorithm for estimating the temporal evolution of the covariance matrix to allow for the inclusion of small-scale model states through wavelet analysis, and he has looked at various norms for the truncated EOF decomposition of the model state.

In addition, Yaremchuk is working with H. Mitsudera, and G. Yuan on synthesizing various types of data collected during the Kuroshio Extension Pilot Study (1997) by using a quasi-geostrophic model (QG). Last year the QG model and its adjoint were configured for this purpose, and twin data-assimilation experiments involving simulated acoustic tomography and TOPEX/POSEIDON altimetry data were completed. This year, the effort was extended to real data (including ADCP and CTD measurements).

Yaremchuk has drawn up plans with N. Maximenko to conduct a variational analysis of the Megapolygon data for the Mixed Water Region north of the Kuroshio Extension. The project is aimed at reconstructing a dynamically and statistically consistent pattern of the ocean state north of the Kuroshio Extension for Fall 1987, the time during which a Soviet expedition conducted a multi-ship survey of the region. They intend to combine *in-situ* hydrographic observations and mooring data from the survey with *Geosat* altimetry and wind data, in order to analyze eddy interactions with the large-scale circulation, and the redistribution of energy and potential vorticity by Eliassen-Palm fluxes. This project is scheduled to be completed in 2001–2002, once the *Geosat* data is available.



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 the Japan Marine Science and Technology Center (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.

Gang Yuan, in collaboration with Mitsudera, has been studying variations in the upper-ocean heat budget and vertical velocity structures in the Kuroshio Extension (KE) recirculation region, as well as the interaction between the recirculation gyre and the KE-front meander. For this research, he has used acoustic tomography (AT) data from the Kuroshio Extension Pilot Study in Summer 1997, TOPEX/POSEIDON (T/P) altimeter data, and net surface heat-flux data from the NCEP/NCAR reanalysis. Yuan has also compared results from these three data sets (Yuan et al., in preparation).

To estimate variations in the upper-ocean heat budget accurately from acoustic data, the team developed a new method to calculate temperature changes in the surface and subsurface layers. These temperature changes were captured in a simple two-layer model. During Summer 1997, the heat content in the surface layer (0–100 m) of the east-west path (T1–T3) in the KE recirculation gyre increased, indicating summer surface warming. During this time, there was in the subsurface layer (100–1500 m) a period of mesoscale eddy activity with a cycle of about 40 days and a decrease in heat content. The surface-layer warming determined from tomographic data agrees well with the heat-content change calculated from the NCEP/NCAR heat-flux data. From the simple two-layer model it is clear that horizontal advection must play a role in the recirculation gyre to balance the heat budget.

A comparison among the tomographic measurements, the NCEP/NCAR model reanalysis data, and the T/P altimetry, reveals that the evolution of steric height derived from tomographic data agrees well with that constructed from the NCEP/NCAR reanalysis, both of them increasing by about 5 cm and reflecting summer surface warming. The evolution of the sea surface height (SSH) anomaly from the T/P data shows the same warming trend during that period.

The vertical velocity structure was determined using four vertical modes (barotropic-, mixed-layer-, 1st baroclinic-, and 2nd baroclinic-modes) of the reciprocal acoustic travel times. The range-averaged velocity profile obtained from tomographic data along the path T1–T3 on 15 September 1997, shows mainly a barotropic component with a 4 cm/s westward flow, except in the upper 500 m. A comparison of the evolution of the range-and-depth averaged (barotropic) current velocity derived from tomographic data along the path T1–T3, with the range-averaged surface geostrophic current derived from the T/P altimetry SSH anomaly along the same path, shows that the mean barotropic and geostrophic velocities are almost same—namely, 4 cm/s and 5 cm/s, respectively. These results suggest that the current in the KE recirculation gyre has a strong barotropic rather than baroclinic component.

Yuan conducted also an acoustic tomography (AT) observing system simulation experiment for the Kuroshio Extension Pilot System to optimize the AT-array design for the planned study. He designed the AT array and chose the locations for each pair of transceiver moorings to be deployed (based on the Smith-Sandwell 2-minute digital bathymetric dataset, Sandwell and Smith, 1996) in such a way that the acoustic rays sample the surface layer without interacting with the bottom.

In collaboration with M. Yaremchuk and H. Mitusdera, Yuan assimilated various data sets (satellite altimetry, hydrographic measurements, velocity measurements, and AT data) into a simplified three-dimensional (3-D), steady stationary quasi-geostrophic (QG) model in order to study the dynamics and thermodynamics of the KE front and the recirculation gyre. The initial density field of the model was based on a combination of climatological data and the 3-D density field obtained from the first day of tomographic inversion. Preliminary results show an evolution of the 3-D density field that indicates the presence of a meander at the KE front. The results from this study will be useful for further analysis of the dynamics and thermodynamics in the KE region.

Theme 1-2 Collaboration

Modeling low-latitude western-boundary currents and the Indonesian Throughflow

T. Miyama, T. Jensen, H. Mitsudera, B. Bang and T. Qu

The objective of this collaborative effort is to diagnose the key ocean processes causing seasonal to decadal climate variability in the low-latitude western-boundary currents (LLWBCs) of the Pacific Ocean. The strategy here is to conduct a set of model experiments to develop and test hypotheses of LLWBC dynamics. These model results will be closely compared with analyses of historical observations and *in-situ* and satellite data and with solutions from existing numerical models and data assimilating models.

The regional modeling study of this effort focuses on the Indonesian Throughflow (ITF) and LLWBC using a version of the Princeton Ocean Model (POM). To include non-local effects, the model domain encompasses both the Pacific and the Indian Ocean. The model grid is gradually refined to 1/3° resolution in the equatorial western Pacific and Indonesian Archipelago in order to resolve the LLWBCs. The POM uses a sigma-coordinate system in the vertical with 40 sigma levels to resolve the thermocline as well as the surface and bottom boundary layers in shallow seas and sills.

The results of the salinity and velocity fields on isopycnal surfaces of (a) σ_θ=26.8 and (b) σ_θ=27.2 indicate that the North Equatorial Current shifts northward with depth as shown by Qu et al. (1999). On the σ_θ=26.8 surface, a low salinity tongue from the North Pacific extends toward the equator; on the σ_θ=27.3 surface, a flow along the western boundary carrying Antarctic Intermediate Water intrudes into the North Pacific Ocean. Bifurcation of these water masses considerably affects the composition of the Intermediate Water in the tropics, as suggested in the intermediate-model study of McCreary and Lu (2001). While the ITF is prescribed externally in the McCreary and Lu model, it develops internally in the full prognostic model used here.

Jensen and Miyama are also conducting numerical experiments using layer models to complement the POM. The POM is dynamically more complete than layer models in that it resolves surface and bottom boundary layers, and includes bottom topography and shallow marginal seas; the layer models, on the other hand, allow more numerical experiments and finer horizontal resolution on account of their computational efficiency, and they are easier to analyze. One result from the layer models shows that vertical structures of LLWBCs and equatorial currents in the lower thermocline are sensitive to vertical mixing. Since some of the equatorial currents in our POM model are different from the observed estimates of Qu et al. (1999), the sensitivity of all models to model parameters is currently being investigated.

Research Activities and Accomplishments
Theme 3: Asian-Australian Monsoon System

Overview

The Asian Australian monsoon system (A-AMS) covers a vast region that stretches nearly halfway around the globe, from East Africa and the Indian Ocean to the western Pacific Ocean. It is not surprising that this most energetic component of Earth's climate system is increasingly found to have a powerful effect on global climate. Variations in this monsoon system affect the economy, and therefore the well-being of millions of people from Africa to China, and perhaps even North America. Records show that the monsoon over this region varies considerably, not only during the course of a single season, but from one year to the next, and from one decade to the next. The primary goal of Theme-3 research is to understand the physical mechanisms responsible for climate variations in the monsoon on seasonal-to-interdecadal timescales.

The first objective under this theme is to describe and understand the annual cycle of the monsoon and its intraseasonal variability. Much work has been conducted this past year at the IPRC on this topic. Fundamental to such a description is how to quantify the monsoon over the vast regions that it affects. The two major heat sources known to fuel the Asian monsoon system—convection over the Bay of Bengal and convection over the Philippine Sea—have been studied. The former drives mostly the Indian (or South Asian) monsoon; and the latter, mostly the western North Pacific–East Asian (WNP–EA) monsoon. Two circulation indexes have been developed for measuring the variability in these two monsoon subsystems (B. Wang). Unique to the western North Pacific monsoon is the northeastward progression of the monsoon convection, which occurs mainly in mid-June and late July. An air-sea interaction mechanism, supported by observations, has been proposed to explain this unique feature (Wu and B. Wang). Furthermore, the northward propagation of convection associated with boreal summer intraseasonal oscillations has been studied with a principal oscillation pattern (POP) analysis (Annamalai and B. Wang). Decadal variations in the strength of tropical intraseasonal oscillations were examined using low-level wind and precipitable water fields (Zveryaev). Analysis of a 300-year baseline run showed that the NCAR Climate System Model (CSM) is capable of simulating the climatological seasonal evolution of precipitation, SST, and surface winds from boreal summer to winter monsoons (Loschnigg).

Several studies have investigated how the monsoon varies over years and over decades, which is the topic of the second objective under Theme 3. Using 50-year NCEP/NCAR reanalysis data, B. Wang and his colleagues revealed that at interannual timescales the South Asian and WNP–EA summer monsoons differ remarkably in their spatial-temporal structures, relationships to ENSO, and teleconnections with the midlatitudes. A study of the relationship between the South Asian monsoon and the Australian monsoon (Li, Zhang, and B. Wang) showed that remote ENSO forcing and local SST anomalies associated with the tropospheric biennial oscillation (TBO) are both important for the phase persistence of anomalous convection from India during boreal summer to northern Australia during boreal winter. Moreover, the processes that determine the interannual variability of the monsoon onset over Indochina were investigated (Zhang, Li, and B. Wang). An anomalous low-level anticyclone over the Philippine Sea was proposed as the teleconnection mechanism by which the impact of El Niño is conveyed to East Asia (B. Wang, Wu, and Fu). This anticyclonic anomaly develops rapidly in the fall before the mature phase of El Niño and persists until the ensuing summer, thus strengthening the western Pacific Subtropical Ridge and causing abundant Meiyu-Baiu precipitation during the following summer. The decadal variability in tropical and North Pacific SSTs has also been analyzed (An, Tomita). Finally, a review of major current TBO theories, including a description of major similarities and differences among them, has been completed (Li, B. Wang, and Chang).

Two major advances have occurred under the third objective, the predictability of the monsoon by using global and regional atmospheric and oceanic models. First a coupled global atmosphere-ocean GCM has been developed (Li). The atmospheric component of this coupled GCM is the ECHAM4 model and the oceanic component is the Modular Ocean Model 2 (MOM2). Long-term simulations by this coupled GCM show that in the tropical Pacific it can reproduce ENSO-like interannual variability with realistic amplitude, structure, and phase. An Indian Ocean dipole that is independent of the Pacific ENSO is also simulated by the coupled GCM. The effect of air-sea coupling on the mean summer monsoon rainfall was investigated using a hybrid coupled GCM in which the ECHAM4 model was coupled to an intermediate 2.5-layer ocean model (Fu, B. Wang, and Li). The second major advance under this objective is the development of the first version of the IPRC Regional Climate Model (IPRC–RegCM V1.0; Y. Wang, Sen). This regional model includes a sophisticated radiation package developed by Edward and Slingo (1996) and the Biosphere-Atmosphere Transfer Scheme (BATS) land-surface model. It successfully simulated the 1998 monsoon onset and precipitation in East Asia, as well as the flow patterns over the region.

Individual Reports

Soon-Il An

Assistant Researcher

Soon-Il An obtained his Ph.D. in atmospheric sciences in 1996 from Seoul National University in 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 simple and intermediate air-sea coupled modeling.

This past year, Soon-Il An focused on understanding the interdecadal modulation of the El Niño–Southern Oscillation (ENSO), the role of thermocline and advective feedback in ENSO, and the mechanism underlying the pentadecadal oscillation in the North Pacific.

To understand the interdecadal modulation underlying long-term changes in ENSO, An together with B. Wang analyzed several data sets of observations. They found that after the Pacific decadal climate shift in the middle 1970s, the period between warm and cold SST states grew longer, the SST differences between these two states grew larger, and the region of maximum SST variability shifted eastward. Such changes in the ENSO properties coincided with significant changes in the background surface winds and SST. Using the coupled atmosphere-ocean model of Cane and Zebiak, they demonstrated that the changes in the background surface winds associated with the Pacific climate shift could qualitatively reproduce the observed changes of the aforementioned ENSO properties, namely, the decrease in zonal gradient of mean SST in the central Pacific and the increase in mean upwelling in the eastern Pacific. The latter increased the importance of vertical temperature advection; the former decreased the importance zonal temperature advection. As a result, the prevailing westward propagation of the SST anomaly was replaced by a stationary oscillation or an eastward propagation. The changes in the winds also affected the structure of the coupled mode by shifting the anomalous atmospheric heating and zonal SST gradients eastward along the equator. An and Wang developed a conceptual model to illustrate that the eastward displacement of the equatorial westerly anomalies prolongs the oscillation period and amplifies the ENSO cycle by enhancing the growth rate of the coupled anomaly and by delaying the transition from one state to the other state (Wang and An, *GRL*, submitted; Wang and An, *Clim. Dyn.*, submitted).

In another study, An investigated further the role of thermocline feedback (vertical advection of anomalous subsurface temperature by mean upwelling) and advective feedback (zonal advection of mean SST by an anomalous current) in ENSO. With a recharge oscillator model that captures the Cane-Zebiak model physics, he demonstrated that these two feedbacks together contribute to the growth and phase transition of ENSO, but they have different effects depending upon which mode leads: the thermocline feedback brings about a coupled mode by merging the damped SST mode and the ocean adjustment mode, whereas the zonal advective feedback tends to destabilize the gravest ocean basin mode. For each feedback, the leading mode in the coupled model can be traced back to its origin by making moderate changes in the model set-up. These results suggest that the growth rate and period of ENSO are sensitive to slight changes in basic-state parameters that control the strength of these feedbacks (An and Jin, *J. Climate*, in press).

An also studied the mechanism underlying climate oscillations in the North Pacific that have periods on the order of 50 years. Using a simple air-sea coupled model, he found that the slow dynamic adjustment produced by oceanic Rossby waves is insufficient to explain the length of the oscillation periods. The model showed that the slow adjustment of the North Pacific Ocean combined with north-south heat exchange through air-sea coupling can bring about such pentadecadal oscillations (An and Jin, *GRL*, to be 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 postdoctoral 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 (ASM) system, prediction and predictability of the ASM and the tropical climate system, the dynamical and physical links between the monsoon and ENSO, and the role of the Indian Ocean in the ASM.

Annamalai has been studying aspects of the summer monsoon over India and Asia. In one study (with W. White, Scripps Institution of Oceanography; and Y. Tourre, International Research Institute for Climate Prediction), he looked at the relationship between the all-India summer monsoon rainfall (AIR) index and eastward propagating waves of covarying SST and sea-level pressure (SLP) anomalies that circle the globe. These SST/SLP anomaly waves show interannual and biennial cycles for the analyzed years 1900 to 1995. The team constructed a statistical climate prediction system based on the association between these anomalies and the AIR index from 1950 to 1995. They noted that for both cycles, AIR correlates best with the SST/SLP anomalies as they slowly pass across the Arabian Sea and the Bay of Bengal. During the anomalies slow eastward passage across the western and central tropical Pacific Ocean, the predictability of AIR rises intermittently in association with ENSO events. Using the predictability of the AIR index based on the biennial and interannual cycles of the anomalies, together with persistence on decadal-interdecadal timescales, Annamalai and his colleagues hindcast the original AIR index over a 45-year time-span. At a 12-month-lead time, the hindcasts accounted for 58% of the original AIR index, and rose to 72% for summer monsoon seasons exceeding one standard deviation in rainfall. (White, Annamalai and Tourre, *J. Climate*, submitted/revised).

In collaboration with B. Wang, Annamalai has extended an earlier study (Annamalai and Slingo, 2001, *Clim. Dyn.*, in press) in order to understand better the physics of the intraseasonal variability in the Asian summer monsoon. Using NCEP/NCAR reanalyses (1958–97) products together with independently observed data, they studied the role of low-frequency processes during northern summer in the year-to-year variability of high-frequency intraseasonal oscillations or ISOs. Based on the number of poleward propagating 20-to-60-day events derived from Hovmoller diagrams and Principal Oscillation Pattern (POP) analysis, they identified a stationary/quasi-stationary (33% of the years) mode and an oscillatory mode (67% of the years). The seasonal mean composites reveal two patterns. The first pattern occurs when the eastern equatorial Indian Ocean is colder than normal and associated with strong subsidence (see Figure 10a). These conditions suppress the seasonal-mean convection over the equatorial Indian Ocean, producing the *quasi-stationary* behavior of 20-to-60-day events and resulting in low-level twin anticyclones on either side of the equator as a Rossby-wave response. The northern anticyclone strengthens the low-level westerlies (and the upper-level easterlies). The greater easterly shear and accompanying baroclinicity favor westward propagation, stronger 10-to-20-day events, and synoptic systems. During El Niño years, this circulation over the Indian Ocean offsets El Niño suppression of the South Asian monsoon; during La Niña years, it strengthens the South Asian monsoon. The second pattern occurs when the equatorial Indian Ocean and the seasonal mean convection are above normal, resulting in *oscillatory* behavior of the 20-to-60-day events. The effects of this second pattern during El Niño and La Niña conditions in the Pacific are shown in Figure 10b and c. Since these two patterns occur regardless of Pacific Ocean conditions, the findings suggest that SST and the atmospheric circulation over the eastern Indian Ocean affect the variability of the ISOs during the summer monsoon and that ENSO variability is not the primary controlling factor (Annamalai and Wang, *J. Clim.*, submitted).

To provide further support for the above findings, Annamalai used the ECHAM4 model to carry out a six-member ensemble of idealized integrations with four different SST-anomaly patterns. He used the outputs of a 17-year model run with climatological, seasonally varying SST as a control run. From these ensemble runs, he diagnosed the propagation of the ISOs. Both observations and model outputs show that changes in the large-scale mean conditions over the monsoon region, caused by SST variations in either the ENSO region or in the Indian Ocean, significantly affect the statistical properties of the various ISOs. Annamalai is now confirming these experiments with the COLA AGCM.

Currently Annamalai (with R. Murtugudde) is examining the physical mechanism by which the monsoon and ENSO influence SST anomalies over the Indian Ocean. They are using the 40-year NCEP/NCAR reanalysis products and the heat-content anomalies from Carton's Simple Ocean Data Assimilation for this study.

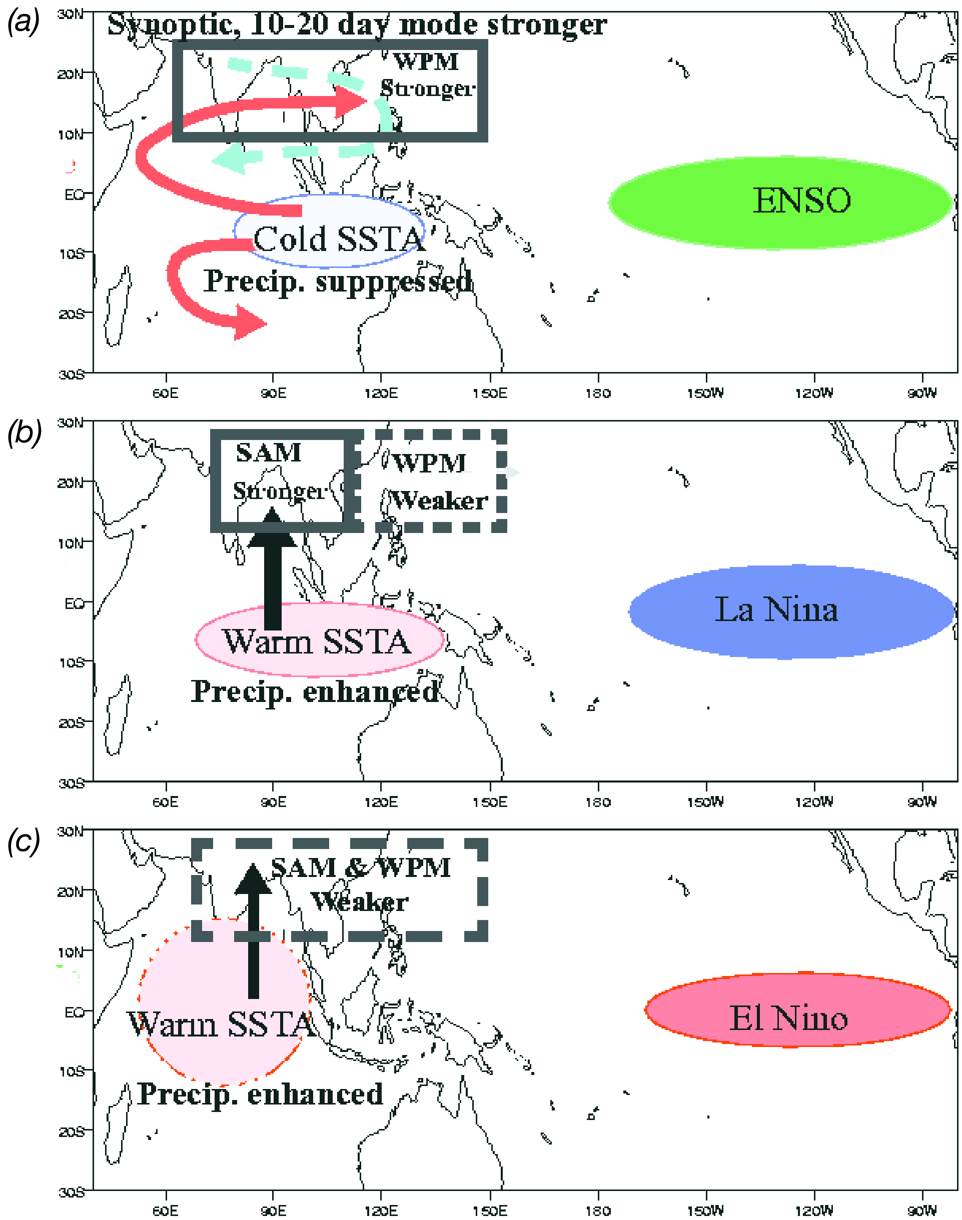


Figure 10. *Patterns of low-frequency circulation effects on high-frequency ISOs over the Asian Monsoon region during boreal summer as derived from summer mean composites. The effects of Pattern 1, that is, cold SST anomalies over the eastern equatorial Indian Ocean (EEIO) and either El Niño or La Niña conditions in the Pacific, are shown in diagram (a). The red arrows represent the low-level (850 hPa) winds and the turquois arrow the upper level (200 hPa) winds. The Western Pacific Monsoon (WPM) is strengthened, while precipitation in the EEIO is suppressed. The synoptic system and the 10-to-20-day ISOs dominate. The effects of Pattern 2, that is, warm SST anomalies over the EEIO are shown in diagrams (b) and (c). La Niña conditions (b) are accompanied by a stronger South Asian Monsoon (SAM), weaker Western Pacific Monsoon (WPM), increased precipitation over the EEIO, and more intense 20-to-60-day ISOs (thick arrow). El Niño conditions (c) are accompanied by basin-wide warming over the Indian Ocean, weaker SAM and WPM, and weaker 20-to-60-day ISOs (thin arrow).*

Tim Li

Associate Professor of Meteorology, SOEST
Theme 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 participated this past year in research projects on the following topics: (1) mechanisms that determine the South Asian monsoon variability on biennial and low-frequency time scales; (2) the interannual relationship between phases of the South Asian and Australian monsoon; (3) dynamics of the Indian Ocean dipole; (4) processes responsible for the monsoon onset over Indochina and its interannual variability; (5) review of current Tropospheric Biennial Oscillation (TBO) theories; (6) thermodynamic regulation of SST over the South China Sea; (7) response of western and eastern maritime continent convection to ENSO; and (8) development and long-term simulation of a coupled atmosphere-ocean GCM.

Indian Ocean SST has been thought to play a lesser role in Indian summer monsoon rainfall than equatorial eastern Pacific SST. Li et al. (*GRL*, 2001) show that on the TBO (2-to-3-year) timescale the Indian monsoon rainfall has a significant positive correlation with Indian Ocean SST and moisture-flux transport during the preceding winter and spring. Processes by which Indian Ocean SST affects Indian monsoon rainfall are quite different from the remote forcing of the eastern Pacific SST, which dominates on a 3-to-7-year timescale. The authors conclude that, although the eastern Pacific SST and the Eurasian land temperature both affect the monsoon on the low-frequency, 3-to-7-year timescale, they are unimportant on the TBO timescale. These results support the tropical and local feedback theories (Chang and Li 2000; Nichols 1984), which suggest that the TBO, the most important component of monsoon variability, is largely influenced by Indian Ocean SST and interactions within the tropical atmosphere-ocean system. The lag relationship between the monsoon and Indian Ocean SST is more useful for prediction than the simultaneous correlation between the monsoon and eastern Pacific SST.

Li and his colleagues constructed a simple coupled atmosphere-ocean-land model to study the processes responsible for the Indian Ocean dipole (IOD). The model contains six boxes that represent the equatorial western and eastern Indian Ocean, the western Pacific/Maritime Continent, the equatorial eastern Pacific, the South Asian monsoon region, and the northwest Pacific monsoon region. Key processes represented in the model are cloud-radiation-SST feedback, remote and local monsoon impacts on the IOD, evaporation-wind-SST feedback, and the effect of equatorial ocean waves and ocean thermocline displacement. Li et al. (manuscript in preparation) propose a coupled ocean-atmosphere instability in the eastern equatorial Indian Ocean, which arises from the atmospheric anticyclonic circulation Rossby-wave response to a cold SST anomaly and the Rossby-wave interaction with the mean flow. The phase-locking feature of the IOD is well explained by this seasonally dependent positive feedback mechanism. This simple coupled model is capable of simulating the preferred biennial tendency of IOD as well as IOD events associated with ENSO when forced by observed SST anomalies in the eastern equatorial Pacific (Li et al., manuscript in preparation).

The major similarities and differences among current TBO theories have been reviewed by Li et al. (2001). In addition, Li has collaborated on the following climate research projects. In a study with Y. Zhang and B. Wang, he examined the phase relationship between the Asian and Australian monsoon on interannual timescales. Another study investigated why the Asian-Pacific monsoon starts in Indochina and what regulates the interannual variability of its onset (Zhang et al., submitted). He participated in projects on annual and interannual SST changes in the South China Sea (Chen et al. 2001, manuscript in preparation) and interdecadal changes in the relationship between east/west maritime continent rainfall and NINO3-SST anomalies (Chang et al. 2001, manuscript in preparation). Li has also coupled the ECHAM4 atmospheric model to the Modular Ocean Model (MOM 2.0). No heat-flux correction is included. A 100-year simulation showed that this model is able to simulate ENSO-like interannual variability in the tropical Pacific and a dipole structure in the equatorial Indian Ocean. The Indian Ocean dipole simulated by the model seems independent of the eastern Pacific SST anomalies. The physical mechanisms that give rise to the dipole in the model are currently under investigation.

In collaborative work with X. Fu, Li coupled the ECHAM4 model with the Wang-Li-Fu's ocean model (Wang, Li, and Chang 1995, *JPO*; Fu and Wang 2001, *J.Clim.*). Coupling results in more realistic monsoon precipitation than solutions with the ECHAM4 alone and shows two zonal rain belts similar to observed rainfall distributions: the stronger monsoon rain belt near 15ºN and the weaker equatorial Indian Ocean rain belt (see Figure 11). Improved results come from local air-sea interactions (produced by changes in shortwave radiation and latent heat flux in the equatorial Indian Ocean) and remote effects, namely, changes in the Walker circulation in the Indian and western Pacific Oceans.

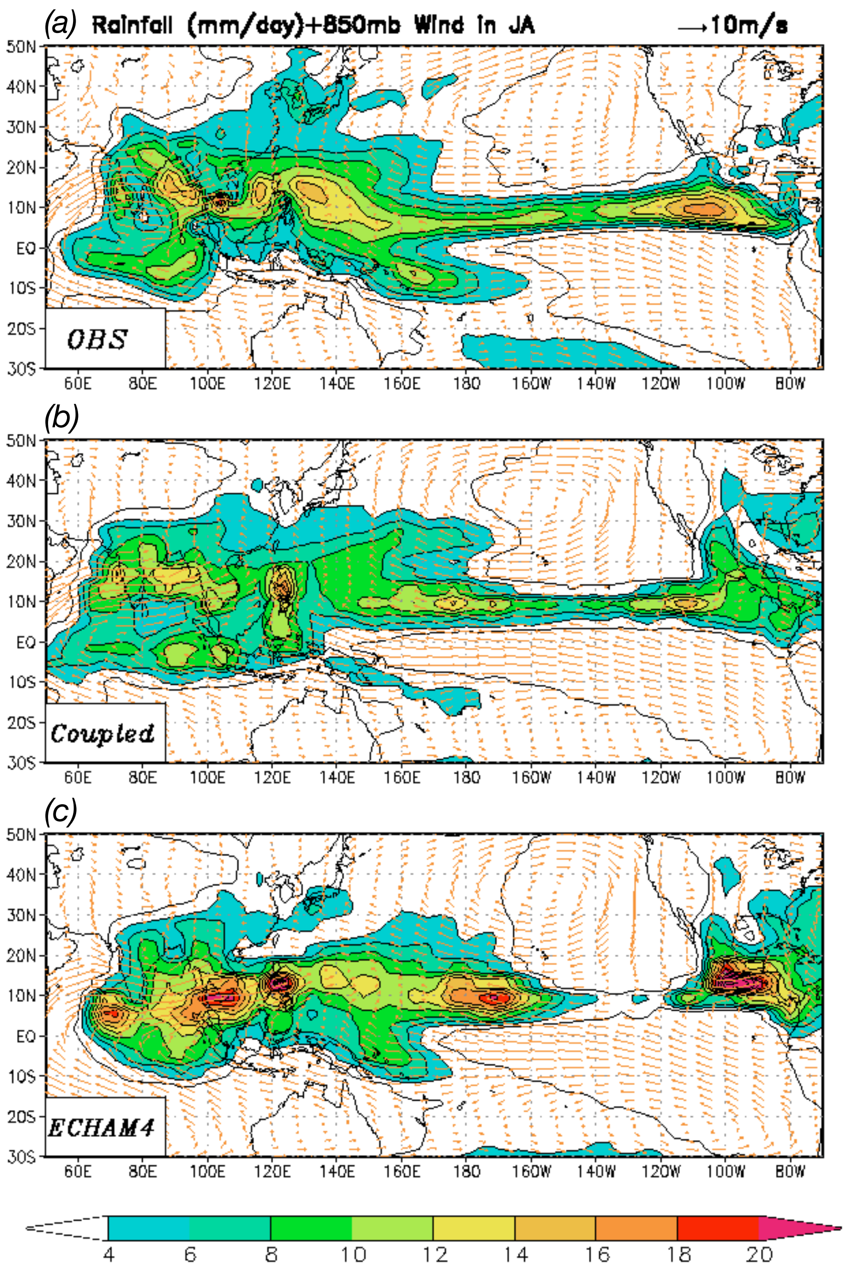


Figure 11. *A comparison of July-August rainfall rates in mm/day and 850-hpa wind vectors among (a) observations (CMAP rainfall and ECMWF winds), (b) solutions from the ECHAM4 atmospheric GCM coupled with the Wang-Li-Fu upper-ocean model, and (c) solutions from the stand-alone ECHAM4 atmospheric GCM.*

Omer L. Sen

Postdoctoral Fellow

Omer Sen received his Ph.D. in hydrology from the University of Arizona in Tucson, Arizona, in 2000. As a postdoctoral fellow at the IPRC, he is applying his knowledge of land-surface modeling to the IPRC modeling effort. His research interests include land-surface atmosphere interactions, hydrometeorological modeling, evaluation of model performance using multi-criteria optimization techniques, and remote sensing in hydrometeorology.

It has become widely accepted in recent years that land-surface processes and their modeling are important, not only in large-scale atmospheric models and GCMs but also in regional and mesoscale atmospheric models (e.g., Chen and Dudhia 2000; Leung et al. 1999; Gong et al. 1999). Mesoscale models, therefore, need to include an advanced and robust land-surface model (LSM) in order to initialize properly the state of the ground during a data-assimilation period and to capture subsequently those mesoscale structures in the free atmosphere and Planetary Boundary Layer that have been forced by the ground surface.

Omer Sen's research at the IPRC has centered on implementing an advanced LSM into IPRC's Regional Climate Model (IPRC–Reg CM; see Y. Wang's report) and on investigating aspects of the land-atmosphere interactions in the Asian-Australian monsoon system through model simulations. His review of the literature revealed that several different LSMs have been used in regional and mesoscale atmospheric models and have improved the representation of land surface–atmosphere interactions in climate simulations. For instance, Chen and Dudhia (2000) included the Ohio State University–LSM (OSU–LSM) in the PSU/NCAR's (Penn State University/ National Center for Atmospheric Research) MM5 modeling system and conducted sensitivity experiments. Gong et al. (1999) studied the effects of land surface-atmosphere interaction on the East-Asia summer monsoon by using a more realistic vegetation-soil scheme, the Simplified Simple Biosphere model (SSiB), in the State University of New York at Albany's regional climate model. The regional climate model of Pacific Northwest National Lab and that of NCAR both include the Biosphere-Atmosphere Transfer Scheme (BATS) as a land surface model. The latter two climate models have been used in several case studies including the study of the 1991-summer severe flood in Yangtze-Huai River in China (Leung et al. 1999). Although the three land surface models (OSU–LSM, SSiB, and BATS) differ in complexity, they have been successfully implemented and used in the above regional and mesoscale atmospheric models.

Although BATS is more complicated than many other LSMs, including the OSU–LSM and SSiB mentioned above, Sen preferred to use BATS for the IPRC–RegCM because of his substantial experience with this widely used, well-documented land-surface scheme. He uncoupled a vector-based version of BATS from NCAR's Community Climate Model—a vector-based version in a regional climate model allows parallel computing machine use and is therefore more efficient—and implemented it into the IPRC–RegCM. At the lower boundary in the IPRC–RegCM, BATS receives incoming shortwave and longwave radiations, air temperature, specific humidity, wind speed, pressure and precipitation as inputs from the model; in turn, it provides the model with the surface temperature, albedo, longwave upward radiation, and latent and sensible heat fluxes. In addition to being properly coupled with the regional climate model, BATS required for each grid-cell the specification of one of the 18 land-cover types, one of the 12 soil types, and one of the 8 soil-color types that it recognizes. Fortunately, such high-resolution data are becoming more readily available from global remote sensing satellites.

For land-cover classification, Sen is using the USGS's (U.S. Geological Survey) 1-km resolution BATS land-cover classification data. When the horizontal grid-increment of the regional climate model is larger than one km, he represents the "grid-level" vegetation characteristics with the dominant vegetation type in each grid box. Soil-texture classification data have been obtained from U.S. Department of Agriculture's (USDA) global 10-km soil data. For soil-color classification, he is currently using downscaled data from a lower resolution dataset. The coupled model has been run for different domains over the Asian Monsoon region. These simulations show that BATS is able to provide realistic temporal and spatial variations in surface variables as boundary conditions for the regional climate model. See, for instance, Figure 15, p. 47, for diurnal variation of air temperature, and Figure 13, p. 46, for spatial variation in monthly mean (May 1998) soil moisture, skin temperature, latent heat flux and sensible heat flux over East Asia from a model integration of the 1998 East Asia monsoon period. Having successfully implemented BATS, Sen is planning to use the coupled model to perform sensitivity experiments to investigate the role of land-surface atmosphere interactions in the hydrological cycle of the Asian monsoon.

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. He rejoined Frontier Research System for Global Change in Japan at the end of March 2001.

To investigate how climate varies in the Pacific over decades, the link between sea surface and subsurface variability must be understood, particularly the effects of ocean dynamics on SST. Only the ocean can store temperature signals over such long periods.

A center of significant decadal SST variability is observed in the Pacific along the subarctic frontal zone at 42°N near the date line. To investigate the cause of decadal variability during boreal winter in this region, Tomohiko Tomita, together with S.-P. Xie and M. Nonaka, developed a tendency equation for low-frequency SST winter variability with which they analyzed long-term observations of the ocean and atmosphere, as well as the output from an ocean GCM. They found that the relative importance of atmospheric surface forcing (heat flux and Ekman advection) and subsurface ocean dynamics is different for decadal SST variations in the northern (38°– 45°N) and in the southern (31°–38°N) midlatitude North Pacific. At northern latitudes, large-scale ocean-gyre circulation, through advection remotely forced by Rossby waves, is a major cause of these SST variations, the effect being comparable in magnitude to surface heat-flux forcing. The resulting upper-ocean temperature anomalies are vertically in phase. At southern latitudes, wind-induced surface heat-flux forcing is a main cause of decadal SST variations; ocean dynamics, on the other hand, tend to counteract this forcing. Hence, large temperature anomalies are confined near the surface, within the winter mixed layer, whereas anomalies below the surface are weak or even of opposite sign. The observed spatial pattern of decadal SST variation reflects the spatial distribution of such surface and subsurface effects. In particular, ocean dynamics seem responsible for a local maximum of decadal SST variation near the date line, 42°N. (Tomita, Xie, and Nonaka, *J. of Clim.*, submitted).

In a study of intraseasonal oscillations (ISO) in the region of the Asian summer monsoon, Tomita and his colleagues compared the development of ISOs in 1979 with those in 1993. There is a distinct difference in the length of the dominant ISO period between these two years: In ‘79 the dominant period with ISOs was 45 days, in ‘93, it was 25 days; furthermore, the ISO-period in ‘79 was characterized by large-scale systematic oscillations that extended from the Arabian Sea to the tropical western Pacific. The oscillations from the northern Arabian Sea to the equatorial western Pacific were in phase and propagated northward as well as eastward. Their speed of eastward propagation was about 8° per day along the equator, which corresponds to the speed of an atmospheric Kelvin wave, as found in previous research. In ’93, the ISO-propagation proceeded differently. The ISOs from the Arabian Sea and the Bay of Bengal propagated mostly northward, whereas the ISOs from the South China Sea to the tropical western Pacific region propagated mainly westward in the 10°–20°N latitudinal belt. The hybrid air-sea coupled model (Wang and Xie, 1997) reproduced a similar spatial pattern. Tomita also explored the physical mechanisms of the ISOs and their differences for ‘79 and ‘93 and compared them with other ISO events. (These findings were published in the Spring 2000 Meeting of Meteorological Society of Japan.)

Bin Wang

Professor of Meteorology, SOEST
Theme 3 Co-Leader

Bin Wang obtained his Ph.D. in geophysical fluid dynamics from The Florida State University in 1984. In 1987, he came to the University of Hawai'i at Mānoa as assistant professor of meteorology and was promoted to full professor in 1992. He joined the IPRC in January 1999. His research interests include the variability and predictability of the Asian-Australian monsoon system from intraseasonal-to-interdecadal timescales, dynamics of the El Niño and the Southern Oscillation and the Intertropical Convergence Zone, and large-scale ocean-atmosphere interaction in the coupled ocean-atmosphere-land system.

Bin Wang conducted several projects on the Asian monsoon this past year. The first is a study of the East Asian Meiyu–Baiu monsoon. The Meiyu–Baiu front is a major rain-producing system in East Asia during summer and, for more than a decade, scientists have recognized that Meiyu rainfall is significantly greater in a summer after an El Niño. The devastating Yangtze River flood in Summer 1998 that followed on the heels of the '97 El Niño is such an example. El Niño episodes, however, mature usually in boreal winter, and by the next summer the warming in the equatorial central–eastern Pacific has disappeared. How then does El Niño have its "delayed" influence on the East Asian summer monsoon (EASM)? Which physical processes link El Niño to the EASM is a fundamental scientific question that has puzzled meteorologists for years. Wang and his collaborators (Wang, Wu, and Fu 2000, *J.Clim.*) have discovered that the link is an anomalous low-level anticyclone located over the Philippine Sea (hereafter PSAC). The PSAC develops rapidly in the fall before the height of El Niño and persists until the ensuing summer, causing the abundant precipitation in the lower reach of the Yangtze River Valley. Given the chaotic nature of atmospheric motion and the decaying remote forcing by El Niño, what mechanisms sustain the PSAC for three seasons? Wang, Wu, and Fu (2000) have put forth a theory that attributes the development and persistence of the PSAC to positive thermodynamic feedback between atmospheric Rossby waves and the underlying

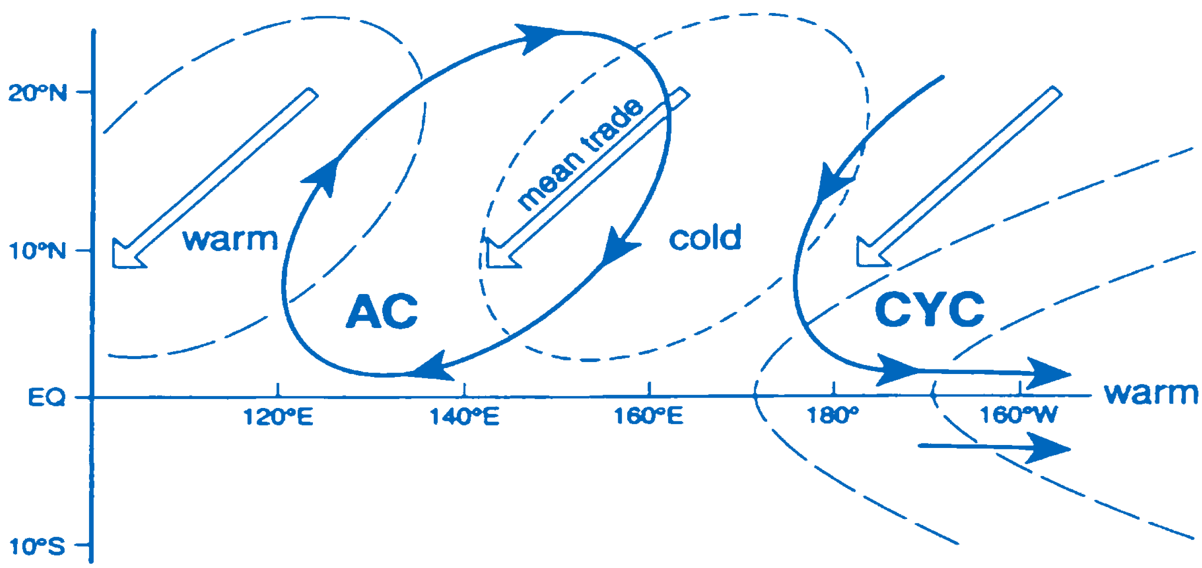


Figure 12. *The schematic shows how* atmospheric Rossby wave-ocean interaction *in the western North Pacific (WNP) maintains the Philippine Sea anticyclone (PSAC) anomaly and associated negative WNP SST anomaly. The open arrows denote the mean trade winds and the heavy lines with black arrows, the anomalous winds. The long (short) dashed lines indicate the contours of positive (negative) SST anomalies. In the presence of the mean northeasterly trades, the ocean to the east of the PSAC cools as a result of enhanced total wind speed that induces excessive evaporation and entrainment. The cooling, in turn, suppresses convection and reduces latent heating in the atmosphere, which excites descending Rossby waves that propagate westward and reinforce the PSAC. Through this mechanism, El Niño impacts the East Asian summer monsoon rainfall two to three seasons after its mature phase.*

warm-pool ocean. This *positive* atmospheric *Rossby wave–ocean* feedback mechanism is briefly explained in Figure 12, p. 44, and its caption.

An important issue in Asian monsoon research is how to quantify its low-frequency variations. Variability of the Asian summer monsoon has been measured by a single parameter, the Webster and Young index. Wang and Fan (1999) discovered that on interannual timescales the two major heat sources that drive the entire Asian summer monsoon—convection over the Bay of Bengal and over the Philippine Sea—vary independently; moreover, convection over the former primarily drives the Indian (or South Asian) monsoon, whereas convection over the latter primarily drives the western Pacific–East Asian (WP–EA) monsoon. Using 50-year NCEP/NCAR reanalysis data, they also found that the interannual variations in the South Asian and the WP–EA summer monsoons differ remarkably in their spatial-temporal structures, their relationships with ENSO, and their teleconnections with midlatitudes. Wang attributes these differences to differences in the two regions' land-ocean configurations, the monsoon-ENSO relations, and local air-sea interactions. Wang and Fang, therefore, proposed two separate circulation indexes for measuring the variability of each monsoon subsystem.

In a further study of the WP–EA summer monsoon, B. Wang, Wu, and Lau (*J. Clim.*, in press) discovered a statistically significant positive correlation between the WP–EA monsoon index and the summer-rainfall index over the North American Great Plains. A suppressed monsoon over the western North Pacific is related to less summer rainfall over the Great Plains. The correlation coefficient in July exceeds 0.6 for the period 1948–1998. Wang proposes that this boreal summer, western North Pacific–North American teleconnection is established through an atmospheric wave train emanating from the Philippine Sea and reaching North America by arching over the North Pacific. Wang and his colleagues have reproduced this teleconnection in ensemble integrations with the ECHAM4 atmospheric GCM, and they are now investigating its dynamics.

With Soon-Il An, B. Wang has conducted research on the question why several properties of El Niño changed in a coherent manner during the 1970s and why these changes concurred with the Pacific decadal climate shift. (For details, see Soon-Il An's report).

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 ocean, the development of high-resolution regional atmospheric models, and numerical modeling of the atmosphere and the ocean.

Over the past year, Yuqing Wang has successfully developed Version 1 of the IPRC Regional Climate Model (IPRC–RegCM V1.0). In particular, he has modified the mesoscale tropical cyclone model he developed previously (Wang 1999; Wang, *Mon. Wea. Rev.*, in press), making it suitable for regional climate research. With the help of Zhian Sun (Bureau of Meteorology Research Centre, Australia), he incorporated a sophisticated radiation package developed by Edward and Slingo (1996) into the model. The package uses explicit cloud microphysics information and accurately models cloud-radiation forcing and radiative flux at Earth's surface. With Omer Sen (see Sen's report), he then incorporated the Biosphere-Atmosphere Transfer Scheme (BATS), a land-surface model, into the regional climate model (see Figure 13). A major part of this effort was the development of an efficient and conservative coupling technique to couple BATS with the regional atmospheric model.

The IPRC–RegCM uses NCEP/NCAR reanalysis data for initial and lateral boundary conditions, and observed SST as the lower boundary condition over the ocean. Using 8 CPUs on the IPRC-Cray SV-1 standard setting, the model can run a monthly simulation of a region covering 201 by 161 grid points at a resolution of 0.25 degrees (0°–40°N, 100°E–150°E) in two days. The model successfully simulated the 1998 monsoon onset over the South China Sea and the associated precipitation in East Asia by realistically simulating the average daily rainfall in May 1998 (compare observations, Figure 14a, with simulation results, Figure 14b). In fact, the comparison with rainfall data from CMAP for the

Continued on page 48

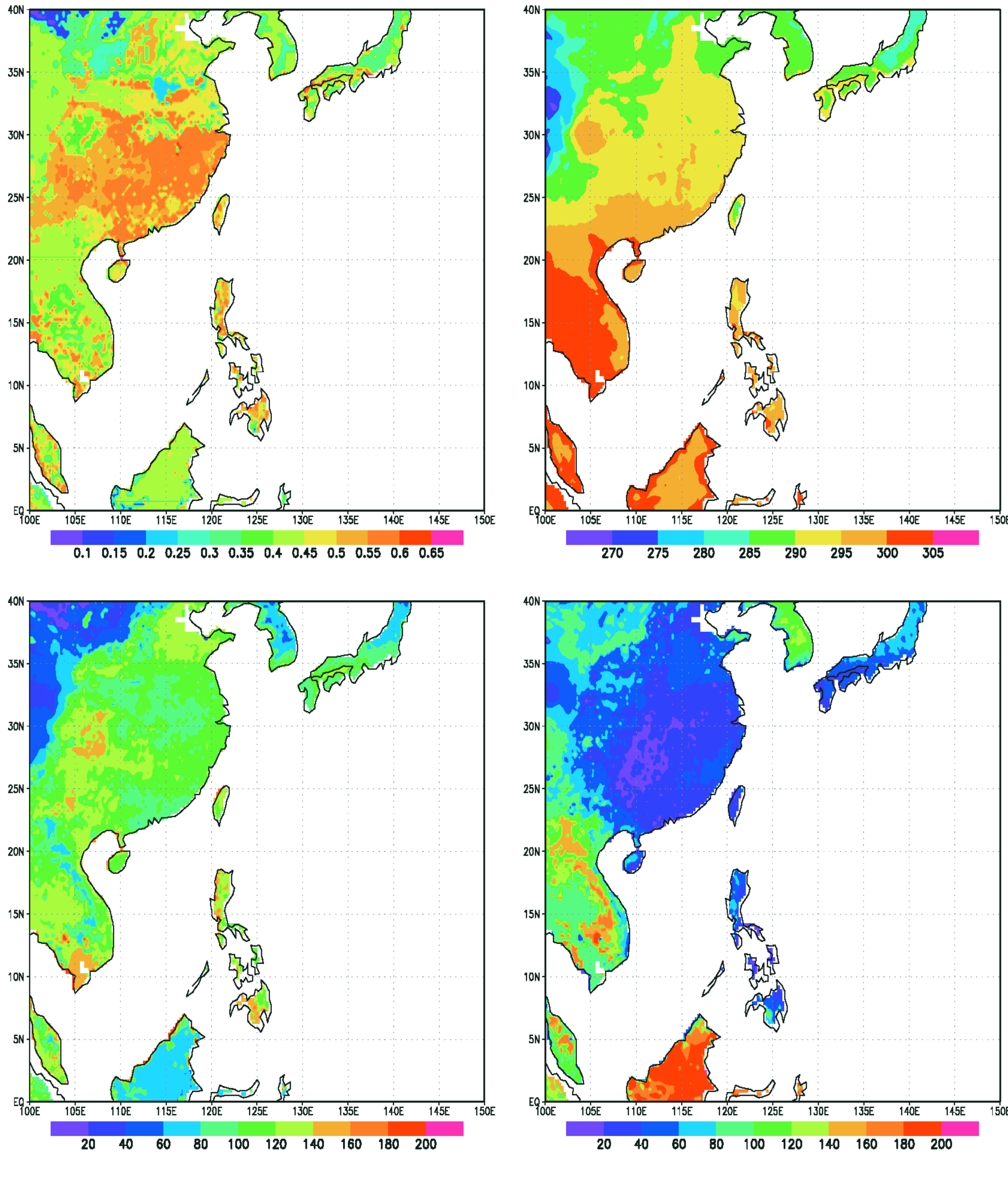


Figure 13. *BATS-estimated surface variables from an IPRC-RegCM simulation over China. Shown are the spatial distributions of May 1998 means for root-zone soil moisture (volumetric; left upper panel), skin temperature (ºK; right upper panel), latent heat flux (W/m^2; left lower panel), and sensible heat flux (W/m^2; right lower panel). Further results from this model solution are presented in Figures 14 and 15.*

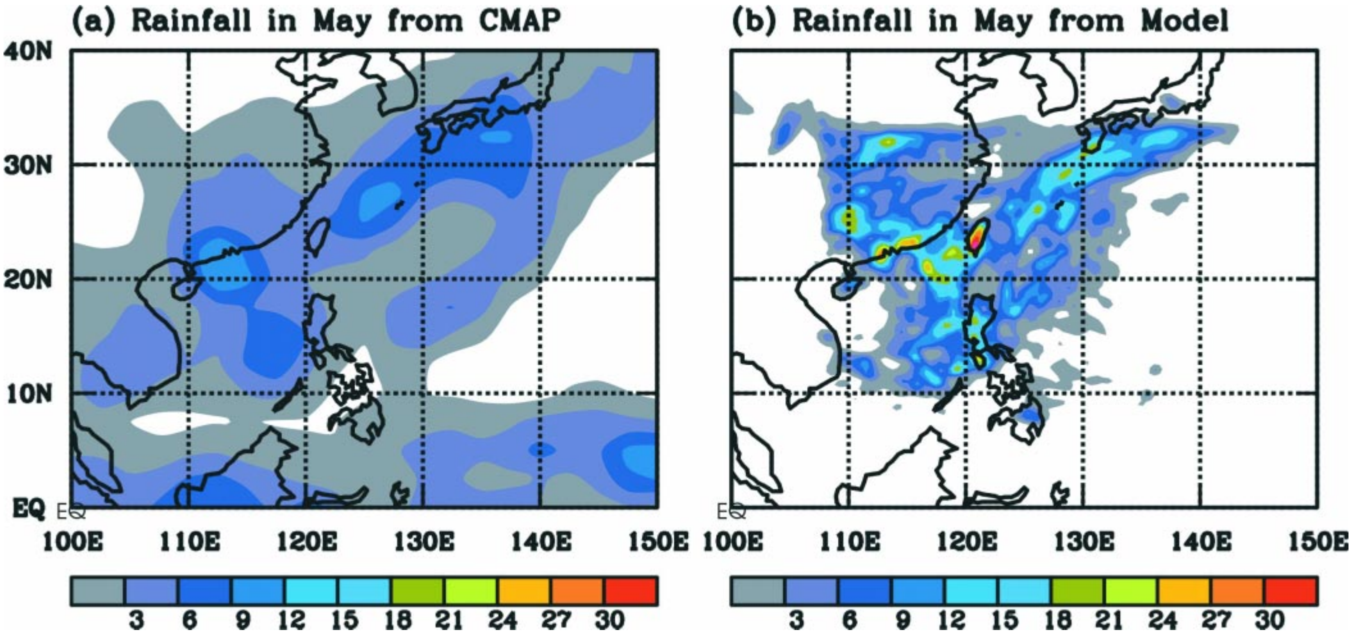


Figure 14. *Average daily rainfall (in mm) in May 1998: (a) CMAP data; (b) simulated by the IPRC–RegCM, Version 1. The comparison shows that the model realistically simulated the rainfall.*

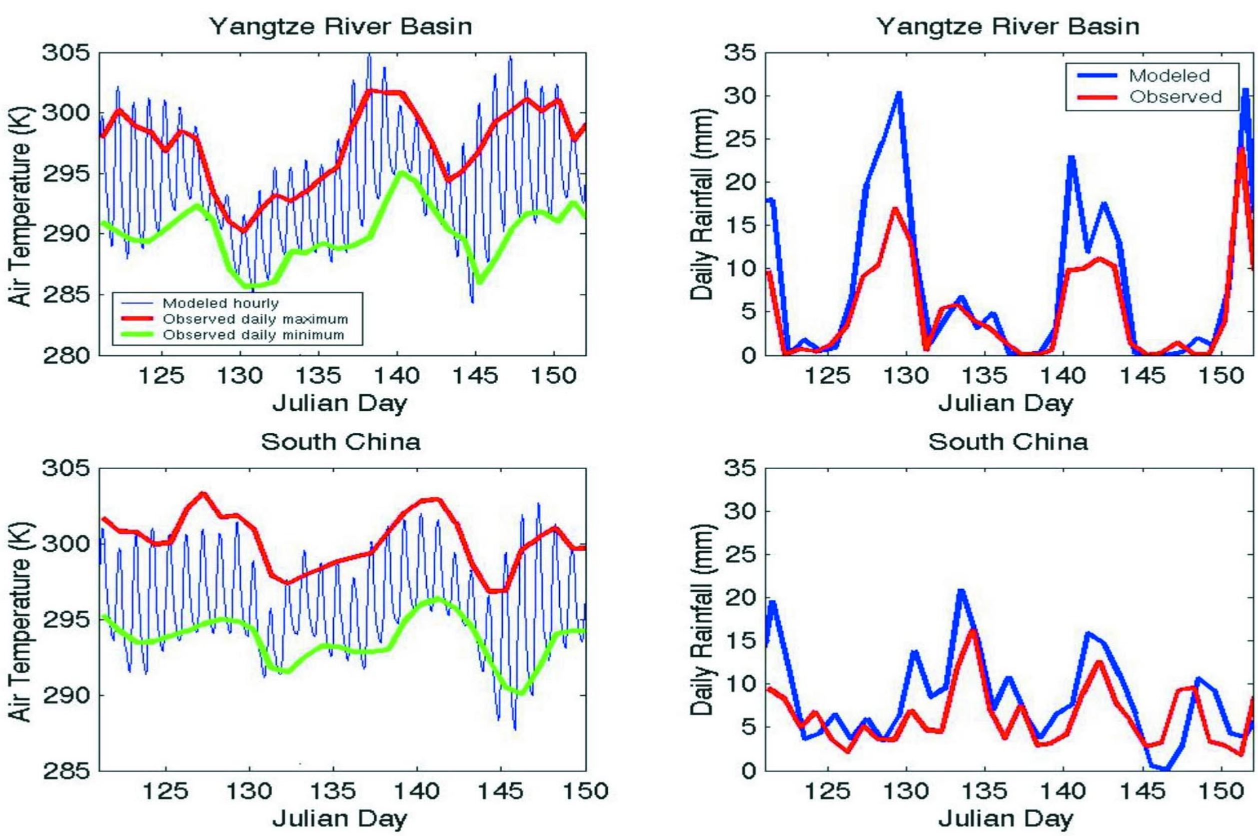


Figure 15. *Comparison between the IPRC-RegCM results and observations. Left panels show simulated hourly surface air temperature (blue line) and observed daily maximum and minimum temperatures for the Yangtze River Basin (30ºN–34ºN, 105ºE–122ºE) and South China (23ºN–30ºN, 105ºE–122ºE). The right panels show simulated (blue) and observed (red) daily precipitation in the two regions.*

same period shows that the model produced the large-scale rainfall patterns with greater detail except near the lateral boundaries where there was a buffer zone without observational data for the mixing ratios of the cloud water, rainwater, cloud ice, snow and graupel used in the cloud microphysics scheme. Moreover, a comparison between observed station data and simulated daily maximum and minimum air temperature and daily rainfall shows that the model captures most of the major events (Figure 15).

Wang also undertook studies to further understand the role of cloud-radiation forcing in general circulation. In collaboration with B. Wang, he looked at the role of cloud-radiation forcing in the oceanic monsoon and in the intertropical convergence zone (ITCZ) by using a zonally symmetric version of the IPRC–RegCM (Wang and Wang, 2001). They found that cloud-radiation forcing enhances the Hadley circulation in the winter hemisphere and convection in the ITCZ (or monsoon trough) in the summer hemisphere. Cloud-radiation forcing also shifts the oceanic ITCZ (or monsoon trough) slightly poleward by increasing the differential radiational heating rates between the summer and winter hemispheres. This differential heating rate results from radiational warming in the deep convective clouds in the ITCZ and strong radiational cooling at the top of the stratus-cloud decks in the subtropical winter hemisphere. They also found that cloud-radiation forcing plays a significant role in forming and maintaining the stratus clouds and temperature inversion in the winter hemisphere subtropics.

Although research on tropical cyclones is not a main theme at the IPRC, realistic simulation of tropical cyclones is important for developing a high-resolution regional climate model. Bearing this in mind, Wang used the IPRC–RegCM to study several aspects of tropical cyclones. In Wang, *Mon. Wea. Rev.* (in press), he described the regional high-resolution hurricane model he previously developed and showed that the model could simulate many aspects of tropical cyclones, especially the vortex Rossby waves in the eyewall, which were simulated and identified for the first time with a full-physics model. In Wang, *J. Atmos. Sci.* a,b (submitted), he further analyzed the characteristics of the simulated vortex Rossby waves, their potential vorticity and kinetic energy sources, and their role in causing both structure and intensity changes in the simulated tropical cyclone. Wang et al. (*Mon. Wea. Rev.*, submitted) examined the potential effect of sea-spray evaporation on the tropical cyclone boundary-layer structure and intensity. This topic is related to climate change as tropical cyclones may become more intense with higher SSTs, and thus may induce more sea spray over the lower boundary layer of the atmosphere. Some researchers argue that global warming will result in more intense tropical cyclones, while others argue that sea-spray evaporation will act as negative feedback and limit tropical cyclone intensity. Wang et al.'s studies with two quite different sea-spray parameterization schemes show that sea spray may increase tropical cyclone intensity slightly (5–10%). This is the first-ever quantitative evaluation of sea spray's effect on tropical cyclone intensity.

The IPRC–RegCM being developed will be extensively used to conduct process studies for improving our understanding of the Asia-Australian monsoon system and its intraseasonal variability, hydrological cycle, and predictability.

Renguang Wu

Postdoctoral Fellow

Renguang Wu received his Ph. D. in meteorology from the University of Hawai'i (UH) at Mānoa, Honolulu, Hawai'i, in 1999. He worked as an assistant researcher at the Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, from 1988 to 1994, before becoming a doctoral student to UH. He joined the IPRC in Spring 2000, after a postdoctoral year with the UH Meteorology Department. He is interested in large-scale air-sea interaction, the monsoon-ENSO relationship, and interdecadal climate change over Asia and the Pacific.

Renguang Wu's research at the IPRC has focused on monsoon variability over Asia and the western North Pacific and on the monsoon-ENSO relationship. This past year, he has (1) studied the role of air-sea interaction in the advance of the summer monsoon over the western North Pacific; and (2) compared the East Asian summer monsoon–ENSO relationship for the periods 1962–1977 and 1978–1993.

Convection over the western North Pacific (110º–160ºE, 10º–20ºN) plays an important role in both regional and global climate variability. Rather unique to the western North Pacific is the northeastward direction of the monsoon progression following its onset in mid-May over the South China Sea. In project 1, Wu noted two prominent northeastward progressions of rainfall and wind: one in mid-June and the other in late July. He proposes that seasonal air-sea interaction over the western North Pacific explains the unusual direction of the monsoon advance. On the one hand, contrasts in shortwave radiation and surface evaporation between the convection and the pre-convection region to the northeast are produced by the monsoon through changes in the clouds and surface winds. These surface-heat-flux contrasts are closely related to a reversal in the SST gradient immediately to the northeast of the convection region. On the other hand, the reversal in SST gradient induces the eastward extension of the westerly winds and the moisture convergence at low levels. Thus, the northeastward monsoon advance results from a monsoon-ocean interaction.

The observed interdecadal change in the background state of the Pacific Ocean during the late 1970s has stimulated many studies devoted to understanding the mechanisms underlying this change and the effects of the change. In project 2, Wu compared the correlation patterns between the East Asian summer monsoon rainfall and the previous winter NINO3 SST index for the pre- and post-shift periods. He found that the correlation patterns for those two periods differ significantly, particularly for North China and central Japan. He noted that before the late 1970s there is a significant positive correlation in eastern North China and a significant negative correlation in central Japan. After the late 1970s, the correlation is negative in eastern North China and weak in central Japan. Furthermore, Wu has identified distinct changes in the dominant circulation pattern over East Asia in the summer following the mature phase of El Niño (La Niña): during the pre-shift period, a low-level anomalous anticyclone (cyclone) lies over Japan and anomalous southerly (northerly) winds blow from the Yellow Sea towards northeastern China; during the post-shift period, a low-level anomalous cyclone (anticyclone) sits over Japan and anomalous easterly (westerly) winds blow over northern Japan towards northeastern China. Wu is currently conducting studies to understand the role of the pre- to post-shift changes in the location and intensity of tropical heating over the western North Pacific and India. Since the rain band in East Asia shows large north-south displacement during the year, another question that Wu plans to study is how ENSO's influence on rainfall in East Asia changes with the seasons. Thus, he intends to investigate the seasonal evolution of the East Asian rainfall–ENSO relationship and to determine whether the decadal change in correlation patterns noted above depends upon season.

Because interdecadal climate changes in Asia have not been well documented due to limited available data, Wu is planning to diagnose the interdecadal variability in atmospheric pressure, wind, and temperature fields over Asia, and the relationship of this variability to changes in the land-surface state and tropical SST. He wishes to answer the following questions: What are the dominant modes of interdecadal variability in the Asian and western Pacific region and what are their spatial structures? How do seasons affect the interdecadal patterns? What mechanisms maintain the interdecadal anomalies from year to year? What roles do land-surface processes and tropical SST play in the interdecadal variability?

Yongsheng Zhang

Postdoctoral Fellow

Yongsheng Zhang obtained his Ph.D. in atmospheric science in 1995 from the Chinese Academy of Science in Beijing. He was a post-doctoral 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 climate dynamics, monsoon variability, monsoon-ENSO interactions, and satellite meteorology.

Yongsheng Zhang has worked this past year on the following projects related to the Asian-Australian monsoon system: (1) interaction between the Asian-Australian monsoon system (A-AMS) and Indian and Pacific Ocean SST anomalies; (2) monsoon onset over Indochina and the South China Sea; and (3) impact of decadal changes in Pacific and Indian Ocean SSTs on the snow accumulation over the Tibetan Plateau. Zhang has also done diagnostic work on the Indian Ocean dipole using observational and coupled-modeling data.

In project 1, Zhang, in collaboration with Tim Li, defined an A-AMS index derived from the sum of the domain-averaged summer Indian rainfall and the following summer northern Australian rainfall. Using a band-pass filter to separate the data into 2-to-3-year (Tropospheric Biennial Oscillation, TBO) and 3-to-7-year (El Niño–Southern Oscillation, ENSO) timescales, he performed a correlation between this index and SST, wind, and other fields. On the 3-to-7-year timescale, he found that SST forcing from the central and eastern Pacific is essential in order for the monsoon anomalies to persist from Indian summer into the Australian summer. On the 2-to-3-year timescale, both remote forcing and local processes associated with SST anomalies over the Indian Ocean and maritime continent are important. In studying the persistence of the monsoon anomaly from the South Asian summer monsoon to the Australian summer monsoon, Zhang and Li documented a southeastward propagation of the SST anomaly from the northern Indian Ocean to the maritime continent and the western Pacific.

In project 2, Zhang, together with T. Li and B. Wang, found that an anomalous convergence between southwesterly winds over the northeastern Indian Ocean together with northeasterly winds along coastal southeast China during the preceding winter and spring are critical for early monsoon onset over Indochina. The anomalous southwesterly winds over the northeastern Indian Ocean result from a stronger overturning east-west circulation related to the SST anomaly in the Pacific Ocean and to a land-sea thermal contrast between southern Asia and the Indian Ocean. The anomalous northeasterlies along coastal Southeast China originate in winter from the thermal contrast between the cold eastern China land-mass and the warm Philippine Sea and continue into spring because of the persistence of an Philippine anomalous cyclone, which maintains itself through a positive thermodynamic feedback between atmospheric Rossby waves and the underlying warm ocean (Wang et al. 2000). Zhang also studied the climatological onset of the summer monsoon over the South China Sea and developed an index to describe the monsoon onset for each individual year on the basis of domain-averaged 850 hPa zonal winds over the South China Sea. An EOF analysis showed that such a domain-averaged index is consistent with the leading EOF pattern describing the evolution of 850 hPa zonal winds over the South China Sea.

Last year, Zhang had reported the sudden deepening of spring-snow cover over the Tibetan Plateau since 1976–1977. This year, he investigated in project 3 the cause of this change using NCAR/NCEP reanalysis data. He found that the increase in tropical air temperatures in low-to-middle levels of the atmosphere, related to Indian Ocean warming after 1977, is associated with notable intensification of the southwesterly winds over the southeastern slopes of the plateau. Intensification of the southwesterlies results in higher atmospheric moisture and atmospheric instability and leads to more precipitation over the area.

Zhang also investigated the circulation and heating-budget changes in the Indian Ocean dipole using NCAR/NCEP reanalysis data and IPRC's coupled-model output. This investigation reveals that several possible air-sea feedback processes might be involved in the Indian Ocean dipole (see Li's report).

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 returned to Moscow to the P.P. Shirshov Institute in March 2001.

Igor Zveryaev focused much of his work this past year on studying atmospheric moisture content in the tropics. An EOF analysis of the year-to-year and interdecadal changes in precipitable water (PW) in the global tropics showed that the first mode (in an EOF analysis) accounts for one-quarter of the variance in annual mean PW and reflects decadal changes. It has four main action centers: the tropical Pacific/South America, the Indonesian Maritime Continent, the equatorial central Pacific, and North Africa. Variations in the first two regions are in phase with each other but opposite to the other two. The second EOF indicates a coherent spatial pattern in PW variations over much of the tropics and is associated with ENSO. The third EOF shows action centers with differing patterns in the central-eastern tropical Pacific, Indonesia /western tropical Pacific, and South America/equatorial Atlantic.

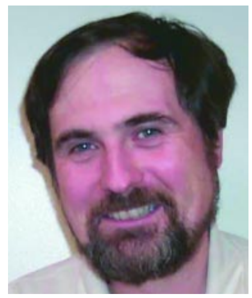
Zveryaev also studied decadal-to-interdecadal changes in the intensity of intraseasonal oscillations (ISO) and in the summer-mean 850 hPa zonal winds in the Asian monsoon system using 51 years of NCEP/NCAR reanalysis data. He noted that decadal-to-interdecadal variations contribute significantly to the variability in the summer-mean 850 hPa zonal winds (30–45%) and the ISO intensity (20–35%). The variations are associated with the strength of low-level westerlies and the meridional dynamics of the Intertropical Convergence Zone (ITCZ). Singular-value-decomposition analysis shows a strong interdecadal correlation among Indian Ocean SST, summer-mean 850 hPa zonal wind, and ISO intensity; decadal correlations, on the other hand, are weak. He noted the following climate shift in the mid-to-late 1970s: During the post-shift period, the Indian Ocean SST increased, lowering the land-sea heat contrast and the strength of low-level westerlies over the northern Indian Ocean, India, and Indochina; in response to sea surface warming and the intensification of convection, 30–60-day ISOs strengthened in the equatorial central and western Indian Ocean and the South China Sea, and they weakened over the Indian subcontinent, northern Arabian Sea, and the Bay of Bengal.

Research Activities and Accomplishments
Theme 4: Impacts of Global Environmental Change

Overview

Understanding the global and regional climate impacts of human activities is one of the most urgent tasks now facing the international scientific community. In recognition of the importance of global change issues, the IPRC science plan includes Theme 4, which is devoted to understanding the Asia-Pacific region impacts of global change. Until last year, no IPRC scientists were working specifically in this theme. With the arrival of Kevin Hamilton last fall, work directly relevant to Theme 4 has begun. The initial focus is on understanding the ability of global atmospheric models to simulate the natural interannual variability in large-scale circulation patterns. In particular, work is underway to understand the role of the stratosphere in modulating the natural interannual variability of tropospheric circulation, as well as the role of stratospheric volcanic aerosols in perturbing Earth's surface climate. Work is also beginning to examine the role of atmospheric climate feedback processes in both climate variability and climate sensitivity.

Individual Report



Kevin P. Hamilton

Professor of Meteorology, SOEST
Theme 4 Leader

Kevin Hamilton received his Ph.D. in meteorology from Princeton University, Princeton, New Jersey, in 1981. Before joining the IPRC in Fall 2000, he was for twelve years a research meteorologist with the NOAA–Geophysical Fluid Dynamics Laboratory and visiting lecturer in the Atmospheric and Oceanic Sciences Program at Princeton University. His research interests include observations and modeling of the global-scale circulation of the atmosphere, climate modeling and climate change, meteorology and chemistry of the stratosphere and mesosphere, and atmospheric and oceanic waves and tides.

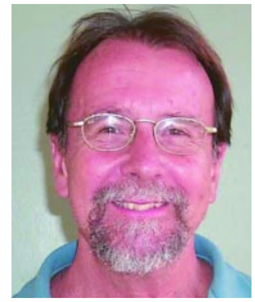
Since his arrival at IPRC, Kevin Hamilton has conducted research relating to the role of the stratosphere in understanding and modeling climate variability and climate sensitivity. There has been much recent speculation that conditions in the stratosphere significantly affect the tropospheric circulation on monthly, seasonal, and longer timescales. In particular, recent observational work has suggested that, in the Northern Hemisphere winter, anomalies in the Arctic Oscillation (AO) have a statistical tendency to form first in the stratosphere and then to propagate downward into the troposphere and to Earth's surface. Such a tendency could be very important since the AO is the leading mode of variability in the large-scale atmospheric flow in the Northern Hemisphere. The surface warming observed at northern extratropical latitudes over recent decades, moreover, seems to reflect a long-term trend in the AO. A clear indication that the stratosphere is involved in the development of tropospheric AO anomalies would have major implications for both seasonal forecasting and modeling long-term climate change. Unfortunately, the extant empirical studies of this possible stratospheric-tropospheric interaction are limited by the brevity of the observed record and the difficulty of accounting for other intra- and inter-annual variations (e.g., sea surface temperatures).

Hamilton is using a comprehensive global atmospheric general circulation model with high vertical resolution in the stratosphere and mesosphere to investigate various aspects of stratospheric influence on the tropospheric circulation and climate. In collaboration with M. Baldwin (Northwest Research Associates), he has compared the variability of the AO in control runs of the model with observations (NCEP analyses) up to mid-stratospheric levels. The results show that the model simulation of the apparent vertical propagation of AO anomalies is quite realistic. Now model experiments are underway to verify that the observational results really indicate a downward causality from the stratosphere to the troposphere. Each of these experiments starts with initial conditions of a winter day in the control run, but with a strong AO-like perturbation to the flow added only in the stratosphere. Each experiment is then integrated for 90 days. Analysis will determine if the stratospheric perturbation produces a systematic and predictable effect in the tropospheric AO pattern (or indeed other aspects of the tropospheric flow).

With other experiments, Hamilton aims to understand whether radiative perturbations in the stratosphere can have significant effects on the tropospheric climate. One very interesting special case is the effect of stratospheric volcanic aerosols on the climate. In collaboration with A. Robock and G. Stenchikov (Rutgers University), and D. Schwarzkopf and V. Ramaswamy (NOAA–Geophysical Fluid Dynamics Laboratory), Hamilton has conducted a series of experiments using radiative forcing based on the detailed observations of the space-time evolution of the aerosol concentrations following the eruption of Mt. Pinatubo in 1991. Preliminary analysis suggests that the model can capture the observed effects of Pinatubo on both the stratospheric and tropospheric circulation. These model calculations are now being refined to include a representation of the quasi-biennial oscillation (QBO) in the tropical stratosphere and also the effects of the Pinatubo aerosols on the chemical destruction of ozone.

In related projects on modeling and understanding interannual variations in the tropical stratospheric circulation, Hamilton has achieved significant progress in simulating a spontaneous QBO in high-resolution versions of the model (Hamilton et al., *J. Atmos. Sci.*, in press). In another collaboration with W. Hsieh (University of British Columbia), Hamilton is analyzing the observed variations in the height-time record of equatorial stratospheric winds using non-linear generalizations of standard principal component analysis.

The Asia-Pacific Data Research Center



Peter W. Hacker

The IPRC is establishing a data research center, the Asia-Pacific Data Research Center (APDRC). Peter Hacker, physical oceanographer and Senior Research Scientist at the Hawai'i Institute of Geophysics and Planetology at the University of Hawai'i, joined the IPRC staff on March 1, 2001, to lead this effort. He is assisted by a steering team, which consists of Julian McCreary, Humio Mitsudera, Takuji Waseda, Gang Yuan, and Ronald Merrill.

The mission of the APDRC is "to promote understanding of climate variability in the Asia-Pacific region by developing the computational infrastructure needed to make data resources readily accessible and usable by researchers, and by undertaking data-intensive research that will both advance knowledge and lead to improvements in data collection and preparation." The center, by linking data management with research, is envisioned to be a powerful research resource, one that will provide one-stop shopping of climate data and products to IPRC researchers and collaborators, and eventually to the national and international climate research community and the general public. 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 major event for the research side of the APDRC last year was the funding by the National Aeronautic and Space Administration (NASA) in October 2000 of a five-year project entitled "Data-intensive research and model development at the IPRC." In this project, IPRC researchers will conduct diagnostic and modeling studies that take advantage of existing and newly available NASA data to advance Asia-Pacific climate research. The recent advances in satellite remote-sensing technology at NASA (resulting in such instruments as the altimeter, scatterometer, microwave imager and precipitation radar) offer an unprecedented opportunity to overcome the limitations of conventional surface-based observations (coarse spatial and temporal resolution, and globally non-uniform coverage). Over the next years, the APDRC will begin to provide easy access to these satellite data and products by building up the local data archive and by establishing data links to other national centers.

The NASA project has four research themes that partly overlap the current IPRC research themes. Theme 1, *Indo-Pacific Climate Variability and Processes* (Theme Leader: S.-P. Xie), will focus initially on decadal variability, atmospheric convergence zones and their interaction with the ocean, and atmospheric boundary-layer processes. Theme 2, *Pacific Ocean Circulations and their Role in Climate Dynamics* (Theme Leader: H. Mitsudera), will focus on subtropical cells and low-latitude western-boundary currents, the influence of salinity forcing on tropical Pacific circulation, and the Subpolar Gyre and its interaction with the subtropics. Theme 3, *Asian-Australian Monsoon System* (Theme Co-Leaders: T. Li and B. Wang), will focus on teleconnections from the western Pacific to North America, the East Asia summer monsoon, interactions between the East Asia monsoon and ENSO, and the Tropospheric Biennial Oscillation. Theme 4, *Model Development* (Theme Co-Leaders: T. Li and S.-P. Xie), is a multi-year activity to enhance the upper end of IPRC's existing set of models.

Progress has been made also on the data side of the APDRC. During January 2001, Hacker and McCreary met with NOAA staff, including the new director of NOAA's Geophysical Fluid Dynamics Laboratory, Ants Leetmaa, and the head of the U.S. Global Ocean Data Assimilation Experiment (U.S. GODAE), Michele Rienecker, to begin to define the climate community's needs over the coming years for a center managing Asia-Pacific climate data, and the role the APDRC could play in meeting those needs. Based in part on discussions at this meeting, a proposal was submitted to NOAA to support the data side of the APDRC. (Notification that funding would be forthcoming was received July 1, 2001.)

A specific goal of the APDRC is to develop and implement a data server system (DSS). In cooperation with Steve Hankin at NOAA's Pacific Marine Environmental Laboratory (PMEL) in Seattle, Washington, Ronald Merrill and Yingshuo Shen of the IPRC have installed and are operating PMEL's Live Access Server (LAS) for gridded data sets. The server is intended to provide four distinct, but well-integrated functions: data location, navigation and evaluation, delivery, and visualization and analysis. The LAS is presently serving local and remote data and is being studied to identify needed improvements. The LAS uses the Distributed Ocean Data System (DODS) software, developed at the University of Rhode Island, for data transfer over the network. In addition, PMEL's EPIC system has recently been installed at the APDRC with the cooperation of Nancy Soreide, Don Denbo, and Willa Zhu at PMEL. EPIC handles non-gridded in-situ data sets. A third system, the Grid Analysis and Display System (GrADS) DODS Server (GDS), which is a popular system used by many scientists in the atmospheric research community, is also being considered as an additional possibility for the APDRC. Both EPIC and GDS will be evaluated over the coming year.

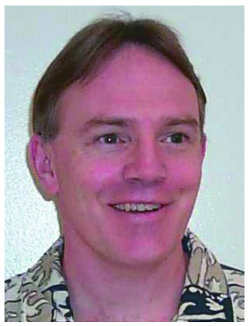
The new IPRC Sun Enterprise 450 with 4 processors will become the server for the APDRC. A wide variety of climate data and products will be available on this server, including subsets of operational atmosphere and ocean model output, model reanalysis fields, satellite products, air-sea flux products from models and satellites, and *in situ* data sets focusing on the ocean and the hydrological cycle. The present LAS already has links to a wide variety of data sets from remote sites.

The local APDRC archive is also being built up by Yingshuo Shen and Yongsheng Zhang. Holdings include the following: Levitus temperature and salinity climatology for the ocean, COADS (Comprehensive Ocean-Atmosphere Data Set) climatology, Reynolds SST products, the SODA (Simple Ocean Data Assimilation) ocean reanalysis product, ECMWF (European Centre for Medium-Range Weather Forecasts) operational data sets, the JAMSTEC (Japan Marine Science and Technology Center) eddy-resolving model output, CMAP (Climate Modeling, Analysis, and Prediction) rainfall data, and NCAR/NCEP reanalysis output. Some of these products are available only to local users at this time due to data distribution restrictions.

IPRC Scientific Computer Programmers and Data Specialists (from left to right) Jan Hafner, Yingshuo Shen, Bohyun Bang, and Xiouhua Fu.

The IPRC Computing Facility

The IPRC high-performance computing facility is administered by Ronald Merrill, computer systems manager, and Gary Tarver, a computer systems engineer. Under their guidance the computing facility continues to expand.



Ronald Merrill

By the end of March 2001, the IPRC had one shared-memory vector-parallel machine and three distributed-shared-memory RISC-based parallel machines. The vector-parallel machine is a CRAY SV1 with 24 CPUs, 16.0 GB shared memory, and 728 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. Two of the 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) and 8 CPUs (300 MHz), 4.5 GB memory, 60 GB of local disk storage, and a peak performance of 11 GFLOPS. A third RISC-based parallel machine is an Origin 3400 with 32 CPU's (400 MHz), 12 GB memory, 36 GB of local disk storage and a peak speed of 25.6 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 four 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). Additional shared computational resources are two Sun Enterprise 450 4-CPU machines, and three dual 2-CPU Alpha machines.

Main storage is served by a 4-CPU Origin 2000 with a 1260-GB SGI Clarion RAID (Redundant Array of Independent Disks) and an additional 20 TB provided by a tape library (StorageTek Timberwolf 9710 with 6 DLT drives and 574-tape capacity). Transfer of files between disks and tapes is automatic and transparent to users, so the storage capacity of the local disks appears to be limited only by the maximum capacity of the tape library. Also, an SGI LSI TP9400 RAID system (1.4 TB) is shared by the four SGI servers in a Storage Area Network (SAN) connected by a Brocade Silkworm 2400 Fibre Channel switch. The SAN provides 100 MB/sec access to data which allows researchers to efficiently use available CPU cycles on any of the four servers without transferring files over the LAN.

Gary Tarver

The main compute servers and the file server are also interconnected via a fast OC-12 link, provided by a Fore ASX-1000 ATM switch. The implementation of the SAN has supplanted one of the main functions of the ASX, so the switch will be re-purposed and should soon provide high-speed data access between the front-end APDRC server running on a Sun E-450 and the IPRC's back-end data resources residing on the SGI servers.

Each IPRC researcher is provided with a UNIX workstation and a PC. The IPRC currently owns 39 Sun workstations, 2 SGI workstations, and 64 PCs. Local Area Network and Internet Connectivity are provided by the Research Computing Facility of the School of Ocean and Earth Science and Technology (SOEST).

Publications

Refereed

PUBLISHED

An, S.-I., and F.-F. Jin, 2000: An eigen analysis of the interdecadal changes in the structure and frequency of ENSO mode. *Geophys. Res. Lett.*, **27**, 2573–2576.

An, S.-I., and I.-S. Kang, 2000: A further investigation of the recharge oscillator paradigm for ENSO using a simple coupled model with zonal mean and eddy separated. *J. Climate*, **13**, 1987–1993.

An, S.-I., and B. Wang, 2001: Mechanisms of locking the El Niño and La Niña mature phases to boreal winter. *J. Climate*, **14**, 2164–2176.

Chang, C.-P., Y.S. Zhang, and T. Li, 2000: Interannual and interdecadal variations of the East Asian summer monsoon and tropical Pacific SSTs. Part 1: Role of subtropic ridges. *J. Climate*, **13**, 4310–4325.

Chang C.-P., Y.S. Zhang, and T. Li, 2000: Interannual and interdecadal variations of the East Asian summer monsoon and tropical Pacific SSTs. Part 2: Meridional structure of the monsoon. *J. Climate*, **13**, 4326–4340.

Feng, M., R. Lukas, P. Hacker, R.A. Weller, and S.P. Anderson, 2000: Upper-ocean heat and salt balances in the western equatorial Pacific in response to intraseasonal oscillations during TOGA COARE. *J. Climate*, **13**, 2409–2427.

Feng, M., H. Mitsudera, and Y. Yoshikawa, 2000: Structure and variability of the Kuroshio Current in Tokara Strait. *J. Phys. Oceanogr.*, **30**, 2257–2276.

Fu, X., and B. Wang, 2001: A coupled modeling study of the seasonal cycle of the Pacific Cold Tongue. Part I: Simulation and sensitivity experiments. *J. Climate*, **14**, 765–779.

Baldwin, M.P., L.J. Gray, T.J. Dunkerton, K. Hamilton, P.H. Haynes, W.J. Randel, J.R. Holton, M.J. Alexander, I. Hirota, T. Horinouchi, D. Jones, J.S. Kinnersley, C. Marquardt, K. Sato and M. Takahashi, 2001: The Quasi-biennial Oscillation. *Reviews of Geophysics*, **39**, 179–229.

Han, W., and J. P. McCreary, 2001: Modelling salinity distributions in the Indian Ocean. *J. Geophys. Res.*, **106**, 859–877.

Han, W., J. P. McCreary, and K. E. Kohler, 2001: Influence of precipitation minus evaporation and Bay of Bengal rivers on dynamics, thermodynamics, and mixed-layer physics in the upper Indian Ocean. *J. Geophys. Res.*, **106**, 6895–6916.

Jameson, L., and T. Miyama, 2000: Wavelet Analysis and Ocean Modeling: A dynamically adaptive numerical model “WOFD AHO.” *Mon. Wea. Rev.*, **128**, 1536–1549.

Jameson, L., and T. Waseda, 2000: Error estimation using wavelet analysis for data assimilation: EEWADAi. *J. Atmos. Oceanic Tech.*, **17**, 1235–1246.

Jensen, T. G., 2001: Application of the GWR method to the tropical Indian Ocean. *Mon. Wea. Rev.*, **129**, 470–485.

Li, T., T.F. Hogan, and C.-P. Chang, 2000: Dynamic and thermodynamic regulation of ocean warming. *J. Atmos. Sci.*, **57**, 3353–3365.

Li, T., C.W. Tham, and C.-P. Chang, 2001: A coupled air-sea-monsoon oscillator for the tropospheric biennial oscillation. *J. Climate*, **14**, 752–764.

Liu, T.W., X. Xie, P. Polito, S.-P. Xie, and H. Hashizume, 2000: Atmospheric manifestations of tropical instability waves observed by QuikSCAT and Tropical Rain Measuring Mission. *Geophys. Res., Lett.*, **27**, 2545–2548.

Loschnigg, J., and P.J. Webster, 2000: A coupled ocean-atmosphere system of SST modulation for the Indian Ocean. *J. Climate*, **13**, 3342–3360.

McCreary, J.P., and P. Lu, 2001: Influence of the Indonesian Throughflow on the circulation of Pacific Intermediate Water. *J. Phys. Oceanogr.*, **31**, 932–942.

Murtugudde, R., J.P. McCreary, and A.J. Busalacchi, 2000: Oceanic processes associated with anomalous events in the Indian Ocean with relevance to 1997–1998. *J. Geophys. Res.*, **105**, 3295–3306.

Nonaka, M., and S.-P. Xie, 2000: Propagation of North Pacific interdecadal subsurface temperature anomalies in an ocean GCM. *Geophys. Res. Lett.*, **27**, 3747–3750.

Nonaka, M., S.-P. Xie, and K. Takeuchi, 2000: Equatorward spreading of a passive tracer with application to North Pacific interdecadal temperature variations. *J. Oceanogr.*, **56**, 173–183.

Panteleev, G.G., N.A. Maximenko, B. deYoung, C. Reiss, and T. Yamagata, 2000: Anisotropic optimization of the current field with the variational method. *Oceanology*, **40**, 451–457.

Qi, L., Y. Wang, L.M. Leslie, 2000: Numerical simulation of a cut-off low over southern Australia. *Meteor. Atmos. Phys.*, **74**, 103–115.

Qu, T., 2000: Upper layer circulation in the South China Sea. *J. Phys. Oceanogr.*, **30**, 1450–1460.

Solomon, A., and R.S. Lindzen, 2000: The impact of resolution on a numerical simulation of the barotropic instability. *J. Atmos. Sci.*, **57**, 3799–3816.

Solomon, A., and P.H. Stone, 2001: Equilibration in an eddy resolving model with simplified physics. *J. Atmos. Sci.*, **58**, 561–574.

Tomita, T., 2000: The longitudinal structure of interannual variability observed in sea surface temperature of the equatorial oceans. *J. Meteor. Soc. Japan*, **78**, 499–507.

Wang, B., and Z. Fang, 2000: Roles of shortwave radiation forcing on ENSO: A study with an intermediate coupled ocean-atmosphere model. *Climate Dyn.*, **16**, 677–691.

Wang, R. and B. Wang, 2000: Phase space representation and characteristics of El Niño–La Niña. *J. Atmos. Sci.*, **57**, 3315–3333.

Wang, D., 2001: A note on using the accelerated convergence method in climate models. *Tellus*, **53A**, 27–34.

Wu, R., and B. Wang, 2001: Multi-stage onset of the summer monsoon over the western North Pacific. *Climate Dyn.*, **17**, 277–289.

Xie, S.-P. and K. Saito, 2001: Formation and variability of a northerly ITCZ in a hybrid coupled AGCM: Continental forcing and ocean-atmospheric feedback. *J. Climate*, **14**, 1262–1276.

Xie, S.-P., T. Kunitani, A. Kubokawa, M. Nonaka, and S. Hosoda, 2000: Interdecadal thermocline variability in the North Pacific for 1958–1997: A GCM simulation. *J. Phys. Oceanogr.*, **30**, 2798–2813.

Yaremchuk, M.I., 2001: A reconstruction of large scale circulation in the Pacific Ocean north of 10ºN. *J. Geophys. Res.*, **106**, 2331–2344.

Yaremchuk, M.I., N.L. Bindoff, J. Schröter, D. Nechaev, and S.R. Rintoul, 2001: On the zonal and meridional circulation and ocean transports between Tasmania and Antarctica. *J. Geophys. Res.*,**106**, 2795–2814.

Yu, Z., J.P. McCreary, W.S. Kessler, and K.A. Kelly, 2000: Influence of equatorial dynamics of the Pacific North Equatorial Countercurrent. *J. Phys. Oceanogr.*, **30**, 3179–3190.

Zhang, Y, and S. Jiang, 2000: Retrieval of the tropical divergent wind from OLR and its application in ENSO diagnosis. *Acta Meteor. Sinica*, **14**, 61–81.

IN PRESS[2]

*An, S.-I., and I.-S. Kang: Sensitivity of the equatorial air-sea coupled system to the zonal phase difference between SST and wind stress. *Adv. in Atmos. Sci.*

*An, S.-I., and F.-F. Jin: Collective role of thermocline and zonal advective feedbacks in ENSO mode. *J. Climate.*

*An, S.-I., and B. Wang: Interdecadal changes of the structure of ENSO mode and its relation to the frequency change. *J. Climate.*

*Annamalai, H., and J.M. Slingo: Active/break cycles: Diagnosis of the intraseasonal variability of the Asian summer monsoon. *Climate Dyn.*

*Baldwin, M.P., L.J. Gray, T.J. Dunkerton, K. Hamilton, P.H. Haynes, W.J. Randel, J.R. Holton, M.J. Alexander, I. Hirota, T. Horinouchi, D. Jones, J.S. Kinnersley, C. Marquardt, K. Sato, and M. Takahashi: The Quasi-biennial Oscillation. *Rev. Geophys.*

*Feng, M., R. Lukas, and P. Hacker: Spin-up of a sub-mesoscale eddy in the TOGA COARE Intensive Flux Array during the spin-down of an intense eastward jet. *J. Phys. Oceanogr.*

*Hamilton, K., R.J. Wilson, and R.S. Hemler: Spontaneous QBO-like oscillations simulated by the GFDL SKYHI General Circulation Model. *J. Atmos. Sci.*

*Hashizume, H., S.-P., Xie, W.T. Liu, and K.Takeuchi: Local and remote atmospheric response to tropical instability waves: A global view from space. *J. Geophys. Res.-Atmos.*

*Kang, I.-S., An, S.-I., and F.-F. Jin: A systematic approximation of the SST anomaly equation for ENSO. *J. Meteor. Soc. Japan.*

*Kemball-Cook, S., and B. Wang: Coherent structures and air-sea interaction in the boreal summer intraseasonal oscillation. *J. Climate.*

*Kepert, J.D., and Y. Wang: The dynamics of boundary layer jets within the tropical cyclone core. Part II: Nonlinear enhancement. *J. Atmos. Sci.*

*Li, T., Y.S. Zhang, C.-P. Chang, and B. Wang: On the relationship between Indian Ocean SST and Asian summer monsoon. *Geophys. Res. Lett.*

*Maximenko, N.A., M.N. Koshlyakov, Y.A. Ivanov, M.I. Yaremchuk, and G.G. Panteleev: Hydrophysical experiment "Megapolygon-87" in the North Western Pacific Subarctic Frontal Zone. *J. Geophys. Res.*

*McCreary, J.P., K.E. Kohler, R.R. Hood, S. Smith, J. Kindle, A.S. Fischer, and R.A. Weller: Influences of diurnal and intraseasonal forcing on mixed-layer and biological variability in the central Arabian Sea. *J. Geophys. Res.*

*Mitsudera, H., T. Waseda, Y. Yoshikawa, and B. Taguchi: Anticyclonic eddies and Kuroshio meander formation. *Geophys. Res. Lett.*

*Nonaka, M., and K. Takeuchi, 2000: Tropical subsurface salinity and tritium distributions in the Pacific GCM: Their differences and formation mechanisms. *J. Phys. Oceanogr.*

Okumura, Y., S.-P. Xie, A. Numaguti, Y. Tanimoto: Tropical Atlantic air-sea interaction and its influence on the NAO. *Geophys. Res. Lett.*

*Panteleev, G.G., B. deYoung, M. Yaremchuk: Mean summer and fall circulation on Western Bank, Nova Scotia. *Atmos.-Ocean.*

*Qu, T.: The role of ocean dynamics in determining the mean seasonal cycle of the South China sea surface temperature. *J. Geophys. Res.*

*Qu, T., H. Mitsudera, and B. Qiu: A climatological view of the Kuroshio/Oyashio system east of Japan. *J. Phys. Oceanogr.*

*Schott, F., and J.P. McCreary: The monsoon circulation of the Indian Ocean. *Prog. Oceanogr.*

*Sen, O. L., L.A. Bastidas, W.J. Shuttleworth, Z.-L. Yang, and S. Sorooshian: Impact of field calibrated vegetation parameters on GCM climate simulation. *Quart. J. Royal Meteor. Soc.*

*Shinke, T., Y. Yoshikawa, T. Kamoshida, and H. Mitsudera: Analysis method for Ocean Acoustic Tomography data using a Kalman filter—Evaluation by identical twin experiment. *Jap. J. Appl. Phys.*

Solomon, A., and P.H. Stone: A study of the sensitivity of the equilibrated state of an intermediate model of the midlatitude troposphere to changes in radiative forcing. *J. Atmos. Sci.*

*Wang, B., and X. Fu: Physical processes determining the rapid reestablishment of the equatorial cold tongue/ITCZ complex. *J. Climate.*

*Wang, B., R. Wu, K.-M. Lau: Interannual variability of Asian summer monsoon: Contrast between Indian and western North Pacific–East Asian monsoons. *J. Climate.*

2 * Signifies acceptance since April 1, 2000.

*Wang, D.: Large-eddy simulation of diurnal cycling oceanic boundary layer: Sensitivity to domain size and spatial resolution. *J. Geophysics. Res.*

*Wang, Y.: An explicit simulation of tropical cyclones with a triply-nested movable mesh primitive equation model–TCM3. Part I: Model description and control experiment. *Mon. Wea. Rev.*

Wang, Y.-F., and B. Wang, J.-H. Oh, 2001: Impact of preceding El Niño on the East Asian summer atmospheric circulation. *J. Meteor. Soc. Japan.*

*Waseda, T., Y. Toba, and M. P. Tulin: On the adjustment process of wind waves to sudden changes of wind speed. *J. Oceanogr.*

*Wu, L., and B. Wang: Movement and vertical coupling of adiabatic baroclinic tropical cyclones. *J. Atmos. Sci.*

*Wu, L. and B. Wang: Effects of convective heating on movement and vertical coupling of tropical cyclones: A numerical study. *J. Atmos. Sci.*

*Wu, R. and B. Wang: Multi-stage onset of summer monsoon over the western North Pacific. *Climate Dyn.*

*Xie, S.-P., W.T. Liu, Q. Liu and M. Nonaka: Far-reaching effects of the Hawaiian Islands on the Pacific Ocean-Atmosphere. *Science.*

Yaremchuk M.I., D.A. Nechaev, and K.R. Thompson: Seasonal variation of the North Atlantic Current. *J. Geophys. Res.*

*Yaremchuk, M., and A. Yaremchuk: Variational inversion of the ocean acoustic tomography data using quadratic approximation to travel times. *Geophys. Res. Lett.*

Yashayaev, I.M., and Zveryaev, I.I.: Climate of the seasonal cycle in the North Pacific and the North Atlantic Oceans. *Int. J. Climatol.*

Zveryaev, I.I., and Selemenov, K.M.: Decadal scale changes in the annual cycle of the North Pacific sea surface temperature. *Int. J. Climatol.*

SUBMITTED[3]

**Annamalai, H.: Teleconnection between tropical cyclones of west Pacific and monsoon disturbances over Bay of Bengal—Results from observations and a GCM. *Mon. Wea. Rev.*

**Annamalai, H., and B. Wang.: Interannual variations in the intraseasonal variability during boreal summer: Role of low frequency large and regional scale circulations. *J. Climate.*

**Davey, M. K., M. Huddleston, K. R. Sperber, P. Bracconot, F. Bryan, D. Chen, A. Colman, C. Cooper, U. Cubash, P. Delecleuse, D. DeWitt, L. Fairhead, G. Flato, C. Gordon, T. Hogan, M. Ji, M. Kimoto, A. Kitoh, T. Knutson, M. Latif, H. Le Treut, T. Li, S. Manabe, C. Mechoso, G. Meehl, J. Oberhuber, S. Power, E. Roeckner, L. Terray, A. Vintzileos, R. Voss, B. Wang, W. Washington, I. Yoshikawa, J. Yu, S. Yukimoto, S. Zebiak: STOIC: A study of coupled model climatology and variability in tropical ocean regions. *Climate Dyn.*

**Donohue, K. A., Firing, E., G. D. Rowe, A., Ishida, and H. Mitsudera: Equatorial Pacific subsurface countercurrents: A model/data comparison in stream coordinates. *J. Phys. Oceanogr.*

Hosoda, S., S.-P. Xie, K. Takeuchi, and M. Nonaka: Eastern North Pacific subtropical mode water in a GCM: Formation mechanism and salinity effects. *J. Geophys. Res.-Oceans.* (revised)

3 ** Signifies submission since April 1, 2000.

**Inatsu, M., H. Mukougawa, and S.-P. Xie: Stationary eddy response to surface boundary forcing: Idealized GCM experiments. *J. Atmos. Sci.*

**Jameson, L., T. Waseda, and H. Mitsudera: Scale utilization and optimization from wavelet analysis for data assimilation: SUgOiWADAi. *J. Atmos. Ocean. Tech.*

Jensen, T.G.: Barotropic mode errors in an Indian Ocean model associated with the GWR method. *J. Global and Planet. Change.*

**Latif, M., K. Sperber, J. Arblaster, Bracconot, D. Chen, A. Colman, U. Cubash, M. Davey, P. Delecleuse, D. DeWitt, L. Fairhead, G. Flato, M. Ji, M. Kimoto, A. Kitoh, T. Knutson, H. Le Treut, S. Manabe, O. Marti, C. Mechoso, G. Mheel, J. Oberhuber, S. Power, E. Roeckner, L. Terray, A. Vinzileos, R. Voss, B. Wang, W. Washington, I. Yoshikawa, J. Yu, S. Zebiak: ENSIP: The El Niño simulation intercomparison project. *Climate Dyn.*

**Li, B., and B. Wang: How do spatial patterns of winds influence the period and amplitude of an ENSO event in a coupled model? *J. Climate.*

**Li, T., B. Wang, C.-P. Chang: Theories of the tropospheric biennial oscillation: A review. *Adv. Atmos. Sci.*

**McCreary, J.P., P. Lu, Z. Yu: A numerical investigation of the Pacific subsurface countercurrents. *J. Phys. Oceanogr.*

**Miyama, T., T. Awaji, and K. Akimoto: Lagrangian analysis of the mass and heat budgets of the Warm Water Pool. *Deep Sea Res.*

**Mitsudera, H., Y. Yoshikawa, B. Taguchi: Blocking of the Kuroshio meander by baroclinic interaction with the Izu Ridge. *Dyn. Atmos. Ocean*: Special Issue on Fronts.

**Nechaev, D.A., J. Schröter, and M.I. Yaremchuk: A 3-D computation and optimization of a steady state oceanic circulation with a stabilized finite element method. *J. Comp. Physics.*

Panteleev, G.G., N.A. Maximenko, B. deYoung, C. Reiss, and T. Yamagata: Variational interpolation of circulation with non-linear, advective smoothing. *J. Atmos. Oceanic Tech.*

**Qu, T., S.-P. Xie, H. Mitsudera, and A. Ishida: Subduction of the North Pacific Mode Waters in a global eddy-resolving GCM. *J. Phys. Oceanogr.*

**Timmermann, A.: Changes of ENSO stability due to greenhouse warming. *Geophys. Res. Lett.*

**Timmermann, A., and F.-F. Jin: Homoclinic chaos: A paradigm for ENSO amplitude modulations. *J. Atmos. Sciences.*

**Timmermann, A., and F.-F. Jin: Mechanism and predictability of decadal amplitude changes of El Niño. *J. Climate.*

**Timmermann, A., and R. Pasmanter: Statistical determination of ENSO's most and least predictable states. *Tellus.*

Tomita, T., B. Wang, T. Yasunari, and H. Nakamura: Spatio-temporal structure of decadal scale variability observed in the global SST and lower-tropospheric circulation fields. *J. Geophys. Res.*

**Tomita, T., S.-P. Xie, and M. Nonaka: Relationship between decadal surface and subsurface variability in the midlatitude North Pacific. *J. Climate.*

**Wang, B., and S.-I. An: Why the properties of El Niño changed during the late 1970s. *Geophys. Res. Lett.*

**Wang, B., and S.-I. An: A mechanism for decadal changes of ENSO behavior: Role of background changes of surface winds. *Climate Dyn.*

**Wang, B., and H. Lin: Rainy seasons of the Asian-Pacific monsoon. *J. Climate.*

**Wang, B., R. Wu, R. Lukas, and S.-I. An: A possible mechanism for ENSO turnabout. *Dyn. Atmos. Gen. Circ. and Clim.*.

Wang, D., and P. Muller: Effects of equatorial undercurrent shear on nighttime convection. *J. Phys. Oceanogr.*

**Wang, Y.: Vortex Rossby waves in a numerically simulated tropical cyclone. Part I: Overall structure, vorticity and energy budgets. *J. Atmos. Sci. (a)*

**Wang, Y.: Vortex Rossby waves in a numerically simulated tropical cyclone. Part II: The role in tropical cyclone structure and intensity changes. *J. Atmos. Sci. (b)*

**Wang, Y., J.D. Kepert, and G.J. Holland: The effect of spray evaporation on tropical cyclone boundary layer structure and intensity. *Mon. Wea. Rev.*

**Waseda,T., and H. Mitsudera: Chaotic advection of the shallow Kuroshio coastal waters. *Geophys. Res. Lett.*

**Waseda, T., H. Mitsudera, B. Taguchi and Y. Yoshikawa: On the eddy-Kuroshio interaction: initialization and evolution of the mesoscale eddies. *J. Geophys. Res.*

**White, W., H. Annamalai, and Y. Tourre: Influence of Global SST/SLP waves on Indian summer monsoon rainfall from 1900–95. *J. Climate*

**Wu, R.: Processes for the northeastward advance of the summer monsoon over the western North Pacific. *J. Meteor. Soc. Japan.*

Yaremchuk, M., and D. Krot: Approximation for the inverse speed of sound in seawater, suitable for assimilating acoustic tomography data into numerical models. *J. Atmos. and Oceanic Tech.*

Yaremchuk, A., M. Yaremchuk, J. Schröter, and M. Losch: Local stability and estimation of uncertainty for inverse problem solvers. *Inverse Methods.*

Zveryaev, I.I: Interdecadal changes in the zonal wind and the intensity of intraseasonal oscillations during boreal summer Asian monsoon. *Tellus.*

Zveryaev, I.I., and P.-S. Chu: Recent climate changes in precipitable water in the global tropics. *J. Geophys. Res.-Atmos.*

Zveryaev, I.I., and B. Wang: Interdecadal changes in the summer means and the intensity of intraseasonal oscillations in the Asian monsoon revealed by the atmospheric moisture. *J. Climate.*

CHAPTERS IN BOOKS AND ENCYCLOPEDIAS

Chang, C.-P., and T. Li: Nonlinear interactions between the TBO and ENSO. In C.-P. Chang et al. (Eds.): *Selected Papers on East Asian and Western Pacific Meteorology and Climate.* Singapore: World Scientific Publishing Company (in press).

Hamilton, K.: The quasi-biennial oscillation. In *Encyclopedia of Global Environmental Change*. New York: John Wiley & Sons (in press).

Fu, X., and Wang, B., 2001: Understanding the annual cycle of the equatorial Pacific as a result of ocean-atmosphere-land interactions. In Institute of Atmospheric Physics, Chinese Academy of Sciences (Ed.): *Dynamics of Atmospheric and Oceanic Circulations and Climate.* China Meteorological Press, Beijing, pp. 697–724.

Wang, B.: Kelvin Waves. *Encyclopedia of Meteorology.* New York: Academic Press (submitted).

Wang, B., R. Wu, and X. Fu: Mechanism of ENSO monsoon interaction during mature-decay phases of ENSO cycle. In C.-P. Chang et al. (Eds.): *Selected Papers on East Asian and Western Pacific Meteorology and Climate.* Singapore: World Scientific Publishing Company (in press).

Wang, Y., and B. Wang, 2000: Toward a unified highly resolved regional climate modeling system. In *Present and Future of Modeling Global Environmental Change: Toward Integrated Modeling*, Eds., T. Matsuno and H. Kida, TERRAPUB, **29-48**.

S-P. Xie, 2000: Formation of desert and monsoonal climates on subtropical continents. *Proceedings of the Asahi Breweries Foundation for the Promotion of Science*, **13**, 119–126. (in Japanese).

Yu, Z.: Validating precipitation products using an ocean model. *A Special Volume for Professor B. Zhu's 80th Birthday* (in press).

REPORTS AND NEWSLETTER PUBLICATIONS

Hoegh-Guldberg, O., H. Hoegh-Guldberg, D.K. Stout, H. Cesar, A. Timmermann, 2000: *Pacific in peril: Biological, economic and social impacts of climate change on Pacific coral reefs.* Greenpeace Report ISBN 1876221100.

Jensen, T. G., and D. A. Randall, 2000: *Mixed layer processes and parameterizations in high-resolution ocean models.* Final Report, U. S. Department of Energy, DOE/ER/62167–4, 32 pp.

Mitsudera, H., Y. Yoshikawa, B. Taguchi, and H. Nakamura, 2000: Kuroshio and recirculation gyres. *JAMSTECR*, **40**, 137–144 (in Japanese with English abstract).

Miyata, M., May 2000: *A note on broad and narrow solitary waves.* 47 pp. IPRC Report 00–01, SOEST 00–05

Mitsudera, H., Y. Yoshikawa, and T. Shinke, 2000: Research on analysis methods for Ocean Acoustic Tomography data using the Kalman filter (I) - Note on connection between quasi-geostrophic equations and properties from acoustic tomography measurement. *JAMSTECR*, **40**, 161–167 (in Japanese with English abstract).

Shinke, T., Y. Yoshikawa, and H. Mitsudera, 2000: Research on analysis methods for Ocean Acoustic Tomography data using the Kalman filter (II): Coupling scheme. *JAMSTECR*, **40**, 167–177 (in Japanese with English abstract).

Shiotani, M., M. Fujiwara, S.-P. Xie, H. Hashizume, T. Saito, T. Watanabe and F. Hasebe, 2000: SOWER/Pacific the Shoyo-maru Pacific ocean-atmospheric survey. *Stratospheric Processes and their Role in Climate (SPARC) Newsletter*, **14**, 17–18.

Taguchi, B., Y. Yoshikawa, H. Mitsudera, and H. Nakamura, 2000: Oceanic variability in the Kuroshio Extension - Comparison between the Kuroshio/Oyashio System Model results and the TOPEX/POSEIDON altimetry data. *JAMSTECR*, **40**, 145–160 (in Japanese with English abstract).

Tanimoto, Y., and S.-P. Xie, Interhemisphere decadal variations in SST, surface wind and heat flux over the Atlantic basin. *JAMSTECR*, **41**, 57–68 (in Japanese with English abstract).

Xie, S.-P., 2000: Japanese team measures tropical instability effects. *Physics Today*, **53** (12), 11.

Xie, S-P., 2000: El Niño and climate variability. *Umi to Minato*, **17**, 108–112 (in Japanese).

External Presentations

An, S.-I.: *Interdecadal changes in the structure and frequency of ENSO.* Department of Meteorology, University of Hawai‘i, Honolulu, Hawai‘i, U.S.A., May 2000.

An, S.-I.: *A simple atmosphere-ocean coupled model for the North Pacific interdecadal variability.* Twelfth Symposium on Global Change and Climate Variations, Annual Meeting of the American Meteorological Society, Albuquerque, New Mexico, U.S.A., January 2001.

An, S.-I., and B. Wang: *Why the properties of El Niño changed during the late 1970s.* Fall Meeting of the American Geophysical Union, San Francisco, California, U.S.A., December 2000.

Annamalai, H.: *The Asian summer monsoon system: Basic physical and dynamical processes.* (Invited) Training Institute on Climate and Society in the Asia-Pacific Region, Honolulu, Hawai‘i, U.S.A., February 2001.

Annamalai, H. and B. Wang: *Interannual variability of the intraseasonal oscillation during northern summer: Role of large- and regional-scale circulations.* Twelfth Symposium on Global Change and Climate variations, Annual Meeting of the American Meteorological Society, Albuquerque, New Mexico, U.S.A., January 2001.

Hamilton, K.P.: *Stratospheric quasi-biennial oscillations simulated in a global climate model.* Department of Meteorology, University of Hawai‘i, Honolulu, Hawai‘i, U.S.A., February 2001. Also given to the Department of Atmospheric Science, University of Washington, Seattle, Washington, U.S.A., February 2001.

Hamilton, K.P.: *Geophysical turbulence in the real world: How is the observed mesoscale energy spectrum maintained?* Northwest Research Associates, Bellevue, Washington, U.S.A., February 2001. Also given at the Canadian Climate Centre for Modelling and Analysis, Victoria, British Columbia, Canada, February 2001, and at the Wall Institute, University of British Columbia, Vancouver, British Columbia, Canada, February 2001.

Jensen, T. G.: *A gravit- wave retardation method applied to an Indian Ocean model.* (Poster) Fall Meeting of the American Geophysical Union, San Francisco, California, U.S.A., December 2000.

Li, T.: *Tropical ocean-atmosphere interactions on seasonal-to-interannual timescales.* (Invited) Qingdao Ocean University, Qingdao, China, November 2000.

Li, T.: *Dynamics of the Indian Ocean dipole mode: Effect of the monsoon, ENSO and ISO* (Invited Plenary speaker) International Workshop of Coastal Circulation and its Impact on Climate, Qingdao, China, November 2000.

Li, T., and X. Jiang: *An intermediate midlatitude-tropical atmospheric model.* Department of Meteorology, University of Hawai‘i, Honolulu, Hawai‘i, U.S.A., April 2000.

Li, T., Y. Zhang, C.-P. Chang, B. Wang: *Characteristics of the monsoon-TBO and monsoon-ENSO relations.* (Invited). International Conference on Climate Variability and Environmental Prediction (CVEP), Shanghai, China, August 2000.

Li, T., Y. Zhang, C.P. Chang, B. Wang: *Biennial and low-frequency variability of the Asian-Australian monsoon system.* (Invited) NASA Japan-USA Monsoon Workshop, Washington D.C., November 2000.

Li, T., C.P. Chang, B. Wang, Y. Zhang, E. Lu, and H. Annamalai: *A theory for the Indian Ocean Dipole Mode.* Department of Meteorology, University of Hawai‘i, Honolulu, Hawai‘i, February 2001.

Loschnigg, J.: *Emerging insights into monsoon prediction.* (Invited) Training Institute on Climate and Society in the Asia-Pacific Region, Honolulu, Hawai‘i, U.S.A., February 2001.

Loschnigg, J., J. Meehl and J. Arblaster: *The Asian monsoon, the tropospheric biennial oscillation and the Indian Ocean dipole in the NCAR CSM.* Twelfth Symposium on Global Change and Climate Variations, Annual Meeting of the American Meteorological Society, Albuquerque, New Mexico, U.S.A., January 2001. Also given at the IPRC Wednesday Discussion Group, IPRC, Honolulu, Hawai‘i, U.S.A., March 2001.

Maximenko, N.A., M.I. Yaremchuk, M.N. Koshlyakov, Y.A. Ivanov, and G.G. Panteleev: *Mesoscale structure of the Western Pacific Subarctic Frontal Zone as observed during "Megapolygon-87."* Western Pacific Geophysics Meeting, American Geophysical Union, Tokyo, Japan, June 2000.

McCreary, J.P.: *Modelling the Pacific Subtropical Cells.* (Invited) CLIVAR Workshop on the Shallow Tropical/Subtropical Overturning Cells and their Interactions with the Atmosphere, Venice, Italy, October 2000.

McCreary, J.P.: *Structure and dynamics of the Indian Ocean Cross-Equatorial Cell.* (Invited) CLIVAR Workshop on Shallow Tropical/Subtropical Overturning Cells and their Interactions with the Atmosphere, Venice, Italy, October 2000. Also given at the Institute for Marine Research, University of Kiel, Kiel, Germany, October 2000.

McCreary, J.P.: *IPRC research on Pacific decadal variability and controversies as to its cause.* (Invited) Symposium on Global Change Research: New Findings and Future Directions, Frontier Research System for Global Change, Tokyo, January 2001.

McCreary, J.P.: *On the dynamics of the Pacific subsurface countercurrents.* (Invited) Jet Propulsion Laboratory, Pasadena, California, U.S.A., February 2001.

McCreary, J.P.: *Pacific decadal variability: Theories as to its cause.* (Invited) PICES/CoML/IPRC Workshop on Impact of Climate Variability on Observation and Prediction of Ecosystem and Biodiversity Changes in the North Pacific, Honolulu, Hawai‘i, U.S.A., March 2001.

Mitsudera, H.: *Modeling of the Kuroshio and Oyashio Confluence.* PICES, Hakodate, Japan, November 2000.

Mitsudera, H.: *On the modeling of the Kuroshio and Oyashio System.* (Invited) Tohoku University, November 2000.

Mitsudera, H.: *The development of CLIVAR's strategy for the Pacific Ocean.* PICES/CoML/IPRC Workshop on Impact of Climate Variability on Observation and Prediction of Ecosystem and Biodiversity Changes in the North Pacific. Honolulu, Hawai'i, March 2001.

Mitsudera, H.: *The International Pacific Research Center.* Annual Symposium of the Frontier Research System for Global Change, Tokyo, March 2001.

Mitsudera, H., Y. Yoshikawa, and B. Taguchi: *Blocking of the Kuroshio Large Meander by baroclinic bottom pressure torque.* Fall Meeting of the Oceanographic Society of Japan, Fukuoka, Japan, September 2000.

Mitsudera, H., Y. Yoshikawa, B. Taguchi, and H. Nakamura: *Modeling of the Mixed Water Region.* Western Pacific Geophysics Meeting, American Geophysical Union, Tokyo, Japan, June 2000.

Mitsudera, H., Y. Yoshikawa, B. Taguchi, and H. Nakamura: *Modeling of the Kuroshio and Oyashio Confluence.* American Geophysical Union, San Francisco, December 2000.

Miyama, T., J.P. McCreary, and B. Qiu: *Numerical investigation of the 3-dimensional connection between the Pacific and Indian Oceans through the Indonesian Seas.* (Invited) Western Pacific Geophysics Meeting, American Geophysical Union, Tokyo, Japan, June 2000.

Miyama, T., J.P. McCreary, T. Jensen, J. Loschnigg, J.S. Godfrey, and A. Schiller: *Structure and dynamics of the surface branch of the meridional cell in the Indian Ocean.* Western Pacific Geophysics Meeting, American Geophysical Union, Tokyo, Japan, June 2000.

Miyama, T., T.G. Jensen, J. Loschnigg, J.P. McCreary, S. Godfrey, and A. Ishida: *Structure and dynamics of the Indian Ocean Cross-Equatorial Cell:* Fall Meeting of the Oceanographic Society of Japan, Fukuoka, Japan, September 2000. Given as poster at the Workshop on Shallow Tropical/Subtropical Overturning Cells and their Interaction with the Atmosphere, Venice, Italy, October 2000; and at the Fall Meeting of the American Geophysical Union, San Francisco, California, U.S.A., December 2000.

Nonaka, M. and S.-P. Xie: *Propagation of North Pacific interdecadal subsurface temperature anomalies in an ocean GCM.* Tenth Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, Ft. Lauderdale, Florida, U.S.A., May 2000.

Nonaka, M. and S.-P. Xie: *Formation of the Hawaiian Lee Countercurrent: Effect of Ekman pumping caused by the Hawaiian Islands.* Spring Meeting, Oceanographic Society of Japan, Tokyo, Japan, March 2001.

Nonaka, M. and S.-P. Xie, and J.P. McCreary: *Decadal variations in the strength of the Pacific Subtropical Cells and their effect on the tropical heat balance.* Fall Meeting of the Oceanographic Society of Japan, Fukuoka, Japan, September 2000. Also given at the CLIVAR Workshop on Shallow Tropical/Subtropical Overturning Cells and their Interaction with the Atmosphere, Venice, Italy, October, 2000 (Poster); at the NASA-IPRC-CLIVAR Workshop on Decadal Climate Variability, Honolulu, Hawai'i, U.S.A., January, 2001; and at the Annual Symposium of the Frontier Research System for Global Change, Tokyo, March 2001.

Okumura, Y., S.-P. Xie, A. Numaguti, and Y Tanimoto: *Response of an atmospheric GCM to tropical Atlantic SST dipole.* Tenth Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, Ft. Lauderdale, Florida, U.S.A., May 2000. Also given at the Chapman Conference on the North Atlantic Oscillation, Galicia, Spain, November 2000.

Qu, T.: *The confluence of the Kuroshio and Oyashio in the mixed water region east of Japan.* IPRC Mini-Workshop on the Subpolar Gyre, Honolulu, Hawai'i, U.S.A., September 2000.

Qu, T., S.-P. Xie, H. Mitsudera, and A. Ishida: *Eddy effect on the formation of the North Pacific mode waters in a global GCM.* Fall Meeting of the American Geophysical Union, San Francisco, California, December 2000.

Solomon, A., and J.P. McCreary: *Modulation of ENSO variability by decadal variations in the North Pacific Subtropical Cell.* IPRC Mini-Symposium on Decadal-Interannual Variability, Honolulu, Hawai'i, U.S.A., May 2000.

Solomon, A., J.P. McCreary, R. Kleeman, and B. Klinger: *Feedbacks between interannual tropical oscillations and decadal extratropical oscillations in an intermediate coupled model of the Pacific Basin.* NASA-IPRC-CLIVAR Workshop on Decadal Climate Variability, East-West Center, Honolulu, Hawai'i, U.S A., January 2001.

Solomon, A., J.P. McCreary, R. Kleeman, and B. Klinger: *Tropical-extratropical interactions in an intermediate coupled model of the Pacific Basin.* European Geophysical Society, Nice, France, March 2001.

Timmermann, A.: *Mechanism for decadal amplitude modulations.* NASA-IPRC-CLIVAR Workshop on Decadal Climate Variability, East-West Center, Honolulu, Hawai'i, U.S.A., January 2001.

Timmermann, A.: *The ENSO cycle.* (Invited) Training Institute on Climate and Society in the Asia-Pacific Region, East-West Center, Honolulu, Hawai'i, U.S.A. February 2001.

Timmermann, A.: *Homoclinic ENSO chaos.* European Geophysical Society, Nice, France, March 2001.

Timmermann, A.: *ENSO's most and least predictable states.* European Geophysical Society, Nice, France, March 2001.

Tomita, T., and S.-P. Xie: *Spatiotemporal structure of decadal variability observed in the North Pacific subarctic frontal zone.* Western Pacific Geophysics Meeting, American Geophysical Union, Tokyo, Japan, June 2000.

Tomita, T., M. Nonaka, and S.-P. Xie: *Decadal surface and subsurface variability in the Kuroshio-Oyashio Extension: GCM simulation and observations.* Western Boundary Current Virtual Poster Session, Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island, U.S.A., November 2000.

Tomita, T. S.-P. Xie, and M. Nonaka: *Decadal SST variability and the vertical structure observed in the mid-latitude North Pacific during 1975–1993.* Fall Meeting of the American Geophysical Union, San Francisco, California, U.S.A., December 2000.

Tomita, T., B. Wang, T. Yasunari, and H. Nakamura: *Spatiotemporal structure of decadal scale variability observed in the global SST and lower-tropospheric circulation fields.* Tenth Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, Ft. Lauderdale, Florida, U.S.A., May 2000.

Wang, B.: *Physical processes by which ENSO impacts the Asian summer monsoon.* Fifth Atmospheric Model Intercomparison Project Meeting on GCM Simulation of East-Asian Climate, Seoul, Korea, April 2000.

Wang, B.: *Climate variability and predictability.* International Forum on 21st-Century Strategy for Developing Marine Sciences, Qingdao, China, July 2000.

Wang, B.: *Interannual variability of the Asian summer monsoon: Critical roles of monsoon-ocean interaction.* (Invited) Symposium on Global Change Research: New Findings and Future Directions, Frontier Research System for Global Change, Tokyo, January 2001.

Wang, B., and X. Fu: *Processes determining the rapid reestablishment of the equatorial Pacific cold tongue.* U.S. CLIVAR Pan American Principal Investigator meeting, Potomac, Maryland, U.S.A., September 2000.

Wang, B., and Y. Wang: *Toward a unified highly resolved regional climate modeling system.* (Invited) The Present and Future of Modeling Global Environmental Change, The 14th Toyota Conference, Mikkabi, Japan, October 2000.

Wang, B., R. Wu, and X. Fu: *Pacific East-Asian teleconnection: How ENSO affects East-Asian Climate.* Tenth Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, Ft. Lauderdale, Florida, U.S.A., May 2000.

Wang, B., R. Wu, and X. Fu: *Pacific–East Asian teleconnection.* (Invited) Western Pacific Geophysics Meeting, American Geophysical Union, Tokyo, Japan, June 2000.

Wang, B., R. Wu, and K.-M. Lau: *Contrasting interannual variability of the Indian and the western North Pacific summer monsoons.* (Keynote speech) International Conference on Ocean and Atmosphere, Taipei, Taiwan, July 2000. Also given at the International Symposium on Climate Variability and Environment Prediction, Shanghai, China, August 2000.

Wang, B., R. Wu, and K.-M. Lau: *A possible linkage between the western North Pacific summer monsoon and the US Great Plains rainfall.* NASA Japan–US Monsoon Workshop, Washington D.C., November 2000.

Wang, Y., and B. Wang: *An explicit simulation of the ITCZ.* International Conference on Climate and Environment Variability and Predictability (CEVP), Shanghai, China, August 2000.

Wang, Y., and B. Wang: *Cloud-radiation forcing and oceanic monsoon.* NASA Japan–US Monsoon Workshop, Washington D.C., November 2000.

Wang, Y., J.D. Kepert, and G. J. Holland: *The effect of sea spray evaporation on tropical cyclone boundary layer structure and intensity.* The 24th Conference on Hurricanes and Tropical Meteorology, Ft. Lauderdale, Florida, U.S.A., May 2000.

Waseda, T.: *The mechanism and the impact of the short-term Kuroshio path variation.* Annual Symposium of the Frontier Research System for Global Change, Tokyo, March 2001.

Waseda, T., L. Jameson, M. Yaremchuk, and H. Mitsudera. *On the construction of the prediction error covariance matrix.* Spring Meeting of the Oceanographic Society of Japan, Tokyo, March 2001.

Waseda, T., H. Mitsudera, B. Taguchi, and Y. Yoshikawa: *Numerical study of the eddy-Kuroshio interaction.* Western Pacific Geophysical Meeting, American Geophysical Union, Tokyo, Japan, June 2000.

Waseda, T., H. Mitsudera, B. Taguchi, and Y. Yoshikawa: *Eddy-Kuroshio interaction.* Western Boundary Current Virtual Poster Session, Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island, U.S.A., November 2000; and at the Joint 140th Meeting ASA/NOISE-CON 2000, Newport Beach, California, U.S.A., November 2000.

Wu, L., and B. Wang: *Effects of convective heating on movement and vertical coupling of tropical cyclones.* The 24th Conference on Hurricanes and Tropical Meteorology, Ft. Lauderdale, Florida, U.S.A., May 2000.

Xie, S.-P.: *Monthly wind variability in the eastern equatorial Pacific.* NASA Ocean Vector Wind Science Team Meeting, Arcadia, California, U.S.A., May 2000.

Xie, S-P.: *Local and remote atmospheric response to tropical instability waves: A global view from the space.* College of Ocean and Atmospheric Sciences, Oregon State University, Corvallis, Oregon, U.S.A., June 2000.

Xie, S-P.: *Atlantic decadal variability and its effects on northern Eurasia.* Institute of Atmospheric Physics, Beijing, China, July 2000.

Xie, S-P.: *Arctic oscillation and subpolar Pacific variability.* IPRC Mini-Workshop on the Subpolar Gyre, Honolulu, Hawai'i, U.S.A., September 2000.

Xie, S-P.: *Coupled aspects of Atlantic Ocean-Atmosphere variability.* (Invited) CLIVAR Workshop on the shallow Tropical/Subtropical Overturning Cells and their Interactions with the Atmosphere, Venice, Italy, October 2000.

Xie, S-P.: *Decadal Variability.* (Invited) Training Institute on Climate and Society in the Asia-Pacific Region, East-West Center, Honolulu, Hawai'i, U.S.A. February 2001.

Xie, S-P, H. Hashizume, W.T. Liu, and K. Takeuchi: *Coupled ocean-atmospheric waves on the equatorial front: A global satellite survey.* College of Marine Environmental Science, Ocean University of Qingdao, Qingdao, China, June 2000. Also given to the National Marine Environment Forecast Center, Beijing, China, July 2000, and to the Second Institute of Oceanology, Hangzhou, China, July 2000.

Xie, S-P., M. Nonaka, A. Kubokawa, and S. Hosoda: *Decadal subsurface variability and its surface expression.* (Invited) Western Pacific Geophysics Meeting, American Geophysical Union, Tokyo, Japan, June 2000.

Xie, S-P., H. Okajima, K. Saito and A. Numaguti: *Formation of a northward displaced ITCZ in a hybrid coupled AGCM.* The 24th Conference on Hurricanes and Tropical Meteorology, Ft. Lauderdale, Florida, U.S.A., June 2000.

Xie, S-P., H. Okajima, K. Saito, and A. Numaguti: *Formation and variability of a northward displaced ITCZ in a hybrid coupled AGCM.* U.S. CLIVAR Pan American Principal Investigator Meeting, Potomac, Maryland, September, 2000.

Xie, S-P., Y.Okumura, A. Numaguti, and Y. Tanimoto: *Atmospheric response to changes in Atlantic cross-equatorial SST gradient: Tropical feedback and extratropical teleconnection.* NASA-IPRC-CLIVAR Workshop on Decadal Climate Variability, Honolulu, Hawai'i, U.S.A., January 2001.

Yaremchuk, M.I.: *Simulations of mesoscale currents in the Kuroshio Extension region: Towards a monitoring system based on acoustic tomography and satellite altimetry.* Western Pacific Geophysics Meeting, American Geophysical Union, Tokyo, Japan, June 2000.

Yaremchuk, M.I.: *A dynamically constrained synthesis of climatological data in the North Pacific Ocean.* International Union for Theoretical and Applied Mechanics (IUTAM) Symposium, Limerick, Ireland, July 2000.

Yaremchuk, M.I., and D. Nechaev: *Variational assimilation of the acoustic tomography and altimetry data into a quasi geostrophic ocean model.* (Invited) Stennis Space Center, Stennis, Mississippi, U.S.A., November 2000.

Yuan, G., H. Mitsudera, H. Fujimori, I. Nakano, Y. Yoshikawa, T. Nakamura: *A comparison of acoustic tomography and TOPEX/POSEIDON altimeter measurements in the Kuroshio Extension region in Summer 1997.* Western Pacific Geophysics Meeting, American Geophysical Union, Tokyo, Japan, June 2000. Also given at the Western Boundary Current Virtual Poster Session, Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island, U.S.A., November 2000; and at the Joint 140th Meeting ASA/NOISE-CON 2000, Newport Beach, California, U.S.A., November 2000.

Yuan, G., H. Mitsudera, Y. Yoshikawa, H. Fujimori, I. Nakano: *Observation of the Kuroshio recirculation gyre with acoustic tomography and comparison with satellite altimetries.* Spring Meeting of the Oceanographic Society of Japan, Tokyo, March 2001.

Yuan, G., H. Mitsudera, H. Fujimori, I. Nakano, and T. Nakamura: *Range-averaged currents and vorticity in the Kuroshio Extension region during Summer 1997 from long-range acoustic tomography.* Fall Meeting of the American Geophysical Union, San Francisco, California, U.S.A., December 2000.

Zhang, Y., T. Li, B. Wang, G. Wu: *Monsoon onset over Indochina and its interannual variability.* (Invited) Intraseasonal-to-Interdecadal Variability of the East-Asian Monsoon, Taipei, Taiwan, March, 2001.

Zveryaev, I.I., and P.-S. Chu: *Interannual-to-interdecadal changes in the atmospheric moisture over the global tropics.* Twelfth Symposium on Global Change and Climate Variations, Annual Meeting of the American Meteorological Society, Albuquerque, New Mexico, U.S.A., January 2001.

Zveryaev, I.I., 2001: *Interdecadal changes in the intensity of intraseasonal oscillations during boreal summer Asian mon soon.* Symposium on Climate Variability, the Oceans, and Societal Impacts, Annual Meeting of the American Meteorological Society, Albuquerque, New Mexico, U.S.A., January 2001.

International Pacific Research Center Seminars

Date	Speaker	Affiliation	Title
4/18/2000	Timothy Palmer	European Centre for Medium-Range Weather Forecasts (ECMWF), Shinfield Park, Reading, United Kingdom	*A Nonlinear Dynamical Perspective on Model Error: A Proposal for Non-local, Stochastic-Dynamic Parameterization in Weather and Climate Prediction Models*
5/8/2000	Takeshige Sugimoto	Ocean Research Institute, University of Tokyo, Tokyo, Japan	*Impacts of ENSO Events and Ocean-Climate Regime Shifts on Marine Living Resources in the Western North Pacific*
5/16/2000	Donald Dazlich	Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, U.S.A.	*Simulations with the Colorado State University General Circulation Model and Flux Coupler*
5/23/2000	Fan Wang	The Institute of Oceanology, Chinese Academy of Sciences, Beijing, China	*Circulation in the Western Equatorial Pacific Ocean and the Mindanao Undercurrent in Assimilation Data*
6/7/2000	Arthur Miller	Scripps Institution of Oceanography, University of California–San Diego, La Jolla, California, U.S.A.	*Modeling California Current System Mesoscale Observations: Fitting Physics and Biology*
6/8/2000	Warren White	Scripps Institution of Oceanography, University of California–San Diego, La Jolla, California, U.S.A.	*Influence of the Antarctic Circumpolar Wave upon Interannual Climate Variability in the Indian Ocean*
6/15/2000	Warren White	Scripps Institution of Oceanography, University of California–San Diego, La Jolla, California, U.S.A.	*Modulation of QBO and ENSO Signals by Decadal and Interdecadal Signals over the Past Century*
6/9/2000	Johannes Loschnigg and Toshio Yamagata	International Pacific Research Center (IPRC) and Frontier Research System for Global Change, Tokyo, Japan	*The Indian Ocean Dipole. IPRC Special Discussion Group on the Indian Ocean.*
7/27/2000	John McGregor	Commonwealth Scientific and Industrial Research Organisation (CSIRO), Mordiallee, Victoria, Australia	*The CSIRO Conformal-Cubic Atmospheric GCM*
8/1/2000	Toru Miyama	International Pacific Research Center (IPRC) and Frontier Research System for Global Change (FRSGC), Tokyo, Japan	*Structure and Dynamics of the Indian Ocean Cross-Equatorial Cell*
8/17/2000	Ngar-Cheung (Gabriel) Lau	NOAA–Geophysical Fluid Dynamics Laboratory, Princeton University, Princeton, New Jersey, U.S.A.	*The Atmospheric Bridge Linking ENSO Events to Extratropical SST Variability*
8/22/2000	Gregory Holland	Bureau of Meteorology Research Centre, Melbourne, Australia	*What Makes a Tropical Cyclone Not Intensify?*
8/23/2000	Alexis Lau	Center for Coastal and Atmospheric Research, The Hong Kong University of Science and Technology, Hong Kong, China	*Real-Time Numerical Weather Prediction System at HKUST*
9/14/2000	Gerold Siedler	Institute of Marine Research, University of Kiel, Kiel, Germany	*The South Atlantic: Passage for the Global Thermohaline Circulation*
10/6/2000	Mingxieng Wang	Institute of Atmospheric Physics, Beijing, China	*ACE-Asia and Mineral Dust Observed in Beijing*
10/13/2000	Zhian Sun	Bureau of Meteorology Research Centre, Melbourne, Australia	*Radiation Research at the Bureau of Meteorology Research Centre*

Date	Speaker	Affiliation	Title
11/2/2000	Gerold Siedler	Institute of Marine Research, University of Kiel, Kiel, Germany	*Pathways of Intermediate and Deep Waters in the Equatorial West Pacific*
11/8/2000	Albert Fischer	Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, U.S.A.	*The Upper Ocean Response to the Monsoon in the Arabian Sea*
12/01/2000	Leland Jameson	Hydrodynamics and Turbulence Theory and Simulation Group, Lawrence Livermore National Laboratory, Livermore, California, U.S.A.	*Various Applications of Wavelet Analysis to Oceanography: 1) Adaptive High Order Numerics 2) Data Assimilation 3) Data Analysis*
12/4/2000	Kaoru Ichikawa	Applied Dynamics Institute, Kyushu University, Fukuoka, Japan	*Variations in the Kuroshio Induced by Offshore Meso-Scale Eddies*
12/15/2000	Gerald Meehl	National Center for Atmospheric Research (NCAR), Boulder, Colorado, U.S.A.	*The Tropospheric Biennial Oscillation and Asian-Australian Monsoon Rainfall*
12/21/2000	N.H. Saji	Frontier Research System for Global Change Research (FRSGC), Tokyo, Japan	*The Dipole Mode: Air-Sea Interactions or ENSO Response?*
1/04/2001	Friedrich Schott	Institute of Marine Research, University of Kiel, Kiel, Germany	*The Three-Dimensional Circulation of the Indian Ocean*
1/17/2001	Brian Mapes	NOAA–CIRES Climate Diagnostics Center, Boulder, Colorado, U.S.A.	*Nested-Grid Modeling of the Daily Weather of Pacific Colombia*
1/23/2001	Kelvin J. Richards	School of Ocean and Earth Science, Southampton Oceanography Centre, University of Southampton, United Kingdom	*How Well Do Tracers Constrain Ocean Models?*
2/13/2001	Richard D. Rosen	Atmospheric and Environmental Research, Inc., Cambridge, Mass., U.S.A.	*Angular Momentum of the 20th and 21st Centuries*
2/2/2001	William Kessler	NOAA–Pacific Marine Environmental Laboratory, Seattle, Washington, U.S.A.	*Mean Three-Dimensional Circulation in the Northeastern Tropical Pacific*
2/9/2001	Pearn P. Niiler	Scripps Institution of Oceanography, University of California–San Diego, La Jolla, California, U.S.A.	*Wind-Driven Ocean Circulation: How Observed Currents and Winds Are Used to Calculate the Pacific Ocean Absolute Sea Level Topography*
2/9/2001	George N. Kiladis	Aeronomy Laboratory, NOAA–Environmental Research Laboratories, Boulder, Colorado, U.S.A.	*Ocean-Atmosphere Interaction Associated with Atmospheric Kelvin Waves*
2/20/2001	Akimasa Sumi	Center for Climate System Research, University of Tokyo, Tokyo, Japan	*Research Activities of the CCSR Relating to Global Change*
2/21/2001	Axel Timmermann	International Pacific Research Center (IPRC)	*Decadal ENSO Amplitude Modulation*
2/20/2001	Michael A. Spall	Department of Physical Oceanography, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, U.S.A.	*Influences of the Leeuwin Current on the Baroclinic Structure of the Indonesian Throughflow*
2/27/2001	Akimasa Sumi	Center for Climate System Research, University of Tokyo, Tokyo, Japan	*Future Direction of Model Development*
2/28/2001	Tim Li	International Pacific Research Center (IPRC)	*A Theory for the Indian Ocean Dipole Mode*
3/14/2001	Shang-Ping Xie	International Pacific Research Center (IPRC)	*Far-reaching Effects of the Hawaiian Islands on the Pacific Ocean-Atmosphere*
3/15/2001	Dmitri Nechaev	Stennis Space Center, Mississippi, U.S.A.	*A Baroclinic Model Designed for Four-Dimensional Variational Data Assimilation*
3/16/2001	Thomas Jung	Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany	*North Atlantic Interdecadal Variability: Oceanic Response to the North Atlantic Oscillation*
3/21/2001	George Philander	Princeton University, Princeton, New Jersey, U.S.A.	*Why Each El Niño Is Unique and Has Very Limited Predictability*

Workshops and Symposia

NINTH CLIVAR SCIENTIFIC STEERING GROUP MEETING

The IPRC hosted the ninth meeting of the CLIVAR (Climate Variability and Predictability Project) Scientific Steering Group at the East-West Center in Honolulu from May 2 to 5, 2000. Work under CLIVAR, a project of the World Climate Research Programme, seeks to uncover how the climate system is responding to natural processes and to human activities. CLIVAR's projects cover such topics as understanding El Niño events, monsoons in Asia and the Americas, and climate variability in Africa. Records from corals, ice-cores and tree rings show that climate has always varied, sometimes quickly (in decades) and sometimes slowly. Population growth and accompanying greater use of Earth's resources, however, are having not only serious social and economic consequences, but also climatic consequences. A major task of CLIVAR, therefore, is to understand and predict the response of the climate system to increases in greenhouse gases and aerosols.

CLIVAR co-chairs Jürgen Willebrand and Antonio Busalacchi organized the meeting together with John Gould, Director of the International CLIVAR Programme Office. Scientists from over 60 nations attended. They reviewed progress made on various CLIVAR research projects and drew up plans for future projects and collaborations.

IPRC MINI-SYMPOSIUM ON THE INTERACTION OF ENSO WITH PHENOMENA ON INTRASEASONAL-TO-INTERDECADAL TIMESCALES

A mini-symposium to promote discussion on how ENSO interacts with atmospheric and oceanic processes at interseasonal-to-interdecadal timescales was held at the University of Hawai'i on August 16, 2000. The mini-symposium was organized by IPRC researchers Amy Solomon and Soon-Il An in order to tap into the expertise of researchers visiting the IPRC: Gabriel Lau from NOAA–Geophysical Fluid Dynamics Laboratory, Lisan Yu from Woods Hole Oceanographic Institute, and Jong-Ghap Jhun from Seoul National University.

IPRC researchers and faculty from the Meteorology and Oceanography Departments of the School of Ocean and Earth Science and Technology, University of Hawai'i (UH), attended the workshop and took part in the lively discussions that followed the presentations. The mini-symposium produced an ideal opportunity for IPRC scientists to discuss with experts their findings, theories, and plans for future research on ENSO.

IPRC MINI-WORKSHOP ON THE SUBPOLAR GYRE

A mini-workshop on the Subpolar Gyre, held September 15, 2000, at the UH Campus Center, was organized by IPRC Theme 2 Co-Leader Humio Mitsudera on the occasion of visits by Moto Ikeda and Shoshiro Minobe, both from Hokkaido University and affliated with the International Arctic Research Center (IARC).

The aim of the workshop was to have IARC, IPRC, and UH scientists share with each other their research interests in the Subpolar Gyre and the Arctic Ocean. They explored common ground in their research efforts and discussed possibilities for future collaboration.

NASA-IPRC-CLIVAR DECADAL CLIMATE VARIABILITY WORKSHOP

The IPRC hosted the Decadal Climate Variability Workshop at the East-West Center in Honolulu from January 8 to 12, 2001. The workshop brought together an international group of over 80 scientists who are studying patterns of climate variations occurring at decadal and longer timescales. It is now well known that the intensity and frequency of El Niño events and their seasonal impacts on global climate vary over decades. The detection and quantification of man-made changes depend on our ability to identify and quantify patterns of natural climate variability over these time frames. One purpose of the meeting, therefore, was to determine present and future observational needs for researching decadal and longer patterns of climate variations.

The scientists spoke on topics such as climate variations noted in paleoclimatic records, observations of decadal climate variations, interactions between decadal climate variability and human activity, the modeling of decadal climate variation, ocean-ice-atmosphere processes, and the nature of current and planned global observation systems. Reports by the scientists indicated a need for the following: measurements that yield better understanding of the vertical structure of the ocean, salinity, and thickness and extent of sea ice; a wider geographical sampling and broader range of paleoclimatic records; and particularly, more measurements in the Southern Hemisphere.

Workshop sponsors were NASA, IPRC, and CLIVAR; lead organizer was Vikram Mehta, research scientist at the Earth System Science Interdisciplinary Center, University of Maryland, and at NASA–Goddard Space Flight Center. Also participating were David Battisti, U.S. CLIVAR chair; Antonio Busalacchi, International CLIVAR co-chair; Eric Lindstrom, NASA Oceanography Program Scientist; and Julian McCreary, IPRC director.

CLIVAR PACIFIC IMPLEMENTATION WORKSHOP

The CLIVAR Pacific Implementation Workshop was hosted by the IPRC at the East-West Center from February 5 to 8, 2001. CLIVAR Pacific's goal is to create a scientific base of observation and modeling for predicting Pacific climate changes on seasonal-to-centennial timescales. From around the world, experts on Pacific oceanography, meteorology, and climate variability attended the workshop. The planning during the workshop formed the basis for a draft implementation plan and for recommending to the International CLIVAR Scientific Steering Group the formation of an International Pacific Panel. One purpose of the Panel is to coordinate regional and basinwide measurements collected by different countries and with various observing systems. Another is to coordinate observational studies and future studies of the as-yet sparsely sampled South Pacific.

Robert Weller, Director of the Cooperative Institute for Climate and Ocean Research at Woods Hole Oceanographic Institution, chaired the workshop and the organizing committee. Support for the workshop came from the International CLIVAR Project Office, national CLIVAR programs, and the IPRC.

PICES-COML-IPRC WORKSHOP ON IMPACT OF CLIMATE VARIABILITY ON OBSERVATION AND PREDICTION OF ECOSYSTEM AND BIODIVERSITY CHANGES IN THE NORTH PACIFIC

The workshop Impact of Climate Variability on Observation and Prediction of Ecosystem and Biodiversity Changes in the North Pacific was hosted by the IPRC from March 7 to 9, 2001, at the usual East-West Center Conference Complex in Honolulu. This workshop brought together marine and atmospheric scientists, oceanographers, and fish biologists from North Pacific Rim nations (Canada, China, Japan, Korea, Russia and the United States).

A workshop goal was to prepare a report outlining the current status and trends in the following North Pacific ecosystem components: the physical and chemical ocean condition; phytoplankton, zooplankton, micronekton, and the benthos; fish, squid, crabs, shrimps, and migratory fish; and birds and mammals. Workshop discussions and presentations showed that many databases that can be tapped for this report already exist among the various participating nations. Another outcome of the workshop was the plan to develop a meta-database listing of all sources of ecosystem data. The use of keywords in this meta-database will ensure uniform terminology that will facilitate searches. Such an integrated data system should be a great step forward in detecting basinwide patterns of change and seeing the effects of oceanic climate variations and effects of human activity on North Pacific marine ecosystems.

The workshop was organized by Patricia Livingston of the NOAA–Alaska Fisheries Science Center; and Vera Alexander, Dean, School of Fisheries and Ocean Sciences, University of Alaska. Cynthia Decker represented CoML. Sponsors were PICES (North Pacific Marine Science Organization), CoML (Census of Marine Life, through the Alfred P. Sloan Foundation), and the IPRC.

The IPRC also co-sponsored the Tropical Atmospheric Radiation Conference at the East-West Center, Honolulu, Hawaii, July 31–August 2, 2000, and the Training Institute on Climate and Society in the Asia-Pacific Region, held at the East-West Center February 5–23, 2001.

Visiting Scholars

To encourage collaboration between scientists at other climate research institutions and scientists at the IPRC, the IPRC has a visiting scholar program. The scholars sponsored from April 2000 to March 2001 are listed below.

Name	Affiliation	Title
Timothy Palmer	European Centre for Medium-Range Weather Forecasts (ECMWF), Shinfield Park, Reading, United Kingdom	4/28–5/1/2000
Fan Wang	The Institute of Oceanology, Chinese Academy of Sciences, Beijing, China	5/21–5/28/2000
Warren White	Scripps Institution of Oceanography, University of California–San Diego, La Jolla, California, U.S.A.	6/5–6/16/2000
John McGregor	Commonwealth Scientific and Industrial Research Organisation (CSIRO), Mordiallee, Victoria, Australia	7/26–7/27/2000
Jong-Ghap Jhun	Seoul National University, Seoul, South Korea	8/12–8/18/2000
Ngar-Cheung Lau	NOAA–Geophysical Fluid Dynamics Laboratory, Princeton University, Princeton, New Jersey, U.S.A.	8/13–8/27/2000
Lisan Yu	Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, U.S.A.	8/14–8/18/2000
Alexis Lau	Hong Kong University of Science & Technology, Hong Kong	8/21–8/28/2000
Gerold Siedler	Institute of Marine Research, University of Kiel, Kiel, Germany	8/21–11/6/2000
Zhian Sun	Bureau of Meteorology Research Centre, Melbourne, Australia	9/18–10/14/2000
Pearn P. Niiler	Scripps Institution of Oceanography, University of California–San Diego, La Jolla, California, U.S.A.	10/30/00–6/30/01
Leland Jameson	Lawrence Livermore National Laboratory, Livermore, California, U.S.A.	11/26–12/2/2000
Kaoru Ichikawa	Kyushu University, Fukuoka, Japan	12/3–12/9/2000
Kazutoshi Horiuchi	Frontier Research System for Global Change, Tokyo, Japan	12/11–12/15/2000
Gerald Meehl	National Center for Atmospheric Research (NCAR), Boulder, Colorado, U.S.A.	12/14–12/15/2000
N.H. Saji	Frontier Research System for Global Change, Tokyo, Japan	12/20–12/22/2000
Friedrich Schott	Institute of Marine Research, University of Kiel, Kiel, Germany	12/26–1/13/2001
Kelvin Richards	School of Ocean and Earth Science Southampton Oceanography Centre, University of Southampton, United Kingdom	1/10–1/30/2001
Brian Mapes	NOAA–CIRES Climate Diagnostics Center, Boulder, Colorado, U.S.A.	1/15–1/18/2001
George N. Kiladis	Aeronomy Laboratory, NOAA–Environmental Research Laboratories, Boulder, Colorado, U.S.A.	2/9/2001
Richard D. Rosen	Atmospheric and Environmental Research, Inc., Cambridge, Mass., U.S.A.	2/12–16/2001
Akimasa Sumi	Center for Climate System Research, University of Tokyo, Tokyo, Japan	2/19–3/2/2001
Dwi Susanto	Lamont Doherty Earth Observatory, Columbia University, New York, U.S.A.	2/3–2/8/2001
Jack Katzfey	Commonwealth Scientific and Industrial Research Organisation (CSIRO), Victoria, Australia	2/5–2/10/2001
William Kessler	NOAA–Pacific Marine Environmental Laboratory, Seattle, Washington, U.S.A.	2/2/2001

Name	Affiliation	Title
Michael Glantz	National Center for Atmospheric Research (NCAR), Boulder, Colorado, U.S.A.	2/14–2/18/2001
Vyacheslav Lobanov	Pacific Oceanological Institute, Russian Academy of Sciences, Vladivostok, Russia	2/23–3/2/2001
Kimio Hanawa	Tohoku University, Sendai, Japan	3/7–3/11/2001
Thomas Jung	Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany	3/13–3/16/2001
Dmitri Nechaev	Stennis Space Center, Mississippi, U.S.A.	3/15–3/21/2001
George Philander	Princeton University, Princeton, New Jersey, U.S.A.	3/18–3/24/2001

Grants

The IPRC received grants from the following United States funding agencies:

Name	P.I./Co-P.I.	Agency	Amount	Period
Support of Research at the International Pacific Research Center	L. Magaard	NASA	$1 million	5/98–4/01
Data-Intensive Research and Model Development at the International Pacific Research Center	J. McCreary S.-P. Xie H. Mitsudera T. Waseda T. Li B. Wang	NASA	$5 million	10/00–9/05
An Investigation of Monthly Wind Variability in the Eastern Equatorial Pacific Using the SeaWinds, In-situ Observations and Numerical Modeling	S.-P. Xie	NASA	$377,487	5/00–4/04
An Investigation of Tropical Convection and Atmospheric General Circulation Using Ensemble Aqua-Planet Experiments	Y.-Y. Hayashi A. Numaguti M. Ishiwatari K. Nakajima S.-P. Xie	Japan Society for the Promotion of Science	$78,000	7/00–3/03
Dynamics of the Boreal Summer Intraseasonal Oscillation	B. Wang T. Li	NSF	$400,000	4/00–3/03
Biennial and Interdecadal Variations of the Tropical Pacific Ocean	B. Wang S.-I. An	NOAA	$315,000	11/00–10/03
Low-Latitude Western Boundary Current in the Pacific	J. McCreary T. Qu H. Mitsudera T. Jensen T. Miyama	NSF	$458,538	3/01–2/04
Support Services, Logistics and Facilities Associated with the Decadal Climate Variability Workshop hosted by IPRC	L. Magaard	NASA	$25,000	12/00–4/01
Establishment of a Data and Research Center for Climate Studies	J. McCreary P. Hacker R. Merrill H. Mitsudera T. Waseda	NOAA	$515,000	10/01– 9/02

Under the cooperative agreement among the Japan Marine Science and Technology Center (JAMSTEC), the National Space Development Agency of Japan (NASDA), and the University of Hawai‘i, the IPRC received $3,097,039 from JAMSTEC and $716,404 from NASDA for the period of April 2000 to March 2001.

Honors

Kevin Hamilton, IPRC Theme 4 Co-Leader and Professor of Meteorology at UH Manoa, was elected a Fellow of the American Meteorological Society (AMS) in recognition of his outstanding contributions to the atmospheric sciences through his investigation of atmospheric dynamics, particularly his studies of atmospheric waves, stratospheric circulation, and comprehensive numerical modeling of global circulation and climate. The award was announced at the AMS Annual Meeting in Albuquerque, New Mexico, in January 2001. The AMS conveys this distinction annually to fewer that 1 in 500 of its members.

Lorenz Magaard, IPRC Executive Associate Director, and Professor of Oceanography at the University of Hawaii (UH) at Manoa, received the prestigious International Award of the Pacific Congress on Marine Science and Technology (PACON) for his significant contribution to the advancement of ocean science and technology. The award was conveyed at the PACON 2000 banquet held June 6, 2001, in the Hawaiian Regent Hotel in Honolulu.

IPRC in the Press...

Honolulu Star-Bulletin

May 2, 2000
Scientists plumb the oceans for climate clues
Interview with Russ Davis, John Gould, and Juergen Willebrand during CLIVAR SSG meeting
http://starbulletin.com/2000/05/03/news/story8.html

June 7, 2000
UH oceanographer awarded for work
Lorenz Magaard receives PACON award
http://starbulletin.com/2000/06/07/news/story8.html

January 13, 2001
Japan's science minister tours Hawai'i facilities
Takashi Sasagawa's visit to IPRC
http://starbulletin.com/2001/01/13/news/briefs.html

January 19, 2001
Climate prediction could ease global warming's impact, geologist says
Interview with Jonathan Overpeck during NASA-IPRC-CLIVAR Workshop on Decadal Climate Variability
http://starbulletin.com/2001/01/19/news/story9.html

January 19, 2001
Space scientists merge resources to detect tiny changes in Earth's climate
Interview with Eric Lindstrom and Vikram Mehta about NASA-IPRC-CLIVAR Workshop on Decadal Climate Variability
http://starbulletin.com/2001/01/19/news/story9.html

February 12, 2001
Isle meet makes strides in predicting climate: International scientists devise a plan to study how the ocean affects climate
Interview with Robert Weller and John Gould during CLIVAR Pacific Implementation
http://starbulletin.com/2001/02/12/news/story7.html

February 17, 2001
Global warming could change day's length, scientist says
Interview with Richard Rosen
http://starbulletin.com/2001/02/17/news/story7.html

March 21, 2001
German physicist contemplates the harmony of weather cycles
Interview with Axel Timmermann
http://www.starbulletin.com/2001/03/21/news/story6.html

The Honolulu Advertiser

May 15, 2000
Experts hope to learn why climate changes
Interview with John Gould and Juergen Willebrand during CLIVAR SSG meeting
http://the.honoluluadvertiser.com/2000/May/15/localnews19.html

July 19, 2000
UH associate dean wins prestigious marine sciences award
Lorenz Magaard receives PACON award
No web address available

January 8, 2001
Ship logs help track rainfall, drought
Interview with Vikram Mehta during NASA-IPRC-CLIVAR Workshop on Decadal Climate Variability
http://the.honoluluadvertiser.com/2001/Jan/08/18localnews16.html

February 11, 2001
Climate study covers Pacific, links nations' weather research elements
Interview with John Gould, Robert Weller, Ding Yihui, Yoshifumi Kuroda, and Jose Rutllant about CLIVAR Pacific workshop
http://the.honoluluadvertiser.com/2001/Feb/11/211localnews27.html

February 19, 2001
Climate changing, but are we?
Interview with Michael Glantz
http://the.honoluluadvertiser.com/2001/Feb/19/jan.html

February 25, 2001
Specialists talk about weather predictions
Interview with Eileen Shea about Training Institute on Climate and Society in the Asia-Pacific Region
http://the.honoluluadvertiser.com/2001/Feb/25/225localnews25.html

March 19, 2001
Oceanic changes a mystery
Interview with Jeffrey Polovina and Dick Beamish about PICES workshop
http://the.honoluluadvertiser.com/article/2001/Mar/19/ln/ln26jana.html

IPRC Staff[1]

Leadership

Julian P. McCreary, Jr.
Director, IPRC
Professor of Oceanography, SOEST
Lorenz Magaard
Executive Associate Director, IPRC
Professor of Oceanography, SOEST
Toshio Yamagata
Director of Frontier's[2] IPRC Program
Professor, Department of Earth and Planetary Science, The University of Tokyo

Researchers

THEME 1
Julian P. McCreary, Jr.
Theme Co-Leader
Shang-Ping Xie
Theme Co-Leader
Associate Professor of Meteorology, SOEST
Gang Huang
Postdoctoral Fellow
Tommy Jensen
Associate Researcher
Johannes Loschnigg
Postdoctoral Fellow
Toru Miyama
Frontier Research Scientist
Masami Nonaka
Frontier Research Scientist
Amy Solomon
Assistant Researcher
Axel Timmermann
Postdoctoral Fellow
Dailin Wang
Associate Researcher
Zuojun Yu
Associate Researcher

1 During the period of April 1, 2000, to March 31, 2001

2 Frontier Research System for Global Change

THEME 2
Toshio Yamagata
Theme Co-Leader
Humio Mitsudera
Theme Co-Leader and Frontier Group Leader
Konstantin V. Lebedev
Postdoctoral Fellow
Nikolai A. Maximenko
Associate Researcher
Tangdong Qu
Associate Researcher
Takuji Waseda
Frontier Research Scientist
Maxim I. Yaremchuk
Associate Researcher
Gang Yuan
Assistant Researcher

THEME 3
Bin Wang
Theme Co-Leader
Professor of Meteorology, SOEST
Tim Li
Theme Co-Leader
Associate Professor of Meteorology, SOEST
Soon-Il An
Assistant Researcher
H. Annamalai
Visiting Assistant Researcher
Omer L. Sen
Postdoctoral Fellow
Tomohiko Tomita
Frontier Research Scientist
Yuqing Wang
Associate Researcher
Renguan Wu
Postdoctoral Fellow
Yongsheng Zhang
Postdoctoral Fellow
Igor I. Zveryaev
Associate Researcher

THEME 4
Kevin P. Hamilton
Theme Leader
Professor of Meteorology, SOEST

Asia-Pacific Data Research Center

Peter Hacker
Manager, APDRC
Senior Research Scientist, Hawaii Institute of Geophysics and Planetology, UH

Computer and Programming Staff

Ronald A. Merrill
Computer Systems Manager
Bohyun Bang
Scientific Computer Programmer
Xiouhua Fu
Scientific Computer Programmer
Jan Hafner
Scientific Computer Programmer
Yingshuo Shen
Data Specialist
Gary Tarver
Computer Systems Engineer

Office Staff

Ellen Bahr
Administrative Program Assistant
Saeko (Sally) Conlon
Administrative Support Assistant
Jean Motooka
Administrative Specialist
Gisela E. Speidel
Public Relations Specialist and Editor
Aimee Tasaka
Fiscal Officer

Liaison Office

Motoyasu Miyata
Frontier-assigned Liaison Officer
Researcher, Earth Science and Technology Organization
Keiko Hall
Secretary

Implementation Committee

CO-CHAIRS
Japan: **Hiroshi Jyodo**
United States: **Eric Lindstrom**

Scientific Advisory Committee

CO-CHAIRS
Japan: **Jong-Hwan Yoon**
United States: **Antonio Busalacchi**

Acronyms

A-AMS	Asian-Australian Monsoon System
ADCP	Acoustic Doppler Current Profiler
AIR	All India Summer Monsoon Rainfall
AO	Arctic Oscillation
APDRC	Asia-Pacific Data Research Center
ASM	Asian Summer Monsoon
AT	Acoustic Tomography
BATS	Biosphere-Atmosphere Transfer Scheme
CEC	Cross-Equatorial Cell
CESG	Cross-Equatorial SST Gradient
CLIVAR	Climate Variability and Predictability Project
CMAP	Climate Modeling Analysis and Prediction
CMW	Central Mode Water
COADS	Comprehensive Ocean-Atmosphere Data Set
COLA	Center for Ocean-Land-Atmosphere Studies
CoML	Census of Marine Life
CPU	Central Processing Unit
CSIRO	Commonwealth Scientific and Industrial Research Organization
CSM	Climate System Model
CTD	Conductivity, Temperature, and Depth
DLT	Digital Linear Tape
DODS	Distributed Ocean Data System
DSS	Data Server System
EASM	East-Asia Summer Monsoon
ECHAM	European Center-Hamburg Atmospheric Model
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Niño-Southern Oscillation
EOF	Empirical Orthogonal Function
EUC	Equatorial Undercurrent
FERHRI	Far East Regional Hydrometeorological Research Institute
FRSGC	Frontier Research System for Global Change
GB	Gigabytes
GCM	General Circulation Model
GDS	GrADS DODS Server
GFLOPS	Giga Floating Point Operations
GLOBEC	Global Ocean Ecosystems Dynamics
GODAE	Global Ocean Data Assimilation Experiment
GrADS	Grid Analysis and Display System
GSFC	Goddard Space Flight Center
GWR	Gravity-Wave Retardation
HLCC	Hawaii Lee Counter Current
IARC	International Arctic Research Center
IOC	Interocean Circulation
IOD	Indian Ocean Dipple
IPRC-RegCM	International Pacific Research Center Regional Climate Model
ISO	Intraseasonal Oscillations
ITCZ	Intertropical Convergence Zone
ITF	Indonesian Throughflow
JAMSTEC	Japan Marine Science and Technology Center
JEBAR	Joint Effect of Baroclinicity and Relief
JGOF	Joint Global Ocean Flux
KE	Kuroshio Extension
KESS	Kuroshio Extension System Study
KOE	Kuroshio-Oyashio Extension
KPP	K-Profile Parameterization
LAN	Local Area Network
LAS	Live Access Server
LES	Large-Eddy Simulations
LLWB	Low-Latitude Western Boundary
LSM	Land Surface Model
MOM	Modular Ocean Module
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environnmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NPIW	North Pacific Intermediate Water
OSU-LSM	Ohio State University Land Surface Model
PBL	Planetary Boundary Layer
PICES	North Pacific Marine Science Organization
PMEL	Pacific Marine Environmental Laboratory
POM	Princeton Ocean Model
POP	Parallel Ocean Program; Principle Oscillation Pattern
PSU	Pennsylvania State University
PW	Precipitable Water
QBO	Quasi-Biennial Oscillation
QG	Quasi-Geostrophic
RAID	Redundant Array of Independent Disks
RISC	Reduced-Instruction-Set Computing
SAN	Storage Area Network
SEEK	Singular Evolutive Extended Kalman
SLP	Sea Level Pressure
SODA	Simple Ocean Data Assimilation
SOEST	School of Ocean and Earth Science and Technology
SSH	Sea Surface Height
SSiB	Simplified Simple Biosphere
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
STC	Subtropical Cell
STMW	Subtropical Mode Water
Sv	Sverdrup
SVD	Singular Value Decomposition
T/P	TOPEX/POSEIDON
TB	Tera Bytes
TBO	Tropospheric Biennial Oscillation
TJ	Tsuchiya Jet
TKE	Turbulent Kinetic Energy
TOC	Thermocline Overturning Circulation
UCAR	University Corporation for Atmospheric Research
UH	University of Hawai‘i
USGS	United States Geological Survey
WHOI	Woods Hole Oceanographic Institution
WNP-EA	Western North Pacific-East Asian
WP-EA	Western Pacific-East Asian
XBT	Expendable Bathothermograph

A publication of the
International Pacific Research Center
School of Ocean and Earth Science and Technology
University of Hawai‘i at Mānoa
2525 Correa Road
Honolulu, Hawai‘i 96822

Tel: (808) 956-5019
Fax: (808) 956-9425
Web: http://iprc.soest.hawaii.edu

Editor: Gisela E. Speidel, Ph.D.
Email: speidel@soest.hawaii.edu

October 2001

For address correction, send name with old and new addresses to speidel@soest.hawaii.edu. Should you no longer wish to receive this newsletter, please let us know.