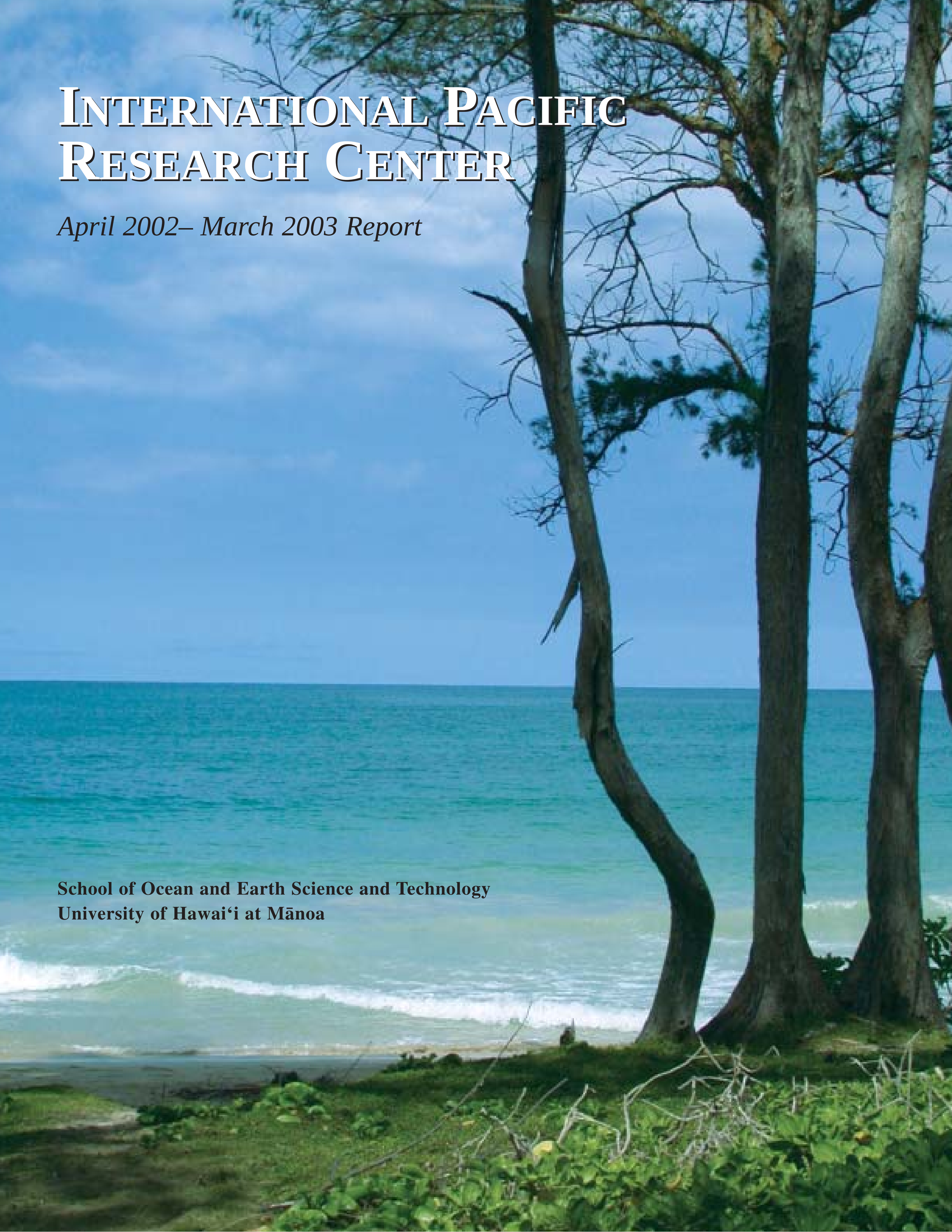

International Pacific Research Center

April 2002– March 2003 Report

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

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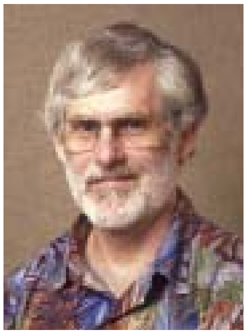
The Year's Highlights



This fourth report of the International Pacific Research Center (IPRC) provides an overview of the center's activities from April 2002 to March 2003. It has been another productive year for the IPRC in fulfilling its mission to expand understanding of climate and climate variability in Asia and the Indo-Pacific region.

Satellite-based remote-sensing technology is greatly increasing observations of Earth's climate system, especially over the vast ocean basins, allowing us to understand air-sea interactions and their role in climate variability better. IPRC researchers are taking advantage of these new measurements. Analyzing recent satellite data, they have shown that sea surface temperature in the extratropics can influence the atmosphere, that the bottom topography of shallow seas can affect winds, and that Rossby-wave atmospheric patterns generate certain tropical cyclones. In addition, they have developed new techniques for assimilating satellite and buoy measurements into numerical models.

The IPRC Regional Climate Model continues to be refined and applied to a growing number of regions, yielding new understanding of climate variability. For instance, the realistic simulation of the background conditions in the eastern Pacific, a key area in the El Niño phenomenon, reveals how the Andes influence climate there, among other things, helping to keep the intertropical convergence zone north of the equator for most of the year. Other modeling developments at the IPRC include the successful coupling of the University of Hamburg's atmospheric general circulation model, ECHAM, both with the Modular Ocean Model of the Geophysical Fluid Dynamics Laboratory and with an intermediate ocean model. By providing more realistic simulations of monsoon rainfall patterns, these improved modeling tools are now helping to answer questions about the complex interactions among air, sea, and land processes in the Asia-Pacific monsoon region.

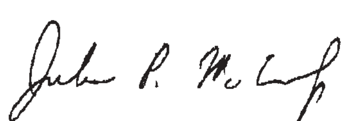
The Asia-Pacific Data-Research Center (APDRC), the branch of the IPRC that provides the international research community with easy access to climate data, has taken on the challenging task of transferring and serving some of the massive model output now being generated by Japan's Earth Simulator in such a way that researchers can easily create subsets and combinations of the products needed for their work. Moreover, the APDRC is developing ways to help the delivery, utilization, and evaluation of data products associated with the Global Ocean Data Assimilation Experiment, a project that will usher in a new era in oceanography, paralleling weather forecasting in meteorology.

In fulfilling its role as an international, state-of-the-art research environment, the IPRC also hosted two major international, interdisciplinary conferences: "Air Pollution as a Climate Forcing," which illuminated the impact of air pollution on global climate and on human health and the environment; and the "The Hadley Circulation: Present, Past, and Future" conference, which brought together scientists who study Earth's past climate system with those who explore future climate through numerical modeling.

Since its inception in 1997, the IPRC has seen significant growth in its research staff. This year, we welcomed two additional faculty members, both with appointments in the Oceanography Department at the University of Hawai'i, and next year we look forward to filling two more faculty positions in oceanography and another in meteorology. With these hires, the IPRC will finally attain the size envisioned by its original planners.

During its initial years, the center's activities were funded mostly by Japan, specifically, by the Japan Marine Science and Technology Center and the National Space and Development Agency through the Frontier Research System for Global Change. Since then, U.S. contributions have grown steadily, and last year, support from the University of Hawai'i and grants from the National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, and National Science Foundation accounted for slightly more than half of the center's funding.

Included in this report are lists of research publications and presentations by IPRC scientists; conferences, workshops, seminars, and visiting scholars to the IPRC; and funding sources for the center and for individual researchers. Summaries of the accomplishments of individual IPRC researchers again make up most of the report. Their intellectual activities are the "heart" of the IPRC and represent a high level of scientific quality and productivity.



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

About the International Pacific Research Center

The International Pacific Research Center (IPRC) at the University of Hawai‘i conducts climate research with a focus on the Asia-Pacific region. Conceived under the "U.S.–Japan Common Agenda for Cooperation in Global Perspective," the center was established in October 1997 through a cooperative agreement between the university and the Japan Marine Science and Technology Center (JAMSTEC) and the National Space Development Agency of Japan (NASDA: reorganized as JAXA in October 2003). The agreement concerned the efforts of Japan's Frontier Research System for Global Change (FRSGC) at the Mānoa campus of the University of Hawai‘i.

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 international group of scientists at the IPRC is guided by the following broad research themes and goals of the IPRC Science Plan.

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 relationships between global environmental change and Asia-Pacific climate.

The IPRC research strategy is to carry out diagnostic analyses and modeling studies of the atmosphere, ocean, and coupled ocean-atmosphere-land system, rather than to conduct field research. Data assimilation, allowing optimal incorporation of observed data into models, is an integral part of this effort.

The Asia-Pacific Data-Research Center (APDRC) is the branch of the IPRC that provides the international research community with easy access to climate data. Ensuring that data sets are easily available and usable, the APDRC is a necessary component for the study of global climate variability.

Institutional funding for the IPRC comes from the Japan Marine Science and Technology Center, National Space Development Agency of Japan, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, and the State of Hawai‘i.

米国ハワイ州ホノルル市にあるハワイ大学に置かれた国際太平洋研究センター(IPRC: International Pacific Research Center)は、アジア･太平洋地域に焦点を絞って気候の研究を行っています。IPRC は、"世界的な展望の下における協力に関する日米コモンアジェンダ"に基づいて発案され、日本の海洋科学技術センター(JAMSTEC)・宇宙開発事業団(NASDA: 2003 年 10 月からは JAXA)とハワイ大学との間の協力取り決めによって、1997 年 10 月設置されました。この取り決めは、日本の地球変動フロンティア研究システム（FRSGC）のハワイ大学マノア・キャンパスでの活動を規定しています。

IPRC の使命は、「アジア・太平洋地域における気候変動についての理解を深め、その予測可能性を向上させるために、現在与え得る国際的にも最高水準の研究環境を提供することにあり、これによって地球的な環境変化の地域的な様相についても理解をする。」とされています。IPRC に集まった国際的な科学者は、「IPRC サイエンス・プラン」(http://iprc.soest.hawaii.edu)中に示された、つぎの幅広く定義された研究テーマとゴールに導かれて、研究をしています：

テーマ 1「太平洋－インド洋地域気候」：太平洋及びインド洋地域における毎年から数十年規模の時間スケールの気候変動を理解すること。

テーマ 2「地域的な海洋の影響」：低緯度西岸境界流、黒潮･親潮、黒潮続流、縁辺海及びインドネシア通過流が、アジア・太平洋地域の気候に与える影響を解明すること。

テーマ 3「アジア・オーストラリア・モンスーン・システム」：アジア・オーストラリア　モンスーンシステムにおける気候変動及び予測可能性並びに水循環サイクルに対して季節内スケールから数十年スケールで影響を及ぼす諸過程について理解すること。

テーマ 4「地球規模の気候変動の影響」：地球規模の気候変動とアジア・太平洋地域の気候との関係を解明すること。

IPRC の研究戦略は、大気、海洋、海洋/大気/陸地複合システムの研究を、観測を行うよりもむしろ、データ解析とモデリングによる研究を推進することにあります。データ同化は、観測データを最適な形でモデルに取り入れることを可能にするので、研究過程での不可欠な部分です。

アジア･太平洋データリサーチセンター(Asia-Pacific Data-Research Center: APDRC)は、IPRC の一部門で、世界の研究者に気候データへの容易なアクセスを提供します。必要データが容易に入手でき、かつ、利用できるようにすることは、地球的気候変動の研究に必要な一部分です。

IPRC 運営資金は、日本の海洋科学技術センター、宇宙開発事業団、そして米国航空宇宙局(NASA)、米国大気海洋庁(NOAA)、米国国立科学財団(NSF)、それにハワイ州から来ています。

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

Overview

The oceans of the earth are of great importance in regulating global climate. The large heat capacity of water, together with the transport of massive amounts of warmer water toward the poles and colder water toward the equator, prevents wide temperature swings, making earth suitable for life. Since many changes in the oceans are slow, however, their effects on climate are not readily detectable. Some changes, though, are quite swift with noticeable consequences; for example, within a few months, El Niño and La Niña events alter the atmospheric circulation and sea surface temperature (SST) patterns across the equatorial Pacific and bring about far-reaching climatic changes. Understanding how Indo-Pacific ocean climate varies from year to year, over decades, and longer is therefore critical for a better understanding and prediction of climate in the Asia-Pacific region. Research under Theme 1 of the IPRC Science Plan investigates the atmospheric and oceanic circulation patterns in the Pacific and Indian Oceans, the variability of these patterns, and the processes that cause this variability.

Research this past year has included observations and modeling of the elusive ocean-to-atmosphere feedback in the extratropics, observational and numerical studies of the generation and role of density-compensating temperature and salinity anomalies, investigation of the effects of the steep Andes on climate, and studies of Indian Ocean variability and its global impact. The common thread of these studies is their relevance for air-sea coupling, either by directly studying the coupling processes, or indirectly by exploring the processes that determine the state of the ocean or atmosphere and the responses to applied forcings.

Regarding ocean-to-atmosphere feedback, evidence for such feedback in the extratropical ocean has been difficult to establish. Observations and models have shown that lower SSTs are typically associated with stronger wind speeds, and higher SSTs with weaker winds, implying that the atmosphere forces SST by transferring heat to the ocean. IPRC research using high-resolution satellite observations, however, shows a ubiquitous and robust signature of the opposite also happening: the ocean forcing the atmosphere, with high SST being associated with high winds. This association is found in the strong temperature-gradient region of the Kuroshio Extension and in other regions, including the Gulf Stream, where the imprint of the current itself can be clearly seen in high-resolution satellite observations of the surface winds. The feedbacks can even transfer the signature of bottom topography to the atmospheric boundary layer and winds in the East Asian marginal seas, where the wintertime surface mixed-layer extends to the bottom and controls the ocean heat reservoir and surface temperature. In all these cases, ocean-to-atmosphere coupling is thought to result from destabilization and increased mixing in the atmospheric boundary layer in response to higher SSTs. The dynamics of this coupling have been analyzed in the region of Tropical Instability Waves with the high-resolution IPRC Regional Climate Model; analyses suggest that in addition to vertical mixing, advection and changes in atmospheric pressure determine the atmospheric response. Idealized experiments with atmospheric general circulation models reveal that the large-scale atmosphere also responds to changes in extratropical SST by adjusting storm tracks, rather than by changing stationary waves.

Several projects have extended knowledge of the Indian Ocean. The Indian Ocean Dipole (IOD) phenomenon, which involves the interaction between an east-west sea surface temperature gradient and zonal wind stress, has stimulated investigations of the relationship between this mode and El Niño events. Correlational analyses suggest that IOD events are independent of ENSO: They affect SST in the Indian Ocean warm pool and deep convection regions and may force large-scale atmospheric teleconnections that are transmitted to remote regions. Modeling studies of the circulation in the Indian Ocean show that freshwater pathways in the Indian Ocean are part of a cross-equatorial clockwise circulation, which is affected by the monsoon and by such extreme climate conditions as El Niño, La Niña, and the IOD. The strength of the spring and fall equatorial jets in the Indian Ocean was explored by analyzing various ocean-data-assimilation products and comparing them with ship-drift data.

With regard to Pacific climate, experiments with the IPRC Regional Climate Model, showed that the steep Andes have a significant effect on the atmospheric circulation in the eastern

Pacific, among other things, helping to keep the Intertropical Convergence Zone north of the equator for much of the year. The hypothesis that inertial instability leads to mixing in the Equatorial Undercurrent and in deep jets was investigated, and further study on this topic was initiated. Another project focused on "spiciness" anomalies—temperature and salinity anomalies that offset their effects on density, with the result that they remain in the same layer when they are carried along by ocean currents. Since such anomalies can be carried from the extratropics to the equatorial upwelling regions, they are potentially important for decadal climate variations and modulation of El Niño. The generation of spiciness anomalies in the extratropics was studied by analyzing long-term observations off the coast of California and by analyzing solutions to coupled ocean-atmosphere models. The observations show that the salinity variations are dominated by multi-year and decadal timescales and result primarily from changes of the flow field. Once these anomalies arrive at the equator, a significant coupled ocean-atmosphere adjustment takes place that includes a modulation of the trade winds, thermocline depth, and El Niño.

Finally, a model development effort, carried out in collaboration with researchers at the Cooperative Institute for Research in Environmental Sciences and Colorado State University, has resulted in the Slippery Sack Model, a fully Lagrangian ocean model, in which a fluid is represented as a pile of conforming sacks whose density can be increased with depth. The model's computational efficiency is comparable to other finite difference models, but has the following advantages: extremely small advection errors, good conservation of quantities, and natural bottom topography.

Individual reports

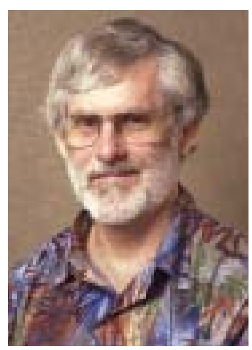
Tommy Jensen
Associate Researcher

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. His research interests include numerical modeling of oceans, coupled ocean-atmosphere models, equatorial dynamics, geophysical fluid dynamics, air-sea interaction, and coastal oceanography.

Tommy Jensen completed his study on salinity exchange between the Arabian Sea and the Bay of Bengal and on the associated cross-equatorial fluxes. Based on solutions to a 4.5-layer ocean model (the Thermodynamic Ocean Modeling System or TOMS) forced by climatology, he demonstrated that pathways of freshwater in the Indian Ocean are part of a cross-equatorial clockwise circulation. During this year, he extended that work to investigate these water exchanges under extreme climatic conditions. Setting up composite forcings for El Niño, La Niña, and Indian Ocean Dipole (IOD) years based on the Florida State University wind-products from 1970–1999, he found that during La Niña years, the clockwise mean circulation in the Indian Ocean is weaker: Less saltier water enters the Bay of Bengal from the Arabian Sea, and less fresher water from the Bay of Bengal is exported across the equator along the coast of Sumatra. The influx of low-salinity water into the Arabian Sea via the Somali Current is also reduced, while the flow of Bay of Bengal water into the Arabian Sea is enhanced. In contrast, during El Niño years, the clockwise mean circulation is enhanced: The flow of Arabian Sea water into the Bay of Bengal increases, as does the cross-equatorial flow of low-salinity water from the Bay of Bengal along the eastern basin boundary. The flow towards the Arabian Sea from the Bay of Bengal during the northeast monsoon is much reduced, further inhibiting the westward pathway of freshwater in the northern Indian Ocean. During IOD events, the clockwise circulation is even further suppressed.

Jensen also continued his study of the Pacific North Equatorial Current (NEC) bifurcation, which determines the boundary between the tropical and subtropical gyres. Using 4.5- and 5-layer global wind-driven models (again TOMS), he showed that the observed seasonal and depth variations of the bifurcation latitude are determined primarily by the wind and that bottom topography is unimportant. The annual cycle produced by TOMS is robust in the sense that runs with winds from the European Centre for Medium-Range Weather Forecasts (1979–1988), Florida State University (1970–1999), Hellerman-Rosenstein and QuikSCAT (1999–2001) produce an annual cycle with the same phase. Systematically changing the magnitude of selected wind-stress products showed that greater wind stress moves the bifurcation latitude poleward and reduces the vertical current shear.

With Patrick Haertel (Cooperative Institute for Research in Environmental Sciences) and David Randall (Colorado State University) Jensen is developing a new, fully Lagrangian ocean model, the Slippery Sack Model. This model represents fluid as a pile of conforming sacks whose density can be increased with depth. The position of each sack is predicted from external forcing and pressure gradients. The main approximation in the model is the calculation of the pressure gradient on a finite grid. The team has improved the efficiency dramatically so that the method is now comparable to the computational cost of finite difference models. The advantages of the model are extremely small advection errors, good conservation of quantities, and natural bottom topography.



Julian P. McCreary, Jr.
Director, IPRC
Professor of Oceanography
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. His research interests include equatorial and coastal ocean dynamics, ocean circulation, coupled ocean-atmosphere modeling, and ecosystem modeling.

Jay McCreary participated in the following studies: (1) the influence of rainfall anomalies on salinity, sea-surface temperature (SST), and sea-level variability in the eastern Indian Ocean (with Claire Perigaud of the Jet Propulsion Laboratory in Pasadena, California); (2) dynamics of low-latitude western boundary currents in the North Pacific (with T. Qu, T. Jensen, T. Miyama, H. Mitsudera, Y.-Y. Kim, and H.-W. Kang); (3) the influence of Pacific decadal variability on the development of Indian Ocean dipole events (with H. Annamalai and J. Potemra); and (4) validation of various rainfall products using an ocean model (with Z. Yu). He also began projects to investigate (5) the response of the equatorial Indian Ocean to intraseasonal forcing (with T. Miyama and Debasis Sengupta of the Indian Institute of Science, Bangalore, India); and (6) the inertial instability of equatorial currents (with K. Richards and D. Wang).

In project (4), Yu and McCreary continued Yu's project summarized in last year's IPRC annual report. Last year, she obtained solutions to an intermediate (4.5-layer) ocean model forced by monthly-mean precipitation climatologies, and compared modeled (S_1) and observed (SSS) sea surface salinity fields. In the Indian Ocean, river runoff significantly influences the long-term mean SSS distribution. Since runoff data are sparse, Yu parameterized its effects by nudging model S_1 to observed SSS, but only at basin boundaries and whenever S_1 > SSS, a parameterization scheme she labeled "virtual runoff." As part of this year's work, the model's runoff field was shown to be consistent with estimates of runoff based on existing observations. The study demonstrates the usefulness of ocean models as a tool for testing precipitation products, despite the existence of model and data errors. The approach is currently limited due to the scarcity of SSS observations, but that limitation will be overcome when satellite SSS observations become available.

In project (5), Miyama, Sengupta, and McCreary are using two types of ocean models, a state-of-the-art ocean general circulation model (GCM) and a linear continuous stratified (LCS) model, to determine the cause of intraseasonal variability detected in velocity records from a current meter in the western equatorial Indian Ocean. Surprisingly, the meridional velocity (v) field has a spectral peak at a period of 12 days, whereas the wind has a peak at 30 days or more. A GCM solution shows clearly that v is primarily wind driven, and that mixed Rossby-gravity (Yanai) waves are strongly excited. In a suite of solutions to the LCS model, Miyama and McCreary showed that v was mostly driven by meridional winds. Further, they duplicated the ocean's preference for 12-day forcing, tracing it to basic properties of Yanai waves and to the presence of vertical mixing.

In project (6), McCreary is exploring the inertial instability of equatorial zonal currents that are functions of latitude only, $U(y)$. Previous studies have typically looked for x-independent unstable waves, that is, waves with zero zonal wavenumber. McCreary, however, demonstrated the existence of bands of inertially unstable waves with non-zero wavenumbers. Moreover, by gradually weakening $U(y)$, he showed that the bands still exist when $|U(y)| < |f|$ (f is the Coriolis frequency) everywhere in the domain, that is, they occur even *outside* the range of traditional inertial instability. Future work will seek to relate these instabilities to the interleaving of water masses in the Equatorial Undercurrent, as discussed by K. Richards.

Masami Nonaka
Frontier Research Scientist

Masami Nonaka obtained his Ph.D. in environmental earth science from Hokkaido University, Japan, in December 1998. His research interests include oceanic connections between the subtropics and the tropics, and the role of the ocean in Pacific decadal climate variation.

Basin-scale North Pacific sea surface temperature (SST) is known to correlate significantly with wind velocity both at the sea surface and aloft. In winter, warm (cool) SST anomalies are often collocated with low (high) wind speed. This negative SST-wind correlation is thought to be due to atmospheric forcing of the ocean: Stronger winds cool the ocean more than weaker winds. The search for oceanic feedback to the atmosphere in the extratropics, on the other hand, has not yielded conclusive evidence, the weather noise-level being high and the data record short. Simulations with atmospheric general circulation models disagree on whether and how the atmosphere responds to extratropical SST anomalies.

Masami Nonaka, in collaboration with Shang-Ping Xie, has focused on this issue of midlatitude feedback from ocean to atmosphere by studying the Kuroshio Current south of Japan and the Kuroshio Extension (KE) to the east, which separates warmer subtropical water to the south from colder subpolar water to the north and appears as a sharp SST front in the North Pacific. The KE is potentially suitable for investigating this issue because it is highly unstable and has large meanders. The strong eddy activity in the KE, moreover, gives rise to large SST variations on sub-seasonal timescales, and these variations conceivably could lead to coherent ocean-atmosphere covariability.

Using satellite measurements, Nonaka and Xie showed that SST and surface wind speed do vary together in this region, with high (low) wind speeds found over warm (cool) SSTs (Figure 1). They confirmed this SST-wind covariability by analyzing *in situ* buoy measurements in the KE region. In spite of the very high weather noise—the KE region is well known for generating storms—the SST-induced wind anomalies were detectable: The buoy data showed that the standard deviation of intraseasonal (10 to 90 days) wind variability is 1.3 m/s, whereas the standard deviation of SST-induced wind anomalies is only 0.3 m/s. This modest SST effect was detectable within the strong weather noise by using an appropriate space-time filter. In late spring and early summer, the close association between the Kuroshio south of Japan and wind becomes readily visible even without such a filter because weather noise is less.

Nonaka explains the SST-induced effect on the winds observed over the Kuroshio and Kuroshio Extension by vertical mixing in the atmosphere as it adjusts to the changing SST. This mechanism has been extensively studied in ocean-atmosphere covariability induced by Tropical Instability Waves at the Pacific equatorial front (~2°N).

The positive SST wind-speed correlation detected by Nonaka over the Kuroshio is in sharp contrast to the basin-wide negative correlation observed so often in the extratropical Pacific and Atlantic and is indicative of atmosphere-to-ocean forcing. Clearly, over the strong Kuroshio meanders, a feedback is operating in which SST anomalies cause the surface wind to change. In short, there is midlatitude ocean-to-atmospheric feedback.

N. H. Saji
Assistant Researcher

N. H. Saji received his Ph.D. in atmospheric sciences in 1997 from the Indian Institute of Science, Bangalore, India. His research interests include the Indian Ocean Dipole mode and intraseasonal variability in Indian Ocean sea surface temperature.

Indian Ocean Dipole (IOD) events, periods during which sea surface temperature (SST) in the Indian Ocean is significantly colder in the east than in the west, have become of great interest to climate researchers. N.H. Saji (Saji and Yamagata, 2003) studied SST and surface wind variability during Indian Ocean Dipole (IOD) events by using monthly ship-based observations from 1958 to 1997. He found that the largest variance in SST and surface wind in the Indian Ocean occurs during boreal summer and fall and that IOD events contribute to nearly 30% (50%) of the variance in western (eastern) Indian Ocean SST. IOD events are even more closely associated with the east-west SST gradient and east-

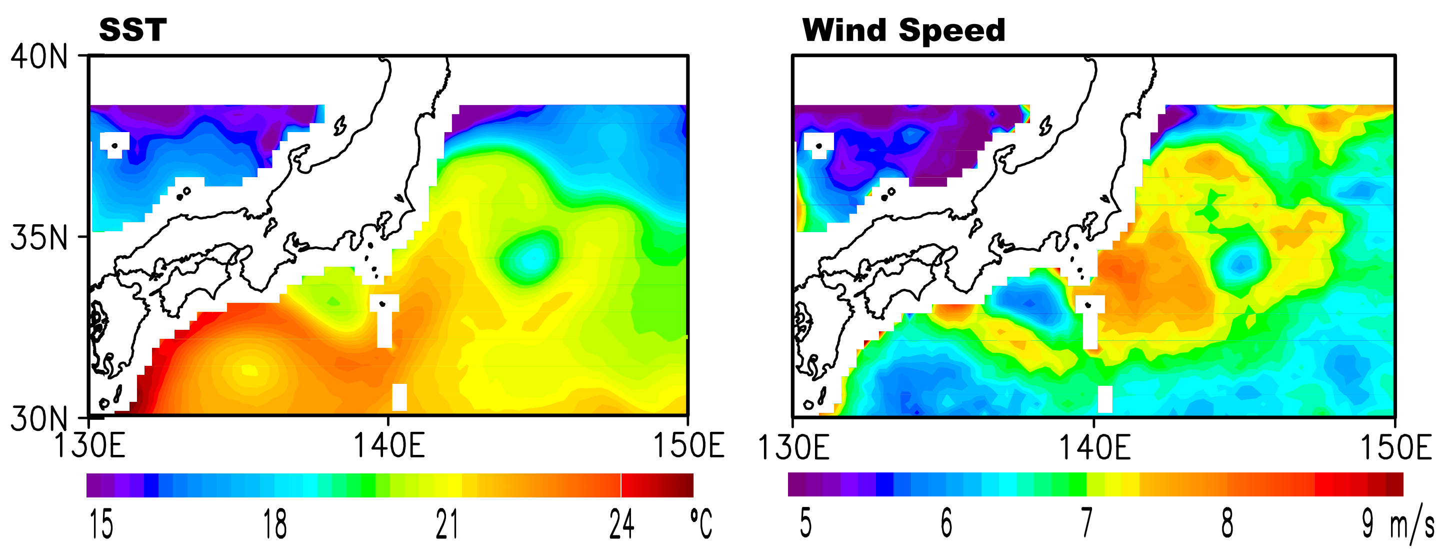


Figure 1. Mean sea surface temperature (left) and sea surface wind speed (right) observed from April to June 2001 by the TRMM microwave imager. Low wind speeds are found over cool waters associated with the meander of the Kuroshio Current along the southern coast of Japan around 137ºE. The same relation between sea surface temperature and winds is also found over the cold ring around 145ºE, 35ºN.

west equatorial winds in the Indian Ocean, accounting for nearly 80% of their variance. Although many IOD events co-occurred with El Niño, IOD events occurring in the absence of El Niño accounted for more of the variance in the east-west SST gradient (60%) than those co-occurring with El Niño (40%). The SST and wind spectra in the Indian Ocean also matched each other more closely than those in the Pacific, suggesting that they are more closely linked than to conditions in the Pacific. Saji, moreover, noted that El Niño events that co-occurred with IOD events were considerably stronger and developed more rapidly than those that occurred in the absence IOD events.

The extent to which IOD events affect global climate is not known. Although SST anomalies in the Indian Ocean are smaller in amplitude than those in the Pacific, they occur in a warm pool with SST on the average higher than 27°C. Because of this backdrop, small SST anomalies in the Indian Ocean could prompt a climatically significant atmospheric response. Observations seem to support this hypothesis, since rainfall anomalies in the equatorial Indian Ocean have nearly the same amplitude as those in the Pacific during El Niño events. This similarity suggests that IOD events may not only strongly affect the regional climate but, given the proximity to the subtropical Australian jet stream, could also easily generate upper tropospheric Rossby waves that propagate out of the Indian Ocean to affect climate to the east.

To investigate whether IOD events could generate Rossby waves that have more global climate effects, Saji and Yamagata (2003b) examined the relationships between Indian Ocean SST patterns and rainfall over land worldwide. Tabulating regions with significant associations (Figure 2), they analyzed them statistically, ruling out coincidental associations. Using a multiple regression analysis to take into account the effects of El Niño, they found that IOD events were uniquely associated with about 36% of the fall rain variance over East African countries and nearly 60% of the summer rain variance over Sumatra. IOD events appeared to be strongly correlated also with surface temperature anomalies over regions as far away as northeastern Asia and Brazil. To determine atmospheric mechanisms that could mediate between Indian Ocean SST patterns and the rainfall anomalies, they studied multilevel atmospheric wind and pressure fields in the NCEP reanalysis data and noted that the tropical atmosphere overlying the SST anomalies had a baroclinic structure, while the remote regions had an equivalent barotropic structure. Moreover, Rossby-wave-like trains extended from the southern Indian Ocean southeastward towards the Pacific Ocean.

Observations show that monsoon rainfall anomalies occur during IOD events, suggesting that at times when the SST gradient is reversed, the Indian monsoon tends to be stronger than normal. Saji (Ashok, Guan, Saji, and Yamagata, 2003) conducted a collaborative atmospheric GCM study indicating that IOD conditions could affect rainfall by modulating the Hadley Circulation over the Bay of Bengal.

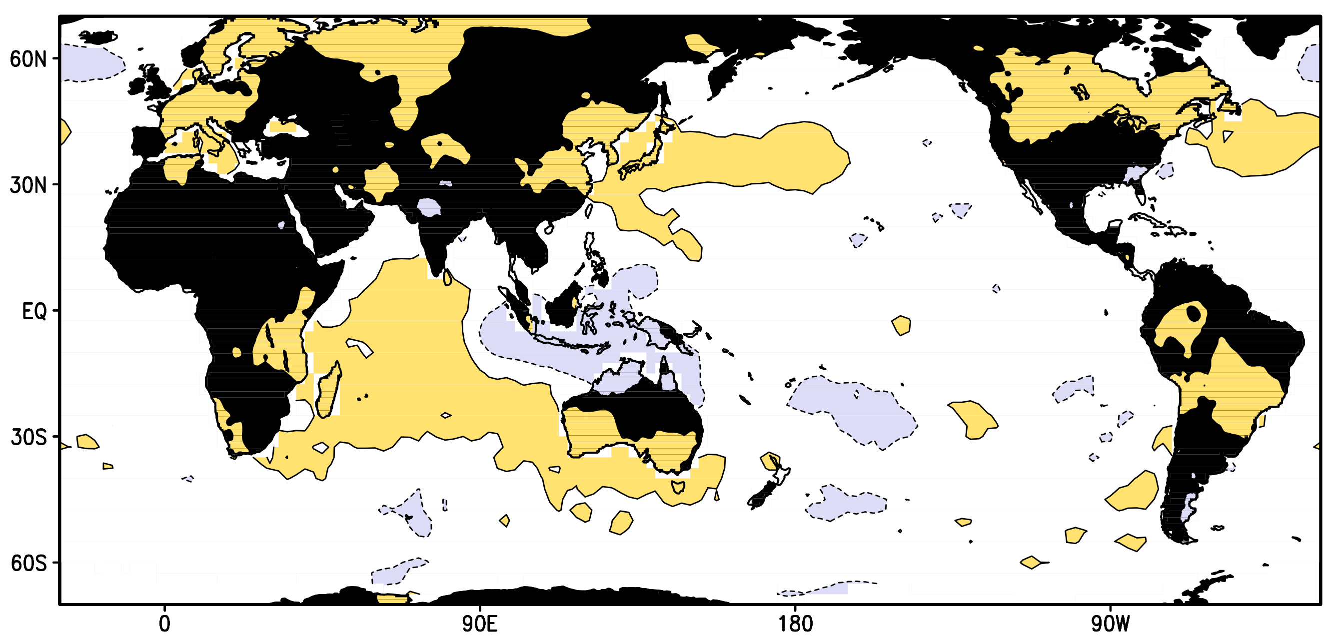


Figure 2. Regions in which the Indian Ocean sea surface temperature is significantly positively (yellow) and negatively (blue) correlated with observed boreal summer land-surface temperatures. The effect of ENSO was removed from the estimate with a linear multiple regression analysis.

Niklas Schneider
Associate Professor of Oceanography

Niklas Schneider received his Ph.D. in physical oceanography in 1991 from the University of Hawai'i at Mānoa. His research interests include decadal climate variability, tropical air-sea interactions, and coupled modeling.

Spiciness anomalies in the upper ocean are temperature and salinity anomalies that offset their effects on density, with the result that they behave much like a water marker—a passive tracer—that is carried along and mixed by ocean currents, and does not influence oceanic motions. Such anomalies in the thermocline are one of the processes that could underlie decadal climate variations in the Pacific. Since joining the IPRC, Niklas Schneider has worked on aspects of this idea, namely, on the generation of these anomalies in the extratropics and the coupled ocean-atmosphere response to their surfacing in the equatorial upwelling regions.

The California Current supplies water to the eastern Pacific, which is subducted into the thermocline as eastern Subtropical Mode Water and then flows equatorwards and westward. More than 50 years of ocean observations obtained during the California Cooperative Fisheries Investigation show that temperature and salinity variations in the California Current have very different low-frequency variabilities. Temperature variations are dominated by interannual variations associated with the large-scale climate indices of the El Niño–Southern Oscillation (ENSO), the Pacific Decadal Oscillation, and local upwelling. The leading mode of salinity variance, on the other hand, is largest at the surface in the salinity minimum; it varies at interannual and decadal timescales and is independent of the three climate indices mentioned above and of ENSO-related heaving of the halocline. The salinity variations, moreover, are inconsistent with observed surface freshwater flux and across-shore flux anomalies, as well as with vertical exchange processes. Alongshore anomalous advection, accumulated along the mean southward trajectory of the California Current, is the only viable explanation and is roughly consistent with observations of the geostrophic flow.

Below the surface, spiciness anomalies can be generated by changes in the flow paths in the thermocline. This process becomes more important with increasing distance from the subduction region and towards the western ocean. This increased variance in thermocline salinity and temperature in the western ocean results from displacements of water parcels on isopycnal surfaces due to wind-stress-induced changes in the ocean currents. Indeed, long-term integrations of coupled ocean-atmosphere models show that decadal anomalies of spiciness at the end of their extratropical-to-tropical paths are associated with wind forcing, rather than with anomalous conditions in the midlatitude subduction regions. Whether changes in the flow paths of the currents generate spiciness anomalies, however, depends critically on the temperature and salinity gradients on isopycnal surfaces. For instance, some coupled models underestimate the gradients and therefore underestimate the anomalies.

When these spiciness anomalies surface at the equator in the eastern Pacific upwelling areas, they initiate a coupled air-sea response. Using a coupled air-sea general circulation model, Schneider showed that anomalous warm and salty upwelling at the equator increases precipitation in the western Pacific and in the Intertropical Convergence Zone, and strengthens the trade winds to the east and weakens them to the west of the dateline. Central equatorial Pacific surface temperatures are raised by the resulting deepened thermocline and the northward-displaced climatological spiciness equatorial front. The warm and salty equatorial anomalies, moreover, increase the air-sea freshwater fluxes and affect the wind-driven flow paths in the extratropical thermocline, thereby producing cool and freshwater anomalies in the subduction regions. The warm and salty water at the equator also diminishes the amplitude of the model's El Niño by decreasing the thermocline feedback.

Justin Small

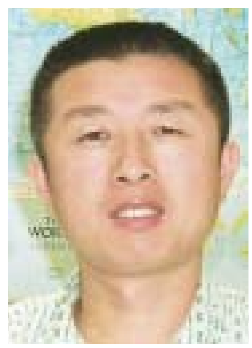
Postdoctoral Fellow

Justin Small received his Ph.D. in oceanography in 2000 from the University of Southampton, Southampton, United Kingdom. His research interests include satellite-data analysis, regional climate modeling and the simulation of nonlinear internal waves in the ocean.

Justin Small has been studying the planetary boundary layer processes over Tropical Instability Waves (TIWs)—the large meanders with wavelengths of about 1,000 km on the northern edge of the equatorial ocean cold tongue. Measures of air-sea temperature differences show that the warm and cold phases of TIWs induce large changes close to the sea surface in the static stability of the atmosphere. These changes lead to more mixing over warm sea surface temperature (SST) and less mixing over cold SST. Using the IPRC Regional Climate Model, Small conducted a numerical investigation of the relative importance of pressure gradient, horizontal advection, and vertical mixing in the atmospheric response to the TIWs. Running the model at a high horizontal resolution of 0.5° and with 29 vertical levels, he found that significant turbulent flux anomalies of sensible and latent heat are associated with the TIWs. Horizontal advection brings about air-temperature and moisture extremes downwind of the SST extremes. The pressure-driven surface wind speeds occur in phase with SST, creating a thermally direct circulation. Small concludes from his findings that pressure gradient, vertical mixing, and horizontal advection all play significant roles in determining the observed atmospheric response to TIWs, and that previous investigations have over-simplified the case by considering only one or two of these factors (see Small, Xie, and Wang, submitted to *J. Climate*).

In two statistical studies, Small analyzed the covariation of SST and properties of the atmospheric planetary boundary that he associated with ocean fronts and eddies. Applying complex Singular Value Decomposition (cSVD) and cross-spectral analysis to observational data, he studied the joint variability of SST and wind speed, and of SST and water vapor. Both methods identify the amplitude and phase of the covariability, as well the wavelength, period and phase speed. Small applied the results from the cSVD method to support his findings in the above TIW study. He applied the cross-spectral methods toward a more general analysis of fronts in the tropical ocean (Small, Xie, and Hafner, in preparation).

Small has continued his work on simulating the refraction and shoaling off a continental slope of the United Kingdom using a weakly nonlinear model. In agreement with observations, he found that the growth of nonlinear internal waves at the continental slope was capped under weakly nonlinear dynamics (Small, under review). In a new study, Small is comparing internal wave shoaling in a weakly nonlinear model and in a fully nonlinear computational fluid dynamics (CFD) model in order to identify the importance of mixing to internal wave shoaling. Preliminary results reported by Hornby and Small (2002), as well as results of the present study, are showing that the capping mechanism identified in the previous study is also seen in the CFD simulations, verifying the weakly nonlinear results and showing that turbulent effects are less important in the case of shoaling at a continental slope.



Dailin Wang

Associate Researcher

Dailin Wang received his Ph.D. in oceanography from the University of Hawaiʻi at Mānoa in 1993. His research interests include ocean general circulation modeling and ocean turbulence.

Dailin Wang's research interests encompass turbulent mixing and equatorial large-scale ocean dynamics. Only his recent studies on equatorial dynamics are highlighted below.

Linear theory predicts that shear at the equator is inertially unstable. The most unstable north-south mode resembles the equatorial Kelvin wave; the most unstable vertical mode has a zero vertical wavelength in the absence of friction. If inertial instability indeed occurs in real oceans, it would have significant implications for vertical mixing and for ocean modeling. Recent support for inertial instability includes the explanation of the so-called equatorial deep jets (Hua et al., 1997), discovered almost three decades ago by Luyten and Swallow (1976), and the existence of western Pacific interleaving (Richards and Banks, 2003).

Using an ocean general circulation model, Dailin Wang investigated the inertial instability of equatorial jets, which, when displaced off the equator, produce shear at the equator.

He found that small random noise is enough to instigate the inertial instability in the model and that initializing the model with the most unstable mode (as in Hua et al., 1997) was unnecessary. Although alternating stacked jets appeared in the anomalous velocity field, the total velocity field revealed no jet structure regardless of the strength of the background shear, and the anomalous jets eventually disappeared, resulting in an inertially stable background shear (Figure 3). Relaxation towards the background flow, as used by Hua et al., was needed to keep the alternating jets from decaying, but relaxation also weakened their amplitude. Moreover, inertial instability did not occur at all with an equatorial shear justifiable for the deep ocean and with a mixing coefficient of 0.1 cm^2/s, typical of the ocean interior. These findings cast doubt on the inertial instability theory of the equatorial deep jets.

Studying the Equatorial Undercurrent (EUC), Wang found that the observed mean shear at the equator is too weak to cause significant inertial instability and that the associated horizontal mixing was rather weak within a narrow range of the equator. It is possible, however, that a meandering EUC at any instant in time might have a larger equatorial shear. The extent of horizontal mixing due to such transient EUC shear will depend on the amplitude of the meander, background mixing rates, and duration of the transient unstable shear compared to the growth rate of the perturbation. Further investigation is needed to fully assess the importance of inertial instability in the upper equatorial ocean.

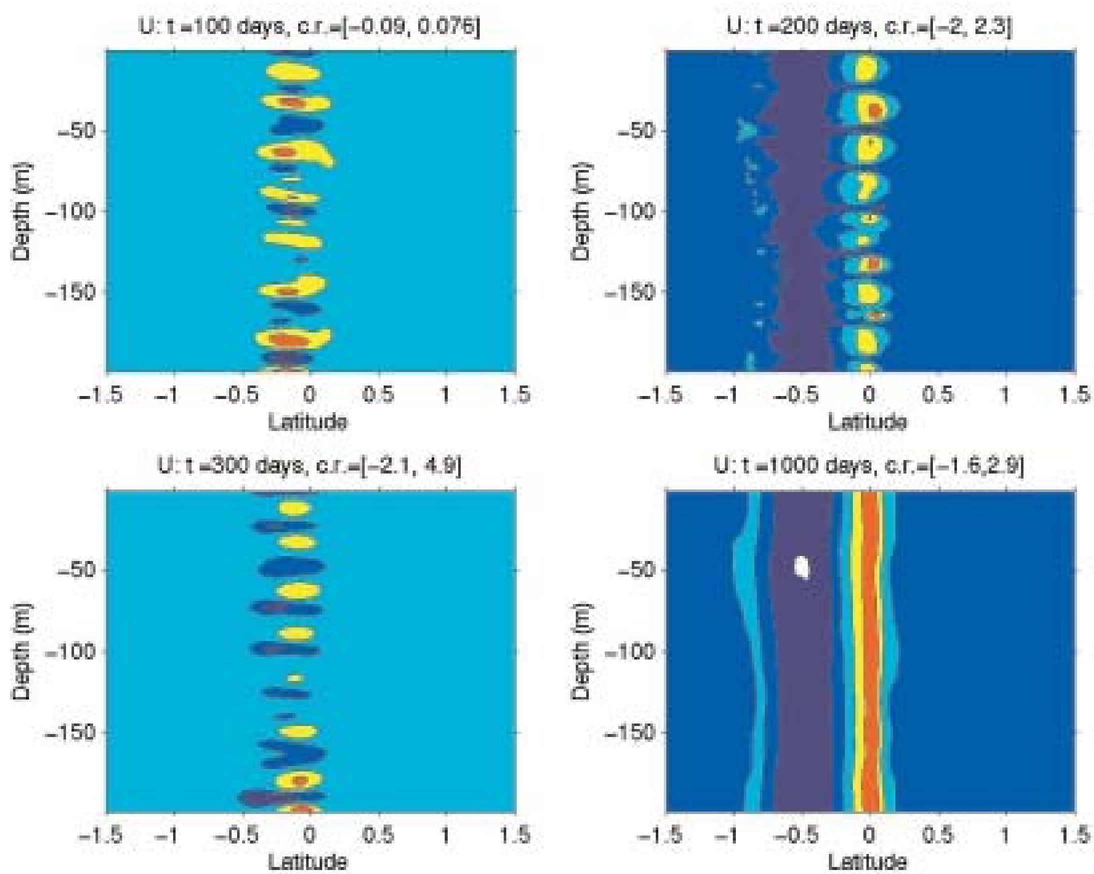


Figure 3. Inertial instability of an easterly jet centered at 1° N with a core speed of 25 cm/s. The figure shows the evolution of anomalous zonal velocity. At day 100, an alternating jet structure appears (note the small amplitude of 0.1 cm/s). By day 200, the jets have grown to about 2 cm/s. By day 300, the westward flow (cool shading) moved away from the equator, while the eastward flow (warm shading) moved towards the equator. By day 1,000, the anomalous flow at the equator is entirely eastward and the total flow field is essentially barotropic, removing the inertial instability.

Shang-Ping Xie
Professor of Meteorology
Theme 1 Co-Leader

Shang-Ping Xie obtained his Doctor of Science in geophysics from Tohoku University, Japan, in 1991. His research interests include large-scale ocean-atmosphere interaction, climate dynamics, and the general circulation of the atmosphere and oceans.

Satellite-based microwave remote sensing is revolutionizing ocean observations by routinely measuring sea surface temperature (SST), sea surface height (SSH), surface wind velocity, and precipitation nearly free of cloud interference. Much of Shang-Ping Xie's efforts this past year have been directed toward applying this suite of new satellite observations to describe and understand better air-sea interaction and its role in climate variability.

The lack of evidence for oceanic feedback to the atmosphere in the extratropics has been a stumbling block in studying non-El Niño climate variability. Analyses by Xie and his collaborators of the new satellite microwave measurements over the Indian, Pacific, and Atlantic Oceans, however, show that from the equator to midlatitudes there is a robust and ubiquitous pattern of ocean-to-atmosphere feedback: Surface wind speed tends to increase on the warmer flank of major ocean fronts and decrease on the colder flank (Xie, 2003; Xie et al., 2002; Nonaka and Xie, 2003; Hashizume et al., 2002; Cronin et al., 2003; Vecchi et al., 2003). Figure 4 shows the effect of the Gulf Stream front on surface winds in the North Atlantic Ocean. The instabilities of strong currents, which often maintain these fronts, cause the fronts to meander and to show large variations over time. Studying the satellite data on these variations, Xie and his colleagues have found positive correlations between anomalies of SST and surface wind speed, a relationship just opposite to that observed on the basin-scale, which is due to one-way forcing from the atmosphere to the ocean. This positive correlation between SST and wind speed appears to be due to enhanced vertical mixing over warm SSTs, bringing higher winds aloft to the sea surface. Over near-equatorial regions, though, the process may be different (Small et al., 2003). Xie is now extending this line of work into a global survey of mesoscale air-sea interaction (with J. Hafner, J. Small, and M. Nonaka).

The above satellite observations demonstrate that the atmospheric planetary boundary layer (PBL) responds to oceanic changes in a robust and systematic way. For example, an atmospheric general circulation model under the aqua-planet (all-water planet) condition shows that SST-induced changes in the temperature gradient in the PBL significantly modulate the storm track downstream by altering the near-surface baroclinicity and the growth of storms (Intasu et al., 2002). Ensemble simulations with a regional atmospheric model, furthermore, show that the Kuroshio front amplifies the growth of Taiwan cyclones (Xie et al., 2002). SST-induced changes in storm tracks can lead to further changes in stationary waves in the upper troposphere (Inatsu et al., 2003). These studies together suggest that not stationary waves—the focus of most previous studies—but storm tracks display the most robust atmospheric response to changes in extratropical SST.

Marginal seas are the regions where satellite observations have a distinctive advantage over traditional datasets because the important small-scale features of these seas require high spatial and temporal resolution. Using satellite observations, Xie et al. (2002) detected that during winter bathymetry leaves an imprint on SST, surface wind, and clouds over the shallow East China and Yellow seas. In another study, satellite data showed that during summer the Indochina mountain range blocks the southwest monsoon in the South China Sea, creating a strong wind jet at its southern end just north of Saigon. This wind jet, with its strong curl, causes a chain reaction in the ocean that includes a strong stationary eddy and the offshore development of a cold filament (Xie et al., 2003).

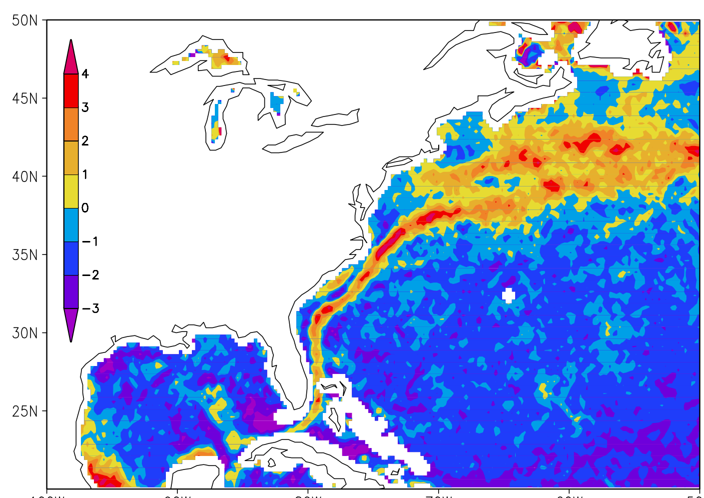


Figure 4. Ekman pumping velocity (10^{-6} m/s) calculated from the QuikSCAT satellite winds, averaged for August 1999-July 2002. The Gulf Stream leaves a strong signature in the wind field through its effect on SST, which might in turn affect the structure of the Gulf Stream.

In his work on basin-scale air-sea interaction, Xie has found that continents shape tropical climate by triggering air-sea coupled waves, notable examples being the northward displacements of the Pacific and Atlantic Intertropical Convergence Zones (ITCZs). In simulations with a coupled model, the climatological ITCZ greatly influences the space and time structures of tropical variability: When the mean ITCZ is symmetric about the equator, the cross-equatorial air-sea interaction organizes SST anomalies into a north-south dipole; when the ITCZ is realistically asymmetric, the cross-equatorial SST correlation becomes insignificant (Okajima et al., 2003). This latter result is consistent with Atlantic observations, in which SST across the equator is not significantly correlated. Xie is now conducting a related study on the interaction of the African monsoon and the Atlantic equatorial cold tongue in an atmospheric GCM (Xie and Y. Okumura).

Xie is also participating in IPRC projects designed to understand and simulate better eastern Pacific climate with the IPRC regional atmospheric model (see summaries on Y. Wang, H. Xu, and J. Small).

Haiming Xu

Postdoctoral Fellow

Haiming Xu received his Doctor of Science in meteorology in 1999 from the Department of Atmospheric Sciences, Nanjing Institute of Meteorology, Nanjing, China. His research interests include tropical meteorology and monsoon circulation, numerical modeling of the atmospheric circulation, and air-land-sea interactions.

During the past year, Haiming Xu has continued to study the effects of the narrow and steep Andes on eastern Pacific climate. In collaboration with S.-P. Xie and Y. Wang, he conducted a series of experiments with the IPRC Regional Climate Model (IPRC–RegCM) at a 0.5° resolution. In the Southern Hemisphere cold season (August–October 1999), the model reproduces key climatic features including the Intertropical Convergence Zone (ITCZ) north of the equator and an extensive low-level cloud deck to the south that is capped by a temperature inversion. Blocking the warm easterly winds from South America, the Andes help maintain the wind divergence, temperature inversion, and hence the stratocumulus cloud deck off South America. In an experiment in which the Andes were removed, warm advection from the South American Continent lowered the inversion height and reduced the low-level divergence offshore, leading to a significant reduction in cloud amount and an increase in solar radiation that reached the sea surface. In the Southern Hemisphere warm season (March and early April 1999), the model simulates a double ITCZ in response to the seasonal warming on and south of the equator, a result that is in agreement with satellite observations. Under the same sea surface temperature forcing, removal of the Andes prolongs the existence of the southern ITCZ for three weeks. Without the mountains, intrusion of easterlies from South America enhances the convergence in the lower atmosphere, and the transient disturbances travel freely westward from the continent. Both effects favor deep convection south of the equator.

The same sensitivity experiments were repeated with the orography used in T42 global models (equivalent to a grid spacing of about 2.8º). The results confirm that under-representation of the Andes reduces the stratus cloud cover in the cold season and prolongs the southern ITCZ in the warm season, both processes acting to weaken the latitudinal asymmetry of eastern Pacific climate (Xu et al., submitted to *J. Climate*).

Using the IPRC–RegCM, the above group of researchers also investigated the physical processes that contribute to the maintenance of the temperature inversion and the boundary layer stratus clouds. The strength of the capping inversion is determined not only by the large-scale subsidence and the local cool sea surface temperature, but also by feedback between the clouds and radiation. A heat budget analysis indicates that the outgoing longwave radiation cools the upper cloud layer at the inversion base, thereby increasing the temperature inversion. This cloud-top cooling also increases local subsidence in and above the inversion layer, which results in greater temperature stratification above the clouds. The stratus clouds' far-reaching effects were studied by conducting a sensitivity experiment, in which the effect of liquid clouds on the radiation budget south of the equator was removed. When the absorption of solar radiation is experimentally removed, the clouds in the boundary layer south of the equator almost disappear and precipitation to the north in the ITCZ decreases 10–15%, indicating that the stratocumulus clouds over the Southeast Pacific have both local and cross-equatorial effects (see Y. Wang's report).

Zuojun Yu

Associate Researcher

Zuojun Yu obtained her Ph.D. in physical oceanography from Nova Southeastern University, Fort Lauderdale, Florida, in 1992. Her research interests include eddy–mean flow interaction, ocean surface-mixed-layer dynamics, simulation of large-scale ocean circulations, and evaluation of data-assimilation products and forcing fields using ocean models.

As a member of the Asia-Pacific Data-Research Center (APDRC), Zuojun Yu spends part of her time comparing various data products, such as ocean surface-wind, precipitation (see 2002 report), or ocean data-assimilation products. The lack of sufficient direct measurements of ocean currents presents a challenge for oceanographers in studying the ocean circulation, even its surface flows. Data assimilation, a synthesis of observations and numerical modeling, has therefore become an increasingly important tool as a means to describe and understand the upper-ocean general circulation.

Yu has been using ocean data-assimilation products to study the surface currents in the equatorial Indian Ocean that reverse direction four times a year, flowing westward during winter and summer and eastward during spring and fall. The eastward currents were first reported by Wyrtki in 1973 and are now commonly referred to as either Wyrtki Jets (WJs) or Equatorial Jets. In spite of many studies on the WJs, two questions remain: Is the fall jet stronger than its spring counterpart, as suggested by ship-drift data? Why do numerical ocean models tend to have a stronger jet in spring than in fall? Yu made an effort to answer the first question using ocean data-assimilation products from SODA (Simple Ocean Data Assimilation; University of Maryland) and ECCO (Estimating the Circulation and Climate of the Ocean: a consortium formed by a group of scientists at the Jet Propulsion Laboratory, the Massachusetts Institute of Technology and the Scripps Institution of Oceanography). Both products are easily accessible on the APDRC server.

First, Yu compared two sets of ship-drift data, one by Mariano and the other by Richardson. Despite differences in detail, both sets show a slightly stronger fall than spring WJ. At 15-m depth (to compare with ship-drift data depth), the SODA time series from 1950 to the present gives a long-term, monthly-mean climatology with a spring jet of 70 cm/s and a fall jet of 60 cm/s. Aware that the measurement instruments changed over the years, Yu looked at the spring and fall jets also by comparing monthly-mean climatology based on measurements from 1950 to 1969 (roughly the mechanical bathythermograph period, or MBT period), 1970 to 1989 (roughly the expendable bathythermograph period, or XBT period), and 1994 to 2001 (TOPEX/Poseidon altimeter period). Interestingly, during the MBT period, the WJ is 20 cm/s stronger in spring than in fall; during the XBT period, the spring and fall jets are of similar strength; and during the TOPEX/Poseidon period, the jet is 30 cm/s stronger in fall than in spring. These inconsistencies point to a potential problem with the SODA product, possibly caused by the changes in measurement techniques. SODA, thus, cannot reliably answer the question regarding the relative strength of fall and spring WJs.

Analyzing the monthly-mean climatology from the ECCO data-assimilation product for the period 1994–2001, Yu found in this product that the jets are about 10 cm/s stronger in spring than in fall. Since this period includes the 1997–1998 El Niño, which had a tremendous impact on the Indian Ocean and in which the fall WJ disappeared, Yu excluded the 1997 record from the monthly-mean climatology. Eliminating this outlier, the jet is 10 cm/s stronger in fall than in spring, consistent with the ship-drift data.

Getting the strength of the Wyrtki Jets correct is important since observations indicate they can carry about 35 Sv warm water eastward and deepen the thermocline in the eastern equatorial Indian Ocean. The advantage of ocean data-assimilation products over ship-drift data is that the former can more easily reveal seasonal and interannual variability and provide estimates of the eastward transport of mass and heat. Yu will now try to answer the second question: Why have models failed to simulate a stronger fall WJ?

Research Activities and Accomplishments

Theme 2: Regional Ocean Influences

Overview

In the western Pacific, the boundary currents and large-scale gyres transport vast amounts of heat and salt from one region to another greatly influencing the climate of eastern Asia and Japan. They include the Kuroshio and Oyashio currents, the low-latitude western boundary currents, the complex equatorial current system, and the subpolar, subtropical and tropical gyres. Transports by the Indonesian Throughflow, connecting the Pacific and Indian Oceans, and by the regional currents connecting the seas along Asia's eastern border to the Pacific Ocean, are also important influences on Asia-Pacific climate.

The research objectives of Theme 2 are aimed at describing the major oceanic transport pathways in the western Pacific and adjacent regions, identifying their variability and underlying processes over a broad range of timescales, and determining the role and impact of regional components on Asia-Pacific climate. To address these objectives, Theme-2 researchers have used a hierarchy of modeling studies together with diagnoses of historical and recent data and of data-assimilation-based model products. The following provides an overview of Theme-2 activities from April 2002 to March 2003.

Observations over the past decade enabled the calculation of decadal-mean, global absolute sea level from a combination of data sets: surface drifters, Aviso/ENACT gridded altimetry, and NCEP/NCAR reanalysis winds. Using a technique to analyze the two-dimensional momentum balance in the upper ocean, global maps were created that reveal all known gyres, currents, jets, meanders, recirculations, and stationary eddies. The maps give an excellent overview of the complexity and spatial scales of global surface circulation. Particularly useful for Theme-2 research is the estimated base state of the surface circulation that these maps provide in the complex region of the North Pacific western boundary currents, the region that is the focus of Objective 1 under Theme 2—the determination of the processes that maintain the Kuroshio, Oyashio, and their extensions and cause their climatic variability.

With regard to understanding these processes, the following progress has been made. Analyses of model simulations of the Kuroshio show that the short-term meanders south of Japan result from baroclinic instability and that they form and dissipate much more rapidly than large meanders. Based on satellite and *in-situ* data, the formation processes, dynamic structures, and water characteristics of small meanders were described. The evolution of the Kuroshio path in response to different transport rates and wind forcing was investigated as well as the transport of inshore coastal waters eastward to the Kuroshio Extension and Kuroshio-Oyashio confluence zone. A study with a high-resolution regional model that represents the main features of the Kuroshio-Oyashio region provided a realistic simulation of the subpolar and subtropical pathways taken by Oyashio water. Analyses of the dynamical processes that form these pathways show they are strongly eddy driven. A related study used the Miami Isopycnic Coordinate Ocean Model to investigate the unusual, near-surface temperature structure of the subarctic North Pacific, where a shallow temperature minimum lies at the surface directly above a temperature inversion. In contrast to previous model studies, this one successfully reproduced the upper-ocean temperature structure including a deep winter-mixed-layer. Such an improved simulation of the winter-mixed-layer is likely to have a large impact on research into the region's nutrient and carbon cycles. In the subtropical gyre, an investigation based on historical temperature data studied the relationship between seasonal variations in the northern subsurface subtropical front and subtropical mode water. A clear seasonal cycle was identified in the newly developed climatology, and mechanisms underlying the variations were studied in terms of potential vorticity dynamics.

Objective 2 deals with the processes that maintain the low-latitude western boundary currents in the Pacific Ocean and that cause their climatic variability. A study using a variational data-assimilation technique combined atmospheric climatologies with drifter, satellite altimetry, and hydrographic data to diagnose the seasonal cycle of the 3-dimensional velocity field in the bifurcation region of the North Equatorial Current (NEC) near the Philippine coast. The analyses show that the north-south migration of the NEC bifurcation point is associated with quantitative changes in the partitioning of the NEC transport between the Kuroshio and Mindanao Current, and that the local monsoon impacts the seasonal variations in the partitioning and in the water mass distribution. A related study used a hierarchy of models, including the general circulation model of the Japan Marine Science and Technology Center (JAMSTEC), to determine the seasonal evolution of the NEC bifurcation latitude and vertical structure. Clarifying earlier conflicting results, the study identified the second vertical mode as being responsible for the northward shift of the bifurcation with depth. Interannual variations in the NEC bifurcation were found to be correlated with ENSO conditions, the bifurcation occurring at the northernmost position during El Niño and southernmost during La Niña years. The influence of the Indonesian Throughflow on the low-latitude bifurcations of both the North and South Equatorial Current (SEC) was studied with a numerical model. Blocking the Throughflow causes the SEC bifurcation's poleward shift with depth to disappear. The Throughflow contributes to tropical and subtropical gyre exchange by strengthening the equatorward western boundary currents in the intermediate layer of the South Pacific. The intrusion of Antarctic Intermediate Water (AAIW) into the western North Pacific through the low-latitude western boundary currents was revisited using historical data and hydrographic sections collected during the World Ocean Circulation Experiment. The water can be traced to only about 15°N. The AAIW pathways and their temporal variations are likely to be important for climate variability on decadal timescales.

Several projects contributed to Objective 3, determining the influence of the East-Asian marginal seas and the Indonesian Throughflow on Asia-Pacific climate. An investigation of upper-ocean heat and freshwater budgets in the Savu Sea showed very large intraseasonal (1996) variations in storage, with smaller annual and interannual variations. Interannual variations in heat storage in the Indonesian Seas could impact the heat exchange between the Pacific and Indian Oceans. Analyses of the output of the 300-year NCAR coupled model run are extending this work to decadal timescales. The higher amplitude and frequency of Indian Ocean Zonal Mode events in the 1960s and 1990s as compared to the 1970s and 1980s could, according to simulations with an ocean general circulation model, result from large-scale changes in the Pacific and Indian Ocean thermocline depth, driven by Pacific decadel variability. The simulated thermocline differences directly affect the magnitude of upwelled water off the coast of Sumatra. Further to the west, in the Bay of Bengal, an analysis of the Joint Air-Sea Monsoon Interaction Experiment (JASMINE) pilot study documented strong intraseasonal variability of the coupled atmosphere-ocean system during onset and development of the southwest monsoon. This study also addresses the Theme-3 objective on intraseasonal variability in the Indian Ocean associated with the monsoon.

Theme-2 research included several other cross-theme objectives. The concern over a central question in modeling, namely, how well ocean mixing processes are parameterized, resulted in the development of a parameterization scheme for interleaving that substantially improves the performance of an ocean model and that can rectify biases in climate models. This work on mixing processes also looked at the impact of ocean stirring and mixing caused by eddying flows on the marine ecosystem. A coupled modeling study on Tropical Instability Waves, a Theme-1 research topic, showed that atmospheric coupling has a negative feedback on the waves, effectively damping them and decreasing SST at the equator, which strengthens surface and subsurface currents.

Finally, a major modeling effort, in support of both IPRC and Asia-Pacific Data-Research Center activities, aims to develop a 4-dimensional data-assimilation system that combines the latest version of the Parallel Ocean Program (POP) and the SEEK (Sequential Evolution Extended Kalman filter). This year, a twin data assimilation test with a 1° resolution, global configuration showed that the SEEK filter performed well in reconstructing small-scale oceanic features from regular satellite altimetry observations and sporadic hydrographic profile data.

Individual reports

Takahiro Endoh

Frontier Research Scientist

Takahiro Endoh received his Ph.D. in science from the University of Tokyo, Tokyo, Japan, in 2001. His research interests include mesoscale ocean processes such as baroclinic instability and geostrophic eddies; the interannual variations in the Kuroshio, the Oyashio, and the Kuroshio Extension; and the 3-dimensional structure of ocean gyres in the North Pacific.

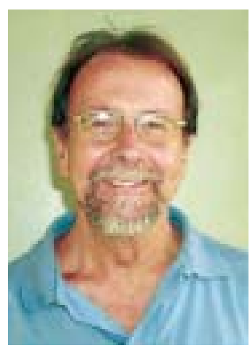
A near-surface temperature minimum and an underlying temperature inversion are remarkable features of the subarctic North Pacific. The temperature inversion is called the "mesothermal structure," and the waters corresponding to the minimum and maximum temperature of the inversion are called "dichothermal" and "mesothermal" water, respectively. Previous numerical modeling studies have not examined how the mesothermal structure forms because ocean general circulation models (GCMs) have generally failed to simulate a winter mixed layer that was deep enough to reproduce it.

This year, Takahiro Endoh, in collaboration with Humio Mitsudera, Shang-Ping Xie, and Bo Qiu, has successfully reproduced the mesothermal structure using the Miami Isopycnic Coordinate Ocean Model (MICOM), which combines a bulk mixed-layer model with a 3-dimensional, primitive, isopycnic coordinate model of the oceanic interior. The most significant difference compared to previous numerical studies is that MICOM successfully simulates a wintertime surface mixed layer deeper than 100 m in both the western subarctic and the Alaskan gyres, and this increased thickness allows MICOM to develop the mesothermal structure.

In the model, dichothermal water originates from cold and low-salinity waters locally formed in the winter mixed layer. During winter, strong cooling and wind mixing deepens the mixed layer. During spring and summer, the seasonal thermocline develops over this layer, forming the dichothermal water.

The source of mesothermal water is warm and saline Kuroshio water in the density range of 26.8–27.0 σ_θ, as shown by the horizontal distribution of a passive tracer injected into the model's subsurface layers south of Japan. Kuroshio waters flow across the boundary between the subtropic and the subarctic oceans by three pathways: in the western boundary region, it is carried to the Alaskan gyre by the northern part of the North Pacific Current; in the eastern basin, it passes through a cross-gyre window; and across the Kuroshio-Oyashio Extension by diffusion, where it enters the western subarctic gyre. The mesothermal water formed in the subarctic region is entrained into the winter mixed layer by Ekman suction weakened by lateral induction; the water flows out again to the subtropics by southward Ekman drift, thereby forming a shallow north-south overturning cell, namely, the subpolar cell.

Recent observational surveys revealed that significant exchange of CO_2 between ocean and atmosphere occurs in the subarctic North Pacific. The water exchange between the surface mixed layer and the permanent pycnocline significantly affects nutrients and primary production in the upper, illuminated zone of the marine ecosystems, and hence the ocean uptake of CO_2. An improved simulation of the winter mixed layer, like the one achieved by Endoh, is certain to have a large impact on research into the bio-geochemical cycles in this region, including the nutrient and carbon cycles.



Peter W. Hacker

Manager, APDRC
Researcher, University of Hawai'i

Peter Hacker received his Ph.D. in physical oceanography in 1973 from the Scripps Institution of Oceanography, University of California, San Diego. He has been a researcher at the University of Hawai'i since 1992 and joined the IPRC in March 2001 to head the Asia-Pacific Data-Research Center and to join Theme 2. His research interests include ocean observations, ocean circulation and mixing, air-sea interaction, and ocean-model evaluation.

Peter Hacker has been working on the completion of the overview paper (Webster et al., 2002) on the Joint Air-Sea Monsoon Interaction Experiment (JASMINE), a large pilot study that began before he joined the IPRC. JASMINE, a study of air-sea fluxes, convection, and the upper-ocean response to atmospheric forcing in the tropical eastern Indian Ocean, is a collaborative field effort among scientists at the University of Hawai'i, University of Colorado, University of Washington, NOAA Environmental Technology Laboratory, and the Commonwealth Scientific & Industrial Research Organisation in Australia. The purpose of the field work was to obtain high-quality upper-ocean, air-sea

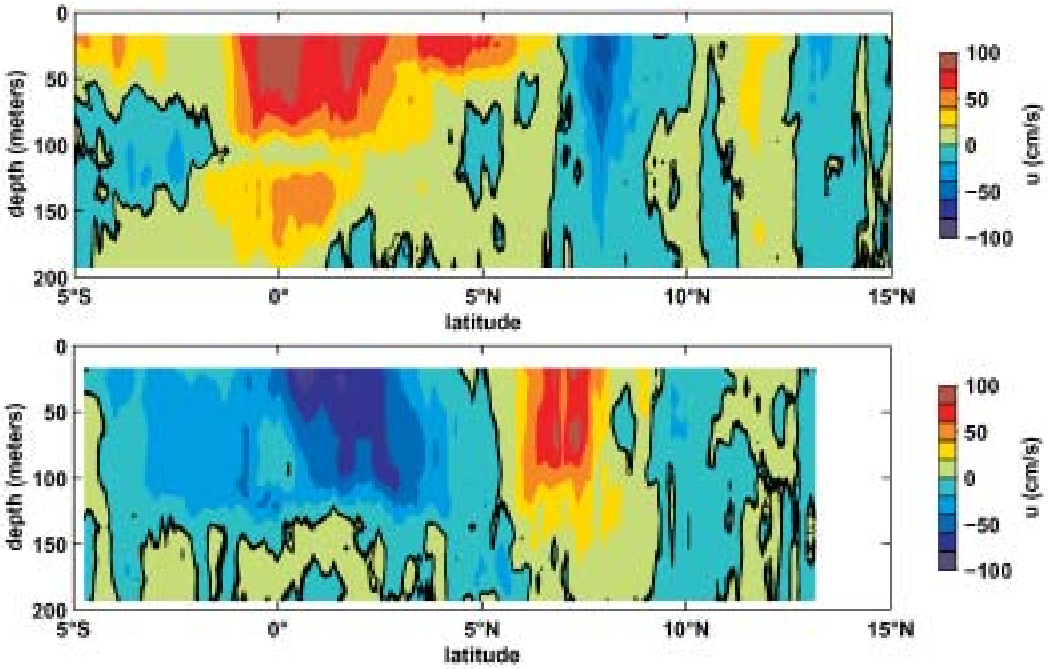


Figure 5. Zonal velocity at 88ºE. Top panel: April 10-15, 1999, during a westerly wind burst in the early southwest monsoon. Bottom panel: May 4-10, 1999, during a period of light winds. Note in April the eastward jet near the equator (Wyrtki Jet) with a banded structure of reversing currents to the north and 25 days later the nearly complete reversal of all currents along the entire section.

flux and atmospheric data sets that focus on the onset phase of the southwest monsoon and its subsequent evolution over the seasonal cycle in the Bay of Bengal. In this region, the monsoon evolution is often characterized by "active" and "break" periods, which produce strong intraseasonal variability. During the active periods the winds are strong, precipitation is heavy, and sea surface temperature drops. The JASMINE pilot study successfully observed active and break conditions during the 1999 southwest monsoon, and provided a unique data set for the further study of coupled processes in this relatively data-sparse region of the world oceans.

University of Hawai‘i investigators P. Hacker, R. Lukas, J. Hummon, and E. Firing carried out the ocean component of JASMINE together with colleagues S. Godfrey and M. Feng at Australia’s Commonwealth Scientific & Industrial Research Organisation. They documented the variations in the meridional structure of temperature, salinity, and velocity; quantified the mixed-layer and barrier-layer structures; and estimated upper-ocean heat and freshwater budgets. During the April 1999 cruise, there was a strong eastward Wyrtki Jet in response to a westerly wind burst (Figure 5). During the May cruise, the currents had reversed and flowed westward contrary to the climatological view of eastward currents for both April and May. The strong reversal of equatorial currents was accompanied by variations in the temperature and salinity fields. At 5°S and at 5°N, the top of the thermocline varied between 50-m and 150-m depth. Further north within the Bay of Bengal, the spatial structure of the freshwater front changed during this period, as did the mixed layer and barrier layer to the north of the front. These changes were due to a combination of advective processes and local air-sea fluxes. Upper-ocean heat and freshwater budget studies from two 5-day JASMINE surveys during active and break periods were done by M. Feng, R. Lukas and P. Hacker. Preliminary budget calculations suggest that future field programs will need velocity observations in the upper 20 m of the ocean (not possible with the present shipboard acoustic Doppler current profiling techniques) in order to obtain information on the very shallow mixed- and barrier-layer structures in the Bay of Bengal. For ocean models of this region to be realistic, they must, therefore, have high vertical and horizontal resolution that resolve these structures affecting sea surface temperature; they must also include atmospheric forcing that captures the intraseasonal variations.

Hacker is now using the JASMINE data to help plan programs of sustained observations and future process studies in the equatorial regions of the Indian Ocean and in the Bay of Bengal. Such planning was a topic of the "First Conference of the Indian Ocean Global Ocean Observing System, IOGOOS" held in Grand Bay, Mauritius, November 1–9, 2002.

Hyoun-Woo Kang
Postdoctoral Fellow

Hyoun-Woo Kang obtained his Ph.D. in physical oceanography from Seoul National University, Korea, in 2001. His research interests include the ocean circulation and its interaction with marginal seas, numerical ocean modeling, and remote sensing of ocean phenomena.

Hyoun-Woo Kang carried out a numerical modeling experiment on the influence of the Indonesian Throughflow (ITF) on the Indian and the Pacific Oceans using the Princeton Ocean Model (POM). By comparing solutions with open and blocked Indonesian passages, Kang was able to study how the ITF affects the subtropical-tropical exchanges. He was especially interested in its influences on the circulation of intermediate water and on the location and vertical structure of the bifurcation latitudes of the North and South Pacific Equatorial Currents, which play a key role in intergyre water-mass exchange.

For the study, Kang configured POM with a variable horizontal grid, centering the finest resolution (1/3°) on the Indonesian passages and increasing the grid size gradually up to 1.2° at the model boundaries; in the vertical, he used 31 levels, with finer resolution in the upper layers. He also conducted the open- and closed-ITF-passages experiment with a 4.5-layer ocean model (LOM) that had a constant horizontal resolution of 0.5° over the same domain as the POM simulation. Monthly averaged ECMWF wind data supplied the surface boundary forcing in both models; the POM simulations also included surface-heat and salt flux from NCEP data and restored surface temperature and salinity data with Levitus data.

The overall influence of the ITF on the Indian and Pacific Oceans in the above experiments was similar to the results of previous numerical modeling studies that concentrated on changes in the upper ocean. Regarding the ITF's influence on the intermediate layer, Kang found in the present study that the ITF has little effect on the North Equatorial Current bifurcation or on the Kuroshio and Mindanao Current transports. In contrast, there are significant changes to the circulations of the South Equatorial Current and Antarctic Intermediate Water (AAIW): the ITF drives a counter-clockwise circulation around Australasia and most changes between open and closed conditions are confined to the western boundaries of the Indian and Pacific Oceans. Regarding the South Equatorial Current (SEC) bifurcation, both models reproduced well the vertical distribution of the observed bifurcation latitude in the open Indonesian passages. POM generated an annual-mean SEC bifurcation at 16°S at the surface and 23°S in the intermediate layers around 800-m depth. Blocking the ITF alters the bifurcation latitude dramatically: The poleward tilting structure with depth disappears completely, the bifurcation latitude remaining around 16°S from the surface to about 1,000-m depth (Figure 6). The LOM solution confirms these results.

The changes in the simulated SEC bifurcation are caused by transport changes in the South Pacific western boundary currents. The open ITF increases the equatorward flows of the

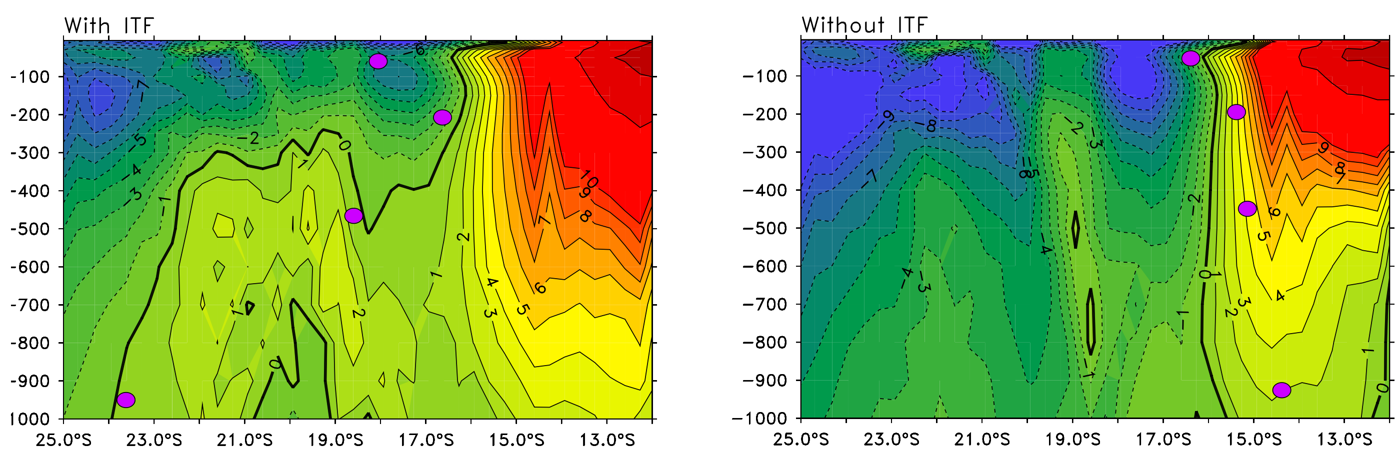


Figure 6. Latitude-depth (in m) plot of the bifurcation latitude of the Pacific South Equatorial Current in the POM solution. Contours show the meridional velocity (cm/s) averaged within 2° of the Australian coast, with the zero line representing the bifurcation latitude. Left panel: The Indonesian Throughflow is open and the bifurcation latitude tilts poleward with depth, similar to observations. Right panel: The Indonesian Throughflow is blocked and the bifurcation latitude remains near 16°S throughout. The bifurcation latitude in each layer of the LOM solution is shown by the purple dots and is dynamically similar to POM results, even though its model spin-up is much longer (100 years) than POM's (10 years).

New Guinea Coastal Undercurrent and the Great Barrier Reef Undercurrent and decreases the poleward-flowing East Australian Current. The changes in the western boundary currents also affect the transport of the AAIW. Distributions of low-salinity water in the western boundary region show that more AAIW is carried to the equator when the ITF is present. Without the ITF, the subtropical gyre at intermediate levels is almost closed at the western boundary. This closure implies that the AAIW flows westward following the SEC and then most of the water returns to the South Pacific. An interesting finding is that salinity in the western equatorial Pacific is much lower without the ITF than with the ITF. This low-saline water can be traced to the Northern Pacific, showing that in the absence of the ITF, southward penetration of North Pacific Intermediate Water expands to the equator. Thus, the ITF contributes to the tropical and subtropical gyre exchange by strengthening the equatorward western boundary currents in the intermediate layer of the South Pacific.

Yoo Yin Kim

Postdoctoral Fellow

Yoo Yin Kim obtained his Ph.D. in oceanography in 1999 from Florida State University, Tallahassee. His research interests include oceanic and atmospheric variability associated with the Madden-Julian Oscillation, El Niño–Southern Oscillation, Pacific Decadal Oscillation, and North Atlantic Oscillation; the relationship between climate and ocean circulation and their teleconnection mechanisms; and the interaction between deep and shallow seas.

Yoo Yin Kim has been studying the bifurcation of the North Pacific Equatorial Current (NEC) with a high-resolution ocean general circulation model (GCM). In the simulation, the NEC bifurcates at 15.5°N and is well defined in the upper 500 m. The bifurcation latitude varies from about 14.3°N near the surface to about 16.6°N around 500-m depth. During the summer, the bifurcation moves equatorward showing a weak poleward shift with depth, while in the winter it shifts poleward. Seasonal variations of heat storage in the upper layer are mainly due to local Ekman pumping and westward propagation of remotely forced Rossby waves. The cold (warm) heat-storage anomalies caused by cyclonic (anticyclonic) wind stress curl in the Philippine Sea shift the northern branch of the cyclonic gyre circulation north (south), and the NEC bifurcation latitude north (south).

A modal decomposition of vertical velocity and dynamic height fields suggests that the NEC bifurcation variation is related mostly to two modes: In the first mode, the formation of an anomalous cyclonic or anticyclonic gyre is associated with Ekman pumping and westward propagating Rossby waves, causing the NEC bifurcation to shift north or south. In the second mode, a dynamic height anomaly with an anomalous circulation gyre at around 150°E propagates westward. From February to June, this anomalous cyclonic gyre moves northward and shifts the NEC bifurcation northward. The northward shift is, however, counteracted by the anticyclonic gyre of the first mode. During winter, the first mode switches to a cyclonic gyre in the northeastern Philippine Sea, which enhances the northward movement of the NEC bifurcation.

On interannual time scales, the meridional migration of the NEC bifurcation latitude is well correlated with the El Niño–Southern Oscillation (ENSO). The highest correlation, $r = 0.8$, is found in the thermocline. The bifurcation occurs at its northernmost position during El Niño years, and its southernmost position during La Niña years. The leading mode in a cyclostationary EOF analysis of zonal wind stress anomalies shows the interannual evolution of strong westerlies in the equatorial central Pacific, which reflect ENSO–related interannual fluctuations. In the western North Pacific, the cold heat storage anomalies, regressed onto the wind stress anomalies, occur at the same time as El Niño warming in the equatorial Pacific and can be accounted for by the Philippine Sea anticyclone. The northernmost (southernmost) position of the NEC bifurcation corresponds to westerly (easterly) zonal wind stress anomalies in the central Pacific and cold (warm) heat storage anomalies generated by the anomalous Philippine Sea anticyclone (cyclone).

The interannual transport fluctuations of the NEC, the Mindanao Current (MC), and the Kuroshio correspond to variations in the NEC bifurcation latitude. Large transports and northward shifts in bifurcation latitude are found during El Niño years, while minimum transports and southward shifts in bifurcation latitude are found during La Niña years. Transport variations of the NEC and the Kuroshio are correlated with variations in the NEC bifurcation latitude, indicating that with a northward shift, the NEC and the Kuroshio become stronger. MC transport is less affected by shifts in NEC bifurcation latitude.

Fumiaki Kobashi

Frontier Research Scientist

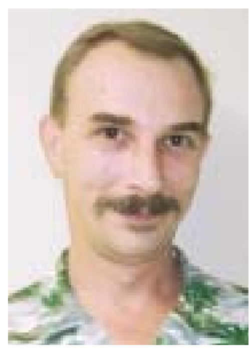
Fumiaki Kobashi received his Doctor of Science in geophysics from Tohoku University, Sendai, Japan, in 2002. His research interests include the generation process of the North Pacific subtropical countercurrent, Kuroshio dynamics, and the role of mesoscale eddies in Kuroshio variability.

Fumiaki Kobashi has been studying the two major features that characterize the upper-ocean structure of the North Pacific subtropical gyre: the subsurface subtropical front (STF) and subtropical mode water (STMW). Recently it was suggested that the STF consists of northern and southern branches, which appear along the southern boundary of different low potential vorticity (PV) waters in the ventilated thermocline. The low PV water north of the northern branch (the northern STF) is STMW.

This year, in collaboration with Humio Mitsudera, Kobashi focused on the relationship between seasonal variations in the northern STF and STMW. To study the STF with its narrow north-south structure, Kobashi constructed annual- and monthly-mean climatologies by compiling historical temperature data. Based on this new climatology, he found that the strength of the subsurface northern STF has a clear seasonal cycle, being stronger in spring and summer and weaker in fall. This seasonal cycle is zonally consistent along the front. He examined the mechanism that underlies the seasonal variations with quasigeostrophic PV dynamics, in which the strength of the front can be approximated from the product of the local stratification strength and the meridional PV gradient, integrated over the depth beneath the front. Kobashi found that while the local stratification intensifies the subsurface front from spring to summer as the seasonal pycnocline develops, it does not significantly affect the phase of the seasonal variation. The negative PV gradient leading to the STF is found below the subsurface front, on the isopycnal surfaces of the STMW and in water just above the STMW. The magnitude of this PV gradient varies with the seasonal cycle and with front strength, which indicates that the PV gradient plays an essential part in the seasonal variation of the front. Moreover, the PV gradient and its seasonal cycle are dominated by the diapycnal PV gradient, which is found mostly in the density layer of the STMW. This strongly suggests that STMW may be the main reason for the PV gradient across the isopycnals.

The STMW with the lowest PV forms in late winter south of the Kuroshio Extension and is advected southwestward. The PV gradient at the front intensifies at the same time as this STMW with very low PV appears north of the front. This very low PV STMW may lead to the larger PV gradient and to a stronger spring-to-summer northern STF. A change in the PV gradient in the STMW is, therefore, a possible mechanism by which the seasonal variations in the northern STF can come about.

Kobashi has collaborated with K. Hanawa (Tohoku University, Japan) on a study of the Kuroshio small meander, which is known to trigger the Kuroshio large meander south of Japan. By combining satellite-derived sea surface height and sea surface temperature data with synoptic *in situ* observations, they described in detail the formation processes, dynamic structures, and water characteristics of small meanders (Kobashi and Hanawa, submitted to *J. Oceanogr.*).



Konstantin Lebedev

Visiting Researcher

Konstantin Lebedev obtained his Ph.D. in physical oceanography in 1995 from the P.P. Shirshov Institute of Oceanology, Moscow. His research interests include numerical modeling of ocean dynamics and of the ocean's response to non-stationary atmospheric forcing, variational and sequential data assimilation into numerical models, and variability of the Indonesian Throughflow.

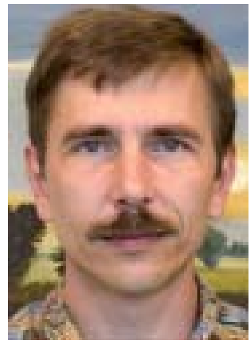
Konstantin Lebedev focused this year on developing a 4-dimensional data-assimilation system that combines the latest version of the Parallel Ocean Program (POP) and the SEEK filter (Sequential Evolutive Extended Kalman filter). The purpose was to construct a tool for analyzing long-term observations in the tropical and subtropical Pacific and Indian Oceans. Collaborators in this project were Bohyun Bang, Humio Mitsudera, Takuji Waseda, and Max Yaremchuk.

Lebedev completed the codes for the SEEK filter and then successfully coupled it with the POP ocean general circulation model in several configurations starting with a small rectangular box and moving to a more realistic configuration (Global Ocean at 1° resolution). Lebedev spearheaded several large sets of experiments that aim to optimize filter-free parameters such as the "forgetting factor" and the number of eigenmodes used to propagate the error covariance. In all model configurations, 8 eigenmodes were sufficient to account for 97% of the model's variability over 3 to 12 months. The filter's performance did not degrade significantly when the model error covariance evolution was approximated by the "forgetting factor" method. In view of its computational efficiency and good performance, Lebedev and his colleagues have conducted further experiments using this method.

A twin data assimilation run with a realistic 1º resolution global configuration of the filter was successful. The experiments covered one model year, in which the reference field was sampled every 5 days, making a total of 73 EOFs available for SEEK filter initialization. The simulated satellite "observations," extracted along their tracks from the benchmark run, were assimilated in sequence along these tracks. Also assimilated, as "observations" into the run, were simulated CTD and Argo data from the North Pacific region. The filter reached a steady state at a 17% error level in less than 10 assimilation steps or 50 days (assimilations were performed every 5 days).

A comparison of the temperature distributions at 1,000-m depth after 3 months integration from (a) the benchmark, "true" solution, (b) the first guess, free model run, and (c) the assimilation solution shows that the SEEK filter reconstructed the small-scale structures using satellite observations and CTD soundings.

In summary, the construction and development of the SEEK filter with the POP model has advanced greatly. The results of the twin data experiments show that the SEEK filter will be a very useful tool for oceanographic research at the IPRC and the APDRC.



Nikolai A. Maximenko
Associate Researcher

Nikolai Maximenko obtained his Ph.D. in physical oceanography in 1987 from the P.P. Shirshov Institute of Oceanology, Moscow. 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 worked on a collaborative project with Peter Niiler (Scripps Institution of Oceanography), James McWilliams (University of California, Los Angeles), and Chester Koblinsky (NASA Goddard Space Flight Center) to develop a method for analyzing the two-dimensional momentum balance in the upper ocean (Niiler et al., 2003). This method enabled the computation of the global 1992–2002 decadal-mean absolute sea level using a combination of measurements from more than 8700 surface drifters and Aviso/ENACT gridded altimetry sea level anomalies. Ekman velocities were estimated from the NCEP/NCAR reanalysis winds by using the parameterization of Ralph and Niiler (1999). The map they created of the average absolute sea level for the last 10 years is shown in Figure 7 at 1° x 1° resolution.

The map reveals a spatially coherent pattern that shows all known gyres, currents, jets, meanders, recirculations, and stationary eddies. It gives an excellent overview of the complexity of the surface circulation. All five subtropical

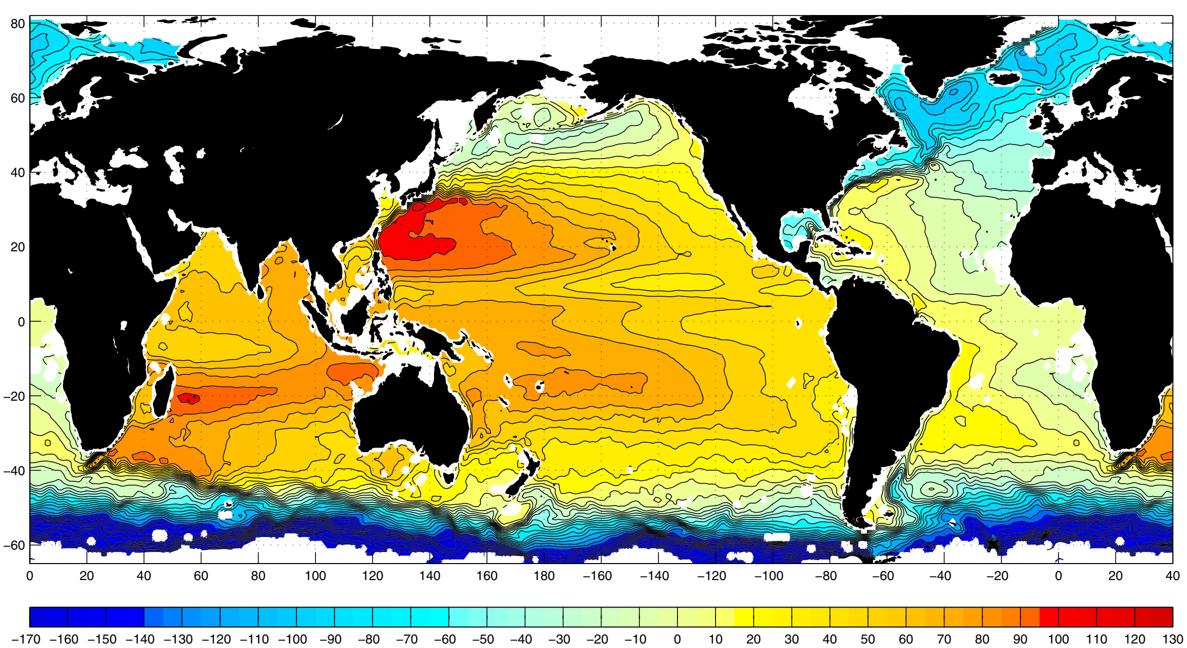


Figure 7. Mean sea level for 1992-2002 obtained from the dynamical balance among drifter and satellite altimetry measurements and NCEP winds. Contour interval is 10 cm.

gyres are clearly seen and have strikingly different shapes. In most areas, the distribution of mean sea level corresponds well to the dynamic topography at the 1,000-m level, computed using data from the World Ocean Atlas 2001. Even better, deviations between mean sea level and dynamic topography at 1,000 m show a realistic pattern of horizontal circulation at 1,000-m depth. The main circulation features at this depth are the Antarctic Circumpolar Current and five anticyclonic recirculations in the western region of each ocean at approximately 40º S or 40º N. These recirculations agree well with current meter and float observations and are also present in hydrographic data that detect a deepening of the thermocline at these locations in the 5 recirculation gyres and in the Antarctic Circumpolar Current.

The mean sea level estimated by Maximenko and his colleagues also corresponds well with the satellite altimetry sea level referenced to the first geoid product of the GRACE mission (NASA Press Release 03-244). Compared to the latter, the former resolves much smaller spatial scales but has a number of large-scale biases. The team is therefore working now to improve parameterization of the Ekman velocities and to evaluate the effects of vertical velocities and sub-mesoscale motions in the mixed layer. The challenge is to detect and eliminate systematic and stochastic imbalances in momentum both by understanding the significant physics and by correcting systematic errors in the pre-processed data they used to compute the sea level estimates. It is helpful to their endeavor that drifter trajectories are denser in the regions of strong currents, providing better coverage (and finer resolution) in the key areas with large mean sea level gradients. They also expect to improve their estimates by constraining the integration of the estimated sea level gradient using the low-resolution, large-scale, direct sea level measurements obtained by the satellites.

Humio Mitsudera
Frontier Group Leader and Theme 2 Leader

Humio Mitsudera obtained his Ph.D. in physical oceanography in 1987 from Tohoku University, Japan. His research interests include dynamics of ocean currents and ocean gyres, and coastal ocean processes.

Humio Mitsudera continued to work on issues related to modeling the subpolar water pathways in the Kuroshio-Oyashio confluence zone, the dynamics of the Kuroshio along the southern coast of Japan and the low-latitude western boundary currents.

The western North Pacific off the east coast of Japan is a crossroad of water masses from the Kuroshio, the Oyashio, and the outflow from marginal seas. Collaborating with Takuji Waseda, Bunmei Taguchi, and Tangdong Qu at the IPRC, Mitsudera investigated the confluence of the Kuroshio and the Oyashio with a regional Kuroshio-Oyashio model. This regional model simulates realistically many features of the confluence, such as the separation of the Kuroshio from the southern coast of Japan. One of most striking results was a realistic simulation of the subpolar-to-subtropic pathways taken by Oyashio water, which is characterized by fresh and low potential vorticity (PV) water that originates in the Sea of Okhotsk.

Mitsudera concentrated this year on investigating the dynamical processes that form these pathways. He found that the subpolar water pathways are strongly eddy-driven. After the Oyashio water intrudes into waters northeast of Japan, it is subducted and pulled into warm core rings, forming a low PV pool. Near the Japanese coast, the Oyashio water flows out from the warm core rings and the Kuroshio Extension. Eddies then distribute the water in the Mixed Water Region and the recirculation gyre.

A dynamical systems theory framework provides insights into the formation of these pathways. Applying this framework to the simulation results, Mitsudera found that the flow field is characterized best by hyperbolic stagnation points, each hyperbolic point being an intersection of a pair of bounding streamlines. The depth-integrated streamfunction describes the Oyashio water pathways well: cross-frontal transport occurs adjacent to the hyperbolic points associated with the streamfunction. Furthermore, the eddy heat- and freshwater-fluxes lying normal to the mean streamfunction are large near the hyperbolic points, indicating that the Oyashio water pathways are primarily eddy-driven.

In another project, Mitsudera worked with Takahiro Endoh on tracing the pathways from the subtropical gyre to the subpolar gyre. This circulation produces a peculiar, large-scale temperature maximum in the subpolar gyre at a depth of about 300 m. Their modeling results indicate that a key aspect in the formation of the large-scale temperature maximum is a wind-driven, shallow north-south overturning circulation that connects the subtropical gyre to the subpolar gyre, the so-called Subpolar Cell. Mitsudera also continued to study with Takuji Waseda the path dynamics of the Kuroshio and the causes of path variations, particularly the effect of the Izu Ridge on the Kuroshio pathways. Lastly, he collaborated on a study of the low-latitude western boundary currents with Tangdong Qu, Hyoun-Woo Kang, Yoo Yin Kim, Tommy Jensen, and Julian McCreary.

Toru Miyama
Frontier Research Scientist

Toru Miyama obtained his Ph.D. in physical oceanography from Kyoto University in 1997. (In Fall, 2002, he returned to Frontier in Japan.) His research interests include the dynamics of the variability in the Indonesian Throughflow and its role in the climate system, tropical and subtropical water exchange, and wavelet-optimized numerical ocean models.

The North Equatorial Current (NEC) divides the tropical and subtropical circulations in the Pacific Ocean. Near the western boundary, it bifurcates into the Kuroshio and Mindanao currents. Determining the latitude of bifurcation is important for understanding the water exchange between the tropics and extratropics. Using a 1.5-layer ocean model, Qiu and Lukas (1996) concluded that the bifurcation of the NEC occurs at its southernmost latitude in February or April, depending upon the method used, and its northernmost position in October. Based on geostrophic calculations of historical hydrology, however, Qu and Lukas (2003) found that the NEC bifurcation occurs at its southernmost position in July and its northernmost position in December. What is the reason for these different conclusions? Which one is true? What determines the seasonal variation in bifurcation latitude?

Toru Miyama used several types of numerical models to address these questions. Specifically he used a 1.5-layer model similar to the one used by Qiu and Lukas (1996) to test the response of the NEC to various wind-stress forcings, a linear continuously stratified model to explore the vertical structure of the current, and a numerical solution from the comprehensive JAMSTEC world ocean GCM (Ishida et al., 1997) to support their conclusions.

Experiments with the 1.5-layer model revealed that the results of Qiu and Lukas (1996) are greatly influenced by the artificial northern boundary in their model, which was closed at 38ºN with a sponge layer of high horizontal viscosity. When the boundary in his 1.5-layer model was also closed at 40ºN, the simulated bifurcation latitude exhibited seasonal changes similar to those found by Qiu and Lukas (1996); when it was closed at 60ºN, however, the seasonal variations in the bifurcation latitude are consistent with the Qu and Lukas (2003) results. Simulations with the JAMSTEC GCM support the above results and, therefore, also the conclusions of Qu and Lukas (2003).

Qu and Lukas (2003) reported a northward shift in bifurcation latitude with depth. The above linear continuously stratified model revealed that the second vertical mode seems to be responsible for this northward shift. Due to resonance, the second mode is sensitive to small structures in the wind stress curl, while the first mode responds only to larger wind structures and depends less on the wind-stress product used (except the NCEP winds, to which the response is exceptionally weak).

James T. Potemra
Assistant Researcher

James Potemra received his Ph.D. in oceanography from the University of Hawai'i at Mānoa in 1998. His research interests include the general ocean circulation and its relationship to climate, and processes in the equatorial, western Pacific, and eastern Indian Ocean and their connection.

Jim Potemra continued this year to analyze *in situ* pressure, temperature, and salinity measurements obtained during the Shallow Pressure Gauge Array (SPGA) program in Indonesia. In particular, he determined the upper-ocean budget (heat and freshwater) in the Savu Sea, one of the main Indonesian seas, by computing geostrophic transport estimates based on the pressure-gauge measurements, temperature and salinity observations (both remote and *in situ*), and numerical model solutions. Results showed that at times, e.g., December 2000, the imbalance between inflow and outflow in the upper layer of the Savu Sea may be as large as 10 Sv. Most of the variation in storage occurred intraseasonally—the 3-day convergence/divergence in the Savu Sea ranged fom +10 to –6 Sv—and seemed to be controlled by the flow through the Sumba Strait on the eastern side of the sea (Figure 8). Variations over the annual cycle ranged from 4 Sv (convergence) in December through February, to –2 Sv (divergence) in August through October. The interannual variations determined from model results were consistent with satellite-derived sea level and sea surface temperatures (SSTs) in the Savu Sea. All estimates showed that in recent years there was an anomalous increase (decrease) in heat storage in the Savu Sea during El Niño (La Niña) events. This interannual variation in heat storage in the Indonesian seas could impact the heat exchange between the Pacific and Indian Oceans, and may link interannual variations in heat content in the western Pacific and the eastern Indian Ocean (Potemra et al., 2003a).

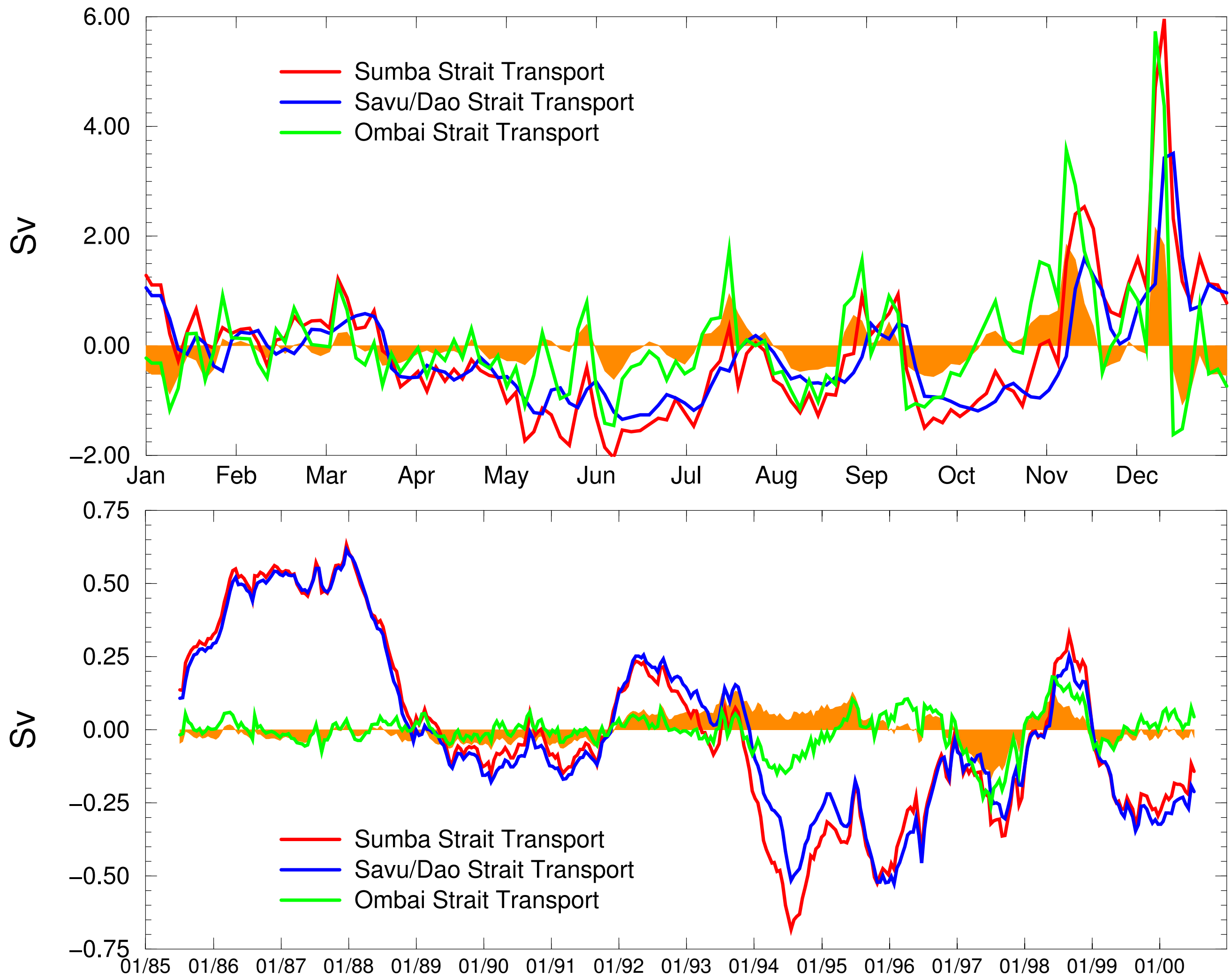


Figure 8. Upper-ocean volume transports–computed from 3-day model output (validated with observations)–through the Savu and Sumba straits, which connect the Savu Sea with the Indian Ocean, and the Ombai Strait, which connects the Savu Sea with the interior Indonesian seas. Upper panel: The 3-day model results for the year 2000, showing the large intraseasonal variability. Lower panel: The entire model integration (1985-2000) fitted with an annual-mean filter, showing the low-frequency variation in the transports. The convergence of upper layer volume is shaded in orange, with positive values indicating convergence. It shows that inflow into the Savu Sea is not always equal to outflow, even at low frequencies, and thus storage of upper ocean waters in the Sea can extend over longer periods. This may be indicative of storage over the larger Indonesian Seas, and therefore would have important implications for heat transport through the Indonesian Seas, for example, during ENSO events.

Potemra is now collaborating with Niklas Schneider on a study of decadal changes in the Indonesian Throughflow (ITF) transport, in which he is analyzing results from a 300-year run of the NCAR coupled model (the PCM-1) to determine the effects of low-frequency changes in the ITF transport on the heat balance in the Indian Ocean. He is corroborating these results with simulations from another coupled model, the SINTEX model.

Interannual SST variations off the coast of southern Sumatra are known to play a key role in the Indian Ocean Zonal Mode (IOZM), but how they are generated is not fully understood. Using an ocean general circulation model, Potemra, together with H. Annamalai, conducted numerical experiments to confirm their hypothesis that El Niño-like conditions in the western Pacific may trigger extreme SST anomalies off southern Sumatra. Furthermore, they found that the higher amplitude and frequency of IOZM events in the 1960s and 1990s compared to the 1970s and 1980s could be due to large-scale changes in the depth of the western Pacific and eastern Indian Ocean that are driven by Pacific decadal variability. Experiments with an ocean GCM, forced with composite winds from the four decades, show that during the 1960s and 1990s the thermocline in both oceans was shallower than in the 1970s and 1980s. During shallow thermocline decades, upwelling off Sumatra leads to cold SSTs and thus to IOZM events, whereas during deep thermocline decades, warmer water is upwelled and upwelling does not necessarily lead to colder SSTs.

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. His current research interests include upper-layer ocean dynamics and the thermal structures of the eastern Indian and Pacific oceans.

Tangdong Qu and his collaborator Eric Lindstrom (Ocean.US) carried out a study on the northward intrusion of the Antarctic Intermediate Water (AAIW) into the western North Pacific. AAIW is formed in the Antarctic Convergence region and spreads throughout the middle and low latitudes of the South Pacific along isopycnal surfaces around 27.2 σ_θ. It is first entrained into the subtropical gyre in the eastern South Pacific as it flows eastward in the Antarctic Circumpolar Current and then moves anti-clockwise around the gyre, flowing westward into the Coral Sea at low latitudes (~20°S). It crosses the equator in the far western Pacific. From there, part of it flows eastward in the equatorial circulation, while the rest continues northward along the western boundary. The main pathways for this northward intrusion have been identified as the New Guinea Coastal Undercurrent (NGCUC) and the Mindanao Undercurrent (MC). How far, however, does AAIW extend in the western North Pacific? This question has been debated over the last decades. The traditional view before the study by Qu and Lindstrom has been that AAIW extends to the midlatitudes of the western North Pacific, as shown in the early map of dissolved oxygen concentration by Reid (1965).

Qu and Lindstrom revisited this problem by analyzing all existing historical data combined with data from six hydrographic sections collected during the World Ocean Circulation Experiment. Careful examination of these data led to the following findings: (1) AAIW can be traced as a salinity minimum to only about 15°N via the NGCUC and the MC. No AAIW flows north of this latitude in the western North Pacific. (2) As previous studies noticed, relatively high-oxygen water does exist in the Okinawa Trough, but there is no indication that this water comes directly from the south along the western boundary. The spreading of the high-oxygen water in the Okinawa Trough is actually connected to the high-oxygen water in the South China Sea (SCS) through the Luzon Strait. (3) The SCS circulation seems to play an essential role in localizing the oxygen maximum in the northern SCS. Qu and Lindstrom hypothesize that the high-oxygen water first enters the SCS as part of the Pacific deep water around the sill depth (~2000 m) of the Luzon Strait. Then, part of it upwells, where it is entrained into low-density surface waters by intensive vertical mixing in the SCS before it eventually flows back to the Pacific through the Luzon Strait at depths around those of the AAIW.

In another study, Qu examined the mixed-layer heat balance in the western North Pacific. He found that, although seasonal variation in sea surface temperature (SST) is mainly due to surface thermal forcing, ocean dynamics also have an effect. From late May to early July, SST increases (>29°C) to the northeast in the region 120°–160°E, 10°–20°N, primarily as a result of vertical entrainment associated with the onset of the summer monsoon. This finding provides evidence for the ocean's role in the development and decay of the summer monsoon in the western North Pacific.

Kelvin J. Richards
Professor of Oceanography

Kelvin Richards received his Ph.D. in physical oceanography in 1978 from the University of Southampton. His research interests include observation and modeling of ocean processes, ocean dynamics, ocean-atmosphere interaction, and ecosystem dynamics.

The robustness of climate predictions depends on the effectiveness of atmosphere and ocean models in capturing the essential physics of the problem. Mixing is a key ocean process that plays an important role in the ocean's dynamics and thermodynamics and in how the ocean interacts with the atmosphere, particularly in the tropics. Unlike vertical mixing, for which various mixing schemes have been tested, the appropriate form for the lateral mixing in the ocean models used for climate research has received scant attention. In this regard, Kelvin Richards has focused attention on the observation that saltier water south of the equator and fresher water to the north are often observed to interleave, producing thin layers of alternately saltier and fresher water. Estimates suggest that this interleaving can produce a significant lateral mixing of momentum and heat and salt, which can then affect the large-scale structure of the equatorial ocean. Using theory and numerical experiments, Richards has been able to quantify the amount of mixing and to develop a parameterization scheme that allows the effects of the interleaving to be incorporated into climate models. Tests of this scheme show that including the effects of interleaving substantially improves the performance of an ocean model and can rectify biases that are exhibited by climate models (one such bias being that the sea surface temperature in the eastern tropical Pacific tends to be too cold). The enhanced mixing brought about by interleaving varies in both time and space on a scale such that it may very well influence the interannual behavior of the tropical ocean-atmosphere system and El Niño.

Richards has also studied the interaction between the atmosphere and Tropical Instability Waves (TIWs). These waves, which exist on the edges of the cold tongue of water on the eastern sides of the tropical Pacific and Atlantic Oceans, are important in the heat balance of the cold tongue. Observations show that they also affect the surface wind. By coupling a simple model of the lower atmosphere to an ocean model, Richards and collaborators have shown that this atmospheric coupling provides a negative feedback on the TIWs, damping them effectively. This damping decreases sea surface temperature at the equator and strengthens the surface and sub-surface currents. The results of this research provide another example of significant interactions between the ocean and atmosphere, and they have implications for the way such interactions are handled in climate models.

On a very different topic, Richards has been studying the impact of ocean stirring and mixing caused by eddying flows on the marine ecosystem. The distribution of both phyto- and zooplankton in the ocean is very patchy in time and space. An important question is whether the patchy nature of the distribution of plankton affects the way the marine ecosystem behaves. Richards finds that there is a delicate balance between the reaction of the phytoplankton and zooplankton, diffusion, and the stirring action of eddies. Too much stirring and the reaction is damped completely, while moderate amounts of stirring can significantly enhance the production of phytoplankton.

Takuji Waseda
Frontier Research Scientist

Takuji Waseda received his Ph.D. in Ocean Engineering from the University of California, Santa Barbara, in 1997. His research interests include wind and water waves, satellite oceanography, data assimilation, and variability of the Kuroshio and Kuroshio Extension.

In the previous year, Takuji Waseda had successfully simulated the processes observed with the TOPEX altimeter, in which a short-term meander of the Kuroshio formed through the interaction between an anticyclonic eddy and the Kuroshio Current (Waseda, Mitsudera, Taguchi, and Yoshikawa, 2002). Detailed analyses of the simulation by Waseda, (Waseda, Mitsudera, Taguchi, and Yoshikawa, 2003a) showed that the basic process underlying the short-term meander is baroclinic instability and that the meander forms and dissipates much more rapidly than is typical of large meanders (Qiu and Miao, 2000). The short-term meander cycle is realized through a rapid discharge and recharge of the available potential energy of the anticyclonic eddy and through rapid production and release of high potential vorticity inshore of the Kuroshio, which results from flow separation at the Kii Peninsula and eddy-shedding to the Kuroshio extension.

In the Waseda et al. (2002) simulation, the Kuroshio inflow rate had been kept at 25 Sv, a condition under which large meanders do not form in the model. Waseda et al. (2003a) extended the study by conducting runs with flow rates ranging from 25 Sv to 45 Sv and with annual-mean forcings. At intermediate flow rates, the Kuroshio path becomes bimodal in either a stochastic or a chaotic manner (Figure 9). Using 35 Sv as a flow rate, the authors conducted simulations with different wind forcings (QuikSCAT-derived daily wind, ECMWF daily-wind, Hellerman-Rosenstein annual- and monthly-wind, and no wind forcing) to see how local winds impact the current. Comparisons between runs with and without wind forcing revealed that the Shikoku recirculation gyre affects the Kuroshio path significantly. The switching of the Kuroshio path from straight to meander (or the reverse) can therefore be understood as a result of the Shikoku recirculation gyre being perturbed by high-frequency wind forcing.

In preparing the wind forcings for the above model runs, Waseda noted that wind stress in the region varies greatly on timescales shorter than one day. An analysis of the ECMWF operational wind showed that this variability is enhanced by the surface wind waves that create high-frequency variability in sea surface roughness. Comparing the QuikSCAT and ECMWF NWP products, they found that the spatial and temporal wind-stress variabilities are statistically equivalent (Waseda, Mitsudera Taguchi, and Kutsuwada).

In a study of the transport of the coastal water inshore of the Kuroshio at the Enshu-Nada Sea, Waseda had used a geometrical method originating in dynamical systems theory (Waseda, Mitsudera, Taguchi, and Yoshikawa, 2002). This analysis revealed that the coastal water can leak out, flow eastward into the Kuroshio Extension region along the northern edge of the Kuroshio Current, and intrude north into the Kuroshio-Oyashio confluence zone. This chaotic transport mechanism may serve as an engine for the transportation of fish eggs and larvae from the Japanese coast into the nutrient-rich Oyashio-Kuroshio confluence region. A similar geometrical method was useful in understanding the intrusion of Oyashio water into the Kuroshio, suggesting a chaotic transport mechanism also determines the Oyashio water pathways (Mitsudera, Taguchi, Yoshigawa, Nakamura, Waseda, and Qu, submitted).

Waseda has continued to work on combining the SEEK filter (Singular Evolutive Extended Kalman filter) with the wavelet error diagnostic scheme (Jameson, Waseda, and Mitsudera, 2002) in such a way that they complement each other in a spectral sense. He has been able to demonstrate that the eigenmodes used in the SEEK filter are, to a good approximation, orthogonal to the wavelet bases of the first few scales (Waseda, Jameson, Mitsudera, and Yaremchuk, 2003).

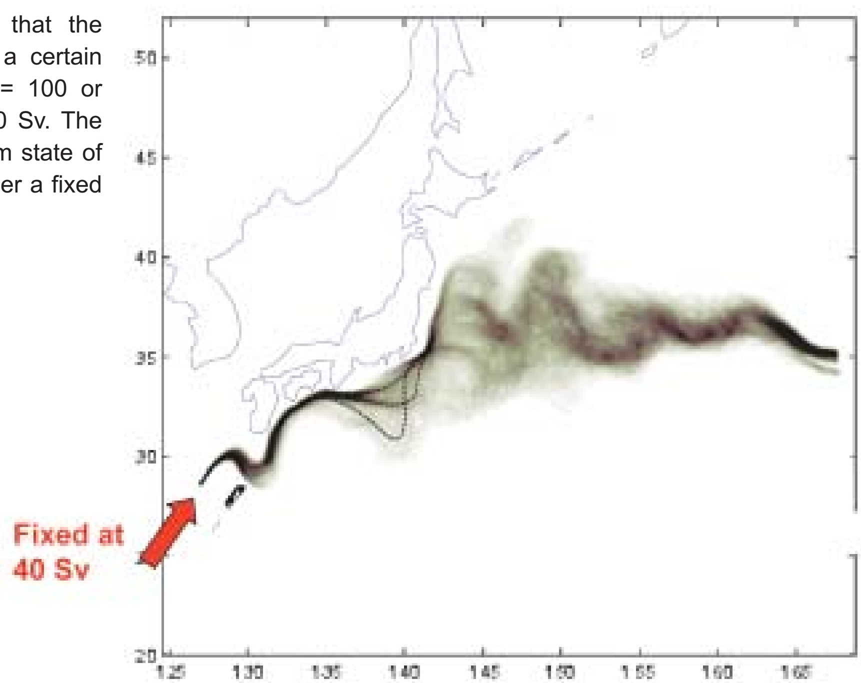


Figure 9. The percentage of time that the Kuroshio axis (0.7m SSH) occupies a certain location (white = 0 or never; black = 100 or permanent) under a fixed inflow of 40 Sv. The figure shows that a multiple equilibrium state of the Kuroshio path can be realized under a fixed inflow.

Max Yaremchuk
Associate Researcher

Max Yaremchuk obtained his Ph.D. in physical oceanography from the P.P. Shirshov Institute of Oceanology, Moscow, in 1984. His primary research interest is in the field of inverse methods of data processing, including variational methods of data assimilation into finite-difference numerical models.

Max Yaremchuk has focused on the following three projects this past year: (1) the inversion of climatological data around the Philippine coast; (2) the development of a 4-dimensional variational data-assimilation system (with Dmitri Nechaev, Stennis Space Center; and Gleb Panteleev, International Arctic Research Center; and (3) the development of the SEEK filter based on the POP model (with IPRC members K. Lebedev, H. Mitsudera, T. Waseda, and B. Bang).

In the first project, Yarmechuk conducted a diagnostic study of the mean seasonal cycle of the western boundary currents in the tropical North Pacific. Using a variational data-assimilation technique, he combined atmospheric climatologies with drifter, satellite altimetry, and hydrological data compiled by Tangdong Qu (IPRC). This approach allowed diagnosis of the absolute 3-dimensional velocity field and assessment of the seasonal cycle of sea surface height and total transports near the bifurcation point of the North Equatorial Current. Errors were estimated by considering multiple data sets and averaging over the results of the corresponding diagnostic computations. The analysis shows that the north–south migration of the North Equatorial Current (NEC) bifurcation point is accompanied by quantitative changes in the partitioning of the NEC transport between the Kuroshio and the Mindanao Current (Figure 10). From February to July, when the NEC transport is 58 ± 3 Sv, the Kuroshio transport is 12–15% higher than the Mindanao Current (MC) transport. In the second half of the annual cycle, the situation is reversed: In October, when the NEC transport decreases to 51 ± 2 Sv, the MC transport exceeds the Kuroshio transport by 25%. The net westward transport through the Luzon Strait is characterized by a minimum of 1.2 ± 1.1 Sv during July to September and a maximum of 4.8 ± 0.8 Sv during January and February. There is a statistically significant correlation between the monthly sea surface height and streamfunction anomalies north of 10°N and the Ekman pumping rate associated with the northeast monsoon, which develops in the region between October and December. These results strongly suggest that the local monsoon is an important mechanism governing the seasonal variations in the NEC partitioning and in the water mass distribution between the tropical and subtropical North Pacific (Yaremchuk, and Qu, submitted to *J. Phys. Oceangr*.).

Apart from developing the data-assimilation capabilities at the IPRC, which are generally of a technical nature, Yaremchuk consulted on the use of an inverse code in two projects associated with the application of variational data-assimilation technique to climatological data in the South Pacific (Grotov and Yaremchuk, 2002) and the western Barentz Sea (Panteleev. Ikeda, Nechaev, Yaremchuk, submitted to *J. Oceanogr.*, 2003).

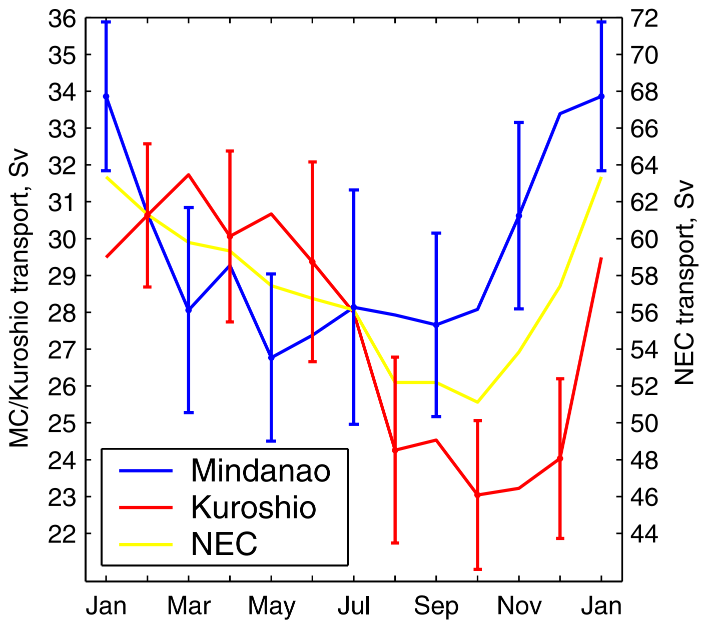


Figure 10. Seasonal cycle of current transports in the western North Pacific: the Kuroshio transport at 18.5°N and the Mindanao Current transport at 11°N are given by the left y axis, while the North Equatorial Current transport is given by the right y axis.

Research Activities and Accomplishments

Theme 3: Asian-Australian Monsoon System

Overview

Climate in the Asia-Pacific region is to a large extent determined by the Asian-Australian monsoon, the most energetic monsoon system on Earth. Agriculture in many regions of Asia depends on monsoon rainfall, which is highly variable in time and space. The largest variations actually occur within a monsoon season, with "active" periods having a daily rainfall of up to 14 mm, followed by "break" periods having at times less than 2 mm of rain a day. These dry and wet spells, which together have a period of 30 to 35 days, originate in the equatorial Indian Ocean and move north over India.

The Asian-Australian monsoon system is driven by complex interactions among air-sea-land processes over a vast area that extends from Africa to the western Pacific and from Australia to Siberia. The goal of Theme-3 research is to understand the physical mechanisms that control the variability of this complex, energetic climate system on seasonal-to-interdecadal timescales. The expectation is that with more reliable and detailed knowledge of the processes underlying the complex air-sea-land interactions, we will come to predict the fluctuations in the monsoons with some accuracy.

Active and break periods of the summer monsoon are caused by northward-propagating intraseasonal oscillations (ISOs), which provide a key link between the equatorial convection zone and the Indian monsoon trough. Physical mechanisms regulating ISO-propagation have not been adequately understood. In the past year, Theme-3 researchers made a breakthrough in understanding the internal atmospheric dynamics and the role of ocean-atmosphere coupling in shaping these intraseasonal variations. Based on observational analyses, numerical modeling experiments, and a theoretical model, they demonstrated that two internal atmospheric dynamic processes are essential for driving the ISO northward: the interaction between convection and vertical shear of the mean-monsoon flow, and moisture-convection feedback. Using a hybrid-coupled general circulation model, they also demonstrated that air-sea interaction increases ISO variance through a distinctive north-south lag among convection, surface wind, and sea surface temperature (SST). Interestingly, this coupled solution is fundamentally different from a corresponding solution when the atmospheric model is forced with daily SST, and it matches observations well and may become useful in forecasting these dry and rainy periods.

Theme 3's efforts in gaining a better understanding of the interannual variability of the Asian-Australian monsoon have led to several important findings. First, they showed that the dominant mode of interannual monsoon variability is strongly season dependent and dominated by two large anomalous circulations—one located over the southern Indian Ocean and the other over the western North Pacific—that peak in fall or the subsequent spring, respectively. These anomalies tend to switch from cyclonic to anticyclonic from one year to another, causing a strong tendency toward biennial variation in the entire Asian-Australian monsoon system. In contrast to the commonly held view that monsoon anomalies are driven by SST anomalies in the warm pool, this research shows that it is the interaction between the monsoon and the underlying warm ocean that causes fluctuations in both the warm pool and the monsoon climate. This interaction, which is regulated by the annual cycle, is characterized by positive feedback between the anomalous atmospheric anticyclone and the SST dipole. The tendency for a relatively strong monsoon to follow a relatively weak one has been called the tropical biennial oscillation (TBO; Meehl, and Ablaster, 2002). These findings, therefore, yield a new paradigm in which the TBO results from ocean-atmosphere interactions in warm ocean regions.

Regarding decadal monsoon variability, Theme-3 researchers found that subcomponents of the Asian-Australian monsoon—the western North Pacific and Indian monsoons—reacted differently to El Niño events before and after 1976, that is, an interdecadal change in the Indian monsoon–ENSO relationship took place about 1976. Concerning El Niño dynamics, the asymmetry between El Niño and La Niña SST deviations seems to result mainly from nonlinear vertical advection processes in the ENSO–monsoon system.

A special team effort of Theme 3 is model development, and this year, much work went into improving the IPRC Regional Climate Model (IPRC–RegCM) and completing a hierarchical suite of coupled models. Tasks accomplished in coupled-model development include (1) replacing the convection scheme in the NCAR Community Atmospheric Model with the convection scheme from the European Center–Hamburg atmospheric model (ECHAM); (2) coupling ECHAM to the Modular Ocean Module (MOM) from GFDL, giving the IPRC a fully coupled atmosphere-ocean general circulation model (GCM); (3) coupling ECHAM to an intermediate ocean model, giving the IPRC a hybrid coupled GCM; and (4) coupling an intermediate atmospheric model developed by Wang and Li (1993) and Fu and Li (1998) to the Wang-Li-Fu intermediate ocean model, providing an intermediate coupled model. The latter model is unique in that it fills the gap between the Cane-Zebiak anomaly intermediate model and complex coupled atmosphere-ocean GCMs. This suite of coupled models now provides a powerful set of tools for understanding complex atmosphere-ocean-land interactions and monsoon variability. Because the models systematically vary the complexity of one component while holding the other components constant, and because the simpler components have been found to reduce the tropical biases in coupled climate models, they are well suited for understanding and correcting the tropical biases in the coupled GCMs, a main focus of a model intercomparison program.

Application of the IPRC–RegCM has led to studies within Theme 3, and in collaborations between Themes 1 and 3 that have significantly advanced our understanding of air-sea-land interactions. For instance, to forecast how climate change will affect vegetation, one must be able to predict not only overall amount of rainfall, but rainfall frequency, intensity, and geographic distribution. Regarding the 1998 monsoon season with the devastating Yangtze River flood, the IPRC–RegCM accurately simulates all these rainfall properties. The model has also shown usefulness in investigating how changes in land surface in Indochina and in northern China affect the atmospheric circulation and rainfall patterns in East Asia. It has also been used to understand important features in the background state of the eastern South Pacific and to simulate the stratus-cloud deck off South America during austral winter, a feature that general circulation models have had difficulty simulating. The model has also helped to elucidate air-sea processes in Theme 1 studies.

As to international collaboration, Theme-3 researchers have actively participated in an atmospheric model intercomparison subproject on the East Asian monsoon and in workshops in the following areas: the Asian monsoon, held by CEOP/GEWEX; the predictability of the Madden-Julian Oscillation; the correction of tropical bias in coupled models; and regional climate modeling, a series initiated by the IPRC in Fall 2001. For the CLIVAR international monsoon intercomparison program, Theme-3 researchers have analyzed and compared the performance of monsoon simulations from 11 different atmospheric GCMs.

Individual reports

Soon-Il An

Associate Researcher

Soon-Il An obtained his Ph.D. in atmospheric sciences in 1996 from Seoul National University in Korea. His research interests include understanding the dynamics of intraseasonal-to-interdecadal climate variability, and simple and intermediate air-sea coupled modeling.

Soon-Il An investigated, in collaboration with Fei-Fei Jin (University of Hawai‘i), the nonlinearity and asymmetry of the El Niño–Southern Oscillation (ENSO). El Niño events (warm) are often stronger than La Niña events (cold). This asymmetry must be due to nonlinear processes. An and Jin used a prototype ENSO model to study nonlinearity and symmetry, proposing two dynamical measures of nonlinearity—maximum potential intensity and nonlinear dynamic heating (NDH)—and a statistical measure (skewness). Their analysis of the observed heat budget of the ocean surface layer shows that NDH is essential to generating the intense El Niño events. The greater NDH associated with the recently enhanced El Niño activity has influenced the recent tropical Pacific warming-trend and may provide a positive feedback mechanism for climate change in the tropical Pacific (Jin et al., 2003).

In collaboration with Fei-Fei Jin and Luis Bejarano (University of Hawai‘i), An studied tropical air-sea coupled modes that have different timescales. In particular, they examined the role of two major tropical ocean feedback systems—thermocline feedback (vertical advection of anomalous subsurface temperature by mean upwelling) and zonal advective feedback (zonal advection of mean SST by anomalous current)—on generating the timescales of various coupled modes. Using an ocean model, they showed that interannual variations in wind forcing have little effect on zonal currents; the thermocline effect, on the other hand, is strong. In coupled modes with interannual periodicity, zonal advective feedback thus appears to be of secondary importance, whereas it plays a major role in modes with approximately annual periodicity. Using a linearized version of the Zebiak-Cane model, the researchers went on to examine the effect of these feedbacks on the co-existence of the main coupled modes and their different timescales. Changes in the basic state of the coupled system appear to change the relative importance of these two feedbacks and affect the periodicity and stability of the major coupled modes of the tropical Pacific climate system.

An also developed a statistical tool, which he labeled "conditional maximum covariance analysis" (CMCA). In contrast to the usual maximum covariance analysis (MCA), also known as "Singular Value Decomposition" analysis, CMCA not only isolates the most coherent patterns between two geophysical fields but also excludes the unwanted signal by subtracting the regressed value of each field that depends on the unwanted signal. Using CMCA, An identified the leading air-sea coupled mode in the tropical Indian Ocean when ENSO signals are removed, which shows an east-west contrasting SST pattern and a monopole zonal-wind-stress pattern. In the CMCA, the corresponding expansion coefficients are uncorrelated with the ENSO index; this result contrasts with the MCA, in which the expansion coefficients are correlated with both the ENSO index and the Indian Ocean east-west contrast pattern index. Thus, the CMCA method detected the coherent patterns induced by the local air-sea interaction independently of the external ENSO signal, whereas the usual MCA detected the coherent patterns, but did not separate the effects of local and external factors (An, *J. Climate*, in press).

H. Annamalai

Assistant Researcher

H. Annamalai received his Ph.D. in atmospheric science in 1995 from the Indian Institute of Technology, Kharagpur, India. His research interests include diagnosis and modeling of the Asian summer monsoon (ASM) system and the predictability of this system, the dynamical and physical links between the monsoon and ENSO, and the role of the Indian Ocean in the ASM.

Annamalai studied the effects of El Niño on precipitation over Asia from 1950 to 2001. Given the changes in El Niño properties around 1976, he compared the pre-1976 (Pre76) and post-1976 (Post76) periods, finding that the Western North Pacific (WNP) and the Indian summer (IS) monsoons react differently to El Niño events in the two periods. During El Niño years, the WNP monsoon was stronger than normal in both periods; the IS monsoon, however, was weaker than normal for the entire monsoon season (from onset to withdrawal) during Pre76, whereas during Post76, it was stronger than usual in the established phase (July–August). Annamalai explored the hypothesis that El Niño affected both monsoons during Pre76, while either one or both of the following happened during Post76: (1) greater El Niño intensity resulted in stronger WPN and IS monsoons in July and August by decreasing precipitation in the eastern equatorial Indian Ocean; or (2) El Niño triggered the Indian Ocean Zonal Mode (IOZM).

Annamalai proposed the following mechanism by which El Niño intensity combines with IOZM conditions during Post96 to affect the IS and WNP monsoons: Both processes reduce precipitation in the eastern equatorial Indian Ocean, forcing anticyclonic circulation anomalies in the lower atmosphere over the entire IS–WNP monsoon region, as well as a local meridional circulation in response to the north-south heating gradient.

Diagnoses of observed precipitation and reanalysis products support the hypothesis. To investigate the hypothesis further, Annamalai (in collaboration with Ping Liu), obtained a 10-member ensemble simulation to an atmospheric GCM forced by both Pre76 and Post76 El Niño conditions. Into the simulation, he inserted sea surface temperature (SST) anomalies in the tropical Indo-Pacific region (TIP), in the tropical Pacific only (TPO), and in the tropical Indian Ocean only (TIO). The TPO solutions simulate fairly realistically the observations for both periods and thus support the above hypothesis. This indicates that remote forcing by Pacific SSTs affects the Asian summer monsoon (both the WNP and IS monsoons) more than is commonly thought. The SST anomalies that develop in the tropical Indian Ocean in response to the insertion of TIP SST anomalies, however, also produce the details of the simulated Asian summer monsoon. In summary, the solutions suggest that all aspects of SST anomalies in the tropical Indo-Pacific region need to be considered to understand the ENSO–monsoon teleconnection, and to predict the monsoon successfully.

Annamalai is also collaborating with Y. Y. Kim (IPRC) on testing the hypothesis that a realistic simulation of the mean monsoon will produce a realistic simulation of intraseasonal oscillation. To find support for this idea, they are analyzing simulations with the ECHAM model using the Cyclostationary Empirical Orthogonal Function method. He is also collaborating with Ken Sperber (Lawrence Livermore National Laboratory) on a study aimed at elucidating the dynamics and vertical structure of intraseasonal monsoon variability.

Xiouhua Fu

Assistant Researcher

Xiouhua Fu obtained his Ph.D. in meteorology from the University of Hawai'i at Mānoa in 1998. His research interests include developing air-sea coupled models and using these models to study the Asia-Pacific climate.

Xiouhua Fu has continued his modeling studies to understand the role that air-sea interaction in the warm-pool region plays in the Asian summer monsoon and to assess the influence of adjacent continental monsoons on the climate of the equatorial Pacific.

Air-sea interaction in the Pacific warm pool appears to be a missing piece in realistically simulating the Asian summer monsoon and the associated intraseasonal oscillations (Fu, Wang, and Li, 2002; Fu, Wang, Li, and McCreary, 2003; Fu and Wang, 2003). The traditional view holds that there is one-way forcing from the underlying sea surface temperature (SST) to the atmosphere (AMIP-type experiments). Thus, when the actual observed SST is used to force atmospheric models, the strongest convection occurs over the highest SST. This property, however, is opposite to observations, in which the highest observed SST is mainly associated with atmospheric subsidence and diminished convection. Because of the geographic proximity of the Asian summer monsoon to the Indo-Pacific warm pool, the dislocated convection over the ocean in a stand-alone atmospheric model distorts the simulation of the Asian summer monsoon.

In Fu, Wang, and Li (2002), Fu and his colleagues have shown that including air-sea coupling in the warm-pool region reduces the systematic errors in simulating Asian-Pacific monsoons. The stand-alone ECHAM4 atmospheric general circulation model (GCM) considerably overestimates the equatorial Indian Ocean rainfall and underestimates monsoon rainfall near 15°N, particularly over the eastern Arabian Sea and the Bay of Bengal. Upon coupling with an ocean model, the simulated monsoon rainfall becomes more realistic, with an intensified rain belt near 15°N and a reduced rain belt near the equator. Including both local and remote air-sea interactions in the tropical Indian and Pacific Oceans improves simulation of the summer monsoon.

In another study with a focus on intraseasonal events, Fu, Wang, Li, and McCreary (*J. Atm. Sci.*, in press) found that northward-propagating atmospheric disturbances of the summer monsoon are strongly coupled with the underlying SST in the Indian Ocean. Atmosphere-only models systematically underestimate the intensity of the northward-propagating intraseasonal oscillations (Figure 11) and produce a false relationship between convection and SST. The hybrid-coupled model developed at the IPRC (the CPL, which couples the ECHAM4 atmospheric GCM to a 2.5-layer-ocean model) not only reproduces the intensity of the northward-propagating intraseasonal oscillations, but also generates a realistic relationship between the rainfall and SST phases (Fu and Wang, submitted to *Geophys. Res. Lett.*).

Using an intermediate air-sea-land coupled model, Fu and Wang (*J. Climate*, in press) showed that both the Asian and South America monsoons affect the SST mean and annual cycle in the equatorial Pacific: the Asian-Australian monsoon significantly influences the mean SST in the western-central equatorial Pacific by altering the strength of the Walker Circulation; the South American monsoon regulates the SST annual cycle in the eastern Pacific cold tongue by changing the southeast trades. Thus, the realistic simulation of tropical Pacific climate in a coupled model probably requires a reasonable representation of both the Asian-Australian and the South American monsoons.

Tim Li

Associate Professor of Meteorology
Theme 3 Co-Leader

Tim Li obtained his Ph.D. in meteorology from the University of Hawai'i at Mānoa in 1993. His research interests include climate dynamics and large-scale ocean-atmosphere interactions on seasonal-to-interdecadal timescales.

Tim Li worked on the following research projects: (1) the structure and mechanism of the northward-propagating boreal summer intraseasonal oscillation (ISO); (2) the role of dynamic and thermodynamic processes in the Indian Ocean dipole; (3) an observational analysis of TRMM microwave imager and QuikSCAT satellite data to study tropical cyclone formation in the western North Pacific; and (4) numerical modeling of the tropical cyclone formation associated with the dispersion of Rossby waves.

Collaborating with Simon Jiang and Bin Wang, Tim Li compared the spatial and temporal structures of the northward-propagating ISO in an ECHAM4 simulation with those in the NCEP/NCAR reanalysis, and found that they were similar. Remarkable among the similarities is the north-south asymmetry of specific humidity and vorticity

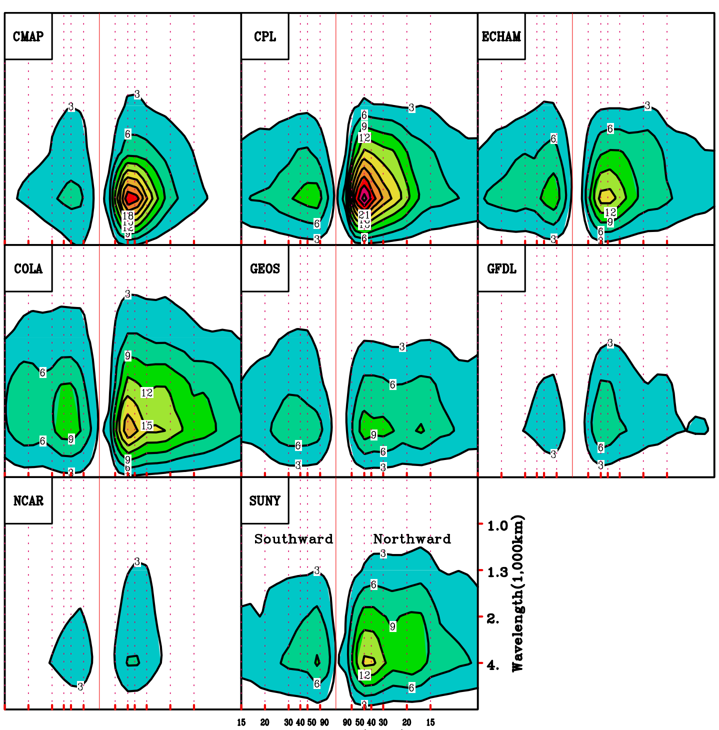


Figure 11: Ten-year-mean wavenumber-frequency spectra of 5-day mean rainfall in (mm/day)^2 are used to show the variability in boreal summer rainfall over India. The left (right) half of each plot shows spectra of the southward (northward) propagating variability. The upper left panel is from the CMAP (Climate Prediction Center Merged Analysis of Precipitation) product, which is used as observation; the remaining plots are from IPRC hybrid-coupled model (CPL) and the following atmospheric GCMs: ECHAM (Max-Planck-Institute for Meteorology), COLA (Center for Ocean-Land-Atmosphere Studies), GEOS (NASA/GSFC, USA), GFDL (Geophysical Fluid Dynamics Laboratory), NCAR (National Center for Atmospheric Research) and SUNY (State University of New York) models. Outputs from the middle and bottom panels are from the CLIVAR/Asian-Australian Monsoon Intercomparison Project (courtesy I.-S. Kang).

(Figure 12): The highest specific humidity in the lower troposphere and a positive vorticity field with an equivalent barotropic structure appear a few degrees north of the convection center. Given this finding, Li and his colleagues propose two mechanisms for the origin of the northward propagation of the ISO. The first is vertical shear in the mean flow, leading to tight coupling between baroclinic and barotropic waves in the free atmosphere and the generation of barotropic vorticity. The induced barotropic vorticity in the free atmosphere causes moisture convergence in the planetary boundary layer, shifting convective heating northward. The second mechanism is moisture-convection feedback. Two processes may contribute to the northward shift of the low-level moisture, namely, moisture advection by the mean southerly summer winds and moisture advection by the ISO winds in the presence of the mean north-south specific humidity gradient. The asymmetric specific humidity distribution leads to the northward shift of the ISO convection.

To understand better the role of these two mechanisms and the effect of air-sea interaction on the instability of the northward-propagating ISO, Li, Jiang, and Wang constructed a theoretical model. An eigenvalue analysis indicates that the northward propagation of the ISO is an unstable mode of the summer-mean flow in the monsoon region. It has a typical wavelength of 2,500 km, close to the observed length. While the easterly shear contributes to the northward propagation primarily north of 5°N, the moisture feedback and air-sea interaction contribute particularly in the region near and south of the equator. The team concluded that internal atmospheric dynamics are essential to the northward ISO propagation over the tropical Indian Ocean.

In a second study, Li, Zhang, Lu, and Wang (2002) used an oceanic GCM to calculate the mixed-layer heat budget in the eastern and western tropical Indian Ocean, in order to determine the relative contribution of surface-heat fluxes and ocean dynamic processes to SST variability in the region. From observations and numerical simulations, they identified four important differences between air-sea interactions in the tropical Pacific and Indian Oceans. Because of these differences, air-sea interactions in the Indian Ocean support a weakly damped oscillator that differs from the self-sustained El Niño mode.

Lastly, using the QuikSCAT and TRMM (Tropical Rainfall Measuring Mission) satellite data, Li and his colleagues studied tropical cyclone formation, which has been a long-standing scientific challenge due to the past lack of observations over the open ocean. They identified several processes that give rise to tropical cyclones in the western North Pacific. Among them are the dispersion of Rossby waves generated by a previous tropical cyclone and the energy accumulation of easterly waves over the monsoon convergence region. They succeeded in simulating in a 3-D high-resolution atmospheric model the tropical cyclone formations associated with these two processes.

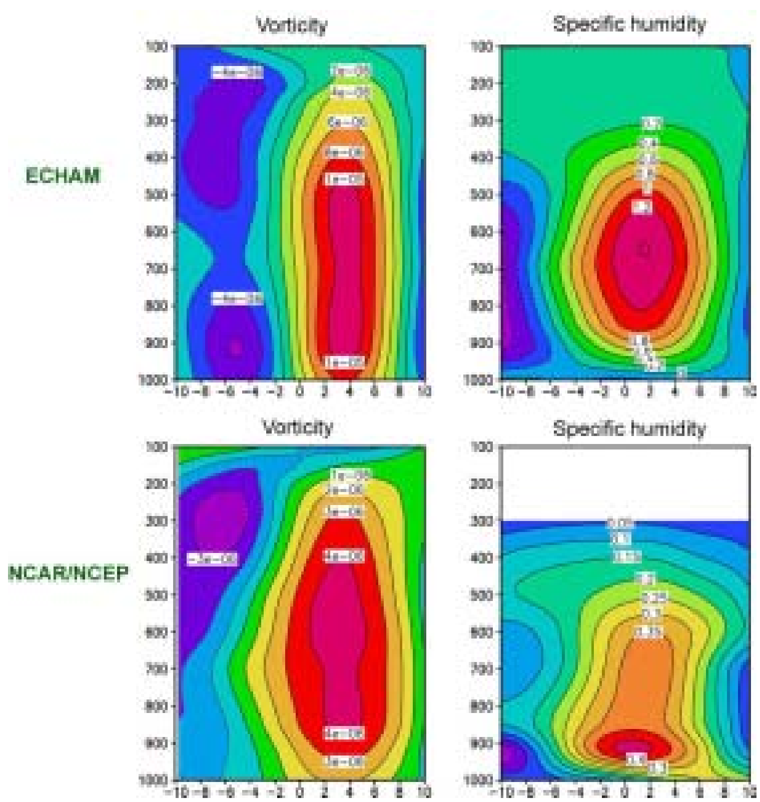


Figure 12. Composite structures of vorticity (s^{-1}) and specific humidity (kg/kg) fields for the northward propagating ISO mode derived from the ECHAM simulation (upper panels) and NCEP/NCAR Reanalysis (lower panels). The vertical axis is pressure (hPa) and the horizontal axis is distance (latitude) with 0 denoting the center of the ISO convection.

Ping Liu
Postdoctoral Fellow

Ping Liu obtained his Ph.D. in climate dynamics in 1999 from the Institute of Atmospheric Physics, Beijing, China. His research interests include comparisons among monsoon climate simulations with models of different resolution, the effects of air-sea interactions over the warm pool on monsoon variability and predictability, the dynamics of subtropical anticyclones, and changes in arid and semi-arid climates accompanying global climate change.

Both the Community Climate System Model (CCSM) from NCAR, a fully coupled atmosphere-ocean-land-ice global model, and the Community Atmospheric Model (CAM), its stand-alone atmospheric component, produce reasonable global climate states. The models are thus candidates for IPRC research on Asian monsoon predictability. Ping Liu has been assessing the ability of the CCSM and CAM (version 2.01) and its predecessor, the Community Climate Model version 3 (CCM3) to simulate the Asian-Pacific summer monsoon. He has analyzed a suite of long-term integrations conducted at several U.S. institutes and at the IPRC.

Liu found that CAM and CCM3 have serious deficiencies in simulating the Asian-Pacific summer monsoon. Analysis of the long-term means of the integrations shows that CAM produces too much rainfall over the Arabian Peninsula (over 800 mm for June–August compared to the less than 300 mm observed total annual precipitation) and the northeastern Tibetan Plateau (over 1,000 mm for June–August compared with less than 300 mm observed total annual precipitation). Moreover, CAM yields much less than observed rainfall over the South China Sea and eastward to the Philippine Sea (about one-third of the observed), and over southern China and southern Japan. The simulated wetter climate of the Arabian Peninsula is accompanied by a low-level cyclone and wind convergence that attracts the Somali Jet, which is actually located further south. The wetter climate over the northeastern Tibetan Plateau generates a strong low-level southerly wind to the south and to the east, and an anticyclone to the east, resulting in an extremely dry climate over observationally wet southern China and southern Japan. The lack of rain in the South China Sea and eastward to the Philippine Sea directly weakens the latent heat release, which further weakens the Nita-Huang pattern and produces a much drier climate over southern Japan. This poor simulation is of great concern because over 70% of the annual rainfall occurs during the summer monsoon in this region, and the latent heat release associated with rainfall generally determines the monsoon circulation.

Liu has explored possible causes of these deficiencies in CAM and CCM3 by increasing their horizontal resolution from T42 (about 300 km x 300 km) to T239 (about 60 km x 60 km), which results in better representation of steep mountains, and by tuning the horizontal diffusion coefficient to adjust the subgrid transport. Results show that very high-resolution versions of CCM3.6 (T170 and T239) produce more realistic rainfall over the Arabian Peninsula and the northeastern Tibetan Plateau, but other deficiencies remain. The steeper orography does not provide a noticeable gain in performance, whereas the horizontal diffusion adjustment yields only a slight improvement.

Liu found that three other fully coupled models that have the atmospheric component of the CAM2 or CCM3—namely, the CSM1.2, PCM1.0, and CCSM2—do produce a wetter climate over the South China Sea and eastward to the Philippine Sea, but their simulated sea surface temperature is too low. As none of these fully coupled models capture the entire monsoon system realistically, it seems that CAM needs to improve or change its convective scheme. Since the ECHAM model simulates realistic rainfall for eastern Asia and the Arabian Peninsula at the coarse resolution of T42, the convection scheme of the ECHAM is a promising candidate, and Liu is currently implementing this scheme into CAM.

Omer L. Sen
Postdoctoral Fellow

Omer Sen received his Ph.D. in hydrology from the University of Arizona in Tucson, Arizona, in 2000. His research interests include land-surface atmosphere interactions, hydro-meteorological modeling, regional climate modeling, remote sensing in hydrometeorology, and anthropogenic climate change.

This past year, Omer Sen has been studying land-surface degradation and vegetation restoration in Southeast Asia and their impact on the East-Asian summer monsoon (EASM) and rainfall. Using the IPRC–RegCM (Wang, Sen, and Wang, 2003), he investigated effects of the deforestation that has taken place on the Indochina Peninsula (Sen, Wang, and Wang, 2003). Results of the modeling experiment indicated that the deforestation had both significant local and far-reaching effects on the EASM and its rainfall; the changes in simulated rainfall are in broad qualitative agreement with the observed trends in Indochina and southern China.

In another study (Sen, Wang, and Wang, 2003), he investigated the local and remote climatic effects of vegetation restoration in northern parts of China, which is one of the regions experiencing profound desertification over the last decades. Indeed, desertification is affecting one-third of China, and the annual expansion of the desert is reaching well over 2,400 km^2/year. China has made plans to bring its land desertification under control by 2010 through a massive restoration of vegetation across the country. The sustainability of the restored vegetation cover, however, remains a big question. Reversing the desertification process depends largely on a consistent increase in precipitation to support the restored vegetation. To investigate whether a relatively large-scale vegetation restoration effort can improve local rainfall enough to help maintain new vegetation in once desertified lands, Sen carried out an idealized land-cover change experiment. In this study, he also looked into how such a large-scale surface-cover change would affect the EASM and its rainfall. He found statistically significant increases in rainfall over northern China, but the increases were largely in intensity and not in frequency, implying that in the lowlands, it will be very difficult to maintain a replanted surface. The increase in rainfall over highlands, which already receive rather frequent rainfall, may, however, support a restored vegetation cover. The simulation further indicates that the land-cover change in northern China significantly increases rainfall in southern China and the lower reaches of the Yangtze River Basin.

Recently, Sen has begun to study the relation between Tibetan Plateau snow and the EASM, again using the IPRC–RegCM for his experiments. First, he obtained realistic measurements of snow cover and snow depth on the Tibetan Plateau by downscaling the ECMWF reanalysis data with the IPRC–RegCM using a 2.5-day e-folding time. Second, he used the realistic snow cover and depth from the first 5 days of April 1998 to initialize an ensemble of 5 simulations, run from April through August 1998. Third, he used the first 5-day snow cover and depth in April taken from climatology (i.e., averaged over many years) to initialize another ensemble of 5 simulations, run for the same period as the previous set. Preliminary comparison of these two ensembles indicates that the changes in snow cover and depth significantly affect the higher, rather than lower, level atmospheric circulation in June, July, and August. At 300 mb, for instance, westerly winds north of the Tibetan Plateau grew significantly stronger, and those over the southeastern flank of Tibetan Plateau and southern China significantly weaker. Significant changes in simulated rainfall were also observed in eastern and northern China.

Bin Wang

Professor of Meteorology
Theme 3 Co-Leader

Bin Wang obtained his Ph.D. in geophysical fluid dynamics from the Florida State University in 1984. His research interests include the variability and predictability of the Asian-Australian monsoon system, tropical intraseasonal oscillations, El Niño–Southern Oscillation dynamics, large-scale ocean-atmosphere interactions, the annual cycle in the coupled ocean-atmosphere-land system, and interdecadal variability of the Asian-Pacific climate.

Bin Wang studied the interannual variability of the Asian-Australian Monsoon (A-AM) this past year. In a project with Randy Wu and Tim Li, he determined the dominant mode of this variability and its causes (Wang et al., 2003) Their major finding is that A-AM variability exhibits a strong biennial pattern, characterized by two low-level anticyclones—the South Indian Ocean and western North Pacific anticyclones. The former is present during the developing El Niño and the latter during the decaying El Niño. The traditional view holds that major causes of A-AM interannual variability are the presence of El Niño conditions in the Pacific and local sea surface temperature (SST) anomalies in the A-AM regions. Wang and his colleagues, however, found that the local SST anomalies result from air-sea interactions and thus cannot be regarded as an external forcing. Moreover, remote El Niño forcing *alone* cannot explain the extraordinary amplification of the South Indian Ocean anticyclone during the developing stage of El Niño, nor the maintenance of the western North Pacific anticyclone during the decaying phase of El Niño. Rather, it is the monsoon's interaction with the underlying warm ocean that plays a critical role in generating and maintaining interannual variations in the A-AM. This interaction is characterized by *a SST dipole with cold water to the east and warm water to the west of the anticyclone center* and consists of feedback between an atmospheric Rossby wave and the SST dipole. Wang, Wu, and Li conclude that the El Niño forcing, monsoon-ocean interaction, and annual variations in the atmospheric circulation are all fundamental causes of A-AM interannual variability.

In a second study, Wang collaborated with I.-S. Kang (Seoul National University) and others to analyze A-AM anomalies in ensemble simulations of 11 different atmospheric general circulation models. Their focus was on the question of why nearly all atmospheric general circulation models simulated the precipitation anomalies poorly during the unprecedented September 1996–August 1998 El Niño period. They noted that lack of skill over the region with heavy precipitation (5°N–30°N, 80°E–150°E) is a striking characteristic of all models. The models' deficiency results from failing to simulate correctly the relationship between local summer rainfall and SST anomalies over the Philippine Sea, the South China Sea, and the Bay of Bengal: The observed rainfall anomalies are negatively correlated with SST anomalies, whereas the modeled anomalies are positively correlated (Figure 13). Although the models' physical parameterizations do have uncertainties, the poor rainfall simulation is primarily due to the experimental design in which the atmosphere is forced to respond passively to the prescribed SSTs, while in nature, SST is partly a function of atmospheric forcing. These findings have important implications for the strategy of climate prediction and the validation of climate models.

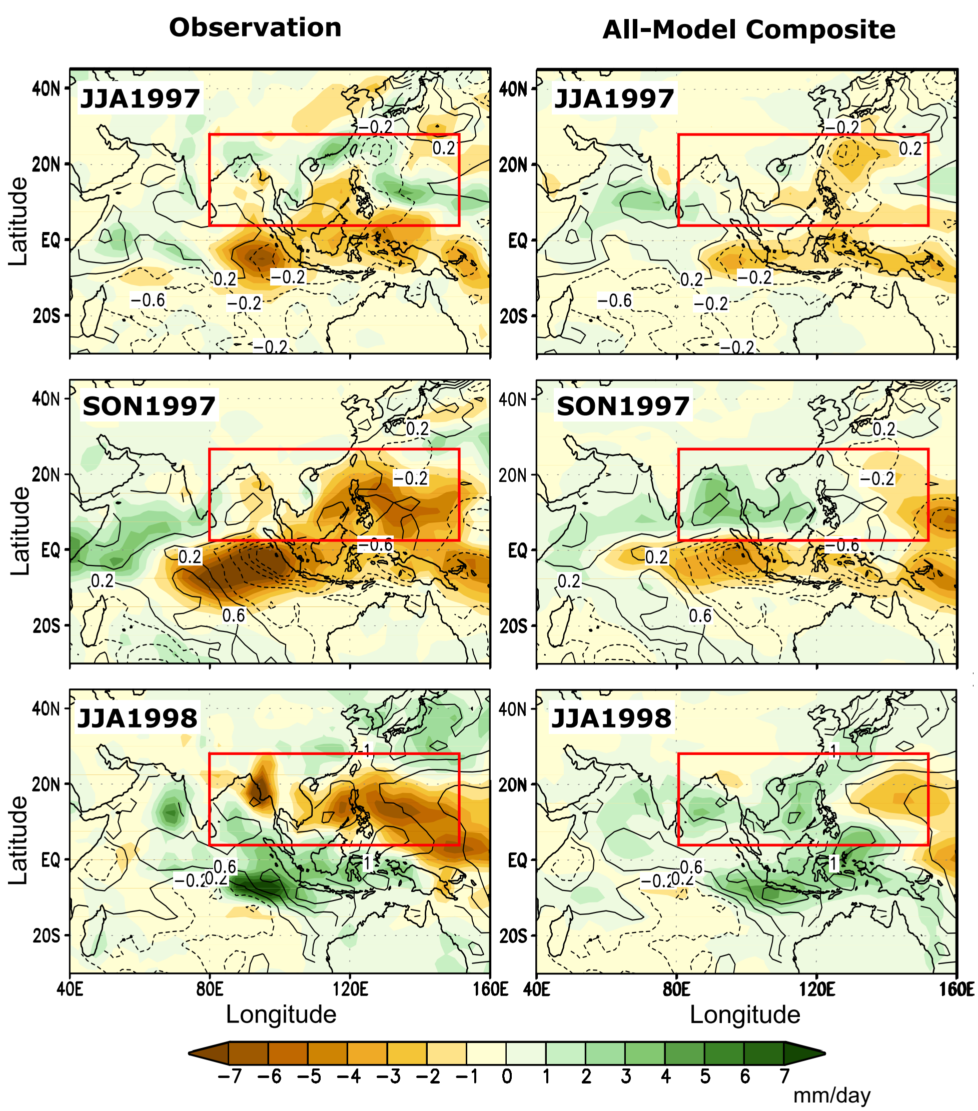


Figure 13. Precipitation (color shading) and sea surface temperature anomalies (contour interval 0.4K) for the following seasons: June, July, August (JJA) 1997; September, October, November (SON) 1997; and JJA 1998 seasons. The left three plots are from observations, the right ones are from the all-model composites. The red-lined box outlines the regions of Southeast Asia and tropical western Pacific, where the models have difficulty in simulating the anomalies correctly.

Yuqing Wang
Associate Researcher

Yuqing Wang obtained his Ph.D. in 1995 in applied mathematics from the Centre for Dynamical Meteorology and Oceanography, Monash University, Australia. 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.

Yuqing Wang continued research with the IPRC Regional Climate Model (IPRC–RegCM). Regarding the East-Asian monsoon, the model successfully simulated the 1998 onset over the South China Sea, the area-averaged daily rainfall, the daily minimum and maximum air temperatures, and their monthly mean geographic patterns (Wang et al., 2003). The model also captured the location and frequency of heavy daily rainfall (Figure 14 shows the rainfall statistics for June), a necessary capability of a model used for studying the climatic effects due to changes in surface boundary conditions and for assessing impacts of global change on regional climate.

Wang also applied the IPRC–RegCM to the eastern Pacific (150°W–30°W, 35°S–35°N), succeeding in simulating the stratocumulus cloud deck off South America during austral spring. The simulated surface winds, precipitation, and cloud-water path compare favorably with satellite observations. The model captures the surface mixed layer, the capping temperature inversion, and the stratocumulus clouds with their drizzle. Experimentally removing the effect of clouds on radiation south of the equator caused the boundary-layer clouds to almost disappear and remotely forced a decrease in precipitation by 10–15% in the ITCZ north of the equator. Further analyses showed that the cloud deck affects the surface north-south circulation in the tropical eastern Pacific by imposing a net cooling at the cloud top, which brings about an anomalous surface high-pressure system. This system, in turn, strengthens the near-surface, cross-equatorial pressure gradient and airflow. This low-level meridional circulation strengthens the local Hadley circulation, increasing the mass and moisture convergence and convection in the ITCZ, as well as the large-scale subsidence and cloud deck off the Peruvian Coast. Thus, positive feedback associated with the cloud deck helps to keep the ITCZ located north of the equator in the tropical eastern Pacific (Wang et al., 2003a and b).

Wang is now developing a global-belt version (45°S–45°N, 0–360°) of the IPRC–RegCM. Tested with a resolution of 1° x 1°, the model shows skill in simulating the subtropical boundary-layer clouds and rainfall in the monsoon regions and in the ITCZ. The new version will be used for studying tropical climate processes, particularly intraseasonal oscillations, cloud radiation forcing, and the role of the boundary layer and convection in the tropics and the monsoon circulation.

In collaboration with the LASG-Institute of Atmospheric Physics, Chinese Academy of Sciences in China, Wang is developing a new generation atmospheric general circulation model (GCM), which will allow two-way nesting with the IPRC–RegCM, that is, also allow feedback from the regional model to the atmospheric GCM. He has already coupled the model physics he developed for the IPRC–RegCM to the dynamical core developed at LASG, which solves the primitive equations for longitude and latitude grid points globally. A simple sea-ice model has also been coupled to the atmospheric GCM. Various components still need to be made consistent with each other, but already the model runs ten-year simulations stably and should be available for use within two years.

Wang continued his research on tropical cyclones, conducting numerical experiments to examine how energy is dispersed from an existing tropical cyclone on a beta-plane without any environmental flow. The low-level and upper-level jets to the southeast of the tropical cyclone are found to be strongly coupled and to produce precipitation bands similar to the stationary rainbands observed in many real tropical cyclones. Detailed analyses and sensitivity experiments to understand the physical processes in the energy dispersion of tropical cyclones are underway.

In collaboration with O. Sen and B. Wang, Wang studied the impact of deforestation in the Indochina Peninsula on the East-Asian summer monsoon. In collaboration with S.-P. Xie, H. Xu, B. Wang, and J. Small, he has researched the effect of the Andes on the eastern Pacific climate system, and the atmospheric reaction to tropical instability waves.

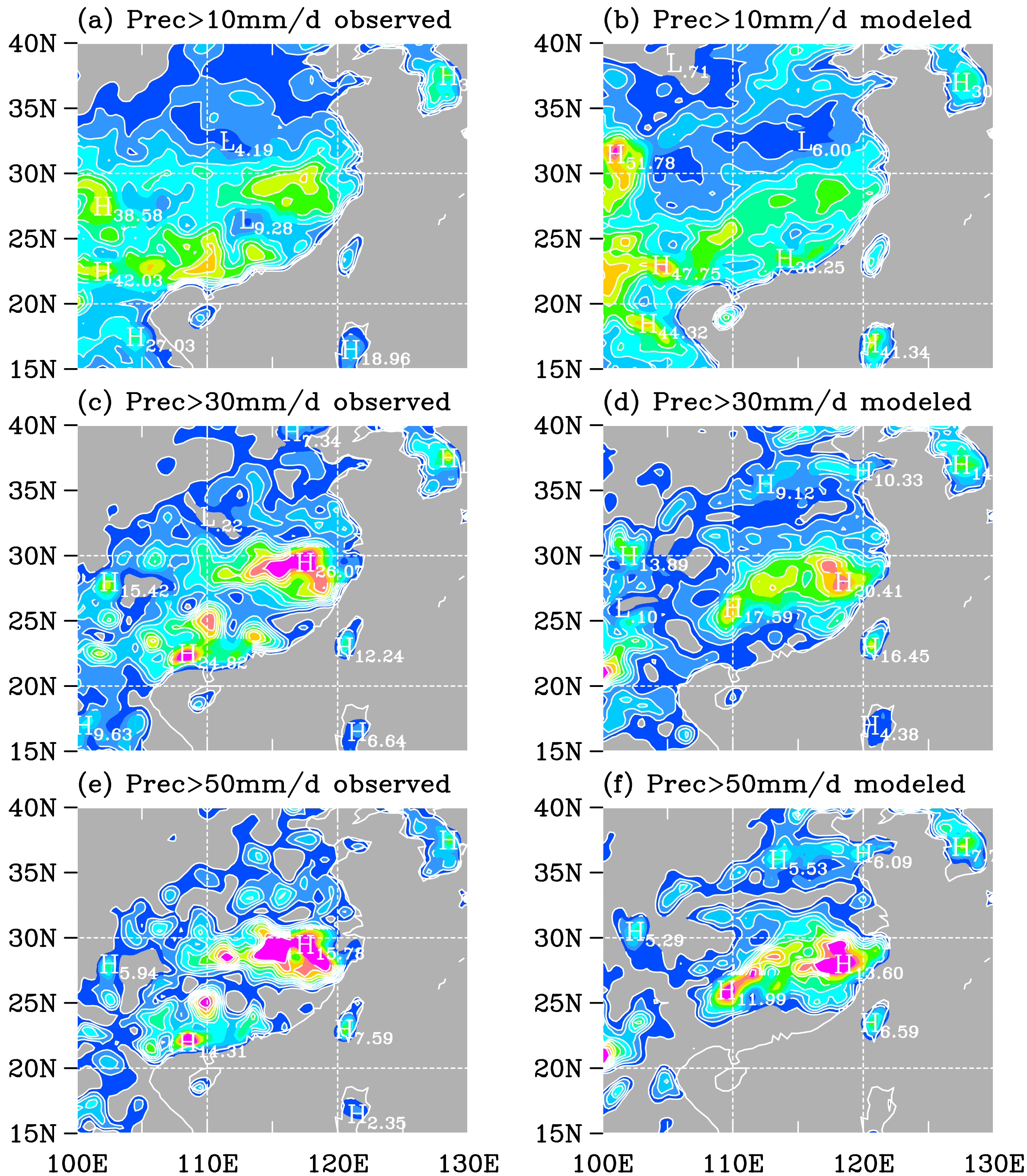


Figure 14. For the month of June, the observed (left panels) and model-simulated (right panels) distributions of the percentage of days of daily rainfall larger than 10 (top), 30 (middle), and 50 (bottom) mm/day.

Research Activities and Accomplishments

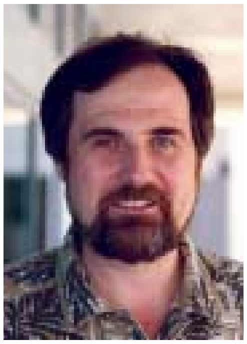
Theme 4: Impacts of Global Environmental Change

Overview

Understanding the global and regional climate impacts of mankind's activities is one of the most urgent tasks now facing the international scientific climate community. Theme-4 research thus aims to improve the understanding of how global climate change impacts, and is impacted by, the Asia-Pacific region. Work is also underway to improve the underpinnings of climate prediction and the confidence that can be placed in model predictions.

Current Theme-4 research focuses on three major topics. The first is an investigation of the nature of regional and global climate feedbacks in coupled-model simulations. So far, simulations with the NCAR coupled atmosphere-ocean global model have been analyzed, but the investigation is expanding to include simulations with models at other major climate research centers. The second focus seeks to understand the nature of intraseasonal and interannual regional climate variability, particularly the variability associated with the Arctic Oscillation. Research on the dynamics of the Arctic Oscillation has blossomed recently as scientists have begun to understand that the geographical pattern of the long-term climate trend in the extratropical Northern Hemisphere, apparent in recent decades, projects onto the Arctic Oscillation. A critical issue is how much of the variability in the Arctic Oscillation can be attributed to internal atmospheric processes and how much to atmosphere-ocean interactions. Research at the IPRC is, therefore, aimed at evaluating the atmospheric aspects of the oscillation's dynamics, particularly those involving the stratospheric circulation. The third research area deals with the application and evaluation of very high-resolution global atmospheric models. As computers grow in power, climate predictions will be made using models with increasingly higher resolution. (Indeed, a threshold has been passed with the development of the Earth Simulator, a threshold that allows limited global atmospheric model integrations to be performed at about 10-km horizontal grid resolution.) As such models are developed, it will be necessary to understand just how to exploit the high resolution in order to gain insight into the dynamics of climate and climate change. IPRC research in this area includes comparisons of circulation statistics from existing high-resolution integrations with satellite, aircraft, and station data.

Individual reports



Kevin P. Hamilton
Professor of Meteorology
Theme 4 Leader

Kevin Hamilton received his Ph.D. in meteorology from Princeton University, Princeton, New Jersey, in 1981. 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.

Kevin Hamilton has continued modeling and observational work designed to understand the role of the stratosphere in the natural and forced variability of the Arctic Oscillation (AO). The AO is the leading pattern of intraseasonal and interannual variability in the extratropical atmospheric circulation of the Northern Hemisphere and has very strong impacts on weather in northern Asia and Europe. Recent observational studies have identified a dominant tendency for the downward propagation of AO anomalies from the stratosphere into the troposphere. Scientists have interpreted this as an indication that knowledge of the stratospheric circulation can be used for monthly-to-seasonal forecasting of surface circulation, and also that long-term trends in stratospheric radiative forcing (e.g., due to ozone trends) could be reflected in regional climate trends at the surface.

To examine possible stratosphere-troposphere dynamical links, Hamilton analyzed control simulations and a series of perturbed simulations performed with the Geophysical Fluid Dynamics Laboratory SKYHI troposphere-stratosphere-mesosphere general circulation model. Figure 15a shows the height and time evolution of the AO index (defined here as the projection onto the first empirical orthogonal function, or EOF, of geopotential determined separately at each level) anomaly, composited for the 90 days *after* the index has fallen below –1.5 standard deviations at the 10 hPa level. Analyzing the November–March data for 68 years of control integration, Hamilton found 20 such anomalies and constructed the composite in Figure 15a based upon these 20 cases. The strong negative AO index in the stratosphere indicates an anomalous weakening of the westerly polar vortex. The composite shows that on average this weakening is followed by a prolonged period of an anomalously negative AO index at the surface, which corresponds to weak circumpolar flow and anomalously cold temperatures in northern Europe and Asia. These model results are very similar to those obtained when observations are analyzed in the above manner.

Are the long-lived tropospheric circulation anomalies in Figure 15a actually caused by a downward dynamical process that propagates AO anomalies from the stratosphere to the

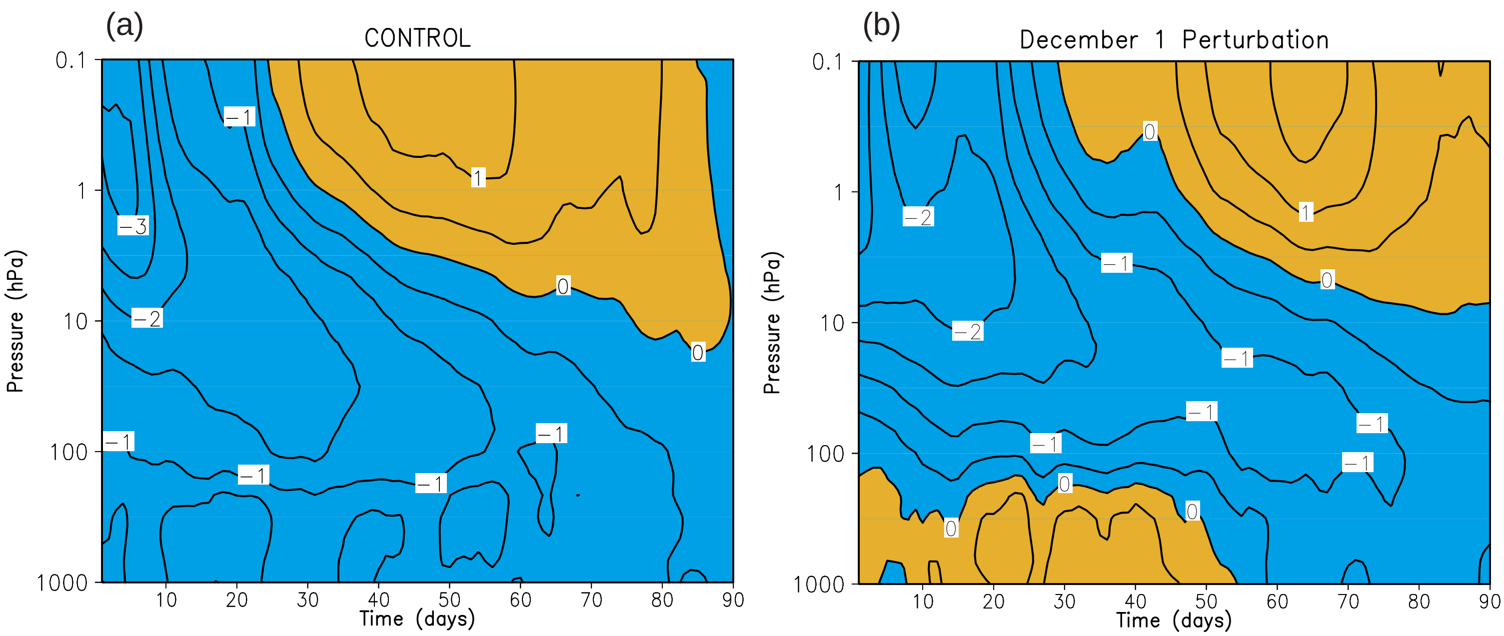


Figure 15. Results from integrations of the SKYHI general circulation model. Panel a: The anomaly in the amplitude coefficient for the first EOF of geopotential in a control integration and composited over twenty 90-day periods after the anomaly at 10 hPa dropped below a threshold of -1.5. The normalization of the coefficient is such that 1 unit at each level corresponds roughly to 1 standard deviation of the time series at that level. Panel b: The anomaly in the amplitude coefficient for the first EOF of geopotential for December 1-February 28, averaged over 18 cases in which the model stratospheric circulation was arbitrarily perturbed on December 1.

troposphere? This is currently a popular view in the community. Geophysics, however, provides warning examples in which apparent phase propagation is not indicative of the direction of causation. Hamilton has performed a series of experiments in which he introduced a perturbation to the circulation that significantly reduces the AO index, but only in the stratosphere. Figure 15b shows the AO anomaly averaged over 18 cases in which the perturbation was introduced on December 1. Over the next 90 days, on average, the stratospheric anomaly propagates downward. Since the initial perturbation in this case was imposed just in the stratosphere, the result shows unambiguously a downward influence of the stratospheric circulation on the surface flow.

Hamilton and his colleagues are conducting related research with the SKYHI model to study the effects of the tropical quasi-biennial oscillation on extratropical Northern Hemisphere surface circulation and to study the effects of stratospheric volcanic aerosol on the tropospheric climate.

In another project, Hamilton has analyzed control integrations of very fine vertical and horizontal resolution versions of the SKYHI model and has assessed high spatial- and temporal-resolution data that can be used for comparison. One specific issue that he is investigating with these model integrations is the contribution of tropical cyclones to the eddy transports of heat, momentum, and moisture.

Weijun Zhu

Postdoctoral Fellow

Weijun Zhu obtained his Ph.D. in meteorology in 1999 from the Nanjing Institute of Meteorology, Nanjing, China. His research interests include the observed and modeled interaction between oceanic and atmospheric processes, general atmospheric mid- and long-term weather forecasting, and short-term climate prediction.

Weijun Zhu is working with Kevin Hamilton on projects aimed at characterizing and understanding the climate sensitivity to global radiative perturbations. These projects have involved analysis of various integrations they have conducted with the NCAR coupled atmosphere-ocean global climate model. The climate perturbation they have introduced into these experiments has been an increase in the solar constant. A novel aspect of the suite of experiments is the inclusion of very large perturbations—up to a 45% increase in the standard solar constant. The character of the response appears to change dramatically once the increase in solar constant exceeds about 20%. Below this threshold, the local- and global-mean surface temperatures increase very nearly linearly with the increase in forcing. Above this threshold, however, the response becomes very nonlinear and the model may be pushed to, or may at least approach, climate instability and consequent catastrophic warming. The possibility of climate instability at higher radiative forcing has been raised before in theoretical and idealized model studies, but the present results appear to be the first to show this can occur in a comprehensive global climate model.

IPRC researchers have interested collaborators at the Canadian Center for Climate Modelling and Analysis (CCCMA) in repeating the perturbed solar-constant experiments with their global coupled atmosphere-ocean model. The global climate sensitivity in the NCAR model is at the very low end of the sensitivity of current comprehensive climate models (the model displays a global-mean surface warming of about 2°C in response to a doubling of atmospheric carbon dioxide). By contrast, the CCCMA model is 50% more sensitive than the NCAR model, a sensitivity level more typical of current models. Zhu and Hamilton are now performing a detailed comparison of the control and perturbed simulations of the two models in order to understand the reasons for the difference in their climate sensitivity.

The Asia-Pacific Data-Research Center

The Asia-Pacific Data-Research Center (APDRC) of the IPRC facilitates climate research conducted within the IPRC and serves the national and international climate communities by providing easy access to climate data and products. The amount of oceanographic data, satellite, and model-derived products available for Asia-Pacific and global climate studies has increased dramatically in the last decade, owing in part to the successful outcomes of recent international observational programs (e.g., TOGA, WOCE) and to advances in satellite and modeling capabilities. Once the currently planned observational programs (e.g., Argo, time-series stations, new satellite missions) are fully underway, the data stream will undergo another jump in magnitude. These products, however, are often underused, largely because they are difficult to access.

The APDRC was therefore established "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." By linking data management with research, the center is striving to be a powerful research resource, one that will provide one-stop shopping of climate data and products.

The overall direction for the APDRC is provided by its steering team. Until the end of March 2003, this team consisted of Jay McCreary (IPRC Director), Peter Hacker (APDRC Manager), Humio Mitsudera (Theme 2 Leader), Takuji Waseda (Frontier Research Scientist), and Ronald Merrill (Computer Systems Manager).

The APDRC has a research and a data branch. The research branch is supported by Frontier and also by the National Aeronautics and Space Administration (NASA) under a five-year project that began October 2000. The research activities are described in the theme overviews and individual accomplishments of this report.

Funding for the data branch began in July 2001 by the National Oceanic and Atmospheric Administration (NOAA) under the project "Establishment of a data and research center for climate studies." Support for the second year came in July 2002 and included funding for our NOAA Pacific Marine Environmental Laboratory (PMEL) partners in Seattle, Washington, to develop software and servers (PIs: Nancy Soreide, Don Denbo, Steve Hankin). The NOAA funding for the APDRC is in part to implement the infrastructure for the Global Ocean Data Assimilation Experiment (GODAE).

The APDRC data branch has four main activities: (1) data-server system (DSS) implementation and development; (2) data management and archive building; (3) value-added activities and product development; and (4) coordination and collaboration, an activity that cuts across the other three and entails interaction with local, national, and international partners. (A new activity—which resulted from writing a proposal for a Pacific Ocean Information System as part of GODAE—is to develop and serve products for ocean applications, as well as research, such as regional ocean nowcasts, forecasts, and climatologies. Serving a broad range of users, this activity will, with all likelihood, grow in coming years.) An update of the accomplishments in the four projects during the past year follows.

DSS implementation and development are headed by Takuji Waseda and Yingshuo Shen (Data Server Manager). Accomplishments for the past year are as follows: server development with Japan (Yingshuo Shen and Kazutoshi Horiuchi) and NOAA/PMEL; APDRC website upgrade at http://apdrc.soest.hawaii.edu; and evaluation and upgrading of our server capabilities, which include the Live Access Servers (LASs) and EPIC Servers developed at PMEL. The APDRC is now operating a system of servers for both gridded and *in situ* products, for novice users through the web-based servers and for more skilled users through their client software and our OPeNDAP (formerly DODS, the Distributed Oceanographic Data System), Aggregation, and GrADS/DODS (GDS) servers. The LAS (version 6.0) was installed and is serving products stored locally or remotely to the public and restricted outputs from ECMWF and Japan's Earth Simulator to IPRC users. The Aggregation Server, which uses a Tomcat Server, allows users to access locally aggregated products stored locally or remotely with their own software and OPeNDAP protocols. A Common Gateway Interface, running with an Apache server, can translate HDF files (a common format for

Left to right, back row: Peter Hacker, Gang Yuan, Ronald Merrill, Yongsheng Zhang, Julian McCreary, Humio Mitsudera, Tangdong Qu, Nikolai Maximenko **Front row:** Max Yaremchuk, Jim Potemra, Yingshuo Shen, Zuojun Yu, Takuji Waseda.

satellite products) into OPeNDAP. This allows the APDRC to serve SeaWinds data (QuikSCAT satellite level–3 data). Several EPIC servers are operational and are serving the complete *in situ* WOCE (version 3) data (CTD, Upper Ocean Thermal, current meter) as well as the international Argo float data as a "test." A more complete discussion of server capabilities and issues appeared in *IPRC Climate*, Vol. 3, No. 1, 2003.

Data management and archive building were headed by Humio Mitsudera until he left the IPRC in March 2003. Our two data specialists, Gang Yuan and Yongsheng Zhang, working together with Yingshuo Shen, are in charge of acquiring new data sets and products and preparing them for the servers. Notable accomplishments over the past year include the following: archiving and serving the complete WOCE (version 3) data released in November 2002; managing and serving several new gridded products, including atmospheric, satellite, GODAE products, and the Navy Research Laboratory (NRL) Layered Ocean Model (NLOM) surface layer output, a 1/16° global product; developing a data-management workplan for uniform quality control of the historical temperature and salinity profile data sets for the global ocean; and beginning an APDRC/JAMSTEC/Frontier collaboration to put together a climate database for global, coupled data assimilation. The latter activity, a part of MEXT's Research Revolution 2002 under Professor Toshiyuki Awaji at Frontier, included efforts by IPRC staff (especially Omer Sen and Jan Hafner) in addition to APDRC staff. As a pilot project, we are managing and serving Argo data and are starting quality control procedures for Argo data from the Indian and western Pacific Oceans (Gang Yuan and Pierre Dutrieux, a UH graduate student.) For the latest information on available data sets and products, visit the APDRC website.

The value-added activities over the past year have produced the following: global absolute sea-level and surface velocity products (Nikolai Maximenko and collaborators) and regional climatological products in the low-latitude western Pacific (Max Yaremchuk and Tangdong Qu); a plan for comparing North Pacific assimilation products as part of GODAE (Humio Mitsudera and collaborators); and a quality control effort for the historic upper-ocean thermal database in the Indian Ocean (through a subcontract to CSIRO, Australia). The latter activity, which will include a transfer of quality control procedures and technology (software) to the APDRC, is part of our multi-year effort with partners to produce a global, uniformly quality-controlled data set for use in GODAE assimilation activities. The above products will be made available on our servers. Activities that have continued from the previous year include the evaluation of surface-flux products using ocean models (Zuojun Yu) and the development of a database for the Indonesian Throughflow region (Jim Potemra).

Coordination and collaboration efforts by the APDRC will ensure efficient implementation of the APDRC activities within the local, national, and international climate research communities. In Hawai‘i, the APDRC is coordinating efforts with the Sea-Level Center and the Acoustic Doppler Current Profiler (ADCP) Data Center. The principle national links are with PMEL and the National Virtual Ocean Data System (NVODS) on DSS development; NOAA Geophysical Fluid Dynamics Laboratory (GFDL) on the development of assimilation-friendly, historical data sets; and with U.S. GODAE on coordination of real-time and delayed-mode data serving. Internationally, the principle links are with Japan on DSS development and assimilation-friendly, data-set assembly; with CSIRO in Australia on the development of historical, quality-controlled profile data sets; with Argo on the definition and implementation of regional data centers for data-set quality-control and distribution of products; and with CLIVAR Pacific on data management and serving by building on the WOCE experience.

The IPRC Computing Facility

The IPRC computer systems continue to expand in their performance and disk capacity. As of March 2003, the IPRC high-performance computing facility is equipped with one shared-memory vector-parallel machine and three distributed-shared-memory RISC-based parallel machines.

The vector-parallel machine is a CRAY SV1, which was upgraded this year to 32 CPUs (central processing units), 32.0 GB (gigabytes) shared memory, and 1016 GB local storage. The upgrade added 8 CPUs, 16.0 GB of memory and 300 GB of disks. This increased the peak speed of the machine from 28.8 to 38.4 GFLOPS (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 of these 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, while the other has a 32 CPU 300 MHz system with 10.0 GB of memory, 60 GB of local disk storage and a peak speed of 19.2 GFLOPS. The third RISC-based parallel machine is an Origin 3400 with 32 CPUs (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 the source codes. The degree of parallelism depends highly on the original code structure; an appropriate code tuning improves performance.

These four systems are the main computational resources of the IPRC. They have been used successfully for integrating a number of scientific codes, including models used widely in the oceanographic and meteorological community (POM, MOM, POP, CSM, etc.) and those developed by IPRC researchers. Some of these models were used as benchmarks to evaluate computers from various vendors, and the results were used to choose the computers for the IPRC (see Jensen, 1999: IPRC/SOEST Technical Report 99-03). In addition to these shared computational resources, the IPRC has two Sun Enterprise 450 4-CPU machines and three 2-CPU Alpha machines.

Main storage is served by a 4-CPU Origin 200 with a 1260 GB SGI Clarion RAID (Redundant Array of Independent Disks) and a StorageTek Tape Library which extends the capacity of the RAID systems with Veritas Storage Migrator hierachical storage management software. The StorageTek library was upgraded this year from a Timberwolf 9710 to an L700, which increased the raw storage capacity from 20 to 106 TB. In addition, a Storage Area Network (SAN) centered around an 8-port Brocade Silkworm Fibre Channel allows 100 MB/sec access to an SGI LSI TP9400 RAID from all 4 SGI Servers. The capacity of the SAN attached disk was doubled to 7.88 TB.

Left to right: Shinya Yarimizo, Ronald Merrill, and Wilfred Malepe.

The IPRC also has 9 working 500 GB IDE SCSI attached RAID enclosures providing an additional 4.39 TB of network accessible storage. Each IPRC researcher is provided with a UNIX workstation and a PC. This year 5 Dell Optiplex PC's, 3 Dell 630 Linux workstations and one Dell Latitude 640 were purchased. These machines will provide desktops for incoming staff and are the first phase of a replacement cycle for the aging inventory of machines. This brings the desktop computer inventory to 49 Sun workstations, 6 SGI workstations, 7 Dell workstations and 70 PCs. The network connections of each machine to the servers as well as to the outside world are made through the LAN (Local Area Network), which is provided by the Research Computing Facility of SOEST.

The Asia-Pacific Data-Research Center (APDRC) used funds from the Research Revolution 2002 project sponsored by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), to purchase 3 AC&NC JetStor III SCSI attached IDE RAID arrays, which together provide 8 TB of usable storage for APDRC related work. The MEXT funds we also used to purchase 4 Sony laptops for APDRC staff.

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Submitted Papers

Ashok, K., Z. Guan, N. H. Saji, and T. Yamagata: On the individual and combined influences of the ENSO and the Indian Ocean Dipole on the Indian summer monsoon. *J. Climate*.

Chang, C.-P., Z. Wang, J. Ju, and T. Li: On the relationship between western maritime continent monsoon rainfall and ENSO during northern winter. *J. Climate*.

Cronin, M.F., S.-P. Xie, and H. Hashizume: Barometric pressure variations associated with eastern Pacific tropical instability waves. *J. Climate*.

Di Lorenzo, E., A. J. Miller, N. Schneider, and J. C. McWilliams: The warming of the California Current: Dynamics, thermodynamics and ecosystem implications. *J. Phys. Oceanogr*.

Edwards N., and K.J. Richards, Nonlinear double-diffusive intrusions at the equator. *J. Mar. Res*.

Fu, X., and B. Wang, 2002: Influences of adjacent continental monsoons and air-sea coupling on the climatological mean and annual cycle of tropical Pacific. *J. Climate*

Hafner, J., and S.-P. Xie: Far-field simulation of the Hawaiian wake: Sea surface temperature and orographic effects. *J. Atmos. Sci*.

Hamilton, K., A. Hertzog, F. Vial, and G. Stenchikov: Longitudinal variation of the stratospheric quasi-biennial oscillation. *J. Atmos. Sci*.

Hamilton, K., and W. Zhu: Large perturbations to terrestrial climate models and a simulated runaway greenhouse effect. *Canadian Meteorological and Oceanographic Society Bulletin*.

Horinouchi, T., S. Pawson, K. Shibata, U. Langematz, E. Manzini, M. Giorgetta, F. Sassi, R. Wilson, K. Hamilton, J. de Grandre, and A. Scaife: Tropical cumulus convection and upward propagating waves in middle atmosphere GCMs. *J. Atmos. Sci*.

Inatsu, M., H. Mukougawa, and S.-P. Xie: Atmospheric response to zonal variations in mid-latitude SST: Transient and stationary eddies and their feedback. *J. Climate*.

Jensen, T., T. Miyama, Y.Y. Kim, and T. Qu : Bifurcation of the Pacific North Equatorial Current in a wind-driven model. *Geophys. Res. Lett*.

Jiang, X., Li, T., and B. Wang: Structures and mechanisms of the northward-propagating boreal summer intraseasonal oscillation. *J. Climate*.

Kobashi, F., and K. Hanawa: Hydrographic features off the southeast coast of Kyushu during the Kuroshio small meanders, Case study for small meanders occurred in 1994 and 1995 spring. *J. Oceanogr*.

Lebedev, K.V., M. Yaremchuk, H. Mitsudera, I. Nakano, and G. Yuan: Monitoring the Kuroshio Extension through dynamically constrained synthesis of the acoustic tomography, satellite altimeter and in situ data. *J. Oceanogr*.

Maximenko, N.: Correspondence between Lagrangian and Eulerian velocity statistics at the ASUKA line. *J. Oceanogr*.

Mitsudera, H., B. Taguchi, Y. Yoshigawa, H. Nakamura, T. Waseda, and T. Qu: Numerical study of the Oyashio water pathways in the Kuroshio-Oyashio confluence. *J. Phys. Oceanogr*.

Nechaev, D. A., M. Yaremchuk, and M. Ikeda: Interdecadal variability of circulation in the Artic Ocean retrieved from climatological data by variational method. *J. Geophys. Res*.

Offermann, D., M. Donner, K. Hamilton, B. Naujokat and P. Winkler: Indicators of long-term changes in middle atmosphere transports. *Advances in Space Research*.

Okajima, H., S.-P. Xie, and A. Numaguti: Interhemispheric coherence of tropical climate variability: Effect of climatological ITCZ. *J. Meteor. Soc. Japan*.

Panteleev, G. G., M. Ikeda, A. Grotov, D. Nechaev, and M. Yaremchuk: Mass, heat and salt balance in the eastern Barents Sea obtained by inversion of a hydrographic section. *J. Oceanogr*.

Pezzi, L., and K.J. Richards: The effects of lateral mixing on the mean state and eddy activity of an equatorial ocean. *J. Geophys. Res.*

Qu, T., and E. Lindstrom: Northward intrusion of the Antarctic Intermediate Water in the western Pacific. *J. Phys. Oceanogr*.

Randel, W., P. Udelhofen, E. Fleming, M. Gelman, K. Hamilton, D. Ortland, R. Swinbank, F. Wu, M. Baldwin, M.-L. Chanin, K. Labitzke, E. Remsberg, A. Simmon, D. Wu: The SPARC intercomparison of middle atmosphere climatologies. *J. Climate*.

Saji, N.H., and T. Yamagata: Interference of teleconnection patterns generated from the tropical Indian and Pacific oceans. *Climate Res*.

Schneider, N.: The response of tropical climate to the equatorial emergence of spiciness anomalies. *J. Climate*.

Sen, O.L., Y. Wang, and B. Wang: Impact of Indochina deforestation on the East-Asian summer monsoon rainfall: A regional climate model study. *J. Climate*.

Small, J.: On the refraction and shoaling of non-linear internal waves at the Malin shelf break. *J. Phys. Ocean*.

Small, J.R., S.-P. Xie, and Y. Wang: Numerical simulation of atmospheric response to Pacific Tropical Instability Waves. *J. Climate*.

Vecchi, G.A., S.-P. Xie, and A.S. Fischer: Ocean-atmosphere covariability in the western Arabian Sea. *J. Climate*.

Wang, Y., S.-P. Xie, H. Xu, and B. Wang: Regional model simulations of marine boundary layer clouds over the Southeast Pacific off South America. Part I: Control experiment. *Mon. Wea. Rev.*

Wang, Y., S.-P. Xie, B. Wang, and H. Xu: Large-scale atmospheric forcing induced by boundary layer clouds over the Southeast Pacific off South America: A regional model study. *J. Atmos. Sci*.

Xie, S.-P.: Satellite observations of cool ocean-atmosphere interaction. *Bull. Amer. Meteor. Soc*.

Xie, S.-P., Q. Xie, D.X. Wang, and W.T. Liu: Summer upwelling in the South China Sea and its role in regional climate variations. *J. Geophys. Res.-Oceans*.

Xu, H., Y. Wang, and S.-P. Xie: Effects of the Andes on eastern Pacific climate: A regional atmospheric model study. *J. Climate*.

Yaremchuk, M. I., K. V. Lebedev, and D. Nechaev: A 4-dimensionmal inversion of acoustic tomography and satellite altimetry using quasigeostrophic constraints. *Inverse Problems in Engineering*.

Yu, Z., and J.P. McCreary: Simulating surface salinity in the tropical Indian Ocean. *J. Geophys. Res*.

Zhang, Y., T. Li, and B. Wang: Decadal change of snow depth over the Tibetan Plateau in spring: The associated circulation and its relationship to the East Asian summer monsoon rainfall. *J. Climate*.

External Presentations

An, S.-I.: *Ocean dynamical adjustment process responsible for determining the time scale of the tropical ocean-atmosphere system.* Fall Meeting of the American Geophysical Union, December 2002, San Francisco, California.

An, S.-I.: *Partial Singular Value Decomposition method and its application to the climate studies*. Fall Meeting of the American Geophysical Union, December 2002, San Francisco, California.

An, S.-I., F.-F. Jin: *Leading modes of tropical Indian Ocean SST anomalies and their association with ENSO*. The 27th General Assembly of the European Geophysical Society, April 2002, Nice, France.

An, S.-I., and F.-F. Jin: *Collective and competitive roles of thermocline and zonal advective feedbacks in the ENSO Mode*. The 25th Conference on Hurricanes and Tropical Meteorology, May 2002, San Diego, California.

An, S.-I., F.-F. Jin, J.-S. Kug, and I.-S. Kang: *The sub-annual variability associated with ENSO: noises or signals*. The 27th General Assembly of the European Geophysical Society, April 2002, Nice, France.

An, S.-I., F.-F. Jin, J.-S. Kug, and I.-S. Kang: *A near-annual coupled ocean-atmosphere mode in the equatorial Pacific Ocean*. Annual Meeting of the American Meteorological Society: 12th Conference on Interactions of the Sea and Atmosphere, February 2003, Long Beach, California.

Endoh, T., H. Mitsudera, S.-P. Xie, and B. Qiu: *Numerical study of the formation of the mesothermal structure in the subarctic region of the western North Pacific*. Fall Meeting of the Oceanographic Society of Japan, October 2002, Sapporo, Japan. Also given as poster at the Fall Meeting of the American Geophysical Union, December 2002, San Francisco, California.

Fu, X., and B. Wang: *Influences of continental monsoons and air-sea coupling on the climate of the equatorial Pacific*. Annual Meeting of the American Meteorological Society: 12th Conference on Interactions of the Sea and Atmosphere, February 2003, Long Beach, California.

Fu, X., B. Wang, and T. Li: *Impacts of air-sea coupling on the simulation of mean Asian summer monsoon in the ECHAM4 model*. The Sixth AMIP Workshop, General Circulation Model Simulations of East Asian Climate, August 2002, Harbin, China.

Fu, X., B. Wang, T. Li, and J. P. McCreary: *Coupling between northward propagating, intraseasonal oscillations and sea-surface temperature in the Indian Ocean*. International Conference on East Asian Climate, August 2002, Harbin, China. (Invited) Also given at the Annual Meeting of the American Meteorological Society: 12th Conference on Interactions of the Sea and Atmosphere, February 2003, Long Beach, California.

Hacker, P.: *The IPRC data and product server in the context of the Global Ocean Data Assimilation Experiment (GODAE)*. Awajishima Symposium on Space Platforms for Water and Climate Observation: Ocean Session, March 2003, Awaji Island, Japan. (Invited)

Hacker, P., P. Dutrieux, E. Desa, K. Radhakrishnan, and S. Wijffels: *Indian Ocean climate research data centers*. First Conference of the Indian Ocean Global Ocean Observing System -IOGOOS-, November 2002, Grand Bay, Mauritius. (Invited)

Hacker, P., J. P. McCreary, H. Mitsudera, T. Waseda, R. Merrill, and Y. Shen: *The Asia-Pacific Data-Research Center (APDRC) for climate studies: Status and plans*. 2002 Western Pacific Geophysical Meeting, July 2002, Wellington, New Zealand.

Hacker, P., Y. Shen, G. Yuan, and T. Waseda: *WOCE data are served by the user-friendly data Servers at the University of Hawai'i's Asia-Pacific Data-Research Center (APDRC)*. WOCE and Beyond, November 2002, San Antonio, Texas.

Hafner, J., and S.-P. Xie: *Far-field effects of the Hawaiian Islands: Satellite observations and model simulation*. TRMM International Science Conference, July 2002, Honolulu, Hawai'i.

Hamilton, K.: *Effects of polar vortex perturbations on tropospheric winter circulation*. International Symposium on Stratospheric Variations and Climate, November 2002, Fukuoka, Japan. (Invited) Also presented at the Frontier Research System for Global Change, November 2002, Yokohama, Japan.

Hamilton, K.: *Overview of DAWEX*. Darwin Area Waves Experiment Workshop, December 2002, Honolulu, Hawai'i. (Invited)

Hamilton, K.: *Surface tides*. International Commission on the Middle Atmosphere Workshop on Modelling of Atmospheric Tides, March 2003, Honolulu, Hawai'i. (Invited).

Jensen, T.G.: *Cross-equatorial transport of drifters, tracers and salinity anomalies in an Indian Ocean model*. WOCE and Beyond, November 2002, San Antonio, Texas.

Jensen, T. G., H.-W. Kang, Y.Y. Kim, T. Miyama, H. Mitsudera, T. Qu, B. Bang, and A. Ishida: *Bifurcation of the Pacific North Equatorial Current in models and in observations*. The 10th Pacific Congress on Marine Science and Technology, July 2002, Chiba, Japan. Also presented at the Frontier Research System for global change, July 2002, Yokohama, Japan. (Invited)

Kim, Y.Y., T. Qu, and A. Ishida : *Seasonal and interannual variations of the NEC bifurcation latitude in a high-resolution OGCM*. Fall Meeting of the American Geophysical Union, December 2002, San Francisco, California, USA.

Kobashi, F., H. Mitsudera, and N. Maximenko: *Relationship between seasonal variations of the North Pacific Subtropical Countercurrent and the subtropical mode water*. Spring Meeting of the Oceanographic Society of Japan, March 2003, Tokyo, Japan.

Lebedev, K., H. Mitsudera, I. Nakano, M. Yaremchuk, and G. Yuan: *Monitoring Kuroshio Extension through dynamically constrained synthesis of the acoustic tomography, altimetry and in situ data*. Fall Meeting of the Oceanographic Society of Japan, October 2002, Sapporo, Japan.

Li, T.: *Monsoon and ENSO as simulated by a coupled ECHAM-MOM GCM*. The Sixth AMIP Workshop, General Circulation Model Simulations of East Asian Climate, August 2002, Harbin, China. (Invited)

Li, T.: *Spatial and temporal structures of the TBO and its mechanism. International* Conference on East Asian Climate, August 2002, Harbin, China. (Invited).

Li, T.: *Tropical cyclogenesis in the western North Pacific: Observational analysis and numerical simulation*. Naval Research Laboratory, February 2003, Monterey, California.

Li, T.: *Spatial and temporal structures and mechanisms of the TBO*. Annual Meeting of the American Meteorological Society: 12th Conference on Interactions of the Sea and Atmosphere, February 2003, Long Beach, California.

Li, T.: *Atmosphere-ocean interactions in the tropical Indian Ocean*. Naval Postgraduate School, February 2003, Monterey, California.

Liu, P., G.A. Meehl, and G. Wu: *Multi-model trends in the Sahara induced by increasing CO_2*. Annual Meeting of the American Meteorological Society, February 2003, Long Beach, California.

Masumoto, Y., V.S.N. Murty, M. Jury, M.J. McPhaden, P. Hacker, J. Vialard, R. Molcard, and G. Meyers: *Tropical Indian Ocean mooring array: Present status and future plans*. First Conference of the Indian Ocean Global Ocean Observing System -IOGOOS-, November 2002, Grand Bay, Mauritius. (Invited)

Maximenko, N.A., P.P. Niiler, G.G. Panteleev, T. Yamagata, and D.B. Olson: *Absolute sea level fields of the Kuroshio Extension derived from drifter and altimetry data*. International Union of Geodesy and Geophysics, June 2002, Torino, Italy. Also given at WOCE and Beyond, November 2002, San Antonio, Texas.

Meyers, G., and P. Hacker: *Review: Rationale and strategies for sustained observations of climate in the Indian Ocean (SOCIO)*. 2002 Western Pacific Geophysical Meeting, July 2002, Wellington, New Zealand. (Invited)

Meyers, G., P. Hacker, and M. Jury: *Status of the Ocean and Climate Observing System*. First Conference of the Indian Ocean Global Ocean Observing System -IOGOOS-, November 2002, Grand Bay, Mauritius. (Invited)

Miyama, T., J.P. McCreary, Y.Y. Kim, T. Jensen, T. Qu, and A.Ishida: *What controls the seasonal variation of the Pacific North Equatorial Current bifurcation latitude?* Spring Meeting of the Oceanographic Society of Japan, March 2003, Tokyo, Japan.

Nechaev, D., M. Yaremchuk, and V. Kamenkovich: *Reconstruction of the large-scale circulation in the Arctic Ocean by a variational method*. WOCE and Beyond, November 2002, San Antonio, Texas.

Nonaka, M., and S.-P. Xie: *Kuroshio front meanders and atmospheric co-variability*. TRMM International Science Conference, July 2002, Honolulu, Hawai'i.

Nonaka, M.: *An ocean circulation connecting midlatitudes and the equatorial region*. Danwa-kai of Department of Earth Sciences, Toyama University, August 2002, Toyama, Japan.

Nonaka, M., J. P. McCreary, and S.-P. Xie: *Sensitivity of equatorial ocean stratification to changes in midlatitude winds*. Spring Meeting of the Oceanographic Society of Japan, March 2003, Tokyo, Japan.

Okajima. H., and S.-P. Xie: *Interhemispheric coherence of climatic variability: Effect of climatological ITCZ*. Fall Meeting of the American Geophysical Union, December 2002, San Francisco, California.

Qu, T., and E. J. Lindstrom: *A climatological interpretation of the circulation in the western South Pacific*. Spring Meeting of the American Geophysical Union, May 2002, Washington, DC.

Qu, T.: *The bifurcation of the North Equatorial Currents in the western Pacific*. Woods Hole Oceanographic Institution Seminar, June 2002, Woods Hole, Massachusetts.

Richards, K.: *Stirring and mixing - their effect on the marine eco-system*. GLOBEC Open Science Meeting, October 2002, Qingdao, China.

Richards, K.: *CLIVAR in the Pacific*. PICES-CLIVAR Workshop, October 2002, Qingdao, China. (Invited). (Co-convenor of the meeting)

Saji, N.H., and T. Yamagata: *Teleconnection patterns associated with the Indian Ocean Dipole Mode*. Frontier System for Global Change, August 2002, Yokohama, Japan.

Saji, N. H., and T. Yamagata: *On the controversial issues related to the Indian Ocean Dipole Mode*. Frontier System for Global Change, August 2002, Yokohama, Japan.

Schneider, N.: *On the coupled ocean-atmosphere response to the equatorial emergence of spiciness anomalies*. NASA-CCR-CRCES Workshop on Decadal Variability, October 2002, Madison, Wisconsin.

Schneider, N.: *Pacific decadal air-sea interaction*. Annual Meeting of the American Meteorological Society: 12th Conference on Interactions of the Sea and Atmosphere, February 2003, Long Beach, California. (Invited)

Schneider, N., E. Di Lorenzo, and P.P. Niiler: *Decadal salinity changes in the California Current*. Annual Meeting of the American Meteorological Society: 12th Conference on Interactions of the Sea and Atmosphere, February 2003, Long Beach, California.

Schneider, N., and E. Yulaeva: *On the coupled response to anomalous Ekman advection of surface temperature*. Fall Meeting of the American Geophysical Union, December 2002, San Francisco, California. (Invited).

Sen, O.L., Y. Wang, and B. Wang: *Effect of Indochina Peninsula surface cover change on the East-Asian summer monsoon rainfall*. The 10th Pacific Congress on Marine Science and Technology, July 2002, Chiba, Japan.

Sen, O.L., Y. Wang, and B. Wang: *Response of the East Asia summer monsoon to the deforestation in the Indochina Peninsula: A regional climate model study*. The 2nd Workshop on Regional Climate Modeling for Monsoon System, March 2003, Yokohama, Japan.

Shen, Y., R. Merrill, G. Yuan, T. Waseda, K. Horiuchi, Y. Oyatsu, and T. Maeda: *Using Aggregation Server to combine local and remote data*. The 2003 OPeNDAP/NVODS/DODS Technical Working Conference, March 2003, Boulder, Colorado.

Small, J.: *Tropical Instability Waves: How does the atmosphere respond?* Oregon State University, College of Oceanic and Atmospheric Sciences Seminar, December 2002, Corvallis, Oregon.

Small, J., S.-P. Xie, and Y. Wang: *Satellite observations and numerical simulation of the characteristics of air-sea interactions associated with Tropical Instability Waves*. TRMM International Science Conference, July 2002,Waikiki, Honolulu.

Small, J., S.-P. Xie, and Y. Wang: *Atmospheric planetary boundary layer response to sea surface temperature gradients in Tropical Instability Waves: Simulation with a high-resolution climate model*. Fall Meeting of the American Geophysical Union, December 2002, San Francisco, California.

Wang, B., R. Wu, and T. Li: *The coupled monsoon-ocean mode and the Asian-Australian monsoon anomalies associated with ENSO*. The 27^{th} General Assembly of the European Geophysical Society, April 2002, Nice, France.

Wang, B.: *How a strong El Niño affects tropical storm activity in the western North Pacific*. The 25^{th} Conference on Hurricanes and Tropical Meteorology, May 2002, San Diego, California. (Invited)

Wang, B.: *Coupled monsoon-ocean mode and its impacts on Asian monsoon variations*. COLA, May 2002, Washington, D. C. (Invited)

Wang, B.: *Monsoon-warm ocean coupling and its impacts on Asian-Australian monsoon*. APEC Climate Network (APCN) Working Group and Steering Committee Meeting, June 2002, Seoul, Korea. (Invited)

Wang, B.: *Asian-Australian monsoon anomalies during the 1997-1998 El Niño: Results from ensemble simulations of eleven AGCMs*. The Sixth AMIP Workshop, General Circulation Model Simulations of East Asian Climate, August 2002, Harbin, China. (Invited)

Wang, B.: *Coupled monsoon-ocean mode and the Asian-Australian monsoon anomalies*. International Conference on East Asian Climate, August 2002, Harbin, China. (Invited)

Wang, B.: *Interannual variability of the Asian-Australian monsoon*. SPIE's Third International Asia-Pacific Environmental Remote Sensing Symposium: Remote Sensing of the Atmosphere, Ocean, Environment, and Space, October 2002, Hangzhou, China. (Invited)

Wang, B.: *Seasonal prediction of the monsoon anomalies*. East Asian Monsoon Workshop, November 2002, Taipei, Taiwan. (Invited)

Wang, B.: *New perspectives of the interannual variability of the Asian-Australian monsoon*. PAOS/Colorado University, November 2002, Fort Collins, Colorado. (Keynote speech)

Wang, B.: *Seasonal prediction of tropical cyclones*. The Fifth International Workshop on Tropical Cyclones, December 2002, Cairns, Australia. (Invited)

Wang, B.: *Challenges in East Asian monsoon research: How to make EA-WPM research a worldwide effort?* Annual Meeting of the Institute of Atmospheric Physics, January 2003, Beijing, China. (Keynote speech)

Wang, B.: *Mechanisms of A-AM variation*. Annual Meeting of the American Meteorological Society: 12th Conference on Interactions of the Sea and Atmosphere, February 2003, Long Beach, California. (Session Chair)

Wang, B.: *Hydrological research plan at IPRC*. Research Revolution 2002, March 2003, Tokyo, Japan. (Invited)

Wang, B.: *New perspectives of Asian monsoon variability*. International Conference on Climate Change, March 2003, Beijing, China. (Invited)

Wang, B., R. Wu, and T. Li: *The coupled monsoon-ocean mode and its impacts on Asian-Australian monsoon*. The 10^{th} Pacific Congress on Marine Science and Technology, July 2002, Chiba, Japan. (Invited)

Wang, Y.: *Sensitivity of tropical cyclone intensification and intensity to cloud microphysics parameterization*. The 25^{th} Conference on Hurricanes and Tropical Meteorology, April-May 2002, San Diego, California.

Wang, Y.: *Regional Climate Modeling at IPRC*. LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences Seminar, July 2002, Beijing, China.

Wang, Y.: *Some issues related to regional climate modeling over East Asia*. East Asian Center, Institute of Atmospheric Physics, Chinese Academy of Sciences Seminar, July 2002, Beijing, China.

Wang, Y.: *Some issues related to regional climate modeling over East Asia*. International Conference on East Asian Climate, August 2002, Harbin, China. (Invited).

Wang, Y.: *Cumulus cloud top detrainment and its effect on model cloud amount in a regional climate model for East Asia*. The Sixth AMIP Workshop, General Circulation Model Simulations of East Asian Climate, August 2002, Harbin, China.

Wang, Y.: *The effect of sea spray on tropical cyclone intensity in numerical models*. The Fifth International Workshop on Tropical Cyclones, December 2002, Cairns, Australia.

Wang, Y.: *Vortex Rossby waves and structure and intensity changes of typhoons*. Shanghai Typhoon Institute Seminar, August 2002, Shanghai, China.

Wang, Y.: *Application of regional climate models to climate process studies*. The 2^{nd} Workshop on Regional Climate Modeling for Monsoon System, March 2003, Yokohama, Japan. (Invited)

Wang, Y., O.L. Sen, and B. Wang: *Simulation of the individual severe weather events over China during 1998 Meiyu season with the IPRC regional climate model*. Summer Workshop on Severe Storms and Torrential Rain, June 2002, Chengdu, China. (Invited)

Wang, Y., O.L. Sen, and B. Wang: *A regional climate model simulation of the 1998 severe precipitation events over China*. National Climate Center, China Meteorological Administration Seminar, August 2002, Beijing, China.

Wang, Y., O.L. Sen, and B. Wang: *A highly resolved regional climate mode developed at the International Pacific Research Center*. Bureau of Meteorology Research Center Seminar, December 2002, Melbourne, Australia.

Wang, Y., H. Xu, and S.-P. Xie: *The effect of the Andes on the eastern Pacific climate*. CSIRO, Division of Atmospheric Research Seminar, December 2002, Melbourne, Australia.

Waseda, T.: *Dynamical and Kinematical study of the Kuroshio using satellite observation and numerical simulation.* Evening seminar, Institute of Environmental Studies, U. Tokyo, April 2002, Tokyo, Japan.

Waseda, T., H. Mitsudera, and B. Taguchi: *Impact of QuikSCAT-derived wind stress on high-resolution Kuroshio modeling*. Fall Meeting of the American Geophysical Union, December 2002, San Francisco, California.

Waseda, T., and H. Mitsudera: *Geometry of the pathway between inshore Kuroshio and the Kuroshio/Oyashio transition region*. Western Pacific Geophysical Meeting, July 2002,Wellington, New Zealand.

Waseda, T., H. Mitsudera, B. Taguchi, and K. Kutsuwada: *High-frequency winds at mid-latitude: their variation and impact on the Kuroshio path*. NASA Ocean Vector Wind Science Team Meeting, January 2003, Oxnard, California.

Waseda, T., H. Mitsudera, B. Taguchi, and K. Kutsuwada: *Impact of the high-frequency wind forcing on the Kuroshio bimodality*. Spring Meeting of the Oceanographic Society of Japan, March 2003, Tokyo, Japan.

Xie, S.-P. *Rich Structures of Ocean-Atmosphere Interaction*. Spring Meeting of the Meteorological Society of Japan, May 2002, Saitama, Japan. (Invited)

Xie, S.-P.: *Satellite observations of East China Sea-atmosphere interaction*. Ocean University of China, August 2002, Qingdao, China.

Xie, S.-P.: *Satellite observations of cool ocean-atmosphere interaction*. Jet Propulsion Laboratory, January 2003, Pasadena, California.

Xie, S.-P.: *Air-sea coupling: A satellite view from space*. Future of our planet in our view: Global warming and extreme weather, March 2003, Tokyo, Japan. (Invited)

Xie, S.-P., H. Annamalai, F. Schott, and J.P. McCreary: *Coupled Rossby waves in the South Indian Ocean*. Chinese Academy of Meteorological Science, August 2002, Beijing, China.

Xie, S.-P., and J. Hafner: *Far-field effects of the Hawaiian Islands: Satellite observations and model simulation*. SPIE's Third International Asia-Pacific Environmental Remote Sensing Symposium: Remote Sensing of the Atmosphere, Ocean, Environment, and Space, October 2002, Hangzhou, China.

Xie, S.-P., J. Hafner, M. Nonaka, R. J. Small, W. T. Liu, and G. A. Vecchi.: *Applications of satellite measurements to air-sea interaction research*. TRMM International Science Conference, July 2002, Honolulu, Hawai'i. Also given at the NASA Ocean Vector Wind Science Team Meeting, January 2003, Oxnard, California.

Xie, S.-P., J. Hafner, Y. Tanimoto, W.T. Liu, H. Tokinaga, and H. Xu: *Ocean-atmosphere interaction that shapes the winter climate of the East China Seas*. SPIE's Third International Asia-Pacific Environmental Remote Sensing Symposium: Remote Sensing of the Atmosphere, Ocean, Environment, and Space, October 2002, Hangzhou, China. (Invited)

Xie, S.-P., M. Nonaka, J. Hafner, and T. Liu: *Satellite observations of air-sea interaction over the Kuroshio*. Fall Meeting of the American Geophysical Union, December 2002, San Francisco, California.

Xie, S.-P., and H. Okajima: *Land effect on ocean climate: satellite observations and model simulation*. International Workshop on Air-Land Interaction and its Impact on Climate. August 2002, Dunhuang, China.

Xu, H., S.-P. Xie, and Y. Wang: *Effects of the Andes on the eastern Pacific climate: A regional atmospheric model study*. Fourteenth Symposium on Global Change and Climate Variations, February 2003, Long Beach, California.

Yaremchuk, M.I., and K. Lebedev: *A 4-dimensionmal inversion of acoustic tomography and satellite altimetry using quasigeostrophic constraints*. International Conference on Inverse problems: modeling and simulation, July 2002, Fethiye, Turkey. (Invited)

Yaremchuk M.I., and K. Lebedev: *A variational estimate of the North Pacific mode water production*. The 10th Pacific Congress on Marine Science and Technology, July 2002, Chiba, Japan.

Yu, Z.: *Simulating surface salinity in the tropical Indian Ocean*. SPIE's Third International Asia-Pacific Environmental Remote Sensing Symposium: Remote Sensing of Atmosphere, Ocean, Environment, and Space, October 2002, Hangzhou, China.

Yuan, G., Y. Shen, Y. Zhang, R. Merrill, T. Waseda, H. Mitsudera, and P. Hacker: *User-friendly data servers for climate studies at the Asia-Pacific Data-Research Center (APDRC)*. Fall Meeting of the American Geophysical Union, December 2002, San Francisco, California.

Yuan, G., Y. Shen, T. Waseda, R. Merrill: *Serving and accessing in-situ data through EPIC and OPeNDAP*. The 2003 OPeNDAP/ NVODS/DODS Technical Working Conference, March 2003, Boulder, Colorado.

IPRC Seminars

Date	Speaker	Affiliation	Seminar Title
05/08/2002	Peter Worcester	Scripps Institution of Oceanography, University of California, Sand Diego, California	*Acoustic remote sensing of the North Pacific: 1997–1999 (ATOC) and 2002–2006 (NPAL)*
*05/08/2002	Brian Dushaw	Applied Physics Laboratory, College of Ocean and Fishery Sciences University of Washington, Seattle, Washington	*Observations of internal-tide variability in the far-field of the Hawaiian Ridge: The far-field component of the Hawaiian Ocean Mixing Experiment (HOME).*
""05/09/2002	Julie Arblaster	National Center for Atmospheric Research, Boulder, Colorado	*Interdecadal modulations of Australian rainfall and ENSO in the NCAR Parallel Climate Model*
05/13/2002	William W. Hsieh	Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, Canada	*Neural network methods for studying the atmosphere and oceans*
05/28/2002	Alan Robock	Department of Environmental Sciences, Rutgers University, New Jersey	*The relationship between snow cover, soil moisture, and the Indian summer monsoon: Observations and model simulations*
05/30/2002	Alan Robock	Department of Environmental Sciences, Rutgers University, New Brunswick, New Jersey	*Mt. Pinatubo as a test of climatic feedback mechanisms*
06/18/ 2002	Adrian Tompkins	European Center for Medium-Range Weather Forecasts, Reading, United Kingdom	*Three-dimensional radiative transfer in idealized stratocumulus clouds and The organization of tropical convection: The ubiquitous role of coldpools*
07/08/2002	Dmitri Nechaev	Department of Marine Sciences, University of Southern Mississippi, Stennis Space Flight Center, Mississippi	*Inverting 1950–990 Arctic Ocean hydrography using a finite element model*
07/18/2002	Brian Mapes	NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado	*Strides, steps and stumbles in the annual march*
***07/29/2002	T.N. Krishnamurti	Department of Meteorology, Florida State University, Tallahassee, Florida	*Multimodel approach to the cumulus parameterization issue*
08/27/2002	Silvio Gualdi	Instituto Nazionale di Geofisica e Vulcanologia (INGV), Bologna, Italy	*The interannual variability in the tropical Indian Ocean as simulated by a coupled GCM*
*10/16/2002	Kevin Hamilton	International Pacific Research Center, University of Hawai'i, Honolulu, Hawai'i	*The inertia-gravity wave field in the middle atmosphere and its connection to global circulation*

Date	Speaker	Affiliation	Seminar Title
*10/17/2002	Mu Mu	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijin, China	*Application of conditional nonlinear optimal growing perturbation to the study of predictability of ENSO*
*10/23/2002	Tim Li	International Pacific Research Center, University of Hawai'i, Honolulu, Hawai'i	*Tropical cyclogenesis in the Northwest Pacific*
10/28/2002	Wolf Grossmann	UFZ Center for Environmental Research, Leipzig/Halle, Germany	*Two-region analysis of changing economic and environmental risks: A modeling study*
*10/29/2002	Mu Mu	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China Institute for Marine Research, University of Kiel, Kiel, Germany	*An adjoint approach to variational data assimilation with physical "on-off" condition*
11/15/2002	Emanuele Di Lorenzo	Scripps Institute of Oceanography, University of California at San Diego, California	*Climate changes of the southern California Current system: Dynamics and thermodynamics*
11/26/2002	Peter Niiler and Nikolai Maximenko	Scripps Institution of Oceanography, University of California, San Diego, California International Pacific Research Center	*The absolute mean sea level distribution maintained by observed surface circulation*
*11/27/2002	Yuqing Wang	International Pacific Research Center, University of Hawai'i, Honolulu, Hawai'i	*Large-scale forcing of subtropical stratocumulus clouds over the East Pacific*
12/10/2002	Gerald Meehl	National Center for Atmospheric Research, Boulder, Colorado	*Mechanisms for projected future changes of south Asian monsoon precipitation*
01/27/2003	Susan Kemball-Cook	No current affiliation	*Simulation of the Intraseasonal Oscillation in an intermediate coupled model*
*02/04/2003	George Boer	Canadian Centre for Climate Modelling and Analysis and the University of Victoria, Victoria, Canada	*Climate sense and sensitivity*
03/10/2003	Ken Sperber	Lawrence Livermore National Laboratory, Livermore, California	*Propagation and the vertical structure of the Madden-Julian Oscillation*
*03/11/2003	George Boer	Canadian Centre for Climate Modelling and Analysis and the University of Victoria, Victoria, Canada	*Dynamical aspects of climate sensitivity*
03/17/2003	Wolf Dieter Grossmann	UFZ Center for Environmental Research, Leipzig/Halle, Germany	*Using economic innovation for mitigation of global climate change*
03/24/2003	Brian Mapes	NOAA-CIRES Climate Diagnostics Center Boulder, Colorado	*Aspects of the annual cycle in the subtropics*

*Joint seminar with the Meteorology Department.
** Joint seminar with the Oceanography Department
***Joint seminar with JIMAR

Workshops and Conferences

AIR POLLUTION AS A CLIMATE FORCING

The impact of air pollution on global climate as well as on human health and the environment was the focus of the workshop "Air Pollution as a Climate Forcing." Held April 29–May 3, 2002, at the East-West Center in Honolulu, the workshop was organized by a committee headed by James Hansen, scientist at the NASA Goddard Institute for Space Studies, and was hosted by the IPRC. The sponsor list was as follows: National Aeronautics and Space Administration, Environmental Protection Agency, National Oceanic and Atmospheric Administration, National Science Foundation, Goddard Space Flight Center, Earth Sciences Directorate, Hewlett Foundation, California Air Resources Board, California Energy Commission, East-West Center, and the International Pacific Research Center.

SECOND ANNUAL IPRC SYMPOSIUM

The Second Annual IPRC Symposium was held May 16–May 17, 2002, at the East-West Center. In the two-day symposium, IPRC scientist gave presentations on their research highlights for the year.

THE HADLEY CIRCULATION: PRESENT, PAST, AND FUTURE

Focusing on the Hadley Circulation, this workshop brought together scientists who study Earth's past climate system with scientists who explore future climate through modeling experiments. The workshop was hosted by the IPRC November 12–15, 2002, at the East-West Center. Workshop organizers were Raymond Bradley, Climate System Research Center, University of Massachusetts, and Henry Diaz, NOAA Climate Diagnostics Center; workshop sponsors were NOAA Office of Global Programs, NOAA Climate Diagnostics Center, National Science Foundation, Climate System Research Center, Past Global Changes, and the IPRC.

ANALYSIS OF DARWIN AREA WAVE EXPERIMENT RESULTS

Workshop participants from 10 institutions in Australia, Japan, and the United States reviewed preliminary observations and developed strategies for integrating the findings from the Darwin Area Wave Experiment, which is a field experiment in northern Australia aimed at studying gravity waves excited by deep convection in the pre-monsoon period. The workshop was organized and chaired by Kevin Hamilton (Theme-4 leader) and was held December 3–5, 2002, at the IPRC conference room.

MODELLING OF ATMOSPHERIC TIDES WORKSHOP

Members of the Working Group on Numerical Modelling, International Commission for the Middle Atmosphere, came from Canada, Australia, France, and the United States to review current understanding and to identify uncertainties in the numerical simulation of atmospheric tides. The workshop was organized and chaired by Kevin Hamilton (Theme-4 leader) and was held March 3–7, 2003, at the IPRC conference room.

OCEAN STUDIES BOARD

The annual spring meeting of the Ocean Studies Board of the National Academies was held at the East-West Center March 5–7, 2003. IPRC Director, Julian P. McCreary, is a member of the Studies Board and hosted the meeting.

Honors

Julian P. McCreary, IPRC Director and Professor of Oceanography, was elected Fellow of the American Meteorological Society (AMS) at the society's annual meeting, February 2003, in Long Beach, California. He received the honor for his outstanding research contributions toward understanding the dynamics of the upper ocean and its influence on atmospheric circulation and climate.

Shang-Ping Xie, IPRC Theme 1 Co-Leader and Professor of Meteorology, received the prestigious 2002 medal of the Meteorological Society of Japan, the highest honor awarded by the society to its members for meteorological research. Xie is the first non-Japanese member to receive this medal.

Visiting Scholars

IPRC has a visiting scholar program. From April 2002 to March 2003, the following scholars visited the IPRC for 1 week or longer.

Scholar	Affiliation	Dates
Ming Feng	Commonwealth Scientific & Industrial Research Organisation, Wembley, Australia	4/20–5 /20, 2002
Yong-Ti Zhu	Shanghai Meteorological Bureau, Shanghai, China	5/2–11/2, 2002
Albert Barcilon	Florida State University, Tallahassee, Florida	5/6–31, 2002
Leland Jameson	Lawrence Livermore National Laboratory, Livermore, California	6/15–23, 2002
Dmitri Nechaev	Stennis Space Center, University of Southern Mississippi, Mississippi	6/22–7/11, 2002
Silvio Gualdi	Instituto Nazionale di Geofisica e Vulcanologia, Bologna, Italy	8/25–31, 2002
Tomohiko Tomita	Kumamoto University, Kumamoto, Japan	9/6–13, 2002; 2/28–3/7, 2003
Wolf Dieter Grossmann	UFZ Center for Environmental Research, Leipzig and Halle, Germany	10/7–11/10, 2002; 2/12–3/19, 2003
Mu Mu	Chinese Academy of Science, Bejing, China	10/10–11/12, 2002
Shigeru Tabeta	University of Tokyo, Tokyo, Japan	11/1–29, 2002
Kazutoshi Horiuchi	Advanced Earth Science and Technology Organization, Tokyo, Japan	11/25–29, 2002
Yutaka Oyatsu	Mitsubishi Research Institute, Inc., Tokyo, Japan	11/25–29, 2002
Peter Niiler	Scripps Institution of Oceanography, San Diego, California	11/11–12/10, 2002; 3/18–26, 2003
Atushi Kubokawa	Hokkaido University, Sapporo, Japan	12/10–16, 2002
Gary Meyers	Commonwealth Scientific & Industrial Research Organisation, Hobart, Australia	1/7–23, 2003
Qiang Xie	Chinese Academy of Sciences, Bejing, China	9/4/02–02/28/03
George Boer	University of Victoria, Victoria, Canada	2/1–3/14, 2003
Raleigh Hood	Horn Point Laboratory, University of Maryland Center for Environmental Science, Cambridge, Maryland	1/6–7/3, 2003
Brian Mapes	NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado	3/9–31, 2003
Kenneth Sperber	Lawrence Livermore National Laboratory, Livermore, California	3/10–21, 2003
Jyu-Wen Hwu	Taiwan Central Weather Bureau, Taiwan	3/23–5/23, 2003

Grants

INSTITUTIONAL GRANTS

Title	P.I./Co-P.I.	Agency	Amount	Period
Frontier Research System for Global Change: Support of Research at the International Pacific Research Center	J.P. McCreary	JAMSTEC	$3,132,214	04/02–03/03
Frontier Research System for Global Change-IPRC: Support of Research at the International Pacific Research Center	J.P. McCreary	NASDA	$721,015	04/02–03/03
Establishment of a Data and Research Center for Climate Studies	J.P. McCreary P. Hacker R. Merrill H. Mitsudera T. Waseda	NOAA	$1,005,000	07/01–06/03
Data-intensive Research and Model Development at the International Pacific Research Center	J.P. McCreary S.-P. Xie H. Mitsudera T. Waseda T. Li B. Wang	NASA	$5,000,000	10/00–09/05

INDIVIDUAL GRANTS

Title	P.I./Co-P.I.	Agency	Amount	Period
Establishment of the Integrated Climate Database for Reanalysis and the International Data Network	P. Hacker	JAMSTEC	$252,000	01/03–03/03
Quasi-biennial Oscillation Modulation of Eddies in the Tropical Stratosphere	K. Hamilton	NASA	$108,287	05/02–05/05
Application of Comprehensive Global Models to Problems in the Dynamics of the Troposphere and Stratosphere	K. Hamilton	NSF	$322,809	09/02–08/06
Tropical Cyclone Energy Dispersion and Self-maintaining Mechanisms for Summer Synoptical-Scale Waves in the Northwest Pacific	T. Li Y. Wang	NSF	$294,262	09/01–08/04
Dynamics of the Indian Ocean Dipole	T. Li	NPS	$25,000	08/01–02/03

Title	P.I./Co-P.I.	Agency	Amount	Period
Mean Absolute Sea Level & Mean Surface Circulation in the North Atlantic	N. Maximenko	UCLA	$25,314	08/02–12/02
Low-Latitude Western Boundary Current in the Pacific	J. P. McCreary T. Qu H. Mitsudera T. Jensen T. Miyama	NSF	$458,538	03/01–02/04
Observation and Dynamics of the Indonesian Throughflow	J. Potemra	University of Washington, NSF	$35,396	11/01–02/04
Upwelling and Its Influence on the Surface Temperature off Java and Sumatra	T. Qu	NASA	$324,265	02/03–01/06
Remote Forcing of the US Warm Season Rainfall and Eastern Pacific Climate	B. Wang X. Fu T. Li	NOAA/PACS	$365,981	07/01–06/06
Biennial and Interdecadal Variations of the Tropical Pacific Ocean	B. Wang S.-.I. An	NOAA/PACIFIC	$311,280	07/00–06/06
Dynamics of the Boreal Summer Intraseasonal Oscillation	B. Wang T. Li	NSF	$399,536	07/00–06/04
Dynamical Control of Rapid Tropical Cyclone Intensification by Environmental Shears	B. Wang Y. Wang T. Li	ONR	$794,658	01/02–12/04
Roles of Ocean-Atmosphere-Land Interaction in Shaping Tropical Atlantic Variability	S.-P.Xie	NOAA	$245,004	07/01–06/04
An Investigation of Monthly Wind Variability in the Eastern Equatorial Pacific Using the SeaWinds, *In-situ* Observations and Numerical Modeling	S.-P. Xie	NASA	$377,489	05/00–04/04
Effects of the Andes on the Eastern Pacific Climate	S.-P. Xie Y. Wang	NOAA	$277,191	07/01–06/06
Mechanisms for the Northward Displacement of the Pacific ITCZ	S.-P. Xie T. Li	NSF	$281,955	09/01–08/04
Numerical Investigation of the Dynamics of the Subsurface Countercurrents	Z. Yu D. Wang J.P. McCreary	NSF	$364,992	03/03–02/06

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Acronyms

AAIW
Antarctic Intermediate Water

A-AM
Asian-Australian Monsoon

AMIP
Atmospheric Model Intercomparison Project

AMS
American Meteorological Society

AO
Arctic Oscillation

APDRC
Asia-Pacific Data-Research Center

CAM
Community Atmospheric Model

CCM
Community Climate Model

CCCMA
Canadian Center for Climate Modelling and Analysis

CCSM
Community Climate System Model

CFD
Computational Fluid Dynamics

CLIVAR
Climate Variability and Predictability Project

CMAP
Climate Modeling Analysis and Prediction

CMCA
Conditional Maximum Covariance Analysis

COLA
Center for Ocean-Land-Atmosphere Studies

cSVD
Complex Singular Value Decomposition

CTD
Conductivity, Temperature, and Depth

EASM
East-Asian Summer Monsoon

ECCO
Estimating the Circulation and Climate of the Ocean

ECHAM
European Center-Hamburg Atmospheric Model

ECMWF
European Centre for Medium-Range Weather Forecasts

ENACT
Enhanced Ocean Data Assimilation and Climate Prediction

ENSO
El Niño–Southern Oscillation

EOF
Empirical Orthogonal Function

EUC
Equatorial Undercurrent

FRSGC
Frontier Research System for Global Change

GCM
General Circulation Model

GEOS
Geodynamics Experimental Ocean Satellite

GFDL
Geophysical Fluid Dynamics Laboratory

GRACE
Gravity Recovery and Climate Experiment

GSFC
Goddard Space Flight Center

IOD
Indian Ocean Dipole

IOZM
Indian Ocean Zonal Mode

IPRC–RegCM
IPRC Regional Climate Model

ISO
Intraseasonal Oscillation

ITF
Indonesian Throughflow

ITCZ
Intertropical Convergence Zone

JAMSTEC
Japan Marine Science and Technology Center

JASMINE
Joint Air-Sea Monsoon Interaction Experiment

JAXA
Japan Aerospace Exploration Agency (formerly NASDA)

KE
Kuroshio Extension

LASG
Institute of Atmospheric Physics, Chinese Academy of Sciences

LCS
Linear Continuous Stratified (Model)

LOM
Layer Ocean Model

MBT
Mechanical Bathythermograph

MC
Mindanao Current

MCA
Maximum Covariance Analysis

MICOM
Miami Isopycnic Coordinate Ocean Model

NASA
National Aeronautics and Space Administration

NASDA
National Space Development Agency of Japan

NCAR
National Center for Atmospheric Research

NCEP
National Centers for Environmental Prediction

NDH
Nonlinear Dynamic Heating

NEC
North Equatorial Current

NGCUC
New Guinea Coastal Undercurrent

NOAA
National Oceanic and Atmospheric Administration

NSF
National Science Foundation

NWP
Numerical Weather Prediction

PBL
Planetary Boundary Layer

PCM
Parallel Climate Model

POM
Princeton Ocean Model

POP
Parallel Ocean Program

PV
Potential Vorticity

QuikSCAT
Quick Scatterometer

SCS
South China Sea

SEC
South Equatorial Current

SEEK
Sequential Evolution Extended Kalman (filter)

SINTEX
Scale Integration Experiment

SODA
Simple Ocean Data Assimilation

SPGA
Shallow Pressure Gauge Array

SSH
Sea Surface Height

SSS
Sea Surface Salinity

SST
Sea Surface Temperature

STF
Subtropical Front

STMW
Subtropical Mode Water

SUNY
State University of New York

Sv
Sverdrup

SVD
Singular Value Decomposition

TBO
Tropical Biennial Oscillation

TIW
Tropical Instability Waves

TOMS
Thermodynamic Ocean Modeling System

TOPEX
Topography Experiment

TRMM
Tropical Rainfall Measuring Mission

UH
University of Hawai‘i

WJ
Wyrtki Jets

WNP
Western North Pacific

WOCE
World Ocean Circulation Experiment

XBT
Expendable Bathythermograph

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