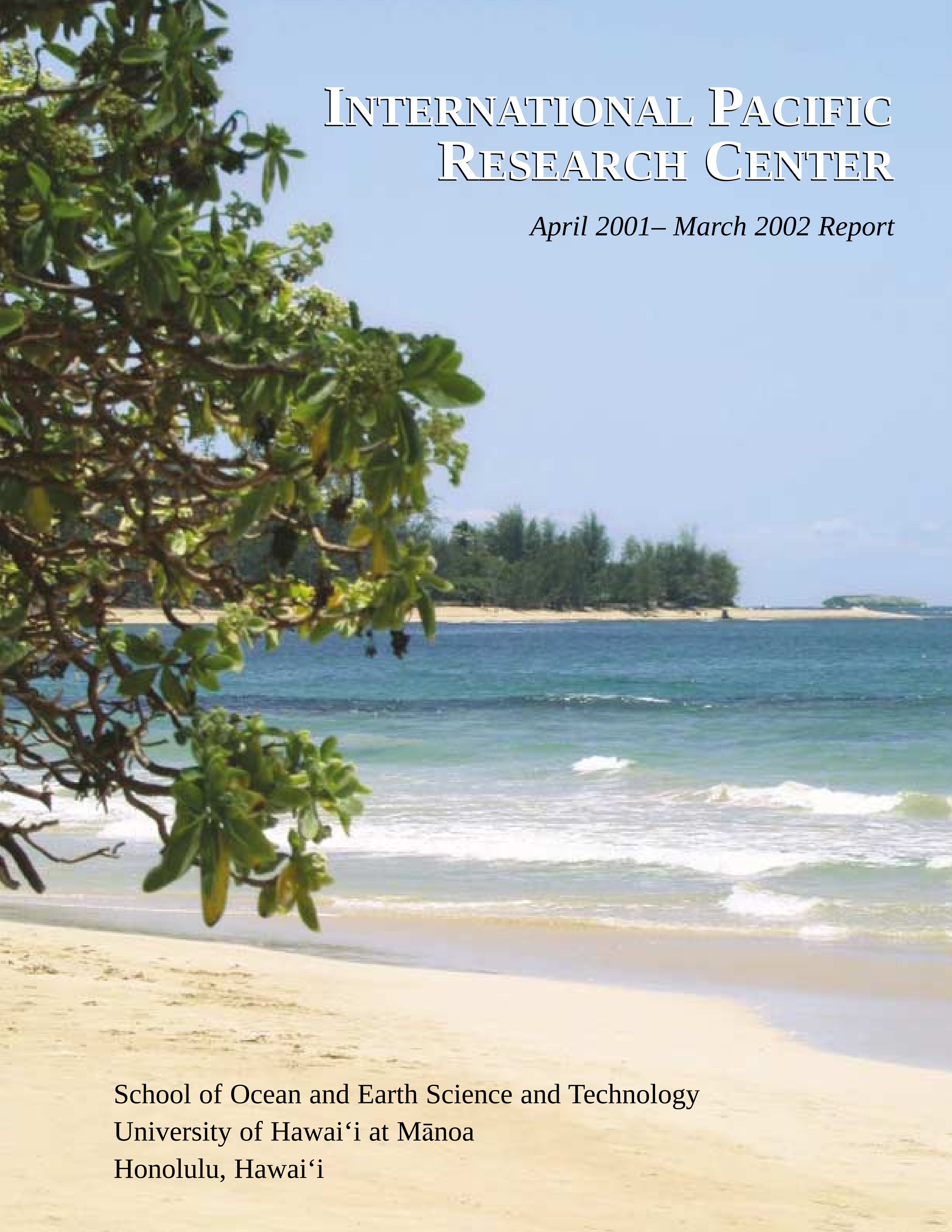
International Pacific Research Center

April 2001– March 2002 Report



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今年のハイライト*

IPRC (International Pacific Research Center)にとって、2001 年度もまた、実り多い年であり、この報告はその2001 年 4 月 1 日から 2002 年 3 月 31 日の間の IPRC の活動と研究業績とについての概観をお伝えする。個々の研究者の研究成果の要約が、今年もまた、この報告の大半を占めており、また、IPRC 研究者による研究論文及び研究発表のリストと、IPRC 支援によるセミナー、ワークショップ、招聘者、会合、会議のリストも掲げている。IPRC への資金拠出者と個別研究者への資金拠出者のリストも載せている。

昨年、IPRC は国際的に定評のある科学者からなる外部評価委員会から高い評価を受けたが、これは我々として誇りに思う成果である。2001 年 5 月、日本の地球フロンティア研究システム(FRSGC)は、東京で、IPRC における研究を含むその研究プログラムについての 5 ヵ年の中間評価を行った。その中間評価委員会の報告は、IPRC の研究戦略－理論的解析、数値モデリング、そして物理的気候プロセスのデータ解析－を、「適切であり」、気候研究にとって「強力な研究ツールである」と考え、異なった専門分野の研究者達が、IPRC の各研究テーマの下の幾つかのプロジェクトに配置されるというマトリックス組織を高く評価した。報告は、要約として、「IPRC での研究計画は、優秀である。なぜならば、IPRC の研究は、太平洋・インド洋地域における気候変動や、モンスーン域の海洋が気候変動に及ぼす影響および、アジア・オーストラリア・モンスーンの変動に関する我々の理解を深めることに対し、多大の貢献を行ったからである……*IPRC の活動レベルは非常に高く*、IPRC の活動は国際協力の最も成功した例の一つである。本評価委員会は、IPRC の現在までの一致協力した努力、研究の進歩と成果、さらに次期 5 ヵ年研究計画に対し、高い評価を与えた」と述べている。

IPRC の科学者達にとって、本年度も実りある年であり、広範な題目に関する 44 の査読付き論文が、専門誌に掲載された。(ページ 59 参照)アジア－太平洋データリサーチセンター(APDRC)は、IPRC の全体にとって必須の部分として、Peter Hacker 研究員をそのマネージャーとして、大きく前進した。(ページ 56 参照。)データ・サーバーは、観測(in situ)データと Grid 化データの双方を取り扱うことができ、2 組の異なるタイプのデータセットをたやすく比較する道具となっている。新しいデータセットが、次々とサーバー上で入手できるようになっており、データセットに関する研究プロジェクトが、例えば日本沖合いの 2 万本のロシアの観測用ビンから新たに得られたデータに関して、進行中である。

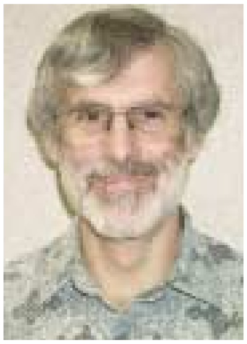
この一年間に、IPRC 研究スタッフは増加を続け、日本からは遠藤貴大(たかひろ)がフロンティア研究員として、James Potemra と N.H.Saji がハワイ大学研究公社(RCUH)雇用の研究員として、それぞれ赴任し、また、6 人の博士課程修了者、Hyoun-Woo Kang、Yoo Yin Kim、Ping Liu、Justin Small、Haiming Xu、Weijun Zhu が加わった。

来年度は、さらに増加し、夏の終わりに、La Jolla にあるスクリップス海洋学研究所から Niklas Schneider が、サザンプトン大学海洋地球科学学部サザンプトン海洋学研究センターから Kelvin Richard が、共にハワイ大学海洋学部のファカルティー(終身雇用身分)として、IPRC に移ってくる。残る 3 人の IPRC でのファカルティー・メンバー探しは、2002 年秋に始まる予定で、また、もう 4 人の博士課程修了者が年の後半に加わる予定である。したがって、来年末までには、IPRC は当初想定された規模に最終的に達する予定である。

ジュリアン・マクレアリー (Julian P. McCreary, Jr.)
IPRC 所長

(*斜体以外の引用及び専門用語は、「地球フロンティア研究システム中間評価報告書(仮訳)」及び[illegible]に拠る。)

The Year's Highlights



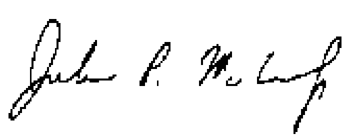
The International Pacific Research Center (IPRC) has had another productive year. This report provides an overview of its activities and research achievements from April 1, 2001, to March 31, 2002. The summaries of the accomplishments of the individual IPRC researchers, once again, make up most of the report, which also lists the research publications and presentations by IPRC scientists as well as the seminars, workshops, visitors, meetings, and conferences sponsored by the IPRC. A list of the funding sources for the center as well as for individual IPRC researchers is also included.

Last year, the IPRC received a high rating from an external review committee composed of internationally acclaimed scientists, an accomplishment of which we are particularly proud. In May 2001, Japan's Frontier Research System for Global Change held in Tokyo a 5-year interim evaluation of its research programs, which include the IPRC. The report of the Evaluation Committee considered the IPRC research strategies—theoretical analysis, numerical modeling, and data analysis of physical climate processes—"fitting" and "powerful tools" for climate research, and lauded its matrix organization in which researchers with different research expertise are mapped onto the various projects under each of the IPRC research themes. The report summary states, "The science program at IPRC is evaluated to be excellent, because it has contributed significantly to understanding of climate variations in the Indo-Pacific Ocean, regional ocean influences on Asia-Pacific climate and Asian-Australian Monsoon System.…The activity level of the IPRC is very high, showing one of the best examples of international cooperation. The IPRC receives high marks from the Evaluation Committee for its concerted efforts, progress and accomplishments up to date and its research plans for the next five years."

IPRC scientists had another productive year, publishing 44 papers in refereed journals (see page 59) on a variety of subjects (see the Theme Overviews). The Asia-Pacific Data-Research Center, an integral and essential component of the IPRC, made great strides forward (see page 56). The Data Server System is now serving both *in-situ* and gridded data with tools for easy comparison between the two types of data sets. New data sets are continually being made available on the server, and research projects on data sets, such as the newly acquired data from the 20,000 Russian bottle stations off the Japan coast, are under way.

During the past year, the IPRC research staff continued to increase with the arrivals of Takahiro Endoh as a Frontier researcher, James Potemra, and N.H. Saji as assistant researchers with the Research Corporation of the University of Hawai'i (UH), and six postdoctoral fellows: Hyoun-Woo Kang, Yoo Yin Kim, Ping Liu, Justin Small, Haiming Xu, and Weijun Zhu.

The coming year will bring further growth. At the end of the summer, Niklas Schneider from the Scripps Institution of Oceanography in La Jolla and Kelvin Richards from the School of Ocean and Earth Science, Southampton Oceanography Center, University of Southampton, will join the IPRC, both as faculty in the UH Oceanography Department. A search for the remaining three IPRC faculty members will begin in Fall 2002, and four more postdoctoral fellows are expected to join later in the year. By the end of next year, then, the IPRC will finally attain the size envisioned by its original planners.



Julian P. McCreary, Jr.
Director, IPRC

副所長からのメッセージ

副所長（Executive Associate Director）として、私はIPRCの管理運営のお手伝いをしています。この仕事は、IPRCのスタッフの数が増えるにつれて、大きなものになっています。量的に、また、その複雑さの点で特に増えているのが、研究員の任用手続きです。IPRC研究員の85%と、客員研究員の殆どが、外国人です。IPRCの管理運営部門の優秀なスタッフは、これらの研究者たちがIPRCに来るのに必要な米国入国ヴィザ（査証）を確保するという、困難で努力を要する仕事をしています。9月11日の連続多発テロ事件の悲劇の後は特に、この仕事はより厄介になり、ヴィザ関係の仕事に費やされる時間は、飛躍的に増加しています。

これらの管理運営的な仕事に加え、私はIPRCとアジア太平洋の気候研究所との国際協力の強化に努めてきました。この目的のために、昨年（2001年）、私はインドネシアにあるいくつかの研究所を訪問しました。インドネシア海洋漁業省海洋漁業研究庁とハワイ大学マノア校との研究協力が現在検討中です。この協定中での重要な事項として、IPRCとLAPAN（インドネシア国立航空宇宙研究所）との協力が挙げられます。LAPANのMezak Ratag氏は、既にIPRCを訪問されており、地域気候モデルについて、IPRCの研究員と研究に取り組かっておられます。

もうひとつの私の役割は、IPRCでの基礎的な科学的研究成果の応用の推進です。この点で、私はワークショップを提案し、海洋生物・環境学者、気候・社会学者、水産業者が一堂に会し、太平洋の気候と漁業との連関を見ることとしました。このワークショップは、国際気候予測研究所（International Research Institute for Climate Prediction, IRI）との共催で、2001年11月、ホノルルで開かれました。（ページ68参照。）これに加え、私は、ドイツのライプツィッヒとハレにある環境研究センターのWolf Grossmann氏とIPRC費用負担の協力事業を始め、気候と社会諸現象との間の相互作用モデルを開発し、政策決定に活用しようとしています。これらのモデルは、社会諸現象（パラメーター）－経済、環境、人間の知識量、人間の態度といったもの－と、気候変動、気候変化との間の相互作用関係を現しています。これらのモデルの活用を通じて、気候変動への適応と、気候変動の抑制とを図りたいと願っています。

IPRCの設立と、その第一段階の展開に深く関わってきた一人として、私は、IPRCがこれまでに達成した成果に印象付けられ、それが、IPRCの将来の更なる発展を保証している、と考えます。

ローレンツ・マガード (Lorenz Magaard)
副所長(Executive Associate Director)

Message from the Executive Associate Director

As Executive Associate Director, I assist in the administration of the IPRC. This task has grown with the growing number of IPRC staff. An area that has particularly expanded in complexity and volume is the hiring process. About 85 percent of IPRC's scientific staff and most of IPRC's visiting scientists are not U.S. citizens. The IPRC has an excellent administrative staff to assist these scientists in the difficult and effortful process of obtaining the necessary visas to come to the IPRC. The tragic events of September 11, 2001, however, have complicated this work greatly, and the amount of time and effort spent on visa matters has increased dramatically.

In addition to my administrative duties, I have concentrated on enhancing international cooperation between the IPRC and other climate research centers in Asia-Pacific. To that end, I visited various institutes in Indonesia last year. A cooperative agreement between the Agency for Marine and Fisheries Research of the Ministry of Marine Affairs and Fisheries of the Republic of Indonesia and the University of Hawai‘i at Mānoa is now under consideration. An important part of this agreement will be the cooperation between the IPRC and LAPAN, the Indonesian National Institute of Aeronautics and Space. Mezak Ratag of LAPAN has already visited the IPRC and is working with IPRC staff on regional climate modeling.

Another of my endeavors is to develop applications for IPRC's basic scientific results. Thus, I conceived of the workshop that brought together marine biologists and ecologists, climate and social scientists, and fisheries managers to look into the link between Pacific climate and fisheries. The workshop became a joint endeavor with the International Research Institute for Climate Prediction (IRI) and took place in Honolulu in November 2001 (see page 68). In addition, I began an IPRC-sponsored cooperation with Wolf Grossmann of the Center for Environmental Research in Leipzig and Halle, Germany, to develop interactive climate and society models and their utilization in policy making. These models describe the interaction between societal parameters—such as the economy, environment, human knowledge, and human attitude—and climate fluctuations and climate change. We hope to use these models to develop optimum policies for adapting to and mitigating climate change.

Having been deeply involved in the establishment of the IPRC and in its first phase of growing, I'm very impressed with IPRC's progress to date which, I think, justifies our high hopes for its future development.

Lorenz Magaard
Executive Associate Director, IPRC

IPRC (International Pacific Research Institute)とは・

IPRC (International Pacific Research Institute、国際太平洋研究センター)は、アジアー太平洋地域の気候の研究を行っています。1997 年 10 月にハワイ大学マノア・キャンパス、海洋地球科学技術学部(SOEST)内に設置された 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、誕生しました。

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。」とされており、この重要な使命をもった、数少ない研究機関のうちのひとつです。

その使命にうたわれている「国際的」という語は、大規模な気候の問題への取り組みを進めるにあたっての最も効果的な方法は国際協力を通じることである、という IPRC 指導陣の信念を反映しています。この目的のために、IPRC 研究者ーハワイ大学教授陣、ハワイ大学研究法人(RCUH)研究員、地球フロンティア研究システム研究員、博士課程終了者(ポスドク)から構成されますがーは、全世界から来ています。IPRC は、また、国際客員研究員の強力な制度を持つとともに、毎年 2 回以上の大きな国際シンポジウムを主催しています。

IPRC の研究者は、「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「太平洋及びインド洋地域における気候」: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解明すること。

テーマ2「モンスーン域の海洋が気候変動に及ぼす影響」: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・モンスーンの変動予測」: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、及びそこにおける季節内スケールから数十年スケールの水循環の予測可能性をもたらす過程を解明すること。

テーマ4「地球規模の気候変動がアジア・太平洋地域の気候に及ぼす影響」: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。

これらのゴールは、それぞれ、さらに目標を設定しており、それらは、IPRC として、与えられた時間内に、はっきり定義された必要手段によって達成可能と考えるものです。

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。これらの活動は、広範な時間、空間規模のデータ群を集中的に使用する必要があります。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プロセスです。必要なデータが用意に入手でき、使用可能にするために、Asia-Pacific Data-Research Center (APDRC、アジアー太平洋データリサーチセンター)が 2001 年に IPRC 内に設置されました。これは、地球的気候変動と変化の研究にあたって、研究戦略を完結させるために必要な要素なのです。

IPRC での研究への支援は、海洋科学技術センターと宇宙開発事業団から地球変動フロンティア研究システム(FRSGC)を通じて、ハワイ州からハワイ大学を通じて、そして、米国の研究支援機関としての航空宇宙局(NASA)、大気海洋庁(NOAA)、国立科学財団(NSF)、海軍研究所(ONR)からそれぞれ、資金が来ています。

IPRC Implementation Committee(IPRC 実施委員会)は、IPRC の全体像設定とその具体化に責任を持っています。現在、この委員会のメンバーは、日本側から、文部科学省、海洋科学技術センター、宇宙開発事業団によって選ばれた 4 人の代表と、米側から、NASA、NOAA、NSF、DOE(エネルギー省)によって選ばれた 4 人の代表、それにハワイ大学代表一人から構成されています。科学的内容の方向性は、Scientific Advisory Committee(科学助言委員会)から与えられ、この委員会は、IPRC に関連のある気候研究分野で国際的に定評のある 8 人の日米の科学者から構成されています。

(*斜体以外の引用及び専門用語は、「地球フロンティア研究システム中間評価報告書(翻訳版)」に拠る。)

About the International Pacific Research Center

The International Pacific Research Center (IPRC) conducts research on Asia-Pacific climate. Founded in October 1997 within the School of Ocean and Earth Science and Technology (SOEST) at the Mānoa Campus of the University of Hawai‘i (UH), the Center was conceived under the “U.S.–Japan Common Agenda for Cooperation in Global Perspective.”

The IPRC mission is “to provide an international, state-of-the-art research environment to improve understanding of the nature and predictability of climate variability in the Asia-Pacific sector, including regional aspects of global environmental change.” The IPRC is one of only a few research organizations focused on this important mission.

The word *international* in the mission statement and in the IPRC name reflects the belief that the most effective way to make progress in answering large-scale climate questions is through international cooperation. Toward this end, the IPRC scientists—consisting of UH faculty, UH Research Corporation appointees, Frontier Research System for Global Change appointees, and postdoctoral fellows—come from around the world. The IPRC also has a strong international visitor program and is committed to hosting two or more major international meetings each year.

Guiding the IPRC scientists are the following broad research themes and goals of the IPRC Science Plan (http://iprc.soest.hawaii.edu):

Theme 1: Indo-Pacific Ocean Climate: To understand climate variations in the Pacific and Indian Oceans on interannual-to-interdecadal timescales.

Theme 2: Regional Ocean Influences: To determine the influences on Asia-Pacific climate of western-boundary currents, the Kuroshio-Oyashio Extension system, marginal seas, and the Indonesian Throughflow.

Theme 3: Asian-Australian Monsoon System: To understand the processes responsible for climatic variability and predictability of the Asia-Australian Monsoon System and its hydrological cycle at intraseasonal through interdecadal timescales.

Theme 4: Impacts of Global Environmental Change: To identify the relationship between global environmental change and Asia-Pacific climate.

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

The IPRC research strategy is to conduct studies of the atmosphere, ocean, and coupled ocean-atmosphere-land system using diagnostic analyses and modeling, rather than to carry out observational studies. These activities require intensive use of data sets covering a wide variety of time and space scales. Data assimilation, which allows optimal incorporation of observed data into models, is an integral part of this effort. To ensure the necessary data sets are easily available and usable, the Asia-Pacific Data-Research Center (APDRC) was established in 2001 within the IPRC. It is a necessary component of a complete research strategy for the study of global climate variability and change.

Support for research at IPRC comes from the Japan Marine Science and Technology Center (JAMSTEC) and the National Space Development Agency of Japan (NASDA) through the Frontier Research System for Global Change (Frontier or FRSGC), from the State of Hawai‘i through the UH, and from the following U.S. granting agencies: National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), National Science Foundation (NSF), and Office of Naval Research (ONR).

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

Research Activities and Accomplishments

Theme 1: Indo-Pacific Ocean Climate

Overview

The oceans of our planet do much to regulate global climate. The large heat capacity of water together with the movement by the oceans of huge masses of warmer water toward the poles and colder water toward the equator prevents huge swings in temperature and makes Earth's climate livable. Usually changes in the oceans are slow and their effects on climate not readily detectable; at times, though, the changes are quite swift with noticeable consequences, such as the arrival of an El Niño, which alters the pattern of sea surface temperature (SST) along the equator in the Pacific and brings about far-reaching climatic changes. Thus, understanding how the climates of the Pacific and the Indian Ocean vary from year to year, over decades and longer, and how these variations affect the atmosphere, is critical for better understanding and prediction of Asia-Pacific climate. Theme 1 focuses on these questions, and IPRC scientists have conducted research this year to determine the circulation patterns in the Pacific and the Indian Ocean, the responsiveness of the atmosphere to SST variations (particularly cool SST), and the interactions between air-sea processes.

The first two objectives under this theme are to identify the oceanic and atmospheric processes that cause decadal variability in the North Pacific and the El Niño–Southern Oscillation (ENSO). Coupled modeling of ENSO and of North Pacific decadal variability has continued (Solomon and McCreary), and a finding from this year's work is that thermocline variability in the off-equatorial western Pacific is coupled with the atmosphere and affects ENSO (Solomon). Another coupled model study demonstrates that the position of the climatological intertropical convergence zone (ITCZ) exerts a strong influence on the time and space characteristics of climate variability (Okajima and Xie).

A great uncertainty in climate research is how, in the extratropics, the atmosphere reacts to changes in SST, and a major effort at the IPRC has been to understand this problem of a cold ocean-atmosphere interaction. The combination of satellite observations and high-resolution regional atmospheric models has proven to be very fruitful and is leading to significant progress in this area. Atmospheric variability induced by cold meanders called tropical instability waves (TIWs) along the Pacific equatorial front is one of the IPRC research areas. A study of the first-ever radiosonde observations that sampled TIWs reveals the vertical structure of the atmospheric adjustment to SST changes and shows that the TIW-induced vertical displacement of the temperature inversion capping the atmospheric boundary layer is very important for atmospheric pressure adjustment (Xie). A simulation with the IPRC Regional Climate Model (IPRC–RegCM) successfully captures the surface-wind and water-vapor variations observed by satellites. In particular, the vertical momentum-mixing that gives rise to surface-wind variations is found to have a deep vertical structure over the whole atmospheric boundary layer, and the adjustment of the near-surface log profile is insufficient to explain the observed wind variations (Small, Xie, and Y. Wang).

The extensive stratus-cloud deck in the South Pacific off South America is important for the global energy budget as well as for keeping the Pacific ITCZ north of the equator during Northern Hemisphere winter. Nearly all atmospheric general circulation models (GCMs) have difficulty simulating this climatically important feature. A modified version of the IPRC-RegCM successfully simulates this low-cloud deck, the simulated precipitation and cloud-water content comparing favorably with satellite measurements. This model is now being used to study how the narrow and steep Andes—an important geographic feature that global models cannot properly represent—affect Pacific climate (Xu, Xie, and Y. Wang).

A different regional atmospheric model has been used to simulate the unusually long wake of wind and water west of Hawai'i. Results confirm that the long extension of the wind wake and cloud band are due to the warm advection by the Hawaiian Lee Countercurrent, which itself is driven by the island wind curl generated as the trade winds pass the tall island mountains. The simulation reveals the vertical structure of the wind wake, thereby complementing satellite observations of surface variables. A new finding is that the dynamic effect of the island topography extends much farther than previous theories predicted because of Rossby-wave propagation (Hafner and Xie).

The third objective of Theme 1 is to determine the basic processes that maintain the Pacific Ocean general circulation and its climatic variability. Progress has been made in understanding the mechanism by which midlatitude wind stress affects the stratification, or the compression of the equatorial thermocline. This compression affects such equatorial coupled ocean-atmosphere variations as ENSO. Changes in the midlatitude winds alter the mixed-layer depth over the western boundary currents and their extension and hence, the thickness of low potential vorticity mode water. Such changes in mode-water thickness propagate to the equator—first following the southward gyre flow and then the low-latitude western boundary—and bring about changes in the thickness of the equatorial thermocline (Nonaka, McCreary, and Xie). Together with last year's work, these results demonstrate the importance of the subtropical cells, the shallow meridional overturning circulation, for equatorial Pacific climate.

The success of simulations with ocean models depends on accurate parameterization of the mixing processes. A unique dataset of large-eddy simulations is being constructed under a wide range of ocean conditions. A novel treatment of the convective effect in bulk mixed-layer modeling has been developed, in which the entrainment is cast as a function of the turbulence Rossby number rather than an arbitrary tunable parameter (D. Wang). Mixing due to internal waves has also been studied from *in-situ* observations in the North Atlantic (Small).

The fourth objective is to determine the nature and causes of Indian Ocean SST variability. The circulation and water exchange between various regions of the Indian Ocean continued to be studied this year. Simulations of cross-equatorial circulation have been made with several models and their results compared (Miyama, McCreary, Jensen, and Loschnigg). In the North Indian Ocean, the water exchange between the Arabian Sea and the Bay of Bengal, and the source of Arabian Sea upwelling have been described and studied with a 4.5-layer model (Jensen). Current measurements along the Indian Ocean equator capture vertically propagating ocean waves, and an analysis using a high-resolution ocean GCM simulation indicates that a semiannual, east-west wind oscillation plays an important role in their excitation. A linear, continuously stratified model is used to explain the salient features of the waves seen in observations as well as in the GCM simulation (Miyama and McCreary).

Estimates of rainfall amount over the oceans are still highly uncertain, both in *in-situ* data and in data derived from satellite remote-sensing methods. Forcing a 4.5-layer ocean model with various precipitation products, Yu and McCreary found that the simulated salinity over the Indian Ocean compares most favorably with observations when they used the CMAP dataset. They examined the effects of runoff, upwelling, the Indonesian Throughflow, and mixed-layer physics on the salinity distribution.

A systematic search for regions in the Indian Ocean where subsurface thermocline variability has a significant effect on SST reveals pronounced coupled Rossby waves that are marked by the amazing co-propagation of anomalies in thermocline depth, SST, precipitation, and wind in the tropical South Indian Ocean (Xie, Annamalai, and McCreary). Affecting the South Indian Ocean cyclone activity, these Rossby waves are partially related to an important mode of Indian Ocean variability that some call the Indian Ocean Dipole (IOD) and that involves strong cooling off Sumatra. The coupled dynamics of this IOD and its interaction with the monsoon have been studied in several projects under Theme 3 (see reports by An, Annamalai, Loschnigg, Li, B. Wang, and Wu). The time and space structure of the IOD is diagnosed from historical ship reports and its global impact documented with various other data sources (Saji and Yamagata).

テーマ1 「太平洋及びインド洋地域における気候」

海洋は地球の気候を調節している。海洋の大きな熱容量、暖流や寒流による熱輸送が気温の急激な変動を抑えているが、その一方で生き生きとした気候変動をもたらしてもいる。通常、海洋の変動はゆっくりとしており、その気候への影響はすぐには分からない。しかし時にはその変化が十分に早くはっきりと分かる場合がある。たとえばエルニーニョの発生で、その時には太平洋赤道域の表面水温が大きく変化し、遠く離れた地域まで気候変動をもたらす。したがって、太平洋とインド洋が年々から十年、さらに長いスケールでどのように変動しそれが大気にいかに影響を及ぼすか、を理解することはアジア-太平洋地域の気候予測をするために不可欠な事柄である。

テーマ1ではこのような問題意識を持ち太平洋・インド洋の海洋循環、比較的低い海面水温に対する大気の応答、大気海洋相互作用の研究を推進してきている。

Individual reports

Jan Hafner
Scientific Computer Programmer

Jan Hafner obtained his Ph.D. in atmospheric sciences in 1996 from the University of Alabama in Huntsville, Alabama. He worked as a research associate at Jackson State University in Mississippi before joining the IPRC in February 2001. His research interests include mesoscale modeling, boundary layer processes, and surface-air interaction processes.

The Hawaiian Islands with their very high mountains (3,055 m on Maui; 4,205 m on the Island of Hawai'i, the Big Island) represent a barrier to trade winds. The wind is forced to flow over and around the islands and forms a wake region behind them. Wind wakes tend to form behind hills and islands and are quite common. The Hawaiian wake, however, is unique because it extends for 3,000 km, which is several times longer than predicted by mechanical theory (Xie et al., 2001). A possible explanation for a wake of such extent lies in air-sea interactions and feedback processes. The wake behind the islands triggers an eastward-flowing oceanic current, which draws warmer water towards the islands. This results in formation of an east-west warm sea surface temperature (SST) tongue pointing toward the Hawaiian Islands.

To gain a better understanding of the physical mechanisms and air-sea interactions involved in the wake formation, Hafner, in collaboration with Xie, adopted a numerical modeling approach and carried out several experiments designed to test the atmospheric response to the islands, topography and warm SST. Using the NCAR/Pennsylvania State University numerical model MM5 (version 3.4.0), which is a non-hydrostatic, primitive equation model with sigma-p vertical coordinates and allows for several different radiation, microphysics, boundary layer and cumulus parameterizations, Hafner set the horizontal model domain to extend 145º zonally and 76º meridionally, centered at 21ºN, 161ºW (slightly west of the Big Island), and included 36 vertical levels. To assess the effect of topography and SST on the wind flow, he conducted three numerical experiments: a control run, a run with a warm SST band (mimicking the observed SST structure), and a run with flat topography. The model run started on August 1, 1999, with NCEP analysis data and SST data derived from the Tropical Rainfall Measuring Mission (TRMM) satellite as the initial and boundary conditions. The results of the last 27 days of the month-long simulation were analyzed.

Vertical Structure of the Hawaiian Wake

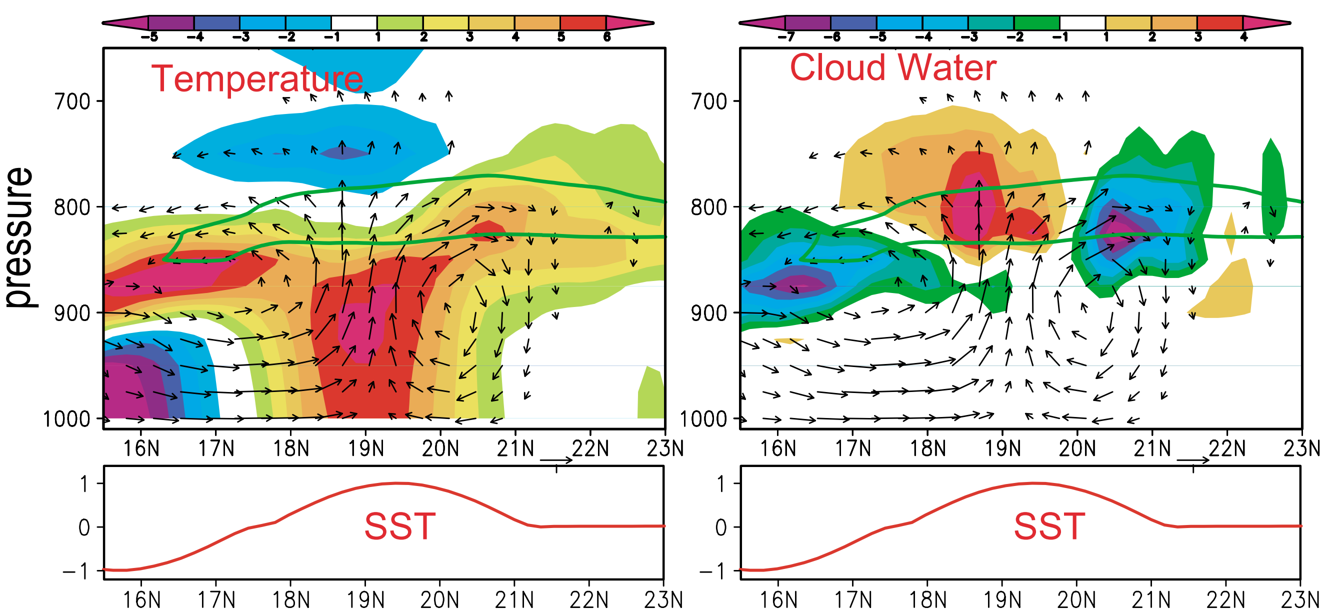


Figure 1: Latitude-pressure sections of temperature (upper left) and cloud-water content (upper right). Superimposed are meridional circulation anomalies of the Hawaiian wake simulated in a regional atmospheric model. The SST anomalies taken from satellite measurements (plotted in duplicate in lower panels) are imposed uniformly in the zonal direction west of Hawai'i.

A comparison between the warm SST experiment (Figure 1) and the control experiment shows that there is enhanced horizontal convergence and convection over the warm SST band, the latter leading to more cloudiness. The increase in cloud liquid water content due to the warm SST is about 0.02–0.03 g/kg.

A comparison between the flat-topography experiment and the control run shows that the tall mountains force the wind to flow beneath the capping trade wind inversion, around the mountains, and to converge behind the islands. The topographically induced wake extends about 10º longitude (~ 1,000 km). Wind convergence has also an effect on cloudiness, which increases in the wake zone by about 0.04 g/kg; the area just downwind of the mountains, however, is cloud free due to diabatic warming of the atmosphere.

Although the atmospheric responses to the warm SST and to the high mountains are similar (convergence and increased cloudiness), these numerical experiments show that the topographic effect is limited to about 1,000 km downwind. The SST effect, on the other hand, is collocated with the warm SST band. Thus, for the Hawaiian wake to continue for 3,000 km, the warm SST feedback is essential.

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 his Ph.D. in geophysical fluid dynamics from The Florida State University. He was a research scientist at Colorado State University, Department of Atmospheric Science, before joining the IPRC in 1998. His research interests include numerical modeling of oceans, coupled ocean-atmosphere models, equatorial dynamics, geophysical fluid dynamics, air-sea interactions, and coastal oceanography.

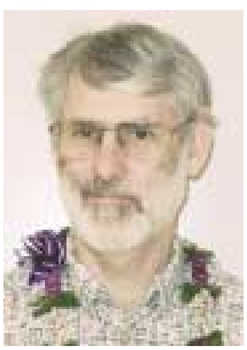
Tommy Jensen has continued studying the high- and low-salinity transports in the tropical Indian Ocean. In his last year's report, he described a study that showed for the first time that Arabian Sea water indeed flows into the Bay of Bengal, where it gets mixed with Bay of Bengal water (Jensen, 2001, *Geophys. Res. Let.*). This year, he analyzed the results from integrations of a 4.5-layer ocean model (Thermodynamic Ocean Modeling System or TOMS) that included prognostic temperature, salinity, and tracers. These new analyses show that the Ekman transport associated with the monsoon transitions enhances the flow of Arabian Sea water into the Bay of Bengal, but prevents Bay of Bengal water from staying in the Arabian Sea. During the northeast monsoon, low-salinity water originating in the Bay of Bengal is advected westward into the southern part of the Arabian Sea; with the onset of the summer monsoon, southward Ekman transport drives the water mass across the equator.

Northward transport of low-salinity water takes place in the mixed layer as well as subsurface in the Somali Current during the summer monsoon. Using artificial drifters in a model simulation, he found that this water originated in the South Equatorial Current, with part of the water coming from the Pacific Ocean. In spite of large variations during the annual cycle, a general clockwise circulation cell is associated with the water exchange in the northern Indian Ocean. Due to conservation of potential vorticity, water parcels can only cross the equator with external forcing, and in order for the parcels to stay on the other side of the equator, their potential vorticity must change. Thus, subsurface floats in the Indian Ocean model simulations crossed the equator only in the Somali Current, an intense western boundary current. Here, lateral friction in the coastal shear zone provides the needed change in potential vorticity. Details of these new results are given in a paper submitted to *Deep Sea Research*.

Jensen collaborated on a related study of the cross-equatorial cell and pathways in the Indian Ocean with T. Miyama, J. McCreary, J. Loschnigg, S. Godfrey and A. Ishida. While the above study focused on pathways of salinity exchanges within given layers, this collaborative work addresses the water mass exchange of the shallow overturning subtropical cell (Miyama et al., 2002, *Deep Sea Research*, submitted). Jensen computed the upwelling rates off Somalia, Oman, Sri Lanka, and Sumatra in TOMS, and compared the results with those from the McCreary and Kundu 2.5-layer model and the JAMSTEC model. While the details differ among the simulations because the models have different resolutions, physics, and boundary conditions, the overall overturning of the subtropical cell is found to be similar in pattern and strength.

Furthermore, Jensen wrote a physical interpretation on the Gravity Wave Retardation (GWR) method to be published in *Global and Planetary Change*. Barotropic gravity waves are internal waves in the coupled ocean-atmosphere system. A large increase in air density reduces the effects of gravity, decreasing the phase speed of ocean waves. This effect is very similar to the original GWR method (Jensen, 1996). In this new paper, Jensen generalized the method and included the case of increased air density and the entire class of reduced gravity layer models as special cases. He computed the root mean square of errors associated with the barotropic mode for models of the Indian Ocean and for a global model. As one might expect from theory, errors increased with latitude, but the method was still sensitive to topographic effects even with a 10-fold speed-up.

Jensen continued his collaboration with Theme 2 researchers on the low-latitude western boundary currents and the Indonesian Throughflow. He demonstrated that a 4.5-layer, global wind-driven model is capable of simulating the seasonal location and depth variations in the bifurcation latitude of the Pacific North Equatorial Current corresponding to observations (Qu and Lukas, 2002). This success indicates that wind forcing must be responsible for these seasonal variations. Previous reduced-gravity models simulated the seasonal cycle of this bifurcation incorrectly, probably because they used a model with a single baroclinic mode. Results from the JAMSTEC model and the IPRC version of Princeton Ocean Model, both full general circulation models, also simulated the bifurcation, and results from the three models were presented at the Ocean Sciences meeting in Honolulu (Jensen et al., Ocean Sciences Meeting abstract).



Julian P. McCreary, Jr.

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

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

Jay McCreary continued to work on projects in both the Pacific and Indian Oceans. He completed studies on: (i) the Pacific Subsurface Countercurrents (with Zuojun Yu); (ii) the dynamics of Pacific and ENSO decadal variability using an intermediate, coupled ocean-atmosphere model (with Amy Solomon); (iii) the Indian Ocean's Cross-equatorial Cell, a shallow, meridional overturning circulation analogous to the Subtropical Cells (STCs) in the Atlantic and Pacific Oceans (with T. Miyama, T. Jensen, and J. Loschnigg); and (iv) Arabian Sea biological variability. He also participated in studies of (v) interannual and decadal variability of the Pacific STCs (Nonaka report), (vi) air-sea interaction in the tropical, southern Indian Ocean (Xie report), and (vii) northward-propagating intraseasonal oscillations (Fu report).

In project (iv), McCreary and mainland colleagues Raleigh Hood, Kevin Kohler, and Sharon Smith developed and used a three-dimensional, coupled physical/biological Indian Ocean model to study the annual cycle of biological variability in the Arabian Sea. The development of ecosystem models like this one is useful in climate research for a variety of reasons. For one thing, biological fields often give clues about the ocean's upwelling field, which is very difficult to measure because the upwelling currents are so weak. Even more importantly, since the marine ecosystem provides a significant sink of CO_2, it is essential for coupled ocean-atmosphere models to contain a good ecosystem submodel in order to predict global warming reliably.

The physical component of the above biophysical model is a variable-density, 4.5-layer model; its biological component is a set of advective-diffusive equations in each layer that determine nitrogen concentrations in four compartments: nutrients, phytoplankton, zooplankton, and detritus. Solutions were compared to horizontal sections and time series from the US JGOFS Arabian Sea Process Study (ASPS) data set, including observations of mixed-layer thickness, chlorophyll concentrations, inorganic nitrogen concentrations, zooplankton biomass, and particulate nitrogen export flux. Through these comparisons, model parameters were adjusted subjectively to obtain a "best-fit," main-run solution, to identify key biological and physical processes, and to identify model strengths and weaknesses. Key adjustments were: (i) reducing the turbulence-production coefficients in the mixed-layer model to limit buoyancy mixing; (ii) changing the sinking and re-mineralization rates of detritus to provide more rapid and increased export flux; and (iii) introducing a parameterization of particle aggregation to lower phytoplankton concentrations in coastal upwelling regions. With these adjustments, the model was able to capture many key aspects of the observed physical and biogeochemical variability in the Arabian Sea.

Despite these successes, significant differences between modeled and observed phytoplankton concentrations remained. In most cases, these discrepancies were attributable to problems with the model's physics, such as misrepresentation of the mixed-layer thickness or the absence of observed mesoscale eddies and filaments. In a planned next stage of the project, data-assimilation techniques will be utilized to represent the state of the ocean better and to estimate biological model parameters objectively.

Toru Miyama
Frontier Research Scientist

Toru Miyama obtained his Ph.D. in physical oceanography from Kyoto University in 1997. Upon receiving his degree, he came to the University of Hawai'i at Mānoa as a visiting scientist with the Wyrtki Center before joining the IPRC as a Frontier research scientist. His research interests include 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.

Toru Miyama has continued to study the structure and dynamics of the cross-equatorial cell (CEC) in the Indian Ocean, a shallow ($z \geq -500$ m) meridional overturning circulation, consisting of a northward flow of Southern Hemisphere thermocline water, upwelling in the Northern Hemisphere, and a return flow as surface water. In his most recent study of the CEC structure and dynamics, Miyama used several types of ocean models, varying in complexity from a 1.5-layer analytic model to a state-of-the-art general circulation model (GCM).

The pathways taken by CEC water are found by tracking drifters in the model from the Northern Hemisphere upwelling regions—forwards in time to follow the surface pathways, and backwards in time to follow the subsurface pathways. In the subsurface branch, cross-equatorial flow occurs in a western boundary current, where strong horizontal mixing can alter the sign of the potential vorticity. In contrast, surface pathways cross the equator in the interior ocean at almost all longitudes. Sources for CEC water are subtropical subducted water, the Indonesian Throughflow, and water flowing into the southeastern Indian Ocean. The solutions from the different models estimate the amounts of water supplied by these sources differently because they have different parameterizations of vertical-mixing processes and basin boundary conditions.

The surface cross-equatorial branch is driven by the annual-mean, east-west wind stress, τ^x. The winds are predominantly westerlies north of the equator, and easterlies south of the equator, the wind stress being a direct function of latitude. This results in negative wind curl that drives a southward Sverdrup flow across the equator. When the wind stress is exactly proportional to latitude y, the Ekman pumping velocity is zero; as a consequence, the wind generates no geostrophic currents, and the Sverdrup transport is equal to the Ekman drift.

In the GCM solutions, the southward cross-equatorial flow occurs just below the surface ($z < -100$ m) typically beneath a northward surface current, so that there is a shallow, cross-equatorial "roll." This feature is the direct (local) response to southerly cross-equatorial winds, and its basic dynamics are linear. Because it is so shallow, the roll has little impact on the CEC heat transport. It does, however, influence where surface drifters can cross the equator; they cross near the eastern boundary where the roll is weak.

This work is done in collaboration with J.P. McCreary, T. Jensen, J. Loschnigg, S. Godfrey (CSIRO) and A. Ishida (JAMSTEC), and a manuscript on this research has been submitted to *Deep Sea Research*.

In a study with Jay McCreary and Fritz Schott (Kiel University), Miyama has studied the characteristics of vertical propagating waves in the equatorial Indian Ocean. The region's semiannual, east-west oscillation of the winds also affects the surface currents. This effect is propagated downward by these waves. In data obtained from the JAMSTEC general circulation model, Miyama found that these waves propagate vertically from the surface to the ocean floor, and that the waves simulated in the model are in good agreement with the observations. The waves are also simulated in a linear, continuously stratified model, indicating that the essential dynamics of these waves are linear and the waves are wind-driven. For the semiannual cycle, the waves are associated primarily with the second vertical mode, forming a packet of equatorially trapped Kelvin and Rossby waves that are resonant because of the width of the basin. For the annual cycle, the waves are more like a "beam." The model data show that interannual variations in east-west fluctuations of the surface currents also reach the ocean floor through these vertical propagating waves. The signal first propagates eastward in a Kelvin wave and then gradually spreads deeper in the ocean as a packet of westward propagating Rossby waves.

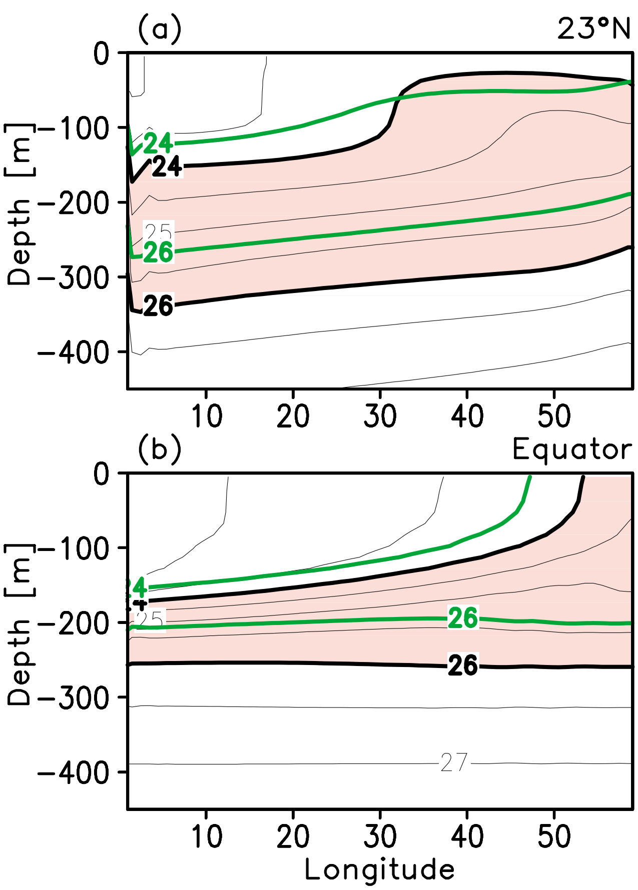
Masami Nonaka
Frontier Research Scientist

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

The temperature stratification in the equatorial ocean thermocline can play a key role in global climate, among other things by affecting the intensity, period, and other properties of El Niño and the Southern Oscillation. The factors that control this stratification are not well understood. Using an idealized ocean general circulation model, Liu and Philander (1995, *JPO*) showed that weaker westerly winds at midlatitudes could compress the equatorial stratification. For weaker winds to affect the layers of the thermocline, higher-order baroclinic signals ($n > 1$) need to arrive in the equatorial region. Wind-stress changes, however, tend to force first-order baroclinic ($n = 1$) waves, which would induce vertical motion of the thermocline rather than compress the layers. So, how can wind changes induce higher-order baroclinic waves? Recent studies (Inui et al., 1999, *JPO*; Xie et al., 2000, JPO) have shown that changes in the midlatitude westerlies change the pathway of low-potential vorticity water (also known as mode water). Subsurface temperature anomalies with a higher baroclinic structure could arise as a result of such pathway changes, and their equatorward propagation could modify stratification of the thermocline.

Masami Nonaka, in collaboration with S.-P. Xie, and J. McCreary, repeated Liu and Philander's experiments. The *control run* in this study was obtained in a rectangular ocean basin and forced by an idealized wind-stress field; the *weakened westerlies* run was the same as the control run, except forced by a wind-stress field with a subtropical wind-stress curl reduced to one-half of that in the control, but with the same tropical wind stress. Since the transport of water depends on the wind stress at the boundary between the subtropics and the tropics, the transport from the subtropics to the tropics and eventually to the equatorial thermocline remains the same in both runs.

The two runs were analyzed by focusing on how higher-order baroclinic signals are generated and either propagate or are advected equatorward (Figure 2). Under weakened westerlies the subtropical gyre spins down and the northward



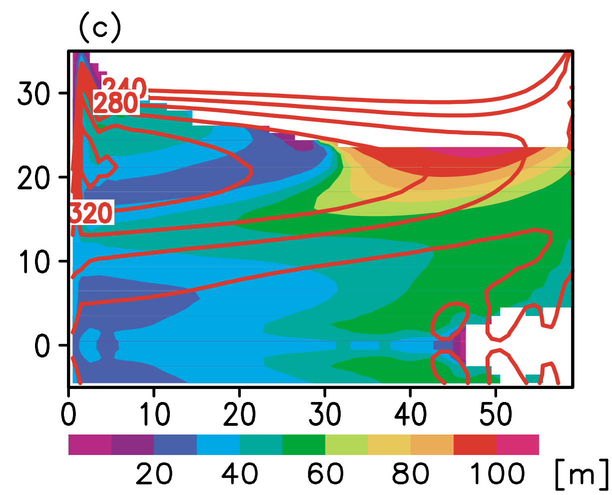


Figure 2: Longitude-depth sections of density (σ_θ) in the control (black) and the weak-westerly winds (green) simulations at (a) 23°N and (b) the Equator. Panel (c) shows differences in layer thicknesses in the range of 24.0 to 26.0 σ_θ (highlighted for the control run) between the two experiments. Larger thickness in the control run represents weaker stratification of the thermocline. Thickness anomalies form in the central subtropics (a) and extend southwest in the direction of the mean gyre circulation presented by the isopycnal depth of 26.0 σ_θ (red contours in c), and eventually to the equatorial region, changing the stratification of the equatorial thermocline shown in (b). Apparently, the equatorial thermocline is more compressed in the weak westerly run.

western boundary current weakens. This leads to less warm advection in the subsurface layer and less Ekman cooling in the surface layer, producing a shallow mixed layer in the eastward extension of the western boundary currents. Because low potential vorticity mode water forms in a deep mixed layer, this shallowing increases the potential vorticity of this water and hence compresses the thermocline stratification in this region. This compressed stratification advects equatorward in the mean gyre circulation, consistent with recent theoretical studies. After the waves arrive at the western boundary, they propagate equatorward as Kelvin waves and then spread eastward along the equator, compressing the thermocline stratification there.

These results suggest that changes in the westerly winds in midlatitudes affect the mixed-layer depth. The changes in the depth of the midlatitude mixed layer, in turn, can influence the stratification of the thermocline downstream through subduction. This suggests that the distribution and variability in the mixed-layer depth can play a significant role in thermocline stratification and in subsurface temperature variations.

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. Before joining the IPRC in January 2002, he was a researcher at the Frontier Research System for Global Change, Tokyo, Japan. His research interests include the Indian Ocean Dipole mode and intraseasonal variability in Indian Ocean sea surface temperature.

The Indian Ocean Dipole (IOD) is a local phenomenon in the tropical Indian Ocean (TIO) that is accompanied by basinwide anomalies in several oceanic (sea surface temperature, sea level) and atmospheric (rain, surface winds) variables and that occurs on an interannual timescale. The distinctive feature of the IOD is a dipole pattern in boreal autumn when the sea surface temperature (SST) is of opposite sign in the western and eastern TIO. The dipole SST anomaly develops from a cold SST anomaly in the eastern TIO that suddenly disappears in the beginning of winter; in the western TIO, however, the SST anomaly continues to be warm until the end of the year. This SST pattern is accompanied by strong anomalous winds over the equatorial Indian Ocean and by sea level anomalies that have a dipole structure similar to the SST anomalies.

N.H. Saji, in collaboration with T. Yamagata (FRSGC), investigated two possible hypotheses that have been put forth to explain the IOD phenomenon: (i) that the IOD is an inherent mode of climate variability arising out of air-sea interactions within the TIO; (ii) the IOD is a response to the El Niño–Southern Oscillation (ENSO). They analyzed SST and wind observations to explore these contradictory hypotheses and identified 19 IOD events during the period 1958–1997, of which 9 are positive events (when the SST anomaly in the eastern TIO was cool) and 10 are negative events (when the SST anomaly over the western TIO was warm). These events were identified using the following three criteria:

- the SST anomaly over the western and eastern TIO are of opposite sign and each exceeds half a standard deviation (sigma) for at least 3 months;
- the zonal SST gradient anomaly exceeds 0.5 sigma for at least 3 months; and
- the zonal wind anomaly over the equator exceeds 0.5 sigma for at least 3 months.

El Niño and La Niña years were identified based on the definition of the Japan Meteorological Agency that the magnitude of the SST anomaly in the eastern Pacific (the NINO3) exceeds 0.5ºC for 6 consecutive months.

Saji and Yamagata found that only 8 out of 19 IOD events co-occurred with ENSO events (i.e., about 40%). They pointed out that the temporal structure of the IOD—particularly, the frequency spectrum and the IOD interdecadal variability—and the relation between the IOD and the lagged ENSO effect are not consistent with the conclusion that the IOD is a response to ENSO. Rather, they showed that the zonal SST gradient anomaly and the zonal equatorial wind anomaly in the TIO evolved coherently and shared about 70% of their interannual variance. Concluding that these properties strongly suggest that the IOD arises from an inherent air-sea interaction in the TIO, they present evidence for the position that the IOD and ENSO are better described as mutually interactive phenomena. (N.H. Saji and T. Yamagata, submitted to *J. of Climate*).

N. H. Saji is also exploring the remote influences of the IOD on global climate (N.H. Saji and T. Yamagata, submitted to *J. of Climate Research*) by analyzing records of land temperature and precipitation for the period 1958–1999. They found that the IOD linearly accounts for about 40% of the autumn rainfall variability over equatorial East Africa and a similar percentage of summer rainfall variability over Sumatra. Moreover, they documented significant relationships between the IOD and land-temperature anomalies over South

America (r = -0.8) during the austral spring and land-temperature anomalies over northeast Asia (r = 0.5) during boreal summer. An examination of atmospheric circulation fields from the NCEP reanalysis project suggests that stationary Rossby wave patterns excited by variations in the Walker circulation over the TIO may be a plausible mechanism for understanding these IOD teleconnections.

Justin Small

Postdoctoral Fellow

Justin Small received his Ph.D. in oceanography from the University of Southampton in 2000. He worked at the Defense Evaluation Research Agency in England before joining the IPRC in August 2001. His research interests include satellite data analysis and the detection and simulation of non-linear internal waves in the ocean.

Justin Small's research during his first year at the IPRC has focused on three main themes. First, in collaboration with S.-P. Xie, he has studied the response of the atmospheric boundary layer to sea surface temperature (SST) gradients in tropical instability waves (TIWs)—large meanders with wavelengths of about 1,000 km along the equatorial front separating the cold upwelled water along the equator from the warmer water to the north. Recent observations have shown that these waves induce a large response in the atmosphere. Small has used Complex Singular Value Decomposition (CSVD) analysis of new satellite data and a regional climate model to establish the nature of the physical processes involved in this air-sea interaction.

With the CSVD analysis, Small looked at whether he could identify propagating coupled air-sea modes in observations, principally in the daily wind fields from QuikSCAT and SST fields from the Tropical Microwave Imager. He has found that CSVD analysis can distinguish seasonal coupled modes from the periodic TIW coupled modes (manuscript in preparation). The physical processes in these two modes appear to be different; in the seasonal coupled mode, wind drives SST, and strong winds lead to more evaporation and upwelling and colder SST; in the TIW case strong winds are found mainly over warm SST. These winds are thought to be due to vertical mixing initiated by an unstable surface layer of air over the warm water. More recent results of a CSVD analysis conducted with Felix Seidel (IPRC visitor; Swiss Federal Institute of Technology) have suggested that the TIW structure changes with longitude and confirmed that similar wind-SST relationships exist in the Atlantic during TIW season.

Small has used the IPRC–Regional Climate Model (IPRC–RegCM), developed by Y. Wang, to investigate the physical response of the atmospheric boundary layer to changes in SST. He chose this model because it has horizontal mesoscale resolution (the grid spacing of the present simulations is 50 km) and has high vertical resolution, including 7 levels in the lowest 1 km. The model is particularly attractive because it has a sophisticated turbulence closure scheme in which turbulent kinetic energy and dissipation rate are diagnostics, allowing the investigation of turbulent processes that are not well simulated in most other global climate models. Small's latest results show that considerable wind divergence is generated in areas where the wind flows across the SST front, and that there is positive wind curl where wind flows parallel to the SST front. These model results, which agree reasonably well with observations, suggest that vertical mixing modifies wind speed over the SST front.

In his second research theme, Small is looking at the impact of surface current stress on wind scatterometer measurements. It has been speculated that surface currents can be inferred by comparing the wind velocity measured by scatterometer with *in-situ* measurements. Small investigated this theory by comparing wind velocity data from the QuikSCAT (Quick Scatterometer) and the ERS (European Remote Sensing Satellite) with TAO (Tropical Atmosphere Ocean Array) *in-situ* data (manuscript in preparation). The strongest impact of surface currents on scatterometer measures was seen during the TIW season when TAO minus QuikSCAT differences had peak-to-trough amplitudes of 2m/s and periods of around a month, which corresponds to the TIW period. (The amplitudes are rather large, but TIW current speeds of almost 1m/s have been reported before.) An analysis of longer records to study seasonal and annual changes in TAO minus QuikSCAT or TAO minus ERS did not, however, find any strong correlations with surface currents derived from satellite altimetry. Work on this is continuing, including analysis of re-processed QuikSCAT data.

Small's third research theme deals with nonlinear internal waves. In collaboration with Bob Hornby (Defense Science Technology Laboratory, England), he has studied the effects of near-shore shoaling in which substantial deformation and mixing of the waves is likely to occur.

Amy Solomon
Assistant Researcher

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

During this past year, Amy Solomon studied, in collaboration with F.-F. Jin (University of Hawai'i), the impact of off-equatorial warm-pool sea surface temperature (SST) anomalies on cycles of the El Niño–Southern Oscillation (ENSO). Observations show large thermocline anomalies in the off-equatorial western Pacific during ENSO cycles. Solomon and Jin analyzed these observations and showed that the large thermocline anomalies cause cold SST anomalies and are primarily associated with Ekman pumping forced by westerly winds that typically occur during the maturing phase of an El Niño event. With an atmospheric GCM simulation, they further showed that, due to a large reduction in atmospheric convection, these anomalies, although small relative to anomalies in the eastern equatorial Pacific, produce a significant surface atmospheric response in the western equatorial Pacific, consistent with a Gill model. They tested the role of these feedbacks in the ENSO cycle by including the relevant processes in a simulation with a modified Zebiak-Cane coupled model. This simulation showed that these additional feedbacks in the western Pacific increase the periodicity and amplitude of ENSO events and increase the likelihood that the peak of an El Niño occurs during the month of November. Solomon presented this research at the European Geophysical Society General Meeting and is now preparing it for submission to the *Journal of Climate*.

Solomon also completed the latest phase of her studies on Pacific decadal variability resulting from transport variations in the North Pacific Subtropical Cell, a shallow north-south overturning circulation. In this collaborative study with J. McCreary, R. Kleeman (New York University), and B. Klinger (Center for Ocean-Land-Atmosphere Studies), Solomon studied processes that cause decadal variability in an intermediate coupled ocean-atmosphere model of the Pacific Basin, both at northern midlatitudes and in the tropics. The model was specifically designed to separate tropical and extratropical interactions, such that the tropics could affect the extratropics through the atmosphere and the ocean, but the extratropics could only feed back to the tropics through the ocean. The results demonstrated that extratropical decadal variability can be transmitted to the equator by variations in the transport rather than in the temperature of the North Pacific Subtropical Cell. These variations were found to modulate near-equatorial SST by altering the amount of cool, thermocline water that upwelled in the eastern equatorial Pacific, which in turn altered the interannual mode. A further result was that a damped extratropical decadal mode could be sustained by atmospheric teleconnections from the tropics, but not by extratropical stochastic forcing. Solomon presented these findings at the AMS 13th Conference on Atmospheric and Oceanic Fluid Dynamics, and they are currently under review by the *Journal of Climate*.

Dailin Wang
Associate Researcher

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

The success of ocean climate modeling relies heavily on the oceanic mixing schemes used in the models. Understanding the mixing processes has greatly progressed, fuelled mainly through microstructure observations and numerical simulations. This progress, however, has not transferred into modeling the mixed layers of the ocean. For example, the original Kraus-Turner (Kraus and Turner 1967, Niiler and Kraus 1977) model, with its understanding of physical processes three decades ago, is still the most widely used bulk mixed-layer model today. This lack of change stems from the fact that it is difficult, if not impossible, to replicate exactly observed ocean conditions in these one-dimensional models. Many horizontal processes such as internal waves, Ekman convergence/divergence, and horizontal advection have been either poorly, or not at all, observed in the ocean, and observations of surface flux conditions are subject to errors. Validation of model parameters, furthermore, requires the isolation of processes.

This is, however, not possible with observations in which processes are constantly interacting.

In short, the precise comparison and validation of one-dimensional models is hampered by the lack of "clean" solutions to the oceanic boundary layer, and the attempt to tune one-dimensional models to field observations has inherent problems. Some studies in the literature have shown that tuning a one-dimensional model to a particular data set will often not work for a different dataset. Changes in model parameters are, therefore, often made *ad hoc* to fit different observational data sets. One cannot then tell, however, whether the change in model parameters reflects an actual difference in boundary layer physics or accounts for missing or unknown large-scale processes (mean flow, waves, and surface fluxes, etc.).

Dailin Wang's research on improving the parameterization of ocean mixing deals with the above problems by conducting large-eddy simulation (LES) experiments under a wide range of ocean conditions. He uses the LES experiments as a virtual laboratory to investigate mixing processes and to derive empirical formulas or parameterizations for use in general circulation models. The rationale for this approach is based on the fact that the eddies contributing the most to turbulent fluxes are resolved in an LES model and that the sensitivity of the LES model to subgrid-scale parameterization diminishes as resolution increases (Wang, 2001).

Based on his findings with these LES experiments, Wang has developed a bulk mixed-layer model for convection that takes into account the effects of Earth's rotation. This model also provides a theoretical rationale for some of the practices in mixed-layer modeling. For example, some researchers use different values of the parameter n (associated with convection) in the Kraus-Turner model for different environments. In the new model, such tuning is unnecessary, since for convection in depths greater than a few hundred meters, the value $n = 0$ can be used because of the effect of Earth's rotation. Researchers have used $n = 0$ in the past, but now Wang has provided a physical justification for this strategy.

Wang also developed a bulk model for the equatorial wind-deepening mixed layer. Simulations with this bulk mixed-layer model agree remarkably well with LES results. Now Wang is expanding this model with the wind mixed layer to include the effects of Earth's rotation, his long-range goal being the development of a comprehensive mixed-layer model that is valid under a wide range of ocean conditions.

Shang-Ping Xie

Associate Professor of Meteorology, SOEST
Theme 1 Co-Leader

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

Shang-Ping Xie has carried out research on air-sea interactions at ocean fronts and on climate variability over the tropical Pacific, Atlantic, and Indian Oceans.

Tropical instability waves (TIWs), with wavelengths of 1,000 km and periods of 30 days, cause the equatorial front to meander and result in sea surface temperature (SST) variations of 1–2°C (see J. Small's report). The first-ever vertical soundings of temperature, humidity, and wind velocity over such TIWs were obtained on board the Shoyu Maru, which sailed during September 1999 from 140°W to 110°W along 2°N through three fully developed TIWs (Hashizume et al. 2002, submitted to *J. Climate*). Analyzing the data, Xie and colleagues have found that throughout the cruise a strong temperature inversion existed along 2°N, capping the planetary boundary layer (PBL), which is 1 to 1.5 km thick in the region (Figure 3). In response to a SST increase, air temperature in the lowest km rises, but cools greatly at the mean inversion height. Because of the opposing effects of this temperature dipole, the TIW signal has little effect on the observed sea level pressure (SLP). The cruise-mean vertical profiles show a zonal and meridional wind-speed maximum at 400–500 m. SST-based composite profiles of zonal wind velocity show weakened (intensified) vertical shear within the PBL consistent with enhanced (reduced) vertical mixing. This causes the surface wind to accelerate (decelerate) over warm (cold) SSTs. Together the temperature and wind soundings explain why vertical mixing dominates over the SLP-driving mechanism. The observed pressure adjustment leads to a physical interpretation of the widely used Lindzen and Nigam PBL model.

Though ignored in large-scale modeling, the above vertical mixing of momentum is important for wind adjustments near oceanic fronts. Satellite and *in-situ* observations have identified this mixing process in the

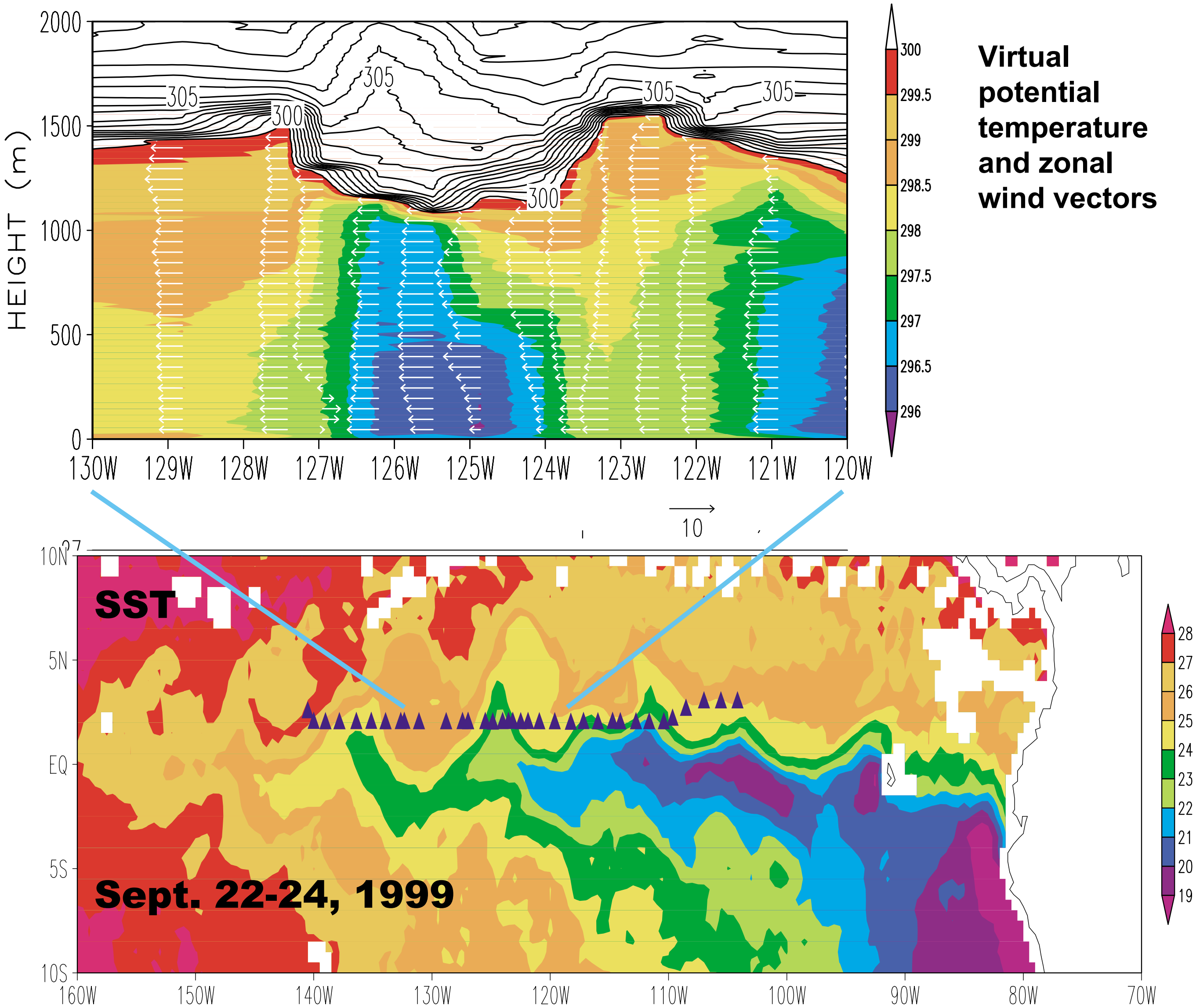


Figure 3: The effects of tropical instability waves (TIWs) were recorded for the first time with radiosonde on the RV *Shoyo-Maru* in September 1999 (upper panel). The lower panel shows the TIWs captured by TRMM SST measurements during that period. The transect reveals that the TIWs affect the whole planetary boundary layer (PBL): over the cold meanders, the atmosphere is colder and vertical mixing is suppressed, resulting in stronger wind shear and weaker surface winds as revealed in QuikSCAT data. The capping inversion over the PBL is up to 500 m lower over regions associated with the cold meanders, generating large atmospheric pressure anomalies important for wind adjustment.

equatorial Pacific and Atlantic Oceans (J. Small), in the Kuroshio Extension (M. Nonaka), and in the East China (J. Hafner) and Arabian Seas (see reports by IPRC lead authors).

In the tropical South Indian Ocean (SIO), Xie and his colleagues (2002) have studied a unique open-ocean upwelling, which results from the negative wind curl between the southeasterly trades and the equatorial westerlies and raises the thermocline in the west. Analysis of *in-situ* measurements and a model-assimilated dataset reveal that the thermocline variations greatly influence SST in this upwelling zone. During an El Niño, anomalous easterlies appear in the equatorial Indian Ocean, forcing a westward-propagating downwelling Rossby wave in the SIO. In phase with this dynamic Rossby wave is a pronounced co-propagating positive SST anomaly. Associated with this anomaly are (i) more rainfall, resulting in a cyclonic circulation in the surface wind field that appears to feed back to the SST anomaly (Figure 4) and (ii) more tropical cyclones. Thus, this coupled Rossby wave may help predict SST changes and the occurrence of tropical cyclones in the western SIO.

The climates of the eastern Pacific and Atlantic Oceans share common features in their climatology, such as the northward-displaced intertropical convergence zone (ITCZ) and an equatorial cold tongue (see H. Xu's report). But their interannual SST variabilities are markedly different, with the equator being the dominant center of action in the Pacific, and the off-equatorial tropics in the Atlantic. Performing separate EOF analysis of SSTs in the North and South Atlantic, Xie and his colleagues have identified a pan-Atlantic decadal oscillation. The leading SST modes in these statistically independent sub-domains feature a tripole in the North and a dipole in the South Atlantic. In the tropics, the statistically independent SSTs in the North and South Atlantic are out phase, forming a dipole. Spatially coherent anomalies of low-level clouds are associated with the tropical Atlantic dipole, with more (less) cloudiness over the cold (warm) lobe. Unlike the deep convective clouds near the equator, these low-level cloud anomalies do not appear to be associated with significant surface wind convergence. By shielding the sea surface from solar radiation, these low-level cloud anomalies act to reinforce the underlying SST anomalies, reducing SST damping by as much as 30% (Tanimoto and Xie, 2002).

To investigate how the mean state of the climate can affect its own variability, Xie and H. Okajima (University of Hawai‘i) performed several experiments with a coupled atmospheric GCM–intermediate ocean model. With a symmetrical continental and ocean climate around the equator, this hybrid model produces a pronounced SST dipole that varies on interannual to decadal timescales. The SST variabilities, winds, and cloud covers are highly negatively correlated across the equator. The SST–wind relation supports the so-called wind-evaporation-SST feedback. When the ITCZ is displaced in the Northern Hemisphere by arranging the continents realistically, the interhemispheric correlation is much lower, a result consistent with observed Atlantic climate variability. The asymmetry weakens the wind-evaporation-SST feedback and hence the interhemispheric interaction in the model.

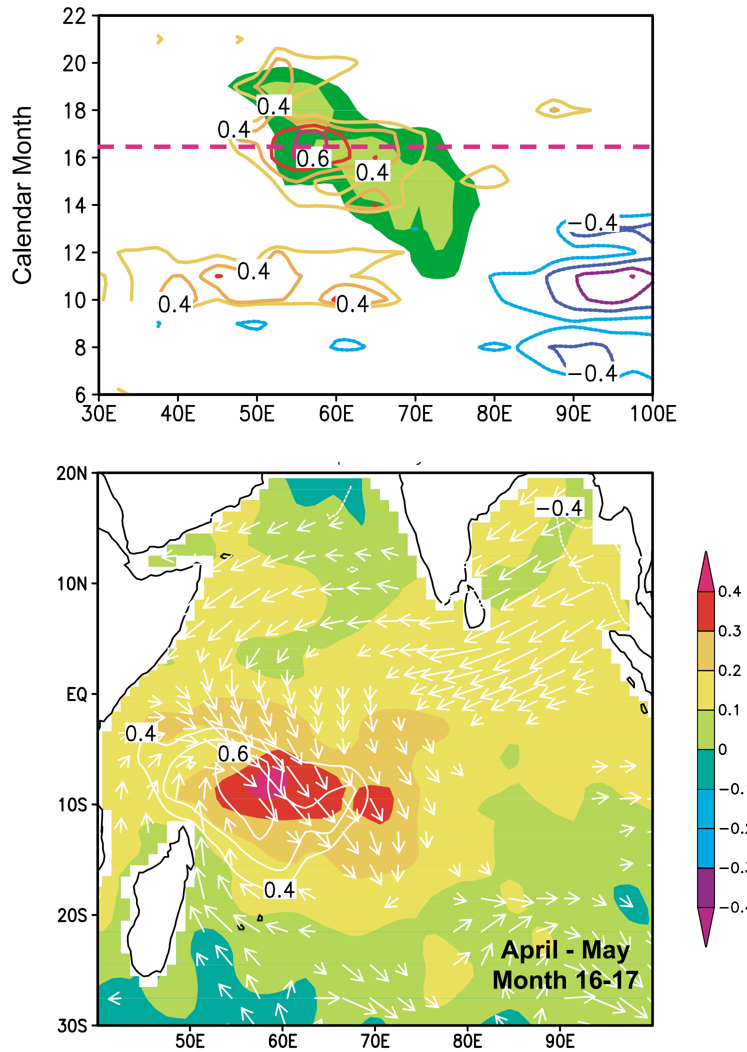


Figure 4: Coupled Rossby wave in the South Indian Ocean. The top panel shows correlations between an ENSO index (anomalies of central and eastern equatorial Pacific SST averaged for October–December) and (i) SST (r > 0.6 is shaded) and (ii) precipitation (contours) along 10°S as a function of longitude and calendar month. The peaking of Pacific El Niño in December together with SST cooling off Sumatra is responsible for the dipole precipitation anomalies over the Indian Ocean and eastern Africa. After El Niño dissipates, positive precipitation anomalies are collocated with westward-propagating SST anomalies induced by oceanic Rossby waves. By April and May after El Niño, the Rossby-wave induced warming (shaded in the bottom panel) dominates the Indian Ocean, leading to an increase in local precipitation (contours) and a cyclonic surface circulation (vectors). Such coupled Rossby waves, increasing the frequency of tropical cyclones in the western South Indian Ocean during December–March of an El Niño year, have not been observed in other tropical oceans, where a lack of perennial upwelling or a shallow thermocline does not allow thermocline variability to affect SST.

Haiming Xu
Postdoctoral Fellow

Haiming Xu received his Doctorate of Science in meteorology in 1999 from the Department of Atmospheric Sciences, Nanjing Institute of Meteorology, Nanjing, China. He was an associate professor at the Nanjing Institute of Meteorology before joining the IPRC in February 2002. His research interests include tropical meteorology and monsoon circulation, numerical modeling the atmospheric circulation, and air-land-sea interactions.

The effects of the Andes on the atmospheric circulation and on the distribution of rainfall over the South American continent have been extensively investigated with general circulation models, or GCMs (Walsh 1994; Lenters and Cook 1995, 1997). In these studies, however, the steep and narrow Andes have been poorly represented because of the insufficient horizontal and vertical resolutions of the GCMs. Haiming Xu has, therefore, been studying the effects of the Andes on the eastern Pacific climate using the IPRC Regional Climate Model developed by Y. Wang. The high-resolution IPRC–RegCM, with cloud physical processes explicitly resolved, corrects many of the problems of the earlier studies.

In collaboration with S.-P. Xie and Y. Wang, Xu conducted two experiments with the IPRC–RegCM at a resolution of 0.5 degrees (35ºS–35ºN, 30º–150ºW). In the control experiment, the model was initialized with NCEP/NCAR reanalysis data on March 1, 1999, and integrated for eight months. Daily NCEP/NCAR reanalysis data and observed weekly SSTs were used as lateral and bottom boundary conditions, respectively. With this control simulation, Xu examined the performance of the model and found that, compared with observations, the IPRC–RegCM successfully simulates the seasonally averaged precipitation, the three-dimensional structures of the stratus clouds, and the boundary temperature inversion off the west coast of South America (see Figure 5). In the second (sensitivity) experiment, the initial and boundary conditions were identical to the control run except that the Andes were reduced to 750 meters. Comparing the two simulation results, Xu found that the Andes drastically change the ITCZ-related precipitation during March, April, and May over both the Southern and the Northern Hemisphere. With realistically tall Andes, the double ITCZs in the eastern Pacific occur only in March and early April, while in the low Andes condition the double ITCZs persist almost 20 days longer. The major reason for this difference is that the high Andes prevent the prevailing warm, moist easterly winds from entering the southeastern Pacific and simultaneously generate rather strong wind divergence over the southeastern Pacific. Both processes hinder the development of cumulus convection over the southeastern Pacific. Without blocking by the Andes, the warm, moist easterly winds migrate into the subtropics from South America and favor the development of cumulus convection associated with the ITCZ.

Another major finding is that increased temperature inversion over the Pacific due to the effect of the Andes increases the stratus-cloud deck over the Pacific off the coast of Peru in the cold season of the Southern Hemisphere. These clouds contribute to the climatic asymmetries in the eastern Pacific reported by Philander et al. (1996). Perhaps the most significant result of the project is that the presence of the Andes may lead to basinwide climate asymmetries through atmosphere-land-ocean interactions and through cloud-radiation-SST feedback.

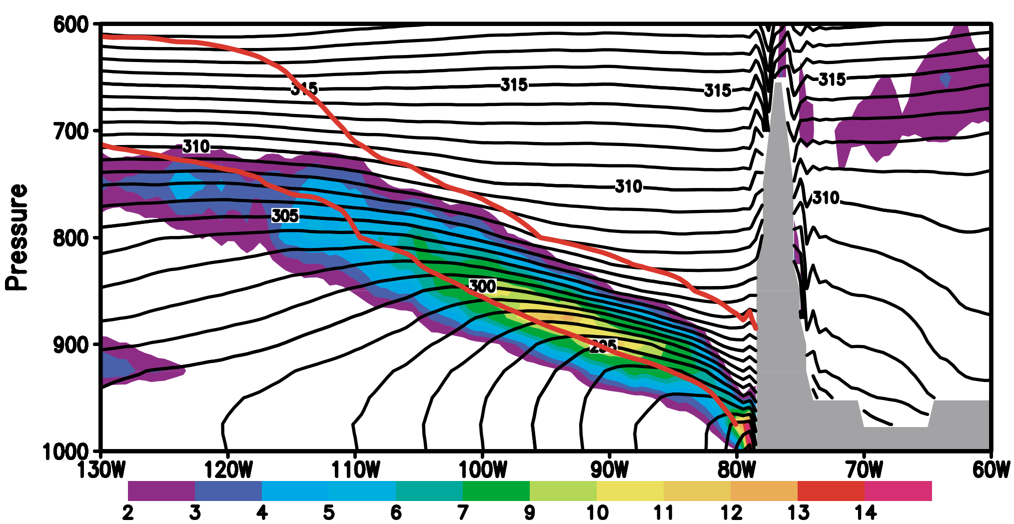


Figure 5: Vertical structure of the simulated stratus-cloud deck at 10ºS in the southeastern equatorial Pacific: cloud-water content (color shade: 10^{-2}g/kg) and virtual potential temperature (black contours, in ºK) averaged for August–October, 1999. The $d\theta_V/dp$ = 8 ºK/100hPa (red curves) marks the mean location of the inversion layer that caps the planetary boundary layer. Note that both the inversion and cloud layer increase in height west of the Andes (gray shaded).

Zuojun Yu

Associate Researcher

Zuojun Yu obtained her Ph.D. in physical oceanography from Nova Southeastern University, Fort Lauderdale, Florida, in 1992. She joined the IPRC in Summer 2000. Her research interests include eddy-mean flow interaction, ocean surface-mixed-layer dynamics, simulation of large-scale ocean circulations, and evaluation of model forcing fields using ocean models and observations.

During the past year, Zuojun Yu has completed two joint projects: one on the Hawaiian Lee Countercurrent (HLCC) with Maximenko, Xie, and Nonaka, and one on the Pacific subsurface countercurrents with J. McCreary (see McCreary's report). In addition, she has extended her work on validating precipitation products from the Pacific Ocean to the tropical Indian Ocean basin.

Regarding the HLCC project, drifting buoy data reveal rich eddy activity west of the Hawaiian Islands. When the data are averaged over time, a narrow eastward current emerges just west of the island of Hawai‘i. This eastward current is a result of changes in wind flow when the trade winds blow against the tall Hawaiian Islands. From the inferred effects of the wind on the ocean in accordance with Sverdrup theory, this eastward current should extend to Asia (see Xie, Liu, Liu, Nonaka, 2001), while the observed HLCC is confined to east of 175^{o}W. Yu and her colleagues have examined the possible role of eddies in modifying the Sverdrup solution by using an ocean model of 0.1° horizontal resolution. The model is able to reproduce an eastward current similar to the observed one when forced by ECMWF winds and under low horizontal eddy viscosity (2.5 x 10^5 cm^2/s to 5.0 x 10^5 cm^2/s), which permits rigorous eddies in the area. Analyses suggest that the eddies in the model limit the westward extent of the HLCC by converting the mean kinetic energy to eddy-kinetic energy.

The validation of precipitation products is important because freshwater affects sea surface salinity, which, in turn, has a significant impact on the depth of the ocean surface mixed layer. The simulation of surface salinity, however, is still far from satisfactory. Yu's study looks into ways of improving the surface-salinity simulation in the tropical Indian Ocean, where the salinity contrast between the Arabian Sea and the Bay of Bengal is large. In particular, she has examined the effects of runoff, coastal upwelling, the Indonesian Throughflow, model surface-mixed-layer dynamics, and the accuracy of precipitation products. She used monthly mean climatology to force a 4.5-layer ocean model and has compared the model surface salinity field with observations in order to evaluate model performance and the precipitation forcing. The results showed that in addition to runoffs in the Bay of Bengal and the Indonesian Throughflow, freshwater is needed along the east coast of the Arabian Sea and around Madagascar in order to keep the model surface salinity from drifting. Yu has taken a practical approach to avoid this drift by using a "virtual runoff" scheme.

With the aid of virtual runoff, the model is able to simulate mean surface salinity and mixed-layer depth resembling observations in the tropical Indian Ocean when forced by CMAP precipitation, a merged product using rain gauges and five kinds of satellite measurements. This finding is encouraging because a main concern with these advanced satellite-based precipitation products is the determination of precipitation magnitude. Yu's research suggests that ocean models can help to evaluate these products and recommends adjustments to the magnitude of precipitation measurements from satellites. In her manuscript, Yu notes the problems with some precipitation products and their implications for air-sea interaction.

Research Activities and Accomplishments

Theme 2: Regional Ocean Influences

Overview

The boundary currents of the western Pacific transport huge amounts of heat and salt from one region to another and are the primary pathways of communication between the large ocean gyres and between the Pacific and the Indian Ocean. Such heat transfer influences climate noticeably. The strong Kuroshio Current along the coast of Japan, transporting heat from the equator poleward, for example, causes a sharp ocean-land temperature contrast that results in a severe winter monsoon in East Asia. The Oyashio Current, in turn, brings cold water southward along the coast of Japan from the subarctic gyre. Where the Kuroshio and the Oyashio meet and leave the Japan coast, they form the Kuroshio-Oyashio Extension. The largest decadal variations in sea surface temperature (SST) have been found in the Kuroshio-Oyashio Extension rather than in the tropics, indicating a key role for this current system in interannual-to-decadal climate variability in both the North Pacific and East Asia.

To the south, the low-latitude western boundary currents (LLWBCs) of the Pacific play an important role in the development and modulation of El Niño events. The North Equatorial Current and the South Equatorial Current bifurcate to feed into the LLWBCs, and the locations of the two bifurcation latitudes affect the strength, and thus the amount of heat and salt transport of the LLWBCs. The Indonesian Throughflow (ITF)—the water flowing through the complex straits and seas of the Maritime Continent between the Pacific and the Indian Ocean—is also a significant component of the global ocean thermohaline circulation and must have a sizeable impact on the heat budget of the western Pacific warm pool as well as the Indian Ocean.

The research objectives of Theme 2, as outlined in the IPRC Science Plan, are aimed at describing these oceanic pathways, asking what maintains them, what causes their variations, and what are their influences on regional ocean circulations? In addressing these objectives this past year, IPRC researchers have mainly used high-resolution numerical modeling, data assimilation, and diagnoses of historical data.

With regard to Objective 1 under this theme—determining the processes that maintain the Kuroshio, Oyashio and their extension and cause their climate variability—the following progress has been made. A study with a high-resolution regional ocean model that represents the main features of the Kuroshio-Oyashio region, revealed distinct, strongly eddy-driven, water pathways forming near the coast of Japan that carry subpolar water into the subtropical gyre (Mitsudera). In another study, a basin-scale model is being used to investigate the impact of Kuroshio Extension water on the subpolar gyre (Mitsudera, Endoh). An application of the new Kuroshio large meander index to hydrographic datasets from the NOAA-NODC World Ocean 1998, the Japan Oceanographic Data Center, and the Marine Information Research Center describes the Kuroshio state south of Honshu better than previous attempts. Sorting the data with this index captures the evolutions of 7 large-meander developments and 5 decays, and it shows remarkable similarities in the evolutions (Maximenko). Moreover, an analysis of a new formation mechanism of the Kuroshio meander by *anticyclonic* eddies reveals a number of dynamically relevant processes, such as the eddy-shedding at sharp coastlines and the existence of a baroclinic structure during the detachment of the anticyclonic eddy from the Kuroshio. Research on the paths of chaotic transport of water off the coast of Japan was extended this year, and recent findings have relevance for fisheries, pollution detection, and recovery procedures (Waseda and Mitsudera).

The Kuroshio-Oyashio region is also being analyzed using four-dimensional variational methods. Thus, a large number of the current meter and conductivity, temperature, and depth (CTD) measurements, collected in the Subpolar Front during Megapolygon '87, were assimilated into a quasi-geostrophic model, together with *Geosat*-altimetric and ECMWF-wind data. The assimilation shows that the observed mesoscale structures are well described by quasi-geostrophic dynamics, explaining 80-85% of the variability in the velocity and density fields (Yaremchuk and Maximenko). Furthermore, acoustic data obtained in the Kuroshio Extension during 1997 was successfully assimilated into the quasi-geostrophic model, demonstrating that acoustic tomography is useful for obtaining information on the deep currents in the Kuroshio Extension. (Yaremchuk, Lebedev, Maximenko, Yuan, and Mitsudera). A group of Theme 2 researchers also began to investigate use of the Singular Evolutive Extended Kalman (SEEK) filter together with the wavelet error diagnostic scheme developed in the previous years (Waseda, Yaremchuk, and Mitsudera).

With regard to the second objective—the processes controlling the LLWBCs—the following has been accomplished. Based upon all available historical data, a new climatology has been constructed of the circulation and water-mass distribution of the western Pacific (Qu), including the South Pacific, a poorly charted region until now. Furthermore, three different models—the JAMSTEC general circulation model, the IPRC version of the Princeton Ocean Model (POM), and a 4.5 layer wind-driven ocean model—were used to study the LLWBCs. Major findings from the climatology and the numerical model simulations are as follows: (i) The mean bifurcation of the South Equatorial Current shifts from about 15ºS near the surface to about 22ºS in the intermediate layers, the origin of the Great Barrier Reef Undercurrent lying at about 22ºS. (ii) A strong water property connection exists between the Coral and Solomon Seas, confirming the earlier speculation of a Coral Sea water-mass origin for the New Guinea Coastal Undercurrent. (iii) The mean bifurcation latitude of the North Equatorial Current (NEC) shifts from about 13.3ºN near the surface to about 20ºN at depths of around 1000 m. (iv) The bifurcation of the NEC is at its southernmost position (14.8ºN) in July and its northernmost position (17.2ºN) in December. This annual shift lags behind the seasonal north-south migration of the zero-zonally integrated wind-stress-curl line by about 4 to 5 months, but corresponds rather well to the local Ekman pumping, suggesting that the Asian monsoon plays an important role in determining the bifurcation latitude of the NEC. (v) Below 700 m, the bifurcation of the NEC reaches as far north as 22ºN in winter (November–January), but becomes unrecognizable in summer (June–August).

With regard to the influence of the ITF on the Pacific warm pool, the Indian Ocean, and Asian-Pacific climate, study this year has focused on describing and understanding the dynamics involved in the water exchange between the Pacific and the Indian Ocean. Heat and fresh-water fluxes in the region, estimated from recent measurements of transport, temperature, and salinity, show that water transport through the Savu Sea, located within the Indonesian archipelago, is primarily controlled by coastal Kelvin waves generated in the Indian Ocean (Potemra). According to a study of the vertical structure of the ITF with a high-resolution numerical model, most of the ITF variability occurs in a few (two or three) vertical layers, a finding that has implications for modeling and observational studies in the region (Potemra). Work on the ITF inflow has also occurred in relation to the research on the Pacific LLWBCs mentioned above. Output from the high-resolution JAMSTEC ocean model, for instance, has revealed a vertical structure to the flow in the Celebes Sea (Kim and Qu). Adaptations to a high-resolution version of the POM have been completed, and the model now, too, is ready for study of the ITF (Kang, Bang).

テーマ2「モンスーン域の海洋が気候変動に及ぼす影響」

太平洋西岸域は境界流が大量の熱や塩分を運ぶとともに、複数の大きな循環と循環との間、及び、太平洋とインド洋との間をつなぐ通路となっており、気候に多大な影響を与えている。例えば、大量の熱を赤道域から運ぶ黒潮は海洋ー陸域間で大きな気温の差を作り出し、東アジアにきびしい冬の季節風をもたらす。一方、親潮は亜寒帯循環から日本の沿岸域へ冷たい海水を運んでくる。これらは日本の東方で合流し、黒潮―親潮続流域を形成する。十年スケールの水温変動が最も顕著なのがこの海域であり、北太平洋・東アジアに数年から数十年の気候変動を引き起こしているものと考えられている。

南方では太平洋低緯度西岸境界流がエルニーニョの形成・変調に重要な役割を持っている。北太平洋海流・南太平洋海流は、それぞれフィリピン沖・オーストラリア沖で分岐し低緯度西岸境界流となるが、分岐の場所が西岸境界流の強さ、熱輸送、塩分輸送に影響を与えると考えられている。インドネシア通過流は複雑な地形を通り太平洋とインド洋を結ぶ流れであるが、それは地球規模の熱塩循環の一部であるとともに、太平洋やインド洋における暖水プールの熱収支において大きな部分を担っている。

テーマ2の目的は、IPRCの研究計画にもあるように、これらの海の中の通り路を記述し、それがどのように維持され、変動し、その海域の海洋循環に影響を与えているか、を解明することである。そのために、高解像度モデル、データ同化、資料解析を用いた研究を進めている。

Individual reports

Takahiro Endoh

Frontier Research Scientist

Takahiro Endoh received his Ph.D. in science from The University of Tokyo in 2001. He joined the IPRC in July 2001 as a Frontier Research Scientist. His research interests include mesoscale ocean processes such as baroclinic instability and geostrophic eddies, interannual variations in the Kuroshio, the Oyashio, and the Kuroshio Extension, and the three-dimensional structure of ocean gyres in the North Pacific.

A remarkable feature of the temperature distribution in the North Pacific subarctic region is an inversion called the mesothermal structure, in which slightly warmer water lies below cooler water. The waters corresponding to the minimum and maximum temperature of the inversion are called the dichothermal and mesothermal water, respectively. Several studies have investigated the formation of the inversion based on observational surveys, but most have focused on the dichothermal water formation resulting from abundant precipitation, strong cooling, and wind mixing in winter. Only a few studies have investigated the mesothermal water formation. One of these is a study by Ueno and Yasuda (2000), which showed that heat and salt, advected from the Kuroshio-Oyashio Mixed Water Region off the eastern coast of Japan, maintain the mesothermal water in the density range of 26.7–27.2 σ_θ. Since the waters in this region are strongly affected by those in the subtropical gyre, the formation process of the mesothermal water is not dynamically isolated, but an essential part of the Pacific general ocean circulation.

This year, Takahiro Endoh, in collaboration with Humio Mitsudera, examined the formation of the mesothermal structure using a numerical model that takes into account not only the dichothermal water formation but also the processes maintaining the mesothermal water. The numerical model used for this purpose is the Miami Isopycnic Coordinate Ocean Model (MICOM), which combines a single-layer model of the mixed layer—developed by Kraus and Turner (1967)—and a three-dimensional, primitive, isopycnic coordinate model of the stratified oceanic interior. Endoh has set up the preliminary numerical experiment configured for a Pacific subdomain with non-eddy-resolving (1°) horizontal resolution and 23 interior layers, covering the density range from 21.5 to 27.79 σ_θ units. From an initial density field prescribed by the Levitus climatologic dataset, the model has been forced with the monthly varying wind stress and surface heat flux taken from the COADS dataset.

The annual mean distribution of the mesothermal water west of the date line is successfully reproduced after a 50-year model run. The calculated distribution of the mesothermal water east of the date line, though, does not agree with observations, possibly because the effect of the Aleutian Islands has not been taken into account properly.

A comparison between the calculated time-depth section of potential temperature at 50°N, 165°E with the Levitus climatology shows that the present model reproduces the dichothermal water formation and the mesothermal structure very well. In winter, strong radiative cooling, abundant precipitation, and wind mixing coupled with downward buoyancy fluxes lead to thickening of the mixed layer to 150 m, where the potential temperature is less than 3.0°C. The seasonal thermocline develops during spring and summer over the cold water thus formed as a result of radiative heating and precipitation. Both processes freshen the surface water, thereby leading to the dichothermal water underneath the seasonal thermocline. Furthermore, the mixed layer deepens just above the mesothermal water in winter. Indeed, the layers of 26.8 and 27.0 σ_θ, which correspond to the mesothermal water, make contact with the base of the thicker mixed layer in winter. This implies that the mesothermal water is entrained into the mixed layer during winter via diapycnal mixing.

Although the 50-year numerical integration might not be long enough to attain the quasi-stationary field, the general characteristics of the observed features are reproduced well, supporting longer numerical integration. Endoh plans to continue improving the model and to analyze the interaction between the evolution of the mixed layer and the formation of the mesothermal structure.

Hyoon-Woo Kang
Postdoctoral Fellow

Hyoon-Woo Kang obtained his Ph.D. in physical oceanography from Seoul National University, Korea, in 2001. He was a research assistant at the Korea Ocean Research and Development Institute before he joined the IPRC in September 2001. His research interests include the ocean circulation and its interaction with marginal seas, numerical ocean modeling, and remote sensing of ocean phenomena.

Since coming to the IPRC, Hyoon-Woo Kang has adapted the Princeton Ocean Model (POM) to investigate the low-latitude western boundary currents (LLWBCs) in the Pacific. He configured the model for the Pacific and the Indian Ocean from 60°N to 60°S and changed the model resolution both horizontally and vertically. The resolution in the equatorial western Pacific, the Indonesian archipelago, and the South China Sea is 1/3° in order to resolve boundary currents and marginal sea circulations. The remaining regions vary in resolution from 1/3° to 1.2°. The original vertical resolution of 51 sigma levels was reduced to 31 levels to increase computational efficiency. Wider configurations of sponge boundaries, with restoration to Levitus climatology, were adopted to maintain the properties of the North Pacific Intermediate Water (NPIW) and Antarctic Intermediate Water (AAIW).

In his initial experiments, Kang forced the model with Hellerman-Rosenstein monthly averaged winds and with surface heat and salinity fluxes from NCEP reanalysis data. He applied Levitus monthly temperature and salinity climatology relaxation to temperature and salinity at depths greater than 2000 m. The results, however, did not correspond well with observations, especially in the LLWBC region. Only after switching to ECMWF climatology wind forcing, was there improvement.

Kang, therefore, adopted ECMWF climatological wind forcing for his simulations with the POM, and after a 20-year spin-up, compared the results with observations. He found that general circulation patterns in the LLWBC region are well simulated both in terms of the annual-mean and seasonal variations (Figure 6). Model-produced annual-mean temperature and salinity distributions in the density layer are in good agreement with Levitus climatology. Water-mass distributions of NPIW, North Pacific Tropical Water, South Pacific Tropical Water, and AAIW in the vertical sections near the Philippine Sea are very similar to the climatological distributions derived from observed data analysis (Qu et al., 1998, 1999).

To validate remote effects in the model, Kang compared the model results with sections of the well-known Hawai‘i-Tahiti shuttle experiment (Wyrtki and Kilonsky, 1984). The zonal velocity, temperature, and salinity derived from the model results are generally in good agreement with observations. The sharp thermocline and thermostad at the equator are not reproduced well, however, probably in part due to rather high background eddy diffusivity ($2x10^{-5}$ m^2/s) in the Mellor-Yamada turbulence closure vertical mixing scheme. Seasonal and vertical variations in the North Equatorial Current bifurcation latitude are well reproduced. Moreover, the temporal trends are in good agreement with

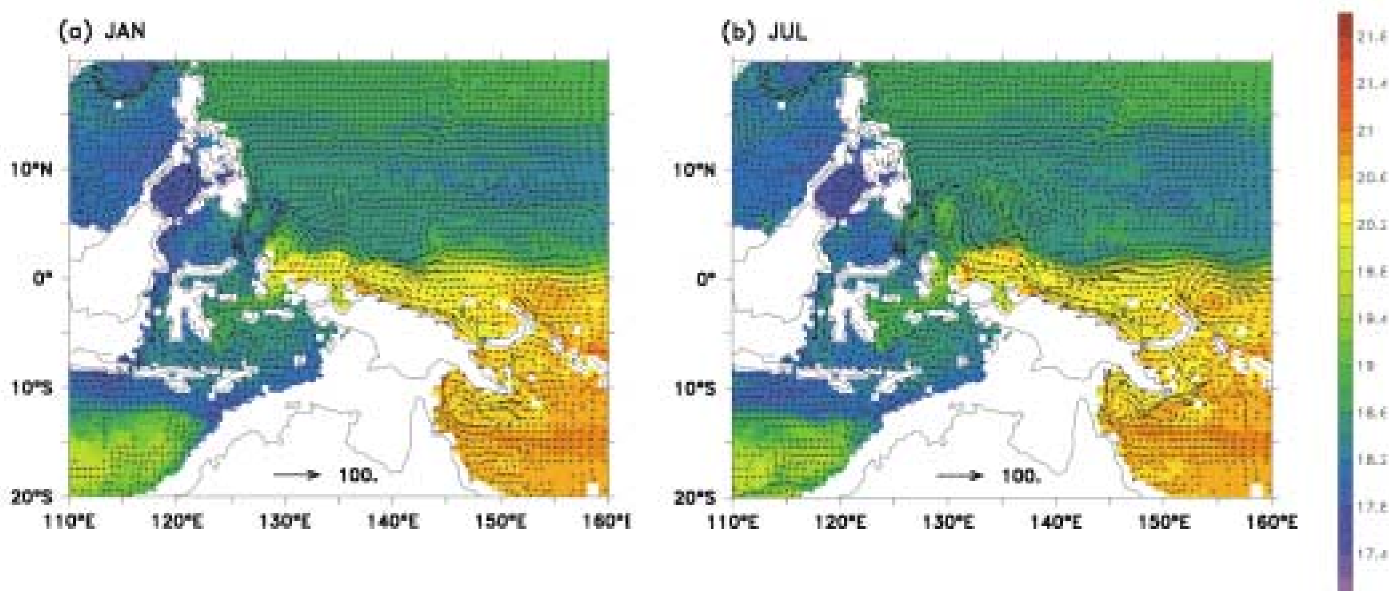


Figure 6: Horizontal velocity (cm/s) overlaid on temperature (ºC) on $\sigma_\theta = 25$.

observational analysis except that the fluctuations are rather small. Similar trends are shown in other model results such as z-grid and layer models. The transport and vertical structure of the Indonesian Throughflow (ITF) are simulated quite realistically. The model reveals a semiannual fluctuation in the Lombok Strait transport and a maximum deep transport in the ITF around 800 m depth. These latter phenomena are dynamically interesting and worthy of further investigation.

These results indicate that the model is now suitable for studying processes in the LLWBC region, and Kang is planning to use it for experiments on sensitivity to wind products, vertical mixing schemes, and the coastline and bathymetry of the Indonesian Seas and the South China Sea. After conducting some experiments on seasonal phenomena with the model, he will extend his model application to study interannual and decadal variability.

Yoo Yin Kim
Postdoctoral Fellow

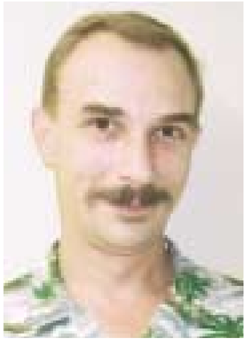
Yoo Yin Kim obtained his Ph.D. in oceanography in 1999 from The Florida State University, where he was a postdoctoral research associate before joining the IPRC in October 2001. His research interests include oceanic and atmospheric variability associated with the Madden-Julian Oscillation, the El Niño-Southern Oscillation, the Pacific Decadal Oscillation, and the 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 is studying the branching, or bifurcation, of the North Equatorial Current (NEC) in the western Pacific and the variability of the bifurcation latitude with depth and seasons. For this research, he has been using output from the JAMSTEC general circulation model (GCM). He first adjusted the structure and format of the output so that it could be handled using the Grid Analysis and Display System or GrADS, the system currently used worldwide for analysis and display of earth science data. Kim's conversion allows an integrated environment for access, manipulation, and display of the JAMSTEC model data.

To assess the quality of the JAMSTEC model simulations of the NEC bifurcation, Kim compared the simulations with observations. The model represents the seasonal and depth variability of the NEC bifurcation latitude well compared with the observational results of Qu and Lukas (2002). The bifurcation latitude in the model occurs at its southernmost position in July and its northernmost position in December, and the bifurcation latitude shifts northward with increasing depth. The zonal and meridional variations in transport with time are also quite reasonably estimated from the model data, and the climatological transport variations around the Philippine Ocean (Mindanao-Kuroshio-NEC) are realistic. Furthermore, the temporal and spatial variations of the Mindanao and Halmahera eddies, which are important for understanding the dynamics of the low-latitude western boundary currents (LLWBCs), are realistically represented in the model output, and transport variations at several vertical sections are quite reasonable compared with previous results.

The model's monthly variations in bifurcation latitude of the NEC are associated with a strong ENSO signal from 1982 to 1998, as shown by a significant correlation between the NINO3 (or SOI) index and a time series of the bifurcation latitude. Lag regression analysis between the bifurcation latitude and the zonal and meridional wind stresses also suggests a strong relation between the bifurcation latitude and ENSO. Lag regression and CycloStationary EOF (CSEOF) analysis of the bifurcation latitude and circulation patterns show that the bifurcation latitude also varies closely with variations in the Mindanao and the Halmahera eddies.

Kim plans to study in detail the effects of the regional ocean circulation patterns on the movement of the NEC bifurcation by carrying out a singular value decomposition (SVD), CSEOF, and multi-modal regression analysis of other relevant variables. Moreover, he intends to study the relationship between variations in the bifurcation latitude and in the monthly transports at several locations (in the Mindanao, Kuroshio, and North Equatorial Currents, the cross-equatorial flow from the southwestern Pacific, and the flow into and recirculation in the Celebes Sea). Careful examination of these transport variations should shed light on the coupled dynamics associated with variations in the NEC bifurcation latitude and on the relationship between the bifurcation latitude and changes in the flow pathways of the LLWBCs.



Konstantin Lebedev
Postdoctoral Fellow

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

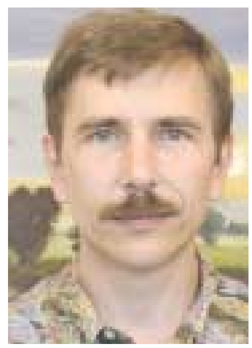
Konstantin Lebedev has been working on reconstructing the ocean state (temperature, salinity, and stream flow) in the region south of the Kuroshio Extension (KE) using four-dimensional varational (4dVar) data assimilation. His goal was to retrieve a quasi-geostrophic component of the ocean state from the acoustic tomography (AT) data acquired during the Kuroshio Extension Pilot Study Experiment conducted from July to September 1997. His study is the first to use 4dVar to assimilate AT data, and was a challenging task because of the technical complexity of retrieving the actual ray paths and because of difficulties in determining travel-time approximations in an energetic region like the KE. The work was done in collaboration with M. Yaremchuk, H. Mitsudera, and G. Yuan.

Using the 4dVar technique, Lebedev found a set of initial and open lateral boundary conditions to use in the quasi-geostrophic model that resulted in a numerical model solution with an optimal fit to the 6 simultaneously measured types of data, namely, 2 types of acoustic observations (direct and reciprocal travel times), TOPEX/POSEIDON altimetry, CTD/XCTD profiles, ADCP velocity measurements, and NCEP wind-stress data.

The major technical challenge of the study was to find a consistent linear approximation to the numerical operators of the acoustic ray data that provides an algorithm for projecting ocean state variables onto the AT data. Accurate simulation of the AT travel times requires high spatial resolution of the model grid. Refining the resolution to desired levels, however, is problematic as it results in too few data points and an undeterminable solution to the inverse problem. Lebedev and his colleagues successfully solved this problem by adopting slightly higher prior error levels in the original AT data.

The results of the assimilation show that 80% of the ocean variability south of the KE front can be explained by quasi-geostrophic dynamics. The optimized ocean state evolved by the model fits all the data types within their observational error range. The reconstructed ocean state is characterized by the net flux of the available potential energy from the large-scale current to mesoscale eddies at the rate of 4.7×10^{-5} cm^2s^{-3}. Potential enstrophy is transferred to the mesoscale at a rate of $5.5 \times 10^{-18}s^{-3}$. Analysis of the available potential and kinetic energy budgets indicates that horizontal advection of these quantities plays an important role in the local dynamics.

Assimilation of AT data is still in the beginning stages of development, and Lebedev hopes that the results obtained will promote research in both experimental and theoretical aspects of the AT technique and that it will be useful for further analysis of the dynamics and thermodynamics in the KE region.



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. He continued at the Institute as a senior research scientist in the Marine Currents Laboratory of the Large-Scale Air-Sea Interaction Division. He joined the IPRC in December 1999. His research interests include dynamics of large-scale fronts and mesoscale eddies, Lagrangian tracers, intra-thermocline lenses and submesoscale coherent vortices, and the formation of North Pacific Intermediate Water.

Nikolai Maximenko has analyzed with Peter Niiler (Scripps Institution of Oceanography) the mean near-surface circulation and the mean, absolute sea level in the Kuroshio Extension (KE). To obtain unbiased mean, velocity and sea-level fields in the KE region from 1992 to 2000, they inter-calibrated Surface Velocity Program drifter data with gridded maps of satellite sea level anomalies (Ducet et al., 2002). They developed a technique that significantly reduces the uncertainties resulting from temporal variations in the drifter distribution and from errors in the geostrophic velocity estimates. The drifter and satellite data correlated at r = 0.8, after correcting the drifter data by subtracting the Ekman drift and after compensating for the effect of the non-uniform spatial distribution of mesoscale eddies of opposite sign (cyclones are most energetic on the southern side, anticyclones most on the northern side of the KE). Integration of the momentum equation in its complete two-dimensional form provided the 1/4º spatial resolution map of the mean absolute sea level. By avoiding the problem of the unknown geoid in the region, this map provides an important reference point for satellite altimetry data.

The unbiased mean velocities and mean absolute sea level reveal two nearly stationary meanders in the KE jet that end in a 300-km northward deflection east of the Shatsky Rise and agree well with historical mean temperature at 200 m depth. The mean KE axis lies outside the region of strong interannual eddy kinetic energy trends (Ducet and LeTraon, 2001) and is quite stable. The orientation of Reynold stress ellipses correlates with the direction of mean velocities, indicating the velocities vary mostly in magnitude, not in direction. The maximum difference in mean sea level across the KE-Subarctic Front-Oyashio system exceeds 170 cm.

Maximenko and Niiler also developed a set of 10-day absolute sea level maps that correspond closely to concurrent drifter trajectories. All strong eddies are found as detached KE rings with Rossby numbers reaching 0.3 in their centers. Moreover, along the whole section between Taiwan to the dateline, the Kuroshio front is a barrier to horizontal water particle exchange. Only about 3% of the drifters were able to cross the front. A strong anticyclonic circulation with velocities greater than 50 cm/s exists near Daito Island.

To determine the processes leading to the development and decay of the Kuroshio large meander (LM), which have been much debated, Maximenko merged hydrographic data from NOAA-NODC World Ocean 1998 with datasets from the Japan Oceanographic Data Center and the Marine Information Research Center, to develop a new Kuroshio LM index that describes the Kuroshio state south of Honshu better than previous ones. Using this index, Maximenko has studied the evolutions of 7 LM developments and 5 LM decays, finding that the evolutions show remarkable similarities. The so-called "trigger meander" south of Kyushu develops 6 months before each LM and propagates eastward along the Japan coast. In composite time series based on the new index, Maximenko identified the following: (i) A warm anomaly on the southern flank of the Kuroshio and a cold anomaly on the northern flank form a dipole structure in the disturbance that finally triggers the LM. (ii) The intensity of the large warm eddy south of Shikoku is negatively correlated with the LM index. (iii) East of the LM, the axis of the Kuroshio shifts towards shore and supplies coastal regions with unusually warm waters; this shift and the temperature anomaly remain for the entire LM period. (iv) The northward shift of the Kuroshio axis in the LM region occurs at the same time as the trigger meander develops, indicating the non-local nature of the trigger meander. The LMs may last from several months to many years, but once the Kuroshio 'jumps' eastward across the Izu Ridge, the LM decays within 6 months. In addition, the large negative correlation between the state of the Kuroshio in the LM area and the latitude of the first meander suggests a relationship between the LM and North Pacific indices.

Maximenko has also collaborated with Zuojun Yu in a study on the role of eddies in the establishment of the Hawaiian Lee Countercurrent, and with Max Yaremchuk in a study of the dynamics of mesoscale eddies and their interaction with jets in the Kuroshio Extension–Subarctic Frontal Zone. He was instrumental in acquiring for IPRC's Asia-Pacific Data-Research Center newly digitized historical bottle data that had been collected from 1969 to 1993 south and east of Japan by the Russian Far Eastern Regional Hydrometeorological Research Institute.

Humio Mitsudera

Frontier Group Leader and Theme 2 Co-Leader

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

Humio Mitsudera has been studying the Pacific western boundary currents including the Kuroshio-Oyashio system and low-latitude western boundary currents. He has focused particularly on the processes involved in the subpolar water pathways in the intermediate layer of the Kuroshio-Oyashio confluence region.

The western North Pacific off the east coast of Japan is a crossroad of water masses from the Kuroshio and the Oyashio Currents and from marginal seas. The Kuroshio transports a large amount of heat and salt northward into the midlatitude Pacific Ocean. The Oyashio, as the western boundary current of the subpolar gyre, transports cold and fresh water from the Bering Sea and the Sea of Okhotsk southward. Where these two currents meet and form the Kuroshio Extension and the Oyashio Front, they exhibit very complicated current structures. These structures are of particular interest for climate study as strong decadal variations have been found in the region.

Mitsudera has been using a high-resolution regional model of the Kuroshio and Oyashio system for his research, a version of the Princeton Ocean Model (see also Waseda's report). This version has a horizontal resolution with a domain variation between 1/6° to 1/12°, and has 32 sigma levels in depth. The model accurately represents major features of the Kuroshio and the Oyashio system, in particular, the mean Kuroshio Extension and the Oyashio Front are situated at their right locations, being regulated by bottom topographic features in the model.

With this model, Mitsudera has been able to simulate successfully for the first time the pathways taken by subpolar water to the subtropics, the simulation matching observations closely (Figure 7). The subpolar water that flows out of the Sea of Okhotsk is fresh and characterized by low potential vorticity. When it encounters the Oyashio Front, it is subducted and pulled into warm core rings. Upon flowing out of the warm core rings, the subpolar water enters the Kuroshio Extension near the Japanese coast, and is finally redistributed to the Mixed Water Region and the subtropical gyre. Near the Japanese coast, the subpolar water pathways are strongly eddy-driven, and there is also an eastward-flowing pathway south of the Oyashio Front, which greatly influences the water properties of the northern Mixed Water Region. The cross-frontal flux of subpolar water in this model is about 3.1 Sv, which is comparable to several estimates from observations.

To study the effects of the outflow from the Sea of Okhotsk, Mitsudera conducted an experiment in which the exchange of water mass between the Pacific Ocean and the Sea of Okhotsk was blocked. The impacts are striking. Without the exchange, warm and salty water originating in the Kuroshio occupies the whole Mixed Water Region because of an abnormally strong cyclonic recirculation north of the KE. When the outflow from the Sea of Okhotsk is included, an anticyclonic circulation is induced in the Mixed Water Region, thereby blocking the northward advection of the Kuroshio water and increasing the intrusion of water from Oyashio's second branch. Intrusion of the low potential vorticity subpolar water, therefore, very likely has a significant dynamic impact on the circulation in the Mixed Water Region.

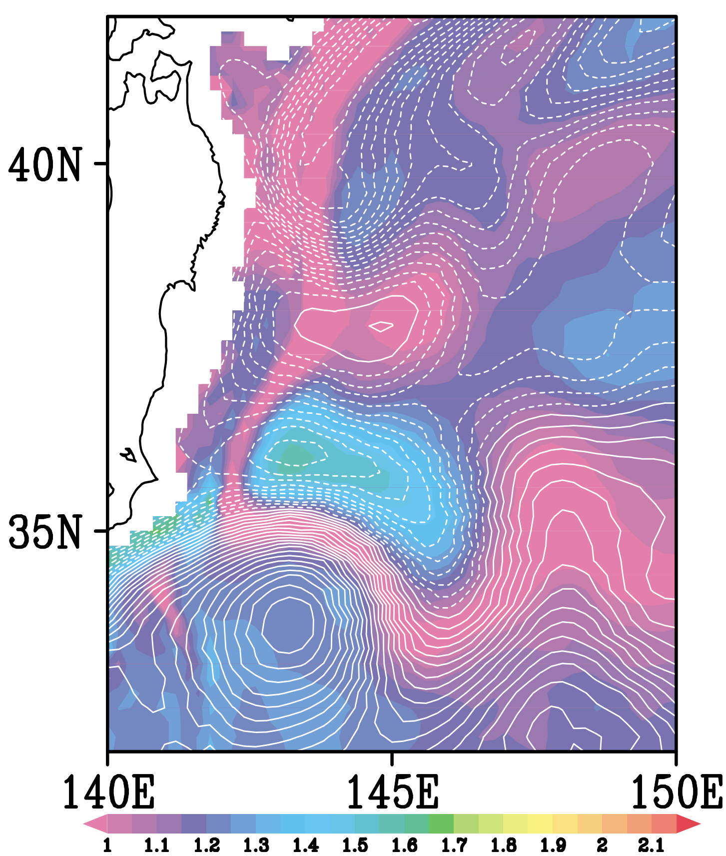


Figure 7: The potential vorticity (PV) field off the coast of Japan superimposed upon the mean streamlines. The low PV bands, indicated in purple, correspond to the subpolar water pathway originating in the Sea of Okhotsk.

James T. Potemra
Assistant Researcher

James Potemra received his Ph.D. in oceanography from the University of Hawai'i at Mānoa in 1998. He was a post-doctoral research associate at the University of Washington School of Oceanography before he joined the IPRC in August 2001. His research interests include the general ocean circulation and its relationship to climate, and processes in the western equatorial Pacific and eastern Indian Ocean and their connection.

Jim Potemra's research has focused on the water exchange between the Pacific and the Indian Ocean known as the Indonesian Throughflow (ITF). Several of his projects involved analysis of data that he had collected in the region over a 3-year period with colleagues at the University of Washington and Scripps Institution of Oceanography. Based on estimates of the transport through the Indonesian straits from surface pressure measurements, Potemra and his colleagues showed that upper-ocean flow in the region is primarily in geostrophic balance. Moreover, they found that flows through the various straits, estimated from pressure gradients across the straits, are determined by different mechanisms (*JPO*, in press). An extension of this work includes an analysis of temperature and salinity measurements made concurrently with the pressure signals. Unlike the pressure data, which vary mainly intraseasonally (10–40 days), the temperature and salinity data vary mainly with tidal (fortnightly) and annual periods (submitted to *Deep Sea Research*).

Potemra is now deriving estimates of heat and fresh-water fluxes in the region. Combining the observations of pressure, temperature, and salinity obtained in the study above with model-derived relationships between surface and depth-integrated flow and with various other observations, he has been studying mass, heat, and fresh-water convergence in the Savu Sea within the Indonesian Archipelago. Model-derived flow patterns in the upper ocean show that water both enters and exits the Savu Sea through the Ombai Strait (in the northern corner of the sea) as well as entering and exiting through the Savu and Dao Straits. Water also enters and exits the Savu Sea through the Sumba Strait. Mass convergence (divergence) occurs when the transport through Sumba Strait is into (out of) the Savu Sea. This transport is primarily controlled by coastal Kelvin waves generated in the Indian Ocean; the Ombai-Dao Strait flow appears to have no effect on mass convergence or divergence in the Savu Sea. The long-term variations in the Savu Sea are similar to those driven by the annual cycle, and most of the conditions during an El Niño mirror those during the Southeast Asian monsoon: Sea level is lower, rainfall is lower, phytoplankton increases, and there is mass divergence and high transport. Upwelling in the Savu Sea during an El Niño, however, is much lower than during the Southeast Asian monsoon, and therefore SST is higher, and does not correlate with El Niño events (results to be submitted to *JGR*).

In a study of the vertical structure of the ITF with a numerical model, Potemra has found that most of the ITF variability occurs in a few (two or three) layers (submitted to *Deep Sea Research*). This finding has implications for future modeling as well as for observational studies of the region.

Currently, Potemra is collaborating with H. Annamalai in a study of the effects of ENSO dynamics on patterns of SST variability in the Indian Ocean. The ITF may provide an oceanic link between Pacific Ocean processes that are under the direct influence of ENSO variations and the Indian Ocean. In particular, Potemra is studying the effect of ITF variations on thermocline-depth in the eastern Indian Ocean. By doing experiments with a large-scale ocean model, he is analyzing the influence of variations in interdecadal wind forcing on the thermodynamics in the region (preliminary findings have been submitted to *Deep Sea Research*).

Tangdong Qu
Associate Researcher

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

Tangdong Qu developed a 0.5^o x 0.5^o climatology of temperature and salinity in the western Pacific by averaging historical data along isopycnal surfaces. This new climatology resolves the narrow western boundary currents better than most, if not all, of the existing climatologies. Qu and his collaborators used the new climatology to study (i) the circulation and water-mass distribution in the western Pacific, (ii) the depth dependence and seasonal variation of the bifurcation latitudes of the South and North Equatorial Currents, and (iii) the water exchange between the South China Sea and the Pacific through the Luzon Strait.

The scientific findings of this work are summarized below:

The bifurcation of the South Equatorial Current shifts southward with increasing depth, from about 15^{O}S near the surface to about 22^{O}S in the intermediate layers. This shift identifies the origin of the Great Barrier Reef Undercurrent to be at about 22^{O}S, somewhat farther south than previously thought.

There is a strong water-property connection between the Coral Sea and the Solomon Sea. Water of South Pacific origin, such as the South Pacific Tropical Water and Antarctic Intermediate Water, can be traced continuously in the pathways of the Great Barrier Reef Undercurrent, the North Queensland Current, and the New Guinea Coastal Undercurrent, supporting the hypothesis that the latter originates from the south through the Coral and Solomon Seas.

The bifurcation of the North Equatorial Current occurs at its southernmost position (14.8^{O}N) in July and its northernmost position (about 17.2^{O}N) in December (Figure 8). This annual shift lags by 4 to 5 months behind the seasonal north-south migration of the zero line of the zonally integrated wind-stress curl, but corresponds surprisingly well with local Ekman pumping, suggesting that the Asian monsoon is important in determining the seasonal bifurcation latitude of the North Equatorial Current.

The bifurcation latitude of the North Equatorial Current depends on depth. On the annual average, it shifts from about 13.3^{O}N near the surface to north of 20^{O}N at depths of around 1,000 m. There is a time lag of 1 to 2 months from the sea surface to the subsurface (300–700 m) in the annual cycle. Below 700 m, the bifurcation of the North Equatorial Current reaches as far north as 22^{O}N during the northeast monsoon (November–January), and as a result, an anomalous transport of subtropical water flows toward the equator along the western boundary. The bifurcation of the North Equatorial Current below 700 m becomes unrecognizable during times when the prevailing wind is from the southwest (June–August).

The dissolved oxygen concentration of seawater is lower on the Pacific Ocean side than on the side of the South China Sea at depths between 700 and 1,500 m (intermediate layer), while the situation is reversed above 700 m (upper layer) and below 1,500 m (deep layer). This observation suggests that water exits the South China Sea in the intermediate layer and enters it from the Pacific in both the upper and the deep layers, supporting a previous speculation that the Luzon Strait transport has a vertically sandwiched structure.

These results contribute toward understanding the interactions between the subtropical and subpolar gyres in the Pacific and provide useful information for further investigations of the oceanic processes that may be important in Pacific decadal climate variability.

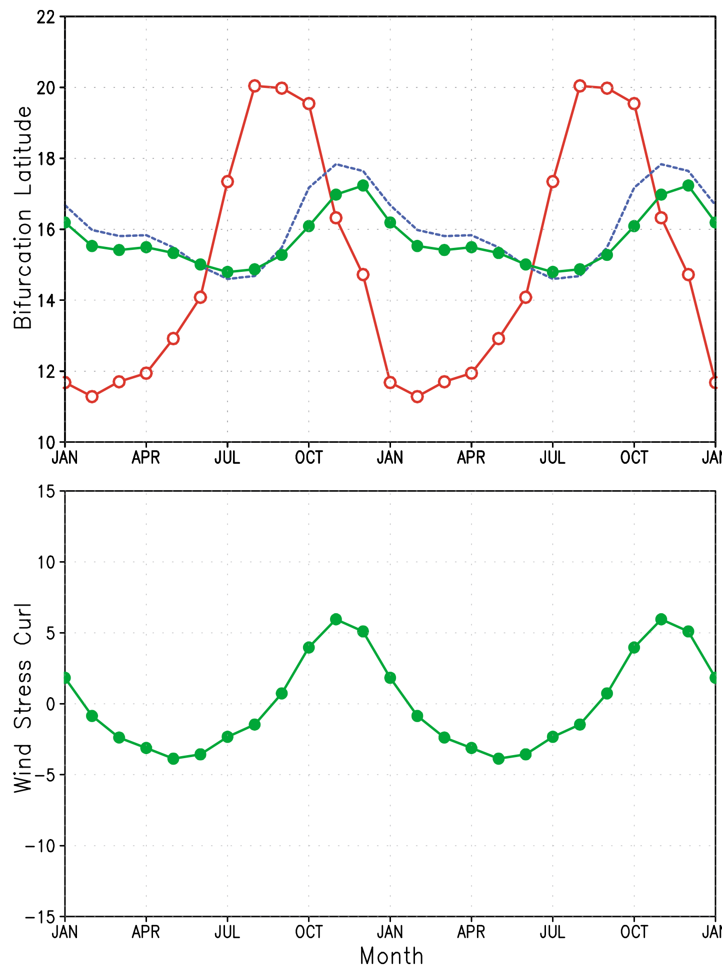


Figure 8: Upper panel: Seasonal variation of the NEC bifurcation latitude determined from Sverdrup transport (red), and the geostrophic transport (blue) and geostrophic + Ekman transport (green) in the upper 1000 m. Lower panel: Wind stress curl (10^{-8} N m^{-3}) averaged in the tropical western Pacific (120º–140ºE, 10º–20ºN), with the annual mean value of 4.2 x 10^{-8} N m^{-3} removed.

Takuji Waseda

Frontier Research Scientist

Takuji Waseda obtained his Ph.D. from the Ocean Engineering Department, University of California at Santa Barbara, in 1997. He joined the IPRC in October 1997 as a Frontier research scientist. His research interests include wind and water waves, satellite oceanography, data assimilation, and ocean processes in the Kuroshio Current.

Takuji Waseda's research relates to the determination of the processes that maintain the Kuroshio-Oyashio Extension system and cause its climatic variability. He has continued to use a high-resolution regional Kuroshio-Oyashio model, an adaptation of the Princeton Ocean Model, for the following projects: (i) a study of the dynamics of Kuroshio path variations; (ii) the chaotic advection of fluid particles in oceanographic applications; (iii) the development of a reduced-rank Kalman filtering scheme using wavelet diagnosis for initializing and updating the prediction error matrix.

With regard to the first project, Waseda successfully simulated the short-term Kuroshio meander with a 25 Sv Kuroshio inflow as an initial condition and by inserting an anticyclonic eddy through simple assimilation of TOPEX/POSEIDON altimeter data (Waseda, Mitsudera, Taguchi, Yoshikawa, *J. Geophys. Res.*, in press; also a manuscript in preparation). Various dynamic features occurring during large meander events were observed in the simulation: formation of a trigger meander, production of high potential vorticity resulting from interactions with currents, coastal topography, and baroclinic instability during the meander development, and release of high potential vorticity as the meander dissipates. These results motivate further study of the large-meander formation process using the bimodal state of the model (35 Sv inflow test case) as an initial condition. In the planned study, the model simulation will be perturbed in two ways: first, by increasing variability in the Kuroshio Extension, and second, by forcing the model with high-frequency winds. (Detailed plans are included in a National Science Foundation proposal with N. Maximenko, H. Mitsudera, and J. McCreary.)

In the second project (Waseda and Mitsudera, *J. Oceanogr.*, in press), Waseda continued to analyze the transport of Kuroshio coastal waters into the Kuroshio-Oyashio transition zone in the simulations with the Kuroshio-Oyashio model. The technique used in this analysis originates in dynamical systems theory, and it significantly reduces the information on the motion of Lagrangean particles by providing material lines that constrain the movement of the particles (finite-time-invariant manifolds; Poje and Haller, 1999). The particles (black dots in Figure 9) expelled from the inshore cyclonic eddy in the simulation are guided by the unstable and the stable manifolds originating in the hyperbolic stagnation point near the Boso Peninsula and near the Kuroshio Extension, respectively. The figure shows how greatly constrained and narrow the passage is between the coast and 147^{o}E. The particles then make a dramatic turn and leave the Kuroshio main flow. These findings should have applications for fisheries, recoveries in maritime disasters, and tracing pollution.

In his third project, Waseda has been working with L. Jameson (Lawrence Livermore National Laboratory) and H. Mitsudera (*J. Atmos. Ocean. Tech.*, in press) on an efficient way to initialize and update the model prediction error covariance matrix using wavelet diagnosis of the model state vector. In the data-assimilation scheme they developed, numerical errors and small-scale variations are detected (rather than prognostically estimated) by wavelet analysis. This latter work has led to investigating the possibility of combining the above data assimilation scheme with the SEEK filter (with L. Jameson, M. Yaremchuk, and H. Mitsudera, *J. Oceanogr.*, under review). The SEEK filter and other typical reduced-Kalman filter schemes approximate the rank of the error covariance matrix by retaining just the dominant modes of the error spectrum. The dominant modes, however, tend to capture only the global features of the error and

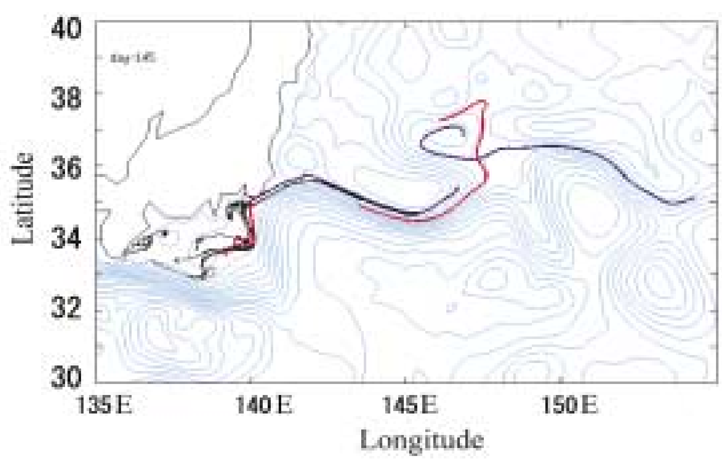


Figure 9: Manifolds bind the motion of the particles released inshore of the Kuroshio. Originating from the two hyperbolic stagnation points, the stable manifolds (red) attract particles towards the stagnation point (intersection between red and blue lines), and the unstable manifolds (blue) repel particles away from the stagnation points.

neglect local errors such as numerical errors and small-scale variations. An analysis shows that, to a good approximation, the global basis sets (EOF modes) and the local basis sets (wavelets) are orthogonal. Waseda and his colleagues, therefore, suggest that the SEEK filter and the wavelet-based data assimilation schemes can be used together without redundancy.

Max Yaremchuk
Associate Researcher

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

This past year, Max Yaremchuk has been developing a four-dimensional variational (4dVar) data assimilation system that is based upon an implicit primitive equations model. He focused on improving the model code and testing it extensively. Specific technical problems that he needed to solve in this process included updating the code with an implicit scheme for momentum diffusion, introducing the K-profile parameterization algorithm for ocean-atmosphere interaction, and modifying the model's tangent linear and adjoint codes. The long-term goal of this research is the construction of a data assimilation system that can be effectively applied to data analysis over a wide spectrum of spatial and temporal scales and that contributes to the IPRC research goals and objectives.

Yaremchuk collaborated in a study with Nikolai Maximenko on the dynamically constrained analysis of *in-situ* data in the Mixed Water Region north of the Kuroshio Extension. They have succeeded in reconstructing the mesoscale variability in the region by synthesizing hydrographic observations and mooring velocity data with Geosat altimetry and ECMWF-wind data using a quasi-geostrophic model. Assimilation has shown that the observed mesoscale structures are well described by quasi-geostrophic dynamics, which explain 80–85% of the variability in the velocity and density fields. The model fits the data within the observational error bars of all the data-types used in the assimilation. The standard harmonic parameterization of the small-scale processes was found to be inconsistent with observations as the best fit between the data, and the model was obtained with zero diffusivity.

Analysis of the interpolated patterns in the study reveals a pronounced mesoscale mixing event that is characterized by the development of a warm streamer (Figure10) swirling around the upper cold core of an old anticyclonic eddy of the Kuroshio Extension. The event was accompanied by a fast northwestward displacement of the eddy and a detachment of a warm, elongated vortex from its eastern rim. Within a week, the vortex penetrated northward into the subarctic zone and eventually split into several, smaller eddies. An energy analysis of the optimal solution indicates that the baroclinic instability of the southern Subarctic Front was a likely source of energy for the event.

Computation of energy exchanges between the depth-averaged and the shear components of the observed currents shows a vertical energy cascade (barotropization) at a rate of $29 \pm 4\text{x}10^{-7}\text{cm}^2\ \text{s}^{-3}$ and a weaker kinetic energy transfer of opposite sign due to topographic interaction. The ocean currents in the region are baroclinically unstable, with an estimate of the available potential energy flux from the mean current to the eddies of $53 \pm 8\text{x}10^{-7}\text{cm}^2\ \text{s}^{-3}$. Potential enstrophy is transferred to mesoscale levels at a rate of $33 \pm 7\text{x}10^{-19}\ \text{s}^{-3}$. These figures supply experimental evidence for the free geostrophic turbulence properties that have been predicted by theory and have been observed in numerical experiments.

Yaremchuk has also collaborated with K. Lebedev, H. Mitsudera, and G. Yuan on a 4dVar assimilation of data obtained in the course of the Kuroshio Extension Pilot Study Experiment. A detailed description of the obtained results can be found in the report by Lebedev. Moreover, Yaremchuk participated with T. Waseda, L. Jameson (Lawrence Livermore National Laboratory) and H. Mitsudera in research on combining the empirical orthogonal functions with wavelets to generate reduced subspaces in sequential data assimilation schemes. A more detailed description of the results can be found in the report by Waseda.

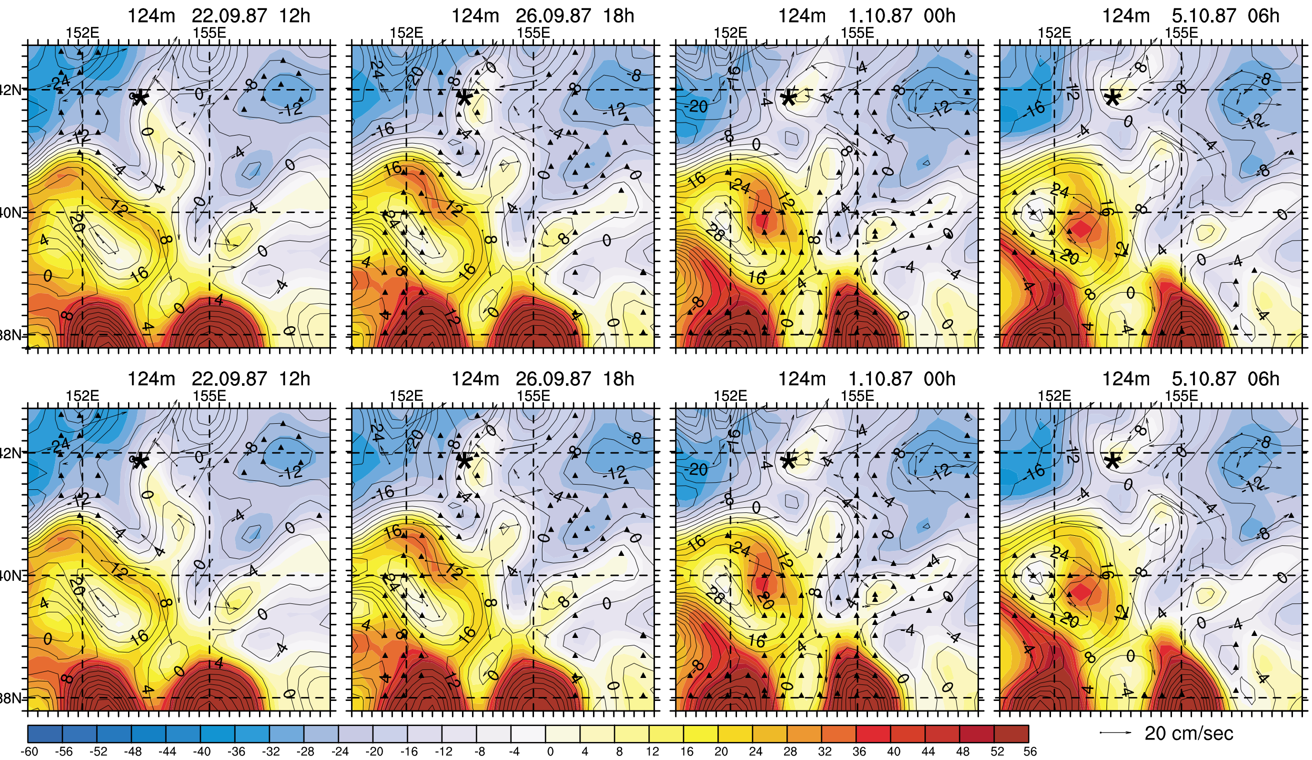


Figure 10: Evolution of the stream function (contours: in 10^3 m^2 s^{-1}) and buoyancy (color: interval = 0.03 kg m^{-3}) at 124 m and 387 m depths in the Mixed Water Region north of the Kuroshio Extension. Maps were obtained by fitting a solution of quasi-geostrophic equations to velocity, hydrographic and satellite data. Arrows denote velocity observations at moorings in operation at corresponding dates. Triangles mark CTC stations occupied by surveying vessels in 72 hours around the same dates. Two warm Kuroshio Extension eddies are seen at the southern rim. An older KE eddy located at 153°E, 39ºN is a negative buoyancy anomaly above 250 m and plays a catalytic role in cross-frontal exchange of water properties. Diagnostic analysis of the optimal model solution has shown that smaller scale eddies north of the Subarctic Front were generated by baroclinic instability processes.

Gang Yuan
Assistant Researcher

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

Gang Yuan has continued his study of the Kuroshio Extension (KE) region using acoustical tomographic data. This year he investigated the barotropic tides in the Kuroshio Extension region with acoustic tomography data collected during summer 1997 as part of the Kuroshio Extension Pilot Study Experiment. Using the travel times of reciprocal acoustic transmissions from a 5-transceiver acoustic tomography array over a 1,000-km domain in the KE region, he measured the barotropic tidal currents, as well as the range-averaged, large-scale low-frequency barotripic currents and their relative vorticity. The 8 major constituents of tidal amplitudes and phases that he derived from the high-frequency acoustic travel times have an uncertainty of 3% or less and agree well with those found in the TOPEX/POSEIDON tidal model TPXO.5 (Egbert, et al., 1994). Moreover, the acoustic tomography data showed that the range-averaged barotropic currents along the section in the KE recirculation gyre flowed westward at about 4 cm/s with an uncertainty of 0.8 mm/s. This finding is consistent with results from the Acoustic Doppler Current Profiler survey by the World Ocean Circulation Experiment at the P-14N section. The estimated daily averaged relative vorticity over a 155,000-km^2 area in the KE recirculation region is near zero (1.84e -07 s^{-1}).

Furthermore, Yuan collaborated with IPRC scientists K. Lebedev, M. Yaremchuk and H. Mitusdera on data assimilation experiments, in which multiple data sets (including satellite altimetry, hydrographic measurements CTD/XCTD/XBT, velocity measurements, and the above acoustic tomography data which supplied the core of the data, were assimilated into a simplified three-dimensional steady, stationary, quasi-geostrophic model to study the dynamics and thermodynamics of the KE front and the recirculation gyre. Using climatological data combined with a three-dimensional density field determined from the first day of the acoustic tomography data set as the initial density field, the first guess of the model provides a time evolution of the three-dimensional density field and indicates a meandering KE front similar to the one obtained from the inversions of the tomographic data. The results of this research will be useful in further study of the dynamics and thermodynamics of the KE system and for the forthcoming Kuroshio Extension System Project.

As a member of the Asia-Pacific Data-Research Center, Yuan has also been working in data management and archive building, with an emphasis on building the oceanic and satellite databases.

Research Activities and Accomplishments

Theme 3: Asian-Australian Monsoon System

Overview

The energetic Asian-Australian monsoon system (A-AMS) affects the climate of a vast region that stretches halfway around the globe, from East Africa and the Indian Ocean to the western Pacific Ocean. Recent research is showing that this monsoon system may also influence North American, and even global climate.

Monsoon rainfall, upon which agriculture and thus the survival of over half of the world's population so heavily depends, varies greatly over regions, years, and decades. To be able to predict these variations has been a hope in Asia for a long time. The complexity of the monsoon climate system, however, is enormous, with air-sea-land interactions among the Indian Ocean and the Indian subcontinent to the southwest, the high Tibetan Plateau to the northwest, the long coastline and the huge Pacific to the east, and the warmest pool of ocean water to the southeast. Understanding the physical mechanisms that govern climate variability of this monsoon system on seasonal-to-interdecadal timescales is the aim of research under Theme 3.

During the past year, projects have focused on the following areas: (i) the mechanisms that give rise to the Indian Ocean dipole; (ii) the spatial and temporal structure of the tropospheric biennial oscillation (TBO); (iii) the effect of air-sea coupling on the mean monsoon structure and the northward-propagating intraseasonal oscillations (ISOs); (iv) regional climate modeling of the East Asian summer monsoon rainfall; (v) the impact of El Niño on western North Pacific storms and monsoon circulations; (vi) interdecadal variability of the relationship between the East Asian monsoon and the El Niño-Southern Oscillation (ENSO); and (vii) the decadal variability of ENSO.

Research on the origin of the Indian Ocean sea surface temperature dipole, the Indian Ocean dipole (IOD) or zonal mode, has yielded varying results. A study based on observational data showed that of 19 IOD events between 1958 and 1997, only 8 co-occurred with ENSO events, whereas the events evolved coherently with an anomalous zonal wind over the Indian Ocean, sharing about 70% of the interannual variance. These findings prompt the conclusion that the IOD arises from an air-sea interaction within the tropical Indian Ocean (Saji and Yamagata, Theme 1). Another study, however, suggests that the IOD is not a purely Indian Ocean occurrence, but part of the Indo-Pacific warm pool variability and an externally forced phenomenon that interacts with the Asian summer monsoon. According to this study, the IOD varies over decades with a climate shift in the Indian and Pacific Ocean basins (Annamalai et al.). In a third study, uniform SST across the tropical Indian Ocean (the first EOF mode) lags El Niño by 3-6 months, while the IOD (the second EOF mode), which is marginally linked to El Niño, shows a 9-month lag. The physical processes that could be responsible for both modes have been analyzed (An). A study of the north-south oceanic heat transport in the Indian Ocean suggests the IOD is an inherent feature of the Asian summer monsoon, linked to ENSO-related SST anomalies in the Pacific Ocean, and thus a part of biennial variability of the Indo-Pacific Ocean region (Loschnigg). Finally, an examination of the Indian Ocean and the western North Pacific variability associated with the entire A-AMS yields the conclusion that the Indian Ocean mode is linked to anticyclonic anomalies that occur during a developing El Niño (B. Wang, Wu, and Li). Remote forcing by El Niño, however, cannot *alone* explain the rapid growth of the southern Indian Ocean anticyclone, and an interaction between monsoon winds and the Indian Ocean probably plays a key role in generating both the monsoon and the SST anomalies in the Indian Ocean. This coupled mode can be triggered by El Niño, but could also be triggered by other events.

The tropospheric biennial oscillation (TBO)—a fluctuation in the monsoon tropospheric circulation that significantly affects rainfall, particularly over India, Indonesia, and East Asia, and has an average cycle of 2 or 3 years—was examined with an extended EOF analysis to reveal its three-dimensional structure and its seasonal evolution (Li, Liu, and Wang). The most pronounced features of the TBO are anomalous convection and cyclonic and anticyclonic centers over the western North Pacific and the southeastern tropical Indian Ocean. Since the centers are closely associated with SST anomalies in the central-eastern equatorial Pacific, an inter-basin teleconnection mechanism is proposed to explain the observed TBO structure and evolution. A study with the NCAR Community Climate System model reproduces the main mechanisms by which the TBO impacts the Asian monsoon, namely, a remote influence from the Pacific and regional influences associated with the north-south temperature gradient between the Asian continent and the Indian Ocean (Loschnigg).

How air-sea coupling affects the Asian summer monsoon and its cycles of wet and dry spells (the ISOs) was studied with an atmospheric GCM (ECHAM4) coupled to an intermediate ocean model (Fu and colleagues). Simulations with the stand-alone ECHAM4 model overestimate the equatorial Indian Ocean rainfall considerably, while underestimating the monsoon rainfall over India. In simulations with the coupled model, two strong rain belts appear similar to the observed summer precipitation pattern. The two rain belts are connected by the northward-propagating ISO, which is significantly enhanced by air-sea interactions. Simulations of mean tropical rainfall and other fields in the ECHAM model were improved significantly by including a dry-adiabatic adjustment scheme (Liu).

Simulation of the 1998 East Asian monsoon with the IPRC Regional Climate Model has captured most major rainfall events, especially those that caused the Yangtze River floods (Y. Wang, Sen, and B. Wang). The model is also being used to examine the effects of deforestation in Indochina on rainfall patterns over China (Sen) and the climate of the tropical East Pacific and South America with special attention to the effects of the Andes and the stratus-cloud deck off the coast of South America (see Theme 1: Xu and Xie).

An analysis of observational data revealed that ENSO influences the strength of tropical cyclones in the western North Pacific (B. Wang and Chan). During an El Niño most tropical storms form in the southeast quadrant (5–17°N, 140–180°E), while during a La Niña most form in the northwest quadrant (17–30°N, 120–140°E). In addition, during strong El Niño years, 2.5 times more tropical storms in the fall recurve northward across 35°N than during strong La Niña years. The more southeastern storm formation and the recurving storm tracks during El Niño years imply that El Niño transports a substantial amount of heat and moisture poleward and may impact extratropical general circulation significantly. The anomalous Philippine Sea anticyclone (PSAC), which conveys the effects of an El Niño on the East Asian monsoon, originates in the fall of an El Niño year and coincides with an early retreat of the monsoon and a strong ISO. The development of the PSAC is attributed to the combined effects of remote El Niño forcing, tropical-extratropical interaction, and air-sea interactions associated with the ISOs (B. Wang and Zhang).

The relationship between ENSO and the Asian-Australian monsoon varies with decades according to an analysis of observational data (Wu and Wang). Before the late 1970s, an anomalous anticyclone develops over East Asia during the decaying El Niño, and anomalous southerly winds increase rainfall in North China. After the late 1970s, this connection weakens, but convection in the western North Pacific is enhanced and shifts northward, which induces a low-pressure area in the North Pacific along 30–40°N, shifting the winds to northerly over eastern North China.

Finally, observational analyses and results from an intermediate coupled model indicate that decadal changes in the background wind and upwelling can explain the decadal variability in ENSO (B. Wang and An).

テーマ3 「アジア・オーストラリア・モンスーンの変動予測」

活発なアジア・オーストラリアモンスーンは、東アフリカから西太平洋にかけての地球を半周するような広大な地域における気候変動に影響を与える。さらに最近の研究によって、モンスーンの影響は北アメリカや地球規模の影響があることさえ分かってきた。

モンスーン域には地球上の人口の約半分が住んでおり、そこでの農業はモンスーンの雨に強く依存しているが、降雨量は地域間、年ごと、十年スケールでの変動が大きい。これらを予測可能とするのはアジア域の長年の希望である。しかしモンスーンシステムは非常に複雑である。南西域はインド洋とインドにおける大気海洋相互作用、北西にはチベット高原などの高山域、東方は太平洋の長大な海岸線、東南には暖水プールが存在する。テーマ3の研究はモンスーンシステムの季節から数十年の変動メカニズムを解明することを目的とする。

昨年度は次のプロジェクトを進めた。(i)インド洋ダイポールのメカニズム、(ii)対流圏準二年振動の時空構造、(iii)大気海洋相互作用の平均場および季節内振動の北方伝播への影響、(iv)東アジアの夏の降雨に関する領域モデル、(v)北太平洋西部の台風とモンスーンに対するエルニーニョのインパクト、(vi)東アジアモンスーンとENSOの関係とその十年変動、(vii)ENSOの十年変動。

Individual reports

Soon-Il An
Assistant Researcher

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

Soon-Il An has been studying the interannual variability of sea surface temperature (SST) in the tropical Indian Ocean, which shows two major modes: a zonally uniform mode (ZUM) in which SST is uniformly distributed across the tropical basin, and a zonally contrasted mode (ZCM) in which SSTs in the eastern and western tropical Indian Ocean have opposite signs. Analyzing observational data, he found that ZUM conditions are highly correlated with El Niño events and lag behind El Niño SST changes by 3 to 6 months; the ZCM conditions, on the other hand, are marginally correlated with El Niño and show a 9-month lag. Below, An describes the mechanisms responsible for both the ZUM and the ZCM conditions.

During an El Niño, the large-scale anomalous depression over the maritime continent, resulting from an eastward shift in the rising branch of the Walker circulation, suppresses convection over the eastern Indian Ocean, thereby allowing more solar radiation over the eastern Indian Ocean. At the same time, anomalous southeasterly winds over the equatorial Indian Ocean force the thermocline in the western Indian Ocean to deepen, especially in the southwest. As a result, SST over the whole tropical region of the basin increases uniformly, establishing the ZUM. As El Niño decays, the depression over the maritime continent disappears and so do the anomalous southeasterly winds. The thermocline perturbation, however, does not shoal back to normal quickly because of inertia but disperses gradually as a packet of Rossby waves. These Rossby waves eventually reflect from the western boundary as an equatorial Kelvin wave, causing the thermocline to deepen in the eastern Indian Ocean and preventing SST cooling in that region. Moreover, lower wind-speed of the monsoon circulation results in less latent heat loss, and thus a warmer eastern Indian Ocean. These two effects, therefore, help to maintain higher SST over the eastern Indian Ocean until fall. During fall, through active air-sea interaction, SST stays higher in the east, while westerly winds cool the western Indian Ocean, bringing about positive ZCM conditions.

In a similar manner, a negative ZUM (a zonally uniform cool tropical Indian Ocean) is attributable to anomalous northwesterly winds associated with La Niña conditions in the tropical Pacific, which cause a shallow thermocline in the western and decreased solar radiation in the eastern Indian Ocean. During the following spring and summer, the northwesterly winds weaken and the shallow thermocline signal from the western Indian Ocean is dispersed to the eastern Indian Ocean. With anomalous easterly winds and much latent heat loss over the eastern equatorial Indian Ocean, the SST in the eastern Indian Ocean cools, bringing about the negative ZCM conditions—warm water in the west and cold in the east.

In another study, An investigated the significant decadal and interdecadal changes in midlatitude high-frequency, transient atmospheric activities that are seen in the NCEP/NCAR reanalysis lower- and upper-level wind and pressure fields. His diagnosis of these changes shows that they are related to changes in SST in the tropics and in the background midlatitude upper-level circulation. In an atmospheric GCM experiment by J.G. Chun (Seoul National University) with prescribed SST anomalies resembling a Pacific Decadal Oscillation pattern, An confirmed that midlatitude SST has little effect on the local transient atmospheric activity. He is now investigating the physical mechanisms that underlie this phenomenon.

H. Annamalai
Assistant Researcher

H. Annamalai received his Ph.D. in atmospheric science in 1995 from the Indian Institute of Technology, Kharagpur, India. He was a postdoctoral research scientist in the Department of Meteorology, University of Reading, United Kingdom, before joining the IPRC in December 1999. 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.

During the last year, H. Annamalai has studied the climate variability of the Indian Ocean, particularly the Indian Ocean Zonal Mode (IOZ mode). This mode consists of an anomalous 1.5 to 3ºC decrease in SST in the eastern equatorial Indian Ocean. His findings regarding this mode are as follows: (i) it is externally forced and interacts with the Asian summer monsoon circulation from July to August; (ii) it varies over decades with the decadal variations (or climate shifts) in the Indian and Pacific Ocean basins; and (iii) it may not be a solely Indian Ocean phenomenon but part of the Indo-Pacific warm pool variability.

In a study with R. Murtugudde (University of Maryland), J. Potemra, S.-P. Xie, and B. Wang, Annamalai has looked for the source region of this IOZ mode. Diagnosis of atmosphere and ocean model-assimilated data show a weak natural cooling of about 0.2ºC in the eastern equatorial Indian Ocean (EEIO) that occasionally intensifies in boreal spring and early summer when El Niño-like conditions exist in the western Pacific. The EEIO has a "time window" in the annual cycle–boreal spring–during which the ocean-atmosphere system is particularly sensitive to external forcing, and spring atmospheric conditions are remotely controlled by SST distribution in the equatorial, western-to-central Pacific. The El Niño-related changes in the Pacific Walker circulation induce subsidence over the EEIO and the maritime continent resulting in decreased rainfall, decreased latent heating, and the formation of a heat sink. Forced by this heat sink, an anticyclone develops as a Rossby-wave response in the lower atmosphere over the southeastern Indian Ocean, and the alongshore, upwelling-favorable winds off Java and Sumatra become strong enough to trigger the cool SST phase of the IOZ mode. Once triggered, the IOZ mode interacts with the monsoon heat sources, generating greater precipitation along the monsoon trough during July and August. Moreover, the north-south temperature gradient in the eastern Indian Ocean favors a local meridional circulation, increasing the alongshore, upwelling-favoring winds off Sumatra.

A 1.5 to 3ºC cooling, signaling a strong IOZ mode, however, has occurred only five times during the last 50 years: 1961, 1967, 1991, 1994, and 1997. In collaboration with J. Potemra, R. Murtugudde and J. McCreary, Annamalai has, therefore, studied the decadal variability of the IOZ mode and its links to the Pacific. Diagnosing atmospheric and oceanic model assimilated data sets from 1950 to 1999, they found no interannual SST signal in the EEIO above a red noise spectrum; but there was a decadal signal. The IOZ mode is present in the 1960s and the 1990s, while in other decades it is weak or absent (Figure 11). During the 1960s and the 1990s, SST in the western Pacific and around the maritime continent was in a cooler, El Niño-like background state. Annamalai and his colleagues propose that such a state raises the thermocline in regions where the mean thermocline is normally deep, thereby strengthening unstable modes of coupled climate variability, which, given the Indian Ocean dynamics, lead to strong IOZ events.

To test this hypothesis, Annamalai collaborated in a study with R. Murtugudde, and J. Beauchamp (ESSIC, University of Maryland). Using an ocean GCM coupled to an advective atmospheric mixed-layer model and forced with NCEP reanalyses winds for the period of 1949 to 2001, they analyzed each IOZ event to see how the precondition-, onset- and growth-phases are related to El Niño events. The composite analyses of the weak, strong, and aborted IOZ events clearly show that the changes in the atmospheric circulation associated with the onset of an El Niño in the western Pacific are crucial for triggering the anomalous cooling off Java, which, in turn, sets the conditions for the coupled IOZ events to grow. The Madden-Julian Oscillation and conditions in the Indonesian Throughflow also play a role in triggering and strengthening the IOZ mode.

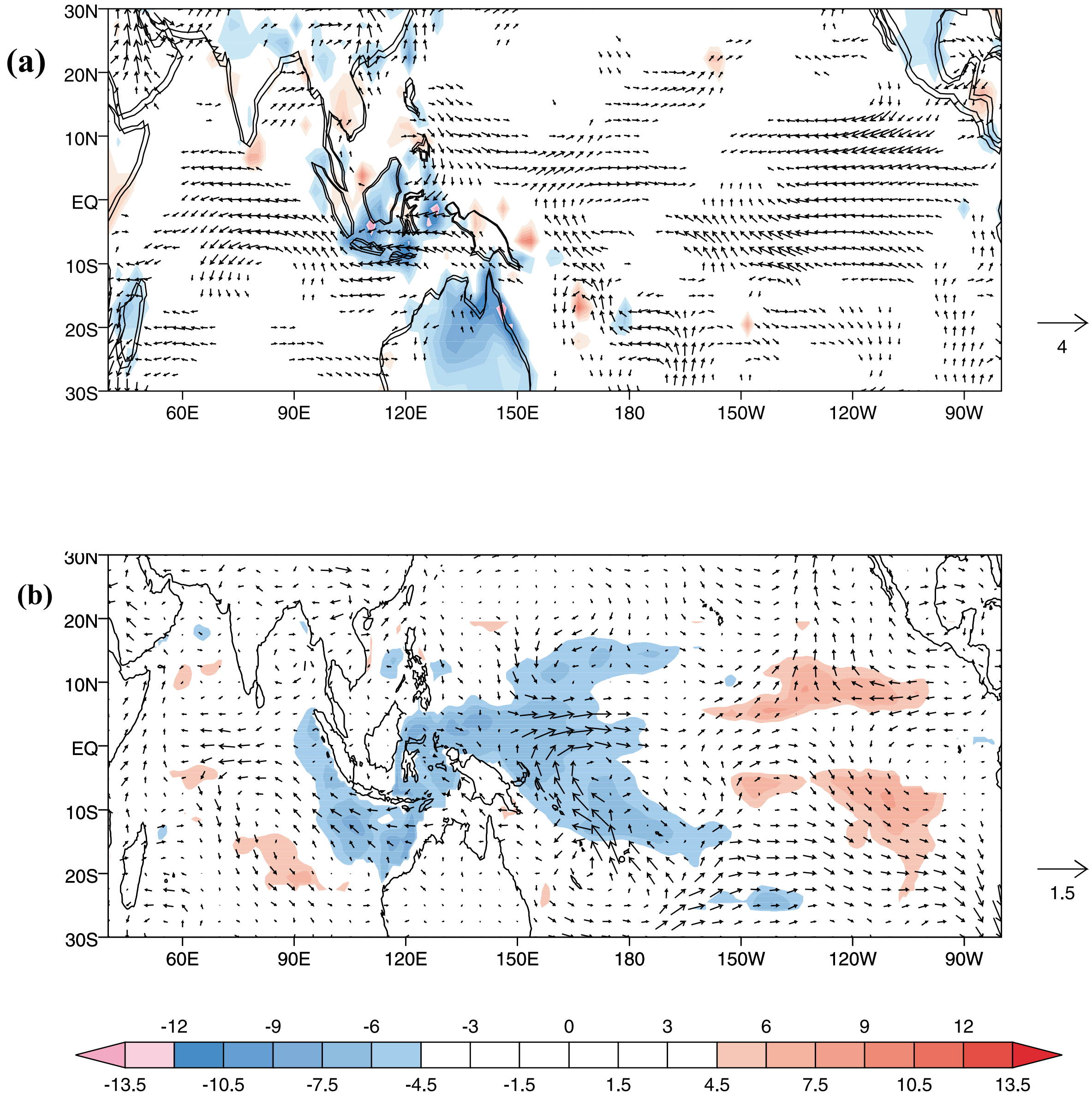


Figure 11: (a) The decadal differences (1960s–1970s) in precipitation (color scale: mm) and surface winds. The reduced precipitation in the eastern equatorial Indian Ocean (EEIO) – maritime continent region acts as a heat sink and, as a Rossby-wave response, results in an anticyclone in the lower atmosphere. (b) EOF2 of the decadal component of the surface winds, (vectors) and the regression coefficients (color: scale m) of the corresponding PC2, regressed onto the decadal component of thermocline depth. The results suggest a shallowing thermocline in the EEIO.

Xiouhua Fu
Scientific Computer Programmer

Xiouhua Fu obtained his Ph.D. in meteorology from the University of Hawai'i at Mānoa in 1998. He joined the IPRC in October 1999 as a scientific computer programmer. His research interests include developing air-sea coupled models and using these models to study Asia-Pacific climate.

Xiouhua Fu has studied the air-sea interactions in the Asian summer monsoon (Fu, Wang, and Li, 2002) that may affect the large fluctuations in atmospheric convection and rainfall occurring in 2 to 3 cycles during a monsoon season. These fluctuations propagate northward from the equatorial Indian Ocean to the Asian continent and are referred to as northward-propagating intraseasonal oscillations or ISOs. In collaboration with B. Wang, T. Li and J. P. McCreary, Fu conducted a study using a hybrid air-sea coupled model, which showed that the northward-propagating ISOs are closely linked to the underlying sea surface temperature (SST) in the Indian Ocean: dry spells follow lower SST and wet spells follow higher SST. The data from the Tropical Rain Measuring Mission support these results (Vecchi and Harrison, 2001). The model simulation shows that the atmospheric convection changes SST by affecting solar radiation, latent heat flux, and ocean upwelling; at the same time, the induced SST changes feed back to affect convection. The preferential northward, rather than southward, propagation of this ISO is explained by an interaction among the summer-mean climate state, the atmospheric disturbances, and the ocean temperature.

To understand the physical processes more clearly, Fu conducted simulations with an atmospheric GCM run under different conditions. In a simulation forced by daily SST from the above coupled model as boundary forcing, the northward-propagating ISOs are much stronger than in a simulation forced by monthly mean SST (Atmospheric Model Intercomparison Project-type run), but even in the daily SST-solution, the strength of the ISOs shown in the coupled simulation could not be reproduced. The reason for this difference is that in the coupled system, SST fluctuations are affected by and allowed to interact with atmospheric convection, which causes the convection and rainfall changes to follow the SST changes by about 10 days, or a quarter of one dry-wet cycle (Figure 12). In the atmospheric GCM, on the other hand, SST acts only as a boundary forcing and a two-way interaction between SST and the atmosphere is not possible. This causes the atmospheric convection change to occur approximately at the same time as the underlying SST change and explains why the intensity of the SST-forced convection in the atmospheric model is weaker than in the coupled model.

Finally, the model solutions indicate that the movement of the off-equatorial convection in the northern Indian Ocean is more closely related to local SST fluctuations than to the equatorial eastward-moving Madden-Julian Oscillation. Since the higher SST phases in the northern Indian Ocean lead rainy spells by about 10 days during boreal summer, and the lower SST phases lead dry spells by about the same time, these SST fluctuations seem to be a very useful index for forecasting the active and break spells of the South Asian summer monsoon.

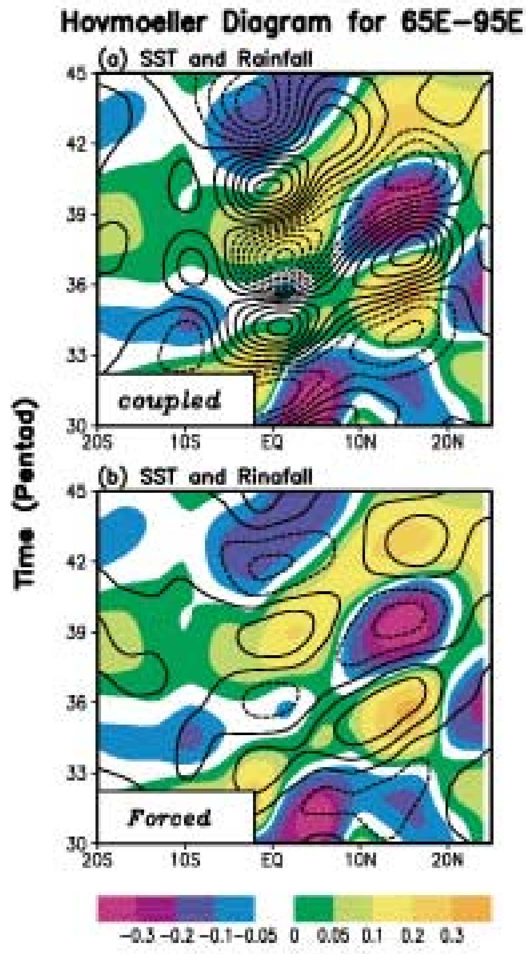


Figure 12: Rainfall (contour interval = 2 mm day^{-1}) and SST (color:ºC) associated with the northward propagating intraseasonal oscillations between 65ºE and 95ºE: (a) from the ECHAM4–-ocean coupled model, and (b) from an ensemble of ten stand-alone ECHAM4 runs forced with daily SST obtained from the coupled model.

Tim Li
Associate Professor of Meteorology, SOEST
Team 3 Co-Leader

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

This past year, Tim Li has studied the spatial and temporal structures and mechanisms of the tropospheric biennial oscillation (TBO). In contrast to the clear structures and phases of the El Niño–Southern Oscillation (ENSO), the spatial structure and evolution of the TBO are still unclear. In a collaborative study with P. Liu and B. Wang, Li sought to reveal the comprehensive three-dimensional structure of the TBO and its seasonal evolution and to understand the physical mechanisms responsible for the observed TBO structure and development. An extended empirical orthogonal function (EOF) analysis showed that the most pronounced feature of the TBO in the Asian-Australian monsoon region is the development of two anomalous anticyclone centers, one located in the southeast Indian Ocean (SIO) and the other in the western North Pacific (WNP).

The seasonal evolution of the two anomalous anticyclones is summarized as follows: From June to August of the first year in the TBO cycle, low-level atmospheric circulation anomalies are dominated by an elongated anticyclonic ridge extending from the maritime continent to India. Associated with this anticyclonic ridge are the following: a tilted belt of pronounced anomalous westerlies extending from the Bay of Bengal to the WNP, suppressed convection over the maritime continent, and enhanced convection over the Philippine Sea. Moreover, convection southwest of Sumatra is severely suppressed, inducing a notable cross-equatorial flow west of Sumatra and a weak anticyclonic cell over the SIO.

From September to November, the SIO anticyclone grows explosively, leading to a giant anticyclonic ridge that dominates the Indian Ocean and has its center at 10ºS, 90ºE. Intense easterly anomalies develop along the equatorial Indian Ocean, and convection is suppressed in the eastern Indian Ocean while it is enhanced in the western Indian Ocean. Easterly anomalies and drought develop over the maritime continent and north of Australia. A weak anomalous low-level anticyclone forms in the South China Sea near the Philippines.

From December to February, the low-level circulation anomalies are dominated by two subtropical anticyclonic systems located in the SIO and the WNP, respectively. The former results from the weakening of the fall anticyclone over the SIO, while the latter results from the amplification and eastward migration of the Philippine anticyclone. Convection is suppressed the most east of the Philippines; summer rainfall is significantly reduced over Indonesia and Australia; excessive rainfall occurs over the western equatorial Indian Ocean.

The period from March to May has a similar anomaly pattern in the WNP, characterized by the pronounced WNP anomalous anticyclone. The intensity of the WNP anticyclone, however, decreases toward summer. From June to August of the second year in the cycle, subsidence controls the atmospheric circulation over the Philippine Sea and Southeast Asia, signifying weakening of the summer monsoon over the WNP and southern Asia. This anomaly pattern is nearly opposite to the one in the previous summer.

To test a hypothesis regarding the observed structure and evolution of the TBO, Li used an intermediate coupled atmosphere-ocean model, in which he excluded the El Niño delayed oscillator dynamics by eliminating the effect of thermocline depth anomalies on SST. Nevertheless, the model reproduced a biennial oscillation in the tropical Indian Ocean and in the western and eastern Pacific. A key premise in the model is that SST anomalies in the SIO influence the eastern Pacific through anomalous heating over the maritime continent while those in the WNP anomalies influence SST in the SIO through anomalous cross-equatorial monsoon flow in boreal summer.

Li has conducted several other studies this past year: (i) Using an atmospheric GCM, he studied the mechanisms responsible for the northward propagation of intraseaonal-oscillation convection over the tropical Indian Ocean; he noted that atmospheric internal dynamics, without air-sea interactions, can lead to northward propagation and proposed three possible mechanisms to account for this phenomenon. (ii) Studying the dynamics of tropical cyclone energy dispersion, he has documented with high-resolution satellite data the spatial and temporal evolution of the observed dispersion of tropical cyclone Rossby wave energy; he is now continuing to analyze the relationship between energy dispersion and tropical cyclone intensity and structure. (iii) Using an atmospheric GCM, he studied the origin of the summer synoptic-scale wavetrain in the WNP; based on results from this model, he proposes that the synoptic-scale wavetrain stems from the instability of the summer mean flow in the presence of feedback from convective heating.

Ping Liu

Postdoctoral Fellow

Ping Liu obtained his Ph.D. in atmospheric sciences in 1999 from the Institute of Atmospheric Physics, Beijing, China, where he was a leading climate modeling scientist at the Laboratory of Atmospheric Sciences and Geophysical Fluid Dynamics (LASG) before joining the IPRC in June 2001. His research interests include comparisons among monsoon climate simulations with models of differing resolutions, the effects of air-sea interactions over the warm pool on monsoon variability and predictability, and changes in arid and semiarid climates accompanying global climate changes.

Ping Liu has been collaborating with B. Wang and T. Li on evaluating and improving the ECHAM general circulation model and has been providing technical support on the use of this model to IPRC scientists.

In order to improve the performance of the ECHAM model, he implemented into the model a dry-adiabatic adjustment scheme. Whenever unsaturated air is statically unstable, free convection occurs, causing mixing of water vapor in the unstable layers. This results in a smaller temperature decrease with height than the dry-adiabatic lapse rate, that is, a neutral lapse rate. A parameterization scheme of these processes for atmospheric GCMs was first developed by Manabe (1965) and parameterization schemes similar to this original one are included in many present-day atmospheric GCMs. However, some models, such as the ECHAM and NCEP models, have a vertical-diffusion scheme in place of free convection.

Excluding free convection, though, seems to be a questionable strategy, since free convection is expected to allow mixing to occur much faster and more completely than vertical diffusion. To verify this idea, Liu implemented a dry-adiabatic adjustment into the ECHAM model. Simulations with both the older 4.6 version and the latest 5.1 version show significant improvements in tropical rainfall and other meteorological fields in the climatological seasonal cycle when the adjustment scheme is included.

Liu also collaborated with G. Meehl (NCAR) and G. Wu (LASG) on a study of climate trends in the Sahara Desert induced by increased CO_2. From 18 climate system models in the Coupled Model Intercomparison Project (CMIP), Liu chose 5 models that simulated reasonably well the rainfall distributions and north-south desert boundaries compared with observations and present-day climatology. When CO_2 concentration was increased at one percent per year for 80 years, simulations with these models showed the Sahara Desert shifting northward as a whole and becoming hotter and even drier. After 70 years of 1% annual CO_2 increases (that is, when CO_2 has doubled), the mean average northward shift is about 0.55° and the surface temperature is about 1.8°C higher compared with the climatology in the 40-year control run. The simulations indicate, moreover, that the local greenhouse effect from higher levels of CO_2 increases the net surface sensible heat flux, which in turn contributes to the warming trend. (Liu has submitted the manuscript describing this research to *Geophys. Res. Lett.*)

Johannes Loschnigg

Visiting Assistant Researcher

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

Johannes Loschnigg has continued to use the NCAR Community Climate System Model (CCSM) for his studies of the Asian monsoon circulation and its links to the Indian Ocean zonal mode (IOZM), known also as the dipole mode, and the El Niño–Southern Oscillation (ENSO). Analyzing the interaction between the Indian Ocean dynamics and the tropospheric biennial oscillation (TBO) in the 300-year control run of the CCSM, he found that sea surface temperature (SST) anomalies and equatorial ocean dynamics in the Indian Ocean were associated with the TBO and with interannual variations in the Asian-Australian monsoon circulation. To diagnose the causes of the SST anomalies and, in turn, their role in the development of a biennial cycle in the Indo-Pacific Ocean region, Loschnigg investigated the air-sea interactions simulated in the CCSM. In particular, he analyzed the ability of the model to reproduce the observed characteristics of the TBO and the role of local and remote influences and boreal springtime transition conditions. An analysis using the singular value decomposition (SVD) statistical technique showed that the model reproduces the dominant mechanisms by which the TBO influences the South Asian monsoon, namely, remote influences from the tropical Pacific and regional influences associated with both the north-south temperature gradient between the Asian continent and the Indian Ocean SST anomalies. A cumulative anomaly pattern correlation showed the degree to which each of these processes affect the interannual variability of both Asian and Australian monsoon rainfall.

In a study with J. Meehl (NCAR), Loschnigg explored the effects of Indian Ocean dynamics on the interannual variability of the Asian-Pacific climate. Specifically, he analyzed the roles of SST anomalies in the IOZM and of the north-south oceanic heat transport in the interannual variability of the monsoon circulation and the TBO. He found that the IOZM, is an inherent feature of the Asian summer monsoon, correlated with ENSO-related SST anomalies in the Pacific Ocean, and thus a part of the biennial nature of the Indo-Pacific Ocean region. Both the coupled ocean-atmosphere dynamics and cross-equatorial heat transport contribute to the interannual variability and biennial nature of the ENSO-monsoon system by affecting the heat content of the Indian Ocean, resulting in SST anomalies that persist over several seasons. Their persistence plays a key role in the TBO.

Loschnigg has also collaborated with Meehl on an observational study of the TBO using output from the Simple Ocean Data Assimilation (SODA) model. The following processes contributed to the heat-content anomalies in the Indian Ocean: slowly eastward-propagating heat-content anomalies (possibly associated with a collection of Kelvin waves), westward-propagating Rossby waves south of the equator in the Indian Ocean, and cross-equatorial heat transport in the Indian Ocean. The ocean's memory of these anomalies is an essential part of the TBO.

Using the NCAR coupled models, Loschnigg and Meehl have begun to study changes in the Asian-Australian monsoon system, the TBO, and ENSO that can be expected from increased CO_2. Preliminary analysis shows projected increases in Asian monsoon mean summer precipitation in model equilibrium simulations with both doubled and quadrupled atmospheric CO_2 concentrations. Interestingly, the Asian monsoon rainfall does not increase significantly from doubled to quadrupled CO_2 because a more frequent El Niño-like SST pattern in the Pacific Ocean causes changes in the east-west Walker circulation that inhibit an increase in monsoon precipitation. As with the TBO in general, changes in monsoon rainfall in climate change projections result from a combination of projected interactions between local and remote processes (Indian Ocean SST, Pacific Ocean SST, and the north-south temperature gradient between the Asian continent and the Indian Ocean).

Loschnigg has continued his study of the effects of climate variability on disease and human health in the Asia-Pacific region. One project analyzes historical data from the Indian sub-continent to study the influence of monsoon variability on outbreaks of malaria and cholera during the period 1869–1940. Another project currently underway in collaboration with researchers at the East-West Center and the Social Science Research Institute, University of Hawai'i, analyzes the impact of ENSO variability on the incidence of Dengue fever epidemics in the South Pacific island nations. Work on this project has resulted in a funded proposal for the fiscal year 2002–2003 from the NOAA Office of Global Programs to study the impact of ENSO on Dengue fever in Fiji and the Cook Islands over the last 50 years. Loschnigg gave several national and international invited talks on this subject.

Omer L. Sen
Postdoctoral Fellow

Omer Sen received his Ph.D. in hydrology from the University of Arizona in Tucson, Arizona, in Summer 2000. He then joined IPRC scientists to apply his knowledge of land surface modeling to the IPRC modeling research. His research interests include land-surface atmosphere interactions, hydrometeorological modeling, regional climate modeling, and remote sensing in hydrometeorology.

During last year, Omer Sen continued with the implementation of an advanced land surface model (Biosphere-Atmosphere Transfer Scheme, BATS, Dickinson et al., 1993) into the IPRC Regional Climate Model, the IPRC–RegCM (Y. Wang et al., submitted to *J. Climate*). He prepared global land-cover/vegetation and soil data sets to allow others to use the model beyond the Asian-

Australian monsoon region. For global land-cover/vegetation data, he used the second version of the global land-cover database from the U.S. Geological Survey, which contains updated land-cover classification from satellite measurements. In addition, he worked closely with Y. Wang in preparing a user-friendly version of the IPRC–RegCM, and he developed post-processing algorithms for the model outputs. Numerous test runs with the model were carried out, and inconsistencies detected and corrected. The current version (1.1) is quite stable and is available to other users.

Once the IPRC–RegCM became available for application research, Sen conducted sensitivity experiments with it to investigate the effect of Indochina surface-cover changes (deforestation particularly) on the East Asian summer monsoon, especially Meiyu rainfall. During late spring and summer, the strong monsoon westerlies bring abundant moisture to the higher latitudes over China, Korea, and Japan and may cause severe floods as in 1991 and 1998. These westerlies essentially flow over Indochina between the high Tibetan Plateau in the northwest and the subtropical high-pressure system over the western Pacific. The question Sen addressed was whether changes in the surface characteristics of Indochina modify this strong monsoon flow and affect its downstream activities. Preliminary results from an ensemble model sensitivity experiment of the 1998 summer monsoon—in which the experimental run consisting of the current vegetation in Indochina is compared with a control run in which the agricultural fields of Indochina are replaced with tropical rainforests—show that the deforestation causes significant changes in rainfall patterns over China.

In another, similar experiment, Sen is investigating the effect of desertification in northern China on the region's climate. In this experiment, the desert and semi-desert grid cells between 36–42°N and 90–110°E were replaced with short grass in the sensitivity simulation. Preliminary results show that the surface cover change in northern China can have significant impact on the large-scale atmospheric circulations and rainfall over eastern and northeast China. Sen is planning to extend this research by investigating the effect of deforestation and desertification on climate over China. The results from these experiments will be further analyzed to identify possible reasons for climate change (drying trend) over China.

In addition to the regional climate modeling studies, Sen has participated in replacing the current land surface model of the ECHAM general circulation model with BATS. He has included BATS in ECHAM without feedback from BATS to ECHAM, and he is now running this new version for 1997 and 1998 in order to compare the two land surface models with regard to differences in surface fields over the Asian monsoon land areas. In order to determine whether the replacement of the land surface model in ECHAM by BATS is justified, the study looks at whether the surface fields estimated by ECHAM's land surface model drift significantly away from those of the more sophisticated BATS.

Bin Wang

Professor of Meteorology, SOEST
Theme 3 Co-Leader

Bin Wang obtained his Ph.D. in geophysical fluid dynamics from The Florida State University in 1984. He joined the Meteorology Department at the University of Hawai'i in 1987 and the IPRC in January 1999. His research interests include the variability and predictability of the Asian-Australian monsoon system and Asian-Pacific climate, the tropical intraseasonal oscillation, El Niño–Southern Oscillation and Intertropical Convergence Zone dynamics, large-scale ocean-atmosphere interactions, tropical storms, atmospheric and oceanic wave instabilities.

Bin Wang and his colleagues Wu and Li have studied the effect of interactions between the atmosphere and a warm ocean on the variability of the Asian-Australian monsoon. They found that low-level monsoon anomalies are characterized by two off-equatorial anti-cyclones—one located over the South Indian Ocean (SIO), the other over the western North Pacific (WNP). The SIO anticyclone originates in boreal summer while an El Niño is developing, amplifies rapidly, reaches its height in fall, and decays before El Niño matures. In contrast, the WNP anticyclone forms in fall, attains its maximum intensity when El Niño matures, and persists through the next spring and summer while El Niño decays. Remote El Niño forcing alone cannot explain the amplification of the SIO anticyclone in the developing stage of El Niño nor the maintenance of the WNP anticyclone in the decaying phase of El Niño. Wang et al. show that the ocean-atmosphere conditions in the two regions of the anticyclones are very similar—a SST dipole with cold water to the east and warm water to the west of the anticyclone center. The researchers believe that these conditions result from positive ocean-atmosphere feedback, intensifying and maintaining the anticyclones, and they conclude that although the anomalies are often triggered by El Niño conditions in the Pacific, the interaction is controlled by the monsoon seasonal cycle and perhaps induced by other local or remote forcing.

Wang and Chan (in press, *J. Climate*) studied how the El Niño–Southern Oscillation (ENSO) affects tropical storm activity in the western North Pacific (WPN). An analysis of 35 years of data (1965–1999) reveals that the life-span, frequency, and formation region of tropical storms over 110º–180ºE, 0º–30ºN are greatly affected by strong, but not moderate El Niño and La Niña events. The study's findings (Figure 13) show that tropical storm activity in this region is highly predictable 1–2 seasons in advance. In strong El Niño years, the mean number of days of tropical storms is 159, and their mean life-span is about 7 days; in strong La Niña years, the mean number of days of tropical storms is 84 and their life-span is 4 days. Significantly fewer such storms form from January to July after an El Niño; significantly more, after a La Niña. The region in which these tropical storms form also differs markedly. During an El Niño, most tropical storms form in the southeast quadrant (5º–17ºN, 140º–180ºE), whereas during a La Niña most form in the northwest quadrant (17º–30ºN, 120º–140ºE). In addition, during strong El Niño years, the mean location of storm formation from July to September is located 6º further south and from October to December, 18º further east. Finally, 2.5 times more tropical storms during the fall recurve northward across 35ºN than during strong La Niña years. The more southeastern storm formation and the recurving storm tracks during El Niño years imply that El Niño events substantially increase the poleward transport of heat and moisture, which may impact extratropical general circulation significantly. Wang and Chan also describe a mechanism whereby ENSO can affect tropical storms, providing a physical basis for seasonal forecasts of tropical storm activity in the western North Pacific.

In collaboration with Soon-Il An, Wang looked at why a number of ENSO properties (period, amplitude, propagation, and spatial structure) changed in a coherent manner and occurred at the same time as the Pacific decadal climate shift (Wang and An, 2002). They found that the changes in the background winds and associated equatorial upwelling were the fundamental factors in altering the model's ENSO behavior. This new mechanism emphasizes the critical role of an atmospheric bridge, which can rapidly convey decadal changes in the extratropical region to the tropics and affect ENSO behavior.

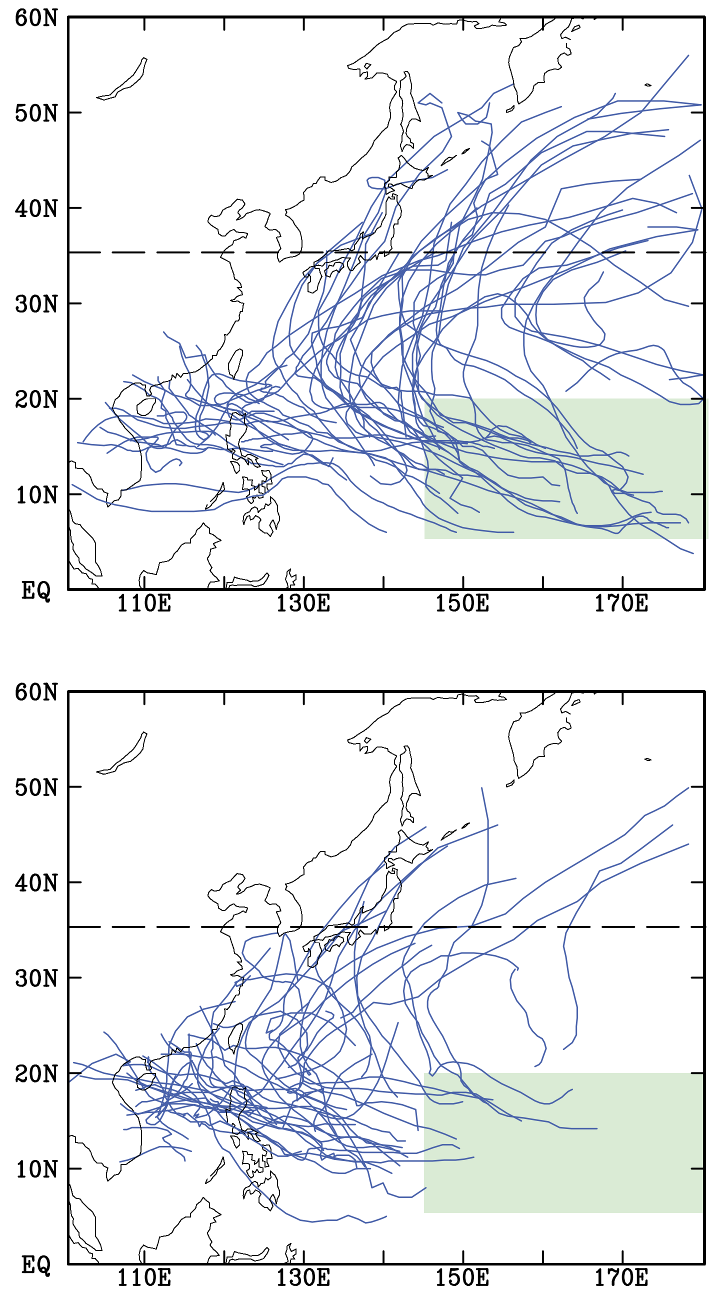


Figure 13: Tropical storm tracks from September 1 to October 31 during (a) six major El Niño years ('65, '72, '82, '87, '91, '97) and (b) six major La Niña years ('70, '73, '75, '88, '98, '99). The number of storms formed in the southeast quadrant (green box) is 23 for the El Niño years and 8 for the La Niña years; the number of storms that recurved northward across 35ºN are 29 for the El Niño and 11 for the La Niña years. Both differences are statistically significant at the 99% confidence level by the two-sample *t*-test.

In a follow-up study of how ENSO impacts the East Asian summer monsoon, Wang and Zhang (in press, *J. Climate*) revealed that the anomalous Philippine Sea anticyclone (PSAC), which conveys the effects of an El Niño on the East Asian monsoon, originates in fall and concurs with an early retreat of the monsoon and a strong intraseasonal oscillation (ISO). The development of the PSAC is attributed to the combined effects of remote El Niño forcing, tropical-extratropical interaction, and air-sea interaction associated with the ISO.

The monsoon-research community has not yet agreed upon a unified definition of the monsoon rainy season, nor has it reached consensus about the nature of the link between the onset of rain over the Asian continent and the adjacent oceans. Wang and LinHo (2002) have developed a single rainfall parameter and a set of universal criteria that define the domain, onset, peak, and withdrawal of the rainy season. Application of this parameter has revealed a cohesive spatial-temporal structure to the Asian-Pacific monsoon rainy season; results of studies using this parameter and these criteria will provide an observational basis for validation of the monsoon hydrological cycles simulated by climate-system models and will improve our understanding of monsoon dynamics.

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. He was senior professional officer at the Bureau of Meteorology Research Centre in Melbourne, Australia, before joining the IPRC in February 2000. His research interests include tropical meteorology, tropical cyclones, air-sea interactions, low-frequency oscillations in the atmosphere and ocean, the development of high-resolution regional atmospheric models, and numerical modeling of the atmosphere and the ocean.

Over the past year, Yuqing Wang has focused mainly on developing the IPRC regional climate model (IPRC–RegCM). He has released Version 1.1, which is much less scale-dependent than Version 1.0. It can be run at relatively coarse resolutions because of its mass-flux cumulus parameterization scheme, which was originally developed by Tietdke (1989) and later modified by Nordeng (1995). This parameterization scheme has a convectively available potential energy closure assumption for the convective mass-flux at the cloud base and includes organized convective entrainment and detrainment. A significant feature of Wang's implementation is that condensed cloud-water and cloud-ice cumulus clouds are allowed to be detrained into the environment as corresponding grid-resolved quantities. Since this improves the cloudiness parameterization, it improves the radiative-flux calculation, the energy balance at the land surface, and simulation of surface temperature, which can, in turn, affect model convection. A new algorithm for solving the leaf-surface energy-balance equation has also been developed. This new algorithm assures convergence of numerical solutions and avoids diverging numerical solutions, a difficulty with the original BATS.

The model is being applied in widely different projects by Wang and his colleagues. The projects include rainfall variations during the Asian monsoon (with O. Sen and B.Wang), the atmospheric response to tropical instability waves (J. Small and S.-P. Xie), the stratus clouds over the cold eastern Pacific and the annual cycle of the intertropical convergence zone (ITCZ) in the eastern Pacific (with H. Xu and S.-P. Xie), and deforestation effects in Indochina (with O. Sen and B. Wang). For example, the IPRC–RegCM successfully simulated the 1998 monsoon onset over the South China Sea and the associated rainfall in East Asia (Figure 14). In this simulation, the model used ECMWF analysis data as both the initial and lateral boundary conditions, included observed Reynolds SST as the lower boundary condition over the ocean, and had a 0.5° by 0.5° resolution. The model simulated quite well (see Figure 14) the average daily rainfall from May 1 to August 31 in southern China (105º–122ºE, 20º–26ºN), in the Yangtze River basin (105º–122ºE, 26º–32ºN), and in northern China (105º–122ºE, 32º–40ºN). It also captured most major rainfall events, especially those during the Meiyu period in the Yangtze River basin (Y. Wang, Sen, and B.Wang, submitted to *J. Climate*).

To understand the eastern Pacific climate, Wang, Xu, and Xie (in preparation) are using the IPRC–RegCM to simulate the boundary layer stratus clouds over the cold eastern Pacific water, the effect of the Andes, and cloud-radiation forcing. Focusing on the convection over the eastern Pacific ITCZ and the South American continent, and on the dynamic and thermodynamic effects of the Andes, they have found that cloud radiation has a significant effect on the eastern Pacific climate system, and that positive feedback occurs among the boundary layer clouds over the southeast subtropical Pacific, convection in the ITCZ north of the equator, and the meridional Hadley circulation. The Andes are important in shaping eastern Pacific climate, contributing to the northward displacement of the ITCZ and the formation and maintenance of stratus clouds over the southeast Pacific(Xu, Xie, and Wang, in preparation).

In collaboration with X. Wang and F.-F. Jin (University of Hawai‘i), Yuqing Wang developed a reduced-gravity shallow-water ocean model to study the equatorial thermocline response to tropical and subtropical wind-stress forcing and the origins of the Pacific decadal oscillation (PDO). They found that off-equatorial wind stress in the eastern tropical and subtropical region can generate zonally uniform thermocline depth variations in the equatorial region (Wang, et al. submitted to *J. of Climate*). This tropical ocean recharge mechanism has implications for Pacific climate variability. When warm SST in the eastern Pacific is coupled with cyclonic wind stress that has a spatial pattern similar to observed wind stress, a 10- to 15-year oscillation can be generated; when warm SST in the eastern Pacific is coupled with westerly wind stress in the central equatorial Pacific, an ENSO-like oscillation can be generated with a 3- to 5-year period. Wang et al. (submitted to *J. of Climate*), therefore, propose that the PDO may be understood as a weakly coupled decadal recharge oscillator similar to the ENSO recharge oscillator.

Wang has continued his tropical cyclone research, which also contributes to development of the IPRC–RegCM. He has studied how sensitive the simulated tropical cyclone structure and intensification are to details in cloud-microphysics parameterizations. Although the cloud structure of the simulated tropical cyclone can be quite different with different cloud microphysics schemes, he found that intensification rate and final intensity are not greatly affected by parameterization details. This is the first quantitative evaluation of the sensitivity of a modeled tropical cyclone to cloud microphysics parameterization (Wang, submitted to *Mon. Wea. Rev.*). Since previous studies have found substantial sensitivity of simulated tropical cyclones to different cumulus parameterization schemes, the present finding suggests that using explicit cloud microphysics in tropical cyclone models will improve forecasting tropical cyclone intensity and intensity changes.

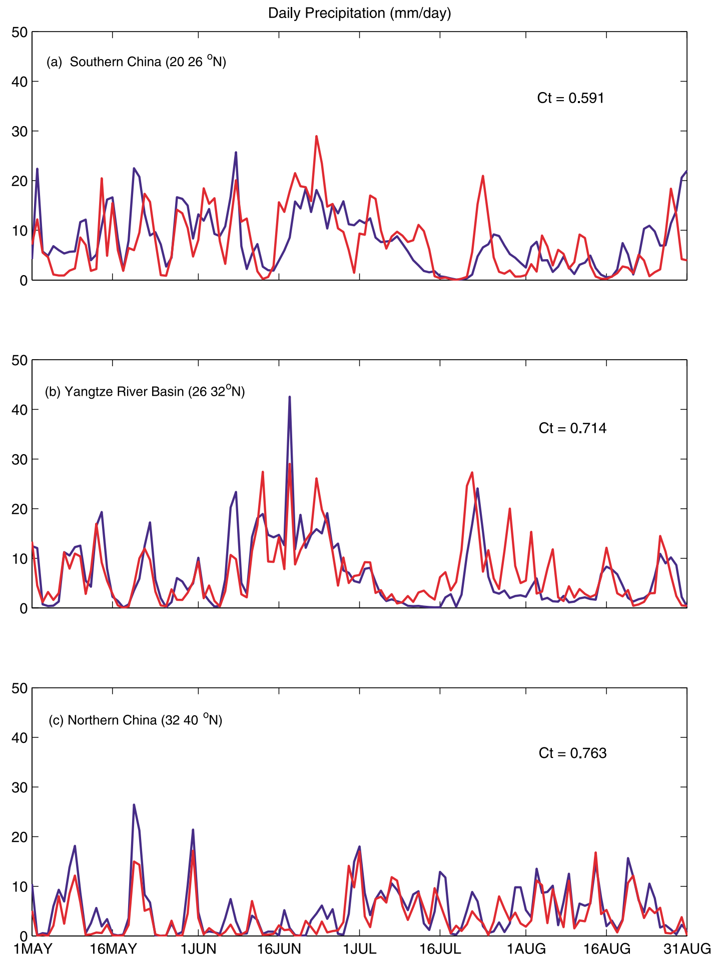


Figure 14: Observed (red) and simulated (blue) area-averaged daily precipitation (in mm) from May 1 to August 31, 1998, for three regions: (a) southern China (105º–122ºE, 20º–26ºN), (b) Yangtze River basin (105º–122ºE, 26º–32ºN), and northern China (105º–122ºE, 32º–40ºN). “Ct” in each panel represents the temporal correlation coefficient between the observed and simulated precipitation over the four months for the particular region.

Renguang Wu
Postdoctoral Fellow

Renguang Wu received his Ph.D. in meteorology from the University of Hawai'i at Mānoa in 1999. He joined the IPRC in Spring 2000, after a postdoctoral year with the University of Hawai'i Meteorology Department. His research interests include large-scale air-sea interaction, the monsoon-ENSO relationship, and interdecadal climate change over Asia and the Pacific.

Renguang Wu has been studying Asian monsoon variability (rainfall and wind) and interdecadal changes in the Asian-Pacific region. He noticed that in the late 1970s the summer rainfall anomalies in eastern North China and central Japan changed significantly during the decaying phases of El Niño and La Niña events. In his research this year, he discovered that the above changes are closely related to changes in the location and intensity of anomalous convection over the western North Pacific (WNP) and over India (Figure 15). Before the late 1970s, an anomalous barotropic anticyclone would develop during the decaying phase of an El Niño over East Asia and anomalous southerly winds would prevail over eastern North China. These conditions were connected to anomalous convection over India through a zonal atmospheric wave pattern along an east-west band stretching from 30º–50ºN. After the late 1970s, the anomalous Indian convection weakened as the influence of the El Niño–Southern Oscillation (ENSO) weakened in relation to its longer oscillation period. This change decreased the impact of convection over India on the East-Asian summer monsoon. The WNP convection anomaly, on the other hand, was enhanced and shifted north as a result of higher summer mean SSTs in the Philippine Sea. This northward shift, in turn, induces an anomalous low-pressure area to shift eastward during the decaying phase of an El Niño, from East Asia to the North Pacific along 30º–45ºN. Accordingly, the anomalous winds over eastern North China and Korea switched from southeasterly to northeasterly.

In a follow-up study, Wu found that the above atmospheric zonal wave pattern over midlatitude Asia is a dominant upper-level anomaly pattern in boreal summer. The connection of this pattern with the heating over India weakened during the late 1970s in response to a shift of the midlatitude westerly jet and a change in the pattern of Indian summer rainfall. His study, furthermore, revealed that changes in East-Asian rainfall patterns depend on the phases of ENSO. The most robust influence is found in southern China during the mature El Niño phase, the anomalous rainfall moving eastward from fall to spring. This rainfall is closely related to low-level southwesterly anomalies along the northwest flank of an anomalous anticyclone over the WNP. After the late 1970s, the heavy rainfall during the mature El Niño phase moved further south in China, consistent with a southward shift of southwesterly wind anomalies along the South China coast. This shift was related to an enhanced and southward displaced upper-level westerly jet over East Asia and a more intense prevailing low-level northerly flow along the East-Asian coast. These changes may have been induced by an intensification of tropical convection, which itself was related to an increase in mean SST in the tropical Indian Ocean and western Pacific.

In a study comparing equatorial central and eastern Pacific wind changes seen around 1977 in NCEP-NCAR reanalysis data and COADS observations, Wu found that the two data sets differ greatly from one another. In the NCEP-NCAR reanalysis, the easterlies weakened over the eastern equatorial Pacific, while the southerlies strengthened over the north equatorial central Pacific. As a result, the low-level convergence and precipitation decreased over the equatorial central Pacific. Since these wind and precipitation changes are opposite to those seen in the COADS observations, Wu used independent observations of ocean-heat content to analyze these equatorial Pacific zonal wind changes and found that the simulation of the zonal thermocline slope is more consistent with ocean observations in an ocean model forced by COADS winds than by NCEP reanalysis winds.

Furthermore, Wu studied changes in land and atmospheric variables in Asia over the last 50 years using the NCEP-NCAR reanalysis data. He identified two interdecadal modes. The first mode shows a clear change in the mid-1960s that concurs with the beginning drought in the Sahel, India, and North China. The second shows a change in the late 1970s that concurs with the warming in the tropical Pacific Ocean. Both modes have a baroclinic vertical structure over midlatitude Asia. The mid-1960s change shows obvious seasonality in the surface variables over the Asian continent, resulting probably from negative feedback between land-atmosphere processes. The late-1970s change does not show clear seasonality, probably because feedback of the land surface to the atmosphere is weak. The mid-1960s and late-1970s changes are both accompanied by higher SST in the tropical Indian Ocean and western Pacific, suggesting that a meridional circulation connects the tropical and midlatitude atmosphere.

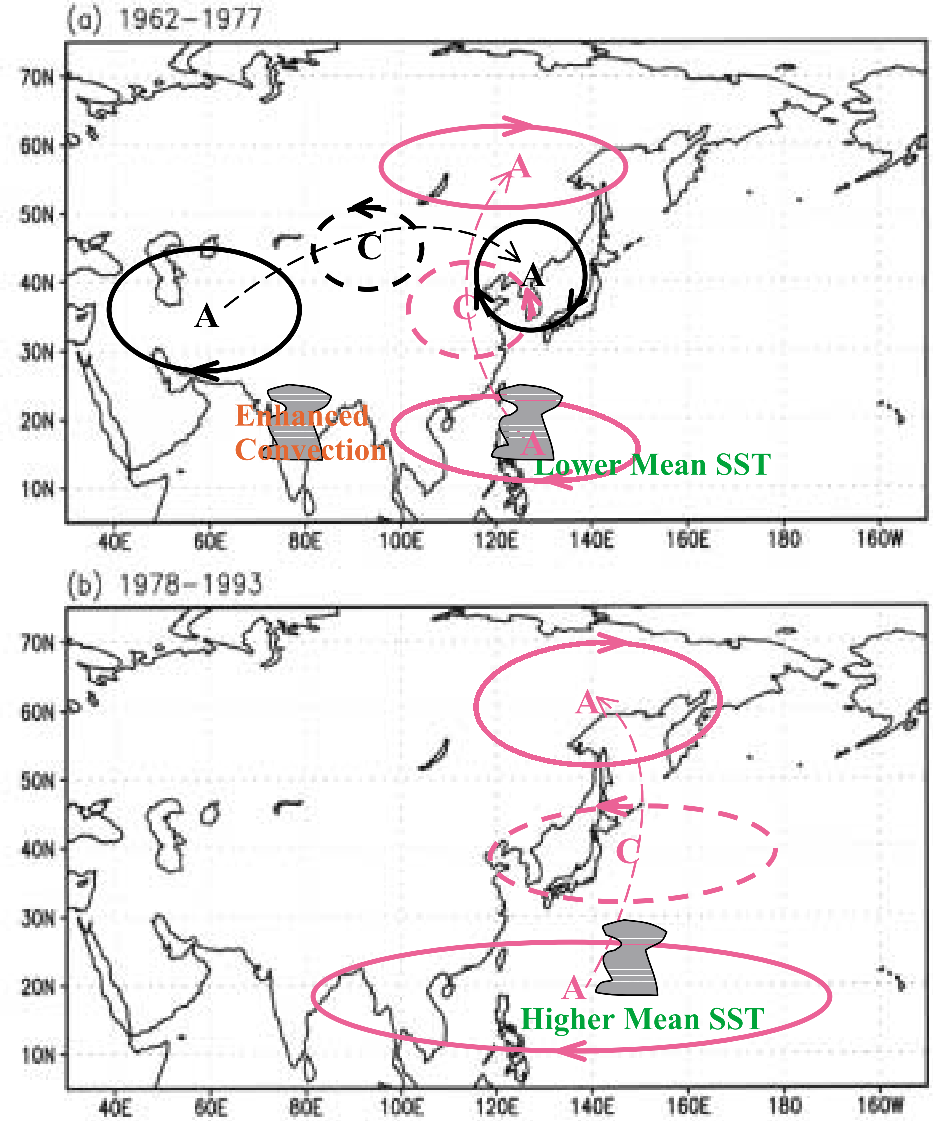


Figure 15: Schematic diagram illustrating the influence of anomalous heating over the western North Pacific and India on the East Asian circulation anomaly in the summer phases of decaying El Niños for the periods (a) 1962–1977 and (b) 1978–1993. Anomalous anticyclones and cyclones are indicated by "A" and "C", respectively; the wave propagation directions are noted by dashed lines.

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 community. Theme 4 is devoted to improving the understanding of the Asia-Pacific region impacts of global change. IPRC scientists, thus, are examining the role of atmospheric feedback processes in both climate variability and climate sensitivity. For example, comprehensive ocean-atmosphere model results are used to assess whether simple empirical approaches can be used to estimate how sensitive the surface climate is to large-scale perturbations in radiative forcing (Zhu and Hamilton).

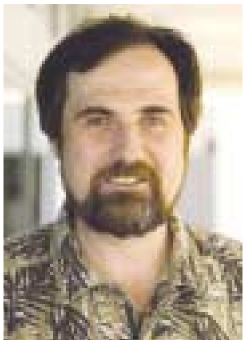
Work is also underway to improve the underpinnings of climate prediction and the confidence that can be placed in such predictions. One research focus addresses a very basic issue, namely, the behavior of numerical simulation of the atmospheric circulation in global models at fine resolution (Hamilton). A second focus addresses the ability of global atmospheric models to simulate the natural interannual variability in large-scale circulation patterns. In particular, research is underway to understand the role of the stratosphere in the natural interannual variability of tropospheric circulation, and how stratospheric aerosols arising from volcanic eruptions perturb surface climate (Hamilton).

テーマ4 「地球規模の気候変動がアジア･太平洋地域の気候に及ぼす影響」

人間活動による気候への全地球的、及び局地的なインパクトに関して理解を深めることは、国際科学界が直面している喫緊の課題である。テーマ4は地球環境変動がアジアー太平洋地域へどのようにインパクトを与えるか、その理解を深めることを目指している。特に気候変動および敏感度に対する大気のフィードバックプロセスの役割を調べる。たとえば、大気海洋結合モデルの結果を用い、大規模スケールの放射強制の変動に対する地上付近の気候の敏感度を、簡単な経験的手法によって評価可能かどうかを検討している。

また、気候変動予測とその信頼性の根拠を改善するための研究を進めている。特に高解像度モデルの大気循環がどのような振る舞いをするか、という基礎的な問題に焦点を当てている。また、大気モデルが大規模・経年スケールの自然変動を表わすことができるかを調べている。とくに、成層圏での経年変動が対流圏に及ぼす役割や火山による成層圏エアロゾルが地上付近の気候変動をいかに引き起こすか、を解明するための研究が進行中である。

Individual reports



Kevin P. Hamilton

Professor of Meteorology, SOEST
Theme 4 Leader

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

Kevin Hamilton has continued modeling and observational research designed to understand the role of the stratosphere in natural interannual climate variability and in the climate response to changes in radiative forcing. A major portion of this work involves analysis of various multi-year control and perturbed climate simulations with the GFDL SKYHI troposphere-stratosphere-mesosphere general circulation model. Previous simulations with the model using control conditions showed that it realistically captures large-scale interannual extratropical circulation variations. Hamilton is now investigating the connection between extratropical, low-frequency climate variability and tropical variability by constraining the tropical zonal-mean winds in model runs.

Hamilton is continuing his collaboration with G. Stenchikov and A. Robock (Rutgers University) and D. Schwarzkopf and V. Ramaswamy (NOAA Geophysical Fluid Dynamics Lab) using the SKYHI model to study the effects of stratospheric aerosols on the large-scale tropospheric circulation. Explosive volcanic eruptions inject massive amounts of sulphur into the stratosphere, which form a sulphuric acid aerosol layer. For the two years after large eruptions, the climate in the Northern Hemisphere is generally observed to be unusual: In summer the extratropical surface temperatures are lower than normal—an expected consequence of the reduced direct solar heating of the troposphere as more of the solar beam is absorbed in the stratosphere. In winter, however, anomalous surface warming occurs over many land areas, particularly in northern Europe and Asia. Simulations with the SKYHI model have been able to capture the observed effects of the stratospheric aerosol resulting from the very large Mt. Pinatubo eruption in 1991. Hamilton and his colleagues are now applying the model to examine the response to stratospheric and tropospheric radiative effects of the stratospheric aerosol. Remarkably, the high-latitude winter warming response is captured even in experiments in which the stratospheric radiative effects of the aerosol are suppressed. This suggests that the stratosphere-troposphere dynamical link has a smaller role in determining large-scale patterns of climate variability than other researchers are now advocating.

In related projects, Hamilton aims at understanding and modeling the interannual variations in the tropical stratospheric circulation. He has assembled the longest available (1950–2001) empirical record for the quasi-biennial oscillation (QBO) wind variations and studied the systematic slow variations in the QBO period over this time record. He has found a rather remarkable systematic, approximately ten-year, modulation of the QBO period. In collaboration with W. Hsieh (University of British Columbia), Hamilton has also studied the QBO empirically with a nonlinear principal component analysis of available data. The application of nonlinear neural-network based fitting techniques has allowed the computation of a composite QBO cycle and a time series of the QBO phase. These new computations are significant improvements over those previously obtained with linear approaches. Hamilton is also analyzing model simulations and observational data to characterize the longitudinal variations in the tropical stratospheric QBO.

Weijun Zhu
Postdoctoral Fellow

Weijun Zhu obtained his Ph.D. in meteorology in 1999 from the Nanjing Institute of Meteorology, China, where he was an associate professor in the Department of Atmospheric Sciences before joining the IPRC in July 2001. His research interests include the observed and modeled interactions between oceanic and atmospheric processes, general atmospheric circulation, mid- and long-term weather forecasting, and short-term climate prediction.

Given the uncertainty involved in detailed modeling of climate feedbacks, there has been an interest in using empirical data from the present climate to estimate the sign and magnitude of various climate sensitivities. For example, the dependence of cloud albedo upon surface temperature over various latitudes can be used to estimate the alteration in cloud albedo expected to accompany a particular change in global-mean temperature. Similarly, the scaling of the infrared contribution to the energy balance with surface temperature can be estimated from present-day data at different latitudes. In recent years, there has been particular interest in using such empirical approaches to estimate the sensitivity of tropospheric water vapor to changes in surface temperature.

During the past year, Weijun Zhu collaborated with Kevin Hamilton in studying the validity of such approaches. They used a coupled-ocean atmosphere model, a version of the NCAR Climate System Model, with which they did a control simulation to establish a baseline climate. Then they performed a perturbed climate simulation in which they increased the solar constant by 2.5% over the control value. They found that the increase in solar constant leads to a simulated climate that has a global-mean surface temperature about 2ºC higher than the control. Zhu is now analyzing the detailed feedbacks that determine the magnitude of the warming, and how well such feedbacks could have been predicted from knowledge of only the control climate simulation.

The top panel of Figure 16 shows results from both the control and warm simulations for the zonal-mean outgoing longwave radiation at the top of the atmosphere and the zonal-mean surface temperature for each of 48 latitude bands. The straight line shows the estimated change of infrared flux with surface temperature obtained by linear regression of the control run values. At most latitudes, the simulated increase in infrared flux with surface temperature resulting from the increase in solar constant is reasonably consistent with the prediction based on the control regression.

The bottom panel shows a similar analysis, but for the total albedo of the earth and atmosphere plotted against the surface temperature. Here, the analysis of the control run suggests a decrease in albedo with increasing surface temperature. The simulated changes observed in response to the increased solar constant, however, are inconsistent with the predictions from the control regression, and at most latitudes the albedo is greater in the warmer climate. This suggests a major limitation in the validity of such empirical approaches. Zhu, moreover, is extending this work to examine more detailed aspects of the climate sensitivity in relation to different internal atmospheric processes (e.g., separating effects of low, middle and high clouds). In particular, he plans to use seasonal and interannual variations in the control run (rather than just geographical changes) as the basis for estimating climate sensitivity.

In related work, Zhu has been conducting experiments and examining climate feedbacks in strongly perturbed climates. The main motivation is simply curiosity to see how robust the linearity of the climate sensitivity response is, and whether the extremely strong nonlinearities (“runaway greenhouse effect”) from the water vapor feedback, which are thought to have played a role in making Venus’ atmosphere so hot, actually can be activated in a terrestrial GCM. After examining the feedbacks in strongly perturbed climate simulations in which the solar constant was increased by as much as 25%, Zhu has found that the response of climate sensitivity to such external solar forcing is still linear.

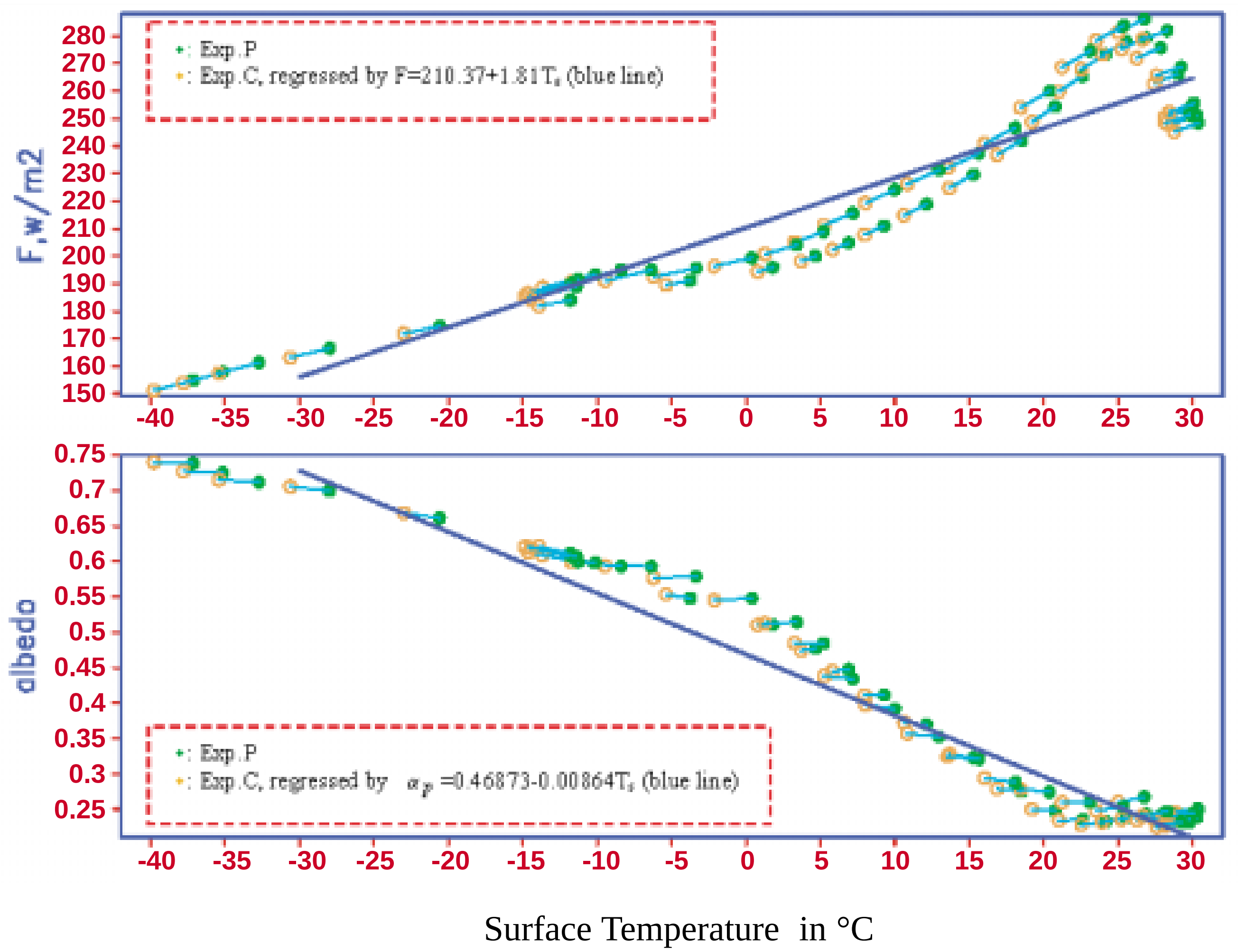


Figure 16: Scatter plots of the zonally averaged, annual-mean net longwave flux (top panel) and planetary albedo (bottom panel) at the top of the atmosphere against surface temperature. Hollow yellow circles represent results from the control simulation, in which the solar constant takes its normal value of 1360 w m^{-2}; the solid green circles represent results from the perturbed simulation, in which the solar constant was increased by 2.5 percent. The regressed line (blue) for these points is $F = 210.37 + 1.81T_s$ in the upper panel, and $\sigma_p = 0.46873 - 0.00864T_s$ in the lower one. Each short cyan line connects the points for the control and the perturbed simulation at the same latitude band.

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 as well, by providing easy access to climate data and products. The amount of in-situ oceanographic data and satellite-derived data products for Asia-Pacific and global climate problems 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 technology. When 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 data sets, however, are often underused largely due to the lack of easy accessibility.

The APDRC was 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 envisioned to be a powerful research resource, one that will provide one-stop shopping of climate data and products to IPRC researchers and collaborators. The collection and distribution of data between the IPRC and other countries in the Asia-Pacific region (one of the APDRC functions) will provide a means for strengthening international collaboration.

The APDRC has both research and data sides. The research side is supported with funding from the National Aeronautics and Space Administration (NASA) under a five-year project that began October 2000. The research activities are described under the research themes and individual reports of this annual report. A major event for the data side of the APDRC was the funding by the National Oceanic and Atmospheric Administration (NOAA) of the project "Establishment of a data and research center for climate studies".[1] The four main activities of this project are: (i) data server system (DSS) implementation and development; (ii) data management and archive building; (iii) value-added activities and products; and (iv) coordination and collaboration, an activity that cuts across the other three and entails interaction with local, national and international partners. The overall direction is provided by the APDRC Steering Team: Jay McCreary (IPRC Director), Peter Hacker (APDRC Manager), Humio Mitsudera, Takuji Waseda, and Ronald Merrill. Activities under this new project began during the summer of 2001, and an update of the project follows.

The DSS implementation and development is headed by Takuji Waseda. During the past year, several servers have been installed on the new Sun Enterprise 450 with four processors. In cooperation with Steve Hankin and his group at NOAA Pacific Marine Environmental Laboratory (PMEL) in Seattle, Washington, Ronald Merrill and Yingshuo Shen of the IPRC have installed and are operating several Live Access Servers (LASs) at the APDRC web site: http://apdrc.soest.hawaii.edu. The LAS, which was developed at PMEL primarily for gridded data sets, provides the user with four integrated functions: data location, navigation and evaluation, delivery, and visualization and analysis. The LASs at the APDRC web site are serving gridded products from local archives, including file aggregation, gridded products from remote sites, and restricted-access data from our local archive. For serving non-gridded, in-situ data, PMEL's EPIC server has been installed and evaluated over the past year in cooperation with Nancy Soreide, Don Denbo and Willa Zhu at PMEL. The EPIC server allows convenient subsampling of profile data in space and time, and should be useful for browsing and downloading the WOCE and Argo profile data. In addition, the web site provides an Aggregation/Catalog DODS (Distributed Oceanographic Data System) server developed by Unidata at UCAR. Any DODS (OPeNDAP) client (e.g., GrADS, Ferret, and ncBrowse) should be able to access this server. The web site also has links to Argo information and data, to Global Ocean Data Assimilation Experiment (GODAE) sites, and to other partner sites. Over the past year, we have worked closely with our PMEL partners

[1] Recently we have heard that NOAA will fund a second year of APDRC activities, including funding for PMEL collaborators on DSS development.

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.

to identify tasks for upgrading the capabilities of the LAS and EPIC servers, and improving desktop tools for data analysis. These activities are part of our joint proposal with PMEL for the coming year.

Data management and archive building is headed by Humio Mitsudera. 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. Over the past year, several new gridded products served by the LAS have been added to the APDRC local archive and are updated regularly. In addition, a large number of remote data sets and products are available on LAS. In-situ profile data available on the EPIC server consist at present of data from the WOCE Hydrographic Program sections for the Atlantic, Pacific and Indian Oceans. A pilot effort serves Argo profile data for the Indian Ocean and western Pacific. Recently the entire WOCE current-meter data set prepared at Oregon State University has been loaded to the EPIC server and is available as time series data records. For the latest information on available data sets and products, visit the website. In the coming year, the APDRC will be emphasizing the Version 3 WOCE data-set to be released in Fall 2002. All these data are to be served through DODS, and some data sets will be available on the LAS and EPIC servers for easy browsing.

The main value-added activity over the past year has been the acquisition and evaluation of data from some 20,000 historical bottle stations south and east of Japan. The data were acquired from the Far Eastern Regional Hydrometeorological Research Institute in Russia. This work, carried out by Nikolai Maximenko, was recently described in the IPRC newsletter (*IPRC Climate*, Vol. 2, No. 1, 2002). Humio Misudera and Max Yaremchuk are planning APDRC regional assimilation products in coordination with GODAE. Tangdong Qu and Jim Potemra have been working with the historical hydrographic data in the western Pacific and Indonesian Throughflow region to produce improved climatologies. Zuojun Yu has continued using ocean models to evaluate surface-flux products. Plans for the near future are to develop quality-controlled temperature and salinity profile data sets spanning the full historical record, especially the past 50 years. This multi-year task involving several institutions should yield data sets and gridded products valuable for climate research and planned assimilation activities.

Coordination and collaboration will ensure efficient implementation of the APDRC activities within the local, national, and international climate research communities. Locally, 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 Australia on the development of historical, quality-controlled profile data sets; and with Argo on the definition and implementation of regional data centers for data-set quality-control and assembly.

The IPRC Computing Facility

The IPRC computer systems continued to expand in their compute performance and disk capacity. As of March 2002, the IPRC high-performance computing facility was 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 with 24 CPUs (central processing units), 16.0 GB (gigabytes) shared memory, and 756 GB local storage. It is capable of up to 28.8 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 RISC-based parallel machines are Origin 2000 systems. One system has 32 CPUs (250 MHz), 14.0 GB of logically shared memory, 180 GB of local disk storage, and a peak speed of 16 GFLOPS. The second Origin 2000 was upgraded this year to a 32 CPU 300 MHz system with 10 GB of memory from a 16 CPU (195 MHz) / 8 CPU (300 MHz), 4.5 GB memory, 60 GB of local disk storage. The upgrade resulted in an increase in the peak performance from 11 GFLOPS to 16 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, and 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 an additional 20 TB (terabytes) provided by a tape library (StorageTek Timberwolf 9710 with 6 DLT drive and 574-tape capacity). Transfer of files between disks and tapes is automatic and transparent to the users, so the storage capacity of the local disks appears to be limited only by the maximum capacity of the tape library. 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 increased by 3.6 TB, to 5 TB.

The IPRC also purchased 14 used 500 GB IDE SCSI attached RAID enclosures, which will be attached to various workstations to provide an additional 7 TB of network accessible storage. Each IPRC researcher is provided with a UNIX workstation and a PC. This year 10 SunBlade 2000's, 4 SGI Octane2's and 4 Dell Linux workstations 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, 4 Dell workstations and 64 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.

Ronald Merrill in the IPRC Computing Facility.

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Annamalai, H., R. Murtugudde, J.T. Potemra, S.-P. Xie, and B. Wang: Coupled dynamics in the Indian Ocean: Externally or internally forced? *Deep Sea Res*.

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External Presentations

An, S.-I.: *Mechanism for long-term changes in El Niño and the Southern Oscillation*. Interim evaluation at Frontier Research System for Global Change, May 2001, Tokyo, Japan.

An, S.-I.: *Basinwide interannual SST changes in the tropical Indian Ocean associated with El Niño*. Symposium on the Ocean-Atmosphere Coupled Dynamics in the Indian Ocean, December 2001, Tokyo, Japan.

An, S.-I., B. Wang, and F.-F. Jin: *A mechanism for decadal changes of the ENSO properties*. Climate Conference 2001, August 2001, Utrecht, The Netherlands.

Annamalai, H.: *Seasonal prediction of the monsoon rainfall and its implications*. Ocean Policy Seminar, SOEST, University of Hawai'i, September 2001, Honolulu, Hawai'i. (Invited)

Annamalai, H., R. Murtugudde, J. Potemra, and S.-P. Xie: *Coupled dynamics in the Indian Ocean: Externally or internally forced*? Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawai'i.

Endoh, T., and T. Hibiya: *Numerical simulation of the transient response of the Kuroshio leading to the large meander formation south of Japan*. Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawai'i.

Endoh, T., H. Mitsudera, and S.-P. Xie: *Numerical study of the formation of the mixed layer in the North Pacific subarctic region*. Spring Meeting of the Oceanographic Society of Japan, March 2002, Tokyo, Japan.

Fu, X., B. Wang, and T. Li: *Roles of air-sea coupling on the simulation of the mean Asian summer monsoon and its climatological intraseasonal oscillation*. Eleventh Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, May 2001, San Diego, California.

Hafner, J., and S.-P. Xie: *Far-field effects of the Hawaiian Islands: Observations and MM5 simulations*. The First IPRC Regional Climate Modeling Workshop, October 2001, Honolulu, Hawai'i.

Hacker, P.: *Indian Ocean Plans* (SOCIO). International Workshop for Review of the Tropical Buoy Network, September 2001, Seattle, Washington. (Invited)

Hacker, P.: *The Asia-Pacific Data-Research Center for Climate Studies: Status and Plans*. CLIVAR Pacific Panel, February 2002, Honolulu, Hawai'i. (Invited)

Hacker, P.: *The University of Hawai'i IPRC Asia-Pacific Data-Research Center (APDRC) for Climate Studies: Status and Plans*. International Argo Science Team Meeting (IST-4), March 2002, Hobart, Australia.

Hacker, P., and J. Cummings: *The Asia-Pacific Data-Research Center (A GODAE Climate Data and Product Server)*. International Workshop on GODAE with Focus on the Pacific, July 2001, Honolulu, Hawai'i.

Hamilton, K.: *Gravity wave interactions with the mean flow in the atmosphere*. Thirteenth Conference on Atmospheric and Oceanic Fluid Dynamics, American Meteorological Society, June 2001, Breckenridge, Colorado. (Invited)

Hamilton, K.: *Free and forced variability of the extratropical circulation*. Eighth General Assembly of the International Association for Meteorology and Atmospheric Science, July 2001, Innsbruck, Austria. (Invited)

Hamilton, K.: *Introduction to the dynamics of the tropical middle atmosphere*. International Centre for Theoretical Physics, School on Physics of the Equatorial Atmosphere, September 2001, Trieste, Italy. (Invited)

Hamilton, K.: *Application of ultra-high resolution global models to problems in tropospheric and stratospheric dynamics*. Workshop for the Next Generation Climate Models, Center for Climate System Research, March 2002, Awaji Island, Japan. (Invited)

Hamilton, K.: *Low-latitude gravity waves in high-resolution GCMs: Source variability and wave saturation*. Scientific Committee on Solar-Terrestrial Physics Equatorial Processes Including Coupling Symposium, March 2002, Kyoto, Japan. (Invited)

Hamilton, K.: *Results from a fine-resolution global general circulation model*. World Climate Research Programme GCM–Reality Intercomparison Project Workshop, March 2002, Tsukuba, Japan. (Invited)

Jensen, T.G.: *A model study of exchanges of salt and tracers in the northern and equatorial Indian Ocean*. Eleventh Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, May 2001, San Diego, California.

Jensen, T.G.: *Modeling of the tropical western Pacific and Indian Oceans*. Department of Atmospheric Science, Colorado State University, August 2001, Fort Collins, Colorado. (Invited)

Jensen, T.G., B. Bang, T. Miyama, H. Mitsudera, and T. Qu: *Modeling low-latitude western boundary currents and the Indonesian Throughflow using POM*. POM Users' Workshop, August 2001, Boulder, Colorado.

Jensen, T.G., T. Miyama, B. Bang, H.-W. Kang, Y.-Y. Kim, H. Mitsudera, T. Qu, and A. Ishida: *Bifurcation of the Pacific North Equatorial Current from model simulations and re-analyzed hydrography*. Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawaii.

Kim, Y.Y., and G.L. Weatherly: *Saline water intrusions into the southernmost Mid-Atlantic Bight Shelf*. Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawai'i.

Li, T.: *On the prediction of El Niño*. Workshop on Network System for Monitoring and Predicting ENSO Event and Sea Temperature Structure of the Warm Pool in the Western Pacific Ocean, Asia-Pacific Network for Global Change Research, February 2002, Macao, China. (Invited)

Li, T., and Y. Zhang: *Monsoon-ENSO relationship during the decaying phase of El Niño*. Third International Conference on the Asian Monsoon, December 2001, Okinawa, Japan.

Li, T., T. Hogan, and C.-P. Chang: *Dynamic and thermodynamic regulation of the western Pacific warm pool*. International Forum on Marine Research and Marine Development Strategy in the New Century, June 2001, Qingdao, China.

Li, T., B. Wang, and C.-P. Chang: *Theories on the tropospheric biennial oscillation: A review*. Workshop on Dynamics of Atmospheric and Oceanic Circulation and Climate, April 2001, Yangzhou, China. (Invited)

Li, T., Y. Zhang, and B. Wang: *Why a strong Australian monsoon often follows a strong Indian monsoon*. SCSMEX Conference, April 2001, Shanghai, China.

Li, T., B. Wang, C.-P. Chang, and Y. Zhang: *A theory for the Indian Ocean Dipole*. Eleventh Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, May 2001, San Diego, California. Also given at the Workshop on the Indian Ocean coupled dynamics, December 2001, Tokyo, Japan.

Liu, P., T. Li, B. Wang, and X. Fu: *Monsoonal climate from ECHAM4.6 and CCM3.6.6 with different resolutions and truncations*. The First IPRC Regional Climate Modeling Workshop, October 2001, Honolulu, Hawai‘i.

Loschnigg, J.: *The impacts of climate variability and climate change on disease and human health*. Marine Policy Seminar, SOEST, University of Hawai‘i, September 2001, Honolulu, Hawai‘i. (Invited) Also given at the Japan-U.S. Technology and Space Applications Program Workshop, October 2001, Waikoloa, Hawai‘i. (Invited)

Loschnigg, J.: *Climate variability and disease in the Asia-Pacific region*. Seminar, Department of Meteorology, Reading University, January 2002, Reading, United Kingdom. (Invited)

Loschnigg, J., G. Meehl, P.J. Webster, J. Arblaster, and G.P. Compo: *The Asian monsoon, the tropospheric biennial oscillation and the Indian Ocean zonal mode in the NCAR Climate System Model*. Eighth Scientific Assembly of the International Association for Meteorology and Atmospheric Science, July 2001, Innsbruck, Austria. Also given at the Symposium on Ocean-Atmosphere Coupled Dynamics in the Indian Ocean, December 2001, Tokyo, Japan.

Maximenko, N.A.: *On the Kuroshio meander formation south of Japan*. Tenth Annual Meeting of the North Pacific Marine Science Organization (PICES), October 2001, Victoria, British Columbia, Canada.

McCreary, J.P.: *On the dynamics of intergyre exchange circulations in the Pacific Ocean*. A series of seven lectures as Henry Houghton Lecturer, Massachusetts Institute of Technology, April 2001, Boston, Massachusetts. (Invited)

McCreary, J.P.: *Coupled ocean-atmospheric dynamics*. NCAR Summer Colloquium. July 2001, Boulder, Colorado. (Invited)

McCreary, J.P.: *Dynamics and the large-scale tropical ocean circulation*. NCAR Summer Colloquium, July 2001, Boulder, Colorado. (Invited)

McCreary, J.P.: *Dynamics of the Pacific subsurface countercurrents*. Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawai‘i. (Invited)

McCreary, J.P., P. Hacker, H. Mitsudera, T. Waseda, R. Merrill, Y. Shen, G. Yuan, and Y. Zhang: *The Asia-Pacific Data-Research Center – APDRC*. U.S.-Japan TYKKI Meeting, July 2001, Honolulu, Hawai‘i.

Mitsudera, H.: *Kuroshio path dynamics*. Department of Science, Tohoku University, May 2001, Sendai, Japan.

Mitsudera, H., and T. Waseda: *The mechanism and the impact of the short-term Kuroshio path variation*. Ocean Research Institute, University of Tokyo, May 2001, Tokyo, Japan.

Mitsudera, H., and T. Waseda: *Chaotic advection of Kuroshio coastal waters*. Tenth Annual Meeting of the North Pacific Marine Science Organization (PICES), October 2001, Victoria, British Columbia, Canada.

Mitsudera, H., B. Taguchi, T. Waseda, and T. Qu: *Pathways of the Okhotsk-outflow water into the Subtropical Gyre*. Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawai‘i.

Mitsudera, H., B. Taguchi, Y. Yoshikawa, H. Nakamura, and T. Qu: *Kuroshio/Oyashio System model: Pathways of the Oyashio water*. Japan Oceanographic Society Meeting, Spring meeting, March 2002, Tokyo, Japan.

Nonaka, M.: *What induces the equatorial temperature variability in the Pacific Ocean?* Frontier Research System for Global Change, Frontier Observational Research System for Global Change Annual Symposium, March 2002, Tokyo, Japan.

Nonaka, M., S.-P. Xie, and J.P. McCreary: *Decadal variations of the STC and equatorial SST in a Pacific OGCM.* International Association for Physical Sciences of the Oceans/International Association for Biological Oceanography, October 2001, Mar del Plata, Argentina. Also given at the Symposium on Marine Environment and Climate Change, February-March 2002, Sanya, China. (Invited)

Nonaka, M., S.-P. Xie, and J.P. McCreary: *Sensitivity of equatorial stratification to changes in midlatitude westerly wind*. Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawai‘i.

Potemra, J.T., S.L. Hautala, and J. Sprintall: *Mass storage in the Savu Sea estimated from in-situ and remote observations and a numerical model*. Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawai‘i.

Qu, T.: *Role of ocean dynamics in determining the mean seasonal cycle of the South China Sea surface temperature.* Eleventh Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, May 2001, San Diego, California.

Qu, T.: *Subduction of the North Pacific mode waters in a global GCM*. Fifth Intergovernmental Oceanic Commission/Western Pacific International Scientific Symposium, August 2001, Seoul, Korea.

Qu, T.: *On the effect of eddies on subduction in the North Pacific*. Institute of Oceanology, Chinese Academy of Sciences, September 2001, Qingdao, China.

Qu, T., and R. Lukas: *Monsoon response of the NEC bifurcation latitude in the Pacific*. Symposium on the Ocean-Atmosphere Coupled Dynamics in the Indian Ocean, December 2001, Tokyo, Japan.

Qu, T., and R. Lukas: *Seasonal bifurcation of the North Equatorial Current in the Pacific*. Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawai'i.

Sen, O.L., and Y. Wang: *Evaluation of the land surface model implemented into the IPRC–Regional CM1*. The First IPRC Regional Climate Modeling Workshop, October 2001, Honolulu, Hawai'i.

Small, J.: *Air-sea interactions in tropical instability waves*. Seminar, Oregon State University, January 2002, Corvallis, Oregon.

Small, J.: *The refraction and shoaling of internal solitary waves*. Seminar, Oregon State University, January 2002, Corvallis, Oregon.

Small, J.: *The shoaling of internal solitary waves*. Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawai'i.

Solomon, A., and J.P. McCreary: *Feedbacks between interannual tropical oscillations and decadal extratropical oscillations in an intermediate coupled model of the Pacific basin*. Thirteenth Conference on Atmospheric and Oceanic Fluid Dynamics, June 2001, Breckenridge, Colorado.

Solomon, A., and J.P. McCreary: *Pacific decadal variability due to transport variations in the North Pacific Subtropical Cell*. NOAA Climate Diagnostics Center, December 2001, Boulder, Colorado. (Invited)

Tomita, T., B. Wang, T. Yasunari, and H. Nakamura: *Spatiotemporal structure of the decadal scale variability observed in the global SST and lower-tropospheric circulation fields*. Eleventh Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, May 2001, San Diego, California.

Wang, B.: *How ENSO affects the East Asian monsoon*. The Scientific Conference on the South China Sea Monsoon Experiment, April 2001, Shanghai, China. (Invited)

Wang, B.: *Interannual variability of the Asian-Australian monsoon system*. Asian Monsoons and Global linkages on Milankovitch and sub-Milankovitch timescales, May 2001, Beijing, China. (Invited)

Wang, B.: *East Asian summer monsoon variability*. International Forum on Marine Research and Development Strategy in the New Century, June 2001, Qingdao, China. (Invited)

Wang, B.: *Roles of monsoon-ocean interaction on Asian monsoon variation*. Eighth General Assembly of the International Association for Meteorology and Atmospheric Science, July 2001, Innsbruck, Austria. (Invited)

Wang, B.: *Asian-Australian monsoon anomalies associated with ENSO: Dynamics of the Indian Ocean dipole mode*. Symposium on the Ocean-Atmosphere coupled dynamics in the Indian Ocean, December 2001, Tokyo, Japan.

Wang, B., and S.-I. An: *A mechanism for decadal changes of ENSO behavior: Roles of background wind changes*. Department of Atmospheric Science Seminar Series, UCLA, November 2001, Los Angeles, California. (Invited)

Wang, B., and S.-I. An: *Why the ENSO properties changed in the late 1970s*. The Thirteenth Workshop on Numerical Modeling: Understanding the Climate of Australia and the Indo-Pacific region, November 2001, Melbourne, Australia.

Wang, B., and J.C.-L. Chan: *How strong ENSO events affect tropical storm activity in the western north Pacific*. The Third International Symposium on the Asian Monsoon System, December 2001, Okinawa, Japan. Also given at the Workshop on Network System for Monitoring and Predicting ENSO Event and Sea Temperature Structure of the Warm Pool in the Western Pacific Ocean, Asia-Pacific Network for Global Change Research, February 2002, Macao, China. (Invited)

Wang, B., R. Wu, and X. Fu: *Mechanism of ENSO-monsoon interaction during mature-decay phase of ENSO cycle*. Joint Session of the 24th Conference on Hurricane and Tropical Meteorology and Eleventh Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, May 2001, San Diego, California.

Wang, D., and P. Müller: *Effects of equatorial undercurrent shear on turbulence and waves*. Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawai'i.

Wang, Y.: *An introduction to the IPRC-RegCM*. Seminar, Institute of Atmospheric Physics, April 2001, Beijing, China.

Wang, Y.: *Effect of sea spray evaporation on tropical cyclone boundary layer structure and intensity*. Seminar, Nanjing Institute of Meteorology, April 2001, Nanjing, China. Also given at Shanghai Typhoon Institute, April 2001, Shanghai, China.

Wang, Y.: *Vortex Rossby waves in tropical cyclones*. International Workshop on Dynamics of Atmosphere-Ocean Circulation and Climate, April 2001, Yangzhou, China.

Wang, Y.: *An introduction to the IPRC regional climate modeling system*. Seminar, Center for Clouds, Chemistry, and Climate and Center for Atmospheric Sciences, Scripps Institution of Oceanography, May 2001, La Jolla, California.

Wang, Y.: *Explicit simulation of tropical cyclones*. Seminar, National Taiwan University, October 2001, Taipei, Taiwan.

Wang, Y.: *Regional climate modeling: An overview*. The First IPRC Regional Climate Modeling Workshop, October 2001, Honolulu, Hawai'i.

Wang, Y.: *Vortex Rossby waves and tropical cyclone structure and intensity changes in a full physics model*. Seminar, Department of Atmospheric Sciences, Colorado State University, February 2002, Fort Collins, Colorado.

Wang, Y.: *Vortex Rossby waves in tropical cyclones: A full physics model verification*. Seminar, Department of Atmospheric Sciences, Colorado State University, February 2002, Fort Collins, Colorado.

Wang, Y., and B. Wang: *A regional climate model developed at the IPRC*. Eleventh Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, May 2001, San Diego, California.

Wang, Y., and B. Wang: *Development of the IPRC regional climate model*. The SCSMEX Scientific Conference, April 2001, Shanghai, China.

Wang, Y., O.L. Sen, and B. Wang: *Development of a highly resolved regional climate modeling system at IPRC*. The First IPRC Regional Climate Modeling Workshop, October 2001, Honolulu, Hawai‘i.

Wang, Y., O.L. Sen, and B. Wang: *Simulation of the 1998 severe precipitation event over East Asia with the IPRC regional climate model*. Third US-Korea Joint Workshop on Storm Scale and Mesoscale Weather Analysis and Prediction, February 2002, Boulder, Colorado.

Wang, Y., O.L. Sen, and B. Wang: *Simulation of the 1998 severe precipitation event over East Asia with the regional climate model developed at the International Pacific Research Center*. Workshop on Network System for Monitoring and Predicting ENSO Event and Sea Temperature Structure of the Warm Pool in the Western Pacific Ocean, Asia-Pacific Network for Global Change Research, February 2002, Macao, China. (Invited)

Wang, Y., B. Yang, and B. Wang: *Asymmetric structure and tropical cyclone intensity*. International Conference on Typhoon and Mesoscale Meteorology, October 2001, Taipei, Taiwan.

Waseda, T., and H. Mitsudera: *Chaotic advection of Kuroshio coastal waters*. Ocean Sciences Meeting, February 2002, Honolulu, Hawai‘i.

Waseda, T., and H. Mitsudera: *Chaotic transport of Kuroshio coastal waters into the Kuroshio/Oyashio confluence zone*. Japan Oceanographic Society Spring Meeting, March 2002, Tokyo, Japan.

Waseda, T.: *Kuroshio pathways*. GODAE Workshop, July 2001, Honolulu, Hawai‘i.

Wu, R., and B. Wang: *Air-sea interaction in the summer monsoon onset over the western North Pacific.* Eleventh Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, May 2001, San Diego, California.

Wu, L., and B. Wang: *Movement and vertical coupling of diabatic baroclinic tropical cyclones*. Joint Session of the 24th Conference on Hurricane and Tropical Meteorology and Eleventh Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, May 2001, San Diego, California.

Xie, S.-P.: *Origin of equatorial asymmetry of the tropical climate*. Seminar, College of Earth & Atmospheric Science, Georgia Institute of Technology, April 2001, Atlanta, Georgia.

Xie, S.-P.: *Origin of South Indian Ocean variability*. Seminar, CSIRO Marine Research, July 2001, Hobart, Australia.

Xie, S.-P.: *Role of local air-sea interaction in tropical Atlantic variability*. CLIVAR Workshop on Tropical Atlantic Variability, September 2001, Paris, France. (Invited)

Xie, S.-P.: *Air-sea interaction over cool oceans*. Japan Marine Science and Technology Center, December 2001, Yokosuka, Japan.

Xie, S.-P.: *Hawaiian Islands cast a long shadow in the Pacific Ocean*. School of Environmental Earth Science, Hokkaido University, December 2001, Sapporo, Japan. Also given at the Center for Climate System Research, University of Tokyo, December 2001, Tokyo, Japan; and the Frontier Research System for Global Change, December 2001, Yokohama, Japan.

Xie, S.-P., H. Annamalai, F.A. Schott, and J.P. McCreary: *Coupled Rossby wave in the tropical South Indian Ocean*. Symposium on the Ocean-Atmosphere Coupled Dynamics in the Indian Ocean, December 2001, Tokyo, Japan.

Xie, S.-P., H. Annamalai, F.A. Schott, and J.P. McCreary: *Structure and mechanism of South Indian Ocean climate variability*. Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawai‘i.

Xie, S.-P., W.T. Liu, Q. Liu, and M. Nonaka: *Far-reaching effects of the Hawaiian Islands on the Pacific Ocean-atmosphere*. International Forum on Marine Research, June 2001, Qingdao, China. (Invited) Also given at the IEEE Geoscience and Remote Sensing Symposium, July 2001, Sydney, Australia. (Invited)

Xie, S.-P., W.T. Liu, Q. Liu, and M. Nonaka: *Long wake of the Hawaiian Islands*: Evidence for ocean-atmosphere interaction. NASA Oceanographic Conference, April 2001, Miami Beach, Florida.

Yaremchuk, M., and N. Maximenko: *A dynamically consistent analysis of mesoscale currents at the North Pacific Subarctic Front.* Seminar at the Stennis Space Center, March 2002, Stennis, Mississippi.

Yaremchuk, M., and D. Nechaev: *Reconstruction of the large-scale circulation in the Arctic Ocean*. International Arctic Research Center, Cooperative Institute for Arctic Research, October 2001, Boulder, Colorado.

Yaremchuk, M., and K. Lebedev: *Inverse modeling of seasonal variability in the subtropical North Pacific*. Fall Meeting of the American Geophysical Union, December 2001, San Francisco, California.

Yaremchuk, M., and N. Maximenko: *Mesoscale processes at the Subarctic Front in the northwestern Pacific Ocean*. Ocean Sciences Meeting, American Geophysical Union, February 2002, Honolulu, Hawai‘i.

Yaremchuk, M.: *Data assimilation activities at IPRC*. The International Workshop on GODAE (Global Ocean Data Assimilation Experiment) with Focus on the Pacific, July 2001, Honolulu, Hawai‘i.

Yu, Z.: *Validating precipitation products using an ocean model*. The International Workshop on Dynamics of Atmosphere-Ocean Circulation and Climate, April 2001, Yangzhou, China. (Invited)

Yu, Z.: *Simulating surface salinity using freshwater fluxes*. WCRP/SCOR Workshop on Intercomparison and Validation of Ocean-Atmosphere Flux Fields, May 2001, Washington D.C.

Yuan, G., H. Mitsudera, H. Fujimori, Y. Yoshikawa, T. Nakamura, and I. Nakano: *Barotropic currents and tides in the Kuroshio Extension region from long-range reciprocal acoustic transmissions*. The 142nd Meeting of the Acoustical Society of America, December 2001, Fort Lauderdale, Florida.

Zhang, Y., T. Li, B. Wang, and G. Wu: *The interannual variations of the summer monsoon onset over Indochina Peninsula and Tropical Pacific SSTs*. Eleventh Conference on Interaction of the Sea and Atmosphere, American Meteorological Society, May 2001, San Diego, California.

Meetings

THE FIRST IPRC SYMPOSIUM

The IPRC held its first in a series of planned annual symposia to review the year's research highlights on June 5 and 6, 2001, at the East-West Center in Honolulu. The symposium featured presentations by IPRC scientists and several IPRC affiliates. Talks on Pacific Ocean climate and circulation covered such topics as the dynamics underlying the Tsuchiya Jets, the formation sites of North Pacific Mode Water, the contribution of equatorial and off-equatorial winds to equatorial decadal SST variations, and an analysis of the atmosphere's response to the cold meanders in the Pacific associated with tropical instability waves. Talks on the Indian Ocean dealt with the nature of cross-equatorial flows and water exchange between the Bay of Bengal and the Arabian Sea. Regarding the western boundary currents, reports included evidence for a new Kuroshio large-meander-formation mechanism involving interaction with an anticyclonic eddy, a new index for analyzing Kuroshio path variations that revealed the importance of deep circulation in the large meander development, and discovery of an Oyashio water pathway from the subarctic to the subtropics. Among the reports on the Asian-Australian monsoon system, three dealt with simulations of monsoon climatology using different coupled GCMs. The simulations revealed the impact of air-sea interactions over the Indian Ocean on the monsoon. A presentation on simulating the East Asian monsoon with the newly developed IPRC Regional Climate Model showed realistic and promising results.

THE INTERNATIONAL WORKSHOP ON GODAE WITH FOCUS ON THE PACIFIC

The International Workshop on GODAE, hosted by the IPRC at the East-West Center July 23–25, 2001, was held to determine the tasks that still needed to be accomplished in the northern and tropical Pacific over the next two to three years in order to conduct the Global Ocean Data Assimilation Experiment (GODAE). The experiment, planned for 2003–2005, is intended to demonstrate that a synthesis of satellite and direct measurements can provide real-time global ocean data assimilation that yields regular and realistic descriptions of ocean salinity, temperature, and currents at high temporal and spatial resolutions. About 50 scientists from Australia, China, Japan, Korea, and the US discussed existing observing systems and data assimilation schemes, methods for assimilating global and coastal ocean data, methods for linking large- and meso-scale assimilation products, selection of data and model products for the experiments, and metrics to assess the quality of model assimilation products for the North Pacific and the adjacent seas. Workshop conveners were Toshiyuki Awaji (Kyoto University, Ming Ji (NOAA National Center for Environmental Protection) and Humio Mitsudera (IPRC).

THE FIRST IPRC REGIONAL CLIMATE MODELING WORKSHOP

To facilitate the development of regional climate models, the IPRC hosted its first regional climate modeling workshop at the East-West Center in Honolulu October 10–12. Regional climate models represent more realistically and in finer detail the atmospheric circulation, surface features (topography, lakes, coastlines and vegetation, etc.) and their effects on regional climate. These models are therefore useful tools for understanding and making predictions about regional climates, but they are still in a fairly early developmental phase. At the workshop, Japanese, Chinese, and US scientists shared their different approaches to regional climate modeling, among other things noting difficulties and ways to overcome them. Discussion topics included assessments of various cloud and convection schemes, and the surface boundary-layer processes that must be included in the models and schemes to represent these processes. Possibilities for collaboration among the various regional climate research groups were discussed. Workshop organizers were C.-W. Wang, State University of New York at Albany, and Bin Wang, Yuqing Wang, and Lorenz Magaard from the IPRC.

THE PACIFIC CLIMATE AND FISHERIES WORKSHOP

The Pacific Climate and Fisheries Workshop, hosted by the IPRC from November 14 to 17, 2001, at the East-West Center in Honolulu, was convened to shed more light on the interaction between Pacific Ocean climate and ecosystems, especially fish ecosystems. From around the world, experts in ocean climate, ecology, fish biology and fisheries management, and social science worked together to determine how to integrate research on climate variability and marine ecology with sustainable fishery management and societal and political concerns. The workshop alternated between plenary discussions and smaller focus-group discussions to facilitate the development of common terminologies, common goals, and common frameworks among these experts with such diverse professional backgrounds. Among the questions discussed were the following: What kind of climate information is useful to fisheries management? Just what constitutes a shift in the marine ecosystem? What mechanisms drive regime shifts, and just what indices provide useful measures. There was consensus that more research is needed in these areas, and the foundation was laid for future interdisciplinary climate-fisheries projects. Lorenz Magaard conceived the workshop and organized workshop logistics. Andrew Bakun (International Research Institute for Climate Prediction, IRI) and Kenneth Broad (University of Miami) developed and organized the workshop program. Jürgen Alheit (Baltic Sea Research Institute) was plenary discussion leader. The IRI and IPRC were primary workshop sponsors.

THE NINTH ANNUAL MEETING OF THE SPARC SCIENTIFIC STEERING GROUP

The IPRC hosted the Ninth Annual Meeting of the Scientific Steering group of SPARC (Stratospheric Processes and their Role in Climate) December 3–6, 2001, at the Tokai University Honolulu Campus. SPARC, one of the 6 main initiatives of the World Climate Research Programme, focuses on understanding and modeling the circulation and chemistry of the stratosphere, and how they affect and are affected by tropospheric climate and climate change. Among the topics discussed were plans for a more integrative assessment of observed trends in stratospheric temperature, ozone, water vapor, and aerosol concentrations and the coinciding changes in atmospheric composition; a SPARC-sponsored effort to rescue, archive, and analyze the wind and temperature data from radiosondes that have been archived only at levels mandated by the World Meteorological Organization (which means that useful information about the atmosphere may have been discarded); SPARC's reaction to the recent surge of interest in the relationship between large-scale stratospheric and tropospheric circulation. Marvin Geller (Stony Brook University) and Alan O'Neill (University of Reading) were co-chairs of the meeting. Kevin Hamilton (IPRC) was the local host.

SYMPOSIUM ON THE OCEAN-ATMOSPHERE COUPLED DYNAMICS IN THE INDIAN OCEAN

The Symposium on the Ocean-Atmosphere Coupled Dynamics in the Indian Ocean, jointly organized by the Frontier Research System for Global Change and the IPRC, took place December 17–19, 2001, in Tokyo. The central theme of the symposium was the Indian Ocean Dipole Mode, or IOD, which is a contrast in sea surface temperature (SST) in the tropical eastern and western Indian Ocean. While only one coupled general circulation modeling group reported success in reproducing the IOD at a similar symposium a year before, now five groups presented successful simulations. Scientists at the symposium generally agreed that the cooling of SST in the eastern equatorial Indian is associated with a major shift in atmospheric convection and ocean circulation; under debate was the nature of the link between this cooling and SST in the western Indian Ocean. Observations show a significant correlation between the IOD and the El Niño-Southern Oscillation, but only during boreal fall. One school holds that the variance explained by this relationship is small and that the IOD is a mode intrinsic to the Indian Ocean, whereas the other holds that this seasonal correlation is evidence for a seasonal effect of ENSO on the IOD. Toshio Yamagata (FRSGC) and Julian McCreary (IPRC) convened the symposium, which was attended by scientists from around the world.

CLIVAR PACIFIC IMPLEMENTATION PANEL

The IPRC hosted the first meeting of the CLIVAR Pacific Implementation Panel at the East-West Center, February 7–9, 2002. The purpose of the Panel, a subgroup of CLIVAR International, one of the 6 main initiatives of the World Climate Research Programme, is to provide an overview and coordination of Pacific climate research, spot gaps and weaknesses in the research, convene meetings for discussions of key issues, and communicate deliberations to the external community. The panel reviewed projects related to CLIVAR-Pacific activities and carried out by Pacific Rim nations: the international Argo project, which at the time consisted of over 700 free-drifting floats measuring ocean temperature and salinity to a 2000-m-depth; the new Global Ocean Timeseries Observing System, a long-term mooring system collecting data for marine ecologists, oceanographers, meteorologists, and solid-earth geophysicists; the East Pacific Investigation of Climate, which is producing interesting data on the ocean-atmosphere boundary layer; and the Pacific Basin Extended Climate Study, a long-term experiment to test and improve dynamical models of ocean processes causing climate variability. The Panel was also briefed on several studies in the planning phase, including the Kuroshio Extension System Study and the Hemispheric Observing System Research and Predictability Experiment, and on activities that are of significance to CLIVAR Pacific, such as the IPRC Asia-Pacific Data-Research Center and the biogeochemical-carbon research programs. Kelvin Richards, chair of CLIVAR Pacific, and John Gould, International CLIVAR Director convened the meeting.

Honors

Lorenz Magaard

Marine Technology Society Fellow, Pacific Congress on Marine Science and Technology, November 2001

Julian P. McCreary, Jr.

Henry G. Houghton Lecturer, Center for Meteorology and Physical Oceanography, Massachusetts Institute of Technology, April 2001

Masami Nonaka

Outstanding Research Accomplishments for the Year 2001 Award, Frontier Research System for Global Change, March 2002

Shang-Ping Xie

Outstanding Collaborative Research Prize, Ocean University of Qingdao, June 2001

IPRC Seminars

Date	Speaker	Affiliation	Seminar Title
*04/19/2001	Alan Robock	Department of Environmental Sciences, Rutgers University, New Brunswick, New Jersey, U.S.A.	*Volcanic eruptions and climate: Winter warming and summer cooling*
*04/20/2001	Georgiy Stenchikov	Department of Environmental Sciences, Rutgers University, New Brunswick, New Jersey, U.S.A.	*Sensitivity of Arctic Oscillation to volcanic aerosols and Quasi-Biennial Oscillation*
*04/23/2001	Alan Robock	Department of Environmental Sciences, Rutgers University, New Brunswick, New Jersey, U.S.A.	*Soil moisture observations for remote sensing, model evaluation, and climatic analysis*
05/08/2001	Tomoo Watanabe	Tohoku National Fisheries Research Institute, Shiogama, Japan	*Interannual variations in the western Subarctic Gyre*
06/01/2001	Masaru Inatsu	Graduate School of Environmental Earth Science, Hokkaido University, Sapporo, Japan	*Zonal variations in the westerly jet and storm tracks in an idealized AGCM*
06/04/2001	Richard Pridmore and James Renwick	National Institute of Water & Atmospheric Research (NIWA), Hamilton, New Zealand	*Ocean and climate research at NIWA/New Zealand*
06/12/2001	Kwang-Yul Kim	Department of Meteorology, Florida State University, Tallahassee, Florida, U.S.A.	*What are cyclostationary EOFs? Concepts and Applications*
06/29/2001	Vikram Mehta	Earth System Science Interdisciplinary Center, University of Maryland, Baltimore, U.S.A.	*Natural decadal-multidecadal variability in the Indo-Pacific Warm Pool and its implications for global climate variability*
07/10/2001	Leland Jameson	Hydrodynamics and Turbulence Theory and Simulation Group, Lawrence Livermore National Laboratory, Livermore, U.S.A.	*Nested grids and higher order schemes*
08/01/2001	Erich Roeckner	Max Planck Institute for Meteorology, Hamburg, Germany	*Simulating the past and future climate with a coupled GCM*
08/07/2001	Amita V. Mehta	NASA Joint Center for Earth Systems Technology, University of Maryland, Baltimore, Maryland, U.S.A.	*Interannual variability of upper tropospheric water vapor as seen from NASA/NOAA Pathfinder Path A Project*
08/08/2001	Mezak A. Ratag	Climate Modeling Division, Indonesian National Institute of Aeronautics and Space (LAPAN), Bandung, Indonesia	*High-resolution nested climate modeling using DARLAM*

Date	Speaker	Affiliation	Seminar Title
08/09/2001	William Lau	Climate & Radiation Branch, NASA-GSFC, Greenbelt, Maryland, U.S.A.	*The Asian Monsoon - North Pacific Climate Regulator*
**08/22/2001	Niklas Schneider	Scripps Institution of Oceanography University of California, La Jolla, California, U.S.A.	*Pacific decadal variability: dynamics and predictability*
**09/18/2001	Le Ly	Department of Oceanography, Naval Postgraduate School, Monterey, California, U.S.A.	*Air-wave-sea coupling and its application to coastal ocean modeling with numerical grid generation*
09/25/2001	Friedrich Schott	Institute for Marine Research, University of Kiel, Kiel, Germany	*Monsoon response of the Arabian Sea and role of the annual Rossby wave*
10/02/2001	Gabriel A. Vecchi	Joint Institute for the Study of the Atmosphere and Oceans, University of Washington, Seattle, Washington, U.S.A.	*Southwest monsoon breaks and sub-seasonal SST variability in the Bay of Bengal*
10/08/2001	Friedrich Schott	Institute for Marine Research, University of Kiel, Kiel, Germany	*Recent changes in North Atlantic water mass transformation and possible relations to the Tropics and climate*
*10/09/2001	Jeff Tilley	Geophysical Institute and International Artic Research Center, University of Alaska, Fairbanks, U.S.A.	*Regional modeling activities at the University of Alaska Geophysical Institute and International Arctic Research Center*
10/16/2001	Jong-Ghap Jhun	Atmospheric Sciences Program, School of Earth and Environmental Sciences, Seoul National University, Seoul, Korea	*Teleconnection between the climatic elements in East Asia and the Tropics*
10/23/2001	Lorenz Magaard	International Pacific Research Center, SOEST, University of Hawai'i, Honolulu, Hawai'i, U.S.A.	*My trip to applied climatology*
*11/14/2001	H. Annamalai	International Pacific Research Center, SOEST, University of Hawai'i, Honolulu, Hawai'i, U.S.A.	*Coupled dynamics in the Indian Ocean: Externally or internally Forced?*
*11/28/2001	Christopher W. Landsea	Hurricane Research Division, NOAA Atlantic Oceanographic & Meteorological Laboratory, Miami, Florida, U.S.A.	*How much 'skill' was there in forecasting the strong 1997-98 El Niño and 1998-2001 La Niña events?* *AND* *The recent increase in Atlantic hurricane activity: Causes and implications*
*12/03/2001	David Karoly	Mathematical Sciences, Monash University, Clayton, Australia	*Describing global climate variability and change using simple indices*
12/20/2001	Mingfang Ting	Department of Atmospheric Sciences, University of Illinois, Champaign, Illinois, U.S.A.	*Atmospheric responses to a midlatitude heat source in an anomaly atmospheric model*

Date	Speaker	Affiliation	Seminar Title
*01/07/2002	Song-You Hong	Department of Atmospheric Sciences, Yonsei University, Korea	*The 1998 Oklahoma-Texas drought: Mechanistic experiments with the NCEP global and regional models AND An evaluation of the WRF model for a heavy rainfall case over East Asia*
***01/10/2002	Claude Frankignoul	University Pierre et Marie Curie, Paris, France	*Sea surface temperature variability and larg- scale air-sea interactions*
01/15/2002	Chun-Chieh Wu	National Taiwan University, Taipei, Taiwan	*Observing-systems stimulation experiments for tropical cyclone initialization based on the four-dimensional variation data assimilation*
01/22/2002	George N. Kiladis	Climate Diagnostic Center, NOAA Aeronomy Lab, Boulder, Colorado, U.S.A.	*Observed structure of equatorial waves coupled to convection*
02/04/2002	Philip Jones	Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico, U.S.A.	*The Parallel Ocean Program (POP): Status, plans and simulation results*
02/15/2002	Peter Chu	Naval Postgraduate School, Monterey, California, U.S.A.	*New development in coastal ocean analysis and prediction*
02/19/2002	Carsten Eden	Department of Oceanography, Dalhousie University, Halifax, Canada	*Prospects for decadal prediction of the NAO*
02/19/2002	Yanli Jia	Southampton Oceanography Centre, University of Southampton, Southampton, United Kingdom	*The Mediterranean overflow and its influence on the North Atlantic circulation in a global ocean model*
02/21/2002	Jürgen Sündermann	Institute of Oceanography, University of Hamburg, Hamburg, Germany	*Circulation and transport in the Bohai Sea*
02/26/2002	Jong-Ghap Jhun	Seoul National University, Seoul, Korea	*Some characteristics of the East Asian winter monsoon*
***03/04/2002	Jimsong von Storch	Institute for Coastal Research, GKSS Research Center, Geesthacht, Germany	*Angular momentum budgets and planetary modes*
03/12/2002	Wolf Dieter Grossmann	UFZ Center for Environmental Research, Leipzig/Halle, Germany	*Coupled sociological–physical climate modeling: Background and outlook*
03/14/2002	Hans von Storch	Institute for Coastal Research, GKSS Research Center, Geesthacht, Germany	*The art and role of climate modeling*

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

Visiting Scholars

To promote collaboration with scientists at other climate research institutions, the IPRC has a visiting scholar program. From April 2001 to March 2002, the IPRC sponsored the scholars listed below.

Name	Affiliation	Dates
Tomoo Watanabe	Tohoku University, Sendai, Japan	5/7–5/13/2001
Masaru Inatsu	Hokkaido University, Sapporo, Japan	5/10–6/4/2001
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Amita Mehta	NASA Joint Center for Earth Systems Technology, University of Maryland, Baltimore, Maryland, U.S.A.	6/18–8/15/2001
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Erich Roeckner	Max Plank Institute for Meteorology, Hamburg, Germany	7/23–8/24/2001
Mezak Ratag	Indonesian National Institute of Aeronautics and Space (LAPAN), Bandung, Indonesia	8/5–8/11/2001
William Lau	NASA Goddard Space Flight Center, Greenbelt, Maryland, U.S.A.	8/7–8/18/200
Jong-Ghap	Jhun Seoul National University, Seoul, Korea	8/1/2001–2/28/2002
Chih Pei Chang	Naval Postgraduate School, Monterey, California, U.S.A.	8/20–8/24/2001
Tomohiko Tomita	Frontier Research System for Global Change, Tokyo, Japan	9/10–9/14/2001
Le Ly	Naval Postgraduate School, Monterey, California, U.S.A.	9/14–9/23/2001
Friedrich Schott	University of Kiel, Kiel, Germany	9/14–10/12/2001
Gabriel Vecchi	University of Washington, Seattle, Washington, U.S.A.	9/30–10/15/2001
Willa Zhu	NOAA Pacific Marine Environmental Laboratory, Seattle, Washington, U.S.A.	10/28–11/4/2001
Yiming Liu	China Meteorological Administration, Beijing, China	10/13–10/18/2001
Jae-Yul Yun	Korea Ocean Research and Development Institute, Seoul, Korea	11/1/2001–1/31/2002
Jong-Seong Kug	Seoul National University, Seoul, Korea	12/16/2001–3/25/2002

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Pearn Niiler	Scripps Institute of Oceanography, University of California, La Jolla, California, U.S.A.	12/20/2001–1/7/2002
Claude Frankignoul	University of Pierre et Marie Curie, Paris, France	1/8–1/14/2002
In-Sik Kang	Seoul National University, Seoul, Korea	1/10–2/10/2002
Chun-Chieh Wu	National Taiwan University, Taipei, Taiwan	1/11–1/20/2002
Phillip Jones	Los Alamos National Laboratory, Los Alamos, New Mexico, U.S.A.	2/3–2/8/2002
Hiroki Tokinaga	Hokkaido University, Sapporo, Japan	2/11–2/15/2002
Raghu Murtugudde	University of Maryland, Baltimore, Maryland, U.S.A.	2/11–2/15/2002
Jürgen Sündermann	University of Hamburg, Hamburg, Germany	2/11–2/25/2002
Wolf Dieter Grossmann	UFZ Center for Environmental Research, Leipzig and Halle, Germany	2/12–3/18/2002
Hans von Storch GKSS,	Geesthacht, Germany	2/18–3/18/2002
Yong-Ti Zhu	Shanghai Meteorological Bureau, Shanghai, China	3/1–5/31/2002
Felix Seidel	Swiss Federal Institute of Technology, Zürich, Switzerland	3/11–5/5/2002

Grants

INSTITUTIONAL

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	$3,132,230	04/01–03/02
Frontier Research System for Global Change: Support of Research at the International Pacific Research Center	J.P. McCreary	NASDA	$721,015	04/01–03/02
Establishment of a Data and Research Center for Climate Studies	J.P. McCreary P. Hacker R. Merrill H. Mitsudera T. Waseda	NOAA	$515,000	10/01–09/02
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
Support of Research at the International Pacific Research Center	L. Magaard	NASA	$1,000,000	05/98–04/01

INDIVIDUAL

Title	P.I./Co-P.I.	Agency	Amount	Period
Observation and Dynamics of the Indonesian Throughflow	J.T. Potemra	University of Washington (NSF)	$35,396	03/02–02/03
Dynamical Control of Rapid Tropical Cyclone Intensification by Environmental Shears	B. Wang Y. Wang T. Li	ONR	$794,658	01/02–12/04
Quasi-biennial Oscillation Modulation of Eddies in the Tropical Stratosphere	K. Hamilton	NASA	$108,287	10/01–09/04
Mechanisms for the Northward Displacement of the Pacific ITCZ	S.-P. Xie T. Li	NSF	$281,955	09/01–08/04

Title	P.I./Co-P.I.	Agency	Amount	Period
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
Remote Forcing of the US Warm Season Rainfall and Eastern Pacific Climate	B. Wang X. Fu	NOAA/PACS	$365,981	09/01–06/04
Dynamics of the Indian Ocean Dipole	T. Li	NPS	$25,000	08/01–08/02
Effects of the Andes on the Eastern Pacific Climate	S.-P. Xie Y. Wang	NOAA	$277,191	07/01–06/04
Roles of Ocean-Atmosphere-Land Interaction in Shaping Tropical Atlantic Variability	S.-P. Xie	NOAA	$245,004	07/01–06/04
Low-latitude Western Boundary Current in the Pacific	J. P. McCreary T. Qu H. Mitsudera T. Jensen T. Miyama	NSF	$458,538	02/01–01/04
Biennial and Interdecadal Variations of the Tropical Pacific Ocean	B. Wang S.-I. An	NOAA/ PACIFIC	$315,000	11/00–10/03
An Investigation of Tropical Convection and Atmospheric General Circulation Using Ensemble Aqua-Planet Experiments	Y.-Y. Hayashi A. Numaguti M. Ishiwatari K. Nakajima S.-P. Xie	Japan Society for the Promotion of Science	$78,000	07/00–03/03
An Investigation of Monthly Wind Variability in the Eastern Equatorial Pacific Using the SeaWinds, *In-situ* Observations and Numerical Modeling	S.-P. Xie	NASA	$377,487	05/00–04/04
Dynamics of the Boreal Summer Intraseasonal Oscillation	B. Wang T. Li	NSF	$400,000	04/00–03/03
Support Services, Logistics and Facilities Associated with the Decadal Climate Variability Workshop hosted by IPRC	L. Magaard	NASA	$25,000	12/00–04/01
Effects of Convective Heating on Tropical Cyclone Motion	B. Wang	ONR	$223,802	01/00–12/01
Physical Processes Determining the Annual Cycle of the Cold tongue / ITCZ Complex	B. Wang	NOAA/PACS	$345,000	05/97–04/01
Impacts of the Asian Monsoon on ENSO	B. Wang	NOAA	$318,000	07/97–06/01

Acronyms

AAIW
Antarctic Intermediate Water

A-AMS
Asian-Australian Monsoon System

ADCP
Acoustic Doppler Current Profiler

APDRC
Asia-Pacific Data-Research Center

ASM
Asian Summer Monsoon

AT
Acoustic Tomography

BATS
Biosphere-Atmosphere Transfer Scheme

CEC
Cross-Equatorial Cell

CLIVAR
Climate Variability and Predictability Project

CMAP
Climate Modeling Analysis and Prediction

CPU
Central Processing Unit

CSEOF
CycloStationary EOF

CSIRO
Commonwealth Scientific and Industrial Research Organisation

CSIVD
Complex Singular Value Decomposition

CSM
Climate System Model

CTD
Conductivity, Temperature, and Depth

DLT
Digital Linear Tapea

DODS
Distributed Ocean Data System

DSS
Data Server System

ECHAM
European Center–Hamburg Atmospheric Model

ECMWF
European Centre for Medium-Range Weather Forecasts

EEIO
Eastern Equatorial Indian Ocean

ENSO
El Niño–Southern Oscillation

EOF
Empirical Orthogonal Function

ERS
European Remote Sensing Satellite

FRSGC
Frontier Research System for Global Change

GB
Gigabytes

GCM
General Circulation Model

GDS
GrADS DODS Server

GFLOPS
Giga Floating Point Operations

GODAE
Global Ocean Data Assimilation Experiment

GrADS
Grid Analysis and Display System

GWR
Gravity-Wave Retardation

HLCC
Hawaiian Lee Countercurrent

IOD
Indian Ocean Dipole

IOZM
Indian Ocean Zonal Mode

IPRC-RegCM
IPRC Regional Climate Model

ISO
Intraseasonal Oscillation

ITCZ
Intertropical Convergence Zone

ITF
Indonesian Throughflow

JAMSTEC
Japan Marine Science and Technology Center

JGOF
Joint Global Ocean Flux

KE
Kuroshio Extension

LAN
Local Area Network

LAS
Live Access Server

LASG
Institute of Atmospheric Physics, Chinese Academy of Sciences

LES
Large-Eddy Simulations

LLWB
Low-Latitude Western Boundary

LM
Large Meander

MEXT
Ministry of Education, Culture, Sports, Science and Technology

MICOM
Miami Isopycnic Coordinate Ocean Model

MOM
Modular Ocean Module

NASA
National Aeronautics and Space Administration

NASDA
National Space Development Agency of Japan

NCAR
National Center for Atmospheric Research

NCEP
National Centers for Environmental Prediction

NEC
North Equatorial Current

NOAA
National Oceanic and Atmospheric Administration

NPIW
North Pacific Intermediate Water

NPS
Naval Postgraduate School

NSF
National Science Foundation

NVODS
National Virtual Ocean Data System

ONR
Office of Naval Research

PBL
Planetary Boundary Layer

PDO
Pacific Decadal Oscillation

PMEL
Pacific Marine Environmental Laboratory

POM
Princeton Ocean Model

POP
Parallel Ocean Program

PSAC
Philippine Sea Anticyclone

QBO
Quasi-Biennial Oscillation

QuikSCAT
Quick Scatterometer

RAID
Redundant Array of Independent Disks

RISC
Reduced-Instruction-Set Computing

SAN
Storage Area Network

SEEK
Singular Evolutive Extended Kalman

SIO
South Indian Ocean

SODA
Simple Ocean Data Assimilation

SOEST
School of Ocean and Earth Science and Technology

SOI
Southern Oscillation Index

SPARC
Stratospheric Processes and Their Role in Climate

SST
Sea Surface Temperature

STC
Subtropical Cell

Sv
Sverdrup

SVD
Singular Value Decomposition

TAO
Tropical Atmospheric Ocean

TB
Tera Bytes

TBO
Tropospheric Biennial Oscillation

TIO
Tropical Indian Ocean

TIW
Tropical Instability Waves

TOGA
Tropical Ocean–Global Atmosphere

TOMS
Thermodynamic Ocean Modeling System

TRMM
Tropical Rainfall Measuring Mission

UH
University of Hawai'i

WNP
Western North Pacific

WOCE
World Ocean Circulation Experiment

XBT
Expendable Bathothermograph

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