INTERNATIONAL PACIFIC RESEARCH CENTER

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Contents

本年度の重要な業績

今回で五回目となる本報告では、IPRC の 2003 年 3 月から 2004 年 4 月までの活動について概説する。この期間は、アジア・太平洋の気候に影響している大気及び海洋のプロセスを理解するという目標へ向けて相当の進展があった。研究員による研究活動は IPRC の活動の中核をなすものであるから、本報告書では IPRC の研究員による個々の成果についても記す。さらに、以下の項目について一覧を掲載する。1)IPRC の研究者による論文や研究発表、2)IPRC 主催の研究集会、3) 共同研究のために IPRC を訪問したり IPRC に滞在したりした研究者、4)IPRC 全体、または個々の研究者が得た外部資金。さて、本序文では以下に過去一年の重要な業績を幾つか紹介する。

大気海洋相互作用の理解に関しては、幾つものプロジェクトがこれに貢献した。あるプロジェクトでは衛星観測の解析により、メキシコ湾流、ソマリ海流、黒潮、太平洋赤道前線といった北緯 40 度から南緯 40 度にかけての海面温度勾配の大きい地域では、海面水温と風速の間の関係が正の相関関係によって特徴づけられることを示した。これは海洋から大気へのフィードバックを示すものである。このパターンは、海洋混合層が大気の強制を受け大規模スケールでは顕著な負の相関関係があることと対照をなしている。さらに海洋前線の大気へのこの効果は、大気境界層を超えストームトラックに影響を与えている可能性もある。また別のプロジェクトでは、新しい衛星観測による解析によって、中央アメリカの山地の谷間から吹き出してくる北東風ジェットが、その地域の暖水域の南端まで東太平洋の降水帯を移動させることを明らかにした。このようなジェットは海洋に影響を及ぼし、その影響が一年以内に大気に返ってくる。例えば、ニカラグアとコスタ・リカの国境に沿った谷間から吹き出してくるパパガヨ北東風により上昇流を伴うロスビー波が海洋に形成される。その上昇流のため温度躍層が海面近くに持ち上げられ、コスタリカ・ドームと呼ばれる海面水温の低い領域が出来る。すると、夏の東太平洋暖水域の降水帯に直径 500 km にも亙る雨の少ない領域がはっきりと現れることとなる。

インド洋の海面水温が周辺や遠方の気候に与える影響は、その重要性が気候学の世界で益々注目されてきている。IPRC で行なわれた研究は、インド洋ダイポール (海面水温の東西勾配) が南アメリカや東アフリカのような遠く離れた所の異常な地表面温度に関連しているという知見に合致するものであった。インド洋の海面水温偏差は蓄熱の働きをするので、エルニーニョの消失が始まってからも数ヶ月間は北太平洋西部の雲や大気循環にエルニーニョの影響を与え続ける。この機構によって、インド洋の海面水温偏差がエルニーニョの与える効果を変える可能性すらあるということが、数値モデル実験で示された。そのため、インド洋の状況に基づく数ヶ月後の気候予測も実現可能かもしれない。

南シナ海を調べた研究も幾つかある。南シナ海は縁辺海であり、地域気候に影響を与えていることが知られている。ある研究では、夏季モンスーン期間中の、インドシナ半島の山脈の谷間、風、南シナ海の冷却の間の関連が明らかになった。別の二つの研究においては、エルニーニョ期間中、西部太平洋の海洋の状態がルソン海峡を経て伝わり、やがて南シナ海の表面温度に影響することを示した。しかしながら、また別の研究では、モデル中での南シナ海の上層循環は使用される海上風データの種類に非常に敏感であることを発見した。従って、この地域における風外力を研究する際には、海上風データを慎重に選ばなければならない。

IPRC の研究者は**熱帯低気圧**の研究に関するプロジェクトを幾つか行った。あるプロジェクトでは、台風の目の壁雲の構造、さらには観測で時々見られる壁雲の二重構造さえも数値実験で再現することができた。衛星観測を使用した別の研究では、西太平洋で熱帯低気圧が形成される二つの異なったプロセスが立証され、後に数値モデルで再現された。現在、このモデルは、その地域の台風予測のために重要な要素であるところの、熱帯低気圧が強まるための条件や衰退するための条件を研究することに使用される予定である。

地球温暖化に対する**気候感度**の研究では、気候強制がある閾値 (現在の太陽常数の約 25% 増加に相当) を超

The Year's Highlights

This fifth report of the International Pacific Research Center (IPRC) provides an overview of the center's activities from April 2003 to March 2004, a year that has seen considerable progress toward our goal of understanding the air and sea processes that affect Asia-Pacific climate. The report describes individual accomplishments of our scientists, whose research activities are the heart of the IPRC. Also included are lists of research publications and presentations by IPRC scientists, IPRC meetings, scholars that visited the IPRC to work with us, and funding sources both for the center and for individual IPRC scientists. In this introduction, I touch upon a few highlights from the past year.

Several projects contributed to understanding *air-sea interactions*. In one project, analyses of satellite observations showed that between 40°N and 40°S around the globe, regions of sharp sea surface temperature gradients—such as the Gulf Stream, Somali, and Kuroshio currents, and the Pacific equatorial front—are characterized by a positive correlation between sea surface temperature and wind speed, which is indicative of ocean-to-atmosphere feedback. This pattern contrasts with the negative correlation prevalent on the basin-scale that is attributed to atmospheric forcing of the ocean mixed layer. Moreover, this effect of ocean fronts on the atmosphere may extend upward beyond the boundary layer, modulating storm tracks. In another project, analyses of new satellite observations revealed that northeasterly jets, emanating from gaps in the Central American mountain ranges, displace the eastern Pacific rain band to the southern edge of the region's warm pool. These wind jets impact the atmosphere later in the year through their effect on the ocean. For example, the Papagayo jet, which passes through a mountain gap along the border between Nicaragua and Costa Rica, forces upwelling-favorable oceanic Rossby waves that lift the thermocline closer to the sea surface, causing a surface cooling called the Costa Rica Dome. During the summer, cool sea surface temperatures within the dome punch a conspicuous 500-km hole into the rain band over the eastern Pacific warm pool.

The importance of *Indian Ocean* sea surface temperatures for local and remote climate has been receiving more and more attention in the climate community. IPRC research supports the finding that the Indian Ocean Dipole, an east-west sea surface temperature gradient, is associated with anomalous land temperatures as far away as South America and East Africa. Numerical modeling experiments indicate that Indian Ocean sea surface temperature anomalies may even modulate the effects of El Niño, acting as a heat reservoir that maintains the impacts of El Niño on atmospheric convection and circulation over the western North Pacific several months after it begins to dissipate. Seasonal climate forecasts based on the state of the Indian Ocean may therefore become feasible.

Several studies investigated the *South China Sea*, a marginal sea known to impact regional climate. One study clarified the link between gaps in the mountain range of Indochina, wind forcing, and cooling in the South China Sea during the summer monsoon. Two studies suggested that ocean conditions in the western Pacific during El Niño are transmitted through the Luzon Strait, eventually affecting surface temperature in the South China Sea. Another study found that in models the upper circulation of the South China Sea is highly sensitive to the type of wind products used, indicating these must be chosen carefully when studying wind forcing over the region.

IPRC scientists undertook several projects in *tropical cyclone* research. In one project, a numerical model was able to simulate the structure of the eye-wall of a cyclone, even the double eye-wall that is occasionally seen. In another study of satellite measurements, two distinct processes by which tropical cyclones form in the western Pacific were verified and later simulated in a numerical model. The model will now be used to study the conditions under which cyclones intensify and dissipate, a key element for cyclone forecasting in the region.

Work on *climate sensitivity* to global warming showed that at some threshold of climate forcing (roughly corresponding to a 25% increase in the present-day solar constant), the model climate becomes unstable, warming indefinitely. Detailed diagnostics of the top-of-atmosphere radiative fluxes in this solution revealed that the main contributor to this catastrophic "runaway" response was a decrease in shortwave albedo associated with low clouds. Related work identified the reasons why

えるとモデル気候は不安定となり、温暖化が止まらなくなることを示した。このとき大気上端の放射フラックスを詳細に診断してみると、この破局的な暴走反応の主な原因となっているのが低層雲に伴う短波反射率の減少であることが分かった。これと関連する研究で、CO_2 増大に伴う地表面気温変化予測が、使用する気候モデルによってどうしてこれ程までに違うのか、その理由を発見した。主な理由は、モデルが雲の長波フィードバックを取り扱う方法にありそうである。このフィードバックは、モデル中のウォーカー循環に影響を与えるのである。

IPRC 地域気候モデルの開発には多くの努力が払われており、それは今では IPRC の研究者にとって有用な道具となっている。例えば、このモデルは、東部熱帯域南太平洋の海洋大気相互作用に重要であると考えられているペルー沖の層雲を現実的に再現することに成功している。また、このモデルは応用研究にも利用されている。例えば、砂漠化が進行している中国東北部での再緑化の研究では、新たに植物を植えることによって、その新たな植生が維持されるように大気循環や降水パターンが変わるかどうか判断することになる。

IPRC の一部である**アジア・太平洋データ研究センター (APDRC)** は、内外の研究者が気候データを容易に閲覧し入手できるようなサービスを提供している。現在、日本の地球シミュレーターからシミュレーション結果が出力されつつあるが、その膨大なデータの必要な部分を取り出したり加工したりすることが容易に出来るような形で、地球シミュレーターからデータを転送し提供するという、大変だが重要な仕事を APDRC は受け持つこととなった。さらに、APDRC は、全球海洋データ同化実験 (Global Ocean Data Assimilation Experiment) に伴うデータの供与、活用及び評価を支援する方法を開発しているところである。全球海洋データ同化実験は、天気予報が気象学に新時代をもたらしたのと同様に、海洋学に新時代をもたらすと期待されている計画である。

研究を促進するためのデータプロダクトを開発することも APDRC の使命である。例えば、高解像度の**全球海洋データセット**は漂流ブイからの海流データと衛星からの海面高度及び風応力データを結合することで構築された。この新しいデータセットによって、10 年平均の場にでさえ複雑な循環構造があることが分かった。例えば、北大西洋のアゾレス海流のような狭く強い流れがこれほどはっきりと確認されたのは初めてのことなのである。また、南大西洋海流の分岐のように、この新しいデータでの流路が従来提案されてきたものと一致しないような強流も見付かっている。この新しいデータセットは海洋表層の力学の研究に活用できるし、地球シミュレーター上で動いている OFES のような、高解像度海洋モデルからの出力との比較にも有効である。

IPRC は、**アジア・オーストラリアモンスーン**研究のリーダーとしての任務を果たすため、一連のモンスーンに関する国際会議を主催した。これらの会議はアジア・オーストラリアモンスーン全体、特に、これまで注目されてこなかった東アジア及び北太平洋西部のモンスーンに対する関心を引き出すことに貢献した。この地域のモンスーンは、人口集中の大きく降雨予測の改良が特に必要であるこの地域の気候に影響を与えているのである。

IPRC に対する日本からの資金は、引き続き日本海洋科学技術センター (現独立行政法人海洋開発研究機構) を通して提供されている。米国からの資金は年々増大しており、昨年はハワイ大学からの資金援助と米国政府機関 (NASA、NOAA、NSF、ONR) からの助成金で IPRC の資金の半分以上を占めた。

最後に、IPRC 設立当初の計画で想定した規模を達成できるよう、教授または助教授をさらに三人増やすべく公募している。その結果、2000 年以来 IPRC の研究員であった Yuqing Wang 氏が、一月から気象学の助教授になった。八月には、海洋学の助教授として Axel Timmerman 氏を迎える。このようにメンバーもほぼそろい、アジア・太平洋気候の本質と予測可能性の理解に向けて、来年度も実りある年となるであろう。

国際太平洋研究センター所長
Julian P. McCreary, Jr.

climate models differ so much in their predictions of surface-temperature change with increasing CO_2. A primary cause appears to be the way models handle long-wave cloud feedback, which impacts the Walker circulations that develop in them.

Much effort has gone into the development of the *IPRC Regional Climate Model*, and it is now a useful tool for IPRC researchers. It has been used to reproduce realistically the stratus cloud deck off the coast of Peru, a feature believed to be critical for ocean-atmosphere interaction in the eastern, tropical South Pacific. The model was also used in several applied projects, for example, in a study of the influence of replanting in areas of Northeast China where desertification is taking place, the research is to determine whether the replanting will alter air-circulation and rainfall patterns in such a way that the new vegetation will be sustainable.

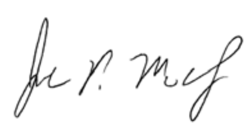
The *Asia-Pacific Data-Research Center* (APDRC), the branch of the IPRC that provides the international research community with easy access to climate data, has taken on the challenging task of transferring and serving some of the massive model output now being generated by Japan's Earth Simulator in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

A part of the data center's mission is the development of data products that facilitate research. For instance, a high-resolution, *global oceanographic data set* was constructed by combining sea-surface height and wind-stress data from satellites with ocean-current data from drifting buoys. This new data set reveals complex circulation structures even after averaging over a 10-year period. Indeed, some jets, such as the Azores Current in the North Atlantic, have never been so clearly identified before. Other jets, such as a branch of the South Atlantic Current, do not follow previously proposed pathways. The new dataset will be used for exploration of upper-ocean dynamics and for comparison with outputs from high-resolution ocean models, such as the ocean model being run on Japan's Earth Simulator (OFES).

In fulfilling its role as a leader in *Asian-Australian monsoon* research, the IPRC hosted a series of monsoon-related international meetings. These meetings helped to draw attention to the entire Asian-Australian monsoon system, particularly to the neglected East Asia and western North Pacific monsoons, which affect the climate in heavily populated regions in need of improved rainfall forecasting.

The IPRC continued to be funded by Japan through the Japan Marine Science and Technology Center (now the Japan Agency for Marine-Earth Science and Technology, JAMSTEC). Our funding from U.S. sources has grown over the years, and last year, support from the University of Hawaii and grants from the U.S. agencies (NASA, NOAA, NSF, and ONR) accounted for more than half of the center's funding.

Finally, we conducted a search for three more faculty so that the IPRC may attain the size envisioned in the original plan. Yuqing Wang, who has been with the IPRC as a researcher since 2000, joined us in January as associate professor of meteorology. In August, we look forward to welcoming Axel Timmerman as associate professor of oceanography. With our team nearly complete, we expect another year of substantial achievements in understanding the nature and predictability of Asia-Pacific climate.



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

The International Pacific Research Center

The International Pacific Research Center (IPRC) conducts research on Asia-Pacific Climate. Designed under the "U.S.–Japan Common Agenda for Cooperation in Global Perspective," the center was founded in October 1997 within the School of Ocean and Earth Science and Technology at the Mānoa Campus of the University of Hawai'i (UH). Its 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."

Financial support for the IPRC comes from Japan through the Japan Agency for Marine-Earth Science and Technology, formerly the Japan Marine Science and Technology Center (JAMSTEC), from the U.S. primarily through the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF), and from the State of Hawai'i through the University of Hawai'i. The support is now divided roughly equally between Japan and U.S. agencies, so that today the IPRC truly represents a Japan–U.S. collaboration for the advancement of climate research.

Research at the IPRC is conducted in four themes:

- *Indo-Pacific Ocean Climate*, aimed at understanding climate variations in the Pacific and Indian Oceans on interannual-to-decadal timescales
- *Regional Ocean Influences*, focused on determining the influence on Asia-Pacific climate of western-boundary currents, the Kuroshio-Oyashio Extension system, the marginal seas and the Indonesian Throughflow
- The *Asian-Australian Monsoon System*, directed toward understanding the processes responsible for climate variability and predictability of the Asian Australian monsoon system and its hydrological cycle
- *Impacts of Global Environmental Change*, centered on identifying the relationship between global environmental change and Asia-Pacific climate

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 and products covering a wide variety of time and space scales. To ensure that the necessary data sets are easily available and usable, the Asia-Pacific Data-Research Center (APDRC) was established in 2001 within the IPRC.

国際太平洋研究センター

国際太平洋研究センター (IPRC) はアジア太平洋の気候に関する研究を行っている。"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、このセンターは、海洋科学技術センター (現在独立行政法人海洋開発研究機構)、宇宙開発事業団 (現在宇宙航空研究開発機構) 等を含む日本の政府機関と合意の基、1997 年 10 月にハワイ大学マノアキャンパス内の海洋地球科学技術学部 (SOEST) 内に設立された。その使命は "アジア・太平洋地域における気候変動についての理解を深め、その予測可能性を向上させるために、現在与え得る国際的にも最高水準の研究環境を提供することにあり、これによって地球的な環境変化の地域的な様相についても理解をする" とされている。IPRC の運営費は、日本から独立行政法人海洋開発研究機構、米国から航空宇宙局 (NASA)、海洋大気庁 (NOAA) 及び国立科学財団 (NSF)、そしてハワイ大学 (UH) を介してハワイ州からの財政でまかなわれている。この資金は現在では日本と米国の間でほぼ等しく分けられており、IPRC は今日、気候研究の発展のための日本と米国の協力関係を真に代表する組織である。

IPRC での研究における四つの主題

- 太平洋及びインド洋地域における気候に関する研究: 年次から数十年の時間スケールでの太平洋及びインド洋における気候変化の理解。
- 西岸境界流、インドネシア通過流などの局所的海洋現象に関する研究: 西岸境界流、黒潮親潮続流システム、沿岸海域及びインドネシア通過流が、アジア太平洋気候に及ぼす影響の解明。
- アジア・オーストラリアモンスーンシステムに関する研究: アジア・オーストラリアモンスーンシステムとその水循環の、気候変動特性及び予測可能性に関連しているプロセスの理解。
- 地球規模環境変化の影響に関する研究: 地球規模の環境変化とアジア太平洋気候の関係の解明。

IPRC の研究戦略は観測を中心とした研究を行うというよりも、診断解析及びモデリングを利用して、大気や海洋、結合大気海洋陸面システムの研究を行うことである。これらの取り組みには、さまざまな時間空間スケールをカバーしているデータセットや成果を集約的に利用する必要がある。必要なデータセットが容易に入手でき、使用できることを確実に保証するため、2001 年、IPRC 内にアジア・太平洋データリサーチセンター (Asian-Pacific Data-Research Center, APDRC) が設立された。

本報告の残りの部分では、IPRC が行った各主題の研究と APDRC の中から、いくつかの成果の抜粋を取り上げて述べている。IPRC に関する更なる情報は、ウェブサイト http://iprc.soest.hawaii.edu/を参照していただきたい。

Research Activities and Accomplishments
Indo-Pacific Ocean Climate

Overview

Research under this theme investigates the ocean's role in climate and climate variability. Activities fall into three general categories: ocean processes, air-sea interaction (or coupling), and climate variability.

Last year, several *ocean process studies* considered the dynamics, forcing, and variability of near-surface currents and their heat and salt transports, as well as the parameterization of ocean mixing. Numerical modeling work on the Indian Ocean's Cross-equatorial Cell, which is important for maintaining the region's freshwater balance, indicated that the cell is enhanced during El Niño and Indian Ocean Dipole events. A numerical investigation of the dynamics of low-latitude, subsurface countercurrents (Tsuchiya Jets) was able to simulate these jets in an ocean general circulation model, suggesting that there may be several operationally distinct types. Exploration of the mixing associated with inertial instability of equatorial currents is continuing. Large-eddy simulations of the Langmuir circulation showed that its effects depend on latitude and season, with the largest impact on the vertical mixing of heat in the extratropics during summer.

Studies of *air-sea interaction* range from the evaluation of precipitation products to identifying local air-sea interactions. Rain over the ocean is difficult to measure. An innovative approach to validate rainfall products uses them to simulate surface salinity in an ocean model, and then compares modeled and observed salinity fields. This technique demonstrates that for the Indian Ocean the best product is one that merges rain-gauge and satellite measurements.

During boreal winter, the Intertropical Convergence Zone (ITCZ) in the eastern Pacific is displaced to the southern edge of the Pacific warm pool, a well-known but so far unexplained feature. Solutions to the IPRC Regional Model attribute this southward shift to the presence of the Central American mountain ranges, which block the northeast trades, thereby causing subsidence and dry conditions on the Pacific (leeward) side. The mountains also affect the summertime ITCZ. The strong wind jets that pass through gaps in these mountains raise the thermocline, lowering sea surface temperatures (SSTs). Analyses of summertime satellite observations in this region show that one such oceanic response, the Costa Rica Dome, in turn affects the atmosphere, punching a distinct, and previously undocumented hole into the summer ITCZ. A similar interplay between air, sea, and mountain ranges has been shown to exist in the South China Sea and the Arabian Sea.

Satellite observations and regional modeling were used to study effects of SST variations on the lower atmosphere between 40°S and 40°N. The study showed that around the globe, the ocean-atmospheric pattern near ocean fronts is characterized by *positive* SST-wind speed correlations, opposite to the negative correlation often observed at large scales. The wind-speed response at the fronts varied 0.5–1 m/s per °C of SST change. A key process accounting for this relationship is the impact of SST on the planetary boundary layer, with warm SST destabilizing the layer and the resulting vertical mixing strengthening the surface winds. Modeling air-sea interaction associated with the equatorial front and Tropical Instability Waves in the eastern equatorial Pacific revealed that changes in atmospheric pressure were also involved. Advection sweeps the pressure signal of the SST gradient downstream, causing wind divergence at the SST front. To study air-sea interactions in the extratropics, shipboard radiosonde observations were conducted over the Kuroshio Extension during the winter of 2003–04 in collaboration with Japanese scientists. Combined with satellite observations, this survey provides a unique view of the effect of SST on the stability of the atmospheric boundary layer and its vertical wind shear. Satellite observations show that wind speed and SST tend to be in phase along ocean fronts throughout the world ocean, consistent with this type of air-sea feedback.

Studies of *climate variability* explored intraseasonal SST variations in the Indian Ocean, climate impacts of the Indian Ocean Dipole, and processes underlying the Pacific Decadal Oscillation. Satellite observations over the equatorial Indian Ocean during boreal winter reveal pronounced intraseasonal variations in SST, wind speed, and convective activity, pointing to strong air-sea interactions. Work on the dipole suggests that it significantly affects land temperatures over remote subtropical regions in both the Northern and Southern Hemispheres. These remote anomalies can be explained by changes in the Walker Circulation associated with the east-west SST gradient of the dipole and by stationary Rossby wave trains originating in the eastern Indian Ocean. In addition, atmospheric-model experiments suggest that the dipole and El Niño affect Indian monsoon rainfall differently: A cold eastern Indian Ocean tends to increase rain whereas El Niño tends to decrease rain over India. An increase in the frequency of Indian Ocean Dipole events therefore accounts for the weaker ENSO–monsoon rainfall relationship noted in recent years.

A study of the processes underlying the Pacific Decadal Oscillation shows that the oscillation results from an auto-regressive process forced by teleconnections associated with El Niño, intrinsic atmospheric variability of the Aleutian Low, and oceanic circulation anomalies in the Kuroshio Extension region. Low-frequency variations in the oscillation are largely due to oceanic anomalies in the Kuroshio Extension. These results call into question attempts to relate the Pacific Decadal Oscillation to low-frequency climate variations over the adjacent landmasses.

インド洋・太平洋地域の気候*

この課題では、海洋が気候と気候変動に果たす役割を研究している。この研究プロジェクトは、「海洋プロセス」、「大気・海洋相互作用」、「気候変動」の 3 分野に大別されている。今年の「大気・海洋相互作用」の研究では、大気・海洋相互作用に果たす山岳の役割が継続して研究された。広く知られてはいながらも説明がついていない現象の一つに、東部熱帯太平洋の熱帯収束帯 (Intertropical Convergence Zone: ITCZ) が北半球の冬の間に太平洋暖水域の南端に移動するということがある。IPRC 領域モデル (IPRC Regional Model: IPRC-RegCM) を利用した研究では、この現象は貿易風の妨げとなっている中央アメリカ山脈の存在に起因するものと考えられている。すなわち、太平洋側 (風下側) に下降風と乾燥状態を引き起こしている。この地域での夏季間の衛星データを解析から、この山脈の谷を通過する強いジェット風が SST を強く低下させていることが明らかになった。そのような海洋の応答の一つであるコスタリカドーム (Costa Rica Dome) は、逐次大気に影響を及ぼし、夏季の ITCZ に明瞭な、しかし明らかに記述されてこなかった穴をあける。他の研究機関の共同研究者と共に、南シナ海及びアラビア海における大気、海洋及び山脈間の同様の相互作用についても注目しているところである。

またもう一つの研究では、全球 40°S から 40°N の範囲で、海洋前線付近での大気-海洋パターンが、大規模な場で頻繁に観測される SST と風速の負の相関関係とは逆の正の相関関係によって特徴づけられることを報告した。その基本的プロセスは、暖かい SST が大気境界層を不安定化し、そのために生じる垂直混合によって地表風を強めているものであると考えられる。赤道前線及び東部太平洋赤道域の赤道不安定波におけるこの大気-海洋相互作用のモデル研究は、気圧変化もこの調整機構に影響を与えていることを明らかにした。

「気候変動」の研究では、インド洋での季節間 SST の変動と、インド洋ダイポール (Indian Ocean Dipole: IOD) の気候インパクト、そして太平洋 10 年規模変動のプロセスについて研究した。IOD に関する研究では、例えば、ウォーカー循環 (IOD の東西 SST 勾配に伴う) と東インド洋に起源をもつ定在的ロスビー波列の変化の結果、遠隔地である南北両半球の亜熱帯地域の陸地気温が影響を受けていることなどが示唆された。大気モデル実験からは IOD とエルニーニョがインドモンスーン降水量に異なる影響を及ぼしていることが示された。冷たい東インド洋はインドの降水を増加させるが、一方でエルニーニョは旱魃をもたらす。それゆえ、IOD 発生数の増加から最近の、ENSO とモンスーンの低い相関関係を説明することができると考えられる。

「海洋プロセス」の研究においては、海洋混合、地域的な海洋の影響に加え、表層流、熱及び塩分輸送の力学、駆動力や変動特性を考慮した。

*JAMSTEC レポートからの翻訳。

Ryo Furue

Postdoctoral Fellow

Ryo Furue obtained his Doctor of Science in geophysics from the University of Tokyo in 1999. His research interests include the vertical mixing in the ocean interior, the dynamics of the thermohaline circulation, and the dynamics and modeling of equatorial subsurface currents.

The equatorial subsurface counter currents, known as the *Tsuchiya Jets* (TJs) in the Pacific Ocean, are believed to be part of the shallow meridional overturning circulation that transports cold water from the midlatitudes to the tropics. To understand and predict decadal oscillations of climate, it is important, therefore, to understand the TJ dynamics and to reproduce them accurately in numerical models. Although several theories have been proposed, the dynamics of the TJs remain unclear. Ryo Furue has been exploring the dynamics of the TJs (in collaboration with Zuojun Yu, Dailin Wang, and Jay P. McCreary) in an oceanic general circulation model (GCM). He first set out to reproduce McCreary *et al.*'s (2002) analytical solution in the ocean GCM for the TJ in the South Pacific. According to this theory, the dynamics of the southern TJ are those of "arrested front." Moreover, it is part of a basinwide interocean circulation, consisting of subsurface inflow into the South Pacific and surface outflow through the Indonesian passages into the Indian Ocean. The water-mass conversion from the subsurface to the surface layer occurs along the eastern boundary by coastal upwelling, which in turn is driven by the alongshore wind stress there.

Furue obtained an ocean GCM solution consistent with the analytical solution under the simplest configuration of a rectangular box ocean with only a meridional wind. This is an important first step toward understanding more complicated and realistic situations. As in the analytical solution, the inflow is crucial to maintaining the model southern TJ. This result is consistent with the arrested-front theory, in which the inflow, coastal upwelling, and the Indonesian Throughflow are indispensable for the existence of the jet. Furue noted that the solution is sensitive to mixing parameterizations, in particular vertical diffusivity. Even when the background vertical diffusivity is as small as 0.1×10^{-4} m^2/s, which is the most widely used standard value, the thermocline becomes diffuse and the model TJ becomes significantly weaker than in cases with smaller diffusivity. This poses a great challenge to the numerical modeling of the TJs because they potentially depend strongly on such poorly known parameters as vertical eddy diffusivity. Not only is the vertical diffusivity crucial to the global thermohaline circulation at extremely long time scales, but also it may be an important controlling parameter of the shallower equatorial currents.

Having obtained a TJ consistent with the theory in a simple configuration, Furue will now include other elements such as the zonal wind to see how the solution changes. With these experiments he will examine if and how the arrested-front theory holds for more realistic situations and assess how well it competes or coexists with other possible mechanisms of the TJ.

Tommy Jensen

Associate Researcher

Tommy Jensen obtained his Ph.D. in physical oceanography from the University of Copenhagen, Denmark, in 1986. In 1989 he received a second Ph.D. in geophysical fluid dynamics from the Florida State University. His research interests include numerical modeling of the oceans and the coupled ocean-atmosphere.

"Could a pile of slippery sacks behave like an ocean?" This question was recently asked by Tommy Jensen's colleagues Patrick Haertel (University of North Dakota) and David Randall (Colorado State University) in a paper proposing an innovative method for computing the motions of fluids, and Jensen has been participating in a model-development project to answer it. The *Slippery Sack Geophysical Model* (SSG model) is a fully Lagrangian fluid-dynamics model, in which fluid parcels are represented by conforming slippery sacks. Including elements from layer models, which essentially use two-dimensional sacks, the SSG model takes these one step further to a three-dimensional formulation. The approach is particularly promising for very long integrations of oceanic flows, since fluid properties such as heat and salt are completely conserved in the individual sacks with no numerical diffusion, a problem in traditional ocean models. Another advantage of the model is that the wetting and drying associated with tides and the flow over steep topography are included by moving fluid parcels, just as in nature.

During last year, important improvements were made towards turning the SSG model into a realistic ocean model by including additional physics, improving numerical methods, and increasing the efficiency of programming. The first step was to include a parameterization of vertical diffusion of momentum and tracers such as heat and salt. A pseudo-Eulerian diffusion scheme similar to that used in layer models was implemented. An experiment compared the modeled vertical diffusion of a passive tracer in a shear flow in the SSG model and in a finite-difference model. The solutions were very similar, proving the validity of the slippery sack approach.

In order to get the SSG model ready for three-dimensional flows, the following changes were made: (1) The time integration was changed from a second-order Adams-Bashforth scheme to a third-order scheme; (2) the shape of the sacks was changed from a cosine-squared mass distribution to a parabolic mass distribution, which resulted in much higher computational efficiency; (3) the capability to use the Gravity Wave Retardation (GWR) method to slow down barotropic waves was implemented; (4) the efficiency of the C++ code was improved and optimized for the Intel Pentium 4 processor; and (5) a parallel version of the code was developed.

The first fully three-dimensional simulation, a case of upwelling in an idealized large lake (Figure 1), was made with the SSG model and compared with simulations using the Princeton Ocean Model (POM) and the Dietrich/Center for Air Sea Technology (DieCAST) models. The model lake was exposed to a northerly wind for 29 hours. In all models, subsurface cold water upwelled along the eastern edge of the basin and, after the wind ceased, an upwelling front propagated counter-clockwise around the lake. Because the SSG model has less artificial mixing than the two other models, the SSG-model solution preserved more of the water mass with extreme temperature in the upwelling fronts. Although this model is still far from ready for more realistic ocean simulations, significant progress has been made toward that goal.

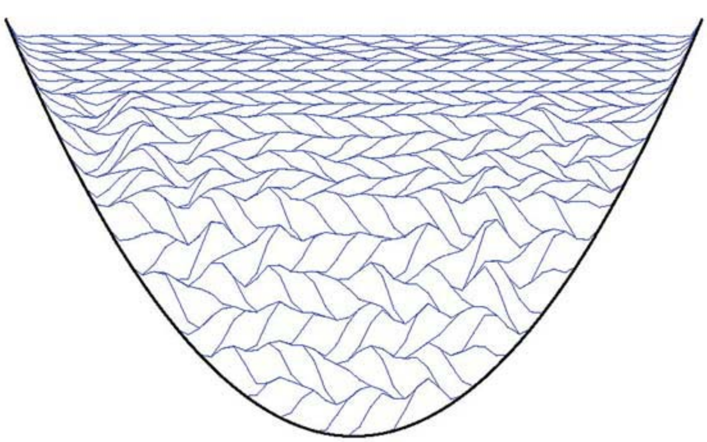
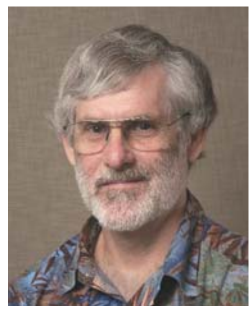


Figure 1: *The initial distribution of sacks in a parabolic lake. Placing small sacks at, and near, the surface resolves the temperature stratification near the surface. In the deeper part of the lake, temperature is more uniform, so that larger sacks may be used to save computing time.*

Jensen also continued to study the interannual variability of the northern Indian Ocean circulation, as reported in last year's report. He also continues collaborations with T. Qu, Y.Y. Kim (IPRC–Regional Ocean Influences Team) and T. Miyama (Frontier) on low-latitude western boundary currents.



Julian P. McCreary, Jr.

Director, IPRC
Professor of Oceanography

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 participated in the following studies: (1) dynamics of the Pacific subsurface countercurrents (with Z. Yu, R. Furue, and D. Wang); (2) dynamics of low-latitude western boundary currents in the North Pacific (with T. Qu, T. Jensen, T. Miyama, H. Mitsudera, Y. Y. Kim, and H.-W. Kang); (3) inertial instability of equatorial currents (with K. Richards, A. Natarov, and D. Wang); (4) the response of the equatorial Indian Ocean to intraseasonal forcing (with T. Miyama of JAMSTEC, and D. Sengupta and R. Senan of the Indian Institute of Science, Bangalore, India); and (5) the influence of midlatitude winds on the stratification of the equatorial thermocline (with M. Nonaka and S. Xie).

Project (4), also mentioned in McCreary's report last year, is almost completed. In this project, McCreary and his colleagues have used two types of ocean models to examine the cause of intraseasonal variability detected in velocity records from current meters in the eastern equatorial Indian Ocean: a state-of-the-art ocean general circulation model (GCM) and a linear continuous stratified (LCS) model, the latter used to understand basic dynamics at work in the GCM. Surprisingly, the meridional velocity (v) field in the eastern Indian Ocean has a strong, sharp, spectral peak at biweekly periods, even though the wind spectrum is considerably broader. During the past year, McCreary obtained an analytic solution to the LCS model that: i) isolates the local (non-radiating) and remote (Yanai-wave) parts of the wind-driven response; ii) demonstrates that both meridional and zonal winds excite biweekly variability in the Indian Ocean roughly equally; iii) shows clearly that the *ocean* favors the excitation of Yanai waves at biweekly periods through resonance and the damping of higher-order baroclinic modes by vertical mixing; and iv) shows that the eastern intensification of the biweekly response results from reflections of Yanai-wave energy from the ocean bottom and near-surface pycnocline.

In project (5), Nonaka, Xie, and McCreary used an oceanic GCM and a 1½-layer model, to investigate processes by which changes in the midlatitude winds affect equatorial stratification. They obtained solutions forced by idealized zonal winds with strong or weak midlatitude westerlies in rectangular basins that extend from the equator to 36°N or 40°N (small basins) or to 60°N (large basin). The GCM solutions all included a "sponge layer" adjacent to the poleward boundary, whereas solutions to the 1½-layer model were found both with and without a sponge layer. In the GCM solutions, first-baroclinic-mode (n = 1) Rossby waves are generated in response to wind forcing. They propagate to the western boundary of the basin, where they reflect as packets of coastal Kelvin and short-wavelength Rossby waves that carry the midlatitude signal to the equator. Subsequently, equatorial Kelvin waves spread it along the equator, leading to a thickening (thinning) of the stratification there in the small (large) basin. In the 1½-layer model, the layer-thickness field h corresponds to thermocline depth and to the n = 1 mode in the GCM. In the small basin, equatorial h thins in response to weakened westerlies when there is a sponge layer, but it *thickens* when there is not. In the large basin, equatorial h is unaffected by weakened westerlies when there is a sponge layer, but it thins when water is allowed to entrain into the layer in the subpolar gyre. We conclude that in the small basin, the thinning of the equatorial thermocline in the GCM solution is caused by the sponge layer (a non-physical process), whereas in the large basin it results from entrainment in the subpolar ocean (a realistic one).

N. H. Saji

Assistant Researcher

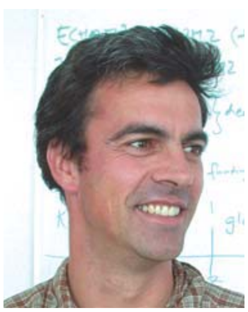
N. H. Saji received his Ph.D. in atmospheric sciences in 1997 from the Indian Institute of Science, Bangalore, India. His research interests include the Indian Ocean Dipole mode and intraseasonal variability in Indian Ocean sea surface temperature.

Intraseasonal variability of the atmosphere challenges both our theoretical understanding of the climate system and our ability to forecast seasonal and subseasonal climate variations in the Asia-Pacific region. A recent paradigm of powerful appeal holds that air-sea interaction may significantly modulate the spatial and spectral character of this variability. The present study is one of several (*e.g.*, X. Fu, B. Wang, T. Li, and J.P. McCreary, 2003) at the IPRC that seek to evaluate this paradigm.

The analysis of air-sea interaction on intraseasonal timescales requires fine spatial and temporal resolution observations of the air-sea interface. Except for the comprehensive TOGA moored network over the tropical Pacific, tropical regions rely on remote sensing from satellites to achieve sampling sufficiency. A major drawback of satellites has been that they use infrared brightness retrievals to estimate sea surface temperature (SST), a procedure highly susceptible to cloud and aerosol contamination. This problem is aggravated by the fact that strong SST cooling is associated with heavy cloud cover. The implication is that conventional satellite (*i.e.*, infrared-based) measurements significantly underestimate intraseasonal SST variations.

N.H. Saji, in collaboration with S.-P. Xie at IPRC and scientists at JAMSTEC, Frontier and the Earth Simulator Center, analyzed intraseasonal variability at the air-sea interface using a relatively new satellite technology that largely overcomes the problems mentioned above. The observations from the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) are based on microwave brightness retrievals over the 10.7 to 85.6 GHz band and they provide SST, wind speed, and rain rate daily at 1/4° resolutions under all weather conditions except severe rain. The remotely sensed data in their study was complemented by high-resolution data from two TRITON buoys in the eastern equatorial Indian Ocean and by climatological simulations of the Indian Ocean from the fine-resolution (10 km in space) ocean general circulation model for the Earth Simulator (OFES). Based on six years of remotely sensed data from 1997 to 2003, the study demonstrated a surprisingly large (1°C) intraseasonal SST variability in the near-equatorial southern Indian Ocean during boreal winters. The SST variability was strongly coupled to such key atmospheric variables as surface winds and cloud cover. The observation that the SST variability shared identical spectral features with the overlying surface winds and convection supports the notion that there is close interplay between the ocean and atmosphere.

To better understand this interplay, air-sea interaction was studied using a composite analysis of SST, outgoing longwave radiation (OLR), and surface wind velocity. Results showed the following sequence: A high-SST phase is accompanied by cloudiness (negative OLR) and stronger westerly winds; the resulting decrease in insolation and greater latent heat loss then lowers SST. These thermodynamic fluxes continue to cool SST, possibly reinforced by entrainment of cool subsurface SST into the mixed layer over a shallow thermocline dome in the western equatorial Indian Ocean. The following reduction in cloud cover and weaker winds result in a rise in SST once again, and the cycle is repeated.



Niklas Schneider

Theme Co-Leader
Associate Professor of Oceanography

Niklas Schneider received his Ph.D. in physical oceanography in 1992 from the University of Hawai'i at Mānoa. His research interests include decadal climate variability, tropical air-sea interactions, and coupled modeling.

The leading mode of sea surface temperature (SST) variability in the North Pacific has been called the *Pacific Decadal Oscillation* (PDO). Its fluctuations are being used as an index for Pacific decadal climate variation, for variations in North American and East Asian climate and the North Pacific ecosystem, and for modulations of teleconnections between the tropical Pacific and North America. The processes underlying the temporal and spatial characteristics of the PDO, however, have not been clarified. Among the processes proposed as explanations of the variability are forcing from the tropics, intrinsic variability of the extra-tropical atmosphere, and coupled interactions between the Pacific atmosphere and ocean. Niklas Schneider explored these possibilities and has found that the PDO can be reconstructed to a high degree of accuracy from its own history and from forcing by El Niño, intrinsic variability in the Aleutian Low, and ocean-gyre anomalies in the Kuroshio Extension.

He arrived at this conclusion by fitting July-to-June annual averages of SST in the North Pacific to a first-order autoregressive model, forced by indices of El Niño, by anomalies in the strength and position of the Aleutian Low, and by ocean-thermocline and zonal-flow anomalies in the Kuroshio Extension region in the western North Pacific. (The Kuroshio Extension anomalies result from slow adjustment of the ocean gyres to changes in wind stress and are estimated from the history of the Pacific wind stress and Rossby wave dynamics.) The fit yields the imprints of these three forcings on North Pacific temperatures and its damping time. El Niño impacts the North Pacific in well-known teleconnection patterns, resulting in unusually warm SST in the eastern North Pacific along the North American coast and in the Alaska gyre, and cool temperatures in the central North Pacific. The deepened Aleutian Low affects SST similar to El Niño in the east, but the cooling extends farther west along the frontal zones at 40°N. Eastward zonal flow anomalies in the Kuroshio Extension lead to warm anomalies there. The damping time of SST in the North Pacific is typically just under one year, with little significant spatial variations.

Most importantly, the leading mode of the reconstructed SST anomalies captures the time evolution and spatial pattern of the PDO, with correlations in space and time between observed and reconstructed fields being higher than 0.9. This agreement allows an evolution equation of the PDO to be derived, and shows that it, too, depends only its own history and the forcing indices—there is little coupling between the PDO and other modes of North Pacific SST variability. The contributions of the three mechanisms depend upon the time scale investigated (Figure 2): At annual and shorter time scales, the Aleutian Low dominates, whereas at interannual time-scales, the teleconnections from the tropics and the intrinsic variations in the Aleutian Low are of equal importance. The gyre anomalies in the Kuroshio extension have little influence on annual time scales, but contribute equally to the other two forcings at decadal time scales.

These findings imply that the covariation of the PDO and the climate modulations over the Northern Hemisphere result from common atmospheric and teleconnected forcings rather than from PDO forcing. That picture is complicated at decadal time scales by the contribution of the ocean circulation anomalies in the Kuroshio Extension. These, however, have little impact on the atmosphere.

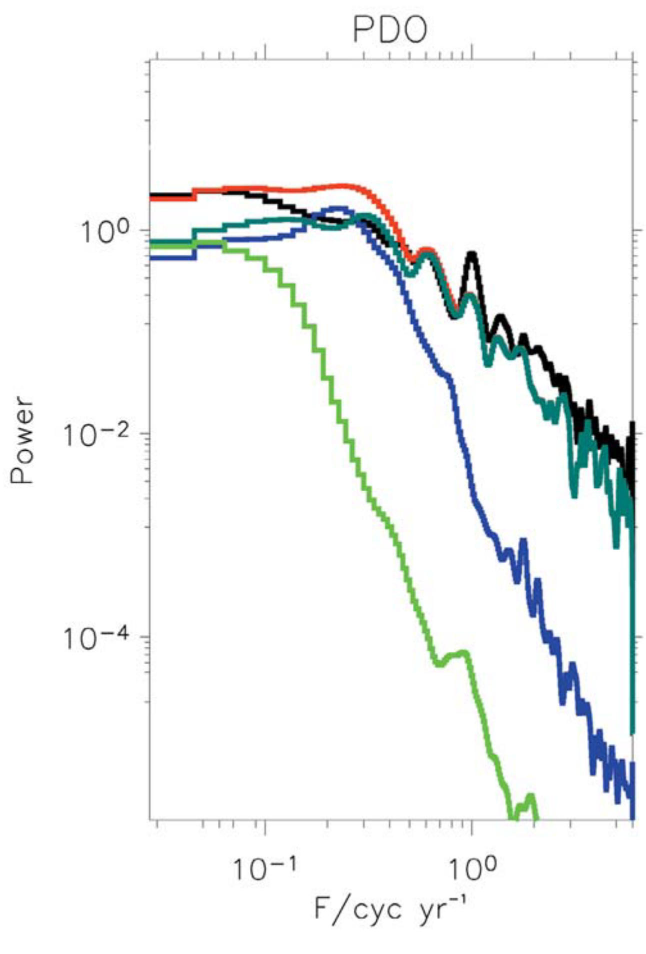


Figure 2. *Power spectrum of the PDO (black) and contributions to its variability by the forcings studied as a function of frequency in cycles/year: depth and position of the Aleutian Low (magenta); Southern Oscillation (blue); and zonal advection in the Kuroshio Extension (green). The sum of the contributions is shown in red and slightly overestimates observations at interannual time scales since changes of the Aleutian Low and the Southern Oscillation share some variance.*

Justin Small

Postdoctoral Fellow

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

Justin Small has been investigating the *response of the atmosphere to the ocean*, a key process of climate dynamics. In his first project, he studied the observed rapid acceleration of winds across the equator and northern SST front of the cold tongue in the eastern equatorial Pacific. The IPRC Regional Climate Model, with its detailed boundary-layer physics, was used to understand the acceleration and the change in boundary layer structure across the front. The model simulations agree well with observations from satellite microwave sensors, Tropical Atmosphere Ocean (TAO) moorings, and the eastern Pacific Investigation of Climate Processes (EPIC) campaign at 95°W. In particular, the change from near-surface velocity shear and a shallow planetary boundary layer (PBL) over the cold tongue (2°S–0°N) to a more uniform velocity and a deep PBL over the warmer water (3°N–6°N) is seen both in EPIC flight observations (Figure 3a) and in model output (Figure 3b). Analysis of the model momentum budget used to determine the physical processes close to the equator found that the hydrostatic pressure gradient, in response to the SST gradient, drives the surface cross-equatorial flow. The model analysis does not support the hypothesis that vertical transfer of momentum is essential for this process, as previously proposed. Collaborators in this project are Shang-Ping Xie, Yuqing Wang, Steve Esbensen, and Dean Vickers.

In the second project, Small investigated the joint propagation in the tropical belt of mesoscale ocean eddies and atmospheric surface wind anomalies between 40ºS and 40ºN. For the analysis, he combined SST and wind vector information at high temporal and spatial resolution from the TRMM and QuikSCAT satellites with dynamic sea surface height measurements from the TOPEX/Poseidon satellite. Cross-spectral and linear regression methods were used to identify robust relationships between the ocean and atmospheric variables. The ocean dynamical features, measured by their sea surface height (SSH) anomaly, affect SST in a manner consistent with advection of the mean temperature gradient by anomalous currents. The response varies from 0.2°K/cm near the equator to 0.05°K/cm at higher latitudes. Furthermore, a remarkably consistent in-phase relationship between SST and wind speed is found over the entire domain. The wind-speed response varied 0.5–1 m/s per °C of SST change. The phase of the response is consistent with previous studies, suggesting that the SST variations cause changes in the vertical exchange of momentum and in the pressure gradient, which alter the wind speed. Collaborators in this project are Shang-Ping Xie and Jan Hafner.

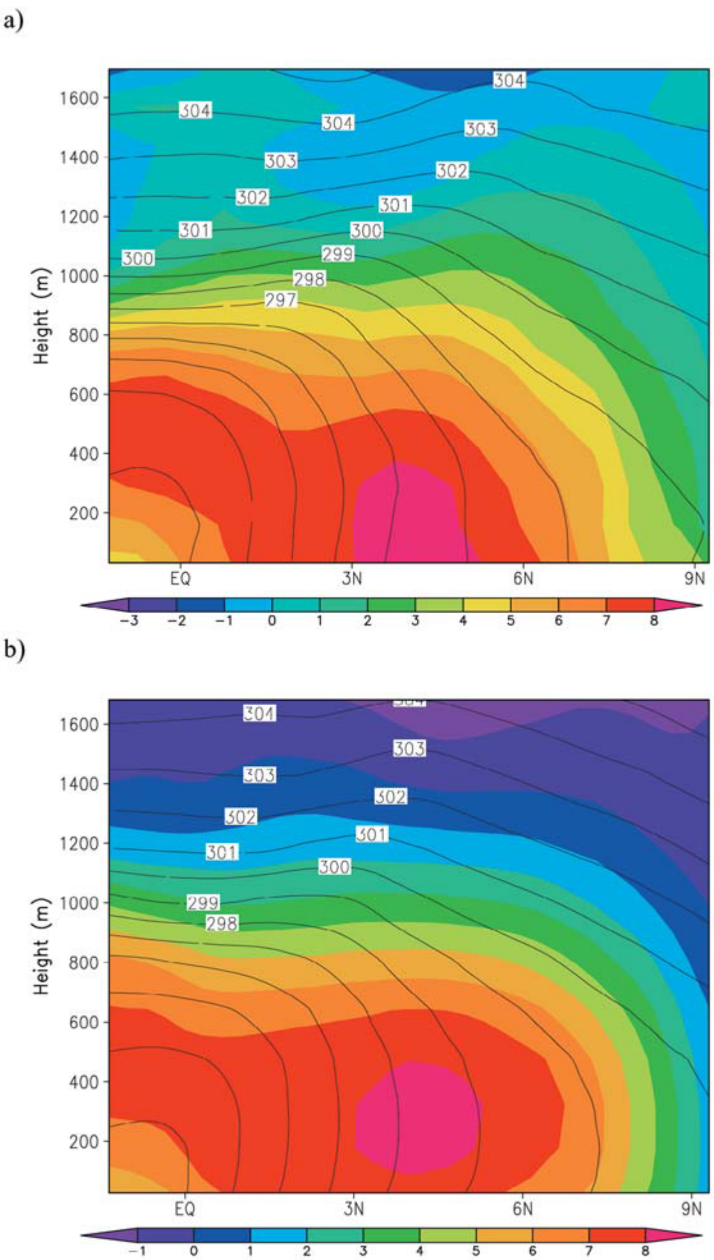
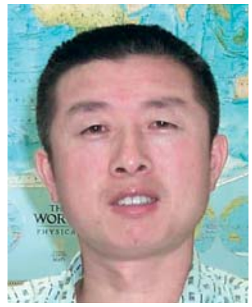


Figure 3. Vertical sections of meridional velocity (color, m/s) and potential temperature (contours: intervals of 1°K) at 95°W: (a) from EPIC2001 NCAR C130 data (8-flight mean); and (b) from the IPRC–RegCM (2-month mean).



Dailin Wang

Associate Researcher

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

Understanding and *parameterizing the ocean mixing processes* are important aspects of ocean and climate modeling. The mixing parameterization is among the most uncertain components in climate models, and deficiencies in this parameterization are often identified as a major reason why climate models fail to reproduce the observed phenomena.

Dailin Wang is studying mixing in the oceanic mixed layer by analyzing outputs of a large-eddy simulation model that resolves the three-dimensional motions of turbulent large eddies. His goal is to understand the mixing processes in the mixed layer and to improve existing parameterizations of the mixed layer and develop new ones. This past year he has studied the effect of the Langmuir circulation on the mixed layer. This circulation consists of cells rotating counter to each other with axes more or less aligned with the direction of the wind. The common belief is that the Langmuir circulation is caused by an interaction between surface gravity waves and wind-driven surface currents. Although the effects of the Langmuir circulation on the mixed-layer temperature and mixed-layer depth have been studied, the studies have not answered definitively the question whether this circulation is significant for the formation and maintenance of the mixed layer, and at present most mixed-layer models do not include its effects. To determine the importance of this circulation and whether it needs to be parameterized in climate models, Wang conducted a suite of large-eddy simulation experiments in which the Langmuir circulation was parameterized by the Stokes vortex force (the so-called Craig-Leibovich theory). In previous studies, researchers often used Stokes drift from a mono-chromatic wave of a given wave length and the Stokes velocity decreases as an explonential function of depth. The problem with this approach is that one does not know *a priori* which wavelength to use for a given wind stress. The *ad-hoc* choice of wavelength makes it difficult to apply the approach to the real ocean in which wind stress varies as well as the surface wave field. Wang, therefore, focused on fully developed waves for a given wind stress (in the form of wind speed) applying the empirical Pierson-Moskowitz (1964) wave spectrum for fully developed seas. He integrated the wave field to calculate the Stokes drift at any given wind speed. Although the Stokes velocity decays increasingly with depth, it does not do so exponentially. Wang's calculations showed the Langmuir circulation does influence mixing, but its effects are secondary to wind and buoyancy forcing. In other words, the mixed layer is affected mainly through direct wind and thermohaline forcing. The Langmuir-circulation effect, however, is not negligible for shallow mixed layers during strong winds.

In collaboration with other IPRC scientists and with Eric Firing and Francois Ascani (both in the Department of Oceanography, University of Hawai'i), Wang is conducting research on the equatorial circulation. One of the issues they are studying is the generation mechanism of the equatorial deep jets, which has defied satisfactory explanation. Deep jet-like structures have begun to emerge in simulations by recent high-resolution ocean models. Wang and his collaborators will be conducting numerical experiments to explore the dynamics of these structures with the hope of determining the origins of deep jets in the real ocean.

Shang-Ping Xie

Theme Co-Leader
Professor of Meteorology

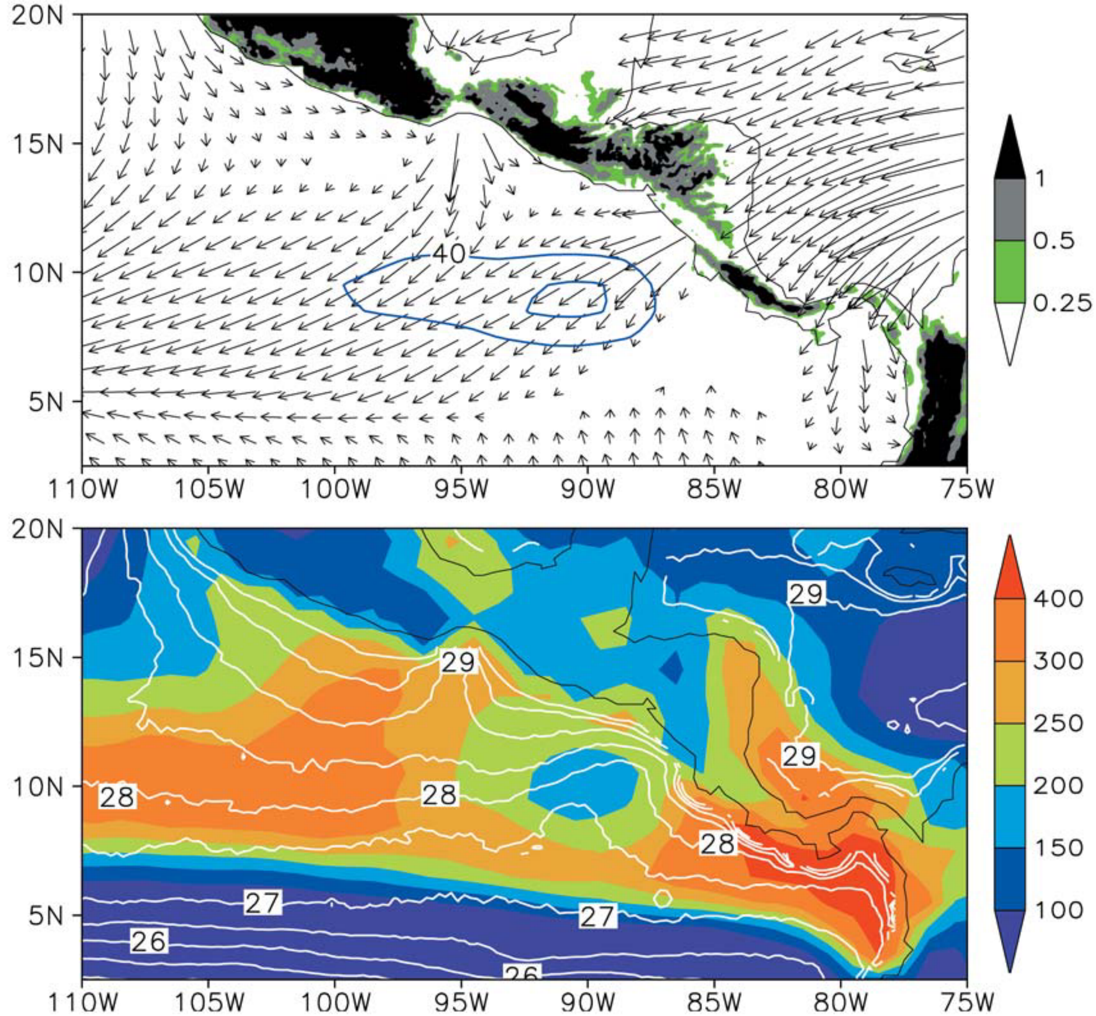
Shang-Ping Xie obtained his Doctor of Science in geophysics from Tohoku University, Japan, in 1991. His research interests include large-scale ocean-atmosphere interaction, climate dynamics, and the general circulation of the atmosphere and oceans.

Poor understanding of how *extratropical oceans affect the atmosphere* has hindered efforts to determine climate variability not directly related to El Niño. In analyzing satellite observations, Xie and colleagues found that sea surface temperatures (SST), winds, and clouds form a pattern prevalent near major ocean fronts and currents such as the Gulf Stream (Xie 2004), Somali (Vecchi *et al*. 2004) and Kuroshio (Nonaka and Xie 2003) currents, and the Pacific equatorial front (Small *et al*. 2003; Cronin *et al*. 2003), all regions of large SST variations. The pattern is characterized by a positive SST-wind speed correlation that is indicative of ocean-to-atmosphere feedback (see Justin Small summary). This contrasts with the negative correlation prevalent on the basin-scale that is attributed to atmospheric forcing of the ocean mixed layer. The positive SST-wind speed correlation over the fronts is consistent with a vertical mixing explanation: The near-surface atmosphere is unstably stratified on the warmer flank of SST fronts, enhancing mixing that accelerates surface winds by mixing down the faster winds from aloft. Recent observational and modeling studies further suggest that the effects of ocean fronts are not limited to the planetary boundary layer (PBL) but may extend over the whole troposphere by modulating storm tracks (Inatsu *et al*. 2003). In collaboration with his Japanese colleagues, Xie helped organize the first joint ocean-atmospheric soundings that took place in the 2003–04 winter to observe the Kuroshio Extension's influence on the atmosphere.

Another important class of air-sea interaction explored by Xie is the *influence on the atmosphere of mesoscale mountain ranges*, such as those in Central America. In winter, the strong northeast trades impinge on the Central American mountain ranges, displacing the eastern Pacific rain band southward, away from the main body of the warm pool there (see Haiming Xu summary). Moreover, these wind jets affect the atmosphere two seasons later in summer. In particular, the zonally oriented Papagayo jet, most intense in winter with air rushing through a mountain gap on the border of Nicaragua and Costa Rica, forces upwelling Rossby waves in the ocean, lifting the thermocline closer to the sea surface on the southern half of the jet, causing the Costa Rica Dome and a surface cooling (Figure 4) there. In summer the cool sea surface over the dome punches a conspicuous 500-km hole in the rain band over the eastern Pacific warm pool (Xie *et al*. 2004). Xie's study of the South China Sea reveals other interesting patterns of air-sea interaction induced by topography of both land (Xie *et al*. 2003) and sea bottom (Liu *et al*. 2004). With increasing computing power, global models such as those developed for JAMSTEC's Earth Simulator will be able to resolve narrow ocean fronts and topographic features such as the mountain ranges of Central America. The small-scale air-sea interaction phenomena documented here and elsewhere will serve as benchmarks for these models to reproduce.

Xie is continuing his *eastern Pacific climate study*, which includes observations and modeling of the stratus cloud deck off the west coast of South America and cross-equatorial flow in the planetary boundary layer, features of climatic importance but poorly simulated in global models (Yuqing Wang, Haiming Xu, and Justin Small summaries). Analysis of an atmospheric sounding transect over the eastern equatorial Pacific revealed a previously unnoted but robust temperature

__Figure 4.__ Delayed effect of winter wind jets on summer climate. Upper panel: QuikSCAT wind stress (vectors in m²/s²) for January–April, topography (color shade in km), and the 20°C isotherm depth for July–October (only values smaller than 40 m are plotted in blue contours at 10 m internals). Lower: TRMM precipitation (mm/month) and SST (white contours in °C) for July–October.



inversion 3 km beneath the tropopause that may be important in material exchanges between the troposphere and lower stratosphere (Fujiwara *et al*., 2003).

Xie is also participating in studies of *Indian and Atlantic Ocean climate*. Combined analysis of new satellite and buoy observations and high-resolution model simulation reveal large intraseasonal co-variations in South Indian Ocean rainfall, winds and SST (see N.H. Saji summary). Atmospheric GCM experiments demonstrate Indian Ocean influences on the surrounding continents and the Pacific, both during and after an El Niño (see H. Annamalai summary), and suggest that the Indian Ocean is a condenser that unleashes the impact of El Niño on atmospheric convection and circulation over the western North Pacific several months after El Niño has dissipated. Monitoring the state of the Indian Ocean may therefore, improve seasonal forecasts.

Comparing similarities and differences among tropical oceans is like working in a natural laboratory. One study of Xie's research team suggests that the tropical Atlantic meridional mode is most pronounced from February through April when the Intertropical Convergence Zone (ITCZ) is nearly symmetric about the equator; it is not well developed June–August when the ITCZ is displaced far from the equator (Okajima *et al*. 2003). Though the seasonal cycle in equatorial winds is known to give rise to a pronounced annual SST cycle in the equatorial Atlantic, the mechanisms are poorly understood. Atmospheric GCM experiments show two distinct mechanisms for the June–July acceleration of the equatorial trades: in the western basin, the interaction with the developing cold tongue; in the eastern basin, the equatorward advection of easterly momentum from the subtropical South Atlantic by intensified southerlies (Okumura *et al*. 2004).

Finally, Xie has authored and co-authored several review papers on the IPRC's efforts to analyze satellite observations (Xie 2004), the history of, and recent progress in, the study of the ITCZ in the Pacific and Atlantic (Xie 2004), and air-sea interaction and its role in climate over the global ocean (Wang *et al*. 2004) and over the tropical Atlantic (Xie and Carton 2004).

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. His research interests include tropical meteorology and monsoon circulation, numerical modeling of the atmospheric circulation, and air-land-sea interactions.

The climatic effects of the *stratocumulus cloud deck off the coast of South America* reach far beyond its immediate borders. Haiming Xu has been studying the intraseasonal variability of this cloud deck, using satellite and buoy observations and the NCEP/NCAR reanalysis. He found that such intraseasonal variations in the stratus cloud deck are closely related to variations in surface wind velocity, water vapor, sea level pressure, and 500 hPa geopotential height. More specifically, his analyses revealed that an increase in cloud liquid water over the subtropical Southeast Pacific is associated with the development of an anomalous anticyclonic circulation to the south, off the coast of Chile. The enhanced southerly and southeasterly winds blow cold and dry air into the stratus region against the mean sea surface temperature (SST) gradient. This cold and dry air, together with increased wind speed, destabilizes the surface layer over the ocean, enhancing surface latent and sensible heat fluxes. North of the anticyclone, anomalous easterlies in the offshore boundary layer support low-level divergence and subsidence in the cloud-deck region. The associated subsidence warming, together with the cold advection in the surface layer, strengthens the temperature inversion, thereby promoting the development of stratus clouds. Buoy observations confirm this relationship between the subseasonal cloud variability and the surface meteorological variables. In a lead-lag composite analysis, Xu found that changes in such circulation variables as sea level pressure and surface wind lead changes in cloud liquid water 1–2 days, which, in turn, lead changes in SST 1–2 days. This result suggests that low-cloud variability is mostly the result of atmospheric circulation changes rather than changes in the underlying ocean (see Xu, Xie and Wang, *J. Climate*, submitted).

In another study, Xu examined why the intertropical convergence zone (ITCZ) is displaced to the southern edge of the eastern Pacific warm pool in boreal winter instead of being collocated with it. He and his collaborators used the IPRC Regional Model to investigate the mechanism for this displaced ITCZ. With observed sea surface temperature (SST) and lateral boundary forcing, the model reproduces salient features of the eastern Pacific winter climate, including the southward-displaced ITCZ and the winds blowing on the ocean through gaps in the Central American mountain ranges. As the northeast trades impinge on the mountains of Central America, subsidence prevails off the Pacific coast, pushing the ITCZ southward. Cold SST patches induced by the intense gap wind jets, as well as the advection of dry air from the land bridge, help to keep the ITCZ away from the coast. In an experiment in which both the Central American mountain range and its effect on SST are removed, the ITCZ moves considerably northward to cover much of the eastern Pacific warm pool (see Xu, Xie, Wang and Small, *J. Climate*, to be submitted).

In collaboration with S.-P. Xie, Xu studied the air-sea interaction over the eastern Pacific warm pool. In collaboration with Y. Wang, S.-P. Xie, he has researched the sensitivity of boundary layer stratus clouds over the subtropical Southeast Pacific to physical parameterizations, and to horizontal and vertical resolutions in a regional climate model.

Zuojun Yu

Associate Researcher

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

As an important component of freshwater flux, precipitation affects sea surface salinity, which, in turn, has a significant impact on the depth of the ocean surface mixed layer. The accuracy of *precipitation products* over open oceans, however, remains problematic owing to the lack of *in situ* measurements. Yu has taken an innovative approach to solving this problem. In a collaborative project with J. McCreary, she has used an ocean model to test the performance of different precipitation products in the Indian Ocean, where large salinity contrasts exist. The model consists of 4 active layers overlying a deep, inert ocean, the top-most layer being a mixed layer governed by Kraus-Turner physics. Solutions are forced by monthly mean precipitation climatologies, and their surface salinity fields are compared with observed surface salinity. In the Indian Ocean, both river runoff and the Indonesian Throughflow significantly influence the long-term mean surface-salinity distribution, and an adequate treatment of these boundary forcings is a prerequisite for a model used to evaluate precipitation products. Yu and McCreary also explored the sensitivity of solutions to various model parameters and forcing to ensure they are not a major source of bias. Results show that the best annual-mean salinity field is produced when forced by the Climate Prediction Center Merged Analysis of Precipitation (CMAP) product, a merged precipitation product based on rain-gauge data and several satellite estimates. An amplitude adjustment of the Global Precipitation Climatology Project (GPCP) product is suggested by the model salinity field, supporting the notion that merged products give reliable spatial patterns but not necessarily correct magnitudes. Problems with several other precipitation products were also noted, particularly in terms of their potential distortion of mixed-layer thickness.

This study is limited by the availability of surface salinity observations because salinity data has been sparsely collected at sea, mostly during summertime along shipping lanes. Help, however, is on the way. Aquarius, a focused satellite mission to measure global sea surface salinity, is scheduled to be launched in 2008 and will provide monthly 100-km resolution sea surface salinity maps over a 3-year mission lifetime. This data will allow precipitation products to be validated at the monthly time scale.

As a member of the Asia-Pacific Data-Research Center (APDRC), Yu is continuing to compare various data products, such as ocean surface wind, precipitation, and ocean data-assimilation products. The lack of *in situ* measurements in the open ocean presents a challenge for determining the accuracy of these data products. Combining knowledge of ocean dynamics and thermodynamics with numerical modeling experience, Yu and her APDRC colleagues have successfully identified specific problems in some datasets. These results will soon be put on the APDRC website.

Yu also participated in a project on the South China Sea summer circulation with Du, Qu, and Xie, and a study of the Pacific subsurface countercurrents with Furue (see Furue's report), McCreary, and Dailin Wang.

Research Activities and Accomplishments

Regional Ocean Influences

Overview

Research under this theme includes studies of the marginal seas adjacent to Asia, the Indonesian seas, and adjoining regions of the Indian and Pacific Oceans. It also includes the Oyashio, Kuroshio, and the low-latitude western boundary currents, which connect the subpolar, subtropical and tropical regions, and the Indonesian Throughflow, which connects the Pacific and Indian Oceans. Circulations in these regions are known to impact the climate of Asia and Japan through ocean-atmosphere interactions, the mixing of water properties, and the transport of heat and salt. Objectives of this theme are to describe these major oceanic transport pathways, understand the processes that maintain them and account for their variability, and determine their influence on Asia-Pacific climate.

The *low-latitude western boundary currents* on the western flank of the Pacific are relatively narrow and intense. Two such currents, the Mindanao Current and the low-latitude part of the Kuroshio, result from a bifurcation of the westward-flowing North Equatorial Current. Previous work at the IPRC has examined seasonal-to-interannual variations of the bifurcation latitude, as well as the relationship between the strengths of the two boundary currents and the El Niño–Southern Oscillation (ENSO). This year, work has focused on the connection between variability in the western boundary currents and the South China Sea. A combined analysis of observations and model simulations (including the Ocean Model for the Earth Simulator, OFES) and the use of four-dimensional variable data-assimilation techniques suggest that such a connection exists *via* the transport through the Luzon Strait. The transport is strongly affected by ENSO, approaching its maximum (minimum) strength during El Niño (La Niña). This oceanic connection appears to play a key role in conveying Pacific conditions into the South China Sea, with water that enters through the Luzon Strait tending to surface 5–7 months later in a cyclonic gyre east of Vietnam.

Consistent with previous work on the *Kuroshio meander*, the impact of high-frequency wind on the Kuroshio path was found to be due to a nonlinear response of an anticyclonic eddy within the Shikoku recirculation gyre. It appears that the high-frequency, high-wavenumber wind perturbs the thermocline depth of the eddy through local Ekman pumping. The observed interannual-to-decadal variation of the western *subarctic gyre* was successfully simulated, and the distribution of dichothermal water appears to vary with a structural change in the western subarctic gyre between a zonally elongated and contracted state. In another project, analyses of historical hydrographic observations of the *subtropical North Pacific circulation* showed that 3 subsurface fronts mainly result from water masses with low potential vorticity just north of the fronts.

A major part of the circulation in the region is the *Indonesian Throughflow*, which is known to affect the Pacific and Indian Oceans. Variability in the Throughflow transport and its dependence on atmospheric forcing has been examined in multi-century runs of two different coupled ocean-atmosphere models. At seasonal time scales, near-surface transport anomalies are most closely related to local winds near Indonesia. At low frequencies, however, variations in the subsurface transport respond to winds in the equatorial Indian and Pacific Oceans. Decadal changes in the Throughflow impact Indian Ocean SST only modestly, at least in the models examined so far. On shorter timescales, however, the Indonesian Throughflow does influence the upper-ocean heat content and circulation in the eastern tropical Indian Ocean, a topic of ongoing IPRC research.

Another activity in this theme is *the production of enhanced datasets of oceanographic variables* for use in climate studies. One example is the development of a combined mean, surface-current and sea-surface-height data set with a resolution high enough to capture the fine-scale structure of the flow field—work that had been plagued by the poorly defined geoid. The data set was constructed by combining sea-surface-height and wind-stress data from satellites and ocean-current data from drifting buoys, and the most recent analysis has included data from the NASA GRACE mission, which has improved the estimate of the geoid. This new data set shows that the detailed structure of the flow field is apparent even with averaging over a 10-year period. Indeed, some jets, such as the Azores Current in the North Atlantic, have never been so clearly identified before. Other jets, such as a branch of the South Atlantic Current, do not follow previously proposed pathways. The new dataset will be used to explore upper-ocean dynamics and will be compared with output from high-resolution ocean models, such as OFES being run on Japan's Earth Simulator.

Lastly we report on work on the *marine ecosystem*, an important part of the climate system that regulates the uptake of carbon dioxide by the ocean. Observations from space and *in situ* measurements reveal a rich complexity in the distribution of phytoplankton on a broad range of scales. A question being addressed is whether this spatial structure affects the functioning of the ecosystem and the overall rates of production. The combined effects of stirring and mixing by the fluid flow on a simple model ecosystem are found to have a large impact. A key time scale is the mix-down time, the time it takes for the spatial scale of a tracer to be reduced to that of a diffusively controlled filament. If the mix-down time is sufficiently short, then the stirring can promote a large phytoplankton bloom.

領域的な海洋の影響*

この課題における研究では、アジア周辺の沿岸域や、親潮、黒潮、低緯度西岸境界流、インドネシア通過流に注目している。これらの循環は、大気海洋相互作用や、水質混合、熱塩輸送を通してアジアや日本の気候に影響を与えることが知られている。この課題では、これらの海洋輸送経路について記述し、それを維持しているプロセスやその変動要因を理解し、アジア・太平洋の気候への影響を明らかにすることを目指している。

「低緯度西岸境界流」に関しては、今年は西岸境界流の変動と南シナ海の関連に注目した。観測結果及び地球シミュレーター海洋モデル (OFES) などのモデルシミュレーション、これに四次元変数データ同化技術の活用をあわせて総合的に解析した結果、そのような関連はルソン海峡を通る輸送を通して存在することが示された。ルソン海峡を通って入る水塊は、5–7ヶ月後にベトナム東方の低気圧性循環の表面に浮上してくる。この輸送は ENSO によって強く影響されており、エルニーニョの期間に最大 (ラニーニャの期間に最小) の強さに近づき、また、東シナ海へ太平洋の状態が伝播することに決定的役割を果たしているようである。

「黒潮蛇行」に関しては、黒潮経路上における高周波の風のインパクトが、四国沖の再循環環流内での高気圧性渦の非線形応答によるものであることを明らかにした。これは先行研究とも矛盾しない。高周波であり且つ高い波数をもった風は、局地的エクマンパンピングによってその渦の温度躍層の深さを変化させているようである。別のプロジェクトの、亜熱帯北太平洋循環の長期的海洋観測データの解析では三つの表層下のフロントは、そのフロントの北側の低いポテンシャル渦度をもった水塊によるものであることを示した。

気候研究に供するための「海洋変数の、高度化されたデータセットの作成」は、この課題の研究の非常に重要な部分である。流れ場の微細構造を把握するのに十分な高解像度を持つ、平均表層流及び海面水位統合データセットの整備に関しては、誤差を含んだジオイドによって悩まされ続けられていた。今年、ジオイドの見積もりが大きく改良された NASA GRACE のデータを採用した。流れの場の詳細な構造は 10 年平均場でも見られている。実際、北大西洋のアゾレス海流のようないくつかのジェットはこれまでこの様に明らかに示されることはなかった。南大西洋海流の分岐にあるような他のジェットは、これまで考えられていたような経路とは一致していない。今後は、海洋表層の力学の研究及び OFES のような高解像度海洋モデルの結果との比較に、この新しいデータセットを活用していく。

*JAMSTEC レポートからの翻訳。

Takahiro Endoh

Frontier Research Scientist[1]

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

A major challenge faced by climate scientists is to determine how *ocean ventilation* affects climate variability, particularly the Pacific Decadal Oscillation and the El Niño–Southern Oscillation. The ocean component of coupled ocean-atmosphere models, therefore, must be able to reproduce the time scales of ventilation. Although mesoscale eddies directly increase ventilation by modifying the subduction rate and diffusing the downstream properties of subducted fluids, long-term eddy-resolving simulations of the global ocean are too costly to be routinely conducted, even on the Earth Simulator. There is, thus, a need for non-eddy-resolving models in which the mixing effects of subgrid-scale eddies are adequately parameterized.

In collaboration with Kelvin Richards and Yanli Jia, Takahiro Endoh has examined the effect of isopycnic-thickness diffusivity, which parameterizes the strength of subgrid-scale eddy-induced tracer transport on ventilation in the North Pacific. The study uses the Miami Isopycnic Coordinate Ocean Model (MICOM), which combines a bulk mixed-layer model and an isopycnic coordinate model of the ocean interior. The bulk mixed-layer model has an advantage over vertical mixing parameterizations for conventional Cartesian-coordinate models in that it simulates a deep-winter mixed layer at high latitudes of the North Pacific, leading to a more realistic representation of Subtropical Mode Waters as well as the subsurface temperature inversion in the subarctic region. The improved simulation of the mode waters in MICOM results in the formation of a reasonably realistic subtropical countercurrent (STCC) in the North Pacific (Figures 5a and 5b).

To investigate the sensitivity of ventilation to the magnitude of isopycnic thickness diffusivity, three numerical experiments with isopycnic-thickness diffusivities of 0 m^2/s, ~500 m^2/s, and ~2,000 m^2/s were carried out. In each experiment, the subduction rate peaks at two density ranges 25.0–25.7 σ_θ and 26.4–26.6 σ_θ. The peak at the lower density range corresponds to Subtropical Mode Water and Eastern

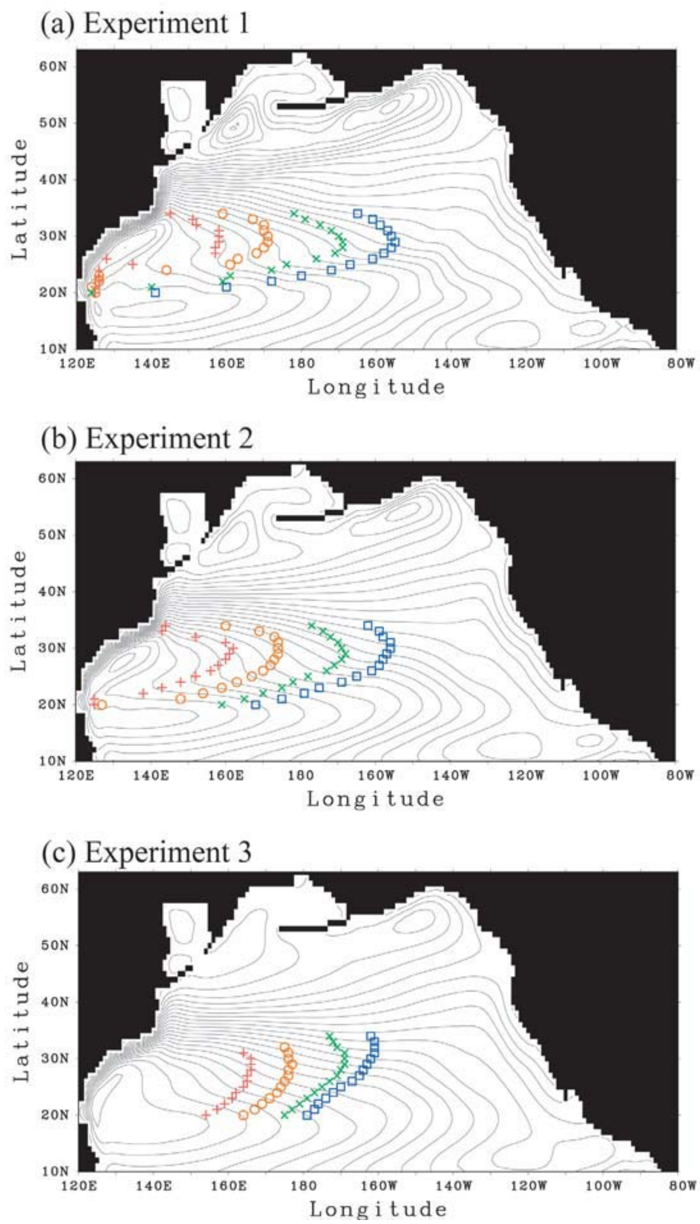


Figure 5. *Contours of the annually averaged Montgomery potential at the sea surface for experiments with isopycnic thickness diffusivities of (a) 0 m^2/s, and around (b) 500, and (c) 2000 m^2/s. Contour interval is 0.5 m^2/s^2. Plusses, circles, crosses, and squares show the minimum annually averaged potential vorticity of the respective layers 25.0, 25.7, 26.0, and 26.2 σ_θ for latitudes 20°–30°N.*

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Subtropical Mode Water, whereas the peak at the higher density range corresponds to Central Mode Water. As thickness diffusivity increases, the latter peak in the subduction rate occurs at higher densities that correspond to a near-surface temperature minimum called the dichothermal water. The subsequent behavior of the subducted water is also affected by isopycnic-thickness diffusivity, which increases the potential vorticity of mode waters along pathways emanating from outcropping regions. This process smears out a pool of low potential vorticity around 20°N in the western subtropical gyre, resulting in the absence of the STCC in the experiment with isopycnic-thickness diffusion of ~2000 m^2/s (Figure 5c).

Another noteworthy result is that westward propagation of baroclinic Rossby waves is evident at the latitude of the STCC only in the experiment with zero thickness diffusivity. This implies that mid-latitude baroclinic Rossby waves might be amplified by instability in the STCC, which is suppressed in the other experiments presumably due to unrealistically high thickness diffusivity. The sensitivity to isopycnic-thickness diffusion seen in both ventilation and wave propagation highlights the need to consider the impact of diffusion processes in the ocean component of coupled ocean-atmosphere models.

Fumiaki Kobashi

Frontier Research Scientist[2]

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

Fumiaki Kobashi continued his studies of the upper-ocean structure of the *North Pacific subtropical gyre* with a particular focus on the subsurface subtropical front. The subtropical front is accompanied by a shallow eastward flow called the Subtropical Countercurrent, a flow inconsistent with the classic Sverdrup theory that requires a southwestward flow there. Several numerical and theoretical studies have tried to explain how the subtropical front is generated; the front, however, has never been fully studied from an observational standpoint.

Kobashi investigated the subtropical front, in collaboration with Humio Mitsudera (Hokkaido University), by analyzing a long-term, mean-temperature climatology that he constructed by combining historical and recent hydrographic data (see 2003 IPRC report). This climatology showed three distinct subtropical fronts, geographically referred to as northern, southern, and central subtropical fronts. The southern and northern fronts, which appear west of the date line, near 19°N and 23°N, respectively, have previously been identified by synoptic hydrographic observations, while the central subtropical front found near 26°N between 180° and 160°W has never been described. The central front is also seen as a robust feature in the mean absolute sea level map created from surface drifters and satellite altimeter measurements (see Nikolai Maximenko summary).

An examination of vertical structures based on potential vorticity (PV) dynamics showed that the appearance of the three subtropical fronts is closely associated with the structure of the ventilated thermocline. The subsurface cores of the fronts, with large positive density gradients, coincide with a large negative PV gradient in the main thermocline, which is primarily caused by low PV water that appears north of the fronts. The low PV water is different among the three fronts, corresponding to the subtropical mode water (STMW) for the northern front, the central mode water (CMW) for the central front, and both the STMW and the CMW for the southern front. Further investigation of geostrophic flow fields indicated that the low PV water advected on different isopycnals has a tendency to converge in the horizontal plane, probably due to the β spiral of the subtropical gyre, and to accumulate vertically just north of the subtropical fronts. Kobashi hypothesizes that this process forms a thick, low PV, water pool that efficiently produces the negative PV gradient at the front. These results indicate that the distribution and circulation of the mode waters play an essential role in the formation and maintenance of the subtropical fronts.

Kobashi has also collaborated with Shang-Ping Xie and Takashi Sakamoto (Frontier Research Center for Global Change) in analyzing simulations of the subtropical front in a high-resolution air-sea coupled general circulation model on the Earth Simulator. Although the model only simulates a single subtropical front, results are similar to observations in that the front coincides with a large PV gradient in the thermocline that is caused by mode water subducted and advected from the Kuroshio Extension front.

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Konstantin Lebedev

Visiting Researcher

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

Konstantin Lebedev continued to develop a *four-dimensional data assimilation system* based upon a combination of the latest version of the Parallel Ocean Program (POP) and the Sequential Evolutive Extended Kalman (SEEK) filter. He has also started to assimilate real observational data streams. The purpose of the research is to construct a tool for the analysis of long-term observations in the tropical and subtropical regions of the Pacific and Indian Oceans. This work was done in collaboration with Max Yaremchuk and Takuji Waseda.

Lebedev was able to improve the SEEK filter performance by parallelizing and adjusting the code structure to optimize memory requirements for the covariance and gain matrices. As a result, the filter performance became 10 times more efficient in terms of CPU and 50% more efficient in terms of memory requirements. At present, the filter is capable of the simultaneous assimilation of 800–1000 observations per assimilation step (typically every 3–5 days). This capability is consistent with the intensity of present data streams at 1/4–1/6° resolution.

Lebedev has now completed a 7-year (1992–1999) assimilation run with sea surface height (SSH), CTD, and XBT data at

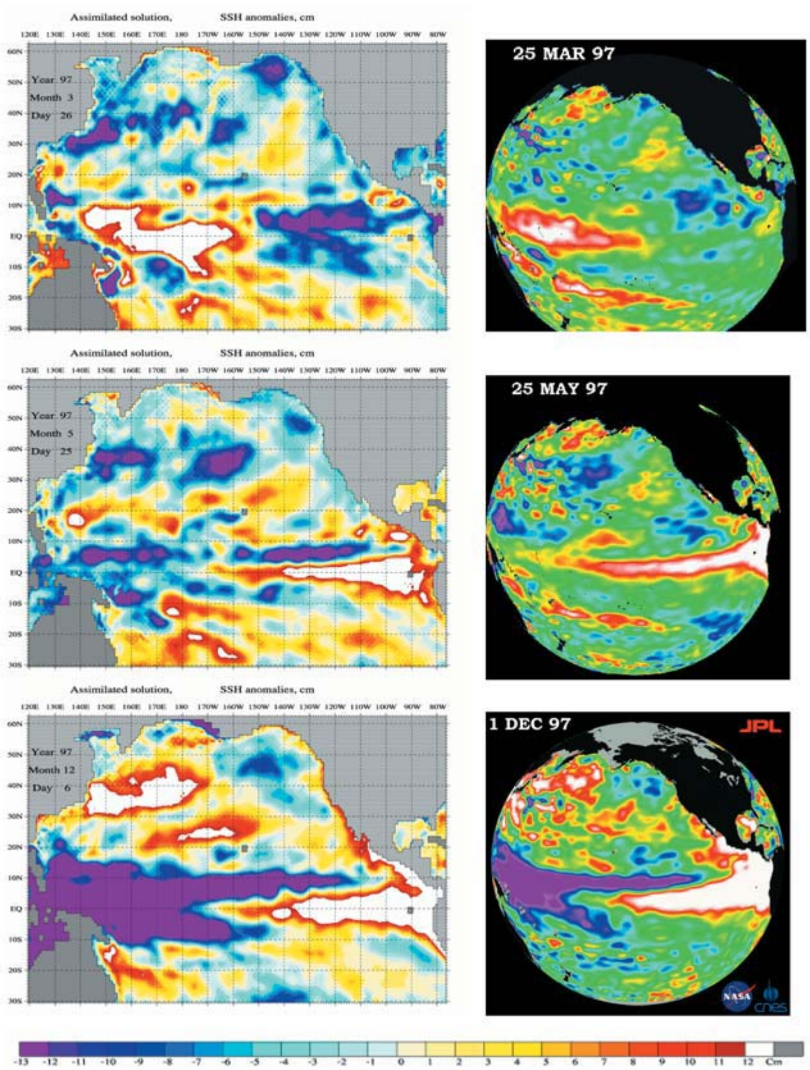
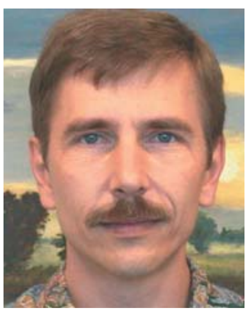


Figure 6. *Pacific Ocean sea-surface height anomalies for March 25, May 25, and December 1, 1997: assimilated solutions (left panels) and TOPEX/Poseidon images (right panels). TOPEX/Poseidon images were obtained from the NASA-JPL website http://topex-www.jpl.nasa.gov/.*

1° global resolution (the total number of assimilated observations was 570,000). The covariance structure of the error fields for the assimilation was based on numerous runs with various forcing products and experimentation with sub-grid parameterizations. The quality of the assimilation was gauged by applying several criteria to the outputs of these experiments: (1) absence of drift from the Levitus climatology; (2) consistency with the TOPEX/Poseidon sea surface height anomalies and CTD/XBT profiles; (3) consistency with the independent (not assimilated) SSH anomalies and the CTD/XBT profiles; and (4) consistency with the drifter-derived mean SSH (Maximenko and Niiler, 2004).

Figure 6 illustrates the SSH anomalies in the Pacific Ocean during 1997–98 El Niño phenomenon derived from the assimilated solution and from measurements by NASA satellites. A comparison of the plates shows very good agreement between the model-assimilated and the observed SSH fields: the assimilated solution captured very well this El Niño event, which affected global weather and climate. In summary, these results show that the SEEK filter is now a useful instrument for oceanographic research at IPRC and APDRC.



Nikolai A. Maximenko
Associate Researcher

Nikolai Maximenko obtained his Ph.D. in physical oceanography in 1987 from the P.P. Shirshov Institute of Oceanology, Moscow. His research interests include large-scale dynamics of the upper ocean, wind-driven currents, mesoscale eddies, Lagrangian tracers, intra-thermocline lenses and submesoscale coherent vortices.

Understanding the dynamics controlling Earth's climate requires a thorough knowledge of the ocean mean state, in particular, the ocean's *mean sea level*, which together with Ekman currents, largely define the surface circulation. Although advanced satellite altimetry provides continuous and accurate observations, determining mean sea level remains a challenge: Spatial variations in mean sea level that maintain the dynamic balances of the ocean do not exceed 3 m, and elevation of the equipotential surface (geoid), used as a reference for mean sea level, varies between about –100 to +100 m, owing to the mass distribution within the Earth. Even the most advanced models of the geoid, based on decades of satellite and ground gravity measurements, contain errors reaching nearly 1 m in some areas. The specially designed NASA twin GRACE satellites collect data to correct the geoid models. Unfortunately, the GRACE geoid released last year by the Center for Space Research, University of Texas at Austin, only resolves horizontal scales 500 km or larger, imposing the same low resolution on mean sea-level estimates referenced to this geoid. Such coarse resolution significantly distorts the pattern of most oceanic fronts and jets, whose accurate representation is necessary for adequate description of the mean ocean circulation.

Nikolai Maximenko, in collaboration with Peter Niiler (Scripps Institution of Oceanography), has managed to increase the spatial resolution of the GRACE-based mean sea level by using information from surface drifters, satellite altimeters, and wind products to estimate the mean sea-level tilt. Estimates are made using the momentum equation, which includes terms representing acceleration, the Coriolis force, pressure gradient, and the vertical divergence of the Ekman stress. Values for the first and second terms are computed from trajectories of the Surface Velocity Program drifters that have large drogues attached at 15-m depth. Interannual bias in the pressure gradient was corrected using Aviso/Enact Merged Sea Level Anomaly maps derived from satellite altimetry. Parameterization of Ekman stress divergence to the NCAR/NCEP reanalysis winds was determined by fitting the mean pressure gradient, smoothed to 9° in the zonal and 3° in the meridional direction, to the GRACE-based mean sea level released recently by the NASA Jet Propulsion Laboratory.

The best parameterization reveals remarkable seasonal differences in the relationship between Ekman velocity and local wind, and in summer, it corresponds well to the parameterization suggested by Ralph and Niiler (1999). In winter, the angle between Ekman velocity and wind vectors as well as the ratio of their magnitudes decreases markedly. Although this tendency agrees with the expected effect of known greater mixing due to winter-time convection, traditional models of the mixed layer, such as the KPP model, are unable to reproduce the observed Ekman velocity at 15-m depth. Maximenko and Niiler are now using NASA QuikSCAT satellite data to validate their results with more direct measurements of wind stress.

When the values of mean sea-level tilt obtained with the momentum equation are combined with the NASA Jet Propulsion Laboratory's large-scale sea-level data within a single cost function to form a "hybrid" mean sea level data set, a precise description of mesoscale structures of the global upper ocean emerges. Several structures are amazingly complex even after averaging over ten years of observations. The fine mesoscale resolution maps of global mean sea level and mean surface velocities show all known currents and reveal some new features. For example, they show that the South Atlantic Current, thought by Stramma and Peterson (1990) to close the subtropical gyre, actually consists of two separate eastward jets (Figure 7). The first, the South Atlantic Current proper, is a continuation of the Brazil Current, shifting gradually southward and eventually merging with the Antarctic Circumpolar Current around 20°E. The second, newly discovered jet is weaker. Appearing around 35°S, 40°W, it flows parallel to the South Atlantic Current and merges with the retroflected Agulhas Current south of Africa. Possibly this jet, analogous to the Azores Current in the North Atlantic and is induced by the subsidence of Atlantic water that occurs while the Aghulhas Current separates from the coast and sheds eddies.

James T. Potemra

Assistant Researcher

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

Jim Potemra has been studying the seasonal and long-term mean water exchange between the Pacific and Indian Oceans known as the *Indonesian Troughflow* (ITF) and the influence of warm and fresh Pacific water on Indian Ocean climate. To determine the low-frequency variations in the exchange and their causes, Potemra has been analyzing simulations from two coupled models, the NCAR PCM and the SINTEX model. While the interannual characteristics are different in the two models, the ITF flow patterns are the same. Computing transport from the PCM and SINTEX velocities, Potemra found that, similar to another modeling study, the ITF transport through a section from Java to Australia occurs at three distinct depths: a surface layer (0–100 m), a thermocline layer (100–500 m), and a deep layer (500 m to the bottom). In both of the models Potemra studied, the upper layer

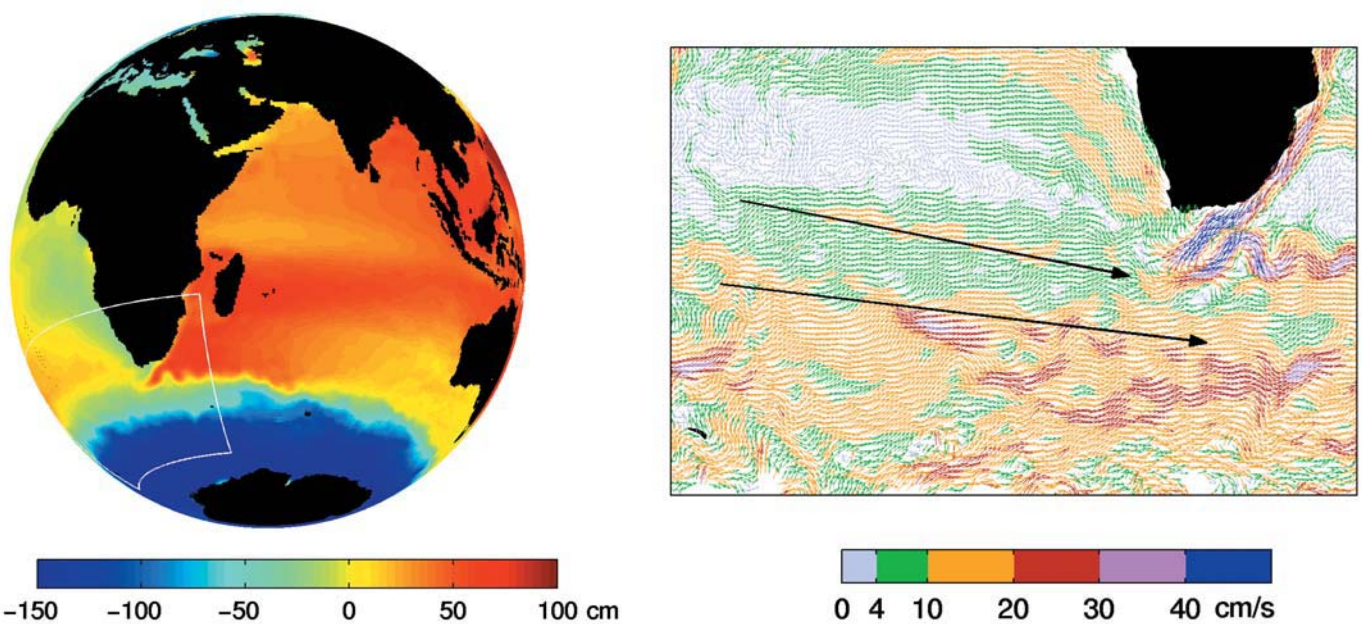


Figure 7. *Maps of 1992–2002 hybrid mean sea level (globe) and mean surface velocity (rectangle) in the region of the Agulhas Current. Black arrows show branches of the South Atlantic Current. Velocity vectors in color are proportional to their magnitude and shown only where drifter data are available.*

transport accounts for about 70% of the total transport (8.2 of 12 Sv in the PCM; 6.9 of 9.6 Sv in the SINTEX), and the rest of the transport occurs mainly in the thermocline layer.

In the surface layer, seasonal anomalies in the model ITF-volume transports are due to local winds near Indonesia: Westerly wind anomalies in the equatorial Indian Ocean create downwelling Kelvin waves. These waves then generate coastal Kelvin waves that reduce the ITF upper-layer transport a month after the anomalous winds appear in the equatorial Indian Ocean. Westerly alongshore winds near Sumatra and Java create an immediate onshore Ekman flow, which also lowers upper-layer transport in the ITF.

In the subsurface (thermocline) layer, seasonal ITF transport is affected by winds in the equatorial Indian and Pacific Oceans (Figure 8). When anomalous easterly winds blow in the equatorial Indian Ocean and at the same time westerly ones in the western and central Pacific, the ITF transport in the thermocline layer decreases. In the absence of the easterly Indian Ocean wind anomalies, the westerly anomalies in the equatorial Pacific raise the thermocline, decreasing the pressure difference between the Pacific and Indian Oceans. Acting alone, the easterly wind anomalies in the equatorial Indian Ocean raise the thermocline on the Indian Ocean side of the ITF by setting in motion equatorial and subsequent coastal Kelvin waves, which increase the pressure below the thermocline. An important difference between the Indian and Pacific basins is that the thermocline depth is shallower on the Indian Ocean side. Therefore, when easterly winds in the Pacific combine with easterly winds in the Indian Ocean, the Pacific-to-Indian Ocean pressure gradient in the thermocline layer is decreased, leading to a reduction in ITF thermocline transport. Such wind scenarios can be independent of the Southern Oscillation and can result from SST anomalies in the Indian Ocean. This latter possibility, together with different responses to the wind anomalies in surface and subsurface transport anomalies, can produce an apparent lack of relationship between variations in total depth-integrated transport and the Southern Oscillation.

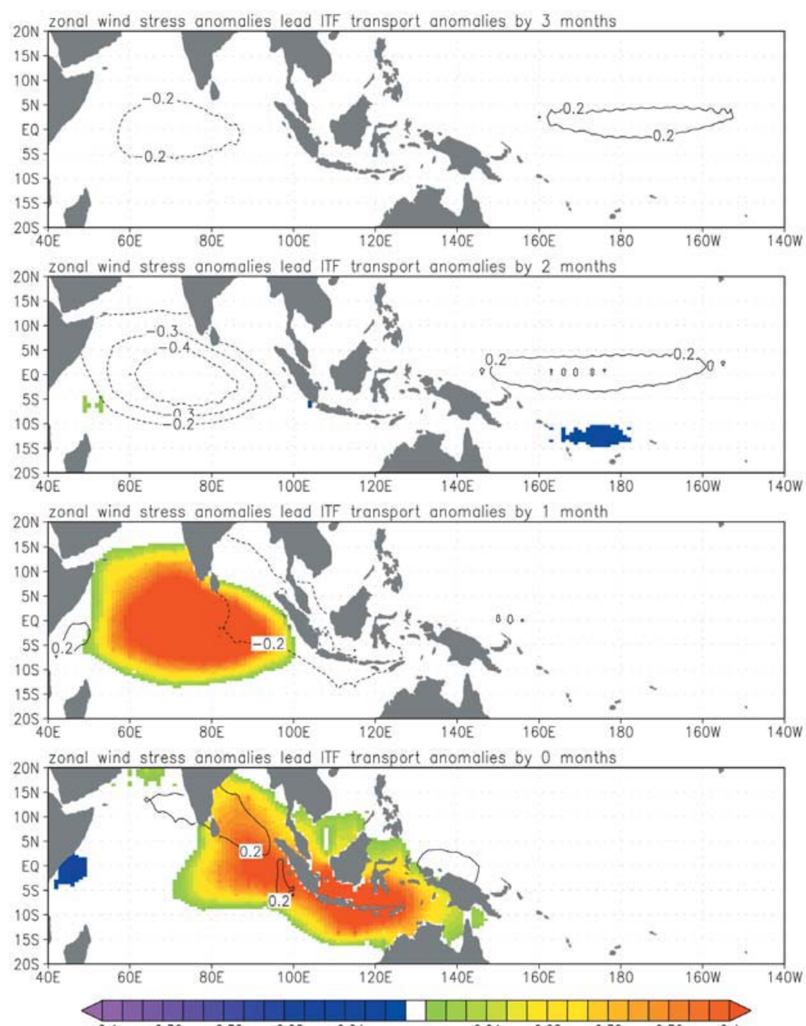


Figure 8. Summary of the wind–ITF-transport relationship at four time lags. Correlations between zonal wind stress and ITF transport anomalies in the upper ocean are represented by color shading, and in the thermocline by contours. Positive correlations indicate either a coincidence of westerly and weaker ITF transport or easterly and stronger ITF transport. Results are from a 300-year integration of the PCM. (A similar relationship was found with the SINTEX model). Surface-layer flow is correlated with local winds at short lags (color shading in lower panels), whereas deeper transport is correlated with divergent winds (contours in upper panels).

Tangdong Qu

Associate Researcher

Tangdong Qu obtained his Ph.D. in physical oceanography in 1993 from the Institute of Oceanology, Chinese Academy of Sciences, Qingdao. His current research interests include upper-layer ocean circulation and the thermal dynamics of the Indian and Pacific oceans.

The *South China Sea (SCS) climate* is a significant aspect of the East Asian monsoon system, and its connection to the El Niño–Southern Oscillation (ENSO) has become an active research area. Previous studies, however, mainly relied on atmospheric data. The role of the ocean in conveying signals of ENSO from the Pacific has not been carefully examined, despite the fact that there is a significant intrusion of Pacific water into the SCS through the Luzon Strait. This intrusion is often referred to as the Luzon Strait transport.

Tangdong Qu, Yoo Yin Kim and Max Yaremchuk (IPRC), and Tomoki Tozuka (University of Tokyo), Akio Ishida (JAMSTEC), and Toshio Yamagata (Frontier), have studied the role of Luzon Strait transport (LST) in conveying the impact of ENSO to the SCS. Analyzing simulations from a high-resolution ocean general circulation model, they confirmed that the LST is affected by ENSO. The transport tends to be higher during El Niño years and lower during La Niña years, with maximum (minimum) transport occurring about 1 month before the mature phase of El Niño (La Niña) (Figure 9). Moreover, the transport tends to be low (high) when the Kuroshio transport is high (low), indicating a possible nonlinear hysteresis of the Kuroshio as a mechanism for driving LST variations. Since on the annual average, water entering the SCS through the Luzon Strait is cooler than the water leaving the sea in the south, there is a cooling by advection in the upper 405 m equivalent to a surface heat flux of –19 W/m^2. Most of this cooling is balanced by atmospheric heating (17 W/m^2). From late spring to early fall, surface heat flux is the primary heating process and only a small part of heat-content change results from heat advection. In winter, however, heat advection is the only significant process responsible for cooling the upper SCS. Interannual variations in upper-layer heat content of the SCS correspond with ENSO phases, with cooling happening during the development of El Niño and warming during the development of La Niña. From this work, it follows that the Luzon Strait transport is a key oceanic process conveying the influence of ENSO to the SCS.

Qu has also been working with his colleague Gary Meyers (CSIRO) on a study that investigates the upwelling off Java and Sumatra and its influence on the sea surface temperature there, a process that is thought to be a major player in the Indian Ocean Dipole. Their findings are as follows: (1) The Indian Ocean South Equatorial Current (SEC) is depth dependent, with its velocity core shifting from 10–11°S near the surface to about 25°S at 500 m; (2) the Eastern Gyral Current is merely a surface flow associated with the meridional gradient of sea surface temperature; (3) the Indonesian Throughflow supplies water to the SEC mainly in the upper 400 m, and below that depth the flow is reversed along the coast of Sumatra and Java; (4) annual variation in dynamic height as shown by TOPEX/Poseidon altimeter data is greatest

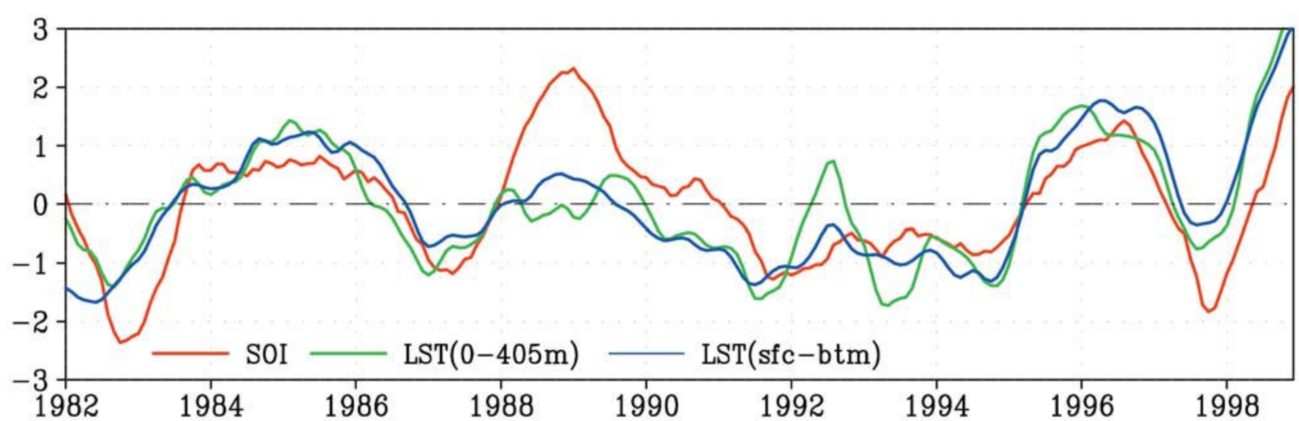


Figure 9. *Relationship between interannual variations in Luzon Strait transport (LST) in the JAMSTEC model and the Southern Oscillation Index (SOI), normalized by their respective RMS variance. RMS variance is 0.68 Sv for LST (0-405), 0.65 Sv for LST (surface-bottom), and 0.77 for SOI.*

at about (90°E, 10°S) and is also large in the surface layer of the coastal wave guides; and (5) the subsurface semiannual variation in dynamic height along the coast of Sumatra and Java is larger and deeper than the annual variation.

Kelvin J. Richards

Professor of Oceanography and Team Leader

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

The ocean's plankton community sustains not only fishstocks, but helps to regulate the uptake of carbon dioxide by the ocean. Observations from space and *in situ* measurements reveal a rich complexity in the distribution of phytoplankton. Kelvin Richards has begun a project that is looking at the *impact of stirring and mixing on the functioning of the marine ecosystem* and its effects. The goal is to determine whether or not the observed patchiness in phytoplankton and zooplankton, brought about by the stirring effects of ocean currents, affects the functioning of the ecosystem. Using simplified ecosystem dynamics, Richards has shown that stirring does indeed influence the ecosystem and can prompt the system to undergo a large-scale bloom of phytoplankton that would not otherwise occur. Recently he has extended his simple ecosystem model so that it will have broader applicability. Early results are promising and hopefully will show how to include these small-scale effects in larger-scale ocean models.

Richards has continued to work on a number of projects that examine the role of *lateral mixing* in the ocean. One of these projects (in collaboration with Andrei Natarov and Jay McCreary) is an ongoing investigation of the impact of lateral mixing in the equatorial thermocline, with particular emphasis on the effects of the observed interleaving of water masses. The goal is to develop a parameterization of interleaving suitable for inclusion in general circulation models used in climate studies. The most promising mechanism for the formation of the interleaving is inertial instability. This past year, historical datasets have been analyzed to determine the susceptibility of the equatorial current system to inertial instability. The flow is found to be unstable (in the linear sense) 25% of the time, with significant decadal variations in the susceptibility. Richards has also extended his previous work on the nonlinear evolution of layering to consider vertical as well as horizontal shear, and a time-varying background state. Early results show that zonal flows similar to those observed can develop significant interleaving through the action of inertial instability with substantial meridional fluxes of zonal momentum and tracers.

Together with Takahiro Endo and Yanli Jia, Richards has investigated the impact of the degree to which lateral mixing affects the characteristics of ventilation in a model of the North Pacific. The strength and patterns of ventilation change with lateral mixing in both the subarctic and subtropical gyres. Perhaps most interesting, very low levels of lateral mixing are required for the model to produce the observed subtropical countercurrent at around 20°N. The countercurrent is formed by the subduction of low potential vorticity water from the north. The current itself is unstable, producing Rossby waves that may be important contributors to the propagation of anomalies in the subtropical cells. This work is being followed up by considering the impact of lateral mixing in coupled models used in climate studies.

Takuji Waseda

Frontier Researcher[3]

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

Analyses of satellite images of the sea surface temperature of the *Kuroshio meander* suggested that a train of extratropical cyclones appeared to amplify the meander. To verify this idea, Takuji Waseda investigated the impact of high-frequency wind on the path taken by the Kuroshio using a regional Kuroshio-Oyashio general circulation model that was able to simulate both the meander and straight-path state of the Kuroshio. Near Japan, the standard deviation of the wind stress curl can be 10 times larger than the monthly mean. Therefore, the synoptic variations in the

[3] Now associate professor, Department of Earth and Planetary Science, University of Tokyo.

wind stress curl cannot be neglected. He conducted sensitivity tests with the model, applying monthly and daily mean QuikSCAT-derived wind stress forcings. A comparison between the two wind-stress conditions showed that the high-frequency local wind perturbed the Shikoku recirculation gyre, causing the straight Kuroshio path to meander. The trigger for the meander was a strong anticyclonic eddy within the Shikoku recirculation gyre. Through Ekman pumping, the high-frequency wind perturbed the motion of the eddy that otherwise would have detached itself from the Kuroshio, migrated south, and terminated the tendency of the Kuroshio to meander. This result reinforces the conclusion from previous studies that the anticyclonic eddy within the Shikoku recirculation gyre plays an active role in controlling the Kuroshio path variations.

The above finding is relevant to understanding the relationship between sub-grid scale wind turbulence and the general circulation of the ocean. It shows that high-frequency wind can perturb the meso-scale eddy, which then perturbs the Kuroshio path. Although the dynamics are nonlinear and local, the induced short-term variation adds to the much longer, climatic Kuroshio path variations. Future study should investigate how such nonlinear, short-term variations contribute to climate change in the western boundary currents.

Max Yaremchuk

Associate Researcher

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

Max Yaremchuk studied the seasonal influence of variations in *Luzon Strait transport* on the South China Sea (SCS) circulation. He established the mean seasonal cycle of the SCS circulation by applying a four-dimensional variational assimilation of ECMWF wind data and World Ocean Atlas data into a numerical model. A statistical and Lagrangian analysis of an OFES (Ocean Circulation Model for the Earth Simulator) simulation and a correlational analysis of the ERA40, Da Silva atmospheric climatologies, and Reynolds sea surface temperature (SST) revealed a seasonal cycle consistent with the one obtained from the assimilation. These analyses together showed that the relatively warm water entering through the southern part of the Luzon Strait tends to surface in a quasi-stationary cyclonic gyre east of Vietnam 5–7 months later. Adjoint sensitivity analysis revealed that an increase in the Luzon Strait transport by 2–3 Sv from November to February raises SST east of Vietnam the following May, a change that has approximately the same impact on SST as a local increase in sea surface heat flux of 4–6 W/m^2. Such an increase in the Luzon Strait transport, which sometimes occurs with a less intense winter monsoon east of Luzon, may affect the summer monsoon over the SCS half a year later by raising the SST in the northern SCS. An independent analysis of atmospheric data (ECMWF 10-m winds) and ocean data (Reynolds and Da Silva SSTs) that were not used in the adjoint analysis shows a statistically significant time-lagged correlation (r = –0.40 to –0.55) between these regions, suggesting that such a negative feedback mechanism between the winter monsoon system east of Luzon and the summer SCS monsoon may indeed exist (Figure 10). Results also show that the annual-mean Luzon Strait transport contributes 3.2±1.2 Sv to the Indonesian Throughflow, two-thirds flowing through the southern

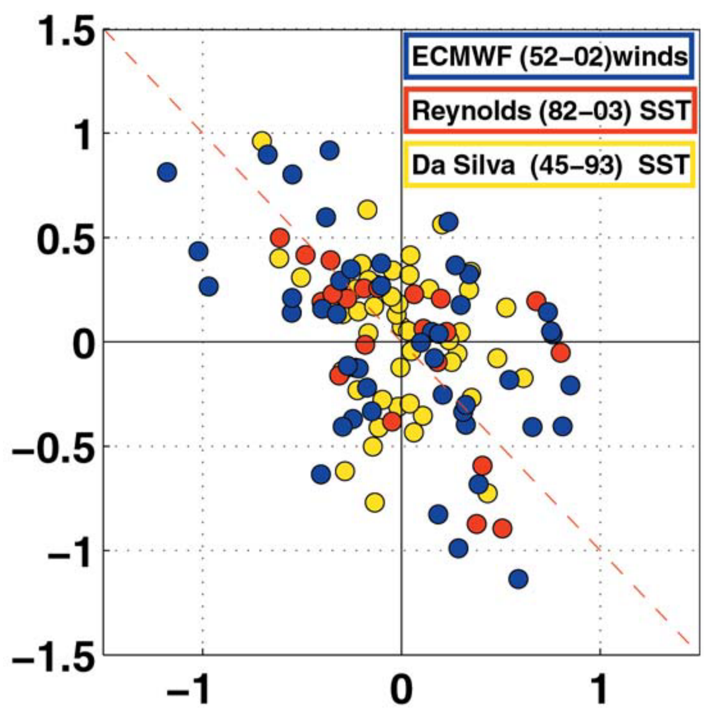


Figure 10. *Scatter plot of the monthly averaged anomalies of ocean surface characteristics east of Vietnam May–June and east of Philippines the preceding October–January. Observations are from 1952–2003 for ERA40 winds (m/s), 1946–1992 for Da Silva SST (°C), and 1982–2004 for Reynolds SST (°C).*

(Karimata) and one-third through the eastern (Mindoro Strait) routes.

In a second project, Yaremchuk collaborated with D. Nechaev (University of Southern Mississippi, Stennis Space Center) in developing a numerical scheme for the semi-implicit treatment of the Coriolis terms in C-grid models. The scheme is free from the grid-scale noise associated with the null space of the averaging operator that is applied to the Coriolis terms in order to collocate them with temporal derivatives. In addition, Yaremchuk continued his work with K. Lebedev (IPRC) and T. Waseda (IPRC) on constructing a SEEK filter based on the Parallel Ocean Program model. Finally, he developed a tangent linear code for a 4.5-layer reduced-gravity model used by Z. Yu (IPRC) and J. McCreary (IPRC). The latter two projects are aimed at increasing the data assimilation capabilities at IPRC. In particular, the tangent linear and adjoint codes for the reduced-gravity model should be a useful tool for the dynamically consistent assessment and reanalysis of upper-ocean satellite data, and may also be useful in sensitivity studies and in exploring large-scale teleconnections driven by upper-ocean dynamics.

Hiroshi Yoshinari

Postdoctoral Fellow

Hiroshi Yoshinari received his Ph.D. in earth environmental science in 2001 from Hokkaido University, Sapporo, Japan. His research interests include the interaction between the North Pacific Subarctic Gyre and Subtropical Gyre; the distribution, formation, modification and transport processes of North Pacific Intermediate Water in the subarctic-subtropical boundary zone; and the relationship between biogeochemical and physical processes in the subarctic-subtropical boundary zone.

The Argo Project deploys battery-powered, autonomous floats throughout the world ocean, which descend up to 2,000 m and measure various properties (*e.g.*, temperature, salinity, and float trajectory). The project is aimed at helping to clarify the manner by which the ocean affects global climate change. Most of the research findings from the project deal with temperature and salinity data and rarely with the available *float-trajectory* (that is, subsurface-velocity) data. One reason for this lack is that processing (calibration) methods for temperature and salinity data are much better than for float-trajectory data. In truth, there is no well-established method to calibrate float-trajectory data. Researchers, thus, avoid this data set because they cannot judge its validity.

Hiroshi Yoshinari is trying to remedy this situation by developing calibration methods for float-trajectory data that will lead to the establishment of a valid intermediate-velocity database. A considerable number of studies deals with surface-drifter (float) data because the trajectory is so easy to trace. In contrast, few studies consider a method for processing subsurface trajectory data. One such study is an as-yet unpublished paper by Park and his collaborators, who noted that the surfacing time and the diving time as well as the float position during those events are estimated better by using statistical methods (*e.g.*, least square method), thereby attempting to remove such trajectory contaminants as inertial sea-surface motion. Though Park's methods permit calculation of trajectory error when the float flows at the sea surface, it does not apply to trajectory error during the float's descent and ascent. To estimate this error, velocity-shear data is needed for the entire depth-to-surface path of the float. Working under the premise that the float ascent (or descent) between 800-m depth and the sea surface takes several hours, he estimated the trajectory error by using the velocity shear reported in the climatological dataset *World Ocean Atlas 2001*. For regions with weak currents (little baroclinicity), he estimated that the largest trajectory error is about 200 m. The significance of this error depends upon the spatial and temporal scales of interest. In regions of comparatively large baroclinicity, such as the western boundary current region, this error would probably be much larger and affect data greatly.

Yoshinari is using various other databases (*e.g.*, OFES output data, HydroBase, direct current measurement data such as Acoustic Doppler Current Profiler) to determine the baroclinicity for spatial and temporal scales in other regions of scientific interest in order to develop a general calibration method for trajectory errors of Argo floats.

Research Activities and Accomplishments
Asian-Australian Monsoon System

Overview

Research under this theme is directed toward understanding the processes responsible for climate variability and predictability of the Asian-Australian monsoon system and its hydrological cycle. Work this year focused on understanding the dynamics of the intraseasonal oscillation (ISO), which among other things determines the active and break periods of rainfall during the monsoon, as well as interactions of the monsoon with other tropical climate systems such as the El Niño-Southern Oscillation, the Indian Ocean Dipole, and teleconnections to midlatitudes. Much work has also been conducted on the numerical modeling of tropical cyclones.

Significant progress was made in understanding the role of ocean-atmosphere coupling in the *Madden Julian Oscillation* (MJO) and the *summertime intraseasonal oscillation*. A theoretical model successfully simulated the main characteristics of the MJO, pointing to the importance of friction-induced moisture convergence in the boundary layer in linking surface heat exchange, the motion of free tropospheric waves, and heating due to condensation. A series of experiments with a hybrid coupled model developed at the IPRC suggests that air-sea coupling is necessary for the realistic rainfall simulation of the summer ISO. In addition, implementation of a better convection scheme in a the Community Atmospheric Model (CAM2) also improved ISO simulation. In a third study, the summertime ISOs over India, Indochina, and the South China Sea were shown not to be distinct components but to interact strongly with each other.

Another research area considered the *interannual monsoon variability and predictability*. One study showed that the interannual monsoon variability is dominated either by two anomalous anticyclones or cyclones, which alternate on average from one year to the other. In each situation, one of the gyre pair is located over the southern Indian Ocean and the other over the western North Pacific, the former peaking in fall and the latter in the subsequent spring. The flip-flop between anticyclone and cyclone pairs results in a strong tendency toward biennial variation of the entire monsoon system, and it can account for the tropical biennial oscillation. Findings also suggest that SST anomalies in the monsoon region are largely a *response* to local atmospheric forcing, rather than a driving force for the atmosphere, implying that the traditional two-tier system for predicting monsoon rainfall from specified local SST is inappropriate. In another study, an atmospheric GCM was used to investigate the regional response associated with the Pacific climate shift in 1976–1977. Before 1976, basin-wide warm SST anomalies in the Indian Ocean during fall generated easterly flow over the equatorial western and central Pacific *via* an atmospheric Kelvin wave, which weakened the westerly winds associated with the developing El Niño. After the climate shift, the Indian Ocean SST anomalies changed sign across the basin (dipole-like); as a result, a significant Kelvin wave was no longer generated, and hence there was little damping of the El Niño-induced westerlies.

The *stratocumulus clouds over the subtropical eastern Pacific Ocean* were simulated using the IPRC Regional Climate Model (IPRC–RegCM). Despite their climatic importance, these clouds are poorly represented in most global atmospheric GCMs, and this deficiency is likely the reason for the models' failure to simulate the region's atmospheric, cloud, and SST conditions realistically. The IPRC–RegCM successfully represented the complex physical processes and feedbacks that maintain this thin cloud deck and their sharp temperature inversion cap. Sensitivity experiments suggest that planetary boundary layer and shallow convective parameterizations, adequate vertical resolution in the lower troposphere, realistic parameterizations for precipitation and drizzle, and sub-grid cloud condensation and variability are all necessary for the accurate simulation of these clouds. These findings point to improvements needed in climate models.

A study of *tropical cyclones* in the western Pacific verified two formation processes using high-resolution satellite data: a Rossby wave train induced by the energy dispersion of a previous tropical cyclone, and energy accumulation of easterly waves in the confluence region between the monsoon westerlies and the easterly trades. The two processes were also shown to generate cyclones in solutions to a 3-dimensional cyclone model. These results are relevant to operational forecasts of tropical cyclones. Moreover, a nonhydrostatic tropical cyclone model was developed; the 1–2-km resolution and other properties of the model make it suitable for studying cloud-scale and mesoscale processes in the core region of cyclones.

Land-surface degradation can impact regional climate by altering the overlying atmosphere. Two types of land-surface degradations, desertification and deforestation, were studied at the IPRC. The success of China's plans to replant desertified lands with forest and grass depends on a persistent increase in precipitation, especially in its frequency. A modeling study to investigate the effects of large-scale vegetation restoration showed an increase in the following: net radiation at the surface, total heat flux from surface to atmosphere, ascending motions over the test area, and moisture to the atmosphere. Rainfall increased mainly in intensity, rather than frequency, indicating that it will be difficult to maintain a vegetated surface in these regions without irrigation.

アジア・オーストラリアモンスーンシステム*

この課題下での研究は、アジア・オーストラリアモンスーンシステムの気候変動と予測可能性に関係するプロセスの理解を目指している。

「マデン・ジュリアン振動 (MJO)」と「モンスーン季節内振動 (Monsoon Intraseasonal Oscillation: ISO)」における海洋・大気相互作用の役割を理解にかなりの進展が見られた。理論モデルが MJO の主な特性をうまくシミュレートすることができ、地表面での熱交換、自由対流圏の波動及び凝結による加熱につながる境界層内での摩擦に起因する水蒸気収束の重要性を提示した。IPRC で開発したハイブリッド結合モデルを用いた一連の実験によって、夏季の ISO の現実的な降水シミュレーションには、大気・海洋結合が必要であることが示された。さらに、一般的な大気 GCM においても、より良い対流スキームを採用することで ISO シミュレーションが改善された。第三の研究では、インド、インドシナ、南シナの各海洋における夏季の ISO は別々のものではなく、強く相互作用していることが明らかになった。

亜熱帯東部太平洋のような地域での「層積雲」の気候的な重要性にもかかわらず、これらの雲はほとんどの全球大気 GCM において十分に示されておらず、この不足がその地域の大気及び SST の状態を現実的にシミュレート出来ない原因と考えられる。今年、IPRC-RegCM はこの薄い雲の層と気温逆転層による蓋を維持する複雑な物理過程とフィードバック機構を表現する事に成功した。これは気候モデルを改良へと向かわせるものである。

西太平洋の「熱帯低気圧」の研究では、高解像度衛星データの中で、二つの形成過程を立証することができた。すなわち、前の熱帯低気圧のエネルギー分散によって誘起されるロスビー波列及び西寄りのモンスーンと東寄りの貿易風が出会う地域における偏東風波動によるエネルギー蓄積である。三次元低気圧モデルでこれら二つの形成過程をシミュレートすることも可能であることから、熱帯低気圧形成に関する物理機構について深い理解ができたものと考えられる。この発見は熱帯低気圧の予測に関連している。

「陸面の荒廃」はその上の大気を変え、その結果地域気候に影響を及ぼす可能性がある。砂漠化と森林伐採について研究を行ってきているのはそれゆえである。砂漠化した土地に森や草地を再移植している中国の取り組みがうまく行っているのは、降雨の増大、特にその発生数の増大による。大規模な植生回復の効果を調査するモデル研究において、植生の増大は地表面の総放射量の増大、地表面から大気への総熱フラックス、試験地域上での上昇流及び大気中の水蒸気を増大させることが分かった。しかしながら、降雨はその回数ではなく、主に降雨強度が増大した。これは潅漑なしでは、これらの地域で植物を生育させるための地表面を保持することが困難であることを示している。

*JAMSTEC レポートからの翻訳。

Individual Reports

Soon-Il An
Associate Researcher

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

Is the *El Niño-Southern Oscillation* (ENSO) a large-scale deterministic system or a linear random system? Soon-Il An sought to answer this question on the basic dynamics of ENSO in a project with W. W. Hsieh (University of British Columbia) and F.-F. Jin (Florida State University). Applying a nonlinear principal component analysis (NLPCA) to the thermocline anomalies in the tropical Pacific, he noted that the thermocline anomalies were mapped as a closed curve, suggesting that ENSO is a cyclical phenomenon. The first-mode NLPCA of the thermocline anomalies, moreover, revealed an asymmetric evolution of the different phases of the ENSO cycle: Weak heat accumulation throughout the equatorial Pacific precedes a strong El Niño, whereas a subsequent strong drain of equatorial heat content off the equator precedes a weak La Niña. This asymmetric evolution in the ENSO phases implies that nonlinear instability enhances the growth of El Niño and diminishes the growth of La Niña. Analyses also showed that there was a change in the nonlinearity of the ENSO cycle in the late 1970s. Before 1980, the ENSO cycle associated with thermocline variability is more symmetrical than after 1980, indicating a stronger nonlinearity since the late 1970s.

In an analysis of the relationship between atmospheric 500 hPa patterns over the extratropical North Pacific and SST patterns in both the tropical and extratropical Pacific, An, together with Bin Wang, identified two distinct coherent ocean-atmosphere patterns. In the North Pacific ocean-atmosphere mode, SST anomalies are mainly confined to the extratropical North Pacific, whereas in the tropical (ENSO) ocean-atmosphere mode, an ENSO-like SST pattern dominates the tropics and extratropical SST anomalies are relatively weak. Since the North Pacific and ENSO modes exhibit distinct spatial and temporal characteristics, the intrinsic coupled mode of the midlatitude North Pacific is distinguishable from the remotely forced mode by ENSO, especially on the interannual time scale.

In a project with Axel Timmermann, An studied the ENSO dynamics during the Last Glacial Maximum (LGM) about 21,000 years ago. An eigenmode analysis of two solutions with an intermediate ENSO model was conducted, in which either the present-day or simulated-LGM background conditions were prescribed. The analysis shows clearly that the stability and frequency of the leading present-day unstable recharge-discharge mode changes are different during the two periods. The simulated-LGM background conditions were favorable to large-amplitude, self-sustained interannual ENSO variations in the tropical Pacific. Crucial factors in amplifying the LGM ENSO mode in this experiment were the equatorial climate conditions and a shoaling of the thermocline.

H. Annamalai
Assistant Researcher

H. Annamalai received his Ph.D. in atmospheric science in 1995 from the Indian Institute of Technology, Kharagpur, India. His research interests focus on the Asian summer monsoon system—its diagnosis, modeling, and predictability, and the manner in which it is affected by the Indian Ocean—and the dynamical and physical links between the system and ENSO.

Intraseasonal rainfall variability during the *Asian summer monsoon* has three co-existing components: poleward propagations of convection over India and over the tropical west Pacific and eastward propagation along the equator. In collaboration with Ken Sperber (Lawrence Livermore National Laboratory), H. Annamalai investigated the hypothesis that the three components influence each other, using observed outgoing longwave radiation (OLR) and NCEP-NCAR reanalysis data, and solutions from an idealized linear model. A cyclostationary (CsEOF) analysis of the OLR, filtered to extract the "life-cycle" of the summer monsoon rainfall, showed that the dominant CsEOF mode is significantly correlated with observed rainfall over the Indian subcontinent. The components of heating patterns from the CsEOF analysis served as prescribed forcings for experiments with the linear model, which allowed the determination of heat sources and sinks instrumental in driving the large-scale monsoon circulation during the rainfall life-cycle.

There were three key results for the study: (1) The Rossby-wave response to suppressed convection over the equatorial Indian Ocean associated with breaks in rainfall results in circulation anomalies that precondition the ocean-atmosphere system in the western Indian Ocean, triggering the next active phase of the cycle. (2) The development of convection over the tropical west Pacific forces descending anomalous motions to the west. This subsidence, together with weakened cross-equatorial flow due to suppressed convective anomalies over the equatorial Indian Ocean, reduces the tropospheric moisture over the Arabian Sea and promotes westerly wind anomalies that do not curve back over India. As a result, the low-level cyclonic vorticity shifts from India to Southeast Asia and break conditions begin over India. (3) The circulation anomalies, forced by equatorial-convective anomalies in the Indian Ocean, significantly influence the active and break phases over the tropical west Pacific. To summarize, the model solutions support the hypothesis that the three components of the monsoon summer-rainfall variability influence each other, rather than originating from the same source.

Annamalai participated in three other projects focused on the role of the Indian Ocean in Indo-Pacific climate variability. In collaboration with Shang-Ping Xie, Jay McCreary, and Ragu Murtugudde (ESSIG, University of Maryland), he examined the hypothesis that a basin-wide Indian Ocean SST anomaly generates an atmospheric Kelvin wave associated with easterly flow over the equatorial western-central Pacific, thereby weakening the westerly anomaly associated with a developing El Niño. In contrast, an Indian Ocean east-west SST anomaly with asymmetry does not generate a significant Kelvin-wave response and hence has little effect on the El Niño-induced westerlies. In a project with Ping Liu and Shang-Ping Xie, Annamalai explored the impact of Indian Ocean sea surface temperature (SST) on the Asian monsoon, particularly the effect of the basin-wide December–May warming that occurs after the mature phase of El Niño. Solutions to the ECHAM5 atmospheric model demonstrate that changes in the Indian Ocean Walker circulation suppress precipitation over the tropical west Pacific and the Maritime Continent. This suppression may, in addition to Pacific SST, maintain the Philippine Sea anticyclone, the anticyclone that increases precipitation along the East Asian winter-monsoon front. A persistent SST anomaly delays the northward migration of the deep moist layer and significantly delays the Indian summer monsoon onset by 6–7 days. In the third project, Annamalai co-authored a comprehensive review article with Murtugudde, entitled "Role of the Indian Ocean in regional climate variability." The review highlights past and recent research on the effect of Indian Ocean SSTs on Asian-Australian monsoon variability, and it stresses the need for accurate SST measurements in the entire tropical Indian Ocean in order to improve the monitoring of the intraseasonal-to-interannual variability of the monsoon system.

Xiouhua Fu

Assistant Researcher

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

Xiouhua Fu has been studying the impact of air-sea coupling on simulations of *tropical intraseasonal oscillations* (ISOs). In a series of small-perturbation experiments, he demonstrated that an atmosphere-ocean coupled model and an atmosphere-only model produce significantly different intensities of the boreal-summer ISO with markedly different phase relationships between convection and the underlying sea surface temperature (SST). More specifically, when the same initial conditions and the SSTs from the coupled model run are used to force the atmosphere-only model, the coupled model and the atmosphere-only model produce identical solutions; when a little noise is introduced into the initial conditions and SST, however, the atmosphere-only model generates an ISO solution very different from the coupled model solutions, although the climatologies they simulate are almost the same (Figure 11). The coupled model not only simulates a stronger ISO than the atmosphere-only model, but also generates a realistic phase relationship between intraseasonal convection and underlying SST. In the coupled model, an increase (decrease) in SST is highly correlated with more (less) precipitation with a time lead of 10 days, approximately the same lead as that seen in observations. This agreement suggests that not only does atmospheric convection affect SST but the changes in SST feed back to intensify convection. By contrast, in the atmosphere-only model, SST is only a boundary forcing for the atmosphere, and short-term variations in convection are less correlated with underlying SST, the maximum correlation between convection and SST occurring when they are in phase with each other—an outcome that is contrary to observations.

Fu has validated these findings by comparing integrations from the coupled model with long-term ECMWF analyses. The validation focused on the three-dimensional water-vapor cycle associated with the summer ISO and its interaction with the underlying sea surface. The coupled model produced a summer ISO that had the following similarities with the observed ISOs over the Asia–western Pacific region: (1) coherent spatio-temporal evolutions among rainfall, surface winds and SST; (2) intensity and period; and (3) tropospheric moistening (or drying) and overturning circulations. The tropospheric moisture fluctuations in the extreme phases (both wet and dry) of the simulated oscillation, however, are larger than those in the ECMWF analysis, and the simulated sea surface cooling during the wet phase is weaker than the observed cooling. Improved representations of interactions between convection and the planetary boundary layer in the GCM, as well as the inclusion of salinity effects in the ocean model, are expected to improve the simulation of the ISO.

Although the major characteristics of the summer ISO are very likely determined by the internal atmospheric dynamics, the studies by Fu show that the interaction between the internal dynamics and the underlying sea surface can only be sustained by a coupled system. The atmosphere-only approach, when forced with high-frequency (*e.g.*, daily) SST, introduces an erroneous boundary interference with the internal dynamics of the oscillation. Fu's findings, therefore, indicate that the air-sea coupled system simulates the summer ISO more realistically than an atmospheric-only system, and that ISO predictability may be significantly improved by including air-sea coupling.

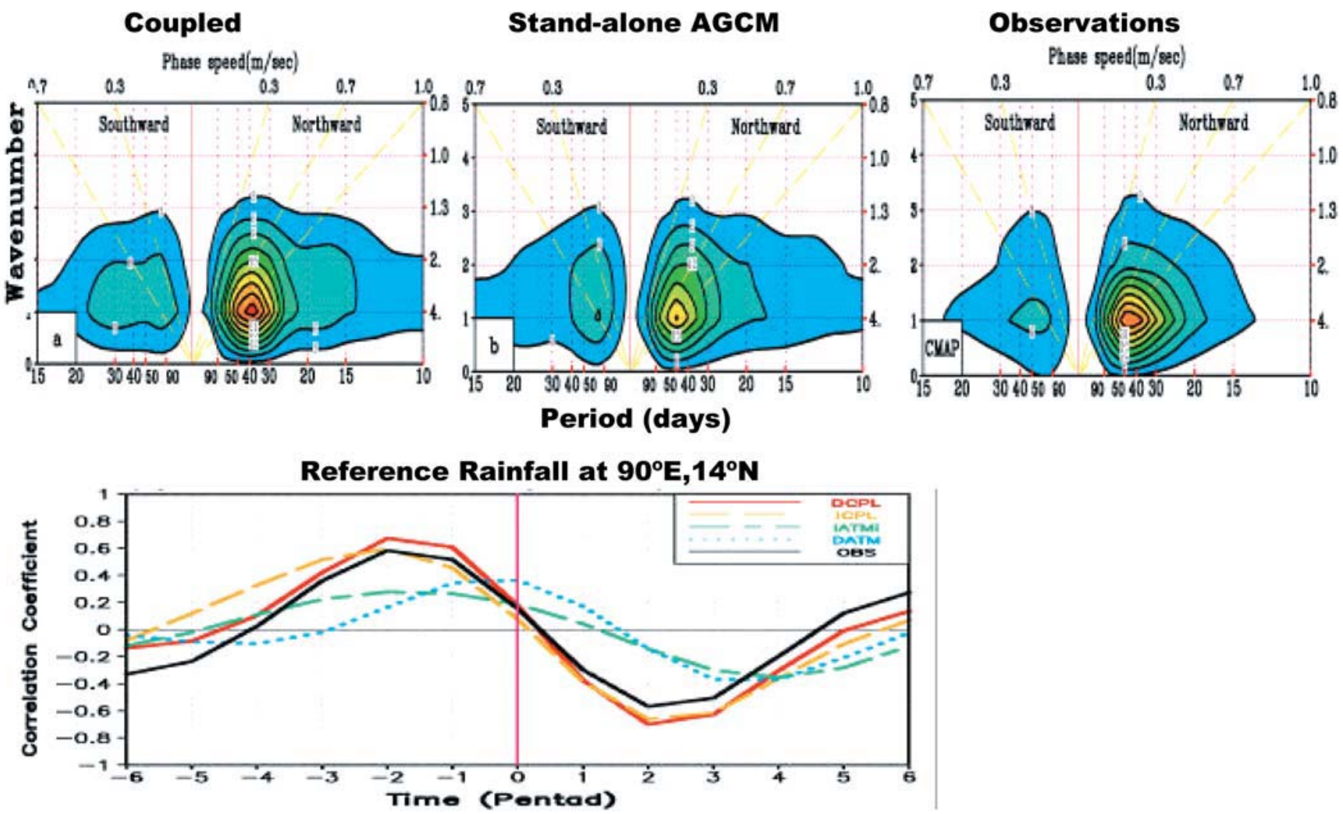


Figure 11. *Top panels: Rainfall variance (contour interval=3[mm/day]²) averaged over 65°E–95°E for north-south waves, ranging from about 1,300km (wavenumber 3) to 4,000km (wavenumber 1) and propagating within 10°S–30°N (left: coupled IPRC hybrid ocean-atmosphere GCM; middle: atmospheric GCM using sea surface temperature (SST) specified daily from the coupled model outputs; right: CMAP observations.) Bottom panel: Lagged-correlations between SST and rainfall anomalies at 90°E, 14°N for observations (black, Reynolds SST and CMAP rainfall), two coupled runs (red and yellow), and two atmospheric GCM runs using specified SSTs (blue and green).*

Tim Li

Associate Professor of Meteorology
Theme Co-Leader

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

The mechanisms by which synoptic perturbations and convective cloud clusters evolve into tropical depressions of a few hundred km in size and then form *tropical cyclones* (TC) are still far from clear. Moreover, the prediction of these depressions remains a challenge for atmospheric science. One of the least understood physical processes during cyclogenesis is the manner in which water vapor transport interacts with the convective circulation. Tim Li's recent numerical modeling experiments point out the importance of atmospheric moisture in TC formation (Li *et al*. 2004). In one experiment, a Rossby-wave train, induced by the energy dispersion of a pre-existing TC, interacts with the large-scale monsoon gyre flow to form a new cyclone. Specifically, in the model used previously by Holland (1997) and Wang (2002), a Rossby-wave train was obtained from integration in a resting environment. The initial vortex was symmetric, but eventually the beta effect induced asymmetry in its structure, resulting in a Rossby-wave train with alternative cyclonic and anticyclonic vorticity. This Rossby-wave train was then superposed on an idealized monsoon gyre flow (similar to the observed monsoon gyre composite by Ritchie and Holland 1999) with a length of 2,500 km and a central pressure 2 mb lower than the surrounding environment. The interaction between the Rossby-wave train and the monsoon gyre led to a new tropical cyclone five days later, which showed realistic dynamic (such as an eye wall) and thermodynamic (such as a warm core and spiral rain band) structures. Introducing only the Rossby-wave train or only the monsoon gyre into the model integration, however, did not lead to cyclogenesis, suggesting that both are needed for the synoptic wave train to grow into a TC, a finding consistent with observations (Fu 2003).

Figure 12 shows the evolution of vorticity, relative humidity, and vertical motion averaged within 60-km radius of the maximum vorticity at the lowest model level. During the

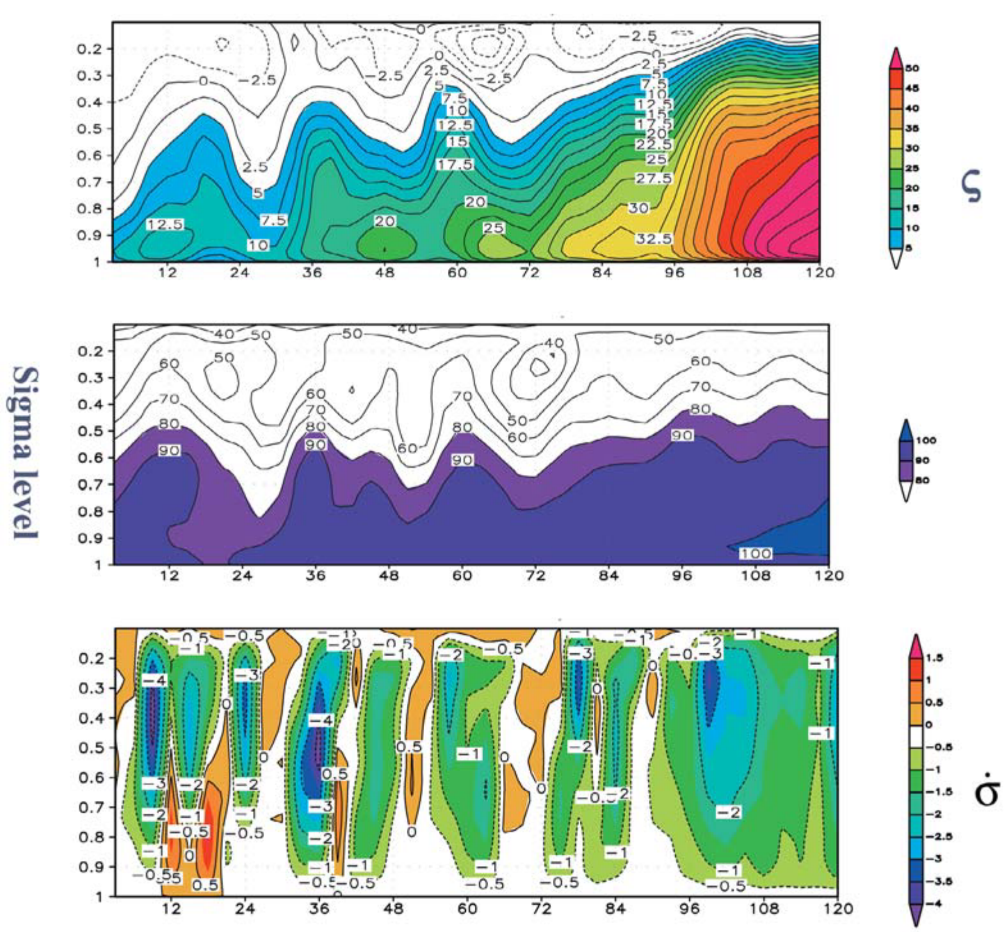


Figure 12. *Time evolution of vertical profile of vorticity (top panel, unit: 10^{-5}/s), relative humidity (middle panel, %) and vertical motion (bottom panel, 10^{-5}/s) averaged within a 60-km radius of low-level maximum vorticity simulated from the TCM3 model. Horizontal axis is time (unit: hour) and vertical axis is the sigma level.*

initial phase of TC development, vorticity grows in stages, increasing rapidly between hours 30 and 36, then slowing down before intensifying once more during hours 56 to 62 hours. The evolution of relative humidity and vertical motion correspond very well with this oscillating development.

To understand the causes of this oscillating growth, a composite of five intensifying and weakening phases during the initial formation period was studied: Intensification was characterized by maximum ascending motion throughout the troposphere, whereas weakening was characterized by downward motion and low-level divergence. The sequence of physical mechanisms that can account for such an oscillating growth is as follows. Surface heating and accumulation of planetary boundary layer (PBL) moisture first leads to convective instability, and thus convection. Convective heating and upward motion induce low-level convergence and increased cyclonic vorticity. Vertical transport of moisture, however, tends to reduce convective instability and stabilize the stratification. Meanwhile evaporation during precipitation causes cooling and downdraft in the middle-to-lower troposphere. This leads to further low-level divergence and a decrease in low-level vorticity. As the downdraft dries the middle-to-lower troposphere and convection diminishes, sensible heat flux and evaporation from ocean surface increase and convective instability builds up again in the PBL and the whole cycle repeats. Thus, atmospheric water vapor helps regulate the strength of convection by controlling atmospheric stratification, precipitation induced downdraft, PBL divergence, and low-level vorticity generation.

In addition to the tropical cyclogenesis study, Li and his colleagues have conducted research on the following topics: the use of satellite products, such as Advanced Microwave Sounding Units, in an operational forecast system; the dynamics of tropical easterly waves using a phase-independent wave activity flux; real-case simulations of cyclogenesis; dynamics of tropical intraseasonal oscillations and the tropospheric biennial oscillation; the origin of summer synoptic wave trains in the western North Pacific; and the temporal asymmetry in the northern summer–winter and winter–summer monsoon-phase transitions.

Ping Liu

Scientific Computer Programmer

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

The NCAR Community Climate System Model (CCSM2.0.1) and other general circulation models have not succeeded in *simulating a realistic monsoon mean state* and the *Madden-Julian Oscillation* (MJO). Since these models are an important tool for research on climate variability and climate change in the Indo-Pacific region, Ping Liu has been working on ways to improve the CCSM2.0.1. Recently, he made progress with the atmospheric component (CAM2) of CCSM2.0.1 by implementing the Tiedtke (1989) convective scheme. This scheme markedly improved the MJO signals in the 850 to 200 hPa zonal winds and allowed the model to simulate a realistic mean state. The modeled MJO has the following properties: periods of 30–70 days, with the dominant spectral power maximum of 40–50 days and concentrated on zonal wavenumber one; a stronger eastward than westward propagating tendency; a source region in the tropical western Indian Ocean; and low-level easterly wind anomalies and frictional convergence that lead precipitation associated with the MJO by 5–10 days and precondition the atmosphere with moisture. Precipitation is closely coupled with the zonal winds and propagates slowly eastward into the western Pacific at a speed of about 5 m/s. A Rossby–Kelvin wave structure is clearly defined in the Indian–western Pacific Oceans. Over other tropical areas, a Kelvin-wave structure is well simulated, supporting the eastward movement of the MJO. All these features agree well with the observed MJO reported in previous studies.

Chi-Yung Francis Tam

Postdoctoral Fellow

Chi-Yung Tam received his Ph.D. in atmospheric and oceanic sciences from Princeton University, Princeton, New Jersey. His research interests include the intraseasonal oscillation, subseasonal and intraseasonal variability of the extratropical circulation Summertime synoptic-scale and tropical cyclone activity, and air-sea interaction.

Tropical cyclones (TC) are an important part of tropical climate, with grave impacts on many coastal and maritime regions. Little is known, however, about the mechanisms leading to the formation of TCs. Chi-Yung Tam, working with Tim Li, has developed a wave-activity diagnostic appropriate for studying TC formation induced by easterly waves. These waves are active in preferred locations or 'storm tracks' and have well-defined propagation characteristics. Over the western Pacific, their associated energy or wave activity can be trapped by the confluent structure of the large-scale flow during the summer monsoon season. Research by Holland (1995) and by Sobel and Bretherton (1999) suggests the accumulation of wave activity is important for TC-genesis in this region.

Tam and Li have extended the phase-independent wave-activity-flux formulation of Takaya and Nakamura (2001) for an easterly basic state and applied it to studying TC genesis. This formulation does not require time averaging and is able to provide snapshots of wave activity. The latter property makes the activity flux ideal for case studies of cyclogenesis, as the waves can intensify rapidly. To illustrate its use, the phase-independent activity flux associated with easterly waves over the western Pacific was computed. Both the basic state and flow perturbations were determined from data at 850 mb within periods of strong TC activity. Computation of the flux was based on just one perturbation pattern, the phase speed of the waves and the basic state circulation; no temporal or phase averaging is required. Products from the NCEP-NCAR reanalyses during the period of 1979–2003 were used.

It was found that wave-activity flux is generally directed westward due to the influence of the ambient low-level flow field. More importantly, there is strong convergence of wave activity in the region of 135–160°E, enhancing the probability for TC formation. Applying this diagnostic tool to individual developing and non-developing conditions should give insight into the dynamics and control of the large-scale circulation on TC-genesis induced by easterly waves. In fact, case studies conducted by Tam and Li show that there are periods with strong easterly waves in which TCs do not form over the western Pacific, apparently because the accumulation of wave activity is disrupted by the intraseasonal oscillation.

Wave-activity flux for easterly waves over the Atlantic was examined using the above method. At the 850 mb level, an activity flux pattern different from that over the Pacific was found. In particular, converging wave activity does not occur over most parts of the storm tracks. The result highlights the sensitivity of the flux pattern to the three-dimensional structure of the basic state. It also suggests that different dynamical processes could be involved in cyclogenesis over the Atlantic and the western Pacific.

Bin Wang

Professor of Meteorology
Theme Co-Leader

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

Bin Wang has studied the *predictability of the summer mean precipitation* in the Asian-Pacific region this past year. In a collaborative project with In-Sik Kang and Kyung Jin (Seoul National University), Shukla (COLA), Doblas-Reyes (ECMWF), Xiouhua Fu (IPRC) and Qinghua Ding (University of Hawai'i), he evaluated the skills of five state-of-the-art atmospheric general circulation models (GCMs) and their multi-model ensemble in hindcasting seasonal precipitation for the period 1979–1998. Their research showed that these state-of-the-art atmospheric GCMs, when forced by observed sea surface temperature (SST), cannot simulate Asian-Pacific summer monsoon rainfall with any accuracy. The models tend to yield positive SST-rainfall correlations in the summer monsoon region, correlations that are at odds with the observed relationship. The observed lag correlations between SST and rainfall suggest that treating the monsoon as a slave to prescribed SST is the cause of the models' failure.

When an atmospheric GCM is coupled with an ocean model, it simulates realistic SST-rainfall relationships; but when it is not coupled, it fails to simulate this relationship. The lack of feedback, apparently, causes the forced and coupled solutions to diverge because of initial noise or tiny errors in the lower boundary. Coupled ocean-atmosphere processes, especially the atmospheric feedback to SST, therefore, appear to be essential for predicting the heavy rainfall in the monsoon convergence zones. This finding calls for reshaping current strategies in monsoon climate prediction and for atmospheric GCM validation studies. The traditional notion that climate is predictable by prescribing the lower boundary (Tier 2 approach) and by forcing the atmospheric GCM with forecasted SST is inadequate for predicting summer monsoon rainfall, especially in the Asian-Pacific region (Figure 13).

In another study of the Asian monsoon, Wang collaborated with LinHo (National Taiwan University), Mong-Ming Lu (Central Weather Bureau, Taiwan), and Yongsheng Zhang (IPRC) to analyze the *summer monsoon onset over the South China Sea* (SCS). The onset of this monsoon signifies the onset of the summer monsoon over the entire East Asian and western North Pacific region. Climatologically, the SCS monsoon onset in mid-May leads the Indian monsoon onset by two weeks and is one of the most abrupt events in the Asian summer. Agreement over the exact onset dates for individual years, however, has been poor, and lack of a universally accepted definition is a major roadblock to studying the interannual variability of the monsoon onset. The authors propose a single index for determining the summer monsoon onset over both the SCS and East Asia, namely, the 850 hPa zonal winds averaged over the central SCS from 5°N–15°N and 110°E–120°E. This local index, U_{SCS}, reflects both the sudden establishment of the monsoon southwesterlies in the SCS and the start of the rainy season in the central and northern SCS. The onset of the broad-scale East Asian summer monsoon over East Asia and the western North Pacific region (0–40°N, 100°E–140°E) can be objectively determined by calculating the principal component of the dominant empirical orthogonal

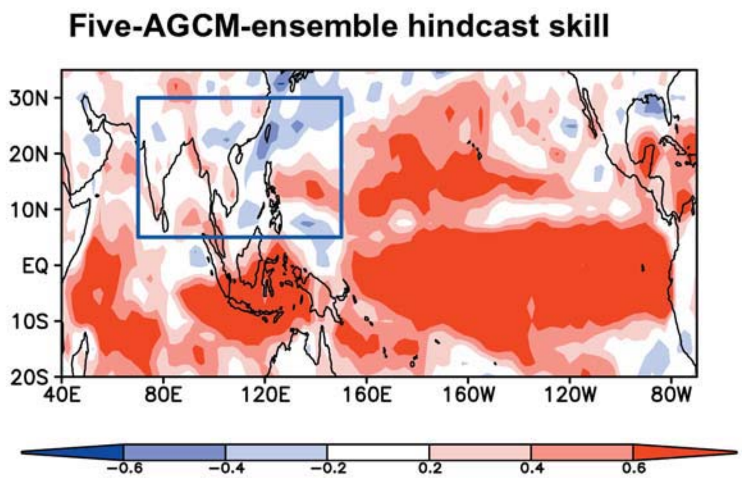
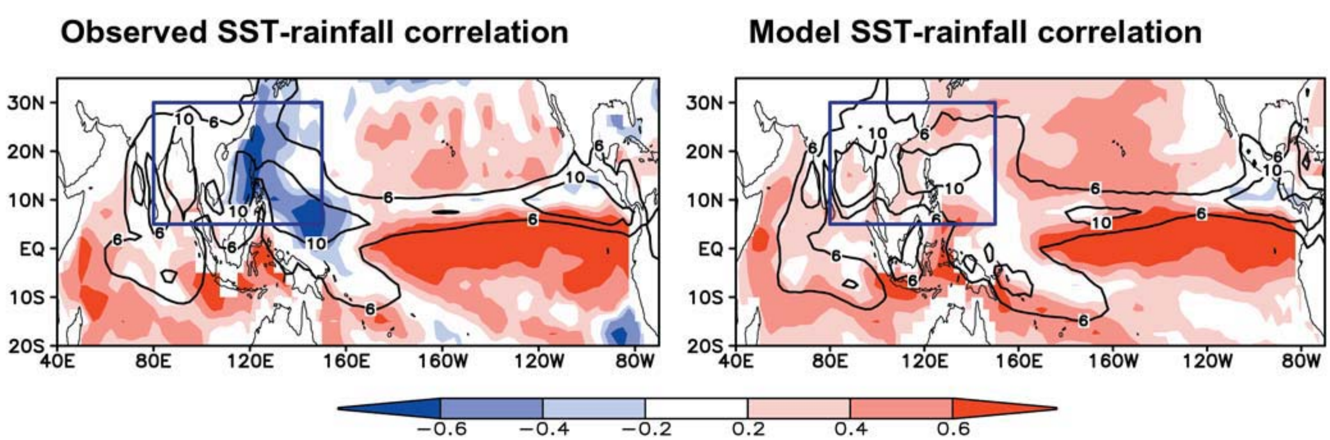


Figure 13. When forced by observed SST, state-of-the-art AGCMs are unable to simulate Asian-Pacific summer monsoon rainfall (top panel). The models tend to yield positive SST-rainfall correlations in the summer monsoon region (lower right panel) that are at odds with observation (lower left panel). Treating monsoon as a slave to prescribed SST results in the models' failure and indicates the need to reform the current tier-2 climate prediction system.



mode, U_{EOF1}, of the 850 hPa zonal winds. The U_{SCS} index though represents U_{EOF1} extremely well and can, therefore, be used to determine both the SCS and East Asian summer monsoon onsets. Evidence is present to show the index is closely related to two salient phases of the onset of the East Asian summer: the start of monsoon over the SCS and the start of the Meiyu (the rainy season in Yangtze River and Huai River Basin and southern Japan).

Yuqing Wang

Associate Professor of Meteorology

Yuqing Wang obtained his Ph.D. in applied mathematics in 1995 from the Centre for Dynamical Meteorology and Oceanography, Monash University, Australia. His research interests include atmospheric dynamics, tropical meteorology, tropical cyclones, air-sea interactions, low-frequency oscillations in the atmosphere and ocean, the development of high-resolution regional atmospheric models, and numerical modeling of the atmosphere and the ocean.

Despite their well-documented influence on climate, the *marine boundary layer stratocumulus clouds* over the subtropical eastern oceans are poorly represented in most global atmospheric general circulation models (GCMs) due to insufficient model resolution or inadequate physical parameterizations, or both. These deficiencies appear to be the reason why many coupled GCMs fail to keep the intertropical convergence zone (ITCZ) north of the equator for much of the year and fail to maintain an equatorial cold tongue of adequate strength in the eastern Pacific. The difficulty in modeling these clouds seems to be that they are only a few hundred meters thick and capped by a sharp temperature inversion, and that they are maintained by a complex array of physical processes and feedbacks that are just beginning to be investigated in models. Having successfully simulated the cloud deck off the Peruvian Coast with the IPRC Regional Climate Model (IPRC–RegCM), Yuqing Wang, in collaboration with Haiming Xu, and Shang-Ping Xie at the IPRC, conducted sensitivity experiments to identify which factors are critical for the realistic simulation of the cloud deck and, thus, for improving GCMs. Results suggest that, in addition to the planetary boundary layer and shallow convective parameterizations, adequate vertical resolution in the lower troposphere, and realistic parameterizations of precipitation-drizzle, subgrid cloud condensation, and subgrid variability in cloud microphysics are all necessary for realistic simulation of the cloud deck.

In another project with the IPRC–RegCM, Wang has collaborated with Omer Sen and Bin Wang in studying the *effects of vegetation changes* on regional climate. China, for example, has experienced profound desertification during the last several decades and has plans for massive restoration of vegetation with forest and grass across the country in order to prevent further desertification. The sustainability of the restored vegetation cover, though, is questionable. Reversing the desertification process depends largely on a persistent increase in rainfall and especially more frequent rainfall. To investigate whether a large-scale vegetation restoration effort can improve local rainfall enough to maintain vegetation in once desertified lands, Wang and his collaborators studied the effects of large-scale replanting on the East Asian summer monsoon and its rainfall in an idealized land-cover change experiment. Replacing desert and semi-desert areas (90°–110°E and 36°–42°N) with grass in the IPRC–RegCM increased the net radiation at the surface and the total heat flux from the surface to the atmosphere, which in turn enhanced ascending motions over the test area and supplied more moisture to the atmosphere. This increased the overall rainfall in the test area, but mainly in intensity, not frequency. The lack of frequent rainfall, especially in the lowlands of the test area, will make it very difficult to maintain vegetation and suggests the vegetation restoration will be limited to areas where water resources are relatively abundant unless there is heavy irrigation. The increased rainfall in the highlands and far eastern parts of the test area, which already receive frequent rainfall, may be sufficient to support restored vegetation in these regions, and the increased runoff noted in the higher elevations may provide some water for irrigation of the lowlands.

Regarding model development, Wang has developed a new nonhydrostatic version (TCM4) of his *tropical cyclone model*. The TCM4 shares the state-of-the-art model physics, the two-way interactive multiple nesting, and automatic mesh movement with its hydrostatic counterpart TCM3. The new model uses fully compressible, nonhydrostatic, water loading, and primitive equations with a mass vertical coordinate, and includes an efficient forward-in-time, explicit splitting scheme for model integration. A major advantage of the TCM4 is that it simulates the inner-core structure of tropical cyclones at

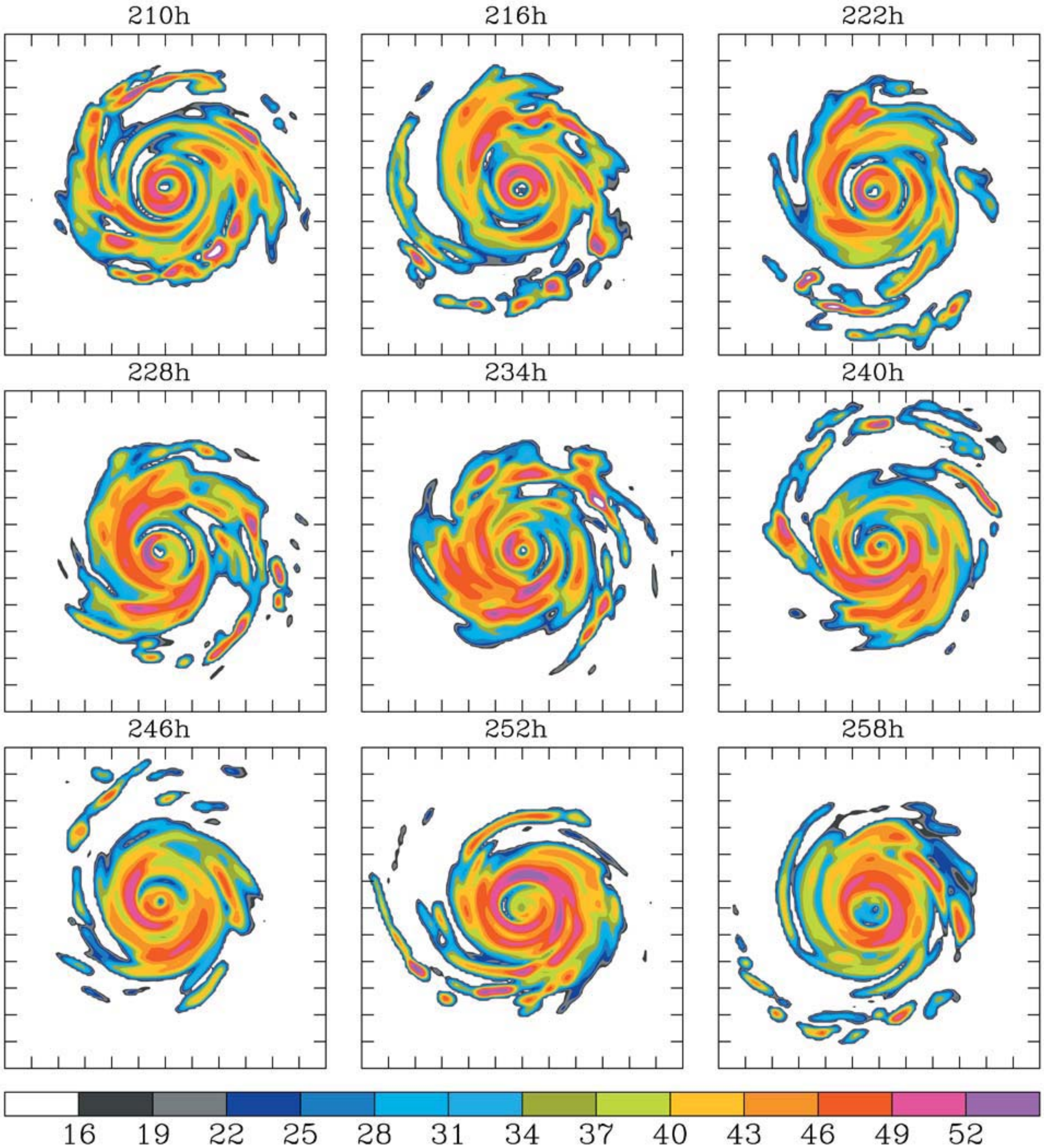


Figure 14. *Evolution of surface radar reflectivity in a tropical cyclone at 6 h intervals as simulated by the TCM4 on a beta-plane at 18°N, in a quiescent environment at 5-km resolution. The figure shows the development of concentric eyewalls and the weakening and subsequent replacement of the inner eyewall by the outer eyewall. These processes in a tropical cyclone have been difficult to simulate.*

cloud-resolving resolutions (1–2 km). This property makes the model ideal for studying many cloud-scale and mesoscale processes in the core region of a tropical cyclone (Figure 14). Preliminary results show that the new model can even reproduce the concentric eyewalls of a tropical cyclone. With this model, Wang plans to study cloud microphysical processes, mesoscale organization, and interactions between clouds and radiation during the formation of tropical cyclones.

Yongsheng Zhang

Atmospheric Data Specialist

Yongsheng Zhang obtained his Ph.D. in atmospheric science in 1995 from the Chinese Academy of Sciences, Beijing, China. His research interests include monsoon variability, monsoon and ENSO/TBO interactions, and satellite meteorology.

The South Asian and North Australian summer monsoons are the two most energetic monsoon systems in the world. Although the two monsoons have the same phase, the reason for this relationship is unclear. Yongsheng Zhang, in collaboration with Tim Li, studied conditions during El Niño and non-El Niño years to explore the processes that account for the relationship. Analyzing rainfall data in India and northern Australia from 1950–1997, Zhang noted that during El Niño years, sea surface temperature (SST) anomalies in the eastern-central Pacific Ocean help to bring about this relationship by changing the Walker circulation; during non-El Niño years, warm summer SST anomalies in the western Indian Ocean move eastward in fall and winter, accompanied by an eastward ascending motion that then leads to a stronger northern Australian monsoon. These results suggest that in the absence of El Niño, the local air-sea interaction in the Indian Ocean plays a role in maintaining the in-phase relationship.

As a high-altitude (4,000 m) summer heating source, the Tibetan Plateau impacts the Asian summer monsoon significantly, and the plateau's snow depth can be expected to modulate this effect. Zhang noted that station-observed snow depth for 1962–1993 revealed a sharp increase in snow depth after the late 1970s, which was found to be concurrent with a deeper India-Burma trough and an intensified subtropical westerly jet around the Tibetan Plateau. SST warming in the northern Indian Ocean and around the maritime continent together with the associated local feedback may have contributed to these circulation changes. Zhang was also able to document a close relationship between increased snow depth and wetter summers in the Yangtze River valley and dryer summers in Indochina. Both the surface cooling and increased surface moisture supply resulting from the greater snow mass and its melting may have led to these changes.

Research Activities and Accomplishments
Impacts of Global Environmental Change

Overview

IPRC research on Impacts of Global Environmental Change this year focused on three areas: climate sensitivity to radiative and land-surface perturbations; global influence on regional climate variability; and development of high-resolution global atmospheric modeling. Much of this research is done in collaboration with other IPRC research teams and with colleagues at JAMSTEC and elsewhere.

One ongoing project considers the *climate sensitivity* of coupled models to changes in the levels of solar radiation. Using NCAR's CSM1.4 coupled system, the solar constant was varied from its current value to a maximum increase of 45%. At some threshold of climate forcing (roughly corresponding to a 25% increase in the present-day solar constant), the model climate became unstable, warming indefinitely. Detailed diagnostics of the top-of-atmosphere radiative fluxes reveal that the main contributor to this "runaway" climate response is the decrease in shortwave albedo associated with low clouds. Long control and perturbed integrations with the NCAR CCSM2 are currently being compared to results from similar integrations with two versions of the Canadian Climate Center coupled model. In the coming year, the climate sensitivity in these two models will be analyzed and compared in detail.

Another climate sensitivity project concerns the effects of global warming on tropical cyclone climatology in the western Pacific. The IPRC Regional Climate Model (IPRC–RegCM) is being used to assess how a warmer climate will affect tropical cyclone occurrence in the western Pacific. The goal is to perform seasonal integrations of a western Pacific version of the model, with horizontal boundary forcing and SST lower boundary forcing taken from the NCAR CSM global model. This past year, the model was set up for an appropriate western Pacific domain and some test integrations were run with boundary forcing taken from observations. Preliminary results are encouraging and demonstrate that the model is able to simulate realistic intensification of tropical cyclones.

Concerning *global influence on regional climate*, results from a global atmospheric GCM and observations are being analyzed to study the effects of stratospheric interannual variations on wintertime, Northern Hemisphere surface circulations. This work has focused on simulation of the response of the global circulation to radiative perturbation from stratospheric aerosol loading during two years following the 1991 large, explosive volcanic eruptions of Mt. Pinatubo using the GFDL "SKYHI" troposphere-stratosphere GCM. Research had shown that the model simulated the basic features of the observed seasonal circulation anomalies following the eruption. This past year, the analyses included a realistic representation of the quasi-biennial oscillation (QBO) in the tropical stratosphere. The presence of the QBO was found to modulate the strength of the tropospheric response to the volcanic aerosol. This may explain the observed differences in the winter Northern Hemisphere circulation anomalies in 1991–92 and 1992–93. The study is now shifting to understanding the role of the stratosphere in unforced natural intraseasonal and interannual variability of the tropospheric circulation. An extensive set of new integrations (88 years) with the SKYHI model has been completed. Many of these runs include a realistic representation of the tropical QBO, and the first step in their analyses will be to characterize the effects of the QBO on the seasonal mean tropospheric circulation and to compare these simulations with relevant long-term observations.

A series of *high-resolution atmospheric integrations* using the Atmospheric Model for the Earth Simulator (AFES) was conducted by colleagues at the Earth Simulator Center. The runs completed include: (1) control integrations at very fine resolution (T1279 horizontal resolution and 96 vertical levels); (2) a set of integrations at T639 horizontal resolution but with different vertical resolutions, horizontal subgrid-scale diffusion coefficients and moist convection parameterization schemes; and (3) a series of runs with constant vertical resolution, but varying horizontal resolution (from T21 to T639). One focus of the analyses is on documentation of wind and temperature variance spectra, and the dependence of these spectra on the model's vertical resolution, horizontal subgrid-scale diffusion, and moist convection parameterizations. Results show that the AFES model can simulate a realistic spectrum over three decades of horizontal wavelengths, including the shallow mesoscale regime that has been observed in the real atmosphere at horizontal wavelengths less than about 500 km. A second focus is on understanding the small-scale variations in the T1279 simulations and investigating the implications of these results for subgrid-scale parameterization in more modest resolution models. As a first step, different reduced data subsets from the T1279 control simulation results were produced and brought to IPRC for more detailed analysis.

地球環境変化の影響*

この課題については地球環境変化とアジア太平洋気候の関係を特定することに重点を置いている。今年のプロジェクトは放射と陸面変化に対する気候の感度の調査、地域的気候変動へのグローバルな影響の研究、及び高解像度の地球大気モデリングの開発を含んでいる。この研究の多くは他の分野の IPRC 研究チームや JAMSTEC その他の研究者と共同で行われている。

気温変化への「気候の感度」を調査するため、当センターでは太陽放射の変化に対する結合モデルの応答を調べている。NCAR の CSM 1.4 結合モデルを利用し、太陽常数を現在の値から最大 45 %増まで変化させた。現在の太陽常数の 25 %増において、モデル気候は不安定となり、温暖化は制御できなくなった。大気上端の放射フラックスの詳細な診断から、この暴走した気候応答へ主に寄与しているものは低層雲に伴う短波放射に対するアルベドの減少であることが明らかとなった。現在、NCAR CSM2 を用いた長期標準積分と摂動積分の結果と、カナダ気候センターの 2 つの結合モデルを用いた同様の積分結果との比較を行っている。もう一つの気候感度プロジェクトでは、西太平洋における熱帯低気圧の平均的状態に対する地球温暖化の影響を研究している。具体的には、IPRC-RegCM を使用して温暖化が東部太平洋の熱帯低気圧発生数にどの程度影響を及ぼすかを事前評価している。

「グローバルな影響」の研究においては、冬季の成層圏経年変動及び北半球表面循環の効果を調べるため、全球大気 GCM の結果及び観測値を解析している。この研究では 1991 年の大規模なピナツボ火山の噴火の際の北半球循環の変化をうまくシミュレートすることができた。最近では、熱帯成層圏の準 2 年振動 (Quasi-biennial Oscillation: QBO) についても考察を始めた。季節平均の対流圏循環への QBO の影響をシミュレートし、長期観測データとこれらの効果を比較する計画である。

「高解像度大気モデル」の開発に関しては、地球シミュレータセンターの共同研究者が、地球シミュレーター大気モデル (AFES) で様々な解像度での一連のシミュレーションを行った。現在、風と気温の分散スペクトルと、モデルの垂直解像度、水平サブグリッド拡散、水蒸気対流パラメタリゼーションに対するそのスペクトルの依存性を記述するため、その積分結果を共同で解析している。その結果からは、約 500 km 未満の水平波長をもって実際の大気で観測される浅いメソスケールレジームを含む水平波長の実際のスペクトルを AFES が 30 年にわたってシミュレートすることができることが示された。現在、より適度な解像度のモデルにおける解像度より小さい規模の現象のパラメタ化への高解像度モデル結果の適用を考察中である。

*JAMSTEC レポートからの翻訳。

Kevin P. Hamilton

Professor of Meteorology[1]
Team Leader

Kevin Hamilton received his Ph.D. in geophysical fluid dynamics from Princeton University, Princeton, New Jersey, in 1981. His research interests include observations and modeling of the global-scale circulation of the atmosphere, climate modeling and climate change, meteorology and chemistry of the stratosphere and mesosphere, and atmospheric and oceanic waves and tides.

The Atmospheric Model for the Earth Simulator (AFES) is a *global spectral general circulation model* (GCM) that has been adapted to run very efficiently on the Earth Simulator. It has been run at extremely high horizontal and vertical resolutions, up to horizontal triangular-1279 (T1279), equivalent to roughly 15-km grid-spacing, and 96 levels in the vertical. Kevin Hamilton and his colleagues at the Earth Simulator Center and Hokkaido University are collaborating on analyzing the horizontal variance spectra simulated by such ultra-high-resolution versions of AFES. The observed atmospheric kinetic energy (*i.e.*, wind variance) spectra on horizontal surfaces show three distinct regimes: one at very large scales (horizontal wavelengths greater than about 5,000 km), a k^{-3} power law regime for intermediate horizontal wavelengths between about 500 km and 5,000 km, and a shallower mesoscale regime (something like $k^{-5/3}$) for wavelengths shorter than 500 km. Before the advent of AFES, the only global GCM that had clearly demonstrated a realistic simulation of the shallow mesoscale power spectrum was the Geophysical Fluid Dynamics Laboratory SKYHI GCM run at a resolution roughly comparable to T450. Hamilton and his colleagues have shown that the AFES model can also produce a simulation with a realistic mesoscale regime, confirming that the earlier SKYHI results were not artifacts of the particular numerical schemes and parameterizations employed. The very fine-resolution AFES results also explicitly resolved the horizontal scales in the shallow mesoscale regime over a full decade. The dependence of the spectrum on vertical model resolution, horizontal subgrid-scale diffusion, and moist convection parameterization are all being investigated.

Hamilton is also using the AFES model to study the important issue of appropriate scaling of the subgrid-scale diffusion coefficient with model resolution. An approach that has often been adopted in atmospheric models is to scale the diffusion so that the timescale for dissipation of the smallest resolvable scale is constant. Earlier studies have all been performed in modest resolution models, which are truncated in the k^{-3} power law and do not explicitly represent the mesoscale. With AFES, this issue can be addressed with a range of truncations that extend into the mesoscale. Hamilton's results suggest that, for high-resolution models, the hyperdiffusion timescale at the truncation wavenumber needs to become shorter as the truncation limit is extended.

Further issues now being investigated with the high-resolution global atmospheric model simulations include the dependence of vertical and horizontal eddy transports of heat, momentum, and water vapor on spatial scales. In particular, since the AFES and SKYHI models have been shown to have a realistically energetic mesoscale, it is of interest to see how much mesoscale motions (unresolved in typical global data analysis products) contribute to zonal-mean heat, momentum, and water budgets.

Hamilton has also continued to study the *response of the global circulation to the radiative perturbation* from stratospheric aerosol loading following large explosive volcanic eruptions. This work has focused on simulation of the circulation for the two years following the 1991 eruption of Mt. Pinatubo using the SKYHI GCM. It had earlier been shown that the model could simulate the basic features of the observed seasonal circulation anomalies following the eruption. This year, the calculations were extended to include a realistic representation of the quasi-biennial oscillation (QBO) in the tropical stratosphere. Hamilton has now shown that the presence of the QBO actually modulated the strength of the tropospheric response to the volcanic aerosol. This may help explain the differences seen in the observed record between Northern Hemisphere winter circulation anomalies in 1991–92 and 1992–93. This work is now shifting to studies of the role of the stratosphere in unforced natural intraseasonal and interannual variability of tropospheric circulation. Extensive runs with an imposed tropical QBO have been completed and are now being analyzed to evaluate the possible role of the stratospheric QBO in forcing interannual anomalies in the tropospheric circulation.

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Markus Stowasser

Postdoctoral Fellow

Markus Stowasser obtained his Ph.D. in meteorology from the University Karlsruhe, Germany, in 2002. His research interests include climate modeling and climate change, the meteorology and chemistry of the stratosphere, and remote sensing of stratospheric trace constituents with infrared spectrometers.

Results for the *sensitivity of the surface climate* to prescribed large-scale perturbations are known to vary widely among current global climate models, even for such a basic quantity as the sensitivity of the global-mean surface temperature. Since such models are used in forecasts of the future response of the climate to expected anthropgenic perturbations (such as increased greenhouse gas concentrations or changes in the atmospheric aerosol loading), it is important to understand why the climate sensitivity varies so much among state-of-the-art models.

Markus Stowasser is working with Kevin Hamilton on an investigation into the very different climate sensitivities displayed by two global climate model families, the National Center for Atmospheric Research (NCAR) CCSM and the Canadian Centre for Climate Modelling and Analysis (CCCma) CGCM. To understand why the climate sensitivities of these two model families differ and what determines their climate sensitivities, they have performed control and global warming simulations with the models and then diagnosed a local feedback parameter field Λ (defined as the change in net top-of-atmosphere radiative flux per unit change in surface temperature). They then decompose Λ into components associated with shortwave and longwave radiative processes, and in terms of cloud-free atmosphere-surface feedback and cloud feedback (Figure 15). This decomposition reveals that the most

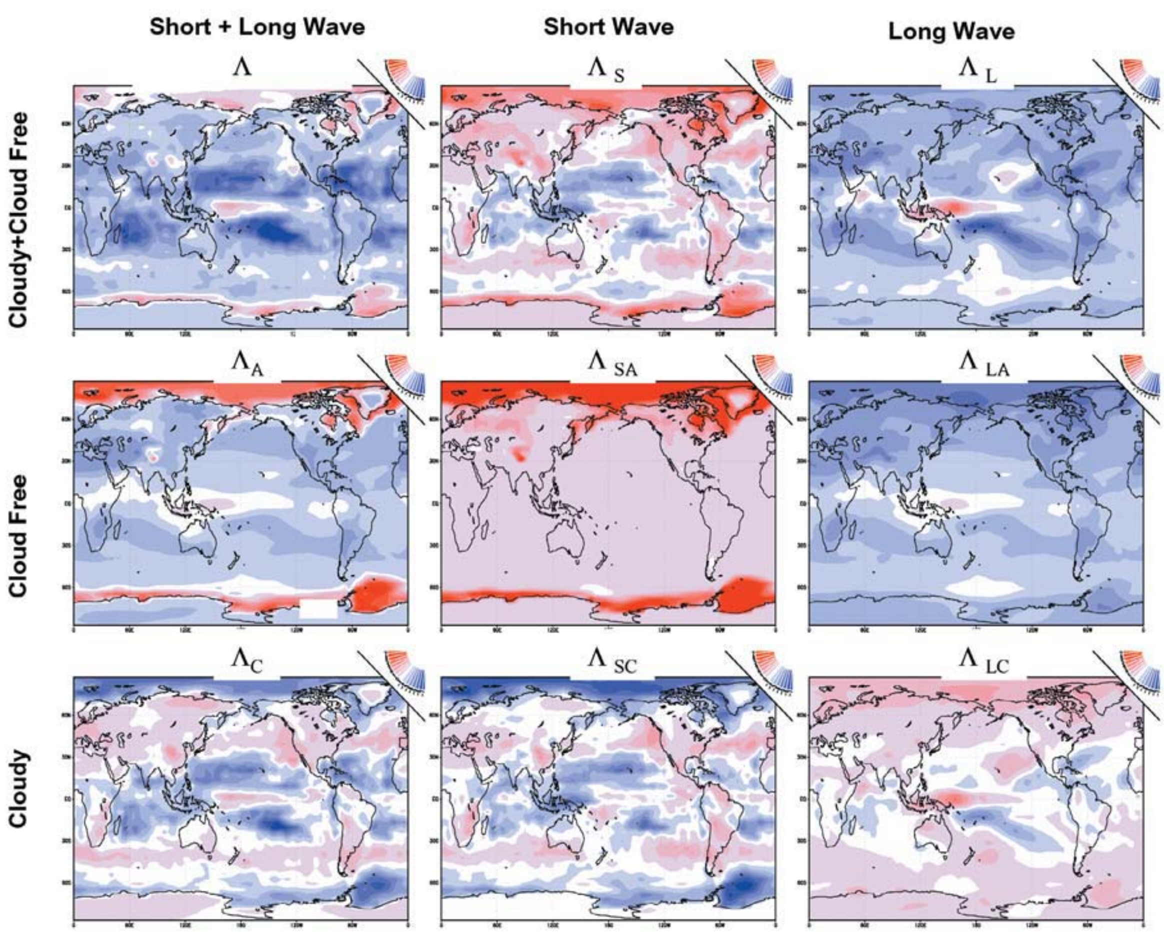


Figure 15. *Geographical distributions of the atmospheric feedback parameter Λ and its component in the CCSM2. Red colors represent positive feedback, blue colors negative feedback. The feedback parameter Λ is decomposed into shortwave and longwave components,* $\Lambda = \Lambda_S + \Lambda_L$ *in the top row of panels and into cloud-free atmosphere/surface and cloud-only feedbacks,* $\Lambda = \Lambda_A + \Lambda_C$*, in the left column. Each of the terms is further decomposed to give the nine components* $\Lambda = \Lambda_A + \Lambda_C = \Lambda_S + \Lambda_L = \Lambda_{SA} + \Lambda_{LA} + \Lambda_{SC} + \Lambda_{LC}$*. Shown is the average of the years 41–50.*

striking variation among the models arises from the different behavior of the shortwave cloud component of the feedback parameter: In the NCAR models this feedback parameter is negative, while it is positive in the CCCma models. The differences are most pronounced in two bands north and south of the equator.

While over much of the globe, the local feedback parameter, Λ, is negative, a region of positive feedback stands out in the tropical Pacific. All the models show this region of positive feedback, but its location and extent is different among the models, and the structure of geographical pattern in each case is mainly attributable to the longwave cloud feedback. The behavior of the feedback parameter in the tropical Pacific appears to be connected with the occurrence of a permanent El Niño-like warming in the models as the global mean temperature rises. In the Canadian model, the tropical Pacific Λ maximum is associated with an El Niño-like SST warming-pattern in the eastern Pacific. In the NCAR CCSM2.0.1, the maximum is shifted further west, and the model SST anomalies are very closely related to the feedback parameter. By contrast, in the CSM1.4, the maximum in feedback lies in the central Pacific region. In all the model warming simulations, the warm SST anomalies in the tropical Pacific expand the convection region over the western Pacific toward the east. The result is an anomalous Walker circulation with rising motion over the region into which the convection has expanded.

Stowasser has also begun a series of simulations with the IPRC atmospheric Regional Climate Model (IPRC–RegCM) to examine the response of western Pacific tropical cyclone (TC) climatology to large-scale global warming. As a start he has performed several seasonal integrations with observed boundary forcing to validate the ability of the IPRC–RegCM to simulate the observed variability and strength of TCs. The model is now being adapted so that it can be forced by boundary conditions taken from the global coupled GCM simulations.

Asia-Pacific Data-Research Center

The Asia-Pacific Data-Research Center (APDRC) is an integral part of the IPRC, facilitating climate research within the IPRC and within other national and international climate communities by providing easy access to climate data and products. This past year the APDRC has made considerable progress in handling and serving extremely large data sets, such as those from large-scale, high-resolution models (*e.g.*, the Ocean Model for the Earth Simulator, OFES; Figure 16), and in serving data from various sources and formats (*e.g.*, gridded and non-gridded data, *in situ* and remote observations). The APDRC also continues to build and improve its data archiving. The partnership with IPRC researchers was enhanced, and this integration of IPRC scientists into the management of the APDRC will improve the variety and selection of archived data sets and will provide data-evaluation that is based on scientific research.

The APDRC data holdings increased in three areas: extremely large ocean model data sets, *in situ* oceanographic observations, and remote and *in situ* atmospheric measurements. With regard to modeling data sets, the APDRC now

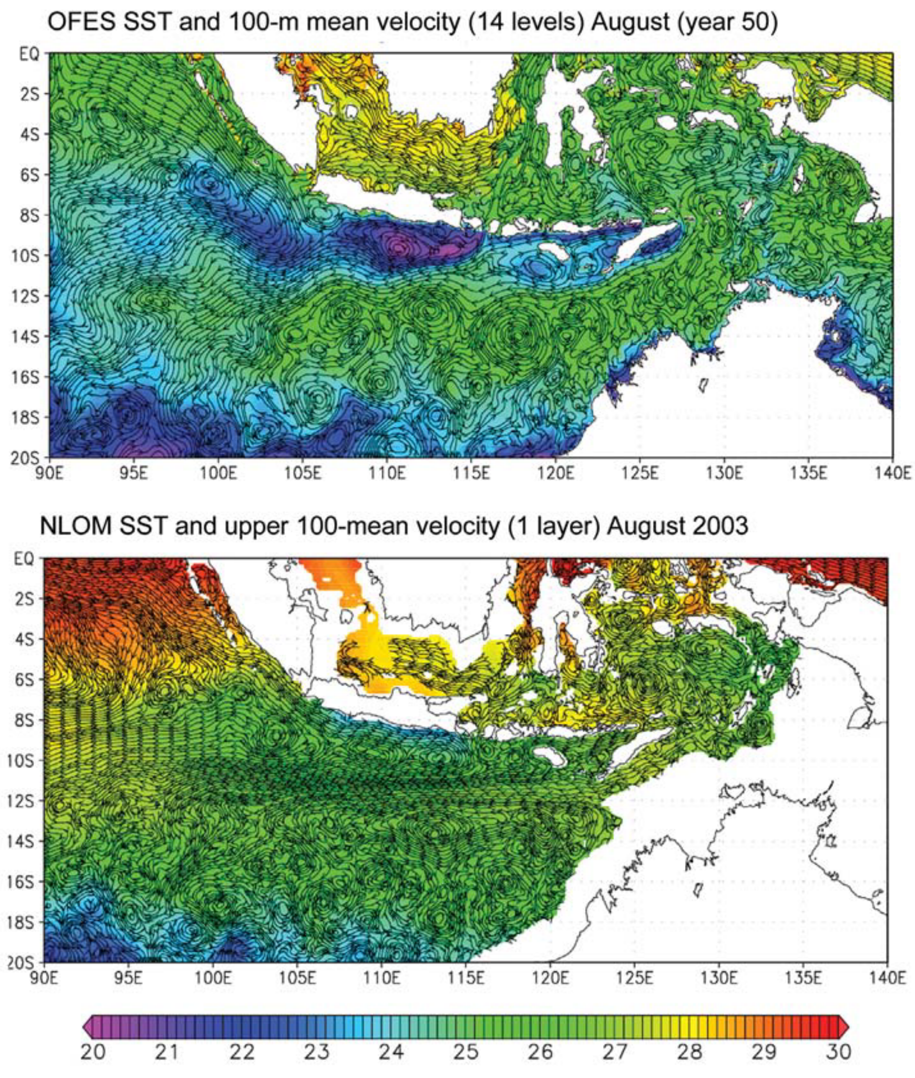


Figure 16. *Created with GDS on the APDRC website, the figure compares SST and velocity for the August-mean climatological run from the Ocean Model for the Earth Simulator (top) and the August-2003 nowcast assimilation run from the Navy Layered Ocean Model (bottom). Both panels show upper-ocean (surface-to-100-m) flows and temperatures (shading).*

serves several products from the Ocean Model for the Earth Simulator (OFES) at 1/10° resolution through the GrADS Distributed Oceanographic Data System (DODS) Server (GDS). The products include monthly mean climatologies (complete three-dimensional velocity, temperature, salinity and mixed-layer fields), three-day snaphots from a specific model year, long-term hindcast surface fields (sea level and SST), and a ten-year climatology. At present, this output is available only to IPRC scientists and the Earth Simulator research group, but these results will be released to the larger scientific community. The APDRC also serves output from the U.S. Navy Research Laboratory Layered Ocean Model (NLOM). Output from the 1/16° NLOM "nowcast" and "forecast" runs are archived daily and served by the GDS. These APDRC services make it possible for scientists to directly access, subsample, compare, and analyze output from these large models in a straightforward way. Figure 16 shows an example of a comparison between mean August SST and upper layer velocity (from OFES) and mean August 2003 conditions from the NLOM.

Regarding *in situ* oceanographic data, the APDRC has acquired and reformatted the following data sets so they can be served by the APDRC: JAMSTEC Argo data, WOCE *in situ* data, and FNMOC/GODAE profile data. New software to search specific atlases and display results, such the Java Ocean Atlas, HydroBase2 and Ocean Data Viewer, are all now available at the APDRC. Considerable effort is being made to increase the atmospheric data sets in the APDRC archive. These data include satellite observations of rainfall (TRMM, GPCP, *etc.*), SST (NOAA), and lightning (LIS), as well as historical measurements of in situ rainfall at various stations (*e.g.* Indonesia, Malaysia, India, *etc.*). High temporal resolution ECMWF data, ERA-40, have also been added to the data center archive.

As part of the MEXT Kyosei Project, the Integrated Modeling Research Program (under Professor Toshiyuki Awaji) at Frontier is developing a cutting-edge four-dimensional atmosphere-ocean-land coupled data-assimilation system on the Earth Simulator for a reanalysis of data from the 1990s. The IPRC has continued to assist with the establishment of an international data network for the project by identifying and collecting global ocean, atmosphere, and land-surface data; by providing quality control and value-added information; and by conducting data analyses. The IPRC, together with AESTO/MRI group, gridded the BUFR atmospheric input datasets compared them with various reanalysis products (NCEP, ERA-40).

The APDRC has upgraded and expanded its data servers. DAPPER, a DODS-type server for *in situ* data, has been installed, and three of the APDRC servers (LAS, CAS and GDS) have been upgraded. Furthermore, APDRC servers have been established as "sister servers" to the US GODAE program, and APDRC has provided technical assistance in setting up Frontier servers in Yokohama as "sister servers", allowing users to access data that is distributed among the three institutions as if they were on a single server.

アジア太平洋データ研究センター*

APDRC の一つの目的は、気候データの入手を容易にすることである。APDRC では今年、大規模で高解像度な非常に大きいデータセット (例: OFES) を処理し、提供する能力、また、様々な情報源からの多様なフォーマットを持つデータ (例: 格子及び非格子データ、現場及び衛星観測データ、等) を供給する能力に進展が見られた。APDRC は次の三つの分野でデータの保有量を増やしている。

1. GrADS の分散型データサーバーによって供給される 0.1 度の解像度を持ったいくつかの OFES の結果 (IPRC 内でのみの利用に制限されている) を含む非常に大きな海洋モデルデータセット、及び 1/16 度の NLOM ナウキャスト及び予測ランからの日々の出力値。
2. JAMSTEC Argo データ、WOCE の現場観測データ、FNMOC/GODAE のプロファイルデータを含んだ現場海洋観測データ。Java Ocean Atlas や HydroBase2、Ocean Data Viewer のような特定の地図を検索したり結果を表示するためのソフトウェアもすべて、現在では APDRC で利用可能となっている。
3. アジアでの様々な観測所における現場観測降水量の過去からのデータに加え、降水量の衛星観測値 (TRMM, GPCP 等)、SST (NOAA) 及び電光 (LIS) を含む大気データ。時間的に高解像度の ECMWF データ、ERA-40 をデータセンター・アーカイブに加えた。

サーバーは現在、直接アクセス、部分データの抽出、比較及びデータ解析を行う能力を有している。例えば、8 月の平均 SST と OFES からの上層流速、NLOM からの 2003 年 8 月の平均場を、比較目的のために容易にプロットすることができる。

APDRC の研究者は、文部科学省共生プロジェクト (MEXT Kyosei project) 課題 7 先端的 4 次元大気海洋陸域結合データ同化システムの開発と高精度気候変動予測に必要な初期値化・再解析統合データセットの構築 (代表: 淡路敏之 GL)、及び地球フロンティア研究システムモデル統合化研究領域の活動の一環として、全球の海洋、大気、地表面データの特定と収集、ならびに品質管理と付加価値情報の提供、またデータ解析の提供等によってそのプロジェクトに資する国際的なデータネットワークの構築に協力した。とりわけ姉妹サーバーとして横浜にある地球フロンティア研究システムのサーバーを構築する際には、日本のパートナーに技術的な助言を与えている。現在、FRSGC、APDRC、US GODAE Monterey にある各サーバーによる姉妹サーバーシステムは、サーバー間に分散している巨大なデータセットに対してあたかも単一サーバーであるかのようにアクセスできる能力をもっている。

*JAMSTEC レポートからの翻訳。

IPRC COMPUTING FACILITY

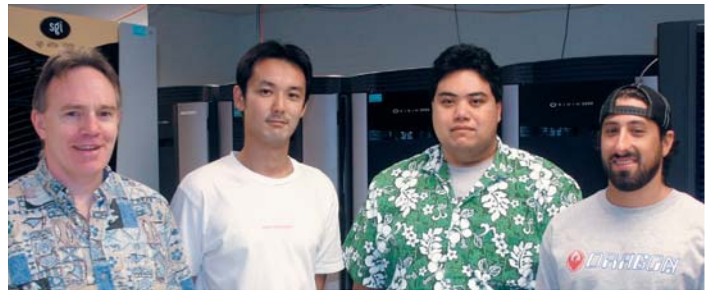
The IPRC computing facility's aggregate performance and disk capacity increased again this past year. The increase in general-purpose computing capacity was afforded with the purchase of an SGI Altix; the APDRC data server received a large increase in direct attached RAID arrays. The Altix has 32, 1.3 GHz Itanium 2 CPUs (central processing units) and 32 GB of memory. Its theoretical peak speed is 166 GFLOPS versus the 99 GFLOPS combined performance for the four other IPRC compute servers described below.

The Altix performs well with just one CPU; satisfactory multiple processor speed-ups, however, have only been achieved with some MPI codes, but not OpenMP codes. Moving the MPI jobs to the Altix has lightened the load on the other servers, which run better with the OpenMP code. Hopefully, as its compilers mature, the Alitx performance with these codes will improve.

The CRAY SV1 has 32 CPUs, 32.0 GB (gigabytes) shared memory, 1016 GB local storage, and a peak speed of 38.4 GFLOPS (billion floating-point operations per second). As a vector-parallel machine, it is most effectively used when the numerical code has both a high degree of vectorization and parallelization. For large applications, it outperforms most desktop workstations even when the code is run on a single SV1 CPU.

Two of the RISC-based parallel machines are Origin 2000 systems; one of these has 32 CPUs (250 MHz), 14.0 GB of logically shared memory, 180 GB of local disk storage, and a peak speed of 16 GFLOPS, while the other has a 32 CPU 300 MHz system with 10.0 GB of memory, 60 GB of local disk storage and a peak speed of 19.2 GFLOPS. The third RISC-based parallel machine is an Origin 3400 with 32 CPUs (400 MHz), 12 GB memory, 36 GB of local disk storage and a peak speed of 25.6 GFLOPS. User-friendly, automatic parallel-code compilers allow easy generation of parallel executables from the source codes. The degree of parallelism depends highly on the original code structure; an appropriate code tuning improves performance.

These five 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 two working 2-CPU Alpha machines.



From left: *Computer Systems Manager Ronald Merrill, Systems Administrator Shinya Yarimizo, and Student System Administrators Wilfred Malepe and Jason Sewell.*

Main storage is served by a 4-CPU Origin 200 with a 1260 GB SGI Clarion RAID (Redundant Array of Independent Disks) and a StorageTek Tape Library, which extends the capacity of the RAID systems with Veritas Storage Migrator hierachical storage management software. The StorageTek library is an L700 equipped with four SDT320 tape drives and 688 tape slots, which gives it a raw storage capacity of 106 TB. In addition, a Storage Area Network (SAN) centered around an 8-port Brocade Silkworm Fibre Channel allows 100 MB/sec access to an SGI LSI TP9400 RAID from 4 SGI Servers. The Altix should be deployed on the SAN shortly. The capacity of the SAN disk storage is 7.88 TB.

Three AC&NC JetStor III SCSI attached IDE RAID arrays, which together provide 8 TB of usable storage, are used by the Asia-Pacific Data-Research Center. The storage arrays were purchased in 2003 specifically for the APDRC with funds from the Research Revolution 2002 project, which is sponsored by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). The IPRC also has nine 500 GB IDE SCSI attached RAID enclosures, which provide an additional 4.39 TB of network accessible storage.

Each IPRC researcher is provided with a UNIX workstation and a PC. This year, 9 Dell Optiplex PC's and 7 Dell Latitude D500 notebook PC's were purchased to replace aging machines. 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.

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An, S.-I., A. Timmermann, L. Bejarano, F.-F. Jin, F. Justino, Z. Liu, and A.W. Tudhope: Modeling evidence for enhanced ENSO variability during the Last Glacial Maximum. *Paleoceanography*. An, S.-I., and B. Wang: Difference between the North Pacific and ENSO modes. *J. Climate*.

An, S.-I., and B. Wang: The forced and intrinsic low-frequency modes in the North Pacific. *J. Climate*.

Annamalai, H., and P. Liu: Response of the Asian Summer Monsoon to changes in ENSO properties. *Quar. J. Roy. Met. Soc*.

Annamalai, H., J. Potemra, R. Murtugudde, and J.P. McCreary: Decadal clustering of extreme climate events in the tropical Indian Ocean. *J. Climate*.

Annamalai, H., and K.R. Sperber: Regional heat sources and the active and break phases of the boreal summer intraseasonal variability. *J. Atmos. Sci*.

Annamalai, H., S.-P. Xie, J.P. McCreary, and R. Murtugudde: Impact of Indian Ocean sea surface temperature on developing El Niño. *J. Climate.*

Annamalai, H., and B. Wang: Interannual variability of the intraseasonal variability during boreal summer and its relationship to large-scale circulation. *J. Climate*.

Boer, G.J., K. Hamilton, and W. Zhu: Climate Sensitivity and Climate Change Under Strong Forcing. *Climate Dynamics.*

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

Endoh, T., K.J. Richards, and Y. Jia: Effect of mesoscale tracer transports on ventilation of the North Pacific. *Journal of Physical Oceanography.*

Fu, X., and B. Wang: The boreal-summer intraseasonal oscillation simulated in a hybrid atmosphere-ocean coupled model. *Monthly Weather Review.*

Hamilton, K., R.A. Vincent, and P.T. May: The DAWEX Field Campaign to Study Gravity Wave Generation and Propagation. *Journal of Geophysical Research.*

Liu, Q., X. Jiang, S.-P. Xie, and W.T. Liu: A break in the Indo-Pacific warm pool over the South China Sea in boreal winter: Seasonal development and interannual variability. *J. Geophys. Res.-Oceans.*

Maximenko, N.A., and R.I. Gouskina: A method for current velocity data correction contaminated by wind effect on surface float of the mooring. *Oceanology.*

Mullen, K.J., M.T. Montgomery, and B. Wang: Re-examining tropical cyclone near-core radial structure using aircraft observations: Implications for vortex resilience. *J. Climate.*

Qu, T., and G. Meyers: Seasonal characteristics of circulation in the southeastern tropical Indian Ocean. *J. Phys. Oceanogr.*

Qu, T., Y.Y. Kim, M. Yaremchuk, T. Tozuka, A. Ishida, and T. Yamagata: Can Luzon Strait Transport play a role in conveying the impact of ENSO to the South China Sea? *J. Climate.*

Richards, K.J., and S.J. Brentnall: Enhancement of the Excitability of Reaction Systems by Diffusion and Chaotic Mixing. *Phys. Rev. Lett.*

Saji, N.H., T. Ambrizzi, and S.E.T. Ferraz: Indian Ocean Dipole Mode events and austral surface temperature anomalies. *Dynamics of Atmospheres and Oceans.*

Schneider, N., E. Di Lorenzo, and P.P. Niiler: Salinity variations in the California Current. *J. Phys. Oceanogr.*

Sen, O.L., Y. Wang, and B. Wang: Impact of Indochina deforestation on the East-Asian summer Monsoon. *J. Climate.*

Sen, O.L., B. Wang, and Y. Wang: Re-greening the desertification lands in northern China: Implications from a regional climate model experiment. *J. Meteor. Soc. Japan.*

Small, R.J., S.-P. Xie, Y. Wang, S.K. Esbensen, and D. Vickers: Numerical simulation of boundary layer structure and cross-equatorial flow in the eastern Pacific. *J. Atmos. Sci.*

Tam, C.-Y., and N.-C. Lau: The impact of ENSO on atmospheric intraseasonal variability as inferred from observations and GCM simulations. Part I: Effects on the Madden-Julian oscillation. *J. Climate.*

Tam, C.-Y., and N.-C. Lau: The impact of ENSO on atmospheric intraseasonal variability as inferred from observations and GCM simulations. Part II: Influences on the extratropical circulation. *J. Climate.*

Xie, S.-P., H. Xu, W.S. Kessler, and M. Nonaka: Air-sea interaction over the eastern Pacific warm pool: Gap winds, thermocline dome, and atmospheric convection. *J. Climate.*

Xu, H., S.-P. Xie, and Y. Wang: Subseasonal variability of the Southeast Pacific stratus cloud deck. *J. Climate.*

Wang, Y., L.R. Leung, J.L. McGregor, D.-K. Lee, W.-C. Wang, Y.-H. Ding, and F. Kimura: Regional climate modeling: Progress, challenges and prospects. *J. Meteor. Soc. Japan.*

Wang, Y., S.-P. Xie, B. Wang, and H. Xu: Large-scale atmospheric forcing by southeast Pacific boundary-layer clouds: A regional model study. *J. Climate.*

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

Wu, C.-C., K.-H. Chou, Y. Wang, and Y.-H. Kuo: Observing-systems simulation experiments for tropical cyclone initialization and prediction based on four-dimensional variational data assimilation. *J. Atmos. Sci.*

Wu, L., and B. Wang: Assessment of global warming impacts on tropical cyclone track. *J. Climate.*

Yu, R., B. Wang, and T. Zhou: Climate effects of the deep continental stratus clouds generated by Tibetan Plateau. *J. Climate*.

Yu, R., B. Wang, and T. Zhou: Distinct tropospheric cooling trend in East Asia: Coming from stratosphere? *Geophys. Res. Lett.*

Zhang, Y., and T. Li: Influence of the Sea Surface Temperature in the Indian Ocean on the Relationship between the South Asian and Australian Summer Monsoon. *Geophys. Res. Lett.*

EXTERNAL PRESENTATIONS

An, S.-I., B. Wang, and F.-F. Jin: *Interdecadal changes in ENSO: What, why, something else*. NASA-CRCES-IPRC Workshop on Decadal Climate Variability, February 2004, Waikoloa, Hawaii.

An, S.-I., and B. Wang: *Differences between the North Pacific and ENSO modes*. 84th AMS Annual Meeting, January 2004, Seattle, Washington.

An, S.-I., and F.-F. Jin: *Fast and slow mode in the equatorial Pacific.* American Geophysical Union 2003 Fall Meeting, December 2003, San Francisco, California.

An, S.-I.: *Various coupled ocean-atmosphere modes in the tropical ocean.* Seminar, Institute for Marine Research, University of Kiel, November 2003, Kiel, Germany. (Invited)

An, S.-I., L. Bejarano, and F.-F. Jin: *Time scales of coupled modes in the tropical climate system.* 2003 EGS-AGU-EUG Joint Assembly, April 2003, Nice, France.

Annamalai, H.: *Dynamics of premonsoon heat waves.* Asian-Australian Monsoon Panel Meeting, February 2004, Pune, India. (Invited)

Annamalai, H.: *Monsoon modeling.* Asian-Australian Monsoon Panel Meeting, February 2004, Pune, India. (Invited)

Annamalai, H., and P. Liu: *Southwest Indian Ocean climate variability: Its impact on West Pacific convection, East Asian winter monsoon and onset of the Indian summer monsoon.* International Workshop on the Role of Indian Ocean in Climate Variability over India (INDO-CLIM), February 2004, Pune, India.

Annamalai, H., and K.R. Sperber: *Dynamics of boreal summer intraseasonal variability.* International Workshop on the Role of Indian Ocean in Climate Variability over India (INDOCLIM), February 2004, Pune, India.

Annamalai, H., S.-P. Xie, J.P. McCreary, and R. Murtugudde: *Role of Indian Ocean SST on developing El Niño.* International Workshop on the Role of Indian Ocean in Climate Variability over India (INDO-CLIM), February 2004, Pune, India.

Annamalai, H., and P. Liu: *Response of the Asian summer monsoon to changes in ENSO properties*. XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Annamalai, H., R. Murtugudde, J. Potemra, and J.P. McCreary: *A conceptual model for the Indian Ocean Zonal Mode.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Endoh, T., K.J. Richards, and Y. Jia: *Effect of mesoscale tracer transports on ventilation of the North Pacific.* Spring Meeting of the Oceanographic Society of Japan, March 2004, Tsukuba, Japan.

Endoh, T., and T. Hibiya: *Numerical simulation of the transient response of the Kuroshio leading to the large meander formation south of Japan.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Endoh, T., H. Mitsudera, S.-P. Xie, and B. Qiu: *Thermohaline structure in the subarctic North Pacific simulated in a general circulation model.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Fu, X.H., and B. Wang: *Two different ISO solutions exist in a coupled system and an atmosphere-only system.* International Asian Monsoon Symposium, University of Hawai'i, February 2004, Honolulu, Hawaii.

Fu, X.H., B. Wang, T. Li, J. McCreary, and F.F. Jin: *Representation of the tropical Asia-Pacific climate in the IPRC hybrid CGCM.* CLIVAR Working Group on Seasonal-to-Interannual Prediction, November 2003, Honolulu, Hawai'i.

Fu, X.H., B. Wang, T. Li, and J. McCreary: *Rectification of air-sea interaction on the simulations of the Asian summer monsoon and its intraseasonal variability*. XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Furue, R.: *Numerical simulations of the Tsuchiya Jets.* Spring Meeting of the Oceanographic Society of Japan, March 2004, Tsukuba, Japan.

Hacker, P.: *JASMINE and WOCE observations in the Bay of Bengal sector as guides to a future mooring array design.* National Institute of Oceanography, March 2004, Goa, India. (Invited)

Hacker, P.: *The Asia-Pacific Data-Research Center at the IPRC.* National Institute of Oceanography, March 2004, Goa, India. (Invited)

Hacker, P., T. Waseda, and Y. Shen: *The IPRC data and product servers at the Asia-Pacific Data-Research Center (APDRC).* CLIVAR Pacific Implementation Panel, July 2003, Yokohama, Japan. (Invited)

Hacker, P.: *The Asia-Pacific Data-Research Center Servers.* The 7th Estimating the Circulation and Climate of the Ocean (ECCO) Meeting, University of California, June 2003, San Diego, California.

Hamilton, K.: *Modelling local and global climate sensitivity over a broad range of climate perturbations.* Kyoto University, March 2004, Kyoto, Japan (Invited). Also given at the Graduate School of Science and Technology, Kobe University, March 2004, Kobe, Japan. (Invited)

Hamilton, K.: *Results from a very fine vertical resolution atmospheric GCM.* The 1st International Workshop on the Kyosei Project and The 6th International Workshop on Next-Generation Climate Models for Advanced High Performance Computing Facilities, February 2004, Honolulu, Hawai'i.

Hamilton, K.: *Gravity waves in explicit fine-resolution global models.* AGU Chapman Conference on Gravity Processes and Parameterization, January 2004, Waikoloa, Hawai'i.

Hamilton, K.: *Thoughts on the role of the stratosphere in seasonal prediction.* CLIVAR Working Group on Seasonal-to-Interannual Prediction, 8th Annual Meeting, November 2003, Honolulu, Hawai'i.

Hamilton, K.: *Effects of polar vortex perturbations on tropospheric winter circulation.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Hamilton, K.: *Stratospheric and tropospheric forcing of the Arctic Oscillation by the 1991 Mt. Pinatubo eruption.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan. (Invited)

Hamilton, K.: *Zonal variations in the equatorial Quasi-biennial Oscillation.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Hamilton, K.: *Atmospheric simulations with an assimilated stratospheric quasi-biennial oscillation.* Frontier Research System for Global Change, June 2003, Yokohama, Japan. (Invited)

Hamilton, K.: *Climate sensitivity and climate response to large external perturbations.* Frontier Research System for Global Change, June 2003, Yokohama, Japan. (Invited)

Hamilton, K.: *Global atmospheric simulation at fine spatial resolution.* Frontier Research System for Global Change, June 2003, Yokohama, Japan. (Invited)

Hamilton, K.: *Modelling stratospheric effects on tropospheric climate.* Department of Earth and Ocean Sciences, University of British Columbia, May 2003, Vancouver, Canada. (Invited)

Hamilton, K.: *Effects of polar vortex perturbations on tropospheric winter circulation.* Workshop on the Role of the Stratosphere in Tropospheric Climate, May 2003, Whistler, Canada. (Invited)

Jensen, T.: *Modeling pathways of salt and passive tracers in the northern Indian Ocean*. Symposium on Upper Ocean Circulation and Air-Sea Interaction: In Commemoration of Professor James J. O'Brien's Forty Years of Scientific Achievement, April 2003, Tallahassee, Florida. (Invited)

Kim, Y.Y.: *Seasonal and interannual variations of the North Equatorial Current bifurcation in a high-resolution OGCM.* Korea Ocean Research & Development Institute, July 2003, Ansan, Korea. (Invited)

Kim, Y.Y.: *Tropical Pacific upper-ocean variability and Kelvin and Rossby waves during ENSO events.* Department of Oceanography, Seoul National University, July 2003, Seoul, Korea. (Invited)

Kobashi, F., H. Mitsudera, and S.-P. Xie: *Structure and formation mechanisms of the North Pacific subtropical fronts.* Spring Meeting of the Oceanographic Society of Japan, March 2004, Tsukuba, Japan.

Kobashi, F., and K. Hanawa: *Formation and structure of the Kuroshio small meander off the southeast of Kyushu.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Lebedev, K.V., M.I. Yaremchuk, H. Mitsudera, I. Nakano, and G. Yuan: *Dynamically constrained synthesis of the acoustic tomography, satellite altimeter and in situ data in the Kuroshio Extension region.* Ocean Research Conference, February 2004, Honolulu, Hawai'i.

Lebedev, K.V., M.I. Yaremchuk, H. Mitsudera, I. Nakano, and G. Yuan: *Mesoscale currents in the Kuroshio Extension region obtained through dynamically constrained synthesis of the acoustic tomography, satellite altimeter and in situ data.* Ocean Sciences Meeting, January 2004, Portland, Oregon.

Li, T.: *Issues on role of air-sea interaction in annual and interannual monsoon variability.* The 7th Workshop on East-Asian Climate, February 2004, Honolulu, Hawai'i.

Li, T.: *Reinitiation of the boreal summer intraseasonal oscillation.* The 7th Workshop on East-Asian Climate, February 2004, Honolulu, Hawai'i.

Li, T.: *Seasonal evolving TBO pattern and mechanism.* International Asian Monsoon Symposium, University of Hawai'i, February 2004, Honolulu, Hawai'i.

Li, T.: *Structures and mechanisms of the northward-propagating boreal summer intraseasonal oscillation.* International conference on earth-system modeling, September 2003, Hamburg, Germany.

Li, T.: *Is the TBO an unstable mode of atmosphere-ocean interaction in the monsoon region?* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan. (Invited)

Li, T.: *Tropical cyclogenesis in the western North Pacific: Observational analysis and numerical simulation.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Liu, P., B. Wang, T. Li, K. Hamilton, G. Meehl, and P. Duffy: *From CCM3 to CCSM2: Asian summer monsoon climatology and the sensitivity to model resolutions, coupling and physical processes.* Community Climate System Model Annual Workshop, June 2003, Breckenridge, Colorado. (Poster)

Maximenko, N.A., P.P. Niiler, J.C. McWilliams, and C.J. Koblinsky: *Dynamically balanced global mean sea level.* American Geophysical Union 2003 Fall Meeting, December 2003, San Francisco, California.

McCreary, J.P.: *Subtropical cells and low-frequency modulation of ENSO.* International Workshop on the Low-Frequency Modulation of ENSO, September 2003, Toulouse, France. (Invited)

Potemra, J.T.: *Low-frequency variations and climate impact of the Indonesian Throughflow.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Potemra, J.T.: *Low-frequency changes in Indonesian Throughflow transport.* Oceanography Department Seminar, University of Hawai'i, June 2003, Honolulu, Hawai'i.

Qu, T., and E.J. Lindstrom: *A new interpretation of the spreading of Antarctic Intermediate Water in the western Pacific.* Ocean Sciences Meeting, January 2004, Portland, Oregon.

Qu, T., and E.J. Lindstrom: *Northward intrusion of Antarctic Intermediate Water in the western Pacific.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Richards, K.J.: *Model sensitivity to lateral mixing.* Layered Ocean Model Meeting, February 2004, Miami, Florida.

Richards, K.J., and A. Bellucci: *Decadal variations of the sub-polar gyre of the North Atlantic.* NASA-CRCES-IPRC Workshop on Decadal Climate Variability, February 2004, Waikoloa, Hawai'i. Also given at the XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Richards, K.J.: *Scale interactions in the tropical Pacific: The role of lateral mixing.* Ocean Sciences Meeting, January 2004, Portland, Oregon.

Richards, K.J.: *Decadal variability in ocean models.* Istituto Nazionale di Geofisica e Vulcanologia, November 2003, Bologna, Italy.

Richards, K.J.: *Stirring and mixing of the marine ecosystem.* Istituto Nazionale di Geofisica e Vulcanologia, November 2003, Bologna, Italy.

Richards, K.J.: *Mixing in the equatorial Pacific.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Richards, K.J.: *Lateral mixing schemes in OGCMs: A new parameterization to solve the cold tongue bias.* Tropical Biases Workshop, May 2003, Princeton, New Jersey.

Saji, N.H.: *Possible Impacts of Indian Ocean Dipole Mode events on Global Climate, New Perspectives of Coupled Tropical Ocean-Atmosphere Dynamics and Predictability.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan. (Invited)

Schneider, N., E. Dilorenzo, and P.P. Niiler: *Low frequency salinity variations in the California Current.* NASA-CRCES-IPRC Workshop on Decadal Climate Variability, February 2004, Waikoloa, Hawai'i.

Schneider, N., and E. Yulaeva: *On the extra-tropical atmospheric response to changes of oceanic heat flux convergences.* Ocean Sciences Meeting, January 2004, Portland, Oregon. (Invited)

Schneider, N.: *Review of North Pacific decadal variability.* International workshop on the Low-Frequency Modulation of ENSO, September 2003, Toulouse, France. (Invited)

Schneider, N.: *Salinity Variations in the California Current.* Seminar, Laboratoire d'Oceanographie Dynamique et Climatologie, September 2003, Paris, France.

Schneider, N.: *On the generation of decadal spiciness anomalies in the ocean.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Shen, Y.: *APDRC's server infrastructures.* Frontier Research System for Global Change, May 2003, Yokohama, Japan. (Invited)

Small, R.J.: *Dynamics of cross-equatorial flow.* International Asian Monsoon Symposium, University of Hawai'i, February 2004, Honolulu, Hawai'i.

Small, R.J.: *Mesoscale ocean features: their effect on the atmospheric boundary layer.* Department of Oceanography Seminar, University of Hawai'i, December 2003, Honolulu, Hawai'i.

Small, R.J., S.-P. Xie, and Y. Wang: *Numerical simulation of boundary-layer structure and cross-equatorial flow in the Eastern Pacific.* US CLIVAR/EPIC Workshop, National Center for Atmospheric Research, September 2003, Boulder, Colorado. (Poster)

Small, R.J.: *Atmospheric response to the oceanic front and long waves in the Eastern Equatorial Pacific.* Department of Meteorology Seminar, University of Hawai'i, August 2003, Honolulu, Hawai'i.

Wang, B.: *New Perspectives of the interannual variability of Asian-Australian Monsoon and the origin of Tropospheric Biennial Oscillation.* International Conference on High-Impact Weather and Climate: Understanding, Prediction and Socio-Economic Consequences (ICHWC 2004), March 2004, Seoul, Korea.

Wang, B.: *Genesis of the break/active Indian monsoon.* Annual symposium of LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, January 2004, Beijing, China.

Wang, B.: *Fundamental dynamics of the tropical intraseasonal oscillation.* International Workshop on Subseasonal Climate Variability, ECMWF, November 2003, Reading, England.

Wang, B.: *On the predictability of the seasonal mean summer monsoon precipitation.* Monthly-to-Seasonal Climate Prediction Workshop, October 2003, Taipei, Taiwan.

Wang, B.: *Why AGCMs fail simulating seasonal rainfall anomalies in the monsoon convergence zones.* APEC Climate Network Symposium on the Multi-Model Ensemble for Climate Prediction, October 2003, Jeju, Korea.

Wang, B.: *Propagation of the intraseasonal oscillation.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan. (Invited)

Wang, B.: *Coupled and forced solutions of MJO.* Workshop on Modeling, Simulation and Forecasting of Subseasonal Variability, June 2003, Washington, D.C. (Invited)

Wang, B., and X. Fu: *How air-sea interaction affects the northward propagating ISO.* Workshop on MJO prediction, June 2003, College Park, Washington, D.C.

Wang, B.: *Variability and predictability of Asian monsoon.* International Research Institute, May 2003, Palisade, New York. (Invited)

Wang, B.: *Interannual variability of the Asian-Australian monsoon system.* Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, April 2003, Seattle, Washington.

Wang, B.: *Roles of monsoon-ocean interaction in Asian monsoon variability.* Symposium on Upper Ocean Circulation and Air-Sea Interaction: In Commemoration of Professor James J. O'Brien's Forty Years of Scientific Achievement, April 2003, Tallahassee, Florida. (Invited)

Wang, B.: *What are the dominant mode and causes of the interannual variability of the Asian-Australian monsoon system?* Coordinated Enhanced Observing System (CEOP) Monsoon Workshop on the Role of the Himalayas and the Tibetan Plateau within the Asian Monsoon System, April 2003, Milan, Italy. (Invited)

Wang, D., F. Ascani, E. Firing, T. Miyama, and A. Ishida: *Inertial instability of equatorial jets.* Ocean Sciences Meeting, January 2004, Portland, Oregon.

Wang, D.: *Entrainment of rotating convection.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Wang, Y., and co-authors: *Regional climate modeling: Progress, challenges, and prospects.* Regional-Scale Climate Modeling Workshop, March 2004, Lund, Sweden. (Invited)

Wang, Y.: *Cloud processes in climate models: Implication from RCM simulation of marine boundary layer clouds.* The 3rd Workshop on Regional Climate Modeling and The 7th Workshop on East Asian Climate, University of Hawai'i, February 2004, Honolulu, Hawai'i. (Keynote)

Wang, Y.: *High-resolution atmospheric model simulation of marine boundary layer clouds.* The 1st International Workshop on the Kyosei Project and The 6th International Workshop on Next-Generation Climate Models for Advanced High Performance Computing Facilities, February 2004, Honolulu, Hawai'i.

Wang, Y.: *RCM intercomparison with the focus on sub-daily variation of clouds and precipitation (a proposal).* International Asian Monsoon Symposium, University of Hawai'i, February 2004, Honolulu, Hawai'i.

Wang, Y., and M.T. Montgomery: *How much vertical shear can a mature tropical cyclone resist?* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan. Also given at the Department of Atmospheric Sciences, National Taiwan University, September 2003, Taipei, Taiwan. (Invited)

Wang, Y., S.-P. Xie, H. Xu, and B. Wang: *A regional atmospheric model study of boundary layer clouds over the eastern Pacific off South America and their large-scale forcing.* NOAA-Pan American Climate Studies Principal Investigators' Meeting, National Center for Atmospheric Research, August 2003, Boulder, Colorado.

Wang, Y.: *A regional atmospheric model study of marine boundary layer clouds over the Southeast Pacific off South America.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Xie, Q., S.-P. Xie, D. Wang, W.T. Liu, and H. Xu: *Gap wind-induced summer upwelling in the South China Sea and its interannual variations.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Xie, S.-P.: *Rich structures of air-sea interaction revealed by satellite.* Ocean Sciences Meeting, January 2004, Portland, Oregon. Also given at the Advanced Earth Observing Satellite-II, Principal Investigators' Workshop, March 2004, Tokyo, Japan.

Xie, S.-P., H. Xu, Y. Wang, J. Hafner, and J. Small: *Satellite observations as benchmarks for high resolution climate model simulations.* The 1st International Workshop on the Kyosei Project and The 6th International Workshop on Next-generation Climate Models for Advanced High Performance Computing Facilities, February 2004, Honolulu, Hawai'i.

Xie, S.-P.: *Air-Sea interaction in monsoonal Asian seas.* International Asian Monsoon Symposium, University of Hawai'i, February 2004, Honolulu, Hawai'i.

Xie, S.-P., Y. Okumura, and H. Okajima: *Tropical Atlantic ocean-atmosphere interaction.* Ocean Sciences Meeting, January 2004, Portland, Oregon. (Invited)

Xie, S.-P.: *Taking the ocean's pulse.* The 30th International Symposium on Remote Sensing of Environment, November 2003, Honolulu, Hawai'i. (Invited)

Xie, S.-P.: *Rich structures of air-sea interaction revealed by scatterometer observations.* NASA Ocean Vector Wind Science Team Meeting, October 2003, Arcadia, California.

Xie, S.-P.: *Atlantic Ocean and seasonal prediction.* Climate System Observational and Prediction Workshop on Seasonal Prediction, October 2003, Honolulu, Hawai'i. (Invited)

Xie, S.-P., Y. Wang, H. Xu, J. Small, and M. Cronin: *Satellite observations and regional atmospheric modeling of eastern Pacific climate.* US CLIVAR Pan American Principal Investigators Meeting, September 2003, Boulder, Colorado. (Invited)

Xie, S.-P.: *Satellite observations of cool ocean-atmosphere interaction.* Hokkaido University, July 2003, Sapporo, Japan. Also given at Tohoku University, July 2003, Sendai, Japan; and at the University of Tokyo, August 2003, Tokyo, Japan.

Xie, S.-P., J. Hafner, Y. Tanimoto, W.T. Liu, H. Tokinaga, and H. Xu: *Bathymetry-induced air-sea interaction in the winter East China and Yellow Seas.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Xie, S.-P., H. Annamalai, F.A. Schott, J.P. McCreary, G.A. Vecchi, and A. Fischer: *Interaction of Indian Ocean dynamics with the atmosphere.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan. (Invited)

Xie, S.-P., Y. Wang, and H. Xu: *Simulating eastern Pacific climate with regional atmospheric/coupled models.* Tropical Biases Workshop, May 2003, Princeton, New Jersey.

Yaremchuk, M., and T. Qu: *Seasonal variability of the large-scale currents near the coast of the Philippines.* Ocean Sciences Meeting, January 2004, Portland, Oregon.

Yaremchuk, M.: *Variational inversion of the acoustic tomography, satellite altimetry, and in situ data using quasigeostrophic constraints.* Oceanography seminar, University of Southern Mississippi, June 2003, Stennis Space Center, Mississippi.

Xu, H., S.-P. Xie, and Y. Wang: *Orographic effect on summer climate in the South China Sea.* International Asian Monsoon Symposium, University of Hawai'i, February 2004, Honolulu, Hawai'i.

Yu, Z.: *Evaluation of precipitation products in the tropical Indian Ocean using an ocean model.* XXIII General Assembly of the International Union of Geodesy and Geophysics, July 2003, Sapporo, Japan.

Yu, Z., and P. Hacker: *Tracking Wyrtki Jets during 1994–2001.* The 7th Estimating the Circulation and Climate of the Ocean (ECCO) Meeting, University of California, June 2003, San Diego, California.

IPRC SEMINARS

Date	Speaker	Affiliation	Seminar Title
March 31, 2004*	Xiouhua Fu	International Pacific Research Center	*Tropical Asia-Pacific climate simulated by the IPRC Hybrid coupled GCM*
March 8, 2004	Hisashi Nakamura	Department of Earth & Planetary Sciences, University of Tokyo, Japan	*Structure and formation mechanisms of the Northern Hemisphere summertime subtropical anticyclones*
March 3, 2004*	Yuqing Wang	International Pacific Research Center	*Atmospheric model simulations of boundary layer clouds over subtropical oceans: Current status and future direction*
March 1, 2004	Ole B. Peters	Imperial College, London, United Kingdom	*A feedback loop to scale-freedom: Rainfall and criticality*
February 27, 2004	Jing-Jia Luo	Frontier Research System for Global Change, Yokohama, Japan	*Climate modeling and seasonal prediction using a coupled GCM*
February 26, 2004	Dongxiao Wang	South China Sea Institute of Oceanology, Guangdong, China	*SCSIO recent understanding of the South China Sea circulation*
February 25, 2004	Jürgen Sündermann	Centre of Marine & Atmospheric Sciences, University of Hamburg, Germany	*Towards decadal predictions of the ecological state of a shelf sea: The North Sea case*
February 23, 2004**	Barry Ruddick	Dalhousie University, Nova Scotia, Canada	*Measuring intrusive heat flux across a front*
February 3, 2004	Brian Mapes	NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado	*Sensitivities of convection and the closure problem in cumulus parameterization*
January 28, 2004*	Markus Stowasser	International Pacific Research Center	*Remote sensing of stratospheric trace gases with MIPAS*
January 16, 2004	Toshio Yamagata	Department of Earth and Planetary Science University of Tokyo, Japan	*The role of the Indian Ocean in climate forecasting with a particular emphasis on summer conditions in East Asia*
January 15, 2004	Fuqing Zhang	Texas A&M University, College Station, Texas	*Ensemble-based data assimilation*
January 7, 2004	Claude Frankignoul	Laboratoire d'Océanographie Dynamique et de Climatologie, Université Pierre et Marie Curie, Paris, France	*On Gulf Stream variability, atmospheric forcing, and the meridional overturning circulation*
December 10, 2003	Jerry Meehl	National Center for Atmospheric Research Boulder, Colorado	*Long-term droughts in the South American monsoon region in a 1000-year global coupled-model simulation*
December 4, 2003	R. Justin Small	International Pacific Research Center	*Mesoscale ocean features: Their effect on the atmospheric boundary layer*
December 3, 2003	Hisashi Nakamura	Department of Earth and Planetary Science University of Tokyo, Japan	*Midlatitude storm tracks, jet streams, and oceanic fronts*
November 4, 2003	Akimasa Sumi	Center for Climate System Research, University of Tokyo, Japan	*Recent results from a high-resolution climate model developed by the K-1 project*
October 29, 2003*	Youichi Tanimoto	Hokkaido University, Sapporo, Japan	*Active role of extratropical sea surface temperature anomalies in determining turbulent heat flux variability*
October 2, 2003	Bin Wang	Institute of Atmospheric Physics, Beijing, China	*A new dynamical core for atmospheric general circulation models*
October 1, 2003*	H. Annamalai	International Pacific Research Center	*Dynamics of boreal summer intraseasonal variability*
September 24, 2003*	Saji N. Hameed	International Pacific Research Center	*Possible impacts of Indian Ocean Dipole events on global climate*
September 10, 2003*	Tomohiko Tomita	Department of Environmental Sciences Kumamoto University, Kumamoto, Japan	*Biennial and lower-frequency variability observed in the early summer climate in East Asia*
August 27, 2003*	R. Justin Small	International Pacific Research Center	*Atmospheric response to oceanic front and long waves in the eastern equatorial Pacific*
August 21, 2003	Fuzhong Weng	NOAA National Environmental Satellite, Data, and Information Service, Camp Springs, Maryland	*Satellite data assimilation in NWP models: Current status and future perspectives*

Date	Speaker	Affiliation	Seminar Title
August 19, 2003	Tong Zhu	NOAA National Environmental Satellite, Data, and Information Service, Camp Springs, Maryland	*Using satellite advanced microwave sounding unit (AMSU) measurements to improve the simulation and prediction of hurricanes*
August 18, 2003	Wataru Ohfuchi	Earth Simulator Center, Japan Marine Science and Technology Center, Yokohama, Japan	*Ultra-high resolution simulations with AFES on the Earth Simulator*
August 13, 2003	De-Zheng Sun	NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado	*The heat-pump hypothesis for ENSO*
August 12, 2003	Nadia Pinardi	Istituto Nazionale Geofisica e Vulcanologia, Bologna, Italy	*Mediterranean Forecasting System toward environmental predictions: Present state and future perspectives*
August 11, 2003**	Tandgong Qu	International Pacific Research Center	*Spreading of Antarctic Intermediate Water in the western Pacific*
August 7, 2003**	Bruce Cornuelle	Scripps Institution of Oceanography, University of California, San Diego, California	*Fitting a model to observations in the California Current*
August 6, 2003	Antonio Navarra	Istituto Nazionale Geofisica e Vulcanologia, Bologna, Italy	*The influence of rotation rates on the general circulation*
August 4, 2003**	Takuji Waseda	International Pacific Research Center	*Kuroshio bimodality and the role of recirculation*
July 31, 2003*	Yu Gu	Department of Atmospheric Sciences, University of California, Los Angeles, California	*Parameterization of cloud/radiation processes in the general circulation model*
July 28, 2003*	Joao Teixeira	Naval Research Laboratory, Monterey, California	*Clouds, radiation and turbulence in the climate system: The parameterization of boundary layer clouds*
July 24, 2003*	Yuqing Wang	International Pacific Research Center	*Development of the IPRC–RegCM and its use in regional climate modeling studies*
July 14, 2003	Ping Chang	Texas A&M University, College Station, Texas	*The challenge of extending seasonal climate forecasts beyond ENSO: Predicting tropical Atlantic variability.*
June 25, 2003**	Albert Fischer	Laboratoire d'Océanographie Dynamique et de Climatologie, Université Pierre et Marie Curie, Paris, France	*Interannual variability in the tropical Indian Ocean: Scale interactions, triggers, and links to the Pacific*
June 19, 2003	Yi Chao	NASA Jet Propulsion Laboratory, Pasadena, California	*Pacific climate variability and its impact on coastal ocean circulation and marine ecosystem*
June 17, 2003	Michael Montgomery	Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado	*The hurricane engine's afterburner, or power to tropical cyclones and typhoons*
June 16, 2003**	Axel Timmermann	Institute for Marine Research, Kiel, Germany	*Nonlinear ENSO dynamics*
June 12, 2003	Shujia Zhou	NASA Goddard Space Flight Center, Greenbelt, Maryland	*Coupling climate models with the Earth System Modeling Framework*
May 30, 2003	Johannes Loschnigg	Office of Senator Lieberman, Washington D.C.	*Science and policy in Washington D.C.*
May 29, 2003**	Raleigh Hood	Center for Environmental Science, Horn Point Laboratory, University of Maryland, Cambridge, Maryland	*Modeling biogeochemical variability in the Arabian Sea: A story about great progress and the challenges that remain*
May 27, 2003**	Ichiro Fukumori	NASA Jet Propulsion Laboratory, Pasadena, California	*Applications of the ECCO Routine Global Ocean Data Assimilation System*
May 14, 2003	Tsutomu Takahashi	Obirin University, Tokyo, Japan	*Rain accumulation and lightning Activity during East-Asian monsoon rain: Videosonde observations*
May 13, 2003	Yong-Run Guo	National Center for Atmospheric Research, Boulder, Colorado	*Variational data assimilation for the MM5 Model and its applications*
April 24, 2003**	Kelvin Richards	International Pacific Research Center	*Lateral mixing in the equatorial Pacific Ocean*

**Joint Seminar with Department of Meteorology, University of Hawai'i*
*** Joint Seminar with Department of Oceanography, University of Hawai'i*

MEETINGS

Third Annual IPRC Symposium

The Third Annual IPRC Symposium was held May 22–23, 2003, at the University of Hawai'i Manoa Campus. In the two-day symposium, IPRC scientists presented the highlights of their research findings during the past year.

Climate System Observation and Prediction Experiment (COPE) on Seasonal Prediction and Eighth CLIVAR Working Group on Seasonal-to-Interannual Prediction

These two workshops, hosted by the IPRC, were held November 3–7, 2003, at the East-West Center in Honolulu. The Joint Scientific Committee of the World Climate Research Programme initiated COPE charging scientists with answering the question, how accurately can climate anomalies be predicted? Experts on different aspects of the climate system—atmosphere, ocean, land surface, and cryosphere—described the observational and modeling status in their fields. Presentations showed that quality climate observational data are lacking on such difficult-to-measure variables as soil wetness and snow depth. Sponsors of the workshops were the World Climate Research Programme, the Climate Variability and Predictability Project, the Center for Land-Ocean-Atmosphere Studies, and the IPRC.

International Asian Monsoon Symposium

The International Asian Monsoon Symposium, held February 18–20, 2004 at the East-West Center, drew the attention of the monsoon research community to the whole Asian-Australian monsoon system, particularly to the neglected East Asian monsoon. At least half of the presentations dealt with East Asian weather and climate variability, ranging from the diurnal cycle and intraseasonal oscillations to interannual and interdecadal variations, to monsoon climates during prehistoric times. Presentations included the significance of monsoon–ocean interactions for monsoon variability over the Indian Ocean, Asian seas, and western Pacific; atmosphere-land interactions; the role of the Tibetan Plateau in global climate; the improvement in simulating intraseasonal monsoon oscillations with air-sea coupling; and the inadequacy of the Atmospheric Model Intercomparison Project (AMIP), two-tiered strategy for predicting monsoon rainfall. The high-resolution climate modeling by the Japan Meteorology Agency, though, shows great promise for resolving the Meiyu/Baiu front, which is so critical for the water supply of East Asia and its population of about 1.5 billion. Sponsors of the symposium were the Frontier Research System for Global Change, the Joint Institute of Marine and Atmospheric Research at the University of Hawai'i, and the IPRC.

Third Workshop on Regional Climate Modeling

The Third Workshop on Regional Climate Modeling, held on February 17, 2004, at the East-West Center in Honolulu, included presentations on the cooling of regions of India due to radiative forcing over Southeast Asia, the effects of orography on the summer climate of the South China Sea, the reconstruction of climate changes in the North Sea over the past decades, and the use of regional climate models in ship design. The IPRC plans to conduct the Regional Atmospheric Inter-model Evaluation project were discussed. The workshop was supported by the Frontier Research System for Global Change and the IPRC.

Seventh Workshop on East Asian Climate

The Seventh Workshop on East Asian Climate, held February 17, 2004, at the East-West Center, was filled with issue-driven short presentations that focused on the research needs in recent climate changes over East Asia, observations and model simulations, seasonal climate predictions, intraseasonal oscillation, cloud-climate interaction, and land-atmosphere and ocean-atmosphere interactions. Although model–observation comparisons, inter-model comparisons, and model sensitivity experiments have identified weaknesses in existing climate models, the need for more in-depth diagnostic and model–observation comparison studies continues. Model simulations are still too unreliable for rainfall predictions. The workshop was sponsored by the State University of New York, the Frontier Research System for Global Change, and the IPRC.

VISITING SCHOLARS

The IPRC has a visiting scholar program. From April 2003 to March 2004, the following scholars visited the IPRC for one week or longer.

Scholar	Affiliation	Dates
Jyh-Wen Hwu	Central Weather Bureau, Taipei, Taiwan	3/24–5/24, 2003
Wolf Dieter Grossmann	GKSS, Germany	4/23–5/16, 2003
Tsutomu Takahashi	Obirin University, Tokyo, Japan	5/6–6/5, 2003
Yong-Run Guo	National Center for Atmospheric Research, Boulder, Colorado	5/9–5/21, 2003
Paula McLeod	University of Southampton, Southampton, United Kingdom	5/12–16, 2003
Johannes Loschnigg	Office of Senator Lieberman, Washington DC.	5/24–30, 2003
David Pierce	Scripps Institution of Oceanography, La Jolla, California	6/2–6, 2003
Francois Dufois	University of Toulon, Toulon, France	6/2–8/3, 2003
Naoki Hirose	Kyushu University, Fukuoka, Japan	6/9–13, 2003
Michael Montgomery	Colorado State University, Ft. Collins, Colorado	6/12–22, 2003
Tierne Fahl	Harvard University, Boston, Massachussetts	6/16–8/15, 2003
Pearn P. Niiler	Scripps Institution of Oceanography, La Jolla, California	6/20–7/2, 2003
Ping Chang	Texas A&M University, College Station, Texas	7/10–15, 2003
Yanjun Qi	Chinese Academy of Meteorological Science, Beijing, China	7/15/2003–7/14/2004
Xiaofeng Wang	Shanghai Typhoon Institute, Shanghai, China	8/1/2003–7/31/2004
Antonio Navarra	Istituto Nazionale di Geofisica e Vulcanologia, Bologna, Italy	8/3–15, 2003
Nadia Pinardi	Istituto Nazionale di Geofisica e Vulcanologia, Bologna, Italy	8/3–15, 2003
De-Zheng Sun	NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado	8/9–20, 2003
Wataru Ohfuhi	Japan Marine Science and Technology Center, Yokohama, Japan	8/12–19, 2003
Yoshiyuki Takahashi	Japan Marine Science and Technology Center, Yokohama, Japan	8/12–19, 2003
Tong Zhu	NOAA National Environmental Satellite, Data, and Information Service, Office of Research and Application	8/15–22, 2003
Fuzhong Weng	NOAA National Environmental Satellite, Data, and Information Service, Office of Research and Application	8/16–22, 2003
Tomohiko Tomita	Kumamoto University, Kumamoto, Japan	9/8–12, 2003
Bin Wang	Chinese Academy of Sciences, Beijing, China	9/29–10/5, 2003
Youichi Tanimoto	Hokkaido University, Sapporo, Japan	10/18–11/17, 2003
In-Sik Kang	Seoul National University, Seoul, Korea	1/24–2/24, 2004
Juergen Suendermann	Institut für Meereskunde, Universität Hamburg, Germany	1/31–3/1, 2004
Dan Bernie	University of Reading, Reading, United Kingdom	2/1–2/29, 2004
Pearn Niiler	Scripps Institution of Oceanography, La Jolla, California	2/11–2/24, 2004
Brian Mapes	NOAA-CIRES Climate Diagnostic Center, Boulder, Colorado	2/2–2/24, 2004
Kenneth Sperber	Lawrence Livermore National Laboratory, Livermore, California	2/2–2/20, 2004
Dongxiao Wang	Chinese Academy of Sciences, Beijing, China	2/21–2/28, 2004
Amy Solomon	NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado	2/29–3/14, 2004
Joseph V. Porathur	Cochin University of Science & Technology, Cochin, India	3/2–5/14, 2004

GRANTS

Institutional Support

Title	P.I. and Co-P.I.	Agency	Amount	Period
Support of Research at the International Pacific Research Center	J.P. McCreary	Japan Agency for Marine-Earth Science and Technology	$3,325,337	04/01/03 - 03/31/04
Support of Research at the International Pacific Research Center	J.P. McCreary	University of Hawai'i*	$478,260	04/01/03 - 03/31/04
Establishment of a Data and Research Center for Climate Studies	J.P. McCreary P. Hacker R. Merrill T. Waseda	NOAA	$554,100	10/01/03 - 09/30/04
Data-intensive Research and Model Development at the International Pacific Research Center	J.P. McCreary S.P. Xie T. Waseda T. Li B. Wang	NASA	$5,000,000	10/01/00 - 09/30/05

*The University of Hawai'i also provides approximately 16,500 sq. feet of office space to the IPRC.

Individual Grants

Title	P.I. and Co-P.I.	Agency	Amount	Period
Establishment of the Integrated Climate Database for Reanalysis and the International Data Network	P. Hacker	JAMSTEC / MEXT	$136,000	04/01/03 - 03/31/04
Dynamics of Boreal Summer Intraseasonal Oscillation	B. Wang T. Li X. Fu	NSF	$452,166	10/01/03 - 09/30/06
Mixing in the Equatorial Pacific: The Role of Interleaving	K. Richards J. McCreary	NSF	$346,315	09/01/03 - 08/31/06
Analysis of Decadal Variability in the Pacific	N. Schneider	NSF (UCSD)	$142,561	08/01/03 - 07/31/05
Warm Pool Dynamics in the Interaction Between Asian Summer Monsoon and ENSO	H. Annamalai	NOAA	$82,817	07/01/03 - 06/30/06
Development of Tropical Cyclone Ensemble Forecast and Cyclogenesis Modeling and Forecast for the DOD's JTWC	T. Li B. Wang	DOD / ONR	$500,000	06/01/03 - 05/31/06
Validation of Mean Absolute Sea Level of the North Atlantic Obtained from Drifter, Altimetry and Wind Data	N. Maximenko	NASA	$37,972	05/01/03 - 09/30/03

Title	P.I. and Co-P.I.	Agency	Amount	Period
A Numerical Investigation of the Dynamics of the Subsurface Countercurrents	Z. Yu J. McCreary D. Wang	NSF	$364,992	03/15/03 - 02/28/06
Upwelling and its Influence on the Sea Surface Temperature off Java and Sumatra	T. Qu G. Meyers H. Mitsudera	NASA	$324,265	01/07/03 - 01/31/06
Application of Comprehensive Global Models to Problems in the Dynamics of the Troposphere and Stratosphere	K. Hamilton	NSF	$322,809	09/01/02 - 08/31/06
Quasi-biennial Oscillation Modulation of Eddies in the Tropical Stratosphere	K. Hamilton	NASA	$108,287	05/01/02 - 05/14/05
Dynamical Control of Rapid Tropical Cyclone Intensification by Environmental Shears	B. Wang Y. Wang T. Li	ONR	$794,658	01/01/02 - 12/31/04
Mechanisms for the Northward Displacement of the Pacific ITCZ	S.-P. Xie T. Li	NSF	$281,955	09/15/01 - 08/31/04
Tropical Cyclone Energy Dispersion and Self-maintaining Mechanisms for Summer Synoptical-Scale Waves in the Northwest Pacific	T. Li Y. Wang	NSF	$294,262	09/15/01 - 08/31/04
Remote Forcing of the US Warm Season Rainfall and Eastern Pacific Climate	B. Wang X. Fu	NOAA / PACS	$365,981	09/01/01 - 06/30/06
Effects of the Andes on Eastern Pacific Climate	S.-P. Xie Y. Wang	NOAA	$277,191	07/01/01 - 06/30/04
Roles of Ocean-Atmosphere-Land Interaction in Shaping Tropical Atlantic Variability	S.-P. Xie	NOAA	$244,990	07/01/01 - 06/30/04
Low-Latitude Western Boundary Currents in the Pacific	J. P. McCreary T. Qu H. Mitsudera T. Jensen T. Miyama	NSF	$458,538	03/15/01 - 02/29/04
Biennial and Interdecadal Variations of the Tropical Pacific Ocean	B. Wang S.I. An	NOAA / PACIFIC	$311,280	07/01/00 - 06/30/06
Dynamics of the Boreal Summer Intraseasonal Oscillation	B. Wang T. Li	NSF	$399,536	07/01/00 - 06/30/04
An Investigation of Monthly Wind Variability in the Eastern Equatorial Pacific Using the Sea Winds, In situ Observations and Numerical Modeling	S.-P. Xie	NASA	$377,487	05/01/00 - 04/30/04

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[1] April 2003–March 2004

ACRONYMS

AESTO
Advanced Earth Science & Technology Organization

AFES
Atmospheric Model for the Earth Simulator

AGCMs
Atmospheric General Circulation Models

AGU
American Geophysical Union

AMIP
Atmospheric Model Intercomparison Project

AMS
American Meteorological Society

AMSU
Advanced Microwave Sounding Unit

APDRC
Asia-Pacific Data-Research Center

APEC
Asia-Pacific Economic Cooperation

BUFR
Binary Universal Format for Records

CAM
Community Atmospheric Model

CAS
Climate Analysis Section

CCM
Community Climate Model

CCCma
Canadian Center for Climate Modelling and Analysis

CCSM
Community Climate System Model

CEOP
Coordinated Enhanced Observing System

CGCM
Coupled Atmosphere-Ocean General Circulation Model

CIRES
Cooperative Institute for Research in Environmental Sciences

CLIVAR
Climate Variability and Predictability Project

CLW
Cloud Liquid Water

CMAP
Climate Modeling Analysis and Prediction

CMW
Central Mode Water

COADS
Comprehensive Ocean Atmosphere Data Set

COLA
Center for Ocean-Land-Atmosphere Studies

COPE
Climate System Observation and Prediction Experiment

CPCM
Climate Prediction Center Merged Analysis of Precipitation

CPU
Central Processing Unit

CsEOF
Cyclostationary

CSIRO
Commonwealth Scientific and Industrial Research Organisation

CSM
Climate System Model

CTD
Conductivity, Temperature, and Depth

DAPPER
Digital Archiving Pilot Project for Excavation Records

DieCAST
Dietrich/Center for Air Sea Technology

DOD
Department of Defense

DODS-type (server)
Distributed Ocean Data System

ECCO
Estimating the Circulation and Climate of the Ocean

ECHAM
European Center-Hamburg Atmospheric Model

ECMWF
European Centre for Medium-Range Weather Forecasts

ENSO
El Niño-Southern Oscillation

EOF
Empirical Orthogonal Function

EPIC
Eastern Pacific Investigation of Climate Processes

ESSIC
Earth System Science Interdisciplinary Center, University of Maryland

FNMOC
Fleet Numerical Meteorology and Oceanography Center

FRSGC
Frontier Research System for Global Change

GB
Gigabytes

GCM
General Circulation Model

GFDL
Geophysical Fluid Dynamics Laboratory

GFLOPS
Billion Floating-point Operations per Second

GODAE
Global Ocean Data Assimilation Experiment

GPCP
Global Precipitation Climatology Project

GRACE
Gravity Recovery and Climate Experiment

GrADS
Grid Application Development Software

GWR
Gravity Wave Retardation

ICHWC
International Conference on High-Impact Weather and Climate

INDOCLIM
International Workshop on the Role of Indian Ocean in Climate Variability over India

IOD
Indian Ocean Dipole

IPRC–RegCM
IPRC Regional Climate Model

ISO
Tropical Intraseasonal Oscillation

ITCZ
Intertropical Convergence Zone

ITF
Indonesian Throughflow

IUGG
International Union of Geophysics and Geodesy

JAMSTEC
Japan Agency for Marine-Earth Science Technology

JASMINE
Joint Air-Sea Monsoon Interaction Experiment

JPL
Jet Propulsion Laboratory

JTWC
Joint Typhoon Warning Center

KPP
K-Profile Parameterization

LAN
Local Area Network

LAS
Live Access Server

LASG
Institute of Atmospheric Physics, Chinese Academy of Sciences

LGM
Last Glacial Maximum

LIS
Lightning Imaging Sensor

LST
Luzon Strait transport

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

MICOM
Miami Isopycnic Coordinate Ocean Model

MIPAS
Michelson Interferometer for Passive Atmospheric Sounding

MJO
Madden-Julian Oscillation

MOM
Modular Ocean Model

MRI
Meteorological Research Institute

NASA
National Aeronautics and Space Administration

CRCES
Center for Research on the Changing Earth System

NCAR
National Center for Atmospheric Research

NCEP
National Centers for Environmental Prediction

NLOM
(US) Navy Layered Ocean Model

NLPCA
Nonlinear Principal Component Analysis

NOAA
National Oceanic and Atmospheric Administration

NSF
National Science Foundation

OFES
Ocean Model for the Earth Simulator

OGCM
Ocean General Circulation Model

OLR
Outgoing Longwave Radiation

ONR
Office of Naval Research

PBL
Planetary Boundary Layer

PCM
Parallel Climate Model

PDO
Pacific Decadal Oscillation

POM
Princeton Ocean Model

POP
Parallel Ocean Program

PV
Potential Vorticity

QBO
Quasi-biennial Oscillation

QuikSCAT
Quick Scatterometer

RAID
Redundant Array of Independent Disks

RMS
Root Mean Square

RISC
Reduced Instruction Set Computers

SAN
Storage Area Network

SCS
South China Sea

SCSIO
South China Sea Institute of Oceanology

SEC
South Equatorial Current

SEEK
Sequential Evolution Extended Kalman (filter)

SINTEX
Scale Integration Experiment

SOI
Southern Oscillation Index

SPARC
Stratospheric Processes and their Role in Climate

SSG model
Slippery Sack Geophysical Model

SSH
Sea Surface Height

SST
Sea Surface Temperature

SSCCs
Subsurface Counter Currents

STCC
Subtropical Countercurrent

STMW
Subtropical Mode Water

Sv
Sverdrup

TAO
Tropical Atmosphere Ocean

TB
Terabytes

TBO
Tropical Biennial Oscillation

TC
Tropical Cyclone

TCM
Tropical Cyclone Model

TMI
Tropical Microwave Imager

TJ
Tsuchiya Jets

TOGA
Tropical Ocean Global Atmosphere Experiment

TRITON
Triangle Trans-Ocean Buoy Network

TRMM
Tropical Rainfall Measuring Mission

UARS
Upper Atmosphere Research Satellite

UH
University of Hawai'i

WOCE
World Ocean Circulation Experiment

XBT
Expendable Bathythermograph Period

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