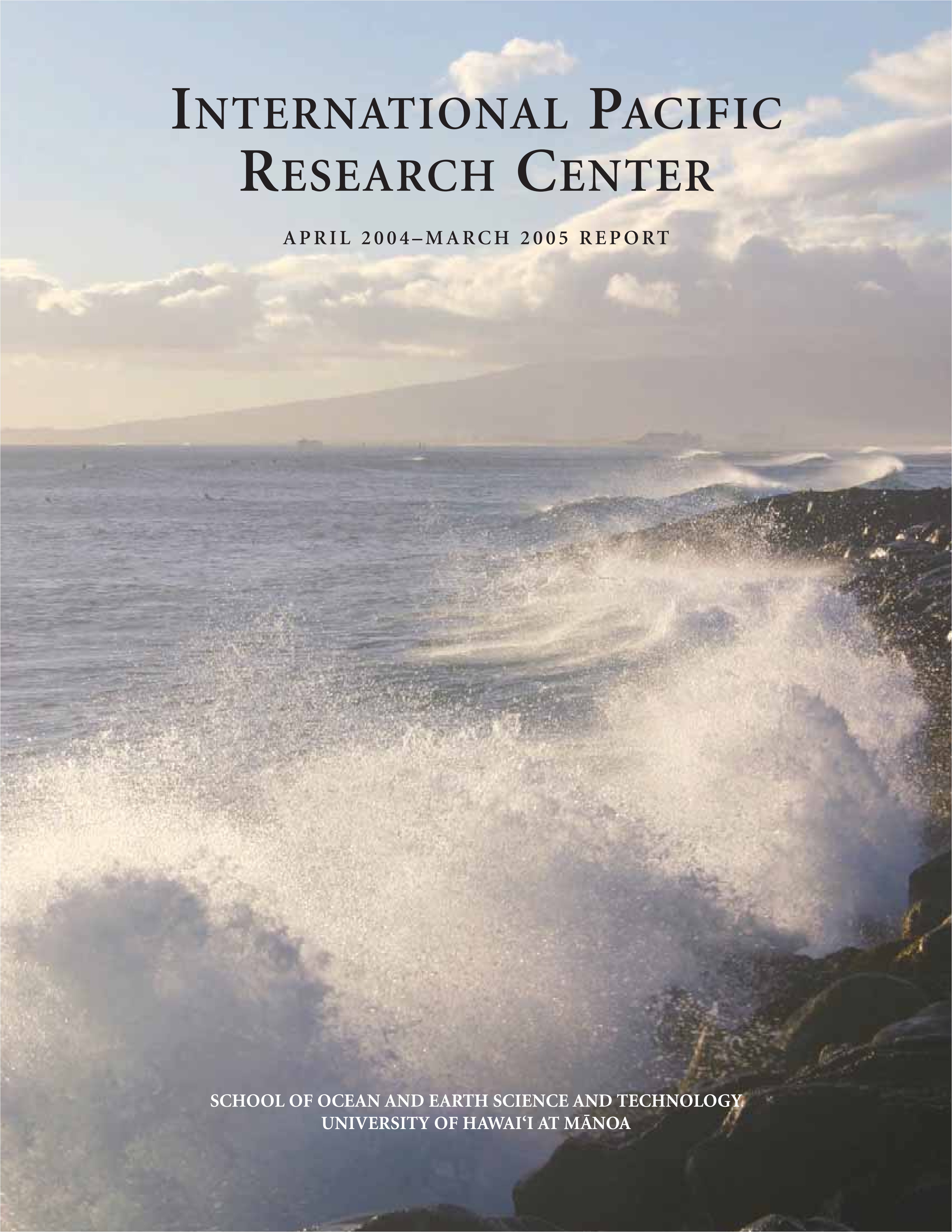
International Pacific Research Center

APRIL 2004–MARCH 2005 REPORT



SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY
UNIVERSITY OF HAWAI‘I AT MĀNOA

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巻頭言

全地球的に気温が上昇している事実はよく知られていますが、気温が上昇すると天気がどのように変わるのか理解するには基礎的な研究がまだまだ必要です。国際太平洋研究センター (IPRC) では、アジア・太平洋地域の気候変動に重点を置いて、そのような基礎研究が行なわれております。この第六回年次報告書には、2004 年 4 月から 2005 年 3 月にかけての IPRC の主な活動が紹介されています。本巻頭言では、この期間の成果を幾つか概観します。

まず、大気海洋相互作用、特に、中緯度の海洋前線上で海面水温が大気境界層に与える影響の理解が目覚しく進んだことが挙げられます。また、これまで気候モデルでうまく再現できていなかった層雲や北寄りの熱帯集束帯などの主要な現象が、地球環境フロンティア研究センターの研究者たちと IPRC が共同で開発した局地大気海洋結合モデル (「iROAM」と呼ばれています) で再現することが出来ました。これで、この地域の気候に対してどの力学や過程が重要かを決めるためのモデル実験を行なうことができます。iROAM は現時点では東部太平洋の設定になっていますが、もっと広い用途に使えることでしょう。

夏期モンスーンの季節内振動は降雨量の振動を伴うので、アジアの農業や経済は大きな影響を受けます。人工衛星データに現れる季節内振動を合成してみると、一カ月程度前から振動を予測できる可能性があることが分かります。別の方法として、大気海洋結合モデルを使えば、降雨の振動はやはり一カ月近く前から予測できることも分かりました。大気だけのモデルによるよりも早くから予測出来るのです。

当研究所での熱帯低気圧の研究も進みました。例えば、中緯度からの擾乱が西太平洋の熱帯低気圧発生の引金となることがつきとめられました。また、西太平洋で発生する熱帯低気圧の移動経路がこの数十年で変化していることが、人工衛星による観測で分かりました。さらに、地球温暖化に伴って移動経路が変化する可能性があることも、数値モデルによる研究で分かりました。熱帯低気圧の強度変化の原因も研究されており、IPRC で開発された非静水圧熱帯低気圧モデルによって、熱帯低気圧の発達や目が二重になるといった重要な現象を再現することが出来ました。

海洋過程の研究にも進展が幾つかあります。中緯度起源の冷たい水が熱帯の湧昇域に達する経路となっている土屋ジェットという流れは、太平洋域の気候にとって重要であると思われておりますが、この流れを数値モデルで再現することに成功しました。また、太平洋と南シナ海の海洋相互作用について調べ、北赤道海流の分岐点の移動を解析しました。最後に、人工衛星データと高解像度海洋大循環モデルの出力を解析した結果、全世界の海洋のほぼどこにでも、様々な時間スケールを持つ不思議な東西流系が存在することが分かってきました。これは全く新しい種類の流れで、海洋力学にとって様々な側面で重要であると思われます。

全球気候モデルの改良は IPRC での重要な研究テーマです。2005 年 3 月には、IPRC 主催で、気候変化に関する政府間パネル (IPCC) 第一作業部会が第四次気候変動評価報告書の準備のために会合を行ない、IPCC 報告書に使われる大循環モデルの解析結果が報告されました。IPRC の研究者たちも会合に参加し、私どもの研究結果が幾つか気候変動評価に含まれることになりました。

IPRC では新たに古気候モデリングの研究を始めました。過去の気候をモデルで正しく再現できるようになれば、そのモデルを使った未来の予測も、より信頼できると言えるのです。

最後に、IPRC 附属のアジア太平洋データ研究センター (APDRC) は世界中の研究者たちに気候データを使い易い形で提供していますが、データ量も増えましたし、ウェブサイトにはデータ検索機能と使用法解説が付け加わりました。APDRC に属する研究者たちは、ハワイ諸島地域に特化した高解像度海洋モデルを開発し始めました。このモデルは、海洋汚染、航海、遭難者捜索などの社会的な有用な応用を目指したものです。将来的には、ハワイ諸島以外の島嶼地域にも適用出来ることでしょう。

本報告書から分かりますように、昨年度は IPRC の研究者にとって多くの成果が得られ活気に満ちた年でした。本報告書に掲載されておりますのは、IPRC の研究者の高い生産性と質の高い研究のほんの一部です。

国際太平洋研究センター所長
Julian P. McCreary, Jr.

THE DIRECTOR'S MESSAGE

The rise in global temperature is now well documented. Much basic research must still be done, however, before the links between rising temperatures and changes in weather patterns are understood. The International Pacific Research Center (IPRC) conducts such research, with emphasis on climate variability and change in the Asia-Pacific region. This sixth annual report highlights the center's research activities from April 2004 to March 2005. In this brief opening message, I provide an overview of some of our successes during this period.

Our understanding of air–sea interactions has advanced markedly, especially our knowledge of how sea surface temperature affects the atmospheric boundary layer at midlatitude ocean fronts. Moreover, a regional coupled ocean–atmosphere model (iROAM) has been developed at the IPRC in partnership with scientists at the Frontier Research Center for Global Change. This model captures such salient features of eastern Pacific climate as the northward-displaced intertropical convergence zone and the stratus-cloud deck—features difficult for climate models to simulate realistically. Experiments can now be conducted with the model to determine the processes and dynamics critical to the region's climate. Though configured for the eastern Pacific, iROAM has possibilities for much wider use.

Intraseasonal oscillations greatly impact Asian agriculture and economy, affecting the summer monsoon rainy–dry cycles. A composite of a typical cycle constructed from satellite data suggests these cycles are predictable one month in advance. Another approach we have taken, the use of a coupled air–sea model, also suggests their predictability approaches one month, an extension over atmospheric-only model predictions by one week.

Our research on tropical cyclones has made headway. A trigger of tropical cyclones over the western Pacific was traced to atmospheric disturbances propagating equatorward from midlatitudes. Analyses of satellite data indicate a shift over the last decades in the western Pacific cyclone tracks, and a modeling experiment suggests that with global warming, cyclone tracks for that region may change. We have also studied changes in cyclone intensity: a nonhydrostatic tropical cyclone model developed at the IPRC simulated the evolution of a tropical cyclone and the important double eyewall.

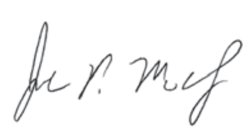
Our work on ocean processes has succeeded in the numerical modeling of a climatically important ocean pathway, the Tsuchiya Jets, by which cool midlatitude water reaches the tropical upwelling regions. We have explored oceanic connections between the Pacific Ocean and the South China Sea and the shifting bifurcation of the North Equatorial Current. Finally, satellite observations and outputs from high-resolution ocean general circulation models have revealed a remarkable system of time-varying geostrophic zonal currents, persisting over a wide range of time scales in almost every region of the world ocean. The study suggests the existence of a previously unknown class of motions in the ocean, motions that seem to be significant for explaining many aspects of ocean dynamics.

Improvement of global climate models is a major IPRC research area. In March 2005, we hosted a meeting for Working Group 1 of the Intergovernmental Panel on Climate Change (IPCC) in preparation of the Fourth Assessment Report on Climate Change. At the meeting, scientists presented their analyses of simulations with the global circulation models to be used in the report. IPRC scientists participated in the assessments, and some of their findings are included here.

We have launched a new research area: paleoclimate modeling. The ability to simulate past climates with our climate models will strengthen our confidence in conclusions drawn from simulations of future climates.

Finally, our Asia-Pacific Data-Research Center (APDRC), which provides the international research community with easy access to climate data and products, has greatly expanded its data sets, and its website now includes data-search tools and tutorials. APDRC researchers have begun to develop a high-resolution ocean model tailored to the Hawai'i Islands region. This model is intended to be portable to other island settings and to be used for such applications as pollution control, navigation, and search and rescue operations.

As this report demonstrates, the past year has been exciting and productive for IPRC researchers. The report is but one example of the high quality of their research.



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

国際太平洋研究センター

ハワイ大学国際太平洋研究センター (IPRC) はアジア・太平洋地域の気候に重点を置いて研究を行っています。当センターは、「地球的展望に立った協力のための日米共通課題」の下、1997年10月にハワイ大学マノア地区の海洋地球科学技術学部内に設立されました。その使命は「最新鋭の研究環境を、アジア・太平洋地域における自然現象、気候変動予測可能性及び地球規模の変動の地域的側面についての研究を促進するために提供すること」です。IPRC では、研究計画と以下に挙げます研究課題とに基づき、様々な国籍の研究者たちが研究を行なっています。

インド洋・太平洋地域の気候: 太平洋及びインド洋における数年から数十年規模での気候変動を理解する。

局地的海洋現象の影響: 西岸境界流、黒潮・親潮続流系、縁辺海、インドネシア通過流などが、アジア・太平洋地域の気候に及ぼす影響を解明する。

アジア・オーストラリア季節風系: アジア・オーストラリア季節風系とその水循環の気候変動特性及び予測可能性を、季節内から数十年の時間規模で決める要因を理解する。

地球規模環境変化の影響: 地球規模の環境変化とアジア・太平洋地域の気候の関係を明らかにする。

アジア太平洋データ研究センター: 世界中の研究者たちに気候データを使い易い形で提供する。

IPRC の研究戦略は、観測研究というよりは、診断解析及びモデリングによって、大気、海洋、大気・海洋・陸面結合系の研究を行うことです。観測データを最適な形でモデルに取り込むという意味で、データ同化もこの取り組みに含まれております。

IPRC は、海洋研究開発機構を通して、引続き日本から研究費を頂いております。また、米国からの研究費も増加し、昨年は、ハワイ大学と米国各種機関 (航空宇宙局、海洋大気庁、国立科学財団、海軍研究局) からの研究費が、IPRC の予算の半分を超えました。IPRC の運営委員会は日本と米国の委員から成っており、昨年度の共同委員長は深井宏氏 (文部科学省 研究開発局 地球・環境科学技術推進室長) と Eric Lindstrom 氏 (米国航空宇宙局 海洋物理課 科学担当官) でした。また、IPRC の科学諮問委員会は、IPRC に関係した気候研究分野で国際的評価の高い専門家で構成され、研究の指針を決めています。この委員会の共同委員長は、尹宗煥氏 (九州大学) と Antonio Busalacchi 氏 (メリーランド大学) でした。

THE INTERNATIONAL PACIFIC RESEARCH CENTER

The International Pacific Research Center (IPRC) at the University of Hawai'i conducts climate research with a focus on the Asia-Pacific region. Conceived under the "U.S.–Japan Common Agenda for Cooperation in Global Perspective," the center was established in October 1997 as part of the School of Ocean Earth Science and Technology, University of Hawai'i at Mānoa. The center's mission is "to provide an international, state-of-the-art research environment to improve understanding of the nature and predictability of climate variability in the Asia-Pacific sector, including regional aspects of global environmental change." The international group of scientists at the IPRC is guided by the following broad research themes and goals of the IPRC Science Plan.

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

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

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

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

The Asia-Pacific Data-Research Center (APDRC): To provide the international research community with easy access to climate data.

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

The IPRC continues to be funded by Japan through the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). Funding from U.S. sources has grown and last year, support from the University of Hawai'i and grants from the U.S. agencies (NASA, NOAA, NSF, and ONR) accounted for more than half of the center's funding. The IPRC has a Governing Committee, which consists of representatives from Japan and the United States. The co-chairs of this committee for the year were Hiroshi Fukai (Director, Office of Earth and Environmental Science and Technology, MEXT) and Eric Lindstrom (Physical Oceanography Program Scientist, NASA). Guidance on scientific matters comes from the Scientific Advisory Committee, composed of scientists internationally recognized for their expertise on climate research relevant to the IPRC mission. The co-chairs of this committee were Jong-Hwan Yoon (Kyushu University) and Antonio Busalacchi (University of Maryland).

Governing Committee with Co-Chairs Hiroshi Fukai (MEXT) and Eric Lindstrom (NASA), Howard Diamond (NOAA), Dean Klaus Keil (SOEST), and IPRC Director Julian McCreary.


Waikiki Surf • Gisela Speidel

INDO-PACIFIC OCEAN CLIMATE

IPRC research on Indo-Pacific ocean climate aims to uncover the ocean's role in the climate system by conducting studies on air–sea interaction, climate variability, and ocean processes. The studies in 2004–05 cover a broad range of topics in these three areas. The sections below highlight some of the work conducted by IPRC scientists and their colleagues during the past year.

Air–Sea Interaction

Interactions between the ocean and atmosphere play an important role in shaping the climate and its variations. The most well-known example is the El Niño–Southern Oscillation (ENSO), which provides the largest source of climate variability in instrumental records. This oscillation owes its existence to the positive ocean–atmosphere feedback mechanism originally described by J. Bjerknes, which involves interactions among ocean dynamics, atmospheric convection, and winds in the equatorial Pacific. Recent observations from space now also reveal surprisingly robust patterns of air–sea coupling over cool oceans, where such coupling had been thought to be weak. Work on both local and global air–sea interactions is a major area of research at the IPRC.

Simulating Eastern Pacific Climate and El Niño's Background State

Research Team: H. Xu, Y. Wang, S. de Szoeke, K. Richards, R.J. Small, S.-P. Xie, and T. Miyama (JAMSTEC)

The region circling the Earth near the equator where the trade winds of the Northern and Southern Hemispheres come together is called the *intertropical convergence zone* (ITCZ). Its location shifts during the annual cycle, affecting rainfall greatly. In the eastern Pacific, climate is characterized by a northward-displaced ITCZ and a pronounced annual cycle on the equator. Although readily observed, these features are difficult for state-of-the-art global climate models to simulate, limiting the models' skill in predicting El Niño and in projecting climate change. Previous work by IPRC researchers has shown that these features are due to air–sea interactions in the eastern Pacific and the shape of the North and South American continents. The difficulty in representing the air–sea feedbacks in this region—particularly the feedback among low clouds and specific features of the ocean and land surfaces, such as the narrow coastal mountain ranges—is thought to produce the biases seen in the climate model simulations.

To understand better the eastern Pacific air–sea processes that shape the basin-wide climate, IPRC researchers have developed a regional coupled ocean–atmospheric model (iROAM). The model consists of the IPRC regional atmospheric model with full physics and version 2 of the Modular Ocean Model developed at the NOAA Geophysical Fluid Dynamics Laboratory. Its resolution is 0.5° horizontally, with 28 atmospheric and 30 ocean levels in the vertical. The ocean model covers the entire tropical Pacific, and the atmospheric model covers the eastern half of the Pacific as well as Central America and most of South America. In the eastern Pacific, the model is fully coupled. Beyond this region, the ocean is driven by the NCEP reanalysis data product. In collaboration with the Kyousei-7 Project at the Frontier Research Center for Global Change (FRCGC), the iROAM has

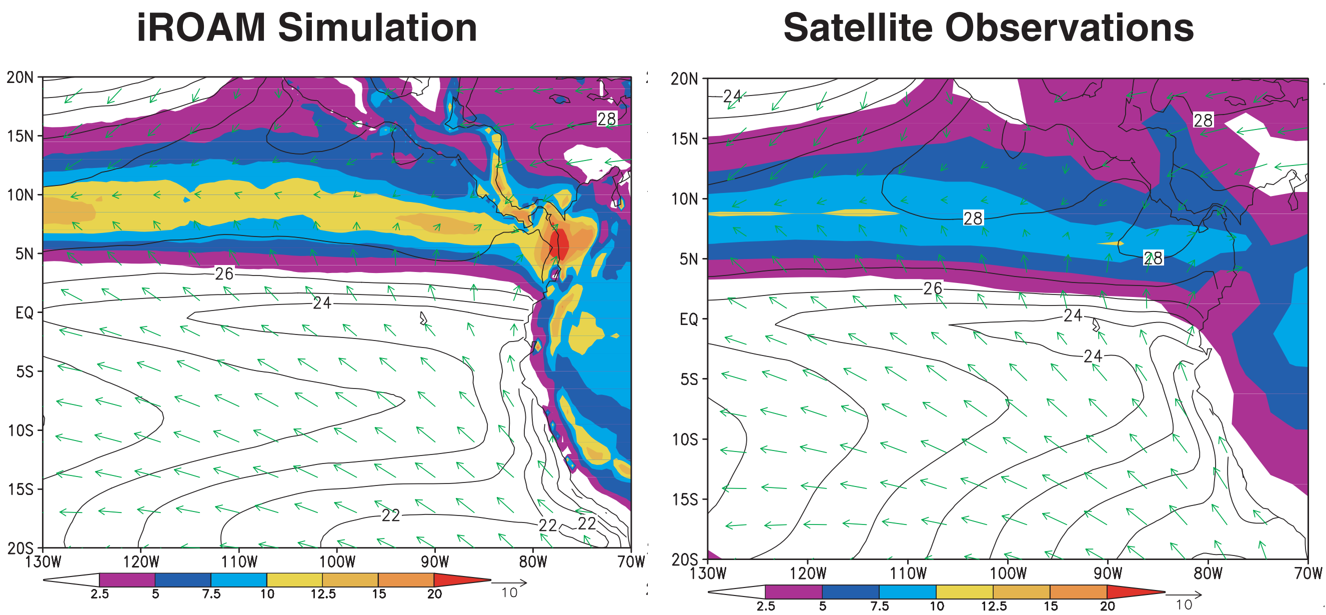


Figure 1.1. Sea surface temperature, precipitation, and surface wind velocity averaged over 1999–2003, as simulated by the iROAM (left) and observed by TRMM and QuikSCAT satellites (right). The model successfully maintains the ITCZ north of the equator and simulates a pronounced annual cycle in the eastern equatorial Pacific, two key features of Pacific climate that global models have difficulty simulating. This multiyear simulation was carried out on the Earth Simulator in collaboration with the Frontier Research Center for Global Change and the Kyosei-7 Project.

been implemented on the Earth Simulator and integrated for seven years, from 1997 to 2003. The model captures the salient features of eastern Pacific climate that have so far been difficult to model, including the northward-displaced ITCZ and the equatorial annual cycle (Figure 1.1). Just as in observations, the model ITCZ stays north of the equator most of the year except for a brief period in March–April when equatorial sea surface temperatures (SSTs) reach their annual maximum. During June–December, when the equatorial cold tongue develops, a temperature front forms north of the equator with meandering tropical instability waves, the large-scale waves with time scales of 20–30 days and wavelengths of the order of 1,000 km.

Its relatively high resolution enables iROAM to resolve the narrow mountains of the Americas. In particular, it reproduces over the Gulf of Papagayo a strong wind jet in winter that rushes through a major gap in the Central American mountain range. The strong upwelling caused by this wind jet forces a thermocline dome that maintains a cool region in the tropical ocean during summer, just as the one actually observed west of Costa Rica.

Regional ocean–atmosphere models for coastal regions and for short integrations of a few weeks to months have been developed at other research centers. The iROAM, however, is among the few models under development for nearly basin-scale and multiyear integrations. Its success in the eastern Pacific is encouraging, supplying scientists with a useful tool to study important climate processes in ways not possible with global models. Although currently configured for the eastern Pacific, iROAM has possibilities for much wider application, for example, for studying the climate of marginal seas and of the Kuroshio Extension and its interaction with the atmosphere.

Exploring Oceanic Temperature Fronts and Their Effects on Atmosphere and Climate

Research Team: R.J. Small, J. Hafner, B. Taguchi, S. de Szoeke, Y. Wang, and S.-P. Xie

Also: Y. Tanimoto (Hokkaido University) H. Tokinaga (Institute of Observational Research for Global Change), M. Nonaka (JAMSTEC), H. Nakamura (University of Tokyo), T. Watanabe (Fisheries Research Agency, Japan)

Over the cool ocean basins at midlatitudes, it is the atmosphere that mainly drives the changes in sea surface temperature (SST): stronger winds lead to more evaporation and more mixing of the ocean's surface layer, thus cooling the sea surface. Several years ago, however, IPRC researchers made a discovery that is changing our view of a "passive" midlatitude ocean. The Kuroshio Current off the coast of Japan transports huge amounts of warm water from the tropics northward and forms an oceanic warm–cold temperature front. The researchers found that wind speeds over the Kuroshio varied directly with SST; that is, wind speeds were higher over the warmer water and lower over the cooler water (Xie 2004). To follow up on this finding, IPRC researchers have been studying ocean temperature fronts and eddies and their interaction with the atmosphere worldwide. Using numerical models and experimental data, they have proceeded to study the mechanisms driving these interactions between the air and the sea.

Based on extensive satellite datasets and numerical model simulations, a global survey of ocean eddies and the overlying atmosphere revealed that unusually high (low) SST is consistently associated with high (low) wind speed at these temperature fronts—the magnitude of the wind response lying between 0.5 and 1.5 m/s for every °C change in SST. For example, across the northern edge of the cold tongue in the eastern equatorial Pacific, there is a 3 m/s difference in wind speed, the higher wind speed lying over the warmer water.

Besides the seasonal cycle, what causes SST to vary on time scales of a year or less? The team's analyses of high-resolution satellite data—such as Tropical Rainfall Measuring Mission (TRMM) SST, TOPEX/Poseidon and ERS altimeter sea surface height, and QuikSCAT vector winds—revealed that major variations arise from oceanic mesoscale eddies (widths of 10–100 miles) and coupled ocean–atmosphere fluctuations with time scales of a few months. The variations, moreover, occur globally, both near western boundary currents and in the interior ocean (J.R. Small, J. Hafner, and S.-P. Xie 2005). A simulation with Japan's Ocean GCM for the Earth Simulator (OFES), driven by climatological air–sea fluxes, reproduced these mesoscale variations. Detailed analyses of the simulation and observation showed that they are generated mostly by eddies advecting the mean SST gradient.

The mechanisms responsible for this air–sea interaction and its effects on winds over SST gradients at fronts and eddies have been investigated in several studies during the last year. One such study focused on the Kuroshio Extension region. Among midlatitude oceanic fronts, the Kuroshio Extension is of particular interest because of the deep wintertime mixed layer there; as a result deeper subsurface ocean conditions are brought to the sea surface, where they can affect the atmosphere by modifying the surface heat flux. Until recently, few observations existed to determine the effect of SST on the vertical structure of the atmosphere.

During Winter 2003–04, IPRC researchers collaborated with scientists at Japan's National Research Institute of Fisheries Science of the Fisheries Research Agency, and at Hokkaido University, University of Tokyo, and Frontier Research Center for Global Change in a field experiment to study simultaneously conditions in the deep ocean and the atmosphere. The field experiment was made possible by Japan's Fisheries Research Agency, which sponsored four cruises during that winter to survey the physical conditions of the ocean and the marine ecosystem. By crossing the Kuroshio Extension front and the subtropical front frequently, the cruises provided ideal conditions for observing the SST differences across the front and their effects on the vertical structure of the atmosphere.

During two of the cruises, by the RV *Shoyo-maru* and the RV *Kaiyo-maru*, 120 global-positioning-system sondes were launched. Y. Tokinaga and H. Tanimoto of Hokkaido

University conducted a composite analysis of the measurements taken during the second cruise (see Figure 1.2) and confirmed that near-surface atmospheric stability controls the vertical structure of the lower atmosphere to a height of 1.0–1.5 km: the larger the temperature difference between the ocean surface and air, the greater the atmospheric mixing and the more uniform the temperature and wind speed in the air column; the smaller the difference, the more stable and stratified the atmosphere and the higher the wind shear.

To understand better the mechanisms producing these observational results, the IPRC Regional Atmospheric Climate Model (iRAM) was configured with high horizontal resolution (0.5°) for the Kuroshio Extension region and integrated with the conditions obtained during the cruises. The effect of the boundary-layer structure on the stability of the atmosphere as determined by the model's "virtual sounding" (Figure 1.2., dashed curves in the lower panels) agrees well with observations (solid curves). The results are now being analyzed further to understand more fully the processes of this interaction.

IPRC researchers have also investigated the mechanisms that drive the wind response at oceanic temperature fronts in the eastern Pacific. The equatorial front there (Figure 1.3a) has a sharp boundary between cold upwelled water along the equator (the cold tongue) and the surrounding warm tropical water. Using observations from the Eastern Pacific Investigation of Climate Processes (EPIC) and numerical simulations with the iRAM, the scientists analyzed the momentum balance in the atmosphere (Figure 1.3b). As relatively cold and dry air from the cold tongue region blows northward across the equatorial SST front, the air–sea interface becomes unstable and surface heat fluxes increase. These changes affect the overlying air temperature and moisture to such an extent that a strong air-pressure gradient forms near the surface, driving winds northward across the equator. Because of thermal advection, the pressure gradient is located downstream of the SST front, so that the wind acceleration occurs at the front and the strongest winds are over the warm water north of the front. (Small, R.J., S.-P. Xie, Y. Wang, S.K. Esbensen, and D. Vickers, *J. Atmos. Sci.* in press)

Both observations and models show that the atmosphere warms the cold tongue and cools the warm water north of the equatorial front. This leads to the question, what maintains the equatorial front? Simulations with iROAM indicate that near-surface meridional currents advect cold water from the equator northward, and in

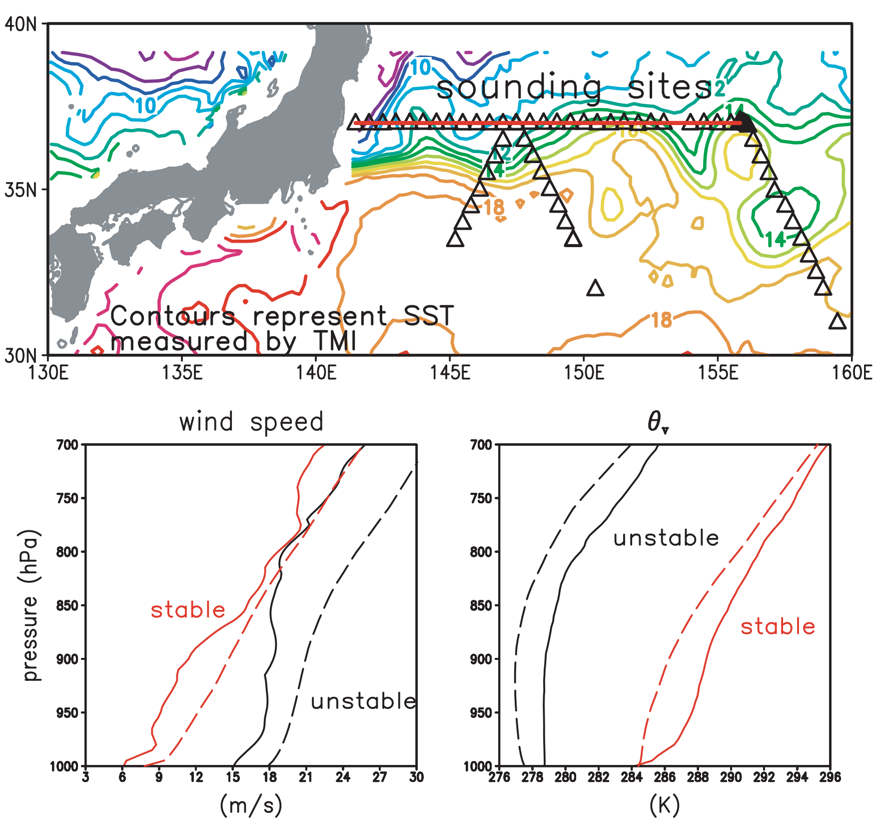


Figure 1.2. Top: Sounding sites of the RV *Kaiyo-maru* cruise (triangle marks) superposed on mean SST measured by TMI during the cruise period (color contours). **Bottom:** Composite profiles, based on near-surface atmospheric stability (T_s–T_a), showing clear differences between stable and unstable conditions, the latter having a deeper mixed layer and being more uniform in both virtual potential temperature (right) and wind speed (left). Solid curves are from the soundings, dashed curves from the regional model.

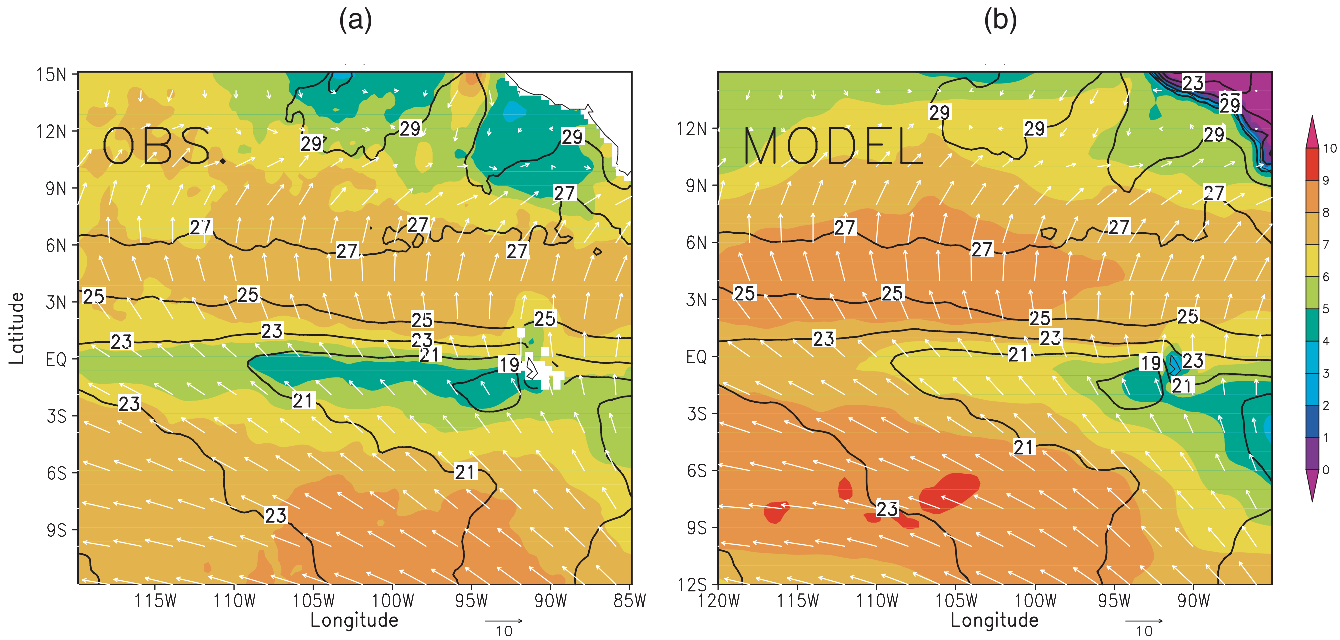


Figure 1.3. **Wind speed at 10 meters (color; m/s), wind velocity (arrows; see scale) and SST (°C; contours) averaged over September and October 2001, showing observed wind and SST fields from QuikSCAT and TMI (panel a) and modeled winds from iRAM together with TMI SST (panel b).**

the lower mixed layer, warm water from the north southward. The sharp equatorial temperature front forms in the region where the cold and warm water masses come together.

Ocean models often assume atmospheric responses across fronts are small, and they specify a constant air–sea temperature difference in their integrations. As the Pacific equatorial front study has shown, however, the atmospheric response to a SST front significantly modifies the surface heat flux. A study now underway at the IPRC uses iROAM to investigate just how the heat flux is affected. In this regard, the heat fluxes simulated by iROAM across the front are being decomposed into ocean- and atmosphere-forced components. Up to 65% of the change in evaporation across the equatorial front is contributed by the atmospheric response to the front and not explained by the change in sea surface temperature alone. (S. de Szoeke and S.-P. Xie, in preparation)

Taken together, the results of these modeling and observational studies show that the atmosphere and ocean are fully coupled over SST fronts and eddies worldwide. This coupling involves heat fluxes, thermal advection, and pressure gradient force, and it leads to in-phase modulations of SST and wind speed. Future projects will study how SST gradients affect the deeper layers of the atmosphere and storm tracks.

Climate Variability

IPRC researchers have continued to explore the dynamics at work in the variability of such significant climate phenomena as the El Niño–Southern Oscillation, the Indian Ocean Dipole, and the Pacific Decadal Oscillation. With the growing awareness of the climatic importance of the Indian Ocean, projects have also looked into the climatic effects of the Indian Ocean on other regions and have evaluated the skill of global circulation models in capturing Indian Ocean climate variability.

Describing the Kuroshio Extension Response to the North Pacific Climate Shift

Research Team: B. Taguchi, S.-P. Xie, H. Mitsudera (Hokkaido University), and A. Kubokawa (Hokkaido University)

The Kuroshio Extension, the swift ocean current extending from Japan's coast to the central North Pacific, has come to be recognized as a key aspect in Pacific decadal climate variability. Knowledge of how this major oceanic front responds to large-scale wind changes is necessary in order to understand the processes that underlie North Pacific climate variability.

Together with colleagues at Hokkaido University, IPRC scientists examined a distinct manifestation of Pacific decadal variability, the 1970s climate shift in the North Pacific and its effect on the Kuroshio Extension. Specifically, they investigated the ocean's response to the stronger westerly winds in the central North Pacific that were associated with this shift. Using a combination of coarse, basin-wide, and high-resolution regional ocean models, they performed ensemble experiments in which they separated the subtle signals of the ocean response from noise. They first applied the decadal changes in westerly winds to drive a coarse-resolution, basin-wide ocean model. This excited Rossby waves in the ocean that propagated westward and altered the thermocline. They then applied these thermocline changes to a fine-resolution regional model of the Northwest Pacific that resolves the Kuroshio Extension front and eddies. Once again, the

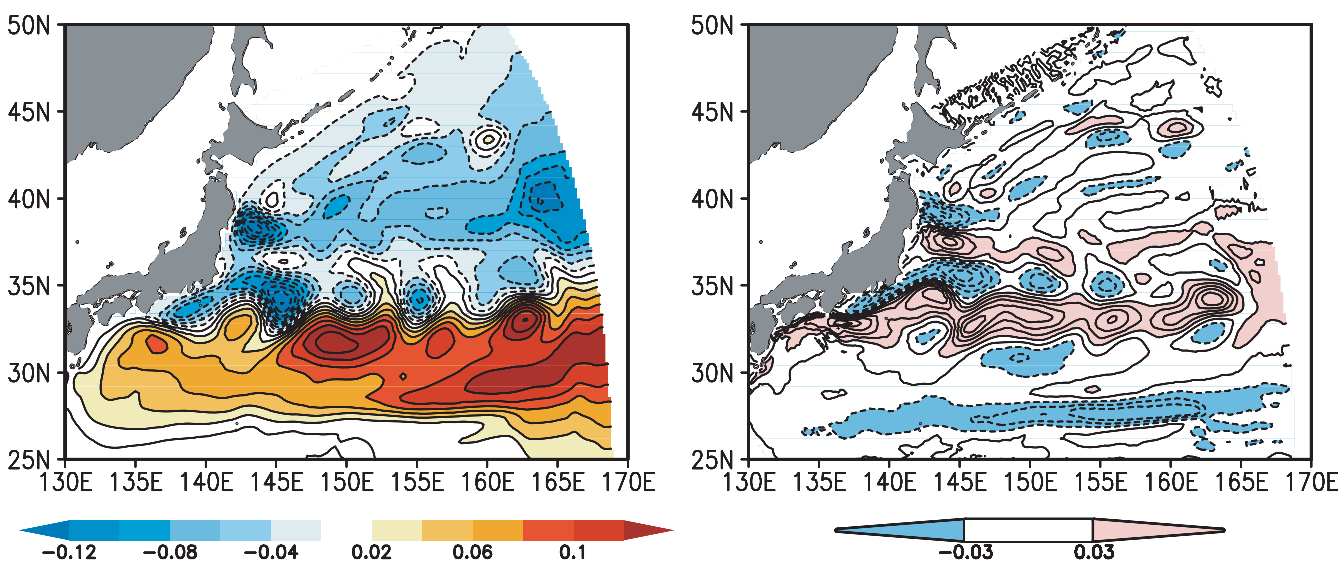


Figure 1.4. Ensemble and temporal mean differences in sea-surface height fields (left panel: contour interval is 0.02 m) and the 50-m zonal velocity (right panel: contour interval is 0.03 m).

model generated Rossby waves. Although the Rossby waves raised the sea surface to the south and lowered it to the north over a broad latitudinal band (Figure 1.4, left panel), they accelerated the Kuroshio Extension jet only in a narrow band (around 33°N–34°N, right panel). The confinement of the accelerating effect of the broad-scale wind forcing (see Figure 1.5, black line) to this narrow jet (red curve) is unexpected from linear dynamics. Analysis of the model output suggests that the generation of the narrow current is due to nonlinear processes, namely, potential vorticity advection and positive feedback from the eddies to the mean current. This unusual, highly localized response is of significance for the marine ecosystem and fisheries in the region.

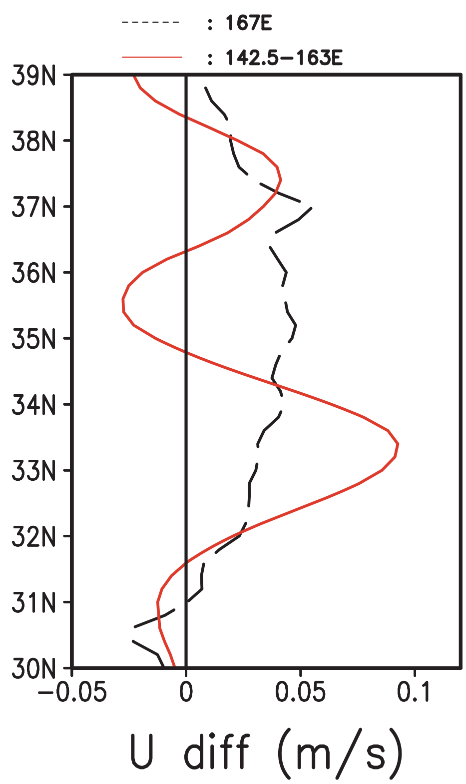


Figure 1.5. Meridional profile of zonally averaged ensemble and temporal mean for the 50-m depth zonal velocity differences. Red solid line shows the zonal average profile over the interior domain of the regional ocean GCM whereas black dashed line shows the profile at 167°E near the eastern boundary of the regional ocean GCM. (Figure adapted from Taguchi, Xie, Mitsudera, and Kubokawa, *Journal of Climate*, in press.)

Modeling Indian Ocean Climate Variability

Research Team: N.H. Saji, S.P. Xie, T. Yamagata (University of Tokyo)

As part of the effort for the Fourth Assessment Report being prepared by the Intergovernmental Panel on Climate Change (IPCC), IPRC researchers evaluated 17 coupled ocean–atmosphere general circulation models (GCMs) and their simulation of the year-to-year SST variability in the Indian Ocean during the 20th century. Simulating realistic Indian Ocean SST variability and its associated climate impacts is challenging because this variability is affected by such climate phenomena as the El Niño–Southern Oscillation (ENSO), the monsoons, regional air–sea processes, and the Indian Ocean Dipole, a pattern of coupled air–sea variability modulating zonal SST gradients along the equatorial Indian Ocean. The task is made more complex by interactions among all of these elements.

Many models succeeded in capturing the variability in SST associated with the Indian Ocean Dipole reasonably well (Figure 1.6). A major factor in simulating this variability realistically seems to be the mean thermocline depth in equatorial regions during the latter half of the year. The simulated dipole in most of the models agrees quite well with observations in both spatial pattern and temporal evolution. Supporting the importance of ocean–atmosphere coupling and positive feedback, the dipole simulated in the models features strong coupling among rainfall, winds, thermocline, and anomalous SSTs. Models that simulate the dipole also simulate the observed out-of-phase relation between rainfall anomalies in the eastern and western Indian Ocean.

The model intercomparison also focused on assessing the models' ability to simulate three Indian Ocean SST patterns that are thought to impact climate and known to vary with ENSO. The first and well-substantiated Indian Ocean pattern is the basin-wide unusually high (low) Indian Ocean surface temperatures following an El Niño (La Niña), a response pattern that is useful in predicting seasonal rainfall over East Africa. Analyses of the model simulations showed that most of those models with

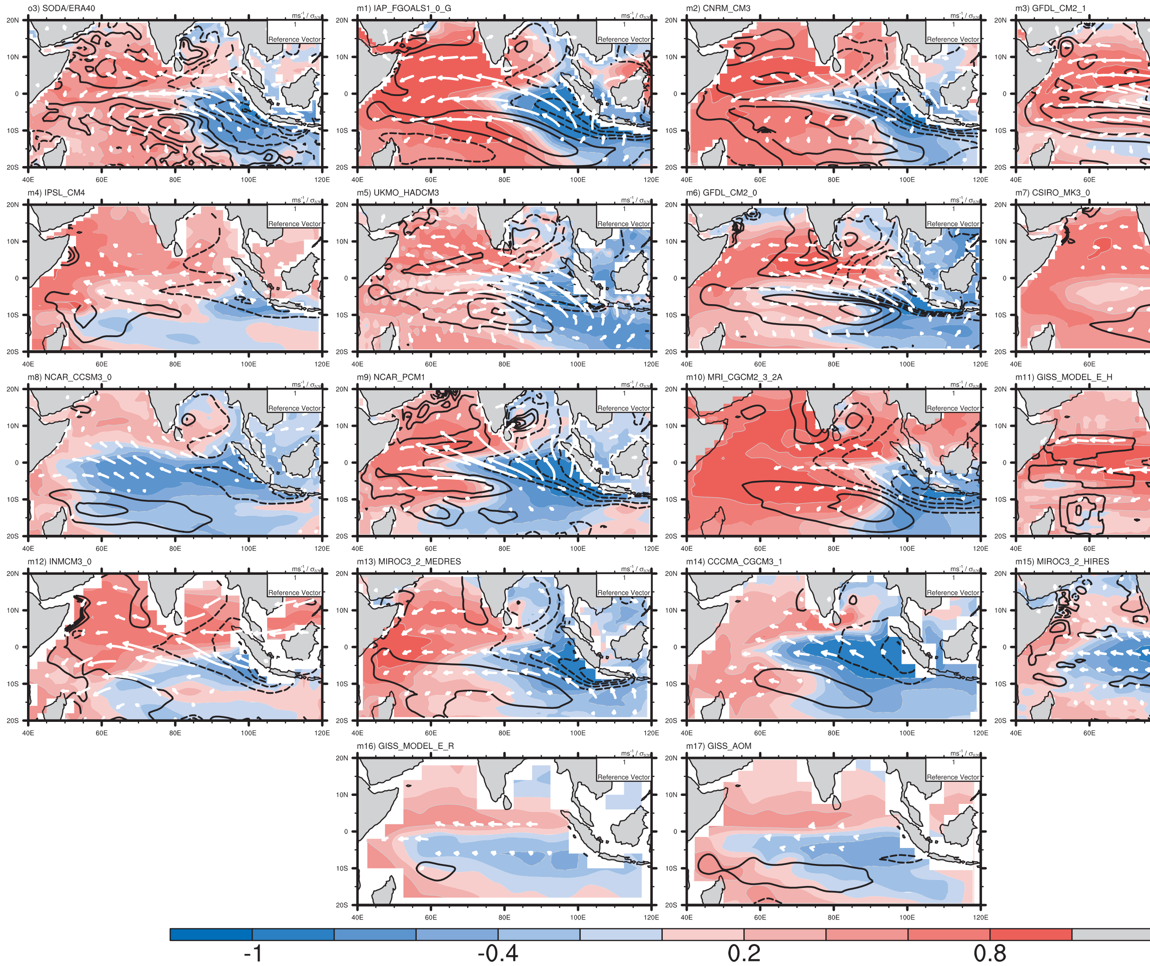


Figure 1.6. Observation (top left) and simulations of the Indian Ocean Dipole by various IPCC coupled models: Contours depict the first Empirical Orthogonal Function (EOF 1) of thermocline variability in the models during boreal fall (September to November). The shaded contours represent the correlation coefficient between SST and the time variability of the thermocline mode; similarly, the vectors represent the regression between surface winds and thermocline variability. Note that SST anomalies are cool (blue) when the thermocline is shallow (negative values) and warm (red) when the thermocline is deep (positive values). The winds are directed from cool towards warm SSTs. These relations are dynamically consistent and depict the mutual interaction between the ocean and the atmosphere during a dipole event in the Indian Ocean. (Figure after N.H. Saji, S.P. Xie, and T. Yamagata, submitted to *J. Climate*.)

reasonably large SST variability in the NINO-3 region captured the basin-wide warming quite well.

The second important pattern is found in the southwest tropical Indian Ocean. There, cooler thermocline water rises closer to the surface than in the surrounding waters, forming a thermocline dome around 10°S. Observations show that oceanic Rossby waves, forced in the mid-basin by ENSO-induced wind changes, affect the depth of this thermocline dome. These depth variations, in turn, affect SST and may play an important role in determining the winter climate in this region. Analyses of the model simulations indicated that many of the high-resolution models capture the amplitude and location of the thermocline dome reasonably well, with models that have larger ENSO variability generally producing larger changes in the dome.

A third important ENSO effect on the Indian Ocean is associated with the propagation of upwelling-favorable, baroclinic signals (*e.g.*, Rossby waves) into the Indian Ocean from the western Pacific Ocean. Through their influence on SST, these signals can affect rainfall over Australia. For instance, cool SST in the Indonesian region during an El Niño is associated with drought in Australia. None of the models are able to simulate the latitude (20°S) at which the Rossby waves, traveling southward along the western coast of Australia, turn westward to radiate into the Indian Ocean.

In summary, the coupled GCMs are only partly successful in simulating the rich spectrum of Indian Ocean SST variability. ENSO is an important forcing of Indian Ocean variability, accounting for a significant fraction of the SST and rainfall variability in this region. It is also one of the important triggers for evolution of the Indian Ocean Dipole. In a changing climate, ENSO may alter its characteristics and hence its impact on Indian Ocean climate through altered teleconnections. Thus it is important for coupled GCMs to simulate SST variability and its climate impacts realistically in both the Pacific and Indian oceans. The possibility that conditions in the Indian Ocean influence ENSO and beyond, as recent studies suggest, adds more importance to their realistic simulation in climate models.

Discovering a New Mode of Climate Variability in the Atlantic

Researchers: Y Okumura and S.-P. Xie

Although the IPRC's focus is on ocean climate processes in the Indo-Pacific region, a comparison with the tropical Atlantic Ocean can lead to a better understanding of the nature of tropical ocean–atmosphere interaction and thus to better climate prediction. The Atlantic tropical climate is similar in many respects to that in the Pacific. The so-called Bjerknes feedback—the feedback loop between size of the east-west sea surface temperature (SST) gradient, strength of the tradewinds, and depth of the eastern thermocline—is also active in the Atlantic, contributing to the variability in the east-west mean SST asymmetry and the associated easterly trade winds. The resulting year-to-year variability in equatorial Atlantic climate, therefore, resembles the El Niño–Southern Oscillation (ENSO) in the Pacific. The Atlantic warm and cold events, however, are weaker and modulated more by the seasonal cycle, and they tend to peak in boreal summer (May–August) rather than in winter (November–January) as the Pacific warm and cold events do. The Atlantic mode affects interannual rainfall variations in the Gulf of Guinea coastal region and the Sahel.

Analyzing the high-resolution satellite data accumulated over the last two decades, IPRC researchers have discovered that a second Niño-like phenomenon exists in the equatorial Atlantic during early boreal winter (Figure 1.7). This Atlantic Niño II mode is significantly correlated with year-to-year rainfall variations during the early rainy season in coastal Congo and Angola and is statistically unrelated to the Pacific warm and cold events and to the previous summer Atlantic Niño. The origin of this variability lies in an overlooked aspect of the seasonal cycle in the equatorial Atlantic. Oceanographers have long been aware that the thermocline shoals twice a year in the Gulf of Guinea in response to the seasonal acceleration of the

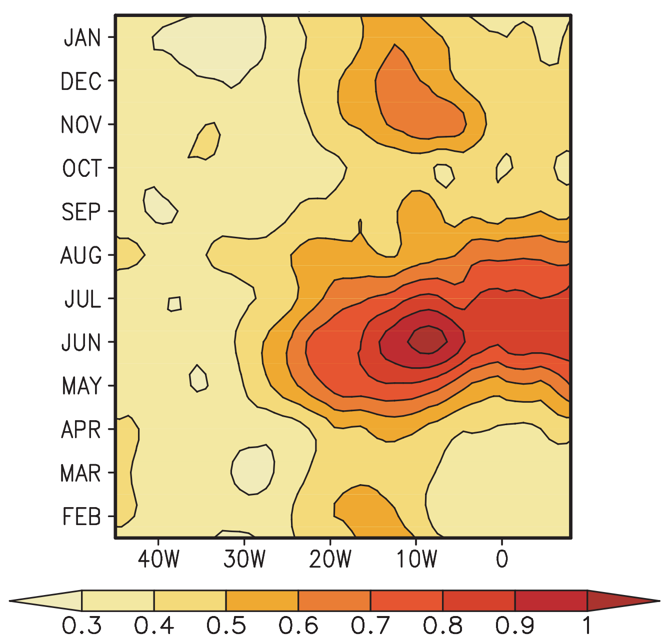


Figure 1.7: Standard deviation of interannual SST (in °C) along the equator as a function of longitude and calendar month. The eastern equatorial SST variations are pronounced in boreal summer (May–August) and early winter (November–December), when the easterly winds intensify and the thermocline shoals in the Gulf of Guinea.

equatorial easterly winds. The major shoaling in boreal summer is believed to cause the phase-locking of the Atlantic Niño. The IPRC research now shows that the second shoaling in November–December also enhances the sensitivity of SST to surface wind changes and hence equatorial ocean–atmosphere coupling (Figure 1.8). Thus, the Bjerknes feedback in the equatorial Atlantic is strongly controlled by the seasonally changing thermocline depth, which is most pronounced in boreal summer and early winter. This situation differs from the eastern equatorial Pacific, where the seasonal thermocline depth varies little compared to the large interannual excursions associated with El Niño and La Niña. The Atlantic Niño II may evolve in the following spring into the north-south dipole mode—a basin-scale variability peculiar to the tropical Atlantic that affects rainfall in northeast Brazil.

The winter-to-spring period has been poorly understood in tropical Atlantic climate. The Atlantic Niño II mode now fills this gap, potentially increasing the climate predictability for the region.

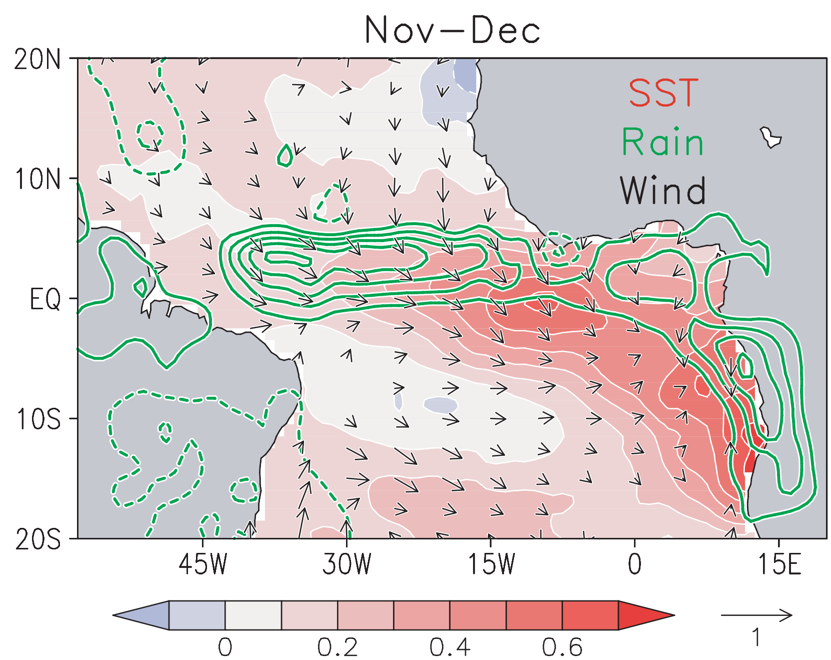


Figure 1.8: November–December anomaly patterns associated with the Atlantic Niño II mode, showing. SST (°C; color shading with white contours), 1000 hPa wind (m/s; vectors;), and precipitation rate (green contours at intervals of 0.3 mm/day). The patterns are determined by regressing each field onto the SST index averaged over the central equatorial Atlantic. Since 1982, there were four warm events (1987, '93, '97 & 2003) and four cold events (1986, '91, '96 & 2001), in which SST fell respectively above and below one standard deviation of the November–December SST. (Figure adapted from Y. Okumura and S.-P. Xie 2004)

Ocean Processes and Circulation

The ocean currents and equatorial thermocline are key to the ocean heat budget and climate. IPRC research this year has examined, among other things, the processes that lead to the formation of subsurface near-equatorial currents, the Tsuchiya Jets, and the sensitivity of the equatorial circulation to various mixing schemes used in ocean general circulation models.

Modeling the Tsuchiya Jets

Research Team: R. Furue, J. P. McCreary, Z.Yu, and D. Wang.

The Tsuchiya Jets are narrow eastward currents, located a few degrees on either side of the equator at depths between 200 and 500 m. They carry about 14 Sv of lower-thermocline (upper-intermediate) water across the tropical Pacific. Believed to form an important pathway by which cool water, formed at mid-latitudes, reaches its upwelling regions in the tropics, they are climatically important. Realistic simulation of these jets, however, has eluded modelers.

This year, IPRC researchers successfully simulated the Southern Hemisphere Tsuchiya Jet in a non-eddy-resolving, oceanic general circulation model (GCM) with idealized wind-stress distributions (Figure 1.9, left panel). They obtained solutions in a rectangular basin with a width similar to that of the Pacific. The model was driven

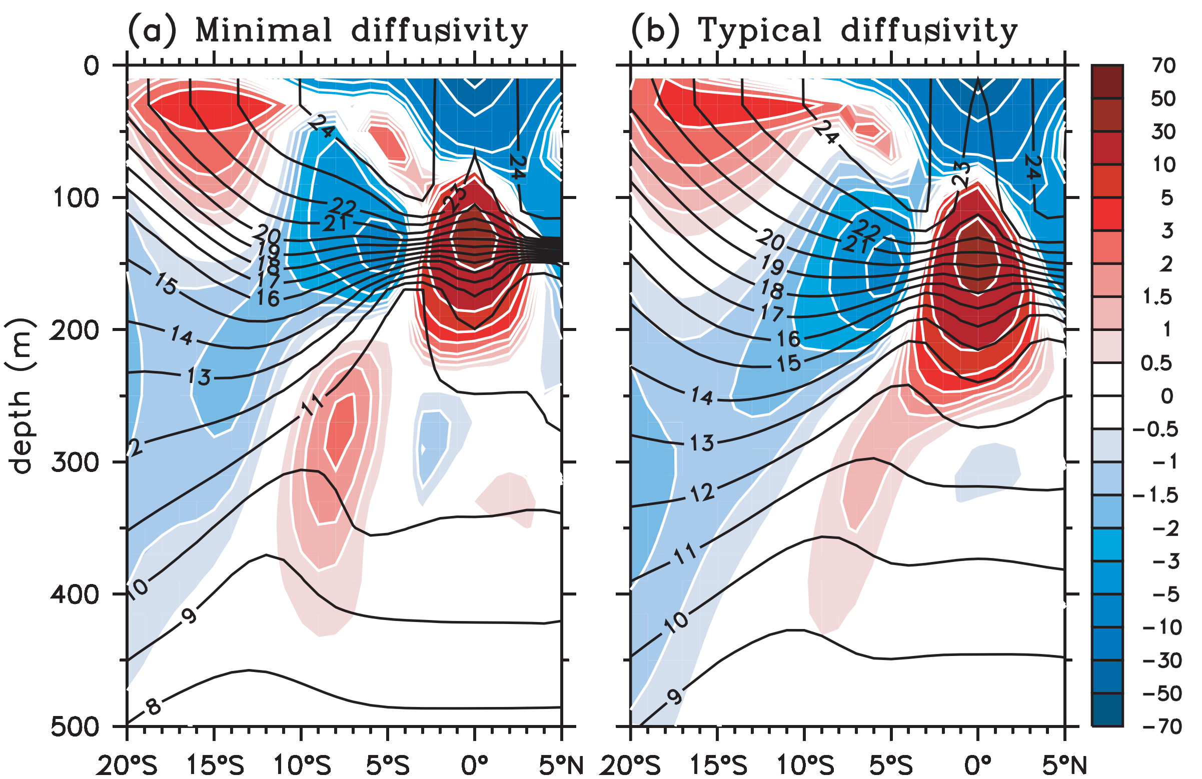


Figure 1.9. **Zonal velocity (red for eastward and blue for westward in cm per second) and temperature (contours in °C) at the center of the idealized model ocean (after Furue *et al.*, 2005, manuscript to be submitted). In the minimal diffusivity condition, a thick layer of nearly homogeneous temperature or a thermostad lies below the thermocline of the equator and a distinct eastward current, the model's Tsuchiya Jet, exists at 9°S and 280-m depth. When background diffusivity is increased to a commonly used value, the thermostad is no longer well defined and the jet becomes weaker.**

by idealized zonal and meridional winds representing the trades and southerly winds near the South American coast, by a prescribed inter-ocean circulation that enters the basin through the southern boundary and exits through the western boundary at 2°N–6°N (the model's Indonesian passages), and by surface heating that warms the ocean in the tropics.

Solutions driven by all aforementioned processes and with minimal diffusion resemble the observed flow field in the tropical South Pacific. A narrow eastward current, the model southern Tsuchiya Jet, flows across the basin along the southern edge of a thick equatorial thermostad, and upwells at the eastern boundary. Its deeper part is supplied by water that leaves the western boundary current somewhat south of the equator; its shallower part originates from water that diverges from the deep portion of the Equatorial Undercurrent. The latter increases and warms the jet's transport as it flows eastward across the basin. In simulations without an inter-ocean circulation or meridional wind, the Tsuchiya Jet is weak or absent. These, and other, properties suggest that the dynamics of the model's jet are those of an arrested front, which is generated in a $2^1/_2$-layer model when characteristics of the flow merge or intersect.

Furthermore, when the background diapycnal diffusivity is increased to values commonly used in models, the thermostad is no longer well defined, again resulting in a weaker jet. In this case, much of the sub-thermocline water upwells along the equator rather than at the eastern boundary. This pronounced influence of diapycnal diffusion on the model jet likely explains why the Tsuchiya Jets have been difficult to simulate in ocean GCMs and pose a great challenge for climate modeling.

Documenting the Sensitivity of the Ocean Circulation to Mixing Schemes

Research Team: D. Wang, F. Ascani (University of Hawai'i), and E. Firing (University of Hawai'i)

Parameterization of the effects of mixing in ocean general circulation models (GCMs) is uncertain. To study the sensitivity of the equatorial circulation to various mixing parameterizations, IPRC researchers and their colleagues conducted a series of studies using a high-resolution, eddy-resolving ocean GCM. They found that with low mixing coefficients, strong North Equatorial Countercurrent instability and tropical instability waves occur. The strength and zonal scales of the instabilities also depend on the mixing scheme: with standard constant Laplacian mixing, the tropical instability waves are unrealistically weak; with Smagorinsky mixing or biharmonic mixing, they are much stronger. Away from the equator, barotropic or first-vertical-mode zonal jets are ubiquitous in solutions for both schemes, consistent with other eddy-resolving models such as JAMSTEC's global ocean model and the Ocean GCM for the Earth Simulator (OFES). The solutions of these latter models will be further analyzed to determine the mechanism generating their zonal jets.

Another finding of significance is that SST and upwelling near the eastern boundary are very sensitive to the specification of vertical mixing. Integrations with the Richardson-number-dependent scheme of Pacanowski and Philander (PP) have an equatorial cold tongue that is colder and extends farther west than in the observations, a common problem in many coupled atmosphere–ocean climate models. Integrations with the K-profile mixing parameterization (KPP) have a warmer cold tongue and higher SSTs in the coastal upwelling region, indicating the sensitivity of these regions to the mixing scheme used. Figure 1.10 shows the difference in SST between solutions using the KPP and the PP mixing schemes. Since upwelling is stronger with the PP scheme, the cold bias in

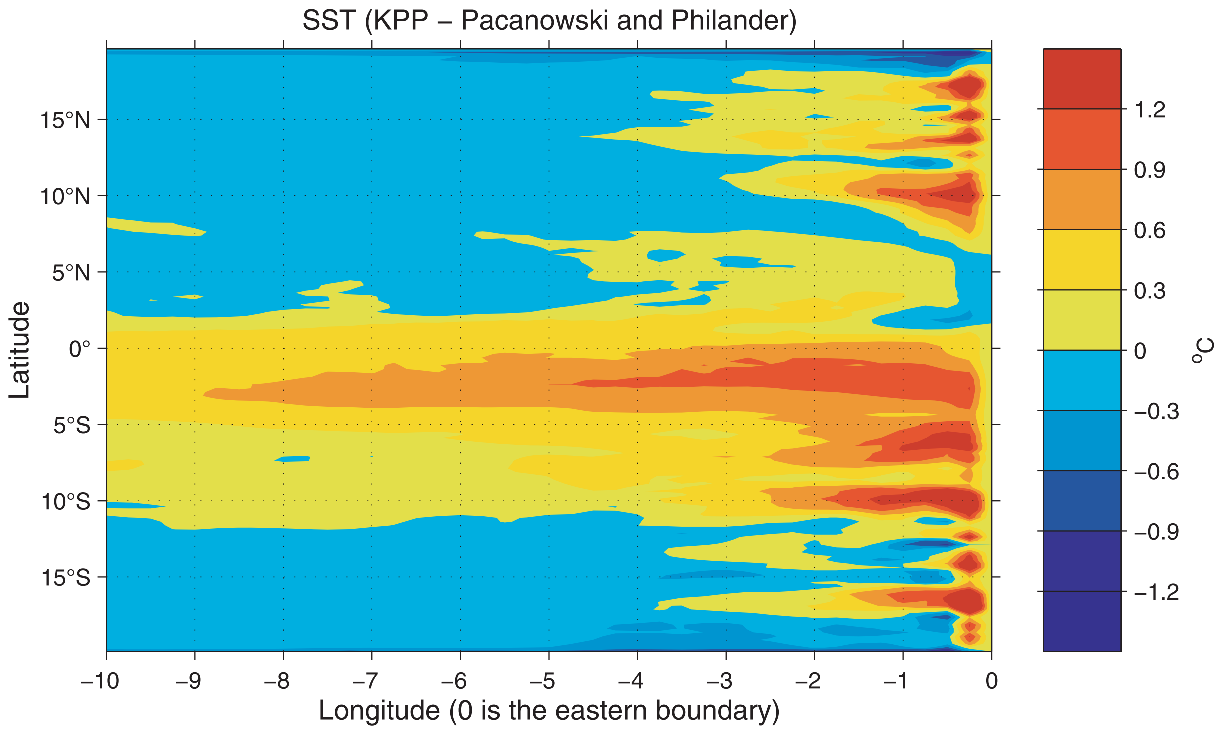
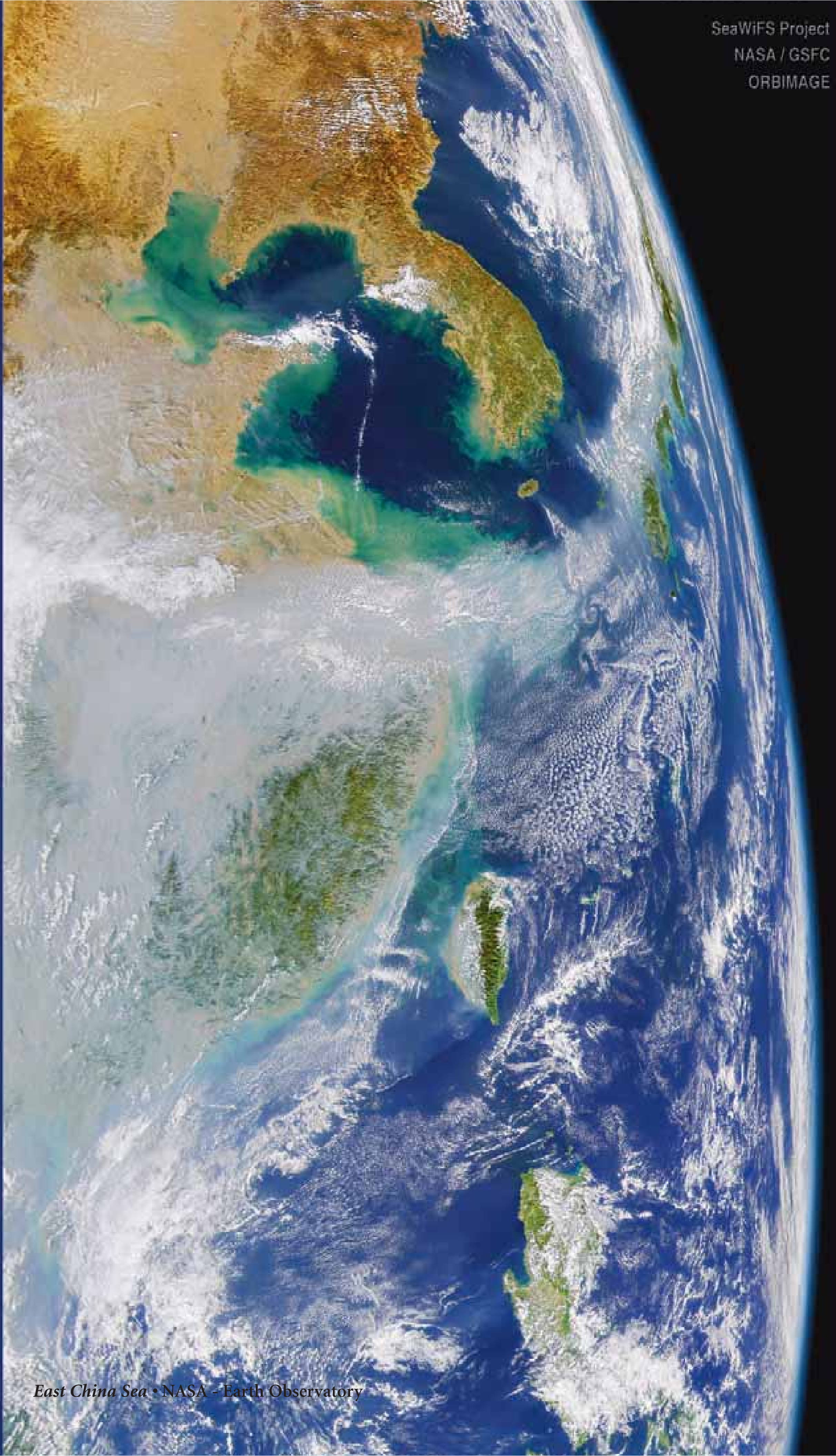


Figure 1.10. The differences between the average yearly SST near the eastern boundary using the KPP mixing scheme and the Pacanowski and Philander mixing scheme.

coupled models due to excessive upwelling using this mixing scheme may be more severe. Given the responsiveness of atmospheric circulation to SST, the sensitivity of SST to mixing schemes found in this study could have important implications for air–sea coupling.

Other ongoing IPRC work that is relevant to improving the ocean component of climate models focuses on assessing the effects of bottom friction on the equatorial circulation. Bottom friction is usually formulated in a manner similar to atmospheric boundary-layer (ocean and land surface) friction, where friction is a function of the 10-m wind and a drag coefficient. Common practice is to replace the 10-m wind in this formula with the horizontal velocity at the lowest grid (typically 100 m or more above the ocean bottom). This practice may be justified near steep orographic features, but not for the vast areas of the ocean floor. The use of such a "bottom friction scheme," therefore, may well overestimate bottom stress. An IPRC experiment without bottom stress (free slip) nearly doubled the mean kinetic energy of the response—almost as much as if wind stress had doubled—and increased the equatorial deep flow dramatically. The solution is currently being examined in detail to understand how the deep flow is generated.



East China Sea • NASA - Earth Observatory

RESEARCH HIGHLIGHTS

REGIONAL OCEAN INFLUENCES

Research on regional ocean influences is aimed at understanding oceanic phenomena and their impact on climate and climate variability in the western Pacific Ocean, its marginal seas, and its connection with the Indian Ocean. Among other work this past year, researchers in this theme have charted the bifurcation of the North Equatorial Current, evaluated an oceanic pathway for climate-signal exchange between the Pacific and the South China Sea, and explored Indian Ocean climate variability and the influence of the Indonesian Throughflow on this variability. In addition, they have determined characteristics of zonal jets detected in high-resolution ocean models and satellite altimetry measurements, studied the impact of stirring and mixing on the marine ecosystem, generated enhanced ocean datasets, and developed and applied data assimilation techniques.

Western-Boundary Currents and Links to Marginal Seas

The low-latitude western-boundary currents of the North Pacific are located along the Philippine coast where the North Equatorial Current branches into the northward-flowing Kuroshio and the southward Mindanao Current, separating the tropical and subtropical gyres of the North Pacific. These currents are known to play an important role in the El Niño–Southern Oscillation and decadal climate variability of the Pacific. Furthermore, the climatic connection between the western Pacific and the adjacent marginal seas, particularly the South China Sea, is an area of research interest at the IPRC.

Taking the Pulse of the North Pacific

Research Team: T. Jensen, Y. Y. Kim, T. Qu, J. McCreary, and B. Bang, T. Miyama (JAMSTEC)

At the western boundary of Earth's ocean currents, the flow and density structure depend on the integrated conditions over the ocean interior, a consequence of the across-basin propagation of westward-propagating Rossby waves. If interpreted properly, then western-boundary current variability can provide a measure of the climatic state of the entire ocean.

Using various numerical models, IPRC researchers found that near the surface, the latitude at which the North Equatorial Current (NEC) branches shifts from 15.5°N in December to 14.2°N in July. This finding agrees well with the latitude derived from previous hydrographic observations by T. Qu and R. Lukas at the University of Hawai'i. The model simulations also confirmed the observed 2°–3° poleward shift of the bifurcation with depth. These results were found in models driven by wind alone and were not very sensitive to the wind climatologies used to force the models, demonstrating that the seasonal cycle of the bifurcation latitude at the surface and at depth is a robust climatic feature.

The bifurcation-shift and its seasonal cycle result from westward-propagating Rossby waves, generated in the interior of the oceans. During northern winter, low surface pressure in the ocean associated with these waves shifts the bifurcation northward, increasing the southward transport anomaly along the Philippines. Conversely, during the summer, the bifurcation shifts southward, strengthening the northward transport anomaly (Figure 2.1).

Numerical experiments comparing the effects of local and remote winds suggest that the effect of the remote wind dominates the bifurcation seasonal cycle. This dominance is to be expected from Sverdrup dynamics, which explain the bifurcation latitude for steady flows. Because the baroclinic response is not in equilibrium with the wind forcing, though, the phase of both the modeled and the observed bifurcation latitude is opposite to that expected under a steady state.

The shifting position of the bifurcation tells us much about conditions in the interior ocean: The latitude of the bifurcation varies with the magnitude of the volume transported by the North Equatorial Current. This link is illustrated in a simulation with the Princeton Ocean Model forced by monthly winds and buoyancy fluxes from the NCEP reanalysis (Figure 2.2). During El Niño years, when transport is at its highest, the bifurcation shifts far to the north; during La Niña years, when transport is at its lowest, it shifts far to the south.

Simulations of interannual variations in the North Equatorial Current transport using the JAMSTEC model (Kim *et al.* 2004) and the Ocean GCM for the Earth Simulator (OFES) show similar high correlations between transport and bifurcation latitude, giving confidence in the validity of these results.

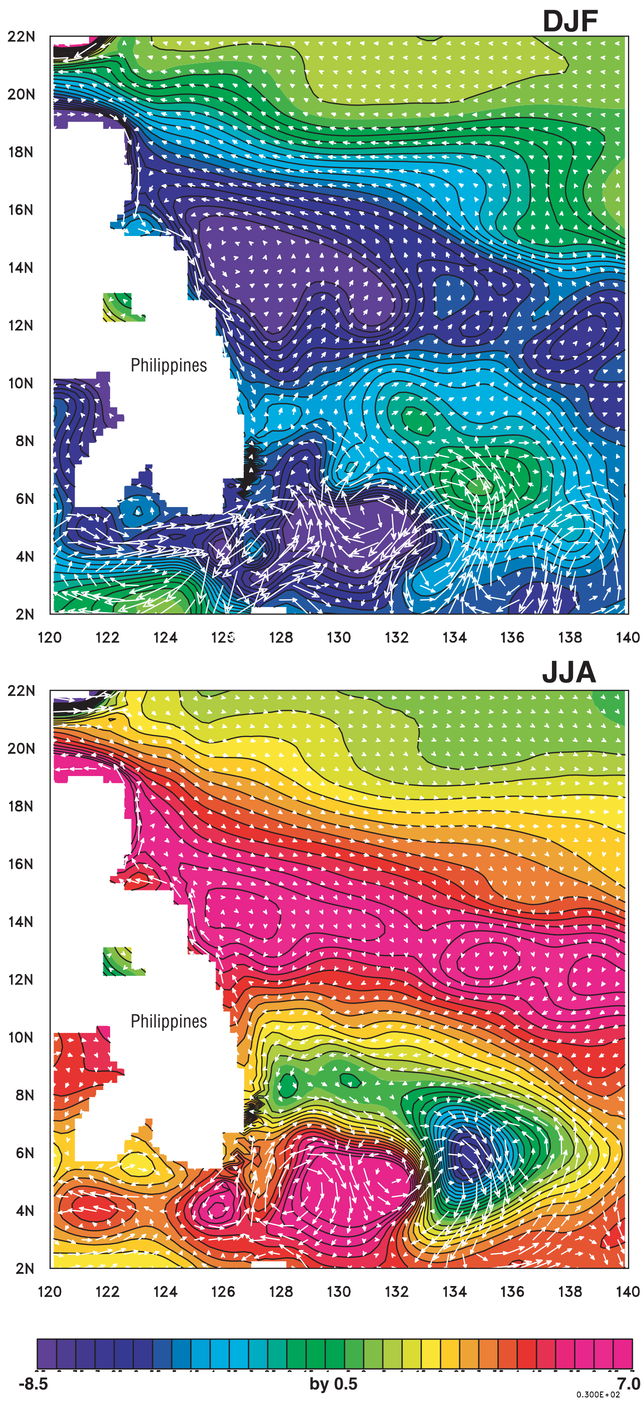


Figure 2.1. The seasonal North Equatorial Current bifurcation shift: Upper-layer thickness (in m) and anomaly transport (in m^2/s). Top: Negative (blue) upper-layer thickness anomalies and associated low pressure in the upper ocean off the Philippines drive geostrophic current anomalies southward along the coast from December to February. Bottom: Positive (red) upper-layer thickness anomalies and associated high pressure drive current anomalies northward from June to August.

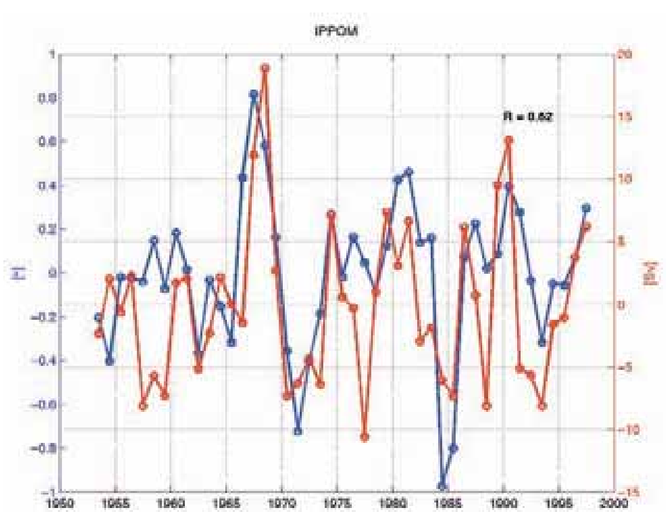


Figure 2.2. Interannual transport anomaly (red, in Sv) and bifurcation anomaly (blue, in latitude deviations) from a simulation with POM, forced by NCEP surface fluxes. Decadal variations have been removed.

Seeking the Link between Pacific Ocean and South China Sea Climate

Researcher: M. Yaremchuk

Although South China Sea climate is part of the East Asian monsoon system, evidence is mounting that the El Niño–Southern Oscillation (ENSO) in the Pacific affects the climate of this sea. IPRC researchers are searching for the means by which the atmosphere and ocean convey this signal. Here we report on the exploration of the oceanic pathway, namely, the transport of water through the Luzon Strait between Taiwan and the Philippines. This connection is well known, but effects of the transport through the Luzon Strait on South China Sea's climate have not been studied in detail.

Water that flows westward through the Luzon Strait comes mainly from a branch of the Kuroshio. Once this water has passed into the South China Sea, it joins a cyclonic circulation in the northern basin. In late fall–early winter, the Kuroshio becomes weaker in response to winter monsoon winds east of Luzon, allowing larger transport through the Luzon Strait. After entering the South China Sea, the relatively warm Kuroshio water is drawn into the cyclonic circulation in the northern part of the basin, and, according to IPRC numerical simulations, after 5–6 months arrives east of Vietnam. In this manner, stronger winter monsoon winds off the Asian Continent can increase the upper-layer heat content east of Vietnam the following May–June and affect the developing summer monsoon over the South China Sea (Yaremchuk and Qu, 2005).

To obtain more evidence for this idea, the effect of transport variations through the Luzon Strait on the surface temperature and upper-layer heat content in the region east of Vietnam was determined from observations. A long-term statistically significant positive correlation was found between December transport and subsequent June SST east of Vietnam. For experimental confirmation, a numerical simulation was conducted, in which the transport through the strait was varied with a realistic seasonal cycle. The May–June SST east of Vietnam changed in accordance with the magnitude of the inflow through the Luzon Strait 6 months earlier, confirming the statistical analysis and yielding an estimate of the Luzon Strait transport influence on the SST in the South China Sea: an increase in transport through the Luzon Strait during November–January by 1 Sverdrup is associated with a 4–6 W/m^2 increase in surface heat flux in the waters east of Vietnam the following May–June, the season of the developing summer monsoon. Because the October–January transport through the strait correlates positively with winter-monsoon wind forcing east of the Philippines, it may account for the negative correlations seen between May–June SST east of Vietnam and October–January SST east of the Philippines; the transport may also account for the negative correlation between the winds in the two regions during those two periods. This possibility is further supported by independent sets of monthly averaged anomalies of ocean surface characteristics in May–June east of Vietnam and the previous October–January east of the Philippines. Thus, the heat transported through the Luzon Strait during late fall–early winter seems, indeed, to affect the South China Sea monsoon the following summer.

In a related study, using results from the JAMSTEC model, IPRC researchers found that the Luzon transport tends to be higher during El Niño years and lower during La Niña years (Qu *et al.* 2004). Associated with variations in the Kuroshio transport east of Luzon, these year-to-year variations appear to be driven by a hysteresis of the Kuroshio (Yaremchuk and Qu 2004). The correlation between the transport and the Southern Oscillation Index (SOI) reaches 0.63. El Niño and La Niña also leave strong signatures in the upper-layer (0–400 m) heat content of the South China Sea. Given the evidence that transport through the Luzon Strait can transmit seasonal-to-interannual, large-scale ocean–atmosphere perturbations from the western Pacific to the South China Sea, IPRC scientists are now investigating in detail the manner in which this transport affects the dynamics of the climate of the South China Sea.

Tracking Deepwater Overflow from the North Pacific to the South China Sea

Research Team: T. Qu, J. Girton (University of Washington), and J. A. Whitehead (Woods Hole Oceanographic Institution)

The Luzon Strait is the only deep connection between the South China Sea (SCS) and the Pacific Ocean, with the deepest sill at about 2,400 meters in the Bashi Channel. In the deep layers of the South China Sea, water properties are relatively homogenous and appear to have the same characteristics as Pacific water at about 2,000-meter depth. This must mean that at depth, this sea is ventilated by water from the Pacific passing through Luzon Strait. Since the deep Pacific water is colder and denser, it sinks after entering the South China Sea. To compensate for this sinking motion, upwelling must occur elsewhere. The implication is that deepwater in the South China Sea is renewed more rapidly than its Pacific counterpart.

Because the South China Sea is a semi-enclosed basin below about 200 m, water entering through the Luzon Strait in the deeper layer must exit in the upper layer (less than 200 m). This produces an advective cooling equivalent to a surface heat flux of about –20 W/m^2 over the entire basin layer. Although the deepwater overflow of the Pacific water through Luzon Strait may not immediately alter the upper-layer heat content of the sea, determination of the sea's upper-layer heat content must include the lower-layer thermal conditions, particularly for determining variations over longer periods of time (Qu *et al.* 2004).

Tangdong Qu and his colleagues James Girton of the University of Washington and Jack Whitehead of the Woods Hole Oceanographic Institution recently provided a fresh look at the deepwater overflow through Luzon Strait (Qu *et al.* 2005). Their analysis of historical data reveals that below about 1,500 m, a persistent baroclinic pressure gradient drives flow from the Pacific Ocean into the South China Sea through the deep Luzon Strait (Figure 2.3). Application of hydraulic theory yields a transport estimate through the Luzon Strait of 2.5 Sverdrup. Implications of this estimate are as follows: (1) the water's residence time in the deep South China Sea is less than 30 years; (2) mean diapycnal diffusivity is greater than 10^{-3}m^2/s; and (3) the abyssal upwelling rate is greater than 3×10^{-6} m/s. These quantities are consistent with a deep-layer heat budget based on the curvature of the mean density profile and consistent with residence times based on oxygen consumption rates. Density distributions within the South China Sea basin suggest a cyclonic deep boundary current system, as might be expected for an overflow-driven abyssal circulation.

The fact that all of the inflowing waters must warm up before leaving the basin in the surface layer (less than 200 m) implies that this marginal sea contributes significantly to the water-mass transformations that drive the north-south overturning circulation in the North Pacific.

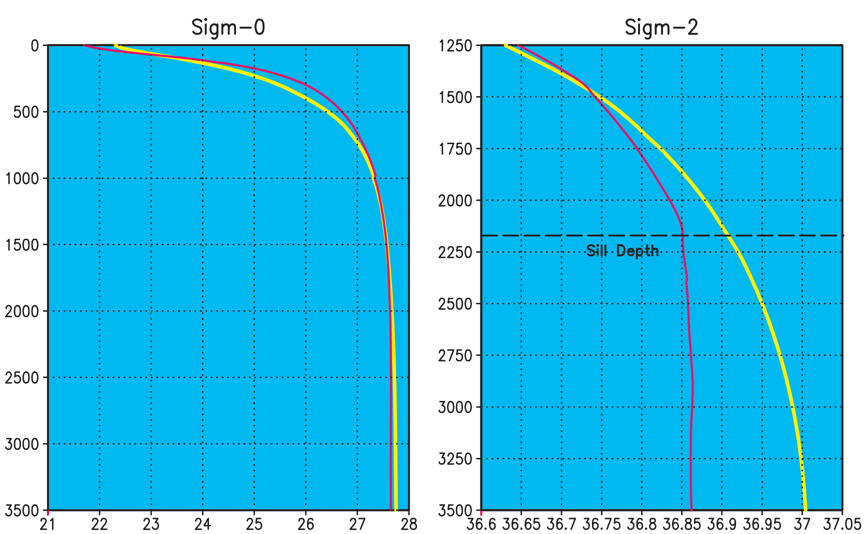


Figure 2.3. Vertical profiles of potential density averaged at (120°E–121°E, 19°N–21°N) on the South China Sea (red lines) and at (122°E–123°E, 21°N–23°N) on the Pacific (yellow lines) side of the Luzon Strait. The plot on the right shows that at 1,500 ft and below, the water is denser on the Pacific than on the South China Sea side, creating a baroclinic pressure gradient driving the flow from the Pacific into the South China Sea.

Influences on Indian Ocean Climate

The changes and variations in Indian Ocean conditions are being recognized increasingly as relevant to climate of a broader reach, as recounted in our earlier Indo-Pacific Ocean Climate section. A logical place to look for such influences is the Indonesian Throughflow, the transport from the Pacific to the Indian Ocean.

Searching for the Source of Seasonal Eddies in the Indo-Australian Basin

Researchers: Z. Yu and J. Potemra

NASA's TOPEX/Poseidon mission, followed by Jason, provides a continuous time series of highly accurate measurements of the ocean surface topography, giving a broad view to many phenomena never seen before. Analysis of TOPEX/Poseidon data at Australia's CSIRO Marine Research has shown that during the second half of the year, many more eddies form in the Indo-Australian basin, resulting in much greater intraseasonal variability than during the first half. With a period of 40–80 days, the eddies were thought to be mainly due to baroclinic instabilities.

To investigate the driving mechanisms of these eddies in greater detail, IPRC researchers obtained solutions to a $4^1/_2$-layer ocean model. Separating the effects of winds and transport variations through individual straits of the Indonesian Archipelago in their solutions, they discovered that the seasonal transport cycle through Lombok Strait (the westernmost strait) and the seasonal cycle of local winds combine to generate mixed barotropic and baroclinic instabilities during July–September. Transport variations through the other main Indonesian passages affected the location and timing of these instabilities, but to a much lesser degree. Figure 2.4 shows the resulting change in sea-level standard deviation due to changes in Indonesian Throughflow specification during July–September. The top panel is the base experiment, using the best forcing fields and parameters possible for a realistic simulation; the standard deviation resembles the TOPEX/Poseidon observations fairly well in terms of tim-

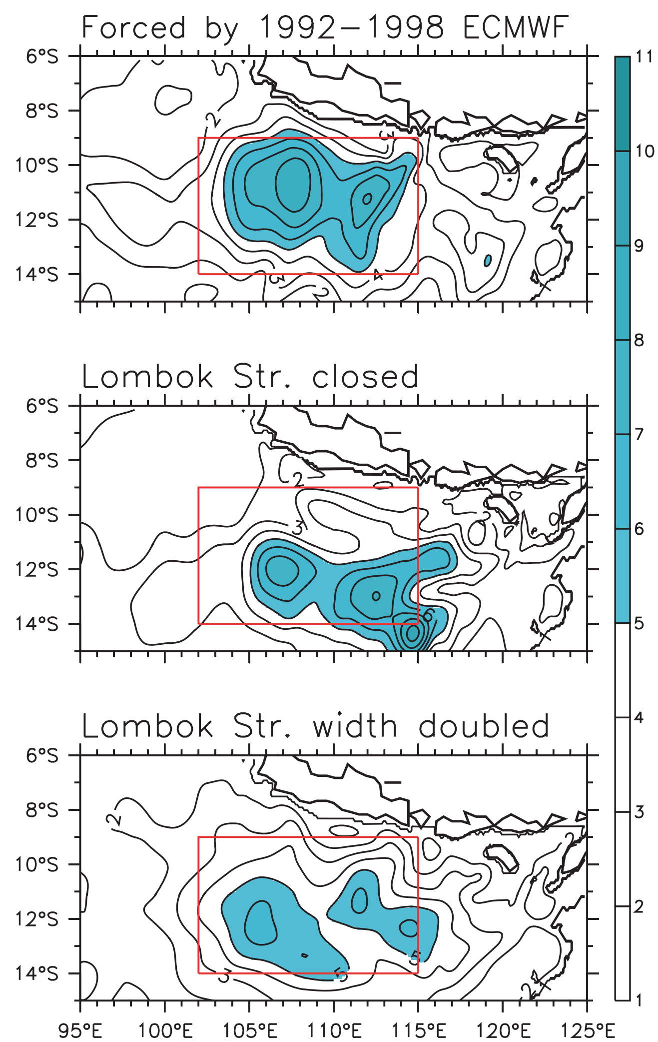


Figure 2.4. Standard deviation of sea-level anomaly during July–September with seasonal-mean removed. The shaded regions highlight standard deviations larger than ~5 cm. **Top:** forced by ECMWF monthly-mean wind climatology over the period of October 1992–December 1998 and observed monthly transports through the Lombok Strait, Ombai Strait, and Timor Passage. **Middle:** The Lombok Strait in the model is closed, and its transport is added to the Ombai Strait. **Bottom:** The Lombok Strait width in the model is doubled, and its transport remains unchanged.

ing and strength. Since the Lombok Strait is only about 35 km wide, most global ocean GCMs do not resolve it, either treating it as closed or arbitrarily widening it, depending upon model grid size. The middle panel shows the result of closing the Lombok Strait, rerouting its transport to the Ombai Strait; the bottom panel shows the result of doubling the width of Lombok Strait, its transport remaining unchanged. The outcomes of the three experiments are significantly different, highlighting the importance of that narrow strait in generating ocean-surface-topography variability, in this case, instabilities.

Sea level variability in this region, thus, is the result of variability in throughflow transport and local wind. Further investigation should focus on linking this variability to other climate phenomena, such as the Indian Ocean dipole mode.

Examining Effects of Indonesian Throughflow Transport on Indian Ocean Surface Temperatures

Researchers: J. Potemra and N. Schneider

The western equatorial Pacific Ocean supplies the eastern Indian Ocean with warmer and fresher water by way of the Indonesian Throughflow. Gradual variations over decades in this transport may therefore change the amount of warm water supplied to the Indian Ocean. Depending upon the depth of the throughflow and internal Indian Ocean dynamics, one might expect Indian Ocean temperatures to rise in response to increased transport from the western Pacific. Indian Ocean temperatures, though, also vary with changes in conditions prevailing in the Indian Ocean. IPRC researchers have therefore sought to answer whether the gradual, low-frequency changes in temperatures of the upper Indian Ocean can be traced back to changes in throughflow transport, or whether they are related to changes in atmospheric conditions over the Indian Ocean.

Most modeling studies seek to chart the effects of the Indonesian Throughflow transport on the Indian Ocean by comparing models runs, both coupled and ocean-only GCMs, with open and artificially closed throughflow passages. A closed throughflow in models, however, creates pressure gradients on either side that do not lead to a realistic absence of throughflow transport.

Therefore, the researchers chose to investigate this question using results from a 300-year-long integration of the coupled ocean–atmosphere climate model NCAR PCM, which simulates realistic climate variations throughout the 300 years. On the annual average, the throughflow from the Pacific to the Indian Ocean was found to transport 12 Sverdrup, mostly in the upper 150 m. Although seasonal variations are large, ranging from 6 Sv in January to 20 Sv in August, the interanual and decadal variations are small, in the order of 2 Sv. To assess the effects of the throughflow transport, a correlation analysis was conducted and the throughflow transport, wind stress, and wind stress curl were regressed on Indian Ocean temperatures in interannual-to-decadal timescale bands.

The interannual-to-decadal Indian Ocean temperatures were found to vary more at the thermocline level (standard deviation ranging from 0.7–0.8°C) than at the surface (standard deviation being less than 0.4°C); any correlations obtained between throughflow transport variations and Indian Ocean temperatures are most likely due to Indian Ocean wind stress, which affects both the ocean temperatures and the throughflow transport. Stronger than usual tropical Indian Ocean winds, for example, raise the thermocline in the equatorial region and subtropical Indian Ocean, lowering near-surface temperatures. Such equatorial disturbances propagate eastward toward the throughflow as equatorial and coastal Kelvin waves, affecting the transport through the throughflow.

In short, in this study, low-frequency variations in the transport of the Indonesian Throughflow had little impact on surface temperatures of the eastern Indian Ocean. The effect on thermocline temperatures was limited to the outflow region between Java and Australia, extending westward along a band between 10°S–15°S (Figure 2.5).

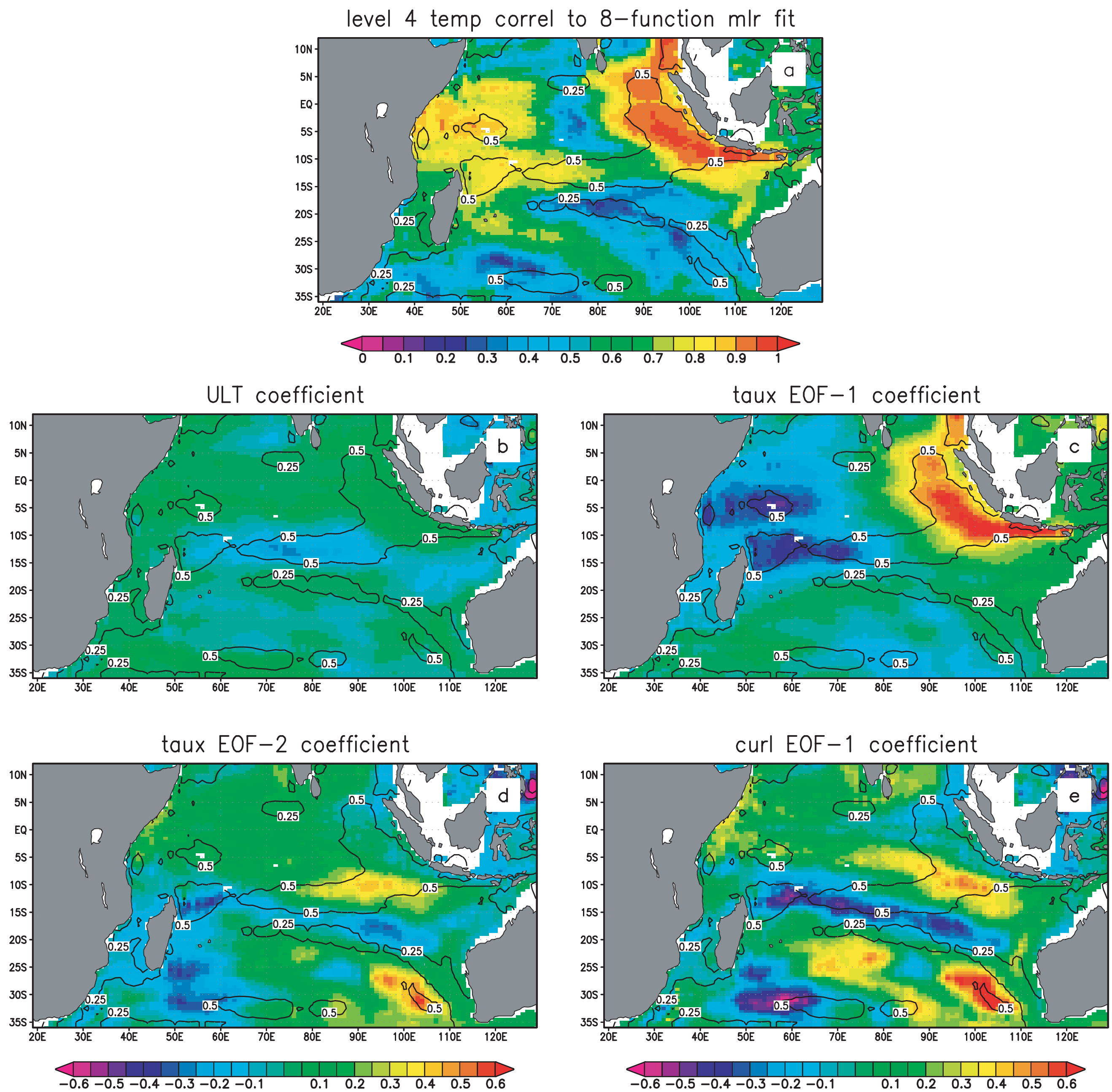


Figure 2.5. Thermocline temperatures (in units of K at a depth of 77–104 m) were reconstructed for the duration of the model integration. At every grid-point, upper-layer Indonesian Throughflow transport and indices of zonal wind stress, and wind stress curl were regressed on the temperature variations. The figure shows results based on these calculations. The contour lines in the plots represent the low-frequency standard deviation (numbers in white boxes) in temperature at this depth. In the top panel, the extent to which the fit based on these variables accounts for SST variance at the different grid points is given in color as correlation coefficients. High-variance regions around the coast of Java and Sumatra show the predictive highest skill (reddish areas). The remaining four panels show the regression patterns of the upper-layer transport, the leading EOFs 1 and 2 of the zonal wind stress and the leading EOF of the wind stress curl for temperature as a function of a standard deviation in the predictors, green indicating zero or minimal contribution to temperature variance. The panels show that most of the temperature variance at this depth is accounted for by coefficients in wind stress and wind stress curl; the throughflow has only a modest impact in its outflow region and the eastern Indian Ocean.

Exploring Upwelling off Java and Sumatra and Its Influence on Sea Surface Temperature

Researchers: T. Qu, Y. Du, and G. Meyers (CSIRO Marine Research)

The southeastern tropical Indian Ocean has been highlighted as an area of ocean–atmosphere interaction by the discovery of the Indian Ocean dipole mode. The variability of regional SST, especially in the region off Java and Sumatra, may affect both regional and global climate. A look at satellite-measured ocean surface temperature and color (Figure 2.6) raises questions about the mechanisms that produce this variability. Although ocean color indicates a distinctive upwelling season from July to September, this upwelling off Java and Sumatra lowers surface temperatures very little (less than a few tenths of a degree). This small effect contrasts with other eastern boundary upwelling regions, where upwelling lowers surface temperatures noticeably. The unusual finding has motivated IPRC researchers to study the regional heat budget of the surface layer.

Analysis of historical and Argo-float profile data showed that during the upwelling season (July–September), the prevailing southeast monsoon (Figure 2.6) shallows the mixed layer. Fresh surface water originating from monsoon rainfall occurs along the southern coast of Timor all the way to the west coast of Sumatra (Qu and Meyers 2000a and b). Because the coastal upwelling is shallow, this freshwater input has little effect on the deeper thermocline and a barrier layer forms (an intermediate layer that separates the mixed layer and the thermocline), which shields the mixed layer from exchanging water with the thermocline. This barrier layer is more than 20-m thick west of Java and Sumatra. Its thickness, however, drops to 5 m south of Java, and it is even less further to the east so that the upwelling can have a larger effect on SST in these regions.

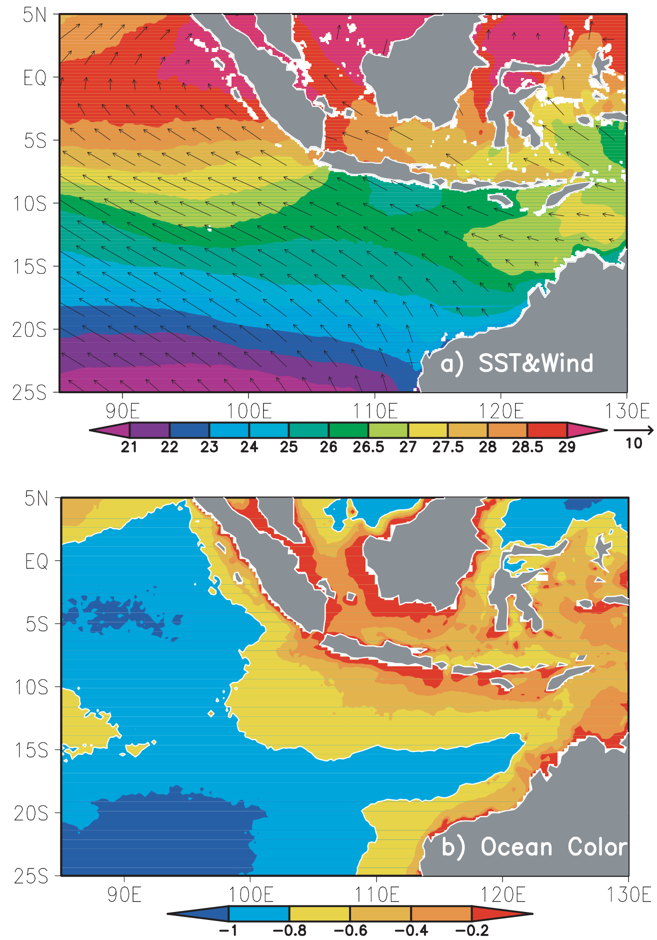


Figure 2.6. July–September a) AVHRR Oceans Pathfinder sea surface temperature (SST, in °C) and Special Sensor Microwave Imager (SSM/I) 10-m wind velocity (in m/s): AVHRR SST is averaged over 1985–1999 with 1/12° resolution; SSM/I wind is averaged over 1987–1999 with 1° resolution. b) Monthly Sea-viewing Wide Field-of-view Sensor (SeaWiFs) chlorophyll concentration averaged from 1997–2003 with 0.25° resolution (Unit: $\log_{10}^{mg/m^3}$). (Adapted from Du *et al.* 2005)

Analysis of results from OFES supports the conclusion that west of Sumatra, the thick barrier layer, indeed, damps the upwelling of cool water from the thermocline, resulting in a small vertical temperature gradient at the bottom of the mixed layer, (Du *et al.*, 2005). South of Java and farther to the east, the cold upwelled water reaches the surface, but it is warmed by water advected from the Indonesian Throughflow. The transport of the throughflow, especially the outflow from the Lombok Strait, reaches its seasonal maximum in July-September, the same time that maximum upwelling occurs.

Measuring Freshwater Flux in the Bay of Bengal

Research Team: M. Yaremchuk, Z. Yu, and J. P. McCreary

The importance of freshwater flux in tropical ocean dynamics has been shown in many recent studies. For example, the presence of a barrier layer due to vertical salinity gradients in the western Pacific and eastern Indian Ocean (as shown in the previous study) significantly changes the structure of the surface mixed layer and its heat content. The amount of freshwater flux can also affect upwelling off Java and Sumatra, and thereby may influence the development of the Indian Ocean dipole. Despite this importance, existing freshwater-flux data are still not reliable enough for driving climate models.

Nowhere in the tropics is the ocean as strongly influenced by freshwater flux as in the Bay of Bengal, where both monsoonal rain and river runoff contribute a significant amount of freshwater. Measurements of the region's precipitation and upper-ocean salinity, however, have large errors. In a newly completed study by IPRC researchers, an inverse ocean model was used to estimate the river discharge, and to evaluate precipitation products and *in situ* oceanographic salinity data.

In particular, the seasonal cycle of the river discharge into the Bay of Bengal was reconstructed using the climatological monthly mean data from the World Ocean Atlas (WOA) from NOAA and the Comprehensive ocean–atmosphere Data Set (COADS) of da Silva and his colleagues. The error range for the retrieved river transports was found to be comparable to that of estimates based on observations (Figure 2.7) and is small enough for the retrieved river discharge to be used to test the accuracy of six selected precipitation products and the WOA's upper-ocean salinity data based on *in situ* observations. These tests showed that of the six precipitation products, the Global Precipitation Climatology Project of Huffman and his colleagues and COADS are most consistent with the WOA salinity data and the Global Runoff Data Center data.

This evaluation technique, described by Yaremchuk *et al.*, is generally applicable to testing precipitation products and mixed-layer parameterization schemes in other ocean regions with a large freshwater seasonal cycle. The technique can also be used to cross-validate measurements from the satellite Aquarius to be launched in 2008 and Hydros in 2009. The former will collect sea-surface salinity, the latter river-runoff measurements.

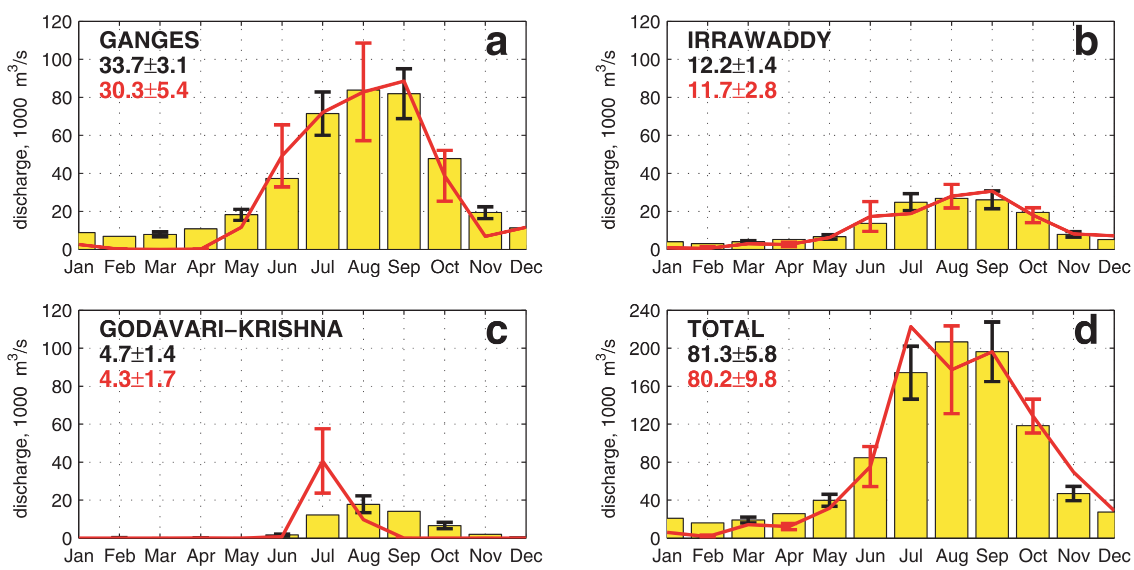


Figure 2.7. Monthly variations of ensemble-mean optimized river transports (red curves) and observations (yellow bars) for the three major river systems in the Bay of Bengal and the total discharge into the Bay. Corresponding error bars are shown in red and black, respectively. The annual-mean transports and their error variances are given in the upper-left corner of each panel, for model in red and for observations in black. (Figure adapted from Yaremchuk *et al.*, submitted)

Structure of the Global Ocean Circulation

Data from satellites and simulations from high-resolution numerical models of the ocean are changing our view of the structure of the global ocean. The following study, for example, points toward the presence of alternating zonal ocean jets in both altimetry measurements and high-resolution ocean models.

Detecting Alternating Zonal Jets in the Ocean

Research Team: N. Maximenko, K. Richards, B. Bang, H. Sasaki (JAMSTEC), and F. Brayan (NCAR)

The tendency for geophysical fluid flows on a rotating sphere to form zonally elongated structures is well known. Extensive study of such bands or jets has historically been based mostly on theoretical and numerical models of two-dimensional, or quasi-geostrophic, turbulence. These models satisfactorily simulate the structure of banded clouds in the atmospheres of Jupiter and Saturn. Such zonal structures are missing in Earth's atmosphere. They were largely unknown in the Earth's ocean until recently because *in situ* observations are so sparse. Hypotheses to account for the preferred zonal flows occasionally observed in various regional experiments include the planetary beta-effect on the inverse cascade of two-dimensional turbulent energy, the instability of meridional currents, the arrest of wind-induced Rossby modes by friction, and various effects of rough-bottom topography.

Analysis of Aviso maps of altimetric sea level anomaly undertaken by IPRC researchers and their collaborators has revealed an amazing system of time-varying geostrophic zonal currents persisting for a wide range of time scales in almost every region of the world ocean (Figure 2.8). This opens the study of a new class of motions in the ocean—motions that seem to be significant for many aspects of ocean dynamics. Are these jets a part of turbulence, are they coherent structures, or are they long-crested waves? Are they related to mesoscale eddies? Are they coherent in the vertical and how strong are they at depth?

Outputs of high-resolution global ocean models that are run on the Japanese Earth Simulator contain similar systems of zonal jets, which are remarkably coherent throughout the entire depth of the ocean (Figure 2.9). The

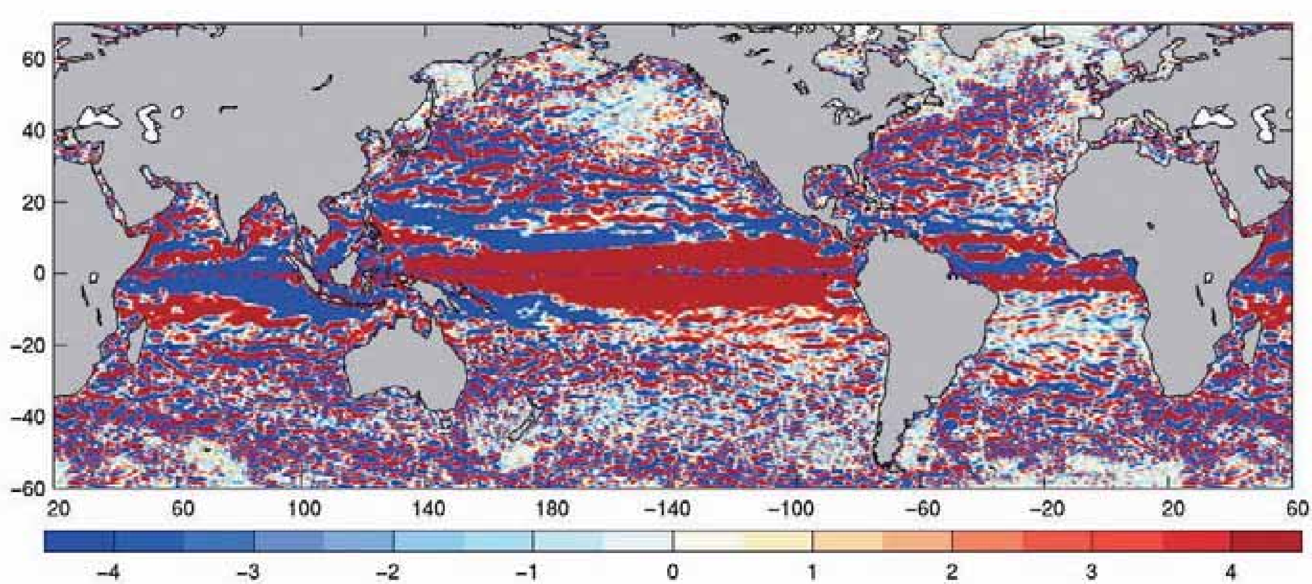


Figure 2.8. Averaged 18-week anomalies of geostrophic velocity (cm/s) derived from the Aviso altimeter dataset.

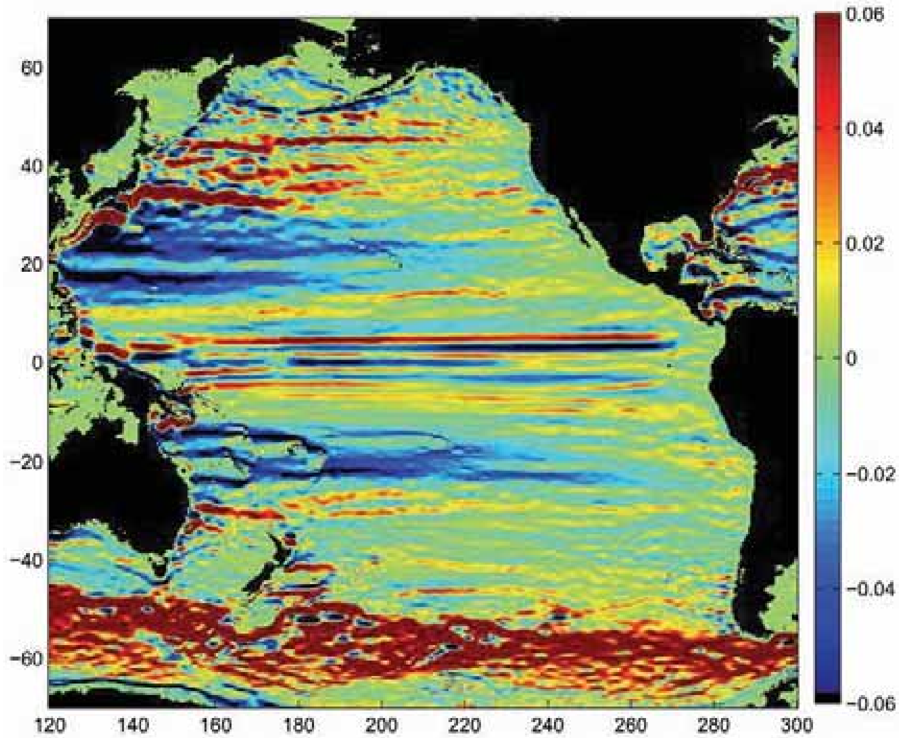


Figure 2.9. Zonal component of velocity averaged over two years at 400-m depth from a high-resolution ocean model. Flow speed is given in m/s.

jets are found to be robust: although their positions, widths, and intensity are functions of model parameters, their existence is unquestionable, once horizontal resolution is sufficiently high and dissipation is sufficiently low. Two principal aspects of these jets now need to be investigated. First, the zonal velocity of the jets varies much more in the meridional direction than the broader-scale gyre flow does. This increased shear should increase the zonal dispersion of tracers to values large enough to influence the large-scale distributions of salinity, temperature, and other properties of the deep ocean. The second aspect relates to the ultimate fate of energy in the ocean. If the eddying action in the ocean tends towards zonal jets rather than towards more isotropic chaotic flow, then the manner in which unresolved motions are parameterized in the coarser-resolution ocean models used in climate studies must be rethought.

Typhoon Matsa • NASA -Earth Observatory

ASIAN-AUSTRALIAN MONSOON SYSTEM

Climate in Asia-Pacific is defined largely by the Asian-Australian monsoon, the most energetic monsoon system on Earth. This monsoon system is driven by complex interactions among air, sea, and land processes over a vast area extending from Africa to the western Pacific and from Australia to Siberia. Work in this research theme aims to determine the physical processes responsible for the variability in this important climate system. This year, researchers examined the summer monsoon intraseasonal oscillations and studied the intraseasonal and the year-to-year variability of monsoon rainfall. Regarding tropical cyclones, they have sought to link changes in tropical cyclone tracks to global warming, located a trigger for tropical cyclones, and developed a tropical cyclone model. They have also investigated recent changes in rainfall patterns in China.

Intraseasonal Oscillations

Summer monsoon rainfall over Asia is highly variable in time and space, the largest rainfall variations occurring within a monsoon season rather than from one monsoon year to the next. Rainy spells, which may have a daily rainfall of up to 14 mm, are followed by dry spells with daily rainfall being at times less than 2 mm. These summer "active" and "break" rainfall periods are referred to as northward-propagating intraseaonal oscillations (ISOs) because they originate in the convection region of the equatorial Indian Ocean and move north to the monsoon trough. At the IPRC, the physical mechanisms that underlie the perpetuation and path of these ISOs are being studied using both high-resolution satellite products and coupled air–sea numerical models.

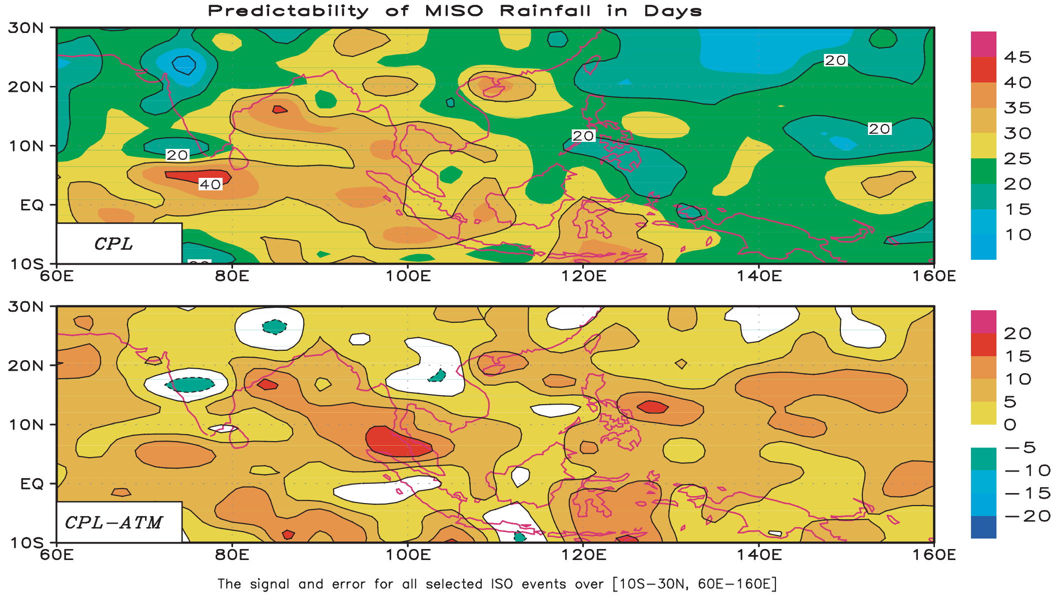
Exploring the Predictability of the Summer Monsoon Intraseasonal Oscillation

Researchers: X. Fu and B. Wang

IPRC researchers have been using atmosphere-only and hybrid coupled models to investigate the air–sea interaction in the intraseasonal oscillation and the predictability of its rainy and dry spells. A series of small-perturbation experiments with ocean–atmosphere *coupled* runs and atmosphere-*only* runs revealed two quite different solutions (Fu and Wang 2004a).

In the atmosphere-only simulation, in which sea surface temperature (SST) was only a boundary forcing for the atmosphere and the atmosphere did not feed back to ocean, the correlation between convection and underlying ocean temperature was only moderate. The closest relationship under these simulation conditions occurs when SST and precipitation are in phase with each other (that is, high SST and rainfall occur together), which is contrary to observations.

The coupled atmosphere-ocean simulation, on the other hand, not only produced a stronger oscillation than the atmosphere-only run, but also generated a realistic phase relationship between intraseasonal convection and underlying SST. In the coupled system, as in observations, temperature fluctuations are highly positively correlated with precipitation with a time lead of 10 days, suggesting that the SST affects, and is affected by, atmospheric convection. In other words, a rise in SST leads to more intense convection, but once convection is so strong that clouds form, the sea surface cools again. The general conclusion from these modeling studies is that an ocean–atmosphere



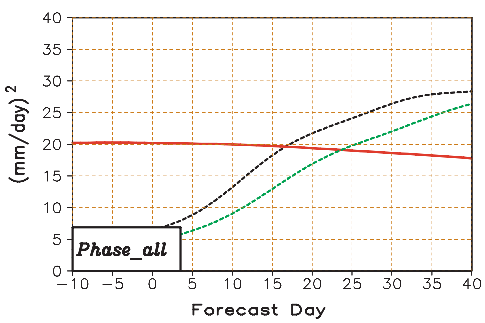


Figure 3.1. Top: The predictability, in days, of the summertime rainfall signal over the Asian-western Pacific region in the hybrid atmosphere-ocean coupled model. Middle: The impact of air–sea coupling on summertime rainfall predictability calculated from the difference in predictability using the coupled model and the atmospheric-only model. **Bottom:** The signal (in orange), defined as the variance of rainfall (in mm/day) obtained in the control run averaged within a 50-day sliding window. The forecast error, defined as the variance of the difference in days between the perturbed forecast and the control run, is shown for the atmosphere-only runs in black and the coupled model runs in green.

coupled model produces a more realistic oscillation than an atmosphere-only model.

Further comparison between the ISO simulated by the hybrid-coupled model and observations showed that the simulated oscillation closely resembles the natural disturbance over the Asian–western Pacific region in such aspects as the evolution of vertical and horizontal structure of the disturbance and the intensity.

How air–sea coupling affects the predictability of the summer intraseasonal oscillation has also been assessed with the hybrid-coupled model. Preliminary analysis indicates that predictability of the evolution of a wet–dry cycle over the Asian–western Pacific region is about 24 days in the coupled model, and only about 17 days in the atmosphere-only model (Figure 3.1). This suggests that air–sea coupling in climate models could extend the predictability of wet–dry events by about a week. Reliable forecasts with this hybrid-coupled model could quite possibly reach one month.

Searching for the Origin of the Summer Monsoon Intraseasonal Oscillation

Research Team: B. Wang, P.J. Webster (Georgia Institute of Technology), and H. Teng (University of Hawai'i)

In another approach to studying the summertime ISO, IPRC researchers in collaboration with Peter Webster at the Georgia Institute of Technology analyzed high-resolution satellite data (TRMM Microwave Imager sea surface temperature (SST), precipitation and cloud liquid water, and QuikSCAT winds), constructing an average or "composite" rainy-and-dry cycle of a summer monsoon intraseasonal oscillation (Wang, Webster, and Teng 2005). Study of the evolution of this average monsoon life cycle has yielded important information

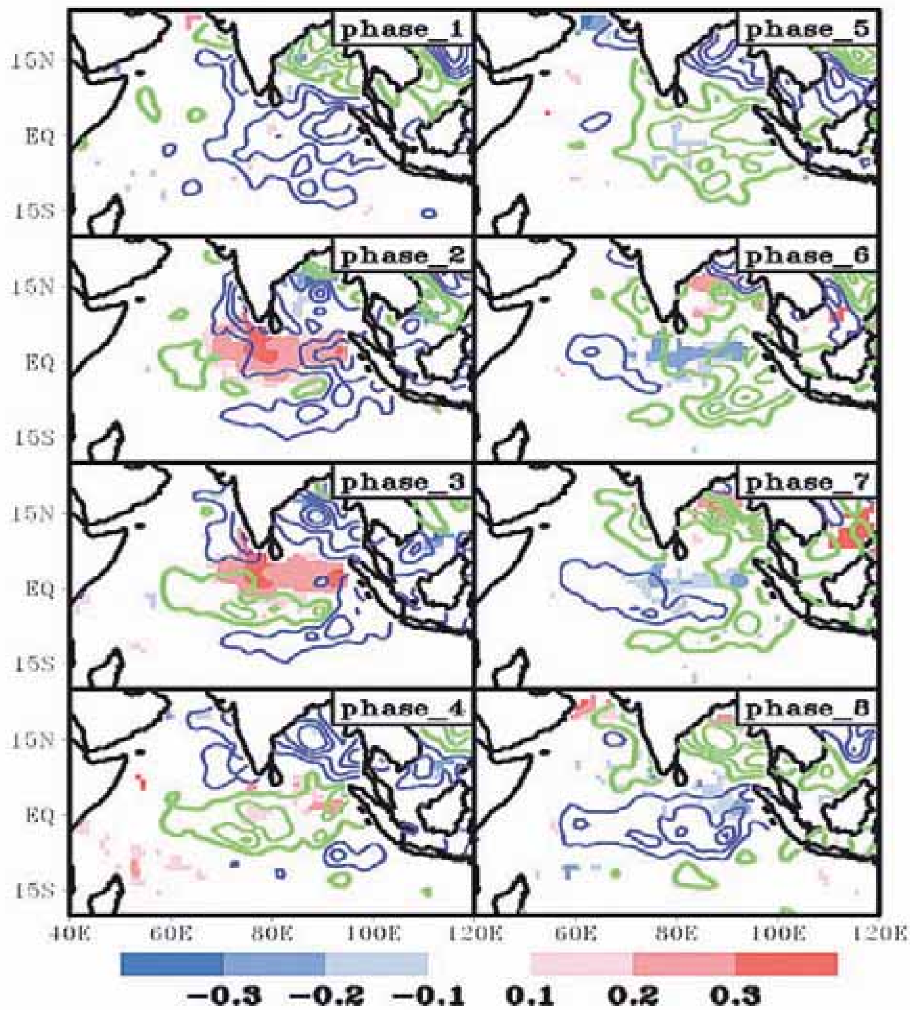


Figure 3.2. Shown here is the life cycle of the rainfall and sea surface temperature anomalies (colored patches in °C) based on a composite of 24 events that occurred during the summers 1998–2003. The mean oscillation period is 32 days so that the interval between adjacent phases is about 4 days. The green contours (lavender) are positive (negative) precipitation anomalies starting from 2 mm/day (–2 mm/day) with a contour interval of 3 mm. The thick green contour outlines the major positive precipitation anomalies. (After Wang, Webster, and Teng 2005.)

about the processes that may be responsible for the origination of this atmospheric disturbance (Figure 3.2).

Phase 1 is characterized by minimum rainfall in the eastern equatorial Indian Ocean and by maximum rainfall over the northern Bay of Bengal. Phase 2 begins about 4 days later when the dry anomalies in the west move eastward and heavy rains start in the western equatorial Indian Ocean between 60°E and 70°E. The latter is the first sign of the next spell of monsoon rain over India. In Phase 3, the rainfall region expands eastward along 5°S, the climatological equatorial convergence zone, and forms in Phase 4 a symmetrical region of heavy rain about the equator. During Phase 5, this intense convection and rainfall in the eastern equatorial Indian Ocean peaks, while the monsoon over India and over South Africa undergoes a break or dry phase. As the intense convection continues to move eastward and passes over Sumatra, it weakens considerably. The wet region then branches poleward, becoming a V-shaped rain band in Phase 6, trailing the main center of the equatorial convection. The V-shaped rain band during this phase is highly asymmetric about the equator. Concurrent with the poleward bifurcation of this rainband, suppressed convection begins again in the west (60°E–70°E). The life cycle continues with the northward and eastward propagation of the enhanced rain band, causing an active period in the Indian monsoon during Phases 7–8.

Because a new rainy phase in the western equatorial Indian Ocean is preceded by surface wind convergence in that region and by a rise in SST in the central equatorial Indian Ocean, and because both of these events are induced by the conditions set up over the eastern equatorial Indian Ocean during the previous cycle, a self-induction mechanism appears to be operating in the monsoon intraseasonal oscillation. The finding suggests that the active and break cycles of the Indian monsoon may be predictable up to four weeks in advance.

Interannual and Decadal Variability

The tendency of the South Asian monsoon to be wetter one year and drier the next has been called *tropospheric biennial oscillation* by Gerald Meehl of the National Center for Atmospheric Research (NCAR). Observational studies show that this two-year cycle occurs over various monsoon regions such as India, Indonesia and northern Australia, East Asia, and the western North Pacific. The physical mechanisms that give rise to this flip-flop in rainfall, however, are unclear and a focus of IPRC research. Moreover, the monsoon system undergoes interdecadal changes, including the monsoon-ENSO relationship, which has changed significantly since the late 1970s. Is this change linked to the North Pacific decadal regime shift? Our research is seeking for answers.

Proposing a New Mechanism for the Tropospheric Biennial Oscillation

Research Team: T. Li, P. Liu, X. Fu, B. Wang, and G. A. Meehl (NCAR)

A team of researchers at the IPRC and NCAR used a season-sequence empirical-orthogonal-function analysis to investigate the observed structure and seasonal evolution of the tropospheric biennial oscillation (Li *et al.* submitted to *J. Climate*). They noted that the major convective centers associated with the oscillation appear in the southeast Indian Ocean and western North Pacific, accompanied by anticyclonic or cyclonic (depending upon whether it is a dry or wet monsoon) circulation patterns with a first-baroclinic-mode structure (Wang *et al.* 2003). The convection and circulation anomalies have distinctive life cycles over those two oceanic regions—the convective anomalies peak during northern fall over the Indian Ocean and the circulation anomalies persist from northern winter into the following summer over the western Pacific.

Hypothesizing that air–sea interaction in the Indo-Pacific warm pool region is at the root of the tropospheric biennial oscillation, the team conducted idealized experiments using a hybrid coupled GCM in which the ocean and atmosphere were fully coupled only in the tropical Indian Ocean and western North Pacific. Results show that air–sea interaction over the warm ocean can alone support a biennial oscillation that has many of the observed characteristics of the oscillation. Based on the diagnosis of the model output and budget analyses, the scientists therefore proposed a mechanism in which the interaction between the monsoon and the warm ocean sustains the tropospheric biennial oscillation. Key processes that contribute to the oscillation are variabilities in the western North Pacific monsoon and cross-equatorial flows, convective activity over Southeast Asia and the maritime continent and associated anomalous Walker circulation, and ocean dynamic responses to anomalous wind stress curl in the western North Pacific.

To explore the existence of a connection between the tropospheric biennial oscillation and the El Niño–Southern Oscillation (ENSO), the team conducted coupled model simulations in which delayed oscillator dynamics were excluded. They found that SSTs in the eastern equatorial Pacific varied on a biennial time scale as a result of three atmospheric teleconnections between the tropical Pacific and Indian oceans: 1) a north–south teleconnection between the western North Pacific monsoon and southeast Indian Ocean, 2) an east–west teleconnection between the Indian Ocean and eastern Pacific, and 3) a teleconnection between eastern Pacific SST and the western North Pacific monsoon. The numerical experiment suggests that the biennial component of ENSO results from an interaction between the eastern Pacific cold tongue and the Indo-Pacific warm ocean.

Investigating Indian Ocean Influence on Local and Distant Climate

Research Team: H. Annamalai, P. Liu, and S.P. Xie (Study 1); Annamalai, H., H. Okajima and M. Watanabe (Study 2)

Until a decade ago, the Indian Ocean was thought to have little influence on climate. This view, however, has been changing. First, there is the growing evidence of Indian Ocean variability, such as the Indian Ocean dipole/zonal mode that describes the variance in the east-west SST gradient across the basin. Moreover, the average SST of the Indian Ocean rose about 0.25 °C from 1992 to 2000. This is the largest warming of any of the world oceans. As a part of Asia's powerful monsoon system and close to Earth's major atmospheric convection center and warmest ocean pool, Indian Ocean variability can be expected to have far-reaching influences. The studies below explore these influences.

During El Niño years, the SST over a large area of the southwest Indian Ocean (15°S–0, 40°E–80°E) is significantly higher than usual, the thermocline being deeper. This condition persists from January through May of the year following the mature phase of El Niño. IPRC researchers have been studying the climatic effects of this anomalous SST signal in a series of modeling experiments. To investigate the local and remote influences on the Asian monsoon, they conducted a suite of experiments with the ECHAM5 atmospheric GCM and demonstrated that during El Niño years, the Walker circulation shifts westward in the Indian Ocean, with anomalous ascending atmospheric motion over the Indian Ocean and anomalous descending motion over the Maritime Continent. This shift suppresses precipitation over the tropical west Pacific and Maritime Continent and contributes to the development of the low-level anticyclone over the Philippine and South China seas. Model results indicate that more than 50% of the decrease in normal rainfall over the tropical western Pacific–Maritime Continent comes from circulation anomalies that can be traced to the unusually high Indian Ocean SST. These anomalies create favorable conditions for the formation of the Philippine Sea anticyclone and provide a mechanism for its generation in addition to the anomalous conditions in the Pacific.

The Philippine Sea anticyclone increases precipitation along the East Asian winter monsoon front from December to May. The anomalous subsidence over the Maritime Continent, together with persisting high SST and rainfall over the Indian Ocean in the following spring, prevents the usual northwestward migration of the intertropical convergence zone and its associated deep moist layer, and delays the onset of the Indian summer monsoon in June by 6–7 days. The modeling study thus suggests that continued monitoring of temperatures in the southwest Indian Ocean will yield important information for predicting the onset of the Indian summer monsoon, where only a few days can be significant for agriculture and the economy (H. Annamalai, P. Liu, and S.P. Xie, in press).

The second study (Figure 3.3) examined possible effects of El Niño-induced high SST anomalies in the

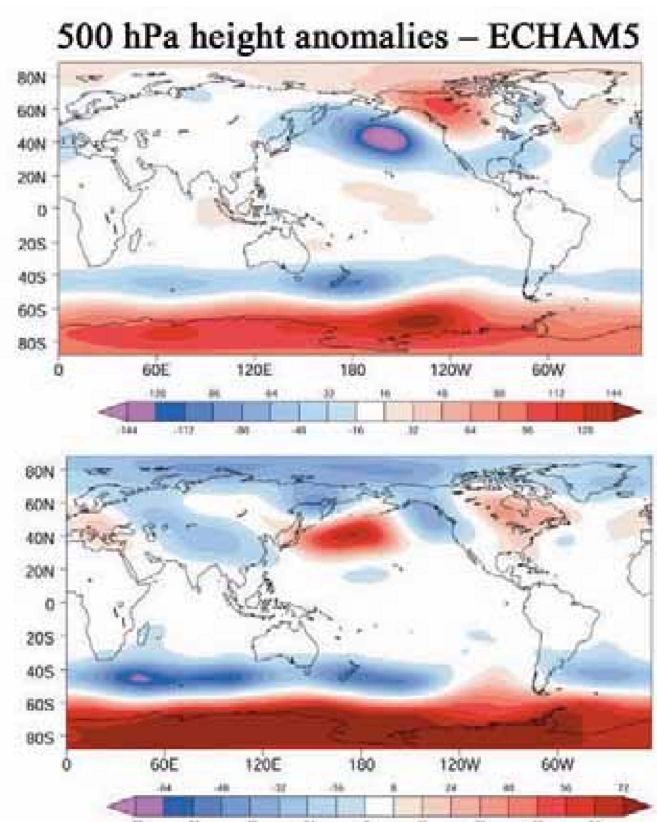


Figure 3.3. **Seasonal average (January–March) 500 hPa geopotential height anomalies from ECHAM5 solutions for SST anomalies imposed over the tropical Pacific (top panel) and over the tropical Indian Ocean (bottom panel).**

Indian Ocean on climate globally. Simulations with two atmospheric GCMs using different climate physics, ECHAM5 and CCSR-University of Tokyo, indicate that the observed increased rainfall over the southwest Indian Ocean results from unusually high local SST. Analyses of the solutions revealed that this anomalous rainfall sets an atmospheric wave train in motion that arches northeastwards into and through the middle latitudes, with the largest amplitude of the disturbance over the northeastern Pacific. The 500-hPa-height anomalies show that over the Pacific–North America region, the circulation effects due to the high Indian Ocean surface temperature "oppose" those due to high SST in the Pacific NINO-3 region. The results imply that for a realistic simulation and prediction of circulation anomalies in the Pacific–North America region, effects of Indian Ocean SST should be considered (Annamalai, H., H. Okajima and M. Watanabe 2005, submitted to *J. Climate*).

Probing Causes of Decadal Variability in North Pacific Climate

Research Team: S.-I. An, J.-S. Kug (Seoul National University), A. Timmermann, I.-S. Kang (Seoul National University), O. Timm

The leading mode of sea surface temperature (SST) variability in the North Pacific changes prominently at time scales longer than the El Niño–Southern Oscillation (about 5 years) and has been called the Pacific Decadal Oscillation (PDO). Its warm phase is characterized by higher than normal SST in the eastern equatorial Pacific and lower than normal SST in a horseshoe-shaped band connecting the North, West, and South Pacific. The processes underlying the temporal and spatial characteristics of the PDO, however, have not been clarified. Proposed explanations include forcing from the tropics, intrinsic variability of the extra-tropical atmosphere, and coupled interactions between the Pacific atmosphere and ocean. Niklas Schneider at the IPRC explored these possibilities and found that the PDO can be reconstructed from three primary factors: forcing by El Niño, intrinsic variability in the Aleutian Low, and ocean-gyre anomalies in the Kuroshio Extension (N. Schneider and B. Cornuelle, submitted to *J. Climate*).

The present study investigates the hypothesis that the PDO is due to El Niño–La Niña asymmetry and nonlinearity in the atmospheric tropical–extratropical teleconnection. For example, Figure 3.4 presents results from a nonlinear regression analysis of North Pacific SST and atmospheric fields on the NINO-3 index, showing that the main teleconnection centers are different during El Niño and La Niña years.

Moreover, El Niño and La Niña responses differ increasingly from each other as the NINO-3 anomaly intensifies. During weak El Niño and La Niña events (±1° C of NINO-3 SST), the geopotential height and SST responses are mirror images of each other. As SST forcing grows (for example, ±2°C of NINO-3 SST), however, these responses become more asymmetric. During a strong La Niña, SST changes by as much as ±2°C in the eastern Pacific depending upon the region, and evolves into a strong temperature dipole. Associated with these anomalies are large geopotential height differences along 40°N, with a high-pressure area east of the dateline and a low-pressure area over the West Coast of North America. In contrast, during a strong El Niño year, SST changes by about ± 0.4°C, and the increasing atmospheric low pressure around 150°W and 40°N has no parallel high-pressure center forming over the West Coast. This asymmetric response, together with the skewed probabilistic distribution of ENSO itself, may generate the decadal variability seen in the PDO. This hypothesis is partly supported by present-day NCEP/NCAR reanalysis data and may explain the large decadal variability in Pacific extratropical SST.

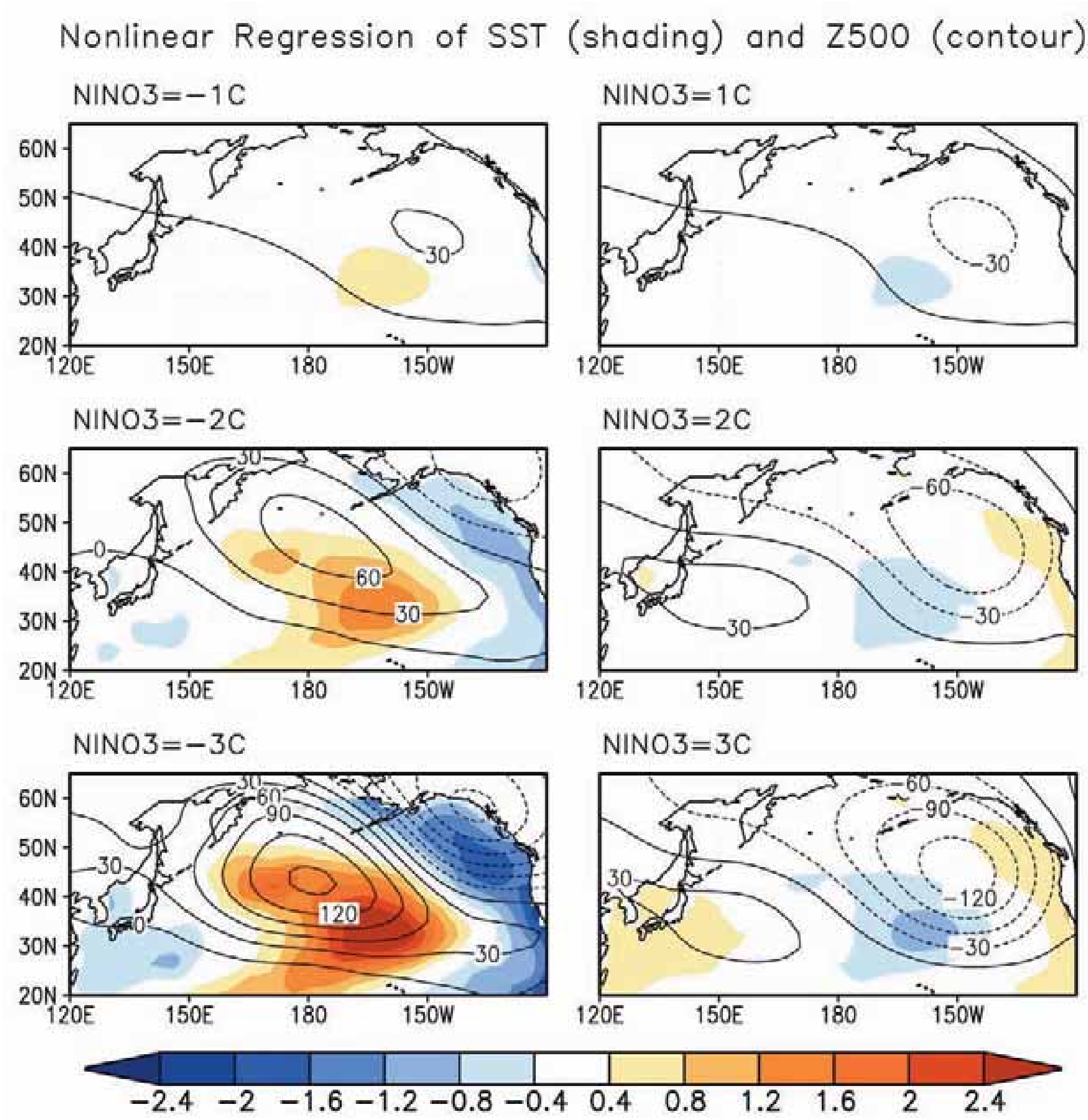


Figure 3.4. Nonlinear regression pattern of SST (color) and 500 hPa geopotential height (contour) anomalies in the North Pacific on the NINO-3 SST anomaly. The nonlinear regression is based on the neural network technique.

Tropical Cyclones and Changing Weather Patterns

Tropical cyclones are an important part of tropical climate, with grave impacts on coastal and maritime regions. Ability to predict their tracks and their power accurately is a worthwhile goal, as is the determination of how these severe atmospheric disturbances will change with a warming planet. At the IPRC, research is being conducted on a number of these issues, and some of these studies are featured below.

Gauging the Effects of Global Warming on Tropical Cyclone Tracks

Researchers: B. Wang in collaboration with L. Wu (NASA Goddard Space Flight Center)

IPRC researchers have participated in work conducted at the NASA Goddard Space Flight Center on how tropical cyclone tracks may change with projected increases in global warming. Using satellite-supported, best-track data from 1965 to 2003, Wu and Wang (2005) showed that the prevailing typhoon tracks over the western North Pacific have significantly changed during the past four decades. The number of tropical cyclones that take a straight westward track has decreased sharply, whereas the two prevailing recurving tracks over the western North Pacific have shifted westward (Figure 3.5). As a result, East Asia has experienced an increasing number of typhoons. These shifts in the typhoon tracks are linked to the westward expansion and strengthening of the western North Pacific subtropical high, which lead to changes in the large-scale steering flow and thereby in the mean translation velocity of typhoons.

In order to assess the possible impacts of future global climate change on the topical cyclone tracks in the western North Pacific, Wu and Wang (2004) designed a trajectory cyclone model that uses outputs from global atmospheric models. Although these climate models cannot yet predict tropical cyclones realistically, they do provide information about changes occurring in the large-scale atmospheric circulation. Changes, therefore, in the large-scale steering flow in two Geophysical Fluid Dynamics Laboratory (GFDL) global warming experiments (A2 and B2) were applied to the tropical trajectory model. The results suggest that by 2030–2059 more tropical cyclones will take a recurving track and move northeastward. The El Niño-like climate change predicted in many climate models may also shift the current tropical cyclone formation locations in the western North Pacific eastward.

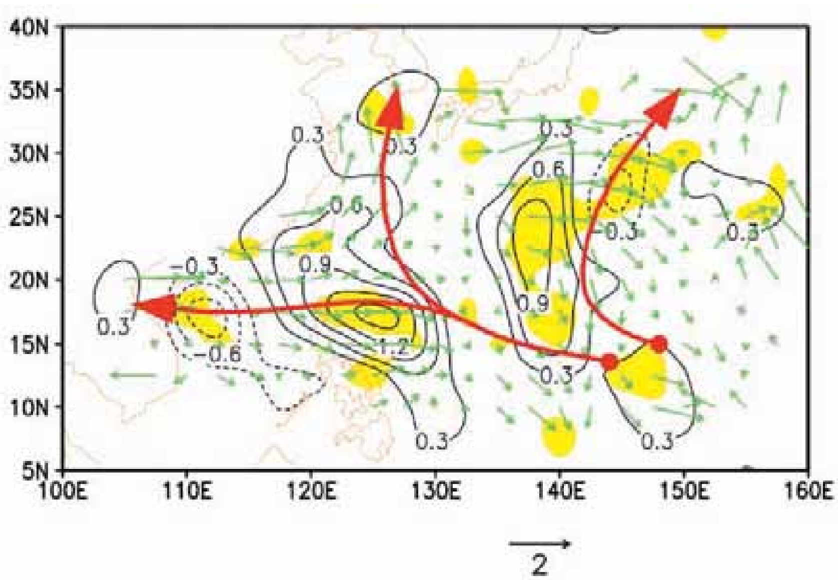


Figure 3.5. Difference in the mean frequency of tropical cyclones and in the associated motion vectors for June–October between the periods 1965–1983 and 1984–2003. The contour interval is 0.3 cyclones/year, with solid lines denoting an increase, and dotted lines a decrease over the period measured; the vector unit is m/s. The areas with confidence level exceeding 95% for the identified changes are shaded. The thick red lines denote the prevailing typhoon tracks for the whole period. (Adopted from Wu, Wang, and Geng, submitted to *Geophys. Res. Lett.*)

Searching for Triggers of Tropical Cyclones

Researchers: Chi-yung Tam and Tim Li

Summertime synoptic-scale waves often provide the initial atmospheric perturbation necessary for the formation of tropical cyclones. A better understanding of the characteristics of these waves may shed light on the formation of tropical cyclones and variability in their frequency of occurrence. Using reanalysis products and QuickSCAT winds, IPRC researchers (Tam and Li 2005) studied the origin of such waves and their three-dimensional energy dispersion over the off-equatorial western-Pacific region. The analyses showed that disturbances are best characterized as synoptic-scale wave packets with westward zonal group velocity. The main reason for the westward propagation is that the wave packets are advected by the mean easterlies. Regions where the wave-activity flux converges have the largest perturbation growth rates. Convection is also associated more with the low-level circulation toward the west than the east, presumably because moisture is transported from the planetary boundary due to Ekman pumping. Both the accumulation of wave activity and the association between convection and circulation are conducive to the growth of synoptic-scale waves as they propagate westward.

These low-level disturbances begin to form near the dateline. Here, downward-directed wave activity from the upper troposphere is found. Figure 3.6 shows the cross-sections of the synoptic-scale wavetrain and its associated wave activity. The negative vertical component of the wave activity (blue shading in figure) indicates downward energy dispersion that reaches the mid- to lower-troposphere. Since the vertical wave activity is proportional to merid-

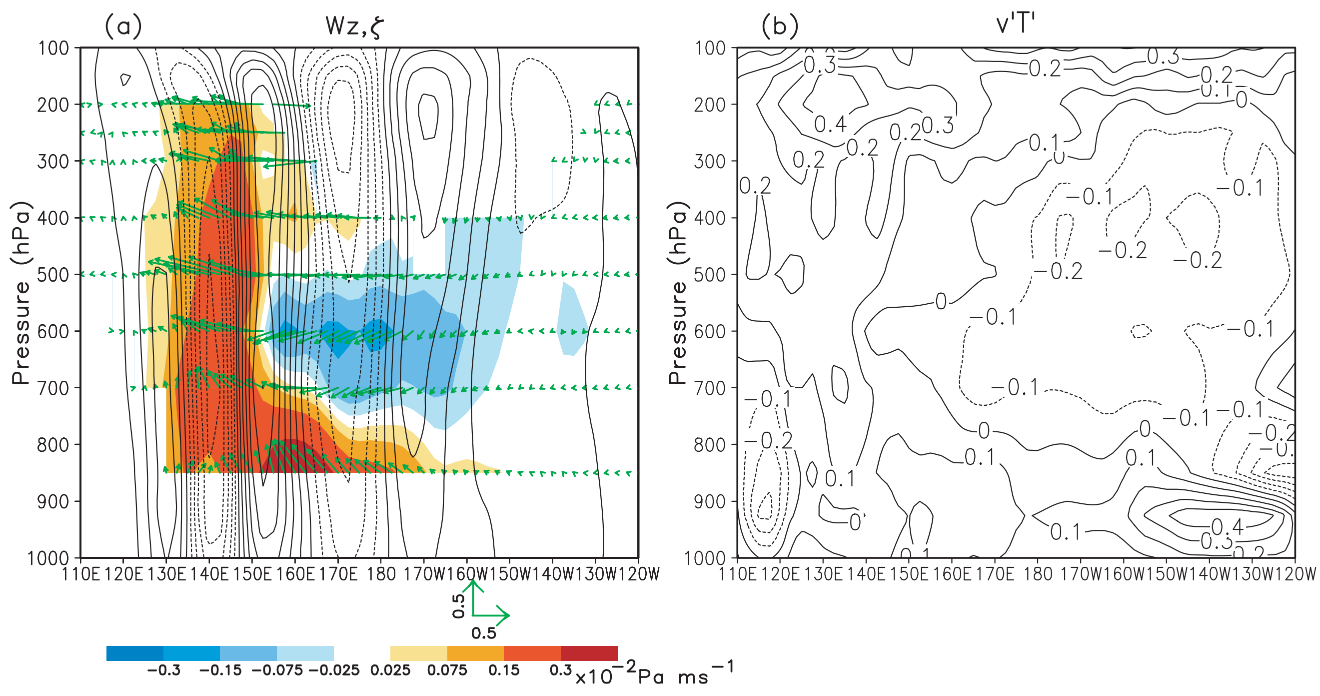


Figure 3.6. Left: Vertical cross-sections of the wave-activity vector (arrows; see lower right of left panel, with horizontal scale of 0.5 m^2/s^2 and vertical scale of 0.5x10^{-2}Pa m/s) and its vertical component (shading; see scale at bottom; blue denotes downward energy dispersion, red upward motion), related to the synoptic-scale wavetrain over the western Pacific. Wave activity is computed based on the circulation associated with the wavetrain averaged over 15°N–25°N. Also shown is the anomalous vorticity (contours with dotted lines denoting negative values; intervals: 0.5x10^{-6}/s). **Right:** Values of the covariance between the 2–8 day bandpass filtered v-wind and temperature averaged over 15°N–25°N for June–September. Computation is based on all bandpass filtered eddies. Units: m/s and K. (After Tam and Li, submitted to *Mon. Wea. Rev.*)

ional eddy heat flux, a comparison with transient-motion heat-flux statistics is instructive. Figure 3.6b plots the covariance between the meridional wind and temperature for the northern summer over a cross-section of the wave-train. The region of negative covariance is also the region where downward dispersion signals are found. Further analysis revealed in the upper troposphere a pattern of southward-directed wave activity that can reach tropical latitudes near the dateline.

Overall, these findings suggest that wave activity that has its source in the extratropics initiates summertime synoptic-scale disturbances in the tropics. Case studies of the development of individual synoptic-scale wavetrains in the western Pacific support this hypothesis. One implication of such a trigger mechanism is that synoptic-scale wave activity and tropical cyclones over the western Pacific are sensitive to elements of the extratropical circulation. The researchers are, therefore, now studying the effects of extratropical forcing on the interannual variability of synoptic-scale disturbances.

Linking Changes in Rainfall and Atmospheric Circulation

Researchers: Y. Wang and L. Zhou

Rainfall patterns in China have changed over recent decades, with the highly populated region of northern China becoming dryer and the Yangtze River delta experiencing more floods. Researchers at the IPRC have quantified these changes and studied their cause. Data collected during 1961–2001 from over 500 rain-gauge stations in China showed that in central and northern China, precipitation decreased by about 10%, whereas in the mid-to-lower reaches of the Yangtze River, it increased by 10% during each 10-year period of the 40 years analyzed. In other words, the rainfall amount changed over 40% in each of these regions over the 40 years of the study (Wang and Zhou, in press).

Data on the heaviest 2.5% precipitation days over the 40 years parallel the overall trends: the number of extreme rainy days in the lower Yangtze River region and in South and northwestern China have increased, while in central and northern China, they have decreased. The rise in very heavy rainfall days in the Yangtze delta during summer is of particular concern as this can result in disastrous floods in this heavily populated region. For the 40-year period studied, extreme summer rainfall events (the top 5% seasonal precipitation events) in this region increased by 0.5–1.0 events every 10 years. Moreover, the top 5% produced 40–50% of the total summer rainfall in eastern China. This finding points to more frequent serious floods for the region in the future—if the trend continues.

The increase in rainfall in the mid- to lower-reaches of the Yangtze River occurred mainly during the summer, while the decrease in rainfall in central northern China occurred mainly in spring and fall. These opposing trends in the two regions paint a coherent picture. During these seasons, the main precipitation belt now stays for a longer time in the lower Yangtze River basin and for a shorter time in northern China than during the 1960s.

IPRC researchers investigated whether these trends in summer rainfall are attributable to changes in the large-scale atmospheric circulation. Using summer monthly mean geopotential height and horizontal wind fields from NCEP reanalyses data, they conducted a linear trend analysis for the 40-year period, noting a weakening of both the Eurasian continental low and the western Pacific subtropical high. From central China to the Pacific in a band around 40° latitude, these two changes in the circulation give rise to a northeasterly wind trend in the lower troposphere, which weakens the southwesterly monsoon and limits the summer monsoon flow into northern China. As a result, the Maiyu fronts, with their heavy rainfall are now staying longer in the Yangtze River basin and shorter in northern China (Figure 3.7).

The circulation trends also explain a change that the researchers discovered in the seasonal precipitation cycle over central and eastern China. During the first two decades of the study, there was a peak in rainfall in May and another one in June; during the last two decades the peaks occurred in June and July. This shift also points to a weaker and later East Asian summer monsoon (Figure 3.8).

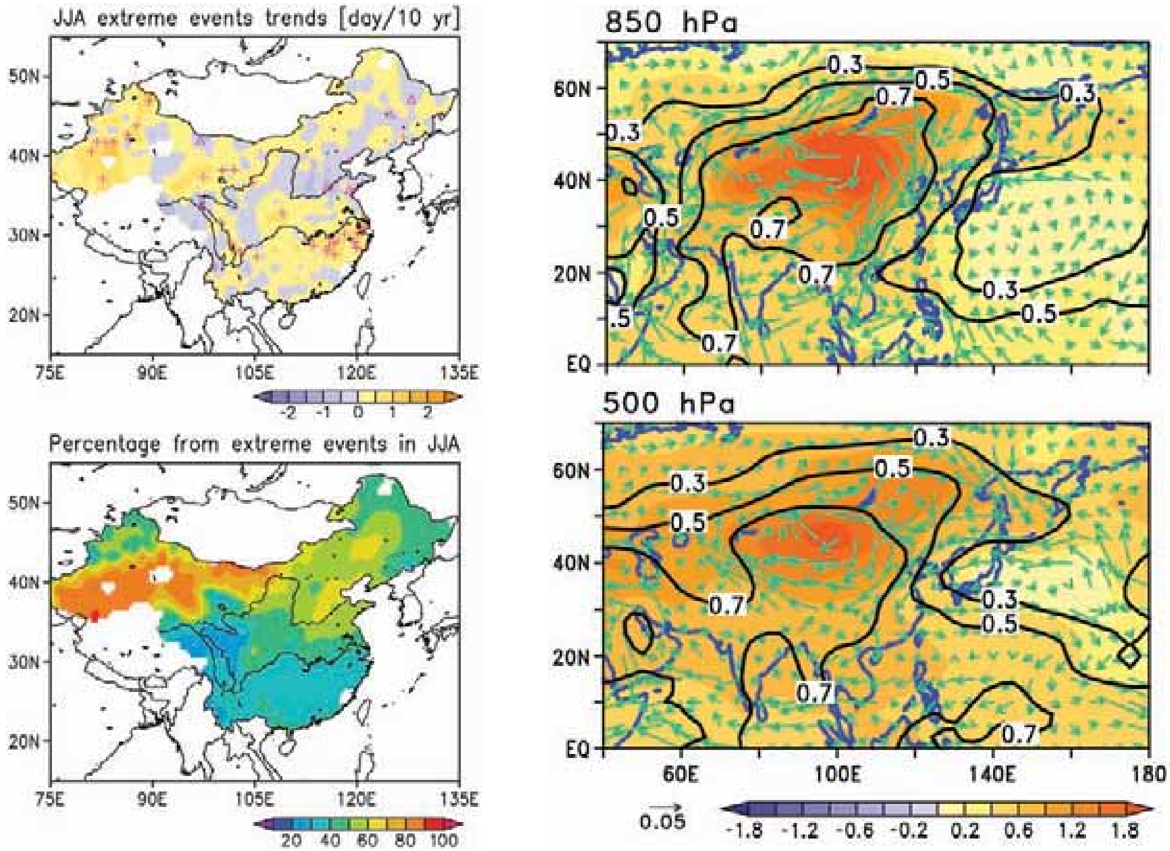


Figure 3.7. Top left: 1961–2001 summer trends (increase in number of days every 10 years) in extreme precipitation events defined as the top 5 percent in precipitation days. **Bottom left:** Percentage of total summer rainfall from extreme events. **Right:** 1961–2001 summer trends in geopotential height (color: change in geopotential height in m every 10 years) and corresponding horizontal winds at 850 hPa and 500 hPa (vector unit: 0.5 m/s per 10 years). The contours represent correlation coefficients between time and the geopotential height; values larger (smaller) than 0.3 (–0.3) are statistically significant at the 95% confidence level. (Figure is adapted from Wang, and Zhou, in press.)

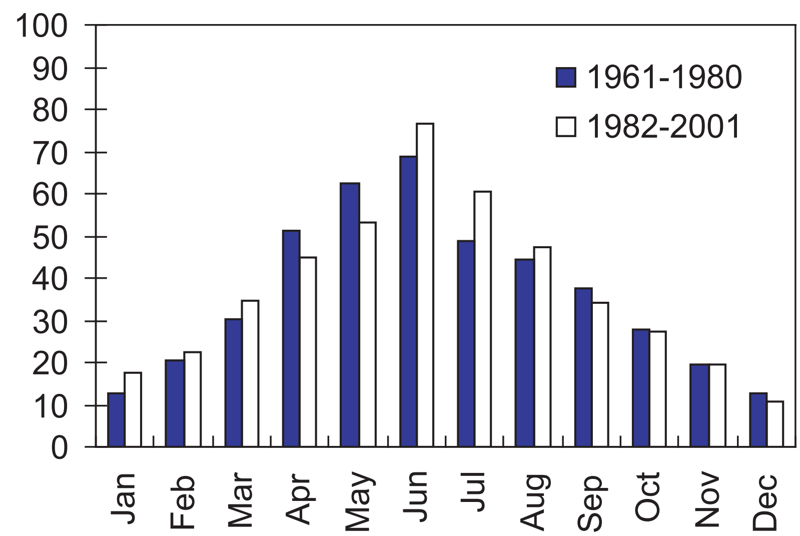


Figure 3.8. Seasonal cycles of monthly mean daily precipitation (mm) over the Yangtze River basin (26–32°N, 105–122°E) during 1961–1980 and 1982–2001. (Figure is adapted from Wang, and Zhou, in press.)

Constructing a Hurricane Model

Researcher: Yuqing Wang

How will global warming affect tropical cyclones? Will they become more frequent, more powerful? Will their tracks change? Can we predict more accurately whether a developing hurricane will intensify or dissipate? IPRC research is laying the groundwork for finding answers to questions such as these by constructing and using a nonhydrostatic hurricane model called TCM4.

The model is an extension of the previously developed hydrostatic model TCM3, in which the hydrostatic dynamical core has been replaced by a fully compressible, nonhydrostatic dynamical core. TCM4 shares with its hydrostatic predecessor TCM3 state-of-the-art model physics, two-way interactive multiple nesting, and automatic mesh movement. An efficient forward-in-time, explicit splitting scheme has been developed for model integration. This scheme is a combination of a forward-backward scheme for integration of acoustic and gravity modes and a third-order up-wind scheme for the three-dimensional advection terms. Because of its nonhydrostatic dynamical core, TCM4 can be run at cloud-resolving resolution (1–2 km horizontal grid), allowing the simulation of a more realistic inner core and intensity of a tropical cyclone than the earlier hydrostatic version. This model is therefore a valuable tool for determining those physical processes that produce rapid intensity changes in tropical cyclones. Because the model resolves clouds, it will also be useful for investigating cloud processes and for parameterizing clouds in large-scale weather and climate models.

The new model has shown its ability to simulate realistically concentric and double eyewall structures (Figure 3.9). The occurrence of concentric eyewalls is a primary mechanism that can cause rapid intensity changes in tropical cyclones. Although this phenomenon has been well documented in observations for more than two decades, no theory yet adequately explains why concentric eyewalls occur in some tropical cyclones but not in others. Both numerical weather prediction models and high-resolution research models still have difficulty simulating the double eyewall. This limitation may be a reason why numerical weather prediction models do so poorly in predicting changes in tropical cyclone intensity.

Given the simulation of the concentric eyewall structure and accompanying intensity changes with the TCM4, the mechanisms responsible for the development of concentric eyewalls are now being investigated. From an initial vortex, symmetrical about its axis and embedded in a quiescent environment on a beta-plane, the model first develops a concentric eyewall and then a double eyewall (see Figure 3.9), with the associated rapid intensity changes. Advection of planetary vorticity (beta-effect) has been found to be the primary driving force for the development of the concentric eyewall; it modifies the radial potential vorticity structure of the cyclone, producing a constant asymmetric forcing that generates the convective spiral rainbands. These may become symmetric about the axis through the so-called axisymmetrization process to form a nearly ring-shaped rainband—the second eyewall.

Key to the formation of the second eyewall ring is the generation of anomalous potential vorticity near freezing temperatures associated with stratiform precipitation outside the eyewall. In the stratiform clouds, condensational heating above freezing temperatures and cooling below due to melting of snow and graupel generate anomalous cyclonic potential vorticity, which is transported downward into the inflow boundary layer by downdrafts and weak descending motions. This anomalous cyclonic potential vorticity produces locally strong surface tangential winds outside the eyewall. These strong winds increase the surface heat and moisture fluxes, supporting strong deep convection that then forms the second eyewall.

The timing of the second eyewall formation is stochastic and sensitive to many aspects of the model parameters. As in real hurricanes, once the second eyewall forms in the model, convection in the inner core starts to weaken and is accompanied by a drop in the strong surface winds and rise in central surface pressure. When the inner eyewall weakens and is replaced by the second eyewall, the second larger eyewall may remain large for a long time, exhibiting a ring-shaped structure. These findings are consistent with the typical concentric eyewalls observed in many real tropical cyclones, including the Atlantic hurricanes during Summer 2004.

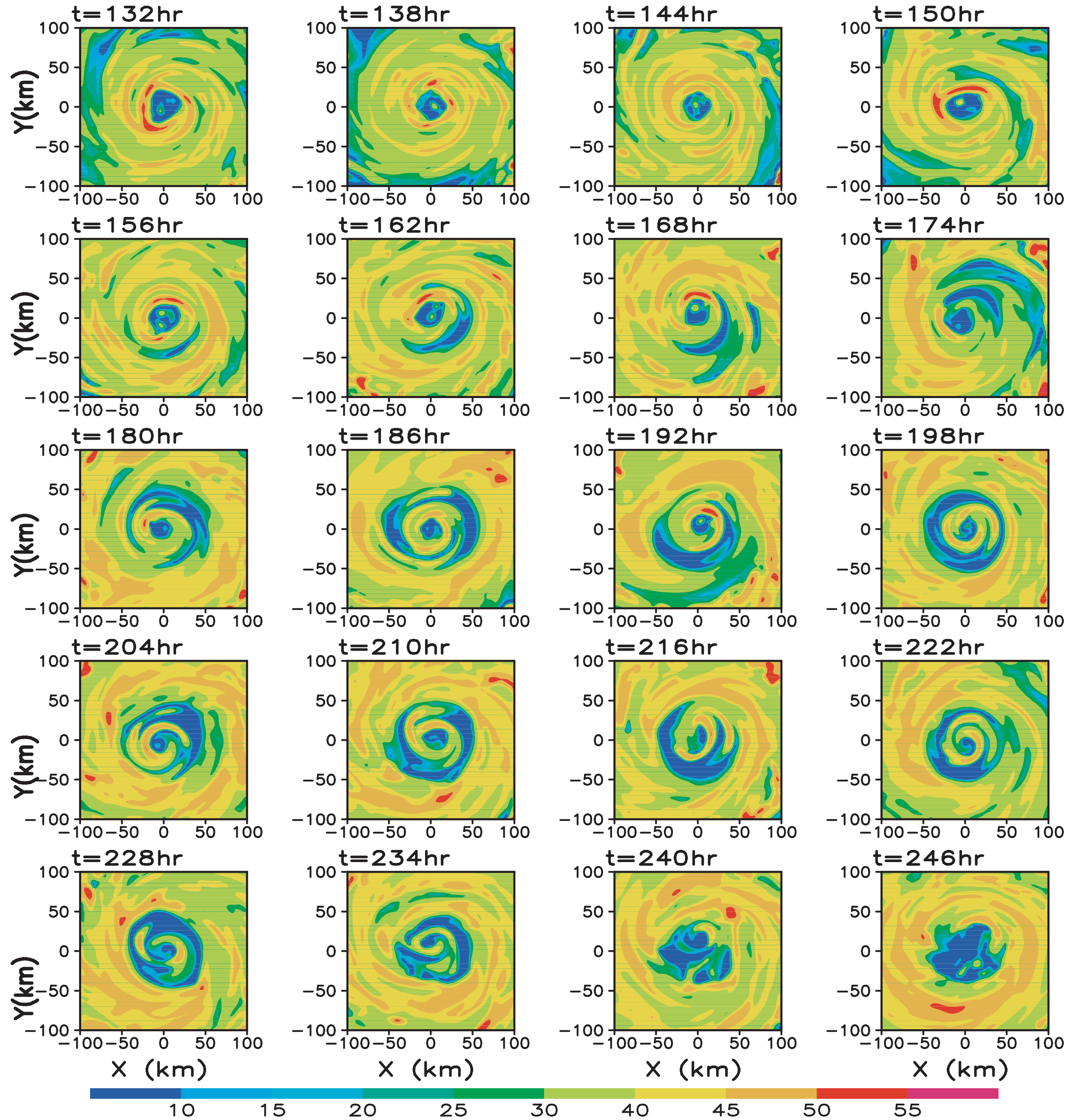


Figure 3.9. The figure shows the radar reflectivity in dBZ at 1-km height above sea level as simulated by the TCM4. During hours 132–150, the second eyewall develops, which lasts from hours 156–228. After about hour 234, the inner eyewall begins to weaken and eventually to disappear. As the inner eyewall weakens (*e.g.*, hour 240), several short-lived eddies exist. The large outer eyewall with an annular structure continues for a long time after hour 246 of the simulation.

A series of sensitivity experiments is now being conducted to determine which model parameters are necessary for the development of realistic concentric hurricane eyewalls. The final goal is to predict changes in the cyclone's intensity that result from changes in the double eyewall.

Torres del Paine, Patagonia • Gisela Speidel

IMPACTS OF GLOBAL ENVIRONMENTAL CHANGE

Research on the impacts of global environmental change at the IPRC has been examining the climate's sensitivity to radiative and land-surface perturbations and global controls over regional climate. The analysis of high-resolution atmospheric modeling aimed at improving climate models has been another thrust of this theme. Moreover, with the arrival of Axel Timmermann, exploration of paleoclimates and their contribution to our knowledge of climate change has been added as an area of research.

Evaluation of State-of-the-Art Global Climate Models

The Intergovernmental Panel on Climate Change (IPCC) plans to release its Fourth Assessment Report (AR4) on Climate Change in 2007. In Spring 2005, the IPRC hosted a major meeting at which the scientific community presented results on the global circulation models (GCMs) that will be used for the report. IPRC researchers took this opportunity to evaluate how well the models perform on two aspects that are central to their work: the ability to realistically represent the response of the atmospheric circulation to aerosol perturbations due to volcanic eruptions, and the connection between cloud-radiative climate forcing and the large-scale circulation in the tropics.

Evaluating the Large-Scale Atmospheric Response to Volcanic Aerosols in Climate Models

Research Team: K. Hamilton, G. Stenchikov (Rutgers), and V. Ramaswamy (NOAA GFDL)

Strong explosive volcanic eruptions have a large, if transient, impact on climate. After a major explosive eruption, the global-mean surface cools because the long-lived volcanic aerosols in the stratosphere reflect more solar radiation than usual; near the equator, however, the lower stratosphere warms because it absorbs more terrestrial infra-red radiation and solar-near infrared radiation. These radiative perturbations appear to change the circulation and its regional structures, particularly during winter in the Northern Hemisphere extratropics. This pattern of responses resembles the positive phase of the Arctic Oscillation. The main thermal and dynamical effects of such eruptions persist for about two years.

IPRC researchers are collaborating with colleagues at Rutgers University, the NOAA Geophysical Fluid Dynamics Laboratory, and other institutions on evaluating the volcanic responses in simulations conducted for the model intercomparisons in the upcoming IPCC assessment report. Using a realistic time series specified for atmospheric composition (greenhouse gases and aerosols), the team is analyzing results from the "historical" runs that simulate the evolution of the circulation over the last part of the 19th century and the entire 20th century.

For each model, a time-height specification of the zonal-mean aerosol concentrations and properties was constructed based on interpretations of various satellite and ground-based observations. Unfortunately, the model groups have not provided the quantitative radiative climate forcing associated with the composition changes imposed during the historical runs. Such values would need to be diagnosed from detailed calculations with the model radiative transfer schemes. From the data provided in the IPCC archive, the closest the IPRC researchers could come to diagnosing the global-mean radiative forcing of volcanic aerosol was through examination of the time series of the global-mean solar radiation reflected at the top of the atmosphere. This time series, averaged for all the realizations performed for each model, is shown in Figure 4.1. The values given are actually deviations from the mean for each calendar month over the entire integration. Only selected segments of the 1880–1999 period are shown, but these include 8 of the 9 largest low-latitude eruptions during the period. This diagnosed quantity includes the effects on the radiative balance from the aerosol that is part of the climate forcing as usually defined, but also includes a contribution from the changes in albedo (*e.g.*, from cloud or snow cover) that are part of the response. With this caveat, the curves in Figure 4.1 in post-volcanic periods should provide a rough comparison of the overall forcing of the global-mean thermal balance resulting from the imposed aerosol in the different models.

All the models show the increased reflectivity due to the stratospheric aerosols after the major eruptions of Krakatau (1883), Santa Maria (1902), Agung (1963), El Chichon (1982) and Pinatubo (1991). More modest increases in reflectivity are also visible in some of the models after the eruptions of Tarawera (1886), Bandai (1888) and Fuego (1974), and also Quizapu (1932, not shown).

To compare the volcanic effects in the models concisely, composites of the anomalies for each model were computed for various tropospheric and stratospheric fields over the two boreal winters (December–February) following each of the 9 largest low-latitude (40°S–40°N) eruptions since 1860. These composites were then compared to composites of available observations. In order to reduce

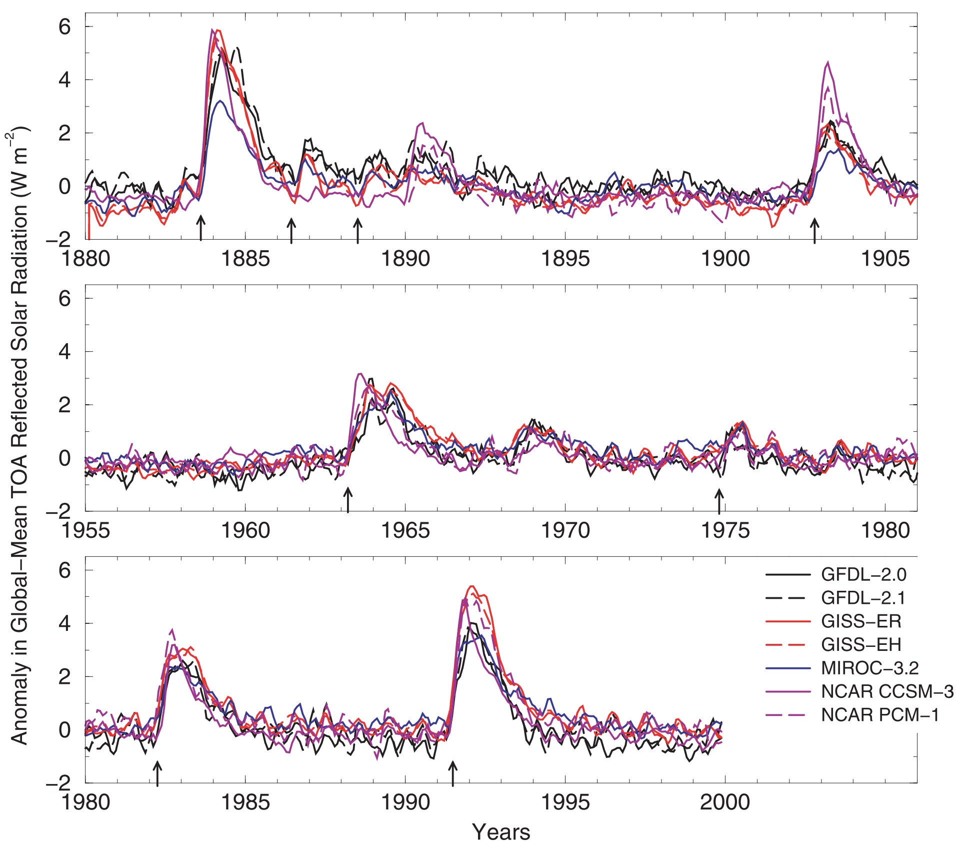


Figure 4.1. Monthly time series of anomalies in global-averaged reflected solar flux for selected periods. Results plotted for seven different models represent averages over all realizations available for the each model. The arrows show the times that eight major explosive volcanic eruptions occurred within the 40°S–40°N band. The anomalies are defined as the deviations of the monthly values from the long-term mean for each calendar month.

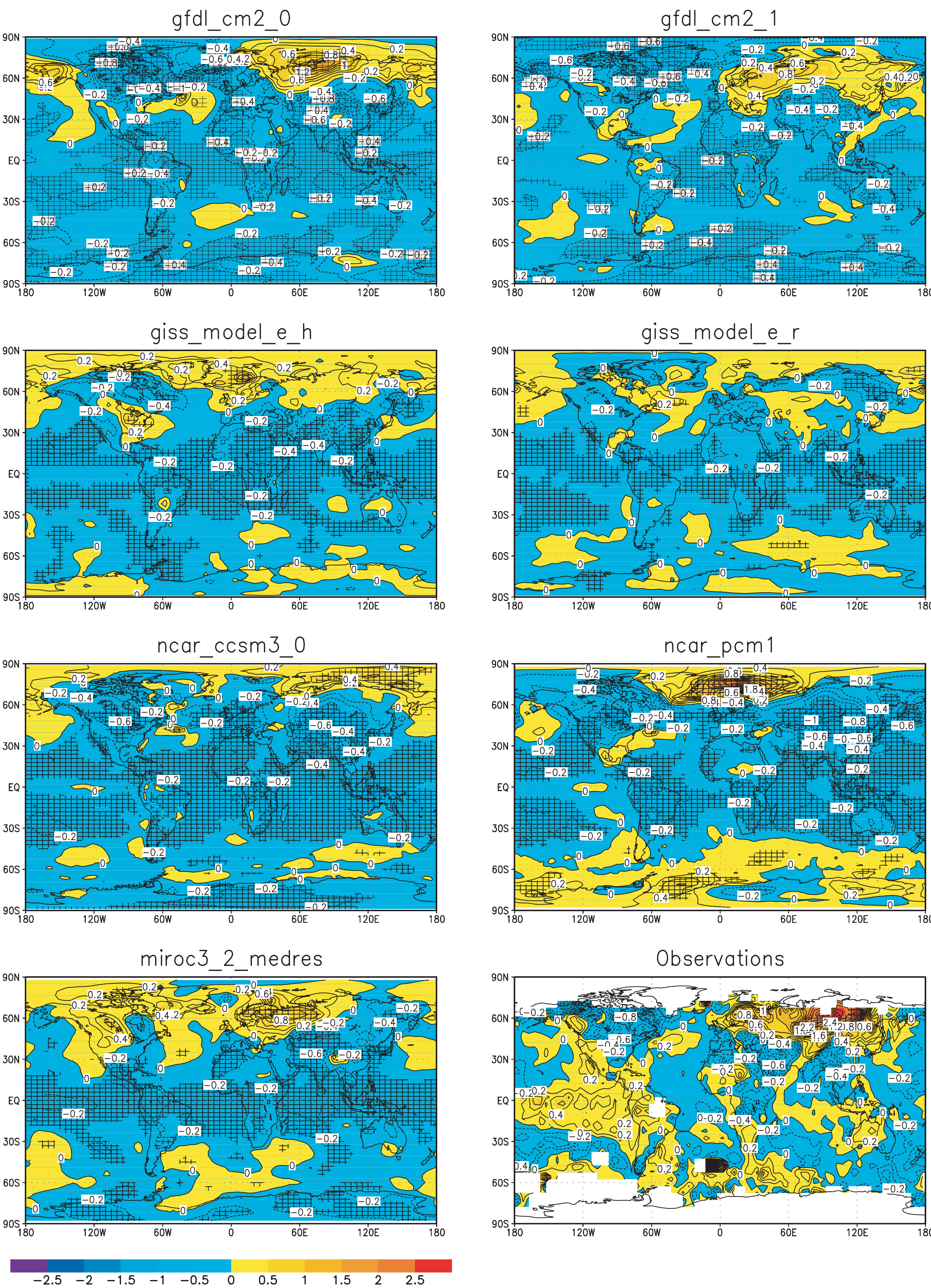


Fig. 4.2. December–February surface-air-temperature anomalies composited for the two years following each of the nine largest explosive low-latitude volcanic eruptions during 1880–2000. The color bars and contour labels are in K, and hatching shows regions where the composites are judged to be statistically different from zero at the 90% confidence level. The bottom right panel shows observations; the remaining panels show results from individual models.

the effects of long-term climate change in the composites, the observed anomalies were defined relative to eruption-free periods close in time to each eruption.

Figure 4.2 depicts the composite of surface-air temperature anomalies for each model, together with the comparable observed composite (panel 2h). The observed temperature pattern during the post-eruption periods is similar to the positive phase of the Arctic Oscillation: surface temperatures rise significantly (90% confidence level) in Northern Europe, Siberia, and Far East Eurasia; they fall in the Middle East (another distinctive feature of the positive phase of the Arctic Oscillation) by about –0.6 K (statistically non-significant) and in North America by about –0.8 K.

Both GFDL and GISS models (Figure 4.2, top 4 panels) produce a winter warming spatial pattern over Eurasia that agrees reasonably with observations, but the magnitude of the anomalies in the GISS model seems unrealistically small. In the GFDL CM2.0, warming is concentrated in central northern Siberia and shifted too far poleward. In the GFDL CM2.1, maximum warming correctly occurs in Europe and Far East Eurasia, but the amplitude is slightly underestimated. The composite anomaly maps for both NCAR models display maximum warming very far to the north. The MIROC2_2 model shows warming mostly over Europe. All models produce cooling in the Middle East, but only the GFDL models capture the observed cooling over Greenland. The GFDL and NCAR models show no significant warming over North America. Both GISS models tend to produce warming over the East Coast of North America.

Comparisons between models and observations of other tropospheric fields, such as sea-level pressure or 200 hPa geopotential height, show much less agreement. Overall, the state-of-the-art climate models in the IPCC intercomparison are rather disappointing in their simulation of the expected dynamical responses to the presence of stratospheric volcanic aerosol. Reasons for their deficiencies are still being investigated. One possibility is that the models simply have insufficient resolution, particularly vertical resolution, to adequately represent stratospheric dynamics and the stratosphere–troposphere interactions. All models considered here have rather coarse vertical resolution in the stratosphere, and the GFDL, NCAR, and MIROC models do not reach the stratopause.

Evaluating Cloud Feedback in Climate Models

Researchers: M. Stowasser and K. Hamilton

The predicted rise in Earth's surface temperature in response to the increase in greenhouse gas concentrations expected over the next century differs by several °C among current global climate models (GCMs). Shortwave cloud-radiative feedback plays a crucial role in determining the predicted response to such large-scale climate forcing. Because cloud feedback greatly affects the sensitivity of local and global-mean climate, it is important to understand why individual models differ in this regard and to develop a measure of how well the cloud feedbacks are simulated in the models.

IPRC researchers have therefore been studying how cloud representations in current climate models respond to natural fluctuations in certain meteorological variables. In a subset of the GCMs that are being used in the upcoming IPCC Fourth Assessment Report (AR4), they examined how cloud feedback over the tropical ocean varies geographically as a function of long-term mean circulation, and temporally as a function of the interannual circulation fluctuations. In particular, they calculated for 11 models the degree to which shortwave cloud-radiative forcing, C, depends on mid-tropospheric vertical velocity and lower-tropospheric relative humidity. The performance of the models was then compared with observations of shortwave cloud-radiative forcing from satellites (ERBE data) and with meteorological field values from ECMWF 40-year reanalysis (ERA-40) data.

The strategy was to stratify cloud data according to physically based regime indicators, X, such as the isobaric coordinate vertical velocity, ω, and relative humidity, h. Of interest was how well the models capture the relationship between shortwave cloud-radiative forcing, C, and the time-mean value of a chosen physical indicator, $[X]$, as well as the response C' to deviations of X' from $[X]$. Only interannual fluctuations were considered, that is, seasonal variations in X' and C' values were removed. The C' values were averaged for all grid-points that fall within each ($[X]$, X') category over the ocean between 30°S and 30°N and for each month over the 5-year analysis period from 1985 to 1989. The resulting response of shortwave cloud-radiative forcing, C', was then displayed in a contour plot as a function of variations in the physical indicator X' and the mean $[X]$. Figure 4.3 (on page 52) illustrates the approach: it compares monthly mean values of 500 hPa large-scale vertical velocities taken from the ERA-40 reanalysis and the shortwave cloud-radiative forcing taken from the ERBE data with the results from each of the 11 models.

The response of shortwave cloud-radiative forcing varied considerably among the models, and all models differed substantially from observations. The most notable deficiency is that the response of the forcing is too linear with regard to vertical velocity; this is especially the case in regions with strong ascending and descending motions. With relative humidity as the regime index, most models tend to underestimate the shortwave cloud-radiative forcing in very humid regions; but the response is too sensitive to humidity variations in very dry regions. This finding suggests that the largest errors in the cloud forcing for the models are likely to occur (1) in the western Pacific warm pool area, an area characterized by very moist, strong upward motion, and (2) in rather dry regions, where the flow is dominated by descending mean motions.

If numerical climate models are to have any credibility in forecasting quantitatively the cloud responses to expected increases in greenhouse gas concentrations, they must reproduce realistically the observed relationship between shortwave cloud-radiative forcing and such meteorological variables as those studied above. Unfortunately, the simulated cloud fields in the models in the AR4 model intercomparison do rather poorly when evaluated by these measures.

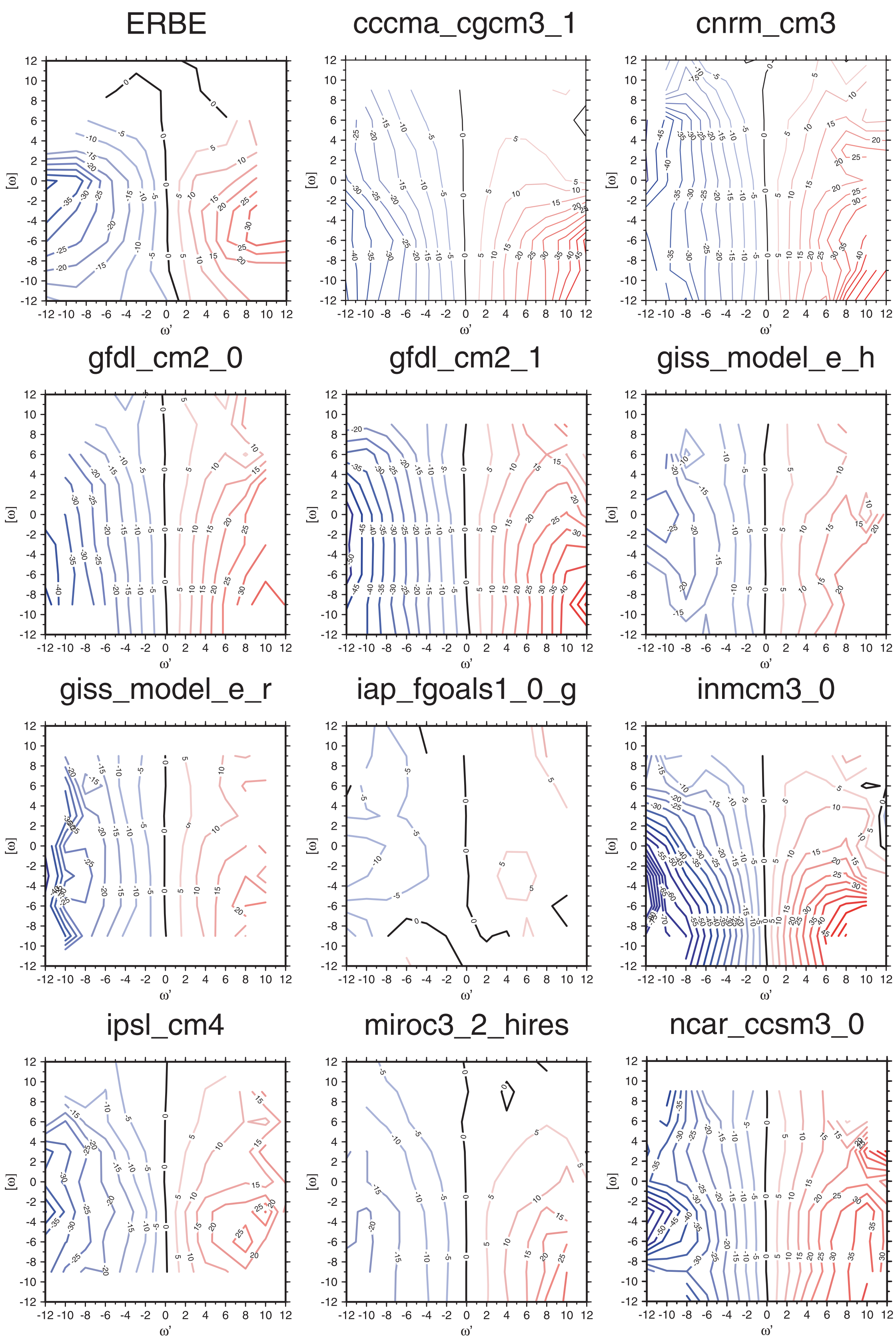


Figure 4.3. The shortwave cloud-radiative response C' to deviations in mid-tropospheric vertical velocity ω' from the mean [ω] for ERBE/ERA-40 data (upper left corner) and for the IPPC models. Units are hPa/s and W/m^2 respectively.

Paleoclimates

The climates of the past hold important clues to the processes driving the climate system, clues that may point to the nature of future climate change with global warming. IPRC research in this field focuses mainly on the last glacial period (100,000–11,000 years ago), the relatively stable Holocene (11,000–100 years ago), and the Anthropocene (the last 100 years).

Tracking the Global Climate Response to Ice-Sheet Melts around the North Atlantic

Research Team: Axel Timmermann and Uta Krebs (Leibniz Institute for Marine Sciences, Kiel, Germany)

The last glacial period was punctuated in the Northern Hemisphere by abrupt climate transitions—the Heinrich events that released armadas of icebergs into the North Atlantic, raised global sea level by about 10–20 meters and led to shutdowns of the meridional overturning thermohaline circulation in the North Atlantic.

IPRC researchers and their colleagues at IFM-GEOMAR in Kiel, Germany, have used a global climate model, the ECBilt-Clio, to study the climate response to such freshwater pulses and the subsequent collapse of the North Atlantic thermohaline circulation. They found that during Heinrich events, the Northern Hemisphere cooled and the Southern Hemisphere warmed; the global intertropical convergence zone (ITCZ) shifted southward, affecting the Asian-Australian and South American monsoons. Oceanic Kelvin waves propagated from the North Atlantic through the Indian Ocean to the Pacific, with Rossby waves readjusting the interior circulation of both oceans. The interior adjustments and wind changes deepened the equatorial thermocline in the Pacific and Indian oceans by 20–30 m. Studying the sensitivity of the El Niño Southern Oscillation (ENSO) to such a thermocline deepening with an intermediate ENSO model, they found that the collapse of the North Atlantic meridional overturning circulation triggered a collapse of ENSO.

The team also studied recovery of the overturning circulation. In forced ocean models and two-dimensional climate models, the North Atlantic thermohaline circulation typically takes several thousand years to recover after strong anomalous freshwater forcing in the North Atlantic has stopped, the recovery time depending on the ocean vertical diffusivity in the model. In three-dimensional coupled atmosphere-ocean models, the thermohaline circulation recovers much more quickly. Research with ECBilt-Clio in fully and partially coupled simulations shows that the mechanism contributing most to a fast recovery of the thermohaline circulation is the coupled air–sea interaction in the tropical Atlantic. When the ITCZ shifts southward during the shutdown phase, the trade winds intensify in the tropical North Atlantic, cooling the ocean further, which, in turn, strengthens the northern trade winds. The stronger trade winds lead to more evaporation and saltier water. The wind-driven circulation and its transport of the accumulated salinity anomaly to the northern North Atlantic provide negative feedback, leading to a more rapid recovery of the thermohaline circulation. When the air–sea coupling in ECBilt-Clio is allowed to occur only in regions outside the North Atlantic, recovery is much slower—the order of a thousand years. Simulations using prescribed climatological freshwater fluxes and interactive coupling for momentum and heat fluxes corroborated the results. This tropical climate feedback involving wind-evaporation feedback and its generation of anomalous salty water is also expected to play a crucial role in the stability of the thermohaline circulation in future climate-change scenarios.

Simulating the Last 21,000 Years of Earth Climate

Research Team: Axel Timmermann and Oliver Timm

Transitions between glacial and interglacial periods are among the most spectacular climate events in the history of early mankind. Yet, the mechanisms that led to these glacial-interglacial transitions are still unclear. Whereas deglaciation in the Southern Hemisphere progressed gradually and rather smoothly, in the Northern Hemisphere it was punctuated first by a warming (the Boelling Alleroed) followed by an abrupt cooling (the Younger Dryas) and then a final rapid warming leading into the early Holocene.

Applying an orbital acceleration technique to speed up the simulations, transient simulations were conducted with ECBilt-Clio over the last 21,000 years, covering the last deglaciation and the stable Holocene. In these simulations, the thermohaline circulation weakens during deglacation, a finding that is contrary to the currently held view. Further analysis of the simulations together with sensitivity experiments are expected to shed more light on the role of boundary forcing (CO_2, albedo, orography, and orbital changes) in ocean circulation changes and the role of two major Heinrich events (H1, H0) during deglaciation.

Results on the Holocene period from this 21,000-year simulation have been validated against reconstructions of seasonal SST based on alkenone sediments (Kim and Schneider at the University of Bremen) and a simulation with a coupled general circulation model (Lorenz and colleagues at Hamburg). The agreement between simulated and proxy records for the precessionally-forced seasonal trends is remarkable. Boreal summer temperatures in the Northern Hemisphere decreased steadily from the mid-Holocene optimum to pre-industrial climates, whereas global boreal winter temperatures rose (Figure 4.4). This latter warming trend can be attributed to changes in insolation associated with precession of the equinoxes. The model simulations suggest that the Asian summer monsoon was significantly stronger during the mid-Holocene climate optimum around 9,000 to 6,000 years ago, owing to the greater surface temperature gradient between the Asian continent and the Indian Ocean. Furthermore, in the model simulation Africa also experiences wetter conditions throughout the early-to-mid Holocene (Figure 4.5).

These climate changes are consistent with paleo-reconstructions of past monsoon activity, African vegetation

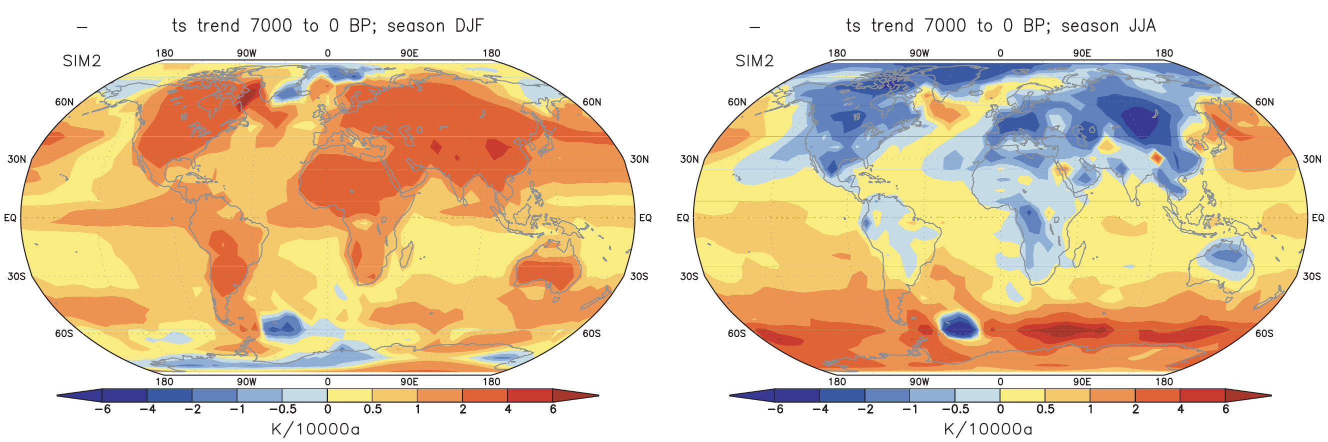


Figure 4.4. Spatial trend surface temperatures from 7,000 years ago to pre-industrial times as simulated with the ECBILT/CLIO model using accelerated orbital and greenhouse gas forcing. **Left:** June, July, and August. **Right:** December, January, and February. During this period, the closest position between Earth and sun has shifted from Northern Hemisphere summer to Northern Hemisphere winter, reducing the difference between summer and winter temperatures in that hemisphere. The summer and winter temperature trends simulated in both hemispheres are therefore consistent with the changes in insolation.

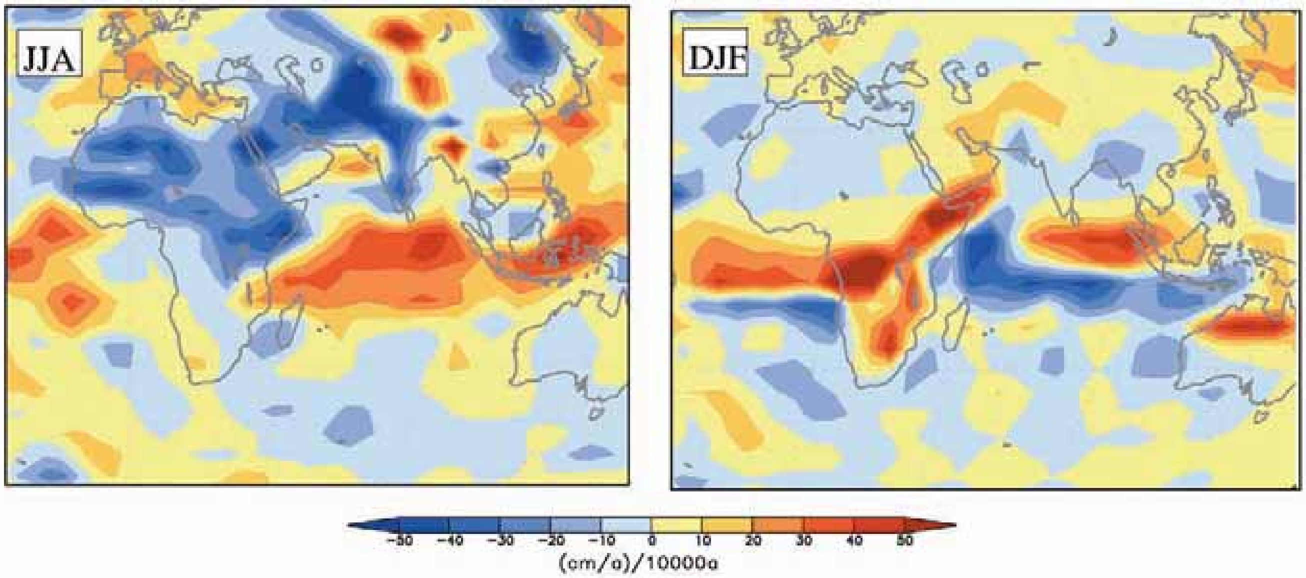


Figure 4.5. Spatial precipitation trend from 7,000 years ago to pre-industrial times as simulated with the ECBILT/CLIO model. **Left:** June, July, and August. Right: December, January, and February. The trend shows that Africa has become drier during summer, particularly northern and central Africa. Most of India has been receiving less and less rain, particularly during summer.

(the green Sahara), and excavations of early human settlements in Africa such as the famous Saharan "Cave of the Swimmers" in the Gilf Kebir.

To test the reliability of the findings from the transition-climate model simulations, results will be compared with paleoclimate records, particularly records reflecting water conditions, such as lake levels and trace metal depositions near river mouths. Moreover, the dynamical, three-dimensional ice-sheet model from the Center for Climate Research at FRCGC will be coupled to ECBilt-Clio, applying a special periodic synchronous coupling technique. Simulations with this coupled model will allow more detailed study of the mechanisms and feedbacks that led to the onset of the last glacial period some 100,000 years ago and those that were responsible for its ending.

Hawaiian Islands • NASA - Earth Observatory

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 research communities by providing easy access to quality climate data products and by conducting research to evaluate and improve such data products and develop tools for climate forecasting.

Easy Access to Quality Climate Data Products

Data sets used in climate research are typically global in scope, span years to decades, and result from a variety of measuring techniques that range from *in situ*, single-point station data to satellite data, to output from fully three-dimensional large-scale coupled models. The users of climate data range from those interested in 'quick looks' at specific data to those who develop climate models and require binary access to huge, complete data sets. The APDRC is setting up easy access to data products in ways that satisfy these differing needs by collecting a wide range of data products and by serving the data in ways designed for different applications and uses.

Expanding the Data Archives

Research Team: J. Potemra, X. Fu, J. Hafner, Z. Yu, G. Yuan, Y. Zhang

This year's advances in data-archiving and data-serving capabilities have greatly improved the handling of extremely large datasets from global high-resolution models. Data holdings have increased in three broad areas: extremely large ocean model datasets, *in situ* oceanographic observations, and remotely sensed and *in situ* atmospheric measurements. The advantage of the APDRC service is that scientists can now directly access, subsample, compare, and analyze output from these large datasets in a straightforward way.

Regarding large ocean model datasets, the APDRC now serves (to IPRC and Earth Simulator Center-affiliated scientists) products from the 1/10° resolution runs of the Ocean GCM for the Earth Simulator (OFES), including monthly mean climatologies (complete three-dimensional velocity, temperature, salinity, and mixed-layer fields), three-day snapshots from a specific model year, long-term hindcast surface fields (sea level and sea surface temperature), and a ten-year climatology. The APDRC also serves output from the U.S. Navy Layered Ocean Model (NLOM), with outputs from the 1/16° NLOM "nowcast" and "forecast" runs being archived daily.

Regarding *in situ* oceanographic data, the APDRC holdings now include JAMSTEC Argo data, World Ocean Circulation Experiment (WOCE) *in situ* data, and Fleet Numerical Meteorology and Oceanography Center/GODAE profile data.

Regarding atmospheric data, the archive has increased considerably this year with a comprehensive assembly of satellite data. The 40-year reanalysis surface- and pressure-level data from the European Centre for Medium-Range Weather Forecasts (ECMWF) have been added as well as the ECMWF 16-year, 6-hourly operational analysis of surface fields. From the Tropical Rainfall Measuring Mission satellite, measurements from the microwave imager, the precipitation radar, and the lightning imaging sensor have been added. Other satellite data now being served include those from the optical transient detector, the monthly International Satellite Cloud Climatology

Project, which contains cloud and radiation parameters, as well as four datasets of the gridded precipitation and air temperature from the NASA Distributed Active Archive Center. Historical atmospheric records being served now include datasets of precipitation from more than six Asia-Pacific countries.

Recently the APDRC has taken an important step and has expanded the data-management group by formally including IPRC researchers, who provide scientific analyses and quality control and make recommendations for data acquisitions. This change will improve the variety and quality of archived datasets and provide data evaluation based on scientific research.

Developing Server Capabilities

Team: Y. Shen and S. Yarimizu

With regard to its servers, the APDRC has installed DAPPER, an OPeNDAP-type (formerly DODs-type) server for *in situ* data and has upgraded the following servers: LAS, CAS and GDS. Progress has also been made in establishing the APDRC as a "sister server" to the U.S. Global Ocean Data Assimilation Experiment (GODAE). In addition, as part of the Kyosei-7 Project, funded by Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT), the servers Tomcat, LAS, and GDS at the Frontier Research Center for Global Change were set up as "sister servers" with the APDRC and the U.S. GODAE.

Improving the APDRC Website and Other Accomplishments

Team: S. DeCarlo. J. Potemra

The APDRC website has been given a major upgrade that includes the development and implementation of a data-search tool and the introduction of tutorials. Figure 5.1 depicts the various components of the new web site. Shown at the top left is the search utility, which has direct links to the data archive. A sample listing of datasets, shown in the center of the figure, gives the name of the dataset followed by an icon indicating the server type (OPeNDAP, LAS or EPIC) on which the dataset is available. The figure also shows a sample output from each server, the yellow arrows indicating the datasets from which the outputs are derived. In support of the NOAA Pacific Region Integrated Data Enterprise (PRIDE), APDRC staff has created a web page for PRIDE that coordinates the organization's various activities.

Work under a subcontract to Woods Hole Oceanographic Institution has been completed on HydroBase2 data, a high-quality historical database on temperature and salinity at various depths for the world ocean (excepting the Southern Ocean). Near completion is the work under the CSIRO Marine Research subcontract for quality control of the historic Indian Ocean upper-ocean temperature database.

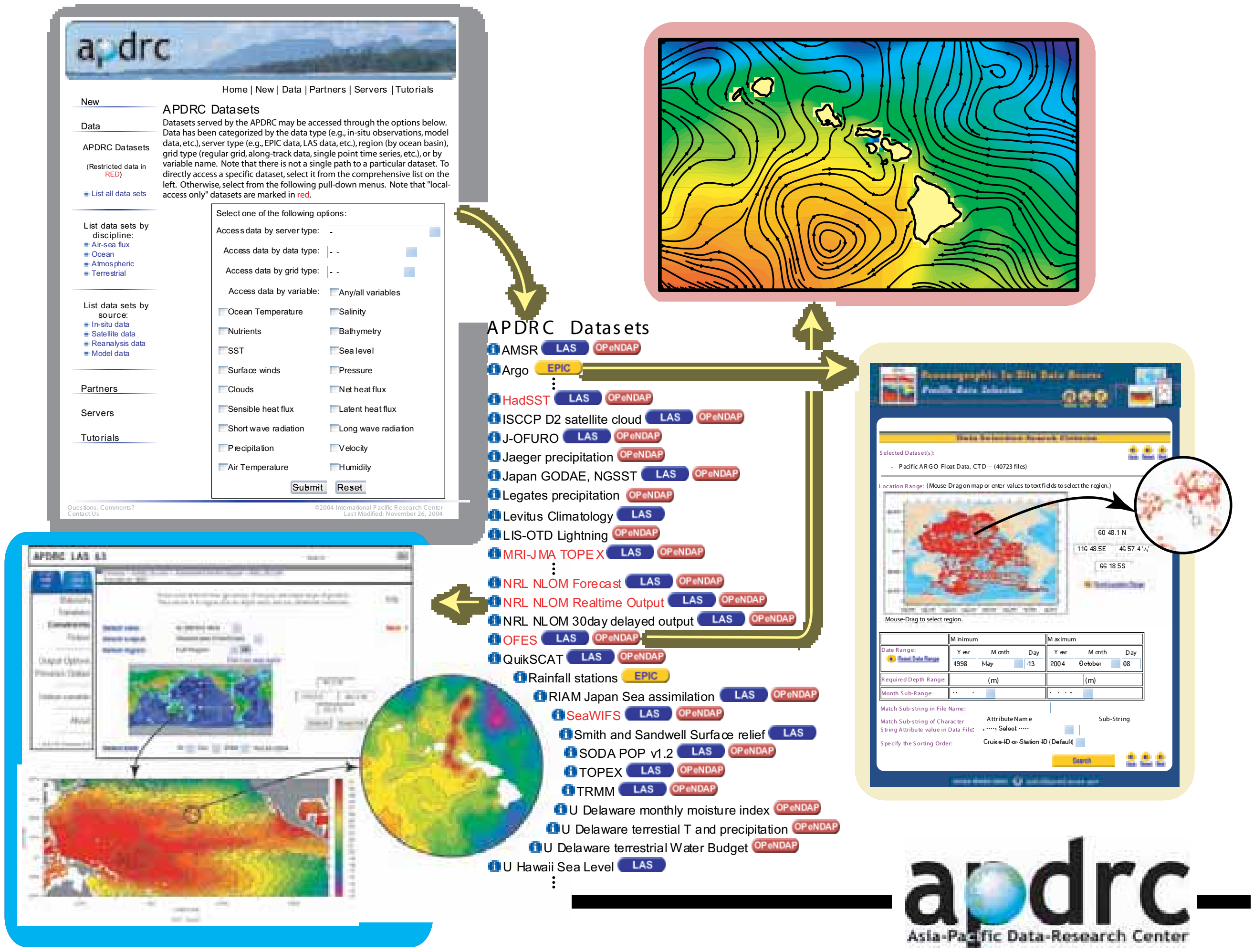


Figure 5.1. Components of the APDRC website. Shown at the top left is the search utility, which has direct links to the data archive. A sample listing of datasets, shown in the center of the figure, gives the name of the dataset followed by an icon indicating the server type (OPeNDAP, LAS or EPIC) on which the dataset is available. Shown also is a sample output from each server, the yellow arrows indicating the datasets from which the outputs are derived.

Want to compare QuikSCAT satellite wind velocity with several model products?

Visit our website at http://apdrc.soest.hawaii.edu/

Better Climate Data Products

The APDRC is also committed to conducting research to improve climate data products and to develop climate products with direct societal applications. For example, the APDRC is participating in the Argo program and in the demonstration of the utility of global models in support of U.S. GODAE. An activity in each of these areas is featured below.

Implementing an Ocean Circulation Model for the Hawai'i Islands

Research Team: Y. Jia, P. Hacker, J. Potemra, and M. Yaremchuk

Standing in the steady northeast trade winds in the middle of the vast Pacific Ocean, the Hawaiian Islands with their tall volcanoes create wakes of weak winds downstream of the major islands and strong wind jets between the islands. These local wind features, often poorly resolved in coarse resolution atmospheric wind products, have a profound effect on the ocean circulation and eddy activity west of the islands. In collaboration with scientists of the Naval Research Laboratory at Stennis Space Center, a team of researchers at the APDRC is therefore tailoring an ocean model to the waters surrounding the Islands of Hawai'i.

The team has taken the Hybrid Coordinate Ocean Model (HYCOM)—developed by the HYCOM Consortium, which is a part of the U.S. Global Ocean Data Assimilation Experiment—and has implemented this model for the Hawai'i Islands' region, which spans 12° in longitude and 10° in latitude. Figure 5.2 depicts a snapshot of the sea surface height from the first test simulation at a resolution of about 4 km, forced at the lateral boundaries by the 8-km-resolution Pacific basin HYCOM version and at the surface by the winds and thermal fluxes from the European Centre for Medium-Range Weather Forecasts (ECMWF). The solutions stay stable despite the fact that the boundaries are open at all four sides, reflecting the robust nature of the HYCOM model. Initial analyses of the output from the test simulation show many aspects of the region's observed circulation characteristics. In particular, cyclonic and anticyclonic eddies (blue and red colors respectively in Figure 5.2) abound west of the island chain. The cyclonic eddies affect primary biological production because upwelling within these eddies bring nutrient-rich water from beneath the surface mixed-layer to the euphotic zone. The eddies are generated west of the Island of Hawai'i through interactions among wind, currents and topography, details of which are not well understood yet.

The initial modeling experiments are aimed at an improved understanding of the eddy-generation mechanisms and factors that govern the region's circulation, such as how the circulation characteristics in the region change with higher resolution in the wind field, and how much they are influenced by the imposed lateral boundary conditions. As the model resolution increases, a finer bathymetry product will be used to represent better the near-shore geographic features of the islands. Model results will be evaluated using the observational datasets available for this region, some of which are already served by the APDRC.

Once the model performs well, data assimilation capability will be introduced to allow regional forecasts of the ocean state. Such a system will benefit not only researchers of ocean phenomena surrounding the Hawaiian Islands, but also the local Hawai'i community in such ways as public safety (*e.g.*, search and rescue operations), coastal-ocean environmental management (*e.g.*, coral reef protection), hazard assessment (*e.g.*, accidental oil spills), and economy (*e.g.*, fisheries). The system will be readily applicable to other island settings in the Pacific, and IPRC researchers intend to explore these.

More uses of the regional model are envisaged. For instance, biogeochemical processes may be introduced to study the ecosystem dynamics of the region. Particle-tracking techniques may be implemented and, for example, applied to understanding fish-larvae dispersion in the Hawaiian archipelago. The model may also be coupled to

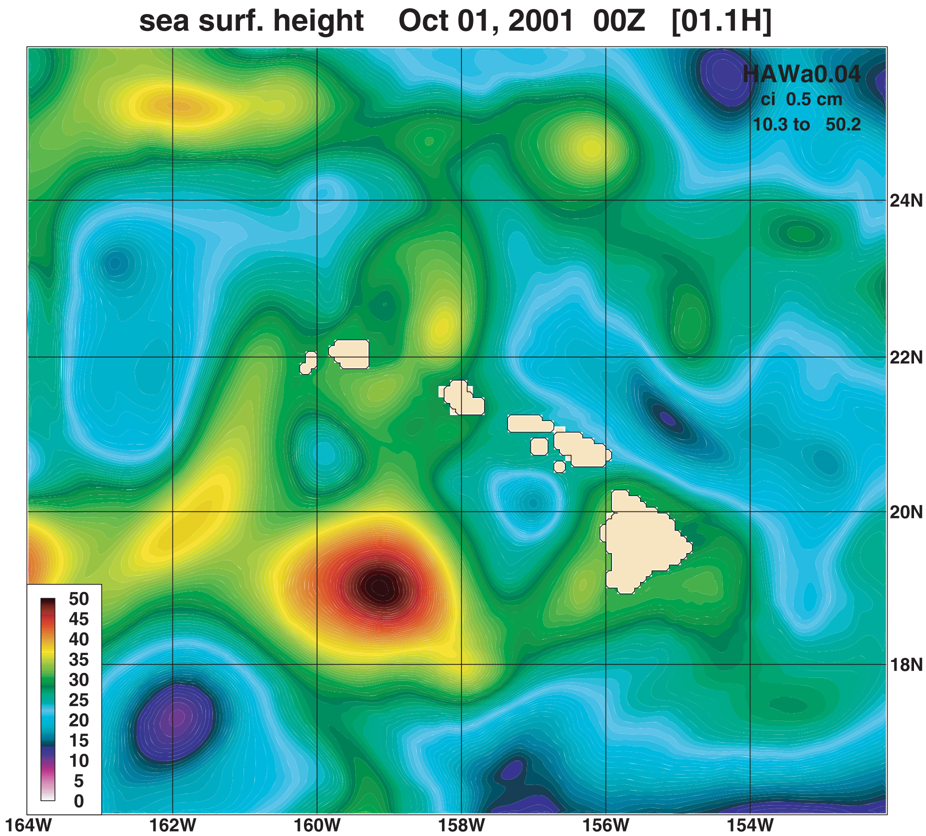
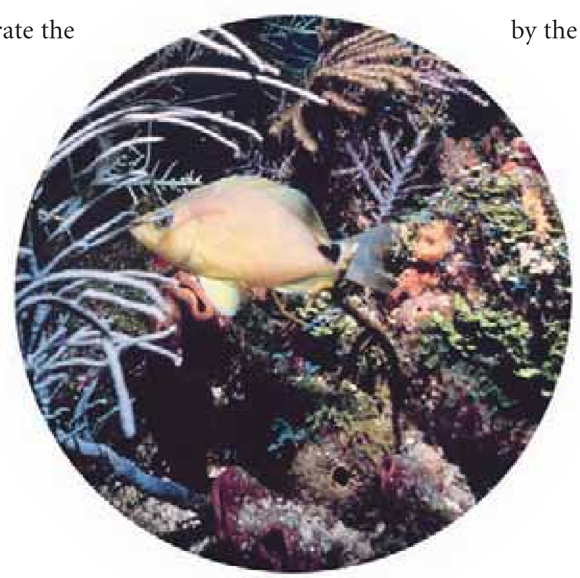


Figure 5.2. Sea surface height on October 1, 2001, as simulated by the Hawai'i regional ocean model using HYCOM at a horizontal resolution of 0.04°. Anticyclonic eddies are indicated by yellow-red patches and cyclonic eddies by blueish patches. Solutions from the HYCOM Consortium's Pacific basin model (at 0.08° resolution) are applied at the four open boundaries. The model is forced at the ocean surface by the ECMWF winds and thermal fluxes.

atmospheric models in order to improve our understanding of the nature of climate variability in the Asia-Pacific region and its predictability—the mission of the IPRC.

The development of this regional model for the waters surrounding the Hawaiian Islands contributes to efforts of the multi-institutional HYCOM Consortium to develop and demonstrate the performance and application of eddy-resolving, real-time, global and basin-scale ocean prediction systems that use the HYCOM. Such prediction systems will be in operational use by several institutions and the results from these will be available to the community at large through designated data servers, one of which is operated by the APDRC within the IPRC.



Devising a Method to Measure Deep Ocean Currents

Researchers: H. Yoshinari, N. Maximenko, and P. Hacker

The international Argo program is filling the global ocean with an array of about 3,000 drifting floats. The floats sink to about 2 km below the surface, and as they rise, they measure temperature and salinity. When they reach the surface again every 10 days or so, they relay the data (conductivity, temperature, and depth) collected on their upward path and their location *via* satellites to national data centers and to the two Global Data Acquisition Centers, which make the data available within 24 hours. The Argo floats are an unprecedented source of hydrographic data, covering all parts of the world ocean in support of ocean climate study.

Along with these measurements, other information is hidden in the Argo data, for instance, the velocity of deep currents. When a float is "parked" at depth, it is advected by deep horizontal currents and travels before resurfacing. Little is known about these deep currents, and any information the Argo floats can give us on these currents would be very useful. It should actually be possible to estimate the currents at depth from the distance traveled during one cycle. This information, however, is not easily extracted. During its brief rise and its stay of several hours at the surface, the float is further displaced by intermediate and surface currents, which are typically much stronger than the deep ones. Researchers at the APDRC are now developing algorithms with which they hope to estimate the velocity of the deeper currents.

The method includes the determination of three critical parameters: surface velocity, correct surface-arrival and diving times, and vertical structure of the currents. Surface velocity is estimated by analyzing float drift on the sea surface. Correct times, if not measured, are estimated from statistics of transmissions during 10–20 consecutive cycles. Estimates of vertical structure still needs to be made based on the first baroclinic mode. This method, once devised, should contribute valuable information to the very sparse database of deep currents, so costly to observe.

INTRODUCING IPRC STAFF

LEADERSHIP TEAM

Julian P. McCreary, Jr.
Director
Professor of Oceanography, UH

Julian McCreary received 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 in 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.

Lorenz Magaard
Executive Associate Director
Director, International Center for Climate and Society, UH
Professor & Chair, Oceanography, UH

Lorenz Magaard received his Dr. rer. nat. in mathematics from the Christian-Albrechts-University, Kiel, Germany, in 1963. He has been with the Oceanography Department at UH since 1975, serving as Department Chair several times and as Associate Dean for the School of Ocean and Earth Science and Technology, which he helped to found. His current main research interests are in the field of climate and society.

RESEARCH TEAMS

Indo-Pacific Ocean Climate

Shang-Ping Xie
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Shang-Ping Xie obtained his D.Sc. 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.

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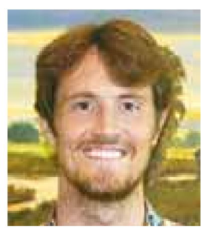
Niklas Schneider received his Ph.D. in physical oceanography in 1992 from the University of Hawai‘i at Mānoa. His research interests include decadal climate variability, tropical air–sea interactions, and coupled modeling.



Simon de Szoeke
Postdoctoral Fellow

Simon de Szoeke received his Ph.D. in the field of atmospheric sciences from the University of Washington in 2004. His research interests include tropical meteorology and equatorial dynamics, planetary boundary meteorology and atmosphere-ocean interaction, and processes affecting climate change.

Ryo Furue
Postdoctoral Fellow

Ryo Furue obtained his Ph.D. in geophysics from the University of Tokyo, Japan, 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.

Addendum to
IPRC April 2004–March 2005 Report,
Introducing IPRC Staff, p.63

Saichiro Yoshimura
Liaison Officer

Saichiro Yoshimura has served as the liaison officer between the Frontier Research Center for Global Change, JAMSTEC, and the IPRC since July 2002. Mr. Yoshimura obtained a Bachelor of Engineering degree from The University of Tokyo and a Master of Business Administration degree from Wharton Graduate School of Business at the University of Pennsylvania. For most of his professional career, Yoshimura has been an administrative officer in the Japanese government.

Jan Hafner
Scientific Computer Programmer

Jan Hafner received his Ph.D. in atmospheric sciences in 1996 from the University of Alabama in Huntsville. His research interests include meso-scale numerical modeling and climate modeling. He is also a member of the air–sea flux team at the Asia-Pacific Data-Research Center.

Tommy Jensen
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Affiliate Researcher, Oceanography, UH
Editor, Journal of Climate

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

N. H. Saji
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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.

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Justin Small received his Ph.D. in oceanography from the University of Southampton, England, in 2000. His research interests include air–sea interaction, regional climate modeling, and the simulation of nonlinear internal waves in the ocean.

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

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Zuojun Yu obtained her Ph.D. in physical oceanography in 1992 from Nova Southeastern University, 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. She is also a member of the air–sea flux team at the Asia-Pacific Data-Research Center.

Regional Ocean Influences

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

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Yan Du received his Ph.D. in physical oceanography from the Ocean University of China, Qingdao, in 2002. His research interests include mixed-layer and thermocline dynamics and their interactions, ocean circulation and its modeling, and the role of Rossby and Kelvin waves in oceanic adjustment.

Konstantin Lebedev
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Konstantine Lebedev received his Ph.D. in physical oceanography in 1995 from the P.P. Shirshov Institute of Oceanology in Moscow. His research interests include variational and sequential data assimilation into numerical models and numerical modeling of ocean dynamics.

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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 the processes and water exchange between the equatorial western Pacific and the eastern Indian Ocean.

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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.

Asian-Australian Monsoon System

Bin Wang
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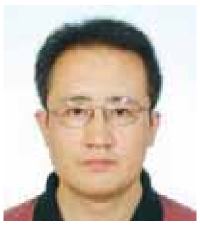

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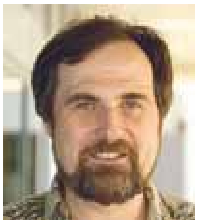
Impacts of Global Environmental Change



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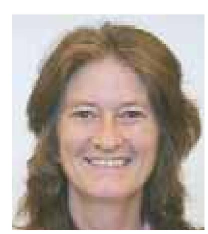

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SUBMITTED

Annamalai, H., P. Liu and S.-P. Xie: Southwest Indian Ocean SST variability: Its local effect and remote influence on Asian monsoons. *J. Climate.*

Chang, P., T. Yamagata, P. Schopf, S.K. Behera, J. Carton, W.S. Kessler, G. Meyers, T. Qu, F. Schott, S. Shetye, T. Stockdale, and S.-P. Xie: Climate fluctuations of tropical coupled system—The role of ocean dynamics. *J. Climate.*

de Szoeke, S. and C.S. Bretherton: Variability in the southerly flow into the eastern Pacific ITCZ. *J. Atmos. Sci.*

Endoh, T., K.J. Richards, and Y. Jia: Ventilation of the North Pacific simulated in an isopycnic coordinate general circulation model. *J. Phys. Ocean.*

Fu, X., B. Wang, T. Li, and F.-F. Jin: The tropical Asian-Pacific climate simulated in a hybrid coupled GCM (HcGCM). *J. Climate.*

Huang, B., V. Mehta, and N. Schneider: Oceanic response to idealized net atmospheric freshwater in the Pacific at decadal timescale. *J. Phys. Oceanogr.*

Jiang, J.H., S.D. Eckermann, D.L. Wu, K. Hocke, B. Wang, J. Ma, and Y. Zhang: Seasonal variation of gravity wave sources from satellite observations. *Adv. Space Res.*

Justino, F., A. Timmermann, U. Merkel, and W.R. Peltier: The impact of ice sheet topography on the circulation of the glacial atmosphere: An initial intercomparison of results for the ICE-5G and ICE-4G models of LGM paleotopography. *J. Climate.*

Kazuyoshi, K., and Y.N. Takayabu: Different propagation characteristics of the MJO during boreal summer and winter: Impact of the monsoonal circulation on the northward propagation over the Indian Ocean. *J. Climate.*

Kwon, M., J.-G. Jhun, B. Wang, S.-I. An, and J.-S. Kug: Decadal change in relationship between East Asian summer monsoon and western North Pacific summer monsoon. *Geophys. Res. Lett.*

Li, J., R. Yu, T. Zhou, and B. Wang: Why is there an early spring cooling trend downstream of the Tibetan Plateau? *J. Climate.*

Li, T., and B. Fu: Tropical cyclogenesis associated with Rossby wave energy dispersion of a pre-existing typhoon. Part I: Satellite data analyses. *J. Atmos. Sci.*

Li, T., X. Ge, B. Wang, and Y. Zhu: Tropical cyclogenesis associated with Rossby wave energy dispersion of a pre-existing typhoon. Part I: Numerical simulations. *J. Atmos. Sci.*

Maximenko, N.A., and P.P. Niiler: Hybrid decade-mean global sea level with mesoscale resolution. *Recent Advances in Marine Science and Technology.*

Maximenko, N.A., B. Bang, and H. Sasaki: Observational evidence of alternating zonal jets in the World Ocean. *Geophys. Res. Lett.*

Nonaka, M., J.P. McCreary, and S.-P. Xie: Influence of mid-latitude winds on the stratification of the equatorial thermocline. *J. Phys. Oceanogr.*

Qu, T., and G. Meyers: Seasonal variation of the barrier layer in the southeastern tropical Indian Ocean. *J. Geophys. Res.*

Qu, T., G. Girton, and J. Whitehead: Deepwater overflow through Luzon Strait. *J. Geophys. Res.*

Richards K.J., and S.J. Brentnall: The impact of diffusion and stirring on the dynamics of interacting populations. *J. Theoretical Biology.*

Saji, N.H., S.-P. Xie, H. Hase, Y. Kuroda, Y. Masumoto, M. Nonaka, and H. Sasaki: Intraseasonal air–sea interaction over the tropical South Indian Ocean: Satellite and *in situ* observations. *J. Climate.*

Saji, N.H., S.-P. Xie, and T. Yamagata: Tropical Indian Ocean variability in the IPCC 20th-century climate simulations. *J. Climate.*

Schneider, N., and B.D. Cornuelle: The forcing of the Pacific Decadal Oscillation. *J. Climate.*

Senchev, A., and M. Yaremchuk: Residual circulation in the English Channel as a dynamically consistent synthesis of shore-based observations. *Cont. Shelf Res.*

Stenchikov, G., K. Hamilton, R. Stouffer, B. Santer, A. Robock, V. Ramaswamy and H.-F. Graf: Climate impacts of volcanic eruptions in the IPCC AR4 climate models. *J. Geophys. Research-Atmospheres.*

Stowasser, M., K. Hamilton, and G.J. Boer: Local and global climate feedbacks in models with differing climate sensitivities. *J. Climate.*

Stowasser, M., and K. Hamilton: Relationship between shortwave cloud radiative forcing and local meteorological variables compared in observations and several global climate models. *Journal of Climate.*

Tam, C.-Y., and T. Li: The origin and dispersion characteristics of the observed summertime synoptic-scale waves over the western Pacific. *Mon. Wea. Rev.*

Timmermann, A., U. Krebs, F. Justino, and H. Goosse: Oceanic synchronization mechanism for millennial-scale global variability during the last glacial period. *Paleoceanography.*

Wang, B., and S.-I. An: A method for detecting season-dependent modes of climate variability: S-EOF analysis. *Geophys. Res. Lett.*

Wang, B., P. Webster, K. Kikuchi, T. Yasunari, and Y. Qi: Quasi-monthly monsoon oscillation: A satellite perspective and mechanisms. *Climate Dyn.*

Wang, B., X. Fu, Q. Ding, I.-S. Kang, K. Jin, J. Shukla, and F. Doblas-Reyes: Challenges in prediction of summer monsoon rainfall: Inadequacy of the tier two systems. *J. Climate.*

Wang, Z., C.-P. Chang, B. Wang, and F.-F. Jin: Teleconnection from tropics to northern extratropics through a southerly conveyor. *J. Climate.*

Watanabe, Y.W., Y. Nakano, H. Yoshinari, A. Sakamoto, N. Kasamatsu, T. Midorikawa, and T. Ono: Reconstruction of dimethylsulfide in the North Pacific surface water during 1970s to 2000s. *Geophys. Res. Lett.*

Wu, L., B. Wang, and S.A. Braun: Impacts of the air–sea interaction on tropical cyclone motion and intensity. *J. Atmos. Sci.*

Xie, S.-P., H. Xu, N.H. Saji, Y. Wang, and W.T. Liu: Role of narrow mountains in large-scale organization of Asian monsoon convection. *J. Climate.*

Yaremchuk, M., and T. Qu: On the possibility of an oceanic teleconnection within the Southeast Asian monsoon system. *J. Climate.*

Yaremchuk M., Z. Yu, and J. McCreary 2005: River discharge into the Bay of Bengal in an inverse ocean model. *Geophys. Res. Lett.*

Zelle, H., G.J. van Oldenborgh, G. Burgers, S.-I. An, and F.-F. Jin: Warm pool El Niño's. *J. Phys. Oceanogr.*

Zhang, Y., and T. Li: Influence of the sea surface temperature in the Indian Ocean on the relationship between the South Asian and North Australian summer seasons. *J. Climate.*

Zhou, T., M. Geller, and K. Hamilton: The role of the Hadley Circulation and downward control in tropical upwelling. *J. Atmos. Sci.*

EXTERNAL PRESENTATIONS

An, S.-I.: *Does ENSO lead Pacific decadal change?* Chapman Conference on Tropical-Extratropical Climatic Teleconnections: A Long-Term Perspective, February 2005, Honolulu, Hawai‘i.

An, S.-I.: *Does ENSO lead Pacific interdecadal change?* The 85th Annual Meeting of the American Meteorological Society, January 2005, San Diego, California.

An, S.-I.: *Interdecadal changes in the nonlinearity of ENSO.* The 13th Conference on Interactions of the Sea and Atmosphere, August 2004, Portland, Maine.

An, S.-I.: *Nonlinearity of ENSO and its interdecadal changes.* Western Pacific Geophysics Meeting, August 2004, Honolulu, Hawai‘i.

An, S.-I.: *Is El Nino linear or nonlinear?* Seminar at Climate Environment System Research Center, Seoul National University, July 2004, Seoul, Korea. (Invited)

An, S.-I.: *ENSO dynamics during LGM.* First International CLIVAR Science Conference, June 2004, Baltimore, Maryland.

Annamalai, H.: *Possible role of Indian Ocean SST anomalies on the Northern Hemispheric circulation during El Niño years.* University of Tokyo, March 2005, Tokyo, Japan.

Annamalai, H.: *Possible role of Indian Ocean SST on El Niño, Asian monsoons and Northern Hemispheric circulation.* Program for Climate Modeling and Diagnosis and Intercomparison, Lawrence Livermore National Laboratory, December 2004, Livermore, California. (Invited)

Annamalai, H.: *Role of ENSO-induced Indian Ocean SST on the Asian monsoons.* American Geophysical Union 2004 Fall Meeting, December 2004, San Francisco, California. (Invited)

Du, Y.: *Seasonal variation of the upper ocean stratification in the South China Sea.* Western Pacific Geophysics Meeting, August 2004, Honolulu, Hawai‘i.

Fu, J.X.: *A hybrid coupled general circulation model (GCM) and its applications.* National Taiwan University, December 2004, Taipei, Taiwan. (Invited)

Fu, J.X.: *The tropical Asian-Pacific climate simulated in a hybrid coupled GCM.* National Taiwan Normal University, December 2004, Taipei, Taiwan. (Invited)

Fu, X.: *Representing tropical intraseasonal oscillation (TISO) in a hybrid coupled model.* The 26th Conference on Hurricanes and Tropical Meteorology, May 2004, Miami, Florida.

Fu, X., and B. Wang: *Two different ISO solutions exist in an ocean–atmosphere coupled system and an atmosphere-only system.* Western Pacific Geophysics Meeting, August 2004, Honolulu, Hawai‘i.

Fu, X., B. Wang, and F.-F. Jin: *ENSO-to-decadal variations simulated in a hybrid coupled GCM.* The 13th Conference on interactions of the sea and atmosphere, August 2004, Portland, Maine.

Fu, X., B. Wang, and F.-F. Jin: *Representation of ENSO-to-decadal variations in a hybrid coupled GCM.* Western Pacific Geophysics Meeting, August 2004, Honolulu, Hawai‘i.

Fu, X., F.-F. Jin, and B. Wang: *Monsoonal impacts on Pacific cold-tongue strength and its implications for cold bias in coupled GCMs.* First CLIVAR International Conference, June 2004, Baltimore, Maryland.

Fu, X., and B. Wang: *Important roles of atmosphere-ocean interactions on realistic simulation of tropical intraseasonal oscillation.* The 26th Conference on Hurricanes and Tropical Meteorology, May 2004, Miami, Florida.

Furue, R., J.P. McCreary, Z. Yu, and D. Wang: *Dynamics of the Tsuchiya Jets: An arrested front in an OGCM.* IORGC/FRCGC Annual Symposium, March 2005, Yokohama, Japan. Also given at the Spring Meeting of the Oceanographic Society of Japan, The Tokyo University of Marine Science and Technology, March 2005, Tokyo, Japan.

Hamilton, K.: *Results from ultrafine resolution global atmospheric models.* Marine Sciences Research Center, Stony Brook University, October 2004, Stony Brook, New York; also given at the Geophysical Fluid Dynamics Laboratory, Princeton University, October 2004, Princeton, New Jersey. (Invited)

Hamilton, K. *Gravity waves in explicit fine resolution global models.* AGU Western Pacific Geophysics Meeting, August 2004, Honolulu, Hawaii.

Hamilton, K.: *Effect of the tropical quasi-biennial oscillation on tropospheric circulation.* Third SPARC General Assembly, August 2004, Victoria, Canada.

Hamilton, K.: *Dynamical stratospheric influence on tropospheric circulation.* Atmospheric Sciences Program,

University of British Columbia, July 2004, Vancouver, Canada. (Invited)

Jensen, T.: *Wind-driven response of the northern Indian Ocean to climate extremes.* CLIVAR "Indian Ocean Modeling Workshop", November 2004, Honolulu, Hawai'i.

Li, T.: *Tropical cyclone initialization and data assimilation.* Naval Research Laboratory, December 2004, Monterey, California.

Li, T.: *Seasonal, intraseasonal and interannual variabilities of the WNP monsoon.* International Workshop on Tropical Weather and Climate, November 2004, Guangzhou, China.

Li, T.: *Western North Pacific monsoon climate variability. World Meteorological Organization.* Third International Workshop on Monsoons (IWM-III), November 2004, Hangzhou, China.

Li, T.: *Application of Advanced Microwave Sounding Unit (AMSU) products to tropical cyclone forecast.* Shanghai Typhoon Institute, August 2004, Shanghai, China.

Li, T.: *Role of annual cycle of SST in Asian-Australian monsoon intensity and phase transition.* First Asia Oceanic Geosciences Society Meeting, July 2004, Singapore.

Li, T.: *Structure and mechanism of northward propagating boreal summer intraseasonal oscillation.* Institute of Atmospheric Physics, June 2004, Beijing, China.

Magaard, L.: *Climate and society.* National Central University, November 2004, Chungli, Taiwan; also given at the Chinese Culture University, November 2004, Taipei, Taiwan; and at the National Taiwan University, November 2004, Taipei, Taiwan. (Invited)

Magaard, L.: *The International Center for Climate and Society (ICCS) at the University of Hawai'i.* APEC (Asia-Pacific Economic Cooperation) Climate Network Meeting, November 2004, Busan, Korea. (Invited)

Magaard, L.: *The new International Center for Climate and Society (ICCS) at the University of Hawai'i.* Central Weather Bureau, November 2004, Taipei, Taiwan. Also given at the National Science and Technology Center for Disaster Reduction, Taipei, Taiwan. (Invited)

Maximenko, N.A., P.P. Niiler, B. Cornuelle, and W.T. Liu: *The dynamics of ocean surface circulation from altimeter and Lagrangian drifter data.* The Second GODAE Symposium, November 2004, St. Petersburg, Florida.

Maximenko, N.A., P.P. Niiler, B. Cornuelle, Y.Y. Kim, and W.T. Liu: *The dynamics of ocean surface circulation studied using altimeter, Lagrangian drifter and wind data.* NASA Ocean Surface Topography Science Team Meeting, November 2004, St. Petersburg, Florida.

Maximenko, N.A., and P.P. Niiler: *Improved decade-mean sea level of the North Pacific with mesoscale resolution.* The 13th Annual Meeting of the North Pacific Marine Science Organization (PICES), October 2004, Honolulu, Hawai'i.

Maximenko, N.A., and P.P. Niiler: *Dynamically balanced decade-mean global sea level at mesoscale resolution.* The 25th IUGG International Meeting on Mathematical Geophysics "Frontiers in Theoretical Earth Science", Columbia University, June 2004, New York, New York.

Maximenko, N.A., P.P. Niiler, J.C. McWilliams, and C.J. Koblinsky: *Dynamical balance of the upper ocean from in situ and remote observations.* The First International CLIVAR Science Conference "Understanding and Predicting Our Climate System", June 2004, Baltimore, Maryland.

Maximenko, N.A., P.P. Niiler, J.C. McWilliams, and C.J. Koblinsky: *Dynamically balanced decade-mean sea level derived from drifter and satellite data.* PACON 2004 "New Technologies, New Opportunities", Waikiki Beach Marriot Resort, May 2004, Honolulu, Hawai'i.

McCreary, J.P.: *Indian Ocean Modeling-Problems and Prospects.* Indian Ocean Modeling Workshop, November 2004, Honolulu, Hawai'i. (Invited)

Okumura, Y. and S.-P. Xie: *Interaction of the Atlantic equatorial cold tongue and African monsoon.* AMS 13th Conference on interactions of the sea and atmosphere, Portland, Maine, August 2004.

Okumura, Y., and S.-P. Xie: *Overlooked November-December cooling of the Equatorial Atlantic and its effects on interannual variability and predictability.* CLIVAR Atlantic Workshop, Miami, Feb 2005

Potemra, J.: *Influence of low-frequency Indonesian Throughflow transport variations on temperatures in the Indian Ocean in a coupled model.* Department of Energy Annual Meeting, October 2004, Seattle, Washington. (Poster)

Potemra, J.: *Depth variability of Indonesian Throughflow inflow and outflow transport from OFES.* Western Pacific Geophysics Meeting, August 2004, Honolulu, Hawai'i.

Potemra, J.: *Low-frequency changes in upper-ocean temperatures in the Indian Ocean and the Indonesian Throughflow.* First Asia Oceania Geosciences Society Annual Meeting, July 2004, Singapore.

Potemra, J.: *Variability of the Indonesian Throughflow and its effect on climate in the Indian Ocean.* Louisiana State University, May 2004, Baton Rouge, Louisiana. (Invited)

Qu, T.: *Deepwater overflow through Luzon Strait.* International Workshop on Dynamic Processes/Circulation in the Yellow, East and South China Seas, November 2004, Qingdao, China. (Invited)

Qu, T.: *Luzon Strait Transport and its influence on the South China Sea thermal balance.* Western Pacific Geophysics Meeting, August 2004, Honolulu, Hawai'i. (Invited)

Richards, K.J.: *Stirring and mixing.* Los Alamos National Laboratory, August 2004, Los Alamos, New Mexico.

Richards, K.J.: *The impact of stirring and mixing on the marine ecosystem.* European Geophysical Union Symposium, April 2004, Nice, France. (Invited)

Richards, K.J.: *Impact of physical processes on the Marine Ecosystem.* LODYC, April 2004, Paris, France.

Schneider, N.: *The forcing of the Pacific Decadal Oscillation.* Climate Research Division, Scripps Institution of Oceanography, April 2004, La Jolla, California; also given at the Department of Oceanography, University of Hamburg, November 2004, Hamburg, Germany; and at the Leibniz-Institut fuer Meereswissenschaften, University of Kiel, November 2004, Kiel, Germany. (Invited)

Schneider, N.: *The forcing of the Pacific Decadal Oscillation.* PICES, 13th Annual Meeting, October, 2004, Honolulu, Hawai'i. (Invited)

Schneider, N., and S. Minobe: *Pacific decadal variability: A review.* First International CLIVAR Conference, June 2004, Baltimore, Maryland.

Small, R.J., S.-P. Xie, K.J. Richards, D.B. Chelton, and B.E. Mapes: *Air–sea coupling in Tropical Instability Waves.* Western Pacific Geophysics Meeting, August 2004, Honolulu, Hawai'i.

Small, R.J., S.-P. Xie, and J. Hafner: *Atmospheric response to mesoscale ocean features in the Pacific Ocean.* Eleventh Pacific Congress on Marine Science and Technology (PACON 2004), May 2004, Honolulu, Hawai'i. To be published in Recent Advances in Marine Sciences and Technology, 2004.

Stowasser, M.: *Climate Sensitivity and Response: Comparisons Between NCAR and CCCma GCM Results.* Western Pacific Geophysics Meeting, August 2004, Honolulu, Hawai'i.

Timm, O.: *Are coral proxies capable of detecting climatic shifts in teleconnection patterns?* Chapman Conference on Tropical-Extratropical Climatic Teleconnections, A Long-Term Perspective, February 2005, Honolulu, Hawai'i.

Timmermann, A.: *Mechanisms for global centennial to millennial climate change.* Frontier Annual Symposium, March 2005, Yokohama, Japan.

Timmermann, A.: *Pan-oceanic connections on centennial to millennial timescales.* Chapman Conference on Tropical-Extratropical Climatic Teleconnections: A Long-Term Perspective, February, 2005, Honolulu, Hawai'i.

Timmermann, A.: *Biological feedbacks in the tropical Pacific.* 2004 AGU Fall Meeting, December 2004, San Francisco, California.

Timmermann, A.: *Decadal El Niño Bursting.* Western Pacific Geophysics Meeting, August 2004, Honolulu, Hawai'i.

Wang, B.: *Current status and challenges in seasonal prediction.* Workshop on coupled model simulation and assimilation, January 2005, Yokohama, Japan. (Invited)

Wang, B.: *Toward prediction of Asian summer monsoon variability.* LASG/IAP Annual Meeting, January 2005, Beijing, China. (Invited)

Wang, B.: *Interannual variability and predictability of Asian monsoon: How important is the monsoon-ocean interaction?* International Symposium on Tropical Weather and Climate, November 2004, Guangzhou, China. (Invited)

Wang, B.: *Summer monsoon intraseasonal oscillation: A satellite view and interpretation.* National Central University, November 2004, Chung Li, Taiwan. (Invited)

Wang, B.: *Current status and problems in ensemble hindcast of rainfall in tropical Asian-Pacific regions.* AGU Western Pacific Geophysics Meeting, August 2004, Honolulu, Hawai'i. (Invited)

Wang, B.: *Dynamics of Boreal Summer Intraseasonal Oscillation.* Hydrospheric and Atmospheric Research Center, Nagoya University, July 2004, Nagoya, Japan. (Invited)

Wang, B.: *Impacts of the monsoon-warm ocean interaction on the variability of the Asian-Australian Monsoon System.* First Joint Meeting of the Asia Oceanic Geophysical Society and the Asia Pacific Association of Hydrology and Water Resources, July 2004, Singapore. (Invited)

Wang, B.: *Interannual variability and predictability of the Asian-Australian Monsoon.* Frontier Research Center for Global Change, July 2004, Yokohama, Japan. (Invited)

Wang, B., O. Sen, and Y. Wang: *Impacts of Re-Greening the Desertified NW China: Implications from a RCM Ensemble Experiment.* Sixth International Study Conference on GEWEX in Asia and GAME, December 2004, Kyoto, Japan. (Invited)

Wang, B., Y. Ding, T. Li, R. Zhang, and H. Wang: *Overview of the East Asian-western North Pacific monsoon.* WMO 3rd monsoon IWM-III, November 2004, Hangzhou, China. (Invited)

Wang, B., P.J. Webster, and H. Teng: *Antecedents of Active-Break Periods of the Indian Summer Monsoon.* Kyoto University, July 2004, Kyoto, Japan. (Invited)

Wang, B., X. Fu, and T. Li: *Dominant mode of Asian-Australian Monsoon variability and the Role of Monsoon-Ocean interaction.* First Joint Meeting of the Asia Oceanic Geophysical Society and the Asia Pacific Association of Hydrology and Water Resources, July 2004, Singapore. (Invited)

Wang, Y.: *Regional coupled ocean atmosphere models in the Southeast Pacific.* VAMOS Modeling Workshop, March 2005, Mexico City, Mexico. (Invited)

Wang, Y.: *A Regional Atmospheric Inter-Model Evaluation (RAIME) Project for Simulations of Diurnal Cycle of Clouds and Precipitation (DCCP).* The Fourth CEOP Implementation Planning Meeting, February 2005, Tokyo, Japan.

Wang, Y.: *Some issues related to regional climate modeling and an introduction to the RAIME Project.* The 4th Workshop of Regional Climate Model Studies, Seoul National University, January 2005, Seoul, Korea. (Invited)

Wang, Y.: *Regional model simulations of marine boundary layer clouds over the Southeast Pacific off South America.* Seoul National University, December 2004, Seoul, Korea. (Invited)

Wang, Y.: *An overview of regional climate modeling for East-Asian monsoon system.* The 6th International Study Conference on GEWEX in Asia and GAME, December 2004, Kyoto, Japan.

Wang, Y.: *The effect of internally generated inner core asymmetric structure on tropical cyclone intensity.* National Taiwan University, November 2004, Taipei, Taiwan. (Invited)

Wang, Y.: *On the effect of internally generated inner core asymmetries on tropical cyclone intensity.* International Symposium on Tropical Weather and Climate, November 2004, Guangzhou, China. (Invited)

Wang, Y.: *Regional climate modeling at IPRC.* Nanjing Institute of Meteorology, July 2004, Nanjing, China. (Invited)

Wang, Y.: *Simulation of stratocumulus clouds over the Southeast Pacific.* LASG, Institute of Atmospheric Physics, July 2004, Beijing, China. (Invited)

Wang, Y.: *Partial eye-wall replacement and rapid tropical cyclone intensity changes.* International Chinese Ocean–Atmosphere Conference, June 2004, Beijing, China.

Wang, Y.: *How much vertical shear can a well-developed tropical cyclone resist?* The 26th Conference on Hurricanes and Tropical Meteorology, May 2004, Miami, Florida.

Wang, Y.: *Regional climate modeling: Progress, challenges, and prospects.* Regional-scale Climate Modeling Workshop, WCRP-sponsored, March–April 2004, Lund, Sweden. (Invited)

Xie, S.-P.: *Orographically triggered air–sea interaction over the eastern Pacific warm pool.* NASA Ocean Vector Wind Science Team Meeting, March 2005, Seattle, Washington.

Xie, S.-P.: *Observations and modeling of Eastern Pacific Ocean-atmosphere interaction.* Cooperative Institute for Marine and Atmospheric Sciences, University of Miami, February 2005, Key Biscayne, Florida. (Invited)

Xie, S.-P.: *Seasonal and interannual variability of tropical Atlantic climate.* Cooperative Institute for Marine and Atmospheric Sciences, University of Miami, February 2005, Key Biscayne, Florida. (Invited)

Xie, S.-P.: *Decipher tropical Atlantic climate variability.* International workshop on variability and predictability of the Earth climate system, January 2005, Tokyo, Japan. (Invited)

Xie, S.-P.: *Rich structures of air–sea interaction revealed by satellite*. American Meteorological Society 13th Conference on interactions of the sea and atmosphere, August 2004, Portland, Maine. (Invited) Also given at the AGU Western Pacific Geophysical Meeting, August 2004, Honolulu, Hawai‘i.

Xie, S.-P.: *Current Issues of Air–Sea Interaction and Climate Research*. Ocean University of China, June 2004, Qingdao, China.

Xie, S.-P.: *Evidence for extratropical air–sea interaction from satellite observations*. CLIVAR International Science Conference, June 2004, Baltimore, Maryland.

Xie, S.-P.: *Air–Sea Interaction in Monsoonal Asian Seas*. Fourth International Symposium on Asian Monsoon (ISAM4), May 2004, Kunming, China. (Invited)

Xie, S.-P.: *Interaction of ocean fronts with atmospheric fronts*. Special session on storm tracks, Spring Meeting of Meteorological Society of Japan, May 2004, Tokyo, Japan.

Xie, S.-P.: *Ocean–Atmosphere Interaction over Monsoon Seas of Asia*. South China Sea Institute of Oceanology, Chinese Academy of Sciences, May 2004, Guangzhou, China.

Xie, S.-P.: *Orographically Induced Air–Sea Interaction*. IPRC Annual Symposium, May 2004, Honolulu, Hawai‘i.

Xie, S.-P., H. Xu, Y. Wang, and J. Small: *Regional coupled ocean–atmosphere modeling*. Workshop on Coupled Model Simulation and Assimilation, January 2005, Yokohama, Japan. (Invited)

Xie, S.-P., M. Nonaka, Y. Tanimoto, H. Tokinaga, H. Xu, W.S. Kessler, W.T. Liu, R.J. Small, J. Hafner, Q. Liu, and G.A. Vecchi: *Satellite observations of South China Sea-atmosphere interaction*. AGU Western Pacific Geophysical Meeting, August 2004, Honolulu, Hawai‘i.

Xie, S.-P., and B. Taguchi: *Preliminary results from radiosonde observations and regional atmospheric model simulation*. First Workshop on Joint Ocean-Atmospheric Measurements near the Kuroshio Extension (JOAMME), May 2004, Tokyo, Japan.

Yaremchuk, M.: *Impact of the Luzon Strait transport on SST east of Vietnam*. Workshop on inverse modeling of the Indonesian Seas, June 2004, Stennis Space Center, Mississippi.

Yaremchuk, M., K. Lebedev, H. Mitsudera, I. Nakano, and G. Yuan: *Combining acoustic tomography with space-borne and in situ observations of an open ocean region*. The 35th COSPAR Scientific Assembly, July 2004, Paris, France.

Yoshinari, H., I. Yasuda, T. Kono, Y. Matsuo, and Y. Shimizu: *Formation and transport processes of North Pacific Intermediate Water in the Kuroshio-Oyashio interfrontal zone with considering cabbeling*. Fall Meeting of the Oceanographic Society of Japan, September 2004, Matsuyama, Japan.

Yoshinari, H., I. Yasuda, T. Kono, Y. Matsuo, and Y. Shimizu: *Advanced analysis of formation and transport processes of North Pacific Intermediate Water in the Kuroshio-Oyashio interfrontal zone*. Western Pacific Geophysics Meeting, August 2004, Honolulu, Hawai‘i.

Yu, Z.: *Research data sets via internet and their applications*. Ocean University of China Qingdao, June 2004, Qingdao, China. Also given at the Meteorological Bureau of Shangdong Province, June 2004, Jinan, China.

Yu, Z.: *Using SSS observation to assess precipitation products in the open ocean*. Chinese American Oceanic and Atmospheric Association 2004 Conference, June 2004, Beijing, China.

Yu, Z., and J. Potemra: *Plausible causes for the intraseasonal variability in the Indo-Australia Basin*. Indian Ocean Modeling Workshop, November 2004, Honolulu, Hawai‘i.

Yu, Z., Y. Du, J. Hafner, and S. Sheng: *A modeling attempt to simulate the South China Sea during the summer of 1999*. First Asia Oceanic Geosciences Society Meeting, July 2004, Singapore.

Yu, Z., J.P. McCreary, and P. Hacker: *Using sea surface salinity observations to assess precipitation products in the open ocean*. Aquarius/SAC-D - SMOS - HYDROS Joint Science and Implementation Workshop, April 2004, Miami, Florida.

Zhang, Y.: *Atmospheric and satellite data service in the Asia-Pacific Data-Research Center*. LASG, Institute of Atmospheric Physics, Beijing, China. July 2004. Also given at the National Meteorological Information Centre, China Meteorological Administration, June 2004, Beijing, China; and Department of Meteorology, University of Yunnan, Kunming, China, July 2004, Beijing, China.

Zhang, Y.: *Decadal Change of the Spring Snow Depth over the Tibetan Plateau*. The Third International Ocean–Atmosphere Conference, June 2004, Beijing, China. Also given at the National Climate Centre, China Meteorological Administration, July 2004, Beijing, China.

SCHOLARS VISITING THE IPRC

The IPRC has a visiting scholar program. From April 2004 to March 2005, the following scholars visited the IPRC for one week or more.

Scholar	Affiliation	Dates
Porathur Joseph	Cochin University of Science and Technology, Cochin, India	3/2/–5/30/2004
Jinwon Kim	University of California, Los Angeles, California	4/4–9/2004
Jyh–Wen Hwu	Central Weather Bureau, Taipei, Taiwan	4/15–10/14/2004
Frederic Million	Université de la Méditerranée, Marseille, France	4/26–5/4/2004
Yunfei Fu	University of Science & Technology of China, Beijing, China	5/1–8/31/2004
Krishna Raghavann	Indian Institute of Tropical Meteorology, Pune, India	6/25–7/2/2004
Benjamin Giese	Texas A & M University, College Station, Texas	7/8–12/13/2004
Ingo Kirchner	Freie Universität, Berlin, Germany	7/19–7/27/2004
Dongxiao Wang	South China Sea Institute of Oceanology, Guangzhou, China	8/11–/8/17/2004
Rieko Suzuki	Frontier Research Center for Global Change, Yokohama, Japan	8/21–8/25/2004
Ya Hsueh	Florida State University, Tallahassee, Florida	8/23–8/27/2004
Guang Jun Zhang	University of California, San Diego, California	8/23–8/28/2004
Min–Ho Kwon	Seoul National University, Seoul, Korea	10/1–12/9/2004
Roland Madden	National Center for Atmospheric Research, Boulder, Colorado	10/1–11/30/2004
Jing Yang	Institute of Atmospheric Physics, Beijing, China	10/4–9/5/2005
Gleb Panteleev	International Arctic Research Center, Anchorage, Alaska	10/7–10/14/2004
Fritz Schott	University of Kiel, Kiel, Germany	10/15–12/14/2004
Dunxin Hu	Chinese Academy of Sciences, Beijin, China	10/21–10/30/2004
Keith Rodgers	Université Pierre et Marie Curie, Paris, France	10/22–10/28/2004
Yolande Serra	University of Washington, Seattle, Washington	10/25–11/24/2004
Zhanyu Yao	Chinese Academy of Meteorological Sciences, Beijing, China	11/13–11/18/2004
Jong–Seong Kug	Seoul National University, Seoul, Korea	11/14–12/18/2004
Kenneth Sperber	Lawrence Livermore National Laboratory, Livermore, California	11/15–11/26/2004
Julia Slingo	University of Reading, Reading, United Kingdom	11/15–11/19/2004
Anthony Slingo	University of Reading, Reading, United Kingdom	11/15–11/19/2004
Gary Meyers	CSIRO Division of Marine Research, Hobart, Australia	11/21–12/12/2004
Pearn P. Niiler	University of California, San Diego, California	11/25–12/9/2004
C. Gnanaseelan	Indian Institute of Tropical Meteorology, Pune, India	11/29–12/8/2004
P.N. Vinayachandran	Indian Institute of Science, Bangalore, India	11/29–12/11/2004
Rahul Reddy	Indian Institute of Tropical Meteorology, Pune, India	11/29–12/10/2004
Hengyi Weng	National Marine Data and Information Service, China	11/29–12/3/2004
In–Sik Kang	Seoul National University, Seoul, Korea	12/28–2/27/2005
Tim Swartz	Simon Fraser University, Vancouver, British Columbia, Canada	1/12–1/22/2005
George Boer	University of Victoria, Victoria, British Columbia, Canada	1/26–2/25/2005
Bo Young Yim	Yonsei University, Seoul, Korea	2/1–2/26/2005
Richard Neale	NOAA–CIRES Climate Diagnostics Center, Boulder, Colorado	2/21–2/25/2005
Rui–Xin Huang	Woods Hole Oceanographic Institution, Woods Hole, Massachusetts	3/1–3/7/2005
Andrey Shcherbina	Woods Hole Oceanographic Institution, Woods Hole, Massachusetts	3/5–3/11/2005
Masahiro Watanabe	Hokkaido University, Sapporo, Japan	3/5–3/11/2005

MEETINGS HOSTED

The IPRC hosts meetings allied to the work in its five research themes. The larger conferences, some of which draw over one hundred participants, are usually held at the East-West Center in Honolulu; others are small working meetings, often called together on short notice at the IPRC conference room in order to take advantage of the presence of scientists visiting Honolulu and the IPRC.

Fourth Annual IPRC Symposium

Every spring, the IPRC holds a symposium at which IPRC scientists give formal presentations on highlights of their research findings during the past year. The yearly sharing is a time to pause and reflect upon the progress that has been made in understanding climate phenomena, particularly for the Asia-Pacific region. The 2004 symposium was held May 13–14 at the East-West Center.

APDRC Workshop on Argo Regional Application Center

The APDRC is participating with the national data centers of India and Australia to develop an Argo regional Indian Ocean data center and with JAMSTEC to develop a regional Pacific Ocean data center. To coordinate the work among these partnerships, a meeting was held June 28–30, 2004 in the IPRC conference room.

Tropical Cyclone Mini-workshop

The Workshop on Tropical Cyclones brought together a group of tropical cyclone scientists who were attending the Western Pacific Geophysics Meeting in Honolulu during August 2004. Held at the IPRC on August 20, the meeting included discussion of large- and mesoscale aspects of cyclone formation, structure and intensity changes, and the effect of climate change on tropical cyclones. The most pressing issues concern the role of the Madden-Julian Oscillation in the genesis of tropical cyclones, understanding processes that lead to their formation and intensity changes, development of methods to improve intensity forecasts, and determining their cooling effects.

Ocean–Atmosphere Modeling at the Earth Simulator Center

The IPRC Ocean–Atmosphere Modeling mini-workshop, held at the School of Ocean and Earth Science and Technology on August 24, 2004, brought together scientists from the Earth Simulator Center and other scientists interested in analyses of the climate models being run on the Earth Simulator. The first results of a high-resolution simulation with the Ocean GCM for the Earth Simulator (OFES) were presented. Two findings are noteworthy: (1) the model showed surprisingly well-organized swift currents at great depths, alternating in narrow bands between eastward and westward flows, and (2) slow ocean variations in the upper 500 meters are associated with the movement of huge amounts of heat from one region to another. Such shifts could affect storm tracks and storm intensity.

Tropical Intraseasonal Variability Mini-Workshop

This workshop on the Madden-Julian Oscillation (MJO), held at the IPRC on November 19, 2004, brought together specialists on this atmospheric disturbance. The meeting included a retelling by Roland Madden (NCAR) of his and Paul Julian's discovery of the MJO, a review by Ken Sperber (Lawrence Livermore Laboratories) of simulations of the MJO in coupled and uncoupled models, and a portrayal of the challenges facing MJO modeling by Julia Slingo (NERC Centres for Atmospheric Science). A lively discussion followed the presentations. Though much has been learned about the dynamics of the MJO, what sets the MJO in motion remains a question.

Indian Ocean Modeling Workshop

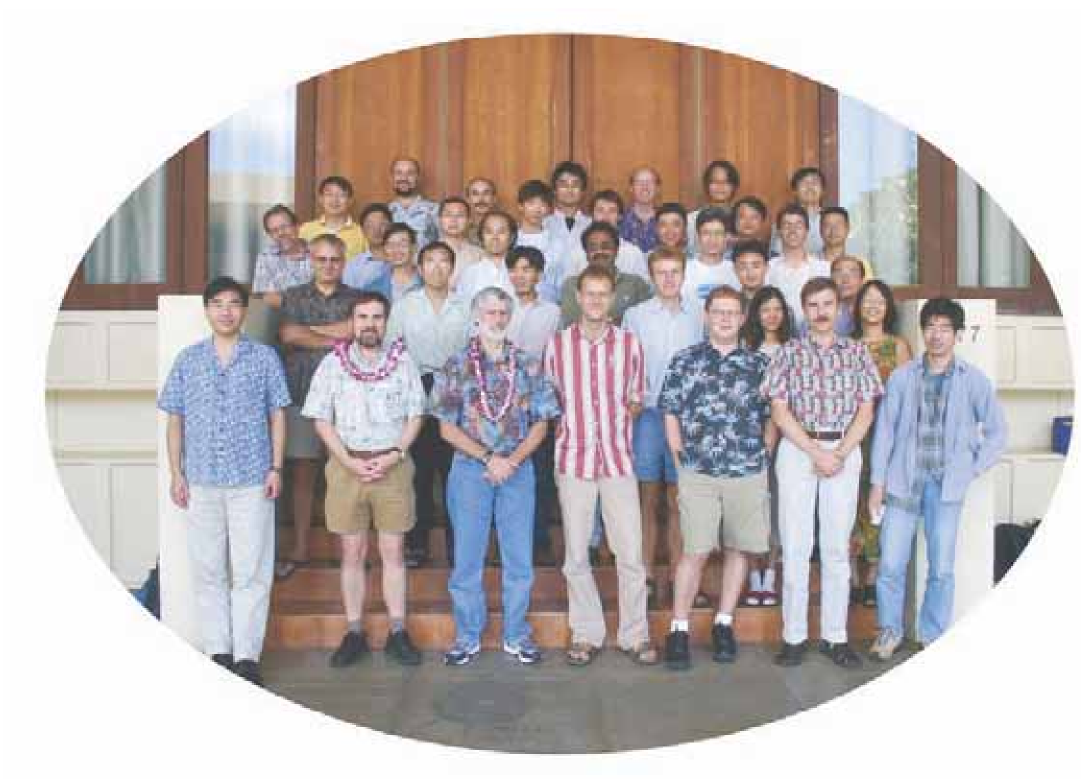
The Indian Ocean Modeling Workshop was held at the East-West Center from November 29 to December 3, 2004. This international meeting was called to discuss the development of the integrated *in situ* observing system in the Indian Ocean, consisting of surface moorings, flux reference sites, Acoustic Doppler Current Profilers, and expendable-bathythermograph and carbon lines. The presentations included reviews of regional climate and ocean dynamics, diagnostic studies, and outputs from numerical models. The model studies supported most of the original plan for placing the measuring instruments, but also contributed valuable information on modifications to the plan. Sponsors for this meeting were the World Climate Research Programme, the Joint Institute for Marine and Atmospheric Research, and the IPRC.

Chapman Conference on Tropical-Extratropical Climatic Teleconnections: A Long-Term Perspective

In bringing together atmospheric scientists, oceanographers, and paleoclimatologists to discuss the issue of tropical-extratropical climate teleconnections, this international conference gave scientists of modern-day climate a better understanding of paleoclimate records, and scientists of past climates an opportunity to place their records into the larger context of climate processes. Proxy records of past climates were shown to be very useful in documenting the nature of past climate change. The presentations suggested that on orbital time scales atmospheric CO_2 was a primary factor in tropical SST changes, whereas on millennial time scales, it was such changes as influx of freshwater in the North Atlantic Ocean, which evoked responses as far away as the tropical Pacific. The conference was held February 8–11, 2005, at the East-West Center; sponsors were the National Science Foundation, Past Global Changes, and the IPRC.

Workshop on Analyses of Climate Model Simulations for the IPCC Fourth Assessment Report

In preparation for the *Fourth Assessment Report on Climate Change* to be published by the Intergovernmental Panel on Climate Change in 2007, the IPRC hosted a meeting that provided the scientific community with a forum for presenting results on analyses of outputs from the global circulation models that will be used in this fourth report. Though the climate models still have many uncertainties, their evidence for the link between increasing greenhouse emissions from human activities and the warming over recent decades is stronger than in the previous report. The meeting was convened by U.S. CLIVAR and was held at the East-West Center in Honolulu, March 1–4, 2005.



Symposium organizer Kevin Hamilton and Director Julian McCreary (wearing leis) with IPRC scientists at the Fourth Annual IPRC Symposium in front of Jefferson Hall at the East-West Center.

IPRC SEMINARS

Date	Speaker	Affiliation	Seminar Title
March 31, 2005*	Axel Timmermann	International Pacific Research Center and Department of Oceanography, University of Hawai'i	*Paleo-ENSO*
March 9, 2005	Dongxiao Zhang	NOAA-PMEL, Seattle, Washington	*Decadal variability of the shallow meridional overturning circulation in the Pacific*
March 8, 2005	Andrey Shcherbina	Woods Hole Oceanographic Institution, Woods Hole, Massachusetts	*North Pacific ventilation: Brine rejection and dense water formation in the Okhotsk Sea*
March 7, 2005	Humio Mitsudera	Hokkaido University, Sapporo, Japan	*Modeling the clockwise circulation in the southern Sea of Okhotsk*
March 4, 2005**	Sumant Nigam	Department of Meteorology & ESSIC University of Maryland	*Warm-season hydroclimate variability over the Great Plains in observations, re-analysis, and atmospheric model simulations*
February 28, 2005**	Masaru Inatsu	Center for Climate System Research, University of Tokyo, Japan	*Mid-latitude storm-track response to terrestrial and global warming forcings*
February 23, 2005**	Jagadish Shukla	Climate Dynamics, George Mason University, Virginia and Institute of Global Environment and Society, Maryland	*From weather forecasting to climate prediction*
February 22, 2005	Richard Neale	NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado	*The sensitivity of convection to the large-scale atmosphere: Theories, observations, and simple models*
February 11, 2005	Peter J. Webster	School of Earth and Atmospheric Sciences & Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, Georgia	*Slow manifold modeling of the Monsoon Intraseasonal Oscillation*
February 10, 2005***	Rui-Xin Huang	Woods Hole Oceanographic Institute, Woods Hole, Massachusetts	*Energetics of the oceanic general circulation*
February 2, 2005	In-Sik Kang	School of Earth and Environmental Sciences, Seoul National University, Korea	*Role of atmospheric-ocean interaction in seasonal predictability*
January 24, 2005**	Yihui Ding	National Meteorological Centre, China Meteorological Administration, Beijing, China	*Climate change in China and its possible cause*
December 13, 2004	Gerald Meehl	National Center for Atmospheric Research, Boulder, Colorado	*The IPCC process, monsoon simulation in CCSM3, and low-frequency changes of El Niño*
December 9, 2004*	Benjamin Giese	Department of Oceanography, Texas A&M University, College Station, Texas	*Tropical Pacific decadal variability in SODA POP 1.2*
November 18, 2004	Julia Slingo	NCAS Centre for Global Atmospheric Modelling, University of Reading, United Kingdom	*Climate in a changing world: CGAM's research programme in understanding and modelling the climate system*

Date	Speaker	Affiliation	Seminar Title
November 18, 2004	R. Justin Small	International Pacific Research Center	*Internal wave conversion in the South China Sea*
November 16, 2004	Tony Slingo	Environmental Systems Science Centre, University of Reading, United Kingdom	*Evaluation of radiation and clouds in the Met Office NWP model using geostationary satellite data and surface observations from ARM sites*
November 10, 2004**	Francis Tam	International Pacific Research Center	*Observations of synoptic-scale disturbances of the western Pacific easterlies*
October 27, 2004	Dunxin Hu	Institute of Oceanology, Chinese Academy of Sciences, Qingdao, China	*On the summer circulation in the southern Yellow Sea*
October 27, 2004**	Simon de Szoeke	International Pacific Research Center	*Variability in the southerly flow into the eastern Pacific ITCZ*
October 26, 2004	Keith Rodgers	LODYC, Université Pierre et Marie Curie, Paris, France	*Using OGCMSs to study anthropogenic CO_2 uptake*
October 19, 2004	Friedrich Schott	IFM-GEOMAR Leibniz-Institut für Meereswissenschaften, Kiel, Germany	*The Atlantic meridional overturning circulation: Has it changed?*
October 14, 2004*	Axel Timmermann	International Pacific Research Center and Department of Oceanography, University of Hawai'i	*The Atlantic Seesaw Effect: Understanding hemispheric millennial-scale climate change*
October 13, 2004**	Roland Madden	National Center for Atmospheric Research, Boulder, Colorado	*Evidence of planetary-scale, free Rossby waves in the NCEP/NCAR reanalysis*
October 7, 2004**	Yign Noh	Department of Atmospheric Sciences, Yonsei University, Seoul, Korea	*Large-eddy simulation (LES) of the ocean mixed-layer and its application in an ocean GCM*
September 29, 2004**	Oliver Timm	International Pacific Research Center	*Interpreting climate variability from proxy data: NAO and ENSO*
September 15, 2004**	Soon-Il An	International Pacific Research Center	*Long-term change in the warm-cold asymmetry of ENSO and its global impact*
September 8, 2004**	Kevin Hamilton	International Pacific Research Center and Department of Meteorology, University of Hawai'i	*Volcanic effects on atmospheric circulation*
August 30, 2004	Akimasa Sumi	Center for Climate System Research, University of Tokyo, Japan	*Simulation results from a high-resolution climate model for the IPCC Fourth Assessment Report*
August 26, 2004*	Ya Hsueh	Department of Oceanography, Florida State University, Tallahassee, Florida	*Kuroshio-generated flows in the northern South China Sea*
August 26, 2004	Niklas Schneider	International Pacific Research Center	*The forcing of the Pacific Decadal Oscillation*
August 25, 2004**	Guang Jun Zhang	Scripps Institution of Oceanography, University of California, San Diego, California	*Design of a new convection parameterization closure and its impact on climate simulation in the NCAR CCM3*
August 23, 2004	Matthew Wheeler	Bureau of Meteorology Research Centre, Climate Forecasting Group, Melbourne, Australia	*Intraseasonal variability of the Australian-Indonesian monsoon region*
August 23, 2004	Walter E. Janach	Department of Mechanical Engineering, Lucerne University of Applied Sciences, Switzerland	*Could El Niño be triggered from the South China Sea?*

Date	Speaker	Affiliation	Seminar Title
August 17, 2004	Hung-Chi Kuo	National Taiwan University, Taiwan	*Dynamics of Concentric-Eyewall Formation in tropical cyclones*
July 22, 2004	Ingo Kirchner	Institut für Meteorologie, Freie Universität Berlin, Germany	*Nudging applied to experiments with climate models: Advantages and disadvantages*
June 30, 2004	R. Krishnan	Global Climate Modelling Division Indian Institute of Tropical Meteorology, Pune, India	*Mixed-layer and thermocline interactions associated with the monsoonal flow over the Arabian Sea*
May 26, 2004	P.V. Joseph	Department of Atmospheric Science, Cochin University of Science and Technology, India	*Asian summer monsoon onset as seen in observations and ECHAM5 simulations*
April 7, 2004*	N.H. Saji	International Pacific Research Center	*Observations of intraseasonal air–sea coupling in the near equatorial Indian Ocean using remote sensed and* in situ *data*
April 6, 2004	Jinwon Kim	Department of Atmospheric Sciences, University of California at Los Angeles, California	*Projected changes in the hydrological cycle of the western United States resulting from increased atmospheric* $C0_2$*-induced climate change*
April 5, 2004	Jinwon Kim	Department of Atmospheric Sciences, University of California at Los Angeles, California	*Effects of SST in the Gulf of California on the warm-season rainfall in the southwestern United States*

* Joint seminar with the Department of Oceanography
**Joint seminar with the Department of Meteorology
***Joint seminar with the Joint Institute for Marine and Atmospheric Research

GRANTS AWARDED

INSTITUTIONAL SUPPORT

Title	PI and Co-PIs	Agency	Amount	Period
Support of Research at the International Pacific Research Center	J.P. McCreary	Japan Agency for Marine-Earth Science and Technology	$3,225,577	04/01/04 - 03/31/05
Support of Research at the International Pacific Research Center	Not applicable	University of Hawai'i*[1]	$442,742	04/01/04 - 03/31/05
Establishment of a Data and Research Center for Climate Studies	J.P. McCreary, P. Hacker, R. Merrill & T. Waseda	NOAA	$1,559,100	07/01/01 - 06/30/06
Enhancement of Data and Research Activities for ClimateStudies at IPRC	J.P. McCreary & P. Hacker	NOAA	$975,000	10/01/04 - 09/30/05
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

INDIVIDUAL GRANTS

Title	PI and Co-PIs	Agency	Amount	Period
Establishment of the Integrated Climate Database for Reanalysis and the International Data Network	P. Hacker	JAMSTEC / MEXT	$127,000	06/01/04 - 03/18/05
Analysis of Climate Change in Korea and East Asian Area and Study of the Atmospheric and Ocean Effects	B. Wang	Yonsei University	$61,131	06/01/04 - 11/30/05
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
South Asian Summer Monsoon Climatology and Variability in the Control and 20th Century IPCC AR4 Simulations	K. Hamilton & H. Annamalai	NOAA	$23,342	12/28/04 - 08/31/05
Mixing in the Equatorial Pacific: The Role of Interleaving	K. Richards & J. McCreary	NSF	$346,315	09/01/03 - 08/31/06
Dynamics of Boreal Summer Intraseasonal Oscillation	B. Wang, T. Li & X. Fu	NSF	$452,166	10/01/03 - 09/30/06
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	07/01/04 - 06/30 06
Tropical Cyclone Forecast	T. Li	DOD (MSU)	$107,440	06/01/04 - 11/30/05
Application of Satellite Data to Improve the Simulation and Prediction of Tropical Intraseasonal Oscillation (TISO)	J. Fu, B. Wang & X. Xie	NASA	$272,333	06/01/04 - 05/31/07
Mean Sea Level and Ekman Currents Derived from Drifter, Satellite and Wind Data	N. Maximenko	NASA	$17,430	03/01/04 - 08/31/04

Title	PI and Co-PIs	Agency	Amount	Period
Dynamic Balance of the Oceanic Mixed Layer Observed by *In situ* Measurements and Remote Sensing	N. Maximenko	NASA (UCSD)	$315,184	10/01/04 - 07/30/08
Predictability and Diagnosis of Low Frequency Climate Processes in the Pacific	N. Schneider	DOE - Dept of Energy	$29,374	09/15/04 - 09/14/05
Study of Processes Leading to Tropical Cyclone Intensity Change	Y. Wang	NSF	$278,840	10/15/04 - 09/30/07
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	$485,767	05/04/00 - 12/31/05
Dynamics of Boreal Summer Intraseasonal Oscillation	B. Wang T. Li	NSF	$399,536	07/01/00 - 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 - 02/28/05
Mechanisms for the Northward Displacement of the Pacific ITCZ	S.P. Xie T. Li	NSF	$281,955	09/15/01 - 08/31/05
Tropical Cyclone Energy Dispersion and Self-Maintaining Mechanisms for Summer Syn-optical-Scale Waves in the Northwest Pacific	T. Li Y. Wang	NSF	$294,262	09/15/01 - 08/31/05
Biennial and Interdecadal Variations of the Tropical Pacific Ocean	B. Wang S.I. An	NOAA / PACIFIC	$311,280	09/24/01 - 06/30/06
Remote Forcing of the US Warm Season Rain-fall and Eastern Pacific Climate	B. Wang X. Fu	NOAA / PACS	$365,981	09/26/01 - 06/30/06
Roles of Ocean–Atmosphere-Land Interaction in Shaping Tropical Atlantic Variability	S.P. Xie	NOAA	$244,990	09/26/01 - 06/30/06
Effects of the Andes on Eastern Pacific Climate	S.P. Xie Y. Wang	NOAA	$277,200	09/26/01 - 06/30/06
Quasi-biennial Oscillation Modulation of Eddies in the Tropical Stratosphere	K. Hamilton	NASA	$108,287	05/15/02 - 05/14/06
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
Application of Comprehensive Global Models to Problems in the Dynamics of the Tropo-sphere and Stratosphere	K. Hamilton	NSF	$322,809	09/01/02 - 08/31/06
Upwelling and Its Influence on the Sea Surface Temperature off Java and Sumatra	T. Qu	NASA	$324,265	01/07/03 - 01/31/06
A Numerical Investigation of the Dynamics of the Subsurface Countercurrents	Z. Yu	NSF	$364,992	03/15/03 - 02/28/06

[1] The University of Hawai'i also provides approximately 16,500 sq. ft. of office space to the IPRC.

ACRONYMS

AGU	American Geophysical Union
AMS	American Meteorological Society
AMSU	Advanced Microwave Sounding Unit
APDRC	Asia-Pacific Data-Research Center
APEC	Asia-Pacific Economic Cooperation
AR4	Fourth Assessment Report on Climate Change
ARM Program	Atmospheric Radiation Measurement Program
AVHRR	Advanced Very High Resolution Radiometer
CAM	Community Atmosphere Model
CCCma	Canadian Centre for Climate Modelling and Analysis
CCM	Community Climate Mdel
CCSM	Community Climate System Model
CCSR	Center for Climate System Research - The University of Tokyo
CEOP	Coordinated Enhanced Observing Period
CGAM	Centre for Global Atmospheric Modelling
CIRES	Cooperative Institute for Research in Environmental Sciences
CLIVAR	Climate Variability and Predictability Project
CNRM	Centre National de Recherche Météorologique
COADS	Comprehensive ocean–atmosphere Data Set
COSPAR	Committee on Space Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAWEX	Darwin Area Wave Experiment
DCCP	Diurnal Cycle of Clouds and Precipitation
DOE	Department of Energy
ECHAM	European Centre-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
ERA-40	Forty-year European Re-Analysis
ERBE	Earth Radiation Budget Experiment
ERS	European Remote-Sensing
ESSIC	Earth System Science Interdisciplinary Center
FRCGC	Frontier Research Center for Global Change
GAME	GEWEX Asian Monsoon Experiment
GDS	GrADS (Grid Analysis and Display System) Data Server
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory
GISS	Goddard Institute for Space Studies
GODAE	Global Ocean Data Assimilation Experiment
HcGCM	Hybrid Coupled General Circulation Model
HYCOM	Hybrid Coordinate Ocean Model
ICCS	International Center for Climate and Society
IFM-GEOMAR	Institute for Marine Science, Research Center for Marine Geosciences, University of Kiel
INMCM	Institute for Numerical Mathmatics
IORGC	Institute of Observational Research for Global Change
IPCC	Intergovernmental Panel on Climate Change
iRAM	IPRC Regional Atmospheric Model
IPSL	Institut Pierre Simon Laplace
iROAM	Regional Coupled Ocean-Atmospheric model
ISAM4	Fourth International Symposium on Asian Monsoon
ISO	Intraseasonal Oscillation
ITCZ	Intertropical Convergence Zone
IUGG	International Union of Geodesy and Geophysics
IWM-III	Third International Workshop on Monsoons
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
JOAMME	Joint Ocean-Atmospheric Measurements near the Kuroshio Extension
JTWC	Joint Typhoon Warning Center
KPP	K-profile mixing parameterization
LAS	Live Access Server
LASG/IAP	State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics/ Institute of Atmospheric Physics (Beijing)
LES	Large-Eddy Simulation
LGM	Last Glacial Maximum
LODYC	Laboratoire d'Océanographie Dynamique et de Climatologie
MEXT	Ministry of Education, Culture, Sports, Science and Technology (Japan)
MIROC	Model for Interdisciplinary Research on Climate
MISO	Monsoon Intraseasonal Oscillation
MJO	Madden-Julian Oscillation
MSU	Mississippi State University
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCAS	NERC Centres for Atmospheric Science
NCEP	National Centers for Environmental Prediction
NERC	National Environment Research Council
NLOM	Navy Layered Ocean Model
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NWP	Numerical Weather Prediction
OFES	Ocean GCM for the Earth Simulator
OGCM	Ocean General Circulation Model
ONR	Office of Naval Research
OPeNDAP	Open-source Project for a Network Data Access Protocol
PACON	Pacific Congress on Marine Science and Technology
PACS	Pan American Climate Studies
PCM	Parallel Climate Model
PDO	Pacific Decadal Oscillation
PICES	North Pacific Marine Science Organization
PMEL	Pacific Marine Environmental Laboratory
POM	Princeton Ocean Model
PRIDE	Pacific Region Integrated Data Enterprise
QBO	Quasi Biennial Oscillation
QuikSCAT	Quick Scatterometer
RAIME	Regional Atmospheric Inter-Model Evaluation
RCM	Regional Climate Model
RV	Research Vessel
SCS	South China Sea
SeaWiFs	Sea-viewing Wide Field-of-view Sensor
S-EOF	Season-reliant Empirical Orthogonal Function
SMOS	Soil Moisture and Ocean Salinity
SOI	Southern Oscillation Index
SPARC	Stratospheric Processes and their Role in Climate
SSM/I	Special Sensor Microwave Imager
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
TBO	Tropospheric Biennial Oscillation
TCM	Tropical Cyclone Model
TISO	Tropical Intraseasonal Oscillation
TMI	Tropical Microwave Imager
TOPEX/Poseidon	Topography Experiment/Poseidon
TRMM	Tropical Rainfall Measuring Mission
UCSD	University of California, San Diego
UH	University of Hawai'i
VAMOS	Variability of the American Monsoon Systems
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WNP	Western North Pacific
WOA	World Ocean Atlas
WOCE	World Ocean Circulation Experiment

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please let us know.

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