INTERNATIONAL PACIFIC RESEARCH CENTER

APRIL 2005–MARCH 2006 REPORT

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

Contents

The International Pacific Research Center	1
The Year's Highlights	3
Indo-Pacific Ocean Climate	4
Regional-Ocean Influences	10
Asian-Australian Monsoon System	14
Impacts of Global Environmental Change	21
Asia-Pacific Data-Research Center	27
Publications	32
Seminars	36
Workshops	37
Funding	38
IPRC Staff and Advisory and Governing Committees	39

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International Pacific Research Center

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THE INTERNATIONAL PACIFIC RESEARCH CENTER

The International Pacific Research Center (IPRC) at the University of Hawaii 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 at the Manoa Campus of the University of Hawaii. 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."

IPRC research is divided into the following five broad research themes:

***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 Hawaii and grants from the U.S. agencies (NASA, NOAA, NSF, and ONR) accounted for two-thirds of the center's funding.

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 の研究は、以下に示すように、大きく五つの研究テーマに分けることができます。

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・オーストラリアモンスーンシステム: 水循環を含めたアジア・オーストラリアモンスーンシステムの気候変動特性、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 の予算の三分の二を超えました。

昨年のハイライト

地球シミュレータのような高速コンピュータの開発により、数値気候モデリングはこの 10 年間で飛躍的な進歩を遂げた。IPRC の研究者は JAMSTEC の研究者と共にこの発展に寄与してきた。地球シミュレータを用いた大気大循環モデル(AFES)、および海洋大循環モデル（OFES）の出力結果の解析により、これらの高解像度モデルが他のモデルに比べ、気候システムの特徴をより現実的に再現する点で優れていることが示された。例えば、AFES の再現する対流圏の水平運動エネルギースペクトルは航空機観測と一致しており、OFES は黒潮続流と人工衛星高度計で観測された近年の黒潮のシフトの再現に成功した。さらに、地球シミュレータで実行された IPRC 領域大気海洋結合モデルは、エルニーニョ現象に重要な東部太平洋上の雲の特徴を捉えることに成功した。これは今まで大循環モデルでは再現困難であった点である。

IPRC の研究は、モンスーンの乾季と雨季の長さに関しても、農業に有用な 2-3 週間程度の予測ができる可能性を提示した。新たに編集された 1951 年から 2005 年の長期にわたるインドの降水量データの解析により、7 日間以上の比較的長い乾季は、短い乾季と異なり、西部太平洋の強い対流活動に関係し、予測可能性があることが示された。さらに、人工衛星から得られた全球水蒸気分布の解析から、降水を伴う対流活動に先行する高い海面水温と湿潤な大気境界層の存在が明らかになった。これらは対流圏を不安定化させ、擾乱を誘導している。

人工衛星データを用いた NASA ジェット推進研究所との共同研究により、ヒマラヤ山麓地帯を除き、主要な対流活動の中心は沿岸部の狭い山脈沿いに固定されていることが明らかになった。これはモンスーン研究においてはほとんど記述されておらず、気候モデルでもあまり良く表現されていない。このような対流活動の分布は大陸規模のモンスーン循環の形成に重要であることが、モデル実験でも示された。

IPRC は APEC（アジア太平洋経済協力）気候センターによる国際プロジェクト「気候予測と社会への応用」にも主導的な役割を果たしている。現在このプロジェクトでは、モンスーンの降水予測のために、最先端の気候モデルの試験を行っている。24 年分のハインドキャスト実験により、大気海洋結合モデルは大気海洋間のフィードバック効果を含まない大気大循環モデルよりも、予測精度が高いことが示された。

熱帯低気圧に関しても昨年、データ解析・モデル実験の両面から多くの研究が行われた。一つ前の熱帯低気圧に誘発された熱帯低気圧の発生過程を調べ、観測データから最大可能台風強度の予測精度を改良する新たな手法を開発した。また、IPRC 領域大気モデルを用いた気候変動研究により、大気中の CO_2 の増加に伴い、南シナ海を除き北太平洋における熱帯低気圧の数は増えないものの、個々の擾乱が強まることが示唆された。

様々な海洋モデルを用いた研究では、太平洋・インド洋の循環とその間を結ぶインドネシア通過流の相互作用について調査した。太平洋から南シナ海とマカッサル海峡を通って太平洋に戻る海流も発見され、この海流が太平洋からインド洋への熱輸送を考える上で重要である可能性が示唆された。

古気候研究からは、21,000 年前に南極大陸で始まった温暖化が北半球起源ではなく、南半球春季における太陽放射の増加とそれに伴う海氷縮小と大気 CO_2 の増加によることが示唆された。この研究は CO_2 レベルに対する気候感度の見積りを提示し、地球温暖化問題を考慮する上で役立つものである。

APDRC(アジア太平洋データ研究センター)は、引き続き気候データの蓄積とサーバ能力の拡張を精力的に行った。APDRC は NOAA PRIDE チームに参加し、PRIDE 資金に絡むプロジェクト設立に一定の役割を担い、現在多くのプロジェクトが、新しい課題として APDRC に組み込まれている。この他の業績として、アルゴフロートデータから推定した新しい表層・深層海流データセットの作成、並びにハワイ諸島への HYCOM モデルの的確なダウンスケーリングなどがある。

これらのハイライト並びに本報告書にまとめられたように、昨年は IPRC の研究者によって多くの成果が得られ、活気に満ちた一年であった。複雑な気候システムの更なる探求と発見が続けられることが期待される。

Julian P. McCreary, Jr.
所長

THE YEAR'S HIGHLIGHTS

The past decade has seen remarkable advances in numerical climate modeling owing to the development of high-speed computers like the Earth Simulator. IPRC researchers have participated in these advances together with colleagues at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). Our joint analyses of output from the Atmospheric GCM for the Earth Simulator (AFES) and the Ocean GCM for the Earth Simulator (OFES) show that these high-resolution models surpass others in realistically capturing overall features of the climate system. For example, AFES produces a horizontal kinetic energy spectrum of the troposphere that matches aircraft measurements and OFES has remarkable skill in simulating the Kuroshio Extension and its recent shifts observed in satellite-altimetry data. Furthermore, the IPRC regional coupled ocean-atmosphere model, run on the Earth Simulator, captures salient features of the clouds in the eastern Pacific that are important in El Niño dynamics but difficult to simulate in general circulation models (GCMs.)

Regarding monsoon dry and rainy periods, our IPRC research suggests they may be predictable sufficiently far in advance (2–3 weeks) for the information to be useful to farmers. Analyses of a newly released India rainfall data set covering the years 1951–2005 reveal that, in contrast to short dry periods, extended dry periods of 7 days or longer are accompanied by strong convection over the tropical western Pacific, a pattern that might be predictable. Furthermore, examination of satellite-derived global water-vapor profiles shows that rainfall and deep convection are preceded by unusually high sea surface temperatures and atmospheric boundary-layer moistening, which destabilize the troposphere and guide the disturbance's movement.

Another satellite-based study, conducted with colleagues at the NASA Jet Propulsion Lab, has revealed that, aside from the Himalayan foothills, the major convection centers are anchored by narrow coastal mountains scarcely mentioned in conceptual depictions of the monsoon and poorly represented in climate models. A modeling experiment demonstrates the importance of these convection centers and how they help to shape the monsoon continental-scale cyclonic circulation.

The IPRC is leading an international project named "Climate Prediction and Application to Society" sponsored by the APEC (Asian Pacific Economic Cooperation) Climate Center. The project is currently testing the skill of state-of-the-art climate models to predict monsoon rainfall. A 24-year hindcast shows that the coupled GCMs yield better predictions than stand-alone atmospheric GCMs without ocean–atmosphere feedback.

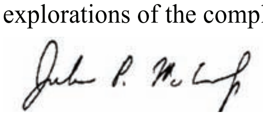
We have carried out much work on tropical cyclones this past year, both observational analyses and modeling studies. We have investigated the formation of tropical cyclones in the wake of a previous cyclone and have derived from observations a new formula that improves the prediction of maximum potential cyclone intensity. Furthermore, a climate change study with the IPRC regional atmospheric model indicates that with higher levels of atmospheric CO_2, the number of tropical cyclones will not increase in the basin-wide North Pacific, but they will be more intense. Furthermore, the South China Sea will see significantly more typhoons.

An extensive study using a hierarchy of ocean models has explored interactions of the Indonesian Throughflow with both Pacific and Indian Ocean circulations. In addition, a current was detected flowing from the Pacific through the South China Sea and Makassar Strait back into the Pacific. The current may be important in the heat transport from the Pacific to the Indian Ocean.

Our paleoclimate research has produced evidence that the warming that began over Antarctica 21,000 before present, resulted not from changes in the Northern Hemisphere, but rather from an increase in solar radiation during austral spring, accompanied by shrinking sea ice and an increase in atmospheric CO_2. The study has implications for global warming, providing an estimate of the climate sensitivity to CO_2 levels.

Our Asia-Pacific Data-Research Center has continued to expand its climate-data holdings and server capabilities. As a participant in the NOAA PRIDE team, the APDRC has helped to identify projects for PRIDE funding. Many of these projects are now included as new tasks within the APDRC. Other accomplishments include compilation of a new data set of deep- and surface-ocean currents derived from Argo floats, and the successful downscaling of the HYCOM model for the Hawaiian Islands.

As summarized in these highlights and reviewed in this report, the past year has been exciting and productive for IPRC researchers. We look forward to continuing our explorations of the complex climate system.



Julian P. McCreary, Jr.
Director

INDO-PACIFIC OCEAN CLIMATE (THEME 1)

Research under this theme aims to determine the role of the Indo-Pacific Ocean in the climate system by conducting studies on climate variability, air-sea interaction, and ocean processes. The accomplishments in FY05 span all three areas. Highlights of this research are described below.

Climate Variability

Several studies focused on climate variations in the North Pacific. In partnership with researchers at the Frontier Research Center for Global Change (FRCGC) and the Earth Simulator Center, IPRC scientists analyzed a 50-year hindcast of the Kuroshio Extension simulated in a solution of the high-resolution Ocean GCM for the Earth Simulator (OFES). The hindcast showed remarkable skill in simulating the variability of this current as demonstrated by a comparison of the model output with 13 years of satellite-altimeter observations (Figure 1). Among other things, OFES captured the southern and northern excursion of the front during this period (Taguchi *et al.*).

A coupled-model study investigated processes underlying decadal sea surface temperature (SST) variability, the Pacific Decadal Oscillation (PDO). Results showed similar dynamical processes noted in observations, with discrepancies attributable to errors in the mean model climate. The model simulated a local feedback to the atmosphere in the western North Pacific, but no coupled feedback loop could be identified (Schneider and Cornuelle, *J. Climate* 2005).

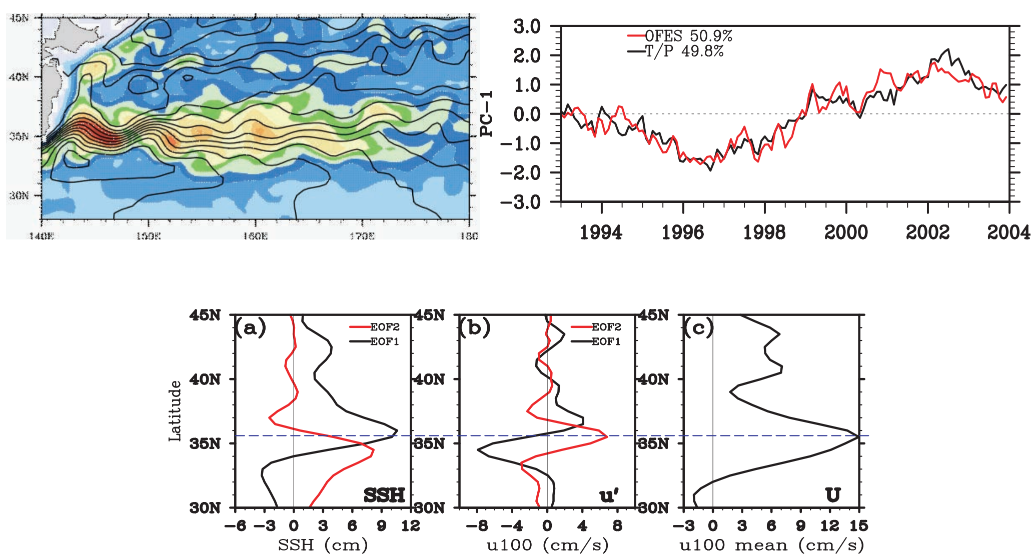


Figure 1. The multi-decadal, eddy-resolving hindcast of the Kuroshio Extension (KE) with the Ocean GCM for the Earth Simulator (OFES) matches satellite-altimeter observations remarkably well. **Top:** Left, sea surface height from OFES; right, the time series of the first EOF mode simulated by OFES (red) and observed by satellite (black) captures the jet's southward shift and subsequent northward migration. The second EOF mode represents variations in the jet's intensity. **Bottom**: (a) meridional structure of the leading modes of the KE variability derived from the EOF of the OFES hindcast; (b) the associated zonal current velocity at 100-m depth; and (c) the mean zonal current profile (blue line represents the mean KE frontal position averaged over 142–180ºE). Taguchi, Xie, Schneider (IPRC), Nonaka, Sasai (FRGCG), and Sasaki (ESC).

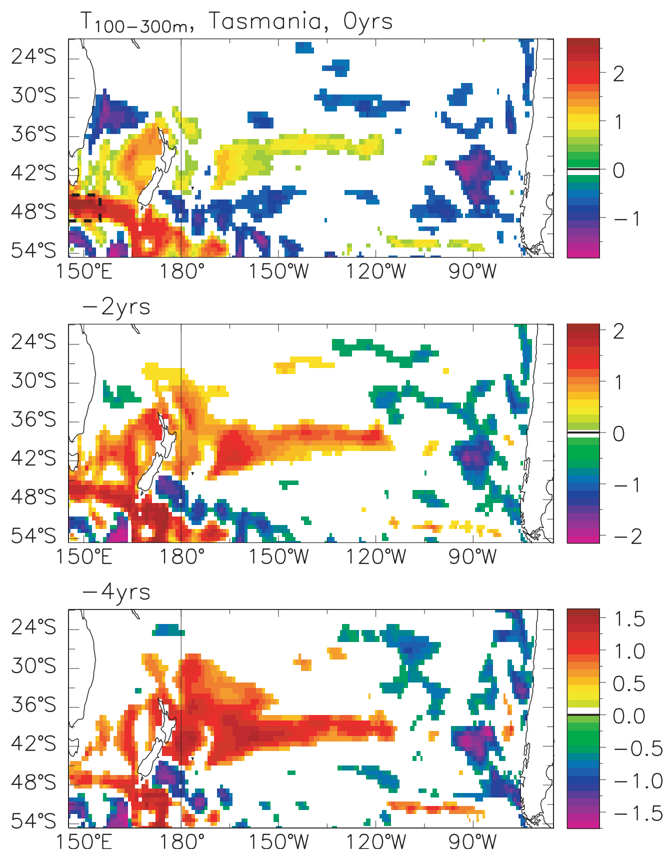


Figure 2. Composite differences of the normalized thermocline-depth temperature, derived from high and low sea surface temperature anomalies off Tasmania. The top panel shows the contemporaneous composite, middle and bottom panels show composites of the two and four years earlier. The large anomalies in SST and thermocline-depth temperature off Tasmania originate in the Central South Pacific.

A parallel study was conducted to determine processes leading to decadal SST variability in the South Pacific (Schneider). Because long observational records are lacking, output from an extended integration of a coupled climate model was analyzed. An EOF analysis showed no leading pattern and no counterpart to the PDO, individual patterns accounting at most for 14% of SST variance. SST anomaly-reconstruction based on autoregressive physics, however, was as successful as in the North Pacific, showing that over large swaths of the South Pacific, temperature anomalies result from a balance of forcing by Ekman advection and damping by air-sea heat exchange. Variations in thermocline depth affect SST anomalies in the East Australian Current, the area of the Campbell plateau off New Zealand, and an arc extending from the tip of South America north-westward towards 30ºS. The former two regions reflect impacts of the western boundary currents and a delayed response of the ocean circulation to changes in the central South Pacific (Figure 2). These processes seem to be a counterpart to processes leading to variability in the North Pacific Kuroshio-Oyashio region. No extratropical atmospheric response to SST anomalies was detected. The results need to be confirmed with other models. Particularly fascinating will be exploration of effects of the SST anomalies in high-resolution coupled integrations.

IPRC researchers continued their partnership with a multi-institutional team of Japanese scientists on a study of the influence of the Kuroshio Extension on the atmospheric boundary layer and the Baiu rain band. The investigation is based on using ship-board atmospheric soundings, satellite data analysis, and numerical climate models.

Air-Sea Interaction

Theme 1 played a key role in the IPRC-wide effort to develop a regional, coupled ocean-atmosphere model (iROAM). In a continued partnership with FRCGC scientists, iROAM has been configured and tested in the eastern tropical Pacific, a region where almost all global climate models suffer large biases, such as a prolonged double intertropical convergence zone (ITCZ). Analyses of iROAM results are very promising, the model simulations showing the salient features of eastern Pacific climate. For instance, the iROAM has a double ITCZ only during March and April, just as in observations. In FY05, sensitivity experiments were conducted to understand the processes underlying the model's successful simulation of this feature (de Szoeke, Y. Wang, and Xie, *GRL*, in press). In one such experiment, turning off shallow convection parameterization resulted in the disappearance of the double ITCZ (Figure 3). This sensitivity suggests that shallow-convection parameterizations affect the asymmetry of eastern Pacific climate and are at root of the double ITCZ-bias in coupled GCMs.

Another study examined periods of intense cooling of the tropical southern Indian Ocean sea surface in 8 years of TRMM observations (Saji, Xie, and Tam, *GRL* in press). Composite maps of SST, OLR, and surface winds, based on 11 events in which the SST decreased by more than 1°C, showed these events tend to be collocated with a thermocline ridge near 60–80°E, 5–15°S. The events tend to occur every year during austral summer when the ITCZ moves south of the equator and the Madden–Julian Oscillation is active. Panel A of Figure 4, shows the evolution of these events; Panel B shows the longitude-time plot of the subseasonal SST anomaly averaged between 10°S and 5°S).

Analyses of the data suggest that reduced solar radiation, enhanced evaporation, and strong entrainment over the thermocline ridge contribute to the SST cooling. Moreover, two modes of OLR – SST relationship were noted. An equatorially symmetric mode is most coherent around a 35-day period, a southern mode is most coherent around 65 day-period (Panel C). The former has a pronounced eastward propagation and dissipates rapidly once it reaches the maritime continent (not shown). The southern mode propagates more slowly and extends farther into the western Pacific. The high coherence between OLR and SST in this latter mode could mean the large subseasonal SST variations in the region feed back to the atmosphere.

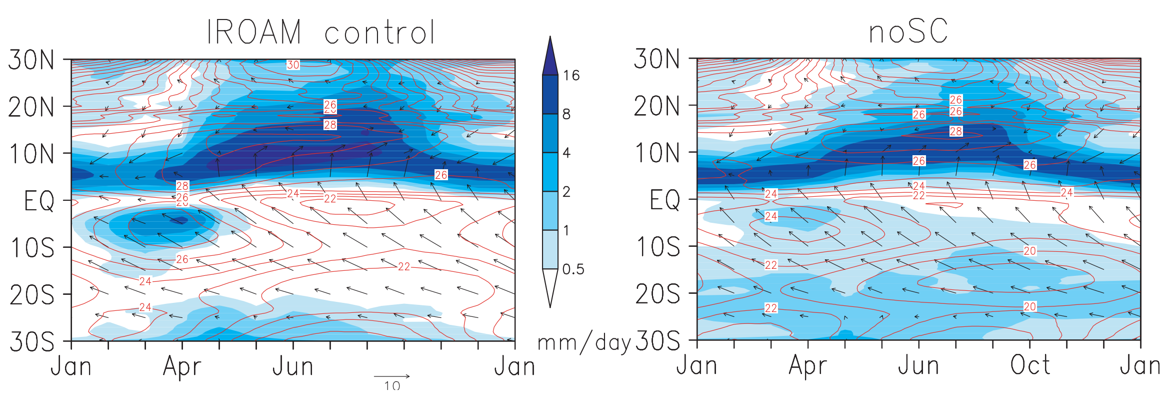


Figure 3. Comparison of simulations with iROAM with the usual shallow convection parameterization (Control) and without shallow convection (NoSC). Shown are the meridional precipitation (blue shading), SST (red contours), and wind vectors averaged over 110-90ºW. The Control run shows an ITCZ in the Southern Hemisphere only during March and April. In the NoSC run, the ITCZ in March-April disappears in the Southern Hemisphere, i.e., there is no double ITCZ at all. This suggests that shallow convection parameterization affects the duration of the double ITCZ.

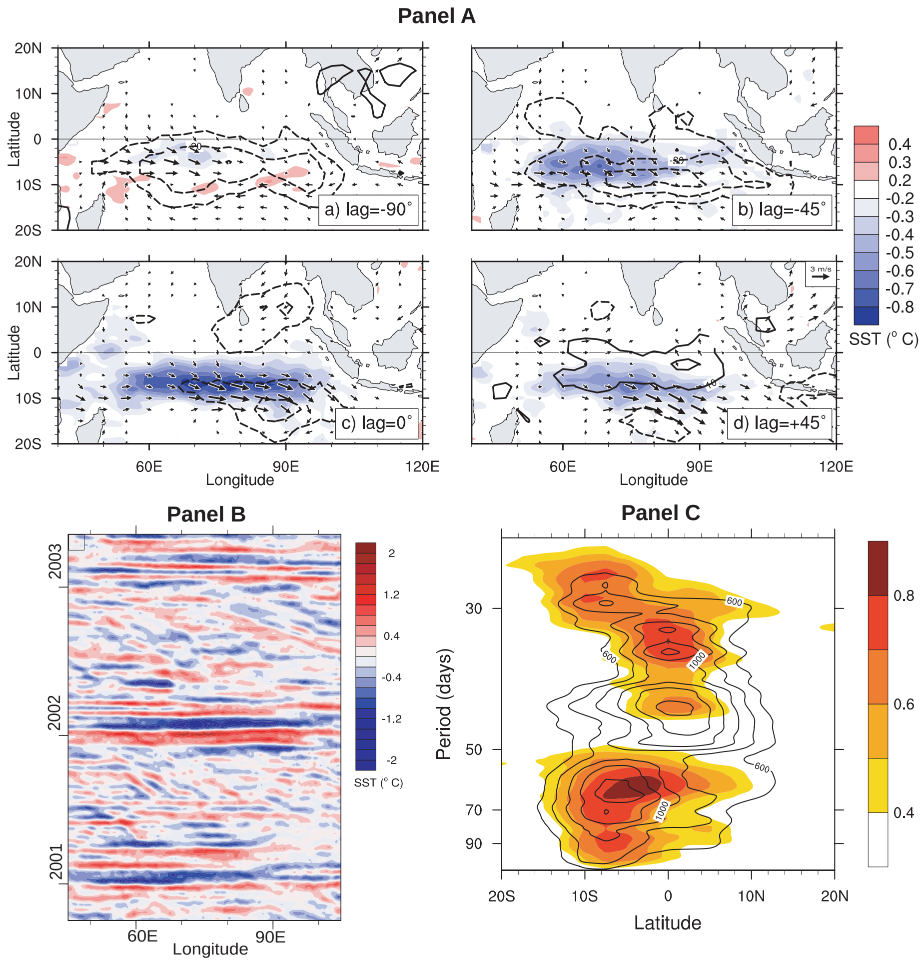


Figure 4. Panel A: Composite maps depicting the initiation, growth, peak, and decay of 11 austral summer SST cooling events in the south equatorial Indian Ocean. Intraseasonal SST anomalies (shaded, in °C), OLR (contours, in W/m^2) and surface wind vector (arrows, in m/s). **Panel B:** Longitude-time plot of intraseasonal SST anomaly (°C) averaged between 10–5°S. **Panel C:** December–February distribution of SST-OLR coherence squared (shaded) and OLR auto power spectrum (W^2/m^4) as a function of latitude and frequency between 60–90°E. (Saji, et al. *GRL* in press).

Ocean Circulation

Using a hierarchy of ocean models (a flat-bottom, linear continuously stratified system, LCS; a 4½-layer model; and an ocean GCM), IPRC researchers carried out a comprehensive investigation of the interaction of the Indonesian Throughflow (ITF) with circulations in the Indian and Pacific oceans (McCreary, Miyama, Furue, Jensen, Kang, Bang, Qu). Among other things, they found that the ITF strengthens the subtropical countercurrent in the South Indian Ocean, accounts for the existence of the Great Barrier Reef Undercurrent off the northeast coast of Australia, and either causes or intensifies the flow of Pacific thermostad water and AAIW to the equator and into the Northern Hemisphere. Furthermore, consistent with observations, the ITF outflow from the Indonesian Seas has two cores: a primary, near-surface core supplied mostly by water from the Northern Hemisphere, and a secondary, subsurface one supplied by Southern Hemisphere water. Figure 5 illustrates the flow in the Indonesian Seas associated with the two cores for an LCS solution. It is noteworthy that basic properties of the ITF can be reproduced in such a dynamically simple system, indicating that they are determined primarily by baroclinic processes in the interior of the Pacific (e.g., upwelling and diapycnal mixing) rather than by processes within the Indonesian Seas (e.g., bottom topography, tidal mixing).

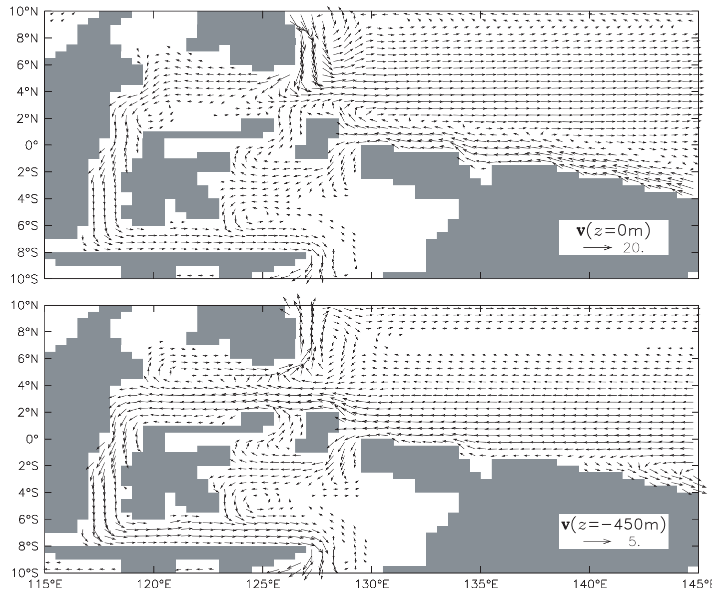


Figure 5: Horizontal maps of current vectors (arrows; cm/s) at the surface (middle) and at 450 m (bottom) from a solution to the LCS model. To illustrate weaker flows better, arrow lengths are proportional to the square root of the vector amplitudes.

Atmospheric Circulation

Two studies were conducted on atmospheric circulation phenomena. The first focused on the extreme event that occurred in the Hawaiian Islands in Spring 2006. During February and March 2006, the Hawaiian Islands endured 6 weeks of heavy rain with repeated flash floods, a tornado, and three severe thunderstorms. IPRC researchers responded by conducting a comprehensive study of the atmospheric conditions that led to this severe weather. What is clear from meteorological records is that beginning mid-February, a high pressure system (blocking high) north of Hawaii blocked the movement of cold air from mid-latitude into the central tropical Pacific until the end of March. This blocking high was paired with a low pressure system, the Kona Low, which persisted for an extraordinarily long period west of Hawaii, transporting moisture toward and causing heavy rain over the islands (Figure 6).

Preliminary analysis showed that from mid-January to mid-February, before the onset of the blocking, a westward-moving planetary-scale wave persisted north of Hawaii (Xie, Yang, and Tam). Moreover, at this time Rossby-wave energy emanated from the tropics, associated with a pronounced Madden–Julian Oscillation traveling to the dateline in the tropical Pacific. The 2005–06 winter was also a moderate La Niña year in the equatorial Pacific, the teleconnection influence of which tends to favor the formation of blocking events in the mid-latitude North Pacific. IPRC researchers are working to untangle the complex interactions among these and other factors that led to the great blocking event of 2006.

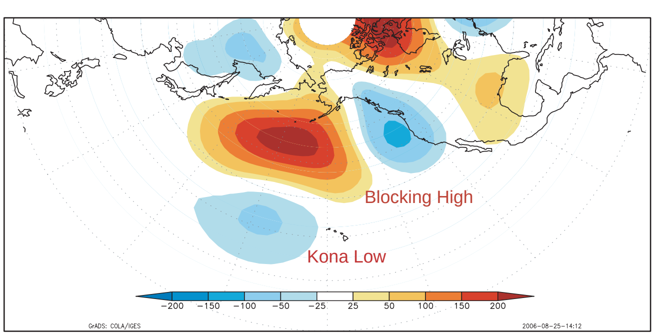
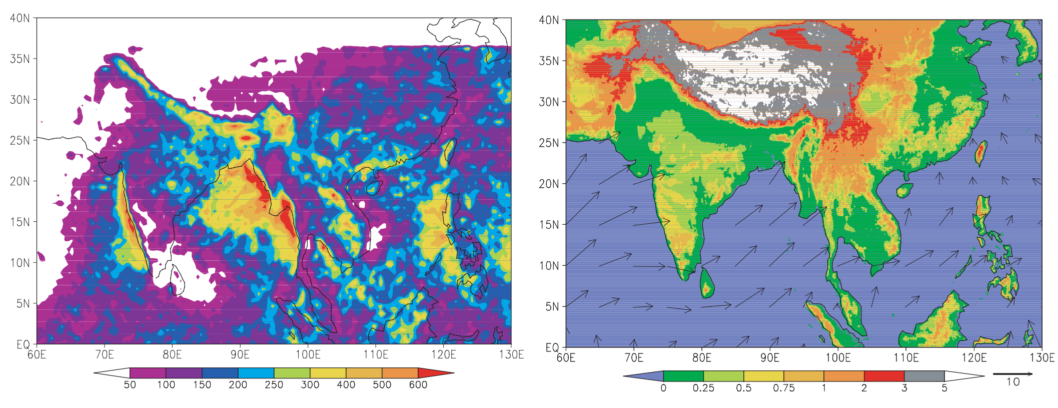


Figure 6: 500 hPa potential height anomalies (m) averaged over 23 February–31 March 2006.

The second study focused on the summer-time circulation over Asia (Xie, Xu, Y. Wang, Liu, *J. Climate* 2006). The Asian summer monsoon is organized into distinct convection centers, but the mechanism for this organization has not been well understood. Analyses of TRMM satellite observations by IPRC researchers and their colleague at the NASA Jet Propulsion Lab revealed that, aside from the foothills of the Himalayas, the major convection centers are all anchored by narrow coastal mountains (Figure 7, top left). These mountains are poorly represented in models and hardly mentioned in conceptual depictions of the monsoon. As a result of this pattern, southeastern India is dry savanna, whereas the region on the other side of the bay is rainforest.

Local "orographic rain" is a commonly observed phenomenon. In most regions, such rains do not impact the large-scale atmospheric circulation. Narrow heat sources were placed into the IPRC regional model along the coast of Myanmar, over Vietnam, and off the western coast of the Philippines to mimic the TRMM rainfall observations. These heat sources induce a continental-scale cyclonic circulation in the lower atmosphere by seeding deep convection (Figure 7, bottom panel).

The strong interaction between atmospheric convection and circulation thus results in far-reaching effects on the continental-scale monsoon. TRMM observations together with these modeling results offer a new perspective on Asian monsoon dynamics and a benchmark for the very high-resolution (~10 km) climate modeling being undertaken by NASA, Japan's Earth Simulator, and elsewhere.



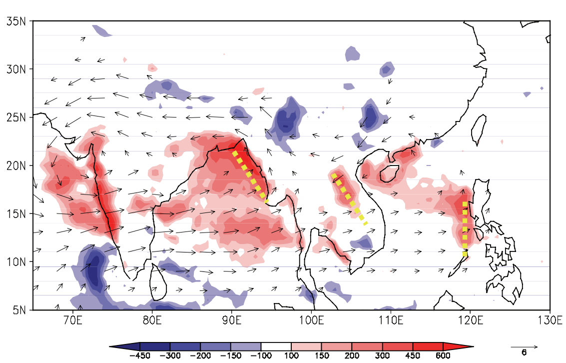


Figure 7. Top left panel: June–August climatology of surface precipitation (mm/month) based on TRMM precipitation radar observations; **right panel**: land orography (km) and QuickSCAT surface wind velocity (m/s). **Bottom panel:** Model response to narrow heating bands (yellow dotted lines) that mimic orographic effects of mesoscale mountain ranges: differences in precipitation (color in mm/month) and 850 hPa wind vectors (m/s) between the perturbed and control runs. (Xie *et al., J. Climate* 2006)

REGIONAL-OCEAN INFLUENCES (THEME 2)

The research objectives under this theme are aimed at investigating oceanic phenomena in the western Pacific Ocean, its marginal seas, and the connections between the Pacific and Indian oceans, which are known (or believed) to be important in the maintenance and variability of the large-scale oceanic gyres and climate. To address these objectives during FY05, IPRC researchers have analyzed historical and recent data, employed a hierarchy of models, and developed and applied data-assimilation techniques. In addition, they have worked on aspects of general ocean dynamics relevant to the world ocean. The following provides an overview of major activities and accomplishments during the past year.

Pacific Western-Boundary Currents

The 2005 field work for the Kuroshio Extension System Study (KESS) was completed with partners at the University of Hawaii (UH), Woods Hole Oceanographic Institute and the University of Rhode Island. KESS is a 5-year project with the goal to quantify interactions between the Kuroshio and the recirculation gyre to the south. The UH component of KESS has deployed an array of profiling Argo-type floats to study the upper ocean heat and salt budgets in the recirculation gyre.

Work has progressed on using newly available *in situ* historical data and recently calibrated satellite data to understand the Kuroshio large meander that formed south of Japan in Summer 2004 and lasted until Fall 2005 (Maximenko). It was the first large meander extensively observed with satellite altimeters. Dynamic topography of the ocean surface derived from satellite altimetry may be used together with trajectories of Argo floats and surface drifters to understand the physics of this phenomenon and to validate regional numerical models. Figure 8 shows the absolute dynamic topography (colors) of the sea surface on May 11, 2005, during the mature meander. Overlaid are the trajectories of all surface drifters (black lines) and Argo floats (white lines) at intermediate depths between July 2004 and July 2005. The topography is derived from sea-level-anomaly maps distributed by Aviso in France and referenced to the mean sea level of Maximenko and Niiler (2005). Trajectories

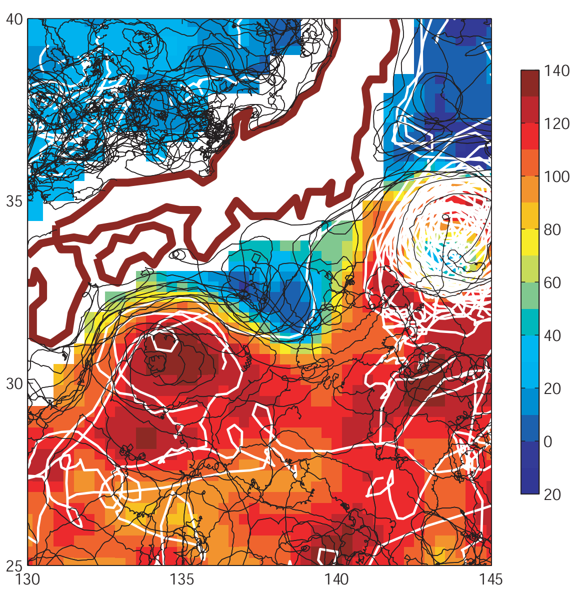


Figure 8. The absolute dynamic topography (colors, in cm) of the sea surface on May 11, 2005, during the mature meander, overlaid with trajectories of all surface drifters (black lines) and of Argo floats (white lines) at intermediate-depth between July 2004 and July 2005. The topography is derived from sea level anomaly maps distributed by the Aviso in France and referenced to the mean sea level of Maximenko and Niiler, 2005.

of deep and shallow buoys outline the characteristic shape of the offshore Kuroshio path south of Japan in its meander state. Anticyclonic recirculations are found south of Shikoku and east of the Izu Ridge, while cyclonic circulations are found within the meander. During meander formation, some drifters and one float crossed the Kuroshio front from the warm to the cold side, entering the interior region of the forming meander. A rare feature also seen in the figure is the cyclonic eddy that formed south of the crest of the first quasi-steady meander of the Kuroshio Extension, which captured many of the Argo-type floats released during KESS at 1500-m depth.

Marginal Seas, Indonesian Throughflow, and Connections with Adjacent Oceans

Results from a high-resolution general circulation model revealed the existence of a South China Sea Throughflow (SCST) circulation in which Pacific water enters the basin in the Luzon Strait and exits the basin through the Karimata and Mindanao Straits. Variations in this flow can convey conditions in the Pacific Ocean to the Indian Ocean. This flow is not forced by local winds, but is affected by variations in the Pacific low-latitude western boundary current and the bifurcation of the North Equatorial Current: It grows stronger during El Niño years and weaker during La Niña years. In the Makassar Strait, the flow is merely a consequence of interplay between the SCST (Qu, Du, Meyers, Ishida, D. Wang, *GRL*, 2005) near the surface and the Indonesian Throughflow within the thermocline. Though its volume transport is only 1–2 Sv, about an order smaller than the Indonesian Throughflow, this flow impacts heat transport from the Pacific into the Indian Ocean (Figure 9).

A comprehensive description of the circulation and mixed-layer properties in the southeastern Indian Ocean and their role in SST variations has been developed from a combination of existing observations and solutions with a high-resolution GCM (Qu, Du). Analyses revealed the presence of a thick (>25 m) barrier layer near the coast of Sumatra that inhibits the vertical entrainment of cold water from the thermocline to the mixed layer. Thus, even during the prevailing southeast monsoon in boreal summer, the region has no upwelling SST signature. The study also found that the Indonesian Throughflow (ITF) affects the region's water temperature in important ways, particularly near the coast of

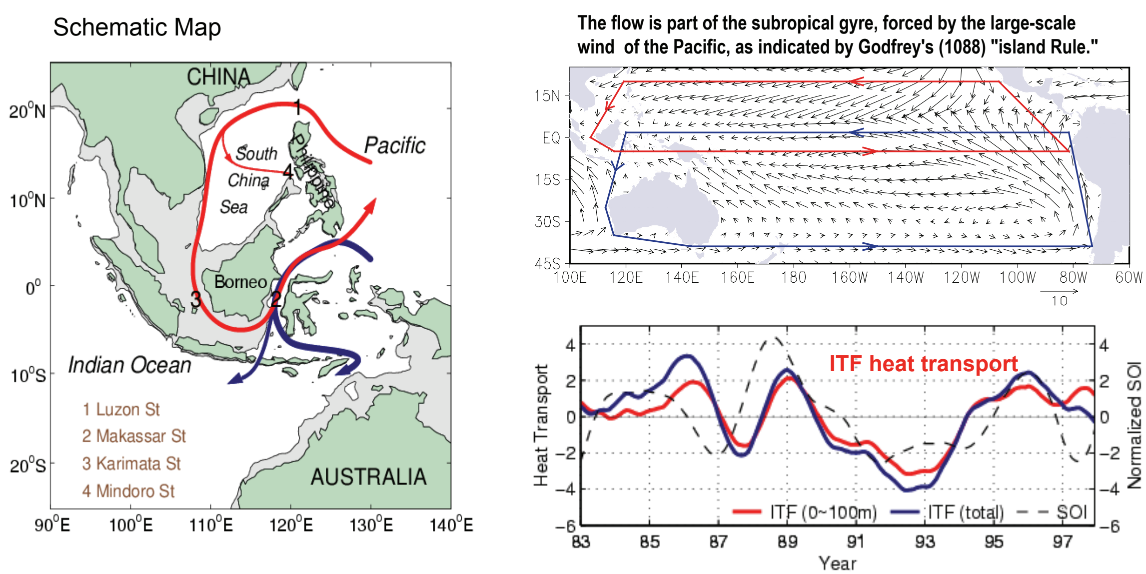


Figure 9. The branch of the South China Sea Throughflow as a part of the subtropical gyre, forced by large-scale winds in the Pacific, and its relationship to the Southern Oscillation Index and variations in the ITF heat transport.

Java and farther to the east, where warming by horizontal advection is the primary process balancing the cooling by upwelling.

Because direct measurements of ITF transport are hard to come by, a recent IPRC study assessed the accuracy of estimating ITF transport using satellite derived sea-level measurements (Potemra, *Oceanography*, in press). Output from the SODA reanalysis product had shown that most of the ITF transport occurs in the upper 200 m and along the southern coast of Java, and that it is driven mainly by large-scale Rossby and Kelvin waves generated in the equatorial Pacific and Indian oceans. Applying the SODA computed relationship between sea level and ITF transport, the transport can be estimated using TOPEX/Poseidon sea level measurements. Since XBT data had been collected from 1990 to 2000 in the region near maximum transport (map below), the TOPEX/Poseidon altimetry transport estimate was made from a track (brown stars) near the XBT transect (purple line). Figure 10 shows the ITF transport as observed by XBTs (filled graph), computed from SODA (green), and estimated from TOPEX/Poseidon sea level (purple). An easily available measure, the sea level-based index appears to be quite accurate for estimating upper-ocean ITF transport, and reasonably good (correlation of 0.51) for the total ITF transport.

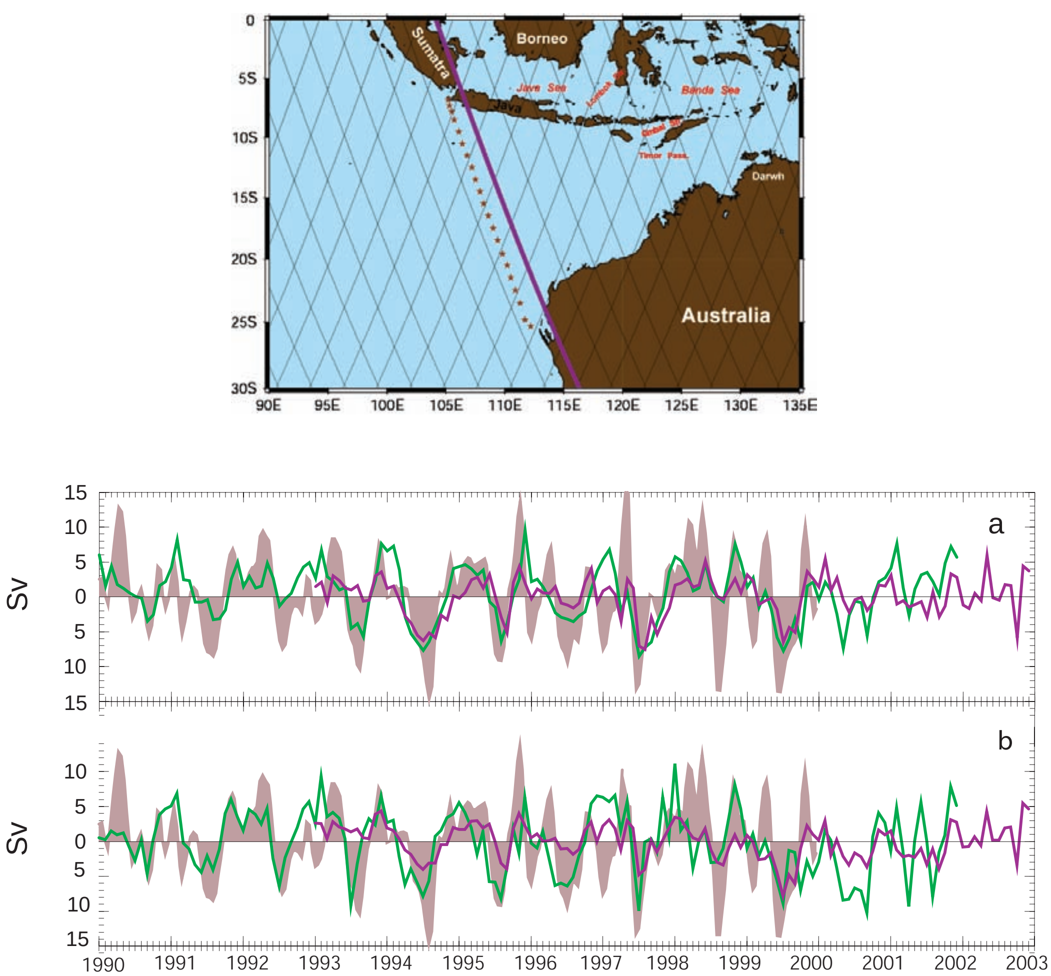


Figure 10. **Map:** Region of XBT (purple line) and satellite altimetry-derived estimates of ITF transports. **Bottom** panels show the seasonal transport variations in the upper 200-m (**panel a**) and of the total (**panel** b) as observed by XBT (brown; from Sprintall et al., 2003), calculated from SODA (green), and estimated from sea-level (purple).

Furthermore, the relationship between interannual (3−10 year) variations in Indian-Ocean temperatures and the ITF transport was examined in a 300-year integration of the NCAR PCM coupled model (Potemra, Schneider). Correlation and regression analyses were used to estimate the relative contributions by changes in ITF volume transport and in Indian Ocean surface-atmospheric forcing to low-frequency temperature variations in the Indian Ocean. Low-frequency variations in the modeled ITF transport are small (~2 Sv) and have little impact on Indian Ocean SST. Most of the low-frequency variance in Indian Ocean SST (r.m.s. > 0.5°C) occurs in the upper thermocline (75−100 m) and largely reflects concurrent atmospheric forcing. ITF-induced temperature variability at this depth is limited to the outflow region between Java and Australia, extending westward along a band from 10−15°S.

Ocean Dynamics

Work has continued on identifying properties of jet-like structures found in altimeter data and high-resolution ocean models (Maximenko, Richards, Nakamura, Yoshinari). Three distinct classes of jets have been identified: quasi-steady, wave-like, and stochastic jets, and methodologies for the analysis of each of these classes have been developed. Analyses of OFES data averaged along density surfaces revealed that some jets show jumps in potential vorticity. This property has implications for the meridional transport of tracers. Further evidence for the jets is now being sought in float data. A global set of Argo float trajectories has been processed to extract velocities of deep currents, in which the jets' signal is expected to be most pronounced (see Asia-Pacific Data-Research Center, p. 29).

Work has also continued on identifying the causes and impacts of the interleaving structures observed in the thermocline of the equatorial Pacific (Natarov, Richards). There is evidence that the time dependence of the flow can have a strong influence on the generation of interleaving structures through a combination of parametric subharmonic instability and inertial instability.

Application of Data Assimilation Techniques

An adjoint for a 4½-layer model has been developed, and the model and its inverse were applied to estimate errors in the monthly mean rainfall data over the Bay of Bengal (Yaremchuk, Yu). It was shown that, despite relatively high errors (~0.5 psu) in the observed sea-surface salinity (SSS) within the bay, the method is capable of reducing errors in climatological rainfall data (from 0.6 m/yr to 0.45 m/yr) over the region. The study illustrates the usefulness of remote sensing of SSS, which has a potential for considerably improving rainfall estimates.

ASIAN-AUSTRALIAN MONSOON SYSTEM (THEME 3)

The Asia-Pacific climate is defined largely by the Asian-Australian monsoon system, the most energetic monsoon system on Earth. This 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. Research under this theme aims to determine the processes responsible for the variability and predictability of this system and its hydrological cycle. The section below summarizes IPRC research achievements during FY05.

Monsoon Intraseasonal Variability

The high-resolution India daily rainfall data set from 1951 to 2005, recently released by the India Meteorological Department, has been analyzed at the IPRC with regard to the break periods (dry spells) in the monsoon. The analysis covers the traditional "monsoon zone", that is, the region 21º–27ºN, 72º–85ºE. The number of breaks in the data-set during July–August in the monsoon zone was calculated according to the following definition of a break: a period of 3 days or longer, in which there was less than 75 percent (1 standard deviation) of the average July–August rainfall. Results are shown in Figure 11, left panel. It is striking that "extended" breaks (lasting 7 days or longer) occur much more frequently than breaks of in-between duration. The observation strongly suggests that the two types of break periods are the result of different atmospheric circulation patterns. An examination of convection over 40ºN–20ºS, 50ºE–180 in AVHRR outgoing longwave radiation (OLR) data for the July–August period from 1979 to 2005 revealed that during extended breaks, there is an east-west oriented dipole, with enhanced convection over the tropical West Pacific and reduced convection over the entire Indian subcontinent. This finding contrasts sharply with the popularly held conception of a north–south dipole structure in the convective anomalies over India. Figure 11, right panel shows the OLR pattern during the extended monsoon break that occurred August 7–15, 2005.

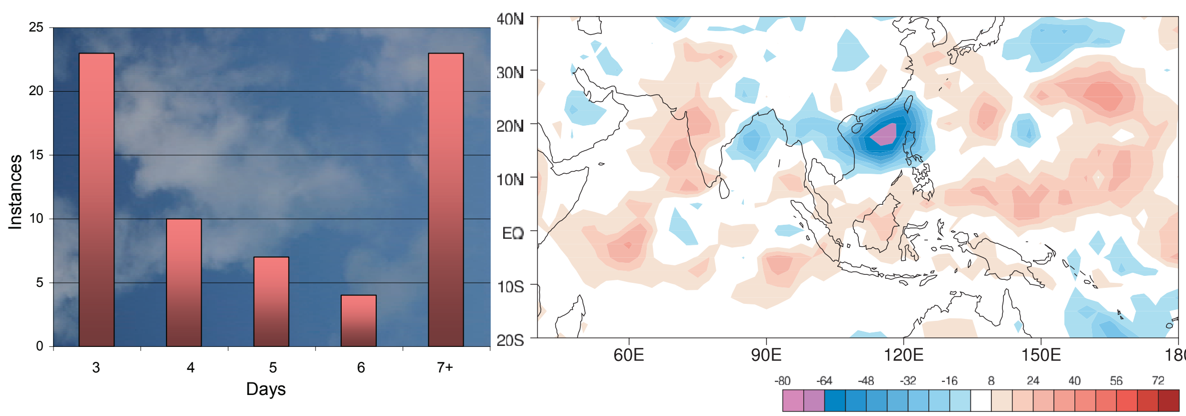


Figure 11. Left panel**:** The instances of different lengths of break periods (in days) from 1951 to 2005. **Right** panel: the outgoing radiation in watts/m^2 over the monsoon region and the western Pacific during the extended break period August 7 – 15, 2005.

During the extended breaks, drought conditions prevail over India instead of the usually heavy July–August rains. Diagnostics of meteorological variables suggest that persistence of deep convection over the tropical west Pacific forces descending Rossby waves to the west, causing anomalous descent throughout the entire troposphere, which maintains the dry conditions over India. The unusually strong convection over the tropical West Pacific is thought to begin with the Madden–Julian Oscillation and then be maintained by slowly varying boundary forcing. These results are an important step towards predicting extended dry periods of the monsoon (Annamalai, in preparation).

Using the new global water-vapor profiles of the Atmospheric Infrared Sounder (AIRS) aboard the Aqua satellite during the summers 2003 and 2004, IPRC scientists have constructed an observational benchmark of the three-dimensional water-vapor cycle associated with the tropical intraseasonal oscillation (Fu et al., *GRL* 2006). Figure 12 shows a snapshot of one composite phase. The greatest moistening is found to be collocated with maximum rainfall and surface wind convergence. The maximum moisture perturbation is much larger than that seen in current analysis and reanalysis datasets. A dry surface layer was observed beneath the deep convection and greatest moistening. This feature is absent in both ECMWF and NCEP reanalyses. The deep convection is preceded by positive SST anomalies and atmospheric boundary-layer moistening, which suggests that the positive SST anomalies moisten the atmospheric boundary layer and destabilize the troposphere, guiding the propagation of the disturbance.

In a study of the tropical, western Indian Ocean, re-iniation of the intraseasonal oscillation was found to be linked to boundary processes associated with the degree of symmetry of the atmospheric response to the previous cycle and the asymmetric summer mean flow (Jiang and Li, *J. Climate* 2005). Another study focused on differences in intraseasonal variability of the Indian Ocean. Strong sea surface cooling events in the southern tropical Indian Ocean are typically observed during December–February, but not during June–August. The reason for this difference was investigated with a 2½-layer ocean model forced by observed daily heat-flux and wind-stress fields. Winter-summer differences in the basic-state wind, strength of the atmospheric intraseasonal oscillation, and ocean mixed-layer depth all contribute to the different ocean response in the two seasons (Tam and Li).

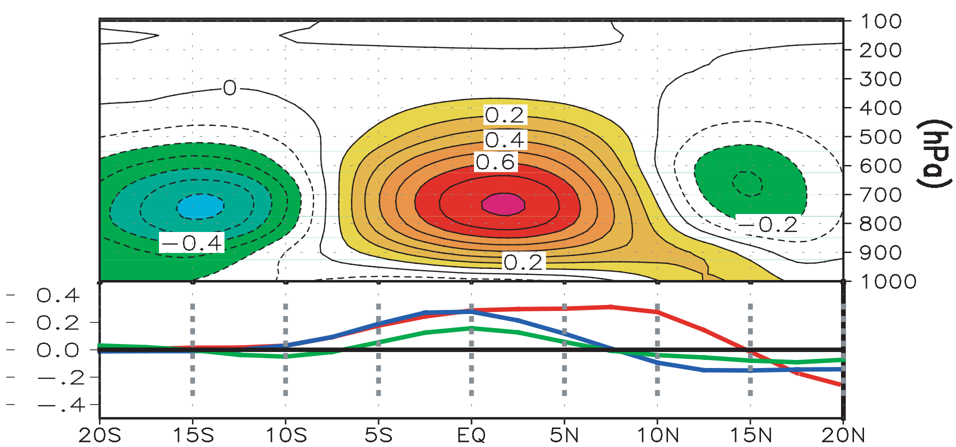


Figure 12. Top: Vertical moisture anomalies from AIRS averaged over 85E-95E associated with the northward-propagating monsoon wet-and-dry spells. **Bottom**: anomalies in sea surface temperature (red line, AMSR_E), surface convergence (green line, QuikSCAT), and rainfall (blue line, GPCP) over the same region and period. (Fu et al., *GRL* 2006)

Finally, a study of the Madden–Julian Oscillation (MJO) with NCAR CAM2 improved simulation of the mean state significantly using the Tiedtke cumulus parameterization scheme (Liu). A composite model-MJO indicates that in the Indian Ocean, wind-induced surface heat-flux exchange helps to sustain the MJO and its eastward propagation, whereas in the western–central Pacific, frictional moisture convergence is more important.

Monsoon Interannual Variability

IPRC scientists' efforts to gain a better understanding of the interannual variability of the Asian Australian monsoon have led to several findings. In contrast to the commonly held view that monsoon anomalies are driven by SST anomalies in the warm pool, our research shows that it is the interaction between the monsoon and the warm ocean that causes fluctuations in both the warm pool and in the monsoon climate. This two-way interaction between SST and the monsoon was shown to account for the observed negative rainfall–SST relationship during the monsoon season (Wang et al., *GRL* 2005). This finding challenges the traditional seasonal forecast approach in which the models are driven by SST predicted from a dynamic-statistical model, i.e., the two-tier system.

Analysis of output from a 220-year run with the SINTEX-F coupled atmosphere–ocean GCM indicates strong interactive feedback between El Niño and the Indian Ocean (IO), a finding matched by observations (Kug et al., *GRL*, in press). This collaborative work with FRCGC scientists in Japan shows that in the SINTEX-F coupled model, El Niño events are either "decoupled" from the IO or "well-coupled" to it. Well-coupled El Niño events decay much more quickly than "decoupled" ones (Figure 13). Moreover, the IO warming is associated with El Niño, leading to rapid decay of El Niño and relatively fast transition to La Niña, while IO cooling tends not to be associated with La Niña,

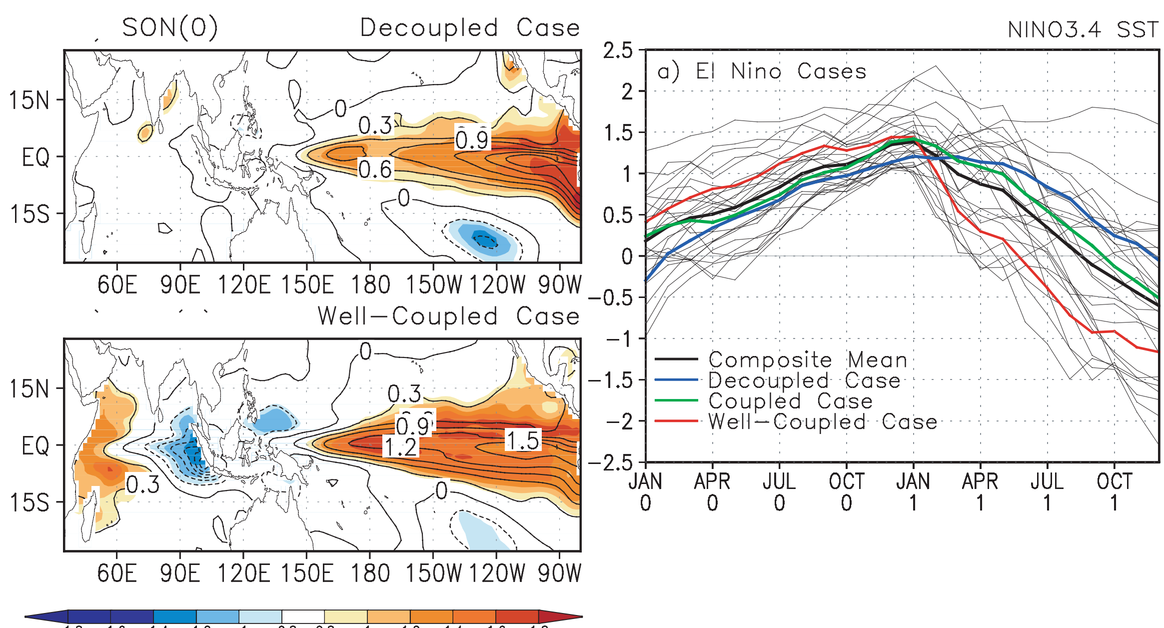


Figure 13. SINTEX-F coupled GCM sea surface temperature (SST) anomaly patterns for El Niño events that are "decoupled" or "well-coupled" to Indian Ocean SST. The right panel shows that well-coupled El Niño events decay much more quickly (red line) than decoupled events (blue line). Kug (Seoul National University), Li and An (IPRC), Kang (Seoul National University), and Luo, Masson, and Yamagata (FRCGC). *Geophys. Res. Lett.*, in press.

leading to slow decay of La Niña and slow transition to El Niño. The proposed mechanism for the IO-El Niño feedback is as follows: During the mature phase of El Niño, IO warming produces easterly wind stress anomalies over Indonesia and the western edge of the Pacific, which in turn facilitate the termination of El Niño and the quick transition to La Niña by generating upwelling Kelvin waves. Thus the IO warming that is a part of the El Niño signal operates as a negative feedback to El Niño. This feedback, which seems to be tied mostly to a strong El Niño, results in La Niña one year after the mature phase of El Niño. This one-year phase transition suggests that IO–El Niño coupling is a key process in the biennial tendency of El Niño.

A new paradigm was proposed in which the tropospheric biennial oscillation (TBO) results from ocean-atmosphere interactions in the warm Indo-Pacific ocean region (Li, Liu, Fu, B. Wang, Meehl, *J.Climate* 2005). IPRC scientists, in partnership with NCAR, used a seasonal-sequence EOF analysis to describe the observed structure and characteristics of the seasonal evolution of the TBO. The major convective activity centers associated with the TBO appear to be in the southeast Indian Ocean and western North Pacific. The convection is accompanied by anticyclonic (or cyclonic) circulation with a first-baroclinic-mode structure. The anomalies have different life cycles in the two regions, with those in the Indian Ocean peaking in northern fall and those in the Pacific persisting from northern winter to the next summer. This time development confirms earlier findings by IPRC scientists (C. Wang, Wu, Li, *J. Climate* 2005). In a supporting coupled-model experiment, in which El Niño was intentionally suppressed, the TBO arises from the monsoon–warm ocean interaction.

Monsoon Predictability and Prediction

IPRC scientists are leading the efforts of the international project “Climate Prediction and Application to Society” (CliPAS) supported by the APEC (Asian-Pacific Economic Cooperation) Climate Center that was launched in Korea in May 2005. The project’s goal is to improve global model capability to predict intraseasonal-to-interannual climate variations by using the multi-model ensemble technique, which reduces individual model errors significantly and improves probabilistic forecast. The current prediction system includes 10 state-of-the-art climate prediction models from the United States, Japan, and Korea: 5 air-sea coupled GCMs (one-tier system) and 5 atmospheric GCMs driven by SST predicted from a dynamic-statistical model (two-tier system). In a hindcast study of the last 24 years, the one-tier system has better predictive skill than the two-tier system. The project will soon include additional models from Australia and other APEC economies. A comprehensive report on the status and challenges of dynamical seasonal prediction is in preparation.

Experimental forecasts of monsoon intraseasonal oscillations (ISOs) were carried out using an air-sea coupled GCM and a stand-alone atmospheric GCM. Results again showed that air-sea coupling can significantly extend the ISO forecast skill by up to 10 days (Fu).

Tropical Diurnal Cycle

The IPRC Regional Atmospheric Model (iRAM) was used to investigate the effect of lateral fractional convective entrainment/detrainment rates on the simulated diurnal precipitation cycle over the Maritime Continent region (Y. Wang, Zhou, Hamilton, *Mon. Wea. Rev.*, in press). Results were compared with observations based on 7 years of TRMM satellite measurements. In a control experiment with the typical parameterization of fractional convective entrainment and detrainment rates, the model produced a diurnal cycle similar to other current regional atmospheric models in which precipitation

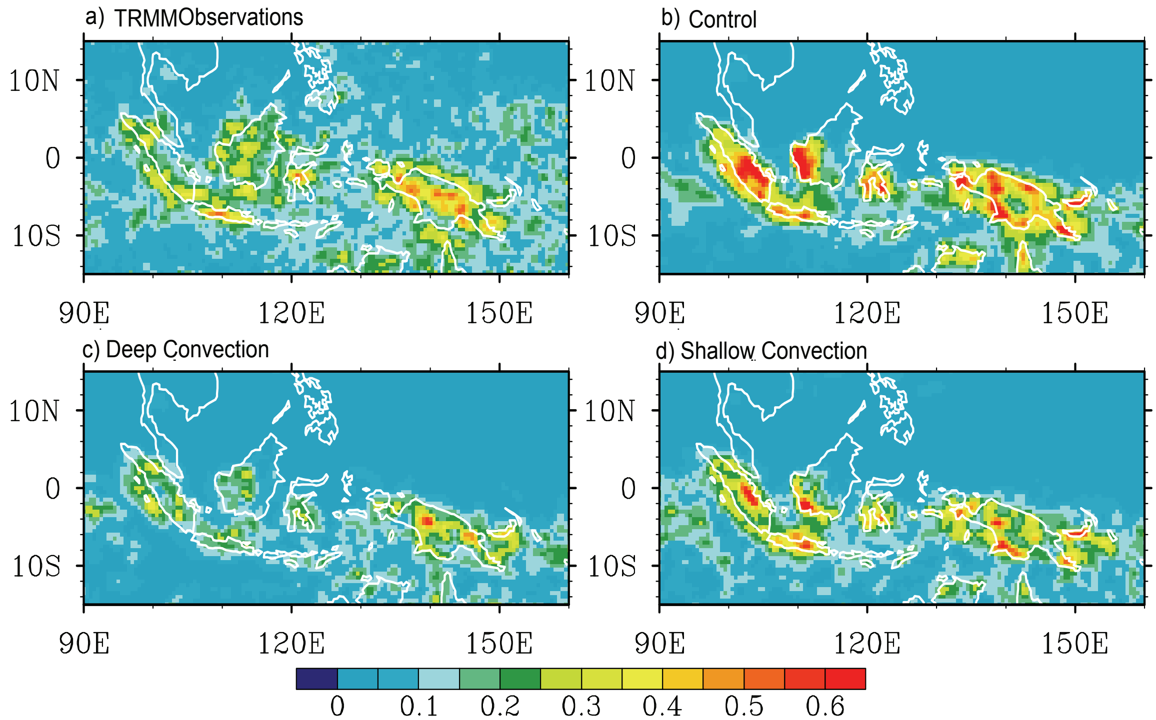


Figure 14. The daily amplitude of rainfall rate in mm/hr from (a) 7 years of TRMM products and from the 3-month model simulations under (b) control, (c) deep convection, and (d) shallow convection modifications in iRAM.

rates over land peak too early in the day and have an unrealistically large diurnal range. Increasing fractional entrainment and detrainment rates in the deep and shallow convection parameterizations leads to more realistic simulation of the diurnal range in precipitation rates. The best results, however, were obtained with increased entrainment and detrainment rates for shallow convection (Figure 14). This improvement was accompanied by a more realistic simulation of temporal variability of daily mean precipitation and a more realistic partitioning of large-scale and convective rainfall.

Tropical Cyclone Studies

IPRC research on tropical cyclones (TC) has investigated the mechanisms of their formation and rapid intensity changes as well as the impact of environmental conditions. In an analysis of 88 tropical cyclones in the western North Pacific during 1975–2003, four distinct synoptic low-level circulation patterns favorable for rapid intensification were identified: monsoon shear lines, confluence zone, easterly winds, and hybrid confluences and shears (Ventham and B. Wang, *Mon. Wea. Rev.*, in press). At interannual timescales, a zonal flow with large low-level cyclonic shear and upper-level anticyclonic shear favors TC intensification (Yang, and B. Wang). Analysis of 106 NOAA/HRD and USAF aircraft-mission data revealed that observed TCs show a positive radial gradient of relative vorticity whereas the currently used bogus profiles show a negative gradient (B. Wang). Vortex Rossby wave theory indicates that the observed TCs are likely to withstand episodes of larger vertical shear than the bogus and theoretical TC profiles. This finding is relevant to improving initialization of models forecasting TCs and their intensity in the northwestern Pacific.

An extensive set of studies was conducted to determine the structure and evolution characteristics of TCs that form in association with Rossby-wave energy dispersion of a preexisting cyclone (Li and B. Fu, *J. Atmos. Sci*., 2006) Analysis of data from QuickSCAT and the Microwave Imager on the Tropical Rainfall Measuring Mission satellite show that about one-sixth of cyclones are formed in the cyclonic circulation region of the Rossby-wave train of a previous cyclone. Not all cyclones generate a Rossby-wave train (Figure 15). In general, the stronger a cyclone is in terms of mean sea level pressure (MLSP), the greater the probability that it generates a wave train (Figure 15b). When a Rossby-wave train is generated, whether it spawns a second cyclone depends on the large-scale dynamic and thermodynamic conditions, such as stronger low-level convergence, cyclonic vorticity, weaker vertical shear, and greater midtropospheric moisture (Figure 16).

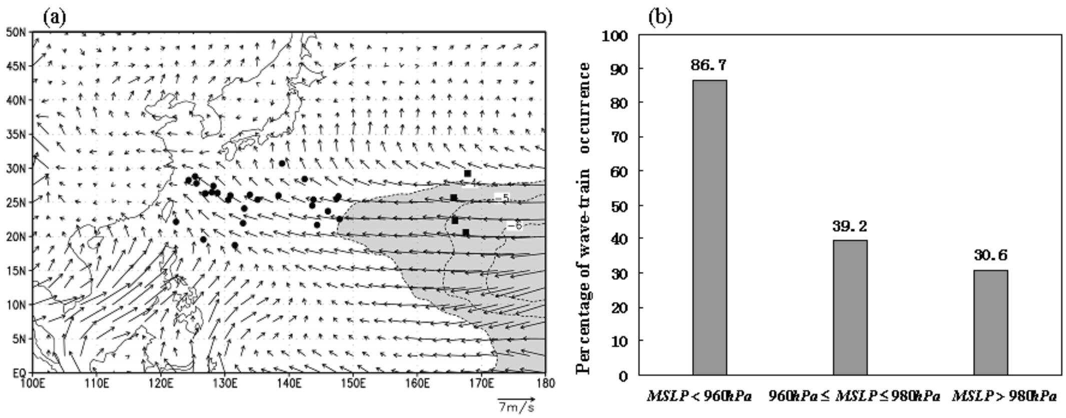


Figure 15. Left: Geographic location of the strong tropical cyclones (mean sea level pressure, MSLP < 960 hPa) that do (closed circle) and do not (closed square) have a Rossby wave train in their wake. Superposed are background June–September-averaged wind vectors at 1000 hPa. The region where the mean easterly wind speed is greater than 4m/s is contoured and shaded. **Right**: Percentage of strong tropical cyclones (MLSP less than 960 hPa), moderate (MLSP 960–80 Pa), and weak (MLSP higher than 980 hPa) whose energy dispersion generates a Rossby wave train.

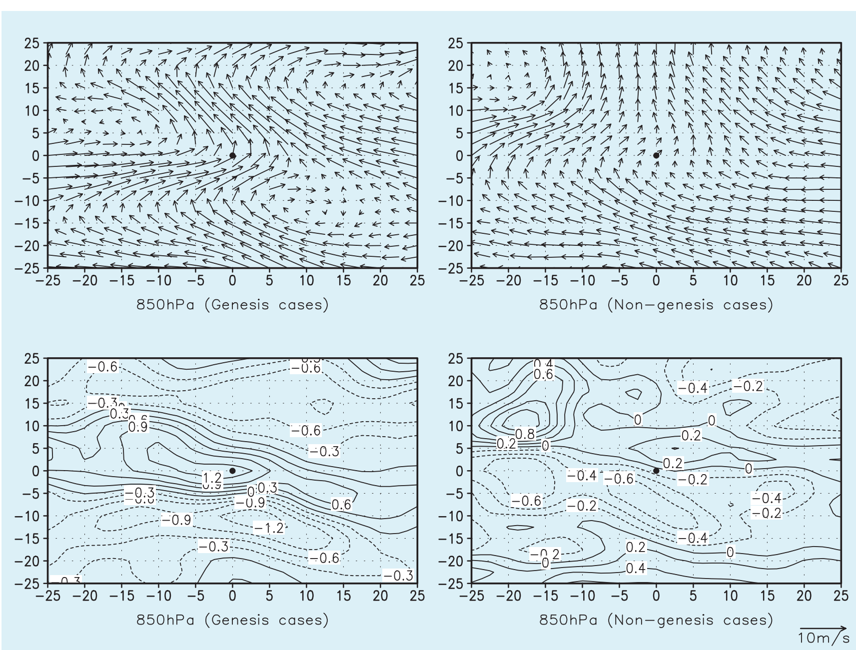


Figure 16. Composites of 20-day low-pass filtered wind fields (**top** panels) and vorticity (10^{-5} s^{-1}) fields (**bottom** panels) at 850 hPa for the cyclogenesis (**left** panels) and noncyclogenesis cases (**right** panels). The vertical (horizontal) axis is relative distance in latitude (longitude) degrees to the center of cyclonic circulation of the wave train. (Li and B. Fu, *J. Atmos. Sc.* 2006).

A numerical study with a 3-dimensional TC model showed that tropical cyclogenesis by Rossby-wave energy dispersion occurs in a large-scale monsoon gyre or monsoon shear-line flow. Maximum vorticity is generated in the planetary boundary layer. Diagnosis of the model output revealed that vorticity oscillates as a result of discharge and recharge of the boundary layer moisture: On the one hand, the ascending motion associated with deep convection transports moisture upward and discharges it, leading to convectively stable stratification; on the other hand, the convection-induced raindrops evaporate, leading to midlevel cooling and downdraft and drying (through vertical advection), and reduction of the equivalent potential temperature. This reduction along with the recharge of planetary boundary layer moisture due to surface evaporation reestablishes a convectively unstable stratification and thus enables new convection. Only when the perturbation reaches a critical level, can it grow exponentially into a new equilibrium state. In reality, many perturbations may oscillate for a while and then die out because of unfavorable environmental conditions (Li et al., *J Atmos. Sc*. 2006).

Another TC study focused on formation of the concentric eyewall. A numerical simulation suggested that adequate asymmetric forcing and the subsequent axisymmetrization are critical to the potential vorticity redistribution beyond the eyewall and the growth of a second, concentric eyewall (Y. Wang). Generation of anomalous cyclonic potential vorticity in stratiform clouds beyond the eyewall and its downward penetration give rise to local maximum tangential winds at the surface and allow wind-induced surface heat exchange (WISHE) to form the convective outer eyewall.

In partnership with the Shanghai Typhoon Institute and the National Taiwan University, effects of thermodynamical (e.g., SST) and environmental dynamical factors on the intensity of TCs were determined in a 1981–2003 western North Pacific data set that consists of “best track data” from the Joint Typhoon Warming Center, Reynolds SST, and NCEP reanalysis. The environmental dynamical factors studied were translational speed (the speed at which a tropical cyclone moves) and vertical wind shear. Based on a statistical analysis of this data set, a new, empirical formula for maximum potential intensity was derived for TCs in the western North Pacific. This new formula, which includes the two environmental dynamical factors, provides a more accurate estimate of the maximum potential intensity than previous formulas and explains observations better. For instance, the analysis showed that very intense TCs and those that are rapidly intensifying occur only at wind speeds between 3–8 m/s and in weak wind shear (Zeng, Y. Wang, and Wu, *Mon.Wea. Rev.*, in press).

Long-term Changes in Monsoon Rainfall

A major question with global warming is how summer-monsoon precipitation will change. Large multi-decadal and centennial fluctuations in monsoon rain as well as lack of long precipitation records make it very difficult to answer this question. Examining changes in global monsoon precipitation during the last 56 years, IPRC researchers noted an overall decrease in global monsoon precipitation over land. This trend is evident mostly during Northern Hemisphere summer monsoon (Wang and Ding, *GRL,* in press). Since 1980, this trend has no longer been significant even though this period has seen a rise in global surface temperatures. Oceanic monsoon precipitation, though, has been increasing since 1980.

A 130-year instrumental rainfall record in India shows no trend. One of the longest instrumental measurements of daily precipitation has been recorded since 1778 in Seoul, Korea. IPRC scientists, together with colleagues at Seoul National University, have analyzed this data (B. Wang, Ding, Jhun, *GRL*, in press). They noted that over the last 50 years, summer rainfall shows a significant trend towards heavier rainfall events: Specifically 67% of the total rain during June–September has been falling in fewer days. These trends provide a rigorous test for climate models.

IMPACTS of GLOBAL ENVIRONMENTAL CHANGE (THEME 4)

Research under this theme aims to determine impacts of global environmental change on Asia-Pacific climate, to understand processes that shaped past climates and shape present climates, and to improve numerical modeling of climate change. During FY05, research has continued on the climate's sensitivity to radiative and land-surface perturbations, global controls over regional climate, and high-resolution atmospheric modeling. Paleoclimate modeling has been conducted on the last deglaciation in Antarctica, effects of the precessional cycle on the Pacific background state, and climate synchrony between the North Atlantic and North Pacific oceans.

Climate Sensitivity to Radiative and Land-surface Perturbations

Analysis was completed of the climate feedbacks in control and global warming runs with the NCAR Community Climate System Model (CCSM) and the Canadian Coupled Global Model (CGCM; Stowasser, Hamilton, and Boer, *J. Climate* 2006). The NCAR model has a rather low sensitivity of global mean surface temperature to radiative forcing, while the Canadian model has about twice the sensitivity of the NCAR model. The sensitivity difference between the models is mostly attributable to feedbacks involving the interaction between shortwave radiation and clouds. In the NCAR model, the total tropical and subtropical cloudiness increases as the globe warms, leading to strong negative feedback. Both models have a region of positive feedback in the equatorial Pacific associated with a local maximum in surface warming that is surrounded by broad areas of negative feedback. The models, however, differ in the zonal structure of this surface warming. The NCAR model shows a mean El Niño-like warming in the eastern Pacific, and the Canadian model a far-western Pacific maximum warming. In an additional simulation with the Canadian model that suppressed the tropical Pacific zonal surface warming gradients, the global mean feedback is nearly unchanged. This insensitivity suggests that the processes that produce the positive feedback in the tropical Pacific region do not contribute greatly to global mean climate sensitivity.

Also completed this year were analyses of hindcast simulations from 12 global coupled models included in the model intercomparison in preparation of the IPCC Fourth Assessment Report (Stowasser and Hamilton, *J. Climate*, in press). Focus was on the connection between local monthly mean shortwave- and cloud-radiative forcing over the tropical and subtropical ocean and the resolved mid-tropospheric vertical velocity and lower tropospheric relative humidity. Model results were compared among each other and with observations (with satellite data for the cloud forcing and with NCEP and ECMWF global reanalysis for the vertical velocity and humidity fields). Results among the models varied considerably and all models show substantial differences from the comparable observed results. The most notable deficiency common to all of them is an under-representation of the cloud-radiative response to variations in meteorological variables in regimes with strong ascending or descending motions. The models perform better in regimes with only modest upward or downward motions, but even in these cases, this varies considerably in the degree to which cloud forcing depends on vertical velocity. The largest differences between models and observations, when results are stratified by relative humidity, are found in either very moist or very dry regimes. Thus, the largest errors in the model simulations of cloud forcing are prone to be in the western Pacific, warm-pool area, which is characterized by very moist strong upward currents, and in rather dry regions, where the flow is dominated by descending motions.

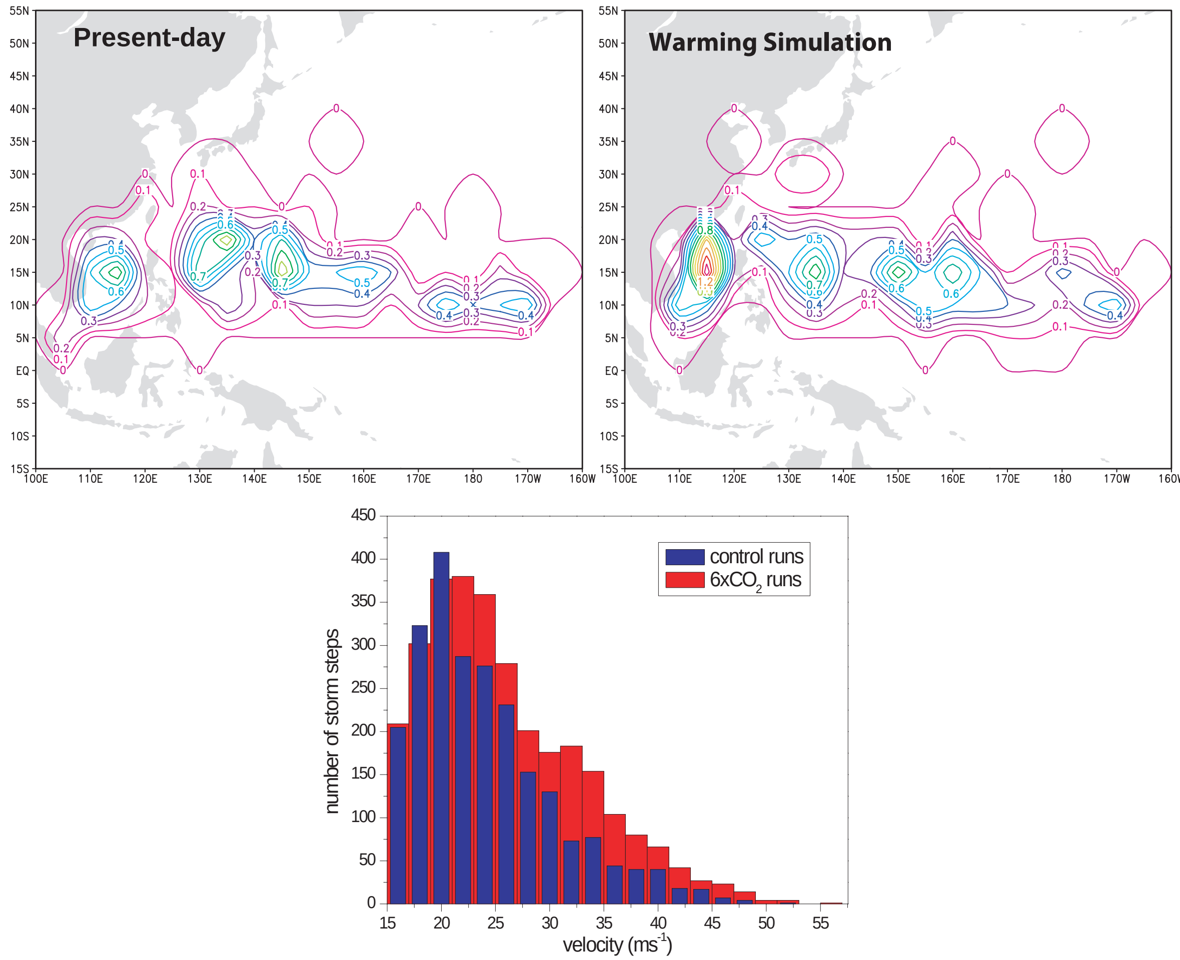


Figure 17. Top: Comparison in iRAM of tropical storm genesis locations in the western North Pacific during July - October with a present-day CCSM2 control run and with a CCSM2 run with 6 times present-day CO_2 levels. Results are shown as number of storms generated in each 5° latitude-longitude box per year. **Bottom:** Histogram of western North Pacific tropical cyclone frequency packing different maximum surface wind speeds. Frequency is given in number of 12-hour time-steps during which a tropical cyclone was present in the domain under present-day and global warming conditions.

In a third project, the influence of global warming on the climatology of tropical cyclones in the western North Pacific basin was examined (Stowassser and Hamilton). A high-resolution version of the IPRC Regional Climate Model (iRAM) was first tested in 10 years of simulation driven by boundary forcing taken from observations. The model produced a reasonably good representation of the observed statistics of tropical cyclone numbers and locations. Then the model was run for 10 years driven by ocean temperatures and horizontal boundary fields taken from a present-day control run of the NCAR CCSM2 coupled global climate model. Finally, the model was run with forcing fields taken from the end of a long run with the CCSM2 with 6 times the present-day atmospheric CO_2 concentration. The global-mean surface air temperature in the perturbed run rose 4.5K, while in the tropical western North Pacific it rose about 3K. Results of these experiments reveal no statistically significant change in basin-wide tropical cyclone numbers in response to the CO_2 increase. The number of tropical cyclones in the South China Sea, however, showed a statistically significant increase (Figure 17, top). Moreover, the average cyclone strength increased significantly as did the number of the storms in the strongest wind categories (Figure 17, bottom panel).

High-resolution Atmospheric Modeling

Colleagues at the Earth Simulator Center have completed a series of integrations with the high-resolution Atmospheric GCM for the Earth Simulator (AFES). The runs varied the horizontal and vertical resolutions, the horizontal subgrid-scale diffusion coefficients, and the moist convection parameterization schemes. They include: (1) control integrations at T1279 horizontal resolution and 96 vertical levels; (2) a set of integrations at T639 horizontal resolution but with different vertical resolutions, horizontal subgrid-scale diffusion coefficients, and different moist convection parameterization schemes; and (3) a series of runs with constant vertical resolution, but varying horizontal resolution (from T21 to T639).

The IPRC is participating in the analyses of these runs. One completed analysis shows that the kinetic-energy spectrum (KE) simulated in AFES depends to some extent on the convection parameterization employed (Takahashi, Hamilton, and Ohfuchi, *GRL* 2006). For example, the more-active convection scheme (relaxed Arakawa-Schubert) leads to about 10% more energy in the mesoscale (and, interestingly, also in the synoptic scale) than the less active scheme (Emmanuel). The basic transition to a shallow mesoscale regime, however, appears when the model is run with either scheme. A comparison of the model's outputs with aircraft data shows that the regular version of AFES spontaneously produces a realistic KE spectrum of the mesoscale for over a decade or longer (Figure 18).

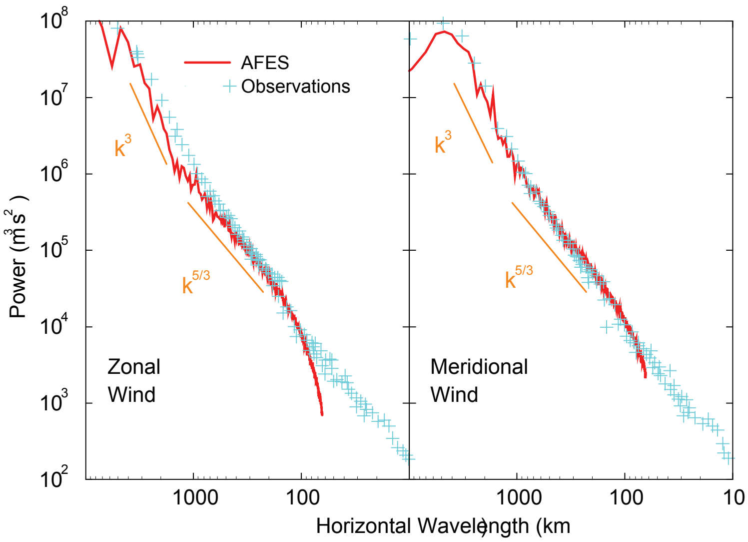


Figure 18. The one-dimensional horizontal power spectra of (left) zonal wind and (right) meridional wind variations near the tropopause. The red curves are computed from wind values taken along the 45N latitude circle at 200 hPa in the T639L24 AFES. The crosses are from Nastrom and Gage [1985] and are computed from wind observations taken by commercial airliners. Orange lines show -3 and -5/3 slopes (Takahashi, Hamilton, and Ohfuchi, GRL 2006)

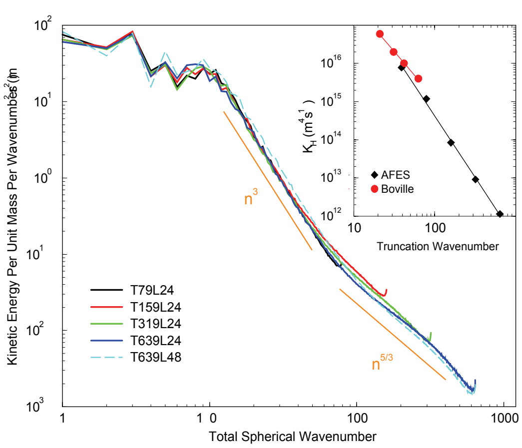


Figure 19. Kinetic energy per unit mass on the 200 hPa surface in the AFES model as a function of the total spherical harmonic wavenumber in integrations run under different numerical resolutions. Results are shown for the 24 level version truncated at T79, T159, T319 and T639, as well as the T639L48 version. At each horizontal resolution a diffusion coefficient has been determined by trial and error to produce the fairly convergent behavior at the high wavenumber end of the spectrum. The black symbols in the inset show the diffusion coefficient as a function of truncation obtained this way. The red dots show results from a similar analysis of a version of the NCAR atmospheric model obtained by Boville [1991]. The lines in the inset are linear regressions.

Global Controls over Regional Climate

Strong explosive volcanic eruptions are known to decrease global-mean surface temperatures for up to two years, an expected consequence of the increased reflection of solar radiation by long-lived aerosol in the stratosphere. Enhanced absorption of terrestrial and solar-near infrared radiation warms the lower stratosphere over the equatorial region and changes the circulation, particularly during Northern Hemisphere extratropical winter, where the response resembles the positive phase of the Arctic Oscillation (AO). In a partnership with colleagues at Rutgers University and the NOAA Geophysical Fluid Dynamics Laboratory, IPRC scientists evaluated the volcanic responses in "historical" simulations produced by seven models included in the model intercomparison in preparation for the IPCC Fourth Assessment Report (Stenchikov, Hamilton et al., *GRL* 2006). All models produce the observed tropospheric cooling and stratospheric warming in response to the radiative perturbations resulting from identifiable volcanic explosions, and they tend to show a response roughly consistent with a positive phase of the AO in the winters following the eruptions. In all the models, however, the high-latitude surface pressure and surface temperature anomalies in these winters are weaker than in observations.

Paleoclimate Modeling

IPRC scientists have investigated the effects of the precessional cycles on the tropical Pacific background state and its variability. A coupled general circulation model (ECHO-G) was run with accelerated orbital forcing for 1650 years, representing the period from 142,000 years before present to 22,900 years after present. Because large cloud decks cover the off-equatorial regions of the Pacific for much of the year, the precessional cycle was found to modulate the annual-mean meridional asymmetry around the equator and hence the strength of the equatorial annual cycle. Such changes in the simulated equatorial annual cycle trigger abrupt changes in the model's ENSO variability. This finding explains the negative correlation between annual-cycle strength and ENSO amplitude noted at precessional timescales in the simulation.

A second project focused on understanding the climate synchrony between the North Atlantic and North Pacific seen in proxy records at multidecadal-to-millennial timescales (Timmerman et al.). Massive freshwater pulses during the last glacial period, known as Heinrich events, affected not only the North Atlantic but also the Pacific. These freshwater pulses, believed to have arisen from slippage of the Laurentide ice sheet into the Atlantic, weakened the Atlantic Meridional Overturning Circulation (AMOC). Using five different coupled GCMs, IPRC scientists and their international colleagues investigated the effects of such AMOC weakening on the tropical Pacific climate mean state, the annual cycle, and ENSO variability. The weakening of AMOC was induced by adding freshwater flux forcing in the northern North Atlantic. In response, the well-known surface temperature dipole in the low-latitude Atlantic set in, increasing the northeasterly trade winds and shifting the Intertropical Convergence Zone southward in the tropical Atlantic and tropical Pacific. This shift is maintained in the model by coupled air-sea interactions such as the wind-evaporation–SST feedback. The evaporative fluxes, mixing, and changes in Ekman divergence generate an anomalous symmetric thermal background state in the eastern equatorial Pacific. In four of the coupled GCMs, this modification leads to a substantial weakening of the annual cycle in the eastern equatorial Pacific and an increase in ENSO variability (Figure 20). This increase is due to the nonlinear frequency-entrainment mechanism in the models. In the fifth coupled GCM, ENSO variability increases because of zonal mean thermocline shoaling.

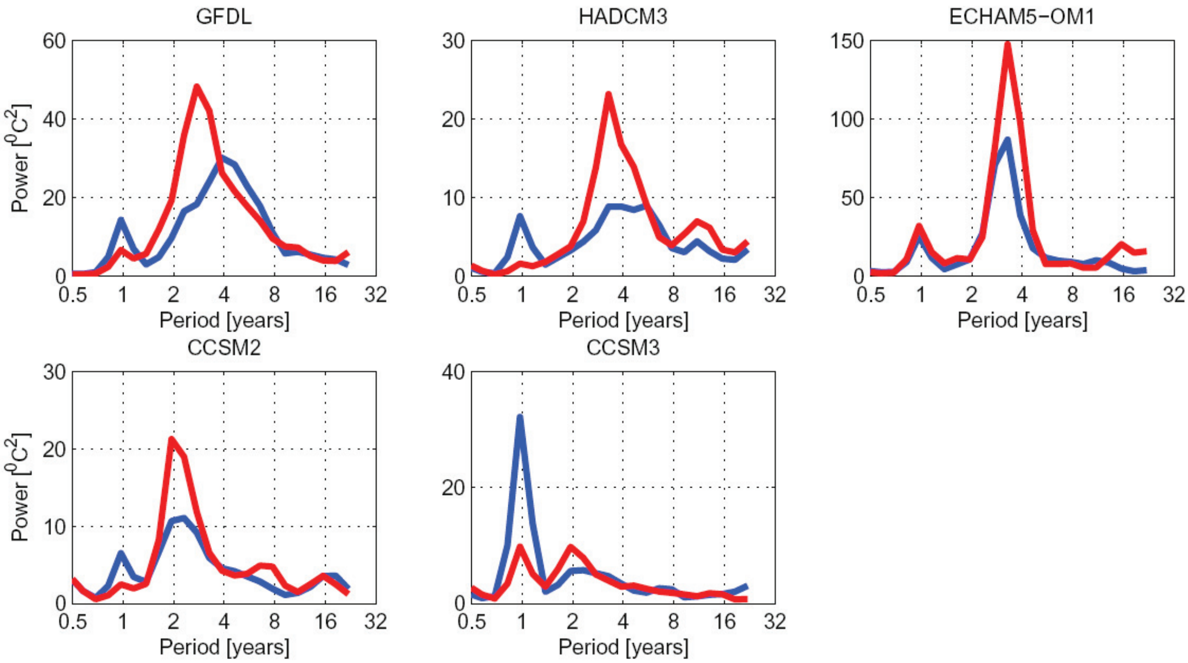


Figure 20. Power spectra of the simulated Niño 3 SST anomaly for the GFDL CM2.1 model (upper left), the HadCM3 model (upper middle), the MPI-OM1 (upper right), the CCSM2 model (lower left) and the CCSM3 model (lower middle). The Niño 3 SST anomaly was obtained by averaging the monthly SST over the region 90ºW–150ºW, 5ºS–5ºN and by subtracting only the long term annual mean, thereby retaining seasonal variability. The power spectra of the Nino 3 SST anomaly for control run (first 200 years) are shown in blue, while the ones for the water hosing experiments (first 200 years) are depicted in red.

Analyses of the simulations suggest that the narrowness of the Central American land bridge plays a key role in the transmission of climate anomalies from the tropical North Atlantic to the tropical eastern Pacific. Furthermore, we conclude that the existence of the present-day tropical Pacific cold-tongue complex and the annual cycle in the eastern equatorial Pacific are partly controlled by the strength of AMOC. If these results are confirmed, they will have important implications for the interpretation of global multi-decadal variability and paleo-proxy data.

Ice cores from Antarctica as well as marine sediment records from the Southern Hemisphere provide compelling evidence for major climatic reorganizations during the last glacial termination (about 20,000−10,000 years ago). During this period, Antarctic surface air temperatures increased by 5−8°C. The origin of this warming has not been fully understood yet. Abrupt millennial-scale transitions of the AMOC, caused by glacial melt water pulses in the Northern Hemisphere, have been suggested as potential drivers for the Antarctic glacial-interglacial climate swings. Recent work by IPRC scientists, though, now provides strong evidence that the warming originated through changes over Antarctica alone (Timmermann, Timm, Stott). In a partnership with Lowell Stott at USC, they conducted transient climate simulations covering the last 21,000 years. Driving the model with ice-sheet cover and greenhouse gas concentrations in accordance with proxy records and with insolation in accordance with known orbital changes, only the austral spring time (September–November) simulation matched the initial rise and leveling off of temperature seen in the Antarctic proxy records (Figure 21, left: black and purple curves). Further experiments conducted to tease apart the effects of orbital insolation and greenhouse gases confirmed that insolation changes together with increased atmospheric CO_2 and shrinking sea ice jump-started the deglaciation in Antarctica. Keeping CO_2 and local insolation forcing south of 60ºS at levels before warming began, and varying only ice-sheet properties over time, the temperature rise was too low (cyan curve). Keeping CO_2 levels and ice-sheet properties at glacial values, and varying only insolation, temperature rose but dropped off around 9,000 before present (red curve). Varying only CO_2 in accordance with proxy records, temperatures rise, but again, not to the extent shown in records. Only the combined insolation and CO_2 forcing showed the temperature pattern in the paleo record. The climate model simulations performed to uncover these forcing mechanisms are the first such simulations covering the entire history of the last 21,000 years with a 3-dimensional atmosphere-ocean-sea-ice model.

The simulated time-evolution for Greenland temperatures agrees quite well with ice-core reconstructions, except for the millennial-scale changes, which were not considered in the model simulations. Greenland temperatures can be explained by a combination of glacial forcings different from those in Antarctica. The result of this analysis underscores how differences in the glacial-interglacial forcing mechanisms can conspire to produce the North–South temperature phasing that is observed in the ice-core records. This result should provide guidance in interpreting ice-core records from Greenland and Antarctica.

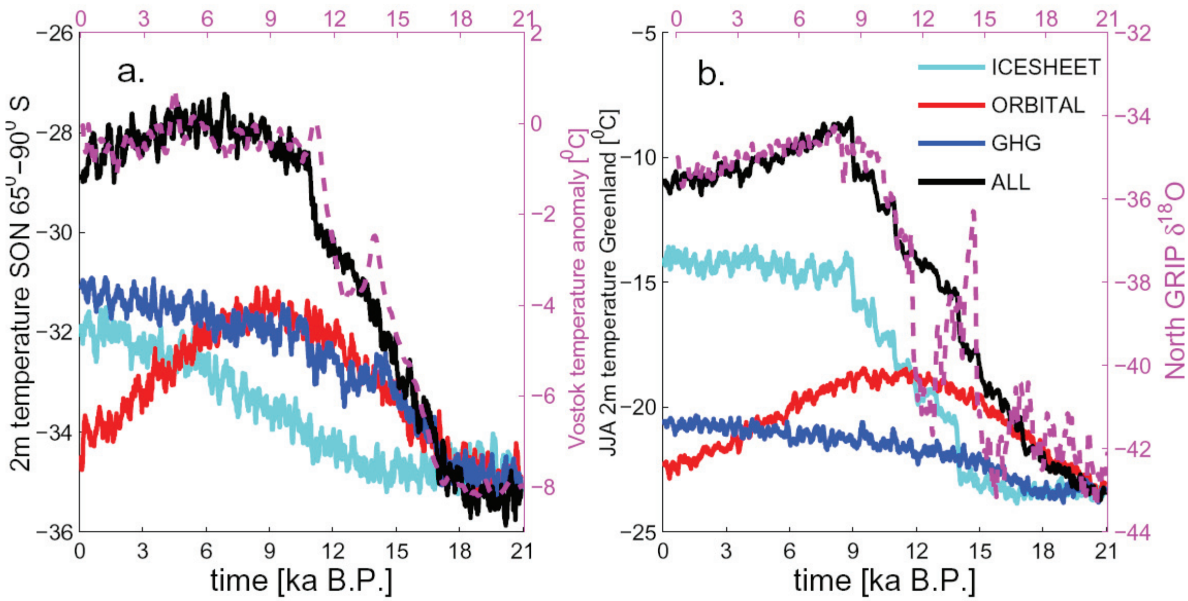


Figure 21. Simulated evolution of Antarctic and Greenland temperatures and sensitivity to different forcings. **Left**: Simulated smoothed austral spring surface airtemperature averaged over 65ºS–90ºS for the transient simulation that includes orbital, greenhouse gas and icesheet changes (black) and the simulations that capture only the time-evolution of the orbital forcing (red), the greenhouse gasses (blue) and the ice-sheet orography and albedo (cyan). Reconstructed temperatures at Vostok are represented in magenta. **Right**: Same as left except for the boreal summer temperatures over Greenland. The magenta line depicts the oxygen isotope ratio δO^{18} of ice as recorded in the North-GRIP ice core in Greenland.

ASIA-PACIFIC DATA-RESEARCH CENTER (THEME 5)

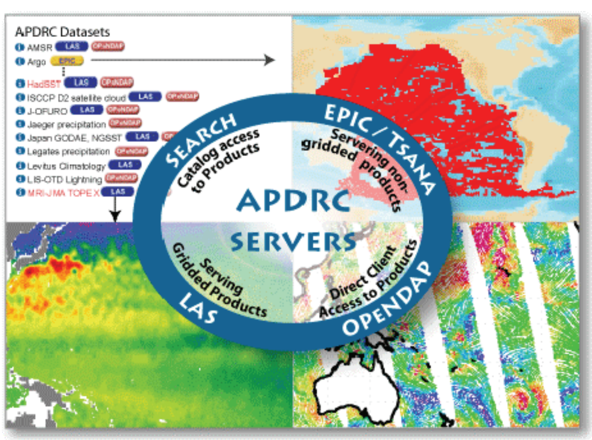
The Asia-Pacific Data-Research Center (APDRC) was established within the IPRC to make climate data and climate products easily accessible for IPRC researchers and their partners, the national-international climate research community, and the general public. The vision for the APDRC is to link data management and data products to research. A summary of the FY05 activities accomplishments follows.

Operate and Develop the Web-based Integrated Data Server System

The APDRC has continued to provide web-based browsing, viewing and downloading of gridded and non-gridded (*in situ*) data sets and products in a user-friendly format on the APDRC servers. Desktop tools are available for powerful display and analysis of data and products on the viewer's computer.

The APDRC currently serves data on two systems: a 480 MHz 4-processor Sun Enterprise 450 with 4 GB of memory, with a total of 6 TB of local disk, 408 GB internally and 5.5 TB of SCSI attached IDE-RAID (AC&NC JetStorIII); and a Linux-based (RedHat Enterprise 4) server installed this year, a 3.2 GHz DELL PowerEdge 2850 with 6 GB of memory. The two systems run in parallel. The plan is to use one for the IPRC and the other for external data requests.

The APDRC operates the following data serving software systems: 1) EPIC is a web-based server for *in situ* data that allows the construction of quick-look plots of oceanographic parameters from station data (recently expanded to include other station data such as rainfall). 2) The Live Access Server (LAS version 6.5) serves a variety of multidimensional gridded data datasets and makes data plots on-line. 3) The Open-source Project for a Network Data Access Protocol (OPeNDAP) allows users to access data on the APDRC servers by using their own client software, such as GrADS, Matlab and/or Ferret; the GrADS OPeNDAP server (GDS) for binary gridded data is used as a front-end to most OPeNDAP requests since it supports the widest range of formats. 4) The OPeNDAP server called DAPPER, still in the developmental stage, provides binary access to station data. 5) The Catalog Aggregation Server (CAS) is for large data sets, split into several files. This software allows seemingly continuous access to data even though the data may physically exist in separate files. The GDS, LAS, CAS and DAPPER servers are all run through a central serving utility called Tomcat version 5.1.



A new server called TSANA was developed last year. TSANA allows selection of *in situ* data from an EPIC-like interface that can be directly imported into Java Ocean Atlas (JOA) or other client software.

Progress has also continued in the APDRC "sister server" agreement with the US GODAE program. APDRC assisted in the upgrade/install of servers, including Tomcat, LAS and GDS, on machines of the Frontier Research Center for Global change, which have been set up as "sister servers" with the APDRC and the US GODAE program.

Provide a Global Data Base and Data Management for Climate Data and Products

Providing one-stop shopping for climate data requires the identification of important oceanographic, atmospheric and air-sea flux data, and checking that the data reflect the latest information, are well documented and, to a certain extent, quality controlled. Data available at the APDRC have increased in three broad areas: Extremely large ocean model datasets, *in situ* oceanographic observations, and *in situ* and remote atmospheric measurements. The atmospheric data archive has improved considerably with a comprehensive assembling of satellite data (TRMM, ISCCP and ERBE experiments), ECMWF products (40-year reanalysis and operational data), and long-term historical records (rainfall, snow depth and air temperature). The APDRC now serves several products from OFES: monthly mean climatologies (complete three-dimensional velocity, temperature, salinity and mixed-layer fields), 3-day snapshots from a specific model year, long-term hindcast surface fields, and a ten-year climatology. At present, this output is available only to IPRC scientists and those associated with the Earth Simulator Center.

The APCRC continues to serve a variety of GODAE products including the output from the US Naval Research Laboratory (NRL) Layered Ocean Model (NLOM). Output from the 1/16 degree (recently upgraded to 1/32 degree) NLOM "nowcast" and "forecast" runs have been archived daily and are served by the APDRC GDS. The APDRC now also serves the regional Tohoku University merged SST product, and reanalysis products such as ECCO and SODA. Scientists can now directly access, subsample, compare, and analyze outputs from these large models in a straightforward way. Serving *in situ* oceanographic data, including Argo data, *in situ* WOCE data, HydroBase2, and FNMOC/GODAE profile data has progressed. New software, such as the Java Ocean Atlas, and Ocean Data Viewer are all now available at the APDRC.

Develop and Disseminate New Climate Products

Together with its partner institutions, the APDRC identifies projects that result in products useful to the climate research community. Thus, in conjunction with NOAA/GFDL and US GODAE, a multi-year, multi-institution task has begun to produce quality controlled, historical data sets for *in situ* temperature and salinity (and nutrient) profiles of the global ocean.

As a participant in the NOAA Pacific Regional Integrated Data Enterprise, which is led by NCDC and NOS' Coastal Services Center, APDRC has helped to identify projects funded by PRIDE in FY05 and FY06 that will produce integrated data products for the climate-research and applications-user communities. The goal of this effort is to "Advance NOAA's mission objectives to help meet critical regional needs for ocean, climate, and ecosystem information to protect lives and property, support economic development and enhance the resilience of Pacific Island communities in the face of changing environmental conditions." Six of the FY05-funded projects from investigators at the University of Hawaii have been included as new tasks within the APDRC. Also included are four tasks funded to various NOAA entities. For a description of the projects see http://apdrc.soest.hawaii.edu/PRIDE.

The APDRC is participating in the effort to develop a global climate product essential to climate research. CSIRO, which created a combined automated and manual procedure for the quality control of the ocean temperature profile data set, completed the Indian Ocean data set as part of a subcontract with the APDRC. The APDRC has installed and begun to use the CSIRO procedure and is also testing Quality Control software from NODC. Regarding the ocean temperature and salinity profile data, the APDRC is using the HydroBase2 methodology for quality control. As part of a subcontract, WHOI has completed the HydroBase2 product for the Indian Ocean, and the data and gridded products are now available on the APDRC servers. The methodology results in products that resolve better than previous products the major narrow boundary currents that are influenced by orography or topographical features (such as the Florida, Mindanao, Leeuwin, and other currents).

Given the many projects in which the APDRC is now participating, the APDRC website and user interface were substantially upgraded. There is now a full-text search tool and online documentation for products. Moreover, the APDRC staff has developed the PRIDE website, which connects the individual PRIDE sites. Progress has also been made on a web site for the Pacific Argo Regional Center (PARC), in which the APDRC is a partner with CSIRO in Australia and JAMSTEC in Japan.

Conduct Research to Develop Climate Products

Argo floats were not designed with measurement of the deep ocean currents in mind. But while parked at depth, deep currents transport the floats horizontally. IPRC scientists have now developed a method by which the velocity of these deep ocean currents can be estimated from the movement of the floats. They calculated deep current velocities from float-displacements during the submerged phase of each cycle, and surface velocities from the float-drift during their surface phase. These new, fully public data sets are now available at the APDRC under the name of YoMaHa'05. The data span the time period August 1997–December 2005, and include about 167,000 values stored in the Data Assembly Centers worldwide.

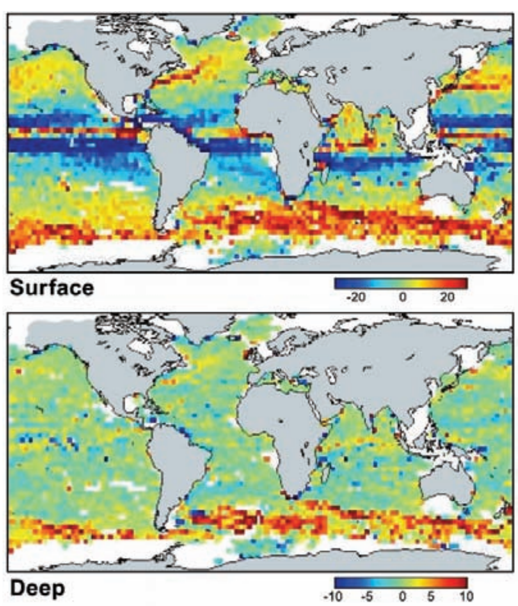


Figure 2. Example application of YoMaHa'05 data. Shown are ensemble mean zonal velocities in cm/s (color bar) averaged over 3º x 3º for surface currents (**top**) and deep currents (**bottom**).

Implement High-resolution Regional Ocean Model Toward Operational Use

In a partnership with the HYbrid Coordinate Ocean Model (HYCOM) Consortium, IPRC scientists implemented the HYCOM for the Hawaii region. The goals are as follows: (1) to run the regional model in near real-time using the output from the Pacific Ocean HYCOM for open-ocean boundary conditions with downscaling, (2) to force the model with high-resolution regional atmospheric products, (3) and to assimilate regional real-time ocean observations. Various model experiments have been performed to test the stability of open-ocean boundary conditions and the downscaling process. Experiments have also been conducted to examine the impacts of different wind and bathymetry products on the regional ocean-circulation characteristics. Figure 22 displays the QuikSCAT wind observations (panels a and b), the ECMWF wind product (panels c and d), and the sea surface height fields from the regional HYCOM forced by the two wind products (panels e and f). The QuikSCAT shows detailed features resulting from the interaction of the trade winds and the islands (weak wind in the lee of the islands and strong wind through the channels between the islands), which are inaccurately represented in ECMWF. The result is fewer cyclonic eddies with low intensity are generated in the lee of the islands when ECMWF is used to force the ocean model. Yet, even the solution forced by QuikSCAT winds produced fewer and weaker cyclonic eddies than observational estimates. This deficiency may happen because the QuikSCAT winds do not extend to nearshore regions, especially in the lee of the major islands where wind reversals (towards land) often occur that are not present in the extrapolation.

The team is now working on a wind product that combines QuikSCAT wind for the offshore regions with output from a high-resolution regional atmospheric model such as MM5 for the nearshore regions. Furthermore, a NOAA funded project has just begun to use an atmospheric forecast system to produce a full set of atmospheric variables at high spatial and temporal resolution for the Hawaii region, including surface wind stress and thermal fluxes for forcing ocean models.

Partner with the Atmospheric Brown Cloud Project

The APDRC has been partnering with US scientists and the international Steering Team of the Atmospheric Brown Cloud in the development of a data management strategy and plan for this project. APDRC's role is to demonstrate the kinds of server technologies now available for this type of research.

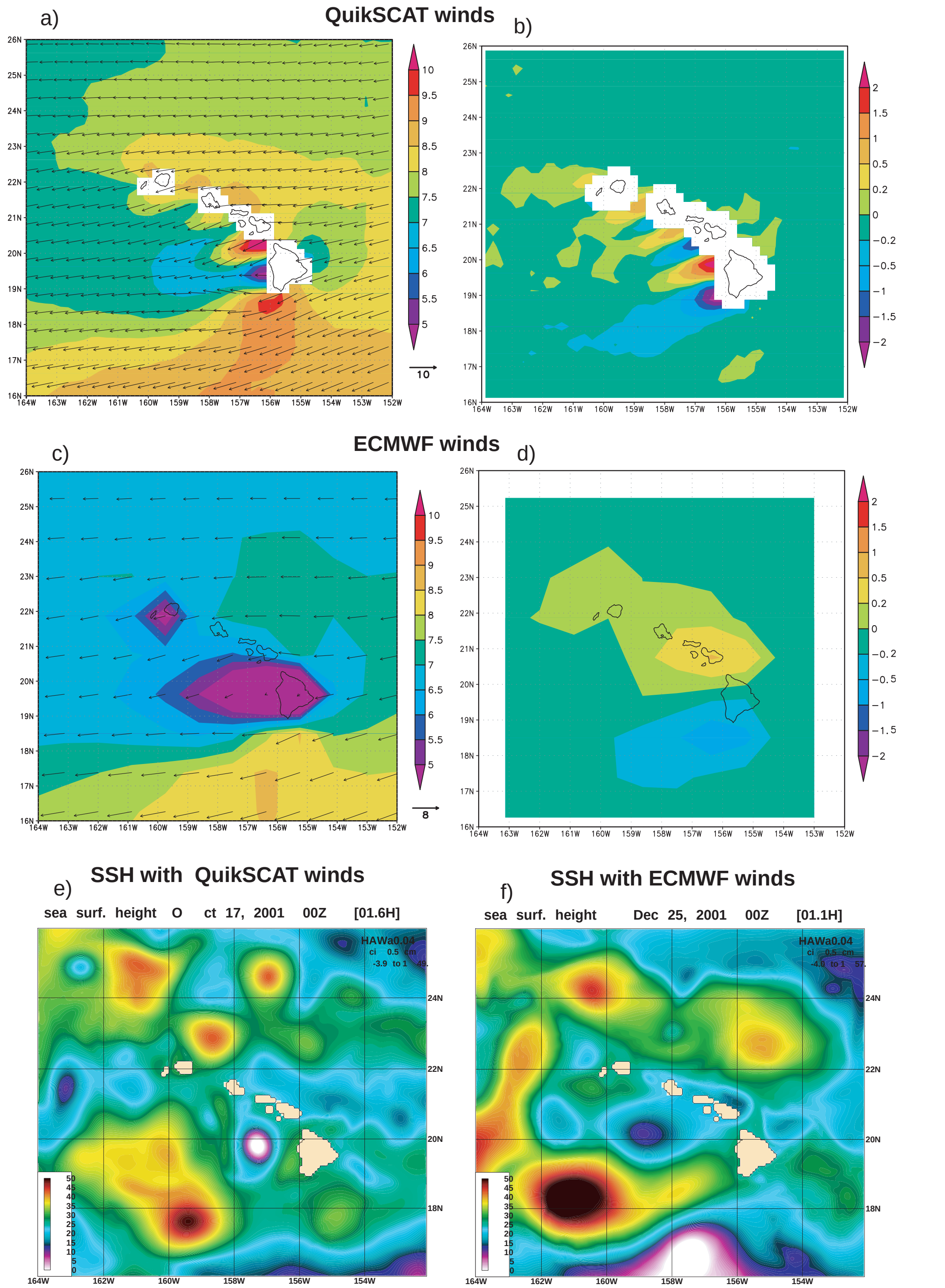


Figure 22. (a) QuikSCAT satellite wind observations at 0.25º resolution averaged for year 2001, wind speed (m/s, color) and wind vector (only every second vector is displayed in both the zonal and meridional directions); (b) QuikSCAT wind stress curl (10^{-6} Pa/m). (c) ECMWF (operational) wind at 1.125º resolution averaged for year 2001, wind speed (m/s, color) and wind vector; (d) ECMWF wind stress curl (10-6 Nm-3); (e) sea surface height snap short from the HYCOM Hawaii regional ocean model, with QuikSCAT winds; (f) as (e) with ECMWF winds. The strongest cyclonic eddy in 2001 in the lee of the islands (blue/white color, low sea surface height) in each case is shown.

The Year's Scientific Publications

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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*, IPRC-347.

Yaremchuk, M., Z. Yu, and J. McCreary: River discharge into the Bay of Bengal in an inverse ocean model. *Geophys. Res. Lett*., IPRC-343.

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Yu, R., B. Wang, and T. Zhou: Tropospheric cooling and weakening of the East Asia monsoon trend. *Geophys. Res. Lett.*, IPRC-326.

Yu, Z., and J. Potemra: Generation mechanism for the intraseasonal variability in the Indo-Australian basin. *J. Geophys. Res.-Oceans*, IPRC-359.

Zhou, T., M. Geller and K. Hamilton: The roles of the Hadley circulation and downward control in tropical upwelling. *J. Atmos. Sci.*, IPRC-377.

The Year's Seminars

April '05 – March '06)

Date	Name	Affiliation	Seminar Title
03/22/ 2006	Simon de Szoeke,	IPRC	*The Effect of Shallow Convection in a Coupled Regional Ocean-Atmosphere Model**
03/0 8/2006	Jerry Meehl	National Center for Atmospheric Research, Boulder, Colorado	*Weather and Climate Extremes in a Future Warmer Climate**
03/02/ 2006	Christophe Messager	Centre National de la Recherche Scientifique, Laboratoire d'étude des Transferts en Hydrologie et Environnement, Grenoble, France	*The effects of the interactions among climate components on the precipitation regime of the West African Monsoon*
03/01/2006	Luke Skinner	Godwin Laboratory for Paleoclimate Research, University of Cambridge, United Kingdom	*The last glacial cycle: Pacemakers and feedbacks**
02/28/2006	Jurgen Theiss	Scripps Institution of Oceanography University of California, San Diego	*New features of geostrophic turbulence: Can they be observed in the ocean?*
02/22/2006	I.-I. Lin	National Taiwan University	*Supertyphoon Boosters in the Northwest Pacific Ocean**
02/15 /2006	John Lyman	Pacific Marine Environmental Laboratory/JIMAR, Seattle, WA	*Tropical Instability Waves in the Tropical Atmosphere Ocean Array****
02/09/2006	Friedrich Schott,	IFM-GEOMAR Leibniz-Institut für Meereswissenschaften, Germany	*Tropical Atlantic variability: Comparison of observations, models and assimilations*
02/08/2006	Oliver Timm,	International Pacific Research Center, University of Hawaii at Manoa	*The seasonal response patterns of the climate system to transient boundary conditions during the last deglaciation and the Holocene**
02/01/2006	George Boer	Canadian Centre for Climate Modelling and Analysis	*Can We Determine Climate Sensitivity From Volcanic Events?**
01/25/2006	Ralph F. Milliff,	Colorado Research Associates Division NorthWest Research Associates	*Atmosphere and ocean signatures of the Madden-Julian Oscillation in an ensemble of surface winds from a Bayesian hierarchical model**
01/18/2006	Kevin P. Hamilton	Department of Meteorology & IPRC University of Hawaii at Manoa	*Adventures with the solar barometric tides**
01/ 10/2006	Claude Frankignoul,	Laboratoire d'Océanographie Dynamique et de Climatologie, Université Pierre et Marie Curie Paris, France	*Observed influence of North Pacific SST anomalies on the atmospheric circulation*
12/20/2005	Sharon Nicholson	Department of Meteorology Florida State University	*A new view of the African "monsoon". An example of the contrast between a land ITCZ and the marine ITCZ*
11/ 30/2005	Yoshiki Fukutomi	IPRC Visiting Assistant Researcher	*Interannual variability of summer precipitation over northern Eurasia**
11/29/2005	Hisashi Nakamura	Department of Earth and Planetary Science University of Tokyo, and Frontier Research Center for Global Change, JAMSTEC	*Structure and dynamics of the Pacific-Japan (PJ) teleconnection pattern associated with anomalous convective activity over the western tropical Pacific*
11/16/2005	Tsutomu Takahashi	IPRC Visiting Scientist	*Precipitation mechanisms in the East Asian monsoon: Videosonde and model studies**
10/26/2005	Minoru Chikira	Visiting Researcher, University of Hawaii	*A GCM study on the Green Sahara during the mid-Holocene: Impact of convection originating above the boundary layer**
10/21/2005	Yuko Okamura	Meteorology Department, University of Hawaii	*Ocean-Atmosphere Interactions in the Seasonal to Decadal Variations of Tropical Atlantic Climate**
10/12/2005	Axel Timmermann	International Pacific Research Center, University of Hawaii at Manoa	*Tropical air-sea interactions and their influences on the thermohaline circulation in the North Atlantic Ocean**

Date	Name	Affiliation	Seminar Title
10/06 6/2005	Detlef Stammer	University of Hamburg, Germany	*Ocean state estimation: Does it live up to it's expectations?***
10/04/ 2005	Takashi Mochizuki	Frontier Research Center for Global Change, JAMSTEC, Japan	*Diagnostic scheme for marine stratocumulus in the K-7 coupled model*
09/28/2005	Justin Small	IPRC	*Mid-summer drought (in tropical North and Central America)**
09/21/2005	Yuqing Wang	International Pacific Research Center and Department of Meteorology, University of Hawaii at Manoa	*Numerical study of the tropical cyclone concentric eyewall**
09/20/2005	Stuart Godfrey	CISRO Marine Laboratories, Hobart, Australia	*What sets the annual-mean net heat flux into the tropical Indian Ocean?*
09/15/2005	Claudia Pasquero,	California Institute of Technology, Pasadena, CA	*Intermittency of oceanic convection*
08/31/2005	Kevin P. Hamilton	IPRC and Department of Meteorology, University of Hawaii at Manoa	*The Intergovernmental Panel on Climate Change (IPCC) and the current IPCC climate model intercomparison**
07/ 19/2005	Cara Wilson	NOAA Pacific Fisheries Environmental Laboratory, Pacific Grove, California	*Late summer Chlorophyll blooms in the oligotrophic Pacific: What are their biological and physical forcings?*
07/01/2005	Wataru Ohfuchi	Earth Simulator Center, JAMSTEC	*Recent results from the Coupled Ocean Atmosphere Model for the Earth Simulator (CFES)*
06/27/2005		NOAA-National Marine Fisheries, Honolulu, Hawaii	*Research at NOAA National Marine Fisheries*
05/02/2005	Syukuro Manabe	Princeton University	*Simulated ENSOs with Interannual and Decadal Time Scales: Amplitude Modulation and CO2 Sensitivity*
04/29/2005 Special Lecture	Syukuro Manabe	Princeton University	*Early Development of Climate Modeling and Prospects for the Future*
04/13/2005	Shang-Ping Xie	IPRC and Department of Meteorology, University of Hawaii	*Issues in understanding the summer monsoon**
04/06/2005	Bin Wang	IPRC and Department of Meteorology, University of Hawaii	*Quasi-Monthly Monsoon Oscillation: A Global, Satellite View and Interpretation**

*Joint seminar with Meteorology
**Joint seminar with Oceanography
***Joint seminar with JIMAR

Workshops

Date	Workshop
02/27–03/02/2006	CLIVAR/GOOS Indian Ocean Panel
02/27/2006	OFES Workshop
02/25/2006	Workshop on Metrics of Ocean Models
02/17/2006	Miniworkshop and Discussion on the South China Sea
02/15–17/2006	CLIVAR Pacific Panel Meeting
09/05/2005	IPRC Regional Ocean-Atmosphere Model Meeting
09/21/2005	Indonesian Throughflow Mini-Workshop
09/13–15/2005	NASA Advanced Microwave Scanning Radiometer for the Earth Observing System
08/31–09/2005	Pacific Argo Regional Center Meeting
05/4–6/2005	Fifth IPRC Annual Symposium

IPRC Funding

INSTITUTIONAL SUPPORT

Title	PI and Co-PIs	Agency	Amount	Period
Enhancement of data and research activities for climate studies at the International Pacific Research Center (IPRC)	J.P. McCreary, P. Hacker & J. Potemra	NOAA	$1,872,000	10/01/05 - 09/30/06
JAMSTEC YR 9, (2005 – 2006)	J. McCreary	JAMSTEC	$2,885,065	04/01/05 - 03/31/06
Support of Research at the International Pacific Research Center	Not applicable	* University of Hawai'i	$480,370	04/04/05 - 03/31/06
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
Data-Intensive Research and Model Development at the International Pacific Research Center	J.P. McCreary, S.P. Xie, T. Waseda, T. Li & B. Wang	NASA	$5,000,000	10/01/00 - 09/30/05

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

INDIVIDUAL GRANTS

Title	PI and Co-PIs	Agency	Amount	Period
Validation of alternating zonal jets detected in satellite altimetry using *in-situ* observations	N. Maximenko	NSF	$170,147	02/15/06 - 12/31/07
Kuroshio Extension System Study (KESS) - Yr 3	B. Qiu, P. Hacker & F. Mitsudera	NSF	$168,000	11/01/05 - 10/31/06
Modeling the flow and larval dispersal around the Hawaiian Archipelago	K. Richards	NOAA	$24,819	10/01/05 - 09/30/06
Establishment of the Integrated Climate Database for Reanalysis and the International Data Network - Year 4	P. Hacker, S.P. Xie & Y. Wang	JAMSTEC	$73,395	10/01/05 - 03/17/06
A Technology Evaluation of Climate, Weather, and Ocean Code Coupling Methodologies and Future Requirement Analysis	T. Li	GSA	$58,094	09/01/05 - 05/31/06
Construction of a high-quality Tropical Cyclone Reanalysis Dataset using 4DVAR data Assimilation Technique	T. Li	NOAA	** $131,415	07/01/05 - 06/30/06
A Technology Evaluation of Climate, Weather, and Ocean Code Coupling Methodologies and Future Requirement Analysis	T. Li	DOD	$19,365	06/01/05 - 08/31/05
Analysis of climate change in Korea and East Asia area and study of the atmospheric and ocean effects	B. Wang	Yonsei University	$60,000	06/01/05 - 03/31/06
Climate Prediction and its Societal Application	B. Wang, I.S. Kang, J. Shukla & L. Magaard	KMA	$280,950	04/01/05 - 03/31/06
Development of an integrated data product for Hawaii climate	S.P. Xie, Y.-L. Chen & J. Hafner	NOAA	** $102,000	04/01/05 - 03/31/06
Ship-board atmospheric sounding over the Kuroshio Extension: A supplement to CLIVAR KESS	S.P. Xie & B. Qiu	NSF	$219,707	04/01/05 - 03/31/07
Roles of Ocean Atmosphere-Interaction in Seasonal and Interannual variation of the Atlantic ITCC	S.P. Xie	NOAA	$291,887	02/01/05 - 01/31/08
Dynamic balance of the oceanic mixed layer observed by *in situ* measurements and remote sensing	N. Maximenko	NASA / Scripps	$87,000	01/01/05 - 12/30/05
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

** Funded as part of the PRIDE proposal, awarded by NOAA 10/01/05

Title	PI and Co-PIs	Agency	Amount	Period
Study of Processes Leading to Tropical Cyclone Intensity Change	Y. Wang	NSF	$278,840	10/15/04 - 09/30/07
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	Dept of Energy	$150,002	09/15/04 - 09/15/07
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
Warm Pool Dynamics in the Interaction Between Asian Summer Monsoon and ENSO	H. Annamalai	NOAA	$82,817	07/01/04 - 06/30/06
Application of Satellite Data to Improve the Simulation and Prediction of Tropical Intra-seasonal Oscillation (TISO)	J. Fu, B. Wang & X. Xie	NASA	$272,333	06/01/04 - 05/31/07
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
Tropical Cyclone Forecast	T. Li	DOD (MSU)	$107,440	06/01/04 - 11/30/05
Dynamics of Boreal Summer Intraseasonal Oscillation	B. Wang, T. Li & X. Fu	NSF	$452,166	10/01/03 - 09/30/06
Diagnosis of Low Frequency Processes in the Indo-Pacific	N. Schneider	UCSD	$52,023	09/15/03 - 09/14/05
Mixing in the Equatorial Pacific: The Role of Interleaving	K. Richards & J.P. McCreary	NSF	$346,315	09/01/03 - 08/31/06
Analysis of Decadal Variability in the Pacific	N. Schneider	NSF (UCSD)	$142,561	08/01/03 - 07/31/05
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
A Numerical Investigation of the Dynamics of the Subsurface Countercurrents	Z. Yu	NSF	$364,992	03/15/03 - 02/28/06
Upwelling and Its Influence on the Sea Surface Temperature off Java and Sumatra	T. Qu	NASA	$324,265	01/07/03 - 01/31/06
Application of Comprehensive Global Models to Problems in the Dynamics of the Troposphere and Stratosphere	K. Hamilton	NSF	$322,809	09/01/02 - 08/31/06
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