International Pacific Research Center

Annual Report

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School of Ocean and Earth Science and Technology
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CONTENTS

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THE INTERNATIONAL PACIFIC RESEARCH CENTER

The International Pacific Research Center (IPRC) at the Mānoa Campus of the University of Hawai‘i conducts climate research with a focus on the Asia-Pacific region. Conceived under the "U.S.–Japan Common Agenda for Cooperation in Global Perspective," the center was established in October 1997 as part of the School of Ocean and Earth Science and Technology. 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 conducted under 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 Hawai‘i 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・太平洋地域を中心に地球環境とその変動に関する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５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３分の２を超えました。

昨年度の主な成果

昨年度も IPRC では様々な研究が行われた。ここではその一部を簡単に紹介する。

気候変動に関する政府間パネル第 4 次評価報告書作成には計算機シミュレーションの結果が用いられている。IPRC はその研究計画に従い、シミュレーション用のモデルが、熱帯海洋上での大気海洋相互作用、アジアモンスーン、その他の地域的変動や全球規模の変動をどの程度再現できているかという点を解析した。その結果、前回の評価報告書の時に比べモデルは良くなっているものの、改良すべき点も多々見つかった。例えば、気候変動予測には対流圏の水平解像度 (ハワイにあるような急峻な山による降水の再現に必要) や成層圏の鉛直解像度がまだまだ足りない、雲の再現・雲のフィードバック・アジアモンスーンの対流や降水の中心を現実的に再現するのはまだ難しい、インド洋の気候やインド洋ダイポールは大体良く再現されているものの、熱帯太平洋と熱帯大西洋での風と雨が観測と一致しない、などの点が IPRC の研究者によって明らかになった。

また、人工衛星のデータから海洋上の強風域の分布が明らかになった。非常に強い風は、海水温の高い領域が低い領域に囲まれている場所や、海岸のそばに急斜面がある場所に集中していることが分かった。強風は、海面での熱交換・二酸化炭素などの気体交換、深層水の形成、栄養塩の湧昇などに影響を与えるため、気候の形成にとって重要な要素なのである。

海洋の分野では、気候形成に重要な循環をいくつか研究した。例えば、北側の土屋ジェットが太平洋を横切り東太平洋で北赤道海流の下部に合流するまでの過程や、インドネシア通過流の太平洋・インド洋への影響を調べた。さらに、経年変化する外力下での地球シミュレーター海洋モデル (OFES) を解析した結果、黒潮直進流路と蛇行流路の遷移を起こす機構が見つかった。また、昨年度も南シナ海の研究が進展した。南シナ海には、熱と水の総量が増えていく年と減っていく年があることが分かった。このような変化は周辺の気候に年毎の変化をもたらしているかも知れない。その他に、海洋の鉛直混合の大気海洋相互作用への影響が調べられ、また、最近発見された帯状ジェットには、要因や発展の仕方の違うものが少なくとも二種類あることが分かった。

アジアモンスーンの研究も進展をみた。例えば、エル・ニーニョが翌年夏のモンスーン降雨を減らすような機構が見つかった。また、人工衛星の観測から、夏のモンスーンに雨をもたらすのはどのような大気の状態なのかが明らかになり、モデル研究でそれが確かめられた。さらに、APEC 気候センターが進めている、多モデルアンサンブルによるモンスーン降雨予測の国際共同研究に、IPRC も参加している。

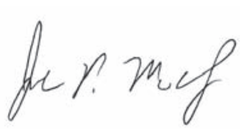
熱帯低気圧の研究も重要な研究項目として続いている。NASA の人工衛星データから熱帯低気圧の発展過程を解析し、熱帯低気圧が発生し易い大気条件を明らかにした。同時に、熱帯低気圧の予報技術も開発している。また、IPRC 熱帯低気圧モデルを使い、熱帯低気圧強度を変える要因の研究も続けている。

全球気候モデルの研究によって、気候系の貯熱量が正確に分かっていれば、火山の噴火によって気候感度を正確に求めることができる可能性が示された。また、地球シミュレーター大気モデル (AFES) の結果を使い大気循環の様相を明らかにする研究も続いており、例えば、急な地形が大気潮汐を遮ることが分かった。

過去の気候は気候系を理解するための重要な手掛かりとなる。その一例として、過去の急な気候変動には大西洋の子午面循環が大きな働きをしていることが分かってきた。計算機モデルによれば、この子午面循環が弱まると、生物生産力が地上でも海洋でも変化し、大気中の二酸化炭素濃度が 15ppmv ほど上がり、南半球の温度が 2℃ほど上昇する。また 12 万 9 千年間の気候シミュレーションを行ったところ、地球の軌道要素が変化すると太陽放射が変わり、モンスーンの循環や降雨が変化することが分かった。

IPRC 内のアジア太平洋データ研究センター (APDRC) では、昨年度も気候データ保有量が増加しサーバー容量も拡大された。NOAA の PRIDE 計画の一員としては、ハワイ付近の気候データを作成している。また、太平洋アルゴ地域センター、太平洋諸島–全球海洋観測システムなどと協力し、太平洋地域における諸活動の調整役も務めている。

本報告書では、ここに挙げたものも含め昨年度の成果を紹介する。本年度もこの複雑で魅力的な気候系の研究を続けることを楽しみにしている。



IPRC 所長
Julian P. McCreary, Jr.

THE YEAR'S HIGHLIGHTS

IPRC scientists worked on a wide variety of research topics this year. This brief overview highlights several of them.

Our scientists have embraced the opportunities opened up by the computer climate simulations conducted for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). In line with our science plan, we have analyzed the ability of the IPCC models to capture air–sea interactions over tropical oceans, the Asian monsoon, and global and regional aspects of climate. The models have improved since the previous report, but IPRC scientists have pointed out several areas for further improvements. For example, climate-change projections require still higher horizontal resolution in the troposphere to resolve rain-producing mountains such as the tall mountains of Hawai‘i and higher vertical resolution in the stratosphere; simulation of clouds, cloud feedback, and Asian monsoon main convection and rainfall centers are still unrealistic; and simulations of the wind and rainfall seasonal cycle in the tropical Pacific and Atlantic do not match observations.

From satellite data, we have created a map displaying the distribution of gale and stronger sea winds. Gales blow most often over regions of warm water surrounded by cold water and over steep coastlines. Impacting climate, strong winds affect heat flux, deep water formation, air–sea gas exchange, including CO_2, and pump nutrients up from ocean depth.

In ocean research, we have studied climatically important currents, tracing the northern Tsuchiya Jet from its source to its junction with the North Equatorial Current in the Eastern Pacific, and tracking the influence of the Indonesian Throughflow on both Indian and Pacific Ocean climates. Work on interannually forced solutions of the Ocean Model for the Earth Simulator (OFES) revealed mechanisms that shift the Kuroshio between straight and meander paths. The South China Sea (SCS) continues as a research focus. The SCS stores heat and freshwater in some years and releases them in others, suggesting the sea modulates climate in the region. Other ocean research has dealt with the impact of vertical mixing on air–sea interaction, and the recently detected ocean zonal jets, which we have identified to be of at least two kinds, with very different origins and evolutions.

Our Asian monsoon research has revealed a mechanism by which El Niño brings about a drier monsoon season during the following summer. Atmospheric conditions leading to the summer monsoon wet spells have been tracked in satellite measurements and confirmed in modeling studies. Moreover, we are participating in an international effort of the APEC Climate Center that uses multi-model ensembles to predict monsoon rainfall.

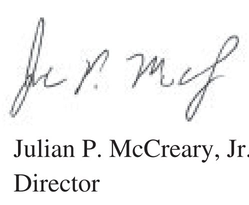
Tropical cyclone research remains a central topic. Using NASA satellite data sets, we have determined atmospheric conditions that spawn such storms and have successfully analyzed their evolution, developing a technique helpful for tropical cyclone forecasts. In experiments with the IPRC Tropical Cyclone Model, we continue to analyze the forces that alter tropical cyclone strength.

Our climate modeling work shows that, given precise determination of heat storage in the climate system, the response to large volcanic explosions may provide accurate assessment of climate sensitivity. Studies with solutions to the Atmospheric Model for the Earth Simulator (AFES) continue to reveal aspects of atmospheric circulation, including a topographical shadow effect on the atmospheric tides.

Past climates hold clues to the climate system. A key player in abrupt climate change is the Atlantic meridional overturning circulation. Our computer modeling work shows that when this circulation weakens, terrestrial and marine productivity changes, atmospheric CO_2 rises about 15 ppmv, and Southern Hemisphere temperatures about 2°C. A 129,000-year simulation shows that as Earth's orbit changes, solar radiation changes, impacting monsoon circulation and rainfall.

Our Asia-Pacific Data-Research Center (APDRC) has continued to expand its climate-data holdings and server capabilities. A participant in the NOAA PRIDE team, the center develops regional Hawai‘i products. The APDRC is also active in coordinating Pacific activities, witness its work with the Pacific Argo Regional Center and the Pacific Islands Applied Geoscience Commission.

This report features these and other accomplishments of the past year. We look forward to the coming year to continue our explorations of the complex and fascinating climate system.



Julian P. McCreary, Jr.
Director

INDO-PACIFIC OCEAN CLIMATE (THEME 1)

Research under *Indo-Pacific Ocean Climate* seeks to determine the role of the oceans in the climate system—particularly the role of the Indian and Pacific Oceans—by conducting studies on air–sea interaction, ocean processes, and climate variability. Accomplishments for the past year (April 2006 – March 2007) span all three areas. Selected highlights of this research are described below.

Air–Sea Interaction

An emerging research field is the study of the effect of small-scale ocean–atmosphere interactions, due to narrow jets or orography, on the large-scale circulation, a research topic that IPRC scientists have been considering for some time. This past year, the studies included mapping regions of frequent high winds over the ocean, and air–sea interactions over the Gulf Stream, Kuroshio, and the eastern tropical Pacific.

Maps of high sea winds. Maps showing regions of frequent high winds over the oceans are useful not only for improving understanding of the climate system and weather prediction, but also for such activities as shipping and oil-rig placements. Given the lack of a published climatology of high winds over the global oceans, IPRC scientists (Takeaki Sampe and Shang-Ping Xie) used the high-resolution (0.25° x 0.25°; twice daily) QuikSCAT wind dataset from fall 1999 to summer 2006 to determine the frequency and location of winds stronger than 20m/s. Large-scale high winds often flow in the wintertime hemisphere at midlatitudes and are associated with extratropical cyclones and the westerlies (North Atlantic, North Pacific, South Indian Ocean). The storm tracks are usually co-located with the mean westerly axis.

Surprisingly, the frequency of occurrence of 20 m/s or higher winds is affected by oceanic fronts. Over sharp sea surface temperature (SST) gradients, higher winds tend to be located more often over the warmer than the cooler flank. A likely mechanism for this remarkable correspondence is that over warmer water the static stability of the atmosphere decreases. This decrease enhances mixing, bringing down stronger winds from aloft. The occurrence of high winds, for instance, can vary by an order of magnitude within a short distance across sharp SST gradients, (e.g., over the Gulf Stream and the Antarctic Polar Front). Figure 1 shows that high winds blow very often over the Gulf Stream off the Canada

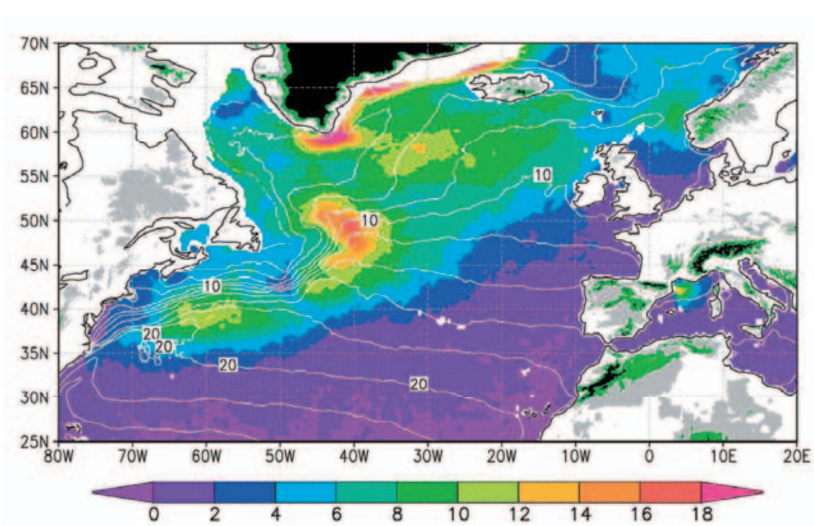


Figure 1. Frequency of QuikSCAT high winds (>20 m/s; color = % of time) and SST (°C; contours) during winter months (DJF).

coast, where there is a sharp SST gradient on the northern side of the Gulf Stream. The figure also shows the orographic impact on wind speed over water. Frequent high winds are seen where air flows along high orographic features: the southern tip of Greenland stands out as the windiest place over the ocean because the wind accelerates at the corners of the high glaciers. Windy is also the coast of southern France, where the mistral, a cold, strong northwesterly wind blows along the coast of the Gulf of Lion.

Mechanism of wind flow over SST gradients. The mechanisms that produce this link between strong winds and the warm flank of sharp SST gradients are being investigated with the IPRC Regional Atmospheric Model (iRAM). The model's high resolution (1/3° horizontally, 29 levels in the vertical with 10 levels in the boundary layer) and state-of-the-art physical schemes make it possible to reproduce accurately the observed spatial distribution of high winds. For example, Small at the IPRC noted both in observations and in the model that high winds occurred least often where the cold Labrador Sea Current intrudes upon the Gulf Stream path, giving rise to a quasi-permanent cold meander. The model results indicate that the airflow across the meander is associated with a boundary layer response similar to that seen over Tropical Instability Waves (Justin Small et al. 2003). Pressure anomalies in the boundary layer (due to changes in air temperature over the meanders) cause low-level wind anomalies with winds accelerating toward warm sea surface temperature (SST) and decelerating towards cold SST (Small, 2006).

The north wall of the Gulf Stream is not only a region of high sea winds but also tends to be covered by a rainband, as seen in satellite data and in several *in situ* investigations. An important question is whether this rainband is a sign of deep convection. If it is, then the latent heat release from deep convection may give rise to propagating Rossby waves that may affect climate in regions further away. Analysis by Small and other IPRC scientists of new NASA satellite data from the Tropical Rainfall Measuring Mission (TRMM) has revealed that the convection over the Gulf Stream extends as high as 5 to 8 km (see Figure 2). How the latent heat released by the convection affects remote atmospheric circulation will be investigated next with an approximate, linear model of the atmosphere.

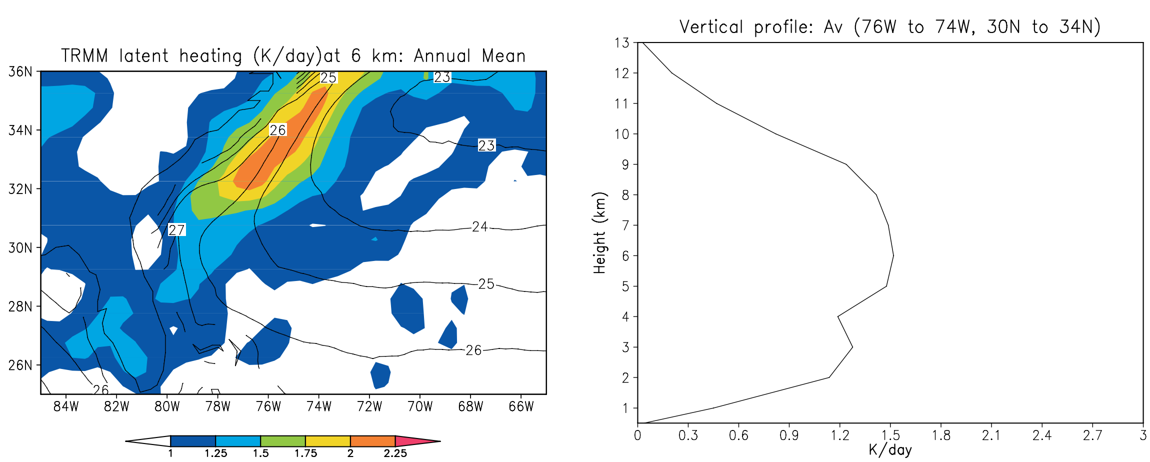


Figure 2. Latent heating over the eastern seaboard of the USA from the Tropical Rainfall Measuring Mission satellite. Left: Spatial distribution at 6-km height (color, K/day). Note that the maximum of heating follows the Gulf Stream, indicated by the SST contours (black, °C). Right: Vertical profile, averaged over 76°– 74° W, 30°–34°N. Note the peak in heating between 5 and 8 km.

Air–sea interaction over the Kuroshio. The third study of air–sea interactions across SST fronts used the ERA40 reanalyses (Mototaka Nakamura). In this data set, anomalous SST at the oceanic fronts of the Kuroshio/Oyashio, the Gulf Stream, and their extensions is clearly associated with anomalous, near-surface baroclinicity in the atmosphere. This baroclinicity is accompanied by large anomalies in the middle- and upper-tropospheric flows (Figure 3). The small-scale nature and location of the anomalous SST accompanying the anomalous, near-surface baroclinicity strongly suggest that fluctuations in the path and/or strength of the Kuroshio/Oyashio, Gulf Stream, and their extensions impact the two major storm tracks in the Northern Hemisphere.

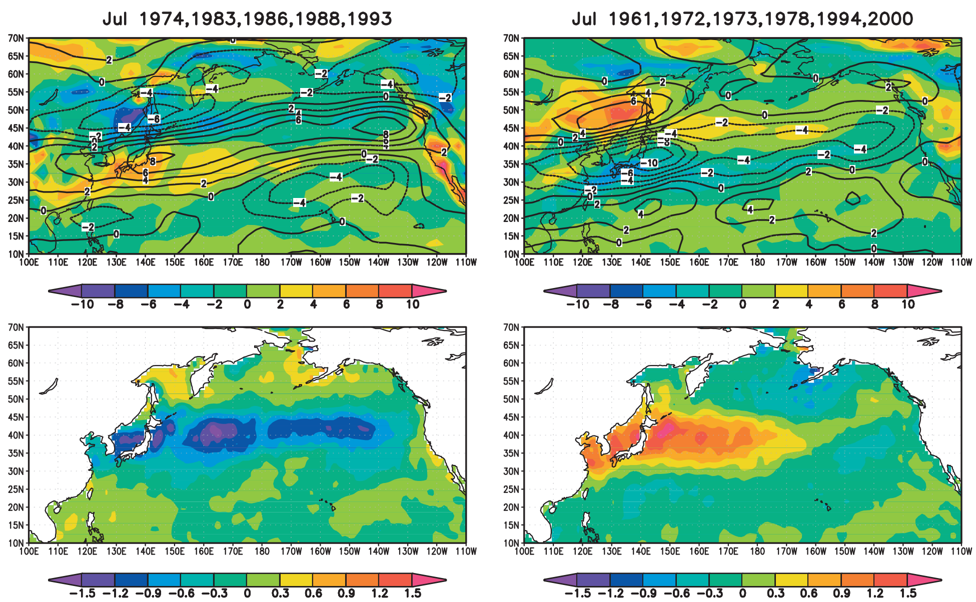


Figure 3. July composites that showed anomalies ±0.5 or greater in the EOF1 time series. Upper panels: the zonal component of the near-surface baroclinic vector (shaded) in 10^{-6}/s, and zonal wind at 200 mb (contours) in m/s. Lower panels: sea surface temperature in K.

Overview of research on air–sea interaction. A broad overview of research on air–sea interaction over ocean fronts and eddies was written by Justin Small and others for *Dynamics of Atmospheres and Oceans*. The review focuses on the atmospheric boundary-layer response to SST gradients and the atmospheric feedback to the ocean. It is novel in that it combines older observational findings (from the 1970s onwards) with recent high-resolution numerical model and satellite data results. Case studies are given of three major frontal zones: the equatorial front in the eastern Pacific Ocean, the Gulf Stream and its extension, and the Agulhas and Return Current. Despite the very different environments of these current systems—equatorial trade wind regime vs. midlatitude storm track region, Northern vs. Southern Hemisphere—the air–sea interactions over these fronts are remarkably similar, and the review proposes reasons for these similarities.

IPCC models and air–sea interaction in the tropical eastern Pacific. The equatorial SST front in the eastern Pacific Ocean is another narrow ocean front with air–sea interactions that affect climate. The climate of the eastern tropical Pacific is unusual in that the Northern Hemisphere has warmer SST and more rain than the Southern Hemisphere throughout the year. Only briefly in March does a rainband straddle the equator (as a double Intertropical Convergence Zone, or ITCZ). This seasonal cycle has been difficult for general circulation models to simulate. Simon de Szoeke and Shang-Ping Xie assessed the tropical eastern Pacific meridional asymmetry and seasonal cycle in the coupled general circulation models (GCMs) used for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). They found that the coupled GCMs have improved considerably over the last 10 years (as assessed by Mechoso et al. 1995), but they still have errors. Of the global models, only the UKMO HadCM3 compares favorably to observations, maintaining strong precipitation in the Northern Hemisphere year-round with a brief double ITCZ in March–April (Figure 4). The IPRC Regional Ocean–Atmosphere Coupled Model, which was not included in the AR4, also simulated the rainfall and winds realistically (Xie et al. 2007).

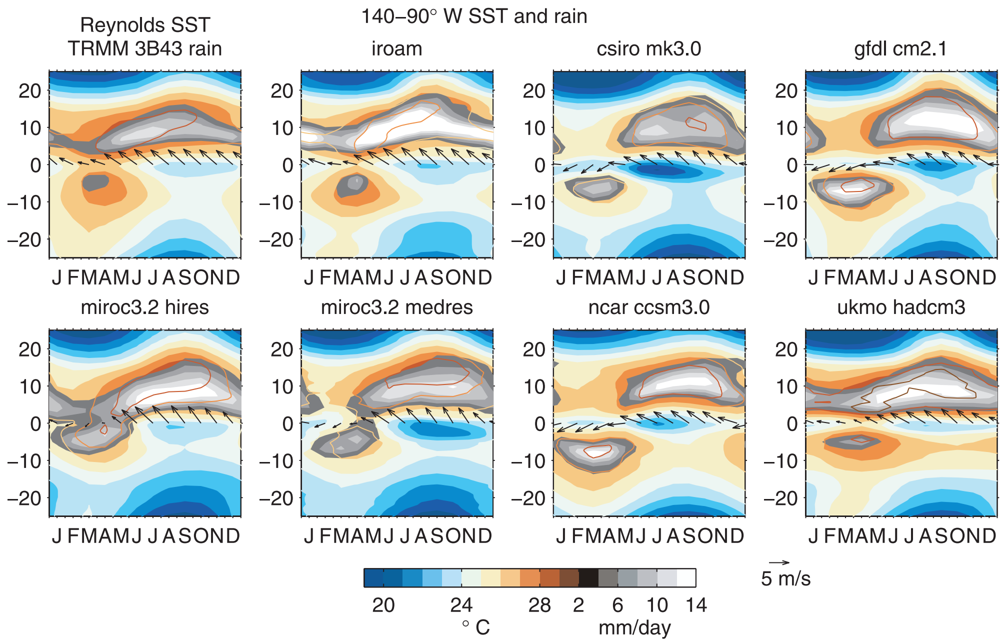


Figure 4. Time plots of the seasonal climatology of SST (colors and contours) and rain (gray) in the tropical eastern Pacific Ocean averaged over 140–90°W, excluding land areas. The horizontal axis is month of the year and the vertical axis is latitude. Vectors denote the seasonal cycle of wind on the equator. The top left panel shows "observations": Reynolds SST, TRMM 3B43 rain, and QuikSCAT wind analyses. The remaining panels represent climatologies of the 20th century runs from the regional iROAM and from six of the coupled general circulation models (GCMS) used for the AR4.

The other IPCC models show a spread in their deviations from observed eastern Pacific climate. Differences among model solutions become a tool to diagnose physical mechanisms responsible for adherence to, or divergence from, the observed climate. Eight of the 15 coupled GCMs analyzed had an alternating ITCZ that crossed the equator in spring and fall, accompanied by the warmest SST and strongest precipitation. Wind across the equator in these models is closely tied to the asymmetry of atmospheric heating across the equator.

Thus, models that have a seasonally alternating ITCZ have two periods with strong winds, one of southerlies and one of northerlies, resulting in a colder equatorial ocean than observed. In some of these models the meridional winds within 1000 km of the South American coast are weaker than observed, resulting in a warm SST bias there. Differences among models in the representation of stratus clouds also affect the underlying SST, but the effect on the meridional atmospheric circulation is difficult to discern. These results therefore suggest that atmospheric and coupled GCMs can be improved. Specifically, by ensuring that the seasonal climatology of the meridional wind and of the ITCZ is correct, the equatorial SST biases in the eastern Pacific should be alleviated.

IPCC models and air–sea interaction in the tropical Atlantic. In a final air–sea interaction study, IPRC scientists analyzed the tropical Atlantic climate simulations in the IPCC AR4 coupled models (Ingo Richter and Shang-Ping Xie). Results showed that the models fail to simulate the seasonal development of the equatorial cold tongue. This failure is illustrated in Figure 5, which shows the equatorial winds and SST across longitude over the year of the ensemble mean from several of the IPCC GCMs. The models' surface westerly winds are too strong, especially during March–May, which leads to a thermocline being too deep in the eastern basin along the African coast. Even though the westerlies relax somewhat during summertime, the deep thermocline prevents a cold tongue from forming, resulting in a warm SST bias in June–August. A study of the atmospheric component of some of the models shows that even when forced with "perfect" SSTs, the models have surface westerly winds along the Atlantic equator that are too strong, simulating too little rain over the western Atlantic Ocean and over South America and too much rain over the eastern Atlantic and Africa. Furthermore, these rainfall errors are linked to an erroneous sea-level pressure gradient that maintains the westerly wind bias in the models. All these model errors are associated with an Atlantic Walker Cell that is weaker than the observed. A comparison of coupled and atmosphere-only runs reveals that coupling amplifies the errors in both surface winds and rainfall.

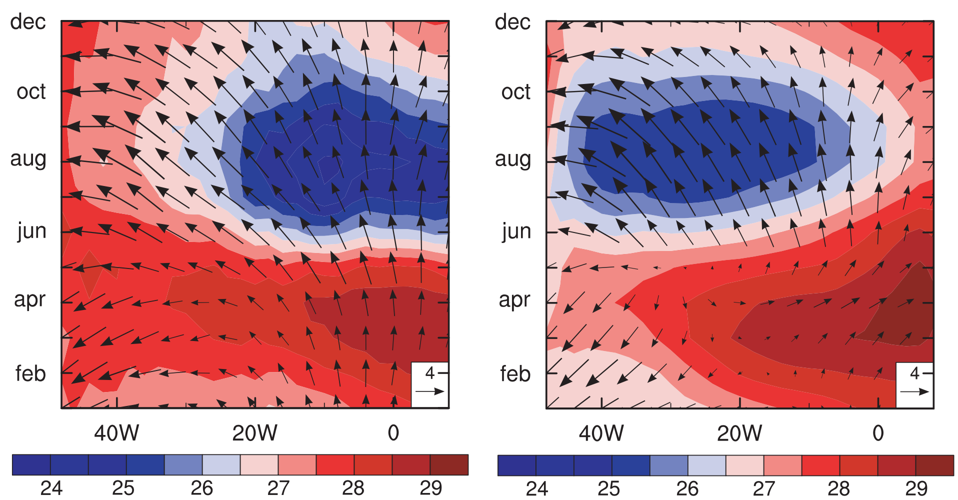


Figure 5. Longitude-time section of equatorial SST (°C) and surface wind (m/s) for the ICOADS observations (left panel) and the ensemble mean of IPCC AR4 models (right panel). Fields are averaged between 2°S and 2°N. In observations SST starts cooling in the eastern equatorial Atlantic around May, with the cold tongue reaching its peak in August. In the IPCC models, the equatorial cold tongue shifts to the western equatorial Atlantic.

Ocean Processes

Studies were conducted last year on several climatically important ocean circulations: the Tsuchiya Jets, the Indonesian Throughflow, and the Kuroshio.

The fate of the Tsuchiya Jets. The work on the Tsuchiya Jets deals with the thick layer of cool water, called the "thermostad," which lies below the Pacific equatorial thermocline. Observations suggest that most of this water sinks from the surface in the mid-to-high-latitude South Pacific, eventually reaching the deeper layer of the tropical western boundary current. Some of this water then turns eastward near the equator to supply much of the thermostad water. The fate of this water is less clear. Modeling studies at IPRC and other institutions indicate that much of the equatorial thermostad water is carried eastward in the form of narrow currents, called Tsuchiya Jets (TJs), located 3°–6° on either side of the equator. Most of this water upwells into the surface layer off the coast of Peru in the South Pacific, and in the interior ocean off Costa Rica in the North Pacific. In these two regions, SST is significantly lower than the surrounding because of the cool upwelled water. This subthermocline circulation thus affects the atmosphere through these "windows."

Details of the Southern TJ were presented in the previous annual report (Ryo Furue, Julian McCreary, Zuojun Yu, and Daileen Wang). This past year, the team reproduced the northern TJ in a rectangular oceanic coarse-resolution GCM forced by idealized winds. The model northern TJ flows across the basin along the northern edge of a thick thermostad, and part of its water upwells in the upwelling region off Costa Rica. Its deeper part is supplied by water that leaves the western boundary current somewhat north of the equator. Its shallower part originates from water that diverges from the deep portion of the Equatorial Undercurrent; as a result, the TJ transport increases and warms as it flows eastward across the basin. Surprisingly, the TJ's deeper part is forced not by direct upwelling in the Costa Rican upwelling region but by eddy stress generated by instability waves there. The TJ is also found to be sensitive to diapycnal diffusivity. These results help to understand how the equatorial thermostad water affects the atmosphere through SST changes. Moreover, these results imply that atmosphere–ocean coupled models must accurately reproduce this subthermocline circulation in order to obtain correct tropical Pacific SSTs. This subthermocline circulation may also contribute to decadal-scale climate variability by exchanging heat with the atmosphere through the upwelling windows.

Impact of the Indonesian Throughflow on Pacific and Indian Ocean circulations. The Indonesian Throughflow (ITF) transports a significant amount of water and heat from the Pacific to the Indian Ocean through the Indonesian Seas and, hence, is a key aspect of the general circulation of both ocean basins and of global climate. Observations suggest that most of the ITF transport exits in the upper ocean above 400 m and comes from the North Pacific. There is also a deep relative maximum, consisting primarily of water from the South Pacific. A long-term modeling study on interactions between the ITF and circulations in the Indian and Pacific Oceans was completed this year (Jay McCreary in collaboration with Ryo Furue, Tommy Jensen, Bohyun Bang, Tangdong Qu, Hyoun-Woo Kang all at IPRC, and Toru Miyama at FRCGC/JAMSTEC). Based upon a hierarchy of models ranging from a linear continuously stratified model to a global oceanic GCM, the study explained, among other things, that the two main suppliers of the ITF result from large-scale baroclinic adjustments involving both the Pacific and the Indian Oceans (Figure 6). Specifically, the subsurface transport minimum is due to the fact that the near-equatorial, eastward-flowing, subsurface currents (including the TJs) in the Pacific Ocean drain subthermocline waters from the western ocean to supply water for the upwelling regions in the eastern ocean (including the coastal upwelling off Peru and the interior upwelling off Costa Rica). The subthermocline circulation in the Pacific that is associated with the TJs discussed above, therefore, could affect not only Pacific climate but also that of the Indian Ocean through the ITF, which

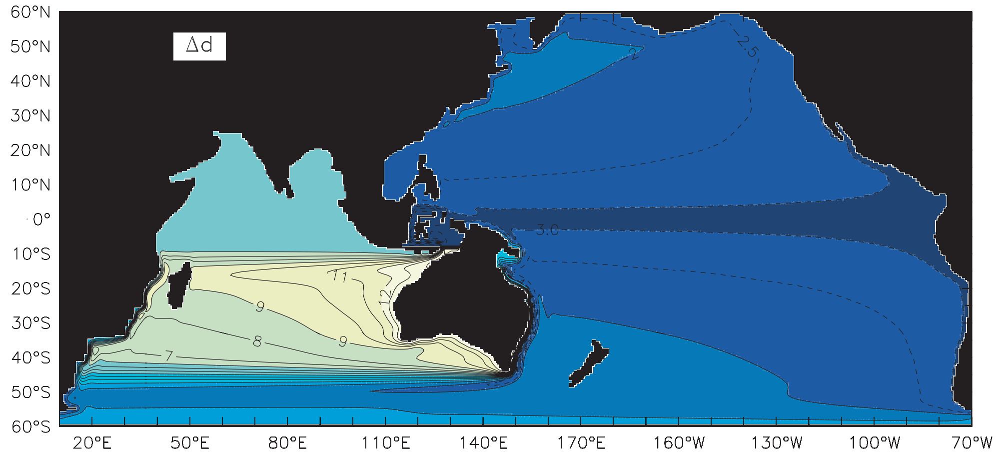


Figure 6. Sea level difference (cm) between solutions with open and closed Indonesian passages in the linear, continuously stratified model used by McCreary and his colleagues (see text). Sea level indicates near-surface geostrophic flows, and subsurface flows tend to be oppositely directed to the surface ones. In the Pacific, therefore, the subsurface flows tend to be directed eastward and poleward, extend throughout the basin, and are closed by upwelling in the eastern ocean and Subtropical Gyre.

connects the upwelling regions in the far eastern Pacific with the tropical Indian Ocean. Other conclusions drawn from the modeling study are that the ITF strengthens the subtropical countercurrent in the South Indian Ocean, accounts for the existence of the Great Barrier Reef Undercurrent, and causes or intensifies the flow of Pacific thermostad water and Antarctic Intermediate Water to, and north of, the equator.

Zonal ocean jets. Recently satellite altimetry and high-resolution ocean models have revealed ubiquitous, persistent zonal structures with properties varying between regions. IPRC scientists are among the first to note these jets. The jets appear to populate nearly every part of the world ocean and the marginal seas, and they extend deep into the ocean, but are significantly more energetic at the surface. Although alternating zonal jets are predicted by the theory of geophysical turbulence, further study by Nikolai Maximenko (IPRC) and Peter Niiler (Scripps Institution of Oceanography) suggests the two most distinct classes of jets—seen in both satellite and model data—are of different origins.

The first class of jets is amazingly steady over 10 years or longer. Most of these jets are located in the eastern parts of oceans with unknown forcing mechanisms. They are stationary waves rather than "inertial jets," in that water particles carried by large-scale currents move across the jets. Moreover, it is essential that they are properly tilted to interact with the mean meridional geostrophic flow like stationary Rossby waves. Interestingly, such well-known currents as the Hawaiian Lee Countercurrent and the Azores Current also act in this manner (Maximenko and Niiler). The first results of a historical XBT data analysis validate the jets seen in the satellite data (Oleg Melnichenko).

A second class of jets, found at midlatitudes (Maximenko and Bohyun Bang), appears as alternating jets only in snapshot maps of altimetry or model data. The jets behave like sets of linear Rossby waves with a nearly meridional wave vector and north–south wavelengths of about 500 km. They propagate toward the equator at a 0.45 cm/s phase speed with a 3.5-year local period. The origin of these jet-like waves remains unknown and is under active investigation.

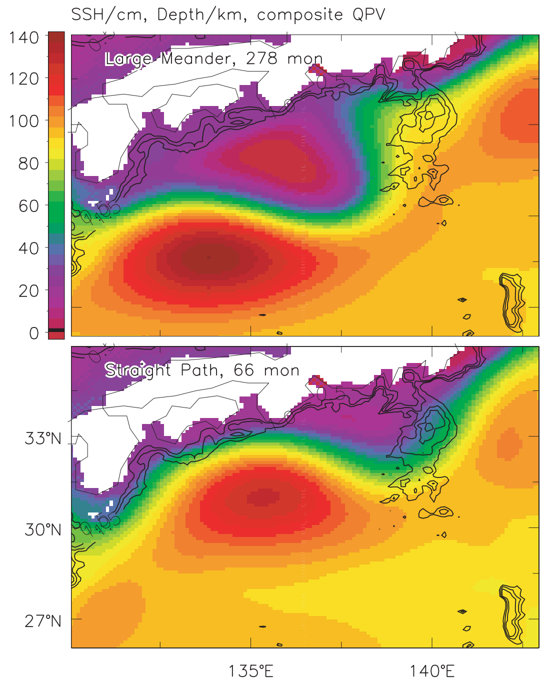


Figure 7. OFES Composites of sea level (in cm) for large meander and straight paths, the preferred states in the principal component of the CEOF. Out of 648 months, the large meander occurs 278 months and the straight path 66 months.

Modeling the Kuroshio meanders. It is well known that the Kuroshio flows along the coast of Japan in one of three paths at any one point in time: a large meander that moves offshore near Shikoku and returns to the coast west of Izu ridge; a rather straight path along the shore; and a small offshore excursion south of Hachijo-Jima. The location of the Kuroshio impacts Japan's coastal ocean and fishing industry. Reasons for the path-switching are therefore of interest, not only for scientific, but also for economic reasons. Theories put forward to explain the sudden switches in Kuroshio paths include lee Rossby waves, multiple steady states selected by upstream variations in the Kuroshio, and accumulation of potential vorticity in the recirculation of the Kuroshio.

To study the Kuroshio meander properties and dynamics, Niklas Schneider (IPRC), Bo Qiu (University of Hawai‘i), and Hideharu Sasaki (JAMSTEC Earth Simulator Center) analyzed output from the JAMSTEC high-resolution Ocean Model for the Earth Simulator (OFES) 1950–2003 hindcast. The simulated Kuroshio path displays a saw-tooth evolution that starts from a straight path, builds up the large meander over several years until the system collapses and restarts with the straight path (Figure 7). Analysis of potential vorticity shows that Kuroshio paths are intimately linked to the recirculation gyres. The potential vorticity budget of the deep anticyclonic circulation south of the large meander appears to determine the time scale and is sensitive to the high potential vorticity generated as the Kuroshio flows past the coastal capes in the region. These properties suggest that the path variations are very sensitive to lateral mixing.

Climate Variability

A focal point of IPRC research is the study of how climate varies seasonally, interannually, and decadally, and what processes drive these variations. Research conducted this past year spans Indian Ocean climate variability, tropical climate dynamics, and decadal climate variability. Further IPRC research on this topic is also found in the section on Impacts of Global Environmental Change, the IPRC research theme that specifically addresses climate change.

El Niño impact on Asian climate. A well-known observation is that El Niño impacts Asian climate. El Niño tends to peak in December and decay rapidly in the following spring. On the other hand, work at the IPRC and elsewhere has documented that the atmospheric disturbances, such as decreased rainfall over East Asia and the anomalous anticyclone over the subtropical northwestern Pacific persist through the following summer. These anomalies are not correlated with the region's SST, but are highly correlated with eastern Pacific SST six months earlier, indicating that El Niño's effects last well after it has dissipated.

Shang-Ping Xie and his research partners at other institutions believe that the anchor for these persistent atmospheric anomalies lies farther west in the tropical Indian Ocean. Following an El Niño event, the tropical Indian Ocean warms basin wide. The warming peaks sometime during late boreal winter and early spring and persists through boreal summer as depicted in Figure 8. Further analyses of the observations show that the Indian Ocean warming induces anomalies in the summer climate of the Indo-West Pacific region. In particular, precipitation increases over most of the Indian Ocean (Figure 9), forcing a Matsuno-Gill wave pattern in the atmosphere. As part of this pattern, the southwest monsoon intensifies over the Arabian Sea and weakens over the South China and Philippine Seas; and

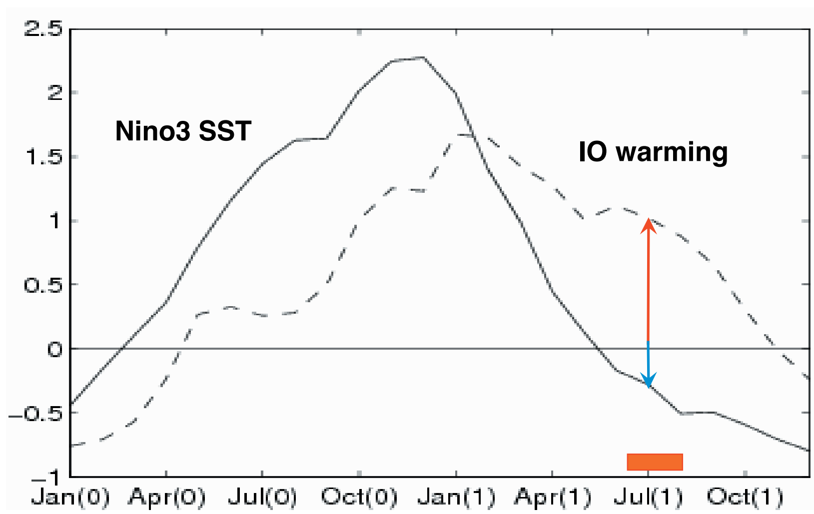


Figure 8. Phase relationship between anomalous sea surface temperatures in the central Pacific and in the Indian Ocean during El Niño.

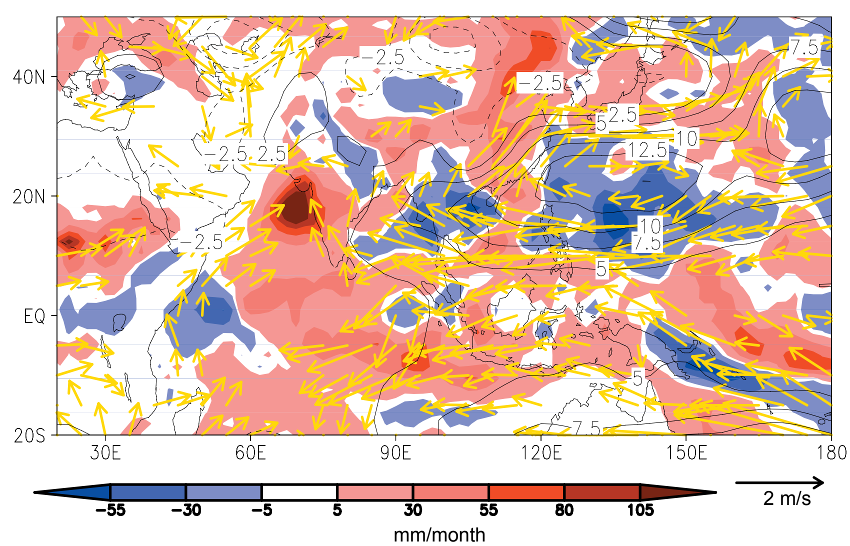


Figure 9. Conditions during July–August following an El Niño: anomalies of precipitation (color in mm/month), 850 hPa (wind vectors in m/s), and geopotential height (contours in m).

an anomalous anticyclonic circulation, collocated with less-than-normal rainfall, forms over the subtropical Northwest Pacific. These anomalous circulation patterns are all reproduced in a coupled model simulation that is initialized with a warmer than usual mixed layer in the tropical Indian Ocean.

These results suggest that the Indian Ocean has a capacitor effect. Like a battery charging a capacitor, El Niño warms the tropical Indian Ocean through atmospheric teleconnections. Then, like a discharging capacitor, the Indian Ocean sustains El Niño influence after SST in the tropical central and eastern Pacific has returned to normal.

Pacific climate variability. Decadal Pacific climate variability was explored in several studies. One study analyzed the impact of the seasonal cycle on El Niño in solutions to coupled GCMs. They typically exhibit a variety of unrealistic behaviors, for example, with El Niño events that peak in summer instead of in December (Schneider). Analytical models are now being applied to understand what causes these errors. A second study analyzed the effects of westerly wind bursts on the dynamics and predictability of the El Niño-Southern Oscillation (ENSO). The numerical ensemble simulations with a conceptual recharge oscillator model of ENSO confirm the main results derived from analytical ensemble-mean theory: the state-dependent stochastic forcing enhances the instability of ENSO and its ensemble spread. Furthermore, the forcing is an important source of ENSO nonlinearity, as reflected by the simulated skewed probability distribution of the eastern equatorial Pacific temperature anomalies.

Hawai‘i Climate

Satellite measurements and high-resolution atmospheric and coupled ocean–atmosphere models now provide the opportunity to study small-scale, regional phenomena, something that was not possible with low-resolution models. IPRC scientists and their colleagues at other institutions have been taking advantage of these model improvements to study climate features over the Pacific Islands.

Cloud trails in the wake of the Hawaiian Islands. The diurnal cycle of clouds over the Hawaiian Islands was studied using Aqua MODIS cloud mask and GOES-10 imagery data (Yang Yang and

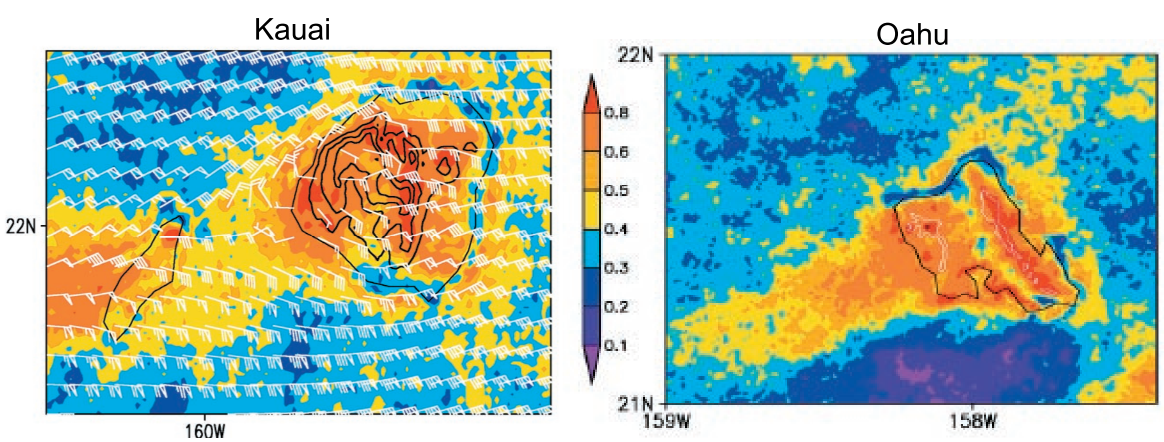


Figure 10. Mean cloud fraction (cloud amount) from Aqua MODIS (1400 HST) during summers 2004 and 2005 for Kaua‘i and O‘ahu. Simulated mean surface winds for summer 2005 are overlaid for Kaua‘i. Pennants, full barbs, and half barbs represent 5, 1, and 0.5 m/s, respectively.

Shang-Ping Xie). The data reveal cloud trails 100 km or longer forming in the lee of the Hawaiian Islands in the afternoon and dissipating during the night (Figure 10). A mesoscale atmospheric model was used to study the mechanisms that determine the cloud trails off Kaua‘i. Results suggest that as solar radiation heats the island during the morning, the generated heat advects downstream, thereby increasing air temperature, decreasing air pressure in the wake of the islands, and causing low-level wind convergence that favors the formation of the afternoon clouds. Clouds trails are commonly observed in the lee of islands, but this analysis shows that the island thermal effect is so important that island cooling suppresses the cloud trails at night. The study is significant also in its combined use of satellite measurements and numerical modeling to understand detailed aspects of cloud formation.

Indian Ocean climate's effect on Hawaiian Islands. The major impacts of El Niño on Pacific climate are fairly well documented. What has not been given much attention, though, is whether other, regional climate anomalies alter the impacts of El Niño. For example, the tropical Indian Ocean witnesses a basin-wide warming with a local maximum over the southwest Indian Ocean (15°S–0, 50°–80°E) during January–March in the year of a dissipating El Niño. In a sensitivity study with the ECHAM5 atmospheric general circulation model, H. Annamalai and colleagues found that for boreal winter El Niño years, the simulated 500-hPa height anomalies corresponded significantly better with the reanalysis-500 hPa height anomalies (the root-mean-squared-error is reduced by about 42%) over the Pacific – North America region when tropical Indian Ocean SST was prescribed in addition to Pacific SST. Motivated by this finding, Annamalai and Hafner investigated the effect of the southwest Indian Ocean SST anomalies on Hawaiian climate. Hawai‘i typically is drier during El Niño winters. There are, however, days with significant rainfall. To see whether anomalous SST in the Indian Ocean has something to do with these rainy days in Hawai‘i, they performed ensemble simulations with the MM5 regional model, in which they took lateral boundary conditions from the ECHAM5 sensitivity simulations. They compared solutions with observed daily station rainfall data over the Hawaiian Islands, global daily outgoing longwave radiation, and reanalysis products. Both regional model solutions and observational diagnostics indicate that intense rainfall events over the Hawaiian Islands during El Niño winters could well be due to circulation anomalies forced by southwest Indian Ocean SST anomalies. The model solutions show that Rossby waves emanate from the Indian Ocean into and through middle and high latitudes, influencing the climate of the Hawaiian Islands.

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 currents, and those connections between the Pacific and Indian Oceans that are known to be, or believed to be, important in the maintenance and variability of the large-scale oceanic gyres and climate. Toward these objectives, 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 of the past year.

South China Sea Throughflow

In the past several years, IPRC scientists have carried out a number of investigations of circulation in the South China Sea (SCS). Recently they have focused on the SCS throughflow (SCSTF), in which a branch of the Kuroshio enters the SCS through the Luzon Strait and exits through the Taiwan, Mindoro, and Karimata Straits.

This year, IPRC researchers (Tangdong Qu and Yan Du) with colleagues at JAMSTEC (Hideharu Sasaki) determined that, according to the Ocean Model for the Earth Simulator (OFES), the SCSTF transfers as much as 0.2 PW (1 PW= 1×10^{15} W) of heat and 0.1 Sv (1 Sv = 1×10^{6} m^3 s^{-1}) of freshwater from the SCS into the Indonesian Seas, and that the SCS stores heat and freshwater in some years and releases them in others, suggesting the SCS acts as a heat capacitor.

The study also showed that the flow in the Makassar Strait is an interplay between near-surface, northward-flowing, SCSTF waters and the thermocline southward-flowing, Indonesian Throughflow. By inhibiting warm Pacific surface waters from flowing southward in the Makassar Strait, the SCSTF reduces the Indonesian Throughflow heat transport from the Pacific to the Indian Ocean. Thus, the SCSTF contributes to SST patterns in the Indonesian Seas and the adjacent Indo-Pacific Ocean. These events are supported by numerical experiments of the ocean using OFES (Figure 1) in collaboration with colleagues at the University of Tokyo (Tomoki Tozuka and Toshio Yamagata).

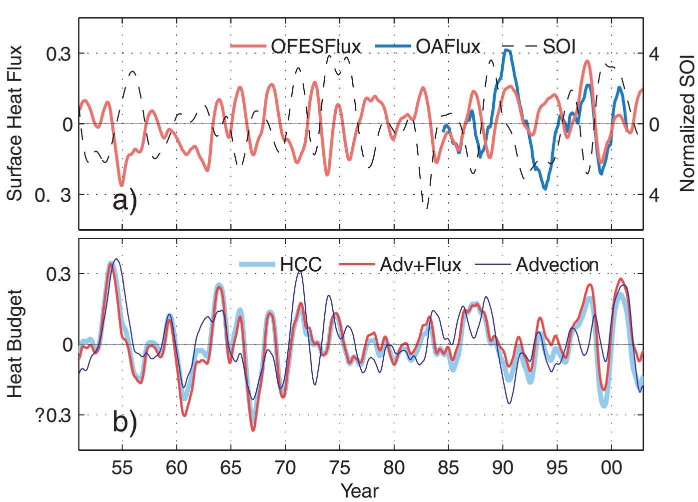


Figure 1. OFES surface heat flux compared with the "objectively analyzed" (OA) surface heat flux and the Southern Oscillation Index (SOI; top panel), and upper layer (0 – 432 m) heat content change (HCC) compared with heat advection and the sum of surface heat flux and heat advection averaged over the South China Sea. The 13-month mean filter has been applied twice to remove the mean seasonal cycle. Unit is 10^{14} W.

IPRC scientists (Zuojun Yu, Max Yaremchuck, Julian McCreary, and Ryo Furue) have shown that the spatial distributions of subsurface salinity can help our understanding of three-dimensional ocean circulation in the SCS. The inflow branch (Luzon Strait) of the SCSTF carries salty North Pacific Tropical Water into the basin (Figure 2, left panel). The importance of this salty inflow is demonstrated by a set of sensitivity experiments, using a 4½-layer ocean model at 0.1° resolution. Results from one of the experiments are shown in the right panel of Figure 2. The model SCS cannot reach an equilibrium state consistent with the observed subsurface salinity distribution (left panel) unless all the following components are in place: the Kuroshio, transports through the three secondary straits, downward mixing of freshwater, horizontal mixing induced by mesoscale eddies, as well as forcing by the local monsoonal winds.

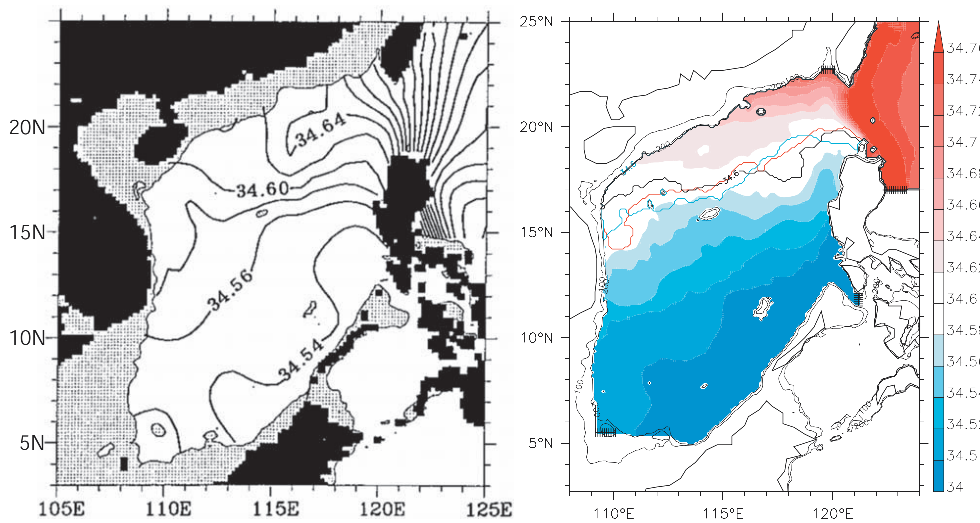


Figure 2. Annual-mean subsurface salinity distributions in the South China Sea (SCS): Left - on the 25.0 σ_θ surface (after Qu et al., 2000). Right - in model layer 3 (after Yu et al., 2007); the shadings are for model year 7, while the red, black, and light-blue curves indicate the locations of the 34.6-psu contour for model years 1, 7, and 10, respectively. This experiment is forced by 50% of the SCS throughflow transport, estimated by Yaremchuck (unpublished data). The salinity distribution from this experiment resembles the observation better than those using 0%, 75%, or 100% of the transport.

In an extension of the previous study, the team used 4dVar to assimilate climatological temperature and salinity data into the 4½-layer model at 0.5° resolution. An equilibrium state consistent with historical hydrographic data in the SCS could be achieved only if the SCSTF was present. The magnitude of the SCSTF transport was estimated to be 2.4 Sv in the inverse analysis. An interesting result is that the annual-mean Karimata Strait transport in the optimized solution is only 0.3 Sv, a value considerably smaller than in unconstrained solutions, including the OFES solution noted above.

Given the importance of ocean temperatures for climate, comprehensive study of the SCSTF should contribute to a better understanding of the region's role in governing the East Asian monsoon, ENSO, and probably the Indian Ocean Dipole. Numerical modeling experiments using a coupled GCM are now underway to further look into the climate impact of this throughflow.

Year-to-Year Variations in the Indonesian Throughflow

Interannual variations in the ITF have been thought to be closely related to the El Niño-Southern Oscillation (ENSO). For instance, using data from a repeat XBT line across the outflow of the ITF to the Indian Ocean, scientists at CSIRO found that during El Niño years, ITF transport was significantly less than during other years. Other scientists found a similar relationship between ENSO and the transport through Makassar Strait.

A study by England and Huang conducted in 2005 noted that in an ocean reanalysis product (SODA) the correlation between the Indonesian Throughflow (ITF) transport and a multivariate ENSO index (MEI) was only r = –0.35. Consistent with these results, IPRC researchers, plotting the transport in the upper 800 m and the MEI, found years in which the ITF transport does not appear to match ENSO variations. Using SODA and output from two coupled models (NCAR's PCM and FRCGC's SINTEX), they noted that the relationship between ENSO and ITF transport depends upon the depth at which the transport is measured. Figure 3 shows the correlation between MEI and transport anomalies (in each model level) through a section from Java to Australia using the SODA velocity field. The highest correlation was found at intermediate depths with a two-month lag. This result implies that the relatively low correlation obtained in the study by England and Huang resulted from their integration that included surface measurements. The upper-ocean ITF tends to respond to local winds, which are not always related to ENSO, whereas the intermediate layer is controlled more by remote Pacific winds. The interaction between variations in the surface and the deeper layers leads to an ITF – ENSO relationship that is more complicated than has been surmised until now.

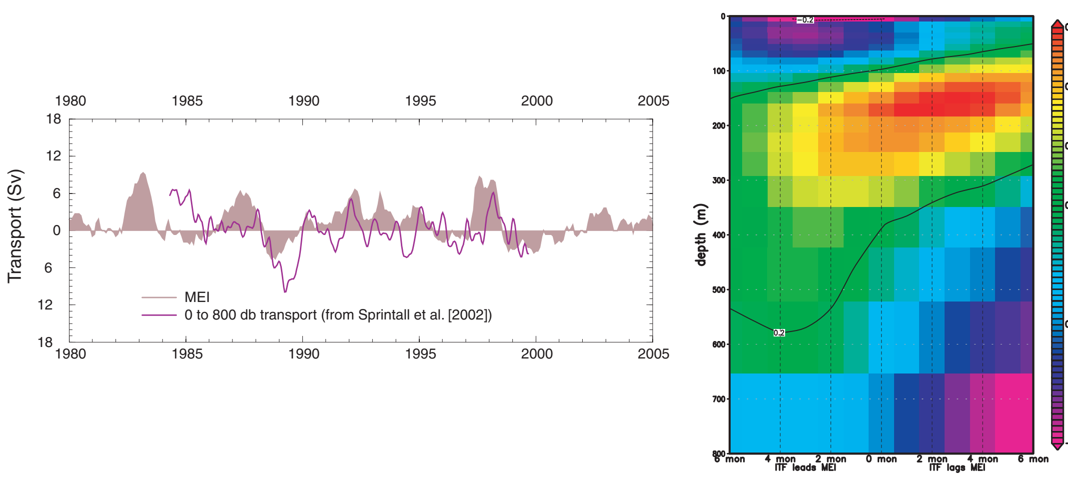


Figure 3. Left - the multivariate ENSO index (MEI) and the Indonesian Throughflow transport estimates of 8-month filtered running-mean from Sprintall et al. (2002). Variations in the ITF transport integrated over the upper 800 m match only moderately the variations in the ENSO index. Right - the correlation between MEI and transport anomalies (in each level) as a function of depth as derived from the SODA velocity field through a section from Java to Australia. The highest correlation occurs between 150 and 200-m depth.

Mixing Processes in the Ocean

Work has continued on the formation and impact of interleaving structures in the equatorial thermocline (Andrei Natarov and Kelvin Richards). The dependence on time and the impact of shear on the stability and equilibration of *x*-independent (symmetric) zonal flows were studied. For a range of flow structures, three distinct regions were found in which the flow is dominated by inertial instability, parametric subharmonic instability, or a mixture of the two. Under certain parameter regimes, nonlinear solutions develop interleaving structures similar to those observed. The interleaving can extend far beyond the initial unstable region and can ultimately result in strong lateral and vertical mixing.

The researchers have extended the analysis to three-dimensional disturbances of *x*-independent background flows. For high mean-shear, inertial instability dominates, and the fastest growing mode has a relatively short zonal wavenumber, *k*. For smaller shears, the growth rate is relatively flat with respect to *k* with the maximum growth rate occurring in bands of both high and low *k*. Thus, nonlinear effects need to be considered in order to determine the scales that dominate at finite amplitudes.

The impact of vertical mixing has also been investigated in the coupled ocean-atmosphere system in the eastern tropical Pacific using the IPRC Regional Ocean–Atmosphere Model (iROAM) (Richards and the iROAM team). A technique to calculate the diapycnic velocity (associated with water-mass conversion) showed that substantial diapycnic velocities are associated with Tropical Instability Waves (TIWs). Ocean–atmosphere coupling is important in assessing the sensitivity of the system to the amount of vertical mixing in the ocean. As an example, Figure 4 shows the change in SST in March brought about by an increase in the background ocean mixing for an ocean-only (left panel) and coupled system (right panel). In the coupled system the cooling spreads further west because of the increase in the strength of the easterlies (the so-called Bjerknes feedback). The cooling in the far east of the region is further intensified by a reduction in the North Equatorial Countercurrent (NECC), brought about by a change in the curl of the wind stress, and an increase in cloudiness. Ocean mixing is also found to affect land temperatures over South America through changes in precipitation. The cooling over land reaches a maximum in October when the reduction in surface temperature is as much as 4°C.

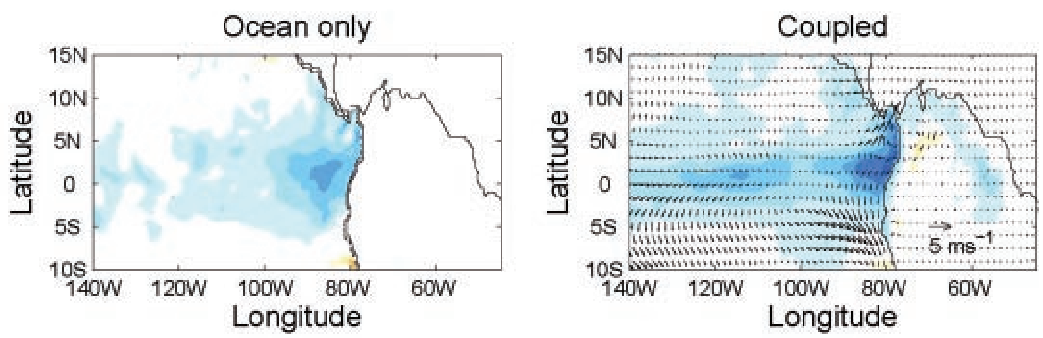


Figure 4. Change in the surface temperature brought about by increasing the background vertical mixing in the ocean component of iROAM from 10^{-6} m^2s^{-1} to 5×10^{-5} m^2s^{-1} (color: contour interval 0.5°C). Left panel is for an ocean-only model. Right panel is the fully coupled case. Arrows show the change in surface wind for the coupled case.

ASIAN-AUSTRALIAN MONSOON SYSTEM (THEME 3)

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 climate system and its hydrological cycle. The section below summarizes IPRC research achievements during the past year.

Monsoon Intraseasonal Variability and Predictability

The summer monsoon over Asia is characterized by alternate wet and dry phases called *intraseasonal oscillations* (ISOs). These phases of rain and drought impact life, particularly agriculture. Understanding the processes that produce such dry and wet spells has been a major research focus at the IPRC. Several satellite data and modeling studies were conducted this past year to understand and predict the phases of the ISO better.

Observing the development of ISO convection. A composite scenario, created from 28 ISO events detected in TRMM satellite measurements over the equatorial Indian Ocean region during April–October from 1998 to 2005, confirmed that the average oscillation period of the ISO over the Indian Ocean is around 32 days (Bin Wang). Convective anomalies start in the equatorial western Indian Ocean, then move eastward. At first, stratiform and convective rain rates are comparable; the prevailing clouds then evolve from shallow-convective to deep-convective clouds, and finally to anvil and extended stratiform clouds (Figure 1). As the equatorial rainfall anomalies reach Sumatra, a major northwest/southeast-slanted rainband forms and rapidly propagates eastward into the Pacific along the Intertropical Convergence Zone and northward into the Philippine Sea. A seesaw teleconnection in rainfall anomalies is found between the southern Bay of Bengal and the eastern tropical North Pacific, in which convection over the former region leads convection over the latter by 16 days. These results provide an observational benchmark for numerical model simulations.

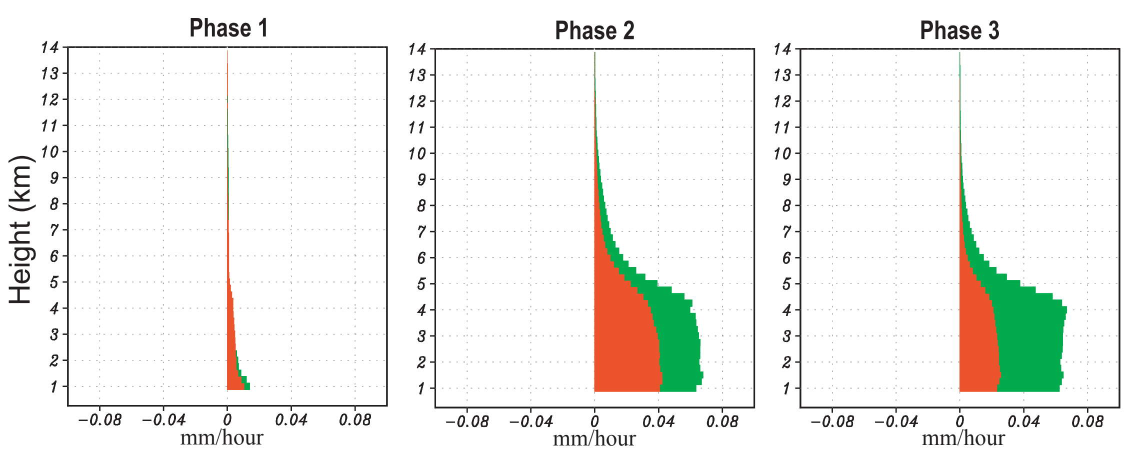


Figure 1. Composite vertical profiles of precipitation rate anomalies associated with the ISO as derived from TRMM precipitation radar (TRMM/2A25) measurements over the equatorial Indian Ocean (5°S–5°N, 60–70°E) where the ISO starts. Each phase lasts about 4 days. Red and green represent convective and stratiform rain rates, respectively.

In a second ISO project, IPRC scientists constructed a composite of the associated water-vapor cycle using water-vapor and air-temperature profiles from the Atmospheric Infrared Sounder (AIRS) on the Aqua satellite (Xiouhua Fu et al.). They found that positive SST anomalies and atmospheric boundary-layer moistening precede deep convection, suggesting that it is these anomalies that destabilize the troposphere and guide the movement of the disturbance. To describe further the spatial-temporal evolutions of the Convective Available Potential Energy (CAPE) associated with the monsoon ISO, AIRS water-vapor and air-temperature profiles, NCEP reanalysis data, TRMM SST and rainfall, and QuikSCAT surface winds were analyzed. A composite, created from 8 wet–dry cycles that occurred during May–October from 2003 to 2005, revealed that CAPE, SST, and surface-wind convergence lead both the northward and eastward moving convection (Figure 2). Moreover, the enhanced CAPE precedes the rise in SST, suggesting that the atmosphere alone could trigger the convective phase of the ISO. The warm SST anomalies, however, feed back to the atmosphere, and there is a smooth transition from boundary-layer moistening, to shallow convection at lower and middle atmosphere, and to deep convection throughout the troposphere. The moist preconditioning of the atmosphere for wet phases stretches across 60–90° of longitude and 15° of latitude, and occurs for ¼ to ½ of the cycle. Not as regular as moisture preconditioning, temperature preconditioning depends on the strength of the convection following it. The moisture preconditioning of the boundary layer is virtually undetectable in the NCEP reanalysis. These carefully documented observations should be very useful for improving the representation of the ISO in global climate models (Bo Yang, Xiouhua Fu, and Bin Wang).

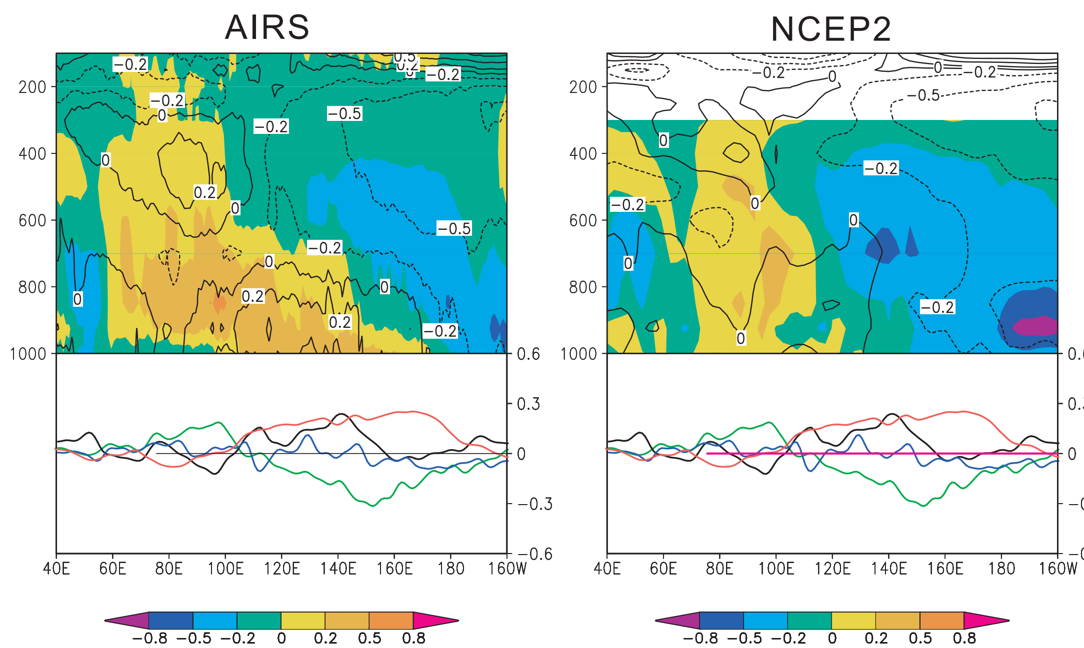


Figure 2. Pressure-longitude cross-sections of humidity (g/kg, shaded) and temperature (K, contour) anomalies from AIRS data and NCEP reanalysis overlying the associated anomalies (bottom polygraphs) of rainfall (mm/hr, green line), CAPE (10^3 J/kg, red line), SST (K, black line), and surface convergence (10^{-5}/s, blue line) for composite ISO.

Modeling the development of ISO convection. The physical processes by which SST might "precondition" the atmosphere were studied in ensemble experiments using 5 different SST boundary conditions in runs with the ECHAM hybrid coupled GCM and the ECHAM atmospheric GCM. The suite of experiments shows that anomalously warm SST, stretching from the northern Indian to the western

Pacific Ocean, triggers convective disturbances by moistening and warming the atmospheric boundary layer in a way similar to the satellite observational findings mentioned above. Seasonal-mean easterly shear enhances surface convergence, intensifying the anomalous convection. An overturning meridional circulation, driven by this off-equatorial anomalous convection, suppresses convection near the equator and strengthens northward flows, further intensifying the off-equatorial surface convergence and the ISO-related convection (see Figure 3). Thus, the boreal-summer mean easterly shear and the overturning meridional circulation in the northern Indo-western Pacific sector amplify the SST feedback to the convection of the ISO (Xiouhua Fu and Bin Wang).

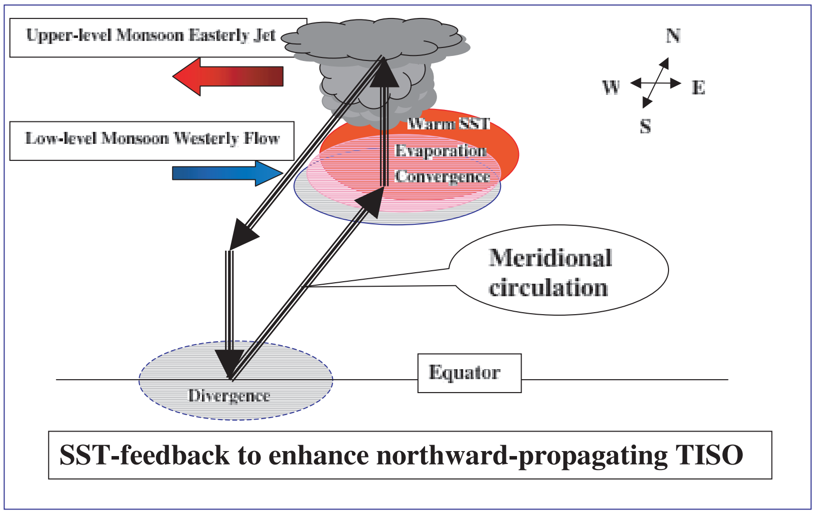


Figure 3. The schematic shows the major components of the SST–feedback that strengthens the northward-propagating tropical intraseasonal oscillation.

Finally, a project has been underway at the IPRC to improve computer modeling of ISOs with the NCAR CAM/CCSM (Liu). This popular climate model has had much difficulty in generating ISOs. Work this year shows that the NCAR model can simulate a rainfall pattern close to that observed by using an 8-hour CAPE lapse time.

Monsoon Year-to-Year Variability

Role of the Tibetan Plateau. As a high-altitude heat source, the Tibetan Plateau can be expected to have a profound impact on the weather and climate in Asia. An IPRC project studied summer heating over the eastern Tibetan Plateau and its possible connection to large-scale atmospheric patterns over Eurasia (Zhang). A monthly surface air temperature index (SATI), averaged from 54 stations over the eastern Tibetan Plateau, was correlated with rainfall, SST, and other fields from the ECMWF 40-year reanalysis. In years when the Tibetan Plateau heats up more than usual, there tends to be a local anomalous upper-level anticyclone, and also an anomalous anticyclone in southeastern Europe, and a cyclone in central–western Asia. This circulation pattern is associated with a dryer-than-normal summer in southern Europe and May–June in northern India, and a stronger Maiyu front in June.

Onset of monsoon rainfall in southwestern China. The summer monsoon rainfall in southwestern China begins suddenly and differs distinctly from the Maiyu front over eastern Asia. The signals for a later or earlier onset of the summer rainy season in southwestern China and its predictability were explored using the onset dates from 16 station over 45 years, ECMWF 40-year reanalysis, and

NCEP forecast system outputs (Yongsheng Zhang and Yu Liu, Yunnan Meteorological Center, China). Warmer (colder) than normal SST over the western Pacific in winter and spring tends to precede stronger (weaker) convection over the northern Indian Ocean–Maritime Continent and an earlier (later) onset of rainfall over southwestern China in the following summer.

Monitoring the monsoon. A real-time, daily updated, monsoon monitoring web page has been constructed, featuring circulation maps and time series of the Indian Ocean and the western North Pacific (Figure 4). A newly defined Australian monsoon index (AUSMI) uses the 850-hPa zonal wind, averaged over 110°E–130°E, 5°S–15°S. This new index captures monsoon rainfall variability over Australia and the Maritime Continent on intraseasonal, seasonal, interannual, and interdecadal time scales. The Australian monsoon onset date shows large interannual variations, with earlier than normal onset tending to be accompanied by a stronger than normal Australian summer rainfall. The monsoon withdrawal tends to vary little and be phase-locked to the seasonal cycle.

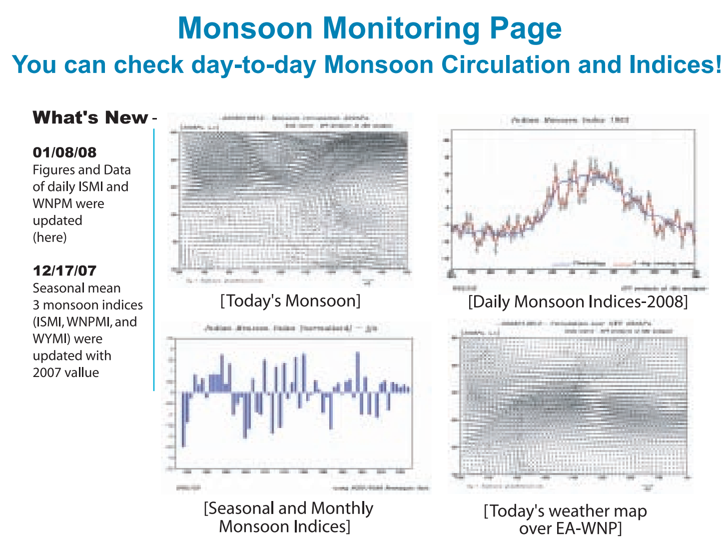


Figure 4. The Australian Monsoon Monitoring Page at http://iprc.soest.hawaii.edu/~ykaji/monsoon/, with links also from CLIVAR AAMP and APDRC websites.

Monsoon Rainfall Prediction

The CliPAS Project. The international project "Climate Prediction and Application to Society" (CliPAS), supporting climate research at the Asian-Pacific Economic Cooperation (APEC) Climate Center, has as its goal to improve prediction of intraseasonal-to-interannual rainfall climate variations by using the multi-model ensemble (MME) technique (Bin Wang, In-Sik Kang at SNU, Jagadish Shukla at Cola, and June-Yi Lee). Currently, 12 state-of-the-art climate prediction models from Japan, Korea, China, and the U.S. are participating; models from Australia and other APEC economies are soon to join the project. The CliPAS team has collected the most comprehensive historical hindcast datasets to date—a gold mine for studying seasonal prediction and predictability. The team is evaluating the extent and quality of prediction possible with this method, and is putting MME on a firm scientific basis. Results, challenges, and future direction of seasonal prediction were presented at the recent Earth System Science Partnership conference, and four manuscripts have been submitted.

Major findings are as follows: (1) MME prediction is better than that by any single model, the improvement occurring mainly in extratropical continental regions and in shorter computational time. The best prediction is achieved by selecting models using a Stepwise Pattern Projection Method: Various combinations of models that have reached a prediction threshold are then tried out in order to determine the model combination that best matches observations. The optimal combination tends to consist of models that have the least variance in common. (2) The coupled GCM MME 6-month forecast of NINO3.4 SST reaches as high as r = 0.86, but forecast skill depends on the phase of El Niño, the most accurate forecasts being during summer and fall before a strong El Niño. (3) Air-temperature prediction is better than SST prediction in the warm pool; MME rainfall prediction is better than empirical prediction, especially during June–August in the tropical Pacific and during December–February in East Asia. (4) MME captures the first two leading modes of Asian-Australian Monsoon System variability better than reanalyses (ERA 40 and NCEP-2), which have model-generated data for regions in which observations are lacking. (5) Seasonal prediction is positively correlated with the coupled models' ability to simulate both the annual-mean monsoon and annual monsoon cycle. (6) Atmosphere–ocean coupling extends intraseasonal predictability by about a week.

Many prediction systems assume that the monsoon responds to SST. The CliPAS research shows, once again, that fluctuations in the warm pool and in the monsoon are due to air–sea interaction. For example, at times SST is lower but rainfall is higher than normal, and this relationship implies that the atmosphere forces SST. Since the reanalysis products ignore this interaction in their data assimilation, their representations of the major modes of Asian–Australian monsoon variability are not very realistic. Operational centers are now planning to use coupled models for generating their reanalyses.

Climate Change and the Monsoon

Several studies at IPRC have looked at how the summer monsoon might change with global warming. The picture is far from clear.

Global monsoon index. One step in studying how climate change will affect the monsoon has been to create a new construct, the *global monsoon* region (B. Wang and Ding), defined as the region in which the summer and winter rainfall differs by more than 180 mm and the local summer monsoon rainfall exceeds the annual mean by 35% (Figure 5, panel a). This domain integrates three continental monsoons, adjacent oceanic monsoons, and a major aspect of their global water and energy annual cycle. Using this definition, trends in land monsoon rainfall during 1948–2003 were determined from four sets of rain-gauge measurements. Globally, monsoon precipitation over land has decreased during this period, mainly due to lesser summer monsoon rainfall in the Northern Hemisphere (Figure 5, panel b). Another analysis using the Global Precipitation Climatology Project Data (1979–2003), which includes both land and ocean rainfall for the last 25 years, shows no change in land monsoon rainfall but increasing oceanic monsoon rainfall (Figure 5, panel c).

To see how well current climate models simulate this global monsoon, IPRC scientists analyzed solutions from 21 models from the *20^{th} century* integrations of the IPCC Fourth Assessment Report (AR4; Hyung-Jin Kim, Bin Wang and Quinghua Ding). The models capture the global-monsoon precipitation domain reasonably well, but the spread among models is large. As resolution increases, the simulations improve the regional details of the monsoon precipitation, especially in areas where topography impacts rainfall. Analysis of the long-term changes reveals that regardless of the prescribed external forcings and the atmospheric horizontal resolution, none of the models faithfully simulates the observed decreasing tendency in the Northern Hemisphere monsoon over land during 1951–1999 and the increasing rainfall of the monsoon over the global ocean during 1980–1999.

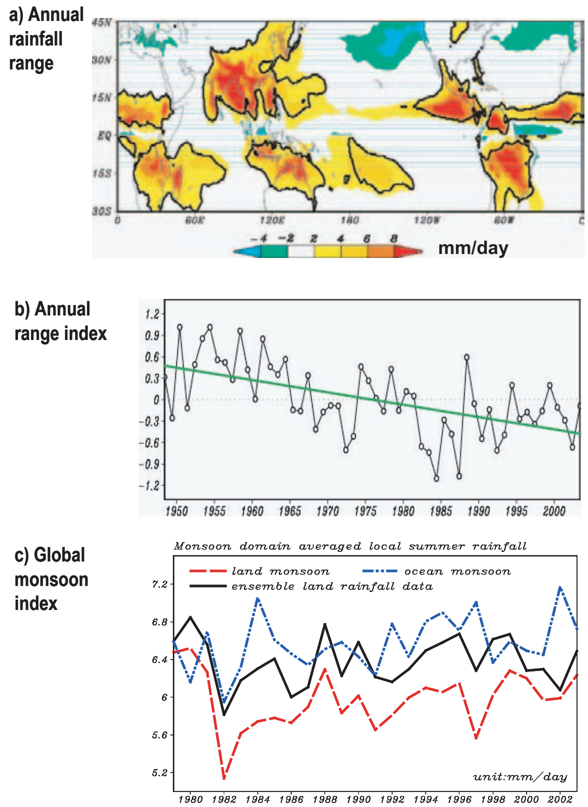


Figure 5. Panel a - The annual rainfall range (in shades; in mm/day) and global monsoon domain (area within the blackened lines). Panel b - Changes in global monsoon rainfall calculated from the arithmetic mean of four sets of rain-gauge precipitation data for the period 1948 – 2003. Panel c – Results from the Global Precipitation Climatology Project Data (1979 – 2003), which includes both land and ocean rainfall over the last 25 year: The global monsoon index (black curve) consists of the averaged rainfall over land for the local summer months (red curve) and ocean (blue curve) in monsoon regions.

Changes in monsoon intensity and global warming projections. Another study focused on the response of the seasonal mean monsoon rainfall and the frequency of monsoon synoptic systems to global warming. (Markus Stowasser and H. Annamalai). A comparison with CMAP observations and ERA-40 reanalysis showed that solutions of the latest version of the GFDL coupled model (GFDL_CM_2.1) represented best the mean monsoon precipitation, the details of the El Niño-monsoon relationship, and the ISO variability. For instance, the monsoon depressions that form over the quasi-stationary seasonal monsoon trough are the main rain-bearing systems over central India, and the GFDL_CM_2.1 captures their genesis location and their west-northwest movement. In a 4xCO_2 warmer climate scenario, the GFDL_CM_2.1 model solutions show more monsoon rainfall over continental India, but less over the Indian Ocean. It seems that a pair of low-level anticyclonic circulation anomalies weakens the cross-equatorial monsoon flow, resulting in less upwelling along the Somali coast. The southern Arabian Sea then warms and evaporation increases, feeding monsoon rainfall over India despite the weaker circulation.

To determine the climate sensitivity of the monsoon depressions to global warming, in other words, whether monsoon depressions could become more frequent or intense with warming, the frequency distribution of monsoon synoptic systems as a function of maximum wind speed of the systems was obtained from model solutions for the Bay of Bengal region (75°E–90°E, 18°N–28°N) The control GFDL simulation (Figure 6 top, blue bars) shows an asymmetric distribution with a peak around 8–10 m/s and very few storms of wind speeds greater than 15m/s. The 4xCO_2 integration shows a similar distribution and only a marginal increase in the number of storms with wind speeds higher than 12 m/s. On the other hand, when the high-resolution IPRC RegCM was integrated for 20 years with lateral boundary conditions taken from the *20^{th} century* control and the 4xCO_2 GFDL simulations, a more realistic representation was generated. With boundary conditions taken from the 20^{th} century, most storms exceed 10 m/s and a fair proportion exceeds 15 m/s (Figure 6 bottom, blue bars). With boundary

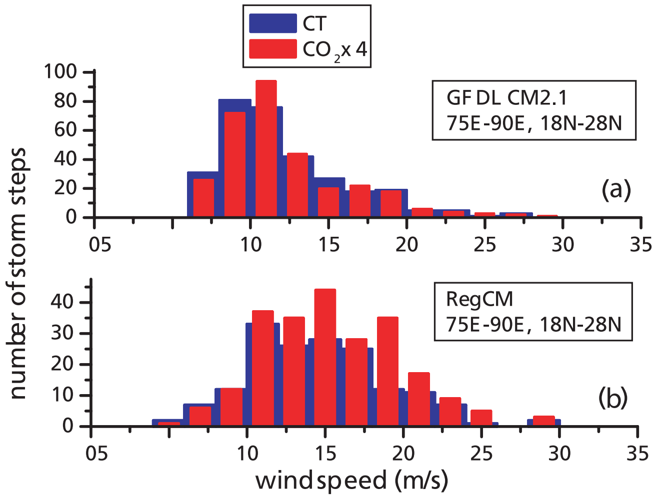


Figure 6. Frequency distribution as a function of maximum wind speed of each synoptic system for a) GFDL CM_2.1 model, and b) RegCM model. The blue and red bars indicate control and 4 x CO_2 integrations, respectively. The frequency is given in numbers of 12-hour time-steps that a system was present in the domain.

conditions from the 21st century, stronger storms become much more common, the frequency distribution peaking at 15 m/s. These results imply that the number of floods over continental India may rise with rising surface temperatures.

The long Korean rainfall record. Yet another picture of changing rainfall with changing surface temperatures comes from a 227-year-long precipitation record from Seoul, Korea. IPRC scientists with colleagues at Seoul National University have shown that over the last 50 years summer rainfall has been increasing and that the record as a whole reflects an increase in heavy rainfall events, with 67% of the rain falling in fewer and fewer days (Wang, Ding, and Jhun, 2006).

Tropical Cyclone Research

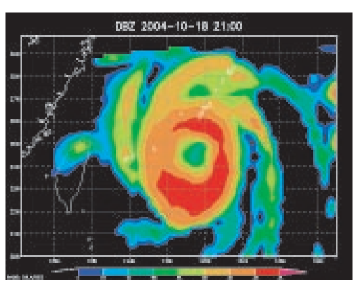
Tropical cyclone (TC) research at the IPRC has been accelerating over the years. Work this past year has dealt with atmospheric circulation patterns favorable to the formation of TCs, the use of data assimilation as a method for improving TC forecasts, and the manner and extent to which environmental factors, particularly global warming, may affect the frequency and intensity of tropical cyclones. To understand and test hypotheses about the structure and evolution of TCs, their behavior is also being studied in a tropical cyclone model developed at the IPRC.

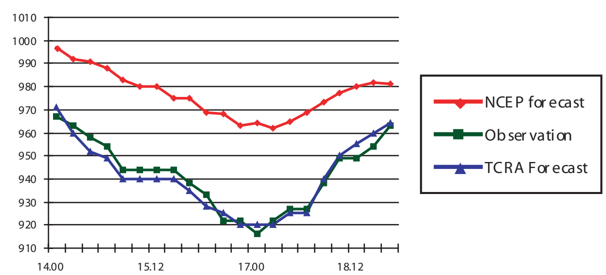
Conditions for tropical cyclone formations. Using high-resolution satellite and NCEP-NCAR reanalysis data, the development of 34 TCs in the western North Pacific was tracked during 2000 and 2001 (Xiouhua Fu, Tim Li, Jiayi Peng, and Weng, 2007). The most common type of synoptic-scale disturbances that led to TCs were the following: (1) the dispersion of energy from an existing TC—6 TCs were generated by the energy dispersion from a preceding TC that was sufficiently energetic and occurred in a background flow favorable for the second TC formation; (2) synoptic wave trains not associated with pre-existing TCs—among the 11 cases associated with synoptic wave trains, 4 cases were triggered by equatorial mixed Rossby-gravity waves; and (3) easterly waves—the 7 TCs associated with easterly waves were generated during the westward propagation of kinetic energy and precipitation. Moreover, tropical ISOs affect TC formation significantly. Examination of the 10 genesis cases without detectable precursors suggests three additional possible genesis scenarios: (1) disturbances excited by upper-tropospheric forcing, (2) interaction of a preexisting TC with monsoon southwesterly winds, and (3) high cloud-liquid water content in the mid-troposphere.

Rapid intensification, a characteristic of the most powerful hurricanes. Another observational study revealed that all category-4 and category-5 hurricanes in the Atlantic basin and 90% of the super typhoons in the western North Pacific have at least one rapid intensification phase in their life cycles (Bin Wang and Li Zhou, 2007). During the past 40 years, the number of rapid intensification phases in western North Pacific TCs has shown no detectable trend. Rather, the variations observed depended upon the latitude at which the tropical storms form. When this latitude shifts southward (either seasonally or from year to year), the proportion of super typhoons or major hurricanes increases. Further analyses showed that this shift is determined by large-scale atmospheric circulation changes rather than by local SST changes. Moreover, the rapid intensification of typhoons in the Philippine Sea and South China Sea can be predicted 10 to 30 days in advance, based on the convective anomalies in the equatorial western Pacific (5°S–5°N, 130°–150°E). The degree to which NINO3.4 SST deviates from climatology in June is a possible predictor for the number of rapid intensification occurrences expected during the peak TC season in the southeast quadrant of the western North Pacific (0–20°N, 140–180°E).

Forecasting tropical cyclones with data assimilation. In a study to test the utility of data assimilation in TC forecasting, the Aqua satellite's Advanced Microwave Sounding Unit moisture and temperature data, QuickSCAT and GOES-track winds, and SSM/I rain data for 12 typhoons in the western Pacific were assimilated into the NCAR/Penn State Mesoscale model (MM5) using four-dimensional variational analysis (Xin Zhang, Tim Li, et al. 2006). The assimilated typhoon intensity in the different runs compared very well with actual measurements of minimum central surface pressure and is significantly more accurate than the final NCEP analysis (Figure 7). The spiral rain bands and strong convective activities along the eyewall are realistic, and the assimilated radar reflectivity agrees well with the independent TMI rain rate. The study represents the first effort of fine-resolution TC reanalysis using the latest NASA satellite products. The success of the method shows that it can be used in operational models to improve actual TC forecasts.

Tropical cyclones and global warming. Will tropical cyclones become more violent this century with the rise in SST expected to accompany air temperature rise? Results of a modeling study conducted





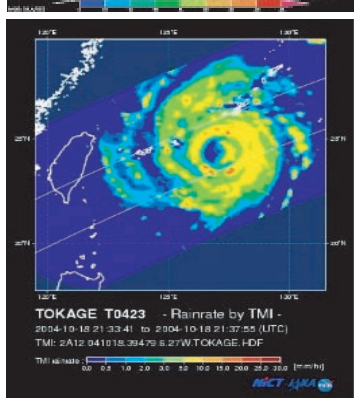


Figure 7. Aqua AMSU moisture/temperature, QuickSCAT and GOES-track winds, and SSM/I rain data for Typhoon Tokage were assimilated into MM5 using 4DVAR. The top-right panel shows the assimilated typhoon intensity (blue) and actual measurements of minimum central surface pressure (black) along with the NCEP final analysis (red). The top-left panel shows assimilated radar reflectivity and the bottom panel shows TMI rain rate measured at the same time: Spiral rain bands and strong convective activities along the eyewall are well simulated.

last year at IPRC by Markus Stowasser, Yuqing Wang, and Kevin Hamilton had suggested that powerful typhoons would become more frequent in the western Pacific. This year, a new empirical formula for the maximum potential intensity, which includes not only SST and outflow temperature but also the effects of the speed with which the storm travels and vertical wind shear, was applied to solutions of the coupled general circulation models from the IPCC AR4 *20th century* and the *CO_2 doubling* runs (Yuqing Wang). The ensemble simulations captured the observed rise in SST during the 20th century, but TC maximum potential intensity did not increase. The TCs in the model appeared to respond to rising SST by "letting off more steam," since the outflow-layer temperature of the TC near the tropopause also rose. On the other hand, when atmospheric CO_2 levels increased beyond present-day levels, this mechanism no longer fully offset the effects of the rising SST: the model SST rose slightly faster than the upper tropospheric temperature of the storm, resulting in a consistent increasing trend in theoretical maximum potential intensity over the entire Northwest Pacific. When the integrations reached doubled CO_2, the theoretical maximum potential intensity, as measured by sustained maximum near-surface wind speed, increased by 3–10% in regions with frequent tropical cyclones (see Figure 8). The sharpest increase in maximum near-surface wind speed occurred near the China's coast. This work is being expanded to include TC basins worldwide and more simulations from available coupled GCMs.

Modeling tropical cyclones. Much still needs to be learned about what determines cyclone intensity. Helpful tools for understanding TC behaviors are numerical models in which aspects of the TCs can be experimentally varied and tested. Such a model is the multiply nested, movable mesh, fully compressible, nonhydrostatic TC model, the TCM4, developed by Y. Wang at the IPRC. Two studies were conducted with this model.

The first study focused on asymmetry in the inner-core region, which is associated with the intensity of a TC. Seeking to determine whether numerical models generate the asymmetry numerically or by physical processes, Y. Wang compared a dry experiment in which the model physics were turned off with a run that included all the physics. In the dry experiment, the asymmetries originated with the nu-

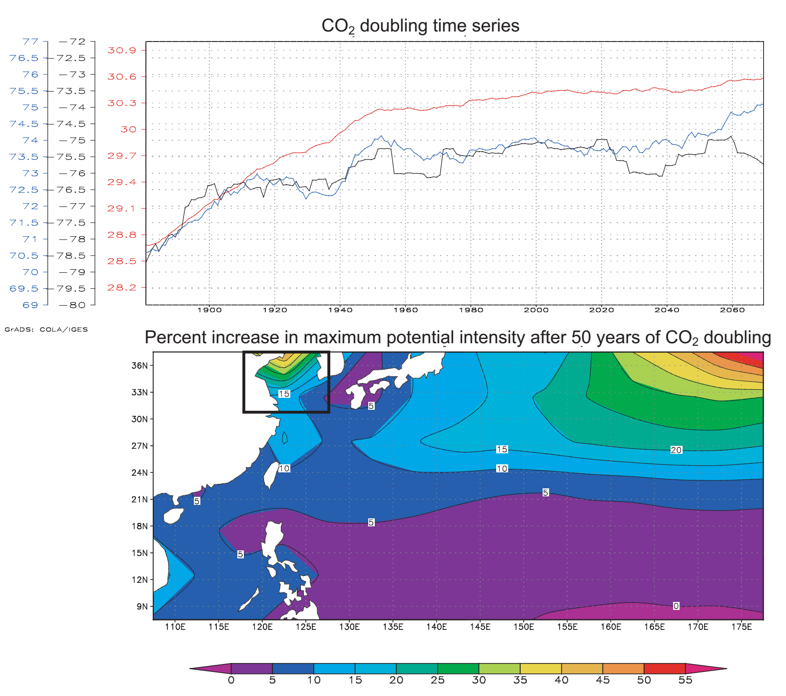


Figure 8. Top - CO_2 doubling time series of August–October mean Vmax (m/s, blue), SST (°C, red), and outflow layer temperature T_0 (°C, black) averaged over the South China Sea. Bottom - percentage of increase in the mean August–October potential intensity of TCs in the western North Pacific after 50 years of CO_2 doubling.

merical finite-differencing scheme on a regular square-grid system and time-splitting error, associated with horizontal advection. Computational asymmetries consisted mostly of azimuthal wavenumber-two and wavenumber-four components. Because the initial cyclonic vortex had a monotonic radial distribution of potential vorticity and thus was dynamically stable, the computational asymmetries remained weak and stationary, affecting the evolution of the dry vortex minimally. In the full-physics, moist experiment, the asymmetries at first developed similarly to those in the dry experiment; however, once convection burst out near the original radius of maximum wind, small-scale convective activities near the original radius of maximum wind determined the asymmetries. The rapid convective outbursts generated strong gravity waves that propagated radially outward; after dynamical adjustment, convection was trapped mostly in the inner core. The heating associated with inner-core convection produced an off-center local potential vorticity maximum of the azimuthal mean vortex in the mid-lower troposphere; barotropic instability developed, and large asymmetries with low azimuthal wavenumbers and vortex Rossby wave characteristics formed in the inner core. Quasi-stationary computational asymmetries modify these physical modes only slightly and do not significantly affect the overall asymmetric dynamics of the model TC.

A second study with the TCM4 model looked at a phenomenon called the "moat." Radar images of TCs show a narrow band of less rain just outside the eyewall of the storms. This moat has been thought to be due partly to the strain-dominated flow outside of the radius of maximum wind and that strong filamentation distorts and suppresses deep convection. Solutions to TCM4 indicated that, rather than suppressing deep convection, the strain flow in the rapid filamentation zone outside the elevated potential vorticity core provides a favorable environment for organized, fine-scale, inner spiral rainbands (Figure 9). Although the moat in the simulated TC is in the rapid filamentation zone, it is mainly controlled by subsidence associated with the overturning flow from eyewall convection and downdrafts from anvil stratiform precipitation outside the eyewall. Rapid filamentation therefore probably plays a secondary role in moat formation. Although the deformation field is determined primarily by the structure of the TC, it can affect the storm's evolution considerably. Moreover, because of strong straining deformation, asymmetries with azimuthal wavenumber > 4 are found to be damped effectively in the rapid filamentation zone. Filamentation time thus provides a quantitative measure of the stabilization and axisymmetrization of high wavenumber asymmetries in the inner core due to shearing deformation and filamentation.

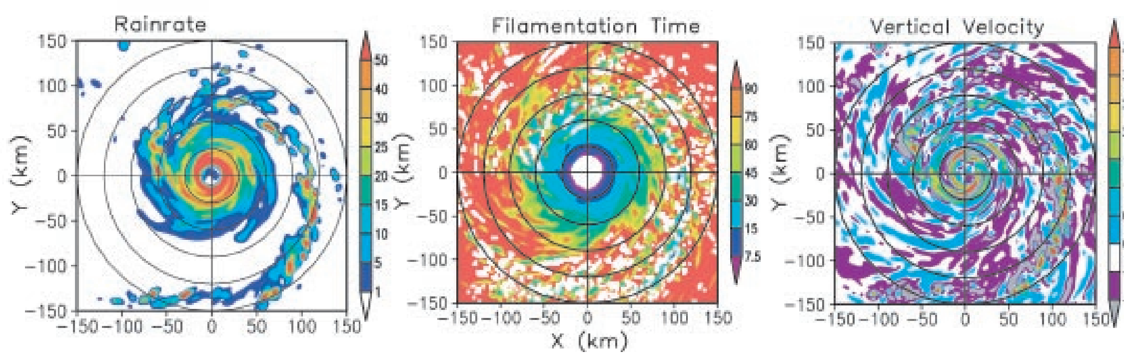


Figure 9. Snapshots of the simulated TC at 120 hours: Panel a - the green band just outside the eyewall represents the moat with lighter rain than in the core. Panel b - the filamentation time is shortest close to the core, and rather than suppressing deep convection, the strain flow in the rapid filamentation zone surrounding the core supports formation of the tightly structured inner spiral rainbands. Panel c - though in the rapid filamentation zone, the moat is controlled mainly by subsidence (purple band) associated with the overturning flow from eyewall convection and stratiform precipitation beyond the eyewall.

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 the numerical modeling of climate change. During the past year, IPRC scientists conducted research into the climate sensitivity to large-scale perturbations, the nature of global controls over regional climate with implications for seasonal forecasting, the behavior of high-resolution atmospheric global models, and the climate impact of variations in solar insolation and a shutdown of the Atlantic meridional overturning circulation.

Issues in Current Climate Modeling

Climate sensitivity to large-scale perturbations. IPRC researchers (Kevin Hamilton and Markus Stowasser) have been comparing climate feedbacks and sensitivities in two current climate GCMs, the NCAR Community Climate System Model (CCSM) and the model from the Canadian Centre for Climate Modelling and Analysis (CCCma). In last year's report, they presented results for the equilibrium climate feedbacks and the overall global climate sensitivities in these two models, noting that the global sensitivity in the CCCma model is twice as large as in the NCAR CCSM. This year they conducted a series of integrations with the NCAR model to test a widely advocated approach for obtaining an observationally based estimate of climate sensitivity, namely, the temperature response in the aftermath of major volcanic eruptions. To approximate the typical climate forcing observed after major explosive volcanic eruptions, they introduced into the NCAR model a 42-month-long global perturbation to the incident shortwave radiation. Colleagues at CCCma repeated the experiments with their model. Results have now been analyzed to see how well the response to such perturbations can be used to estimate equilibrium feedbacks and climate sensitivity.

Despite the models' very differing equilibrium climate sensitivities, their global-mean surface temperature responses to the volcano-like transient forcing are very similar. This outcome shows that climate sensitivity cannot be inferred from the surface temperature record alone even if the forcing is known perfectly. Equilibrium climate sensitivities can be reasonably determined only if the forcing and changes in heat storage in the system are both known precisely. On the other hand, the geographic patterns of clear-sky atmosphere/surface and cloud feedbacks are similar for both the transient volcano-like and near-equilibrium constant forcing simulations, showing that the same feedback processes are involved and that they determine climate sensitivity under both conditions and in both models. Thus, if an accurate determination of the heat storage in the climate system can be obtained (either through accurate top-of-the-atmosphere radiation measurements or ocean temperature measurements), then the observed response to large volcanic eruptions may provide accurate assessment of the equilibrium climate feedbacks.

Global controls over regional climate. IPRC scientists continued to study the effects of the stratospheric quasi-biennial oscillation (QBO) on natural intraseasonal and interannual variability of the tropospheric circulation (Kevin Hamilton and George Boer at CCCma). For seasonal ensemble numerical forecasts, they developed a simple statistical correction procedure based on the phase of the QBO. The procedure has now been applied to extensive sets of winter seasonal hindcasts produced by different forecasting models that are part of the Canadian Historical Forecast Project 2 effort. Surprisingly, the use of this QBO-phase-related correction improves the 3-month extratropical numerical forecast skill more than a similar correction based on tropical Pacific Ocean temperature anomalies.

Work is also underway to characterize the extratropical effects of the QBO in seasonal forecast ensembles and in long climate integrations performed with atmospheric GCMs in which a realistic tropical QBO is imposed.

High-resolution atmospheric modeling. Over the past years, a series of fine-resolution atmospheric GCM integrations have been conducted on the JAMSTEC Earth Simulator by colleagues at the Earth Simulator Center (ESC). These very high-resolution experiments were made with the Atmospheric Model for the Earth Simulator (AFES) and include runs with T1279L96 resolution (a 10-km horizontal grid spacing). The integrations offer the first opportunity to study the impact of realistically high and steep topography on the solar tidal oscillations of the atmosphere. Analysis of the distribution of the semidiurnal surface pressure oscillation showed the model oscillation tends to be weaker to the west of large and steep topographic features (Kevin Hamilton and Wataru Ohfuchi, ESC). The limited available observations seem to confirm this feature. The weakness may be due to a shadow effect of topography on the tide (which itself can be regarded as a westward- and downward-propagating global-scale gravity wave).

The space-time variability of simulated tropical rainfall was also studied with a very fine spatial resolution version of AFES (Hamilton, and Takahashi and Ohfuchi at ESC). The model was run with two parameterizations of moist convection: the Emanuel and the Arakawa-Schubert (RAS) schemes. The space and time variations of rainfall differ greatly in these two versions of AFES, with the model using the RAS scheme simulating more intermittent rain and significantly more energetic circulation at all horizontal scales shorter than about 4000 km (Figure 1). Thus, despite their fine explicit horizontal resolution, these global model simulations are still very sensitive to details of the convective parameterization.

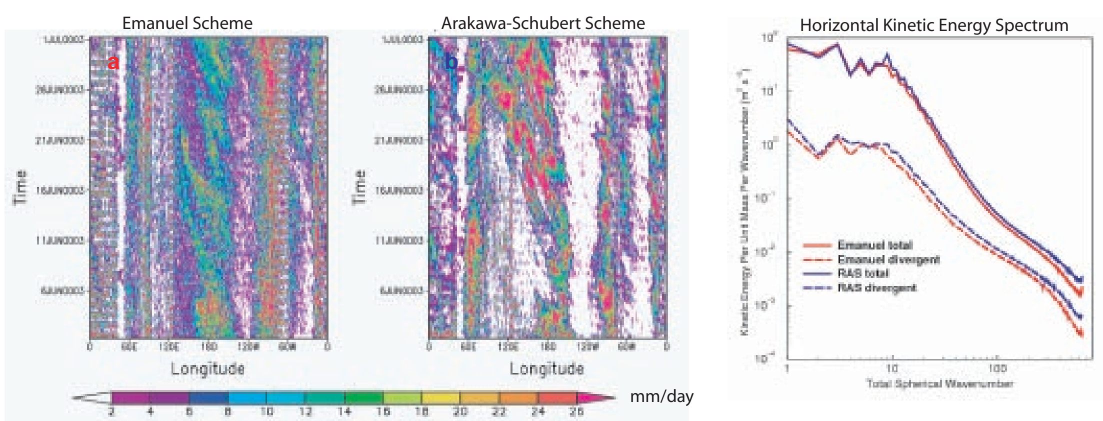


Figure 1. The space-time variability of simulated tropical rainfall in high-resolution (20 km) versions of the Atmospheric GCM for the Earth Simulator (AFES) model. The left panels are longitude-time plots of the equatorial rainfall rate for one month, when moist convection is parameterized using the Emanuel (left panel) and the Arakawa-Schubert (RAS; middle panel) schemes. The rainfall variations differ significantly, with steadier rain using the Emanuel parameterization. The right panel shows the horizontal spectrum of kinetic energy in the upper troposphere for the two versions. The RAS circulation is significantly more energetic at all horizontal scales shorter than about 4000 km.

Paleoclimate Modeling

Atlantic meridional overturning circulation. Past climates hold important clues into the processes driving climate—clues that may point to the nature of future climate change with global warming.

The Atlantic meridional overturning circulation (AMOC) has been a key component of abrupt climate change in the past, and IPRC researchers have conducted several projects on the effects of changes to this circulation. First, in a study on the global carbon cycle response to a weakening of the AMOC, freshwater perturbation experiments under pre-industrial atmospheric conditions were conducted using LOVECLIM, an earth-system model of intermediate complexity (Axel Timmermann, L. Menviel, and Oliver Timm). In the model, a shutdown of the AMOC leads to substantial cooling of the North Atlantic, a weak warming of the Southern Hemisphere, intensification of the northeasterly trade winds and a southward shift the ITCZ (Figure 2). The resulting southward shift of winds and rains, in turn, affects marine and terrestrial primary productivity respectively. The terrestrial (bound up) carbon stocks decrease mainly in northern Africa and northern South America, the ocean acts as a carbon sink primarily through increased solubility. The net atmospheric CO_2 increases by ~15 ppmv and this overall rise in CO_2 results in ~2°C warming in the Southern Hemisphere and shrinking sea-ice in the Southern Ocean. This sequence of events can explain important elements of the bipolar temperature seesaw identified in Greenland and Antarctic ice cores.

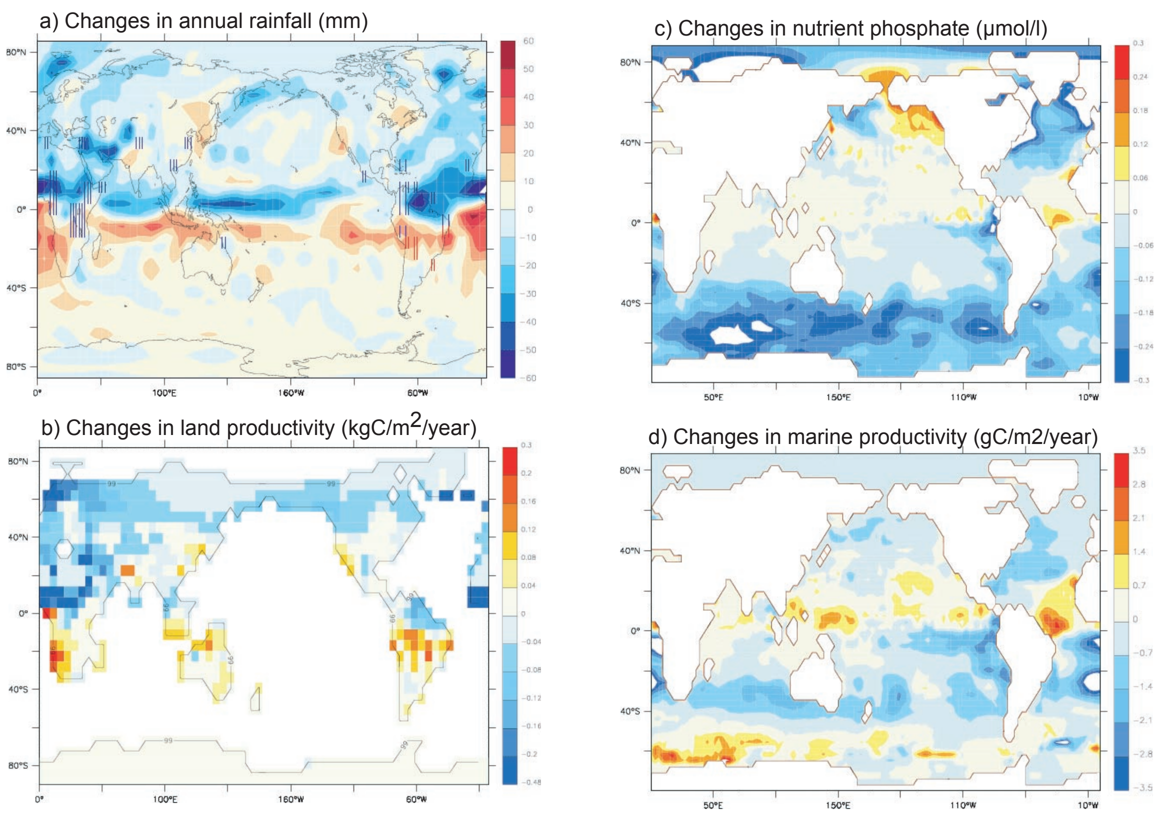


Figure 2. The climate and biosphere response in global GCMs to a shutdown of the Atlantic meridional overturning circulation (AMOC) due to a freshwater pulse. The Northern Hemisphere (NH) oceans in the mid- to high-latitudes cool, and the Southern Hemisphere (SH) oceans warm, changing the wind patterns: panel a - the ITCZ shifts southward and the NH becomes drier, and the SH becomes wetter; panel b – as a result of the change in rainfall pattern the terrestrial primary productivity and forest declines in the NH, while the primary productivity increases in the SH. These productivity changes increase atmospheric CO_2 by 15 ppmv; panel c –the collapse of the AMOC affects upwelling patterns and marine productivity; panel d - marine productivity around the equator shifts northward.

A second project on the AMOC shutdown focused on the question why in models the shutdown consistently cools the Northern Hemisphere, whereas in the high latitudes of the Southern Hemisphere, some models show warming, others cooling. To understand these conflicting outcomes, IPRC scientists (Axel Timmermann and Oliver Timm) and a colleague at the University of Bern (Thomas Stocker) conducted a set of North Atlantic freshwater hosing experiments with a comprehensive coupled climate model (CCSM3) and a coupled model of intermediate complexity: in one set of experiments, a small and globally uniform salt flux was applied at the surface in order to keep the global mean salinity constant; in the other set, no compensating salt flux was applied. The two models responded similarly: the freshwater addition induces a slowing of the AMOC, a cooling in the North Atlantic, and a warming in the South Atlantic. The compensating salt flux condition, however, causes much more widespread warming in the Southern Ocean than the uncompensated simulation. This warming is mainly due to heat transport anomalies caused by the specific parameterizations in the ocean models to represent eddy mixing. Surface salt fluxes tend to move outcropping isopycnals equatorwards. Because the density perturbation originated at the surface, changes in isopycnal slopes are generated that lead to anomalies in the bolus velocity field. The associated bolus heat flux convergence creates warming that enhances the bipolar seesaw response. The importance of this eddy-mixing mechanism is illustrated in comparisons of coupled model simulations in which this parameterization in the ocean model component is switched on or off.

Effects of Earth's orbital paths on climate. In the previous year, IPRC scientists had studied the conditions surrounding the last warming of Antarctica around 18,000 before present. Based on modeling results, they argued that warming was triggered in part by increasing Austral spring insolation and resulting sea ice shrinkage, and in part by increasing greenhouse gas concentration. This year, they expanded their study of climate effects resulting from insolation changes due to orbital cycles to the last 129,000 years (Axel Timermann and Oliver Timm). In addition to changes in the orbitally driven insolation and the atmospheric CO_2, the earth-system model LOVECLIM was driven by ice-sheet-related changes in topography and albedo as time-dependent forcing (boundary conditions). These latter changes were taken from solutions of runs with the recent IcIES ice-sheet model that were provided by partners Ayako Abe-Ouchi (CCSR, Univ. of Tokyo, FRCGC/JAMSTEC), Tomonori Segawa (FRCGC/JAMSTEC), and Fuyuki Saito (FRCGC/JAMSTEC). For this experiment, an acceleration technique was applied with a factor 20 (which compressed the 129,000 forcing history into 6450 years). The model solutions show that the precessional cycle affects the strength of monsoon systems (Figure 3). The precessional increase (decrease) in summer insolation leads to a periodic increase (decrease) in the seasonal temperature, with seasonal precipitation anomalies following the temperature changes. The precessional signals in the global monsoon circulation are negatively correlated between hemispheres, a pattern that has also been found in paleorecords of the monsoon systems in East Asia and South America. A comparison with speleothem paleo-records (proxies for the strength of the summer monsoon) indicated a remarkable agreement with our simulation.

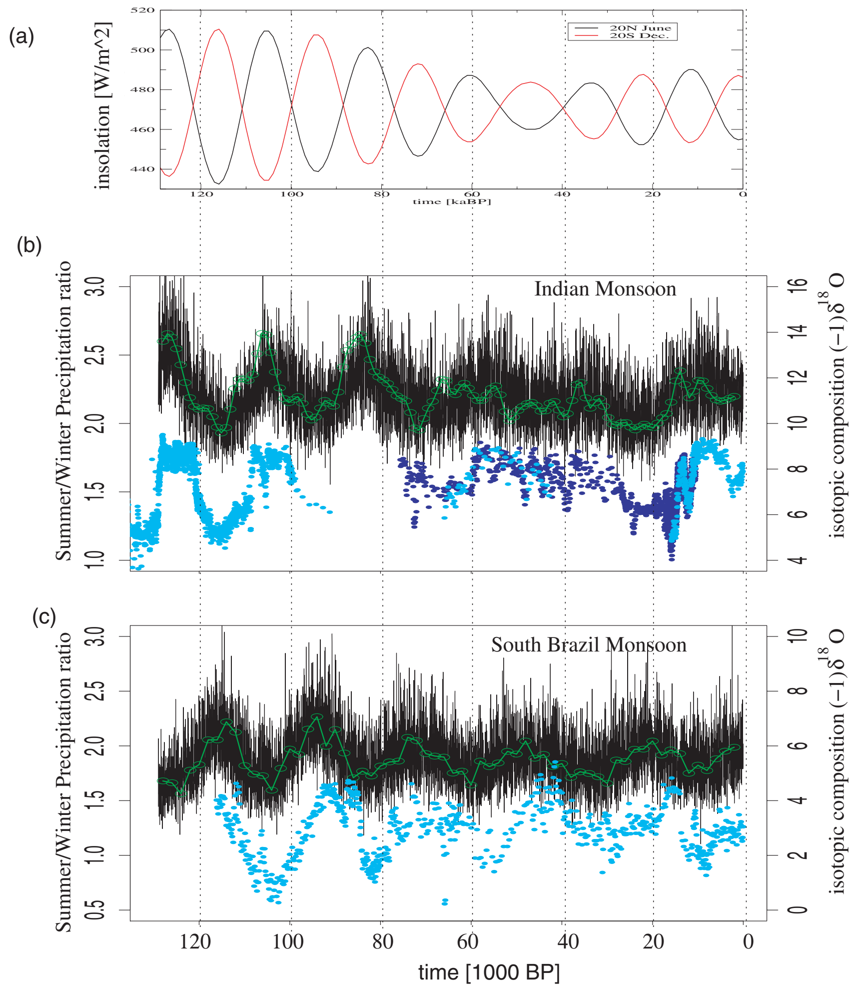


Figure 3. Simulation of Earth's orbital paths and climate effects. Panel a - top-of-atmosphere incoming solar radiation (in W/m^2) at 20°N in June (black) and at 20°S in December (red) from 129,000 years before present (BP) to present. Panel b - Indian Monsoon seasonality index (ratio of June–November/December–May precipitation). The indices based on seasons for the accelerated 129,000-year simulation are shown in black. The open green circles represent 10-year averages. The speleothem $\delta^{18}O$ records from Hulu Cave (blue; from Wang et al., 2001, 2005) and Dongge Cave (cyan; from Dykoski et al., 2005) are shown as a qualitative comparison between model and proxies. Panel c - South Brazil Monsoon seasonality indices together with the speleothem proxy record from Botuvera (cyan; from Cruz Jr. et al., 2005). Open green circles indicate the 10-year averages of December–May/June–November precipitation ratio. Note that all isotope records have been multiplied by (−1).

ASIA-PACIFIC DATA-RESEARCH CENTER (THEME 5)

The amount of atmospheric and oceanographic data available to study Asia-Pacific climate problems has increased dramatically over the last decade, owing to the successful outcomes of recent international observational programs and to advances in satellite technology and modeling capability. Further observational programs, both satellite and *in situ*, are currently being implemented and will result in another major increase in data and products. Despite the availability, however, the data and data-products are often underused by researchers and the broad user community. This is largely because much of the data is difficult to access. The Asia-Pacific Data-Research Center (APDRC) was established within the International Pacific Research Center (IPRC) at the University of Hawai'i in 2001, with a vision to link data management and preparation to research within a single center and to provide one-stop shopping of climate data and products to the research community and the general public.

This past year, the APDRC operated and continued to develop its web-based, integrated Data Server System, provided a global data base and data management for climate data and products, and developed and served new climate-related products for research and applications users.

The Data Server System

The APDRC data server system is designed to provide the following: web-based browsing and viewing capabilities for both gridded and non-gridded (*in situ*) data sets and products; easy access for downloading data in their original formats and in user-friendly and assimilation-friendly formats; and easy access to desktop tools for powerful display and analysis of data and products on the client's computer.

This past year, the APDRC continued to maintain its three main servers, the Live Access Server (LAS), OPeNDAP, and EPIC. Upgrades to these servers were made in close collaboration with their developers at NOAA/PMEL and the OPeNDAP consortium. One such upgrade is the use of THREDDS, an OPeNDAP tool developed at Unidata, to aggregate remote-access data sets (Figure 1). The APDRC now maintains two additional servers, TSANA (developed last year) and DAPPER/DCHART (implemented this year). The TSANA server allows users to query the *in situ* database for subsets by time and/or space and to download requested data sets. The DAPPER/DCHART was developed at PMEL and allows OPeNDAP connection and display of *in situ*, station data.

The APDRC completed its transition to a Linux-based server system and is now in the process of configuring the old, Solaris-based machine as a back-up system. Two additional disk arrays were purchased and configured, bringing the total APDRC storage to 24TB on each machine. Finally, the APDRC assisted in the establishment of similar server systems at the South China Sea Institute of Oceanology, the University of Tokyo for the MEXT/K7 project, and the Pacific Islands Applied Geoscience Commission (SOPAC).

Data Management

During the past year, the APDRC data archives increased in size mainly as a result of daily downloads of high-resolution, global ocean model output from the Navy Layered Ocean Model (NLOM). These downloads include daily output from a real-time simulation as well as four weekly data sets from a forecast simulation. Other major increases were due to several new products from the Ocean Model for the

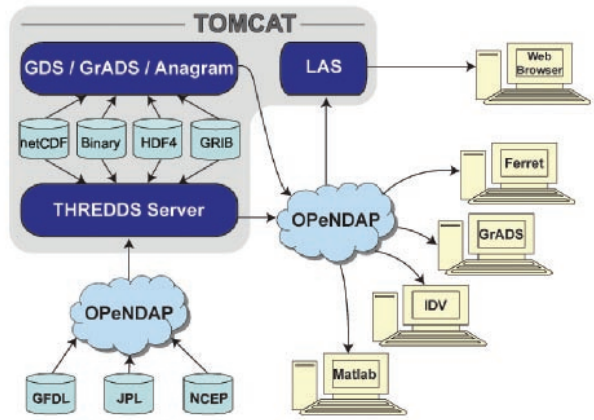


Figure 1. Example of the THREDDS server functions: NCEP runs a numerical model of the atmosphere every day and places the output files on its OPeNDAP server. These files use the date as the file name and may further exist in separate directories for different years, or model runs. Formerly, if a user wanted to make a time series of the model results, he would have had to load separately each file for each day. Using THREDDS, the APDRC can concatenate these files in a virtual sense, and the user needs to process only a single file to get the time series. The APDRC can also use THREDDS to present the data in a meaningful way, for example through the data search tool, or directly through the LAS server for web-based plotting.

Earth Simulator (OFES) and the acquisition of output from high-resolution atmospheric models of the Hawaiian Islands. This latter data set will be used, among other things, to force a high-resolution ocean model (described in the next section). Of the 14TB of data archived by the APDRC, 50% is taken up by OFES, 14% each is occupied by the Hawai‘i atmospheric model output, NLOM, and iROAM; 8% is taken up by all remaining data sets. Upgrades to the APDRC web pages this year include new, consistent documentation pages for all on-line datasets, and updates to the projects page. The projects page lists a brief description of the projects that the ADPRC supports, along with direct links to them (http://apdrc.soest.hawaii.edu/projects). Most of last year's effort was again spent in support of NOAA's Pacific Regional Integrated Data Enterprise (PRIDE), the Earth Simulator Center (ESC), and the Pacific Argo Regional Center (PARC). These are just three of the projects listed on the APRDC projects page.

Applied Research: Product Development and Distribution

This activity of the APDRC deals with developing research data-products useful to the climate-research community. Projects are identified in collaboration with our partner institutions. Beginning in 2005, we worked closely with the NOAA PRIDE team to identify and produce new integrated data products for both climate research and applications. The following sections describe PRIDE activities and other such projects.

PRIDE Projects. The NOAA PRIDE team, formed in March 2004, is led by the National Climate Data Center (NCDC). PRIDE's vision 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." The intent of PRIDE is to leverage activities such as those of the APDRC with other ongoing NOAA and other federal government activities in the Pacific region in order to create more integrated data and information service products for the region's users. The APDRC supports PRIDE by maintaining a web-page portal for integrating NOAA data activities in the Pacific. The link to the PRIDE site is: http://apdrc.soest.hawaii.edu/PRIDE.

Two years ago, an informal request by NOAA to develop integrated data products led to several proposals that came from investigators at the University of Hawai‘i and that were included as new tasks within the APDRC. The following projects were supported: (1) Development of Seasonal

Precipitation Prediction Maps for Pacific Islands, (2) Development and Improvement of High-Resolution Weather Models and Products for the Hawaiian Islands, (3) Global Warming Effects on Extreme Weather Events in Hawai'i, (4) A Nearshore Ocean Modeling Tool for Ecosystem Research and Environmental Impact Assessment for Islands in the Pacific Region, (5) Analysis of Extreme Events and Trends in Pacific Ocean Water Level Data, (6) High-Resolution Atmospheric and Surface Wind Stress/Thermal Fluxes Products for the Hawaiian Islands and the Surrounding Oceans, (7) Construction of a Nested Regional Climate Modeling System for Hawai'i, (8) Development of an Integrated Data Product for Hawai'i Climate. Two papers have been submitted (Xin Zhang, et al., 2007; Yang Yang et al., 2007); some products are described on the PRIDE website.

As a result of the September 2004 PRIDE meeting at the East-West Center in Honolulu, several possible infrastructure-building activities were identified within the Pacific Islands nations to which the APDRC could contribute. One task was to work with the Pacific Islands Global Ocean Observing System (SOPAC) staff in Fiji to implement a regional data server in order to identify and overcome data and product transfer difficulties resulting from low-bandwidth service in many island regions, and to demonstrate to SOPAC users the usefulness of available application products. During 2006, the APDRC purchased, configured, and installed a server in Fiji. The server was set up with data sets that can be expanded depending upon future needs.

New ocean product obtained from Argo floats. During 2006, the APDRC released a new product, YoMaHa, as a technical report and data set in "Velocity data assessed from trajectories of Argo floats at parking level and at the sea surface" (Hiroshi Yoshinari et al., 2006). These global velocity estimates covering the past several years were derived from the Argo float trajectory files. Although these individual profiles have been available from the Global Data Assembly Centers, an easily accessible, global dataset in user-friendly format has not.

GODAE. The Global Ocean Data Assimilation Experiment (GODAE) Strategic Plan and the GODAE Implementation Plan call for "GODAE Product Servers" to assist with the distribution of GODAE data and products. The APDRC is such a GODAE Product Server, providing a broad range of research and applications based on satellite and model-derived products.

APDRC staff members have participated in the US GODAE Steering Team Meetings and the GODAE 2nd Symposium, at which the APDRC activities and plans in support of GODAE were presented. Moreover, the APDRC showcased itself at the Spring 2006 Ocean Sciences Meeting, at the NOAA/OCO annual review in May 2006, and at the August 2006 GODAE Global intercomparison project meeting in Reading, United Kingdom.

Regional modeling. The goal of this activity is to establish ocean and atmosphere nowcast and forecast systems for the Pacific Islands. These systems are downscaled from coarser global operational systems by using output from the global systems for initial and lateral boundary conditions. The Hawaiian Islands are the initial focus, with the intent to apply the methodology to other island settings in the Pacific. Three regional atmospheric models, the MM5, WRF and the IPRC Regional Atmospheric Model, have been selected for this activity. These models produce near-real-time atmospheric variables as well as surface wind stress and thermal fluxes for driving ocean models.

For the ocean part, APDRC scientists have implemented the Hybrid Coordinate Ocean Model (HYCOM) for the Hawai'i region in collaboration with the HYCOM Consortium. The basin-scale 0.08° resolution HYCOM has been downscaled to a 0.04° regional domain that encompasses the major Hawaiian Islands. Hindcast simulations have been run to test the procedures and to incorporate high-resolution bathymetry and wind products. Particle tracking tools have also been implemented in the down-scaled HYCOM to study dispersion characteristics of the region. These tools are useful for search and rescue operations, tracking oil spills and pollutant discharges, as well for determining larval dispersion and fish population replenishment around the Hawaiian Islands.

Most recently, HYCOM has been further downscaled from the 0.04° Hawai'i region to a 0.01° single island domain (O'ahu). At 0.01°, the near-shore eddy features are enhanced as shown in Figure 2. In addition, the Princeton Ocean Model (POM) has been implemented for Kāne'ohe Bay (O'ahu) as a PRIDE project, and this bay-scale POM makes use of the flow field from the 0.01° HYCOM as lateral boundary conditions. In summary, this progressive downscaling allows the capability of large-scale operational systems to be extended to near-shore areas where human activities are most concentrated.

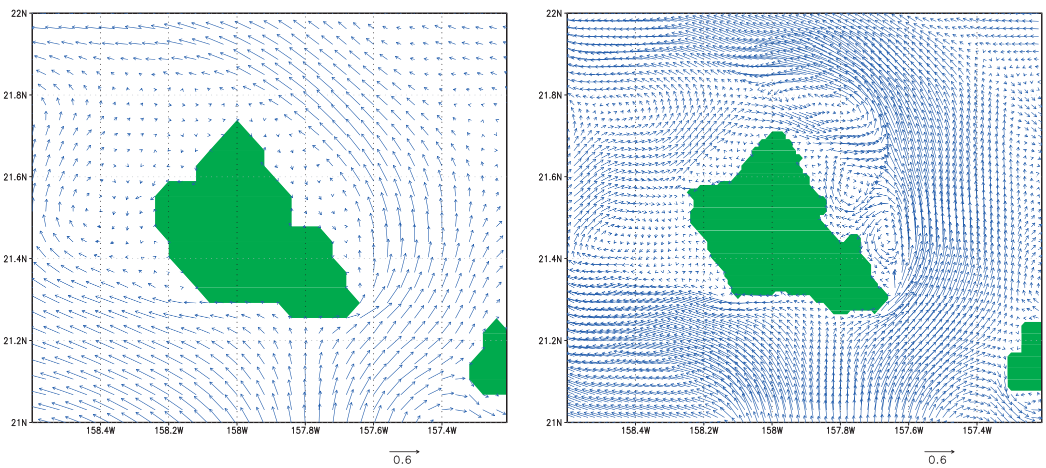


Figure 2. HYCOM simulation snapshots of mixed layer velocity (blue arrows in m/s) around the Island of O'ahu: left panel - 0.04° resolution plot; right panel - 0.01° resolution plot. In the high-resolution plot, vectors are plotted on every second model grid points for clarity. Note the small-scale eddy features along the east shore of the island in the 0.01° simulation.

As part of the APDRC's GODAE activity, output from the assimilative global HYCOM at near-real time will be available for use with the downscaled Hawai'i regional models. A near-real time ocean nowcast and forecast system is, thus, within sight. On a longer term, a coupled system is envisaged, combining the HYCOM and the IPRC Regional Atmospheric Model.

Data rescue and quality control. The overall goal of this activity has been to help produce high-quality, quality-controlled data sets of temperature, T(z), and salinity, S(z), profiles for the entire historical data acquisition period (the 20th century), which can then be easily used by the numerical modeling community in support of GODAE and other climate modeling and prediction activities. The APDRC began this activity through collaborations with CSIRO in Australia, and Woods Hole Oceanographic Institute; it has also been collaborating with National Oceanographic Data Center on Global Temperature and Salinity Profile Program (GSTPP). Accomplishments include: 1) the completion by CSIRO scientists (through a subcontract from the APDRC) of quality control of the historic T(z) data set for the Indian Ocean through 2000; and 2) completion by APDRC scientists, in collaboration with NODC, of quality control of T(z) data for the Pacific Ocean for 2000 – 2002.

Regional Coordination and Activities

Participation in the Pacific Argo Regional Center. Almost 3000 Argo floats are now reporting ocean conditions (temperature and salinity) in near-real time. These data are transmitted to two global data assembly centers and nine national centers. The Argo program is setting up procedures to combine, compare, and create products from Argo-float data for specific ocean regions. The APRDC has been active in setting up the Pacific Argo Regional Center (PARC) and has participated in several Argo-related meetings this year: the Fourth PARC Meeting, the Argo Trajectory Meeting, and the Sixth Argo Data Management Meeting. At the PARC meeting, the APDRC, together with JAMSTEC, Japan Meteorological Agency, Korea Ocean Research and Development Institute, and other Pacific oceanographic institutes, determined the Pacific region's needs for Argo data, products, and applications.. At the Argo Trajectory Meeting in South Korea, the APDRC featured its new Argo product YoMaHa05.

SOPAC partnership. As part of its work with NOAA, the APDRC has been providing data to communities in the South Pacific through the Pacific Islands Applied Geoscience Commission (SOPAC). The commission is an intergovernmental, regional organization dedicated to promoting sustainable development in its member countries, which include nearly all the South Pacific Island nations: American Samoa, Australia, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, New Zealand, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu. SOPAC's work is carried out through its Secretariat based in Suva, Fiji.

Bandwidth limitations had restricted serving many of the larger APDRC data sets to SOPAC members. In September 2006, the APDRC, therefore, installed in Fiji a stand-alone server, essentially a single computer having all the functions of the APDRC machines but serving only a subset of the available data. The APDRC is working with SOPAC members to determine which data sets and products are most useful to these island nations, and will help to keep these data sets up-to-date.

SCSIO Partnership. As part of IPRC's new partnership with the South China Sea Institute of Oceanology (SCSIO) in Guangzhou, China, the APDRC helped to set up data servers on the SCSIO machines in November 2006. The OPeNDAP server was set up for gridded products to serve SCSIO model outputs; the DAPPER/DCHART was set up as an *in situ* data server, giving the institute a platform by which it can integrate its own datasets into publicly available datasets (such as the World Ocean Database and Argo).

Participation in the Ocean Observing System. The ocean component of the international effort to monitor and understand the global climate system is the Global Ocean Observing System (GOOS), and the U.S. is contributing to this effort through the Integrated Ocean Observing System (IOOS). Both GOOS and IOOS have regional subdivisions, with PI-GOOS and PacIOOS representing the Pacific region for the international and the U.S. efforts, respectively.

An APDRC member is serving on the PI-GOOS Steering Committee and participated in the PI-GOOS Steering Committee Meeting that took place in Honiara on the Solomon Islands. The PacIOOS effort consists largely of serving integrated climate data for the Pacific region, and the APDRC is at the forefront of this activity.

Collaboration with Bishop Museum's Science on a Sphere. The Bishop Museum in Honolulu has installed one of the NOAA Science on a Sphere exhibits. Animated images of atmospheric and oceanic data can be projected on the sphere to show complex environmental processes. The APDRC has been working with the museum exhibit to generate animations from APDRC's large holding of global climate data for the sphere-display. For instance, for the opening of the exhibit, APDRC had made animations of global mean surface temperatures, precipitation, and ice-cover from four different IPCC model runs.

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Yang, B., Y. Wang, and B. Wang: The Effect of internally generated inner-core asymmetries on tropical cyclone potential intensity. *J. Atmos. Sci.*, IPRC-435.

Yoshimori, M., C.C. Raible, T.F. Stocker, and M. Renold: On the interpretation of low-latitude hydrological proxy records based on Maunder Minimum AOGCM simulations. *Climate Dynamics*, IPRC-381.

Zhang, X., T. Li, F. Weng, C.-C. Wu, and L. Xu: Reanalysis of western Pacific typhoons in 2004 with multi-satellite observations. *Met. and Atmos. Phys.*, IPRC-434.

THE YEAR'S SEMINARS

Date	Speaker	Affiliation	Title
03/28/2007	Hans Huang	Danish Meteorological Institute, Copenhagen, Denmark	*4-Dimensional Variational (4D-Var) data assimilation for the Weather Research and Forecasting model (WRF) model*
03/21/2007	Gary Geernaert	Institute of Geophysics and Planetary Physics, Los Alamos National Laboratory, NM	*Advances in similarity turbulence theory for air–sea fluxes*
03/14/2007	Norbert Schorghofer	Institute for Astronomy, University of Hawai'i	*The ice ages of Mars*
03/07/2007	Qinghua Ding	Department of Meteorology, University of Hawai'i	*Intraseasonal teleconnection between extratropical wavetrain and Indian summer monsoon*
03/06/2007	Raghu Murtugudde	ESSIC/DAOS, University of Maryland, MD	*Urban water harvesting and rural watershed management through agrohorti-forestry*
03/05/2007	Ping Chang	Department of Oceanography, Texas A&M University	*Internal Atmospheric Variability, Pacific Meridional Mode and ENSO*
02/28/2007	DaNa L. Carlis	Howard University, Washington, DC	*Numerical simulation of the diurnal variation of the Maui Vortex and island-scale airflow under summer trade-wind condition*
02/22/2007	Seita Emori	Climate Risk Assessment Research Section, National Institute for Environmental Studies, Tsukuba, Japan	*Dynamic and thermodynamic changes in mean and extreme precipitation under changed climate*
02/20/2007	Bill Kuo	Mesoscale Prediction Group, NCAR/MMM, and COSMIC Program Office, University Corporation for Atmospheric Research, Boulder, CO	*Early Results from the COSMIC/FORMOSAT-3 Mission*
02/15/2007	Dudley Chelton	College of Oceanic and Atmospheric Sciences, Oregon State University, OR	*Global observations of westward energy propagation in the ocean: Rossby waves or nonlinear eddies*
02/14/2007	Dudley Chelton	College of Oceanic and Atmospheric Sciences, Oregon State University, OR	*The impact of SST specification on surface winds in the ECMWF operational model, with evidence for SST influence on tropospheric winds*
02/07/2007	Jin-Song von Storch	Max Planck Institute for Meteorology, Hamburg, Germany	*Towards climate prediction: Gain in predictability due to increase in CO2 concentration as diagnosed from an ensemble of AO-GCM integrations*
02/02/2007	In-Sik Kang	Seoul National University, Seoul, Korea	*High-resolution climate modeling*
02/02/2007	Yign Noh	Yonsei University, Seoul, Korea	*Large eddy simulation (LES) of the ocean mixed layer and its application*
01/31/2007	Hans von Storch	Institute for Coastal Research and Meteorological Institute, University of Hamburg, Germany	*Assessing present and future coastal risks - the CoastDat Project for the NE Atlantic and first results for the SE Asian region*

Date	Speaker	Affiliation	Title
01/29/2007	Jeff Yin	National Center for Atmospheric Research, Boulder, CO	*The Influence of Low-Frequency and Synoptic Variability on Extreme Wind Events*
01/26/2007	Jim O'Brien	Florida State University, FL	*A modern history of equatorial oceanography*
01/25/2007	Tangdong Qu	IPRC	*South China Sea Throughflow*
01/25/2007	Tetsuzo Yasunari	Hydrospheric Atmospheric Research Center, Nagoya University and JAMSTEC Hydrological Cycle Research Program, Japan	*Propagating diurnal disturbances (PDD) over the maritime continent associated with the MJO*
01/24/2007	Kerry Emanuel	Massachusetts Institute of Technology, MA	*The hurricane embryo*
01/22/2007	Michael McIntyre	Department of Applied Mathematics and Theoretical Physics, University of Cambridge, UK	*Multiple Jets, Beta turbulence and the Phillips Effect*
01/18/2007	Axel Timmermann	IPRC	*Dynamics and Impacts of a weakened Atlantic meridional overturning circulation*
01/17/2007	H. Annamalai	IPRC	*Southwest Indian Ocean - Additional source for regional and global climate predictability*
01/16/2007	Shinichiro Kida	IPRC	*The effect of the Mediterranean overflow on the general circulation in the Atlantic*
01/12/2007	Masahiro Watanabe	Environmental Earth Science, Hokkaido University, Japan	*Inter-basin coupling and a birth of the equatorial warm pool*
12/18/2006	Jerry Meehl	National Center for Atmospheric Research, Boulder, CO	*Effects of black carbon aerosols on the Indian monsoon*
12/08/2006	Motoki Nagura	JAMSTEC Institute of Observational Research for Global Change, Yokohama, Japan	*Pausing mechanism of transition from La Nina to El Nino: A view from observational heat balance in the mixed layer from 1999 to 2002*
12/05/2006	Tomoe Nasuno	JAMSTEC Frontier Research Center for Global Change, Yokohama, Japan	*Development of the Nonhydrostatic Icosahedral Atmospheric Model (NICAM): Global 3.5-km mesh experiments*
12/01/2006	Albert J. Gabric	Environmental Sciences, Griffith University, Nathan, Australia	*The influence of the 2002/03 Australian dust storm season on phytoplankton growth and CO2 draw-down in the Southern Ocean (135-150E)*
11/28/2006	Hisayuki Kubota	JAMSTEC Institute of Observational Research for Global Change, Yokosuka, Japan	*Seasonal variations of precipitation properties associated with the monsoon observed over the Republic of Palau in the tropical western Pacific*
11/22/2006	Joshua Xiouhua Fu	IPRC	*Impacts of air–sea coupling on the monsoon intraseasonal oscillation: Model study and satellite observations*
11/09/2006	Akihiko Shimpo	Japan Meteorological Agency, Tokyo, Japan	*Comparison of climate sensitivity over land and ocean, and impact of cloud schemes on the climate sensitivity*

Date	Speaker	Affiliation	Title
11/08/2006	Tsutomu Takahashi	IPRC	*Electrical Sprites and Jets in the Atmosphere*
11/02/2006	Wolf Grossmann	Germany GKSS Research Center Geesthacht, Germany	*Hyperbolic growth of human knowledge - implications for living, jobs, science, universities, and nations*
10/27/2006	Greg Holland	National Center for Atmospheric Research, Boulder, CO	*Changing characteristics of Atlantic hurricanes*
10/18/2006	Ingo Richter	IPRC	*Controlling the strength of the South Atlantic anticylcone in austral winter - a GCM study*
09/27/2006	Shang-Ping Xie	IPRC and Meteorology Department, University of Hawai'i	*The Indian Ocean: An emerging active player in climate variability*
09/20/2006	Hiroaki Ueda	University of Tsukuba, Tsukuba, Japan	*Formation, fluctuation and projected future change of the Asian Monsoon*
09/08/2006	Satish R. Shetye	National Institute of Oceanography, India	*Convection and SST gradients in the Bay of Bengal*
09/06/2006	Yuqing Wang	IPRC and Department of Meteorology, University of Hawai'i	*TRMM Observations and a regional model study of tropical precipitation diurnal cycle*
09/05/2006	Satish R. Shetye	National Institute of Oceanography, India	*Local and remote wind forcing of the West India Coastal Current: An empirical study*
08/30/2006	Takeaki Sampe	IPRC	*Importance of midlatitude oceanic frontal zones for the general circulation of the atmosphere*
08/22/2006	Dongchull Jeon	Korea Ocean Research & Development Institute, Ansan, Korea	*Hydrography and bottom current measurements in the Bismarck Sea*
08/09/2006	Teruyuki Nakajima	Center for Climate System Research, University of Tokyo, Japan	*A study of the effects of air pollution on the earth's climate using climate modeling and satellite remote sensing*
08/04/2006	Ole Peters	Santa Fe Institute, NM & UCLA, CA	*The geometry of rainfall*
08/03/2006	Alan Robock	Department of Environmental Sciences, Rutgers University, New Brunswick, NJ	*Climatic response to high-latitude volcanic eruptions*
08/01/2006	Alan Robock	Department of Environmental Sciences, Rutgers University, New Brunswick, NJ	*Climatic effects of regional nuclear conflict*
06/26/2006	Mark Baldwin	Northwest Research Associates Bellevue, WA	*The stratosphere and climate*
05/24/2006	Tony Song	Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA	*Representing satellite-observed ocean-bottom-pressure and SSH in Non-Boussinesq oceans*
05/11/2006	Akimasa Sumi	Center for Climate System Research, University of Tokyo Japan	*A new initiative for sustainable sciences at the university of Tokyo*
04/21/2006	Michael Alexander	NOAA Earth System Research Laboratory, Boulder, CO	*Pacific decadal variability in a physical-ecosystem ocean model*

Date	Speaker	Affiliation	Title
04/20/2006	Thomas Stocker	Climate and Environmental Physics, University of Bern, Switzerland	*Latest results from the EPICA ice cores: Greenhouse gas records and bipolar seesaw*
04/19/2006	Saji Hameed	IPRC	*Role of air–sea interaction in the Madden-Julian Oscillation*
04/18/2006	Shoshiro Minobe	Graduate School of Science, Hokkaido University, Sapporo, Japan	*Gulf stream influence on the atmosphere*
04/13/2006	Chris Bretherton	Department of Atmospheric Sciences, University of Washington, Seattle, WA	*Improving AGCM simulations of boundary layer clouds and their feedbacks on climate sensitivity - A climate process team approach*
04/12/2006	Chris Bretherton	Department of Atmospheric Sciences, University of Washington, Seattle, WA	*New insights into cumulus parameterization from a simulation of a transition from shallow to deep cumulus convection*
04/04/2006	Stephan Kempe	Institute for Applied Geosciences, Technische Universitaet Darmstadt, Darmstadt, Germany	*The Caldera Lakes of Niuafo'ou: Its stromatolites and what they tell us about the evolution of ocean chemistry*

LUNCHEON DISCUSSIONS

Date	Speaker	Affiliation	Title
March 6, 2007	Markus Jochum	National Center for Atmospheric Research, Boulder, Colorado	*ENSO mechanisms in the new CCSM*
February 20, 2007	Shoshiro Minobe	Hokkaido University, Sapporo, Japan	*Deep penetration of Gulf Stream influence to the troposphere: A synthesis of satellite observation, operational analysis and AGCM*
January 19, 2007	Wen Chen	Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China	*Modulation of Northern Hemisphere wintertime planetary wave activity - East Asian climate relationships by the Quasi-Biennial Oscillation (QBO)*
January 18, 2007	Markus Jochum	National Center for Atmospheric Research, Boulder, Colorado	*From equatorial mixing to Hawaiian Rainfall: Tropical instability waves as an example of multiscale interaction*
December 21, 2006	Ernesto Munoz	Earth System Science Interdisciplinary Center, University of Maryland, College Park, Maryland	*The Caribbean low-level Jet: Seasonal structure and summer interannual variability*
December 7, 2006	Tomoe Nasuno	Frontier Research Center for Global Change, JAMSTEC, Japan	*Large-scale tropical convective disturbances in a cloud-resolving aqua planet experiment*
November 21, 2006	H. Annamalai	IPRC	*Current climate conditions in the tropical oceans and their possible local and remote impact*
November 20, 2006	Elodie Martinez	IPRC	*Circulation of thermocline waters in the Exclusive Economic Zone of French Polynesia from satellite data and from a numerical regional ocean modeling system*
November 15, 2006	Sachiko Yoshida	Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Fukuoka, Japan	*Numerical experiments for global barotropic ocean variability induced by surface disturbances*
October 27, 2006	Jianyin Liang	Guangzhou Tropical Marine Meteorology Institute, Guangzhou, China	*The predictable pattern of precipitation in the Asian-Australian region revealed by the NCEP Coupled Forecast System*
July 26, 2006	Takuji Waseda	University of Tokyo, Tokyo, Japan	*Freak waves: myths, science and engineering*
April 11, 2006	Zuojun Yu	IPRC, University of Hawai'i	*The South China Sea Throughflow--Connecting the Pacific and Indian Ocean*
April 6, 2006	Thomas Stocker	University of Bern, Bern, Switzerland	*The global signature of abrupt climate change: seesaws and other beasts*

WORKSHOPS AND CONFERENCES

Date	Title
03/19 – 03/21/2007	CLIVAR Asian-Australian Monsoon Panel, Eighth Meeting
02/12/2007	Mini-workshop on Satellite Data Analysis
01/22 - 01/26/07	GEWEX (Global Energy and Water Experiment) - 19th Scientific Steering Group Meeting
11/15 – 11/17/2006	Multidecadal to Centennial Global Climate Variability
10/30 – 11/02/2006	Federal Advisory Committee Meeting: CCSP Synthesis and Assessment Product 3.3
09/06/2006	Mini-Symposium on Indian Ocean Research at the IPRC
08/09/2006	Climate Feedback Festival
05/8 – 05/9/2006	Sixth Annual IPRC Symposium
04/12/2006	The IPRC Mini-Workshop on Climate Process Studies

IPRC VISITING SCHOLARS

The IPRC has a visiting scholar program. From April 2006 to March 2007, the following scholars visited the IPRC for one week or longer.

Date	Name	Affiliation
03/27/07–03/31/07	Xiang Yu Huang	University Corporation for Atmospheric Research
03/03/07–03/07/07	Raghuram Murtugudde	University of Maryland
02/19/07–02/23/07	Shoshiro Minobe	Hokkaido University, Sapporo, Japan
02/15/07–02/26/07	Chung-Kyu Park	APEC Climate Center, Busan, Korea
02/12/07–02/23/07	Yoshinori Sasaki	Hokkaido University, Sapporo, Japan
02/12/07–02/17/07	Dudley Chelton	College of Oceanic and Atmospheric Sciences, Oregon State University
01/28/07–02/28/07	In-Sik Kang	Climate Dynamics Laboratory, Seoul National University, Seoul, Korea
01/27/07–02/10/07	Byong-Kwon Moon	Climate Dynamics Laboratory, Seoul National University, Seoul, Korea
01/27/07–02/10/07	Jong-Ghap Jhun	Climate Dynamics Laboratory, Seoul National University, Seoul, Korea
01/21/07–01/31/07	James O'Brien	Florida State University, Tallahassee, Florida
01/18/07–04/19/07	Fei Huang	Ocean University of China, Qingdao, China
01/16/07–02/20/07	Jin Son von Storch	GKSS Research Center, Germany
01/16/07–02/20/07	Hans von Storch	GKSS Research Center, Germany
01/08/07–05/08/07	Markus Jochum	National Center for Atmospheric Research, Boulder, Canada
01/03/07–01/27/07	George Boer	Canadian Centre for Climate Modelling and Analysis, Victoria, British Columbia
12/03/06–12/09/06	Tomoe Nasuno	JAMSTEC Frontier Research Center for Global Change, Yokohama, Japan
11/28/06–12/09/06	Yi Hanse	APEC Climate Center, Busan, Korea
11/01/06–01/31/07	Wen Chen	Chinese Academy of Sciences, Beijng, China
10/26/06–10/31/06	Jianyin Liang	Institute of Tropical and Marine Meteorology
10/01/06–09/30/07	Hisayuki Kubota	JAMSTEC Institute of Observational Research for Global Change, Yokosuka, Japan
09/07/06–03/03/07	Hiroaki Ueda	Tsukuba University, Tsukuba, Japan
09/03/06–09/10/06	Shetye Satish	National Institute of Oceanography, Goa, India
09/02/06–09/16/06	Mingyu Zhou	National Centre for Marine Environment Forecast, Beijing, China
08/24/06–08/31/06	Xiaosu Xie	Jet Propulsion Laboratory, Pasadena, California
08/03/06–08/14/06	Ole Peters	University of California, Los Angeles, California
08/01/06–07/31/07	Chi-Cherng Hong	Graduate School of Environmental Education, Taipei Municipal University of Education, Taiwan
04/25/06–06/07/06	Lingling Xie	Physical Oceanography Laboratory, Ocean University of China, Qingdao, China
04/11/06–04/15/06	Chris Bretherton	University of Washington

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	$1,819,000	10/01/06 - 9/30/07
JAMSTEC YR 10 (2006 – 2007)	J. McCreary	JAMSTEC	$2,316,000	04/01/06 - 3/31/07
Support of Research at the International Pacific Research Center	Not applicable	*University of Hawai'i	$480,370	04/01/06 - 03/31/07
Data-Intensive Research and Model Development at the International Pacific Research Center	J.P. McCreary, S.P. Xie, & P. Hacker	NASA	$1,000,000	03/01/07 - 02/29/12

* 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
Collaborative Research: Decadal Coupled Ocean-Atmosphere Interactions in the North	N. Schneider	NSF	$72,365	03/01/07 - 02/28/10
Dynamics of Boreal Summer Intraseasonal Oscillation	B. Wang & X. Fu	NSF	$167,641	03/01/07 - 02/29/08
Acceleration of the Last Glacial Termination Due to Climate-Carbon Cycle Feedbacks	A. Timmermann	NSF	$42,465	02/01/07 - 01/31/08
Western Pacific Tropical Cyclone Reanalysis with the NRL Atmospheric Variational Data Assimilation System (NAVDAS)	T. Li & X. Zhang	ONR	$105,957	01/01/07 - 12/31/08
Using a Digital Filter As a Weak Constraint in WRF 4D-VAR	T. Li & X. Zhang	NCAR	$105,816	11/01/06 - 01/31/08
Collaborative Research: Origin, Pathway and Fate of Equatorial 13°C Water in the Pacific	T. Qu & I. Fukumori	NSF	$486,210	09/01/06 - 08/31/09
Dynamics of Tropical Cyclone Intensity Change	T. Li	ONR / NRL	$42,000	09/01/06 - 08/31/09
Sensitivity of MJO to the CAPE Lapse Time in the NCAR CAM 3	B. Wang	P. Liu	$25,000	09/01/06 - 08/31/07
Using Climate Information to Identify Coral Communities That Are Positioned to Survive Global Climate Change	A. Timmermann	NOAA / Nature Conservancy	$55,000	07/01/06 - 07/31/07
The Atmospheric Response to Ocean Heat Flux Convergences	N. Schneider	UCSD / Scripps	$51,327	07/01/06 - 04/30/07
Orographically Induced Ocean-Atmosphere Interaction: Satellite Observations and Numerical Modeling	S.P. Xie	NASA	$248,162	06/15/06 - 06/24/10
Further Testing and Evaluation of Code Coupling Methodologies and Application of a Leading Coupling Framework to Atmospheric and Oceanic Models	T. Li, X. Zhang & Y. Jia	DOD-PET / MSU	$93,500	06/01/06 - 05/31/07
Effects of the Stratospheric Quasi-biennial Oscillation on Seasonal Predictability of Tropospheric Circulation in the Northern Hemisphere Extratropics	K. Hamilton	NOAA-CLIVAR	$166,355	06/01/06 - 05/31/09
APCC Multi-Model Ensemble Seasonal Prediction System Development	B. Wang, I.S. Kang & J. Shukla	APCC	$167,617	05/15/06 - 06/30/07

Title	PI and Co-PIs	Agency	Amount	Period
Collaborative Research: Eddy Dynamics and Impacts of Low Frequency Variations in the California Current System	N. Schneider	NSF	$193,340	03/01/06 - 02/28/09
Validation of Alternating Sonal Jets Detected in Satellite Altimetry Using In-Situ Observations	N. Maximenko	NSF	$170,147	02/15/06 - 01/31/08
Tropical Cyclone Genesis and Sudden Changes of Track and Intensity in the Western Pacific	B. Wang, T. Li & Y. Wang	ONR	$643,500	01/01/06 - 09/30/08
Modeling the Flow and Larval Dispersal around the Hawaiian Archipelago	K. Richards	NOAA	$24,819	07/13/05 - 03/31/07
Ship-board Atmospheric Sounding over the Kuroshio Extension: A Supplement to CLIVAR KESS	S.P. Xie & B. Qiu	NSF	$219,707	04/01/05 - 03/31/08
Kuroshio Extension System Study (KESS) -Yr 3	B. Qiu, P. Hacker & F. Mitsudera	NSF	$168,000	11/01/05 - 10/31/06
A Technology Evaluation of Climate, Weather, and Ocean Code Coupling Methodologies and Future Requirement Analysis	T. Li	GSA	$56,949	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 - 06/30/07
Climate Prediction and its Societal Application	B. Wang, I.S. Kang, J. Shukla & L. Magaard	KMA	$289,005	04/01/05 - 06/30/06
Development of an Integrated Data Product for Hawai'i Climate	S.P. Xie, Y.-L. Chen & J. Hafner	NOAA	$102,000 **	07/01/05 - 06/30/07
Roles of Ocean Atmosphere-Interaction in Seasonal and Interannual variation of the Atlantic ITCC	S.P. Xie	NOAA	$244,990	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	$148,130	01/01/05 - 02/14/08
Predictability and Diagnosis of Low Frequency Climate Processes in the Pacific	N. Schneider	Dept of Energy	$150,002	09/15/04 - 09/15/08
Analysis of Climate Change in Korea and East Asia Area and Study of the Atmospheric and Ocean Effects	B. Wang	Yonsei University	$149,199	06/01/04 - 03/31/08
Study of Processes Leading to Tropical Cyclone Intensity Change	Y. Wang	NSF	$278,840	10/15/04 - 09/30/08
Predictability and Diagnosis of Low Frequency Climate Processes in the Pacific	N. Schneider	Dept of Energy	$150,002	09/15/04 - 09/14/08
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 Intraseasonal Oscillation	X. Fu, B Wang, & X. Xie	NASA	$272,333	06/01/04 - 05/31/08
Dynamics of Boreal Summer Intraseasonal Oscillation	B. Wang, T. Li & X. Fu	NSF	$452,166	10/01/03 - 09/30/06
Mixing in the Equatorial Pacific: The Role of Interleaving	K. Richards & J.P. McCreary	NSF	$346,315	09/01/03 - 08/31/07
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 - 12/31/07
A Numerical Investigation of the Dynamics of the Subsurface Countercurrents	Z. Yu	NSF	$364,992	03/15/03 - 02/28/07
Upwelling and Its Influence on the Sea Surface Temperature off Java and Sumatra	T. Qu	NASA	$348,592	01/07/03 - 01/31/07
Application of Comprehensive Global Models to Problems in the Dynamics of the Troposphere and Stratosphere	K. Hamilton	NSF	$322,809	09/01/02 - 05/31/08

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

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