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School of Ocean and Earth Science and Technology

South China Sea Takes Center Stage

At the Fourth Annual Symposium of the International Pacific Research Center, several researchers presented their recent findings on South China Sea climate. A group has now formed under the leadership of IPRC's **Tangdong Qu** to coordinate the research in this important climate region. The following pages feature the discovery of how the play among winds, ocean, and the Annamese Cordillera in Indochina results in an unusual cooling of the South China Sea during midsummer, and the search for an oceanic link that conveys El Niño's signal to the South China Sea.

Figure 1. Map of the region around the South China Sea: White to light blue denotes the continental shelf (depth < 200 m) and the red line, Admiral Zheng's voyage to the Indian Ocean.

Satellite Images Reveal a Dynamic South China Sea

Linking the Indian and the North Pacific oceans, the South China Sea has been an important sea lane for over thousand years. It formed part of the "oceanic Silk Road" on which Marco Polo returned from China to Venice in 1292–1295. The Chinese Admiral Zheng He's legendary fleet of 27,000 men and over 200 ships sailed seven times during 1405–1433 through the sea into the "West Ocean" (the Indian Ocean), reaching India and even East Africa (Figure 1).

Climatically, the South China Sea is part of the Indo-Pacific warm pool that anchors the strong atmospheric convection of the rising branches of the Walker and the global Hadley circulations. It is the moisture source for rain in southern China in spring and summer and for coastal Vietnam in fall and winter; it is a monsoonal sea, with winds and ocean currents reversing direction during the year. Admiral Zheng understood this reversal well 600 years ago, waiting to leave China during the winter northeasterlies and returning during the summer southwesterlies.

Today a half billion people live along the coast of the South China Sea with its fisheries and other important resources. Despite the region's economic and climatic importance, observations of this sea have been sparse, the few ships traveling the sea at any one time taking only limited surface measurements. The resolution of nearly all the popular climatic datasets is therefore too coarse (about 200 km) for close study of this sea. Satellite remote sensing, especially use of cloud-penetrating microwave sensors with resolutions of about 25 km, however, now make possible a detailed study of the South China Sea and other marginal seas smaller than 1000 km. Taking advantage of this emerging opportunity, IPRC scientists are coming to understand this sea's climate better.

One discovery occurred while **Gordon Xie** from the South China Sea Institute of Oceanology (SCSIO) was visiting the IPRC and conducted a satellite study of the summer South China Sea with **Shang-Ping Xie** (co-leader of the Indo-Pacific Ocean Climate research at the IPRC). Together with **Dongxiao Wang** (SCSIO) and **Tim Liu** (NASA Jet Propulsion Laboratory), they set out to explain the seasonal upwelling that takes place off the Vietnamese coast and spreads eastward into the South China Sea, resulting in unusual cooling in midsummer. Previous studies had failed to determine whether this was a typical summer phenomenon and what caused the offshore cold filaments that extend for more than 1000 km over the ocean. Analyzing a suite of images by the QuikSCAT, Tropical Rain Measuring Mission, European Remote Sensing, and TOPEX/Poseidon satellites, the researchers found

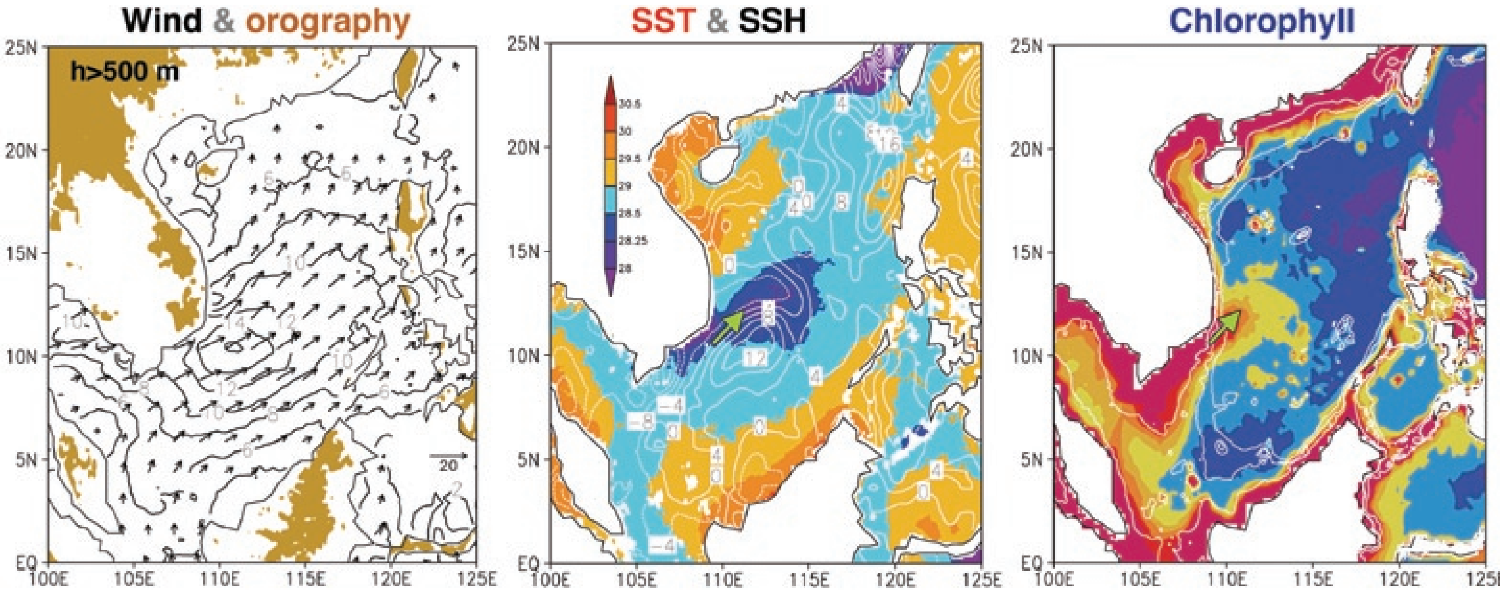

Figure 2. Summer climatology over the South China Sea. From left, wind stress vectors and land orography (brown > 500 m); SST (color bar in ºC) and sea surface height deviation from the annual mean (cm); chlorophyll concentration (high values red, low values blue and purple) and 50-, 200-, and 500-m-depth contours. Green arrows in the middle and right panels indicate the offshore jet that advects cold and nutrient-rich upwelled water from the coast.

that the Annamese Cordillera affects the winds along Indochina's eastern coast, causing the upwelling filaments. Blocked by this coastal range, about 1 km high, the southwest monsoon accelerates at its southern tip, forming a strong offshore wind jet (Figure 2). This jet upwells coastal water; Ekman downwelling on the southern flank of the wind jet forces a stationary oceanic anticyclonic eddy east of Saigon. Reaching 50 cm/s, the offshore jet of the eddy draws in the cold, upwelled water from the coast and spreads the cooling. The wind jet also cools the ocean offshore through strong evaporation and open-ocean Ekman upwelling on its northern flank.

This sequence of events happens each summer except during unusual climate conditions in the Pacific. For instance, in 1998, an El Niño year, little midsummer cooling took place. A statistical analysis shows that the extent of the cooling is affected by sea surface temperature (SST) in the eastern equatorial Pacific six months earlier.

This study, thus, casts the mountain range's blockage of the monsoon as the cause of the cooling along the coast and the open sea, with conditions in the eastern equatorial Pacific modulating the mountains' effect. Recently Gordon Xie obtained a grant from the Natural Science Foundation of China to study further the South China Sea upwelling and the remarkable eddy.

Another noteworthy South China Sea climate feature occurs in winter, when the northeast monsoon dominates the sea. Markedly cool SST (<28°C) stretches toward the equator (Figure 3, page 4). Over the cool ocean south of Vietnam, atmospheric convection is suppressed. Analyzing satellite data, Shang-Ping Xie and his colleagues (**Qinyu Liu** and **Xia Jiang** of Ocean University of China, and Tim Liu of JPL) discovered a surprising reason for this cold tongue: ocean bottom topography. An extensive continental shelf (Sunda Shelf) lies south of Indochina, with a deep basin that reaches in places a depth of more than 4000 m to the east (Figure 3). In response to the cyclonic winter monsoon, the steep shelf break along 108°E steers a southward jet as a western boundary current. Flowing up to 50 cm/s (as determined from calculations using satellite altimetry observations), this swift current draws in cold water from the northern South China Sea, where the chill and dry continental air cools the warm ocean. A close look shows that the center of the cold tongue is systematically displaced to the west of the southward ocean jet, something that Xie and colleagues attribute to the advection by a shallow westward Ekman current that flows to the right of the prevailing winds in the Northern Hemisphere. Over the deep eastern basin, a broad northward-moving current which is part of the same cyclonic gyre, advects warm water from the south. As a result, large SST gradients develop in the east-west as well as the north-south direction.

During and following an El Niño (which tends to peak in December), the winter and summer monsoons both weaken, causing the ocean circulation to spin down. As a result, the winter cold tongue and the summer upwelling filaments are weaker or disappear altogether. Such changes in ocean circulation, in turn, affect SST and the monsoon. Indeed, SST varies the most from one winter to the next south

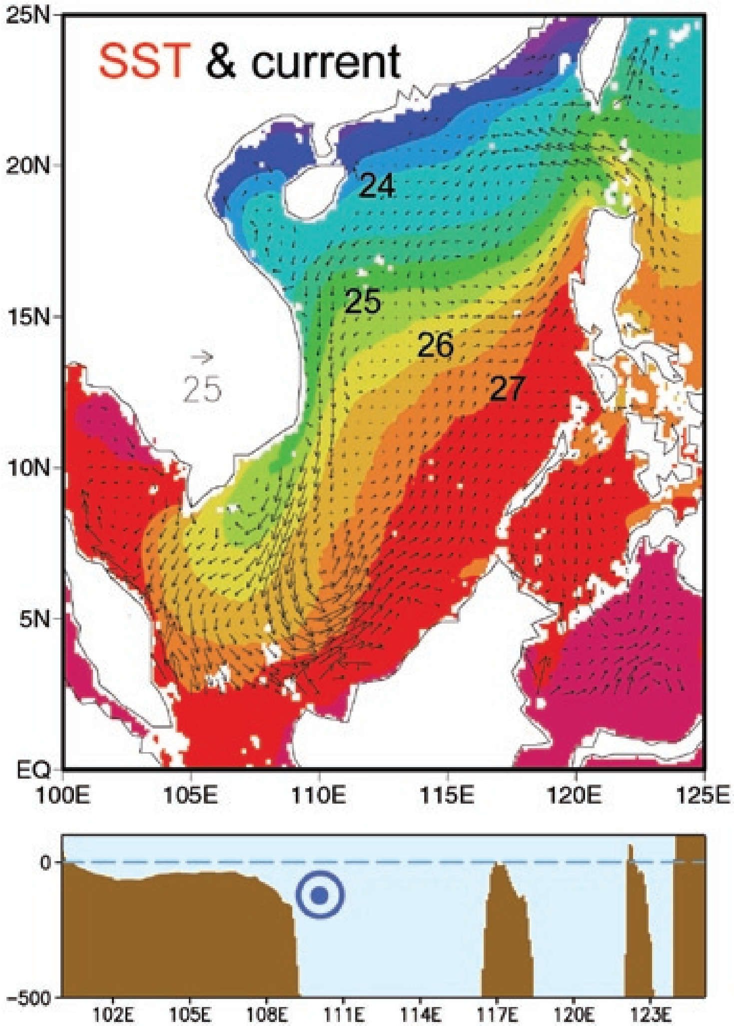

Figure 3: (Top) Winter climatology with SST (color in °C) and surface geostrophic current vectors (cm/s); (bottom) bathymetry (m) along 7° N. The steep continental break steers a southward jet in the upper ocean.

of Vietnam and from one summer to the next east of South Vietnam. Both regions have strong seasonal ocean jets, and their SSTs correlate highly with El Niño as measured by an SST index in the eastern Pacific.

In modeling its SST variations, scientists have often treated the Indo-Pacific warm pool as a motionless mixed layer 50 m deep. The above studies, however, reveal a highly dynamic South China Sea circulation that affects SST greatly and has an atmospheric teleconnection from the Pacific El Niño contributing to its interannual variations.

Variations in Pacific climate may also be communicated to this sea by oceanic pathways such as the water exchange through the Luzon Strait. In the next section, IPRC scientists explore this communication pathway.

Anthropogenic increase in atmospheric carbon dioxide is contributing to global warming. Moreover, the amount and types of nutrients discharged by rivers are changing the physics and biology of marginal seas around the world. A better understanding of the dynamics of South China Sea climate and its interaction with the larger-scale ocean-atmosphere system would be a significant step toward tackling difficult issues of the climate variability and climate change in such regions. The complex bathymetry and dynamic nature of the circulation in the South China Sea require, however, studies with high-resolution models and comparisons of their solutions with satellite images in order to project how climate may change in this important sea. The next step is now to synthesize the various research approaches described above and in the next section by using a regional ocean-atmosphere model, such as the IPRC Regional Atmospheric Model.

Does an Oceanic Pathway Transmit El Niño's Signal to the South China Sea?

Although South China Sea climate is part of the East Asian monsoon system, evidence is mounting that the El Niño–Southern Oscillation (ENSO) in the Pacific affects also this sea. The transmission of this signal has been sought mainly in atmospheric data. For example, the work of **Bin Wang**, co-leader of IPRC's Asian-Australian Monsoon System research team, and his colleagues showed that during and after the mature phase of El Niño, an anomalous anticyclonic circulation over the Philippine Sea cools the sea surface of the western North Pacific and warms that of the South China Sea.

Tangdong Qu, with colleagues at IPRC and elsewhere, is exploring an oceanic connection: the transport of water through the Luzon Strait between Taiwan and the Philippines. This connection is well known, but how transport through the straits affects South China Sea's climate has not been studied in detail.

The Luzon Strait transport is formed by a branch of the Kuroshio. Once this water has passed through the strait into the South China Sea, it becomes part of a cyclonic circulation in the northern basin (Figure 4). In their 2004 study, **Max Yaremchuk** and Qu used a 3-dimensional variational data-assimilation technique to diagnose the mean seasonal cycle of the circulation east of Luzon. They found that in late fall–early winter, in response to the general upward Ekman pumping resulting from the monsoon winds east of Luzon, the Kuroshio becomes weaker, allowing deeper penetration and larger transport through the Luzon Strait (Figure 5). After entering the South China Sea, the relatively warm Kuroshio waters are drawn into the cyclonic circulation in the northern part of the basin. Numerical simulations show that it takes approximately 5–6 months for a water parcel to travel from northern Luzon to the region east of Vietnam (Figure 4). Increased monsoon winds in October–January, therefore, may increase the upper-layer heat content east

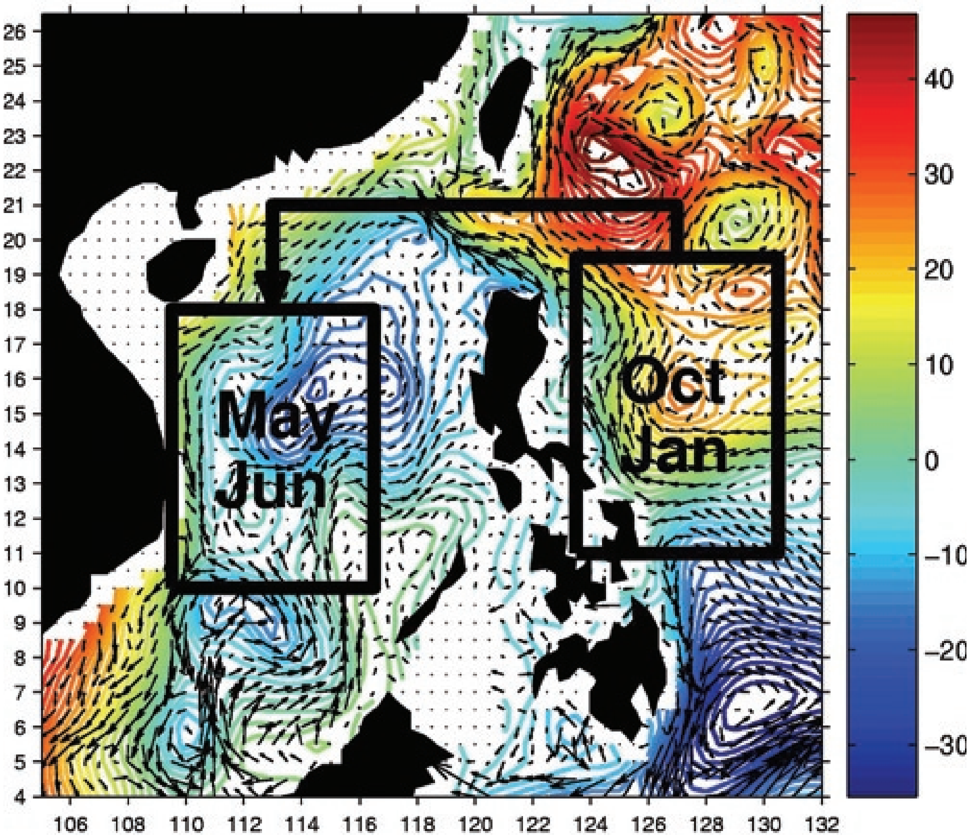

Figure 4. Mean January sea surface height (color) and currents at 30-m depth in the 6-year OFES model simulation. Black rectangles show the regions of late fall–early winter monsoon forcing of the Kuroshio (right) and the sea surface temperature response during late spring–early summer (left).

of Vietnam the following May–June and may affect the development of the summer monsoon over the South China Sea.

To verify this hypothesis, Yaremchuk and Qu studied the effect of transport variations through the Luzon Strait on the SST and upper-layer heat content in the region shown in the left box of Figure 4. First, they analyzed statistically long-term numerical model runs of the circulation and characteristics of the South China Sea and found that December transport variations and subsequent June SST east of Vietnam are significantly correlated. Then using a numerical simulation that captures more realistically the South China Sea seasonal cycle, they reconstructed the seasonal cycle by assimilating climatological variational data into a regional South China Sea model that was controlled by open boundaries and surface forcing. In the model solution, they assessed the sensitivity of SST to the transport by computing the derivative of the mean May–June SST east of Vietnam with respect to the magnitude of inflow velocities in the Luzon Strait during the preceding months (Figure 6). These computations support the result from the statistical analysis of the long-term numerical simulations and give an estimate of the impact of the Luzon Strait transport on SST in terms of the local heat-flux anomalies: 1 Sv increase in transport during November–January is equivalent to a 2 W/m^2 increase in surface heat flux during the development of the summer monsoon the following May–June. Since the October–January transport through the strait correlates positively with the winter monsoon wind forcing east of the Philippines, the transport may account for the negative correlations seen not only between the SSTs but also between the winds in the two regions. Indeed, they noted these negative correlations in independent sets of monthly averaged anomalies of ocean surface characteristics during May–June east of Vietnam and during the previous October–January east of the Philippines

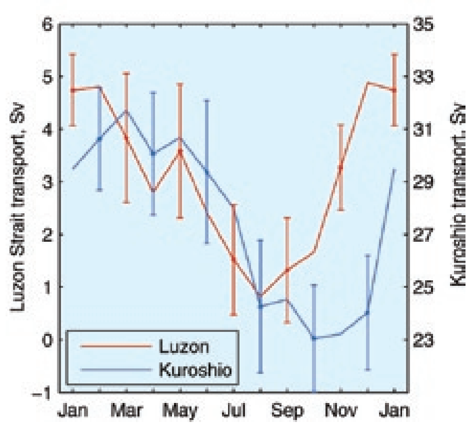

Figure 5. Mean annual cycle of the Luzon Strait and Kuroshio transports obtained by a 3-dimensional diagnostic analysis of climatological data (Yaremchuk and Qu, 2004).

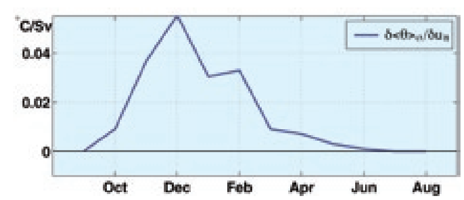

Figure 6. Time evolution of the derivatives of the mean SST $<\theta>_\sigma$ with respect to the Luzon Strait transport temperature averages. The $<\theta>_\sigma$ are defined as the mean values from end of April to end of May over the region in the left rectangle in Figure 4.

(Figure 7). Thus, the heat transported through the Luzon Strait during late fall–early winter seems, indeed, to affect the South China Sea monsoon the following summer.

In a related study, Qu and his colleagues (2004) analyzed results from the JAMSTEC model and found that the Luzon transport tends to be greater during El Niño years and lesser during La Niña years. Being associated with variations in the Kuroshio transport east of Luzon, these interannual variations appear to be driven by hysteresis of the Kuroshio. The correlation between the transport and the Southern Oscillation Index (SOI) reaches 0.63 (Figure 8). El Niño and La Niña also leave strong signatures in the upper-layer (0–400 m) heat content of the South China Sea. Thus, in the summer following an El Niño, the heat content in the upper layer of the South China Sea increases owing to increased Luzon Strait transport, which could have been one of the reasons why the midsummer cooling in the South China Sea during the 1998 was much weaker (p. 3).

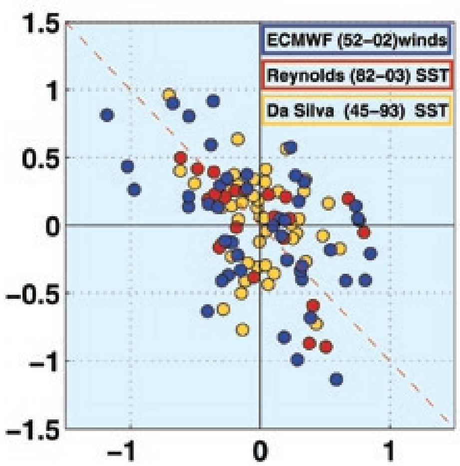

Figure 7. Scatter plot of the monthly averaged observations east of Vietnam in May–June and east of the Philippines in the preceding October–January. Observations cover 1952–2003 (ERA40 winds, in m/s), 1946–1992 (Da Silva SST in °C), and 1982–2004 (Reynolds SST in °C). The axes are in °C for SST and in m/s for wind.

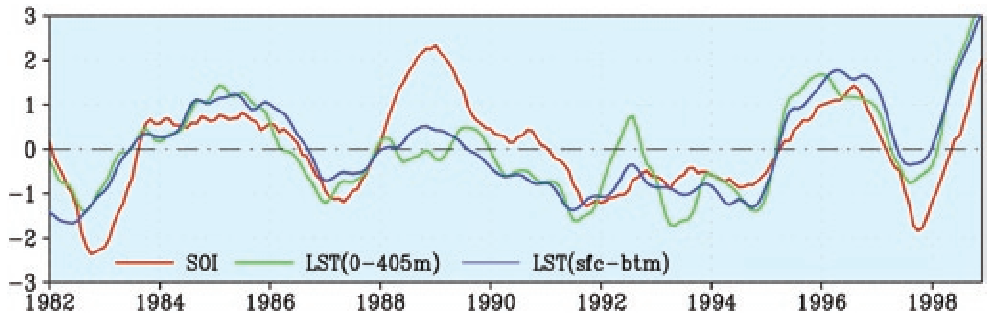

Figure 8. Interannual variations in Luzon Strait transport and the Southern Oscillation Index normalized by their respective root mean square variance from the JAMSTEC model (after Qu et al., 2004).

Given this evidence that transport through the Luzon Strait is capable of transmitting seasonal and interannual large-scale ocean-atmosphere phenomena from the western Pacific to the South China Sea, IPRC scientists are now determining in detail how this transport affects the dynamics of South China Sea climate.

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Explosive Volcanic Eruptions and the Atmosphere

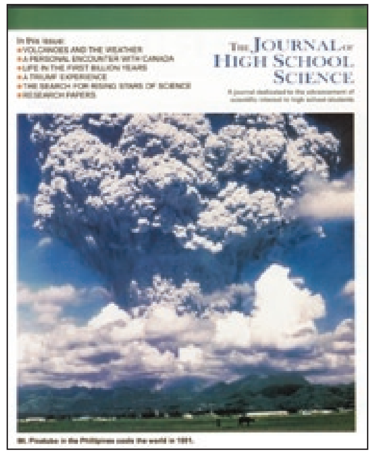
A Personal Reflection by Kevin Hamilton

The energy generated by radioactive decay inside the earth is eventually released to the atmosphere through various geothermal processes. On rare occasions, some of this energy is released in extremely brief and powerful explosive volcanic eruptions, sometimes called **Plinian eruptions** after the Roman naturalist **Pliny the Elder**, who perished studying the great eruption of Mt. Vesuvius in 79 AD. Plinian eruptions are devastating, the hot gases, debris falls, and tsunamis often killing many people.

The abruptness and enormous dynamical and chemical effects of such eruptions, however, also make them natural experiments that can be studied to elucidate important aspects of atmospheric behavior. Recently I was asked to write a cover article on "Volcanoes and the Weather" for the *Journal of High School Science*, a Canadian journal aimed at a worldwide audience of high school students (Hamilton, 2004). This invitation led me to reflect on how much meteorologists have learned through studying the aftermath of major eruptions, and on my own engagement with several very different aspects of volcanic effects over my career.

Summer Cooling

My introduction to the area of volcanic effects came unexpectedly in the mid-1980s when, as a new faculty member at McGill University in Montreal, Canada, I visited the university archives to study the long, continuous record of daily weather observations taken on the McGill campus. In the archives I happened to discover two of the earliest manuscript diaries of amateur instrumental



weather observers unearthed anywhere in Canada. Most notably, I found the daily diary and weather record of **Rev. Alexander Sparks**, a clergyman living in Quebec City (47°N, 71°W) who took temperature observations at 8 a.m., noon, and 3 p.m. local time every day from December 1798 until the day of his death in March 1819. I recognized that this record included 1816, which is remembered in New England as the "year without a summer" and was famous for very cold summer weather and resulting crop failures. Coincidentally, the first thorough history of the weather in 1816 had just been published by the famous oceanographer **Henry Stommel**, with a focus on U.S. data (Stommel and Stommel, 1983). I was able to use the detailed records of Rev. Sparks, diaries from other amateur observers, and contemporary newspaper accounts to demonstrate that the anomalies seen in the United States in the summer of 1816 had clear counterparts in eastern Canada (Hamilton, 1986). The June–August 1816 mean temperatures at Quebec City were about 2°C lower than those during the previous decade. Even a heavy snowstorm was recorded on June 7, 1816—a month later than any snow accumulation at Quebec City in modern records. The following year, 1817, was also unusually cold in Rev. Sparks' observations.

Stommel and Stommel (1983) made a strong case that the climate anomalies in the summer of 1816 were geographically widespread (at least in the Northern Hemisphere) and resulted from the Plinian eruption of Mt. Tambora that had occurred a year earlier (April 1815) on the Indonesian island of Suwa. Today we know that a major explosive eruption ejects hot gases and solid aerosol material that can rise high into the stratosphere. Even the finest solid aerosol material mostly falls out over the first few weeks after the eruption, but a long-lasting effect is provided by increased sulfur content due to the stratospheric injection of sulfur dioxide. The sulfur dioxide reacts with the water vapor in the stratosphere to produce a thin layer of very small (typically <0.5 micron diameter) sulfuric acid droplets. These droplets do not settle gravitationally but remain in the stratosphere until the large-scale circulation flushes them back to the lower atmosphere, a process taking about two years. Since the aerosol layer reflects incident sunlight, we expect global-mean cooling of the lower atmosphere for the first two years following major Plinian eruptions, and that this cool anomaly may be most intense in the summer hemisphere (where the incident sunlight is strongest). This effect can be seen in the instrumental surface-air temperature record, and the spectacular Tambora eruption almost certainly caused the exceptional weather anomalies of 1816.

The Free Oscillations of the Global Atmosphere

The Tambora eruption is thought to be the largest in the last millennium in terms of total explosive power and volume of material ejected; but another very large and spectacular Indonesian eruption occurred in 1883, when the island of Krakatoa exploded. In 1815 it took several months for the world to get a clear picture of what had happened at Mt. Tambora, and little scientific investigation of the eruption's effect was conducted until the 20th century. By contrast, the existence of a world-wide telegraph network and an active international scientific community in 1883 meant that the eruption of Krakatoa was followed in near real-time by much of the world, and scientific investigation of the effects began immediately. The initial scientific studies were reviewed in *The Eruption of Krakatoa and Subsequent Phenomena*, published in 1888 by the Royal Society of London.

This report documented the propagation of a pressure (or infrasound) wave front around the world: Barographs recording pressure traces were operating at a number of observatories throughout the world. The pressure wave from the final explosion at Krakatoa was observable in all the recorded pressure traces several times at about 33-hour intervals. This was thought to indicate the passage of the wave several times around the world with a propagation speed of about 330 m/s (the circumference of the earth divided by 33 hours). The great English physicist **G.I. Taylor** showed that this was consistent with the propagation of a non-dispersive wave with properties similar to those for barotropic waves in a constant-depth fluid, and that the observations of the speed of the Krakatoa wave front pinned down the "equivalent depth" of the atmosphere (Taylor, 1929).

Half a century later, **Taroh Matsuno** combined Taylor's insight with his own classic treatment of the linear theory of planetary scale motions in the tropics (Matsuno, 1966) and showed there should be a discrete set of global normal modes or "free oscillations" of the atmosphere (Matsuno, 1980). The mode with the largest horizontal scale corresponds to an equatorial Kelvin wave and has a predicted period equal to the 33 hours observed for the passage of the Krakatoa pressure wave. Matsuno was able to show that long timeseries of atmospheric surface pressure data actually display a spectral peak around 33 hours. With my colleague **Rolando Garcia** of NCAR, I was able to follow up Matsuno's work with a more detailed investigation of the normal mode signals detectable in long surface pressure records (Hamilton and Garcia, 1986). I even speculated that similar phenomena should be observable in the Martian atmosphere. This hypothesis helped to motivate me to begin a project on modeling the Martian general atmospheric circulation when I joined the Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton in 1987. This work eventually showed that the normal mode Kelvin wave on Mars is indeed observed and is important for the Martian circulation (Wilson and Hamilton, 1996).

"History" of the Quasi-biennial Oscillation

Another chapter of the 1888 Royal Society report on Krakatoa was devoted to describing the spread of the volcanic aerosols. Colorful twilights are produced by the sun's illumination of stratospheric aerosol, and the years after major eruptions are often remembered for spectacular sunrises and sunsets. The Royal Society investigators gathered reports from such sources as ship logs, diaries, and newspaper stories of the first observations of the twilight phenomena following the eruption. This enabled them to trace the spread of the aerosol cloud over several months. Figure 9 reveals the spread during the first two weeks after the eruption. Specifically, the western boundary of the area in which the twilight phenomena were reported is plotted for each day. The prevailing wind at the altitudes where the volcanic aerosol was located must have been strong (~30 m/s) easterlies.

This was the first indication of the nature of the wind field in the stratosphere (even though the existence of the stratosphere itself was not to be discovered until 1902). Much later, modern balloon observations showed that the winds in the tropical stratosphere actually undergo a Quasi-biennial Oscillation (QBO) involving transitions between prevailing easterlies and westerlies over a roughly 27-month cycle. The existence and properties of the QBO have been well observed with regular daily balloon sonde measurements since about 1950. As a hobby over many years, I collected whatever scattered observations of winds in the tropical stratosphere in the pre-1950 period I could find. In 1998, I published a review of these early observations, including the optical observations of the strong "Krakatoa easterlies" in 1883 (Hamilton, 1998). I concluded that the QBO has been a persistent feature of the circulation since at least 1883.

Winter Warming in Northern Europe and Asia

Like most atmospheric scientists, I was fascinated by reports of the eruption of Mt. Pinatubo in the Philippines in June 1991. This was the largest eruption in terms of ejected material since Mt. Tambora. My research at the time focused on meteorology and chemistry of the stratosphere, and I recall that many of

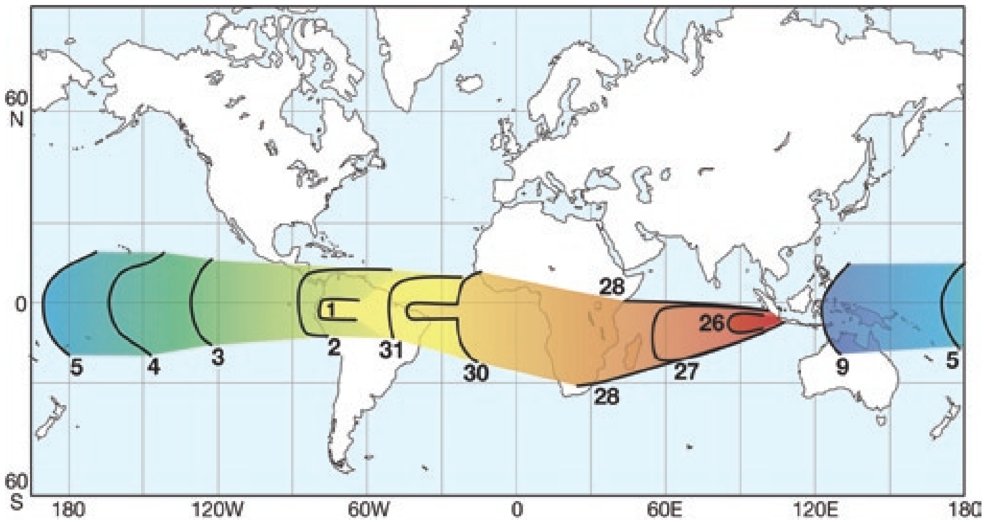


Figure 9. The black lines show the estimated western boundary of the aerosol cloud from Mt. Krakatoa on August 26, 27…September 9, 1883.

my colleagues in stratospheric science were irritated at first by the news of the Mt. Pinatubo eruption! NASA had just launched the one-billion-dollar Upper Atmosphere Research Satellite (UARS) to study stratospheric chemistry. My colleagues were unhappy that the eruption had "contaminated" the stratosphere and UARS would not measure in a clean-background stratosphere! In fact, many UARS instruments functioned for over a decade, and the Pinatubo eruption turned out to be beautifully timed for us—we could study the detailed evolution and effects of the aerosol layer in the early 1990s and then the clean stratosphere in the late 1990s when the Pinatubo aerosol had been flushed out. The satellite allowed the evolution of the aerosol layer and resulting chemical effects (the volcanic aerosol acts to catalyze ozone destruction) to be observed continuously and in three dimensions. This then set the stage for very detailed modeling of the atmospheric effects of the volcanic aerosol.

At the IPRC I have been working (with my colleagues **Georgiy Stenchikov** and **Alan Robock** of Rutgers University, and **V. Ramaswamy** of GFDL) on very sophisticated GCM simulations of the atmospheric circulation perturbation caused by the Pinatubo aerosol during 1991–94. The overall global cooling is easily reproduced in my model. More interesting to me, however, is a more subtle effect—namely the anomalously warm surface air temperatures that occurred in Northern Europe and Asia during the first two boreal winters after Pinatubo (and after most previous large eruptions). My model reproduces this winter warming (Stenchikov et al., 2002, 2004). Analysis of the simulation suggests that a downward dynamical coupling between the stratosphere (which is radiatively perturbed by the volcanic aerosol) and the lower atmosphere determines partly the geographical structure of the surface perturbation.

My work on modeling the effects of volcanic aerosol was discussed in *IPRC Climate,* Vol. 1, Fall 2001, and I wrote a review of the general issue of stratospheric dynamical influence on the troposphere for *IPRC Climate*, Vol. 2, Spring 2002. This is ongoing work, and I hope to report more results on the atmospheric effects of major volcanoes in a future issue of *IPRC Climate*.

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What's Happening at the Asia-Pacific Data-Research Center?

APDRC receives NOAA Grant

The Asia-Pacific Data-Research Center (APDRC) at the IPRC provides the research community and general public with one-stop shopping for climate data and products. The center received nearly one million dollars from the National Climate Data Center of NOAA's National Environmental Satellite, Data, and Information Service.

The grant is being used to

- expand data sets and products by increasing APDRC archives and access to data sets stored at other institutions,
- serve Global Ocean Data Assimilation Experiment products for research purposes and for practical applications,
- participate in data quality control as a regional Argo application center, and
- implement a high-resolution regional ocean model that downscales operational models for use around Hawai‘i and other Pacific Islands.

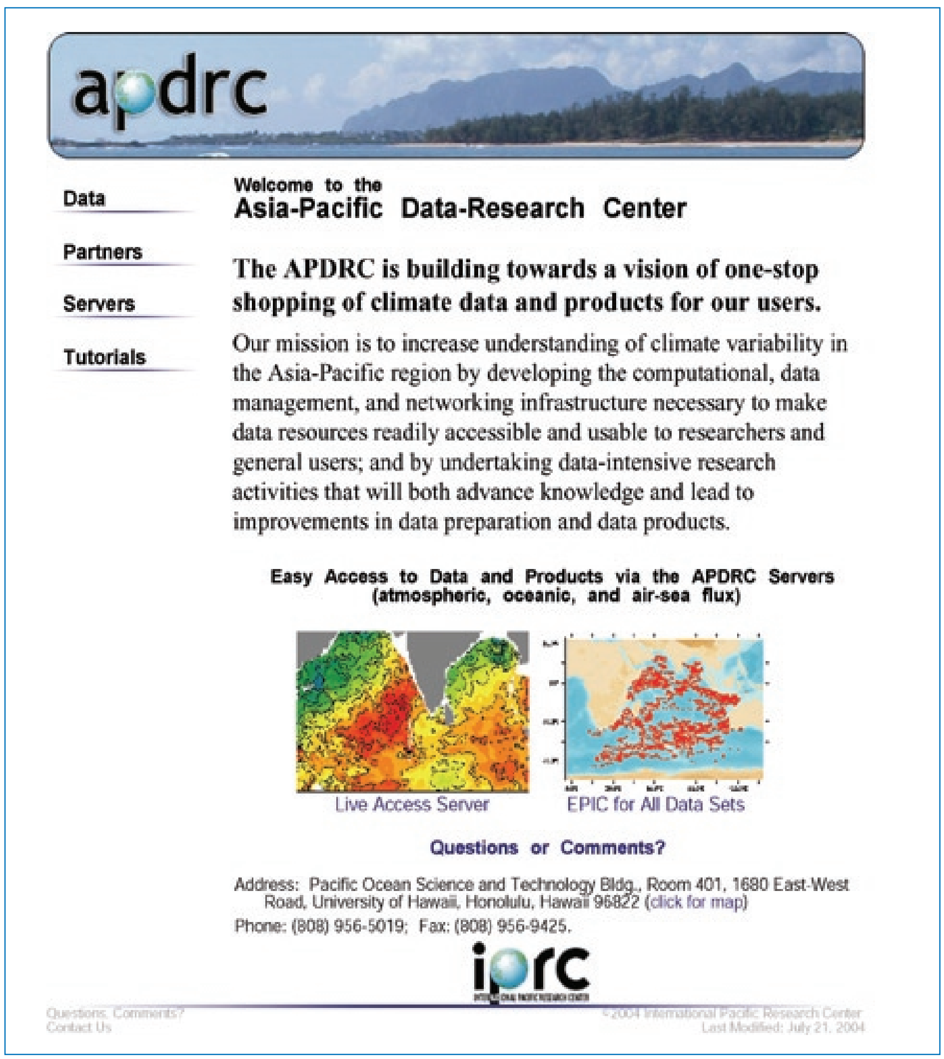
IPRC scientists help build data archives

Several IPRC scientists have been chosen to help with building the APDRC data holdings. **Jim Potemra**, as data manager, heads this activity; he is assisted in acquiring and maintaining oceanographic data by **Gang Yuan**, atmospheric data by **Yongsheng Zhang** and **Xiouhua Fu**, and air-sea flux data by **Zuojun Yu** and **Jan Hafner**. These scientists bring their research expertise to the data-acquisition effort, ensuring that the APDRC serves useful, quality data and flags problematic sets. This combination of research with data acquisition and archiving is unusual and should benefit climate research and improve the quality of the products served by the APDRC.

APDRC website changed

Much has changed and will continue to change at our APDRC website. If you go to our portal, **apdrc.soest.hawaii.edu**, this page (*below*) now welcomes you.

The **Data** link at the top left of the **Welcome** page brings you to the page that provides access to the APDRC datasets in different ways: by data, server, grid, or by variable name. We now also have links to tutorials for the various servers.



Credit for our new APDRC website appearance and structure goes to **Jim Potemra**, assistant researcher with the Regional Ocean Influences team at the IPRC. Potemra is being assisted in maintaining this website by **Sharon DeCarlo**, who recently joined the IPRC (see p. 23).

SODA POP 1.2 now available on APDRC server

***Benjamin Giese**, one of the developers of the new reanalysis of the global ocean SODA POP 1.2 (Simple Ocean Data Assimilation – Parallel Ocean Program) from the University of Maryland/Texas A&M consortium, visited the IPRC from July to December, 2004. During his stay, he worked with our scientists to make this new reanalysis available on the APDRC server, and below he describes the most important changes.*

The ocean model in SODA POP 1.2 has a much higher resolution than the previous SODA analysis. (The upcoming article by Carton and Giese 2004 in the *Bulletin of the Meteorological Society* provides details on the reanalysis). As an intermediate resolution version of the POP (Parallel Ocean Program) code developed at Los Alamos National Laboratories, this global model has 40 vertical levels, varying in depth from 10 m at the surface to 250 m in the deep ocean; a grid resolution of 0.4° longitude and 0.28° latitude; and a "displaced pole" to avoid the singularity that arises from the converging meridians at the North Pole. This change results in a complete Arctic Ocean.

The model is forced with daily averaged reanalysis winds from the European Center for Medium Range Weather Forecasts ERA-40 reanalysis spanning January 1958–2001. Surface freshwater flux for 1979–2001 is provided by a combination of the Global Precipitation Climatology Project monthly merged product and evaporation obtained using bulk formulae, which are also used for surface heat flux. Vertical mixing is parameterized using the KPP mixing formulation and biharmonic horizontal mixing coefficients.

The most important aspect of the reanalysis is the multivariate sequential data assimilation scheme, developed at the University of Maryland (Carton et al., 2000), which updates the ocean model with ocean temperature and salinity observations every 10 days. The subsurface temperature and salinity data sets consist of about 7 x 10^6 profiles. Two-thirds of the profiles have been obtained from the World Ocean Database (WOD) 2001, which has 1.7 million profiles more than the WOD98. (For further changes in WOD2001 see **www.nodc.noaa.gov/OC5/WOD01/ch98to01.html**.) Additional mixed-layer temperature observations are taken from the COADS surface marine observation set.

The SODA reanalysis includes checks for duplicate reports and for errors in the recorded position and time of observations, static stability, deviations from climatology, and checks on the temperature–salinity relationship. In spite of substantial quality control in the WOD2001, the SODA quality control (including buddy-checking, examination of forecast-minus-observation differences, and vertical stability) eliminates an additional 5% of the profiles.

Researchers at the IPRC have been using SODA POP 1.2 to study such climate features as the nonlinear dynamic heating of the El Niño-Southern Oscillation, aspects of the Indonesian Throughflow, and variations in the circulation of the subtropical cells in the Pacific.

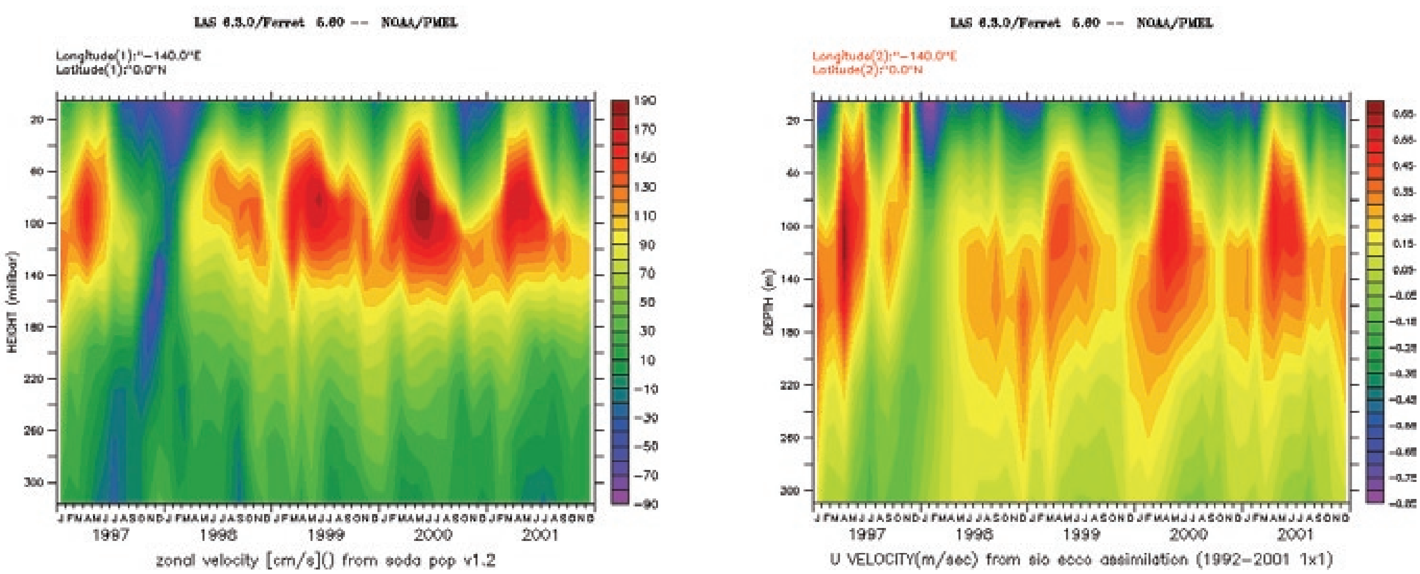


Figure 10. Zonal currents at 140°W on the equator from SODA-POP 1.2 (left panel) and from ECCO (right panel). This figure, which allows comparison of currents as described by two products, was generated using the APDRC LAS.

Interested in this reanalysis? Visit the APDRC and take a test drive of SODA POP 1.2!

APDRC becomes a GODAE product server

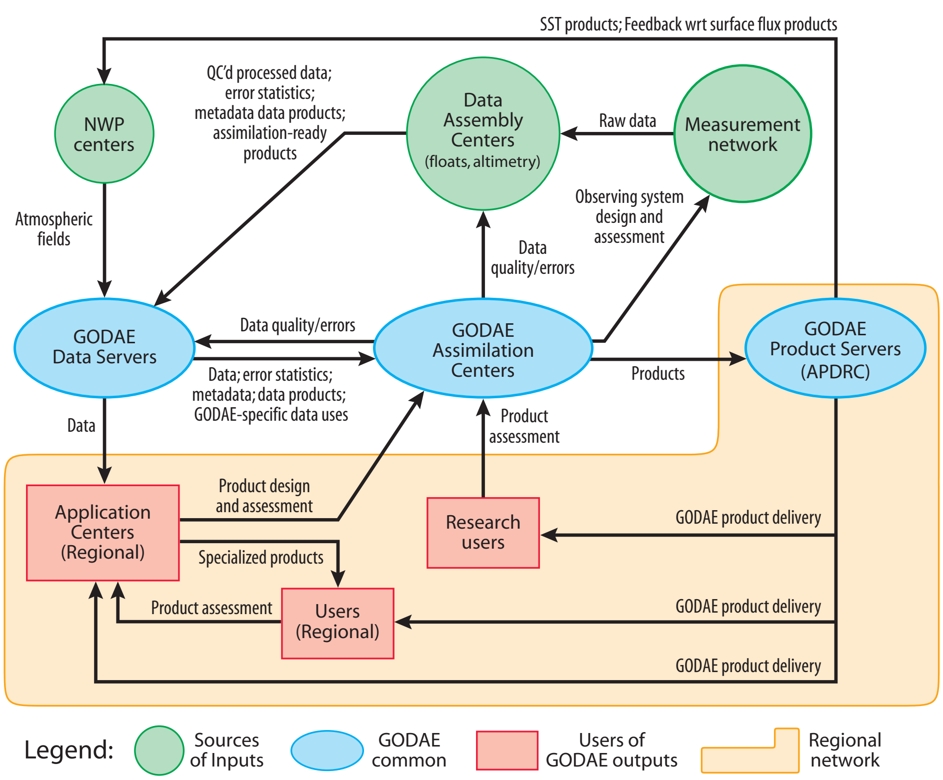
The vision of the Global Ocean Data Assimilation Experiment (GODAE) is to create "a global system of observations, communications, modeling and assimilation that will deliver regular, comprehensive information on the state of the oceans." Involving global telecommunication systems and using the newest technology, GODAE is a huge effort by a great number of international scientific teams to make ocean monitoring and prediction as routine as weather forecasting. This monitoring is to serve interests ranging from climate and climate change to such things as sea level rise, ship routing, and fisheries.

The measurement networks of GODAE include different types of satellites that remotely collect data from *in situ* measurements by Argo floats, moored buoys, tide gauges, and ships, and model-based products from numerical weather prediction centers. Gathered by various national data centers, the data is sent on to the two GODAE Data servers: the US GODAE Real-time Data Server in Monterey (established by the Navy Fleet Numerical Meteorology and Oceanography Center, FNMOC) and the French Coriolis Center (established by the French Research Institute for Exploitation of the Sea, IFREMER). This means massive amounts of information are being collected, ranging from raw instrument data (level 0), to data products that often take the form of a homogeneous gridded field or model assimilation products, to products derived from further processing (level 4).

Having completed the conceptual (1998–99) and development (2000–02) phases, GODAE is now in its operational demonstration phase and making its products available to the public. The APDRC is a designated product server and is already serving several GODAE products.

These products are available on our GDS, the server that combines the Grid Analysis and Display System with the Distributed Ocean Data System for formatting oceanographic data. We are also serving GODAE products on our Live Access Server (LAS), the server that has become the main medium for serving GODAE data because it provides maximum control over data flow. Users can obtain precise subsets of variables, eliminating the transfer of large volumes of superfluous data that is typical of "data push" systems, and users can chose the format in which they get the data, many of the historical format dependency issues having been resolved. LAS users can get an integrated view of real-time, recent-past, and archived data.

Aside from being a GODAE product server, the APDRC is taking part in two other GODAE related activities: application of the HYCOM model to shores surrounding the Pacific Islands, and participation as an Argo regional application center.



The APDRC role as a GODAE product server.

A high-resolution ocean model for the Pacific Islands

The Hybrid Coordinate Ocean Model (HYCOM) fulfills the GODAE objectives of giving users a three-dimensional depiction of the ocean state at fine eddy-resolving resolution in real time and of providing boundary conditions for coastal and regional models so that these models can be used for ocean forecasting as well as research. The improved open-ocean nowcasts and forecasts will be applied, among other things, to search and rescue operations, ship routing, tracking icebergs and major pollutants, and to commercial fisheries. Originally developed at the University of Miami, HYCOM is a model that is isopycnal in the open, stratified ocean, yet reverts smoothly to a terrain-following coordinate model in shallow coastal regions, and to a z-level coordinate model in the mixed layer or unstratified seas.

Yanli Jia (see p. 24) is working with IPRC scientists **Maxim Yaremchuk**, **Jim Potemra**, and **Peter Hacker** and with scientists at the National Research Laboratory Stennis Space Center to implement the HYCOM for the ocean around the Hawaiian Islands. The first test run is being completed just as this issue goes to press. The team will make use of existing ocean measurements to evaluate the model's ability to produce known features of the circulation around the Hawaiian Islands. They expect the complex ocean bathymetry, from deep ocean to shallow shelf, and the open boundaries on all sides to be challenges.

From left (seated) Ruth Curry and Ann Gronell; (standing) Mark Ignaszewski. Charles Sun, Taiyo Kobayashi; Hiroshi Yasunari, Peter Hacker, Shinya Minato, Shiyeki Hosoda, Gang Yuan.

Once the model performs well enough, it will be useful as a research tool to study such physical processes in the region as eddies and wave and topography interactions, biogeochemical processes (by including ecosystem dynamics), and regional influences on climate (by coupling to atmospheric models). Eventually the model will have data-assimilation capability so that it can be used for near real-time regional ocean forecasting and will provide useful information on such things as ocean currents, temperature and sea level variations for fisheries, environmental management, hazard assessment, and search and rescue operations. In the future, the model will be applied to other island settings in the Pacific.

APDRC helps build Argo regional application centers

The international Argo program is filling the global ocean with an array of about 3,000 drifting floats. As the floats rise from a depth of about 2 km, they measure temperature and salinity. When they surface every 10 days or so, they relay these data and location information *via* satellites to national data centers (DACs), where the records are quality checked, coded into NetCDF, a standard file format for internet distribution, and sent on to the two Global Data Acquisition Centers, or GDACs, mentioned above (U.S. GODAE at Monterey and the French IFREMER Center), which make the information available to users within 24 hours. The data are also sent to the principal investigators for delayed-mode quality control. This system will allow continuous monitoring of the ocean, forming the oceanic equivalent of an operational observing system of the atmosphere, and will be invaluable to ocean nowcasting and forecasting as well as weather forecasting and climate change research and detection.

The Argo regional application centers are, among other things, to assist in the scientific quality control of this massive data stream, including checks on internal consistency and systematic errors in the data, and real-time and delayed-mode calibration using, for example, CTD/hydrographic data available from other sources. The centers are to prepare quality-controlled Argo products and distribute these in delayed mode. They also coordinate Argo-float deployment plans for the region and give feedback to principal investigators to improve the real-time data sets.

The APDRC plans to participate with India's DAC (INCOIS) and Australia's DAC (CSIRO) as a regional center for the Indian Ocean, and with JAMSTEC as a center for the Pacific Ocean. To plan for this participation, manager **Peter Hacker** hosted a workshop June 28–30, 2004, sponsored by the IPRC. Joining IPRC scientists for the workshop were **Shinya Minato**, Argo data manager from the JAMSTEC Argo Regional Center, who was accompanied by scientists **Taiyo Kobayashi** and **Shiyeki Hosoda**; **Ruth Curry**, research specialist, Woods Hole Oceanographic Institution; **Ann Gronell** from the Ocean Observing Networks, CSIRO Division of Marine Research; **Mark Ignaszewski**, co-chair of the Argo Data-Management Group and with the Fleet Numerical Meteorology and Oceanography Center (the Department of Defense's main production site for operational meteorological and oceanographic analysis and forecast products worldwide, and the host of the US GODAE server); and **Charles Sun**, deputy chief of the Data Base Management Division of the National Oceanographic Data Center.

At the workshop, Ann Gronell described the CSIRO quality-control system for oceanographic data that she had helped to

Charles Sun presenting to participnts of the workshop on the Argo Regional Application Center.

develop and which we will be applying to upper-ocean thermal data served by the APDRC. Ruth Curry gave a training session on her HydroBase2, a global database of hydrographic profiles and tools for climatological analysis. The database includes the original raw, and quality-controlled data from several sources; the grid-resolution is 0.5–1° and data can be fully interpolated without smoothing; the time record is monthly, topography is included. This database comes with different modules that allow flexible analyses of horizontal or vertical slices, or of different timeseries, and that make it easy to create 5-, 10-, or 15-year climatologies, and study climate change. The software works on all platforms. (For further information on this database visit **www.whoi.edu/science/PO/hydrobase**.) Work is underway to make the HydroBase 2 database and user modules accessible on the APDRC server; the APDRC will use the database for comparison in its quality control of Argo data, and Argo data will be stored in the database.

Kyosei Project

The Japanese national Kyosei Project studies variability and changes in Earth's natural environment. One of its sub-projects, the Kyosei-7 (K7), is taking advantage of the computing power of the Earth Simulator and has developed a coupled ocean-atmosphere data-assimilation system. Until the arrival of the Earth Simulator, data assimilation was carried out mostly in stand-alone ocean or atmospheric models that are forced by surface observations in the other medium. K7's coupled approach should improve the physical consistency and accuracy of data assimilation. As part of the K7 team, IPRC is working with scientists in JAMSTEC to improve coupled model simulation, data assimilation, and product delivery.

Model improvement. Coupled models have long had trouble maintaining the Pacific Intertropical Convergence Zone (ITCZ) north of the equator, in part because of poor representation of the stratus cloud deck in the eastern South Pacific off the coast of South America. The newly developed IPRC regional ocean-atmosphere model (IPRC–ROAM) simulates this climatic asymmetry over the tropical Pacific well and can be used to improve physical parameterizations in global circulation models. In collaboration with **Toru Miyama** and **Takashi Mochizuki** of JAMSTEC, **Yuqing Wang**, **Haiming Xu**, and **Simon de Szoeke** from IPRC are adapting the IPRC–ROAM to run on the Earth Simulator. The first Earth Simulator runs with this regional model will focus on stratus clouds and their interaction with the ITCZ and the ocean.

Product diagnosis. Outputs from multi-decadal simulations with the first version of the K7 coupled global model will soon be available, and IPRC scientists will begin analysis and diagnosis of these outputs and provide feedback to model and assimilation-system developers. The initial focus will be on the assimilated products that deal with the tropical Pacific and the Asian-Australian monsoon.

A K7 workshop on coupled simulation and assimilation is taking place on January 17–18, 2005, in Yokohama. **Shang-Ping Xie**, **Bin Wang**, and **Haiming Xu** from IPRC are participating in this workshop and discussing further collaboration with JAMSTEC scientists.

Server technology upgrade. To enhance data analysis capabilities for the K7 project, our server specialist, **Yingshuo Shen**, has been working with **Kazutoshi Horiuchi** to implement server technology in Japan similar to that at the APDRC. During June 21–25, 2004, they improved and upgraded the LAS and GDS systems for K7, including the system's ability to handle *in situ* data on the LAS and to provide access control for restricted-distribution products. Shen plans to visit Japan again in February 2005 to continue the server collaboration on "sister-server" definition and activities.

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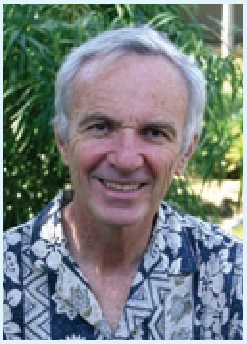
Data Surprises



by Roland Madden

Senior scientist at the National Center for Atmospheric Research, ***Roland Madden*** *visited the IPRC during October and November 2004. Below he writes about how, with his colleague Paul Julian, he came to discover the atmospheric disturbance that has become known as the Madden-Julian Oscillation. The late 1960s witnessed a flurry of discoveries that revolutionized tropical meteorology, among them the Yanai and Kelvin waves, which Taroh Matsuno's theory predicted, and the Madden-Julian Oscillation, which was not in the theory and still eludes a satisfactory theoretical explanation.*

Several circumstances came together in the late 1960s to facilitate the discoveries in the tropical atmosphere of mixed Rossby-gravity waves (MRGW), Kelvin waves, and the oscillation with a 40–50 day average period. One was the theoretical treatment of wave motions confined to the equatorial region (Matsuno, 1966) describing the first two waves. Another was the growing use of spectrum analysis by tropical meteorologists that allowed a quantitative description of large-scale phenomena with few and far-between observations. Spectrum analysis helped researchers "fill the gaps." With spectrum and cross-spectrum analyses, Yanai and Maruyama (1966 and 1967) examined meridional winds from the western Pacific and identified MRGW, and Wallace and Kousky (1968) studied the zonal winds and identified Kelvin waves. These were among the first demonstrations of zonally propagating, planetary-scale waves in the tropics (other than atmospheric tides). Consisting at times of data from only two locations, or from two vertical levels at one location, or even from just two variables at a single location and vertical level, the studies showed the power of spectrum analysis in interpreting tropical observations.

Technological advances also contributed to increasing knowledge about tropical meteorology. The first geosynchronous satellite making visible observations of clouds was launched over the central Pacific in December 1966. To provide "ground truth" for the satellite, the National Center for Atmospheric Research (NCAR) led its first field program, the Line Islands Experiment (LIE) at Christmas, Fanning, and Palmyra islands during March and April 1967.

I came to NCAR in 1967, and my first responsibility was to compute winds and thermodynamic variables from raw rawinsonde measurements made during the LIE. Paul Julian, a senior member of the group I joined, had just demonstrated with spectrum analysis that there was no quantitative evidence to support a long-held belief in an Index Cycle, and thus had established himself as an expert in applying the new analysis technique to meteorology. Aware of the work of Matsuno, Yanai, Wallace and collaborators, I was happy to learn from Julian how to spectrally analyze my LIE winds. I presented the results at the Symposium on Tropical Meteorology here at the University of Hawai'i in June 1970. Determined from only 60 days of data, the LIE spectra differed from several of Yanai and Maruyama's similarly short records. Someone suggested that longer records must be available and to look at the time variations in these statistical measurements.

Julian and I were in a good position to look at longer records because NCAR's Data Support Section had begun to collect long timeseries of data from tropical stations. One was a 10-year record of daily rawinsonde observations at Canton (now Kanton) Island, longer than any timeseries that earlier investigators had an opportunity to study. NCAR also had the biggest computer available to meteorologists (Control Data Corporation 6600), with a clock speed of 10mHz and a memory of 64kb (compare with 1400mHz and 262, 144kb of a Dell 8600 of today!) Moreover, with the new fast Fourier transform, the spectrum of a 10-year daily observation timeseries needed only about 10 times more computer time than our 60-day LIE timeseries with conventional methods.

Soon we were running newly coded programs on the Canton timeseries to document behavior changes in MRGW and Kelvin waves over time. (Running programs in those days meant submitting decks of hundreds of computer cards to a card reader and waiting hours for results.) To our surprise, the spectral analyses revealed the 40–50 day oscillation that is sometimes now referred to as the Madden-Julian Oscillation (1971, 1972).

In closing, I want to stress the serendipity and "data surprises" in these stories. Yanai and Maruyama, and Wallace and Kousky state in their papers that they had set out to explain the momentum budget of the recently discovered Quasi-biennial Oscillation (QBO). It's hard to imagine they anticipated the MRGW and Kelvin waves they found. Similarily, Reed, Ebdon and others who discovered the QBO, must, too, have been surprised to see the amazing and unmistakable 26-month variation in the winds of the equatorial stratosphere. Julian and I began a study of time variations in the MRGW and Kelvin waves and ended up describing a different, unanticipated but interesting, and as it turned out, important phenomenon.

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When Do the Monsoon Rains Start?

***P.V. Joseph**, retired director of the India Meteorological Department and emeritus professor of Cochin University of Science and Technology, visited the IPRC in Spring 2004 to do modeling research with the monsoon scientists in support of his theory on the onset of the monsoon rains. The onset of the monsoon rains is of great importance to people in Asia. Over India this onset can be anywhere between May 11 and June 18, the long-term average date being June 1. Predicting the actual onset date remains a challenge, and Joseph is a key player in this high-stakes prediction game. Working in weather forecasting for many of his 32 years with the India Meteorological Department, Joseph has been looking at data—data from rain gauges, radiosondes, ship-based measurements, and later from satellite images—and searching for clues to predict monsoon onset. What follows is a story of how he developed this theory.*

The traditional view of the physics of the onset of the monsoon rains is that as the Asian continent heats up with the coming summer, the warm air rises over the land, and the winds start to blow from the cooler ocean to the warmer land bringing the rains. Joseph holds a different view: "These winds are the planetary summer monsoon. They are not very strong and do not bring the rain that has been associated for centuries with the monsoon." According to Joseph, what happens is this: In late May–early June, the warmest ocean waters shift from the western Pacific to the Arabian Sea. Over this 30°C or warmer water, a large amount of moisture converges. As this moist air rises and produces copious rainfall, the latent heat released warms the atmosphere even more; the rising air then sucks in air from as far away as across the equator and turns into a low-level jet stream. This jet carries with it very moist air and forms the monsoon rain band over India. Joseph's proposed sequence of physical processes remains a hypothesis and to test this hypothesis with a model, Joseph visited the IPRC from March to May 2004 to work with our monsoon researchers.

How Joseph has arrived at this controversial but plausible hypothesis is a story spanning nearly 40 years. The first piece to his monsoon onset scenario came when he was assigned to aviation meteorology in 1965. He noted that during the monsoon, the flight paths of airplanes were affected by a low-level jet over peninsular India. This jet, which later came to be called the Findlater Jet after the person who continued further research into it, creates heavy rains on its northern flank.

In 1979 Joseph became director of the Meteorological Training School in Pune. There his attention was drawn to another player in the monsoon, the ocean, for Pune was home to all the archived data collected by ships plying the Indian Ocean. This data he studied with keen interest. He patiently analyzed sea surface temperature (SST) and other variables and related them to rainfall. He discovered a pattern: after dry monsoons (10% below average rain), the northern Indian Ocean would be unusually warm. This would create easterly winds that push the westerlies of the upper troposphere northward and make for a wetter monsoon the following year. Similarly, a wet monsoon would be followed by a colder Indian Ocean and a drier monsoon the next year. These observations formed the beginning of the tropical biennial oscillation concept.

Then there was the 1980 seminal paper by **Sikka** and **Gadgil**, and also **Yasunari** 1979, which described three sets of northward moving rain bands during the summer monsoon, with a 30–50-day interval between the bands. What is the reason for this banding structure? Could not such a band form before the monsoon begins? Analyzing 25 years of rain gauge data and matching it to the monsoon onset, Joseph discovered that about 40 days before onset such a rain band extended from the tip of India eastward. Although this band brought rain to the southern tip of India, it did not move northward, but was a "bogus" monsoon onset. The first appearance of this band, though, was very closely related (r = .87) with the real monsoon onset 40 days later. Once several years of satellite images became available, they confirmed for Joseph the picture he had drawn from the rain gauge data. They also pointed to something he hadn't realized from his rainfall plots: the formation of twin cyclones, which are now known to be associated with this pre-monsoon rain band.

A very significant event for Joseph came in 1989. Invited to become a research associate for two years at the Cooperative Institute for Research in Environmental Sciences at the University of Colorado, he retired from the India Meteorological Department and went to Boulder. There he came upon an atlas that showed 80 years of tropical cyclone tracks around Australia. And once again Joseph found a pattern when he put this wealth of information together with the record of monsoon onset dates over India: When the cyclone season in the Southern Hemisphere stops early, say by March, the Indian monsoon comes early; when the cyclones continue into April–May, the Indian monsoon starts late. Regrettably, this information is of limited use for prediction because one can never tell which cyclone will be the last of the season, but the pattern gave Joseph a clue. Relating outgoing longwave radiation (OLR) to SST patterns, he noticed that during years of very delayed and very early monsoons, the date at which the maxi mum equatorial convective cloudiness—which lies over the warmest ocean waters and is called the Intertropical Convergence Zone—shifts to the Northern Hemisphere is closely related to the monsoon onset date. Now Joseph turned his attention to changes in SST in the Indian Ocean and noted the shift of the warm pool from the western Pacific into the Indian Ocean and then into the Arabian Sea just before monsoon onset, accompanied by the rain band formation and the low-level jet that brings the real monsoon rains to India.

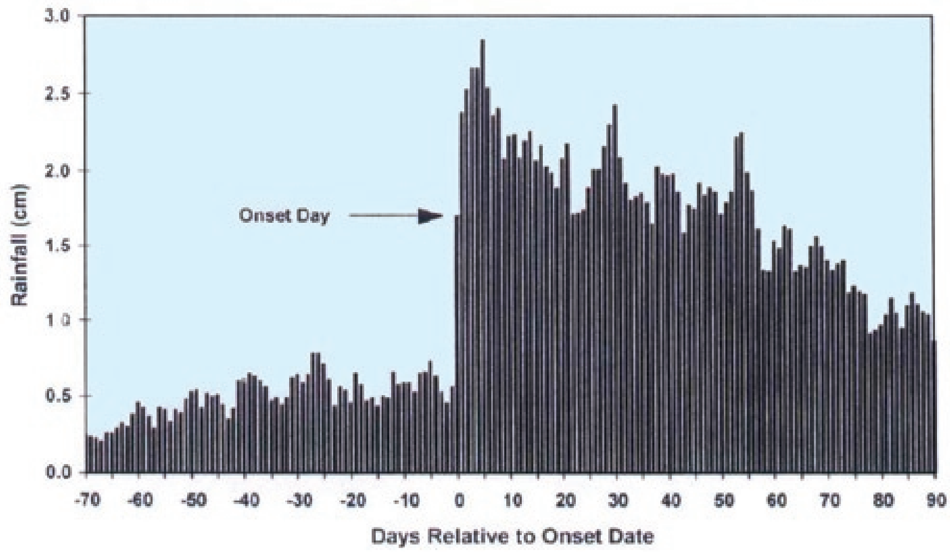

Figure 12. Composite mean daily rainfall in South Kerala from 1901 to 1980 (daily rainfall is the average of 44 well-distributed rain gauge stations) with respect to the date of monsoon onset over Kerala (date-0). Note the abrupt increase in rainfall at monsoon onset. Pre-onset and post-onset rainfall regimes are vastly different (taken from Ananthakrishnan R. and Soman M.K., 1988, *Journal of Climatology*, **8**, 283–296).

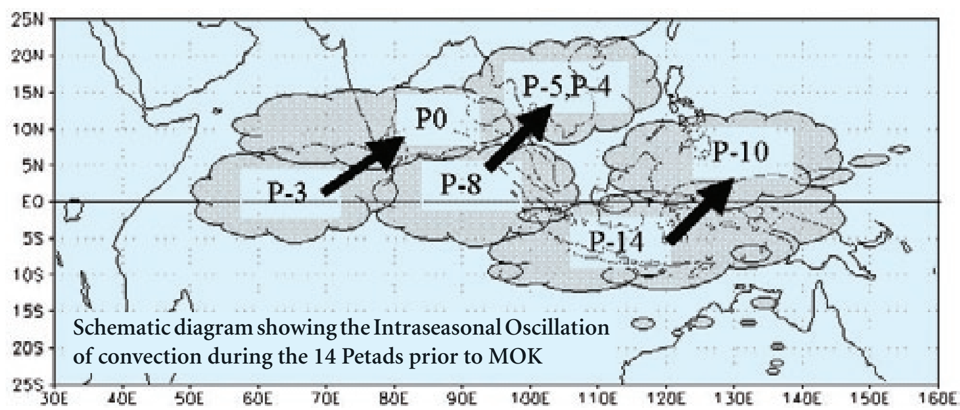

Figure 13. Schematic showing the temporal and spatial evolution of extensive cumulonimbus clouds that pump much moisture and heat into the atmosphere before the monsoon onset over Kerala at day 0 (P-0) and backwards in time to 70 days (P-14), when the convection was still south of the equator. At day 40 (P-8) before onset, the convective clouds form near the equator, just south of the warm pool; at day 15 (P-3) before onset, they form in the Arabian Sea, which now has the large south-north sea surface temperature gradient (from ongoing research work by Joseph, P.V. and Sooraj, K.P.).

Studying the correlation patterns among SST, OLR, and the monsoon onset date, Joseph concluded that delayed northward movement of the equatorial convection maximum, and therefore delayed onset, could result from one or more of the following conditions: from warm anomalies in the central Pacific together with cold anomalies in the western Pacific (usually those associated with El Niño), and from unusually warm water south of the equator in the Indian Ocean, and cold water in the Arabian Sea. Correlations, though, do not mean causation. In the modeling experiments at the IPRC, Joseph could experimentally manipulate the SST in the regions of interest, and see whether these manipulations will have their expected effect on the Arabian warm pool, the convection there, and the onset of the monsoon.

The first set of experiments that Joseph conducted together with **H. Annamalai** and **Bin Wang** consisted of placing into the model the SST anomalies that had occurred during the four times when the monsoon was more than 12 days late and comparing their effects on rain-band formation with a simulation under climatological SST conditions. Initial results show that the simulated convective cloud band and the low-level jet over the Arabian Sea and the southern tip of India form about 10 days later than in the climatological SST runs—just as Joseph had predicted.

However controversial his position is, Joseph has started to successfully predict the fickle onset date of the monsoon. In 2002, he had predicted a two-week delayed monsoon onset, but it rained heavily in Kerala on May 29 and the India Meteorological Department declared the monsoon had begun. That rain, though, was followed by two weeks of clear skies and searing heat; the same has happened once again this past summer.

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Atmospheric Gravity Waves and their Effects on the Global Circulation

A fundamental difficulty in modeling global atmospheric circulation is the strong interaction among motions on a wide range of space and time scales. Explicit numerical representation of all the spatial scales that determine the global atmospheric circulation is impractical. An example of such difficulties is the effect of small-scale inertia-gravity waves on the circulation. Inertia-gravity waves have relatively high frequency (typically periods between a few minutes to a few hours) and usually represent only a minor component of the tropospheric circulation. The waves propagate vertically, however, and the associated wind and temperature perturbations grow rapidly with height as the mean density drops. Thus the higher one looks in the atmosphere, the more significant inertia-gravity waves become.

Gravity waves act to exchange mean momentum between the surface and the atmosphere and among different layers of the atmosphere and, as such, are crucial in forcing the global-scale circulation in the stratosphere. Since the distribution of many trace constituents in ozone chemistry is strongly affected by the atmospheric circulation, an understanding of gravity-wave effects in the middle atmosphere has become a central issue for practical modeling of stratospheric ozone, and hence for comprehensive climate-chemistry modeling of the global atmosphere. It is likely that waves with horizontal wavelengths as short as about 25 km are significant for mean momentum transport. The development and application of parameterization schemes to adequately account for the effects of gravity waves that cannot be explicitly resolved is now an important task for scientists in global climate-chemistry modeling.

Kevin Hamilton, co-leader of Impacts of Global Environmental Change research at the IPRC, organized an American Geophysical Union Chapman Conference on "Gravity Wave Processes and Parameterization" that addressed key issues in this area. Held in Waikoloa, Hawai'i, January 10–14, 2004, the conference was co-sponsored by the World Climate Research Programme through its SPARC initiative (Stratospheric Processes and their Role in Climate). There were 64 participants from 11 countries, including experts in observations, theory and numerical modeling of gravity waves, and colleagues interested in the practical impact of subgrid-scale gravity-wave parameterization schemes on global model simulations of atmospheric circulation and chemistry.

The meeting highlighted advances in observational knowledge of the atmospheric gravity-wave field. One theme was the influence of global positioning system (GPS) technology on both *in situ* and satellite observations of the gravity-wave field in the atmosphere. GPS technology can now track very accurately the three-dimensional positions of long-lived balloons in the lower stratosphere, allowing unprecedented observations of the three-dimensional wind with frequent time sampling. Since the balloon drifts with the ambient flow, the calculated spectrum of the high-frequency wind and temperature variations at the balloon location is the effective "intrinsic" frequency spectrum, an important function that thus far has had to be derived indirectly. Another recent development is the use of satellite GPS tomography to measure vertical profiles of temperatures in the stratosphere. The measurements can be taken whenever paths between two individual satellites intersect the planetary limb, leading to a widely scattered geographical coverage that supplements the fixed station distribution typical for many other profiling measurements.

The most pressing theoretical issues underlying parameterization of gravity-wave effects relate to wave forcing and wave dissipation. Much work has been based on systems idealized in various ways. Almost all theoretical models have involved at least a simplified geometry such as considering zonally propagating waves in a mean flow that depends only on height and time. Such restrictions mean that in a steady-state, waves transfer mean momentum from regions where they are forced to where they dissipate. The Chapman conference provided one of the first forums for discussion of recent work that has emphasized the new effects introduced with more complicated geometries in which waves refract in such a way that the wave vector at absorption no longer parallels that at forcing. Whether these refraction effects are important in practical terms or whether they can be ignored is unclear. Future research should focus on modeling studies that quantify the real-world importance of this effect.

The question of how a broad spectrum of vertically propagating waves saturates is fundamental to formulating practical parameterization schemes for gravity-wave effects. It is convenient to formulate the parameterizations in terms of the vertical wavenumber spectrum, particularly if the hydrostatic assumption is invoked (in which case the vertical wavenumber is inversely proportional to the intrinsic wave horizontal phase speed). One currently popular parameterization, the Doppler spread parameterization (DSP), considers the statistical effects of nonlinear advection terms on the high wavenumber of the vertical wavenumber spectrum (corresponding to small Doppler-shifted phase speeds in a hydrostatic system); another, the Warner-McIntrye parametrization (WMP), uses an empirically based saturation condition that constrains the growth of the large wavenumber end of the spectrum. The first detailed comparison of the performance of these two parameterizations was presented at the conference. In particular, the gravity-wave drag on the mean flow for various profiles and input spectra at the lower boundary (near the tropopause) was computed using both the DSP and WMP. The two schemes performed very differently: The WMP removed much more of the wave spectrum in the lower atmosphere than the DSP. The momentum flux and flux divergence profiles computed by the two schemes become similar when the saturation fluxes for the WMP are raised by a factor of 25 over their standard values. Why models with empirically based wave-saturation conditions differ from those based on something closer to a self-consistent, first-principles determination of the saturation conditions, needs to be specified.

Advances in understanding and quantifying gravity-wave sources have come from increasingly realistic and fine-resolution explicit numerical simulations using limited-area models. One focus of such studies is the generation of vertically propagating gravity waves associated with intense tropospheric jet streams. For example, one paper described a dry simulation of a growing baroclinic wave in a multiply nested version of a non-hydrostatic regional model. The multiple nesting allowed motions to be considered from the continental scale down to small scales. It was found that there was a very significant flux of gravity waves above the jet exit region, and a measure of the deviation from diagnostic cyclostrophic balance in the jet-level flow indicated the regions of strong gravity wave generation well (Figure 14).

Over the last decade, much work has been performed using 2- and 3-dimensional, cloud-resolving simulations of gravity waves, forced by concentrated regions of convection. The conference provided a chance to review the latest results, including explicit simulations of tropical squall lines, localized diurnal convection forced by local land-sea contrast, and tropical cyclones. The first steps have also been taken in connecting such detailed studies to explicit formulae that can be used to specify the tropopause gravity-wave fluxes in parameterizations.

The conference provided a forum for discussion of the practical issues of implementing parameterization schemes in global circulation models. Since the input spectra are not very well constrained by direct observations, there is still significant scope for tuning the parameters employed in a gravity scheme for a global model. Recent work has expanded from trial-and-error to more systematic objective techniques that constrain the schemes in order to provide the required wave drag for realistic simulations of large-scale circulation. One study using these techniques has inferred that the horizontal phase-speed spectrum of the waves entering the stratosphere must be broader at low latitudes that in midlatitudes.

Though rapid progress has been made on understanding the gravity-wave field and the more immediate engineering aspects of designing and implementing parameterizations in global models, a completely satisfactory parameterization scheme remains a goal for the future. Further progress requires both continued advances in detailed numerical modeling and in constructing a more complete empirical picture of the space and time variability of the atmospheric gravity-wave field.

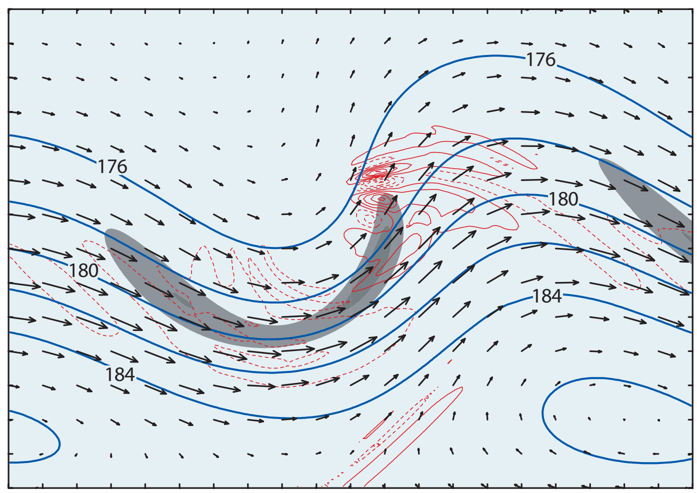


Figure 14. Results from a simulation of an idealized, midlatitude, growing baroclinic wave in a limited-area atmospheric model. Arrows show horizontal winds, the thick blue lines the isobars, and the thin red lines the horizontal divergence, all in the lower stratosphere (13-km altitude). The grey shading shows the region of peak tropospheric jet speeds (at 8-km altitude). The structure of the divergence field reveals the gravity-wave packets emerging from the jet stream. (Courtesy Fuqing Zhang)

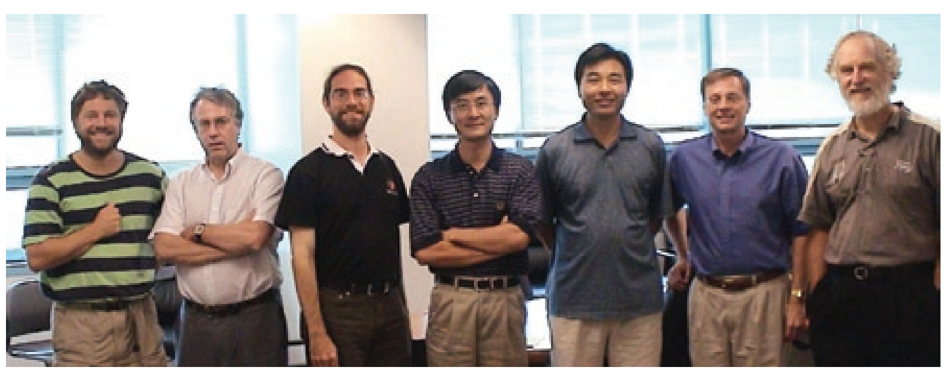
Fourth Annual IPRC Symposium

The Fourth Annual IPRC Symposium was held on May 13 and 14 at the East-West Center in Honolulu. At this event, IPRC scientists present the highlights of their year's research. The annual sharing is a time to pause and reflect upon the progress that has been made in understanding climate phenomena, particularly those affecting the Asia-Pacific region. It is an occasion to solicit comments and suggestions from peers and to detect common research threads. **Kevin Hamilton**, co-leader of the Impacts of Global Environmental Change research team, organized this fourth symposium. As shown in the first pages of this newsletter, a number of talks focused on aspects of the South China Sea climate. Presentations on oceanic research included the development and results of a method for determining accurately global mean sea level, the seasonal variations in water transport through the Indonesian Throughflow, a successful numerical simulation of the Tsuchiya Jets, the development of a slippery sack ocean model, an analysis of the processes causing the Pacific Decadal Oscillation, and the impact of stirring and mixing on the marine ecosystem. Presentations on air-sea interactions included studies of orographically induced air-sea interactions, the impact of ocean mesoscale features on the atmosphere, the formation of the stratus cloud deck in the tropical Southeastern Pacific, and effect of air-sea interaction on intraseasonal variations in the Indian Ocean. Several presentations dealt with tropical cyclone formation, and research into climate change included a study of why the climate sensitivity to increased levels of atmospheric carbon dioxide differs significantly in different climate models.

For the agenda, visit the IPRC website at **iprc.soest.hawaii.edu/meetings/workshops.html**.

Predicting Tropical Cyclones

Tropical cyclone research was on the upswing at the IPRC even before Florida and Japan were struck by an unusual sequence of violent storms this summer. **Yuqing Wang,** IPRC researcher and associate professor of meteorology, organized the "IPRC Workshop on Tropical Cyclones" on August 20, 2004. A small, but representative group of the tropical cyclone research community from Australia, Japan, Taiwan, Korea, and the United Sates discussed large-scale and meso-scale aspects of tropical cyclone formation, structure, and intensity changes, and the relationship between climate change and tropical cyclones. Under the leadership of **Kerry Emanuel**, **Greg Holland**, **John Molinari**, **Michael Montgomery**, **David Raymond**, **Da-Lin Zhang**, and **Yuqing Wang**, progress in these areas was briefly reviewed, and critical issues and future directions were extensively discussed. A list of the most pressing questions for research was drawn up: (1) How does the Madden-Julian Oscillation modulate the genesis of tropical storms and what is the role of vertical wind shear in this process? (2) How do merger, maintenance, and regeneration of convection contribute to the successive development of the "hot



Participants at the Tropical Cyclone Workshop: Michael Montgomery (CSU), Kerry Emanuel (MIT), Sim Aberson (NOAA-HRD), Chun-Chieh Wu (NTU, Taipei), Yuqing Wang (IPRC), John Molinari (SUNYA), and Greg Holland (NCAR).

tower" associated with moist convection in the formation of tropical cyclones? (3) What are the key processes that lead to the formation of a tropical cyclone and affect the cyclone's intensity, and what limits the intensity of tropical cyclones? (4) What improvements can be made in forecasting cyclone intensity, and will models be able to forecast intensity as well as they now forecast cyclone tracks? (5) Do tropical cyclones cool the atmosphere through their impact on the ocean circulation and poleward energy flux? What do paleoclimatic records tell us about such cooling?

A very important concern raised is that present-day climate models lack representations of severe tropical storms and, therefore, cannot directly predict how climate change will affect such storms.

(*Above*) Participants at the Earth Simulator Workshop; (*Left*) Wataru Ohfuchi, group leader of the Earth Simulator Atmosphere and Ocean Simulation Research.

Studies with Japan's Earth Simulator

The IPRC is collaborating with Japanese scientists on analyses of climate simulations run on Japan's Earth Simulator, one of the most powerful supercomputers in the world. Lead scientists at the Earth Simulator Center (ESC) and Frontier Research Center for Global Change (FRCGC) of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) met with IPRC scientists in Honolulu on August 24, 2004, to discuss initial findings from climate simulations with the Earth Simulator and to plan further collaboration.

Global climate models have been limited greatly by lack of computing power and have had to use resolutions somewhere between 200 and 300 km for the atmosphere, allowing only blurred pictures of Earth's climate. These low-resolution models cannot take full advantage of the high-resolution satellite observations, which have been available now for some time. The Earth Simulator, with its over 35 trillion calculations per second, is revolutionizing climate research. Climate models run on this computer now match the resolution of observations from space and are breaking new ground for modelers to exploit available data: Testing these new well-resolved numerical models against satellite observations is critical for gaining confidence in the models' forecasts of regional variations in the ongoing global warming.

At the IPRC–JAMSTEC meeting, the initial results of a high-resolution ocean model (OFES) simulation on the Earth Simulator revealed surprisingly well-organized swift currents at great depths that alternate in narrow bands between eastward and westward flows. These currents persist for years and extend over much of the Pacific Ocean.

Another noteworthy result in simulations with this model on the Earth Simulator concerns slow ocean variations in the upper 500 meters that are associated with movement of huge amounts of heat from one region to another and affect storm tracks and storm intensity. The Earth Simulator results show these movements to be spatially very organized and concentrated across narrow ocean-fronts at the surface. This new knowledge will help climate and fisheries scientists in designing observation systems to monitor changes in these fronts and in their location.

With its highly skilled scientists in atmospheric and oceanic modeling and in analyzing satellite data, the IPRC is well positioned to take advantage of this new frontier created by the Earth Simulator. By weaving information from the Earth Simulator together with satellite observations from space and observations from the new Argo-float ocean measurements, scientists will be able to see what the climate in places like Hawai'i may be like in the next several decades.

Organizers of the PICES/CLIVAR workshop: Kelvin Richards (IPRC), Jim Overland (Pacific Marine Environmental Laboratory), Kimio Hanawa (Tohoku University) and Skip McKinnell (Institute of Ocean Sciences). (Not shown: Dick Beamish, Fisheries and Ocean Canada) and Kuh Kim (Seoul National University).

Scale Interactions in Climate and Marine Ecosystems

The marine ecosystem, like the complex physical climate system, has many interacting scales, from small-scale patchiness to global extent, from shelf to deep-sea populations, and from individuals to communities. To date, most studies of the impact of climate variability on the marine ecosystem have used correlational statistics between a given population and physical climate indices. If we are to understand what controls what, however, we need to go beyond simple correlations and tease out the relationships between the changing physical and biological systems. How do the various scales of climate variability project onto the variability of the population of a given species or the ecosystem as a whole? How does the changing climate impact the scale interactions of the biogeochemical system? What do we need to get right in models used to predict the impact of climate change on the marine ecosystem and fisheries?

A joint PICES and CLIVAR workshop, held in Honolulu in October 2004 as part of the PICES XIII meeting and co-sponsored by the IPRC, focused on these questions. The talks given by experts in Pacific physical oceanography, climate dynamics and variability, marine ecosystems and biogeochemistry, and in fisheries reflect the recent progress in our understanding of factors that affect the physical environment on interannual to decadal timescales and in our ability to model these changes locally and basinwide. Both *in situ* and satellite observations reveal changes in the ecosystem from the regional to the basinwide scale, and in many instances these changes can be linked to changes in the physical environment. Managing fisheries in the face of uncertainties of climate change is particularly challenging, but we understand better now how the timing of environmental changes impacts the growth of populations at various stages of their life cycle.

Much discussion at the workshop dealt with the so-called "regime shift" of the mid-70s, first revealed in biological data and later discovered to coincide with basinwide physical changes, and whether it was truly a regime shift or just a relatively rapid change in a randomly varying system. The prevailing view is that there is no evidence for a regime shift in the physical system, but that one should look in the ecosystem for thresholds that trigger regime shifts in this system.

Nate Mantua's paper "To upscale or downscale" perhaps captured best the essence of the workshop. He notes that statistically comparing large-scale climate indices to local and regional fishery data does not reveal the key processes. Rather "upscaling" locally varying parameters to large-scale climate variability promises to yield a better understanding of the linkages between climate and the marine ecosystem cause and effect. Abstracts of the talks can be found at **www.pices.int/meetings/annual/Pices13.**

IPRC scientists play key role in Western Pacific Geophysics Meeting

The biennial Western Pacific Geophysics Meeting of the American Geophysical Union was held in Honolulu from August 16 to 20, 2004, and brought together over 700 scientists from Asia, Australia, New Zealand, and the United States. IPRC scientists contributed much to the meeting: The Scientific Program Committee included IPRC's **Kevin Hamilton**, and IPRC affiliate members **Bo Qiu** (University of Hawai'i, Department of Oceanography) and **Humio Mitsudera** (Hokkaido University). Moreover, Hamilton convened the Union session "Earth Science on the Earth Simulator," **Shang-Ping Xie** the Ocean Sciences session "Air-Sea Interaction in the Indo-Pacific Oceans," and **Yuqing Wang** the Atmospheric Sciences session "Challenging Issues on Tropical Cyclone Research and Forecasts in the Western Pacific." IPRC scientists authored or coauthored 35 papers and posters presented at the meeting.

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NEW STAFF

Axel Timmermann returned to the IPRC in August 2004 as an associate professor of oceanography and co-leader of the Impacts of Global Environmental Change research team. Timmermann started his higher education in quantum field theory, writing his master's thesis on recreating in a particle accelerator the early universe, one microsecond after the Big Bang. Although this work is still being referenced by physicists who study characteristics of these particles during collisions, Timmermann found, "This kind of science is interesting, but completely worthless for society." He switched to climate research and obtained his PhD in meteorology from the Max Planck Institute, University of Hamburg, in 1999. For his dissertation, he conducted a multi-century simulation with a coupled atmosphere-ocean model to show that decadal and interdecadal variations in the North Atlantic can result from an interaction between the thermohaline circulation and the Arctic Oscillation: Strong winds in the North Atlantic change the ocean salinity, which in turn affects the winds by changing the meridional overturning circulation and the associated temperature.

Timmermann has several research projects at the IPRC. He is studying the emergence and physics, not of regional, but of global climate anomalies, those that affect all three major ocean basins. These basins can communicate by atmospheric bridges or, on longer timescales, by oceanic wave adjustments. Paleoclimate analysis suggests that global oceanic seiches may synchronize climate variations on timescales longer than a decade. Their relevance to climate, particular to greenhouse warming, however, has not been studied yet, something that Timmermann is now exploring with a hierarchy of climate models. Furthermore, together with **Max Yaremchuk**, **Konstatin Lebedev** and **Soon-Il An,** Timmermann is conducting a project that combines the advantages of two approaches to seasonal forecasting—assimilation of the best oceanic or atmospheric observations into an uncoupled system, and nudging observed sea surface temperature or wind anomalies into a coupled system. This work will yield a procedure for coupled air-sea data assimilation. With **Oliver Timm**, he is simulating the transition from glacial to interglacial climates with a 3-dimensional coupled atmosphere-ocean-sea ice model in order to look at the role of the North Atlantic thermohaline circulation in triggering abrupt climate transitions.

Finally, Timmermann is continuing work on the absorption of solar light by phytoplankton in the ocean. Recent studies by his research team in Germany have shown that the vertical redistribution of solar energy in the ocean due to the absorption of light by chlorophyll may change the upper-ocean thermal structure considerably.

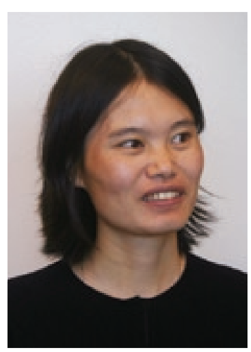
Sharon DeCarlo joined the IPRC in October 2004 as a computer systems engineer. Already before she obtained her bachelor's degree in computer science from the University of Hawai'i, DeCarlo accepted a job as a computer programmer with **Eric Firing** at the Joint Institute for Marine and Atmospheric Research. Little did she realize that this work would lead to a career in oceanography. She later became **Roger Lukas'** first employee after he obtained his PhD in 1981. During the more than 20 years of working for Lukas, Sharon developed data acquisition, processing, and analysis software for such projects as NORPAX, WEPOCS, LIA, TOGA/COARE, JASMINE and HOT. With her expertise in programming and knowledge of ocean and climate data sets and products, DeCarlo has a dual role at the IPRC: She is in charge of the APDRC web development under the direction of **Peter Hacker**, and she works with the IPRC computer facility team under **Ron Merrill** to keep our computers and servers running.

Kazuyoshi Kikuchi joined the IPRC as a postdoctoral fellow in Spring 2004, having obtained his Doctorate of Science from the University of Tokyo in Fall 2003. For his doctoral dissertation, he studied the following aspects of the important tropical atmospheric disturbance, the Madden-Julian Oscillation (MJO, p. 15): the triggering of a new cycle by the preceding one, the development of convection in the MJO over the warm pool, and a comparison of the propagation of the MJO during winter and summer. Kikuchi's long-term goal is to determine how this tropical disturbance changes with climate change, and how a changed MJO will, in turn, affect climate change. As a first step towards this ambitious goal, he is working with **Bin Wang** at the IPRC to determine the precipitation properties of the MJO by analyzing data from the Tropical Rainfall Measuring Mission.

Simon de Szoeke came to the IPRC in September 2004 as a postdoctoral fellow, shortly after receiving his PhD in atmospheric sciences from the University of Washington. His thesis on the evolution of the cross-equatorial atmospheric boundary layer in the eastern Pacific consists of large-eddy simulations to show the interactions among turbulence, clouds, and surface fluxes in the planetary boundary layer (PBL) and of an analysis of planetary boundary layer observations from the EPIC 2001 95W field project. de Szoeke was drawn to climate research because of concern for the environment and the desire to apply his knowledge of physical science to understand how climate varies and changes. Interested in the boundary layer's response to the ocean and its downstream effects on the Intertropical Convergence Zone, de Szoeke is working at the IPRC with **Shang-Ping Xie** and **Yuqing Wang**. With the IPRC Regional Climate Model, he is studying easterly wave dynamics in the eastern Pacific ITCZ, and with the coupled IPRC Regional Ocean-Atmosphere Model, he is studying the widespread stratocumulus clouds over the eastern Pacific, which cool the ocean surface by reflecting solar radiation and cool themselves by emitting infrared radiation, affecting the boundary layer and regional-scale circulations.

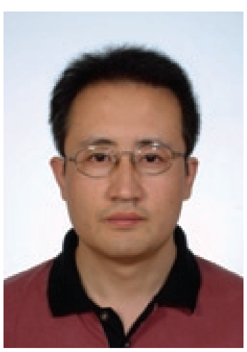
Yanli Jia joined the IPRC in May 2004 as a visiting associate researcher. She went to England in 1985, to the Department of Oceanography, University of Southampton, under a PhD scholarhip sponsored by the British Council and the Chinese Ministry of Education. Joining a project on the seasonal and interannual variability of the equatorial Pacific and the 1982–83 El Niño, Jia quickly became familiar with oceanography and ocean modeling. Upon completing her PhD work in 1988, she stayed at Southampton to study the effects of advection and diffusion on tracer dispersion in ocean gyres. She experimented with idealized tracers in simple gyre circulation patterns and studied deep and thermocline ventilation processes with transient tracers (tritium and CFCs) using a general circulation model of the North Atlantic. In 1990, Jia joined the present James Rennell Division for Ocean Circulation and Climate at the Southampton Oceanography Centre, working in a group that was implementing a version of the Miami Isopycnic Coordinate Ocean Model (MICOM) for the North Atlantic to study the North Atlantic circulation. This experience has prepared her well for her work at the IPRC, where, together with **Peter Hacker**, **Jim Potemra**, and **Max Yaremchuk**, she is setting up a high-resolution ocean model to study the circulation around islands (see p. 12).

Jiayi Peng joined the IPRC in August 2004 as a postdoctoral fellow. His interest in weather forecasting came as a child when he heard how the eastern wind helped Zhugeliang defeat Caocao's army in the story *Three Kingdoms.* After study at the Nanjing Institute of Meteorology (NIM), he became a weather forecaster at the Chongqing Meteorology Bureau. Frustrated with the poor predictability of severe storms, he returned to NIM for graduate studies, obtaining his PhD in 1999. At Nanjing University and National Taiwan University from 2001 to 2004, Peng studied the temporal and spatial thermodynamics mesoscale convection in the Wuhan area on July 21, 1998, the day of the disastrous torrential rains and flooding. He found that low-level tropospheric potential vorticity perturbations helped trigger the convection system. Recently he has been studying tropical cyclones, particularly the formation of double eyewalls. At the IPRC, Peng is working with **Tim Li** and the Asian-Australian Monsoon team. Using a semi-spectral baroclinic model, he is looking at how hurricane structure and intensity interact with the vertical shear flow.



Li Tao, who joined the IPRC as a postdoctoral fellow in July 2004, received her PhD in 2000 from Nanjing Institute of Meteorology (NIM), her thesis entitled "Free mode analysis of the subtropical high over the western Pacific in summer." She continued at NIM as assistant professor until in 2003 she became a visiting assistant researcher at the Goddard Earth Science and Technology Center, University of Maryland, Baltimore, and then at the Center for Earth Observing and Space Research, George Mason University, Virginia, where she investigated the influence of Tropical Rainfall Measuring Mission precipitation products on the structure and underlying physics of the Madden-Julian Oscillation using a general circulation model and the data assimilation system of the Goddard Earth Observing System. Interested in atmospheric dynamics, short-term climate change, and mesoscale model-design and simulation, Li will be working at the IPRC with **Xiouhua Fu** in the Asian-Australian Monsoon team on developing a procedure for predicting seasonal oscillations from satellite data and simulations with the ECHAM model.

Oliver Timm joined the IPRC as a postdoctoral fellow in August 2004. He obtained in 2003 his PhD in meteorology from the University of Kiel. For his thesis, Timm estimated the natural variations in the North Atlantic Oscillation (NAO) over the past 300 years by means of such proxy data as tree-ring and ice-core records. Results showed that during the 17th and 18th centuries the NAO varied much as it does today, suggesting that anthropogenic forcing has not altered the variability. After completing his PhD, he worked with the Paleo-Oceanology group at the GEOMAR Institute in Kiel, analyzing coral proxy records to detect the El Niño-Southern Oscillation and NAO signals in these records. Working at the IPRC with **Axel Timmermann** in the Impacts of Global Environmental Change team at the IPRC, Timm is now looking even further back into Earth's climate history. With a coupled ocean-atmosphere climate model (ECBILT-CLIO), he is simulating the effects of orbital, orographic, albedo, and greenhouse gas forcings during the last 21,000–100,000 years to study the Atlantic bipolar seesaw in glacial climates and to find links between Pacific and Atlantic climate change on millennial time scales.



Hongwei Yang came to the IPRC in Fall 2004 as a postdoctoral fellow. In 2000 he received from the School of Mathematical Sciences, Peking University, Beijing, his PhD in computational mathematics with a two-part dissertation: the first part consists of a series of numerical experiments to improve the design for a new detonation shock tube test facility in the National Laboratory for High Temperature Gas Dynamics, Institute of Mechanics, Chinese Academy of Sciences; the second part of his dissertation is a mathematical proof for a scalar non-homogeneous hyperbolic equation. Yang was drawn to climate research because it allows the application of computational mathematics. While doing postdoctoral research at LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, he found that many mathematical problems in climate research had not been solved satisfactorily and that the field has many opportunities for "reality mathematics" work. At the IPRC, Yang is working with the Asian-Australian Monsoon team, studying the interaction between land-surface processes and the East Asian monsoon, particularly the effect of snow cover and changes in the underlying surface on the behavior and variability of the East Asian monsoon.

Xin Zhang joined the IPRC in September 2004 as a visiting assistant researcher. Zhang worked for three years as a weather forecaster at the Wuhan Meteorological Center, Hubei Province, China, before returning for graduate study. In 2002, he obtained his PhD in meteorology from the Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, with a dissertation on data assimilation and parallel computing in climate models. Zhang will be working with **Tim Li** on 4-dimensional variational data-assimilation, using satellite data to improve the numerical modeling and prediction of hurricanes and typhoons.

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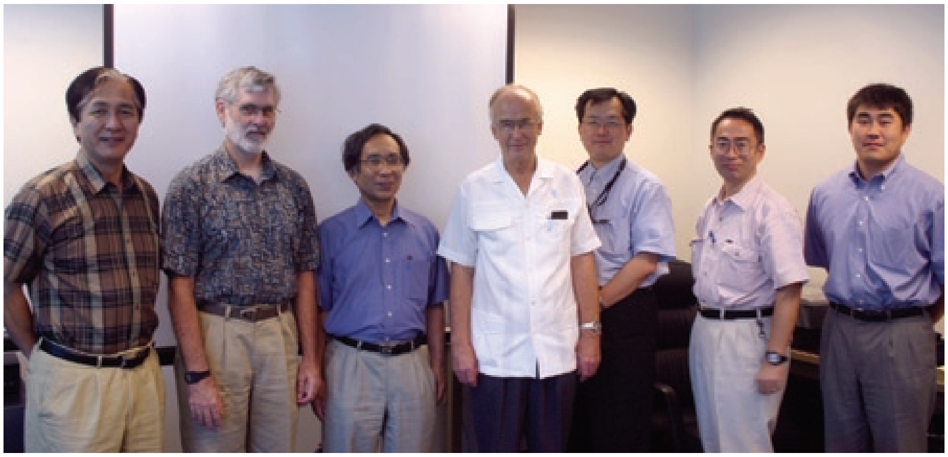


From left: Toshio Yamagata. Jay McCreary, Taroh Matsuno, Lorenz Magaard, Hideyuki Tsunoda, Ichio Asanuma, and Tetsuro Isono.

Agreement between JAMSTEC and IPRC elaborated

Taroh Matsuno, Director-General of the Frontier Research Center for Global Change, and **Toshio Yamagata,** Program Director of Climate Variations Research at Frontier, visited the IPRC on July 1, 2004, to discuss with IPRC Director Jay McCreary and IPRC research team leaders the scientific work to be done under the new five-year cooperative agreement between the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and the University of Hawai'i (*IPRC Climate*, Vol. 4, No. 1).

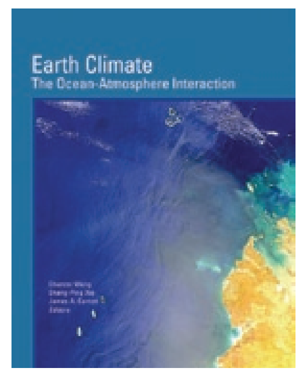
Our visitors were accompanied by **Ichio Asanuma** and **Tetsuro Isono**, both from the Frontier Research Promotion Office, and by **Hideyuki Tsunoda**, manager of the Knowledge Infrastructure Division Planning Department, JAMSTEC.

Awarded

IPRC's postdoctoral fellow **Haiming Xu** and his research team at Nanjing University and Nanjing Institute of Meteorology were awarded the 2003 First Prize in Natural Science by the Chinese Ministry of Education for Research. They received the prize of 50,000 Chinese yuan (about $6,000) for their work dealing with the thermodynamic effect of Indochina on the South China Sea monsoon onset. The team found that strong and persistent surface sensible heating in Indochina before the onset results in strong local temperature and geopotential-height gradients and strong local southwest winds. The team showed that this sensible heating and the subsequent convective latent heating lead to the summer monsoon onset over the South China Sea, the area with the earliest onset in Asia.

Published

The book *Earth's Climate: The Ocean-Atmosphere Interaction* was published this fall by the American Geophysical Union. "The book represents the climate community's first effort to summarize the modern science of ocean-atmosphere interaction and the roles that the interaction plays in climate variability in the Pacific, Atlantic, and Indian Oceans as well as interactions across basins and between the tropics and extratropics," (*Eos* 2004, **85** (46), p. 486). This book on the most recent observations, theories, and models of the ocean-atmosphere interaction that shape climate over the global ocean is co-edited by **Chunzai Wang**, research oceanographer at the Physical Oceanography Division of the NOAA Atlantic Oceanographic and Meteorological Laboratory in Miami, **Shang-Ping Xie**, co-leader of Indo-Pacific Ocean Climate research at the IPRC, and **James A. Carton**, professor of meteorology at the University of Maryland.

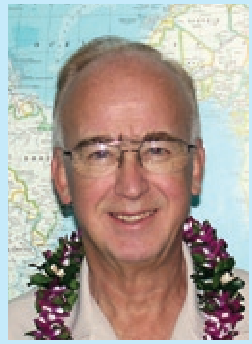


Papers summarizing findings from the Darwin Area Wave Experiment (DAWEX) are collected in a special section of the *Journal of Geophysical Research*, October 2004 issue. The DAWEX field campaign was conducted during 2001 in northern Australia in order to examine the effects of deep tropical convection. **Kevin Hamilton**, IPRC co-leader of the Impacts of Global Environmental Change research and host of the 2002 workshop on the results from DAWEX held at IPRC, is the lead author of the overview paper for this special section: K. Hamilton, R.A. Vincent, and P.T. May, "Darwin Area Wave Experiment (DAWEX) field campaign to study gravity wave generation and propagation." The special section is also available online at **www.agu.org/journals/ss/DAWEX1**.

A full list of IPRC publications are at **iprc.soest.hawaii.edu/publications/publications.html**.

IPRC scientists head meteorology and oceanography departments at UH

Kevin Hamilton, co-leader of the IPRC Impacts of Global Environmental Change research and professor of meteorology, began on July 1, 2004, a three-year term as chair of the University of Hawai'i Department of Meteorology.



Lorenz Magaard, IPRC executive associate director and professor of oceanography, starts in January 2005 a three-year term as chair of the University of Hawai'i Department of Oceanography.

Celebrated!

IPRC Director **Jay McCreary** and his contributions to tropical oceanography were celebrated at a day-long special session of the Indian Ocean Modeling Workshop held from November 29 to December 3, 2004, at the East-West Center in Honolulu. The occasion, McCreary's 60th birthday, spurred his friends and colleagues to relate the scientific impact of his work and to reminisce about past research endeavors. (The workshop will be described in the next issue of the *IPRC Climate*.)

At an evening reception during the workshop, the 60th birthday of **Bin Wang**, co-team leader of the IPRC Asian-Australian Monsoon team, was celebrated together with Jay McCreary's at the Halekulani Hotel in Waikīkī.

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IPRC Director Jay McCreary is receiving 60th birthday gifts from colleague Toshio Yamagata, Director of the Frontier Climate Variations Research Program, during the special session of the Indian Ocean Modeling Workshop.

Bin Wang, IPRC co-team leader of the Asian-Australian Monsoon System research, with colleague Julia Slingo, Director of the Centre for Global Atmospheric Modeling, during the evening celebration at the Halekulani Hotel.

On Television

The IPRC was featured several times on Hawai'i television in late summer–early fall. IPRC Director Jay McCreary was interviewed about the movie *The Day after Tomorrow* and whether such an extreme climate event could happen on Earth. McCreary was again interviewed about El Niño and what effects it may have on Hawai'i, following NOAA's announcement of the arrival of El Niño. Then in the beginning of October, the IPRC was featured as the climate research center at the University of Hawai'i. Video clips can be viewed at **iprc.soest.hawaii.edu/news/inthenews.html**.

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Should you no longer wish to receive this newsletter, please let us know.

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