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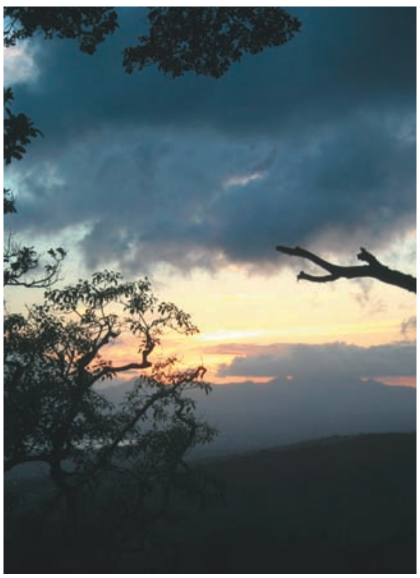


During summer, the northern Bay of Bengal shows the deepest convection on Earth; yet the eastern regions of the bay along the coast of Myanmar record more rainfall. See "Narrow Mountains of Asia Shape Monsoon Circulation," starting on page 3.

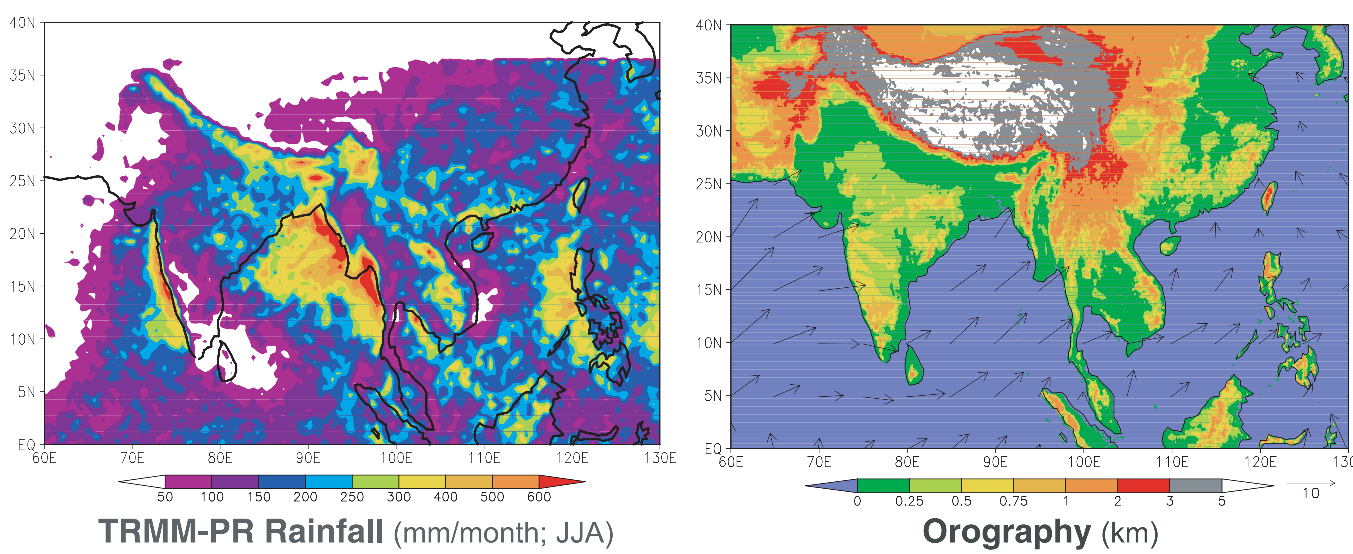
University of Hawai'i at Mānoa
School of Ocean and Earth Science and Technology

Narrow Mountains of Asia Shape Monsoon Circulation

Imagine a world without mountains! Temperature, wind and rainfall patterns would differ greatly from what we know. In Asia, the very high Tibetan Plateau exerts a strong influence on climate. Heated directly by intense solar radiation during summertime, the temperatures in June–August form a regional maximum. Lhasa at 3.65 km above sea level, for example, has an average comfortable 15°C during summer, a far cry from the nearly freezing temperatures found at the same altitude and latitude a few thousand kilometers to the east over the North Pacific. The high-altitude heat source intensifies the summer monsoon of Asia and draws the monsoonal flow towards the plateau. The impact of the Tibetan Plateau on the summer monsoon circulation was recognized in the late 1950s and explicitly demonstrated by Syukuro Manabe and colleagues in the 1970s with a general circulation model of the atmosphere they developed at Princeton (see *IPRC Climate*, Vol. 5, No. 2).

While the effect of the massive Tibetan Plateau on the monsoon is now well known, the role of other, less massive mountains has not received much attention. IPRC team co-leader for Indo-Pacific climate **Shang-Ping Xie** and **Haiming Xu** and their colleagues at IPRC and NASA's Jet Propulsion Laboratory decided to study the role of these mountains in images from the first precipitation radar flown in space on the Tropical Rain Measuring Mission (TRMM) satellite. They noticed that, except for the rain band hugging the foothills of the Himalayas, all the major rain bands over South and Southeast Asia during summer are anchored on the windward side of mountain ranges (Figure 1).

Figure 1. June–August climatology of surface precipitation (mm/month) based on TRMM precipitation radar observations (**left panel**); land orography (km) and QuikSCAT surface wind velocity (m/s; **right panel**).



The rain band at the foot of the Himalayas is associated with the daily heating and cooling of the mountains. All the other rain bands form as the prevailing southwest monsoon impinges on the north-south oriented mountain ranges and the air is forced to rise. These mountain ranges are not much more than 200 km wide in most places and, as a whole, are not very high. They each anchor an intense rain band on their windward side.

The Western Ghats in India, for example, capture the rain on their windward side, the side facing the Arabian Sea. In the rain shadow of these mountains to the east, southeastern India is dry as savanna. Across the Bay of Bengal, however, rainforest flourishes with heavy rainfall on the coastal mountain slopes of Myanmar. Even more telling, during summer, the northern Bay of Bengal features the deepest convection on Earth; yet the eastern regions of the bay along the coast of Myanmar record more rainfall.

Orographic effects on rainfall are seen elsewhere, for instance in Hawai‘i. The Hawai‘i rainfall has little effect, however, on the large-scale circulation of the atmosphere because the strong trade wind inversion prevents the vertical development of convection. High surface temperatures and moisture over the vast Asian monsoon region, though, are conducive to atmospheric deep convection.

Could the heat released in the rain bands along these mountain ranges affect the large-scale circulation? Xie and his team tested this possibility. Using the IPRC regional atmospheric model, they placed narrow heat sources along the coast of Myanmar, over Vietnam, and off the western coast of the Philippines to mimic the TRMM rainfall observations, the mountains being too poorly resolved in the model to create significant rainfall. Comparing this simulation with an unperturbed run without the rain-band heating, they found that the latent heating of these rain bands induced a continental-scale cyclonic circulation in the lower atmosphere (Figure 2). Changes in convection occurred even in the Arabian Sea and Bay of Bengal, where no convection had been placed. Thus, these rather unimpressive mountains not only influence rainfall nearby but, in the model at least, they exert a far-reaching influence on the monsoon system by seeding convection, which then interacts with the large-scale circulation.

The findings have implications for understanding the large-scale organization of convection, a long-standing problem in tropical meteorology. In the tropics, circulation and convection are tightly coupled. Convection and precipitation are always found where wind converges in the lower troposphere.

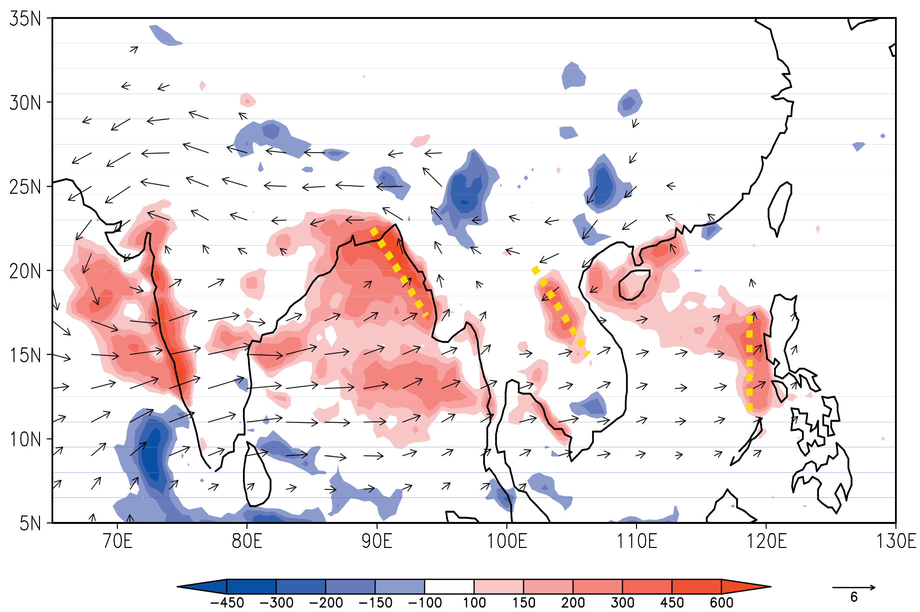


Figure 2. Model response to narrow heating bands (yellow dotted lines) that mimic orographic effects of mid-sized mountain ranges: differences in precipitation (color in mm/month) and 850h Pa wind vectors (m/s) between the simulation with heating bands and without. The wind vectors show the cyclonic circulation resulting from the release of latent heat in the rain bands.

This is a fundamental principle of tropical meteorology, but what causes what? Is a particular rainfall pattern induced by wind convergence or is it the other way around? This question is particularly acute in the study of the planetary disturbances of tropical convection, such as the important Madden-Julian Oscillation (see *IPRC Climate*, Vol. 4, No. 2, Data Surprises). Understanding the dynamics of this dominant tropical disturbance and simulating it in state-of-the-art numerical models remains a challenge. The IPRC study now shows that these rather modest mountain ranges, which have usually been not well resolved in general circulation models, block the path of the moisture-laden winds and short-circuit the interaction between convection and circulation. A conceptual model of the Asian monsoon therefore must include the mountain ranges.

The ability of general circulation models to simulate the orographic anchoring of monsoon convection is a critical test for the new-generation, high-resolution models. At the Frontier Research Center for Global Change in Yokohama, Japan, for instance, researchers are developing a super-high resolution global atmospheric model on Japan's supercomputer, the Earth Simulator. They have just completed a 3.5-km-resolution run of a hypothetical water-covered Earth and are now adding continents and mountains. This model will resolve mountains ranges of the size discussed here, and will, for the first time, explicitly simulate cloud clusters. These cloud clusters are tens to hundreds of kilometers in scale and an important building block for planetary-scale organization of tropical convection. Will this model be able to represent the rain bands in the Asian monsoon region that Xie and his colleagues have detected in the satellite images and that affect the large-scale atmospheric circulation?

The anchoring of rain bands by these mountains has also implications for scientists studying climates of the distant past. Asia was less mountainous before the Indian Plate collided with the Eurasian Plate. The tectonic building of the Tibetan Plateau has had a large impact on climate in Asia, the Indian Ocean, and beyond. The IPRC study means that the paleoclimate records must now take into account also the narrow mountain building and the rainfall patterns that they generate. The finding, furthermore, has implications for studying the interactions between wind, rainfall, and weathering, and how they shape the landscape of Asia, an upcoming line of research that cuts across meteorology, hydrology, and geology.

Above: View of the High Himalaya from the central Yarlang Valley in Tibet. (Courtesy of John Mahoney.) **Below:** Photo of rain clouds. (Courtesy of Axel Timmermann.)

Reference

Xie, S.-P., H. Xu, N.H. Saji, Y. Wang, and W.T. Liu, 2006: Role of narrow mountains in large-scale organization of Asian monsoon convection. *J. Climate*, in press (available at http://iprc.soest.hawaii.edu/~xie/meso-orog.pdf)

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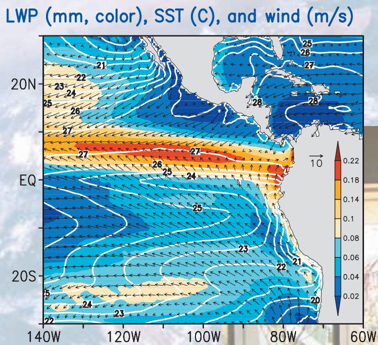
More Realistic Simulation of Eastern Pacific Climate



Kelvin Richards and Simon de Szoeke with Toru Miyama. Courtesy Toru Miyama.

The climate of the eastern Pacific plays an important role in the El Niño-Southern Oscillation and thus in global climate. This region, though, has been notoriously difficult to simulate realistically in climate models. IPRC researchers have developed a model, the iROAM (IPRC regional ocean-atmosphere model) that couples the IPRC regional atmospheric model (*IPRC Climate*, Vol. 2, No. 2) with the GFDL Modular Ocean Model. The ocean model covers the entire tropical Pacific, and the atmospheric model covers the eastern half of the Pacific as well as Central America and most of South America. In collaboration with the Kyousei-7 Project at the Frontier Research Center for Global Change (Frontier), the model has been adapted to run on Japan's Earth Simulator. The iROAM has successfully captured the salient features of eastern Pacific climate that have been so difficult to simulate, including the northward-displaced intertropical convergence zone (ITCZ) and the equatorial annual cycle. As in observations, the model ITCZ stays north of the equator most of the year except for a brief period in March and April when equatorial sea surface temperatures reach their annual maximum.

In March 2006, **Simon de Szoeke** and **Kelvin Richards** traveled to Frontier for further iROAM experiments. De Szoeke worked closely with **Toru Miyama**, a former scientist at IPRC and now at Frontier, on running new simulations with iROAM on the Earth Simulator. These simulations were designed to study the sensitivity of the eastern tropical Pacific climate to particular atmospheric and oceanic processes. The physics of these processes is uncertain, and their representation in coupled climate models is believed to cause the biases in the eastern tropical Pacific. For example, in one simulation, the shallow cumulus convection was decreased. This decrease in shallow convection increased stratiform cloudiness and changed the seasonal north-south migration of the ITCZ.

De Szoeke and Richards also participated in a mini-workshop with the K-7 scientists. They showed how insights on physical processes drawn from experiments with iROAM can improve the representation of tropical climate and constrain important physical parameters in coupled climate models.

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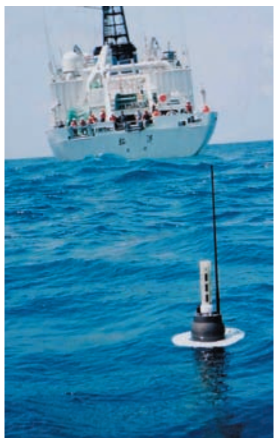
Measuring Deep Ocean Currents: A New Velocity Data Set



The international Argo program is observing the global ocean with more than 2400 profiling floats (Figure 1). These floats are an unprecedented source of hydrographic data and necessary for climate monitoring and keeping track of the ocean state. The floats sink to about two kilometers below the surface and as they rise, they measure temperature and salinity. When they reach the surface again, which is every 10 days or so, they relay conductivity, temperature, and depth measurements and their location via the Argo satellites. National Data Assembly Centers and two Global Data Acquisition Centers make the data available within 24 hours.

The Argo floats were not designed with deep-ocean current measurement in mind. While “parked” at depth, however, the floats are transported by deep horizontal currents. **Hiroshi Yoshinari**, **Nikolai Maximenko**, and **Peter Hacker** at IPRC’s Asia-Pacific Data-Research Center (APDRC) developed a method by which they could estimate the velocity of such currents with these floats. They calculated deep current velocities from float-displacements during the submerged phase of each cycle, and surface velocities from the float-drift during the sea surface phase (Figure 2).

These new, fully public, data sets are now available at IPRC’s Asia-Pacific Data-Research Center under the name

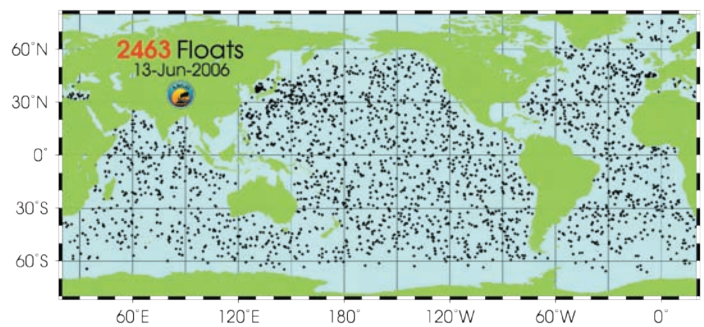


Figure 1, left: A PROVOR float shortly before recovery by the Japanese coastguard vessel Takuyo. Courtesy Argo Picture Gallery. **Above:** Position of floats that delivered data during May 13–June 13, 2006 .

“YoMaHa’05” (the first two letters of the three scientists’ last names). The set includes almost 167,000 values of velocity from 3039 floats, stored at nine Data Assembly Centers worldwide. The data span the period August 1997 to December 2005. Because the floats are transported by intermediate currents during their brief rise and descent and by time-varying surface currents during their stay of several hours at the surface, both surface and deep velocity data are accompanied by error estimates. These estimates are typically an order of magnitude smaller than the velocity values.

To illustrate how the YoMaHa’05 data can be used, the team calculated mean velocity at depth and at the sea surface by averaging data in 3° x 3° bins. The deep velocities were calculated from all measurements at parking levels deeper than 750 m and velocity errors less than 2 cm/s. The surface velocities were calculated from all measurements with the sur-

Figure 2 (top right): Schematic of float descent, at depth, and ascent. Courtesy of the Southampton Oceanography Center.

Figure 3 (below right): Example application: Shown are ensemble mean zonal velocities in cm/s from the YoMaHa'05 3° x 3° averaged values for the surface currents (**top**) and the deep currents (**bottom**).

face velocity errors less than 15 cm/s (Figure 3, top). The surface circulation pattern matches the one Maximenko and Niiler 2005 obtained using surface drifters. Figure 3, bottom, portrays the deep currents as charted by this new method. The currents are extraordinarily strong at depth in the Antarctic Circumpolar Current and contain a number of peculiar structures that invite further study.

The team plans to combine the CTD (conductivity, temperature, and density) profiles from the Argo floats with the trajectories of the floats to create a high-resolution map of large-scale deep circulation. With such data they will explore the alternating deep zonal jets found by Maximenko and Richards (*IPRC Climate*, Vol. 5, No. 1) in satellite altimetry images and in such high-resolution ocean models as OFES.

The IPRC technical note, *YoMaHa'05: Velocity data assessed from trajectories of Argo floats at parking level and at the sea surface*, is available at iprc.soest.hawaii.edu/publications/tech_notes.html. In the paper, the authors describe the data-distribution in space, time, and among Data Assembly Centers, as well as probability distributions of programmed float parameters and statistics of their displacements.

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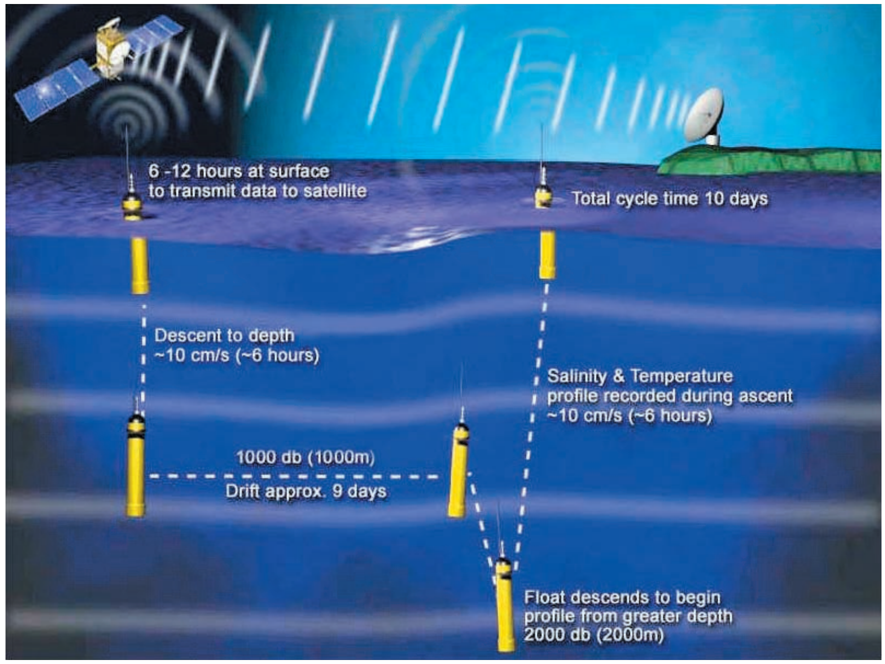
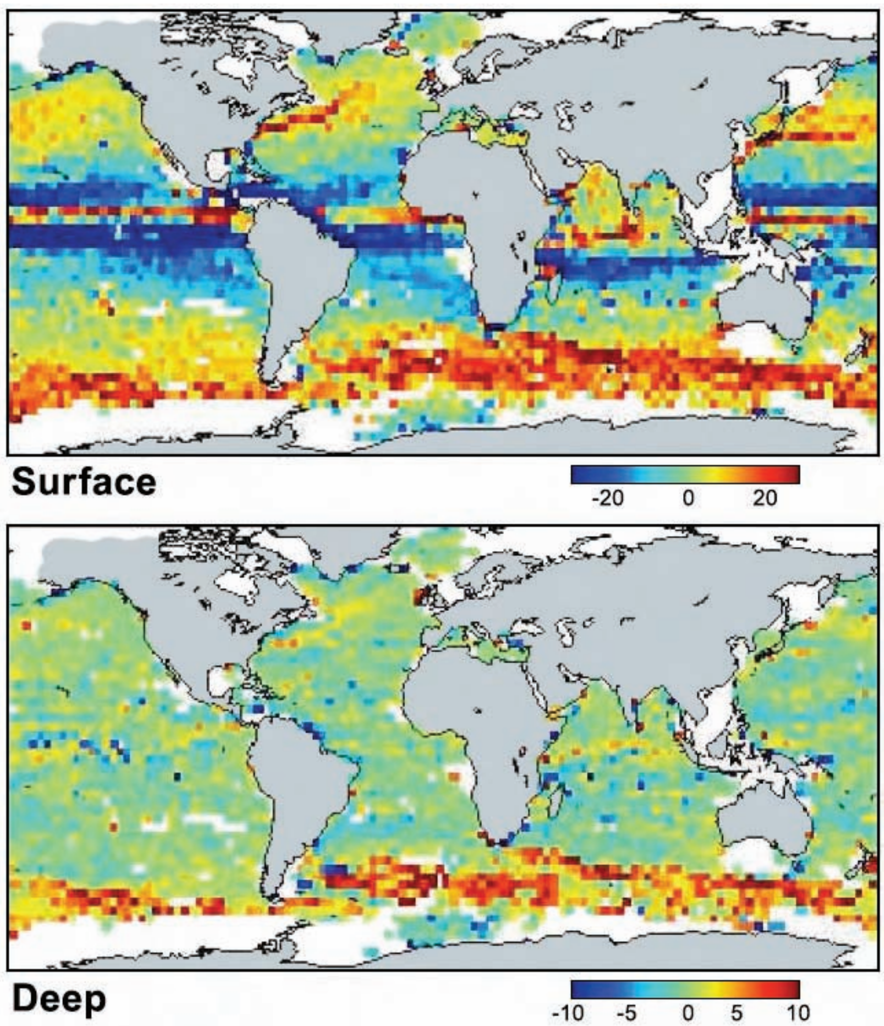




Klaus Wyrtki and El Niño

Gisela Speidel [1]

When an El Niño is announced, it means a warm current appears in the usually cool eastern Pacific. As part of a global climatic event, occurring on average every three to seven years, El Niño impacts weather around the world. Although El Niño has been known for centuries to people living and fishing along the South American coast, much of our understanding of El Niño dynamics has come about only in the last 35 to 40 years. An interaction between the ocean and the atmosphere, its cycles are not fully understood, and reliable prediction more than a few months in advance lies still in the future.

It was **Klaus Wyrtki**, oceanography professor at the University of Hawai‘i from 1964 to 1994, who provided a key piece to the El Niño puzzle that helped to forecast such events by several months. The weak trade winds over the tropical eastern Pacific had been thought to reduce the upwelling of cold water there, resulting in the accumulation of warm water. Wyrtki showed that under "normal" conditions, the trade winds in the Northern and Southern Hemispheres act to pile up warm water in the western Pacific, so that sea level is higher in the western than the eastern Pacific. When the wind field changes during El Niño, warm water surges eastward, a phenomenon he demonstrated with changes in sea level.

Wyrtki has received numerous awards for his research on El Niño and his contributions to understanding ocean dynamics: the Rosenstiel Award, the Maurice Ewing medal from the American Geophysical Union, the Sverdrup Gold Medal from the American Meteorological Society, the Albert Defant Medal from the German Meteorological Society, the Prince Albert I Medal from the International Association of the Physical Sciences of the Ocean, and the Alexander Agassiz Medal from The National Academy of Sciences.

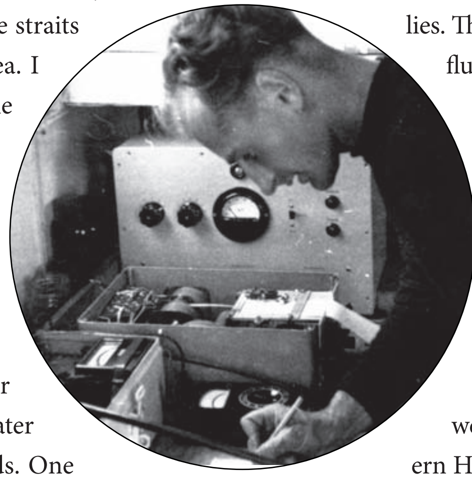
"Wyrtki was the first to understand that there are large-scale connections over the ocean, such that oceanic events near Peru and Indonesia could be linked together," says IPRC Director Julian McCreary. "Today, the idea seems so obvious. But in the 1970s it was a tremendous leap. The idea that combining sea level measurements from islands, separated in longitude by thousands of kilometers, could give a coherent picture about changes in ocean circulation was a great advance in scientific thinking."

What led Wyrtki to this "tremendous leap"? The story begins in post-war Germany, just after the universities opened their doors to students once more. "I was studying physics and mathematics at the University of Marburg. I knew I didn't want to be a physicist or a mathematician," Klaus Wyrtki recalls. "I was looking for applied things… took a course in climatology, read books on meteorology, and discovered that oceanography exists. I loved the sea. During the war, I was in the navy, on a little escort vessel. The captain treated me like his son. He taught me a lot and sometimes let me run the ship."

In Spring 1948, Wyrtki followed his dream and studied oceanography with Georg Wüst at Kiel University where he obtained his PhD in 1950 with *magna cum laude*. The years that Wyrtki spent analyzing the Baltic and North Sea water-mass budgets during and just following his dissertation work impressed upon him the astonishing variations that occur in the ocean. Through his work, he realized the power of the winds to influence the ocean, and just how much information sea-level variations provide about changes in ocean circulation.

"My first job was at the German Hydrographic Institute working for the British navy. I studied the wind field. Dietrich[2] gave me the assignment, and we computed the winds over the North Sea. We had wind data for a 50-year period, and we saw how much they varied. I studied how the winds influenced the flow through the Straits of Dover, and how sea level in the North Sea changed in step. That is where meteorology and oceanography came together for me, right in the beginning of my career."

"In April 1951, I returned to Kiel to study the water exchange through the Belt Sea, the straits connecting the Baltic with the North Sea. I made many measurements with paddle wheel current meters. I also studied existing long records of sea level and of surface currents from several light vessels. The combination of the short direct measurements and the long time series gave me insight into the fast response of the in- and outflow of water to the Baltic. The dynamics of these water movements were controlled by the winds. One very striking event occurred when large wind-produced seiches of the Baltic resulted in a flooding at Kiel… This research opened my mind to the importance of short, intense events for the circulation and water structure in the ocean. Ever since observing the seiches in the Baltic, I was wondering whether similar events might not happen in the large ocean basins. … Yes, as I found out later, they do occur, and it is called El Niño."[3]



It was many years, however, before Wyrtki turned his attention to the mysteries of El Niño. By then his work had taken him around the world, first to Indonesia (1954–1957), a brief stint in Monaco (where he lived next door to Winston Churchill), and then on to Australia (1958–1961) and Scripps (1961–1964). At Scripps, Wyrtki met the famous meteorologist Jacob Bjerknes, who was spearheading the El Niño research. Wyrtki remembers, "Bjerknes from UCLA often came down to us at the Tuna Research Program, and he talked about El Niño a lot. At the time, I saw El Niño as something unimportant, as a curiosity."

Only after his move to the University of Hawai'i and completion of his significant *Oceanographic Atlas of the International Indian Ocean Expedition*, did Wyrtki turn to climate and to El Niño. It was 1971. "The North Pacific Experiment (NORPAX) started, and Namias and Bjerknes wanted to find out how the Pacific Ocean affects North American climate. And I jumped on it. I was intrigued by Namias' work on how surface temperatures affect the weather downstream over North America, and by Bjerknes' work on how the equatorial ocean has something to do with these changes."

Bjerknes had been doing research on El Niño for over a decade. He had determined that El Niño was linked to unusual warm water in the eastern tropical Pacific that extended far to the west and resulted in large-scale weather anomalies. These unusual conditions he connected with fluctuations in the trade winds in the Northern and Southern Hemisphere and to the Southern Oscillation. Bjerknes thought the warm water off the coast of Peru stemmed from less upwelling when the trade winds were weak. In 1969 he concluded: "The maxima of the sea temperature in the eastern and central equatorial Pacific occur as a result of anomalous weakening of the trade winds of the Southern Hemisphere with inherent weakening of the equatorial upwelling." Bjerknes had not looked at what was happening below the sea surface and to the currents.

The next years whirled Wyrtki into the center of El Niño research. This is how it began: "I had to write a proposal for NORPAX, and I went to my computer programmer Shikiko Nakahara, and said, 'Shikiko, we have to make a discovery. We have monthly maps in the Indian Ocean Atlas of the depth of the 20°C isotherm (the depth at which the ocean temperature is 20°C). Why don't you make monthly difference maps for the whole year.'" Wyrtki chose the 20°C isotherm as, in this region, this temperature marks the center of the thermocline, the layer in which water rapidly gets colder. The depth of the thermocline varies greatly and therefore tells oceanographers much about the ocean structure and such things as ocean currents.

"A few days later, Shikiko brought all these maps, and there we saw that in May along the coast of Somalia the 20°C isotherm went up—this was the case all the way from the Arabian Sea to Madagascar—and it went down off the coast of Sumatra. I calculated the change in the level of the thermocline and got a huge volume of water. There must be a current of 15 to 20 Sverdrups between the two coasts and that is not peanuts! (one Sverdrup equals a flow of one million cubic meters per second.) In October, the current flows again. It's because of the winds. During the transition between the summer and the winter monsoons, the winds are westerly on the equator. They push the water eastward across the Indian Ocean and the water piles up along Sumatra. These jets gave me an explanation for El Niño."

Between the westward-flowing North and South Equatorial currents, the Equatorial Countercurrent, carrying warm water, flows eastward across the Pacific between about 4°N and 10°N. "I knew from my research that these currents vary during seasons and over years. So when the transport of the Countercurrent is stronger than normal, sea surface temperatures in the eastern Pacific should be higher." The warm water off Peru during an El Niño, therefore, might not be the direct result of local weaker trade winds and less upwelling in the east, but water that comes across the Pacific from the west.

To confirm his hunch, Wyrtki needed data on the winds and currents in the Pacific. Although daily wind data existed at some islands, there were no analyses over time. He recalls: "I asked our meteorologists, 'How do the trade winds change?' and the answer was, 'We don't really know!' I said, 'We have to know because the trade winds drive the circulation, and so we must know how they vary with time.' In 1972, about 3 million ship observations in the Pacific Ocean became available from the National Climate Data Center. My graduate student Gary Meyers reduced the data into monthly wind charts. People thought we should stop at the equator… I said, 'The equator is only a mathematical line. We must include the entire southeast trades.' That was an important decision. El Niño, it turned out, is connected with events spanning the equator."

The wind data were ready for use only a year later. The ocean data to demonstrate variations in the Countercurrent were also hard to come by. After the war, tide gauges had been put onto some islands in the Trust Territories by the United States Coast and Geodetic Survey. The 20 years of tide-level data could be converted into the times series of the sea level that Wyrtki needed. With tide gauges in only four central Pacific locations—two islands located near the northern flank and two islands on the southern flank of the countercurrent—Wyrtki set out to confirm his hypothesis: "Combining the dynamic topography from ship records with the sea level observations from the tide gauges, I developed my method to compute the strength of the equatorial currents in the central Pacific. The high correlation between the transport and the sea level differences allowed me to measure current strength. I found that the currents between pairs of islands undergo large fluctuations. My simple conclusion was that if the Countercurrent runs very fast, it must bring much more warm water to Central America. So I compared over the years the strength of the countercurrent in the central Pacific with sea surface temperatures in Costa Rica, and they agreed wonderfully. Although my measurements were on the other side of the equator, I thought that a very strong countercurrent must be related to El Niño off Peru. That led to my Teleconnections paper, and that's when I got together with Bjerknes. Bjerknes was absolutely delighted when he saw that… It was a most exciting time."

In the Teleconnections article, Wyrtki concluded: "The countercurrent carries warm water into the eastern tropical Pacific, and fluctuations in its strength give rise to temperature anomalies off Central America. Periods of exceptionally high transport by the countercurrent in the western Pacific coincide with occurrence of El Niño several thousand kilometers downstream and demonstrate the existence of teleconnections between events in the Pacific… Such teleconnections have been found in the atmosphere by Bjerknes, but I believe, have not before been established in the ocean."[4]

At a NORPAX meeting at Lake Arrowhead in 1974, Wyrtki presented his theory on El Niño that now included the trade winds. In the publication that followed the meeting and became a citation classic, Wyrtki wrote: "During a period of strong southeast trades… the circulation in the subtropical gyre is intensified, in particular the South Equatorial Current. This coincides with a buildup of east-west slope of sea level and an accumulation of water in the western Pacific. … As soon as the wind stress of the southeast

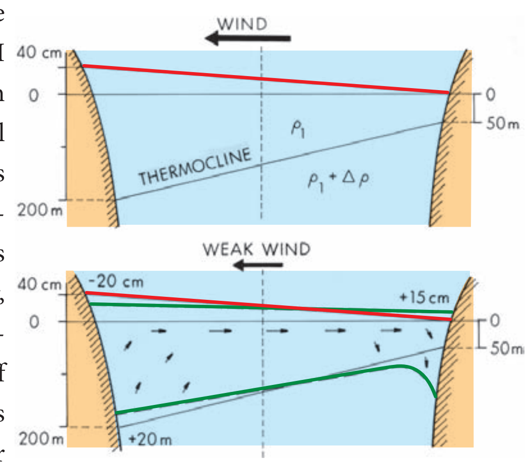


Figure 1: Driven by trade winds, the sea level slopes upward across the Pacific from east to west (**red line**). During a period of weak winds or westerly winds, sea level falls in the west and rises in the east. With such sea level changes, measured at island stations across the Pacific, Wyrtki documented fluctuations in sea level and thermocline depth (**green lines**) and in the strength of the tropical current system, from which he then developed his theory of El Niño.

Klaus Wyrtki receives the Alexander Agassiz Medal from Bruce Alberts, President of The National Academy of Sciences. The medal was awarded to Wyrtki in 2004 "for fundamental contributions to the understanding of the oceanic general circulation of abyssal and thermocline waters and for providing the intellectual underpinning for our understanding of ENSO (El Niño)."

trades relaxes, the water accumulated in the western Pacific will tend to move back. This may happen in the form of an internal seiche or internal equatorial Kelvin wave… In any case, it must happen in a mode consistent with the hydrodynamics of the system. It can be assumed that eastward flow in those currents which normally transport water to the east… will be intensified. The result will be an accumulation of warm water in the area off Peru… in essence, El Niño." [5]

"The first speaker at the Lake Arrowhead meeting was Bjerknes," Wyrtki recalls. "We had just started to have satellite-observed clouds, and Bjerknes showed the cloud development related to El Niño. The second speaker was Bill Quinn. Quinn said, 'Whenever the Southern Oscillation reaches a maximum (the southern trade winds are strong) and then weakens, that gives an El Niño. And next year is an El Niño.' That was the very first El Niño prediction. Then came my talk. I explained my El Niño theory… the collapse of the wind field, the water rushing east.

"That evening, the three of us decided that we should verify the prediction. There should be an expedition into the waters south of the Galapagos, to see whether the water warms and sea level goes up. I wrote a grant proposal and received funding within a few weeks. We sent our new University of Hawai'i research ship, the *Moana Wave*, to Peru. Unfortunately, the El Niño was aborted… it came a year later."

"The year 1975 will not enter oceanographic history as a year of a large El Niño. However, as predicted an El Niño situation started to develop with a characteristic overflow of warm, low salinity water… along the coast," said the *Science* article that summarized the expedition.

Given this discouraging outcome, Wyrtki awaited anxiously more sea level data from the island tide gauges that covered the 1972–73 El Niño period and the tropical Pacific from the Solomon Islands to the Galapagos. When the data came, he remembers, "Now we will see whether my theory is correct. And there, this figure (he points to a figure of sea level changes in the Solomon Islands and in the Galapagos) shows that before the 1972 El Niño, sea level in Galapagos Island is persistently 5 cm lower than normal; in the west, at the Solomon Islands it is 10 cm above the mean. When El Niño sets in, the water around Solomon Islands drains. Sea level goes down by 30 cm and some time later at Galapagos it goes up. And that is the classical El Niño figure. This verified my theory. Up to that point it was a theory." [6]

But the theory was shaken by the 82–83 El Niño. Wyrtki: "The story is that the 1982–1983 El Niño started in a mysterious way. There was a volcanic explosion in Mexico that spoiled all the satellite data world wide. Nobody knew what the real sea surface temperature distribution observed from satellites was. In October 1982, at a Climate Diagnostics Workshop held at the National Center for Atmospheric Research in Boulder, some said, 'An El Niño is coming,' and others said, 'None is coming.' And I said, 'None is coming, because I do not see it in the sea level.' And this became the biggest El Niño of the century!"

"Because at that meeting I claimed there must be a buildup of warm water ahead of El Niño, people said, 'So this buildup is not necessary.' But this is not true, it is necessary. The Kelvin wave can only happen when there is a buildup of warm water in the western Pacific."

Once data became available, Wyrtki documented in several scientific papers what happened to the ocean and the atmosphere during this surprise El Niño. And indeed, the important sea level changes were there. Before El Niño began in June 1982, sea level was about 40 cm higher in the western Pacific than at Galapagos. In January, the sea level across the Pacific was essentially flat. It was the wind that was different from the expected.

In one paper Wyrtki explained, "Previous El Niño events were usually preceded by periods of strong southeast trade winds, which led to a considerable depression of the thermocline in the western equatorial Pacific and to a rise of sea level. Such anomalously strong southeast trade winds did not precede the El Niño of 1982/1983. With the appearance of *westerly winds*

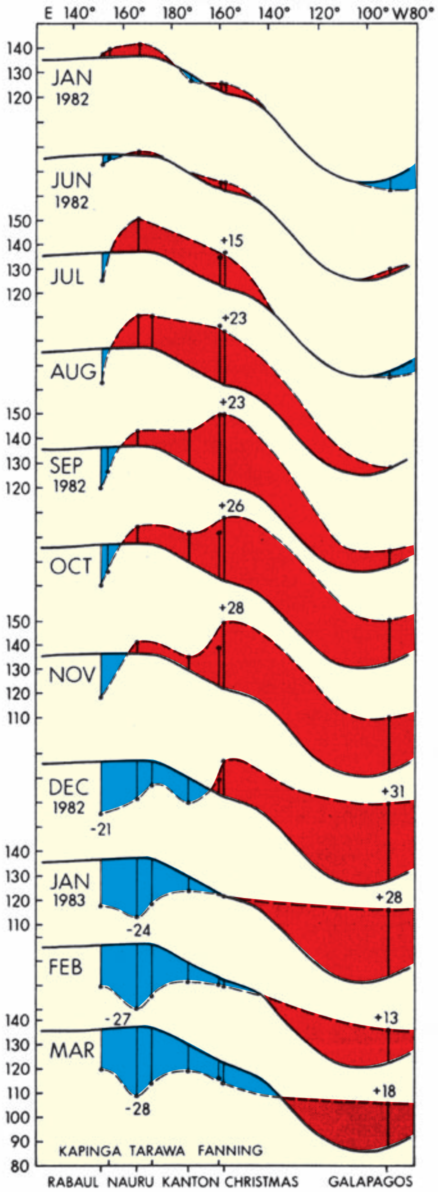


Figure 2: The changes in sea level at the eight stations across the Pacific from January 1982 through March 1983. The Kelvin wave bulge can be seen moving eastward beginning July 1982. By December the sea level across the Pacific is nearly flat. (Adapted from Wyrtki, 1984.)

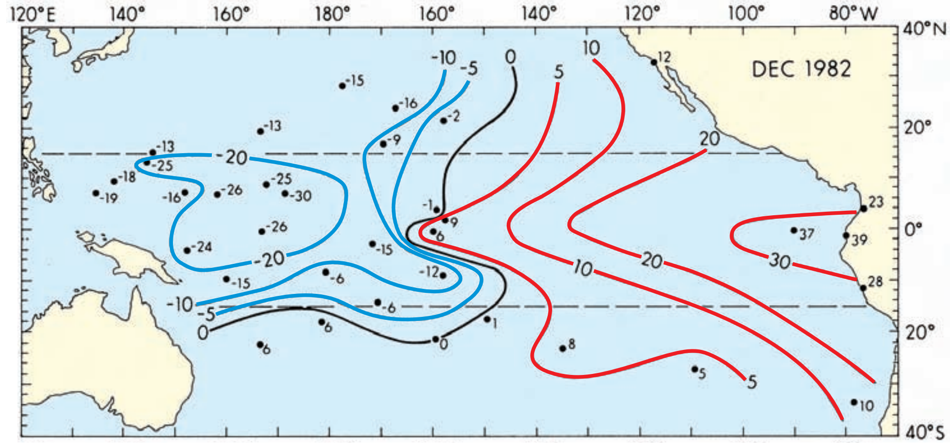


Figure 3: The extent of the Pacific sea level anomalies (in cm) in December 1982. **Red contours** indicate higher sea level (and warmer water), **blue contours** lower sea level (and cooler water) than normal. Dots denote sea level stations. (Adapted from Wyrtki, 1985.)

(italics added) over the western Pacific in July 1982, sea level immediately responded… The generated bulge of water advanced eastward as an equatorial Kelvin wave… As the westerly winds propagated eastward from July through November, sea level in the western Pacific decreased… By December 1982 the Kelvin wave had passed Christmas Island, and a peak in sea level of 31 cm had reached the Galapagos Islands."[7] The warm water had arrived along the coast of Peru.

Wyrtki took time to adopt the term *equatorial Kelvin wave*. In 1975, he wrote "water flows eastward, probably in an internal equatorial Kelvin wave." In his 1977 article, he concluded, "The… oceanic response seems to take the form of an equatorial Kelvin wave." With the analysis of data now from 8 sea level gauges strewn across the Pacific along the equator, he could demonstrate how, in the 82–83 El Niño, "the generated bulge of water advanced eastward as an equatorial Kelvin wave." (See Figure 2.) He noted, moreover, that "changes in the east-west slope are not limited to the equator. … The draining of water from the western Pacific affects the area from 20°N to 15°S… The entire equatorial current system is affected and altered." Asked during the interview about the term equatorial Kelvin wave, Wyrtki says, "That is a mathematical term. I prefer to call it a Kelvin surge because observations show that the whole equatorial current system is affected." (See Figure 3.)

In his last years of El Niño research, Wyrtki focused on documenting the evolution of a complete El Niño cycle to answer the question still challenging scientists today: What starts and stops an El Niño? Again, his main tool was sea level measurements.

Numerical models suggested that El Niño events are linked with strong heat transport away from the tropics towards the poles. Using sea level height as an indicator of the volume of water above the thermocline and, therefore, an indicator of heat, Wyrtki showed that over time warm water accumulates in a warm pool on the western Pacific boundary, both north and south of the equator. Periodically, a Kelvin wave "displaces" this warm water to the central and the eastern Pacific, where it then flows poleward along the coasts of North and South America. El Niño is a way for the tropical Pacific to get rid of its heat. "A complete El Niño cycle results in a net heat discharge from the tropical Pacific toward higher latitudes. At the end of the cycle the tropical Pacific is depleted of heat, which can only

Wyrtki on the School of Ocean and Earth Science and Technology research vessel that bears his name.

be restored by the slow accumulation of warm water in the western Pacific by the normal trade winds. Consequently, the time scale of the Southern Oscillation is given by the time required for the accumulation of warm water in the western Pacific. Its release is triggered by fluctuations in the tropical atmosphere."[8]

Another observation by Wyrtki seems associated with El Niño cycles: "I was intrigued by the fact that the North and South Equatorial Currents vary out of phase. When one is strong, the other is weak. Are the North and South Pacific subtropical gyres also operating out of phase? I was hoping they would be. To measure this asymmetric response, we compared sea level variations in Honolulu and Pago Pago, the only two stations that had sea-level time series good for characterizing changes in the gyre of each hemisphere. The result came out nicely: the gyres alternate, one would be stronger, the other weaker on time scales of four to eight years. I proposed that these oscillations are linked to El Niño.[9] I asked many theoreticians to investigate that problem. Nobody has done so until now."

In his last scientific talk on El Niño at a TOGA COARE meeting in Noumea, Wyrtki showed how the heat discharge–recharge theory, the out-of-phase relationship between the two subtropical gyres, the fluctuations in the various equatorial currents, the accumulation of water in the warm pool could all be linked with El Niño.[10] "Between two El Niño events the southern gyre accelerates. During these periods the South Equatorial Current is strong, adding warm water to the warm pool, and the Countercurrent is weak, draining less water from the pool. The two effects allow the warm pool to grow. During El Niño, the southern gyre becomes weaker, the Countercurrent stronger, and water drains from the warm pool." He concluded, "The interaction of the two subtropical gyres is intimately involved in the fluctuations of the warm pool and in the creation of El Niño events." Critical for this interaction is the Countercurrent, "It is the boundary current between the two subtropical gyres."

Wyrtki has made many significant contributions to physical oceanography, among them a theory of the thermohaline circulation and a theory of the layer of minimum oxygen. Here only a few highlights have been retold of how Wyrtki has advanced our understanding of El Niño. His students, Roger Lukas, Bill Patzert, Gary Meyers, and William Emery, themselves now all well-known oceanographers, succinctly captured his forty years of contributions to oceanography: "Klaus Wyrtki is an oceanographer in the classical interdisciplinary sense: providing the grand synthesis whenever possible, making pioneering new observations where data limitations are too great, and approaching his research with an understanding of meteorology and other disciplines."[11]

1 This "story" was compiled from interviews with Klaus Wyrtki, his written reflections, and excerpts from his publications. I thank Jay McCreary for his clarifications and editing.

2 Gunter Dietrich, German Oceanographer

3 From Klaus Wyrtki's "My Scientific Work" written for his children.

4 Wyrtki, K., 1973: Teleconnections in the equatorial Pacific Ocean. *Science*, **180**, 262–264

5 Wyrtki, K., 1975: El Niño: The dynamic response of the equatorial Pacific Ocean to atmospheric forcing. *JPO*, **5** (4), 572–584, p. 578.

6 Wyrtki, K., 1977: Sea level during the 1972 El Niño. *JPO*, **7** (6), 779–787.

7 Wyrtki, K., 1984: The slope of sea level along the equator during the 1981/83 El Niño. *JGR*, **89**, 10419–10424.

8 Wyrtki, K., 1985: Water displacements and the genesis of El Niño cycles. *JGR*, **90**, 7129–7132.

9 Wyrtki, K., and Wenzel, J., 1984: Possible gyre-gyre interaction in the Pacific Ocean. *Nature*, **309**, 538–540.

10 Wyrtki, K., 1989: Some thoughts about the West Pacific Warm Pool. In J. Picaut et al. Eds., *Proc. of the Western Pacific International Meeting and Workshop on TOGA COARE*: 99–109.

11 Lukas, R., B. Patzert, G. Meyers, and W. Emery: Klaus Wyrtki's forty years of contributions to oceanography: His students' perspective. *Oceanography*, April 1990, p. 38.

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Weather Extremes in a Warmer Climate

Extreme weather often leads to disasters. The societal impacts of a warmer climate, thus, depend on how such a climate will affect the nature and frequency of weather extremes. These can be seen as falling loosely into three groups: prolonged extreme conditions such as droughts, heat waves, and cold waves; short-term extremes such as a sequence of rainy days leading to local flooding; and individual brief and violent events such as tornadoes and hurricanes or typhoons that do their damage to a particular place within minutes to a few hours.

In March 2006, NCAR senior scientist **Gerald Meehl**, a member of the IPRC Science Advisory Committee and a JIMAR Visiting Senior Fellow, gave a seminar on weather extremes to scientists at IPRC and the Department of Meteorology, University of Hawai'i. In his talk, Meehl considered aspects of all three kinds of extremes.

Regarding prolonged extreme conditions, Meehl discussed the occurrence of heat waves, defined in two ways. One definition, based on the deadly Chicago 1995 heat wave, is the occurrence of unusually high night-time minimum temperatures for at least three consecutive nights. In projections simulated by versions of the NCAR global coupled atmosphere-ocean general circulation model, Meehl found that the intensity, frequency, and length of heat waves are predicted to increase in the late 21st century in most regions, but most notably in southern and western North America, western Europe, and the Mediterranean.

Meehl also spoke about the occurrence of frost days and the length of growing seasons projected in his atmosphere-ocean GCM. As might be expected, the warmer climate at the end of this century is predicted to have, on average, longer growing seasons (duration of frost-free conditions). The increase in growing season length is far from uniform, however, even for locations at the same latitude. Notably the frost-free season is predicted to increase much more in the U.S. Pacific Northwest than in the Northeast. The change is accompanied by regional patterns of atmospheric pressure trends that promote more warm air advection along the west coast of North America. The predictions concerning the frost-free days are consistent with observations. These show a trend of about 2 more frost-free days per decade since the 1950s in the Pacific Northwest, while no significant trend has been observed along the U.S. Atlantic coast. Meehl noted that the practical consequences of more frost-free days, and therefore longer growing seasons, are not all positive since the latter may allow harmful pests to proliferate.

Hurricane Katrina, August 28–29, 2005. (Image courtesy of NASA.)

All climate models participating in the current assessment of climate change by the Intergovernmental Panel on Climate Change (IPCC) predict an increase in global average precipitation for the warmer climate toward century's end. This increase in precipitation is easily understood as an inevitable consequence of increased evaporation in a warmer world. The models predict more intense precipitation almost everywhere, in both arid and wet regions. At the same time, however, the models generally predict less frequent precipitation events. Thus, on average, the rain in the globally warmed world is predicted to be more intense but also more intermittent than in the present climate.

With respect to violent weather extremes, Meehl remarked on the current surge of interest in global warming effects on tropical cyclone frequency and intensity. He mentioned four recent model studies that deal with this issue. One study, conducted by the Japanese on the Earth Simulator in Yokohama, used a high-resolution (20 km) global GCM. The other three used various kinds of limited-area models. Among the latter, is the study by **Markus Stowasser**, **Yuqing Wang**, and **Kevin Hamilton**, who used the IPRC regional atmospheric model (*IPRC Climate*, Vol. 5, No. 1). The studies agree that in a globally warmed world the total number of tropical cyclones in each major ocean basin may either decrease or not change dramatically but the number of the most intense and destructive storms will increase significantly.

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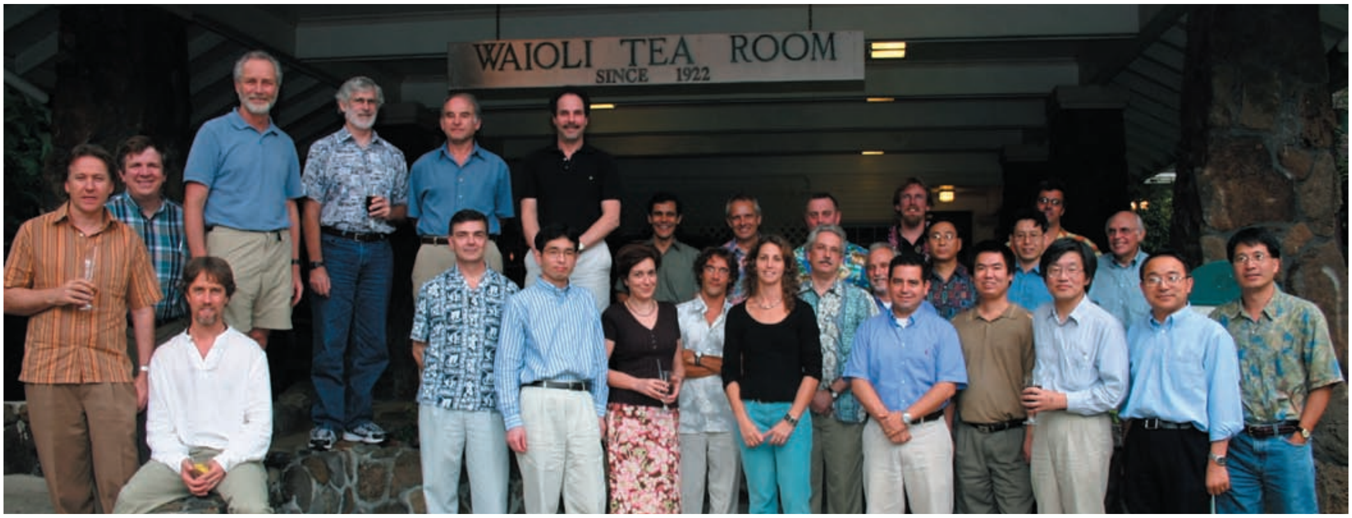
New Thrusts, New Field Programs in the Pacific



Pacific Panel of International CLIVAR and their guests.

Surrounded by lush Hawaiian flora, and fighting mosquitoes and centipede attacks, the Pacific Panel of International CLIVAR (Climate Variability and Predictability) and their guests met February 15–17, 2006, in beautiful Manoa Valley in Honolulu. The retreat introduced the new panel (chaired by IPRC's **Axel Timmermann**), identified new scientific thrusts, and discussed new observational programs.

The new panel members are **Magdalena Balmaseda** (ECMWF, UK), **Wenju Cai** (CSIRO, Australia), **Amy Clement** (RSMAS, USA), **Bill Crawford** (IOS, Canada), **Dick Feely** (PMEL, USA), **Alexandre Ganachaud** (IRD, New Caledonia), **Rodney Martinez** (CIIFEN, Ecuador), **David Neelin** (UCLA, USA), **Scott Power** (BoM, Australia), **Bo Qiu** (University of Hawai'i, USA), **Toshio Suga** (Tohoku University, Japan), and **Dongxiao Wang** (SCSIO, China).

With regard to *ENSO dynamics*, the westerly wind bursts and their coupling with sea surface temperature were discussed as triggers of large El Niño events. These disturbances contribute to the wide spread in El Niño-Southern Oscillation (ENSO) forecasts among ensemble members. The challenges still remaining in forecasting El Niño and La Niña were noted in several reports. Recognizing the incomplete understanding of ENSO dynamics and the slow progress in seasonal prediction, the panel is organizing an international ENSO meeting in Australia in 2007.

A report on the *state of coupled general circulation models*, used for example in the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), shows that in most models the tropical mean state of the Pacific is severely biased, with the eastern tropical Pacific being too cold and the southeastern tropical Pacific being too warm (see page 6). Reasons for the biases were discussed. The new field program VOCALS (VAMOS Ocean-Cloud-Atmosphere-Land Study) may provide some answers. VOCALS studies feedbacks between upper-ocean dynamics, sea surface temperature (SST), stratocumulus clouds, and climate in the southeast Pacific. Another new program PUMP (Pacific Upwelling and Mixing Physics), which is looking at the effects of mixing on the mean thermocline temperature and variability in the eastern equatorial Pacific, should also provide answers. The panel plans to have close ties with these two programs.

The *warm pool of the western tropical Pacific* affects the strength of the Walker circulation and the position of the stationary wave patterns in the extratropics. Paleo proxy data reveal that the warm pool was about 4°C colder under glacial conditions than today. This suggests the heat balance of the warm pool is subject to long-term changes. Since climate modeling of this region is still problematical, an accurate assessment of the warm pool's effect on global climate change is not yet possible. Concerned about possible temperature changes in the warm pool, the panel members recommend that more field programs target the region. The ongoing and planned field campaigns of the South China Sea Institute of Oceanology should improve our understanding of this region.

The *western boundary currents*, which transport heat away from the tropical oceans and release it to the atmosphere at higher latitudes, modulate the climates of Japan, New Caledonia, Australia, and indeed global climate. Changes in wind-stress can shift the fronts of these currents and alter the surface temperature in ways that affect atmospheric circulation. The Kuroshio Extension System Study (KESS) has looked into these front-shifts, and results suggest that long-term prediction of thermocline anomalies in the western North Pacific is feasible. Given this encouraging news, the panel decided to evaluate the hindcast and forecast skills of simple ocean prediction models that are driven by observed wind-stress anomalies and to assess their utility in climate predictions.

The *subtropical-tropical connections of the western boundary currents in the South Pacific* were outlined. SPICE (Southwest Pacific Ocean Circulation and Climate Experiment) is starting to monitor the dynamics and boundary currents in the southwest Pacific. Since the program is conducting experiments in the South Pacific analogous to KESS's North Pacific work, the panel recommended that SPICE establish links with KESS to learn from its experiences, and also with activities conducted by China on monitoring the low-latitude western boundary currents.

The topic *panoceanic connections* included descriptions of the supergyre in the Southern Hemisphere, the oceanic connections between the Pacific and Indian oceans, and results from Coupled Model Intercomparison Project water hosing experiments. The latter suggest that a weaker North Atlantic thermohaline circulation shifts the intertropical convergence zone in the Atlantic and Pacific southward. This shift changes the meridional sea surface temperature gradient, altering the annual cycle and ENSO. These oceanic and atmospheric teleconnections between ocean basins will be a major topic of the CLIVAR Multidecadal-to-Centennial Climate Variability Workshop to be held by the IPRC in Honolulu November 15–17, 2006.

The *climate change* section covered the following topics: a sketch of how our understanding of paleo climates can be used to assess future climate sensitivities; a study of estimates of radiation reduction due to aerosols, which account for 0.6–0.8°C cooling in the central equatorial Pacific and for over 1°C cooling in the subpolar North Pacific. This aerosol effect may be diminishing the greenhouse warming signal in the Pacific Ocean and its polar amplification.

Modeling Pacific climate is still fraught with uncertainties that hamper projections on how global warming will affect the region's climate. The panel debated the possibility of weighting simulations from different models in multi-model runs in accordance with their ability to meet certain standards. No conclusion was reached.

Standards for Ocean Models

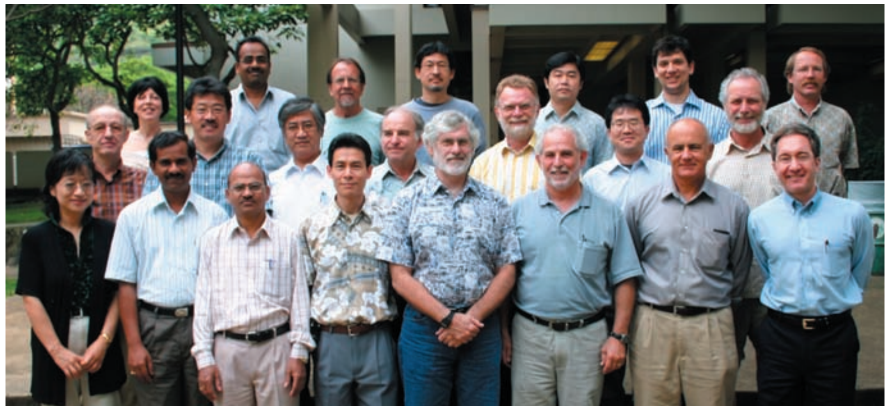
The development of high-resolution, large-scale ocean models will help to understand how the ocean state is changing and to predict such changes. The physical processes and space and time scales of such models, however, must be carefully compared against observations, and their thermodynamic and dynamic balances, and such features as eddy sizes and eddy structures must be assessed. The creation of a model-evaluation system that permits comparisons across models is therefore urgent. To help with the development of such a system, the IPRC hosted the "Workshop on Metrics of Ocean Models" at the East-West Center, February 25, 2006. About 60 researchers and scientists from U.S. research funding agencies participated in the workshop.

Data sets derived from various satellite measurements and from direct measurements of the ocean are complex and diverse. The idea is to distill these different sets into a format that is relatively simple to use and allows comparisons among models and between models and observations. Two types of measurements or metrics were discussed: those characterizing the ocean state, and those characterizing the response of the ocean to a forcing imposed upon it. A standard grid for averaging data and clear identification of errors will make ocean observation sets more useful for model evaluation.

Workshop participants suggested creating a website dedicated to the development and use of metrics for ocean-model evaluation. The site would feature, among other things, descriptions and links to observationally derived data sets as well as a comparison between metrics derived from ocean models and from observations.

The workshop was organized by **Julie McClean**, Scripps Institution of Oceanography, and **LuAnne Thompson**, University of Washington, and sponsored by the Office of Naval Research and the International Pacific Research Center.

Plan Completed for Indian Ocean Observing System



Indian Ocean Panel Chair Gary Meyers (front row third from right) with IPRC Director Jay McCreary to his left and members of the Indian Ocean Panel.

The Indian Ocean Panel Workshop was held in early March 2006 at the IPRC in Honolulu instead of, as originally planned, in Reunion, where a mosquito-borne Chikungunya epidemic had broken out. Established in 2004, the panel was charged by the Climate Variability and Predictability (CLIVAR) Program and the Global Ocean Observing System (GOOS) with creating a plan for a comprehensive and continuing observation system to monitor Indian Ocean climate (*IPRC Climate*, Vol. 5, No.1).

At the Honolulu meeting, the panel's accomplishments were reviewed. The most important one is completion of the observation plan. The plan calls for a mixture of moored buoys, Argo floats, Acoustic Doppler Current Profilers, and ships to supplement remote satellite observations. It is published at eprints.soton.ac.uk/20357/. As a result of the panel's work, funding of the observing system by other countries has been forthcoming.

The monitoring system will be invaluable in answering such important climate questions as: Which surface and subsurface conditions in the Indian Ocean affect climate in Africa, Australia, Asia, and beyond? How do ocean conditions affect atmospheric disturbances, particularly the Madden-Julian Oscillation? Sea surface temperature (SST) in the Indian Ocean has increased rapidly in recent decades, while the heat flux into the ocean has decreased. What processes control this rise in SST?

Having published their observing system plan, panel members decided the panel should continue with a new charge. For instance, the panel is well positioned to provide the scientific and technical oversight needed for implementing the system, coordinate the work of participating organizations, ensure the observing system's functioning, recruit new participants, and develop links with the Indian Ocean Tsunami Warming and Mitigation System. The panel is also the appropriate group for coordinating and planning future research on Indian Ocean climate and its effects on the climate system as a whole. The Panel has presented recommendations for its continuation to the International CLIVAR program and GOOS.

High-Resolution Ocean Modeling on the Earth Simulator

The IPRC is participating with scientists from the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) in analyses of outputs from high-resolution climate models run on the Earth Simulator (see page 6). IPRC's visiting scientist **Justin Small** hosted a workshop on February 27 on the University of Hawai'i campus for scientists working with OFES, the Ocean General Circulation Model for the Earth Simulator. Scientists from the Earth Simulator Center, the United Kingdom Met Office, and the IPRC discussed technical issues, reviewed recent research outcomes, and looked into possible collaborations. The workshop talks included low-frequency (decadal) variability, zonal jets, throughflows, countercurrents, parameterizations of eddy mixing, and chemical and biological transports. Work with OFES that may spawn further collaboration is summarized below.

OFES simulations on year-to-year and decadal variations in sea surface temperature (SST) and ocean currents were presented for the Oyashio Current, the South Pacific, the Kuroshio Extension, and the Gulf Stream. How these variations come about and how they affect SST, the atmosphere, and storm tracks promise to be fruitful topics for collaborations between IPRC and JAMSTEC. Among the first high-resolution models to have made hindcasts of many decades, OFES is suited for such studies. In particular, its high resolution allows study of the impact of eddies and sharp fronts on decadal variability.

Using QuikSCAT scatterometer wind measurements to force OFES can improve simulations. For instance, the Hawaiian Lee Countercurrent, a zonal jet flowing eastwards towards Hawai'i, was more realistic in the QuikSCAT-forced run than in a run forced with NCEP/NCAR reanalysis winds. In another study, OFES was used together with an offline nitrate-phytoplankton-zooplankton-detritus model to study how strong wintertime winds through the mountain gaps in Central America generate ocean eddies and upwelling that bring nutrients to the surface.

Tracers such as the modal distribution of chlorofluorocarbon (CFC) are being used to study the meridional overturning cell and its seasonal variations and higher frequency variations due to eddies. Also of interest is research on the Indonesian Throughflow, for example OFES simulation of water transports through this complicated network of channels.

Aside from the boundary currents and equatorial currents, the ocean was thought to flow in broad, graceful gyres. **Nikolai Maximenko** and **Kelvin Richards** at the IPRC recently found in both satellite images and high-resolution models that long, narrow zonal jets are almost ubiquitous in the ocean (*IPRC Climate*, Vol. 5, No. 1). These jets, which extend over tens of degrees longitude and a few degrees latitude, may have a similar origin to the banded structure seen on large planets such as Jupiter and Saturn. OFES is helping to understand the dynamics of these deep ocean jets.

Future research plans at the Earth Simulator Center include the development of an extremely high-resolution model (1/30 degree) of the North Pacific. The model will be nested into OFES. At present OFES does not simulate well the SST off the coast of Japan; this nesting may improve the situation. Another possible improvement to OFES is inclusion of the tides or parameterization of their effects on ocean circulation. Tides over shallow water and internal waves generated by tides give rise to patchy ocean mixing. At present OFES does not include these effects, and mixing coefficients, aside from those used in the mixed layer, are unrealistically uniform.

And there is good news for the climate research community. The OFES climatological run will soon become accessible to everyone on the servers of IPRC's Asia-Pacific Data-Research Center!

From left to right: Y. Sasaki, K. Richards, N. Schneider, R. Furoe, T. Jensen, Y. Sasai, M. Nonaka, S.-P. Xie, A. Ishida, Z. Yu, H. Sasaki, J. Potemra, B. Taguchi, R. J .Small. ***Not pictured:*** P. Hyder, H. Aiki, N. Maximenko, Y. Jia.

Collaboration with the South China Sea Institute of Oceanology

Left: Director of the South China Sea Institute of Oceanology Ping Shi (right) at IPRC meeting and IPRC's Team Leader for Indo-Pacific Climate Research, Shang-Ping Xie.

Right: R/V *Kilo Moana* with Diamondhead Crater and Waikiki in the background.

The Director of the South China Sea Institute of Oceanology (SCSIO) **Ping Shi**, and the Director of its Laboratory of Environmental Dynamics **Dongxiao Wang**, visited the IPRC in February 2006. Based in Guangzhou and part of the Chinese Academy of Sciences system, the SCSIO is a major national Chinese laboratory with a staff of nearly 400. The South China Sea plays an important role in research on climate and the Pacific warm pool. Collaboration between the SCSIO and the IPRC has been growing over recent years and includes the development of a South China Sea *in situ* dataset, satellite data analysis, and numerical modeling. At a meeting on February 17, IPRC Director **Jay McCreary** and Director Shi agreed to establish closer ties by developing a memorandum of understanding that will include a joint research group to study the circulation and climate of the South China Sea.

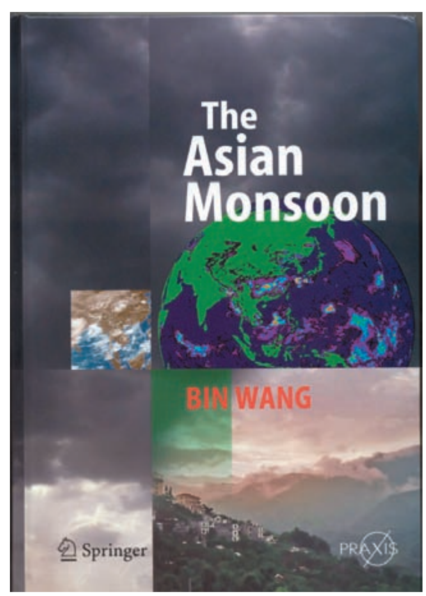
Shi capped his visit to the University of Hawai'i with a guided tour by Captain **Gray Drewry** of the double-hulled Research Vessel *Kilo Moana*, which is administered by the School of Ocean and Earth Science and Technology at the University of Hawai'i. The SCSIO is in the process of building a twin-hull research vessel, and Director Shi's visit to the *Kilo Moana* will help the design and instrumentation of this planned ship.

Published: *The Asian Monsoon*, edited by IPRC's Bin Wang

The Asian Monsoon, edited by **Bin Wang** (see page 20, "Seasonal Climate Forecasts for the APEC Region") has just been released by Springer Verlag. The giant Asian monsoon system dominates the climate of the entire tropical and subtropical Eastern Hemisphere and influences climate in regions far beyond. The social and scientific importance of the monsoon cannot be overemphasized.

Our scientific knowledge of this complex monsoon system has advanced enormously over the last two decades due to a wealth of new data from satellite observations and field experiments and due to advances in computing power and mathematical representations. In this book, scientists at the forefront of monsoon research provide an account of our ever-expanding understanding of the physics associated with monsoon weather and climate and offer timely and authoritative summaries of recent progress and remaining gaps in our knowledge.

The book is intended as a comprehensive interdisciplinary text for college students, both graduate and undergraduate, and as a reference for scientists and professionals in the Earth sciences and social sciences.



IPRC Featured in Newsletter of Japanese Ocean Think Tank

The Ocean Policy Research Foundation in Tokyo has published in its *Ship and Ocean Newsletter* an essay by IPRC Director **Jay McCreary** that features the International Pacific Research Center and its activities. The Foundation functions as a think tank for Japan on ocean matters, and the Foundation's white papers and newsletter are a source of important information for legislators, government officials, and ocean policy decisions. Advocating that mankind live harmoniously and sustainably with the ocean, the Foundation encourages international collaboration and exchange of views on ocean affairs. The *Ship and Ocean Newsletter* publications are to facilitate a wide range of discussion and exchange on oceanic topics to raise the awareness of the importance of the world oceans and their resources.

McCreary wrote "the IPRC is an ideal model of cooperation between Japan and the United States, focused on the most serious world-wide challenge facing us today—understanding the causes of climate variability and change and the effects of global warming. Such bilateral cooperation contributes not only to science but to the exchange and understanding between Asian and western cultures." Professor **Toshio Yamagata**, co-chief editor for the newsletter, translated the article into Japanese.

This essay in the *Ship and Ocean Newsletter* is an excellent medium to apprise Japan's decision-makers of the IPRC and its research on the ocean and climate. The article is available in English at www.sof.or.jp/index.html.en and in Japanese at www.sof.or.jp/index.html.ja.

Seasonal Climate Forecasts for the APEC Region

The new project "Climate Prediction and its Application to Society" or CliPAS (*IPRC Climate*, Vol. 5, Nos. 1 and 2) is helping the Asia-Pacific Economic Cooperation (APEC) Climate Center (APCC) with the development of a system for forecasting seasonal temperature and rainfall. Principal investigator, **Bin Wang**, co-leader of the IPRC Asian-Australian Monsoon Research Team, is spearheading this research effort that includes ten institutions in the United States, Korea, and Japan, and leading scientists in the field of climate prediction and societal application. The CliPAS strategy, called multi-model ensemble prediction, uses a set of well-validated climate models to make forecasts from their pooled simulations. The current prediction system includes five air-sea coupled models (called one-tier system) and five atmospheric circulation models driven by sea surface temperature data predicted from a dynamic-statistical model (called two-tier system).


Bin Wang

As a first step, climate features over the last 24 years have been simulated with the group of models in a "hindcast" (1981–2004) study. The data set is now being compared with observations for that period to see how well the one-tier and two-tier systems have "predicted" the climate.

The initial seasonal prediction efforts will focus on forecasting features of the El Niño-Southern Oscillation and the Asian-Australian Monsoon. Understanding and predicting subseasonal climate variations is also planned. To assess, for example, the models' ability to predict conditions favorable to hurricane and typhoon activity, simulation of these high-impact weather events is being planned. This experiment is based on a proposal by NASA scientist **Siegfield Schubert**.

CliPAS held its first annual meeting at the Center for Ocean-Land-Atmosphere in May 2005 and its second annual meeting at the University of Hawai'i in January 2006. At the meetings, scientists from the various research teams reported on the status of seasonal climate prediction, discussed major issues, and produced a specific coordinated work plan.

The project is currently supported by the APEC Climate Center in Busan, whose executive director is **C.-K. Park**. The air-sea coupled models are from National Centers for Environmental Predictions, Frontier Research Center for Global Change, NASA (GMAO), Seoul National University, and the University of Hawai'i. The two-tier system atmospheric models are from Florida State University, Geophysical Fluid Dynamic Laboratory, Seoul National University, and the Community Atmospheric Model (CAM2)-University of Hawai'i version. The Australian Bureau of Meteorology Research Centre (BMRC), the Beijing Climate Center, and the Institute of Atmospheric Physics of the Chinese Academy of Sciences will soon join the project.

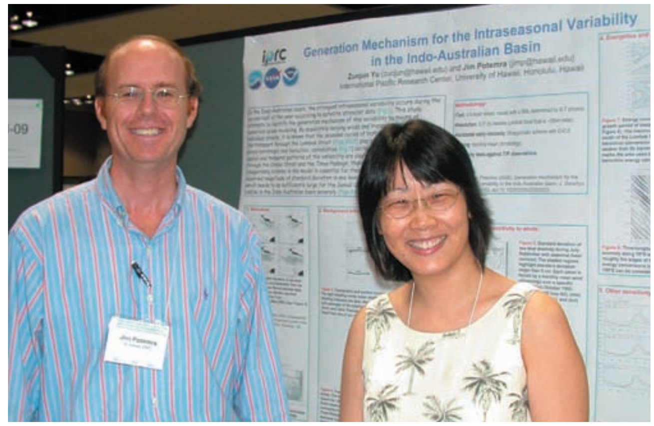
IPRC Scientists Active in the Climate Research Community

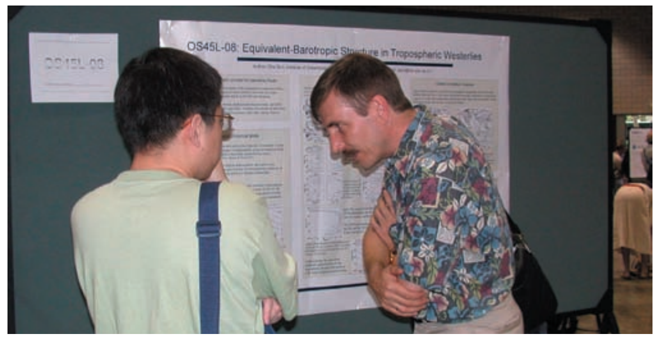
Kevin Hamilton, co-leader of the IPRC Impacts of Global Environmental Change Research and chairman of the University of Hawai'i Meteorology Department, is serving on the External Advisory Committee for the NCAR Institute for Integrative and Multidisciplinary Earth Studies (TIIMES). TIIMES conducts and promotes Earth science research across disciplines, and provides leadership and fosters interactions in support of initiatives on multi-disciplinary Earth studies. Hamilton is also serving as President of the International Commission for the Middle Atmosphere (ICMA), which fosters international cooperation in research of the middle atmosphere (the tropopause into the lower thermosphere). Recent ICMA activities include coordinating the middle atmospheric science sessions at the next IUGG General Assembly to be held in Perugia, Italy, in 2007.

Axel Timmermann, also co-leader of the IPRC Impacts of Global Environmental Change Research Team, is serving as chair of the International CLIVAR Pacific panel, an international effort to oversee, coordinate and facilitate CLIVAR objectives related to the Pacific Ocean. He is also vice-president of the Division on Nonlinear Processes in Geophysics of the European Geosciences Union. The division is an international, interdisciplinary organization for promoting knowledge on nonlinear processes in all branches of Earth, planetary and solar system science.

Niklas Schneider, co-leader of the IPRC Indo-Pacific Climate Research Team, was co-convener for the 14th Conference on the Interaction of the Sea and Atmosphere, which was held as part of the 86th Annual Meeting of the American Meteorological Society in January in Atlanta, Georgia.

Two IPRC monsoon researchers were invited to give key note speeches at the Workshop on the Organization and Maintenance of Tropical Convection and the Madden-Julian Oscillation, held in Trieste, Italy, in March 2006. **Bin Wang**, co-leader of the Asian-Australian Monsoon System Research Team, spoke on "Fundamental Processes in the Tropical Intraseasonal Oscillation." IPRC researcher **H. Annamalai** spoke on the "Quadrupole Structure in Convection and its Implications for the Asian Summer Monsoon Intraseasonal Variability." The workshop focused on the current state of knowledge of the initiation and maintenance of organized tropical convection and its relationship to tropical weather systems. Future directions in observing, simulating, modeling, and predicting the Madden-Julian Oscillation were planned. The meeting was sponsored by the Observing System Research and Predictability Experiment and the World Climate Research Programme.





Top, L to R: Jim Potemra and Zuojun Yu at the Ocean Sciences Meeting. **Above:** Nikolai Maximenko (on the right) during the Poster Session he convened for Ocean Sciences.

Moreover, **Bin Wang** and **Tim Li** were invited to give talks at the Symposium on the Winter Asian Monsoon, "Winter MONEX: A Quarter Century and Beyond" this past April in Kuala Lumpur. Wang's speech dealt with dominant modes of Asian-Australian Monsoon interannual variability in observation and climate prediction models; Li spoke on the interaction between the monsoon and the warm ocean and its effect on the tropospheric biennial oscillation.

IPRC scientists also contributed to the American Geophysical Union Ocean Sciences Meeting, held this spring here in Honolulu. **Jay McCreary** was co-convener for sessions on the Tropical Pacific, Biochemistry and Air-Sea Interaction, and **Nikolai Maximenko** on Zonal Jets in Geophysical Turbulence: Theory and Observations. IPRC scientists also authored and coauthored over 15 papers and posters presented at the meeting.

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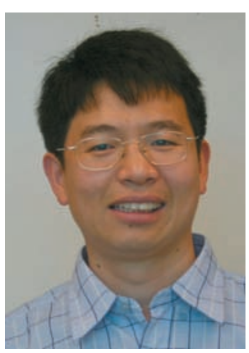
NEW IPRC STAFF

Yang "Edward" Yang

Yang "Edward" Yang joined the IPRC as a postdoctoral fellow after receiving his PhD in meteorology from the University of Hawai'i in December 2005. His dissertation focused on the island-scale atmospheric summer circulation of the island of Hawai'i. Having improved simulation of the island's diurnal cycle circulation, Yang studied the effects of trade-wind strength and directions, terrain size, and height on island summer circulation and weather. He showed that in the model, terrain height impacts the thermodynamics of the circulation and affects island weather. Island area also affects the orographic lift and surface thermal impact, showing that rainfall over islands depends partly on their area size.

Yang is now working with **Shang-Ping Xie**, co-leader of IPRC Indo-Pacific Climate Research, on the PRIDE project Development of an Integrated Data Product for Hawai'i Climate. Together with IPRC's **Jan Hafner**, the group is integrating NOAA ground-radar and satellite observations with other observations and meso-scale model output into a single format. From this integrated data set they will produce Hawai'i monthly and seasonal mean precipitation maps at unprecedented spatial resolution. These precipitation maps will then be used for further applications, for example, the development of brush-fire probability tables for certain locations as a function of wind and drought conditions. Such applications will be very useful for Hawai'i residents and such industries as tourism, fishery, and US naval operations in Hawai'i.



Linlin Pan

Linlin Pan joined the IPRC as a postdoctoral fellow in January 2006. Growing up in a small village in southeastern China, Pan recalls, "My father was a farmer and very concerned about the weather. Everyday he listened carefully to the weather forecast. It was a real ritual. One time the forecast predicted sunny weather for the next several days. Instead a severe storm came… the Meiyu season had started. The harvested crop was still outside and got totally ruined by the storm." Realizing how important weather forecasts are for agriculture and how much they can affect people's daily lives, Pan studied meteorology and in 1994 obtained his master's degree in atmospheric science from Beijing University. Pan then wanted to "delve deeper" into climate dynamics and climate change and came to the University of Hawai'i, where he received his PhD in meteorology in 2003 with a dissertation on the dynamic origin of the annular (ring-structured) modes, which include the Arctic Oscillation (AO), the Antarctic Oscillation (AAO), and the North Atlantic Oscillation (NAO), which can be regarded as the regional expression of AO.

Pan has expanded his research interests to large-scale air-sea interaction, climate change, climate dynamics and prediction. His studies involve theoretical, numerical, and observational analyses and are geared toward understanding the physics governing the variations in low-frequency climate variability seen in such climate phenomena as the Arctic and Antarctic Oscillations and the Pacific–North American pattern. With **Tim Li**, co-leader of IPRC Asian Australian Monsoon System Research, Pan is studying the connection between the Madden-Julian Oscillation and midlatitude atmospheric disturbances.

IPRC Bids Sayonara

Dailin Wang, who has been an associate researcher with the IPRC since its inception, has joined the NOAA Pacific Tsunami Warning Center in Hawai'i. As oceanographer with the Center, he must determine quickly the location and magnitude of an earthquake and assesses whether a tsunami can be generated. The main detection tools are tide gauges and so-called DART buoys. Wang finds his new work challenging and rewarding: challenging in that he must broaden his knowledge of seismology and rewarding because it serves the public. He wrote in an email: "We receive visiting requests from people around the world. There are also individuals who would like to receive tsunami warning messages on their cell phones or via emails." Wang's many years of experience in ocean modeling at the IPRC will definitely be useful in modeling tsunamis.

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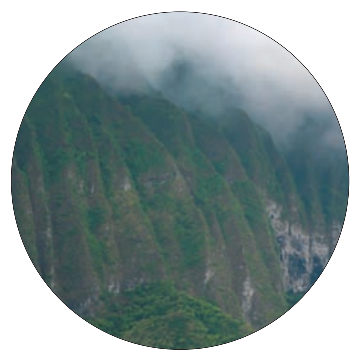

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