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The center for the study of climate in Asia and the Pacific at the University of Hawai'i at Mānoa

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Steam clouds rise from hot lava pouring into the ocean off the south-shore cliffs on the island of Hawai'i. Photo courtesy of Axel Lauer.

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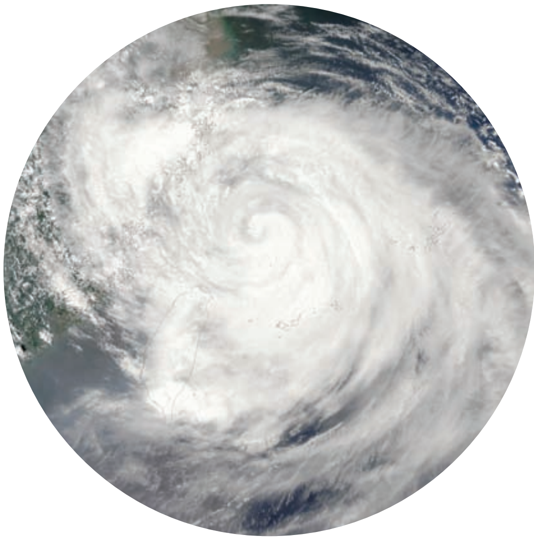

What Controls Tropical Cyclone Size and Intensity?

The white shimmering clouds that spiral towards the eye of a tropical cyclone can tell us much about whether or not the storm will intensify and grow larger, according to computer modeling experiments conducted by IPRC's **Yuqing Wang**. Scientists have speculated for some time that the outer spiral rainbands could impact significantly a storm's structure and intensity, but this process is not yet completely understood. With the cloud-resolving tropical cyclone model he had developed, the TCM4, Wang conducted various experiments in which he was able to increase or decrease the activity of the outer rainbands. These changes impacted the strength and size of the storms the model generated.

In their mature phase, strong tropical cyclones typically develop a structure characterized by a clear eye at the center and an eyewall with strong convection and high winds surrounded by the rainbands. The inner rainbands are located about two to three times the radius of maximum wind; beyond lie the outer rainbands. Some tropical cyclones are midgets that stretch less than 200 km across, others grow into giants, their rainbands extending over hundreds of km. The largest tropical cyclones are seen in the western Pacific; over the Atlantic they tend to be smaller.

The amount of rain produced in the outer spiral rainbands is closely related to heating or cooling rates due to evaporation or condensation in the rainbands. In some experiments, Wang changed TCM4's cooling rate in the outer rainbands by changing the rate of melting of snow and graupel and the rate of evaporation of rain, melting snow and graupel. In other experiments, he changed the heating rate by changing the rate of condensation, moisture-deposition and freezing. For the control storm he did not tinker with the heating and cooling rates (Figure 1). By systematically

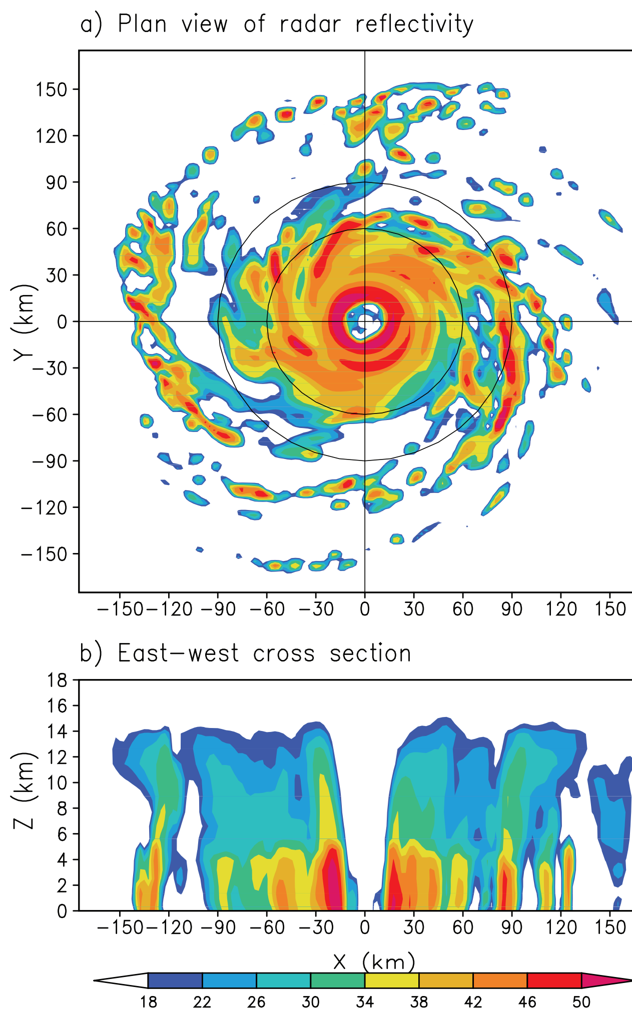

Figure 1. Model-simulated radar reflectivity (in dBZ) after 9 h of simulation in the control experiment (after the model has been spun up for a tropical cyclone-like vortex on an f-plane in a quiescent environment): (a) plan view and (b) vertical cross-section along the east-west direction across the storm center. Two circles in (a) show the radii of 60 km and 90 km from the storm center, respectively.

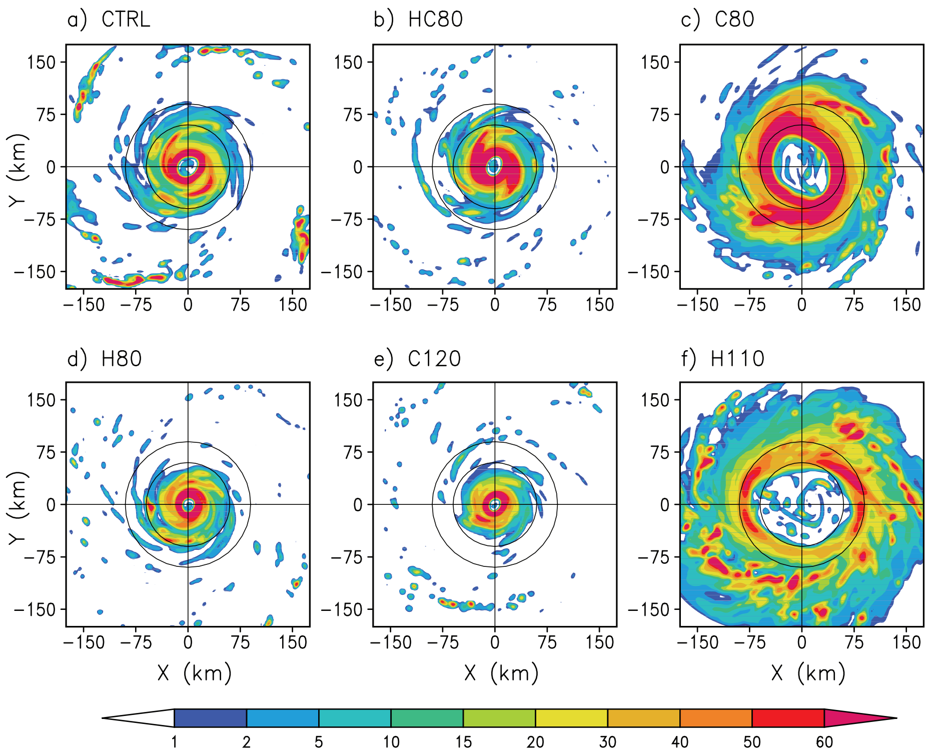

Figure 2. Plan views of rain rate (mm/h) of the tropical cyclones simulated in TCM4 after 120 h of simulation: (a) CTRL with default settings, (b) in HC80, both heating and cooling rates are reduced by 20%, (c) in C80, cooling rate is reduced by 20%, (d) in H80, heating rate is reduced by 20%, (e) in C120, cooling rate is increased by 20%, and (f) in H110, heating rate is increased by 10%. The changes in the experimental cyclones were introduced beyond a radius of 60 km from the storm center. The two circles in each panel show 60-km and 90-km radius from the storm center, respectively.

altering heating and/or cooling rates associated with the rainband activity in the TCM4 storms, he was able to study how these manipulations impacted the evolution of storm intensity, size, and structure.

The most powerful storm in Wang's suite of experiments reached a central surface pressure of 887 hPa and a wind speed of about 280 km per hour, compared to the control storm of 905 hPa and 250 km per hour (Figure 2). To create this intense storm, Wang had lowered both the heating and cooling rates in the outer rainbands. It was probably the lowered heating rate that dampened the rainbands' activity and made the winds so intense, for in the only other storm with winds more powerful than the control storm, Wang had increased the cooling rate. The storm with increased heating rate never reached the wind speed of the control storm. In short, cooling in the outer spiral rainbands intensifies winds; heating in the outer spiral rainbands puts a lid on their intensity—at least in TCM4.

Decreasing the heating rate—or increasing the cooling rate—not only made for more intense winds but also for storms with a smaller eye and a more compact core (eye, eyewall, and moat) than the control storm. Increasing the heating rate, on the other hand, resulted in tremendous growth of the eye and eyewall and the biggest storm in the experiment. This was also the storm that developed a typical secondary, or concentric, eyewall as a result of the axisymmetrization of the inward propagating spiral rainbands. As the secondary eyewall formed and contracted, the inner eyewall started to weaken and was eventually replaced by the secondary eyewall. A second concentric eyewall cycle took place, in which the secondary eyewall formed, and as it contracted, the inner eyewall weakened and broke up, leaving a very large, single-eye structure.

Wang sought to understand why altering the cooling or heating rate alters the intensity and size of a tropical cyclone. For one thing, he found that cooling increases the downdrafts in outer spiral rainbands. This finding is supported by research by MIT's **Kerry Emanuel**, who showed that in tropical cyclones, shallow clouds with little rain lead to strong downdrafts. The downdrafts keep the boundary layer relatively dry and reduce deep convection outside the core, concentrating the net convective mass flow in the inner core and increasing intensity. Such downdrafts outside the inner core result in higher pressure outside the core, increasing the radial pressure gradient and accelerating the winds near the core. Thus, rather than limiting the intensity of storms, as has been proposed by others, downdrafts in the outer rainbands act to keep the inner core compact with strong winds.

For another, the TCM4 experiments showed that storm changes in structure and intensity were due mostly to hydrostatic pressure adjustment in response to changed cooling or heating rates in the outer spiral rainbands: heating outside the core decreased the surface pressure outside the core, decreasing the horizontal pressure gradient across the radius of maximum wind and weakening the winds in the lower troposphere. Heating also expanded the inner core of the storm. In contrast, cooling outside the core increased surface pressure outside the core and the pressure gradient across the radius of maximum wind, resulting in stronger winds.

In a real cyclone, the cooling or heating rate of the outer rainbands is affected by the relative humidity of the surroundings—the more moisture available, the more heating can occur. The TCM4 experiments therefore imply that large storms are more likely to develop in an environment with high relative humidity that leads to condensation, freezing and deposition, and thus to more heat in the outer rainbands. Small, intense storms are more likely to develop in a drier environment in which evaporation of cloud droplets, rain water, and melting snow and graupel are more likely to cool the rainbands. These two scenarios would explain, at least partly, why hurricanes travelling across the Atlantic tend to be smaller and more intense than the typhoons that travel across the western Pacific. North Atlantic hurricanes are often affected by the dry Saharan Air Layer, whereas the storms in the western Pacific usually form in the moisture-rich, low-pressure monsoon trough. The high background vorticity in the western Pacific monsoon trough may also be conducive to large storms. The tropical cyclones that affect Hawai'i tend to be small because of the shallowness of the moist surface layer and the low humidity above the trade wind inversion.

The difference in the large-scale moisture fields over the North Pacific and the North Atlantic can also explain why **D. Hawkins** and **M. Helveston** at the Naval Research Laboratory in Monterey found that about 80% of the intense tropical cyclones over the western North Pacific develop a concentric eyewall in their lifetime compared to only about 40% of the intense ones in the North Atlantic.

Wang's tropical cyclone modeling study helps to pinpoint the processes that control a tropical cyclone's intensity and overall structure: cooling seems to favor powerful winds and a compact storm; heating, in contrast, seems to favor large inner cores but limits wind intensity. Since heating or cooling outside the inner core region depends on the environmental relative humidity near the core, the TCM4 results indicate that the presence of a deep, moist layer near the core should make for large tropical cyclones, annular hurricanes, and concentric eyewalls, whereas a dry environment should produce small, compact tropical cyclones without concentric eyewalls. What is needed now are observational studies to confirm these implications from the present idealized TCM4 simulations.

Hurricane hunter Dewie Floyd flies into the eye of Hurricane Katrina. Photo courtesy of NOAA.

This story is based on Wang, Y., "How do outer spiral rainbands affect tropical cyclone structure and intensity?" which will appear in the Journal of the Atmospheric Sciences.

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The Cloud Trails of the Hawaiian Isles

Satellite images show puffy cloud trails up to 100-km long in the lee of most Hawaiian Isles. Scientists have thought these trails are due to the trade winds flowing over and around the islands, and then coming together again and rising to form clouds in the islands' wake (Figure 1). The daytime trails, however, dissipate at night, IPRC postdoctoral fellow **Yang Yang** and research team leader **Shang-Ping Xie** discovered. If only wind convergence causes the trails, the trails should be there day and night. The sun's daily cycle must therefore have something to do with their formation also. Intrigued, Yang and Xie applied a computer model to see whether it could be used to study the cloud trails. The model successfully captured the cloud trails, their formation and dissipation. It confirmed the hunch that thermal processes related to daily heating and cooling of the islands combine with the converging winds to create the cloud trails.

Yang, now research meteorologist at the National Institute of Water & Atmospheric Research in New Zealand, has been specializing in observing and modeling Hawai‘i rain, clouds, and wind patterns, first for his dissertation research with **Yi-Leng Chen** at the University of Hawai‘i and then with Shang-Ping Xie at the IPRC. In this latest study, the IPRC team consisting of Yang, Xie, and **Jan Hafner** combined satellite analysis with computer modeling. Taking the observations from the polar orbiting MODIS Terra and Aqua and the geostationary GOES-10 satellites, they mapped the summer (June–August) cloud climatology in the vicinity of Ni‘ihau, Kaua‘i, and O‘ahu, and of the island of Hawai‘i known as the "Big Island." East-northeast trades with an inversion height of about 1500–2000 m and a typical wind speed of 8 m/s prevail over the islands much of the year. It is well known that the typical trade wind flow-pattern for the Big Island, with mountain peaks rising above 4000 m, differs from that for the islands of Ni‘ihau, Kaua‘i, and O‘ahu with peaks below 2000 m. The lower profile islands have winds flowing directly over the mountains, and the peak mean rainfall is on the highest mountains. With the Big Island, the trade winds tend to flow around the high mountains, and the mountain tops receive very little precipitation. Because of the descending trades, the leeward slopes of the islands are much drier than the windward slopes. Nevertheless, the team's analysis of the satellite images reveals that during early afternoon, cloud cover in specific lee regions can be comparable to that on the windward side.

The satellite analysis, moreover, shows that over the lee sides of the islands of Ni‘ihau, Kaua‘i, and O‘ahu, clouds form by 11 o'clock in the morning, reaching their peak around two o'clock in the afternoon (Figures 1 and 2). Extending from the lee coasts, the cloud trails grow westward for more

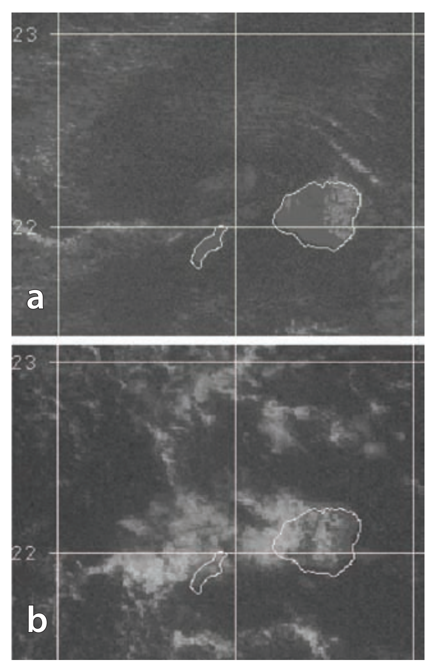


Figure 1. GOES-10 visible images at (a) 10:30 am and (b) 2:15 pm on 5 September 2006.

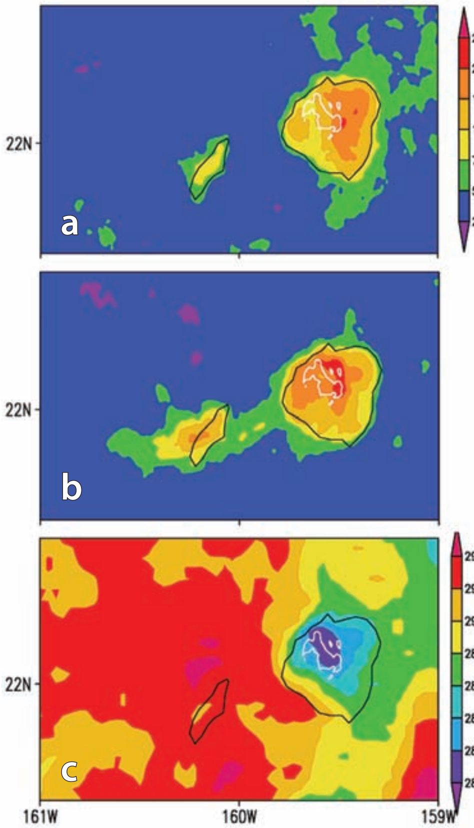


Figure 2. For the island of Kaua'i during August 2005, mean effective albedo (%), indicating reflecting clouds, derived from GOES-10 visible radiance at (a) 11:00 am and (b) 2:00 pm, and (c) brightness temperature (K) derived from the GOES-10 IR channel at 2:00 am Hawai'i Standard Time. Terrain elevation of 1000 m is shown by the white contours; black lines show island outlines.

than 70 km over the ocean. In late afternoon, they start to disappear again, but without any obvious westward progression. By two o'clock in the night, the GOES-10 infrared channel shows the cloud bands have dissolved, registering a brightness temperature that is 3–4 K higher over the lee than the windward ocean (Figure 2c).

To confirm their hunch about the thermal mechanism in generating the cloud trails, the team supplemented the satellite cloud study with simulations using the Mesoscale Model of Pennsylvania State University and NCAR, the MM5. The model was coupled with a land surface model that codes the vegetation, soil type and vegetation fraction compiled by the US Geological Survey. Yang and Chen had already shown that the MM5 captures well the overall observed Big Island daily cycle of wind and rainfall.

The team ran the MM5 with daily data from June 1 to August 31, 2005, and analyzed 92, two-hour snapshots of the output. For Kaua'i, O'ahu, and even tiny Ni'ihau, standing below the trade-wind inversion, the MM5 simulates the expected winds flowing over and around the islands; in the islands' wakes, the winds converge and rise, continuing on their southwest journey. As the sun heats the islands, the MM5 shows first the clouds beginning to form over the leeside land and the trades carrying, or advecting, the warmed island-air downstream. As the surface pressure downstream falls, convergence becomes stronger, the warm, moist air rises, condenses, and the cloud trails grow. When the islands cool at night, the MM5 simulates cold air moving downstream from the island and suppressing cloud formation in its path. Atmospheric soundings from a recent cruise survey conducted onboard the University of Hawai'i Research Vessel *Kilo Moana* support this thermal mechanism for the cloud trails.

The satellite images on the lee side of the Big Island, the Kona Coast, show a quite different picture from that of the lower profile islands. Though clouds form along the Kona Coast by 11 o'clock in the morning, further away from the coast, the ocean remains cloud free (Figure 3a). Only by two o'clock in

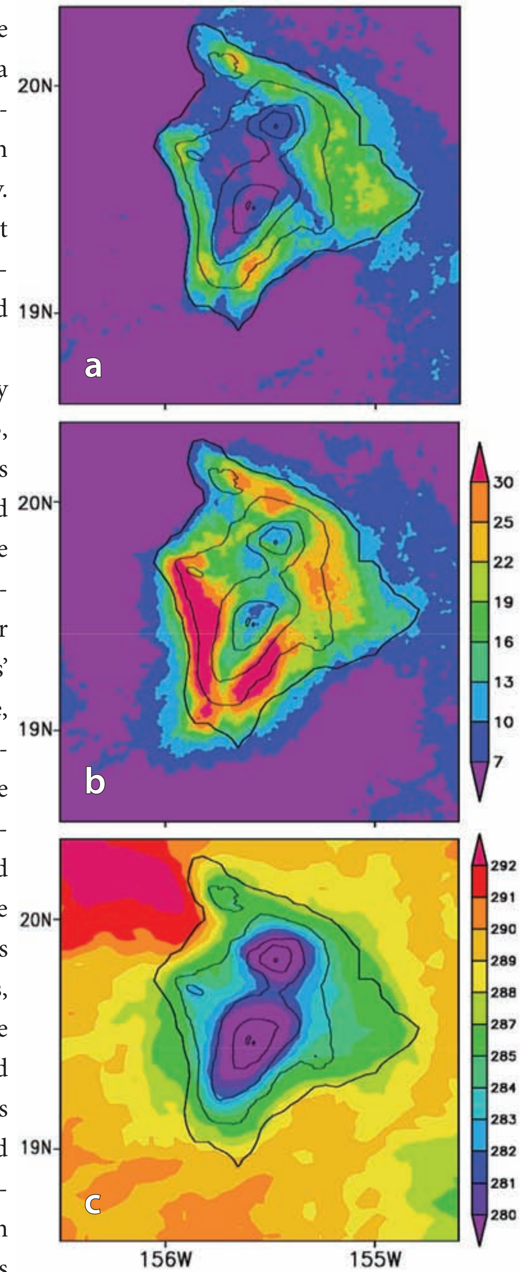
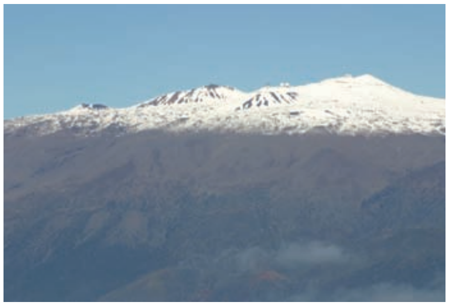
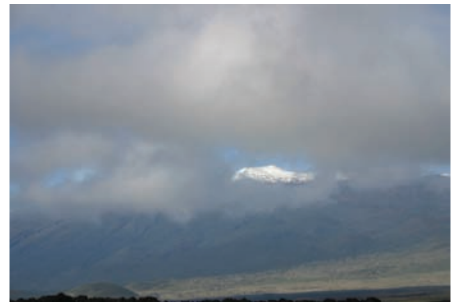


Figure 3. For the Big Island during August 2005, mean effective albedo (%), indicating reflecting clouds, at (a) 11:00 am and (b) 2:00 pm from GOES-10 visible channel, (c) IR temperature at 2:00 am from GOES-10 IR channel-5. Contour interval is 1000 m (black lines; outermost lines show island outlines).

the afternoon do the clouds that have formed along the coast begin to extend out over the ocean, but at the most for 20 km (Figure 3b). At night, the temperatures are lower (284–287 K) in the

wake off the Kona Coast than to the north or to the south (Figure 3c), an indication that a cloud deck has formed there. The nighttime Kona cloud deck is consistent with coastal rain gauge data that registers maximum rainfall in the evening and night for parts of the Kona Coast.

MM5 reproduces clearly how the island's tall mountains and saddles shape the overall Big Island wind and cloud patterns very differently from the other islands. Strong 12–14 m/s easterly winds blow around the southern and northern tips of the Big Island and, in the wake of the island, form the known westerly reverse flow that flows with up to 3 m/s towards the Kona Coast. The westerly return flow reaches about 2000 m high, above which the easterly trades flow. The MM5 also reveals how the daily heating and cooling of the island affects the winds and the clouds. As the sun heats the island, sea breezes strengthen the western reverse flow and carry moist air toward the Kona Coast. Clouds develop on the Kona slope, but the strong day-time reverse flow prevents the generated heat from being transported downstream and forming a cloud trail. During the night, the down draft of trades together with the land breezes blow cold air offshore and encounter the now warmer reverse flow. Consistent with the increased nighttime cloudiness seen in the satellite images, the MM5 has the upward motions form a cloud band extending up to 20 km from the Kona Coast.

The cloud trails tell a further surprising story. Off the southwestern tip of the Big Island, the satellites images do have clouds appearing in the morning, and by afternoon the clouds have grown into a well-defined cloud band that tilts in the southwest direction, stretching for more than 70 km offshore (Figure 3 a and b). This is the first time this diurnal

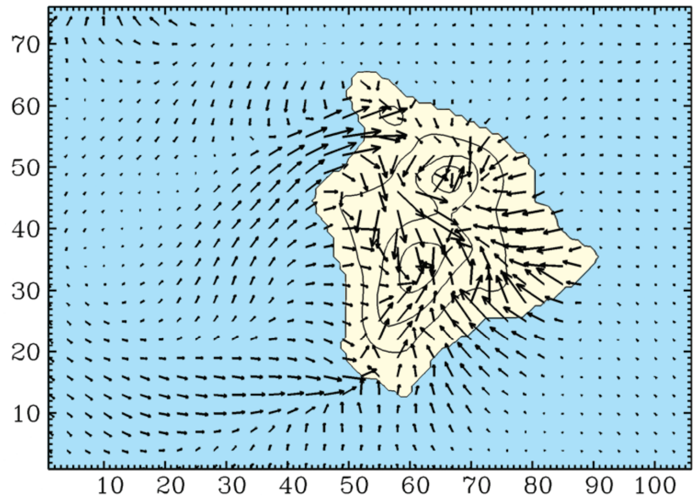


Figure 4. For the Big Island, 2:00-pm minus 2:00-am wind-differences at 50 meters above the surface from MM5 simulations for June–August 2005. The figure shows the wind patterns associated with the southwest cloud band. On the coast near Kauna Point, the rising motion is enhanced in the afternoon by the three-way convergence of the (anomalous) sea breezes/anabatic flow from the west and east slopes of the south extension of Mauna Loa, and from the southwest (perpendicular to the coast between Kauna and South Points). The convergence line extends offshore, separating the anomalous westerlies to the north and the anomalous south-to-southwesterly winds to the south. The formation mechanism for this sharp convergence line probably involves complicated interactions of thermal and dynamical forcing of the island.

cloud trail seen in the satellite images has been recorded in the literature. By 2 o'clock in the early morning, the infrared brightness temperature from GOES-10 is somewhat higher in the region of the southwest tilted band, indicating that the lee southwest cloud band has dissolved (Figure 3c). The MM5 also shows a sharp line of converging winds (Figure 4)

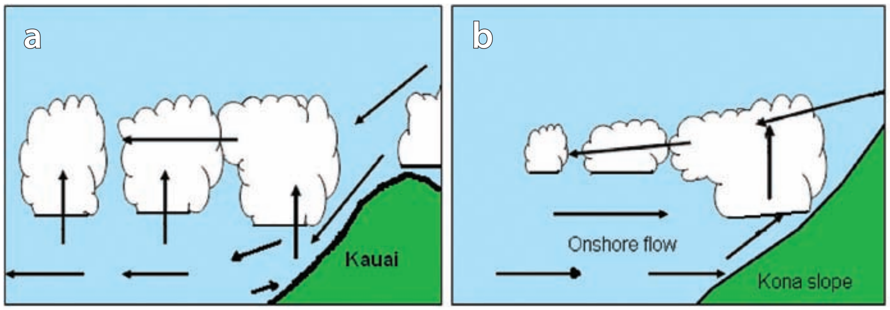


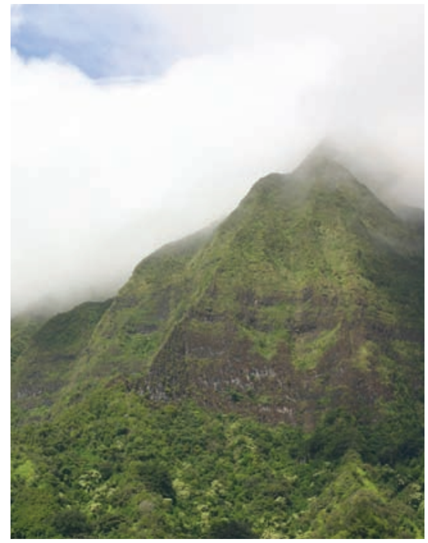
Figure 5. Schematics of the afternoon winds and cloud formations in the wakes of (a) low-profile Kaua'i and (b) tall Big Island.

that develops during mid-morning and stretches, as in the satellite images, from the southwestern tip of the Big Island for at least 70 km offshore. The convergence line forms where daytime sea breezes meet the easterly trades (Figure 4), and the line anchors the southwest lee cloud band observed in the satellite images. During night, the MM5 simulates the convergence line weakening substantially and the associated cloud trail dissipating.

On the northwestern tip of the Big Island, the satellite images reveal no cloud trails, and MM5 simulates convergence too weak for cloud formation. A reason for the asymmetry, according to the research team, could be the interaction between the trade winds that become very strong as they are forced around the Big Island and the Coriolis force. This interaction can lead to wind convergence at the southern tip of the wake and divergence at the northern tip.

The MM5 analysis shows how the complex interaction among winds, mountain height, and heating and cooling by the sun affects the daily cycle of the leeward clouds, favoring the cloud trails seen in the wake of the lower profile islands, but not in the wake of the tall mountains of the Big Island (Figure 5). The clouds stretching from the southwestern tip of the Big Island are formed by a different mechanism.

The Hawaiian Isles make a superb natural laboratory for studying how macro and micro processes work together to create clouds and rainfall: the winds—the sea and land breezes, the trade winds differing in strength from one day to the next, the moisture they carry and the vortices and eddies they form; the varied Hawai'i mountain topography and vegetation, ranging from lush rain forest to barren lava; and the daily heating cycle. This study on the trail clouds is just one example of how high-resolution computer models that adequately resolve the Hawaiian Isle topography can help to understand these many interactions.



This story is based on Y. Yang, S.-P. Xie, and J. Hafner, 2008: The thermal wake of Kauai Island: Satellite observations and numerical simulations, Journal of Climate, *21, 4568–4586; and Yang, Y., S.-P. Xie, and J. Hafner, 2008: Cloud patterns lee of Hawaii Island: A synthesis of satellite observations and numerical simulation.* Journal of Geophys. Res.-Atmos., ***113****, D15126, doi: 10.1029/2008JD009889.*

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The North Pacific Subtropical Countercurrent

Mystery Current with a History

By Fumiaki Kobashi*and Shang-Ping Xie

In the subtropical North Pacific, the surface wind field is characterized by westerlies to the north and the northeasterly trade winds to the south. For the most part, these winds have an anticyclonic spin and their wind stress curls drive the North Pacific subtropical gyre. In the central to southwestern part of the subtropical gyre around 19°–26°N, an unusual current flows eastward in the otherwise westward current (Figure 1). Called the North Pacific Subtropical Countercurrent (STCC), this shallow current flows against the broad westward flow and against the flow predicted from the wind field. Discovered more than 40 years ago, the unexpected counter flow was first thought to be driven by a local change in the wind field, a theory later disproven. Together with **Naoto Iwasaka** at Tokyo University of Marine Science and Technology and **Takashi T. Sakamoto** at JAMSTEC, we recently revisited the wind field over the STCC and found something surprising: the STCC actually drives the winds!

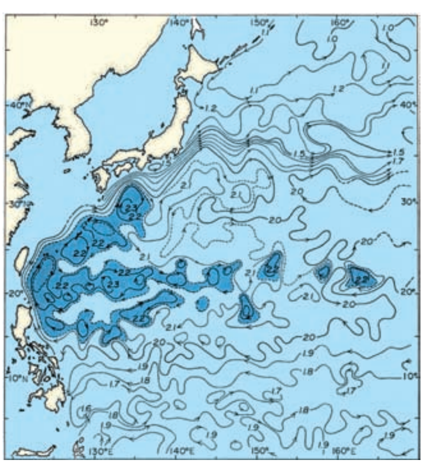


Figure 1. Long-term mean sea surface dynamic height anomaly relative to 1000 dbar, in dynamic meters (10 m^2/s^2). The STCC is marked by the filled contours (darker blue areas) stretching eastward around 19°–26°N. From Hasunuma and Yoshida (1978).

Michitaka Uda of Tokyo University of Fisheries (now at Tokyo University of Marine Science and Technology) and **Keiichi Hasunuma** (an undergraduate at Tokyo Fisheries University at the time of the discovery and later at the University of Tokyo) discovered the STCC from hydrographic observations and direct current meter measurements. They presented their discovery at the annual meeting of the Oceanographic Society of Japan in 1967 (the paper was formally published two years later in 1969). Their analysis revealed that the STCC persists throughout the year and accompanies the subsurface subtropical front, which shows large north-south temperature and density gradients at 100–200-m depth.

Uda and Hasunuma's discovery caught the attention of **Kozo Yoshida**, the great University of Tokyo theoretician, who is known for the prediction of the Yoshida-Wyrtki jet on the equator. He and his secretary **Toshiko Kidokoro** immediately proposed a wind-driven theory for the STCC and supported it with an analysis of historical ship-based wind data compiled by **Koji Hidaka** of the University of Tokyo. In a pair of papers in 1967, they reported weak anticyclonic wind curls roughly along the STCC and suggested that this minimum, or trough, in anticyclonic wind curls forces the STCC.

The Yoshida and Kidokoro explanation was, however, overturned 17 years later in 1984 by Yoshida's own student, **Kensuke Takeuchi** (former co-chair of the IPRC Scientific Advisory Committee). Takeuchi simulated an STCC using an idealized ocean general circulation model and found that the STCC is reproduced even under wind stress forcing that does not have the wind curl trough, indicating that the wind curl trough proposed by Yoshida and Kidokoro is not essential for the STCC. He also showed that the STCC is not caused by frontogenesis due to meridional Ekman convergence, another possible mechanism that was suggested at the time for STCC formation.

Much debate about what drives the STCC then followed in the 1980s and 1990s, and several theoretical and numerical studies were conducted to unravel the mystery. In 1999 **Atsushi Kubokawa** of Hokkaido University proposed that the STCC and the subtropical front form along the southern edge of the North Pacific mode waters, the vertically homogeneous water masses that form in the deep mixed layer east of Japan and ventilate the thermocline to the south in the subtropical gyre. Kubokawa's mode-water ventilation mechanism quickly won support from observational studies at Tohoku University (Yoshikazu Aoki, Toshio Suga, and Kimio Hanawa) in 2002 and at the IPRC (Fumiaki Kobashi, Humio Mitsudera, and Shang-Ping Xie) in 2006. Generating the STCC with smooth wind forcing, this mechanism does not require the wind curl trough that Yoshida and Kidokoro reported.

There have been no follow-up studies of the wind curl trough since Yoshida and Kidokoro's study. The Hidaka wind charts they used were based on sparse ship observations prior to 1958. Is their wind curl trough a robust feature or an artifact of the Hidaka's wind charts?

Recently our team of scientists at Tokyo University of Marine Science and Technology, the IPRC, and JAMSTEC revisited the winds and the wind curl trough using QuikSCAT and TRMM satellite observations and an atmospheric reanalysis. We discovered that a wind curl trough similar to the one described by Yoshida and Kidokoro really does exist but it is the atmosphere's response to the STCC instead of the other way around!

Satellite observations reveal that the wind stress curl turns slightly cyclonic around 22°N during April and May, forming a wind stress curl trough in the general background of anticyclonic curls (Figure 2a). The wind curl trough is collocated with a band of a tall column high in water-vapor content and is anchored by the higher sea surface temperature (SST) of the subtropical front (Figure 2b). The team has found that during April and May, midlatitude weather disturbances trigger subsynoptic-scale low-pressure systems along

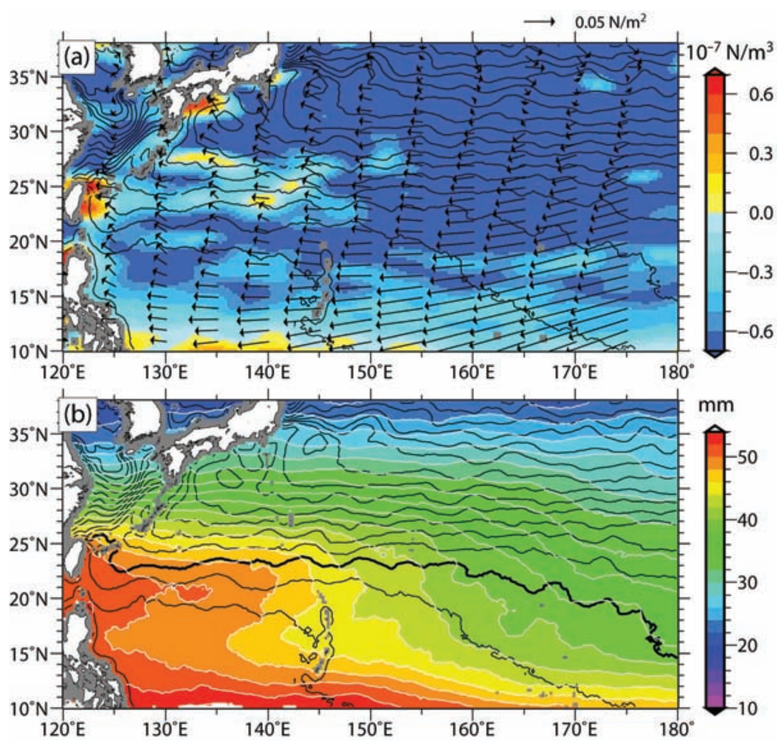


Figure 2. May climatology of satellite observations: (a) vector wind stress and its curl (color: the light blue, at times yellow color, around 25°N shows a trough of wind curl over the STCC), and (b) columnar water vapor (color), along with sea surface temperature (black contours at intervals of 1°C). The thick black contour marks the 27°C isotherm. The wind curl trough accompanies a high water-vapor band to the south.

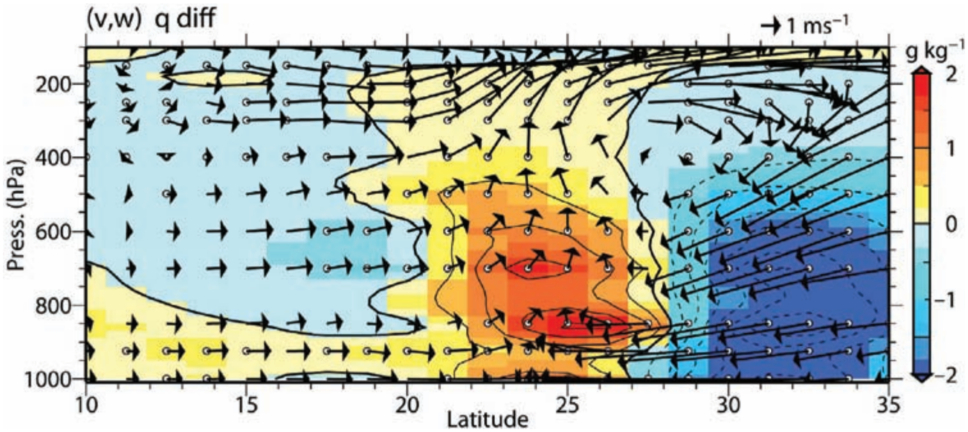


Figure 3: Latitude-height section at 142.875°E showing composite differences in cyclonic minus anticyclonic curl between meridional and vertical winds (vectors) and specific humidity (color). The vertical wind speed is multiplied by 100. Open circles show grid points where specific humidity is higher than the mean humidity field with 95% or greater certainty.

the SST front. In the lows, convective rain takes place, with deep upward motion moistening the entire troposphere (Figure 3). The lows are enhanced by condensational heating and grow on the baroclinicity anchored by the SST front, giving rise to the formation of cyclonic wind curls. The subtropical front seems unique among major SST fronts in featuring temperatures above 27°C on its southern flank, temperatures high enough to support deep convection.

We found enhanced rainfall associated with the wind curl trough. Previous meteorological studies have noted that this increase in rainfall appears to correspond to the so-called pre-Baiu/Meiyu front. The pre-Baiu/Meiyu front is manifested as a cloud and rain band just before the onset of the Baiu/Meiyu, one of the most remarkable events in the East Asia summer monsoon. The subtropical front seems to anchor this pre-Baiu/Meiyu band, a hypothesis that needs further investigation.

Thus, 40 years after the original work by Michitaka Uda and Keiichi Hasunuma, our study shows that the wind curl trough is not the cause but an effect of the STCC. Although not essential to the formation of the STCC, the wind curl trough, however, may yet influence and feed back onto the STCC. For example, the STCC varies on seasonal and interannual timescales but the mechanism by which this happens has not been pinpointed. For a fuller understanding of STCC variations, we are now studying the impact of the wind curl trough and potential vorticity on the STCC.

***Keiichi Hasunuma**, the co-discoverer of the STCC and now owner of an ocean consulting company in Japan, kindly commented on this news article and gave his perspective of future STCC research. A translated summary of his comments follow.*

I really enjoyed reading this article and was amazed by the advance in STCC research. The article tells well the history of how the research has evolved over the past four decades. Here I first would like to tell you a bit of history how we discovered the STCC.

Since I liked the ocean and wanted to become a sailor, I entered Tokyo University of Fisheries. In my junior year, I wavered whether to go into the training for ship officers or to study fisheries and ocean science. Prof. Uda taught classes in the latter field. At the time I belonged to the Ocean Study Club, which I helped to start. One of the senior students at the club told me about interesting features of the ocean such as cold water upwelling around the equatorial islands of the Galapagos, where amazingly one can find penguins and iguanas living side by side. His talks attracted me to ocean science, and I decided to work with Prof. Uda.

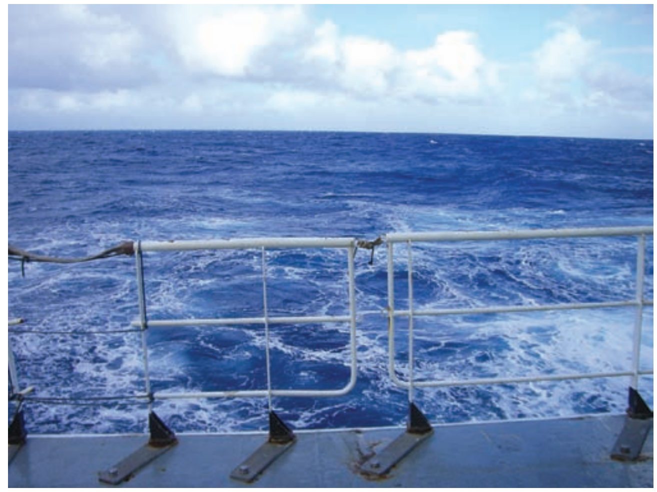
One day I asked Prof. Uda about what I should do for my graduation thesis. He gave me a few volumes of hydrographic data, and advised me to look at the ocean by graphing plots from the data. He also suggested that I focus first on the Oyashio front region east of Japan where there were relatively many observations. In studying and graphing the Oyashio front, I realized that in regions of high temperature, a change in temperature causes a relatively large change in density (due to nonlinearity of the seawater equation of state). This means that modest temperature gradients in a warm ocean can form a substantial density front. I hit on an idea that, though the temperature gradient of the subtropical convergence zone is much weaker than at the Oyashio front, it could produce a density front and support an eastward current. I got to work and was very happy that we got enough results for Prof. Uda to give a talk on the STCC at the Oceanographic Society meeting.

Prof. Yoshida reacted very strongly to our talk at the meeting. His secretary, Toshiko Kidokoro, immediately went to work with a mechanical computer. The results were the Yoshida and Kidokoro papers in 1967. While my study with Prof. Uda was purely hydrographical, Prof. Yoshida thought of the same phenomenon in terms of wind-driven ocean circulation. I vividly remember that one of their papers had the subtitle "A prediction of eastward flows." I was impressed by their dynamical approach of simulating the STCC from the wind atlas. Yoshida and Kidokoro's papers were published quickly, right after we presented our discovery. We were really excited and began to prepare publishing our results. Around that time I moved to the University of Tokyo for graduate school. I worked with Prof. Yoshida on another project and did not spend much time on STCC research. Our observational paper was finally published two years after Yoshida and Kidokoro's.

Though many new observational facts have come out since then, I still feel that they do not fully capture all the features of the STCC. For further understanding, we should have a new perspective for STCC research. In the paper published in 1978, Yoshida and I showed that the North Equatorial Current, which flows westward along the southern side of the subtropical gyre, veers to the north near the western boundary and then mostly connects to the STCC, forming a subgyre of anticyclonic circulation with the STCC. The STCC is considered to interact with this subgyre system, though it has not been studied so far from this point of view. Evaluating the STCC not alone but as part of the subgyre system could open a new door for STCC research.

Finally I would like to tell you that at an international meeting held in Japan in 1972, I had an opportunity to talk with Prof. **Raymond B. Montgomery** of Johns Hopkins University. He showed great interest in the STCC, and after returning home, wrote a short letter to me. He said that he thought that it would be more appropriate to use the term "Tropical Countercurrent" than "Subtropical Countercurrent." Although he did not explain the reason, I guess he thought this because the countercurrent flows along the tropic of Cancer. I really liked the name "Tropical Countercurrent," but after all, did not use it in our papers. I hope that we will reconsider the nomenclature most suitable for "STCC."

** **Fumiaki Kobashi** is a former IPRC postdoctoral fellow and now a faculty member at Tokyo University of Marine Science and Technology.*



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Tracking Ocean Debris

Mankind generates large amounts of debris that end up in the ocean: plastics thrown carelessly overboard, torn fishing nets, cargo ship losses, and all the junk carried by rivers into the ocean. Such debris is a hazard to shipping and to marine life. As more and more of the stuff accumulates, tracking and even removing it becomes necessary. But the oceans are vast and the debris is hard to track over the huge distances. Coastline surveys and air-borne monitoring systems are costly efforts. IPRC's **Nikolai Maximenko** has been heading a team that has developed a computer model to chart the likely paths of floating marine debris and where it may end up in the World oceans.

Maximenko's work on the debris problem started with basic research. In collaboration with **Peter Niiler** at Scripps Institution of Oceanography, he wanted to improve maps of ocean currents. Surface currents are mainly a combination of Ekman currents driven by local wind and geostrophic currents maintained by the balance between pressure gradients and the Coriolis force. These surface currents are detectable from the paths taken by drifters released into the ocean. Almost 12,000 freely drifting buoys of a unified design have been deployed in the Global Drifter Program during and after such experiments as WOCE and CLIVAR. Maximenko thus determined the recent paths of the drifters tracked by satellites and combined the information with satellite altimetry, wind and gravity measurements. In this way, he was able to create a high-resolution map of the mean dynamic ocean topography and derive the mean geostrophic and Ekman circulation in the upper ocean (Figure 1, Maximenko et al., *submitted*).

The distilled data reveal, among other things, the existence of narrow east-west jet-like streams that give the ocean-current map a striped look (Maximenko et al., 2008). Oceanographers had begun to detect such flows

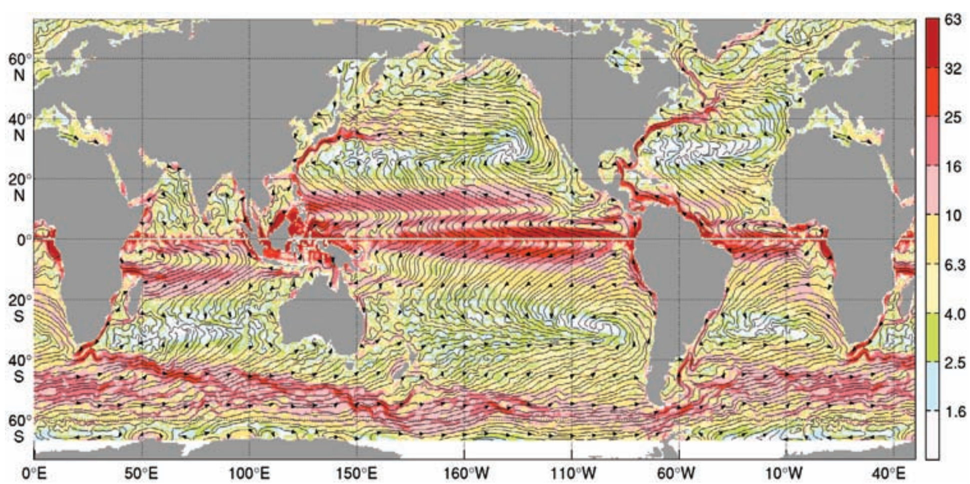

Figure 1. Mean near-surface current streamlines and mean zonal velocity (colors; unit cm/s) calculated at 1-m depth. Currents are calculated as a combination of geostrophic and Ekman currents.

at depth in high-resolution ocean general circulation model results, but were uncertain whether they were real or just a model artifact (*IPRC Climate*, vol. 5, no.1). Maximenko's observational data showed the "jets" are a real phenomenon and even more pronounced at the surface than indicated by the general circulation model simulations. The origin of the jets is still a mystery.

The freely drifting surface buoys also happen to provide a unique opportunity for tracking ocean debris. Carried along by ocean currents, the trajectories of these buoys yield estimates not only of ocean current velocities, but also, where the flows separate or diverge and where they come together or converge. Where flows diverge and water wells up from the deep, the ocean is often rich in nutrients for marine life. Where flows converge, debris can be expected to collect.

One approach to using drifters for determining flow divergence and convergence is to analyze the density of drifters. As a Lagrangian "particle," a drifter will stay longer in regions of surface convergence. Unfortunately, drifter density is affected by not only ocean currents but also the deployment scheme. The drifters have been deployed over many years and often in small areas for special regional experiments. Figure 2 illustrates how deployment and currents interact. Hundreds of drifters were let loose close to the equator but they were soon pushed to higher latitudes by the divergence associated with the equatorial upwelling forming the famous "cold tongue" along the equator. Other massive drifter launches occurred off the California and the US East Coast, as well as in the Japan Sea. These drifters have not been dispersed much by ocean currents. In contrast, although deployments in the mid-latitude South Pacific are scarce, the density of drifters, the blue dots in Figure 2c, is high and must therefore be ascribed to the ocean currents.

To skirt this problem of non-uniform drifter-distribution due to deployment, Maximenko developed a computer model that can use even short drifter trajectories to chart the probable paths of drifters over long time periods. The movement of each drifter in the model is based on the actual paths that the nearly 12,000 drifters took over five days from their various locations in the ocean. Maximenko first divided the globe surface into thousands of two-dimensional bins of a half degree in size; for each drifter, he used all its positions as given by the satellite determinations. From these displacements, he calculated the probability of a statistical drifter to move in 5 days into, or over, bins surrounding its original location. This calculation yields estimates of both mean distance and dispersion of the drifters. The process can then be repeated in the model every five days for as long as is needed to determine the final maximum drifter density.

Once he had computed the behaviors of real drifters, Maximenko initiated his ocean model with uniformly distributed drifters (Figure 3a) and tracked the evolution in drifter density for as long as 1000 years, the assumption being that statistics of the winds and currents remain steady over this long period.

In the model, the drifters are lost only when they enter, but never leave, a bin. This typically occurs in shoreline bins where drifters are washed on shore. The model shows that such drifter losses are surprisingly scarce, implying that debris tends to stay in the ocean for a very long time. Wind-

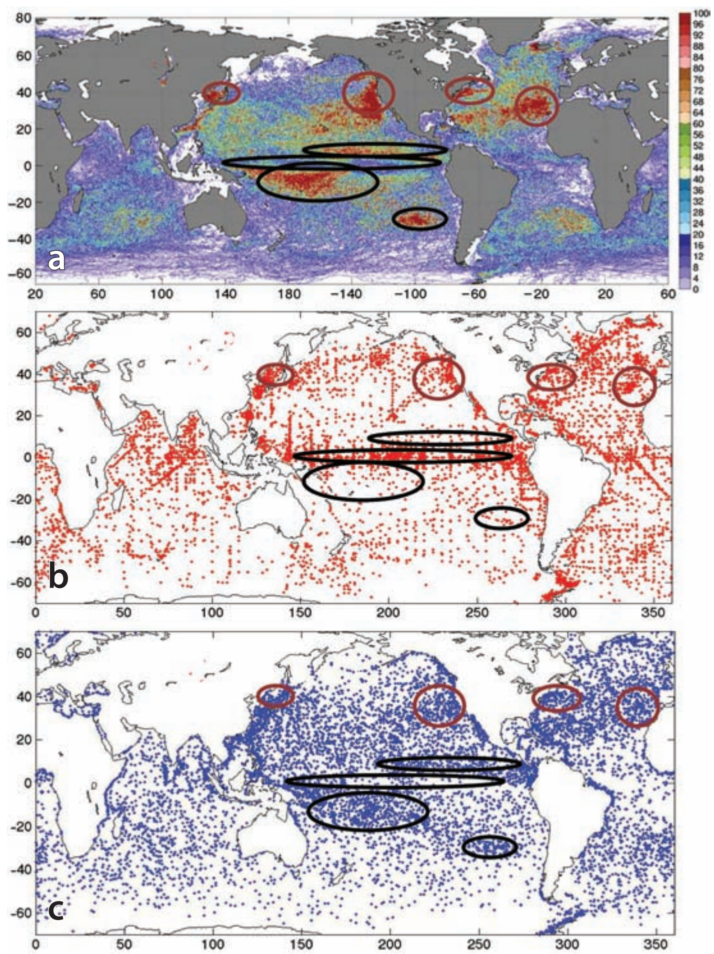

Figure 2. (a) Number of 6-hourly drifter fixes in 1/4-degree boxes, (b) locations of the drifter releases, and (c) last reported coordinates. Brown ellipses indicate regions where higher density of drifter data is consistent with the drifter deployments. Black ellipses indicate regions of highest and lowest drifter density that results from ocean currents.

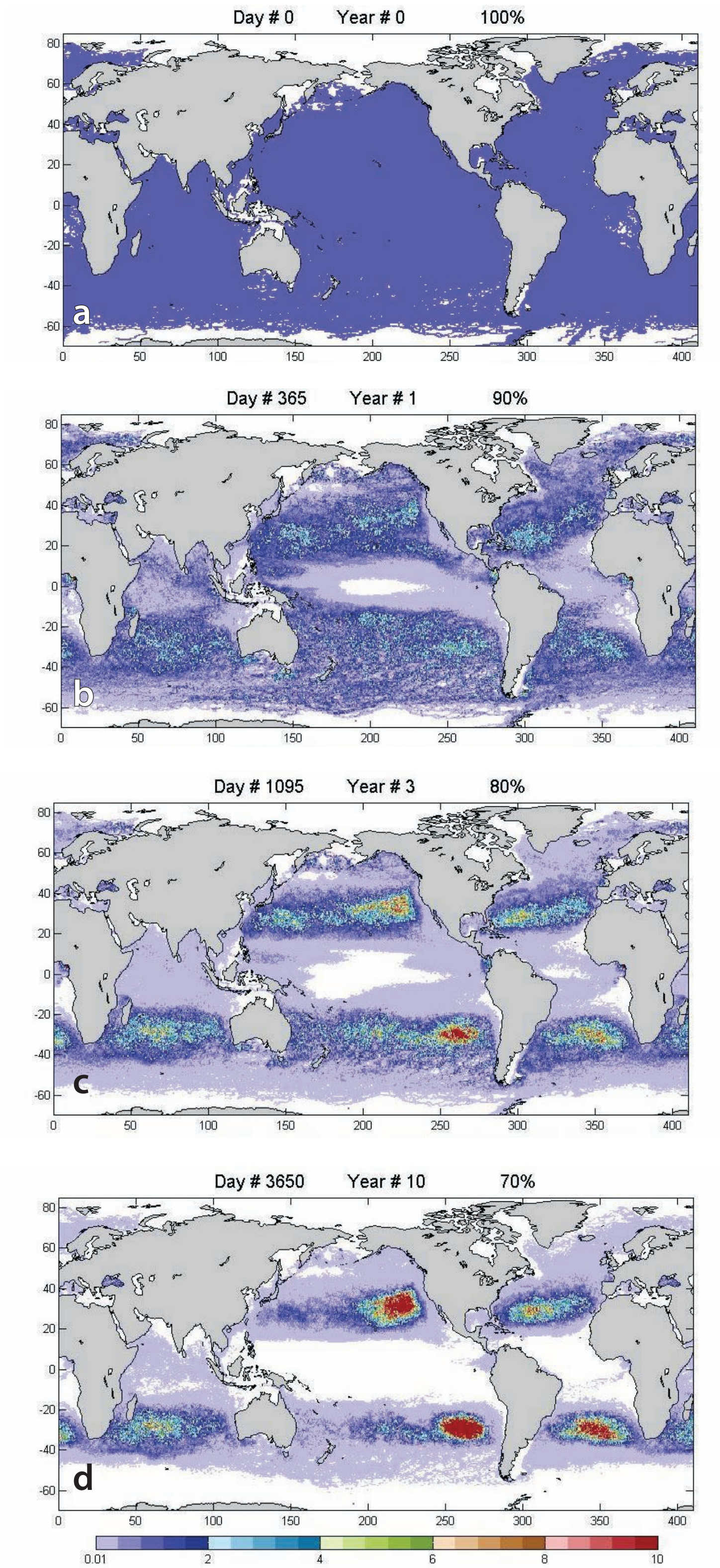

Figure 3. Simulation of evolution of drifter density (or marine debris): (a) from an initially homogeneous state, (b) after one year, (c) after 3 years, (4) after 10 years of advection by currents, as determined from real drifter movements. Units represent relative change in drifter concentration.

driven ocean currents are organized in such a way that most of the drifters are pushed offshore and kept in regions of convergences, which are far from the coast. After ten years of integration, only 30% of the model drifters had been lost.

Calculations show that the drifters tend to collect in five regions (Figure 3). These regions correspond to the centers of the five subtropical gyres.

The model shows that, before the drifters start to dissipate, their density increases to as much as 15 times their original density in the North Atlantic and South Indian Ocean, 30 times in the South Atlantic, 45 times in the North Pacific, and 150 times in the South Pacific.

The two regions where most drifters collect or converge are in the eastern North and South Pacific. In the North Pacific this place lies between Hawai'i and California and has been recently identified as the location of the Great Floating Garbage Patch, a huge cluster of partly defragmented plastic and ghost nets and other flotsam endangering marine life. The South Pacific patch has an even higher drifter-density in the model. Despite its predicted location being so close to Easter Island, this patch has not yet been detected in the real world. Perhaps this is because much less long-living debris is produced in the Southern Hemisphere than in the Northern Hemisphere.

In support of the NOAA Marine Debris Program, Maximenko is now developing further this diagnostic technique for identifying places in the ocean where debris is likely to collect and be retrieved.

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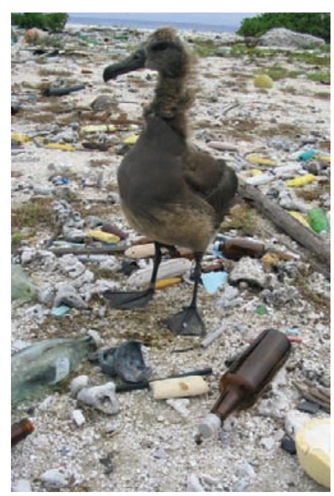

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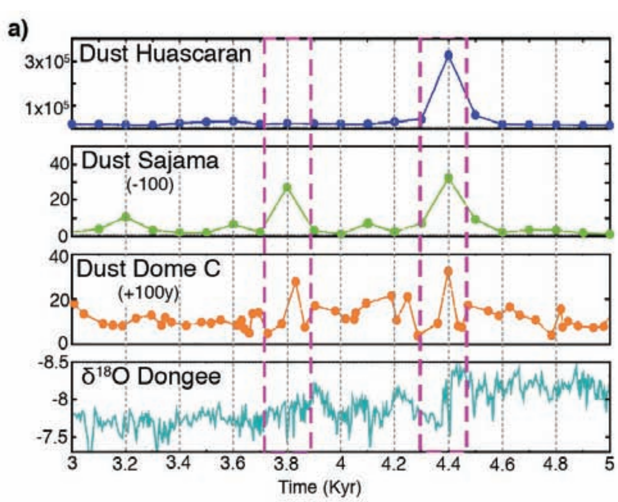
"ENSO Dynamics and Predictability" Summer School

The interdisciplinary summer school "ENSO Dynamics and Predictability" took place in the lush jungle of Puna on the Big Island of Hawai'i, June 14–24, 2008. IPRC's **Axel Timmermann**, who is CLIVAR (Climate Variability and Predictability) Pacific Panel co-chair, organized the school, bringing together budding young scientists from diverse scientific fields to study the El Niño–Southern Oscillation (ENSO) climate phenomenon. Sixteen graduate students in oceanography, meteorology, and geology from 12 countries gathered to learn about a broad swath of ENSO-related topics from experts in the field: ENSO theory (**Fei-Fei Jin**, University of Hawai'i, USA), ENSO phenomenology (**Michael McPhaden**, PMEL, NOAA, USA), ENSO predictability (**Magdalena Balmaseda**, ECMWF, UK), **Richard Kleeman** (Courant Institute, USA) and ENSO's sensitivity to past and future climate change (**Scott Power**, CSIRO, Australia, and Axel Timmermann). Energized by fresh goat milk kefir, exotic local fruit smoothies, and island-style cuisine, the students listened daily to the three- to four-hour-long lecture marathon and then worked on research projects. In teams, they examined the effects of ENSO on the Antarctic Peninsula, the rapid end of the 2008 La Niña event, the dynamics of warm pool El Niño events, the effects of Atlantic multidecadal SST variability on ENSO, the role of equatorial waves in the ENSO recharge mechanism, the geographical reaches of a tropical mega drought about 4,200 years ago, and more. The students applied in their research projects the concepts taught during the lectures, such as the recharge oscillator paradigm, ENSO frequency entrainment, equatorial waves, basin modes, teleconnection patterns, and multiplicative noise.

Understanding ENSO-past requires understanding the coupled instability mechanisms of ENSO and the annual cycle in the eastern equatorial Pacific. Many simulations with coupled general circulation computer models have demonstrated that for certain ENSO regimes a less pronounced annual cycle corresponds to stronger ENSO variability. This means that the underlying mechanism of frequency entrainment has not been fully understood. To reconstruct the ENSO-past, the computer model-derived outcomes need to be compared with such paleo-proxy data as corals, lake and ocean sediments, speleothems, and tree rings.

The benefit of the interdisciplinary nature of the summer school is shown in the student-team project of **Intan Nurhati** (Georgia Tech, USA) and **Gabriel Bayona** (EAFIT, Medellín, Colombia). As geology students, they were fascinated by the geographical extent of the 30–50-year-long megadrought that occurred about 4,200 years ago and affected the civilizations of Egypt and Mesopotamia. By compiling and synthesizing such paleo-data as speleothems, lake sediments, and ice cores, they drew a map that shows the tropic-wide extent of the drought (Figure 1). To determine what may have



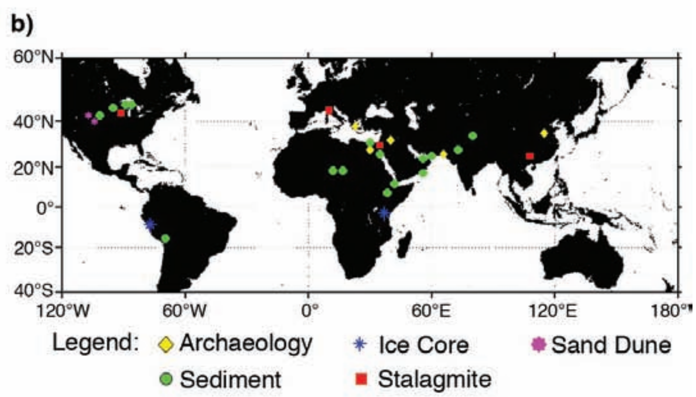


Figure 1: (a) Time series of dust fluxes at Huascaran (Peru), Sajama (Bolivia), EPICA, Dome C (Antarctica) and $\delta^{18}O$ from Dongee Cave (China) indicating major drought periods around the tropics (purple boxes). (b) Extent of the 4.2-kyr-drought event, as derived from different paleo-archives.

caused this drought, they analyzed cosmogenic isotope variations and temperature variability. Results are still inconclusive.

The summer school projects illustrate the value of joint events between CLIVAR and Past Global Changes (PAGES), which was launched in 1991 to support research on Earth's past environment in order to predict future climate. Climate modelers need paleo-records to validate their models, and paleo-climate scientists profit from the dynamical insights provided by climate modeling experiments. The summer school was generously supported by PAGES, CLIVAR, the World Climate Research Programme (WCRP), the National Oceanic and Atmospheric Administration (NOAA), the Australian Research Council Research Network for Earth System Science (ARCNESS), and the International Pacific Research Center.

Students and faculty of the ENSO Summer School at the Mauna Loa Observatory. Axel Timmermann, summer school organizer, is second from the left.

Research for Agricultural Risk Management

In August the IPRC hosted a meeting of scientists from various departments of the University of Hawai'i at Manoa and from the East-West Center to consider research efforts to support the development of practical tools for risk management of agriculture in Hawai'i. IPRC scientists are expected to play an important role in this effort since agricultural risk is driven largely by variability of weather on various timescales.

Participants of the Agricultural Risk Management Meeting: from left, Nancy Lewis (East-West Center), Tom Giambelluca (UH Geography Department), Xiouhua Fu (IPRC), Melissa Finucane (East-West Center), Xuyang Ge (IPRC), Goro Uehara (UH College of Tropical Agriculture), Richard Ogoshi (UH College of Tropical Agriculture), Pao-Shin Chu (UH Meteorology Department), Kevin Hamilton (IPRC).

Participants of the OFES International Workshop at the JAMSTEC Yokohama Institute for Earth Science.

First OFES International Workshop

Since the arrival of Japan's powerful computer Earth Simulator in 2002, scientists at the Earth Simulator Center have been conducting simulations of the ocean circulation using the Ocean General Circulation Model for the Earth Simulator (OFES), a nearly global, eddy-resolving ocean model. Output from the OFES hindcast of the ocean state during 1950–2006 and from subsequent simulations with chlorofluorocarbon tracers and biological processes are being studied by scientists worldwide. In order to exchange experiences and results from analyses of the model runs, to stimulate new ideas for research, and to encourage collaborations for future work, the first OFES International Workshop was held in the Miyoshi Memorial Auditorium of the JAMSTEC Yokohama Institute for Earth Science, Yokohama Japan, on August 25–26, 2008.

Much of the analysis of OFES data has been performed in collaborative projects between the Earth Simulator Center and the IPRC. This collaboration extends to data management issues, as IPRC's Asia-Pacific Data-Research Center (APDRC) serves OFES data to the worldwide research community. The central role of the JAMSTEC-IPRC partnership for OFES analysis was reflected in the participation of eight IPRC scientists: **Hidenori Aiki, Nikolai Maximenko, Oleg Melnichenko, Mototaka Nakamura, Kelvin Richards, Niklas Schneider, Shang-Ping Xie, Sachiko Yoshida**, as well as three IPRC "alumni" now employed at JAMSTEC or elsewhere: **Masami Nonaka, Bunmei Taguchi,** and **Yan Du.** The IPRC was an official organizer of this OFES workshop along with the Earth Simulator Center, the Frontier Research Center for Global Change, and the JAMSTEC Application Laboratory on Climate Variations Studies.

The keynote presentation was given by **Kirk Bryan** of Princeton University, who together with **Mike Cox**, was the architect of perhaps the most influential ocean general circulation model, the Bryan and Cox model, which is at the core of a number of present-day ocean GCMs including OFES. Professor Bryan noted that, although the computer technology 30–40 years ago was inadequate to allow ocean models to capture much of the important physics, the pioneering efforts of those times provided the foundation for our ability to run ocean models that now have a striking degree of realism. The challenge for the future will be to explore the rich physics revealed at these high resolutions.

The papers presented at the meeting covered an impressive array of topics: from decadal variability to small scale physics, from regional dynamics to the dynamics of the marine ecosystem. The vast majority of the results were based on analyses of the output from runs of OFES. The talks were grouped into sessions on the mid- to high-latitude ocean, the marine ecosystem, ocean dynamics, and the tropical ocean. Rather than highlight individual talks, we direct the reader to the workshop web page for a full list of talks together with abstracts (**www.jamstec.go.jp/esc/event/ofes-workshop/**).

The future is bright. Reports at the workshop were given on two new developments. The first is an even higher resolution version of OFES. At 1/30 degree, the Pacific basin version will have enough resolution to capture sub-mesoscale physics, a topic of much recent interest. The second is the use of OFES in a high-resolution coupled model (CFES). These tools will help the research community meet Professor Bryan's challenge.

The workshop was convened by **Yukio Masumoto**, group leader in the Climate Variations Research Program of JAMSTEC's Frontier Research Center for Global Change, and **Hideharu Sasaki**, scientist at the JAMSTEC Earth Simulator Center.

IPRC Participates in PaCIS

Attending PaCIS: (from left) Howard Diamond (NOAA/NESDIS), Jim Potemra, Jim Weyman (PaCIS Executive Director), Eileen Shea (PaCIS Steering Committee Chair), and Kevin Hamilton.

IPRC's **Kevin Hamilton** and **Jim Potemra** participated in a meeting of the Working Groups of NOAA's Pacific Climate Information System (PaCIS), which was held at the East-West Center from August 5 to 7, 2008. PaCIS is a new initiative to provide a framework for the development of an integrated program of climate observations, research, forecasting, operational services, assessment, data management, and education to meet the needs of the people of the Pacific Islands. The meeting attracted almost 60 participants from governmental, academic, and other groups across the Pacific. IPRC will be an important partner with PaCIS, particularly in the research and data management aspects of its activities. For more information about PaCIS, please visit **www.ideademo.org/pacis/**.

Pacific Climate Data Meetings

PI-GOOS steering team, from left, Phil Parker (Bureau of Meteorology, Australia), Keisuke Mizuno (JAMSTEC), Dean Roemmich (Scripps), Jim Potemra (IPRC), Steve Piotrowicz (NOAA Program Manager for US Argo), Alan Butler (CSIRO Australia and PI-GOOS ST Chair), Howard Diamond (NOAA Program Manager for PI-GCOS, PI-GOOS, and IPRC), Paul Eastwood (SOPAC, PI-GOOS coordinator).

At the end of October and beginning November, three meetings took place at the University of Hawai'i that related to the work of IPRC's Asia-Pacific Data-Research Center (APDRC). The first meeting, the Global Temperature and Salinity Profile Project (GTSPP) took place at the East-West Center on October 27 and was organized by **Charles Sun**, director of GTSPP. An international effort of the NOAA National Oceanographic Data Center, GTSPP is constructing a high-quality temperature and salinity profile database for all oceans. Different institutes are working to quality-control historical data from the different ocean basins. These data will be included in the GTSPP data set. The APDRC has participated in the quality control of both the Pacific and Indian Ocean historical data sets.

The 9th Annual Argo Data Management Team (ADMT-9) meeting was held at the East-West Center from October 28 to 31. The ADMT is charged with managing the data collected from the network of autonomous Argo profiling floats. Now more than 3000 of these floats send their data in real time to two data archive centers (DACs). The data from these centers are then processed by various groups, after which they are provided to the public. The ADMT ensures that the data are of high quality, in the correct format, and consistently processed. The APDRC is a partner in the Pacific Argo Regional Center (PARC) and provides web-based access to the Argo data. IPRC researchers **Nikolai Maximenko, Konstantin Lebedev, Peter Hacker,** and **Jim Potemra** described the APDRC data servers and APDRC Argo products.

The steering team meeting of the Pacific Islands Global Ocean Observing System (PI-GOOS), a regional alliance of GOOS among the Pacific Islands, was held at the IPRC on November 1. The APDRC has provided data server systems to SOPAC as part of the PI-GOOS activity. With the emerging US contribution to the Pacific Islands Ocean Observing System (PacIOOS), more collaboration will take place between the SOPAC-led PI-GOOS and the University of Hawai'i-led PacIOOS.

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The IPRC 10th Anniversary

The IPRC marked the completion of 10 years of scientific achievements with a series of events in May 2008. The previous issue of the *IPRC Climate* described the special IPRC Annual Symposium held on May 5 and 6 at the East-West Center. In their invited symposium talks, University of Tokyo Professor **Toshio Yamagata** remembered the history and evolution of the IPRC, and University of Maryland Professor **Antonio Busalacchi** described the scientific accomplishments of the IPRC over the last 10 years and speculated about IPRC's future in the international climate research community. In the evening of May 5, the IPRC staff held a reception and dinner to honor **Jay McCreary**'s service as IPRC Director and to mark Professor Yamagata's 60th birthday.

On May 9 the IPRC held an Open House for local school children and their parents. About 40 homeschooled students and their parents came to watch animations with the Magic Planet, a smaller version of the NOAA Science On a Sphere. The Magic Planet demonstrations were conducted by **Leon Geschwind**, who gives the NOAA Science On a Sphere demonstrations at Honolulu's Bishop Museum. In addition to the solar system, featuring spacecraft images of the planets and their moons, Geschwind showed animations from models of climate-change projections, including one that predicts how much of Waikiki would be under water with a 3-foot sea-level rise. In age, the students ranged from kindergarten to high school. They were fascinated by the images displayed on the Magic Planet, as were their parents, and asked many questions about the animations displayed on this truly magical sphere.

From left, Grant Mason, Josiah Gill, and Mary Mason are gazing at the Magic Planet.

A final event in our celebration was an informal review workshop on May 16, in which younger IPRC scientists showcased their research.

Bin Wang Elected AMS Fellow!

AMS Fellow Bin Wang

IPRC Team Leader and Professor of Meteorology **Bin Wang** has been elected Fellow of the American Meteorological Society (AMS) for his "outstanding contributions to the atmospheric and related oceanic and hydrologic sciences during a substantial period of years." The AMS bestows this prestigious, lifelong title each year on no more than 0.2% of the Society's world-wide membership. The ceremony will take place at the AMS Annual Meeting to be held from January 11 to 15, 2009, in Phoenix, Arizona.

IPRC Interim Director Visits JAMSTEC

In his new role as IPRC Interim Director, **Kevin Hamilton** travelled to Japan this summer to meet with several top-level administrators of the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). At Yokosuka Headquarters, he visited with JAMSTEC Executive Director **Kiyoshi Suyehiro** and Operating Executive Director **Shiro Imawaki**. In Yokohama, he enjoyed the opportunity to talk with Frontier Research Center for Global Change (FRCGC) Director-General **Tatsushi Tokioka** and the FRCGC Program Directors **Hajime Akimoto, Toshio Yamagata,** and **Akira Noda** about the overall progress of IPRC–JAMSTEC collaborations. Hamilton was also able to discuss JAMSTEC–IPRC relations with key personnel of the JAMSTEC International Affairs Division including Manager **Masakuni Hanada**, Deputy Manager **Takero Kasaya**, and **Shiro Matsugaura**. Hamilton

Kevin Hamilton with Wataru Ohfuchi (left) and Takeshi Enomoto (right) at the Earth Simulator Center.

also enjoyed a discussion of science issues with **Taroh Matsuno**, formerly Director-General and currently Senior Scientist at FRCGC.

While in Japan, Hamilton paid an extended visit to the Earth Simulator Center, where he was hosted by Senior Scientist **Wataru Ohfuchi** and Scientist **Takeshi Enomoto** of the Atmospheric and Oceanic Simulation Group with whom he is collaborating on the analysis of high-resolution AFES global atmospheric model results. This work is part of the JAMSTEC–IPRC Initiative on Model Development, Diagnosis, and Application Research. He also got a chance to talk with several members of **Masaki Satoh**'s NICAM (Nonhydrostatic ICosahedral Atmospheric Model) group about other work underway at the IPRC on this research theme, including the analysis of NICAM global atmospheric model results.

Wang and Hamilton Hosted by Japan's Meteorological Research Institute

Japan's Meteorological Research Institute (MRI) in Tsukuba hosted consecutive seminars by IPRC's **Bin Wang** and **Kevin Hamilton** on July 9 for scientists from the MRI and the University of Tsukuba. Wang spoke about his recent work on Tibetan Plateau warming and its effect on rainfall in East Asia.

Wang's seminar came in the middle of his month-long visit to the MRI, where he worked with **Akio Kitoh** and his group in the Climate Research Department analyzing outputs from the very high-resolution (20 km) MRI global model outputs to see what future changes may occur in the diurnal cycle and in tropical cyclone activity in the western North Pacific.

In his MRI seminar, "Late 21st Century Climate Change in Hawai'i Simulated with a Fine Resolution Global Model," Hamilton discussed the results for the Hawaiian region from the pioneering simulations performed at MRI with its TL959 atmospheric model (see also Hamilton's article in *IPRC Climate* vol. 7, no. 2).

Front from left, Hiroaki Ueda (University of Tsukuba), Shoji Kusunoki (MRI), Masamichi Ohba (University of Tsukuba), Tomoshige Inoue (University of Tsukuba); back from left, Bin Wang, Kevin Hamilton, Akio Kitoh (MRI), Ryo Mizuta (AESTO).

IPRC Scientists Active in the Climate Research Community

Interim IPRC Director **Kevin Hamilton** has been appointed to the External Advisory Panel of the National Center for Atmospheric Research (NCAR) Earth and Sun Systems Laboratory (ESSL). ESSL includes the main scientific divisions at NCAR. He has also been appointed to the inaugural Editorial Advisory Board of the *Journal of Advances in Modeling Earth Systems* (JAMES), a new international, electronic, open-access scientific journal on environmental modeling. For further information, please visit **adv-model-earth-syst.org**.

Yuqing Wang has been appointed to the Scientific Working Group of the VAMOS Ocean-Cloud-Atmosphere-Land Study (VOCALS), a program of the CLIVAR World Climate Research Programme. The goal of VOCALS is to develop and promote scientific activities that lead to a better understanding of the coupled ocean-atmosphere-land system in the Southeastern Pacific. For further information on VOCALS, please visit **www.eol.ucar.edu/projects/vocals/**.

Research Team Investigates Arabian Sea Oxygen Minimum Zone

The Arabian Sea oxygen minimum zone (ASOMZ) lies at a depth of 200–1000 m in the central and eastern Arabian Sea. As all OMZs, the ASOMZ is caused by the sinking of surface-produced detritus and its consumption at depth by bacteria. An unusual feature of the ASOMZ is that it is not located in the western Arabian Sea, where surface production is largest, but in the central and eastern basin. A possible physical cause for its eastward shift is the presence of oxygenated Red Sea water (RSW) in the western Arabian Sea. A group of scientists consisting of **Jay McCreary, Zuojun Yu,** and **Kelvin Richards** at IPRC; **Akio Ishida** at JAMSTEC; **Raleigh Hood** at Horn Point Environmental Laboratory; and **P. N. Vinayachandran** at the Indian Institute of Science, Bangalore, have formed a research team to investigate this idea.

From July 22 to August 3, Raleigh Hood and P. N. Vinayachandran visited the IPRC to work with McCreary and Yu on including an oxygen compartment in the biological component of their 6½-layer, biophysical Indian-Ocean model (LOM). Preliminary solutions to the updated model showed that (1) subsurface oxygen concentrations are largely controlled by local processes, namely, the sinking rate of detritus and vertical mixing of oxygen; and (2) the oxygen flux due to the transport of RSW by mean currents may not be sufficient to shift the ASOMZ to the eastern basin. Earlier this year, Akio Ishida had studied the transport of a tracer from the Gulf of Aden to the Arabian Sea using OFES and found that the transport by eddies was much stronger than that by the mean currents. Based on this finding, the next step in the project is to run an eddy-resolving version of LOM for the region.

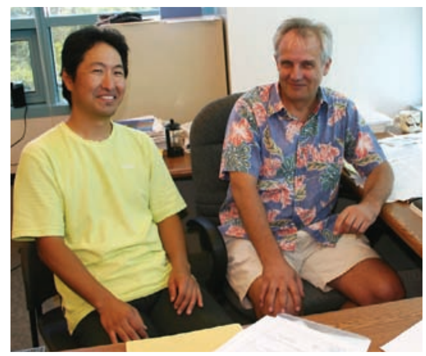
From left: Raleigh Hood, Jay McCreary, and P. N. Vinayachandran.

IPRC–Hokkaido University Partnership Continues

The IPRC–Hokkaido University partnership in educating climate scientists continues (see last *IPRC Climate* issue). IPRC's **Kelvin Richards** visited Hokkaido University at the invitation of Professor **Youichi Tanimoto**. Richards gave a series of five lectures over two days, as part of the on-going lecture series given in English by IPRC scientists to graduate students of the Division of Earth System Science, Hokkaido University. The well-attended lectures focused on the transport, dispersion, and reaction of tracers in the ocean and atmosphere.

An Ecosystem Model for OFES

Yoshikazu Sasai, research scientist at the Frontier Research Center for Global Change, visited the IPRC in Spring 2008 for three months. Sasai has implemented and run an ecosystem model embedded in OFES. At the IPRC, Sasai worked with IPRC's **Kelvin Richards** on output from the model and in particular, on the impact of the eddying Kuroshio on the primary production in the area.



Yoshikazu Sasai and Kelvin Richards discussing the link between the eddying flow around the Hawaiian Islands and the patterns of phytoplankton.

IPRC Climate Research to Help Sustainable Rice Production

IPRC's **H. Annamalai** is participating in ClimaRice, a project that is to contribute to the development of regional and national adaptation strategies to sustain rice production and ensure food security in a changing climate. The project is supported by the Norwegian Ministry of Foreign Affairs and aims to assess the climate variability and its impacts on the water availabil-

Cauvery River, courtesy of Wikipedia, the free encyclopedia.

ity and rice production in the Cauvery River Basin of Tamil Nadu in India. In addition to the IPRC, the Tamil Nadu Agricultural University (TNAU) in Coimbatore, India, and the Norwegian Institute for Agricultural and Environmental Research (Bioforsk) are participating. The role of the IPRC in this project is to assess the value of high-resolution regional model simulations for describing the future impacts of climate change on the Indian monsoon and the frequency and intensity of drought in the region. The results from this assessment will provide input to the hydrological and crop-weather modeling, which will be conducted by Bioforsk and TNAU. For more information see **www.tnau.ac.in/climarice/index.html**.

IPRC Hosts Alan Plumb

Professor **R. Alan Plumb**, FRS, former Director of the Program in Atmospheres, Oceans, and Climate at the Massachusetts Institute of Technology, visited the IPRC from November 5 to 14, 2008. Plumb is a leading authority in the field of geophysical fluid dynamics and is well-known for his contributions to the science of the stratosphere and atmospheric transports. He is also a leading scientist in the field of eddy-mean flow interaction, a field that has become very relevant to oceanographers in recent years. While at the IPRC, Plumb gave two seminars, one on the role of the stratosphere in climate and the other on the effects of eddy transports in the atmosphere and oceans. IPRC scientists took the opportunity to discuss their research with Plumb and to tap into his broad knowledge of large-scale fluid dynamics. Visiting Associate Researcher **Mototaka Nakamura**, a former student of Professor Plumb, was his host at the IPRC.

From left, Alan Plumb with Takeaki Sampe and his IPRC host Mototaka Nakamura.

Published!

The article "Trends in Hail in China during 1960–2005," which IPRC's **Yuqing Wang** co-authored with colleagues **Baoguo Xie** and **Qinghong Zhang** of Beijing University was chosen as a highlight of the July 2008 issue of *Geophysical Research Letters* by the journal's editor and subsequently by the editor of *Nature China*. The study showed that the mean number of annual hail days in northern China decreased significantly from the early 1980s to 2005. The decrease was thought to stem from the fact that the freezing-level height has risen.

The study "Rise in Tibetan Plateau Temperatures May Affect East Asian rainfall," spearheaded by IPRC's **Bin Wang** and also published in the July issue of the *Geophysical Research Letters* was highlighted in the September issue of the *Nature Geoscience*. The 1.8°C rise in temperatures on the Tibetan Plateau over the last 50 years may have had a notable effect on East Asian rainfall according to the experiments with atmospheric general circulation models. Projected increases in Tibetan Plateau temperatures may further enhance summer rainfall in East Asia. Co-authors of the study are **Qing Bao, Guoxiong Wu,** and **Yimin Liu** of the Chinese Academy of Sciences, and **Brian Hoskins** of the University of Reading.

The article "Topographic Effects on the Solar Semidiurnal Surface Tide Simulated in a Very Fine Resolution General Circulation Model" by IPRC's **Kevin Hamilton**, NOAA's **Steve Ryan** and JAMSTEC's **Wataru Ohfuchi**, published in September in the *Journal of Geophysical Research*, was selected as an *AGU Journal Highlight*. The study used both high-resolution global model simulations and observations from a network of surface pressure sensors on the island of Hawai'i to explore small-scale topographic modulation of the semidiurnal atmospheric tide (*IPRC Climate*, vol 8, no. 1).

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NEW IPRC STAFF

Tobias Friedrich

Tobias Friedrich joined the IPRC as a postdoctoral fellow in June 2008, just after obtaining his PhD from the Leibniz Institute for Marine Sciences GEOMAR at the University of Kiel in Germany. His dissertation focused on quantifying North Atlantic carbon uptake from data taken on transects by volunteer-observing ships in the North Atlantic. Using a high-resolution model, he simulated the present-day monitoring of carbon dioxide partial pressure (pCO_2) at the ocean surface in the North Atlantic and then examined several methods for extrapolating the individual local observations to create a basinwide view of pCO_2. He found that he could create monthly mean maps of pCO_2 for the North Atlantic by using neural network techniques to combine remotely sensed data of sea surface temperature and chlorophyll as well as Argo float data with ongoing measurements of pCO_2 and related variables. The high spatial and temporal variability of ocean-surface pCO_2 and insufficient optical satellite and observational coverage of the ocean, however, he feels limit the accuracy of the mapping procedure he designed.

At the IPRC, Friedrich is working with **Axel Timmermann** and **Oliver Timm** on mechanisms that cause centennial-to-millennial scale variations of the Atlantic Meridional Overturning Circulation. "My studying physical oceanography in Kiel," he says, "was arranged by fate and gives me the opportunity to become a scientist with social responsibility, while at the same time I can enjoy the ocean."

Xuyang Ge

Xuyang Ge joined the IPRC as a postdoctoral fellow in June 2008. He became interested in meteorology, particularly in tropical cyclones, because typhoons threaten his hometown, Zhejiang, China, nearly every year and can cause severe damages. After obtaining a master's degree in meteorology at the Nanjing University of Information Science and Technology in 1997, he worked at the Shanghai Climate Center for several years. He then came to the University of Hawai'i and received his PhD in meteorology in 2008.

For his dissertation, Ge investigated the energy dispersion from a tropical cyclone in a three-dimensional baroclinic model and how this energy dispersion leads to the formation of a synoptic-scale Rossby wave train in its wake. This Rossby wave train can then trigger a new tropical cyclone. Analyzing the model results of such a sequence of events, he found that a concentrated vorticity band formed in the upper levels of the wave train, which then propagated downward. A possible explanation is that smaller inertial instability in the upper-level wave branch can lead to stronger vorticity there. Once an intense asymmetric outflow jet has been generated, it can propagate to the lower level of the Rossby wave train. The development of the outflow jet results in a more intense and larger tropical cyclone, affecting the strength of the Rossby wave train since the energy dispersion is sensitive to tropical cyclone intensity and size. The downward propagation of the Rossby wave energy strengthens the lower-level wave train branch.

At IPRC, Ge is further investigating tropical cyclogenesis with **Tim Li** and is studying the application of satellite data to tropical cyclone and hurricane prediction with numerical models.

Jasti Sriranga Chowdary

Jasti Sriranga Chowdary joined the IPRC as a postdoctoral fellow in June 2008. He received his PhD in December 2007 from the Indian Institute of Tropical Meteorology at the University of Pune, where he continued to work as a research associate until coming to Hawai'i. Chowdary recalls, "I became fascinated with meteorology and oceanography while studying for my master's degree in atmospheric physics at the University of Pune. I was especially interested in learning about the El Niño-Southern Oscillation and its influence on the Indian Ocean. This led me to do my dissertation research on surface and subsurface variability of the tropical Indian Ocean."

Using various observational and modeling data sets, Chowdary studied several Indian Ocean climate-related phenomena for his dissertation. He evaluated the Indian Ocean basin-wide warming due to El Niño during years with and without an Indian Ocean Dipole. He studied the effects of La Niña—before 1976, La Niña was associated with wintertime basin-wide tropical Indian Ocean cooling, but not after 1976. He also compared the atmospheric and oceanic conditions of the Arabian Sea during the contrasting southwest monsoon years of 2002 (drought year) and 2003 (normal year). He noted that during the 2002 monsoon season, early onset and weak winds stress curl cooled the Arabian Sea, whereas in 2003, late onset of the southwesterlies in June and downwelling Rossby wave propagation probably kept the Arabian Sea warm until late July.

At the IPRC, Chowdary is working with **Shang-Ping Xie** in the areas of ocean-atmosphere interaction, and climate variability and change in the Indo-western Pacific.


Minoru Kadota

Minoru Kadota joined the IPRC as a postdoctoral fellow in fall 2008 after receiving his PhD in applied mathematics from the Courant Institute of Mathematical Science at New York University.

After high school, Kadota worked as a commercial fisherman for four years. He ploughed through 30- to 40-foot waves, fought through fierce storms, even typhoons, and became awed by the power of nature. No wonder that, when he decided to go to university, he first went into oceanography before turning to mathematics.

For his dissertation, Kadota examined the ensemble predictability of mid-latitude weather associated with the Madden-Julian Oscillation (MJO), the dominant mode of intraseasonal variation in the tropical atmosphere. Observations indicate that rainfall patterns over North America and South America are associated with phases and the spatial range of the MJO. General circulation models, however, still have major problems with producing the MJO patterns and variance distribution, and therefore are poor in predicting these MJO-related weather disturbances. Kadota built a simple numerical model of the MJO, which he drove with the MJO latent-heat pattern, and inserted this MJO model into a GCM. Using information theory, he was able to show that with his more realistic simulation of the MJO, the relevant medium-to-long-range weather predictions will improve.

At the IPRC, Kadota is investigating with **Kevin Hamilton** the extent to which the stratosphere impacts weather in the Northern Hemisphere and whether winter-weather forecasts can be improved with knowledge of stratospheric activity.

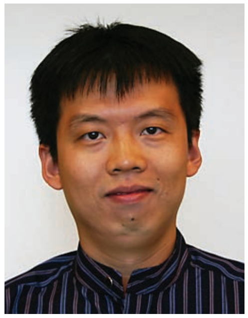

Hyodae Seo

Hyodae Seo joined the IPRC in August 2008 as a NOAA Climate and Global Change Postdoctoral Fellow. After receiving his bachelor's degree in atmospheric sciences at Yonsei University in 2002, he switched to Scripps Institution of Oceanography, where he received his PhD in climate science in 2007.

"My initial focus for my dissertation," Seo recalls, "was to investigate the mesoscale air-sea coupling of the California coastal oceans. So I helped construct a regional coupled ocean-atmosphere model that would capture such air-sea coupling. But coming across one of **Shang-Ping Xie**'s papers on tropical instability waves (TIWs) and the Central American gap winds, I applied the model to the eastern equatorial Pacific. The first model results revealed surprisingly realistic TIWs and the atmospheric responses that Xie and others reported from the satellite measurements. I turned, therefore, to study how, in the model, the observed mesoscale coupling feeds back to the tropical atmosphere and ocean. I also looked at whether resolving the Atlantic TIW mesoscale air-sea process in this coupled model improves simulation of mean climate in the tropical Atlantic Ocean. The coupled model showed that including representation of TIWs and other oceanic eddies improves the Atlantic meridional sea surface temperature gradients and meridional winds, and hence the location of the inter-tropical convergence zone (ITCZ). Moreover, including small-scale convergence and convective processes associated with the synoptic-scale African Easterly Waves (AEWs) in the atmospheric component of the coupled model substantially improves simulation of the amount of Atlantic ITCZ rainfall. The processes arising from TIWs and AEWs are poorly resolved in today's global coupled climate models, a fact that probably accounts for why those models show large climate biases in the Atlantic and the Pacific."

For his fellowship research, Seo has been focusing on coupled climate modeling of the tropical Atlantic, Indian, and North Pacific oceans. At IPRC he will continue to study various coupled climate processes of these oceans with Shang-Ping Xie and other scientists.

Lei Wang joined the IPRC as a post-doctoral fellow in August 2008 after obtaining his PhD in atmospheric science from the Department of Mathematics at Hong Kong University of Science and Technology. His bachelor's and mater's degrees were actually in physical oceanography, a field he chose without knowing much about, but it sounded interesting. He recalls, "After taking part in several field ocean investigations, during which I could observe and get to know the ocean better, I began to understand what physical oceanography is about, and I enjoyed doing the research. The switch to atmospheric science for my PhD was a big change and challenge for me. I chose my topic—atmospheric vortices and tropical cyclones—because of my experiences with ocean eddies. In my dissertation, I tried to answer the question, How do tropical cyclones form? This is still one of the great mysteries of the tropical atmosphere. Based on results of my study, I proposed that the critical condition for tropical cyclogenesis is the persistent release of large amounts of latent heat induced by lower-upper tropospheric coupling. The reason that many tropical disturbances do not develop into tropical cyclones is that lower-upper tropospheric coupling, either dynamical or thermal, is not strong enough."


Lei Wang

At the IPRC, Wang is working with **Yuqing Wang** on developing a new version of the IPRC regional coupled model (iROAM) with which he plans to study the air-sea interaction in the eastern Pacific. "It is a new research topic for me, and I hope my previous experiences in both oceanography and tropical cyclones will be helpful."

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IPRC Bids Sayonara

Associate Researcher **Tommy Jensen**, who has been a part of the IPRC since 1998, took a position with the Navy Research Laboratory-Stennis Space Center in Mississippi this past summer. While at the IPRC, Jensen explored, among other topics, the upper-ocean water mass exchanges between the Arabian Sea and the Bay of Bengal using the numerical layer model he developed. He served, furthermore, as editor of the *Journal of Climate* from 2003 to 2007. At Stennis, he is with the Planning Systems Inc., part of QinetiQ, North-America. He is analyzing coupled atmosphere-ocean-wave models and has participated in a validation study of Hurricane Katrina for the Coupled Ocean Atmosphere Prediction System.

Associate Researcher **Maxim Yaremchuk** has also been with the IPRC since 1998. His research at IPRC focused on regional climate studies at seasonal time scales using different methods of variational data assimilation into numerical models. He also joined Stennis Space Center in Mississippi and is now doing research on the data assimilation methods themselves; specifically, he is trying to combine ensemble and variational approaches to interpolate oceanographic data in open-boundary domains.

Postdoctoral Fellow **Shinichiro Kida**, who joined the IPRC in 2006, returned to Japan in November to work as a researcher at the JAMSTEC Earth Simulator Center, where he joins another former IPRC colleague, Bunmei Taguchi. Kida continues to do climate variation research on the Indonesian Throughflow and marginal seas in the western Pacific.

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