

iprc climate

Vol. 11, No. 1, 2011

Newsletter of the International Pacific Research Center

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





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Global Warming Shifts Monsoon Circulation

The impression that South Asia has been getting drier over the last 50–60 years is supported now by analysis of the trends in the widely used All-India Monsoon Rainfall (AIR) index. The 110-year-old AIR index is computed from stations well-distributed throughout India, and begins the 20th century with alternating dry and wet phases lasting 30–40 years. The last wet phase was from 1930 to 1960, but the next one, which might have been expected to begin in the 1990s, has not set in. Indeed, the AIR index shows monsoon rain has fallen by 8–10% from 1961 to 2009.

After studying various aspects of the changes in the Asian summer monsoon, IPRC researchers **H. Annamalai, Jan Hafner, K.P. Sooraj, and P. Pillai**

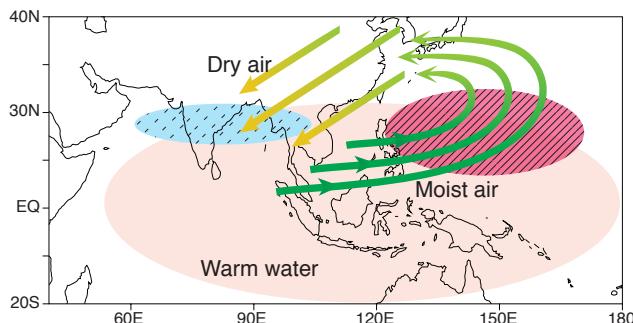
conclude that the monsoon atmospheric circulation now brings more rain to the western Pacific and less to South Asia than before. The proximate cause appears to be warming sea surface temperatures (SSTs) across the whole region that affect the regions of monsoon convection differently. The rising SSTs are plausibly attributed to global warming resulting from increased atmospheric greenhouse-gas concentrations.

Monsoon Changes in Observations

The team's examination of monsoon-related measures from 1949 to 2000 in a range of climate products draws a remarkable picture. SST rose in both the tropical Indian Ocean and

the western tropical Pacific (10°S – 30°N , 60° – 150°E), in the former region by $\sim 0.75^{\circ}\text{C}$ and in the latter by $\sim 0.5^{\circ}\text{C}$. Even though the SST increased more in the Indian Ocean, sea level pressure (SLP) there rose instead of falling, the climatological southwesterly low-level monsoon winds weakened, and rainfall over India decreased by 10% from 1951 to 2000, a decrease comparable to the AIR index. By contrast in the tropical western Pacific, SLP has dropped, and the low-level westerlies and cyclonic circulation have strengthened. Direct rainfall observations are not available, but the drop in SLP and the increased sea surface salinity (SSS) and atmospheric water vapor content over the last decades suggest that the region is seeing more rainfall than before. In short, the observations point to a shift in the monsoon circulation that has resulted in less rainfall over South Asia and more over the western tropical Pacific. The shift does not appear to reflect changes in the El Niño – Southern Oscillation (ENSO) because SST in the equatorial central and eastern Pacific has not increased.





The rise in SST over the tropical Indian Ocean and western Pacific (pink oval) increases moisture transport (green arrows) towards the western Pacific (red oval) resulting in increased rising motion and rainfall. This circulation change drives a northeasterly wind (green-yellow arrows) bringing dry, cold air from the north, reducing monsoon convection and rainfall over India (blue oval).

Monsoon Changes in a Climate Model

Annamalai and his team also studied the monsoon changes in historical runs of the latest version of the coupled climate model of the Geophysical Fluid Dynamics Laboratory (GFDL_CM2.1) included in the Fourth Climate Assessment Report of the Intergovernmental Panel on Climate Change. The model was forced with time series of the estimated historical record of well-mixed greenhouse gases, tropospheric sulfate and carbonaceous aerosols, volcanic aerosols, ozone, solar irradiance, and land-use changes.

These forced historical simulations paint a picture similar to the observations, capturing the South Asian monsoon interannual variability and the regional rainfall distributions from 1861 to 2000 together with the SST rise across the warm-pool region. In South Asia the model simulates a wet period beginning 1930 and then around 1945 a drying trend (~10% reduction during 1945–2000). In the western Pacific, the model simulates the increased rainfall from 1940 to 2000 together with the stronger low-level cyclonic circulation and lower SLP. The model also captures the timing and amplitude of the ENSO – monsoon relationship. Because ENSO, the major contributor to the year-to-year variations in South Asian monsoon rainfall, is simulated so well by the model, and because the long-term rainfall changes are significantly greater than year-to-year variations, the simulated shift in monsoon rainfall in the model is credible.

Global Warming and the Monsoon Circulation

A 200-year control run *without* forcing from increased greenhouse-gas and aerosol concentrations simulates drier

and wetter monsoon decadal periods, but not the rise in SST and changes in the rainfall pattern. Thus, man-made emissions seem to be at the root of the long-term rainfall changes.

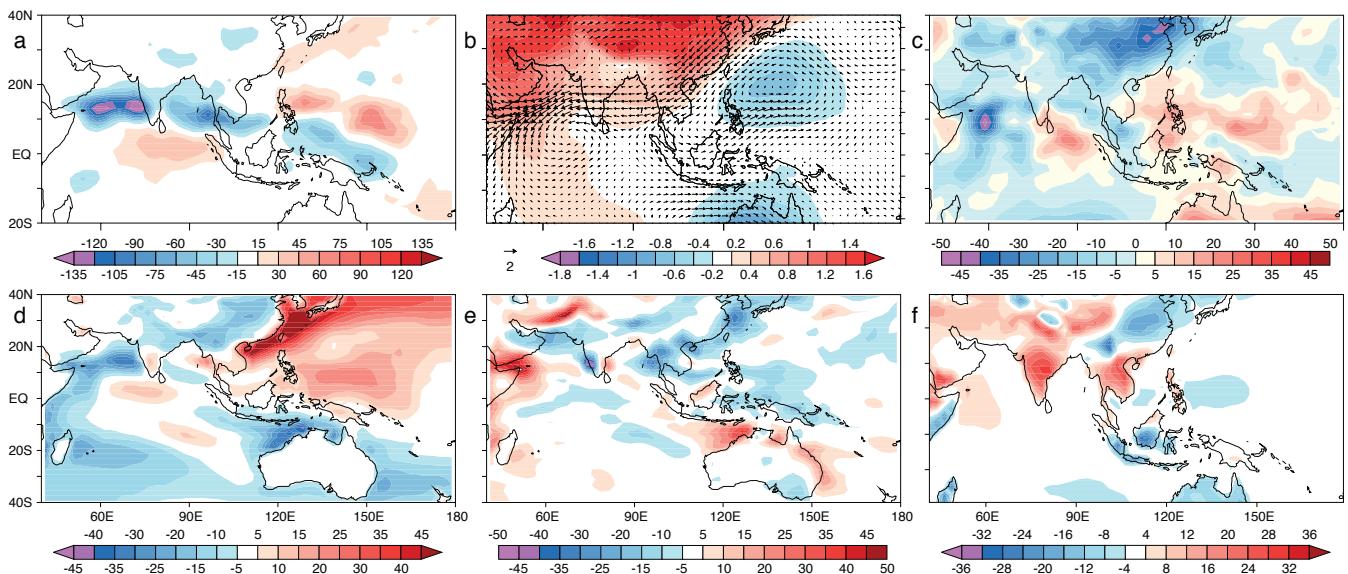
Could the circulation changes come about because SST warming due to greenhouse gases altered the interaction among the three main regions of deep convection of the Asian summer monsoon: the western tropical Pacific, the Bay of Bengal extending into the Indian subcontinent, and the tropical Indian Ocean? In a further experiment with the atmospheric component of CM2.1, the scientists forced the model with monthly increments in observed SST trends from 1949 to 2000 in (1) the western Pacific only, or (2) the Indo-Pacific, or (3) the whole tropics. Compared to a control run forced with climatological SST over the period, all 3 experimental runs showed a wetter tropical western Pacific and drying over South Asia. Since the western Pacific experiment by itself simulated this pattern, the rise in western Pacific SST appears to have initiated the monsoon circulation changes.

Analysis of the moist static-energy budget in the western Pacific model-run reveals that the rise in SST increases humidity in the lower troposphere, leading to deep convection in the tropical western Pacific. The strong low-level circulation enhances evaporation and rainfall, which in turn strengthens the low-level winds, setting up a positive feedback loop. Over South Asia, the budget shows that evaporation and advection of dry air contribute about 40% to the reduced rainfall trend, with only small contributions from other processes.

The increased rainfall in the western Pacific is thought to excite a Rossby wave (see schematic). The northerly component of this wave brings dry air from the continental subtropics into South Asia, particularly into the Bay of Bengal and the plains of Indochina. This dry, cool air reduces rainfall over the Bay of Bengal, damping convection there and reducing the moisture laden cross-equatorial monsoon flow. The weakened monsoon results in decreased evaporation, sustaining a dryer circulation over South Asia.

Regional and Global Perspective

Some scientists propose the decadal swings in rainfall over South Asia are related to the Atlantic multi-decadal oscillation (AMO). Since the AMO is currently in a warm phase, the monsoon should be in a wet phase. The drying trend over India, thus, contradicts the AMO connection. Others propose that the increase in black carbon aerosols from 1950 to



The 52-year trend (1949 – 2000) during boreal summer (June through September) simulated by the GFDL atmosphere model (AM2.1), forced by the observed SSTs over the tropical Indo-Pacific warm-pool region. The trend is obtained by subtracting the values from a control run that was forced by climatological SST: (a) precipitation (W/m^2), (b) sea level pressure (hPa) and 850 hPa wind (m/s), (c) vertically integrated moist static energy divergence (W/m^2), (d) surface evaporation (W/m^2), (e) vertically integrated moisture advection (W/m^2), and (f) vertically integrated temperature advection (W/m^2). Note that precipitation unit conversion is $28 \text{ W/m}^2 = 1.00 \text{ mm/day}$.

2000 has narrowed the north-south SST gradient in the tropical Indian Ocean. This should have moved the monsoon trough southward toward the equator, drying northern regions of South Asia and increasing rainfall along the equator. The observations and modeling experiments here, however, all point to an eastward, not southward shift in monsoon rainfall. Since the shift in monsoon rainfall is seen only in the run with increased greenhouse-gas concentrations, this forcing very likely resulted in the surface warming of the Indian and western Pacific oceans, the latter, in turn, producing the atmospheric circulation shift.

As mankind's use of greenhouse-gas emitting energy is not expected to wane over the next decades, the drying trend is likely to continue, and appropriate adaptation strategies are urgently needed for this densely populated region.

"The Indian summer is long and relentless. ... But...eventually... a prolonged and punishing summer attracts new elements in the sky: the clouds. A visible mass of droplets rise from the horizon and begin to dissipate in a thin and almost imperceptible vapour over the sky fast turning gray. Perceptibly, the horizon gathers blackness, and the sun finds its glory diminishing ... With sun's splendour veiled from human sight by a long gloomy period of storm and turbulence, the masses of heavy clouds begin to appear far more frequently, and come howling over the southern coast of India. As the days pass, the portentous bodies of water continue to roll over the peninsular India and then gradually envelop the entire landscape ... Apart from the wondrous play of raw elements of nature, the monsoon also means absolute sustenance for more than two-thirds of Indian population. During the normal duration of monsoon - roughly 100 days beginning from 1st June - about 75,000 million tonnes of water vapour are transported across the west coast of India every day. Out of which a third ... is converted into rain ... bringing joy to the farmers. Monsoon means singing crops. It guarantees the food for the rest of the year. It means extra income. It means trouble-free education for the children for yet another year."

--Shailendra Kumar ©, reproduced with permission

Monsoon Region Expands



Monsoonal Thunderstorm over Arizona: Credit NOAA

Measuring the impacts of a warming climate on monsoon rainfall is not a straightforward task and depends, among other things, on the definition of the term “monsoon domain” and on the rainfall products used for analysis. In past studies, the global monsoon domain was viewed as a fixed geographical area and was defined based on long-term climatology. The monsoon system may have changed in recent decades as land surfaces have warmed more than the ocean, especially in the Northern Hemisphere. The geographical boundaries of the regions dominated by a monsoon climate may have changed as well.

With this possibility in mind, **Pang-chi Hsu, Tim Li, and Bin Wang** at the IPRC decided to look at the global monsoon domain not as a fixed region, but defined each year as the area in which the year’s rainfall range exceeds 2 mm/day and the local summer precipitation exceeds 55% of the annual rainfall. They used the Global Precipitation Climatology Project (GPCP) and the Climate Prediction Center Merged Analysis of Precipitation (CMAP) products for their 30-year (1979–2008) analysis.

Despite rather large year-to-year fluctuations, the global monsoon area shows a clear trend growing from 1979

through 2008. Over the 29 years, the global monsoon area expanded by $6.3 \times 10^6 \text{ km}^2$ in GPCP data and by $3.39 \times 10^6 \text{ km}^2$ in CMAP data (see Figure 1), and the spatial distributions of the expansion are quite similar in the two rainfall products. The monsoon climate tends to expand at the poleward edges of the tropical monsoon region near $15^\circ\text{--}30^\circ \text{ N}$ and S . Charting the rainfall in the expanding monsoon regions in the Northern and Southern Hemispheres shows that these regions have shifted toward more summer rainfall and less winter rainfall. This poleward expansion of the global monsoon area could result from a widening tropical circulation over recent decades that is associated with the poleward expansion of the Hadley cell during summer.

To show the effects of the fixed and variable global-monsoon-area definitions on amount of rainfall, Hsu calculated the global monsoon rainfall for both a fixed area derived from the 30-year climatological rainfall field and for the interannually varying area as defined earlier. In the fixed global-monsoon area, the monsoon rainfall

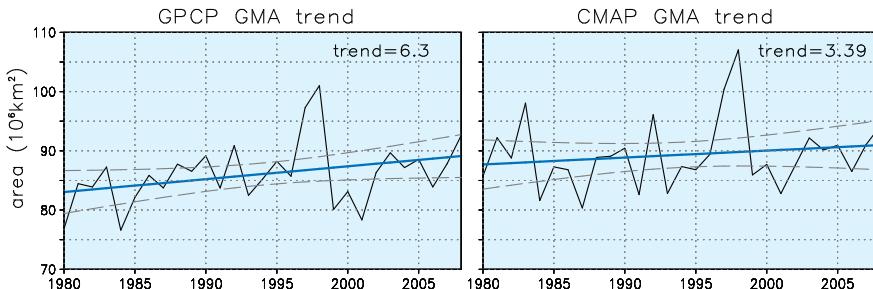


Figure 1. Time series of the global monsoon area (GMA) based on the GPCP (left) and CMAP (right) datasets for the period 1979–2008. Thick blue lines represent the linear trend of each time series ($10^6 \text{ km}^2/29 \text{ years}$) shown in each panel. Dashed lines represent 95% confidence intervals for the GMA trends.

increases $10.6 \times 10^9 \text{ m}^3/\text{day}$ (Figure 2, upper left panel) in the GPCP, but decreases $7.19 \times 10^9 \text{ m}^3/\text{day}$ in the CMAP data (Figure 2, upper right panel) over the period. In the monsoon area defined each year, rainfall increases significantly in both data sets, though the increase is much greater in GPCP ($42.5 \times 10^9 \text{ m}^3/\text{day}$) than in CMAP ($2.57 \times 10^9 \text{ m}^3/\text{day}$).

That monsoon rainfall has increased globally should not surprise given that the area over which monsoon rainfall was computed has expanded. What counts for people living in the region, though, is the intensity of rainfall. To quantify the change in the global monsoon strength, Hsu computed a global monsoon intensity index, defined as the global monsoon rainfall amount divided by the area of the global monsoon domain. The GPCP and the CMAP products both show slightly less intense monsoon rainfall over the past 30 years: in GPCP this change is -0.03 and in CMAP it is -0.24 mm/day (Figure 3).

The finding that the monsoon climate, with wetter summers and drier winters, is expanding poleward will have agricultural and other economic consequences for these regions. The slightly weaker global monsoon intensity seems not too worrisome, but, as the previous story on the drying trend in South Asia showed, consequential local changes in rainfall intensity have been observed in some places.

This story is based on
 Hsu, P.-c., T. Li, and B. Wang, 2011: Trends
 in global monsoon area and precipitation
 over the past 30 years. *GRL*, **38**, L08701,
 doi:10.1029/2011GL046893.

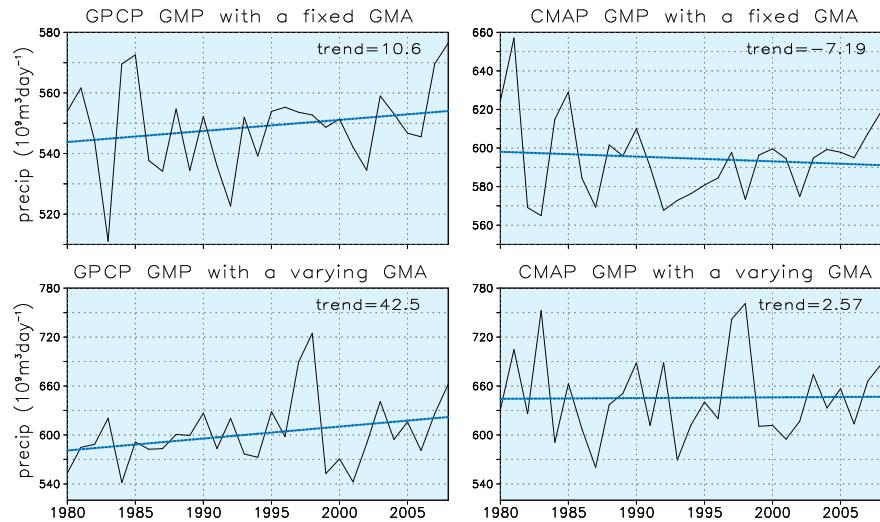


Figure 2. Time series of the global monsoon precipitation (GMP, unit: $10^9 \text{ m}^3/\text{day}$) based on a fixed (top panels) and varying (bottom panels) global monsoon domain using the GPCP (left) and CMAP (right) datasets for the period of 1979–2008. The linear trend of each time series is shown by a blue line (unit: $10^9 \text{ m}^3/\text{day}$ over 29 years) in each panel.

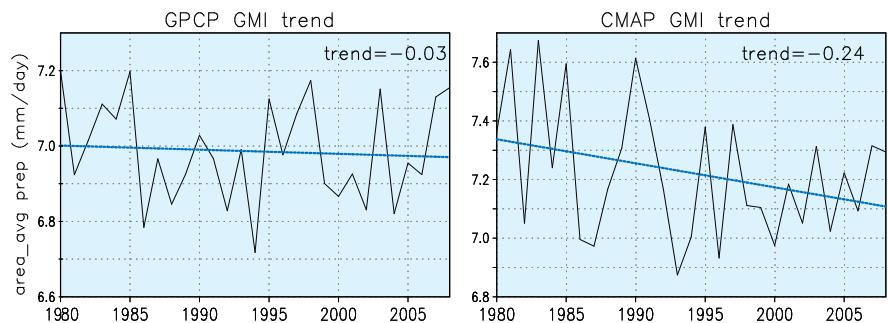
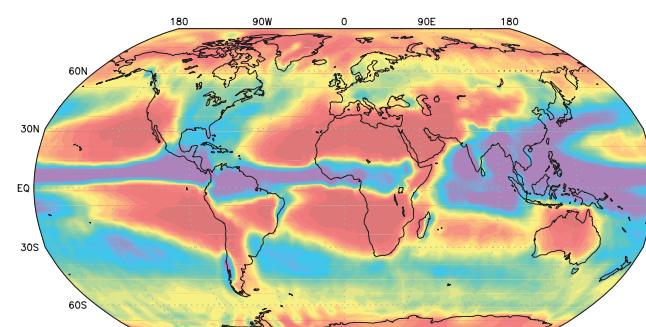


Figure 3. Time series of the global monsoon intensity (GMI, unit: mm/day) based on the GPCP (left) and CMAP (right) datasets for the period of 1979–2008. The linear trend in each time series is shown by a blue line (unit: mm/day) in each panel.



CMAP Precipitation Climatology: Credit APDRC



Rain shaft over Man-of-War Bay: Credit NOAA

Is the Threshold Rising for Tropical Convection?

Deep, moist convection over the ocean tends to occur only when surface temperatures exceed about 27°C. What will happen to this threshold for convection as global temperatures rise? If the threshold were to stay around 27°C, then the region of the ocean surface characterized by deep convection would expand as climate warms. A definitive answer has eluded scientists because reported measurements of the tropical atmosphere temperatures conflict with each other, and the mechanism determining this threshold has not been well understood.

Nat Johnson and Shang-Ping Xie at the IPRC have now demonstrated that even though over the past 30 years

sea surface temperature (SST) and the threshold for convection have varied greatly from year to year, they have varied in tandem, and over the long term both have risen. This implies that SST and the convection threshold are closely linked.

At the center of their study is the theory of moist adiabatic lapse rate (MALR) adjustment. “According to this theory, when surface temperatures rise, so should the temperature in the upper troposphere,” explains Johnson. “We hypothesized that the convective threshold is closely linked to tropical mean SST and should rise along with ocean temperatures because the moist adiabatic lapse rate varies with the underlying SST.”

Radiosonde and satellite measurements of the tropospheric temperature, however, have given conflicting pictures, with some studies actually indicating that the upper troposphere has not warmed since 1979. If the warming of the upper troposphere is, in fact, substantially lower than expected by MALR adjustment, then the tropical atmosphere would be more unstable and more frequent convection could be expected.

Rather than relying on satellite and radiosonde measurements of the upper tropospheric temperature, Johnson and Xie used indirect measures of atmospheric stability, analyzing changes in the annual-mean tropical rainfall from 1979 to 2009 in two widely used

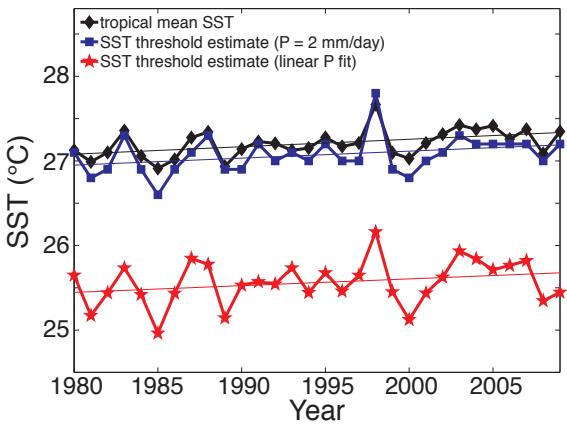


Figure 1. Time series of tropical (20°S to 20°N) annual mean SST (black) and two estimates of the SST threshold for convection (blue and red) together with their linear trends. The blue curve is estimated from the lowest SST at which the mean precipitation rate (P) exceeds 2 mm/day; the red curve is estimated from P that was approximated as a linear function of SST above a threshold. The linear trends for the tropical mean SST and SST threshold estimates are all approximately 0.1 °C/decade.

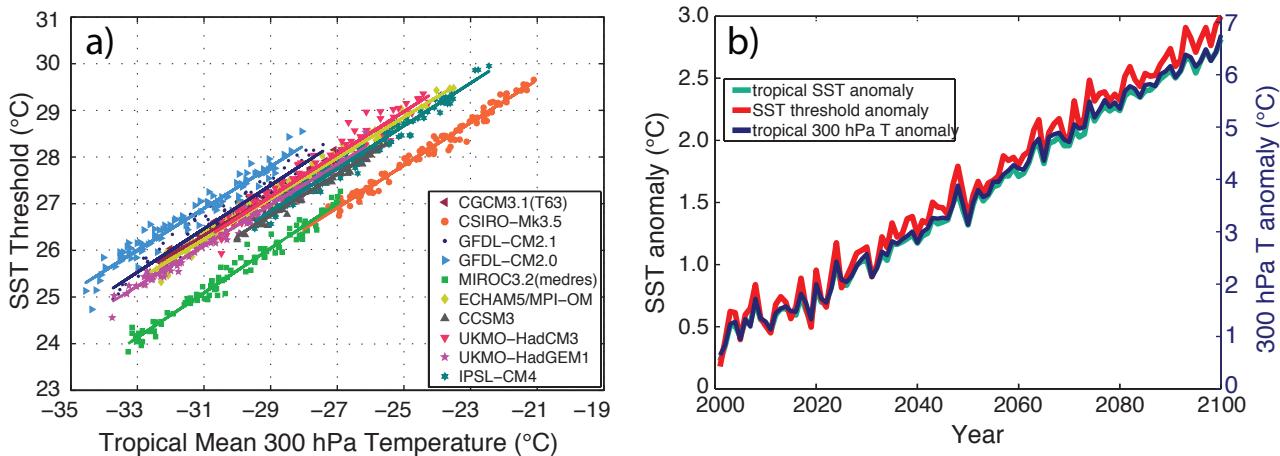


Figure 2. The relationship between the SST threshold for convection and upper tropospheric temperature in global climate models. (a) Scatter plot of SST threshold against tropical mean 300 hPa temperature with regression lines for each of 10 CMIP3 models under emissions scenario A1B in simulations of the 21st century. **(b)** Time series of the CMIP3 ensemble-mean deviations from the 1961–1990 averages for tropical mean SST (green), SST threshold for convection (red), and tropical mean 300 hPa temperature (blue). The right y-axis for 300 hPa temperature has been scaled to follow MALR adjustment of tropical mean SST (left y-axis); thus, the overlap among the three curves suggests that the convective threshold is following MALR adjustment of the tropical mean SST.

global precipitation products, the Global Precipitation Climatology Project and the Climate Prediction Center Merged Analysis of Precipitation. They computed the convection threshold in two ways: (1) by finding the lowest SST for which the mean precipitation rate exceeds 2 mm/day, and (2) by approximating the precipitation rate above a threshold as a linear function of SST. Although the precise value of the SST convective threshold depended to some extent on the definition employed, the variability did not: both methods show a remarkable correspondence between mean tropical SST and the convective threshold (Figure 1) and both methods reveal an upward trend of about 0.3°C over the 30 years. Results obtained with the two precipitation products are similar.

Johnson and Xie then examined the relationship between the convection threshold, tropical mean SST, and tropical mean 300 hPa temperatures in 20th and 21st century climate simulations in ten global climate models from the World Climate Research Program Coupled Model Intercomparison Project 3 (CMIP3) archive.

The model simulations, including the 21st century runs that featured an approximate doubling of atmospheric CO₂ concentrations under rapid world economic growth (emissions scenario A1B), show a close correspondence both between the convective threshold and tropical mean SST and between the convective threshold and tropical mean 300 hPa

temperature (Figure 2a), supporting the idea that the convective threshold is responding to MALR adjustment of a warming tropical troposphere. Thus, MALR adjustment theory, global climate model simulations, and observations are all in agreement that the upper tropospheric temperature is rising more rapidly than surface temperatures. Figure 2b shows the mean tropical SST anomaly and determined threshold temperatures rising together through the 21st century in the CMIP3 ensemble mean results. The 300 hPa mean tropical temperature in the ensemble mean also rises in tandem with the mean SST, but at almost three times the rate.

“If moist instability would be increasing as tropical oceans warm with global warming, then we could see more frequent tropical cyclones and an expansion of the regions and seasons in which tropical cyclones occur. The close correspondence that we noted between tropical mean SST and the convective threshold, however, shows the convective stability of the tropical atmosphere has changed little over 30 years, despite rising SST,” explains Shang-Ping Xie. “The study thus provides some reassurance that rising tropical ocean temperatures with global warming will not by itself cause substantially more tropical cyclones.”

This story is based on

Johnson, N. C., and S.-P. Xie, 2010: Changes in the sea surface temperature threshold for tropical convection *Nature Geoscience*, 3 (12), 842–845.

Trade Winds Weaken over the Atlantic



Tracking climate trends is essential, if we wish to understand and project future climate changes. This task is hampered by deficiencies in data sources, one of the most serious having been a lack of accurate historical observations of winds over the World's oceans. Before satellites, meteorologists relied on extensive surface-wind-related observations taken on ships-of-opportunity. These raw observations, though, have biases that may mask real long-term trends. For example, the reported ship-based wind measurements include direct anemometer observations. As reporting ships have on average become taller over the years, anemometers are being placed higher, biasing direct wind observations towards higher wind speeds. Hiroki Tokinaga and Shang-Ping Xie at the IPRC have developed a method to minimize the biases and have constructed a long-term (1950–2009) product of monthly mean near-surface winds over the global ocean called "Wave- and Anemometer-based Sea surface Wind" (WASWind; see *IPRC Climate*, Vol. 10, no. 2).

Tokinaga and Xie have now used WASWind to track the winds in the tropical Atlantic from 1950 to 2009. According to raw wind measurements from major shipping lanes in the tropical Atlantic, the southeasterly trade winds have intensified during the last six decades. The corrected WASWind, however, suggests a weakening of the trade winds over the eastern tropical Atlantic, as illustrated by the westerly trends in Figure 1a. The long-term relaxation of the trade winds explains other findings: Not only has sea surface temperature (SST) over the whole basin risen, but the cold tongue of water stretching westward from the African Coast has warmed more than the adjacent regions (Figure 1b). The flattened east-west gradient of SST leads to a climate reminiscent of the Atlantic Niño that replaces from time to time the usual cold tongue of the eastern tropical Atlantic.

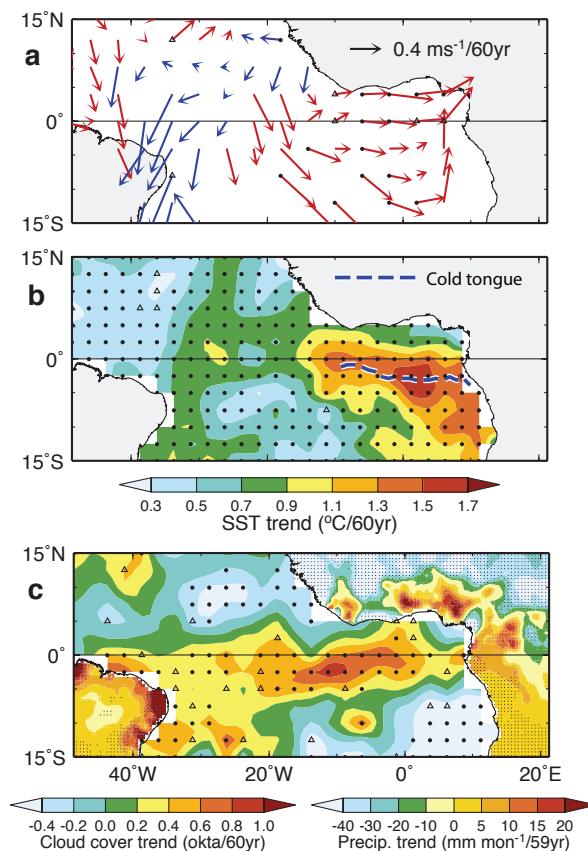


Figure 1. The tropical Atlantic patterns of the 60-year trend: (a) May–July surface wind. Westerly (easterly) trends are shown by red (blue) arrows; (b) June–August SST, the blue dashed line denotes the axis of the climatological equatorial cold tongue; (c) June–August marine cloud cover and land precipitation. Grid points marked with filled circles (triangles) exceed the 95% (90%) confidence level based on the Mann–Kendall test.

The 60-year decline of the cold tongue is accompanied by a significant warming of subsurface ocean temperature. Expendable bathymograph observations with bias corrections show that in the eastern equatorial Atlantic, the warming extends down to 250-m depth, indicating a deepening of the thermocline. This deepened thermocline suppresses equatorial upwelling, affecting marine ecosystems through reduction in ocean nutrient.

The equatorial warming and the slackening trade winds have altered the tropical Atlantic climate in other ways. The intertropical convergence zone with a large amount of rainfall has shifted equatorward, according to cloudiness data from historical ship observations. Associated with this cloud- and rain-band shift, land rainfall has also increased in the adjacent areas—the equatorial coastal regions of the Amazon and the Guinea Coast—according to rain gauge-based observations (Figure 1c). For example, the August rainfall at Ibadan, one of the largest cities in Nigeria, has increased by 79 mm/month from 1950 to 1998, representing a remarkable 93% increase in the long-term August average for 1900–1949. This enhanced coastal rainfall has been accompanied by a trend to even drier conditions in the Sahel. Tokinaga and Xie's results also suggest that the year-to-year variations of the cold tongue and the Guinea Coast rainfall are less during recent decades, implying fewer extreme events.

An experiment with an ocean general circulation model forced with WASWind reproduces many of the changes seen in the observations over the last six decades and confirms the impact of the weakened trade winds. But what has caused these changes in tropical Atlantic climate?

"We could not find any observational evidence that the changes are linked to a weakened Atlantic Meridional Over-



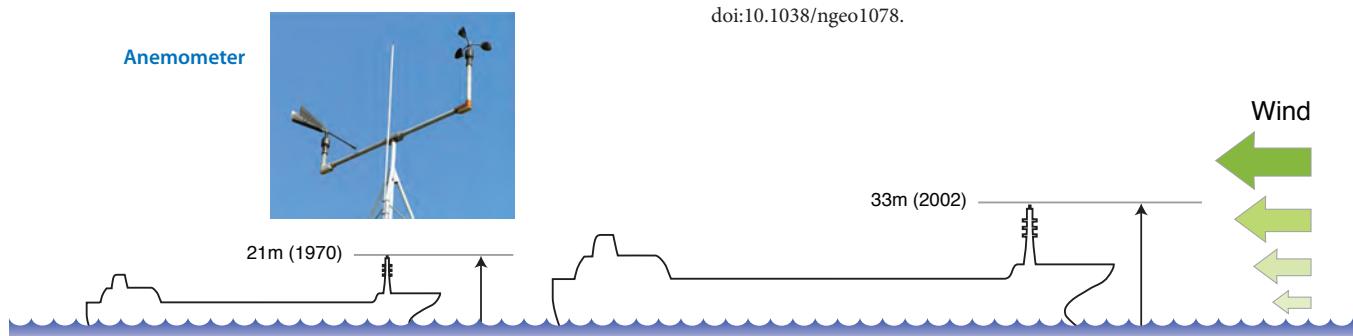
Antique Dutch map of Guinea Coast. Credit antiquemaps-fair.com.

turning Circulation or multidecadal climate variations in the North Atlantic. Rather, we speculate the change is due to a greater concentration of man-produced aerosols in the Northern than in the Southern Hemisphere, reducing solar radiation asymmetrically and weakening the north-south SST gradient. This weakened interhemispheric SST gradient relaxes the cross-equatorial trade winds," explains Tokinaga.

There is evidence for this scenario: The CMIP3 20th century experiments that include sulfate aerosols simulate regional patterns of climate change similar to the observations. If aerosol emissions decrease over the next decades but greenhouse-gas concentrations increase, the tropical Atlantic climate may shift yet again. If such climate shift recovers the year-to-year variability of the Atlantic cold tongue, the resulting increase in climate extremes would add burdens to an ecosystem and to a society already stressed by global warming.

This story is based on

Tokinaga, H., and S.-P. Xie, 2011: Weakening of the equatorial Atlantic cold tongue over the past six decades. *Nature Geoscience*, **4** (4), 222–226, doi:10.1038/ngeo1078.



Change in average ship height and anemometer placement from 1970 to 2002 and increasing wind strength over the ocean with height (green arrows). Image courtesy Hiroki Tokinaga.

The Science of Climate Change in Hawai'i

By Kevin Hamilton

Hawai'i's dominant industries - first agriculture and then tourism - have been crucially linked to its generally favorable weather. Hawai'i has also on occasion displayed its vulnerability to extreme adverse weather, including droughts, flash floods and tropical cyclones. The islands' extensive coastal regions leave them particularly vulnerable to both extreme individual events such as hurricanes and to effects of gradual environmental change. Hawai'i's isolated location makes its fresh water resources completely dependent on local rainfall. Not surprisingly, there is great public interest in how anticipated climate change may affect the natural, economic and cultural resources of Hawai'i. A great deal of relevant research on this issue is now being performed at the IPRC and elsewhere.

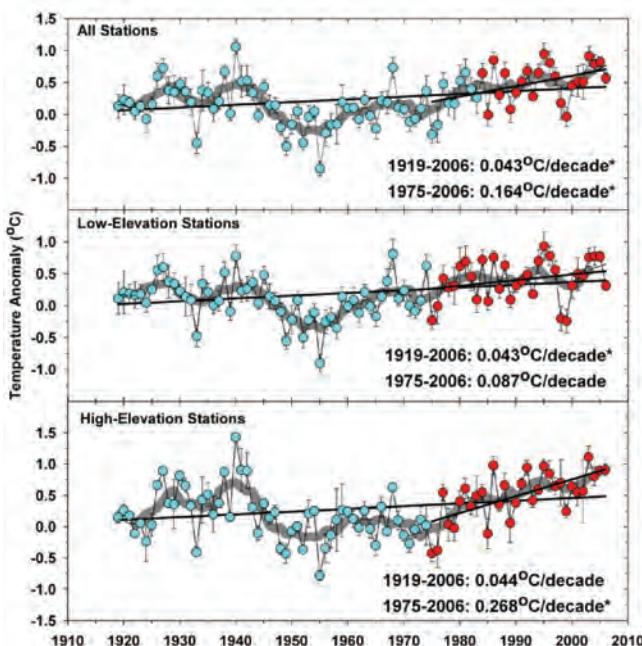


Fig. 1. Annual mean surface air temperature anomalies averaged over Hawaiian stations with elevation above 800 m (bottom), below 800 m (middle) and a weighted average of the low and high-elevation stations (top). The smooth curves are 7 year running means. The asterisks beside the linear regression trends in each panel indicate statistical significance. Adapted from Giambelluca et al., *Geophys. Res. Lett.*, 2008.

At the initiative of Dean **Brian Taylor** of the University of Hawai'i School of Ocean and Earth Science and Technology (SOEST), a symposium was held January 19 and 20, 2011, to review research on the science of climate change in Hawai'i and to discuss avenues for future progress. The IPRC took the lead as host of the meeting, which was intended for IPRC scientists, colleagues elsewhere in SOEST and in other units of the university, as well as scientists from local Hawai'i partners such as the US Geological Survey, NOAA, and the East-West Center. To keep the meeting scope manageable, the focus was on observing and attributing the physical climate changes over roughly the last century and projecting such changes for the next century.

The meeting produced ample evidence for changing Hawaiian climate in the recent past. Figure 1 presented by **Tom Giambelluca** (UH Geography Department) shows temperature indices based on daily air temperature observations at several surface stations on Kaua'i, O'ahu, Maui, and the Big Island of Hawai'i. The tendency for rising temperatures since about 1975 is apparent, and indeed the trends based on 1975 – 2006 observations are quite large, particularly for high-elevation stations. The behavior over the full ~90 year record is more complicated, however, and may be affected by long-period natural variations. The difficulty of separating long-term trends that may be reasonably attributed to anthropogenic forcing from other long-period sources of variability is apparent in other climate variables as well. However, an overall long-term trend toward drier conditions over the islands, with reduced rainfall and flow in Hawai'i's streams, was apparent in the observations discussed by **Delwyn Oki** (US Geological Survey) and others at the Symposium. **Roger Lukas** (Oceanography Department) presented a summary of observed trends in the oceans near Hawai'i, making use of the long Hawai'i Ocean Time Series of measurements at Station ALOHA north of O'ahu. A trend in recent decades to warmer and more saline surface waters is apparent in these data.

Several talks at the meeting aimed to present the local climate changes seen in Hawai'i in a broader regional (i.e., tropical and subtropical Pacific) context. A particular issue identified was the quality of available meteorological data over the large ocean areas, as both global reanalysis data and raw

ship-report data are suspect in some ways. The lack of reliable observations complicates even such basic aspects as determination of trends in the strength of the regional-scale surface winds.

A critical practical issue for an island state like Hawai‘i is sea level rise. A long record from a tide gauge at Honolulu presented by **Mark Merrifield** (Oceanography Department) reveals a rather relentless increase of the sea level for the past century, but at a relatively modest and constant rate. By contrast the best estimates of global sea level suggest an acceleration of the rising trends in the last couple of decades. Of course, the local sea level trend at any location depends on a number of factors and will be driven to a significant extent by changes in the regional-scale surface winds. Satellite data for the last 2 decades show substantial regional trends in sea level across the Pacific, with Hawai‘i located in a region characterized by relatively modest rising trends.

The issue of projecting climate changes into the future was also addressed in a number of presentations. The current climate projections from global coupled atmosphere-ocean models have limited direct application to Hawai‘i, as most very long climate forecast integrations have been performed using atmospheric component models with effective horizontal grid-spacings of ~200 km. This is a significant issue for representing many aspects of the atmospheric circulation, but is a particular problem for Hawai‘i where the climate is strongly affected by the steep topography present on all the major islands. Typical global models represent all the Hawaiian Islands as a single land grid-box or even ignore Hawai‘i entirely. With-

out further analysis, the predicted changes in climate variables from such models are made at a resolution far too coarse to provide input into typical application studies. There are comparable issues in modeling climate impacts on local and regional ocean circulation. Presentations by **Axel Lauer** (IPRC), **Yi-Leng Chen** (Meteorology Department) and **Brian Powell** (Oceanography Department) addressed the current state of regional atmospheric and ocean modeling for application to the climate change problem in Hawai‘i.

While current coupled models used in extensive climate integrations have relatively coarse horizontal resolution, some experimental global warming projections have been made using higher resolution global atmospheric models forced by ocean surface-temperature changes simulated in lower resolution coupled models. Presentations by **Tim Li** (IPRC) and IPRC visitor **Hiroyuki Murakami** discussed applications of such high-resolution global model projections to study the effects of global warming on the climatology of tropical cyclones that could affect Hawai‘i.

Held at the East-West Center’s Imin Conference Center, the meeting attracted a standing-room-only audience, and a telecast to another seminar room helped accommodate the overflow crowd of climate science enthusiasts. The scientific program was organized by IPRC Director **Kevin Hamilton** and SOEST Associate Dean **Chip Fletcher**. IPRC staff members **Ron Merrill**, **Dave Burns**, and **Jeanie Ho** provided critical technical and administrative assistance. The full program can be viewed at http://iprc.soest.hawaii.edu/meetings/workshops/11_01_SOESTSymposium_final.pdf



Participants at the Science of Climate Change in Hawai‘i Symposium.

Charting the Origin and Fate of Marine Debris

By Audine Laurian

Rubbish in the ocean is endangering marine ecosystems and shipping. *The 5th International Marine Debris Conference* in March 2011 at the Waikiki Beach Marriott Resort & Spa dealt with the manifold issues arising from such debris. IPRC's Senior Researcher **Nikolai Maximenko**, who is studying the ocean currents that gather the floating debris in patches, organized a workshop with **Kara Lavender Law** (Sea Educational Association/Woods Hole Oceanographic Institution) on *Hydrodynamics of Marine Debris* for the opening day of the conference. The workshop aimed to quantify the major sources and sinks of marine debris and their variability, pathways and effects on ecosystems. Over 70 people from various disciplines and countries shared their knowledge of observed and modeled marine debris and discussed efforts needed to determine the global inventory of marine debris and how it changes over time.

Doug Woodring (Kaisei) reported how trash and refuse are collected in rivers, making rivers the main source of land rubbish that ends up in the ocean. How debris in the ocean is swept back to shore by tides and storms was described by **Scott Wilson** (Centre for Environmental Management, Australia) and **Chris Pallister** (Gulf of Alaska Keeper). In the past 24 years of sampling the North Atlantic Garbage Patch region, Kara Lavender Law and her students estimated that

1100 tons of microplastic had accumulated in the area. With increased plastic production over those years, the amount of plastic dumped into the ocean has very likely increased, but surprisingly, Lavender Law found no increasing trend in her yearly samples. Is the plastic deposited on shores or on the ocean floor? Is it ingested by marine organisms? Studying the distribution of marine debris within the mixed layer, **Giora Proskurowski** (Woods Hole Oceanographic Institution) found that strong winds mixed the plastic down to 10–20 meters, decreasing temporarily surface concentration of debris.

To locate the debris in the ocean, computer models are crucial. **Mary Crowley**, an experienced sailor from the Ocean Voyages Institute, has been sampling worldwide marine debris ranging from microplastic to derelict fishing gear. When she tested equipment designed to collect microplastic in the North Pacific Garbage Patch last August, the model projections by Maximenko and IPRC's **Jan Hafner** guided her in finding the debris.

Scientists study near-surface ocean currents using Lagrangian drifters, which include a surface float and a drogue centered at 15-meter depth. Such equipment behaves like abandoned fishing gear and **Luca Centurioni** (Scripps Institution of Oceanography) and **Andrew Sybrandy** (Pacific Gyre) suggested that drifters help to understand the movements of bulky marine debris. Such drifters also furnished the data for the model that Maximenko developed and which showed the pathways the debris from the March 11 tsunami in Japan may take: first it will flow eastward in the North



Participants at the Hydrodynamics of Marine Debris Workshop.

Pacific Subtropical Gyre; in about a year and a half, some will wash up on Hawai‘i’s beaches; much will continue to circulate in the gyre toward the US West Coast, then equatorward and westward, reaching the eastern Hawaiian coasts in about 5 to 6 years.

IPRC’s **Jim Potemra** described other state-of-the-art models that simulate trajectories of marine debris, and **Kathleen Dohan** (Earth & Space Research) gave details of the currently most popular model, the Ocean Surface

Current Analyses - Real time (OSCAR). Finally, IPRC’s Jan Hafner showed how an ocean surface-current-model driven by satellite wind and altimetry data can reveal changes in the position of high marine-debris concentration. Models, Hafner said, need to be extended to include the vertical structure of marine debris, coastal processes, and marine debris deposition mechanisms.

During the workshop and the following days of the conference, the observational scientists and modelers

seized the opportunity to talk together and form partnerships for future studies on marine debris trends, the three-dimensional distribution of marine debris and its dynamics, and the development of remote-sensing techniques for better observation of marine debris.

With the help of IPRC’s **Ron Merrill**, **Oleg Melnichenko**, **Ali Reda Bel Madani**, and **Audine Laurian** the workshop was broadcasted and materials are available at: <http://iprc.soest.hawaii.edu/users/nikolai/2011/HMD/>

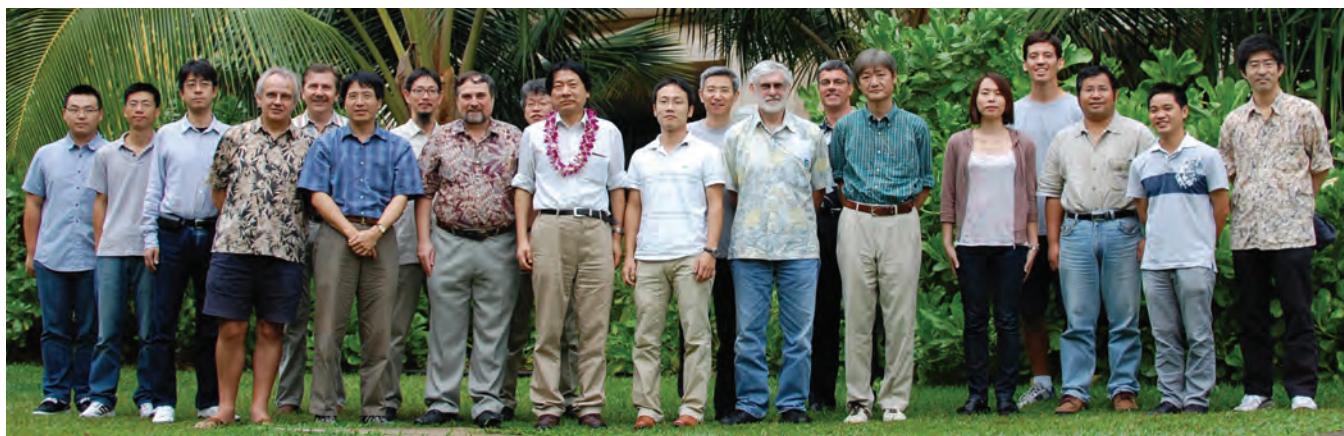
A “Hot Spot” in the Climate System: Air-Sea Interaction during the East Asian Monsoon

By Yu Kosaka

The midlatitude ocean was thought to be a rather passive player in climate, but in recent years, high-resolution satellite data and modeling have revealed that the western boundary currents supply the midlatitude atmosphere with intensive heat and moisture, conditions that make for strong climate events. One such “hot spot” in the extratropical climate system is the Kuroshio/Oyashio in the Northwest Pacific.

Hisashi Nakamura (The University of Tokyo and JAMSTEC) leads a Japanese nation-wide project on the Northwest Pacific hot spot. Nakamura and his collaborators on this project **Atsuhiko Isobe** (Ehime University), **Youichi Tanimoto** (Hokkaido University), **Yoshimi Kawai**, **Masami Nonaka**, **Wataru Ohfuchi** and **Bunmei Taguchi** (JAMSTEC) visited the IPRC in December 2010, and IPRC scientists took this opportunity to hold the workshop *Air-sea interaction and climate variability over the Northwest Pacific*. **Shoshiro Minobe** (Hokkaido University) joined the meeting by making a presentation from Japan via Skype. The hot-spot project team described their research plans and preliminary results

from their recent studies on the project. They are using regional and global models and a wide variety of observations from satellites, research vessels, buoys, radiosondes, and aircraft to investigate atmosphere-ocean-ecosystem interactions over the Kuroshio/Oyashio extensions. Scientists from the IPRC and the UH Mānoa Department of Oceanography discussed their related work on air-sea interaction, decadal variability, and the East Asian monsoon. At the end of the workshop, the scientists talked over possible future collaborations between the hot spot project and work at IPRC, including joint ship observations over the Northwest Pacific.



Hot Spot scholars. Project leader Hisashi Nakamura with lei.

Atmospheric Gravity Waves and their Effects on Global Circulation

By Kevin Hamilton

Inertia-gravity waves account for a significant fraction of the observed variability in the atmosphere with periods from tens of minutes to tens of hours. The wind and temperature variance associated with high-frequency gravity waves is generally observed to increase with height from near the ground up to the lower thermosphere, and studies of gravity waves in the upper atmosphere have been a staple of middle and upper atmospheric dynamics for many years. Gravity waves act to exchange mean horizontal momentum between the earth's surface and the atmosphere and among different layers of the atmosphere, and so they play a role in forcing the global-scale atmospheric circulation. Recent work on dynamical coupling of the troposphere with the middle

atmosphere has made it clear that gravity waves have a significant influence on the general circulation even in the lower atmosphere. Global climate simulation models, therefore need to adequately treat the effects of atmospheric gravity waves that are not explicitly resolved.

In order to review recent developments in this rapidly evolving field, the IPRC hosted an American Geophysical Union (AGU) Chapman Conference on *Atmospheric Gravity Waves and their Effects on General Circulation and Climate*, which was held February 28–March 4.

The meeting was organized by Northwest Research Associates Senior Research Scientist **Joan Alexander**, University of Tokyo Professor **Kaoru Sato**, and IPRC Director **Kevin Hamilton**, and it attracted over 90 participants from around the world. The meeting was held at the East-West Center's Imin Conference Center and was cosponsored by the National Science Foundation, the World Climate Research Programme (WCRP), the



Program organizers **Kaoru Sato**, **Kevin Hamilton**, and **Joan Alexander**.

WCRP Stratospheric Processes and their Role in Climate (SPARC) project, the University of Tokyo School of Science, the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) and the International Commission on the Middle Atmosphere (ICMA). The program and files with the presentation slides and posters from the conference are at http://iprc.soest.hawaii.edu/meetings/workshops/11_02_Chapman_Conference.



Scientists at the Atmospheric Gravity Waves and their Effects on Global Circulation Conference.

IPRC NEWS

Governing Committee Meets

The IPRC Governing Committee held its 2011 annual meeting April 18 – 19, 2011 at the IPRC. The meeting was co-chaired by **Yoshihisa Shirayama**, JAMSTEC Executive Director for Research, and **Eric Lindstrom**, NASA Physical

Oceanography Program Scientist, and Chair, GCOS/GOOS/WCRP Ocean Observations Panel for Climate. The meeting reviewed governance and funding issues and the overall scientific achievements and progress of the IPRC.

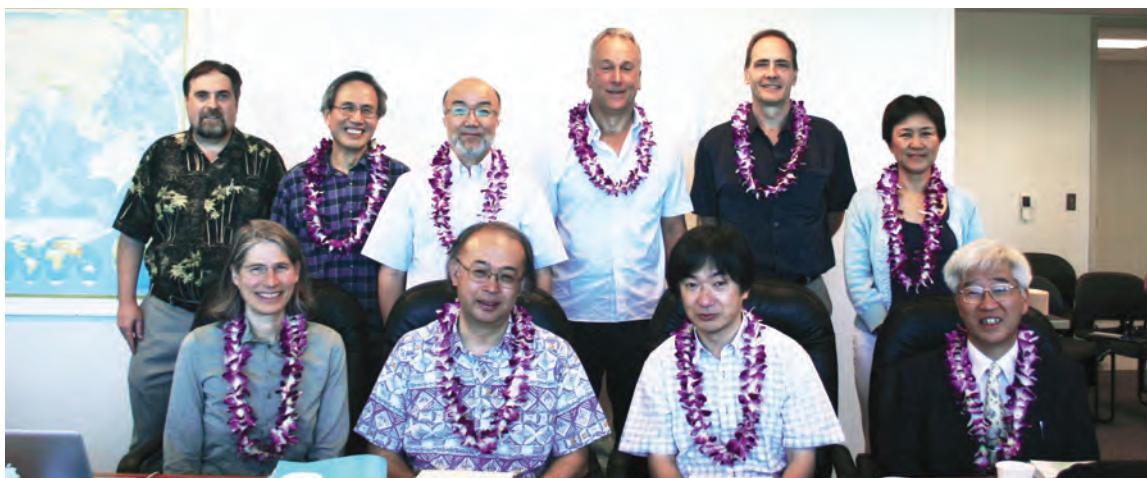


Front from left: Toru Kimoto (JAMSTEC), Shiro Imawaki (JAMSTEC), Yoshihisa Shirayama, Eric Lindstrom, Howard Diamond (NOAA), Chihiro Baba (JAMSTEC); back, Kevin Hamilton, Brian Taylor (SOEST, University of Hawai'i at Manoa), Katsufumi Akazawa (JAMSTEC), and Tetsuro Isono (JAMSTEC).

Science Advisory Committee Meets

IPRC's Science Advisory Committee met on April 19–21 at the IPRC to review the recent research achievements and progress and to learn about ongoing research and plans for future research as laid out in the *IPRC Science Plan*. The pres-

ent co-chairs of the committee are **Humio Mitsudera** from the Institute of Low Temperature Science at Hokkaido University and **Clara Deser** from the National Center for Atmospheric Research in Boulder, Colorado.



Seated: Clara Deser, Humio Mitsudera, Toshiyuki Hibiya (University of Tokyo) and Masahisa Kubota (Tokai University); standing: Kevin Hamilton, Leo Oey (Princeton University), Takehiko Satomura (Kyoto University), Harry Hendon (Australian Bureau of Meteorology), Duane Waliser (Jet Propulsion Lab), and Rong Fu (University of Texas).

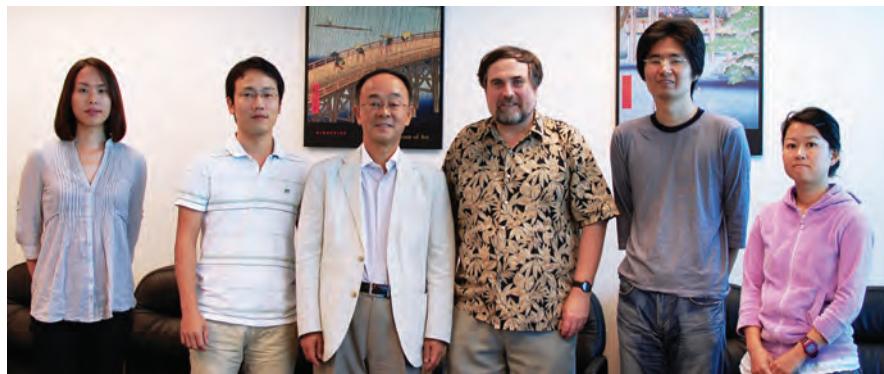
Jim Potemra Named APDRC Manager

On January 1, 2011, **Jim Potemra** became the Manager of IPRC's Asia-Pacific Data-Research Center (APDRC). A 1998 Oceanography Ph.D. from the University of Hawai'i at Mānoa, Potemra has been affiliated with IPRC since 2001 and has been a faculty member since 2008. Potemra replaces **Peter Hacker**, who led the APDRC development since its inception in 2001. Hacker remains a faculty member at UH Mānoa from which he is currently on an extended leave, working at NASA Headquarters.

Japanese Consul General Visits

The Consul General for Japan in Honolulu, the Honorable **Yoshihiko Kamo**, visited the IPRC in March. He was pleased to learn about the broad scope of the longstanding JAMSTEC

collaboration with the IPRC. Kamo was particularly interested in being briefed on IPRC's role in mentoring early career Japanese scientists, and he met with several of the Japanese post-doctoral fellows and researchers currently at the IPRC.

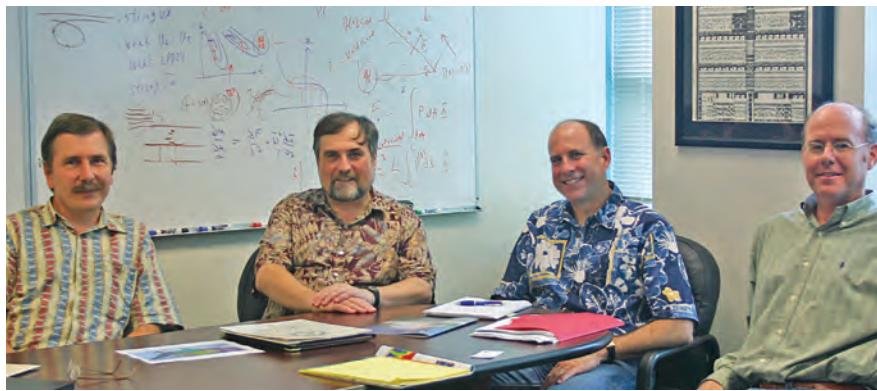


From left: Yu Kosaka, Hiroki Tokinaga, Consul General Kamo, IPRC Director Kevin Hamilton, Tomomichi Ogata and Miho Ishizu.

NOAA Officials Visit

Andy Winer, NOAA's Director of External Affairs, visited the IPRC on December 21, 2010. Before taking up his position in the Obama Administration, Winer was a lawyer in Honolulu for many years, and he served as Barack Obama's campaign chair for the State of Hawai'i during the 2008

presidential election. Winer was very interested in learning about the scope of the work conducted at Hawai'i's own NOAA-supported climate center, the IPRC. As Director of External Affairs, Winer interacts with stakeholders who have practical interests in NOAA services. He was, therefore,



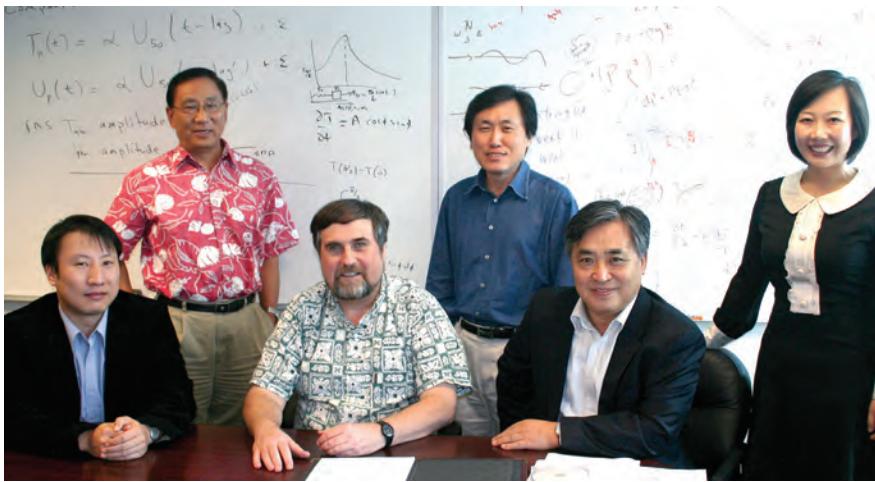
Senior Researcher Nikolai Maximenko, IPRC Director Kevin Hamilton, NOAA's Andy Winer and APDRC Manager Jim Potemra.



Charlie Baker with Jim Potemra.

pleased to learn about IPRC's service to the community through its APDRC and also about IPRC's recent work studying marine debris.

Charlie Baker, Deputy Assistant Administrator of NOAA's National Environmental Satellite, Data, and Information Service visited IPRC on February 24, along with **Laura Hamilton** NOAA's Pacific Regional Coordinator. They talked with APDRC Manager **Jim Potemra** about IPRC's contributions to management and serving of environmental data for the Asia-Pacific region.



From left, Jin Ho Yoo, IPRC Professor Bin Wang, IPRC Director Kevin Hamilton, Seoul National University Professor In-Sik Kang, Chin-Seung Chung, IPRC Assistant Researcher June-Yi Lee.

IPRC and the APEC Climate Center

The APEC Climate Center (APCC) was founded in Busan, Korea in 2005, with the endorsement of the First Senior Officials Meeting of the Asia-Pacific Economic Cooperation

(APEC). The APCC mission is “to enhance the socio-economic well-being of member economies by utilizing up to date scientific knowledge and applying innovative climate prediction techniques.” The IPRC shares with the APCC both a broad international orientation in its operations and a prime

science focus on climate in the Asia-Pacific sector. As an important partner of the APCC since its inception, the IPRC seeks to enhance cooperation wherever possible. Thus it was gratifying that the APCC Director, **Chin-Seung Chung**, and the Head of the APCC External Affairs Department, **Jin Ho Yoo**, visited IPRC in January to discuss possibilities for further collaboration. An exciting topic of conversation was the *2011 APCC Annual Symposium*. Each year the APCC holds an annual scientific symposium in a different APCC country, and this year it is to be in the USA. The IPRC is delighted to continue our special relationship with the APCC by being the local host for its 2011 Symposium, which will be held October 17–20, just three weeks before the *APEC Leaders’ Meeting* will bring heads of government from the 21 APEC economies to Honolulu.

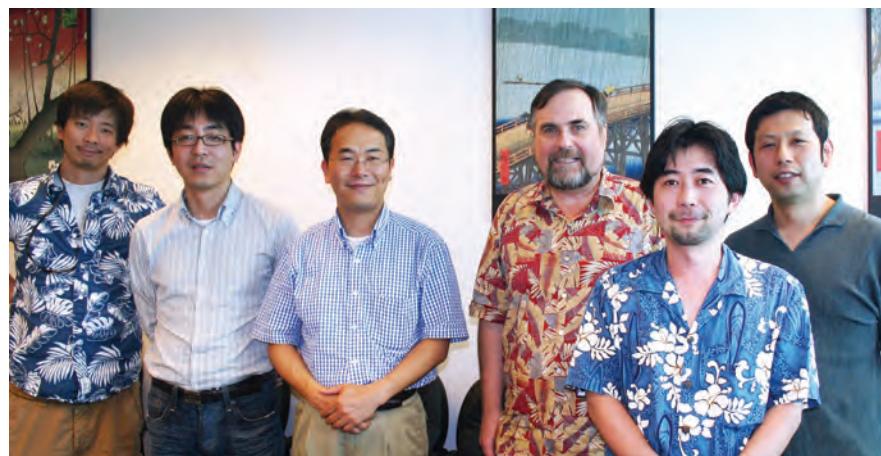
IPRC and Japanese Colleagues Discuss Next Generation Global Models

The 13th International Specialist Meeting on Next Generation Models on Climate Change and Sustainability for Advanced High Performance Computing Facilities was held in Honolulu on March 28–30. Organized by University of Tokyo Professor **Akimasa Sumi**, the meeting included presentations from several IPRC scientists as well as many

of IPRC’s close Japanese colleagues. A number of Japanese participants with interests in global atmospheric modeling visited the IPRC for informal discussions after the workshop. The group included **Masaki Satoh** and **Masahiro Watanabe** of the Univer-

sity of Tokyo’s Atmosphere and Ocean Research Institute, **Michio Kawamiya** of JAMSTEC’s Research Institute for Global Change, and **Hirofumi Tomita** of the RIKEN Advanced Institute for Computational Science.

From left, IPRC Assistant Researcher Kazuyoshi Kikuchi, Hirofumi Tomita, Masaki Satoh, Kevin Hamilton, Masahiro Watanabe and Michio Kawamiya.



JAMSTEC - IPRC Partnership on Marine Ecosystem Research

In early March 2011, the new director of the JAMSTEC Environmental Biogeochemical Cycle Research

Program, **Toshiro Saino**, and JAMSTEC senior scientists **Akio Ishida** and **Yoshikazu Sasai** visited the IPRC to discuss collaborations on marine ecosystem research. These collaborations include analysis of the impact of



Akio Ishida, Yoshi Sasai (left) and Toshiro Saino (right) with Kelvin Richards and postdoctoral fellow Miho Ishizu.

climate variability on the ecosystem in the eastern tropical Pacific, the Arabian Sea oxygen minimum zone, and the impact of submesoscale processes on the marine ecosystem. Saino described the details of a pair moorings placed on either side of the Kuroshio extension to measure physical and biological parameters. The discussions also highlighted the exciting possibilities of comparing and contrasting the physical environments and ecosystems seen at the moorings with long-term measurements at Station ALOHA east of the Hawaiian island of Kaua'i by using the Ocean General Circulation Model for the Earth Simulator and process studies to elucidate the results.

Senior Advisor at Norway's Bioforsk Visits

In January, **Udaya Sekhar Nagothu**, Senior Advisor and International Coordinator for India and Southeast Asia at Bioforsk, the Norwegian Institute for Agriculture & Environmental Research, visited the IPRC where **H. Annamalai** has been guiding the climate modeling efforts for ClimaRice, one of Bioforsk's projects in India. At Bioforsk, Sekhar, who had worked for many years in the Indian Forest Service, focuses on socio-economic, institutional and policy analysis in such areas as water, forestry, bio-energy, aquaculture, and fisheries. South and Southeast Asia need to develop suitable adaptation programs to meet the threats from climate change and extreme weather events. During his visit, Sekhar described how he uses the latest knowledge gained from research to promote the development of sustainable agriculture and viable farming practices geared to regional agro-cultural conditions. Much of his success rests on his skills of coordination and his ability to bring together different stakeholders, ranging from farmers to government

ministers and policymakers, and from local governments to scientists. His work with ClimaRice is an example, as seen in the publication of the book *Sustainable Rice Production on a Warmer Planet*, which has emerged from the first phases of the project (see p. 23).



Udaya Sekhar Nagothu (left) with IPRC's Senior Researcher H. Annamalai.

IPRC Scientists in the Community

Guide to the Rainbows of the Hawaiian Garden Isle

Shang-Ping Xie joined a Japanese TV crew in Kaua‘i in February to be a guide in the film “A Magical, Rain-sculpted Land – Rainbow Island, Kaua‘i” for the *Nippon Hōsō Kyōkai* (NHK), Japan’s national public broadcasting organization. The movie is part of the series “Experience Nature’s Grandeur,” a series that invites viewers to experience the wonders of nature. This particular episode showcases Kaua‘i, the rainiest place on Earth that “has created an environment found nowhere else.” Xie was invited as a meteorological expert to explain how the mountains act as the rainmaker for the “Garden Isle”

and its many rainbows. The moisture-laden trade winds from the Pacific are forced to rise up the mountain slopes of tall Mt. Waialeale; as they rise, the winds cool and form persistent rain clouds.

The rainfall over the mountains has supplied the rivers and irrigated the taro fields for generations of Hawaiian farmers. The 1½-hour-long film was aired in Japan on April 23, 2011.



Shang-Ping Xie (middle) with the show's director, Ryo Enami (second from left) and the TV crew. Hanalei River and the taro fields it irrigates form the backdrop.

Traditional Knowledge Applied to Food Sustainability

Climate Change and Food Security was the title of the panel at the Kamakakuokalani Center for Hawaiian Studies on November 16, 2010. IPRC Director **Kevin Hamilton**, invited to participate on the panel, described the global and regional context for under-

standing and projecting climate change in Hawai‘i. The panel was a lively mix, including **Lilikala Kame‘elehiwa**, Professor of Hawaiian studies at UH Mānoa; **Kanekoa Shultz**, Kane‘ohe Marine Coordinator for the Nature Conservancy; and **Kukui Maunakea-Forth**, Executive Director of MA‘O Organic Farms on O‘ahu. The discussions

considered adaptation strategies appropriate for Hawai‘i, among them the usefulness of traditional and historical Hawaiian knowledge. The strategies used to manage resources within the traditional ahupua‘a (triangular slices of land running from the mountains in the center of an island down to the ocean) provided some measure of resiliency that has been lost in modern land and water management practices. Most individual ahupua‘a contained all the resources necessary for reliable food production: a seashore for fishing and perhaps aquaculture, streams for drinking and irrigation of taro fields, and forested highlands for hunting and gathering wild foods. The possible use of official records of the Hawaiian Kingdom related to land use to infer climatic conditions was raised.



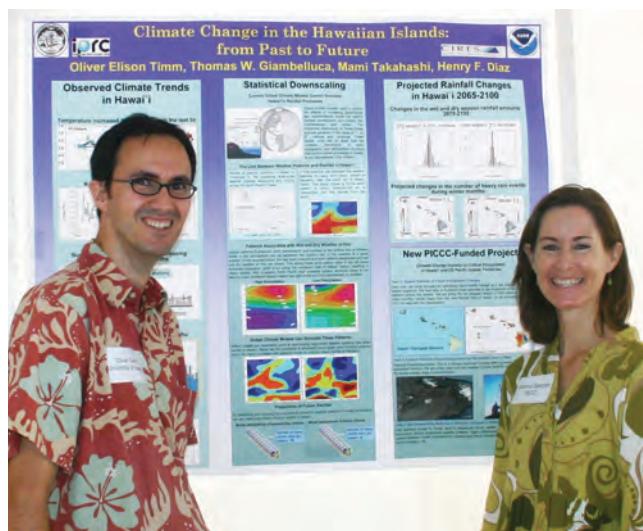
Lilikala Kame‘elehiwa, Kevin Hamilton, Kanekoa Shultz, Kukui Maunakea-Forth at the Climate Change and Food Security Panel.

Climate-Change Impacts in Hawai‘i and US Pacific Islands

Rainfall in Hawai‘i has decreased in the last 30 years as has the frequency of weather conditions, such as Kona Lows, that produce heavy rainfall events over Hawai‘i. These are the conclusions of IPRC’s Assistant Researcher **Oliver Elison Timm**, who has been studying the effects of climate change on rainfall, drought, and evapotranspiration across the Hawaiian Islands with **Mami Takahashi**, **Tom Giambellucca** (UH Mānoa Geography Department), and **Henry Diaz** (U. Colorado). To study whether these trends will persist through the 21st century, the team statistically downscaled six models that were run under global warming scenarios for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Definitive conclusions were not possible as the global model predictions for Hawai‘i disagree substantially.

Elison Timm was asked to showcase the team’s findings during the December 2010 visits to Honolulu of **Tom Strickland**, the US Department of Interior (DOI) Assistant Secretary for Parks and Wildlife, and **Dan Ashe**, DOI’s Deputy Director for Fish and Wildlife. The study is funded by the Pacific Islands Climate Change Cooperative (PICCC), for which IPRC scientists are the spearheading the atmo-

spheric climate-change research component. IPRC Director **Kevin Hamilton** leads the regional numerical modeling of future climate change and Elison Timm the statistical climate-change analysis. PICCC unites over 20 federal, state, non-profit agencies, and educational centers and research institutes under the umbrella of supporting climate-change research and developing adaption strategies for Hawai‘i and other Pacific Islands.



Oliver Elison Timm with PICCC Coordinator Deanna Spooner.

Hurricane Forecast: Unraveling the Storm’s Dynamics

Hurricane research at UH Mānoa is the subject of the cover story in the spring issue of *Mālamalama*, the University of Hawai‘i magazine. The story, written by IPRC Outreach Specialist **Gisela Speidel**, described longstanding efforts to understand hurricane dynamics at IPRC and the UH Meteorology Department. This work includes case studies of individual storms by Professor **Gary Barnes**, who has been flying for decades into hurricanes with NOAA’s hurricane hunters. Professor **Steven Businger** conducts research to improve the Weather Research and Forecasting (WRF) Model of tropical storms as well as trying new technologies to garner better information about

these storms. At the IPRC, Professor **Yuqing Wang** has developed his own hurricane model and is leading many studies on aspects of hurricane genesis and development. While basic understanding is a key goal, these scientists are motivated by a desire to discover the elusive “holy grail”—a confident prediction of hurricane intensity through a storm’s lifecycle.



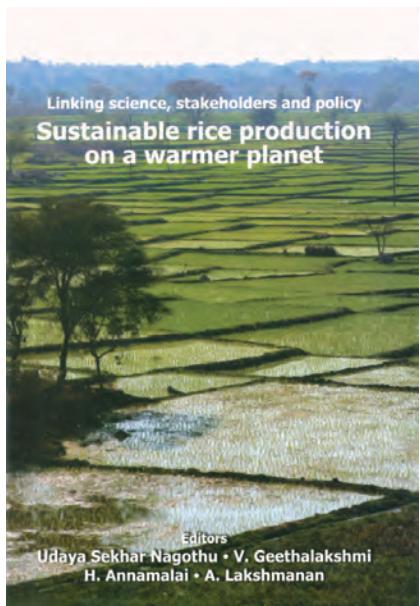
The Making of Future Scientists

UH Mānoa hosts annually the *Pacific Symposium for Science and Sustainability* for Pacific Island high school students. Students with the most outstanding research at the regional level are invited to speak at the symposium. At this year’s symposium, **Jim Potemra**, manager of IPRC’s Asia-Pacific Data-Research Center, moderated and helped select the best presentations. His group of students, who came from as far away as American Samoa, had such research topics as beach erosion, invasive species, and health and environmental issues. The symposium proceedings are published, and five finalists go on to the National Junior Science and Humanities Symposia.

Climate Modeling for Sustainable Rice Production

H. Annamalai is co-editor and co-author of the book, *Sustainable Rice Production on a Warmer Planet*, based on his work with ClimaRice, a project funded by the Ministry of Agriculture in Norway (see p. 20; IPRC Climate Vol. 10, no. 2)

"This book nicely summarizes the findings from ClimaRice, the three-year multi-disciplinary project supported by the Government of Norway, to assess climate change impacts and vulnerability of rice ecosystems and farming communities in the Tamil Nadu region of India. I believe that sharing experiences of workable solutions between farmers, researchers and other stakeholders is the only environmentally sound and socially just way... towards sustaining rice production in India. The book provides some flexible measures for climate adaption to meet the needs of farmers under different local conditions," writes Lars Peder Brekk, the Norwegian Minister of Agriculture and Food, in the book's foreword.



National news on the CBS Early Show on April 8 features IPRC tsunami-debris trajectory.

IPRC in the Media

The Fate of Ocean Debris from Japan's Tsunami

The powerful tsunami, triggered on March 11 by the Tohoku earthquake, destroyed coastal towns near Sendai in Japan and washed much of the region's infrastructure into the ocean. The large amount of debris now floating in the ocean represents a potential hazard to marine traffic and will eventually impact shorelines in remote parts of the Pacific basin. The long-term impact of the debris will depend on how the individual pieces break up and how much sinks, but a key determinant is the surface current field. IPRC's Senior Researcher **Nikolai Maximenko** has developed a statistical model of the ocean surface-currents based on many years of observations of satellite-tracked drifting buoys. Along with IPRC's Scientific Computer Programmer **Jan Hafner**, Maximenko was able to use his model to project the likely fate of the floating debris over

the next several years. Maximenko and Hafner predict that Hawai'i could see some debris on its shores in about 1½ years and the North American West Coast in three years. But a great deal will be trapped for several years in the North Pacific Garbage Patch. In five or six years, Hawai'i shores can expect to see another, stronger and longer-lasting barrage of debris. Maximenko and Hafner presented their results in an animation, http://iprc.soest.hawaii.edu/users/nikolai/2011/Pacific_Islands/Simulation_of_Debris_from_March_11_2011_Japan_tsunami.gif

Given the great public interest in this topic, the IPRC work was featured by a large number of the many news media, including CNN, Voice of America, and the *Asahi Shimbun*. The IPRC prediction was a story covered on the national news broadcast on the CBS television network's *Early Show* on April 8.

Ships Add to Air Pollution and Global Warming

The report on ship emissions by the German Aerospace Center's SeaK-LIM, to which IPRC's **Axel Lauer** contributed, received media attention in Europe and elsewhere. In the year 2000 (year with most recent available data), ships contributed around 2.7% of carbon dioxide anthropogenic emissions, 15% of nitrogen oxides, and 8% of sulphur dioxide. Ships released about the same amount of carbon dioxide as air travel, about 10 times more nitrogen oxides and 100 more times sulfur dioxide. Of all anthropogenic aerosol sources, ship-stack emissions provide the clearest demonstration that these particles can modify the microphysical and optical cloud properties.



Climate Feedback from Low Marine Clouds

As noted in the story "How will Low Clouds respond to Global Warming?" (IPRC Climate Vol. 10, no. 2), a key component of the feedbacks that determine the sensitivity of the global climate to large-scale forcing is the response of low marine clouds. IPRC scientists **Axel Lauer**, **Kevin Hamilton** and **Yuqing Wang**, along with colleagues at UH Manoa and the

University of Wisconsin, addressed the issue with a regional-model study that suggested that such clouds make a strong positive contribution to the climate feedbacks. Published at the end of 2010 in *Journal of Climate*, their study received widespread media attention from *New Scientist* to the *Tehran Times* and *Japan Herald*.

Tropical Atlantic Sees Weaker Trade Winds and More Rainfall

Developing a method to remove the systematic bias in wind measurements over the ocean due to increased the height of the anemometer placement, IPRC's **Hiroki Tokinaga** and **Shang-Ping Xie** examined long-term trends in the tropical Atlantic with their corrected observations (this issue, p. 10). They found that, rather than having strengthened as indicated in the raw data, the trade winds in the tropical Atlantic have actually weakened and the pattern of ocean surface temperature has changed. As a result, the equatorial Amazon and the Guinea Coast are seeing more rainfall and the Sahel less. The findings, published in the January issue of *Nature Geoscience*, received media attention, including the Honolulu *Star-Advertiser*, India's *Daily News and Analysis*, *ScienceDaily*, *Weatherwise Magazine*, and on such webpages as the China Meteorological Administration and NOAA.

How Mountains Help Shape the Tracks of Tropical Cyclones

Among the atmospheric science highlights featured in the Winter 2011 edition of *UCAR Magazine* was a study on the effects of island topography on tropical cyclones published by IPRC's **Yuqing Wang** along with colleagues

at National Taiwan University. Titled "The influence of island topography on typhoon track deflection," the study was published in the *Monthly Weather Review*.

IPRC Contributes to the Science Community

The WRF Model

With its Pacific focus, the IPRC has had a longstanding interest in simulating marine clouds in the stratus and trade wind regimes. Working with the IPRC Regional Atmospheric Model (iRAM), **Yuqing Wang** and his collaborators have produced a modified version of the Tiedtke cumulus parameterization that has shown considerable success in capturing these clouds. Compared with model results obtained using other popular convection schemes, simulations with the IPRC parameterization display a very active shallow convection, resulting in a dryer subcloud layer, a warmer cloud layer, and a cooler and moister layer immediately above the cloud due to evaporation of cloud water detrained from the cloud top. This success has been recognized by the scientific community, and the IPRC scheme has been added as a standard option in the latest release of the Weather Research and Forecasting (WRF) model (version 3.3 released April 6, 2011). This model is a community project led by the National Center for Atmospheric Research and NOAA. WRF is now widely applied in a range of research and operational forecast efforts around the world.

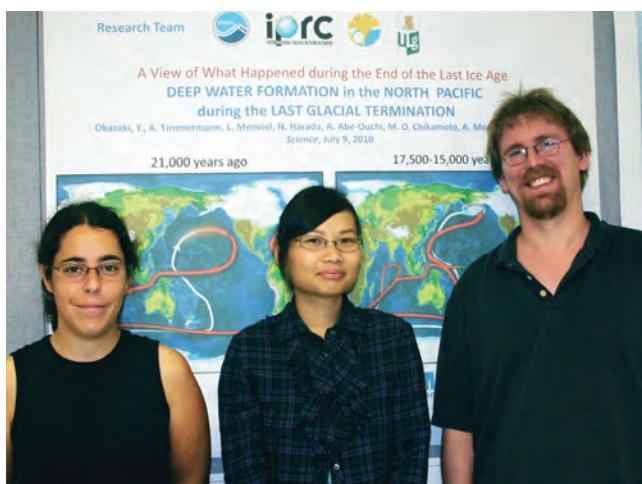


VISITING SCHOLARS

Searching for the Carbon during the Last Glacial Maximum

The CO₂ concentration in the atmosphere has fluctuated over Earth's life more or less in unison with global surface temperature. Today it is around 380 ppm, in the early 1800s, before industrialization took off, it was around 280 ppm, and during the Last Glacial Maximum (LGM), 20,000 years ago, it stood at 190 ppm. Given the importance of the carbon cycle in climate, scientists want to know where the additional 90 ppm CO₂ in the atmosphere during pre-industrial times was stored during the LGM and what caused its release to the atmosphere during the last glacial termination. According to a recent review, changes in ocean circulation, biological production, and sediment burial have been made responsible.

Megumi Chikamoto, research scientist at the JAMSTEC Research Institute for Global Change, visited the IPRC for 6 months to work with **Axel Timmermann** and his team on tracking down the missing LGM carbon. Their tool is the MIROC: Model for Interdisciplinary Research On Climate, developed at the Atmosphere and Ocean Research Institute of The University of Tokyo, the National Institute for Environmental Studies, and the Japan Agency for Marine-Earth Science and Technology, in combination with an offline marine carbon cycle model. Run under glacial boundary conditions and freshwater forcing, MIROC simulates a deep ocean circulation that is quite similar to the reconstructed glacial ocean state.



Megumi Chikamoto (middle) with Audine Laurian and Axel Timmermann

When the scientists calculated the ocean carbon response to the glacial climate state in MIROC, they noted that an intensification of Antarctic Bottom water production clearly increased the carbon storage of the abyssal oceans, as predicted by numerous studies before. To the great surprise of Chikamoto and Timmermann, this effect was almost completely compensated in their model by the decreased uptake of carbon in the North Atlantic. According to their modeling results ocean circulation changes alone are unlikely to have been the main driver for glacial-interglacial variations in atmospheric CO₂ concentration.

In their future collaborative work, Chikamoto and Timermann will explore the role stratification-dependent mixing and North Pacific circulation changes on the fate of glacial carbon in the ocean.

Black Sea Coastal Processes

Viacheslav Kremenetskiy, senior researcher at the P. P. Shirshov Institute of Oceanology in Moscow, visited the IPRC for several weeks in January 2011 to continue his study of the Black Sea mean dynamic topography with IPRC's Senior Research **Nikolai Maximenko**. The project is funded by the US Civil Research & Development Foundation and the Russian Foundation for Basic Research. Despite the large number of available historical observations of this inland sea with its densely populated coastline, a firm understanding of the dynamics of its marginal and inner sea has been elusive. The Black Sea intrigues oceanographers on account of the complex interplay among the coastal process, which take place on small space- and time-scales over an intricate shoreline topography, not yet resolved by today's satellites or global models.



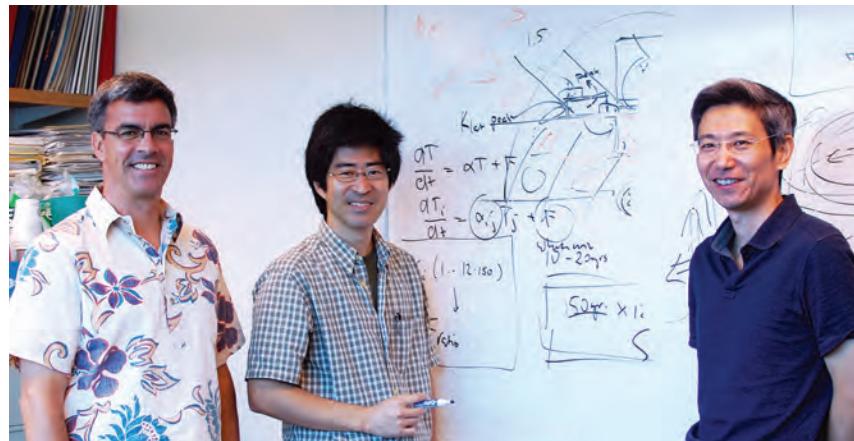
Nikolai Maximenko with Viacheslav Kremenetskiy.

Explorations with the Coupled GCM for the Earth Simulator

Along with their global atmospheric model and global ocean model, the JAMSTEC Earth Simulator's Geophysical Fluid Simulation Research Group has developed a coupled version, the Coupled GCM for the Earth Simulator (CFES). The Earth Simulator group has been able to run CFES at a much higher resolution than most models currently available for climate assessments. **Bunmei Taguchi**, Earth Simulator scientist, spent 3 months during the 2010 – 2011 winter at the IPRC to work on different CFES projects. This was a return home for Taguchi who received his 2006 Ph.D. at UH Mānoa under the mentorship of IPRC faculty member **Shang-Ping Xie**.

The first of Taguchi's projects deals with the Pacific Decadal Oscillation (PDO), a well-known Pacific climate pattern with phases typically of 20-to-30-year duration. In one phase, the water north of 20°N is warm in the eastern and cool in the western North Pacific, during the other phase, it is just the opposite. The phases have a detectable impact on climate and marine life. Taguchi wants to track down the causes of the temperature shifts. "Finding the mechanisms, though, is not so easy; the model is nearly as complicated as nature," says Taguchi. "But in the model, the phenomenon can be followed over a longer period of time than in historical observations. And once we've zeroed in on a mechanism, we can carry out an experiment to test our hypothesis." IPRC's **Niklas Schneider** and Xie are project consultants.

Another CFES project deals with the following sequence of climate events: El Niño warms the Indian Ocean; the



Bunmei Taguchi (middle) with Niklas Schneider and Shang-Ping Xie.

warming lasts through the summer long after El Niño has decayed and makes for a dryer Indian monsoon; this Indian Ocean warming, which Xie dubbed the *capacitor effect* (see *IPRC Climate*, Vol. 9, no. 2), excites in the summer after El Niño the Pacific – Japan pattern with intense convective activity over East Asia and the tropical Northwestern Pacific. After the so-called mid-70s climate shift in the Pacific, the relationship between the three climate phenomena has become tighter. By analyzing 170 years of CFES output, Taguchi wants to confirm that this relationship waxes and wanes over decades.

Taguchi's third project focuses on the mysterious east-west "stripes" in ocean currents and surface temperature. These stripes that IPRC's **Nikolai Maximenko** was among the first to detect in satellite images, are surface signals of deep ocean currents. CFES is able to simulate their surface signatures, and Taguchi and IPRC's Assistant Researcher **Ryo Furue** intend to study how the atmosphere and surface winds respond to these signals.

Tropical Cyclones in a Warming Climate

Hiroyuki Murakami from JAMSTEC and Japan's Meteorological Research Institute (MRI), visited the IPRC from November to February to work with **Bin Wang** on tropical cyclone research. Their paper with MRI's **Akio Kitoh**, "Future change of western North Pacific typhoons: Projections by a 20-km-mesh global atmospheric model," concludes that there will be fewer tropical cyclones in the western North Pacific due to weaker large-scale rising motion, and that the region where



tropical cyclones form will shift eastwards during the peak season because the low-level vorticity is predicted to be greater and vertical shear to be weaker further east than today. The model's changes in tropical cyclone tracks and formation depend on the spatial pattern of future sea surface temperature in a warming Earth. Murakami presented his findings at the SOEST Symposium: *The Science of Climate Change in Hawai'i* on January 20 (see pg. 12). The paper appeared in the February 2011 issue of *Journal of Climate*.

Discussing the Generation of Gravity Waves

A participant at the IPRC-hosted AGU Chapman conference *Atmospheric Gravity Waves and their Effects on General Circulation and Climate*, (see pg. 16), Takeshi Horinouchi, Associate Professor at the Faculty of Environmental Earth Science, Hok-

kaido University, took the opportunity to visit the IPRC in March 2011. He discussed with IPRC scientists his research on the atmospheric general circulation and on the generation of gravity waves. While at the IPRC, he also gave a seminar "Moist Hadley circulation: Constraints and the role of wave-convection coupling in an aqua-planet AGCM."



From left, Shang-Ping Xie, Takeshi Horinouchi, Kazuyoshi Kikuchi, and Yu Kosaka.

Aloha and Welcome to the IPRC

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A publication of the
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Editor Gisela E. Speidel, PhD

Designer SOEST Publications: Brooks Bays and Nancy Hulbert
Printer Hagadone Printing Company, Honolulu, Hawai'i

June 2011



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The IPRC is a climate research program funded by agencies in Japan and the United States and by the University of Hawai'i.

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