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Satellites Are Changing Our View of the World Ocean

The classical view of the ocean circulation at mid-latitudes, away from the sea surface and coastlines, is one of broad, graceful gyre-like flows. Although this view has been modified to include eddying motions that vary with time, it is still one of a broad, time-averaged circulation. Results from ocean models, which typically have had poorly resolved eddying motions and relatively high dissipation rates, have tended to conform to this view. Results from higher resolution models and analyses of data from satellite-borne altimeters are now changing that classical view, according to work by **Kelvin Richards**, professor of oceanography at the University of Hawai'i and leader of the IPRC Regional Ocean Influences Team, and **Nikolai Maximenko**, associate researcher with the team.

Richards and his colleague **Frank Bryan** at the National Center for Atmospheric Research have analyzed the flows in a simulation from a high-resolution global ocean model with a 10-km resolution in the horizontal that was run on the Japanese Earth Simulator. They found an unexpected feature when they studied the eastward velocity component in the deeper ocean. Although the flow shows a signature of the broad mid-latitude gyres, it is dominated by a series of jets that alternate coherently in the east-west direction. Figure 1 shows the eastward component of velocity at 400-m depth in the Pacific, averaged over two years.

Maximenko has been looking at altimeter data relayed from satellites to study ocean currents detectable in sea surface height variations. Remarkably, the altimeter data revealed structures in the surface dynamic topography of the ocean that are similar to those seen by Richards and Bryan.

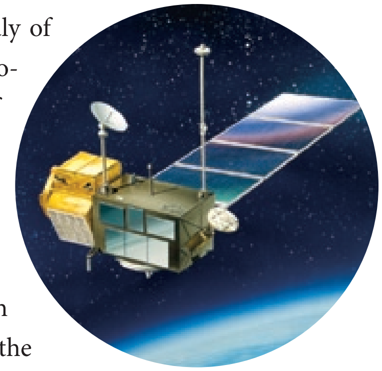
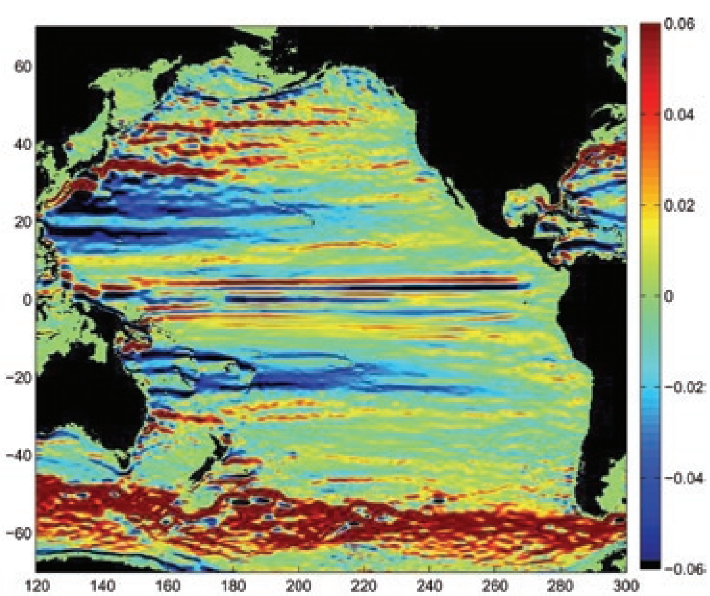


Figure 2 shows the anomaly of the geostrophic zonal velocity derived from maps of altimeter data averaged over 18 weeks. Again, the structures are coherent in the east-west direction and have a north-south scale similar to that in the model results.

Several questions spring to mind. Do such jets really exist in the deep ocean—is the structure seen in the altimeter data only an artifact of the sampling or indeed the surface signature of deeper jets? Why do the jets form? What is the significance of the presence of the jets? At present, only partial answers to these questions can be given.

The most direct observational evidence for the existence of deep multiple jets comes from the equatorial Pacific where measurements with acoustic Doppler current profilers have been taken in several sections across the equator to a depth of about 400 m. The region has multiple jets in addition to the many near-surface zonal flows, such as the Equatorial Undercurrent. The meridional scale of the observed jets is similar to that seen in the model results. Analysis of the high-resolution Ocean Model for the Earth Simulator (OFES) by Maximenko and his colleagues revealed that such deep jets

Figure 1. Zonal component of velocity averaged over two years at 400-m depth from a high-resolution ocean model. Flow speed is given in m/s. (Richards and Bryan, 2005)



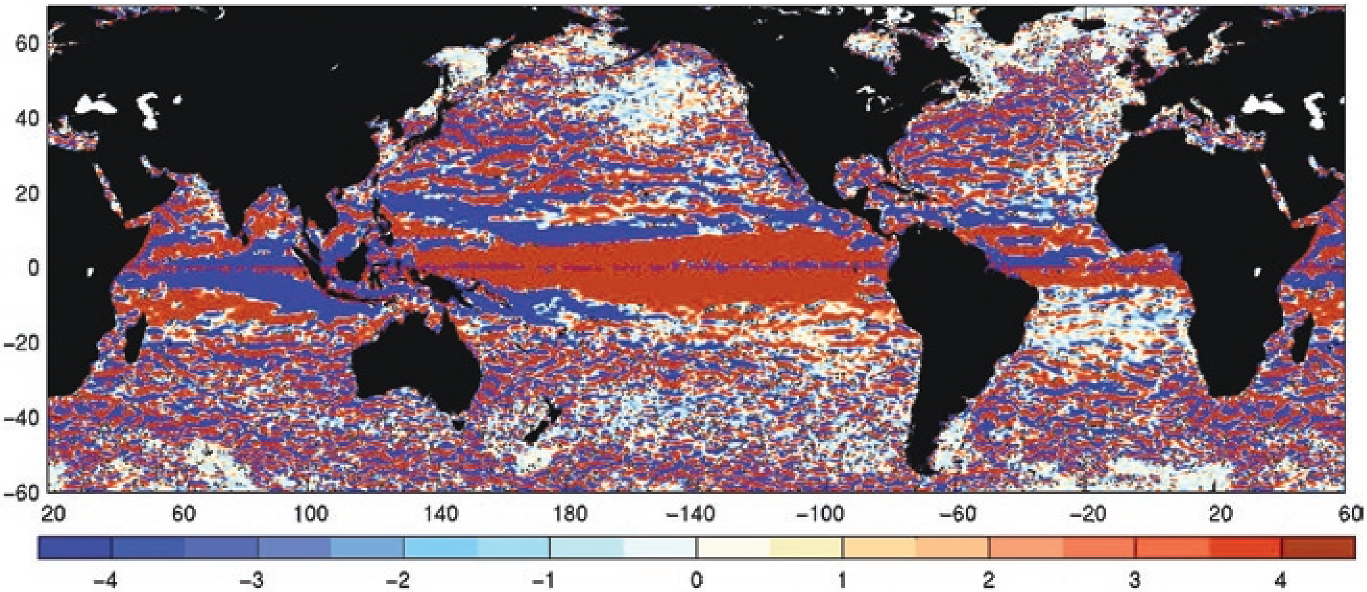


Figure 2. 18-week average of anomalies of geostrophic zonal velocity (cm/s), derived from the Aviso altimeter dataset. (Maximenko et al., 2005)

do indeed have a surface signature in sea surface height that is detectable by satellite altimeters.

The zonal jet structure brings to mind similar banded structures seen in the atmospheres of Jupiter and Saturn. The alternating jets on these giant planets are thought to result from the evolution of quasi two-dimensional turbulence, in which the turbulent energy cascades from smaller to larger eddies, which are eventually halted in their meridional expansion by the fact that the vertical component of the planet's rotation rate increases towards the poles. The resultant jets are often referred to as Rhines jets, whose latitudinal scale is set by the strength of the eddying motions and the rate of change in the Coriolis parameter with latitude. Earth's oceans show large spatial variations in the level of eddy activity and this activity is greatest in regions of intense currents such as the Kuroshio and the Antarctic Circumpolar Current. In the model results, the spatial variation in the meridional scale of the jets (Figure 1) is consistent with the variation in the model's eddy energy, with the latitudinal scale being close to that given by the Rhines scale. This suggests that, in the model at least, the jets may well be formed by the same mechanism as the cloud bands on Jupiter and Saturn.

But what are the implications of the existence of the jets for other aspects of ocean circulation? There are at least two. The zonal velocity of the jets varies much more in the meridional direction than the broader-scale gyre flow does. This increased shear will increase the zonal dispersion of tracers. An estimate suggests this zonal dispersion is many times greater than the meridional dispersion rate and is large enough to influence the large-scale distributions of salinity, temperature, and other properties of the deep ocean. The second reason why the jets may be important relates to the ultimate fate of energy in the ocean. If the eddying action in the ocean tends towards zonal jets rather than more isotropic chaotic flow, then scientists need to rethink the way unresolved motions are parameterized in coarser-resolution ocean models used in climate studies.

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Simulating Turbulence in the Ocean

Turbulence on scales of only a few hundred meters or less can impact the large-scale ocean circulation. Yet, such small-scale turbulence cannot be directly represented in ocean general circulation models, but must be parameterized. Even the finest-resolution global ocean general circulation model being run today cannot explicitly resolve processes smaller than 10 km in the horizontal.

To represent sub-grid processes such as eddy mixing and turbulence in climate studies, many ocean and climate modelers have been using constant mixing coefficients. They are starting to realize, though, that more realistic simulations require more realistic parameterization of the mixing processes. "The good old days of modeling climate using constant mixing coefficients are over," according to a recent comment by a well-known oceanographer.

The field, however, is still far from having a comprehensive system of parameters that capture the physics of the various types of ocean turbulence and their effects. In fact, most of the mixing parameters used in today's ocean models are not derived from observations of actual ocean turbulence, but are either borrowed from atmospheric boundary layer models (*e.g.*, the KPP parameterization developed by William Large and colleagues) or derived from laboratory experiments and closure theories. Because the three-dimensional nature of turbulence makes it difficult to observe in the open ocean, observations of naturally occurring turbulence in the ocean are still sparse and insufficient to develop comprehensive mixing schemes.

Modern computing, though, has made possible the development of limited-area models in which the larger 3D structures of turbulent flow can be explicitly represented. The technique is called large-eddy simulation (LES). Oceanic mixing processes can be studied with LES models and the derived mixing coefficients can then be used to represent small-scale flow in basin-scale models.

Dailin Wang, with the IPRC Indo-Pacific Ocean Climate Team, has been conducting series of large-eddy simulations to study various small-scale mixing processes and develop a parameterization scheme for vertical mixing. His approach

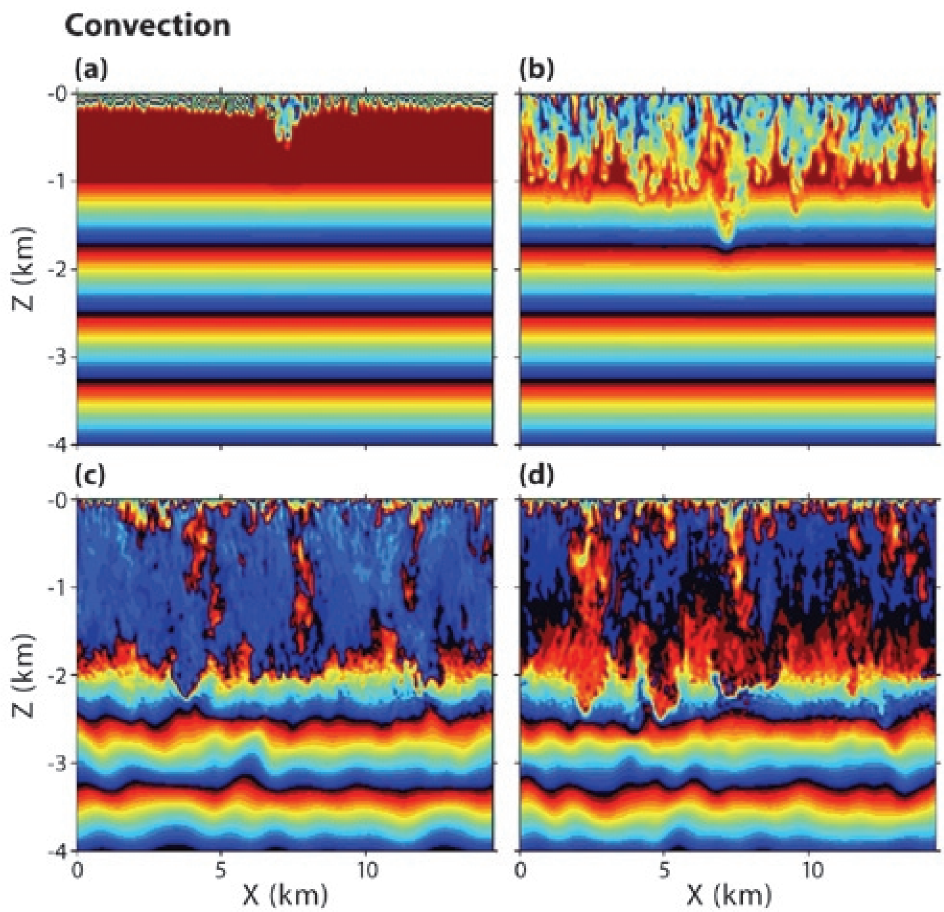

Figure 1. Temperature sections of the deepening of the mixed layer due to convection: (a) surface cooling generates a temperature gradient in the surface layer, with cooler water forming over warmer water; (a–d) as the gradient increases and becomes unstable, convection occurs. After 131 hours, the convective plumes have penetrated the ocean to a depth of about 3000 m, and have deepened the mixed layer.

is to conduct experiments under a wide range of oceanic conditions, such as different seasons and latitudes. From the results, he extracts laws that capture the essence of the particular mixing process, and he derives an appropriate mixing scheme.

For example, to develop a parameter for convection in the ocean, Wang has been conducting a slew of large-eddy simulations under a wide range of Rossby numbers, which represent the ratio of inertial forces in a fluid to the (apparent) forces arising from Earth's rotation. Figure 1 is an example of a solution of a large-eddy simulation. It is a snapshot of ocean temperature at different stages during deep convection induced by surface cooling. The convective plumes have horizontal scales of only a few hundred meters. Shallow convection, for instance nighttime convection in the tropics, occurs on scales even smaller than this.

In this set of experiments on the effects of different Rossby numbers, Wang found that the ratio between heat-flux mixing due to turbulence and surface-buoyancy flux, a key parameter in the Kraus-Turner-Niller mixed-layer model, is a function of the Rossby number (Wang, 2003). As the Rossby number decreases (Earth's rotation becomes more important), the ratio decreases. The equation Wang developed can also be used to test and construct other one-dimensional models of convection.

Wang is now extending this approach to other mixing processes. For instance, Figure 2 shows the deepening of the mixed layer at the equator due to wind mixing. A comparison of Figures 1 and 2 shows that convection and wind stirring bring about ocean mixing in different ways: Convection deepens the mixed layer through penetration of convective plumes, whereas wind stirring does so through Kelvin-Helmholtz shear instability, which forms large eddies in the shape of rolls.

With such experiments as these, Wang is learning more about how different forms of turbulence affect ocean mixing. The new parameterizations, with their improved physical basis, should help to make climate-change simulations with the next generation of ocean circulation and ocean-atmosphere coupled models more realistic.

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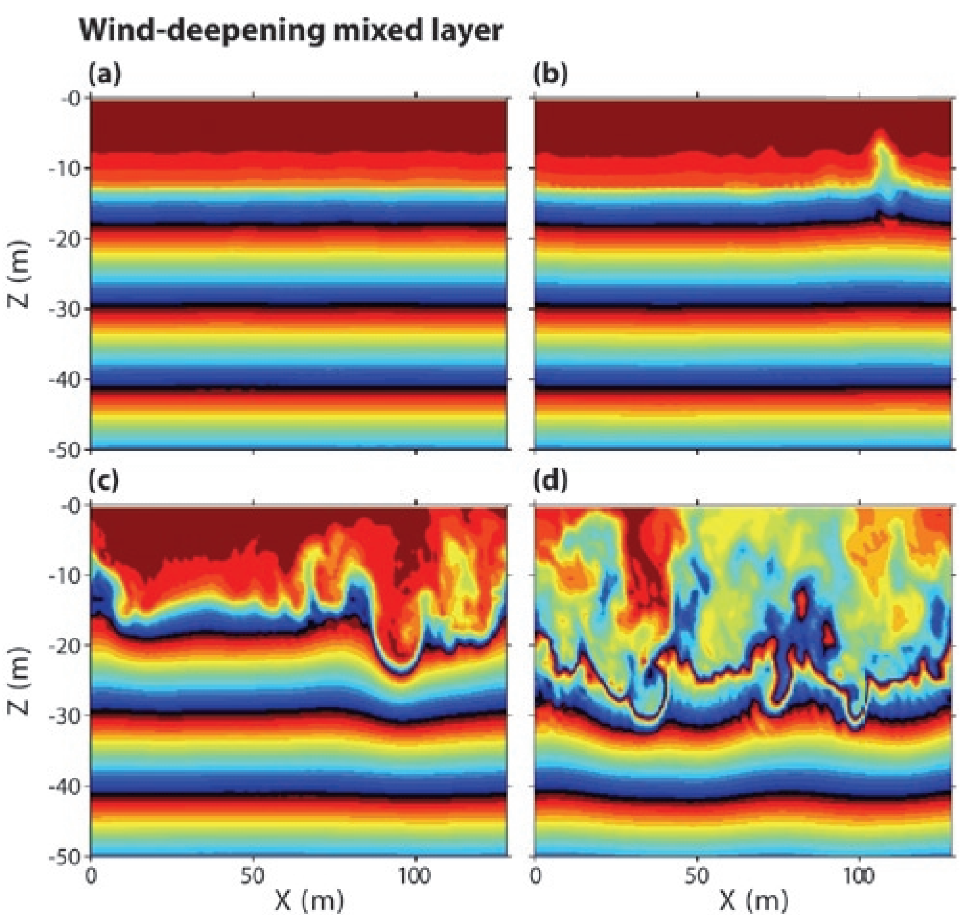
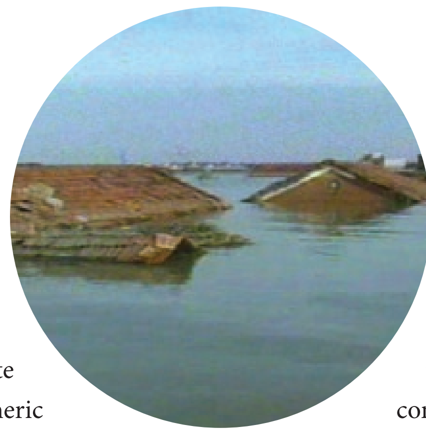


Figure 2. Temperature sections of the deepening of the mixed layer due to wind stirring; (a) as the surface shear grows, it becomes unstable and rolls begin to form; (b–d) with time, many rolls form, overturn, and cause turbulent mixing, stirring the ocean to a depth of 30 m.

The Changing Rainfall in China



Over the last decades, China has experienced significant changes in snow- and rainfall patterns. Where do these changes come from, and do we have the tools to predict them over the long-term? At present, climate models can project changes in atmospheric circulation and temperature due to global warming, but prediction of precipitation changes is uncertain.

Yuqing Wang, associate professor of meteorology at the University of Hawai'i and part of IPRC's Asian-Australian Monsoon Team, and his student **Li Zhou** have been comparing precipitation data with atmospheric circulation patterns. Analyzing data from over 500 rain-gauge stations in China, they found that the seasonal rainfall cycle in China has changed over the last 40 years. Moreover, the observed trends in the changing rainfall patterns and rise in extreme precipitation events in certain regions are plausibly associated with changes in the large-scale atmospheric circulation over Asia.

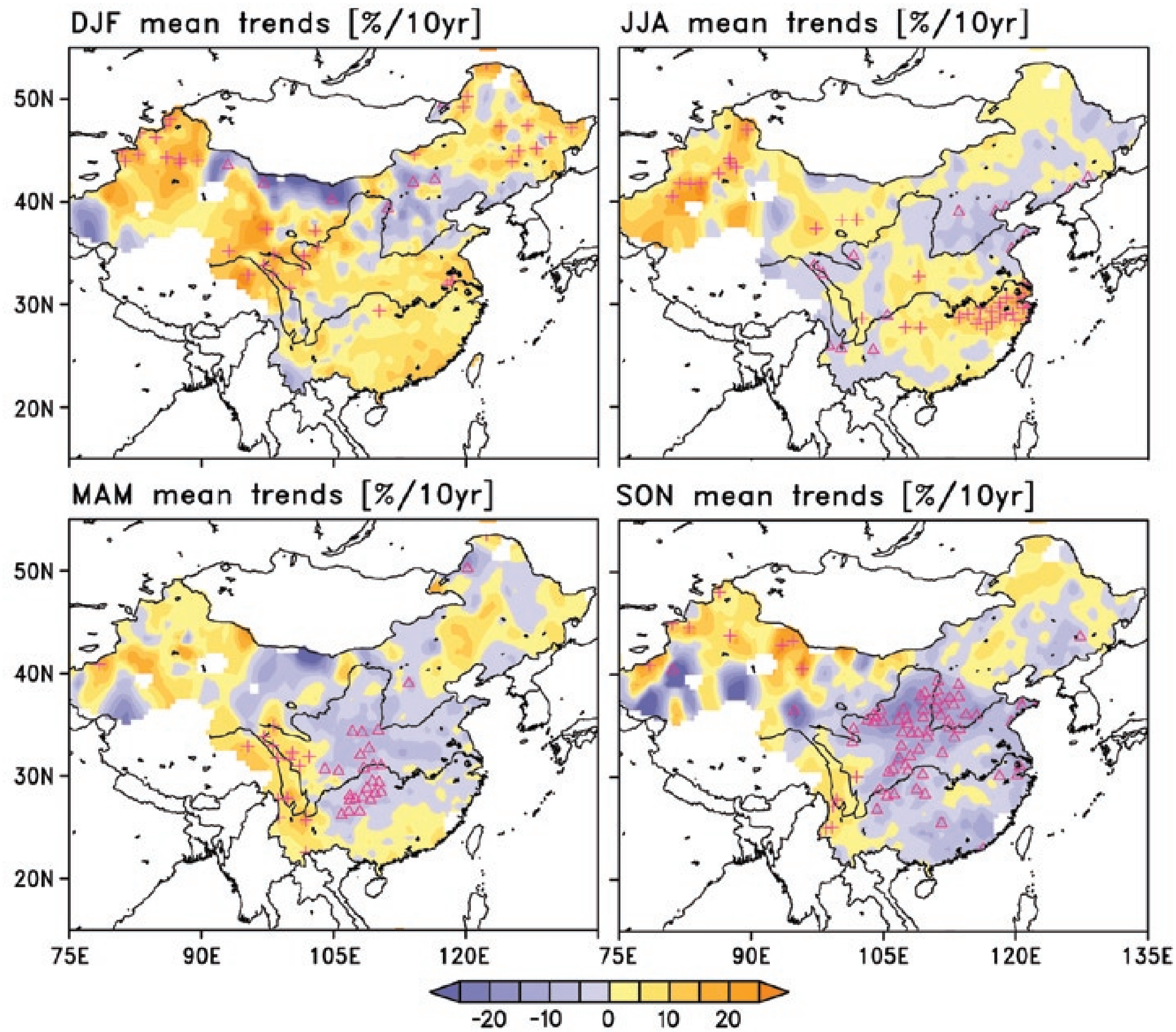
Precipitation

The rain-gauge data show that in central, northern, and northeastern China the average annual precipitation has decreased significantly from 1961 to 2001, whereas in southwestern, northwestern, and eastern China it has increased. Wang and Zhou studied the linear trend over those 40 years. In some regions of northwestern China, the increase has been between 10 and 20% during each 10-year period, indicating that these arid/semi-arid regions have been getting more rain. In central and northern China, precipitation has decreased by about 10% over each 10-year period. In fact, these heavily populated regions have had considerable water shortages in recent years.

The precipitation trends from 1961 to 2001 are not evenly distributed during the year, however (Figure 1). The northwest has now more rain during all four seasons. In spring, southwestern China has significantly more rain, while central and northern China have less rain; in summer, the Yangtze River delta and northwestern China have significantly more rain, while the far south- and northeastern regions have less; in fall, central and northern China have less rainfall, particularly the region between 40–45°N.

The increase in rainfall in the mid-lower reaches of the Yangtze River basin occurred mainly during the summer, while the decrease in rainfall in central and northern China occurred mainly in spring and fall (Figure 2). These opposing trends in summer and fall in the two regions paint a coherent picture. During these seasons, the main precipitation belt stays for a longer time in the lower Yangtze River basin and for a shorter time in northern China.

Do these changes in rainfall patterns have any implications for the occurrence of extreme precipitation events? Wang and Zhou examined the heaviest 2.5% of the daily mean precipitation from 1961 to 2001, and found that the change in extreme events over the 40 years parallels the



spatial pattern noted in the precipitation trends. For example, extreme events in the lower reaches of the Yangtze River, in south- and northwestern China increased along with the overall annual precipitation, while in central and northern China, extreme events decreased in parallel with an overall decrease in precipitation.

The rise in number of extreme rain events in the mid- and lower reaches of the Yangtze River occurred during summer and winter. The rise in extreme events in the Yangtze delta (eastern China) during summer could have great societal impact because it is one of the most developed areas in China. For the period studied, extreme summer rainfall events (the top 5% seasonal precipitation events) increased in this region by 0.5–1.0 events every 10 years (Figure 3). Moreover, the top

Figure 1. Linear rainfall trends (in percentage of seasonal mean precipitation every 10 years) for (*from top left*) Winter (DJF), Spring (MAM), Summer (JJA), and Fall (SON). Plusses (triangles) show stations with positive (negative) statistically significant trends (95% level).

5% produced almost 40–50% of the total summer rainfall in eastern China. Consistent with the observed rise in number of floods in the region, the findings point to more frequent serious floods in the future—if the trend continues.

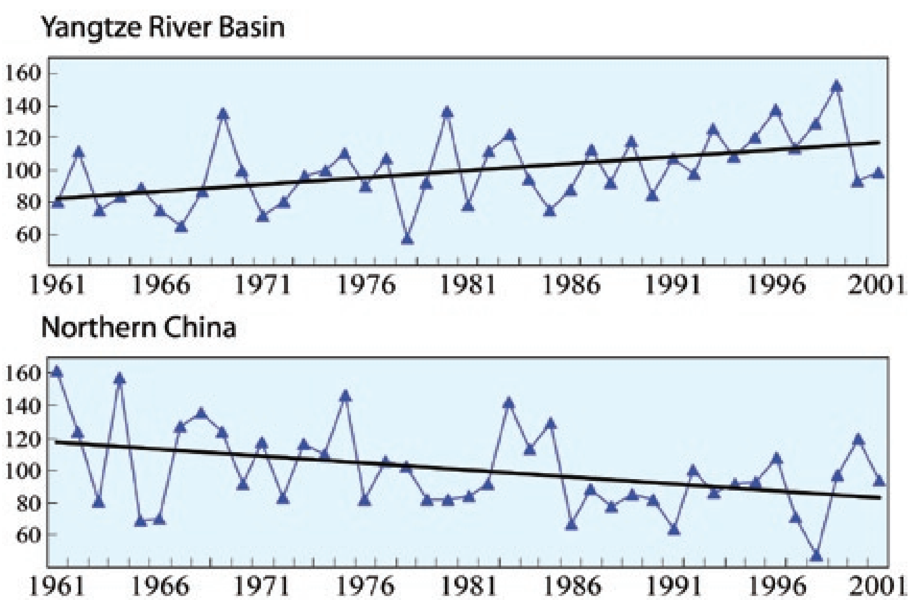


Figure 2. Changes in daily precipitation for 1961–2001 as a percentage of the climatological seasonal mean (top) in summer over the Yangtze River basin (112–122°E, 26–32°N), and (bottom) in fall over north China (100–120°E, 32–40°N).

Atmospheric Circulation

To see whether the trends noted in the summer rainfall patterns and in extreme events are attributable to changes in the large-scale atmospheric circulation patterns, Wang and Zhou conducted a linear trend analysis for the 40-year period using the summer monthly mean geopotential height and horizontal wind fields at 850 hPa and 500 hPa levels from the National Centers for Environmental Prediction/National Center for Atmospheric Research reanalysis data (Figure 4).

From 1961 to 2001, the geopotential height generally increased over Eurasia and the western North Pacific because of rising tropospheric temperatures. The rise in geopotential height over Eurasia however, has been greater than that over the western Pacific and was accompanied by an increasingly anticyclonic circulation; over the western Pacific, the circulation has become increasingly cyclonic. These trends indicate a weakening of the Eurasian continental low and a weakening of the western Pacific subtropical high. The associated increasing northeasterly winds in the lower troposphere from central China to the Pacific Coast weaken the southwesterly monsoon and limit the summer monsoon flow into northern China, something that other researchers have also recently found. As a result, the Maiyu fronts, which are nearly stationary fronts with heavy rainfall systems stretching mostly from west–southwest to east–northeast during late spring to midsummer, are now staying longer in the Yangtze River basin and shorter in northern China. This lingering of the Maiyu fronts increases the annual and mean summer

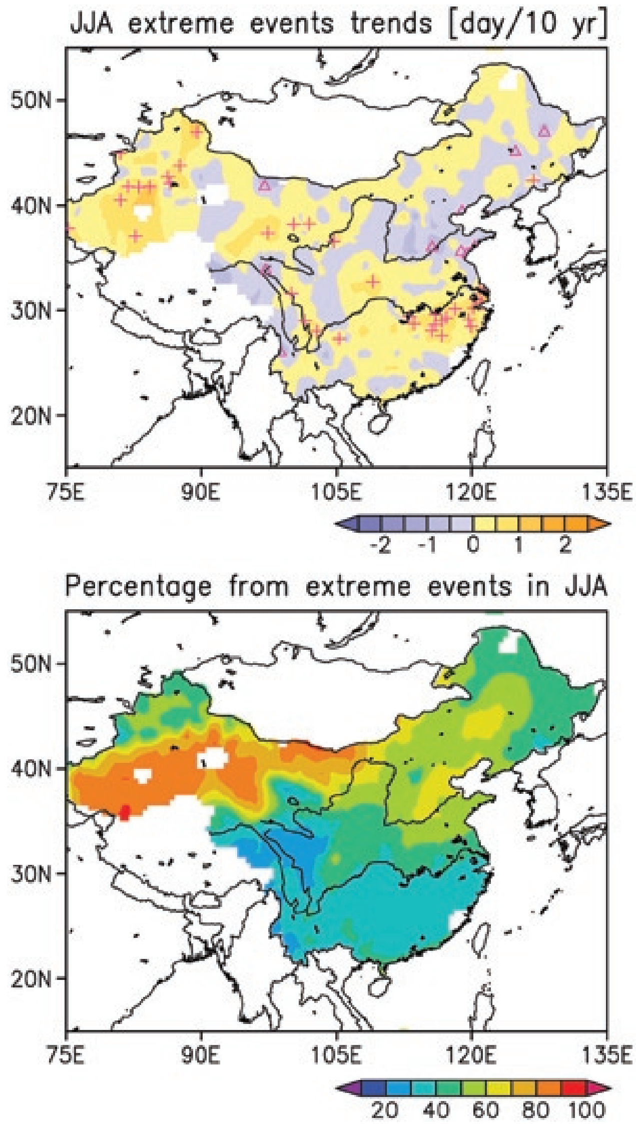


Figure 3. Top: Summer trends (increase in number of days every 10 years) in extreme precipitation events defined as the top 5% in precipitation days. **Bottom:** Percentage of total summer rainfall from extreme events.

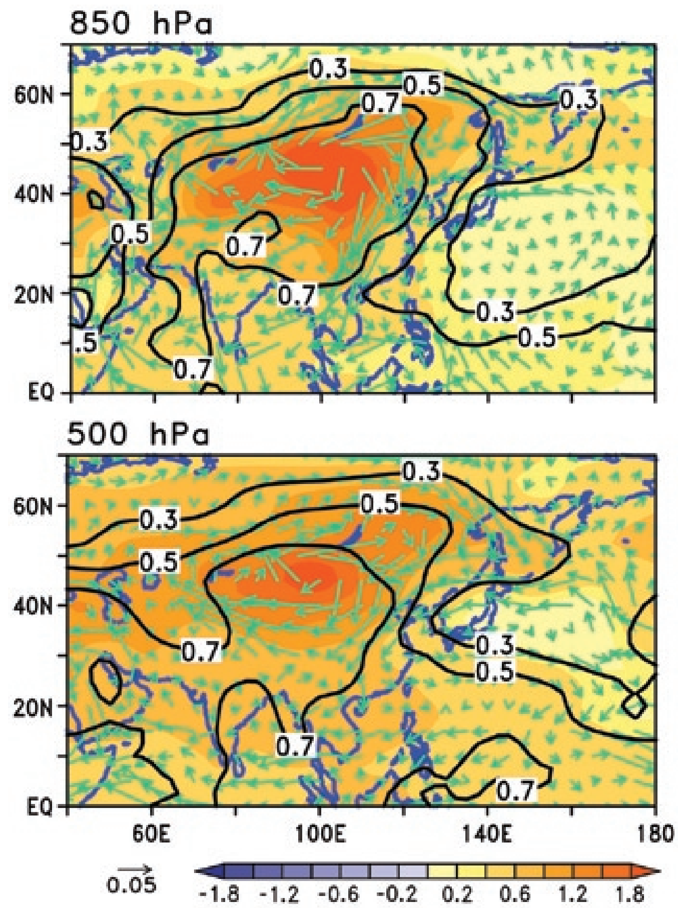


Figure 4. 1961–2001 summer trends in geopotential height (color: change in geopotential-height meters per 10 years) and corresponding horizontal winds at 850 hPa and 500 hPa (vector unit: 0.5 m/s per 10 years). The contours represent correlation coefficients between time and the geopotential height; values larger (smaller) than 0.3 (-0.3) are statistically significant at the 95% confidence level.

precipitation as well as the extreme events in the middle-lower reaches of the Yangtze River, and decreases them in northern China.

These circulation trends also explain changes that Wang and Zhou discovered in the seasonal precipitation cycle over central and east China. The monthly mean precipitation in that region has been decreasing during spring but increasing during summer: During the first two decades of the study, there was a peak in rainfall in May and another one in June; during the last two decades the peaks occurred in June and July. These changes, too, imply a weaker and later East Asian summer monsoon.

Changes in atmospheric circulation can explain changes in rainfall

The changes Wang and Zhou noted in the large-scale summer atmospheric circulation over the 40-year period can explain the rise in rainfall and extreme events in the mid-lower reaches of the Yangtze River basin during summer and the decrease in precipitation in central and northern China during fall. Those coupled general circulation models that simulate realistically and reliably the atmospheric circulation responses to changing temperatures, therefore, are useful for inferring precipitation trends that may result from global warming.

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Did Ocean Waves Transmit Abrupt Changes in Glacial Climate?

Mountain avens (*Dryas octopetala*) loves cold arctic climates.

The climate of the last glacial period, 80,000–11,000 years ago, is of particular interest for climate research because it furnishes a testing ground for scientific hypotheses about how climate changes. The large continental glacial ice sheets that covered North America and Europe affected climate greatly. Being 2,000–4,000 m high, they acted as a topographic barrier for the atmospheric circulation. They also changed Earth's albedo. Insolation from the sun, fluctuating with Earth's orbital paths around the sun on periods of 21,000, 41,000 and 100,000 years, was also different. Although the North American ice sheet accumulated snow only gradually, it was very unstable, melting and surging into the North Atlantic every 7,000 to 10,000 years.

Our understanding of the nature of these surges, their abruptness and their effects on climate, started with a tiny flower—the mountain avens (*Dryas octopetala*)—that flourishes in arctic climates. Paleo-botanists, studying sediments in Scandinavia in the early 20th century, found to their surprise fossils of this tundra flower right on top of soils on which trees had grown during a mild recovery from glacial conditions 14,000–11,800 years ago. The close proximity of such different vegetation layers could only mean that the climate had abruptly grown colder again.

We now know that this so-called Younger Dryas climate transition is one of the main hiccups of the glacial climate period. Data from ice cores in Greenland and sediment cores from the North Atlantic reveal that the Younger Dryas was not the only abrupt transition during the glacial period but that it belongs to a series of similar climate fluctuations. In 1988, Hartmut Heinrich discovered glacial debris deposits in sediment cores of the North Atlantic Ocean, which must have come from huge numbers of icebergs flowing into the North Atlantic. The surges were accompanied by global sea level rises of up to 20 m, and the impact of these so-called Heinrich events on climate is found in proxy records all over the globe: Greenland temperatures dropped rapidly several degrees; deep-sea ventilation—the exchange of water properties between the surface and the deep-ocean circulations—halted temporarily; and Antarctic temperatures rose by up to 3°C. In the tropics, Heinrich events were associated with a saltier Pacific warm pool and less monsoon rainfall over India.

The quest for mechanisms that cause such global climate swings is now on. Some researchers believe the observed synchronized climate effects seen around the globe during these ice-sheet surges result from atmospheric adjustments. Others are looking at oceanic adjustments, particularly the effects of the infusion of so much cold fresh water into the North Atlantic.

At the IPRC, **Axel Timmermann**, co-leader of the Impacts of Global Environmental Change Team, and his European colleagues are using an efficient global coupled atmosphere-ocean-sea ice model (ECBilt-Clio) to study the oceanic adjustment to changes in freshwater inflow into the North Atlantic under glacial conditions. More specifically, to mimic a Heinrich event, such as the Heinrich event II, they injected into the northern North Atlantic a glacial meltwater pulse of about 0.6 Sv [1 million m^3/s] for about 200 years. In response to this freshwater pulse, the thermohaline circulation in the North Atlantic collapsed and the North Atlantic cooled several degrees; in the Southern Hemisphere,

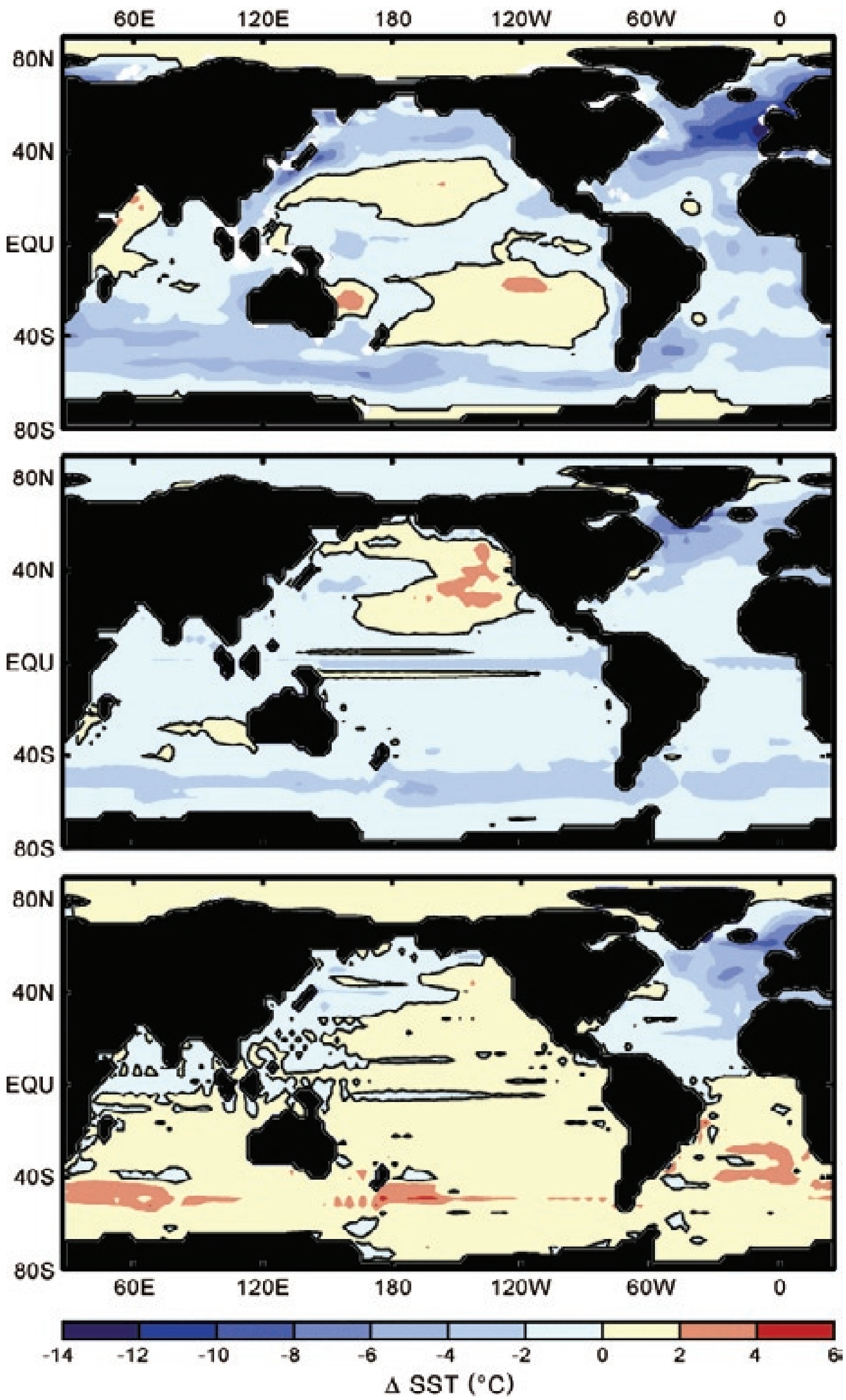

Figure 1. Top: Difference between sea surface temperatures (SST - average of February and August temperatures) reconstructed for the Last Glacial Maximum (LGM), and present-day observations. **Middle:** Difference between annual mean SSTs in the LGM experiment and in a pre-industrial control experiment. **Bottom:** Difference between SSTs during thermohaline circulation shutdown and normal LGM conditions. The North and South Atlantic temperature seesaw is apparent.

oceans warmed by as much as 3°C (Figure 1, lower panel). The simulated glacial climate is similar to recent climate reconstructions for the Last Glacial Maximum (Figure 1, upper panel). The model underestimates, however, the cooling of the North Atlantic during that period because of its weak climate sensitivity and strong glacial thermohaline circulation.

In agreement with the reconstructions of paleoclimates, the warm pool in the model grew saltier during Heinrich events, and the Indian monsoon grew weaker. The simulation not only showed the seesaw in North and South Atlantic temperatures that has been described and explained in detail in Knutti et al. (2004), but also a North Pacific–North Atlantic seesaw. That is, when the North Atlantic cools, the eastern North Pacific warms, and *vice versa*.

To see whether these changes can occur through purely oceanic adjustments, the researchers conducted the same simulation experiment except that the connections between the atmosphere and ocean were prevented world wide. This resulted in climate changes in the Pacific Ocean that were much like those noted in the first experiment. Analyses of the model output show that the ocean circulation can account for many of the synchronized changes seen in the global ocean over 100 to 1000 years in response to Heinrich events.

When the thermohaline circulation in the model weakens, the tropical thermocline in the Indian and Pacific oceans deepens as a result of a global baroclinic wave adjustment: The density changes stemming from the influx of freshwater generate Kelvin waves in the North Atlantic that travel to the equator. At the equator, they are forced to move towards the coast of Africa, where they split into a northern

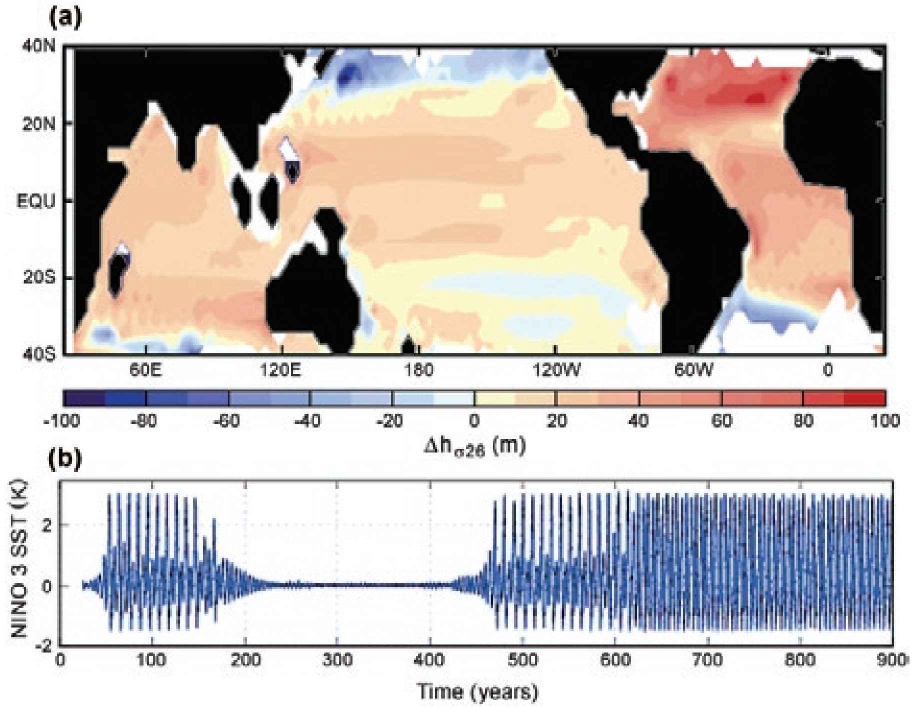

Figure 2. Top: Difference in the depth of the isopycnal 26.0 kg/m^3 surface during shut-down and normal thermohaline circulation (THC) in the LGM experiment. This isopycnal surface separates upper-ocean thermocline waters from deep-ocean waters. **Bottom:** Response of ENSO to the thermohaline circulation-induced changes: time-series of the NINO 3 SST anomalies [K] simulated by the intermediate ENSO model. The background thermocline depth is updated every year to capture the spatial and temporal thermocline changes that correspond to a collapsed thermohaline circulation in the North Atlantic during Heinrich events.

and southern branch. While moving poleward, they radiate Rossby waves, which readjust the interior transport of the North and South Atlantic after reaching the western boundary. The southern wave branch travels around the southern tip of South Africa into the Indian and subsequently into the Pacific Ocean. The global baroclinic adjustments to the initial density anomaly in the North Atlantic happen within a few years to decades, whereas adjustments due to advection of the density anomalies are much slower. The overall sea level and thermocline-depth changes can be viewed as a standing wave pattern—a global seiche as Cessi et al. (2004) have called it.

In the model, the collapse of the thermohaline circulation in the North Atlantic deepens the tropical Pacific thermocline about 20–30 m. What will happen to El Niño–La Niña, a major mode of modern-day climate variation, when the tropical Pacific thermocline lies deeper? In a simulation with an intermediate model of the El Niño–Southern Oscillation (ENSO), Timmermann and his colleagues found that the temperature variability in the tropical Pacific also collapsed, and there were no El Niño and La Niña events for many years (Figure 2). Several elements of the ENSO suppression mechanism, however, may be model-dependent. Paleo-reconstructions for ENSO may soon become available for the Younger Dryas event or other Heinrich events to confirm or disprove this ENSO collapse. Timmermann also plans to conduct sensitivity experiments with more realistic state-of-the art coupled general circulation models to test the robustness of the results.

Are similar oceanic adjustment mechanisms operating under present-day climate conditions? Timmermann is now exploring how much of the Northern Hemispheric interdecadal variance in temperature and ocean currents seen in instrumental records can be explained by oceanic global adjustments or atmospheric bridges such as the Arctic Oscillation. **Oliver Timm**, IPRC postdoctoral fellow working with Timmermann, is conducting transient glacial interglacial simulations using a global atmosphere-ocean-sea ice model. He hopes to understand why our present Holocene climate is so much warmer and more stable than climate during glacial times.

Cessi, P., K. Bryan, and R. Zhang, 2004: Global seiching of thermocline waters between the Atlantic and the Indian-Pacific Ocean Basins. *Geophys. Res. Lett.*, *31*, doi 10.1029/2003GL019091.

Knutti, R., J. Flueckiger, T. Stocker, and A. Timmermann, 2004: Strong hemispheric coupling of glacial climate through freshwater discharge and ocean circulation, *Nature*, *430*, 851–856.

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The Latest on Tropical Atmospheric Disturbances: The MJO

The Madden-Julian Oscillation (MJO) is a major within-season atmospheric disturbance that travels around the world in the tropical belt. Understanding and modeling this disturbance is of great interest to IPRC scientists, who hope to develop procedures for its prediction. In late Fall 2004, several well-known MJO researchers visited the IPRC: **Roland Madden**, senior researcher at the National Center for Atmospheric Research (NCAR); **Julia Slingo**, director of the Centre for Global Atmospheric Modelling at Reading University in England; and **Ken Sperber**, research scientist, Program for Climate Model Diagnosis and Intercomparison at Lawrence Livermore National Laboratory. It was a great opportunity for discussing the most recent findings and challenges in this field of research. Accordingly, **Xiouhua Fu** and **H. Annamalai**, scientists with the IPRC Asian-Australian Monsoon System Team, organized the "Tropical Intraseasonal Variability Mini-Workshop" on November 19, 2004.

Madden gave a historical perspective on his and **Paul Julian's** discovery of the MJO. During the 1960s, the study of tropical phenomena was blossoming. The stratospheric quasi-biennial oscillation had just been discovered; interest in its governing mechanism abounded and prompted a search for large-scale waves in the tropical stratosphere. In 1966,Yanai and Maruyama identified waves with a westward phase speed that turned out to correspond to mixed-Rossby gravity waves, consistent with Matsuno's theory of equatorial waves. Later, Kelvin waves, also predicted by this theory, were identified. Analyzing the Line Island data, Madden and Julian noted disparate results in the 60- and 120-day records. To understand what this might mean, they studied a 10-year record of winds, temperatures, humidity, and surface pressure from Kanton Island. Their analysis of this record, unusually long for the late 60s, was made possible by the new "fast" computers and recently developed Fast Fourier Transform (FFT). To their surprise, they found strong variations with a period of 40–50 days. Co-spectra revealed the zonal winds at 850 hPa and 150 hPa were out of phase. Madden and Julian interpreted the phenomenon at first as zonal circulation cells: Because the data were not seasonally stratified, the coherent relationship between the zonal and meridional winds on intraseasonal time scales went unnoticed. Though much has been learned about the MJO since its discovery, Madden mused at the end his talk, "Much still remains a mystery, and we still cannot explain why the MJO has this time scale, why it propagates eastward, and why it has this very large spatial scale. The more observations we gather, the more complex the disturbance is becoming."

Slingo raised several challenges in modeling the MJO. First, current cloud schemes represent only two types of clouds and cannot capture the important MJO cloud build-up from cumulus to cumulus congestus to cumulonimbus stages. Research conducted at her center revealed that increasing vertical resolution in the free troposphere resolves the freezing level better and gives a more realistic representation of a tri-modal cloud distribution; this, in turn, improves the MJO in the Hadley Centre climate model. Second, to understand the physics of the MJO better, Slingo believes air-sea coupled models are needed. Third, the suppressed phase of the MJO needs more investigation. For instance, since the cumulus congestus clouds have a strong diurnal cycle, the cycle needs to be resolved to accurately represent the rise in sea surface temperature (SST) that precedes deep

Visiting scientists at the MJO workshop (*from left*) Fritz Schott, Ken Sperber, Julia Slingo, Tony Slingo, and Roland Madden.

convection. To resolve the SST change, high vertical resolution (about 1 m) is needed in the ocean mixed layer.

Sperber presented an analysis of the MJO in coupled and uncoupled models. Most of the models had difficulty in simulating variance patterns of daily and intraseasonal outgoing longwave radiation and the eastward propagation of MJO convection. Flux-adjusted coupled models using the ECHAM4 atmospheric GCM gave credible simulations of the MJO, including the lead-lag relationship between convection and SST, and the vertical structure of divergence and humidity. Similar to observations, low-level moisture convergence and free-tropospheric interactions were central for maintaining the eastward propagation of the simulated MJO. Unanswered questions include why a systematic MJO develops in some models and not in others, and why the oscillation is strong in some years and weak in others.

The talks by IPRC scientists are listed on our website at **iprc.soest.hawaii.edu/meetings/workshops/iprc_tropical_intraseasonal_vari.htm**.

A lively discussion followed the presentations. The gist was that global reanalysis data have given a quite good understanding of the large-scale dynamics of the MJO: the disturbance is manifested as a coupled Rossby-Kelvin wave. How the dynamics interact with relevant physical processes, however, is not well understood. The role of extra-tropical events in the evolution of the MJO remains unclear: Convection is observed to be excited by an upper-level trough over the Indian Ocean, which brings in energy from mid-latitudes. Perhaps the biggest unknown is what sets the MJO in motion—according to Slingo, "What starts it is the holy grail. Once one is able to start the MJO in a model, the oscillation continues." Though plenty of challenges remain, Slingo summarized optimistically, "At least we have models now that produce the MJO and that take it slowly enough through the (Pacific) warm pool."

Tracking Indian Ocean Climate

Gary Meyers

Senior Principal Research Scientist,
CSIRO Marine Research
Hobart, Australia

The Indian Ocean is taking an ever more important place in Earth's climate system, climatologists are finding. For one, the seesaw in the east-west sea surface temperature (SST) contrast may affect not only rainfall in regions bordering the Indian Ocean but in regions as far away as North America. For another, from 1992–2000 the average SST of the Indian Ocean rose by approximately 0.25°C, the largest warming of any of the world's oceans.

It is thus not surprising that scientists on two international climate panels (CLIVAR Asian/Australian Monsoon and CLIVAR Indian Ocean panels) recognized the need to identify gaps in their knowledge of ocean-circulation processes in the Indian Ocean as they relate to the climate system and to improve capabilities in modeling these processes. The panels also recognized that simulation experiments could contribute information to the observational and diagnostic studies for developing an *in situ* observing system in the Indian Ocean. To lay the groundwork for such information gathering, **H. Annamalai** and other IPRC researchers organized the "Indian Ocean Modeling Workshop" November 29–December 3, 2004, at the East-West Center in Honolulu. More than 70 participants from 10 countries attended.

The workshop opened with a celebration of the 60th birthday of IPRC Director **Julian McCreary**, a leading theoretician and ocean-modeler. Talks by friends and colleagues reviewed his many contributions to understanding the circulation of the global oceans and provided a broad background to the specific topics of the workshop—monsoons and the Indian Ocean.

The presentations included reviews of regional climate and ocean dynamics, diagnostic studies and results from forced, stand-alone ocean models and from coupled ocean-atmosphere models. The talks and discussions demonstrated that scientists are capable of simulating the observed behavior of the Indian Ocean and its role in the climate system, such as the large-scale variability of surface currents in response to basin-scale variations in the monsoon and its seasonally reversing winds. They can also simulate realistically the reversing cross-equatorial winds, the zonal winds during monsoon transitions, and the relatively steady trade winds of the Southern Hemisphere. Interannual variation in currents associated with the Indian Ocean Dipole is also simulated reasonably well (see **www.jamstec.go.jp/frcgc/whatsnew/2004/1227/index_e.html**).

Present-day ocean and coupled models, however, do not simulate well some of the most important regional climate phenomena. Because the Asian landmass blocks currents near 25°N and there is an opening to the Pacific near the equator through the Indonesian archipelago, the Indian Ocean has a unique, three-dimensional, overturning circulation in its uppermost layers. This circulation plays a crucial role in the ocean-atmosphere heat budget and its variability. Aspects of this unique circulation and its variability are not understood and not modeled well, for example,

- the upwelling and subduction processes that connect the horizontal surface and subsurface current systems;
- the thermodynamics of thin low-salinity surface layers prevalent beneath some of the most important atmospheric action centers (*e.g.* Bay of Bengal, Indonesian Seas);
- the dynamics and thermodynamics of the so-called Eastern Gyral Current and its relationship to the origin and maintenance of the Leeuwin Current along the coast of Australia, which is a key element of the regional climate system;
- the relationship between the surface Somalia Current and the monsoon-driven equatorial Rossby waves, which seem to propagate to deeper levels in the western ocean.

All these processes affect SST and feedbacks to the atmosphere. For instance, the Indian Ocean Dipole and intraseasonal oscillations are important coupled ocean-atmosphere modes. The above shortcomings in the ocean component will need to be resolved before coupled models can realistically simulate these phenomena. Better modeling will come from a better understanding of the physical processes based on observations.

The first results of the observing-system simulation experiments were also presented at the workshop. Model runs had started after the February 2004 meeting of the CLIVAR/GOOS Indian Ocean Panel, at which the planning took place for the Indian Ocean sustained ocean climate observing system. The system will have an integrated mooring array consisting of Argo floats, XBT lines, surface drifters and tide gauges. The panel recognized that a basin-scale mooring array is essential to observe the fast, upper-ocean fluctuations associated with the intraseasonal oscillations. In anticipation of certain problems, compromises to the system had to be made. For example, because of heavy fishing and anticipated vandalism, surface moorings were not planned near the eastern boundary and in a few other places. Moreover, the southwestern Indian Ocean is poorly covered owing to its remoteness. The modeling experiments helped to answer such questions as What are the consequences of the compromises? Does the plan have the best possible mixture of Argo and XBT sampling to complement the moored array?

The simulation experiments ranged from evaluating the performance of the planned observation-system to determining the ideal set of observations, assuming a "perfect" model. The experiments also evaluated time scales ranging from intraseasonal variability to decadal and longer changes. The results from the experiments improved approaches for integrating different types of

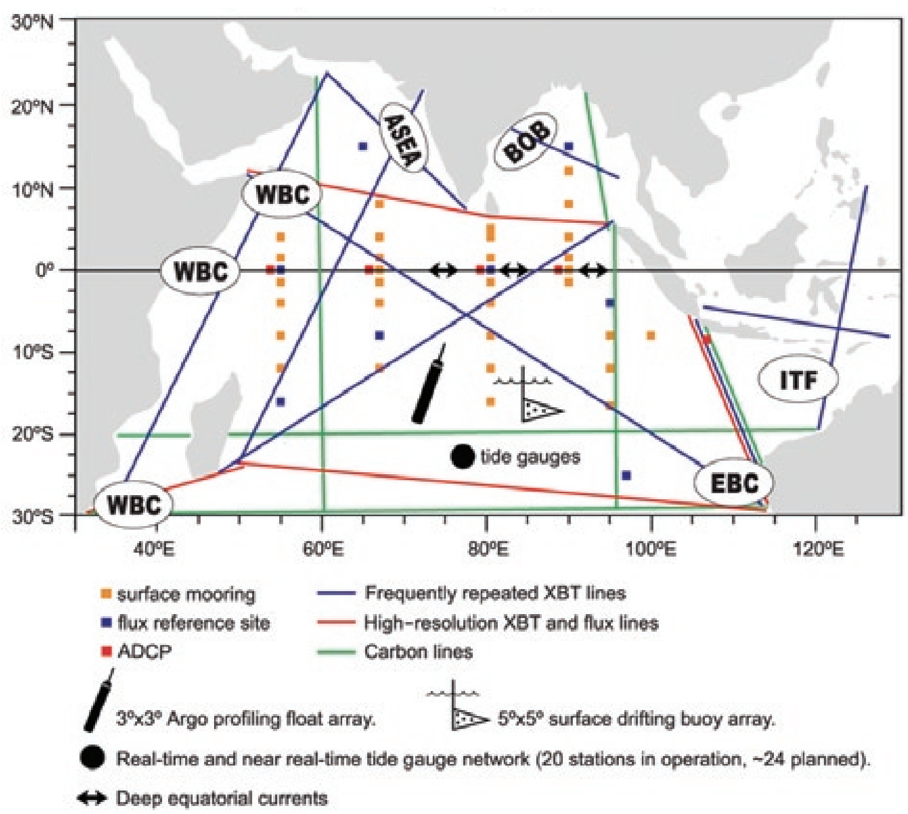


Figure 1. Indian Ocean Integrated Observing System.

observations in regions where upwelling and remote forcing of the thermocline affect SST (*e.g.* Java/Sumatra upwelling and the SECC ridge), and identified observations critical for observing change in the cross-equatorial heat transport.

The simulation experiments confirmed that the original plan for an initial observing system was adequate, but they also contributed to important modifications to the final plan (Figure 1) that emerged from the following findings:

- The planned system is able to map much of the interannual variability in the Indian Ocean well (high-frequency IX-1 XBT is essential to cover the Indonesian region, and the normal 10-day sampling by Argo floats is adequate);
- Not much is gained by 5-day Argo sampling because it does not fully resolve the intraseasonal time scale;
- Regarding variability in cross-equatorial heat transport, (a) on interannual time scales, variability is determined mainly by zonal wind in the eastern equatorial zone off the equator (Ekman pumping); on longer time scales, surface heat flux in the subduction zone (~100°E, 20–30°S) becomes important; (b) full-depth moorings are not necessary for interannual variability; (c) all the flux reference sites in the plan are helpful for long-term observation of this variability, but the one east of Madagascar (which is needed for intraseasonal-to-interannual variability) is most important.

In sum, the simulation experiments were a useful test of the observing-system plan and contributed to its improvement. Panel members recommended these experiments should continue until their evaluation of the plan is complete.

Workshop organizers (*from left*) Henry Diaz, Raymond Bradley, Bette Otto-Bliesner, and Jamie Schulmeister.

Ancient and Modern Pathways of Climate Signals

Bette Otto-Bliesner
National Center for Atmospheric Research, Boulder, Colorado

Raymond Bradley
University of Massachusetts, Amherst, Massachusetts

Henry Diaz
NOAA, Climate Diagnostics Center, Boulder, Colorado

Sponsors of the workshop on "Tropical-Extratropical Climatic Teleconnections" were the National Science Foundation, Past Global Changes (PAGES), and the IPRC.

Recent research shows that climate changes in regions that are far apart are often linked. An excellent example is the tropical El Niño–Southern Oscillation (ENSO) that brings about anomalous weather patterns around the globe. Changes in mid-latitude Pacific climate and sea surface temperatures (SSTs) feed back to the tropics through the ocean circulation; changes emanating from the western tropical to high-latitude Pacific can have a global signature. Climate changes in the North Atlantic may lead to synchronous and phased climate responses in the tropical Atlantic, the Southern Hemisphere and even in the far away western North Pacific. Although the recent global impacts of ENSO and other natural climate signals are becoming evident, the teleconnections—the atmospheric and oceanic pathways and mechanisms by which these signals affect climates in far away regions—are still not fully understood.

To bring together atmospheric scientists, oceanographers, and paleoclimatologists on this topic of telecon-

Participants of the "Tropical-Extratropical Climatic Teleconnections" workshop gather in the Japanese Gardens of the East-West Center.

nections, the American Geophysical Union held a Chapman Conference on "Tropical-Extratropical Climatic Teleconnections, A Long-Term Perspective" February 8–11, at the East-West Center in Honolulu, with the IPRC as host. The meeting was dedicated to the late **Geoff Seltzer**, the 1998–2004 leader of PAGES Pole-Equator-Pole-1 focus. Seltzer had originated the idea of a Chapman Conference to help remove barriers that separate researchers studying distant-past and modern climates: The conference was to provide scientists of modern climate with a better understanding of paleoclimate records, and paleoclimatologists with the opportunity to place their records into the larger context of climate processes. Over 65 specialists in climate and ocean dynamics and in paleoclimate attended the conference from 8 countries. The group included experts in observations, theory, and modeling of modern atmospheric and oceanic teleconnections between the tropics and extratropics, and experts in analyses of past records of interannual-to-millenial climate variability. Topics centered on tropical climates, monsoon dynamics, mid-latitude circulation, and ocean dynamics.

The workshop's paleoclimate presentations showed how useful proxy records are for reconstructing past climate periods, ranging from the last millennium, the Quaternary, to the Pliocene. Records found in ocean-, lake- and peat-sediments, fossil corals, ice cores, speleothems, paleosols, and tree rings reveal connected climate changes in the tropics and extratropics. These climate fluctuations appear on various time scales—over thousand-year periods and over Earth's orbital phases and solar radiation fluctuations. The causes for climate changes in different periods, however, may differ. Records of changes in tropical SST, for instance, suggest that on orbital time scales, atmospheric CO_2 is a primary factor; on millennial time scales variations correspond to prominent changes in the North Atlantic, such as the fresh-water influx during the Younger Dryas, which evoked a response, though muted, as far away as the western tropical Pacific. Similarly, well-preserved fossil corals in eastern Indonesia record a cooling event of about 100 years in duration at the same time that an anomalous cold event occurred in the North Atlantic about 8200 years ago. Such synchrony supports the idea that atmospheric teleconnections (and even oceanic teleconnections, see p. 10) rapidly propagate this kind of climate signal to the tropics.

The paleoclimate record of the Asian summer monsoon winds also shows a robust teleconnection between ENSO and North Atlantic climate. Strong monsoon winds correlate with strong winds in the tropical Pacific (La Niña) and warm North Atlantic conditions; weak monsoon winds correlate with a cool North Atlantic, a cooling that includes a southward displacement of the Intertropical Convergence Zone when extensive land- and sea-ice covered the Northern Hemisphere. Antarctic ice cores have different layers that may be tied to variations in moisture sources at low latitudes.

Modern teleconnection pathways and mechanisms, identified through observational diagnostic analyses and model simulations, provide the basis for understanding the paleoclimate records. The global heat budget constrains the climate system greatly by requiring systematic movement of energy. The major atmospheric heating process and source of atmospheric teleconnections is the latent heat released in precipitation. In the tropics, precipitation patterns are anchored in the land-sea contrasts (monsoons) and SST patterns (ENSO). As ENSO and the monsoons change, the westerlies and storm tracks at higher latitudes change, and so do the precipitation patterns. The monsoons, dominating large areas of the tropical and subtropical climate, result from coupled atmosphere-ocean-land phenomena that are characterized by a strong cross-equatorial atmospheric pressure gradient and regulated by negative feedbacks within the system.

In climate models, teleconnections originating from changes and variations in tropical SST patterns are sensitive to changes in the magnitude of the oscillation between El Niño and La Niña phases and to patterns of warming in the tropical Pacific and Indian oceans. The ocean's thermohaline circulation, too, affects interactions between tropical and extratropical climate. Simulations with a coupled atmosphere-ocean model demonstrate that millennial-scale abrupt climate changes in the model are associated with sustained freshwater addition to the North Atlantic, and are synchronized globally through rapid adjustments in both the ocean and the atmosphere.

The interdisciplinary mix of researchers at this Chapman Conference led to lively discussions and provocative questions; new contacts have forged new collaborations to study the climate system over longer times. Further meetings are being planned to continue application of paleo-proxy and instrumental data, and numerical modeling of past, present, and future climates to our understanding of climate change and our ability to predict it.

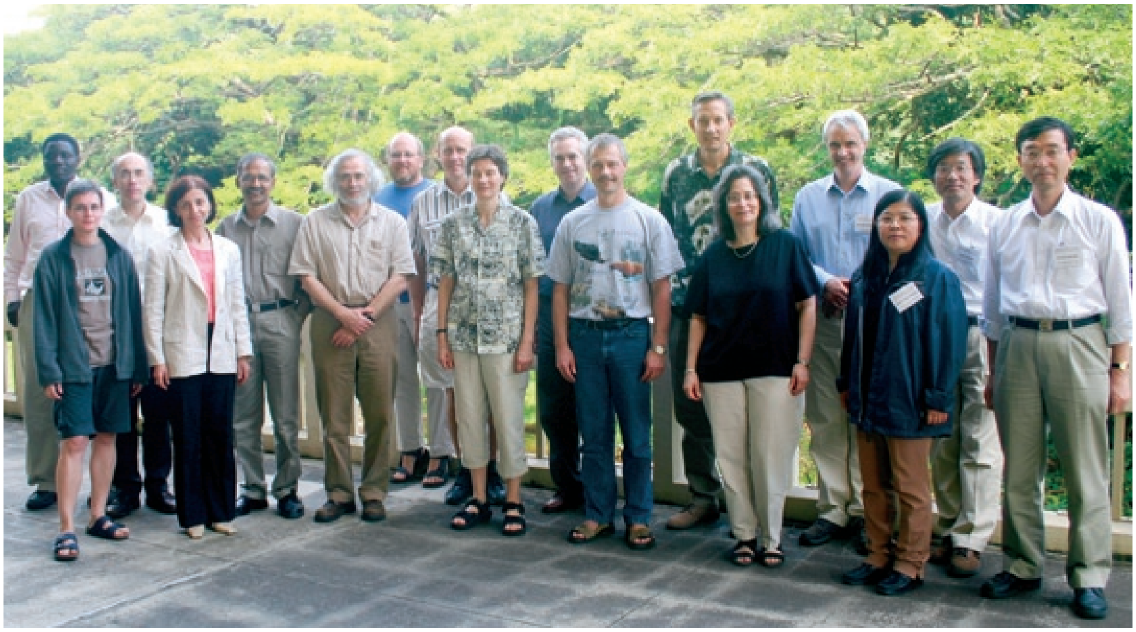
Meeting organizer Gerald Meehl with IPRC's Axel Timmermann at the IPCC Workshop.

IPRC Hosts Workshop for Upcoming Climate Assessment Report

The Intergovernmental Panel on Climate Change (IPCC) plans to release its Fourth Assessment Report on Climate Change in 2007. Like the previous IPCC reports, this one will reflect the current state of scientific knowledge on climate change and assess the extent to which climate change is human induced. The IPCC assessments are huge efforts that extend over several years. On March 1–4, the IPRC hosted a major meeting that provided a forum for the scientific community to present results on analyses of climate change seen in the global circulation models used for the IPCC report. The meeting was convened by U.S. CLIVAR and took place at the East-West Center in Honolulu.

Meeting organizer **Gerald Meehl**, senior scientist at the National Center for Atmospheric Research, explained the process for developing the large part of the report content dealing with model simulations: "Fourteen research centers ran simulations with ocean-atmosphere coupled climate models under 20th century climate conditions and three different 21st century greenhouse-gas emission scenarios. Simulations with these models were also run with greenhouse gases

Opening the "Workshop on Analyses of Climate Model Simulations."



Lead authors of IPCC Working Group 1 at the East-West Center.

stabilized at current levels to determine how much we are already committed to future climate change. The outputs from these simulations were then posted on the internet so that climate researchers worldwide could analyze the simulations according to their interests."

At the workshop, scientists presented their findings on analyses of these global climate simulations. Among the 125 scientists from 21 countries who presented their analyses were four IPRC scientists: **H. Annamalai**, **Kevin Hamilton, Markus Stowasser**, and **Axel Timmermann**. The 'input' from the papers that will come out of the work discussed at this conference is a key part of the report.

The link between greenhouse gas emissions from human activities and global warming is becoming clearer. "Reconstructions of past temperatures from proxy records, such as tree rings, sediments, and corals, all tell us that temperatures during the last 1,000 years were never as high as during the last decades," says Meehl. "Earth's temperature, however, is affected by different things, for example, aerosols, volcanic eruptions, and changes in radiation from the sun. The beauty of these ocean-atmosphere coupled models is that we can do experiments to isolate the response of the climate system to specific individual forcing factors. We can run all these elements affecting temperature together in the models, and then separately. This gives us the fingerprint of each element on climate change. What we find is that if you pull out greenhouse gases in the simulations, it does not get as warm, and sea level does not rise as much."

A peculiar aspect of global temperature evolution in the 20th century has puzzled scientists. During the first part of the 20th century, Earth got warmer, then temperatures leveled off or even dropped a bit, only to rise again in the last 30 years. Because these fluctuations were poorly understood, some scientists questioned the link between increased greenhouse gases and warming.

"Now we can say that the early 20th century warming was mostly due to increasing solar radiation, and temperatures leveled off after WWII when there were large increases of sulfate aerosols whose cooling effects masked the effect of increasing greenhouse gases. These aerosols started to be reduced in North American and western Europe in the 1970s because of the recognition of their damaging effect on the environment, while greenhouse gases concentrations continued to increase. It was then that it became clear that the increase in global surface temperatures was due mostly to greenhouse gas emissions from human activities."

The upcoming report will state climate information in probabilities, something that progress in modeling has made possible. "Many of our climate change forecasts will be worded similar to weather forecasts, for example: 'By the year 2050, there is an 80% chance that average temperatures will have gone up by three degrees in a particular region,'" explains Meehl.

"Extreme climate events matter a lot to people, and the report will also assess new research on what we can expect with such events," said Meehl, remembering the 2003 heat wave in Europe and the deluge that caused over $50 million damages to the University of Hawai'i library in October 2004.

The assessment report still has to go through several drafts, including a technical review by outside scientists. Since the report is to provide information to governments, there will be a special summary for policy makers, and participating governments will also review the report. In a plenary session in early 2007, government delegates of the countries participating in the UN Framework Convention on Climate Change Parties, along with the scientists who were the authors, will then adopt the final version of the report.

Implementing iROAM at the Earth Simulator Center: (*from left*) Takashi Mochizuki, Yuji Sasaki, Toru Miyama, and Yuqing Wang.

Forecasting Climate: The Kyosei-7 Project

IPRC scientists are participating in the Japanese Kyosei-7 Project, an ambitious project to develop a coupled ocean-atmosphere simulation and assimilation system for improving seasonal-to-interannual climate forecasts. In January 2005, project members and scientists from the Frontier Research Center for Global Change held a workshop on "Coupled Model Simulation and Assimilation" in Yokohama. Over 50 scientists from Frontier, the University of Tokyo, the Japan Meteorological Agency, the Earth Simulator Center, Yonsei University (Korea), and the U.S. National Centers for Environmental Prediction presented designs and results from their climate models. Their presentations showed the headway being made in modeling and assimilation. IPRC scientists **Bin Wang**, **Shang-Ping Xie**, and **Haiming Xu** described results from the IPRC global and regional models.

The IPRC regional ocean-atmosphere model (iROAM) has been implemented to run on the Earth Simulator as part of this project and is producing promising results. In a multi-year integration, the model kept the Pacific Intertropical Convergence Zone north of the equator. This is a major accomplishment that many global models still have difficulty achieving. IPRC and other Kyosei-7 researchers also had the opportunity to discuss current challenges and future directions in monsoon research and coupled ocean-atmospheric modeling. Among pressing issues identified are the ability to distinguish atmospheric forcing of the ocean from ocean feedback and to represent stratus clouds and their interaction with the ocean. The Kyosei project is supported by the Japan Ministry of Education, Culture, Sports, Science and Technology.

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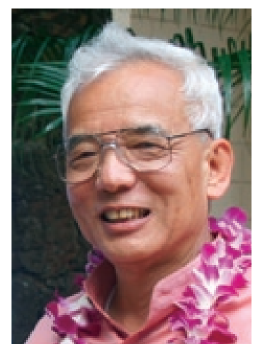
(*From left*) UH President McClain with governing committee's Hiroshi Fukai (MEXT), Katsuhiko Masuda (FRCGC/JAMSTEC), Howard Diamond (NOAA), Klaus Keil (SOEST), Julian McCreary (IPRC), Eric Lindstrom (NASA), Saichiro Yoshimura (IPRC/AESTO), Tetsuro Isono (FRCGC/JAMSTEC), and Kazutoshi Horiuchi (AESTO).

UH President Welcomes IPRC Governing Committee

University of Hawai'i Interim President **David McClain** welcomed the IPRC Governing Committee at a breakfast meeting on March 1, 2005, at the Mānoa Campus. The committee members represent the IPRC supporting agencies MEXT and JAMSTEC in Japan, NASA and NOAA in the U.S., and the University of Hawai'i. President McClain surprised everyone when he addressed the Japanese members in fluent Japanese. He expressed his appreciation to the agencies for their support of the IPRC, acknowledging particularly JAMSTEC, which has contributed over $22 million since IPRC began in 1997. He remarked on the importance of the IPRC mission to conduct research that improves our understanding of climate variation and change. In light of the accumulating scientific evidence on global warming, no other issue challenging us today is as significant as climate change. Climate affects such things as water resources, agriculture, sea level, marine ecology, and fisheries around the globe. President McClain recognized the uniqueness of the IPRC with its international team of scientists and commended it for its scientific accomplishments and leadership role in climate research.

Following the breakfast, the Governing Committee met at the IPRC. The members reported on recent events in their agencies that may impact the IPRC, heard about the most recent IPRC research activities, and discussed governance issues. They also considered how to enhance collaboration between scientists at Frontier and the IPRC. A major step in this regard is being taken by Frontier, which is dispatching at least two Japanese researchers to the IPRC, one at the postdoctoral level and one at a more senior level.

Pioneer of General Circulation Modeling Visits IPRC

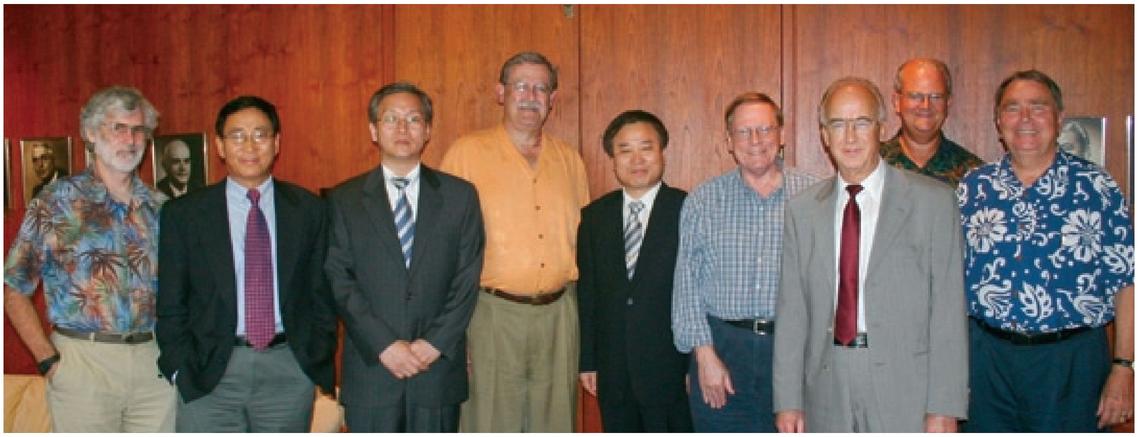


Prof. Syukuro Manabe

Just before this issue the *IPRC Climate* went to press, Professor **Syukuro Manabe** visited the IPRC. He gave two talks: "The Early Developments in Climate Modeling and Prospects for the Future" and "Simulated ENSOs with Interannual and Decadal Time Scales and Their Amplitude Modulation." Interviews with Professor Manabe will be featured in the next issue of the *IPRC Climate*.

Forging Collaborations with Climate Researchers in Korea

Much is happening to strengthen ties between climate research at the University of Hawai'i and Korea. In April 2005, UH Interim President **David McClain** and Mr. **Kwang-Joon Park**, the Director General of the Climate Bureau, Korea Meteorological Administration, signed a Memorandum of Understanding to cooperate on research to improve climate predictions for Asia-Pacific economies and countries. The economic and societal impact of climate change and the increasing occurrence of droughts, floods, and temperature extremes in APEC (Asia-Pacific Economic



Cooperation) regions have prompted APEC to establish the APEC Climate Center (APCC) in Korea. A major task of this new center is to develop a seasonal climate prediction system for the APEC region. At the IPRC, Meteorology Professor **Bin Wang** has been working with **In-Sik Kang**, the director of the Climate Environment Systems Research Center at Seoul National University, on developing such a climate prediction system. As a first step in this collaboration, the Korea Meteorology Administration is funding the "Joint U.S.-Korea Research Project in support of APCC for Climate Prediction and its Application to Society." Principal investigator for the project is Bin Wang; co-investigators are the Director of the International Center for Climate and Society **Lorenz Magaard**, the President of the Institute of Global Environment and Society **Jagadish Shukla**, and In-Sik Kang. The project includes scientists from the Climate Environment System Research Center and from the following U.S. institutions: George Mason University, Center for Ocean-Land-Atmosphere Studies, NOAA Geophysical Fluid Dynamic Lab, NASA Goddard Space Flight Center, National Center for Environmental Prediction, and Florida State University.

Top: (*from left*) IPRC Director Julian McCreary, Professor Bin Wang, Director of the Climate Prediction Division at KMA Chung-Kyu Park, UH President David McClain, Director General of the KMA Climate Bureau Kwang-Joon Park, Professor James Marsh, ICCS Director Lorenz Magaard, Dean of CBA Vance Roley, and Dean of SOEST Klaus Keil. **Middle:** (*from left*) Chung-Kyu Park, Kwang-Joon Park, and Bin Wang. **Bottom:** (*from left*) Bo Young Yim and Zuojun Yu.

Bin Wang is also principal investigator of another joint Korean-IPRC research project, "Analysis of climate change in Korea and the East Asian area and study of the atmospheric and ocean effects." The project is funded by the Korea Institute of Environmental Science and Technology. **Hyung-Jin Kim**, a new postdoctoral fellow at IPRC (see p. 21) is working on the regional modeling component. As part of this project, **Bo Young Yim**, a graduate student of Professor Yign Noh at Yonsei University, visited the IPRC in February 2005. During her visit, she worked with IPRC Director **Julian McCreary** and Associate Researcher **Zuojun Yu** on implementing the "virtual runoff" scheme into an ocean general circulation model used at Yonsei University.

IPRC Scientists Active in the Climate Research Community

Kevin Hamilton, co-leader of the IPRC Impacts of Global Environmental Change Team and chair of the UH Department of Meteorology, has been appointed to the External Advisory Committee for The Institute for Multidisciplinary Earth Studies (TIMES) of the National Center for Atmospheric Research.

Bin Wang, co-leader of the IPRC Asian-Australian Monsoon Team, has become co-chair of the CLIVAR Asian-

Australian Monsoon Panel. The panel coordinates CLIVAR's research program for the Asian-Australian monsoon region. Investigations deal with climate variations and climate change for the entire monsoon system on time scales ranging from within seasons through decades. Bin Wang has also been appointed to the editorial board of the *Journal of the Atmospheric Sciences*. He will be responsible primarily for papers on tropical meteorology.

Tommy Jensen, an associate researcher with the IPRC Indo-Pacific Ocean Climate Team, continues as an editor for *Journal of Climate*. He is currently editing a special issue on "The Indian Ocean Climate System," which has many contributions by speakers at the Indian Ocean Modeling Workshop (p. 13). He was also serving this spring as a member of the National Science Foundation Review Panel for Physical Oceanography.

IPRC Welcomes…

Hyung-Jin Kim

Hyung-Jin Kim joined the IPRC as a postdoctoral fellow in April 2005. He received his Ph.D. in 2003 from Yonsei University in Korea, with a dissertation that deals with the effects of radiation on climate and the role of land-surface processes in an atmospheric general circulation model. Upon receiving his doctorate, he became a special researcher at the Institute of Natural Sciences, Kangnung National University, Kangnung, Korea, where he used Korea's Weather and Research Forecasting modeling system to study the East Asian monsoon.

Kim will work with Bin Wang, co-team leader of the Asian-Australian Monsoon System Team, to develop and implement a dynamical downscaled version of the Weather and Research Forecasting system at the IPRC. The work is part of a four-year research project funded by the Korea Institute of Environmental Science & Technology.

The goal of this project is to assess the impacts of changing land surface on Korea and East Asia with the regional Weather and Research Forecasting model. Kim will first implement an advanced land surface scheme into the model, then couple the model to a state-of-the-art ocean mixed-layer model developed at Yonsei University, and finally, he will couple the regional model to the Seoul National University coupled general circulation model. The model should then be ready for analyzing climate and climate change over the East Asia monsoon region.

IPRC Bids *Sayonara*…

IPRC's liaison officer with Japan **Saichiro Yoshimura** has returned to Japan where he will continue working on behalf of the IPRC.

Haiming Xu, who worked as a postdoctoral fellow with Shang-Ping Xie and Yuqing Wang, has taken a faculty position at the Department of Atmospheric Sciences, Nanjing University of Information Science and Technology (NUIST). At the IPRC, he used the IPRC regional atmospheric model to study the effects of the Andes on eastern Pacific climate and the effects of Central American mountains on the eastern Pacific winter ITCZ and on moisture transport. He also analyzed satellite observations to describe the within-season variations of the Southeast Pacific stratus clouds. At NUIST, he will continue to use the IPRC regional atmospheric model and satellite observations to study air-sea-land interactions and climate change in East Asia and the western Pacific.

Shinya Yarimizu, computer system administrator at the IPRC for the past 3 years, has moved across town to work with Pipelinefx, a computer software development company dedicated to providing workflow production tools. One of the company's tools is called qube! Remote ControlTM, software that manages thousands of simultaneous 3D graphics programming tasks on large clusters of computer servers called renderfarms. This type of software development is not new to Yarimizu, who participated in the group's development of the groundbreaking *Final Fantasy: The Spirits Within*, the first fully animated 3D feature film.

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International Pacific Research Center
School of Ocean and Earth Science and Technology
University of Hawai'i at Mānoa
1680 East-West Road
Honolulu, Hawai'i 96822

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