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– A center for the study of climate in Asia and the Pacific
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Research

Workshops

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

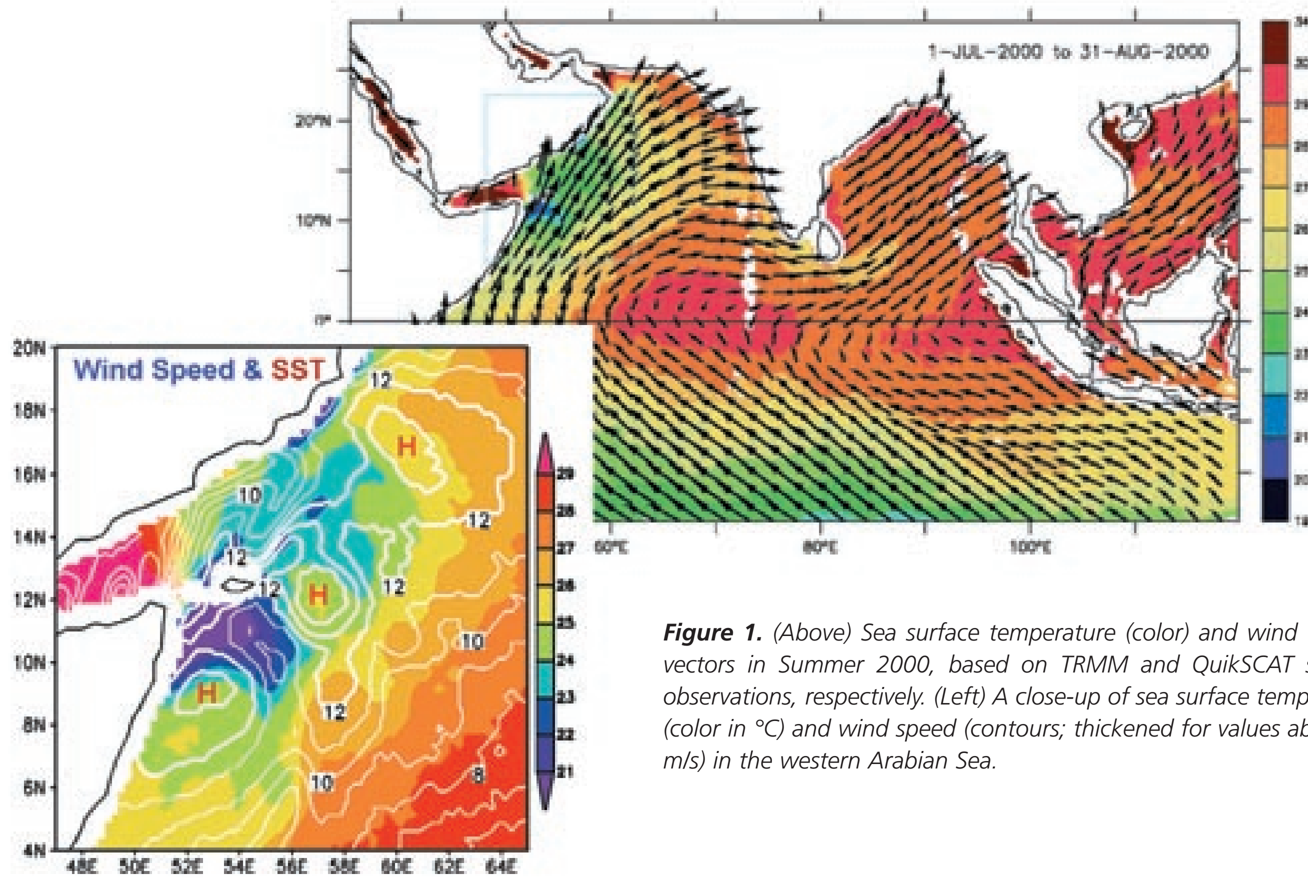

Figure 1. *(Above) Sea surface temperature (color) and wind velocity vectors in Summer 2000, based on TRMM and QuikSCAT satellite observations, respectively. (Left) A close-up of sea surface temperature (color in °C) and wind speed (contours; thickened for values above 12 m/s) in the western Arabian Sea.*

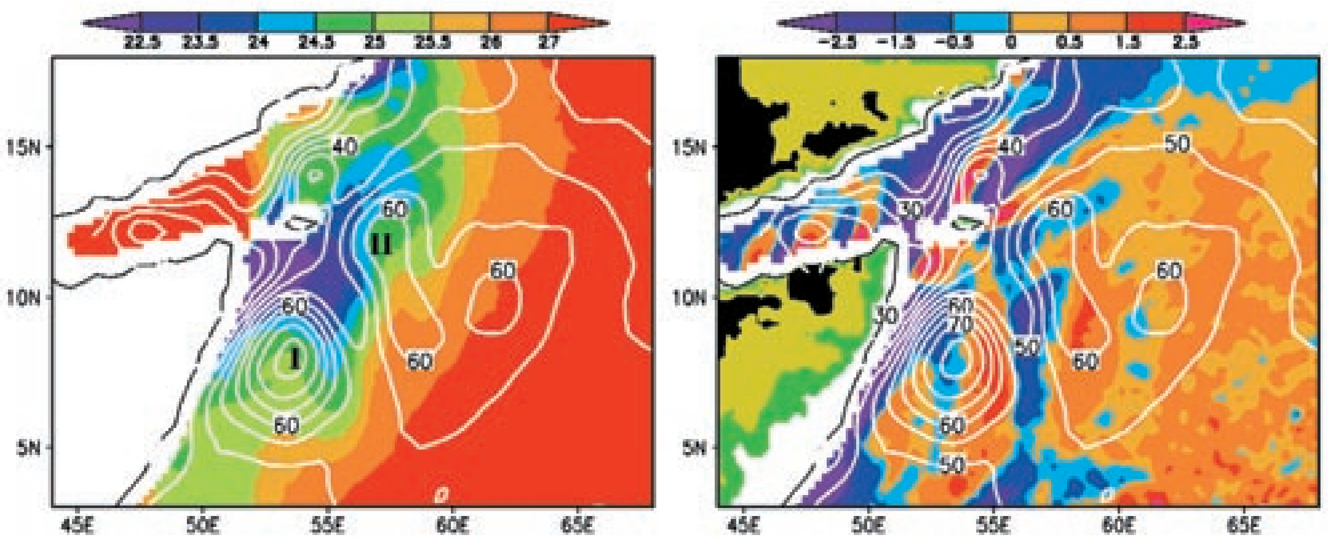

Figure 2. *July climatology—sea surface height (contours in cm): - left - sea surface temperature (color); - right - Ekman pumping velocity (color in 10^{-5} m/s) and land topography (green > 250 m, grey > 500 m, and black > 1000 m). SSH based on satellite and in situ observations. SST and Ekman pumping based on TRMM and QuikSCAT observations, respectively.*

Ocean Upwelling Slows Wind Jet off Africa's Coast

Each April residents of Socotra Island in the Arabian Sea are busy fetching food and other supplies from the mainland to prepare for the southwest monsoon that will prevent them from navigating safely for the whole summer. Off the coast of Somalia, near-gale winds start blowing steadily in the second half of May, often at speeds above 15 m/s. This wind jet, the Findlater Jet, is part of the planetary-scale South Asian summer monsoon system. Steered by the coastal mountains of Africa, the Findlater Jet has been seen as a broad and smooth jet, but new satellite observations reveal it is strongly modulated by sea surface features a few to several hundred kilometers in size (Figure 1). These new results are reported in recent articles by **Shang-Ping Xie** (International Pacific Research Center) and his collaborators, **Gabriel Vecchi** (Princeton University), and **Albert Fischer** (Université Pierre et Marie Curie), who used observations by NASA's QuikSCAT, the joint US–Japan Tropical Rain Measuring Mission (TRMM), and the joint US–France TOPEX/Poseidon satellites.

The southwest monsoon wind jet drives near-surface offshore Ekman transport, forcing cold and nutrient-rich water to rise from depth off the coast of Somalia and Arabia. This upwelling fertilizes the western Arabian Sea just off the barren desert, making it one of the most productive oceans in the world. The highly variable coastal upwelling includes cold filaments or patches formed by nearly stationary ocean eddies (Figure 2).

In response to the monsoon and its general downward Ekman pumping over a large portion of the Arabian Sea, the Somali Current becomes an intense western boundary current. Figure 2 (left panel) shows the averaged mid-summer sea surface height based on satellite observations, superimposed on sea surface temperature (SST). After the Somali Current leaves the coast south of Socotra Island around 9–10°N, it breaks into several nearly stationary anticyclonic eddies. The eddy off the Somali coast is known as the Great Whirl (I). Northeast, centered at 57°E, 9°N, the sea surface height map has another eddy-like structure (II), visible on a 10-year averaged field. A third anticyclonic eddy appears yet further to the east. The eddies shape the Somali upwelling into two nearly stationary cold filaments or wedges. Near the coast, the intense upwelling keeps the water below 20°C. The Great Whirl draws this cold coastal water offshore, first eastward and then southward. Eddy II generates a secondary cold wedge on its eastern flank.

These cold wedges are associated with marked changes in the surface wind, disrupting the Findlater Jet in its path: Wind speeds are less than 10 m/s over the cold filament south of Socotra but increase to 15 m/s over the warm water east of the island (Figure 1 inset). This surprising covariation between SST and wind is another example of the recent discovery by Xie and his colleagues at IPRC and elsewhere, that SSTs and winds correlate positively in regions of cold-warm ocean fronts. This ubiquitous feature of air-sea interaction near major ocean currents is probably due to SST modulation of atmospheric static stability and vertical wind shear: When wind blows over cold ocean surfaces, the atmosphere becomes stably stratified, preventing the mixing with faster winds from aloft and slowing down the surface wind. Indeed, a research cruise in the western Arabian Sea noted such increased atmospheric stability and suppressed surface turbulent heat flux over a cold filament.

The SST-induced mesoscale features in the wind field create strong Ekman pumping (Figure 2, right panel). A wind curl pattern favoring downwelling tends to be on the windward side, while an upwelling favorable curl pattern, on the leeward side of the mainly north-south oriented cold filaments. Ekman pumping velocity associated with these wind patterns is 1 m/day, large enough to modify the thermocline topography substantially in a month, the lifetime of these ocean eddies. (The thermocline perturbation associated with the Great Whirl is about 60 m.)

Since the intense Somali current and the Great Whirl are known to result from the basin-scale wind structure, attention has focused on ocean processes in understanding the evolution of the eddy features. The present study shows, however, that the eddies affect the regional wind, and this air-sea coupling may contribute to their evolution. Very likely, this wind pattern has also a significant impact on the local dynamics and marine ecosystem.

Xie, S.-P., 2004: Satellite observations of cool ocean-atmosphere interaction. *Bull. Amer. Meteor. Soc.*, **85**, 195–208.

Vecchi, G.A., S.-P. Xie, and A.S. Fischer, 2004: Ocean-atmosphere covariability in the western Arabian Sea. *J. Climate,* **17**, 1213–1224.

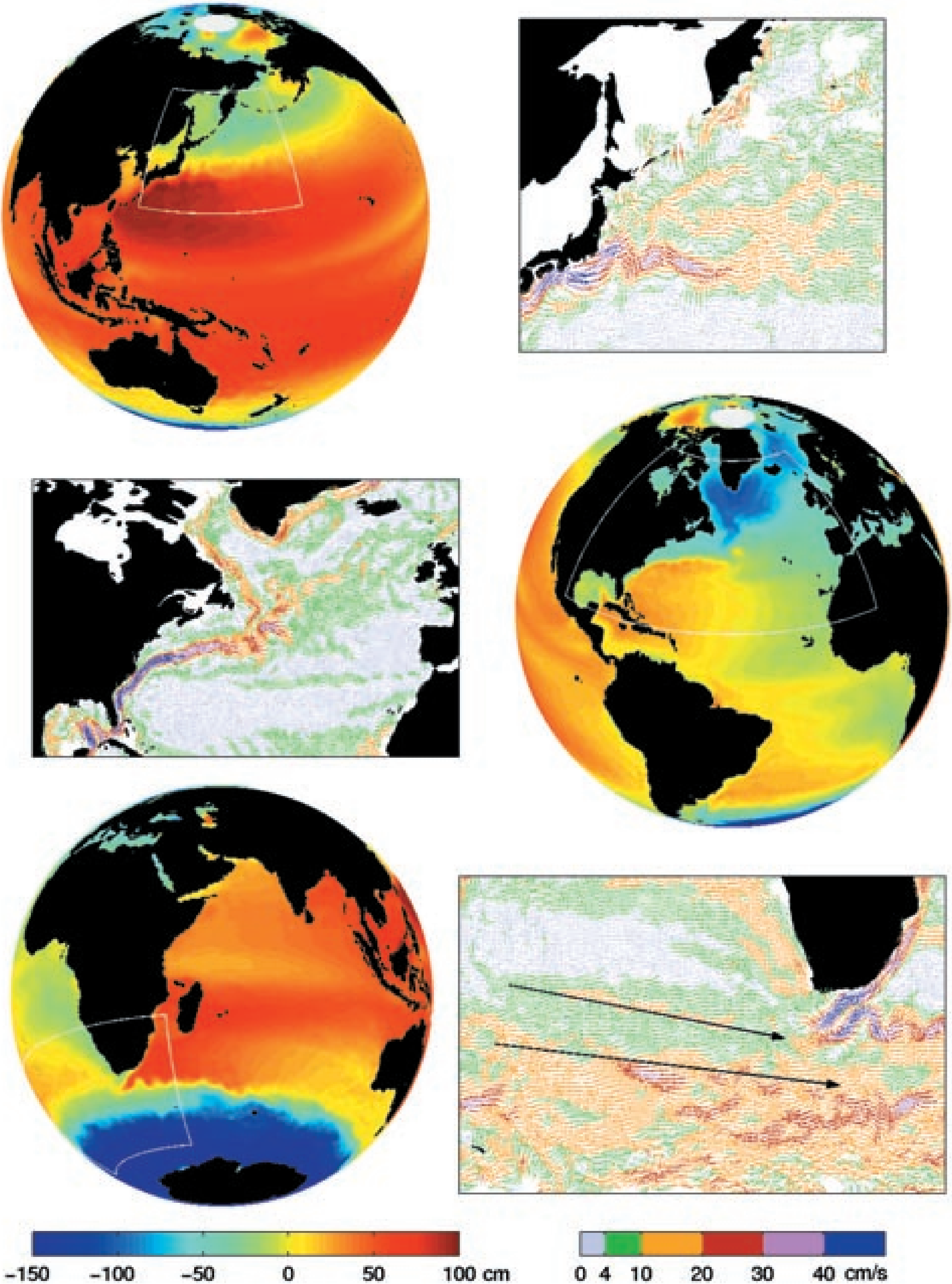

Figure 3. *Maps of hybrid 1992–2002 mean sea level (globes) and mean surface velocity (rectangles) in the three strongest western boundary currents: Kuroshio, Gulf Stream, and Agulhas. Black arrows show branches of the South Atlantic Current. Velocity vectors in color are proportional to their magnitude and shown only where drifter data are available.*

The Global Ocean: A 10-Year Portrait of the Near-Surface Circulation[1]

Understanding the dynamics controlling Earth's climate requires a thorough knowledge of the ocean mean state, particularly of mean sea level. Sea level, together with Ekman currents, largely defines the surface circulation. Horizontal velocities lend stability to Earth's climate by advecting and mixing the properties of the seawater to compensate for the effects of air-sea fluxes that vary in space and time. Although since 1992 advanced satellite altimetry provides continuous and accurate observations of the time-variable sea level anomaly, determining mean sea level remains a challenge: Spatial variations in mean sea level that maintain the dynamic balances of the ocean do not exceed 3 m, while elevation of the equipotential surface (geoid), used as a reference for mean sea level, varies between about –100 to +100 m, owing to the mass distribution within the Earth. Even the most advanced models of the geoid, based on decades of satellite and ground gravity measurements, contain errors reaching nearly 1 m in some areas. The specially designed twin-satellite NASA mission GRACE, launched in 2002, collects data to correct the geoid models. Unfortunately, the GRACE model of the geoid released last year by the Center for Space Research, University of Texas at Austin, resolves only horizontal scales 500 km or larger, imposing the same low resolution on mean sea level estimates referenced to this geoid. Such coarse resolution significantly distorts the pattern of most oceanic fronts and jets, whose accurate representation is necessary for adequate description of mean ocean circulation.

Nikolai Maximenko (International Pacific Research Center) and **Peter Niiler** (Scripps Institution of Oceanography) have managed to increase the spatial resolution of the GRACE-based mean sea level by using information from surface drifters, satellite altimeters, and wind products to estimate the mean sea level tilt. Estimates are made using the momentum equation, which includes terms representing acceleration, the Coriolis force, pressure gradient, and the vertical divergence of the Ekman stress. Values for the first and second terms are computed from trajectories of the Surface Velocity Program drifters that have large drogues attached at 15-m depth. Interannual bias in the pressure gradient was corrected using Aviso/Enact Merged Sea Level Anomaly maps derived from satellite altimetry. Parameterization of Ekman stress divergence to the NCAR/NCEP reanalysis winds was determined by fitting the mean pressure gradient, smoothed to 9° in the zonal and 3° in the meridional direction, to the GRACE-based mean sea level released recently by the NASA Jet Propulsion Laboratory.

The best parameterization reveals remarkable seasonal differences in the relationship between Ekman velocity and local wind and, in summer, it corresponds well to the parameterization suggested by Ralph and Niiler in 1999. In winter, the angle between Ekman velocity and wind vectors as well as the ratio of their magnitudes decreases markedly. Although this tendency agrees with the expected effect of known greater mixing due to winter-time convection, traditional models of the mixed layer, such as the KPP model, are unable to reproduce the observed Ekman velocity at 15-m depth. Maximenko and Niiler are now using NASA QuikSCAT satellite data to validate their results with more direct measurements of the wind stress.

When the values of mean sea level tilt obtained with the momentum equation are combined with the NASA-JPL large-scale sea level data within a single cost function to form a "hybrid" mean sea level data set, a precise description of mesoscale structures of the global upper ocean emerges. Several structures are amazingly complex even after averaging over ten years of observations. The fine mesoscale resolution maps of global mean sea level and mean surface velocities show all known currents and reveal some new features. For example, they show that the South Atlantic Current, thought by Stramma and Peterson (1990) to close the subtropical gyre, actually consists of two separate eastward jets. The first, the South Atlantic Current proper, is a continuation of the Brazil Current, shifting gradually southward and eventually merging with the Antarctic Circumpolar Current around 20ºE. The second, newly discovered jet is weaker. Appearing around 35°N, 40°W, it flows parallel to the South Atlantic Current and merges with the reflected Agulhas Current south of Africa. Possibly this jet, analogous to the Azores Current in the North Atlantic, is induced by a local sink that may be part of the Agulhas eddy-formation or it may result from an interaction between the Agulhas Current with the Southern Ocean.

[1] This work supplied the data for the Natural World Plate #9, *National Geographic Atlas of the World*, 8th Edition, in press.

Tropical Rainfall: Within-Season Variations

In the tropical belt of the Asian Pacific region, there are rainy spells, between two weeks to a couple of months in duration, that are associated with the tropical intraseasonal oscillations (ISO). The major disturbance of this kind is the Madden-Julian Oscillation (MJO), which typically has a period of 40–50 days and is linked to the deep convection over the Indian Ocean and western Pacific warm pool and accompanied by rain. The MJO is most active from November to May during which time such disturbances move eastward around the globe, weakening over the eastern Pacific, growing somewhat stronger over South America, and weakening again over the Atlantic and Africa, until they return to the Indian Ocean (Madden-Julian 1971, 1972). Included in this category of tropical intraseasonal oscillations are also northward and westward moving disturbances that prevail from May to October and are called the monsoon oscillations.

These disturbances affect human activities and particularly agriculture in the heavily populated Asian continent, and improvements in their forecast would be valuable. Most global general circulation models still have great difficulty in simulating the properties of these tropical oscillations, which originate in complex interactions among many physical processes taking place on different scales of time and space. Modelling these oscillations entails a series of interacting parameterizations of such processes as moisture transport, evaporation, cloud dynamics, convection, and radiation transfer. Uncertainties in the mathematical descriptions of any of these parameterized interactions jeopardize a model's ability to simulate the disturbances. Progress in predicting the wet and dry spells requires a more complete understanding of the mechanisms underlying these complex interactions.

Many studies have already been devoted to developing a theoretical understanding of the MJO. These studies have invoked a broad range of processes and feedback mechanisms to account for the growth and maintenance of the disturbance. The major mechanisms that have been proposed can be summarized as follows: (i) cooperative interaction between convection and atmospheric waves; (ii) instability driven by wind-evaporation feedback or wind-induced surface heat exchange, in which spatial variation in surface heat fluxes associated with variations in surface wind speeds controls the structure of convection; (iii) instability arising from friction-induced moisture-convergence feedback, in which boundary-layer friction organizes convection and couples the equatorial Kelvin and Rossby waves moving eastward; and (iv) cloud-radiation feedback, which results from interactions among convection, radiative heating anomalies, and the surface flux of moisture and sensible heat. The intraseasonal oscillations in the monsoon region are furthermore greatly affected by seasonal variations in the atmospheric circulation and sea surface temperature.

In spite of all the work in this field, many aspects of these oscillations are not well understood and present the scientific community with a challenge. **Bin Wang**, co-leader of the Asian-Australian Monsoon System research team at the IPRC, has developed a model that simulates the major characteristics of both the MJO and the summer monsoon oscillations and provides a unifying framework for these tropical oscillations. Wang considers his model to be relatively simple. It is a time-dependent, primitive-equation model on an equatorial beta-plane that has two free-troposphere levels and a well-mixed planetary boundary layer. Figure 4 highlights the physical processes in his model. At the center of the model are the nonlinear interactions among convective-condensational heating, low-frequency equatorial (Rossby and Kelvin) waves, boundary-layer moist dynamics, and wind-induced heat exchange at the surface. These nonlinear interactions he calls, for short, "convective interaction with dynamics," following Neelin and Yu (1994). Variations in net radiative heating, parameterized as a longwave radiative cooling, are included as a feedback mechanism, and the model allows for the impacts of sea surface temperature and the three-dimensional background atmospheric circulations. Thus, the physics of the model integrate, to varying degrees, all of the mechanisms listed above.

Despite its simplicity, the model is able to reproduce atmospheric disturbances that have features closely resembling those of the observed MJO and monsoon oscillation. The simulated atmospheric disturbances have the following MJO characteristics (Figure 5): an east-west circulation that spans the globe and is coupled to a large complex of convective cells;

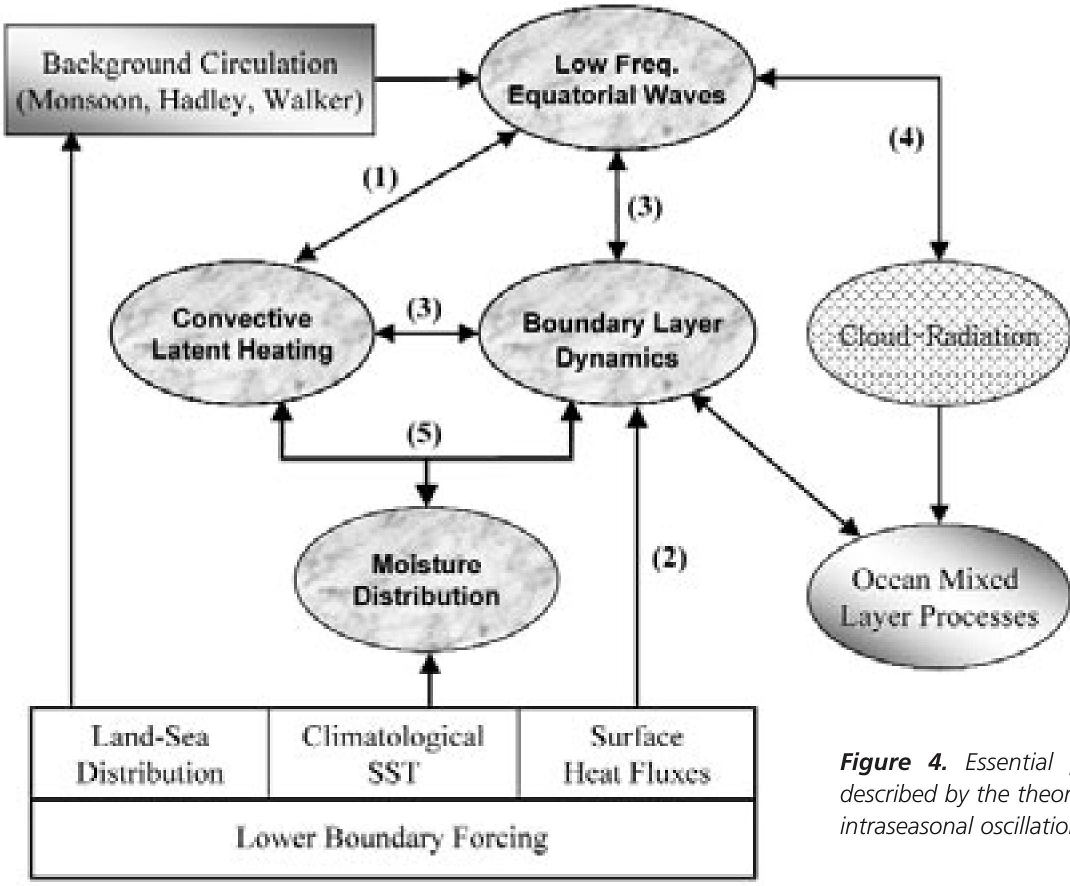

Figure 4. *Essential physical processes described by the theoretical model of the intraseasonal oscillation.*

a baroclinic structure, with winds converging in the boundary layer ahead of the main precipitation; a horizontal circulation consisting of both equatorial Kelvin and Rossby wave components and a slow eastward (about 5 m/s) movement that gives rise to a subseasonal timescale (30–60 days). Given the boundary forcing for the monsoon season, the simulated intraseasonal oscillation also shows appropriate seasonality, with prominent northward propagating and off-equatorial westward propagating disturbances during the summer monsoon. Simulation with Wang's model of this aspect of the tropical oscillation will be described in a later issue of the newsletter. The focus here is on the eastward moving Madden-Julian Oscillation.

The fact that the simulated intraseasonal oscillation has such realistic properties suggests that the essential physical processes represented by the crude parameterizations within the model are also reasonably realistic. Analyses of the simulations can therefore provide insight into the fundamental dynamics of the MJO. Figure 5 shows a schematic of the atmospheric flows in the simulation, once the wet phase of the MJO is established. When SST exceeds a critical value (about 28°C) in the Indian Ocean or in the warm pool, warm moist air rises above 500 mb, and Kelvin waves (blue circulation) are excited. Moving eastward along the equator, these waves leave a low-pressure trough east of the main convection. In this trough, boundary-layer frictional convergence accumulates and stimulates convection east of the major convection region. The convective heating released in the major precipitation region also generates Rossby waves. The most trapped Rossby wave (red circulation) becomes coupled to the Kelvin wave in the following way: Air rises in the two off-equatorial lows of the Rossby wave (R-Low) as well as in the equatorial trough in the region of deep convection that generated the Kelvin wave in the first place. The convergence of air in the region of major convection couples the two waves, strengthening the disturbance. Because the eastward movement of the Kelvin wave is slowed by the westward tendency of the Rossby wave due to meridional variation in the Coriolis force, the coupled Rossby-Kelvin wave takes on the approximate eastward speed of the MJO.

Perhaps the most important finding from analyses of the simulations is the role played by friction-induced convergence in the boundary layer, which links surface heat exchange, the motion of free tropospheric waves, and heating due to con-

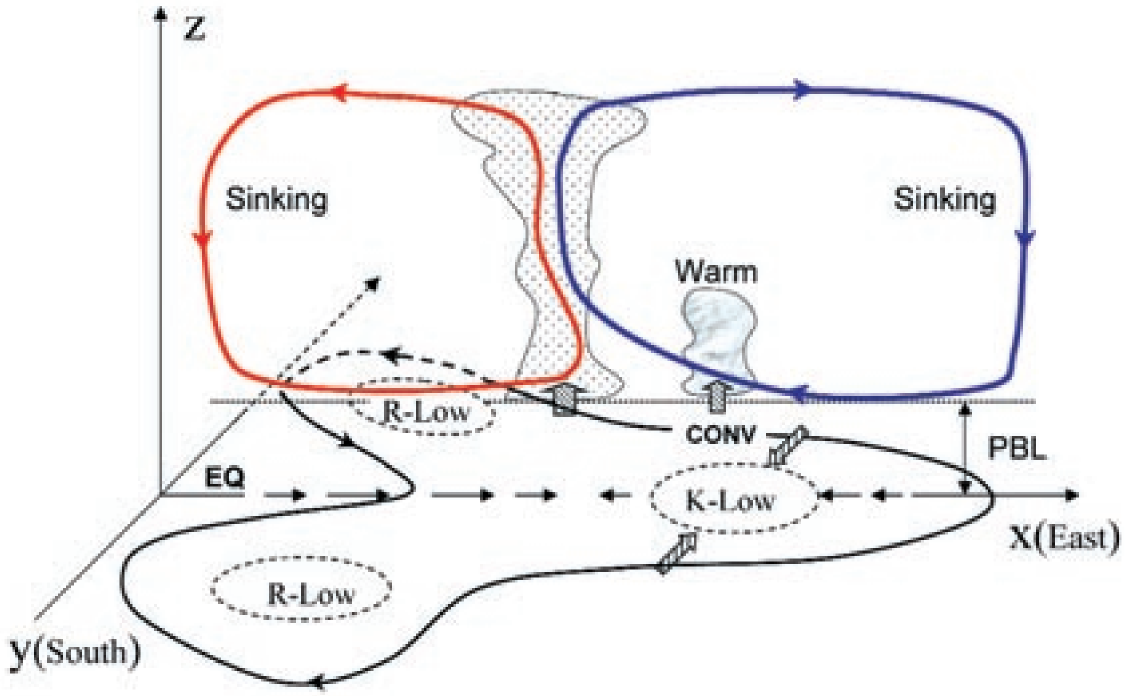

Figure 5. *Schematic structure of frictional moisture feedback thought to occur in the Madden-Julian Oscillation. In the horizontal plane, 'K-low' and 'R-low' represent the low-pressure anomalies associated with the moist equatorial Kelvin and Rossby waves, respectively. Arrows indicate wind directions. In the equatorial vertical plane, the free tropospheric wave circulation is shown. The wave-induced convergence is in phase with the major convection, whereas the frictional moisture convergence in the K-low region precedes the major convection owing mainly to meridional wind convergence.*

densation. What happens is that the returning flow of the eastward moving Kelvin wave warms the region east of the major convection and precipitation region, creating a low-pressure (K-Low) region in the surface layer that results in the convergence of moist air. The moist converging air rises, but condenses before reaching 500 mb. The heat released by condensation now provides energy that is available not only to support the growth of the perturbation, but also to maintain the original perturbation, including the area of deep convection, drawing everything eastward. The eddy available potential energy originating in this convergence is also the reason why the disturbance grows slowly and does not result in a catastrophic conditional instability of the second kind (CISK). Being ahead of the main convective region, the energy for growth of the instability, supplied by evaporative heat flux and the condensational heating associated with the friction-induced moisture convergence, is not converted to kinetic energy for a CISK. Moreover, a portion of the energy is carried away from the convective regions by fast moving, dry Kelvin and Rossby waves, which spread perturbed circulation around the globe, accounting for the planetary circulation scale of the MJO.

The MJO has many time and space scales, and the major drawbacks of the present theoretical model are that its simple representation of diabatic heating cannot deal with the interactions among the scales and that it presumes direct coupling between the MJO disturbance and convection. The current model results suggest that to simulate the MJO realistically, the cumulus parameterization scheme has to let the large-scale low-frequency waves 'feel' the effects of the parameterized convective heating, and it has to have some effect on the parameterized heating either directly (through grid-scale precipitation) or indirectly (through a complete description of the multi-scale interactions). In complex general circulation models, one does not know the correct partitioning between convective and stable precipitation. If all convective heating were consumed by high-frequency disturbances, and if there were no appropriate upward energy transport, how could the model maintain the MJO? Learning how interactions among the various space and time scales and how the up-scale (from meso scale to planetary scale) energy transfer sustains the MJO presents a major challenge, but should shed light on why many current models fail to simulate the MJO.

The Future of Shelf Seas

The shallow seas overlying the continental shelves around coastlines are of great economic value. From the Mascarene Plateau in the Indian Ocean to the continental shelf between Japan and the Asian continent, to the Grand Banks and the North Sea, these shallow seas are supplying huge amounts of seafood. Their ecosystems, though, are in jeopardy. Not only are the continental margins the world's biggest pollution dumps, but also climate change and global warming may change the temperatures, winds, water levels, currents, and waves around which the ecosystems have evolved.

Jürgen Sündermann, former director of the Centre of Marine and Climate Research, University of Hamburg, and a visitor during February 2004 to the International Pacific Research Center and the International Center for Climate and Society (*IPRC Climate*, Vol. 3, No. 1), is now spearheading North Sea under Global Warming (NORGLOW), a very ambitious international project that is developing a model to see how climate change and human impact may affect the physical, chemical and biological states of the North Sea over the next decades and century. Findings from this model will help to also answer questions about the future of other shallow seas, and the model, itself, should be adaptable to other shelf-sea regions.

Sündermann spoke at the IPRC on the conditions in the North Sea and changes over the last 40 to 100 years, conditions that the model must be able to reconstruct before any confidence can be placed in its predictions. In the North Sea, the wind direction and the ocean-bottom topography determine the circulation. Under the prevailing westerlies, the currents in the North Sea flow predominantly anti-clockwise around the basin. This direction is important for the fishes, which spawn near the entrance to the Atlantic and whose larvae drift with the current southeastward to the main nursery grounds, the very shallow Wadden See, also a way station for migrating birds.

Despite large interannual fluctuations in the atmosphere and ocean, some trends are noticeable. The average wind over the North Sea has become stronger in the last forty years (by about 0.6 m/s) and windy periods have become longer. Over the last 100 years, sea surface temperature has risen by ½°C, the tidal high in the North Sea has risen 25 to 30 cm, and storm surges have become more frequent and more dangerous owing to the overall sea level rise.

Marine life has also seen changes. The over-fertilization, resulting in nutrient pollution by nitrogen and phosphates, has led to changes in phytoplankton species and to algae blooms, with severe consequences for the ecosystem. Zooplankton seems to becoming earlier during the year, macro benthos species are becoming more varied, and horse mackerel, which were hardly seen before 1985, are now abundant. Marine biologists see a phase shift occurring during the 1990s.

The North Atlantic Oscillation (NAO), a large-scale atmospheric circulation in the Atlantic region, seems to be implicated in these changes. The state of the NAO is often measured by the NAO index, which is the surface pressure difference between the Azores and Iceland. When this index is large, winters in northern Europe tend to be warm, windy, and rainy; when small, cold and dry. The superposition of the NAO index on plots of the number of macro benthos species and horse mackerel over recent years reveals a close overlap between changes in the atmospheric pressure pattern and marine life.

Sündermann's group is developing a series of complex models representing the relevant physical, chemical, and biological processes and is conducting field experiments to validate the models. The process models will be combined into an aggregated model, which is to be coupled to an air-sea model. Ensembles of the aggregated model will then be run for the period 1900–2000 to see how well the model reconstructs the change described above. Once the aggregated model has been tested on past reconstructions, it will be used for experiments with various climate change scenarios to see what may lie in store for this shelf sea and, perhaps, others.

Jürgen Sündermann (left) with Lorenz Magaard (IPRC) and Wolf Dieter Grossmann (UFZ Center for Environmental Research).

“Partly Cloudy, Chance of Showers”

“Partly cloudy, chance of showers,” chimes the morning weather forecast most days in the Hawaiian Islands. The lovely skies of Hawai‘i, however, illustrate two challenges for climate modeling in the Asia-Pacific region: the very complicated and irregular shape of low clouds, and the rain production in rather shallow cumulus clouds. To work with IPRC researchers on these two scientific issues, **Brian Mapes** (NOAA-CIRES Climate Diagnostic Center) has visited the IPRC several times during the past four years. Below is a brief summary of this work.

Partly Cloudy

Low clouds over tropical oceans exert a powerful cooling influence on the Earth, reflecting sunlight that would otherwise warm the dark ocean surface. How such clouds will respond to global warming is a major unknown in predicting climate change. A simple test of these cloud-radiation processes in climate models is to compare their response to sea surface temperature (SST) anomalies with observations. Such a comparison is clearest when measuring the response of clouds to a strong, well-defined SST signal.

One very well-defined SST signal is found in tropical instability waves (TIWs), the warm and cold meanders on the equatorial front in the eastern Pacific Ocean. The impact of these waves on low-level clouds has been examined at the IPRC by **Shang-Ping Xie** and **Justin Small**, both in satellite data and in simulations with the IPRC Regional Climate Model (IPRC–RegCM), developed by **Yuqing Wang**, **Omer Sen**, and **Bin Wang**. Their work, and related work by IPRC researchers **Haiming Xu** and **Jan Hafner**, shows that for such small-scale SST anomalies, the main changes in clouds are due to SST-induced atmospheric convergence patterns in the boundary layer, which the IPRC–RegCM successfully captures.

Next we may ask, how well does the model perform quantitatively in simulating the radiative impacts of the cloud response to TIWs? To provide observations for evaluating the model’s skill, Mapes has analyzed radiation measurements taken by a Tropical Atmosphere Ocean buoy moored at 95°W on the equator. From June to October 2000, 8 wave-cycles of TIWs caused SST at the buoy to vary between about 19° and 25°C. Figure 6 shows a scatter plot of 2-minute averages of longwave radiation versus the fraction of solar radiation reaching the buoy (relative to a hypothetical clear-sky value) on days of high (red) and low (blue) SST. Naturally, only daytime data, between about 8 am and 4 pm, appear in the plot.

The points on Figure 6 cluster into two quadrants: the upper left—clear sky, with most solar radiation getting through to the surface, but relatively little downwelling longwave radiation since clear air is an inefficient emitter—and the lower right—cloudy, with less sun and more downward longwave radiation. Individual histograms of the longwave and shortwave values at the top and right of Figure 6 show that both radiative fluxes are strongly bimodal, with a mode separation at the same value for both warm (dotted) and cold (solid) phases of the TIWs. The data indicate that on days with warmer SST, clouds are both more frequent and optically thicker (as is evident on the low end of the shortwave histogram).

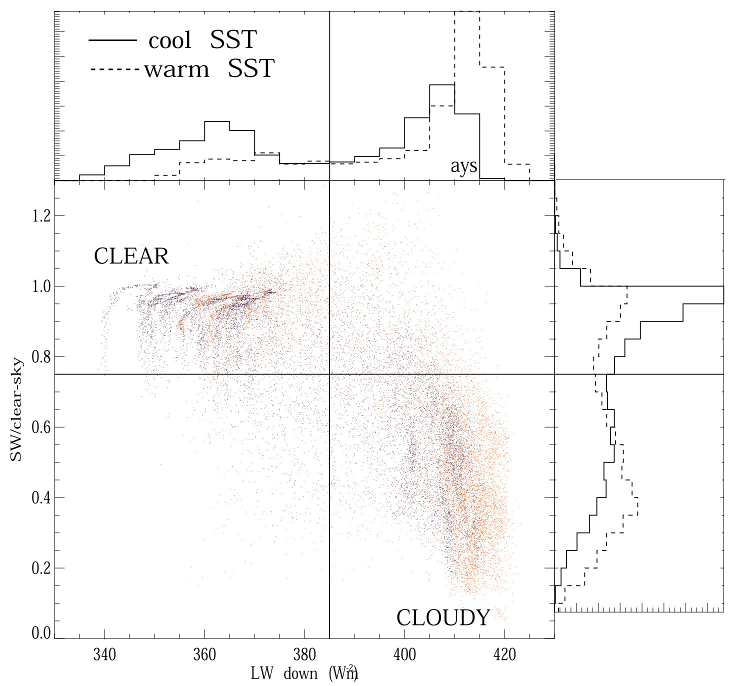

***Figure 6.** Scatter plot of the fraction of clear-sky shortwave and downwelling longwave radiation reaching the buoy, for daytime data during the extreme warm (red) and cold (blue) phases of TIWs. Histograms for each variable during warm (dotted lines) and cold (solid lines) phases are shown at the top and the right. In partly-cloudy skies, the sunlight reaching the buoy can be greater than the clear-sky value, as diffuse light reflecting off the sides of the clouds can add to an unobscured solar beam.*

If we define *cloudy* radiation as *above*, and *clear* radiation as *below* the longwave histogram minimum of 385°W/m², we have a convenient definition of cloudy that is applicable 24 hours a day. Using this definition, the multi-scale nature of cloudiness can be appreciated from diagrams of the time-lagged conditional probability of the occurrence of clouds (Figure 7). The mean cloud fraction is shown as a horizontal line in each panel. The rapid change in the probability of clouds away from time zero for both cloudy (solid) and clear (dotted) conditions means that both cloudy and clear patches have small-scale characteristics. Large-scale structure to cloudiness is also indicated, however, as the conditional probability never relaxes fully to the unconditional cloud fraction even after 12 hours.

With this high-frequency buoy data, the IPRC–RegCM's simulation of cloudiness, along with cloudy and clear sky radiative fluxes, can now be evaluated. A preliminary examination suggests that the model simulates the TIW effects on clouds fairly well. Based on this initial finding, Mapes and his IPRC colleagues are beginning to run simulations aimed at more direct and precise model-buoy comparisons.

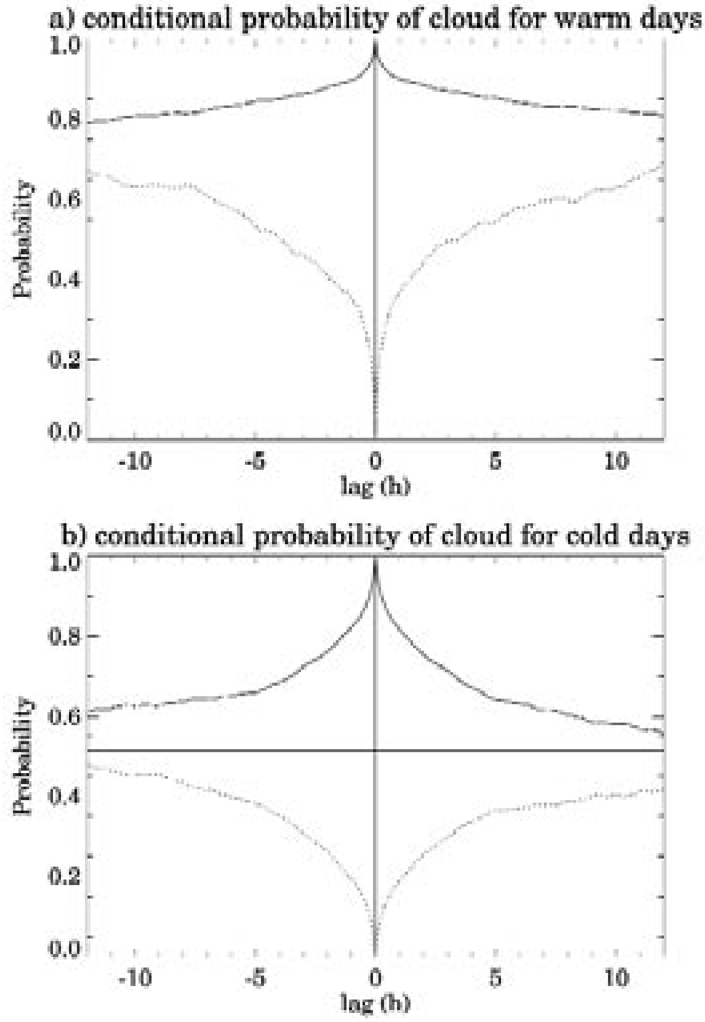

Figure 7. *Conditional probability versus time lag, a depiction of the typical scales of clear (dotted) and cloudy (solid) segments of the time series. To convert time lags to spatial scales, multiply by the typical wind speed of 6–7 m/s, so that 12 hours correspond to ~280 km.*

Chance of Showers

How medium-depth cumulus clouds produce rain is a question that has interested Mapes since he first came to visit the IPRC in 1999 to work with **Bin Wang**, co-leader of the IPRC Asian-Australian Monsoon research team. At the time, their aim was to add a fourth layer to the simple 3-layer atmosphere model described by Fu and Wang in 1999, in order to make room for the medium-depth "cumulus congestus" convection emphasized by Johnson and his colleagues (1999). They soon found that making room for such clouds is easy, but parameterizing their occurrence, or even understanding why they occur in nature, is much harder. These clouds are mysterious: The tropical troposphere has a thermal structure in which the buoyancy of lifted air parcels increases rapidly above the middle troposphere, for reasons discussed in section 3c of Mapes (2001). Why then do cumulus clouds stop rising at about 8–9 km as indicated by Johnson and his colleagues? Possible explanations are the effects of ice particles, including delays in the nucleation of freezing in cumulus towers, and the effects of a weak, large-scale inversion found at the melting level. But these explanations seem incomplete—mixing (entrainment) must also be invoked.

When rising clouds draw in dry air from the environment, they become less buoyant. Most cumulus schemes assume such environmental entrainment, but since no simple entraining plume in a typical vertical sounding can explain cumulus congestus clouds well, Mapes and his IPRC colleagues turned to a model in which clouds draw in existing clouds, growing successively as sketched in Figure 8. In fact, this is a physically satisfying picture to anyone who has watched cumulus cloud fields grow and develop and organize. It opens up, however, a spate of new issues in parameterization: What governs the probability of such cloud "collisions"? Mountainous islands like Hawai'i certainly have an effect! More generally, precipitation is very important in generating new updrafts near previous ones—a local positive feedback process that is absent from most large-scale models. Mapes has formulated these basic ideas into a convection scheme, and some experiments with the scheme should be published within the year.

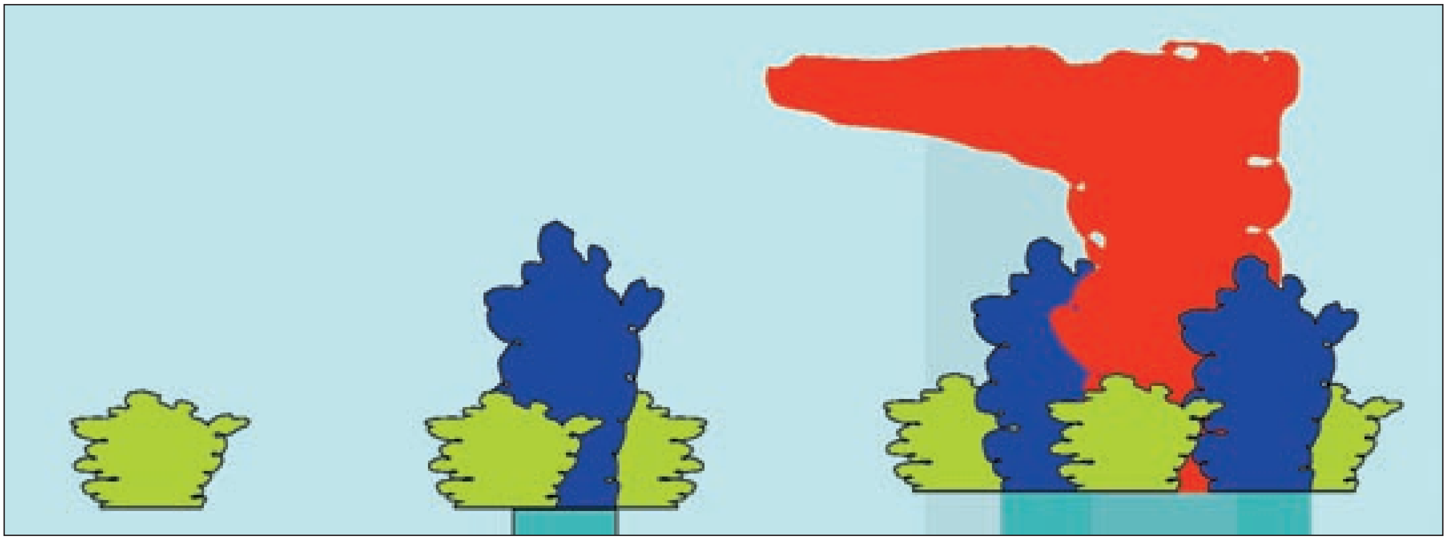

Figure 8. *Schematic of the cloud-collision model of the manner by which cumulus clouds give rise to showery cumulus congestus and cumulonimbus clouds.*

Understanding the formation of low- and medium-high convective clouds, their effects on radiation, and their rain-making will ultimately help us to predict how these beautiful and complex clouds participate in climate variations and climate change.

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Monsoon Meetings at IPRC

During February, the IPRC hosted a series of monsoon-related meetings: The Seventh East Asian Climate Workshop and the Third Regional Climate Modeling Workshop on February 17, 2004, were followed by the International Asian Monsoon Symposium February 18–20. Sponsors of the meetings were the Japanese Frontier Research System for Global Change, the International Pacific Research Center, the Joint Institute of Marine and Atmospheric Research at the University of Hawai'i, and the State University of New York at Albany. The following pages feature highlights from these meetings.

Third Workshop on Regional Climate Modeling

Regional climate models are already showing their usefulness in studying real-world issues. Here are some highlights from the Third Regional Climate Modeling Workshop, held February 17, 2004, and from the regional climate modeling session at the International Monsoon Symposium, February 18.

Consistent with previous findings on general circulation models, a study with the PSU/NCAR mesoscale model MM5 shows that atmospheric aerosol radiative forcing over Southeast Asia is cooling the land surface over India and Southeast Asia up to 1°C; but the simulation also found that the Tibetan Plateau is warming due to reduced cloud cover. In another study, simulation with the new version of the Common Land Model coupled to the MM5 improved reconstruction of the 1998 East Asian summer monsoon by reducing the land-surface cold bias. A project with the high-resolution IPRC Regional Climate Model has found it useful for studying effects of topography on the South China Sea summer monsoon. The mountains along coastal Vietnam deflect the southwesterly monsoon flow, which turns into a narrow low-level jet over the ocean south of Vietnam and enhances coastal upwelling, thereby reducing regional rainfall. This local feedback may have effects on monsoon rainfall reaching as far as the South China Sea.

In northern Europe, changes over the past 40 years in regional storminess, ocean wave conditions, and storm surges are being reconstructed with a regional climate model of high temporal and spatial resolution. The model is also being used to determine the transport and deposition of harmful spills, and to help in designing ships.

A variable-resolution Conformal-Cubic Atmospheric Model, developed by the Australian Commonwealth Scientific & Industrial Research Organisation, has simulated fairly realistically aspects of regional climate in Australia and Southeast Asia. Compared to regional models, the variable-resolution global model has the advantage that lateral boundaries do not need specification, thereby eliminating a source of error.

Regional climate models that are run at resolutions below 10 km must take nonhydrostatic effects into account. This requires conversion of the governing equations. An analysis of five versions of fully compressible nonhydrostatic Eulerian equations established which set was the most accurate. This set is now available for developing new nonhydrostatic models.

Finally, the plans of the IPRC to conduct the Regional Atmospheric Inter-Model Evaluation (RAIME) were discussed. The aim of this project is to improve simulation of the regional cloud and precipitation diurnal cycles. Fourteen state-of-the-art regional climate models, together representing the physical parameterizations in models, will participate. The objectives are to 1) assess and analyze the diurnal cycle simulated in these regional climate models in order to identify common biases and disagreements; 2) improve understanding of the important physical processes that drive the diurnal cycle and to identify the factors necessary for realistic simulation of the diurnal cycle; and 3) guide development of physical parameterizations in climate models that will lead to more realistic simulation of the warm-season hydrological cycle. The proposed research may become a regional (East Asian monsoon region) perspective of the CEOP Inter-monsoon Model Validation Project (CIMVP), an initiative to assess, validate, and improve the ability of climate models to simulate physical processes in monsoon regions around the world.

Yuqing Wang, International Pacific Research Center and Associate Professor of Meteorology, University of Hawai'i

Seventh Workshop on East Asian Climate

The Seventh Workshop on East Asian Climate was hosted by the IPRC February 17, 2004. The one-day East Asian Climate workshop was filled with issue-driven short presentations, while presentations on East Asian climate observations and modeling were given at the International Asian Monsoon Symposium. The workshop focused on research needs in the following seven areas: recent climate changes over East Asia, observations and model simulations, seasonal climate prediction, intraseasonal oscillation, cloud-climate interaction, land-atmosphere interaction, and air-sea interaction. In all seven areas, research has progressed significantly since the last East Asian climate workshop. Particularly, model-observation comparisons, intermodel comparisons, and model sensitivity experiments have identified the weaknesses in existing climate models. Many uncertainties remain, however, and model predictions are still too poor to be useful for rainfall predictions. The workshop discussions pointed to the need for more in-depth diagnostic studies and model-observation comparisons in order to understand more fully the processes governing the East Asian monsoon. The Eighth East Asian Climate Workshop will be held in Taiwan and is tentatively scheduled for Fall 2005.

Wei-Chyung Wang, Professor,
Atmospheric Sciences Research Center,
State University of New York, Albany

International Asian Monsoon Symposium

The International Asian Monsoon Symposium, hosted by the IPRC February 18–20, 2004, did much to raise the profile of East Asian–Western North Pacific monsoon research. At least half of the presentations dealt with East Asian weather and climate variability, ranging from the diurnal cycle and intraseasonal oscillations to interannual and interdecadal

Participants of the International Asian Monsoon Symposium in the Japanese Gardens at the East-West Center.

Organizers of the three monsoon meetings (from left): Bin Wang (International Pacific Research Center, University of Hawai'i), Wei-Chyung Wang (State University of New York at Albany), Jerry Meehl (National Center for Atmospheric Research), Tetsuzo Yasunari (Nagoya University), Yuqing Wang (International Pacific Research Center, University of Hawai'i), and Takehiko Satomura (Kyoto University).

variations and ancient monsoons. Because the East Asian monsoon is an important component of the Asian-Australian monsoon system, this emphasis is a welcome change from the past, nearly exclusive, focus on the Indian monsoon. The East Asian monsoon covers the region roughly 105–160°E, 0–45°N, and climate research in this region is significant for both practical and scientific reasons. Rainfall over the last 50 years is uncorrelated with Indian summer monsoon so that this monsoon cannot be treated as the "tail" of the Indian monsoon. The monsoon of East Asia, moreover, flows over an east-west, land-ocean contrast downstream of the world's tallest mountains and between the largest ocean and continental mass. Finally, over 1.5 billion people live in this monsoon region, and the fast-changing environmental conditions are very likely to affect global climate.

The monsoon-ocean interaction is one of the significant physical processes governing monsoon variability in the Indian Ocean, Asian seas, and western Pacific. Atmosphere-land interaction has also caught the attention of climate researchers, with GAME providing a rich source of data and model experiments pinpointing the effects of soil moisture, albedo, and topography on the monsoon. The papers presenting the experiments on raising the Tibetan Plateau point out the role of this geographical feature in global climate. The intraseasonal oscillation, especially the monsoon oscillation, was another focus. According to the general consensus, air-sea coupling improves simulation of these oscillations and will be a research direction over the next 5–10 years. Monsoon predictability and prediction is a rapidly developing area, and multi-model ensemble forecasting has advanced. The East Asian summer monsoon, however, varies much more than the Indian monsoon, and the current state-of-the-art general circulation models do a much poorer job in simulating the former than the latter. The AMIP-type strategy of a two-tiered approach for climate prediction is simply inadequate for predicting monsoon rainfall. Regarding numerical modeling, high-resolution climate modeling (20 km for a two-year integration) by the Japan Meteorology Agency shows great promise for resolving the Meiyu/Baiu front, which has been a long-standing roadblock in climate modeling. This subtropical front is critical for the water supply of East Asia and its 1.5 billion people. Adaptive-grid global modeling is another appealing intermediate strategy for producing regional climate details.

In closing, the symposium drew the attention of the monsoon research community to the whole Asian-Australian monsoon system, and particularly to the neglected East Asian monsoon. This broader focus, I'm sure, will continue in the World Meteorology Organization Third International Monsoon Studies conference to be held in November 2004.

Bin Wang, Team Leader, International Pacific Research Center, and Professor of Meteorology, University of Hawai'i

Predicting Monsoon Rainfall?

Accurate prediction of summer rainfall in the region of the Asian-Australian monsoon system has been a long-standing aim, and this prediction problem is the research focus of many of the scientists who participated in the International Asian Monsoon Symposium, hosted by the IPRC February 18–20, 2004. In-Sik Kang (Seoul National University) reported at the symposium that, in spite of much effort, the general atmospheric circulation models used for prediction still have systematic biases. Bias corrections improve predictions, but leave them only somewhat better than predictions based on the long-term average seasonal rainfall.

The picture is not all glum, though. Several studies presented together paint a fascinating, coherent picture. For some time now, it has been known that conditions in the Pacific Ocean influence the monsoon and that summers following an El Niño may be dry in India. Only about half of the El Niño events in recent history, however, have been followed by such droughts. For example, the summer of the 1997 El Niño, dubbed the El Niño of the century, had slightly above normal monsoon rainfall. The moderate 2002 El Niño, on the other hand, was followed by a drought in which July rainfall was less than half the usual amount.

Recently, the Indian Ocean has been detected as a player in the yearly monsoon variations, and the number of studies that include or focus on Indian Ocean conditions has risen sharply. At the symposium, Ben Kirtman (George Mason University) presented research showing that when two-way interaction between atmosphere and ocean is allowed in models, the following interaction occurs among Pacific Ocean sea surface temperature (SST), Indian Ocean SST, and the strength of the monsoon and precipitation: Lower than average SSTs in the western Pacific cool the Indian Ocean the following summer. An overall cooler Indian Ocean produces less convective heating over the equatorial Indian Ocean, which then results in a weak monsoon and less rainfall over India. A weak monsoon, though, allows both the western Pacific and the Indian Ocean to warm, resulting in a stronger monsoon the next summer.

This sequence of events is akin to the flip-flop of the tropospheric biennial oscillation, which is a tendency for weak monsoons to follow strong monsoons, and strong monsoons to follow weak monsoons. But, Jerry Meehl (National Center for Atmospheric Research) pointed out, only about half of the monsoons follow this pattern. What other factors contribute to these monsoon variations? Conditions in the Indian Ocean and the Pacific, he noted, can vary independently and alter the flip-flop pattern. For example, the Indian Ocean occasionally shows a sharp SST gradient between western and eastern regions, an event called the Indian Ocean Dipole that appears to vary independently of the El Niño–Southern Oscillation. Information about the dipole alone, however, has also been found insufficient for useful monsoon rainfall prediction.

Sulochana Gadgil (Indian Institute of Science) has been pursuing a further aspect of varying Indian Ocean conditions, the atmospheric conditions during monsoons. Composites of El Niño and of La Niña show that the former events are associated with anomalous easterly, and the latter with anomalous westerly winds over the equatorial Indian Ocean. Gadgil noted that during the 1997 El Niño, the equatorial Indian Ocean winds were westerly, counteracting effects of the drought-producing El Niño, whereas in 2002, they were easterly, strengthening the El Niño effects. She has developed a composite index of SST conditions in the Pacific (NINO 3.4 Index) and atmospheric conditions in the Indian Ocean (east-west winds between 2.5°N and 2.5°S) and found, in reconstructions studies, the index to be an excellent predictor of extreme monsoons, those that are one standard deviation wetter or dryer than normal. This index should now be included in longer-range rainfall forecast models. If successful, a major step forward will have been taken in predicting these extreme conditions, at least for rainfall over India.

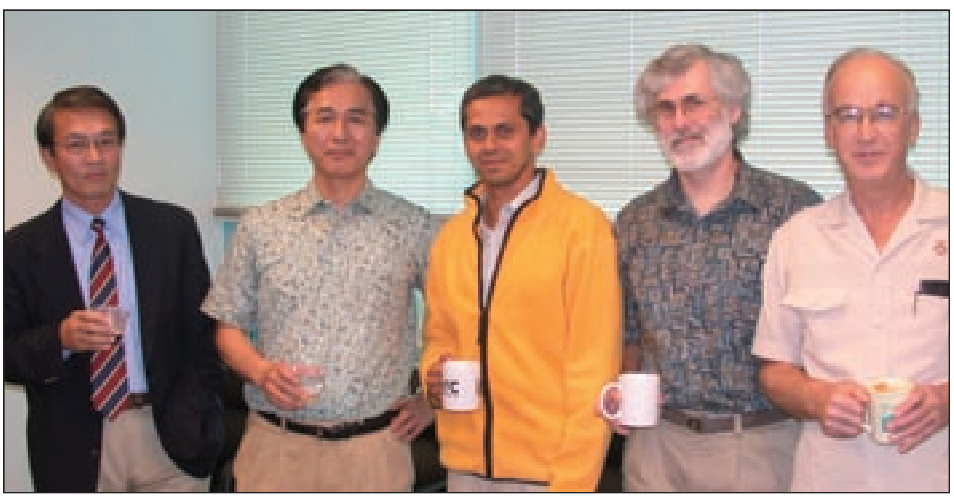
Gisela E. Speidel, Public Relations Specialist
International Pacific Research Center

The Fifth Decadal Climate Workshop

At what point does climate variation become climate change? This question must have been on the minds of many participants of the Fifth Decadal Climate Workshop, held February 23–26 at the Waikoloa Resort in Kona, Hawai'i. For four days scientists focused on climate variation occurring over decades or longer, its societal impacts, predictability, and processes. Among the 90 participants from around the world were representatives from the Intergovernmental Panel on Climate Change, the International Climate Variability and Predictability Project of the World Climate Research Programme, the White House Office of Science and Technology Policy, as well as NASA and NOAA program managers.

There is a recap of the meeting at the DecVar Auditorium (http://www.decvar.org/auditorium.php), which features in the form of Adobe Portable Data Files many of the 75 oral and poster presentations. A summary of workshop conclusions and recommendations will be published in the *Bulletin of the American Meteorological Society*. The Center for Research on the Changing Earth System and the IPRC were the workshop organizers; sponsors were the NASA–Oceanography Program, the NSF–Climate Dynamics Program, and the NOAA–Office of Global Programs. The Organizing Committee consisted of Tom Delworth (NOAA–GFDL), Chet Koblinsky (US Climate Change Science Program, NASA), Eric Lindstrom (Ocean.US, NASA), Zhengyu Liu (CCR, University of Wisconsin), Jay McCreary (IPRC, University of Hawai'i), Jerry Meehl (NCAR), Vikram Mehta (CRCES), and Jim O'Brien (COAPS, Florida State University).

IPRC News



From left to right: *Hitoshi Hotta, Toshio Yamagata, Saji Hameed (who obtained his Ph.D. with Professor Yamagata), Julian McCreary, and Lorenz Magaard.*

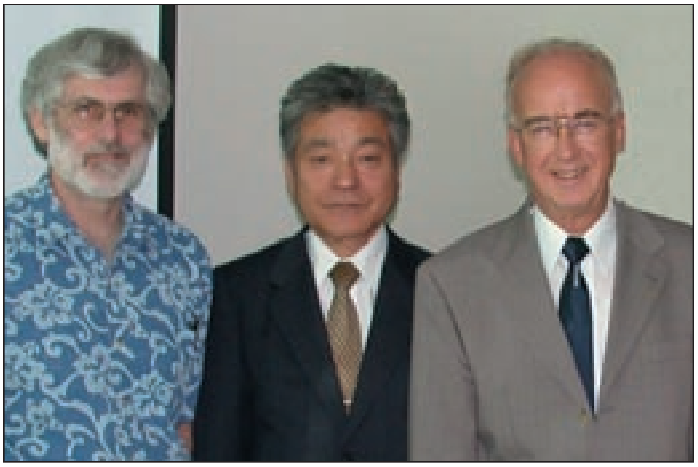
Toshio Yamagata, Professor in the Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo, and Director of Climate Variations Research, Frontier Research Program for Global Change, JAMSTEC, visited the IPRC in January 2004 after receiving the Sverdrup Gold Medal at the American Meteorological Society Annual Meeting in Seattle. At the IPRC, Yamagata gave a seminar, "The role of the Indian Ocean in climate forecasting with a particular emphasis on summer conditions in East Asia." A small gathering followed his talk.

Kevin Hamilton (left), team leader of the Impacts of Global Environmental Change research at IPRC, has been appointed Chief Editor for the book series *Atmospheric and Oceanographic Sciences Library* by Kluwer Academic Publishers. **Gert-Jan Geraeds**, the publishing editor of this publishing house, visited Hamilton in February 2004 to discuss plans for this scientific monograph series.

IPRC News

IPRC's Japan–US Relation Renewed

Conceived under the "US–Japan Common Agenda for Cooperation in Global Perspective," the IPRC was established October 1997 through an agreement between the University of Hawai'i and the Japan Marine Science and Technology Center (JAMSTEC) and the National Space Development Agency of Japan. As of April 1, 2004, the cooperation between JAMSTEC and UH is renewed under a somewhat different framework that reflects the reorganization of JAMSTEC into the Japan Agency for Marine-Earth Science and Technology (retaining the acronym JAMSTEC) as an autonomous Japanese research and development institution, established under a special law but still funded by the Japanese Government. The new JAMSTEC President **Yasuhiro Kato** and UH President **Evan S. Dobelle** have signed a Memorandum of Understanding covering the next 5 years as well as a Cooperative Agreement for the first year (April 2004–March 2005), which was signed also by JAMSTEC Executive Director **Masato Chijiya**. In conjunction with the renewal, Chijiya visited the university on March 10, meeting with Interim Vice Chancellor for Research and Graduate Education **Rolf-Peter Kudritzki** and Interim Dean of the School of Ocean and Earth Science and Technology **Klaus Keil**, as well as with IPRC Director **Julian McCreary**, and Executive Associate Director **Lorenz Magaard**.



IPRC Director Julian P. McCreary (left) with JAMSTEC Executive Director Masato Chijiya and IPRC Executive Associate Director Lorenz Magaard.

IPRC Bids Sayonara

Takuji Waseda has taken a professorship at the University of Tokyo, with a split-appointment between the Department of Systems Innovation and the Department of Environmental and Ocean Engineering. In the latter department he will be teaching in English a graduate course in environmental fluid modeling, which is part of a joint program between the University of Tokyo and the University of Sidney. Waseda was the first Frontier scientist to join the IPRC in October 1997. In collaboration with Humio Mitsudera, he conducted numerical modeling research that showed that the collision of an anticyclonic eddy with the Kuroshio could be a meander trigger. Waseda contributed significantly to the development of the Asia-Pacific Data-Research Center at the IPRC, and, during this past year, he was co-leader of the IPRC Regional Ocean Influences research team.

Fumiaki Kobashi, who joined the IPRC as a Frontier researcher in Summer 2002, has taken a position as tenured assistant professor in the Faculty of Marine Technology at Tokyo University of Marine Science and Technology, a new university that has resulted from a merger of Tokyo University of Mercantile Marine and Tokyo University of Fisheries. He will be teaching introductory physical oceanography classes. Interested in the mechanism that generates the North Pacific Subtropical Countercurrent, he conducted research at the IPRC on the North Pacific subtropical gyre, particularly the subsurface subtropical front and subtropical mode water.

Takahiro Endoh, a Frontier researcher at the IPRC since Summer 2001, has taken a postdoctoral research position with the Oceanic and Atmospheric Science Group, Department of Earth and Planetary Science, University of Tokyo. He will be working on a project called "Sustainable Coexistence of Humans, Nature and the Earth." Conducting experiments with an ocean general circulation model, he aims to clarify the global mapping of diapycnal mixing rates in the abyssal ocean, which affect the dynamics of the meridional overturning circulation and hence, climate.

New IPRC Staff

Yan Du joined the IPRC in March 2004 as a postdoctoral fellow. Upon completing his undergraduate work in physical oceanography at the Ocean University of Qingdao (now the Ocean University of China), Du continued graduate work in this field at Qingdao. He recalls his supervisor, Professor Guo Peifang: "He was a specialist on ocean waves and the application of satellite altimeter data. From him, I learned the significance and purpose of ocean research, how to deal with *in situ* and remote sensing data, and how to analyze information from observations. One project, especially, taught me research procedures and made me aware of the importance of collaboration."

In spring 1999, after finishing his Ph.D. coursework, Du began work with Professors Shi Ping and Wang Dongxiao at the Laboratory of Tropical Marine Environmental Dynamics at the South China Sea Institute of Oceanology. Just after having arrived at Guangzhou, he took part in a research cruise of the South China Sea. "From that voyage, I got an understanding of the South China Sea…currents, waves, tides, temperature and salinity structure. It made me realize the importance of *in situ* observation."

Collaborating with others at the institute, he wrote several papers on the ventilated thermocline and the mixed layer of the South China Sea and wrote his dissertation, The seasonal dynamics of the mixed layer and the thermocline in the South China Sea. "Looking back, those five doctoral years put me in touch with a field of physical oceanography that interests me, and they gave me experiences in the ocean dynamics of the monsoon area…from observation to theory, to stratification and circulation interactions, and numerical modeling."

After obtaining his Ph.D. from the Ocean University of Qingdao in 2002, Du stayed at the South China Sea Institute and extended his research to ocean stratification adjustment and planetary waves—the ocean dynamics important in the monsoon dominated region.

At the IPRC, working with Tangdong Qu and the Regional Ocean Influences research team, Du is studying upwelling and its impact on sea surface temperature in the East Indian Ocean. "I personally think ocean dynamics are especially important in the seasonal and annual variability of the Asian-Australian monsoons, which in turn affect Asian climate and even the global climate."

Andrei Natarov came as a postdoctoral fellow to the IPRC in January 2004. "I loved the physics competitions, the challenge of solving the problems," he recalls from the time he was growing up in the historical city of Belgorod, in Russia. "If I didn't solve a problem, I'd keep on thinking about it." After

visiting the Moscow Institute of Physics and Technology, he knew he wanted to study there, "because the students were having so much fun." Once at the institute, he quickly settled on fluid mechanics: This could be felt and seen, in contrast to abstract quantum mechanics; and since he needed to focus on a subject, he chose the ocean. Analytical modeling became his field. "There you can capture the interplay among parameters in a single stroke. Analytically solvable models generate a lot of useful information."

Interested in research in the United States, Natarov spent 1994 at the University of Michigan's Department of Atmospheric, Oceanic, and Space Sciences. He liked Michigan so much, and he must have impressed his professors, that as soon as he graduated from the Moscow Institute in 1996, he returned to Michigan on a Regent Scholarship. Focusing on the very stable equatorial Kelvin waves for his dissertation research, he confirmed mathematically the conjecture of John Boyd, his supervisor, that when the phase speed equals the current velocity, these waves will be destabilized by horizontally sheared flow.

After completing his Ph.D. at Michigan in 2001, Natarov headed to Hawai'i to work on the dynamics of internal waves with Peter Müller, professor of oceanography at the University of Hawai'i. Internal waves caught his interest, he says, "Because they are a curious phenomenon, they behave so differently from regular waves. For example, when a wave with small amplitude reflects off the ocean bottom it may suddenly have a large amplitude."

Now at the IPRC, Natarov is exploring inertial instability, double diffusion, and equatorial interleaving with Kelvin Richards, leader of the Regional Ocean Influences research team. Why? "Increasing resolution of equatorial ocean models has not improved model outputs as expected. Some important physics are missing that should be parameterized"…a good hunch is that the missing physics have to do with equatorial lateral mixing. Natarov plans to find out!

International Pacific Research Center
School of Ocean and Earth Science and Technology
University of Hawai'i at Mānoa
2525 Correa Road
Honolulu, Hawai'i 96822

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School of Ocean and Earth Science and Technology
University of Hawai'i at Mānoa
Tel: (808) 956-5019 Fax: (808) 956-9425
Web: http://iprc.soest.hawaii.edu

Editor:
Gisela E. Speidel, Ph.D.
Consulting Editors:
Kevin P. Hamilton, Ph.D.
Kelvin J. Richards, Ph.D.

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For inquiries and address corrections, contact
Gisela Speidel at gspeidel@hawaii.edu.
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It has now embarked upon its 8th year of an agreement between UH and JAMSTEC.