

# Field Experiment Examines Effects of Deep Tropical Convection

A key issue for modeling atmospheric climate and chemistry is the parameterization of the unresolved effects of gravity waves on the explicitly resolved flow. This has been difficult to achieve due to a lack of empirical data on the details of the wave spectrum and its relation to sources such as moist convection, flow over topography, and jet stream instabilities. IPRC Theme-4 leader, **Kevin Hamilton**, helped to organize the Darwin Area Wave Experiment (DAWEX), a field experiment in northern Australia to study the gravity waves excited by deep convection in the pre-monsoon period. During the Southern Hemisphere winter, there is little convection over northern Australia. This changes in the late pre-monsoon period, typically from November to mid-December, when intense convection over the Tiwi Islands develops virtually every afternoon. Known locally as “Hector,” this convection results from an interaction of convectively driven cold pools and sea breeze fronts. It builds into a bundle of intense thunderstorms over the western portions of the islands, reaching up to the tropopause by mid-afternoon. Hector thunderstorms are among the most intense and penetrative convection observed on earth, with updrafts as strong as 40 m/s and cloud tops sometimes reaching above 20 km.

Scientists from 10 institutions in Australia, Japan, and the USA took part in the DAWEX field campaign, which was organized around three intensive observing periods in 2001: October 13-18, November 15-20, and December 11-16. Convection over the Tiwi Islands and in the Darwin area was observed by the Australian Bureau of Meteorology Research Centre C-band polarized Doppler radar located near Darwin. Five airglow imagers recorded wave responses in the vicinity of the mesopause. A boundary-layer radar on the Tiwi Islands profiled low-level winds. At Katherine, about 400 km southeast of the Tiwi Islands, a medium-frequency radar measured horizontal winds near the mesopause. Three-hourly balloon soundings of the wind and temperature were made on the Tiwi Islands, at Darwin, and at Katherine.

At the “Analysis of DAWEX Results” workshop, held at the IPRC December 3-5, 2002, experiment participants reviewed preliminary observations and developed strategies for integrating the findings from the different types of observational systems. Analysis showed that convection differed from one observing period to the next as the prevailing circulation changed from pre-monsoonal to mon-

soonal. October had three days with modest Hectors and two days with only disorganized convection. November had three consecutive days with very strong Hectors and more extensive areas of convection. December showed a more monsoonal pattern with widespread convection over the mainland.

The airglow imagers, which yielded rich data on the horizontal wavelengths and phase velocities, all recorded a southward propagation tendency. This suggests their dominant source in this season is convective activity in northern Australia or the Maritime Continent region. Detailed analyses are now being performed on the behavior of the waves at each station and their relation to the weather each day.

The radiosonde observations revealed systematic wavelike variations at both shorter and longer time scales. One prominent component near the tropopause in the October and December observations is a large-scale wave (coherent at Darwin and Katherine) with a period near 84 hours. Small vertical-scale variations tend to be stronger near the tropopause and also above 25 km, but suppressed in the 20 to 25 km height range, an unexpected finding awaiting explanation. The workshop also reviewed current efforts at the detailed numerical modeling of the Hector convection and of the gravity wave field excited by isolated deep convection.

Plans for a follow-up experiment to study also the chemical and microphysical effects of the Hector convection are summarized in a draft White Paper posted at <http://www.soest.hawaii.edu/~kph/EXP2>.



Workshop participants, front row: Shin Suzuki, Alan Liu, Toshitaka Tsuda, Kevin Hamilton, and Joan Alexander. Back row: Kazuo Shiokawa, Mike Taylor, Peter May, Andrew McKinnon, Bob Vincent, Jim Hecht, Richard Walterscheid, and Gera Stenchikov.

# Capturing the Daily Cycle in Global Atmospheric Models

The daily cycle of solar radiation has a number of important signatures in the climate system. On a local scale, differences in surface heating over land and ocean produce the familiar land-sea breezes; over topographic slopes it produces mountain-valley breezes. Restricted mostly to the lowest 2 to 3 km of the atmosphere, these local diurnal circulations typically involve a rough balance between the radiatively driven horizontal pressure gradients and small-scale turbulent “friction.” On a larger horizontal scale, the Coriolis force and acceleration terms balance the atmospheric pressure gradients caused by diurnal heating variations, resulting in large-scale inertia-gravity waves. On the global scale, this yields a large sun-following wave that can propagate vertically upward and downward from its forcing altitudes.

Atmospheric scientists have resolved this sun-following wave into diurnal (24 hour), semidiurnal (12 hour), terdiurnal (8 hour), and shorter components that are called the sun-synchronous or “migrating” atmospheric tides. These waves have fairly modest amplitudes: near the ground, generally less than 3 hPa peak-to-peak surface pressure. At low latitudes, however, this pressure variation exceeds typical day-to-day synoptic changes. This was first noticed by the famous 18<sup>th</sup> century explorer Alexander von Humboldt, who wrote that at low latitudes, the daily cycle of air pressure is so regular that a barometer can serve as a clock!

Regional modulation of the diurnal heating amplitudes and local-time phase yields other diurnal and semi-diurnal tide components, the so-called non-sun-synchronous tides. These are caused by regional variations in the diurnal cycle of latent heat released in moist convection, which involves many aspects of tropospheric meteorology.

Global climate models cannot adequately represent the small-scale land-sea breeze circulations, but they simulate both the migrating and non-sun-synchronous tides. Simulation of the tides is of particular interest as it is one of the best tests of how numerical models respond to a well-defined forcing.

To review current understanding and identify uncertainties in the numerical simulation of atmospheric tides, the Working Group on Numerical Modelling of the International Commission for the Middle Atmosphere held the “Modelling of Atmospheric Tides” workshop at the IPRC March 3-7, 2003. **Kevin Hamilton**, chairman of the working group, organized and chaired the workshop.



*Workshop participants. Seated, from left: William Ward (University of New Brunswick), Robert Vincent (University of Adelaide), Rashid Akmaev (University of Colorado), and Xun Zhu (Johns Hopkins University). Standing, from left: Rolando Garcia (NCAR), Ruth Liebermann (Northwest Research Associates), Francois Vial (Ecole Polytechnique), Kevin Hamilton (IPRC), Anne Smith (NCAR), Charles McLandress (University of Toronto), Dan Marsh (NCAR), and David Ortland (Northwest Research Associates).*

Twelve scientists from Canada, Australia, France, and the USA participated. They brought to the workshop expertise in lower atmospheric meteorology and in upper atmospheric dynamics and chemistry. Perhaps no other phenomenon in atmospheric science requires such a wide range of expertise.

The workshop presentations revealed some successes in simulating the diurnal cycle in state-of-the-art global models. In particular, such models appear to reproduce reasonably well the overall amplitude and phase of the migrating tides. The models, however, perform less well on reproducing the observed geographical and intraseasonal variability of the non-sun-synchronous tides. The problem seems to lie mainly in poorly simulating the daily moist convection cycle in the troposphere. Another issue identified at the workshop, but left unresolved, is how the interannual variability in mean wind distributions affects seasonal and year-to-year variations in the tides.

Hamilton is now coordinating a review article on atmospheric tides based on the presentations and discussions at the workshop. The preparation for the meeting has also inspired IPRC Researcher **Yuqing Wang** to draft another review paper focused specifically on simulating diurnal cloudiness and rainfall variations in global and regional atmospheric models.

# The Hadley Circulation: Present, Past, and Future

The Hadley Circulation is Earth's main distributor of heat. The very warm, moist air near the equator rises high into the atmosphere. As it moves poleward, it loses much heat and sinks again, according to the textbook definition around 30 degrees latitude; there the cooler air then travels as trade winds toward the equator. Letting off the equator's "steam," and warming the mid-latitudes, the Hadley Cell is thought to have a major role in climate variations. Climate researchers, therefore, want to know how global warming will affect this circulation. Will the circulation strengthen or weaken? How will it affect precipitation? As yet, there is no agreement as to what will happen. One approach to understanding more about how global warming might affect the Hadley Circulation is to see how it has changed in the past. Extensive instrumental records go back less than two centuries, but there are proxy records of ancient climates.

November 12-15, 2002, the IPRC hosted "The Hadley Circulation: Present, Past, and Future" workshop at the East-West Center, bringing together over 50 climate dynamics scientists and paleoclimate researchers from 10 countries. The workshop covered two main areas: proxy records and what they can tell us about past climates, and recent numerical modeling research on the Hadley Circulation.

The reports on paleoclimates included records of ocean corals and fossilized corals now on land; speleothems, such as stalagmites or stalagmites; lake, riverbed, and deep-sea sediments; ice cores; tree rings, planktonic foraminifera, and other plant biomarkers. These records, which span the globe and cover the last 130,000 years, are being used to reconstruct such past climate conditions as air and sea surface temperatures, precipitation, winds, storm activity, ocean currents, and the chemical composition of the atmosphere. For example, the oldest records presented at the workshop are from fossilized corals in New Guinea and suggest that the El Niño-Southern Oscillation has existed for at least 130,000 years, through warming and glacial cycles (Tudhope).

Several reports showed that past climate changes in the high latitudes of the Northern Hemisphere are also seen in paleo records from the tropics and even the Southern Hemisphere (Hughen; Cobb). The rapid warming periods occurring within decades, as recorded in the Greenland Ice Cores, are found in stalagmite records in the tropics (Burns; Fleitmann). The mechanisms that can lead



Workshop organizers Raymond Bradley and Henry Diaz with IPRC Director Julian McCreary.

to such a rapid, large rise in temperature are not known. A change in the distribution of solar irradiation does not seem to account for their large amplitudes, but natural fluctuations in CO<sub>2</sub> and other greenhouse gases are suspects.

Not all proxy data, though, are so consistent across the globe. For example, in many parts of the tropics and subtropics, glacier formation and starvation are more in line with wetter and drier conditions than with surface temperatures (Thompson), although oxygen isotope changes that record prevailing air temperature do reflect the cooling and warming cycles of the last glacial-interglacial cycle. The highest mountains in the Southern Hemisphere were ice-free during a time when Earth was in the grip of a global glaciation. Moreover, subtropical ice-core records from glaciers in the Himalayas show that they were formed during the Early Holocene warm period.

By the end of the workshop, the accumulated reports made it clear that once the diverse proxy records are pieced together into a cohesive global picture of past climates, they will be a most useful data source for testing general circulation models (GCMs). At present, the main tools for climate change predictions are the comprehensive GCMs, which do fairly well in simulating the current climate and the current Hadley Cell. GCM simulations of past climates are an active area of research, and improvements in the detailed reconstructions of past climates from proxy data would enhance our confidence in their predictions of how climate may change in response to increasing concentrations of greenhouse gases.

The reports on experiments with atmospheric and coupled ocean-atmosphere circulation models ranged from simulating climate conditions 58 million years ago to future global warming scenarios. The findings on how different forcings affect the Hadley Circulation, particularly the intensity of the winds and the circulation's poleward reach, presented a complex picture. For example, a comparison of GCM simulations using surface temperatures existing in the Paleocene, the Last Glacial Maximum, the present, and a doubled CO<sub>2</sub> scenario found that the intensity and the poleward extent of the Hadley Cell are not related in a straightforward way to global or equatorial temperatures; intensity of the circulation correlated the most with differences in sea surface temperature between the tropics and subtropics (Rind). A study of changes in conditions over the last 50 years suggested that the changes in the Hadley Circulation depend on season: the Hadley Cell has intensified during the northern winter, but has changed little during northern summer (Quan). A modeling study covering the period from the Last Glacial Maximum to the present also suggests that any changes in the Hadley Cell intensity arising from global-mean surface temperature changes depend upon the season (Valdes).

Effects of incoming solar-radiation changes on the Hadley Cell depend upon the nature of the change: obliquity variation seems to affect the circulation, but not precession (Clement). A modeling study comparing the effects of increased solar irradiance and increased CO<sub>2</sub> in the 20<sup>th</sup> century, suggests that they have different effects: increases in solar irradiance strengthened the Hadley Cell, exacerbating local droughts and floods, while the effects of increased CO<sub>2</sub> are distributed more evenly (Meehl).

On the whole, the presentations showed that the textbook definition of the Hadley Circulation, in which air rises at the equator and symmetrically moves toward both poles, is a drastic oversimplification. The circulation varies in complex ways across the globe: the location and strength of the ascending and descending branches are affected greatly by geographic features and seasons, and sometimes behave as a single cell with strong flow across the equator. The general thinking at the workshop was that the symmetrical circulation with its averaged yearly east-west characteristics was still a useful concept when combined with local and seasonal variations in its expression. An unresolved debate is whether the Hadley Cell is driven mostly from the tropics or the subtropics.

The workshop abstracts are posted at <http://www.geo.umass.edu/climate/hadley/abstracts/abstracts.html>. A book on the workshop presentations is in

preparation. Moreover, workshop participants thought the dialog between researchers from paleoclimatology and modern climate dynamics, including observationalists and modelers, was most helpful. To continue this cross-discipline dialog, the group decided to suggest to the National Science Foundation that it should develop a programmatic theme and a call for proposals on projects in which scientists from different climate-related disciplines could study the variation of the intertropical circulation over the last 1,000 years.

**Raymond Bradley** (Climate System Research Center, University of Massachusetts) and **Henry Diaz** (NOAA Climate Diagnostics Center) organized the workshop. Sponsors were NOAA Office of Global Programs and NOAA Climate Diagnostics Center, NSF, the Climate System Research Center, Past Global Changes (PAGES), and the IPRC.

## Stewards of the World Oceans

The IPRC hosted the spring meeting of the **Ocean Studies Board** of the National Academies March 5-7, 2003. The board provides the US federal government with balanced, unbiased scientific and technical advice on ocean issues. Among other things, presentations on two recently completed reports were given: *The Decline of the Steller Sea Lion in Alaskan Waters* concluded that the main suspects in the present decline of the endangered Steller sea lions are killer whales. Their former food source dwindling, killer whales go for smaller catch: one beached whale had 14 sea lion tags in his stomach. The report recommends an adaptive management program with numerous areas of "take" and "no-take" or sanctuaries in the region. Complicating matters is that killer whales are also endangered. The *Ocean Noise and Marine Mammals* report concluded that we know little about the noise budget in the ocean. The report recommends establishing a long-term ocean-noise monitoring program in marine habitats and studying how marine animals react to different aspects of noise. NOAA needs standards to guide its approval process for ocean noise-producing projects; yet, lawsuits brought to protect the marine environment are hindering research to develop such standards.