“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).

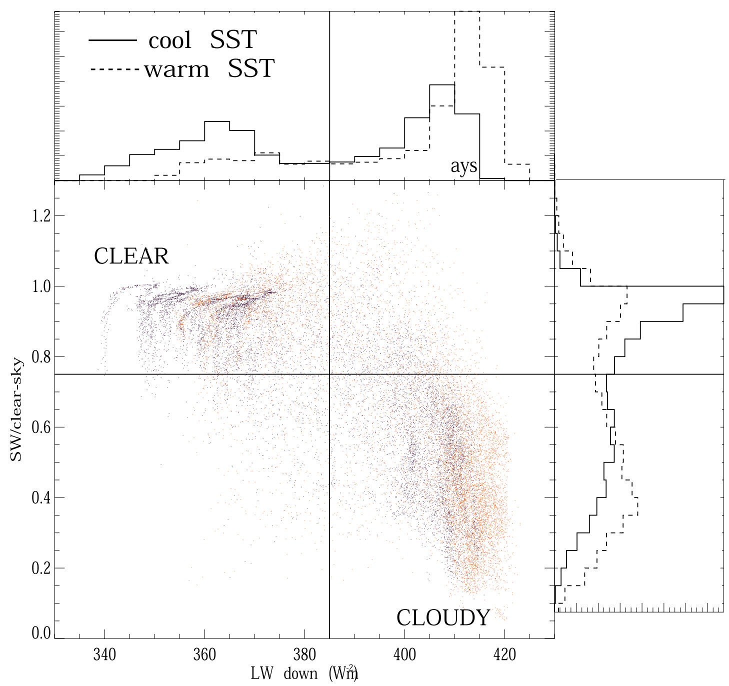

Figure 6. *Scatter plot of the fraction of clear-sky shortwave and downwelling longwave radiation reaching the buoy, for daytime data during the extreme warm (red) and cold (blue) phases of TIWs. Histograms for each variable during warm (dotted lines) and cold (solid lines) phases are shown at the top 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.

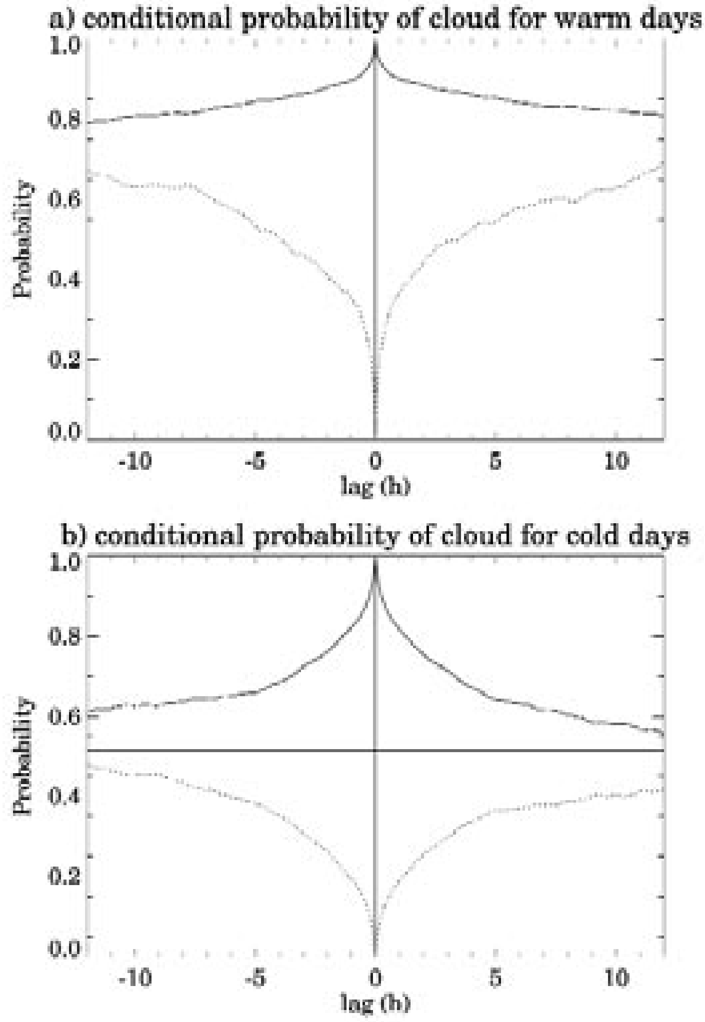

Figure 7. *Conditional probability versus time lag, a depiction of the typical scales of clear (dotted) and cloudy (solid) segments of the time series. To convert time lags to spatial scales, multiply by the typical wind speed of 6–7 m/s, so that 12 hours correspond to ~280 km.*

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.

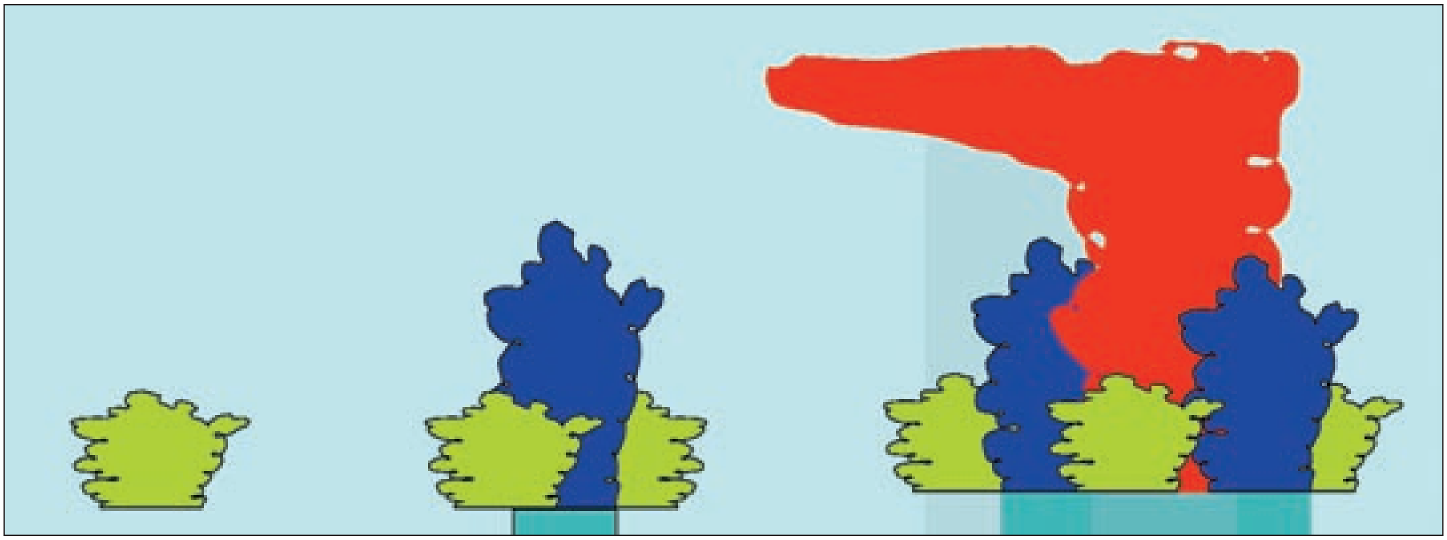

Figure 8. *Schematic of the cloud-collision model of the manner by which cumulus clouds give rise to showery cumulus congestus and cumulonimbus clouds.*

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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