Radiatively Forced Diurnal Circulations and the Distribution of Tropical Water Vapor

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Overview

Because the tropical ocean regions are the primary source of available energy for the general circulation, their principal cyclic variations (e.g., factors governing the diurnal convective cycle) must be accurately represented in global climate models (GCMs). The observed morning maximum of intense convection over the tropical oceans occurs in opposition to the effects of direct solar heating, which maximize during late afternoon. As such, the morning maximum occurs as the result of a complex set of cloud-radiative interactions and feedback processes. Presently, the overall nature, strength, importance, and even the fundamental causes of observed tropical diurnal variability are in dispute, as is their likely significance both for real and simulated long-term climate change. The parameterization of radiative transfer processes in some long-term climate simulations may systematically bias the accommodation of diurnal variations of broad-scale cooling processes, which become an additional source of bias in long-term numerical climate simulations. At present, we have limited knowledge of the nature and amplitude of these effects but our work is beginning to offer some insight.

Conditionally unstable atmospheres, and hence convection, can be viewed as being in large part due to the effects of efficient deep radiative cooling. However, strong differences occur in the time and space distributions of net tropospheric radiative cooling rates. Greater nighttime cooling rates in comparatively clear areas accelerate nocturnal subsidence circulations leading to a morning maximum, typically between 0400 and 1000 local time (LT; Figure 1). This enhanced nocturnal subsidence accommodates increased divergence to adjoining cloudy areas, and in effect, drives the morning maximum of intense convection over the tropical oceans. These cloud/moisture modulated, radiatively driven circulations appear to be a primary forcing process for the strong morning maxima of very cold cloudiness and heaviest rainfall events over the tropical oceans, as well as causing variable moisture transport and heating processes over maritime tropical areas as discussed by Gray and Jacobson (1977) and Foltz and Gray (1979). We also find that diurnal subsidence cycles associated with intense convection are linked to observable diurnal variations of broad-scale net column water vapor (see Gray and Sheaffer 1997, 1998), and hence, with the alterations of the cooling process. As such, the effects of these day-night radiative differences are a fundamental mechanism of the broad-scale dynamics and energy budget of the tropical and sub-tropical environment.

Recent Work

Considerations for Global Change/ Variability

The real issue for global change concerns how atmospheric water vapor distributions may be altered as CO_2 concentrations rise. This is a complex, multidimensional problem with specific uncertainties for each latitudinal belt and climatic regime (Sherwood 1996; Sun and Lindzen 1993; Sun and Oort 1995). Though some of these effects are already included implicitly as a component of cloud forcing, the impact of altered rates of deep cooling on the current configuration of systematic day-night differences constitutes a distinct set of problems critical to the evolution and overall net intensity of much broad-scale intense tropical convection. In modulating the most intense convection, these processes define the upper limits of the climatic effects of the largest and most intense convective modes for redistributing moisture in the tropics (Gray and Sheaffer 1998). These differences and the related production of both moist and dry air in the upper troposphere through their close association with most intense modes of convection have important implications for understanding convection and for anticipating climate effects. An extended discussion of these issues has been prepared by Gray (1998).

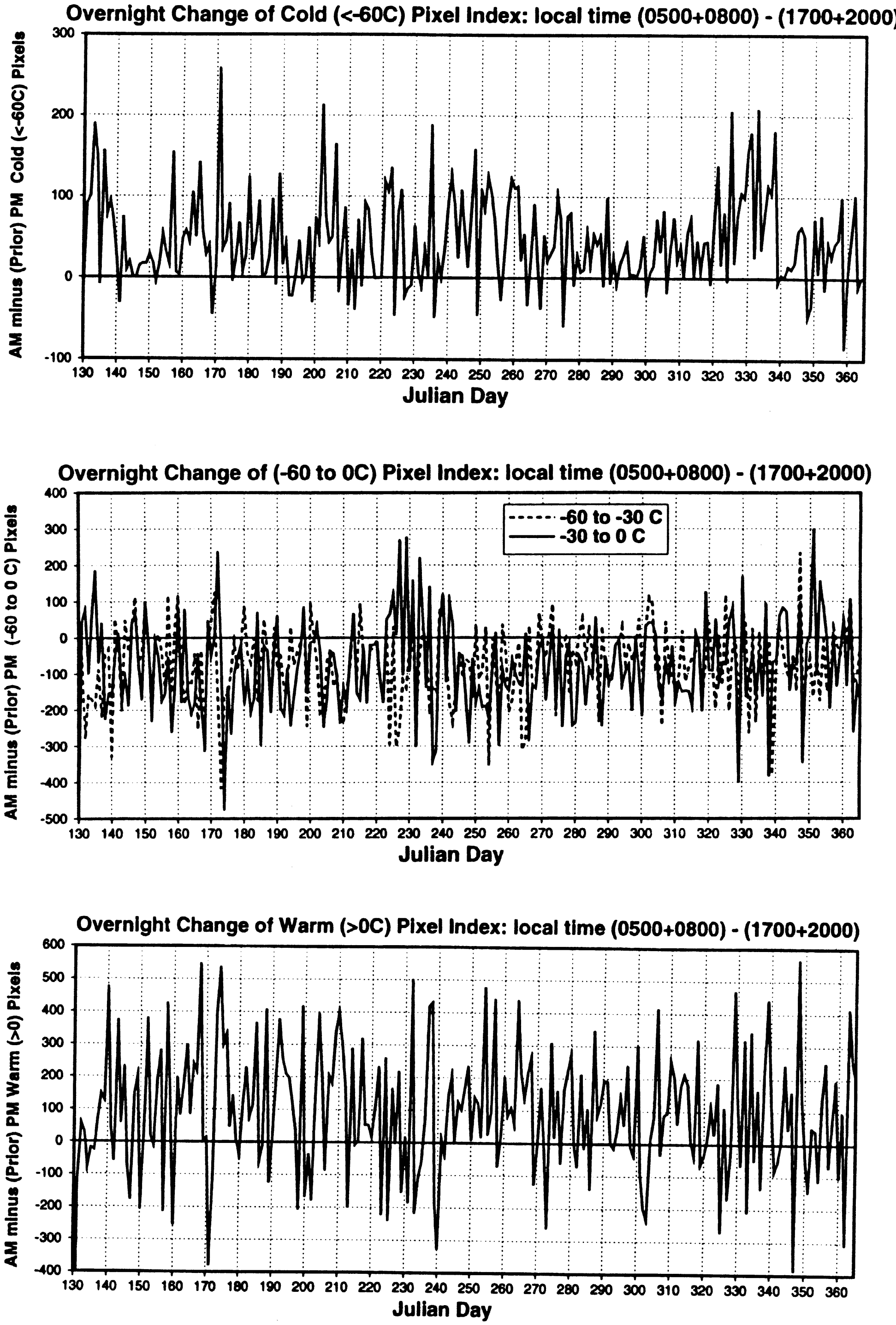


Figure 1. (top) Time series of the overnight (i.e., from 1700 to 0800 the following morning) change of "cold" (-65°C) pixel index for the western Pacific area bounded by 0°N to 20°N, 150°W to 170°W. Positive values represent an overnight increase for this temperature range. The time period shown is for 10 May (Julian day 130) through 31 December (Julian day 365) 1986. (middle) As in top but for the net overnight change of -60°C to -30°C (solid) and -30 to 0°C (dashed) pixel indices. (bottom) As in "top" but for overnight change of the "warm" pixel index for brightness temperatures warmer than 0°C.

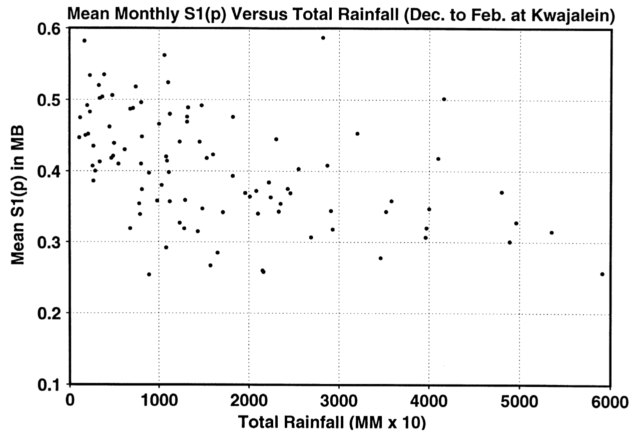
Thermal Tides

We have added the analysis of differences in observed diurnal surface pressure variations between relatively clear versus cloudy locations in the open ocean of the Tropical Western Pacific (TWP) to our recent work. Daily surface pressure variations at these sites are dominated by the 12-hour, semi-diurnal thermal tide [S2(p)], which is forced by solar heating of ozone in the stratosphere and mesosphere. When the rather steady S2(p) component is removed, the highly variable residual is composed almost entirely of the first (24-hour) diurnal harmonic, [S1(p)], which reaches its maximum at about 0600 (LT). Over the open ocean, S1(p) is entirely due to the combined effects of (daytime) solar heating of tropospheric water vapor and deep nocturnal cooling. As such, the amplitude of this mode varies appreciably in space and time following cloudiness and ambient water vapor distributions. Results for data taken at Kwajalein reveal that mean monthly amplitude of S1(p) decreases for greater total monthly rainfall (Figure 2, top). A clear tendency to weaker S1(p) amplitudes occurs for increasing rainfall amounts as more extensive cloudiness inhibits both heating and cooling; this averaged effect generally levels off for rainfall totals greater than about 250 mm/month. Hourly S1(p) values (Figure 2, bottom) illustrate the range of monthly mean diurnal S1(p) amplitudes for comparatively dry versus rain (cloudy) conditions.

A further perspective on the day-to-day variability of S1(p) values appears in Figure 3 as a compressed time series rendering of the amplitude at Kwajalein for calendar year 1982. Not surprisingly, this time series seems to contain Madden-Julian Oscillation (MJO)-like transience, becoming increasingly strong for some weeks, followed by sharp collapse and subsequent reintensification. Note that the amplification seems to occur simultaneously in at least two amplitude modes (see annotation on Figure 3), the origins of which are of interest. The differences in day-to-day S1(p) values are appreciable and under good conditions, an associated 1 mb to 2 mb pressure wave likely propagates from the clear areas. These thermal tide data also provide an excellent diagnostic tool for assessing the adequacy of the associated radiative processes in numerical simulations.

Summary

Current objectives for these studies include completing ongoing work on quantification of these effects throughout the global tropics and subtropics, and assessing their nature and influence as a source of systematic errors in numerical climate models. We are working to verify these effects in terms of variations of the hydrologic cycle and middle and upper-level water vapor distributions including the time/space differences with active and inactive convective modes. Having studied this topic for some time, we are also pressing to complete a draft version of a comprehensive monograph on the topic, perhaps by the end of the current year.



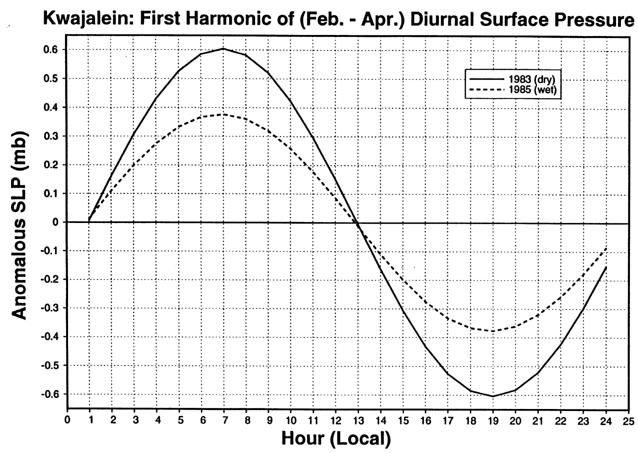


Figure 2. (top) Scatter plot of mean monthly (December to February only) S1(p) versus total rainfall at Kwajalein (1957 to 1992). (bottom) Three-month mean diurnal cycle of S1(p) thermal tide at Kwajalein for generally dry (low rainfall) and wet (heavy rain) conditions.

References

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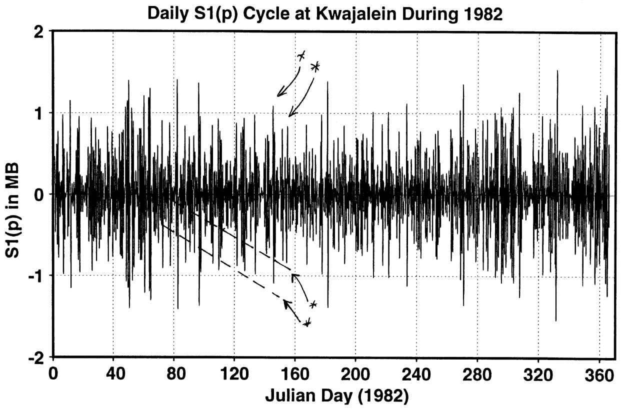

Figure 3. Time series of the first diurnal harmonic of sea surface pressure [S1(p)] at Kwajalein for 1982. The annotation directs attention to multiple concurrent modes of amplification on an approximate MJO time scale.

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Other Publications in Progress

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