On the Fundamental Role of Tropospheric Radiative Cooling on the Diurnal Cycle of Intense Tropical Convection

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Summary

The atmosphere performs a day versus night (DVN) radiation experiment for us each 24 hours; we should attempt to study and learn from this ever-repeating DVN cycle of radiative cooling. The Atmospheric Radiation Measurement (ARM) Cloud and Radiation Testbed (CART) tropical western Pacific (TWP) experiment presents an ideal opportunity for the study of these radiatively induced diurnal variations.

Introduction

Any systematic misrepresentation of the diurnally varying distribution of cloudiness type, amount, and related radiative transfer processes in a numerical study feeds back to skew the simulation and compromise any inferences drawn from it. In this vein, we seek to more accurately describe the main aspects of the diurnally varying heating, moisture, rainfall, circulation, cloudiness and related cycles of the tropical atmosphere. More accurate descriptions will enhance the parametric representation of these elements and allow better checks on the accuracy of related ongoing numerical studies. Our studies, which are specifically directed to the radiative forcing of the tropical oceanic diurnal cycle, can be roughly grouped under the following general headings:

- revised diagnostic studies of the diurnal cycle, arising in part from the principal investigator's prior work in this area, but expanded to include the vast new and improved tropical data bases now available
- new initiatives in the analysis of the diurnal cycle on larger space scales and its variability on interannual time frames
- participation in the TWP-CART field program
- collaborative interactions with general circulation model (GCM) research groups to better maintain the focus of our work on mutually beneficial outcomes.

Background

Strong differences occur in the DVN net radiative cooling of clear versus cloudy areas in the tropical atmosphere. Daytime average (-0.7°C/day) versus nighttime (-1.5°C/day) tropospheric cooling rates differ by a factor of approximately two to one (see Jacobson and Gray 1977). Comparatively strong nocturnal cooling in clear areas gives rise to a diurnally varying vertical circulation cycle which has multiple manifestations, including the observed early morning heavy rainfall maxima over the tropical oceans. This concept is illustrated in Figure 1. Radiatively driven DVN circulations appear to modulate the resulting diurnal cycle of high cloudiness and temperature over maritime tropical areas and are likely a fundamental mechanism governing both small- and large-scale dynamics of the tropical environment.

How effectively do numerical models capture the influence of such diurnal radiation variations on diurnal variations of vertical motion and cloudiness? And where such responses occur, do they have the observed 4-8 hour time lag of response to the radiational forcing?

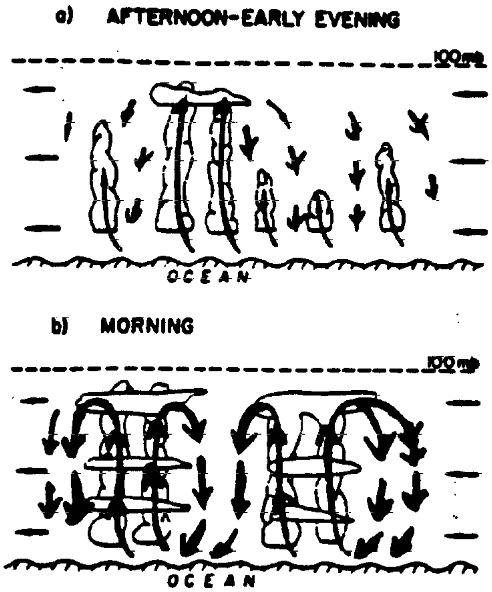

Figure 1. Idealized illustration of a diurnal variation in subsidence due to a regional diurnal variation in deep cumulus convection. No regional diurnal variation in divergence need be present. A morning maximum and afternoon-early evening minimum in subsidence is present (from Foltz and Gray 1979).

Observational Evidence of (Oceanic) Tropical Diurnal Cycle

Hourly rainfall variations at Western Pacific atoll and small islands were previously analyzed by Gray and Jacobson (1977) and Ruprecht and Gray (1976) for the two standard rawinsonde periods. They showed a strong morning peak in heavy rainfall, in agreement with the rawinsonde divergence measurements. The results in Table 1 show that the heavier the rainfall rate, the larger the observed diurnal variation; these differences can be as large as three to one.

The results in Figure 2 summarize vertical motions for morning versus afternoon-evening in the West Pacific,

Table 1. Comparison of morning versus evening occurrence of rainfall events of various intensities during two 5-hour time periods for western Pacific cloud clusters (from Ruprecht and Gray 1976).

Rain Intensity	(07-12 LT)	(19-24 LT)
Cluster Precip.		
> 1.0 cm/hr	~75	~25
0.25-1.0 cm/hr	~60	~40
trace-0.1 cm/hr	~55	~45
Total	~70	~30
> 2.0 cm/hr	70	30
1.0-2.0 cm/hr	60	40
0.5-1.0 cm/hr	57	43
0.1-0.5 cm/hr	55	45
trace-0.1 cm/hr	50	50
Total	57	43

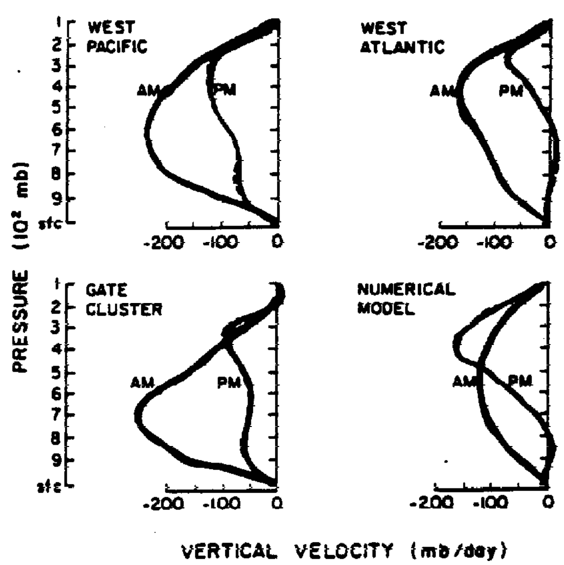

Figure 2. Diurnal variation of cloud cluster vertical motion for the three oceanic regions and for a numerical radiation model. Actual observed curves are shown for data for 00Z versus 12Z in the West Pacific and West Atlantic and for 7:30 AM and 7:30 PM for GATE; 8 AM and 8 PM curves are shown for the numerical model (from McBride and Gray 1980).

West Atlantic, and GARP[(a)] Atlantic Tropical Experiment (GATE) region. Note the approximately two-to-one difference for AM versus PM vertical motion. As shown in Figure 3, we find similar compensating diurnal variations in satellite-observed clear region (or partly cloudy) subsidence wherein 09 LT sinking motion is about twice as large as 21 LT sinking motion.

In Figure 4, large amplitude single-cycle diurnal variation with a morning maximum is shown for very cold outgoing longwave radiation (OLR) (-55°C, -65°C, -75°C, -85°C infrared threshold) cloud areas. Cloud areas defined by warmer infrared temperature ranges (-15°C to -55°C) typically exhibit a phase difference with the maximum area occurring up to 12 hours later (hence, opposite) to the deep cloud cycle. The overall tropical cyclone cloud shield (colder than -15°C) shows only very small diurnal variations.

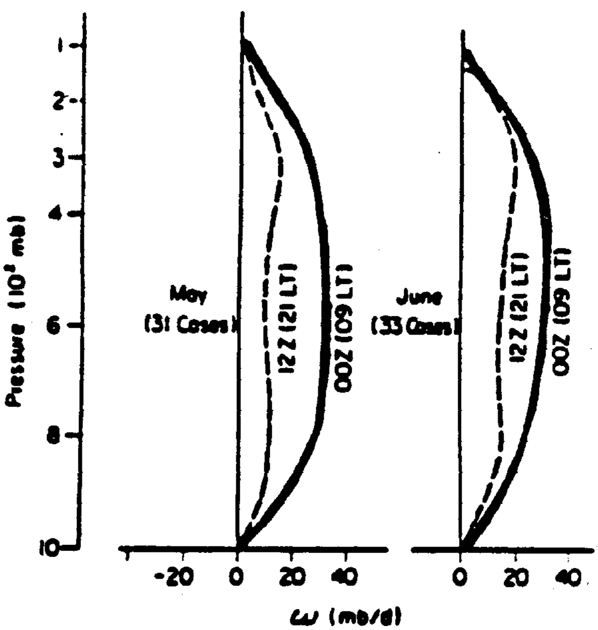

Figure 3. Comparison of 00Z versus 12Z wide area (10°) subsidence in western Pacific subtropical clear regions during May and June 1979. Data from large-scale analysis from the European Centre for Medium-Range Weather Forecasts.

(a) Global Atmospheric Research Program.

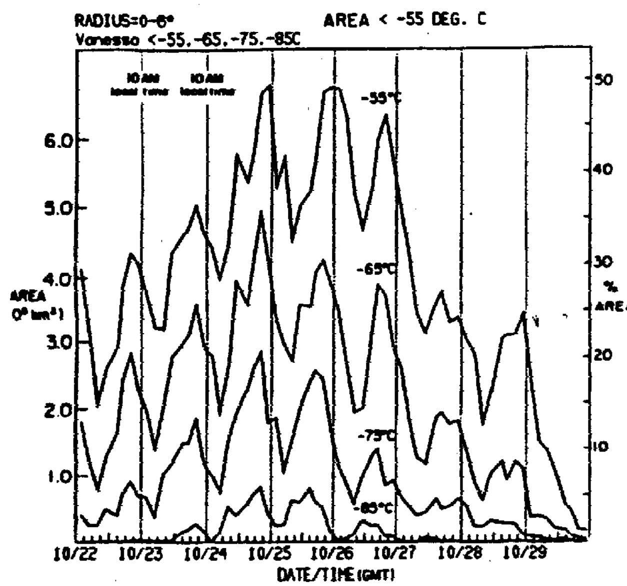

Figure 4. Time variation of percent of area with black body temperature (T_B) thresholds of -55°C, -65°C, -75°C, and -85°C for Typhoon Vanessa (Zehr 1992).

Results in Figure 5 illustrate preliminary work with basin wide Geostationary Meteorological Satellite (GMS) OLR data, in this case composited for an entire month. A sharp maximum is evident for the incidence of coldest clouds in the early morning hours, and the incidence of warmer (than -55°C) cloud tends to run out of phase, with an afternoon maximum.

Closely related results shown in Figure 6 include a strong diurnal cycle in the Tropical Global Ocean Atmosphere-Tropical Atmosphere Ocean (TOGA-TAO) equatorial Pacific buoy array (figure courtesy of C. Deser) and in larger averaged vertical motion from profiler data at Christmas Island (data courtesy of K. Gage). We consider these observations to be strong evidence that the troposphere (with a time lag of only 4-8 hours) responds directly and rapidly to its diurnally varying radiational cooling differences.

Lapse-rate changes great enough to influence convection this strongly are very difficult to bring about in the tropical maritime troposphere. Hence, day-night radiation-induced lapse-rate variation is not a satisfactory explanation for large variations we observe in oceanic day-night deep convection. We believe two factors to be the likely cause:

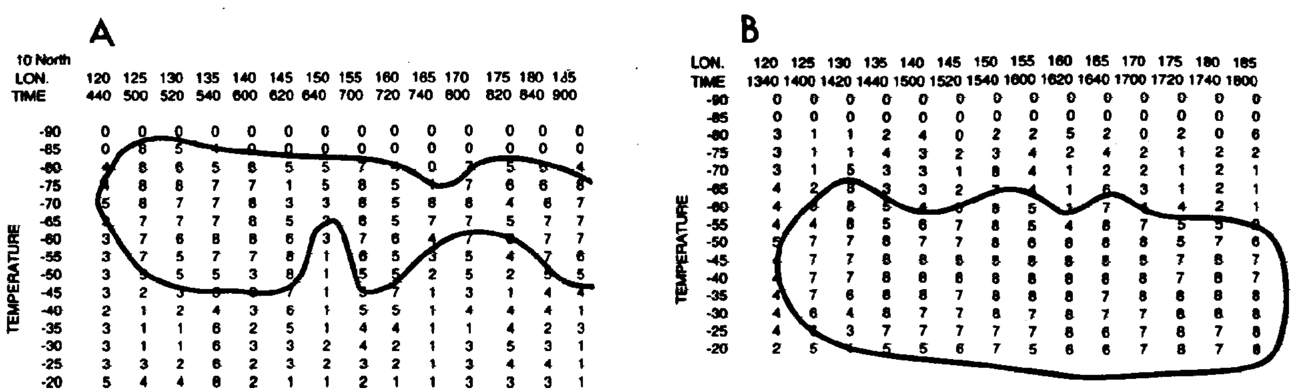

Figure 5. Analysis of the relative incidence of cold cloud, for 10-15°N, spanning the Pacific from 120°E to 175°W for the entire month of July 1986. Values in the two panels show the rank of total pixel counts (1=least, 8=most) for each longitude-temperature bin for two (of eight) diurnal time periods. The temperature ranges are from -20°C to -90°C, with coldest values at the top. Local time is shown for each longitude belt, indicating that areas of greatest pixel incidence (i.e., enclosed areas of ranks 5-8) of coldest clouds (i.e., near the top of each panel) occur during the early morning (panel A), whereas the least incidence of cold cloud (and hence, deep convective plumes) is during the late afternoon (panel B). Zeros signify no pixel counts were observed for those specific time, temperature, latitude/longitude bins.

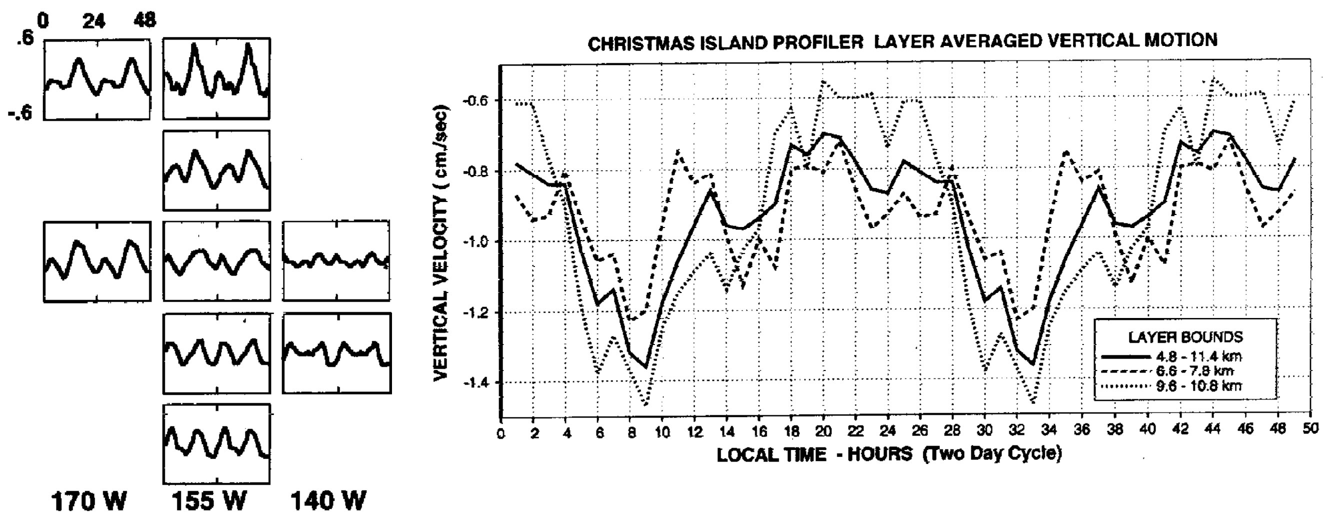

Figure 6. (left) Diurnal cycle of meridional wind along the equator in the TOGA-TAO array (after Deser 1994). (right) Diurnal cycle of layer averaged vertical motion (wind speed; cm/sec) at Christmas Island (2N,170E) (Data courtesy of Ken Gage). Each panel shows two complete diurnal cycles (i.e., 48 hours).

1. Day versus night variations in radiation-induced subsidence occur throughout the tropics. Greater subsidence occurs as a result of greater nighttime cooling, but with a 4-to 8-hour time lag and a 12-hour lag for the minimum subsidence.
2. In addition to net differences in DVN subsidence, cloud versus cloud-free radiation differences also appear to play a role. Cloud areas with deep tropospheric cloudiness lose IR radiation to space less rapidly than do areas of clear sky or low cloudiness.

Current and Future Research

Evidence shows that the multiple manifestations of the observed Maritime Tropical Diurnal Cycle (MTDC) are likely driven by DVN differences in clear versus cloudy regions of the maritime global tropical areas. As this is primarily a radiative transfer problem, we are working to develop reliable detailed MTDC observations which can be used in support of efforts to devise improved parameterizations for GCMs. These descriptions include statistical data on cloud cover variability in relation to observed aspects of diurnal variability. We are employing the following new tropical Pacific data:

1. Three years of three-hourly IR data from GMS and satellite years. We have detected a large diurnal cycle.
2. NOAA profiler data which show large diurnal cycles.
3. TOGA-TAO surface buoy data (see Deser 1994) from which large diurnal cycles in surface convergence are being detected.
4. Extensive rawinsonde data for diurnal moisture (revised interpretations) and temperature differences.
5. A synthesis of the items 1, 2, and 3 to assess the time (i.e., diurnal) variations of vertical circulations, tropospheric heating and cloudiness, etc., for both large and regional spatial scales.

We are proceeding with comparative analyses of observed aspects of the MTDC versus its fundamental counterpart in several operational numerical forecast models and in several GCMs. Currently, we have obtained commitments for informal collaborative cooperation in this activity; most notably from D. Randall's GC modeling group at Colorado State University and from the operators (i.e., J. Hack) of the National Center for Atmospheric Research's community climate modeling groups.

Forthcoming initiatives will extend our analysis on the MTDC to larger spatial scales and will include assessments of primary modes of intraseasonal and interannual variability. Refinements will include updating, revising and, possibly, repeating prior work using new TWP-CART derived data. Ideally, these analyses will be done in parallel with more intensive interactions with GCM groups, iteratively testing revised representations of model physics and parameterization based on our results, plus more revised analyses to further examine the implication of model results for the nature of the diurnal cycle.

Acknowledgment

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