On the Fundamental Role of Day Versus Night Radiation Differences in Forcing Nocturnal Convective Maxima and in Assessing Global Warming Prospects

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Abstract

An analyses of Geostationary Meterological Satellite (GMS) data for the tropical West Pacific yields new perspectives on clear/cloud area radiative forcing of enhanced nocturnal convection. Consideration of the tendency for two-to-three-day cycles of intense broadscale convection becomes an important factor in assessing the actual amplitude of clear/cloudy area diurnal forcing. Recurrent systematic net nocturnal removal of moisture over relatively clear areas of the tropical oceans via subsidence appears to have implications for assessing prospects for global warming as well as for enhancing nocturnal convective maxima.

Introduction

Subsidence due to stronger net nocturnal radiative cooling in relatively clear areas of the tropical oceans enhances lower-level convergence into convective areas with the result of a net nocturnal enhancement of strong convection. The effects of enhanced net subsidence in the relatively clear areas includes notable diurnal drying of the upper troposphere and diminished cloud amount throughout the subsidence areas. These subsidence effects constantly feedback to gradually enhance net cooling and subsidence throughout the night and likely, in a cumulative way, on longer-term day to daytime scales as well.

The rate of net cooling and, hence, broadscale subsidence in tropical clear areas is sensitive to the vertical distribution of water vapor; cold moist air at high levels results in slower net column cooling and less subsidence than occurs when a deep layer of very dry air caps moist low level layers of generally warmer air.

Both the causes and effects of differential day-night deep long-wave radiation cooling rates between broad-scale clear versus cloudy areas are discussed by the principle investigator (PI) in a series of papers dating back nearly 20 years. Our new studies have shown these diurnal convective effects to be more pervasive and appreciably stronger than some recent numerical simulation studies have suggested. The work has expanded to create climatological statistics characterizing seasonal and interannual variability of the diurnal cycle of the tropical oceans in time and space as well as links to 30- to 60-day variations in the amplitude of regional convection. The implications of deep drying/moistening for net cooling of the atmosphere are an important issue for assessing the prospects for CO_2-induced global warming. For this reason we are looking closely at these relationships on multiple time scales.

New Results

Various new results are clarifying the basic processes by which diurnal forcing of intense convection occurs in association with spatially varying cooling rates in cloudy versus clear areas. Our recent experiments once again utilize GMS data (8 observations/day; approximately 10-km pixel sampling resolution) for the West Pacific area shown in Figure 1. However, we have recently taken up analyses of extended 8-month time series of 3-hour (i.e, eight per day) observations in place of monthly averaged data studied previously. The tendency for morning maxima of very cold cloud cover (hence, intense convection) is shown in Figure 2. Comparative time series of early morning versus (prior) evening very cold ($<^{-}60$ºC) pixel counts in area 1 (see Figure 1) show a nearly universal morning maximum throughout the 230-day period. The morning convective maximum in Figure 2 is well known; a more important result is shown in Figures 3 and 4 wherein a portion of these same early morning pixel counts are shown, in comparison with estimates of the changes in net outgoing longwave radiation (OLR) between the current morning and the prior evening. Note first that both net OLR and cold pixel counts increase overnight, suggesting that within the domain, increased intense convection is accompanied by increased OLR heat loss within the clear portions of the same general

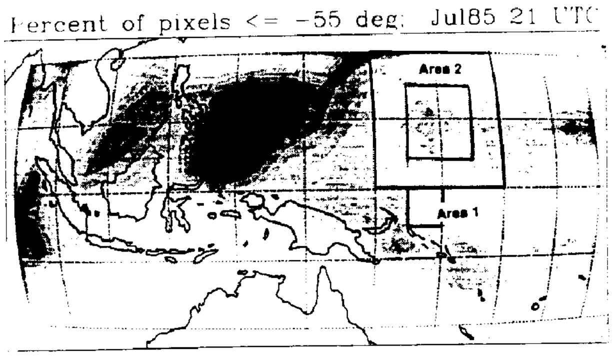

Figure 1. Locator map showing analysis domain for diurnal cycle of intense convection and related processes in three-hourly (i.e., eight images per day) GMS data. The shading indicates time averaged concentrations of intense convection during July. The four areas labeled areas on the map correspond to areas of specific analyses shown in the following figures.

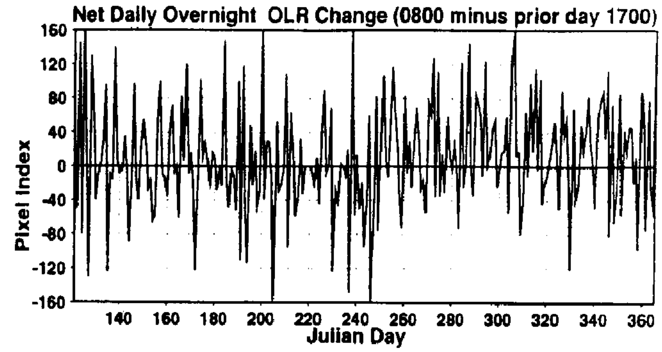

Figure 3. (Dashed line) Time series of the daily net change of pixel index values expressed as morning (0800) minus the value for the prior evening (1700) in Area 1 of Figure 1. Positive values mean increased intense convection in the morning relative to the prior evening. The strong day to day positive/negative alternation of these values indicate a tendency to a two day convective cycle.

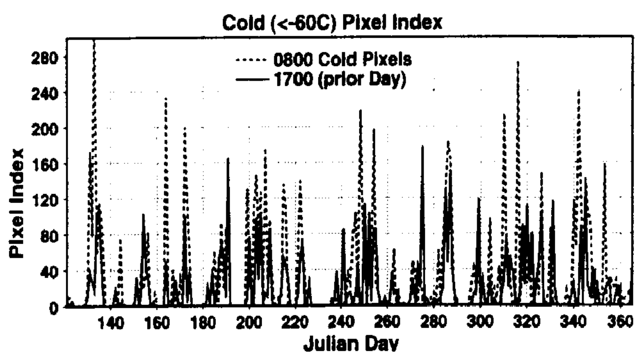

Figure 2. Pixel counts for temperature colder than -60°C in Area 1 (see map in Figure 1). The dashed lines local time 0800 (morning) whereas the sold line local 1700 (late afternoon). Time is represented as the Julian Day.

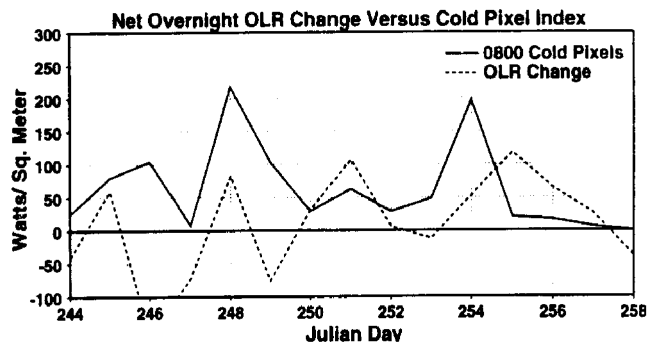

Figure 4. Comparison of morning 0800 minus (prior) afternoon 1700 estimated net OLR (W/m^2) in an adjacent area to the SE versus an index of cold (<-60°C) pixel counts in Area 1.

domain. This tendency occurs on day 248 and again on day 254. Secondly, note that once the deep intense convection is formed (day 248), its effects tend to persist as mid- and higher-level cirrus cloud causing low net cooling values for several days. The latter result illustrates the tendency for strong convection to begin and, when conditions permit, to amplify sharply overnight followed by the formation of a large amount of fairly persistent mid- and high-stratiform cloudiness that lingers (day 249). This lingering cloud tends to inhibit cooling processes which might further intensify (or reintensify) convection on the second day.

This distinct tendency to a 2-day (bidiurnal) or longer cycle of intense convective activity in this region has been discussed recently by Chen and Houze (1996). The prospect of a dominant 2-day cycle of intense convective forces a critical rethinking of the implication of various published time averaged diurnal harmonics of net tropical cooling as they relate to assessments of the strength of various potential diurnal forcing processes. The strong tendency in time to alternating values of the opposite sign arises from the following sequence (in part, after Chen and Houze 1996). Overnight intensification of convection is attended by clearing and subsidence in adjacent areas and hence increased clear area cooling rates and cold pixel counts. This concurrence then gives way to convective decay with rapid expansion of cold cirrus anvil clouds and decreasing net cooling over the area—this trend persisting for 24 or more additional hours—followed by general clearing and the opportunity for a new, clear-area-induced episode of differential nocturnal cooling enhanced intense convection a day or two later. Inspection of Figure 4 shows this tendency to strong 2- to 3-day oscillation but where, on average, net increased morning cooling attends the periods of most active convection. The latter consideration of lower frequency variability is further illustrated in Figure 5 which shows 30- to 60-day band pass filtered net total afternoon (1700) cooling plus the morning minus (prior) afternoon net estimated cooling, similarity filtered. Whereas the net average cooling decreases with generally active convective (MJO) conditions (days 240-270), the net early morning minus late afternoon difference becomes (comparatively) positive with the clear link of the foregoing tendencies to the active versus inactive periods of the MJO. Finally, in Figure 6 we show time-averaged (and hence, to some extent aliased) diurnal variability for broad-scale convection within the inner domain of area 2 (in Figure 1) versus that for the outer day a convectively active 10-day period. A distinct 15 Watt/m^2 nocturnal enhancement of nocturnal cooling is obvious in the outer vicinity area.

Concerning Global Warming

An analysis of 00Z versus 12Z composite rawinsonde data in the West Pacific (Figure 7) shows reduced upper and middle level moisture in the morning hours (08-10LT) in comparison with early evening hours. A radiation model

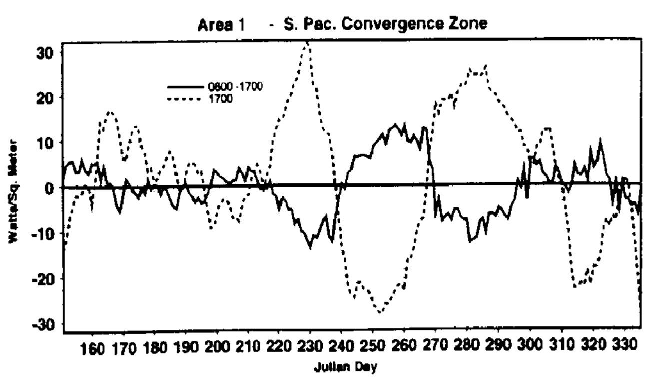

Figure 5. Dashed line band pass filtered (30-60 day) of 1700 (local evening) estimated anomalous cooling whereas the solid line is for similarly filtered morning minus evening (0800-1700) differences (Area 1). Note that convectively active (MJO) periods are indiated by negative values of anomalous 1700 OLR which tend to be concurrent with positive values (increases) of overnight net OLR changes.

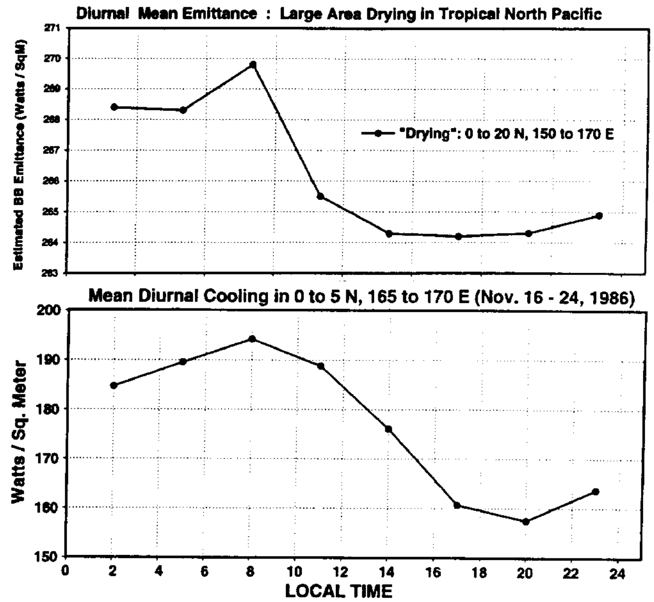

Figure 6. Diurnal cycle of estimated cooling for the inner convectively active portion of Area 1 (see Figure 1) is shown in the top panel and for the surrounding vicinity in the bottom panel.

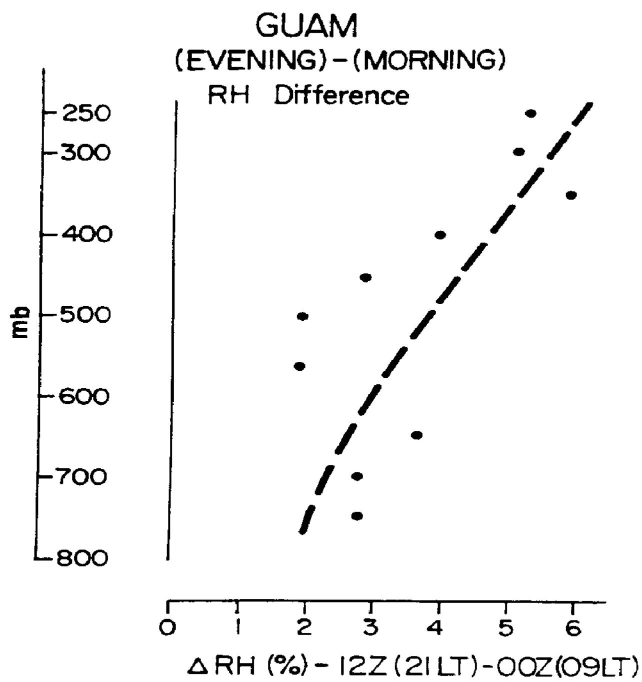

Figure 7. Verticial profile of the mean diurnal change (evening minus morning) of relative humidity expressed as percent during May to August (two years) at Guam. The positive differences signify net drying during the night.

simulation by Stackhouse and Stephens (1991) verifies that the diurnal variation of upper and middle level atmospheric humidity of 5 to 10% would be sufficient to cause a 5 to 10 W/m^2 diurnal variation in longwave radiation. Hence, in a cloud-free tropical oceanic environment a 1% relative humidity (RH) variation at middle and high levels causes an approximate variation of one W/m^2 in infrared (IR) fux to space.

Portions of the cooling differences that we observe in the subsidence areas (e.g., Figures 2 through 6) are due to variable cloud and vapor. We are attempting to partition nocturnal changes in cooling so we can determine which can be attributed to deep moisture change versus variable cloudiness. The actual amplitude of time variations of (diurnal) IR loss to space is due to diurnal variations (low morning, high evening) in middle- and upper-level water vapor resulting from radiational-forced diurnal subsidence differences is potentially important for assessing feedback processes tied to hypothetical greenhouse gas effects. For example, increased CO_2, although causing direct atmosphere and surface radiational gain (~ 4 W/m^2 for CO_2 doubling) may also lead to a tropospheric water vapor decrease which may allow greater IR energy loss to space. Such an association would help to counterbalance much of the direct CO_2 radiation energy gain. The response of the troposphere to CO_2 gain thus has inherent negative feedback processes which should act to greatly reduce or cancel most of the positive warming influence of the humankind-induced CO_2 gains.

Conclusions

The interpretation of the diurnal cycle of OLR over the tropical oceans in terms of a simple 24-hour convective cycle may greatly oversimplify the process and understate the strength of the various radiative forcing components. Inspection of the time series data in the various time/space averaged forms suggests that the radiative forcing associated with clear/cloudy day/night difference may be much greater than recent numerical simulations have suggested. The importance of the diurnally varying vertical distribution of moisture as brought out in these studies also has important implications for the correct interpretation of possible CO_2-induced global warming scenarios.

References

Chen, S., and R. Houze, 1996: Diurnal variation of deep convection systems over the tropical Pacific warm pool. Submitted to *QJRMS*.

Stackhouse, P.W., Jr., and G. Stephens, 1991: A theoretical and observational study of the radiative properties of cirrus: Results from FIRE 1986. *J. Atmos. Sci*., **48**:2044-2059.