Cloud-Radiative Forcing of the Diurnal Cycle of Intense Convection in the Tropical Pacific

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Introduction

This U.S. Department of Energy-Atmospheric Radiation Measurement (DOE-ARM) supported research is concerned with better delineating the nature of the diurnal cycle of intense convection over the tropical oceans and a comparative review of these observations with their implications for numerical (general circulation models [GCM]) climate simulations. Our most recent results further demonstrate that 1) broad scale subsidence at night in relatively clear areas of the tropical Pacific is likely the preeminent factor forcing the observed morning maximum of intense convection, and 2) a systematic diurnal drying effect in the free troposphere also occurs in these subsidence areas wherein the subsidence areas are dryer at sunrise than at dusk. The latter result suggests cumulative drying effects may occur due to this diurnal subsidence cycle acting on various time and space scales with likely positive feedback enhancements. Regardless, comparison of observations versus model results show that numerical simulations of the complex, radiatively driven diurnal subsidence cycles in clear areas are variously weaker and/or out of phase with actual observations. Such model discrepancies have obvious implications for systematic error growth in long-term climate simulations.

Recent Work

This study is focused on clarifying the nature and effects (for climate modeling) of the observed morning maximum of intense convection over the tropical oceans. We have shown: 1) a much sharper diurnal morning maximum of deep convection by carefully focusing on the largest and most intense convective systems in the newer and better data now becoming available; 2) that these cycles and the associated (time) lag factors and spatial scales are consistent with theory emphasizing strong subsidence and divergence due to clear area radiative forcing at night; and 3) that these basic processes are not well (diagnosed) simulated in global numerical (analyses) simulations. Basically, we have concluded that subsidence due to stronger *net* nighttime radiative cooling in clear and/or partly cloudy areas of the tropical oceans enhances lower-level convergence into convective areas, resulting in overnight acceleration, leading to a morning maximum of deep convection.

We have previously explored the effects of enhanced nocturnal net subsidence in the relatively clear areas in causing net overnight drying of the upper troposphere and diminished morning cloud amount within the surrounding subsidence areas (Gray and Sheaffer 1996). The rate of net cooling and, hence, broadscale subsidence in tropical clear areas is sensitive to the vertical distribution of water vapor, where variably moist air at specific levels affects net column cooling and similarly variable rates of net sinking and related ancillary effects. Consequently, these subsidence-drying effects may feed back to gradually enhance net cooling and further subsidence by acting cumulatively on longer-term multi-day time scales.

The results shown in Figure l were developed from the National Oceanic and Atmospheric Administration (NOAA) water vapor project (NVAP) data set (see Randel et al. 1996; data and figure courtesy of D. L. Randel and C. Deser). The darker areas in Figure 1 indicate areas of net overnight (0615 minus 1704 local time) loss of water vapor. The vapor change values in areas of greatest overnight change are on the order of 3-6 percent water vapor in the mid-and-upper levels. The analysis shows clear evidence of mean net nocturnal drying of the troposphere on monthly time scales in the subsidence areas spanning the equator in the tropical Pacific. Light shading indicates convergent-convective areas with net deep tropospheric moistening.

It is well known that the precipitation and high-level outflow from very large intense tropical convective systems acts to dry out the troposphere, whereas smaller less intense convection tends to moisten the tropical troposphere above the boundary layer (see Chen and Houze 1997; Spencer and Braswell 1997). As it is the very large, most intense convective

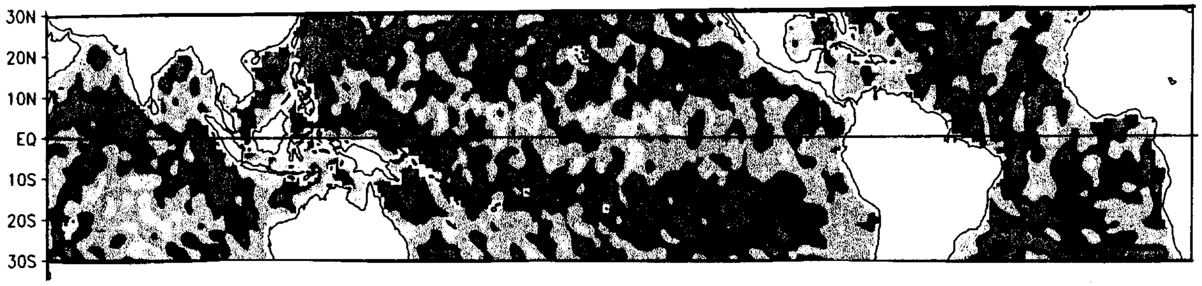

Figure 1. Morning (0615 local time) minus evening (1704 local time) differences in NVAP total column water vapor data for October 1995. Dark areas are negative differences (mornings drier than prior evenings) and the largest monthly mean difference values in subsidence (dry) areas are on the order of 2 mm (data and figure courtesy of D. L. Randel and C. Deser).

systems that show the most pronounced morning maxima, then the observed subsidence drying and the forcing of diurnal variability of intense convection are consistent, compatible processes.

Further, other considerations being equal, atmospheric cooling manifested as net outgoing longwave radiation (OLR) at the top of the tropical atmosphere is greatest for a completely dry-free troposphere. But, because such an atmosphere cools largely at its lower surface, there will be relatively little net nocturnal subsidence induced mass convergence by deep cooling of the free troposphere, as required to drive enhanced intense convection to the observed morning maxima. Rather, some favorable vertical distribution of moisture and a fairly sharp vertical temperature gradient will provide optimal rates of subsidence and mass convergence to regional intense convective systems. Of interest then is the specific vertical distributions of temperature and moisture, which are most effective for engendering maximum rates of net clear-area subsidence/divergence in the Tropical Western Pacific (TWP), and to what extent does the atmosphere converge to this optimum condition in relation to outbreaks of intense morning peaking convective activity (e.g., the active Madden Julian Oscillations [MJO]).

Our current objective is expanding our data base in these efforts to tie observed diurnally variable vertical/spatial moisture distributions in the TWP to subsidence and intense convection; hopefully, to clearly implicate specific moisture distributions as active factors for at least partially modulating the MJO and related low frequency variability of intense convection. This work, in turn, may then establish the very fundamental role of enhanced clear area nocturnal subsidence for accurate numerical simulations of intense tropical convective activity and related deep tropospheric moisture distribution in large scale models.

To these ends, recent work centers on comparative assessments of the diurnal cycles (primarily of vertical motion) occurring in GCMs and in some “reanalysis” (i.e., European Centre for Medium Range Weather Forecasting [ECMWF] and National Centers for Environmental Prediction [NCEP]) data; this work yielding statistics characterizing seasonal and interannual variability of the diurnal cycle of the tropical oceans in time and space as well as links to 30-60 day variations in the amplitude of regional convection. A related goal is to further expand these studies as new TWP data become available.

In general, global models do not resolve a diurnal cycle similar to that which we find in our rawinsonde, satellite, sounder, rainfall and buoy observations. This illustrates two primary model deficiencies: 1. Cloud microphysics and precipitation (efficiency) parameterizations; and global model convection typically function to stabilize lapse-rates. Observations germane to the diurnal processes considered here, however, show that intense convection is more closely related to conditions promoting mass convergence to the convective areas which, we argue, occurs primarily as a consequence of enhanced nocturnal radiational forced subsidence and divergence from the clear and partly cloudy areas 2. Model response to lapse-rate variations are instantaneous and, thereby, lack important lag response characteristics consistently found in the observations. These problems must arise from the climate model microphysics and precipitation schemes.

Acknowledgments

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