A "New" Mechanism for the Diurnal Variation of Convection over the Tropical Western Pacific Ocean

D. B. Parsons
Atmospheric Technology Division
National Center for Atmospheric Research (NCAR)
Boulder, Colorado

J.-L. Redelsperger
Centre National de Recherches Météorologique (CNRM)/GAME
Toulouse, France

K. Yoneyama
Japanese Marine Science and Technology Center (JAMSTEC)
Yokosuka, Japan

Introduction

In the companion abstract in this proceedings (Parsons and Yoneyama 1998), we discussed dry intrusions and their origins. It was found that these dry intrusions over the equatorial waters actually originated in the middle latitude westerly winds. The reader is referred to that paper for discussion of the origins and for further background information on these dry intrusion events. In this paper, we will discuss the impact of these dry intrusions on the atmosphere-ocean system over the Tropical Western Pacific (TWP). We will concentrate on the diurnal cycle of convection that forms in the wakes of these events.

The General Impact of Dry Intrusions on Clouds and Radiation over the TWP

A more detailed study on the impact of a dry intrusion on the atmosphere-ocean system in this region can be found in Parsons et al. (1998). In this section, we will summarize the general results of that study. These results include the following:

- A dry intrusion was shown to impact the boundary layer causing a sudden decrease of ~2 g kg^{-1} to 3 g kg^{-1} in the water vapor mixing ratio in the boundary layer. There was also a deepening of the mixed layer from ~500 km to ~1 km. The mixed layer grew deeper through the incorporation into the boundary layer of dry air from aloft. This dry air had higher momentum, which resulted in a general increase in the wind speed in the boundary layer. This drier, gusty air caused a factor of two increase in the latent heat flux toward values of over 200 W m^{-2}. Strong enhancement of the surface fluxes following a dry intrusion was also noted by Numaguti et al. (1995). Such a large enhancement in the fluxes is typically thought to be only associated with deep convection over the warm pool. These intrusions are common, yet underestimated, in some global circulation models (GCMs). The relatively poor horizontal resolution and the over estimation of vertical mixing are likely reasons for this underestimation. Thus, because GCMs are extremely sensitive to the surface fluxes over this region, there is clearly a need for the better treatment of dry intrusions and their boundary layer effects in GCMs.

- Another suggestion that these events are important in GCMs is the general magnitude of the drying relative to the latent heat flux, which is the primary local source term for water vapor over the warm pool. The estimate of the water vapor budget provided by Parsons et al. (1998) indicates that the water vapor losses from the dry intrusions are nearly ten times the daily gain to the tropospheric water vapor from the latent heat flux. The large magnitude of these values is even more striking when one realizes that a successful climate simulation over this region must typically get the surface fluxes to within ~10% of the mean heat fluxes. The scouring of the water vapor field by these dry intrusions is thus nearly 100 times greater than acceptable error in the latent fluxes.

- From the estimation of the local water vapor budget, Parsons et al. (1998) also suggested that the atmosphere should take on the order of 10 to 20 days to completely recover from a drying event. The details of the recovery process are that the lower troposphere recovers much quicker in only about 7 days due to shallow, precipitating clouds that erode the moist layer from below. The tops of these clouds were typically found to be between 3 km and 7 km. The upper troposphere, however, remains dry long after the arrival of a dry intrusion, which is consistent with the time scale of the recovery estimated from the water vapor budget. The recovery time is larger than the ~3- to 5-day impact proposed by Mapes and Zuidema (1996) on the basis of considering radiative processes.

- During the recovery, the pattern of clouds was modulated and there was a general absence of deep convective activity with stratiform anvils (Figure 1). The link between the arrival of a dry intrusion and a decrease in deep convection has been suggested by previous studies (e.g., Numaguti et al. 1995; Mapes and Zuidema 1996). In terms of the radiation budget at the surface, the decrease in water vapor in the troposphere leads to a modest decrease in the longwave radiation received at the surface. This slight relative cooling of the ocean surface is far exceeded by warming due to solar shortwave heating resulting from a general suppression of anvils clouds. The middle latitude air, thus, has the overall effect of increasing both the sea surface temperatures and the convective available potential energy recharging the energy of the region until the passage of the next active phase of the Intraseasonal Oscillation.

Diurnal Cycle of Convection

The shallow convective clouds that remoisten the lower and middle troposphere following the arrival of a dry intrusion were found to have a precipitation maximum in the evening (Figure 1). This evening maximum was found to be typical of clouds during suppressed periods (e.g., Chen and Houze, Jr. 1997). Prior to the detailed measurements of clouds over the TWP, it was generally thought that clouds with an evening precipitation maximum were most likely forced by nearby land effects. The Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) studies brought the importance of the diurnal variation in the heat fluxes at the ocean surface and proposed that this forcing was responsible for generating convective clouds during the afternoon that had a precipitation maximum in the evening. The process is similar to that of cloud forcing over land masses making the terminology for the TWP as a maritime continent very appropriate.

However, the study by Parsons et al. (1998) suggests that the forcing of clouds does not take place solely by surface processes following the arrival of a dry intrusion. In that study, the vertical profile of long and shortwave radiative transfers was generated using the radiative transfer code of the version 2 of the National Center for Atmospheric Research's (NCAR's) Community Climate Model following the arrival of a dry intrusion (Figure 2). From the vertical profile of long wave cooling, it is clearly evident that there is strong cooling air just below the extremely dry air with values in excess of 5 K^{-1}. Thus, the net effect of this vertical profile is to in general stabilize the atmosphere to convection and specifically to create a stable layer at the base of the dry layer. This effect is well documented in Mapes and Zuidema (1996). The absorption of shortwave radiation acts in the opposite sense to destabilize the atmosphere as there is negligible absorption in the dry layer, but strong absorption of in excess of 4 K day^{-1} in the moist boundary layer.

The quantitative importance of the shortwave absorption term to the diurnal cycle of convection can be obtained from comparing the impact of this term relative to the contribution to the latent and sensible heat flux. In their study, Parsons et al. (1998) found that this term was the most effective at reducing the convective inhibition generated by the long wave cooling and that only the diurnal variation in the latent heat flux had a greater impact on the convective available potential energy. This term will be largest immediately following the arrival of the dry air and decreasing in magnitude as the lower and middle troposphere moistens. It acts in the same sense as the surface fluxes so that as this term gets smaller the diurnal cycle will be of the same sense, but weakened.

It should be noted that there is also a diurnal cycle of deep convection that has an early morning maximum. This diurnal cycle is generally thought to be at least partly related to differences in the radiation budget between clear and cloudy regions. During the intrusions, these types of convective systems are suppressed.

Future Work

Past studies of the diurnal cycle of convection over the TWP were limited by an inability to properly resolve the diurnal cycle as rawinsondes were launched at intervals of twice or four times per day. During the Tropical Ocean and Climate System cruise by the R/V Kaiyo over the TWP, which was partly sponsored by the Atmospheric Radiation Measurement (ARM) Program, the soundings were eight times per day allowing better resolution of the diurnal cycle.

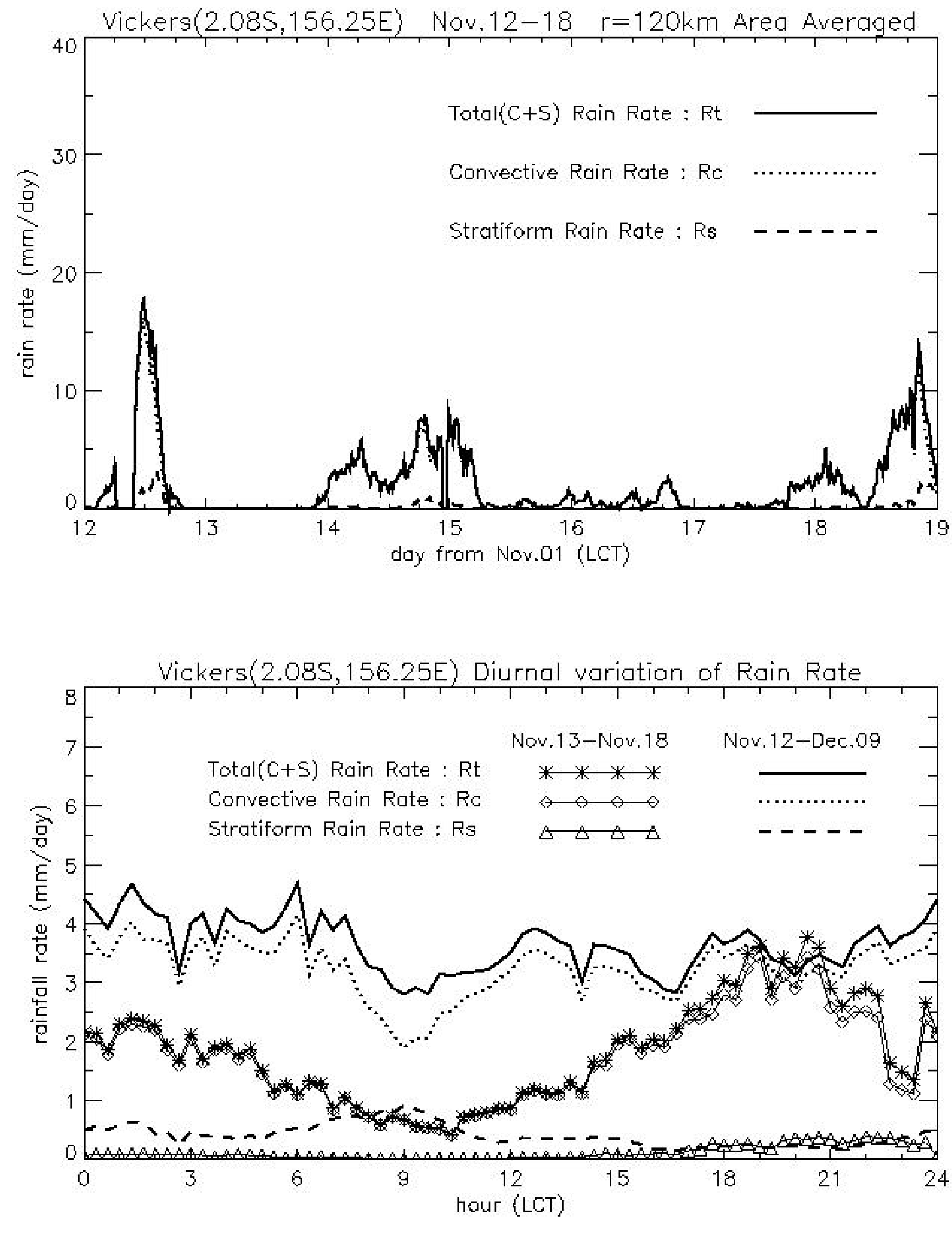

Figure 1. Rain estimates from the Doppler radar aboard the R/V Vickers for the time period of 12 to 18 November 1992. The various curves include total rain rates and rates partitioned into contributions from convective and stratiform rain. a) Time series of rainfall. b) Diurnal variation from compositing the different days during this period. The cruise total is also shown in the panel.

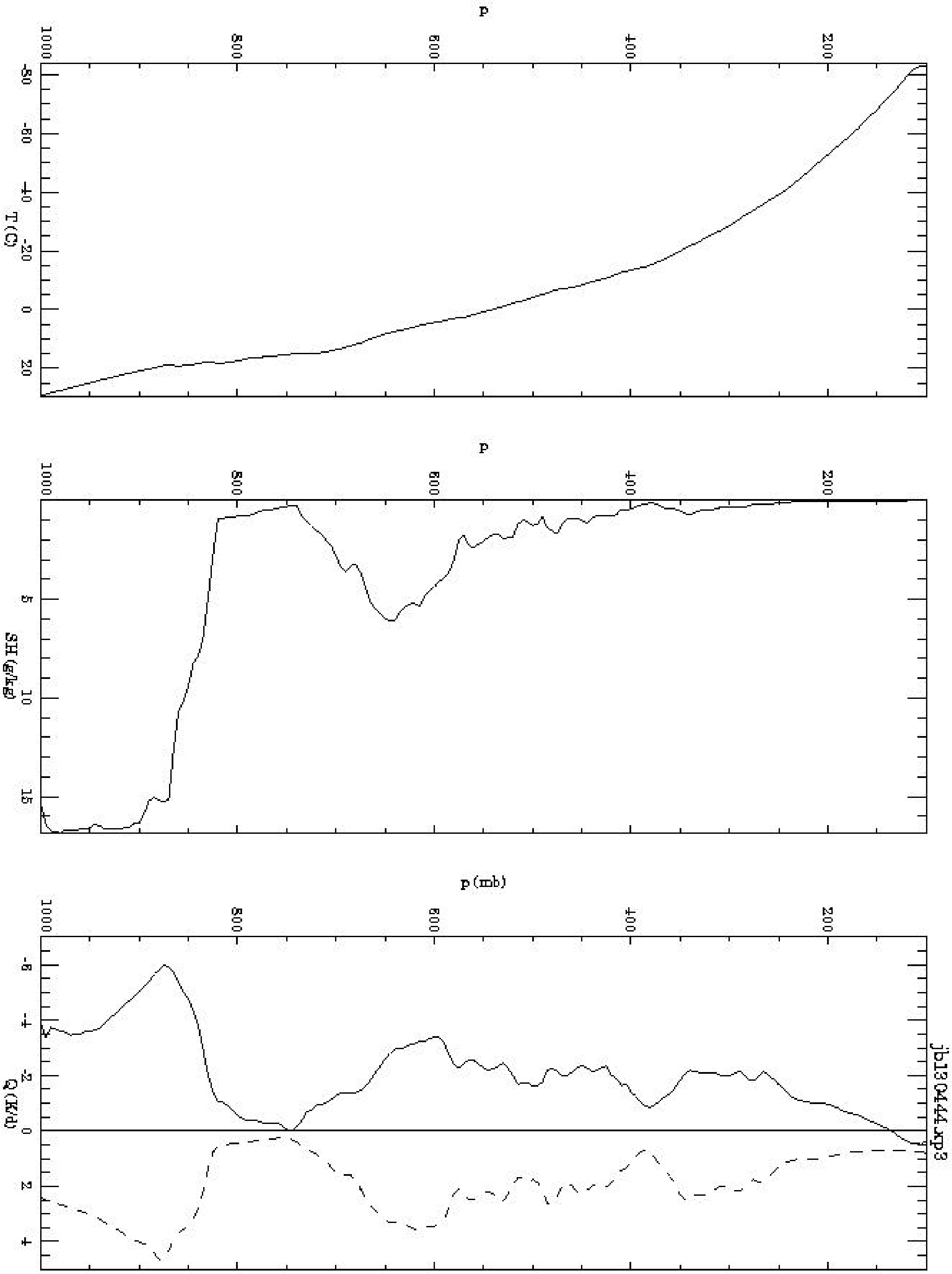

Figure 2. Vertical profile of temperature and specific humidity from a rawinsonde launched at 0440 UTC on 13 November from the R/V Shiyan #3. Also shown is the long wave cooling and shortwave heating profiles obtained from the radiation package used by the NCAR Community Climate Model. This figure was kindly provided by Brian Mapes.

Analysis of the lidar and rawinsonde data is under way in order to better understand the diurnal cycle of clouds and convection over this region. The data set also affords a unique look at the cloud-radiative feedbacks over the open ocean during the formation of an unusually strong El Niño. Cumulus ensemble simulations are also under way using the radiation scheme employed by the European Center for Medium Range Weather Forecasts (ECMWF).

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Other Publications in Progress

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