A Middle Latitude Cause for Drought Periods Over the Tropical Western Pacific

D. B. Parsons
National Center for Atmospheric Research
Boulder, Colorado

K. Yoneyama
Japan Marine Science and Technology Center
Yokosuka, Japan

Introduction

Studies of conditions over the Tropical Western Pacific (TWP) have found instances of extremely dry air in the middle troposphere (e.g., Parsons et al. 1994; Numaguti et al. 1995; Yoneyama and Fujitani 1995; Mapes and Zuidema 1996). These dry air masses can have a zonal extent of ~1000 km and a width of several hundred kilometers. There is often a strong inversion at the base of the dry air, which can tend to inhibit deep convection. An example of a sounding from one of these dry periods is evident in Figure 1.

Recently, Brown and Zhang (1997) have termed these dry periods as tropical droughts due to the general absence of deep convection. At the present time, the cause of these periods of pronounced drying is uncertain with various researchers proposing different theories to explain the existence of these extreme drying events. For example, Mapes and Zuidema (1996) suggested that the dry air arrived over the tropics due to chaotic advection of air from the subtropics into the tropical latitudes. Numaguti et al. (1995) instead proposed that the dry air arrived over the equatorial western Pacific due to horizontal advection from organized waves with periods consistent with mixed Rossby gravity waves. In contrast, Sheu and Liu (1995) suggested that the dry air was advected into the tropics by equatorward flow in association with westerly wind bursts. Thus, while these different researchers agree on the importance of horizontal advection, there is no consensus on the dynamic cause of this advection.

In this study, we will attempt to diagnose the cause of these advective drought events and discuss some implications of our proposed mechanism. Further details on this study can be found in Yoneyama and Parsons (1998). In our companion paper in this volume of extended abstracts (Parsons et al. 1998), we will detail these so-called drought periods in greater detail focusing in on the nature of the cloud and radiation fields.

Frequency of the Events and Trajectories

From our examination of Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) data, we suspect that these events are fairly common. During the 4-month intensive observation period (IOP), the dry events were present at the TWP between ~10% and 17% of the time. The range in the estimates depends on how one defines a drying event. Examples of the frequency and duration of dry air over this region is shown in Figure 2 for both a single site and an average over the region. From this figure, it is evident that the extreme drying lasts on an order of 3 to 7 days. From Figure 2c, it is evident that the global analysis underestimates the magnitude of the drying.

In order to determine the mechanism by which the dry air arrives over the TWP, we calculated three-dimensional trajectories using data from two operational general circulation models: the Global Analysis Dataset (GANAL) of the Japan Meteorological Agency and the European Center for Medium Range Weather Prediction (ECMWF). The starting point for these trajectories was when there was a dry air event over Kapingamarangi Atoll located just off of the equator.

The horizontal and vertical projections of these trajectories are shown in Figures 3 and 4. From these figures, it is evident that the dry air does not originate in the subtropical trade wind environment, but instead originates on the fringes of the middle latitude westerlies. The dry air most frequently originates in the winter hemisphere with only one

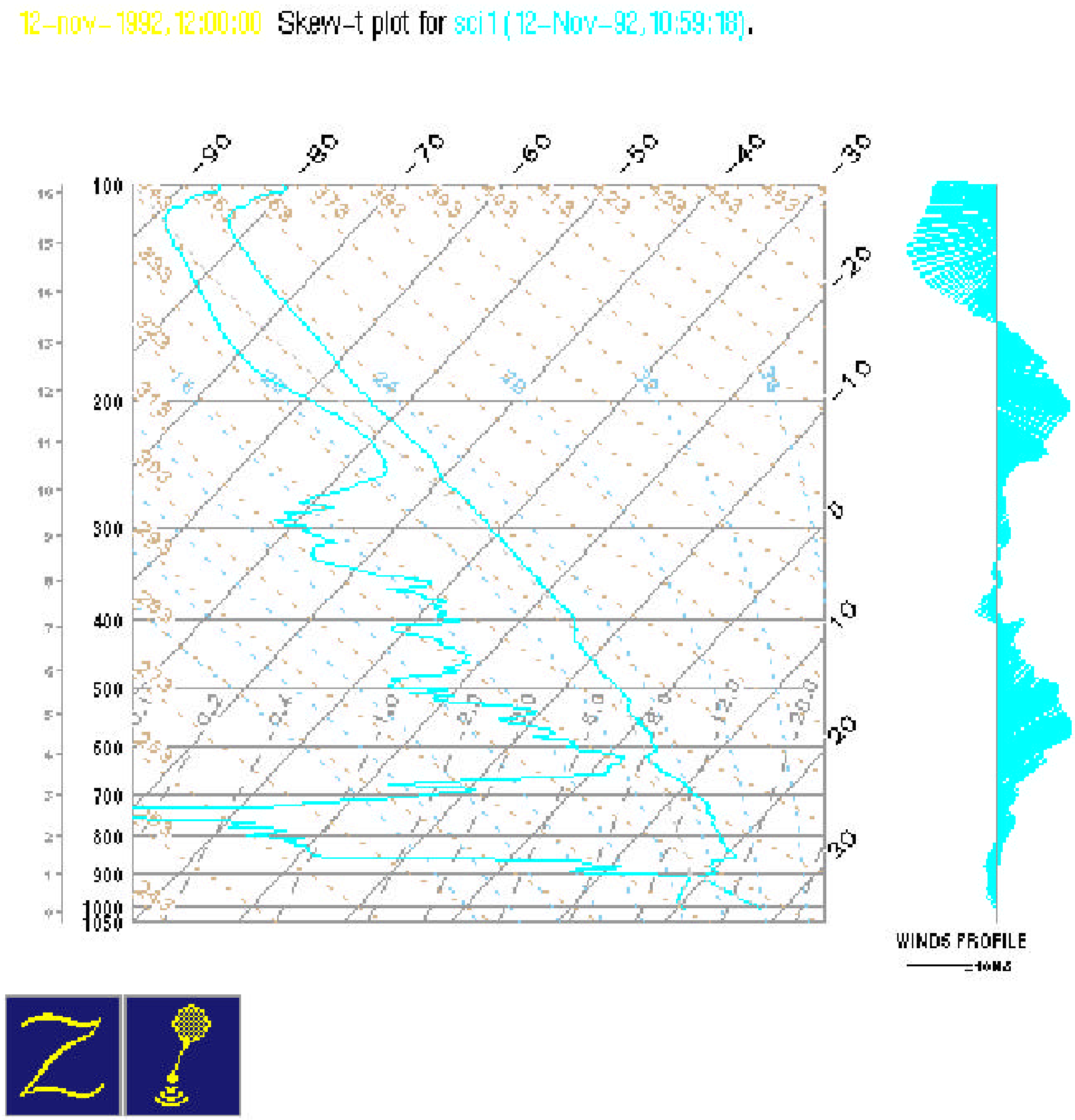

Figure 1. Data from a rawinsonde displayed on a skew-t plot. The sounding was launched from the R/V Kexue #1 on 1100 UTC on 12 November 1992. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/parsons-98.pdf*.)

event from the southern hemisphere. The general consistency of the trajectories from the different events is inconsistent with the chaotic advection mechanism proposed by Mapes and Zuidema (1996).

The nature of the vertical component of the trajectories suggests that the air subsides gently as it moves equatorward. During this period, only one case originated in tropical latitudes. This single tropical trajectory had the strongest descent. In general, however, the very dry air in the troposphere over the TWP does not come about from strong subsidence of tropical air, as perhaps generally thought, during the suppressed phases of the Intraseasonal Oscillation, but from the importation of air from higher latitudes.

Mechanism

Through a synoptic analysis of each of the dry air events shown in the previously discussed trajectories, we propose that the dry air was advected from the fringes of the middle

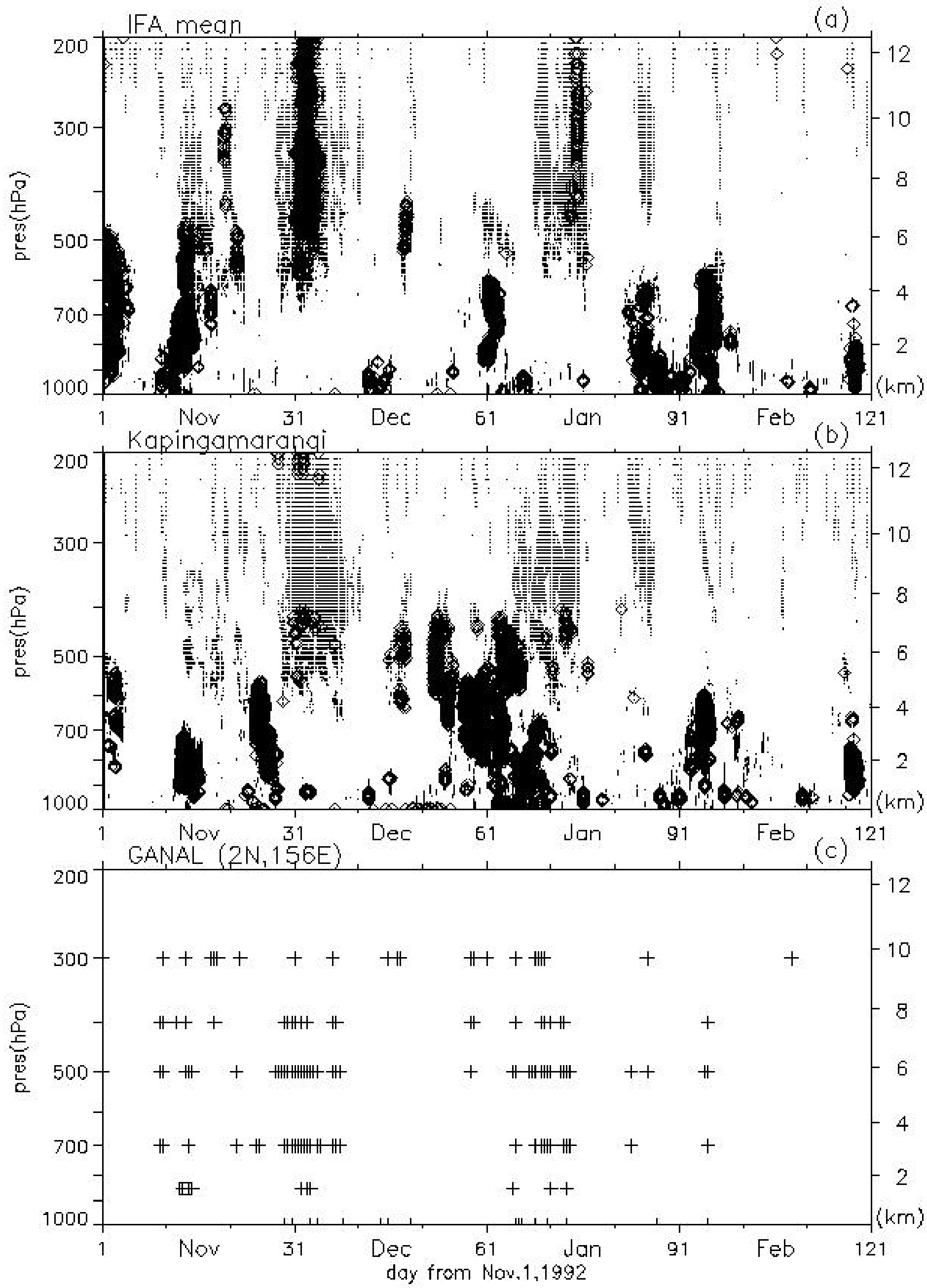

Figure 2. A time-height diagram showing the characteristics of the dry air over the TOGA-COARE Intensive Flux Array. Panel (a) represents the average of the inner sounding sites and (b) represents the conditions at a single site (Kapingamarangi Atoll). Both panels are based on soundings at 6-h intervals. In (a) and (b) the dashes and diamonds indicate the depressions in the water vapor mixing ratio of 1 and 2 standard deviations from the 4-month IOP mean, respectively. Panel (c) represents data from the GANAL global analysis showing that this analysis underestimates the total drying. In this panel the plus symbols replace the dashes to better show the events in this twice daily analysis.

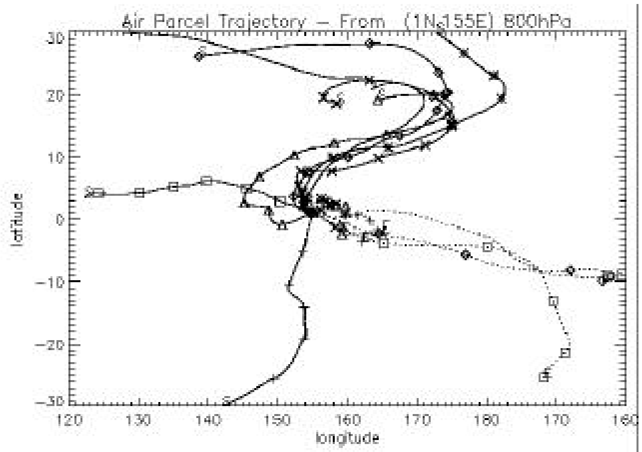

Figure 3. Horizontal components of the trajectories calculated for the dry air events that took place over the Kapingamarangi Aatoll during TOGA-COARE.

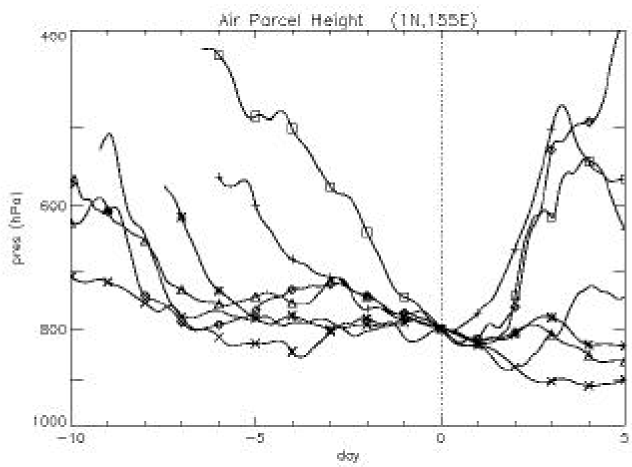

Figure 4. Vertical components of the trajectories shown in Figure 3.

latitude westerlies into the tropical regions in association with the troughs of middle latitude baroclinic waves. As these waves propagated toward the tropics, the troughs thinned and became oriented NE-SW (for troughs in the northern hemisphere). The dynamics of this process are described in Thorncroft et al. (1993) and can be thought of as Rossby wave breaking.

The supporting details for our proposed mechanism can be found in Yoneyama and Parsons (1998). In this paper, we will only show that for each dry period, there was a trough extending from higher latitudes into the tropics (Figure 5). The trough is responsible for depositing middle level air into the tropics, where it can reach equatorial areas when the flow in the tropics is favorable (i.e., equatorward). Because favorable flow includes confluent flow associated with westerly wind bursts and disturbances with time periods similar to mixed Rossby gravity waves, it is not surprising that past studies concentrated on these mechanisms. These previous studies, however, concentrated on the tropics and, therefore, were not able to link these events to middle latitude processes.

Some Implications

Although the behavior of the atmosphere-ocean system and the radiation budget will be treated in our other extended abstract in this volume, we will briefly discuss some implications of these results to our larger-scale understanding of conditions over the TWP. The general budget of water vapor in the tropics is a critical parameter in the prediction of global change and, of course, in the general characteristics of radiation transfer over the tropics. This study suggests that the lateral advection of dry air into the tropics is an important component of the moisture budget in the TWP. The journal article on which this extended abstract is based makes the case that this advection may be poorly represented in some global climate models (GCMs). The poor representation is expected since the Throncroft et al. (1993) study of wave breaking events shows that accurate representation of the wave breaking process depends on the horizontal resolution of the model. A direct implication of this study is that there is significant room for improvement in the prediction of the radiative transfers over the TWP in some climate models through better prediction of the exchange of air between the tropics and higher latitudes. Fortunately, some of this improvement should be a natural function of the general trend toward increasing the resolution of numerical models brought about by improvements in computer technology.

A strong limitation of this study is the dependence on TOGA-COARE data over the western Pacific. Thus, there is little known about the seasonal and interannual variation in these dry intrusions. For example, it is not known whether these intrusions tend to vary in magnitude and frequency according to changes in the El Niño-Southern Oscillation (ENSO) cycle. Because there are strong changes in the tropical and to some degree even the middle latitude circulations with the ENSO cycle, one should expect changes in the nature of the intrusions as wave breaking may take place at different zonal and meridional locations. There may also be seasonal changes as our results suggest that most of the dry air originates in the winter hemisphere. The data from the ARM Atmospheric Radiation and Cloud Sites in the TWP, particularly at Nauru, is especially well suited for the examination of the long-term variation of these parameters.

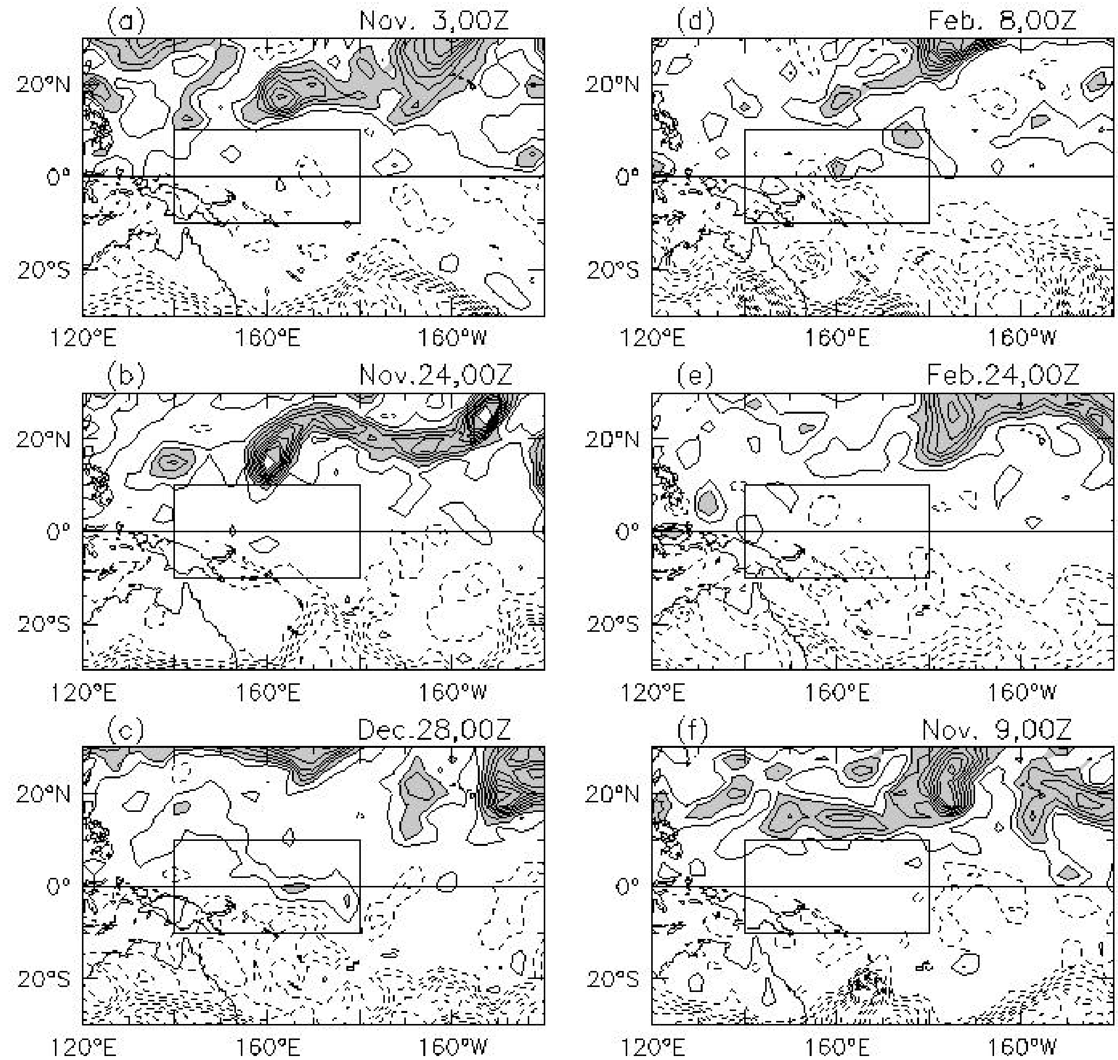

Figure 5. Horizontal cross-sections of absolute vorticity from the ECMWF analysis at the 200 hPa level at 00 UTC on (a) 3 November 1992, (b) 24 November 1992, 24 November 1992, 28 December 1992, (e) 24 February 1993 for the northern hemispheric events, and (f) 9 November 1992 for the single southern hemispheric event, respectively. The Contour interval is 2 x 10^{-5} s^{-1} and the 0 s^{-1} interval is not shown. Vorticity greater than 1 x 10^{-4} s^{-} is shaded. The rectangle denotes the TWP region.

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