Wind Profiler Related Research in the Tropical Pacific

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ABSTRACT

This paper is broadly concerned with the application of wind profiling Doppler radar technology to tropical atmospheric research. Examples of the use of wind profilers in the tropics are drawn from the Aeronomy Laboratory's wind profilers located on Pohnpei (7°N, 158°E) and Christmas Island (2°N, 157°W). The Pohnpei wind profiler was constructed in 1984 and has been used exclusively to observe vertical motions. The Christmas Island wind profiler has observed horizontal and vertical velocities routinely since 1986. These two wind profilers form part of a planned trans-Pacific network of wind-profiling radars that will eventually span the tropical Pacific.

1. Introduction

The past decade has seen a rapid increase in the use of wind-profiling Doppler radars in atmospheric research (Gage, 1989). With a few notable exceptions most atmospheric research using wind profilers has been carried out with individual radars. With the current wide-spread acceptance of clear-air radar wind-profiling technology, field programs are increasingly taking advantage of the continuous wind observations available from wind profilers. While much of the wind profiler research community has been focused on mid-latitude atmospheric research, the Aeronomy Laboratory's Tropical Dynamics and Climate Program has focused its attention on the use of wind profilers in the tropics to study the scale interactions that take place between tropical convection and large-scale atmospheric circulation systems. Because the wind profilers observe vertical as well as horizontal motions, the relationship between atmospheric vertical motions and convective systems in the tropics can now be examined directly.

The wind observations from the new wind profilers augment the existing base of conventional observations available in the tropics. For example, wind observations from Christmas Island are routinely transmitted via GOES satellite and input into the Global Telecommunications System (GTS) for world-wide dissemination. These observations are already being used routinely by the National Meteorological Center (NMC) and the European Center for Medium Range Weather Forecasts (ECMWF) in their analysis and forecast products (Gage et al., 1988).

This paper is broadly concerned with the application of wind profiling technology to tropical atmospheric research. Specifically, we will present some preliminary results of wind profiler studies of tropical convection using observations of vertical motions from the Pohnpei wind profiler and present some sample of wind observations made by the Christmas Island wind profiler. We conclude the paper with a discussion of plans to construct a trans-Pacific wind profiler network designed to support studies of equatorial waves and large-scale atmospheric circulation systems associated with El Nino-Southern Oscillation (ENSO) phenomena.

2. Studies of tropical convection using the Pohnpei profiler

The Aeronomy Laboratory has pioneered the use of wind profilers in the tropics since 1984 when the Pohnpei wind profiler was installed. The Pohnpei profiler has been used to measure continuously vertical velocities over Pohnpei. These vertical motions have been related to convective storms and rainfall by Balsley et al (1988) and the influence of topography at Pohnpei on the observed vertical motions has been considered by Balsley and Carter (1989).

The ability of wind-profiling Doppler radars to measure directly vertical motions provides a useful technique for observing tropical convective systems. Figure 1 shows the signature of a deep convective system as it passed over the Pohnpei radar on 20 November 1984. Strong updrafts as shown here probably represent the first direct measurement of the convective "hot towers" discussed by Riehl and Malkus (1958). These convective storms are invariably associated with heavy rain as recorded at the surface.

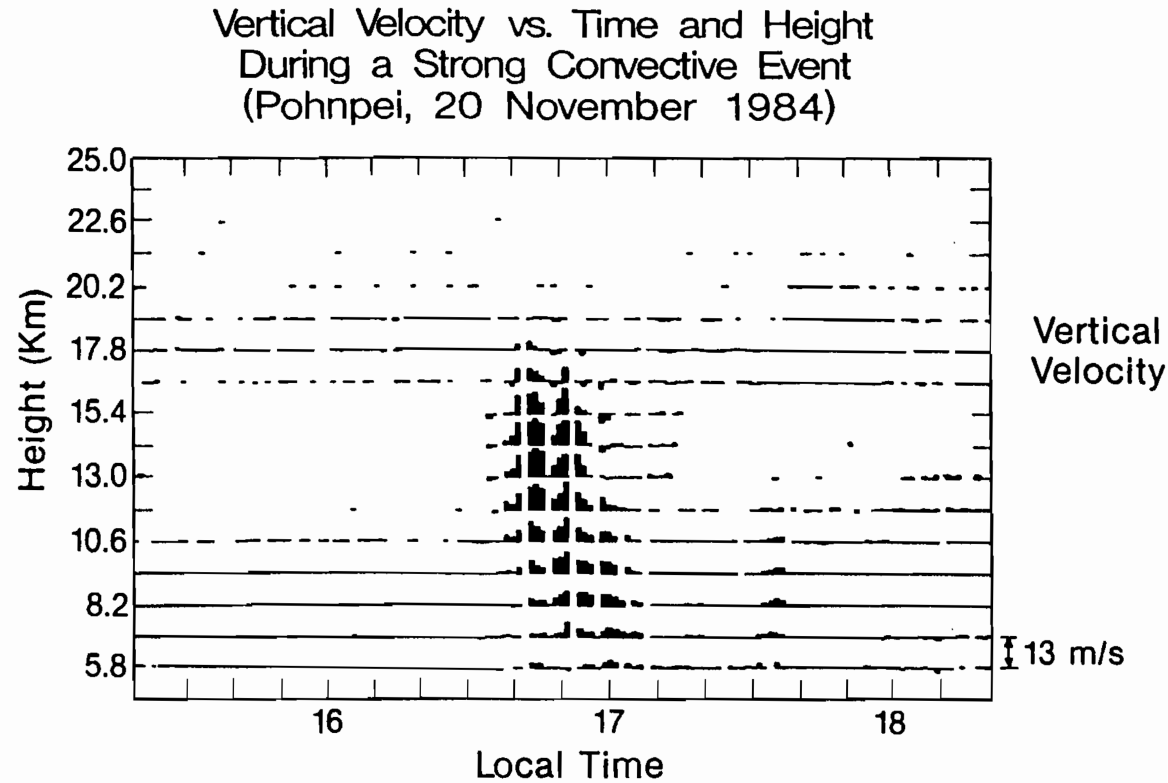

FIG.1. Signature of convective "hot tower" as seen by the Pohnpei wind profiler.

Average vertical motions seen by the Pohnpei wind profiler during its first two years or operation have been stratified by rainfall rate from surface measurements to reveal how the vertical motion field is affected by the presence or absence of convection. The results of this study published by Balsley et al (1988) are shown in Figures 2-4. Figure 2 shows the results obtained when the heaviest rainfall periods are averaged. The most intense vertical motion of magnitude 100 cm s^{-1} are observed in the height range of 8-14 km. Also shown in Figure 2 is the vertical velocity profile deduced by Gamache and Houze (1982) for the eastern Atlantic during GATE. The direct measurements are seen to yield peak velocities to considerably higher altitudes than for Gamache and Houze's result. Indirect measurements of average vertical motions in convective systems

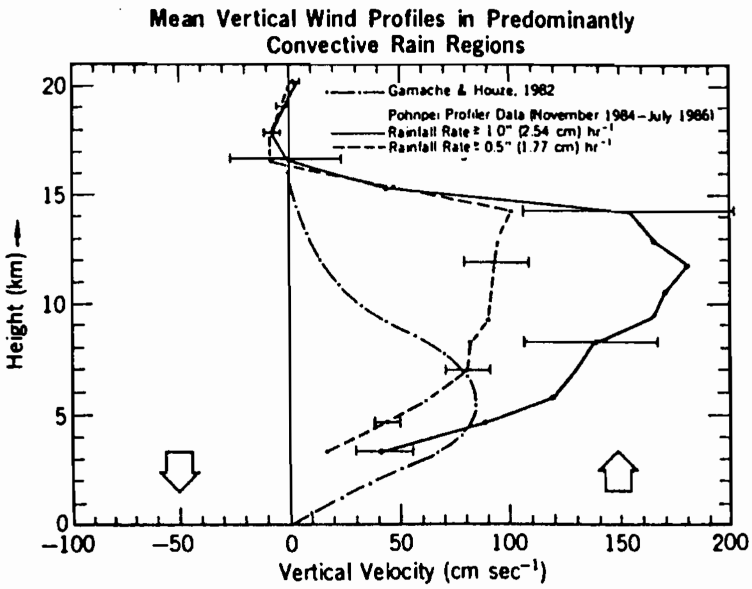

Fig. 2. Average vertical wind profiles from the Pohnpei profiler for rainfall rates corresponding as closely as possible to convective conditions. (After Balsley et al, 1988.)

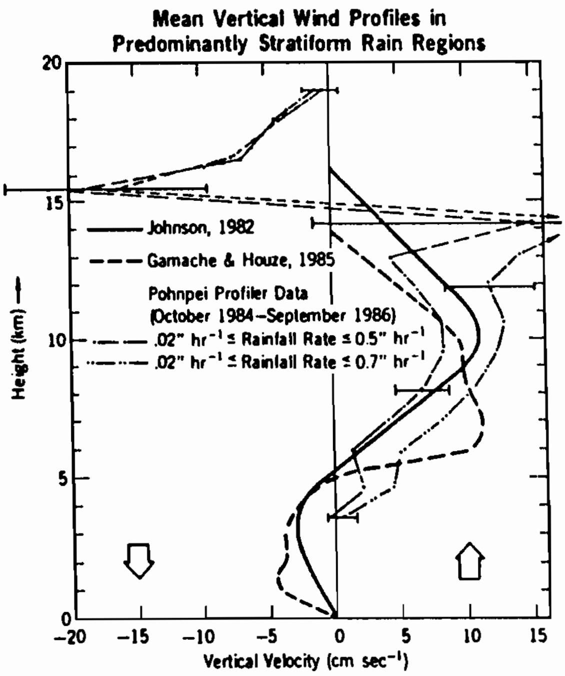

Fig. 3. Average vertical wind profiles from the Pohnpei profiler between Oct. 1984 and Sept. 1986 for rainfall rates corresponding as closely as possible to stratiform conditions. (After Balsley et al, 1988.)

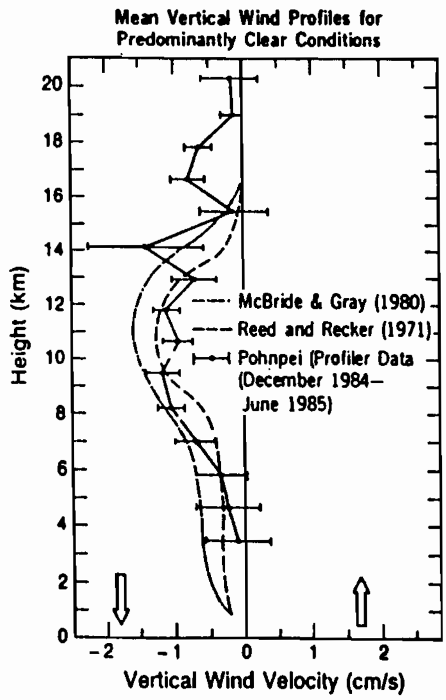

Fig. 4. Average vertical wind profile determined by the Pohnpei wind profiler for 250 hourly periods between Dec. 1984 and June 1985, when the sky cover was ≤ 30% as determined by the Pohnpei weather station. (After Balsley et al, 1988.)

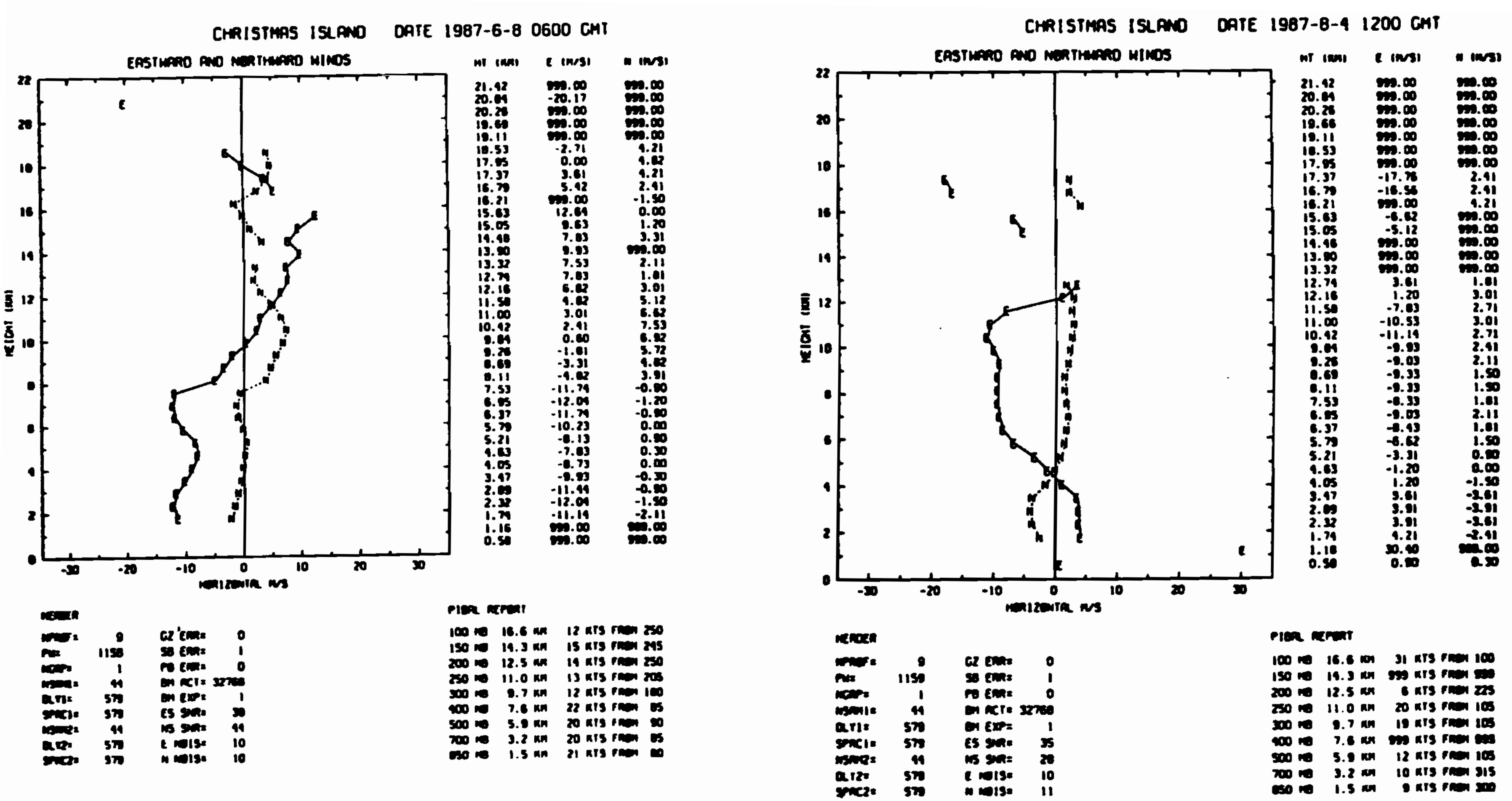

Fig. 5. Sample wind profiles as transmitted via GOES. A typical profile with easterly trades is shown in (a). A profile with westerly low-level winds during the 1986-1987 El Niño is shown in (b).

have been determined by Reed and Recker (1971) and these also show a similar disparity with the GATE results. The vertical profile of condensation heating is related to the vertical motion profile. As pointed out by Hartmann et al (1984), the vertical distribution of diabatic heating in the tropics is important for the parameterization of global climate models.

Much of the rain that falls in the tropics is now thought to be associated with mesoscale convective systems. Rainfall in the tropical convective systems is comprised of heavy showers of limited duration and lighter more persistent rainfall. The persistent rainfall is called stratiform rain and is inherent to the mesoscale convective system. Figure 3 shows average vertical motions in predominantly stratiform rainfall regions as deduced from the direct vertical velocity measurements using the Pohnpei wind profiler. The observed profile at Pohnpei is very consistent with the profile determined for GATE by Gamache and Houze (1985). The downward velocity at the lowest heights is commonly associated with stratiform rain in mesoscale convective systems.

For predominantly clear conditions at Pohnpei, average vertical motion is observed to be downward at all heights as shown in Figure 4. The magnitude of the mean descending motion is what is required to balance the radiative cooling to space. In magnitude and shape the Pohnpei measurements agree well with indirect determinations by Reed and Recker (1971) and McBride and Gray (1980).

3. Observations of tropical winds using the Christmas Island wind profiler

The Christmas Island wind profiler was constructed by the Aeronomy Laboratory in 1985 and became operational in March 1986. The Christmas Island wind profiler has three fixed beams and routinely measures horizontal and vertical velocities. Hourly-averaged wind observations from the Christmas Island profiler are routinely transmitted four times daily via satellite and input onto the GTS. Examples of the wind profiles as transmitted over satellite and received in our laboratory are reproduced in Figure 5. In addition to the summaries of wind transmitted via satellite, detailed horizontal and vertical velocities are recorded at the profiler site on christmas Island and archived in our laboratory.

Wind observations from Christmas Island are routinely used by NMC and ECMWF in their operational analysis and forecast products. Gage et al (1988) compared the Christmas Island observations with the analyses of both centers. A sample comparison for zonal winds at 500 mb is shown in Figure 6. Statistics of the standard deviation and bias of the observed winds relative to the analyses is show, in Figure 7 and Figure 8, respectively. Improvement is considerable in both standard deviation and bias after the introduction of the winds into the analyses. The Christmas island winds were first used in the NMC analyses in mid-January 1987 and in the ECMWF analyses in April 1987.

Monthly summaries of Christmas Island winds are published in NOAA's Climate Diagnostics Bulletin. A sample monthly vector plot of Christmas island winds for April 1989 is reproduced in Figure 9. The monthly summaries are useful for detecting the presence of intraseasonal wind oscillations. Such oscillations are very common in the Christmas Island winds especially in the upper troposphere.

Zonal wind profiles for Christmas Island are shown as annual summaries in Figure 10 and Figure 11. These figures show clearly low-frequency variations associated with the changing phase of the Southern Oscillation. Much of 1987 shows fairly deep weak easterlies during the El Nino. In marked contrast 1988 shows strong low-level easterlies and strong upper tropospheric westerlies. Unfortunately, the length of wind observations at Christmas Island is too short to permit us to define the annual mean winds.

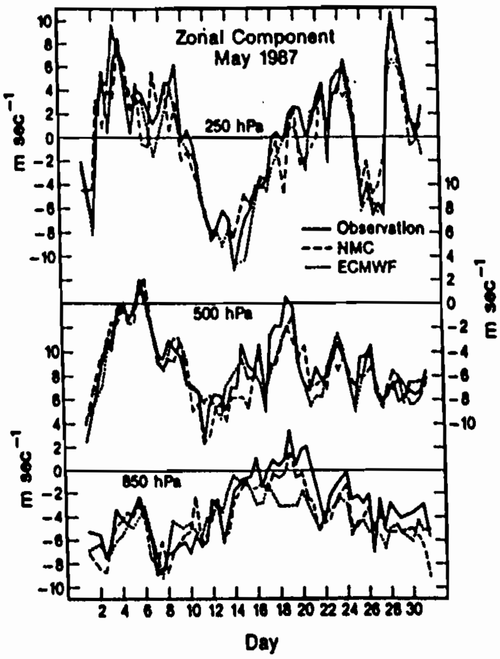

Fig. 6. Multi-height time series of zonal winds observed at Christmas Island for the month of May 1987. Interpolated NMC and ECMWF analyses are shown for comparison. (After Gage et al. 1988).

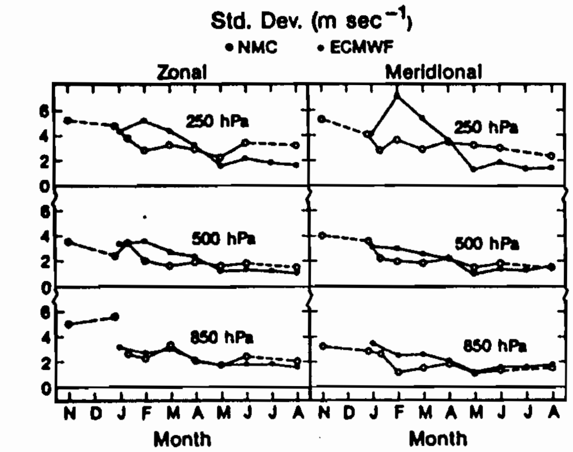

Fig. 7. Time series of monthly standard deviation of Christmas Island winds compared to NMC and ECMWF analyses. (After Gage et al, 1988.)

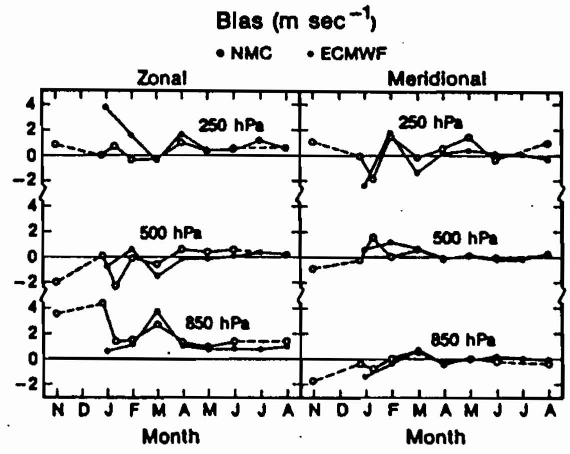

Fig. 8. Time series of monthly bias of Christmas Island winds compared to NMC and ECMWF analyses. (After Gage et al, 1988.)

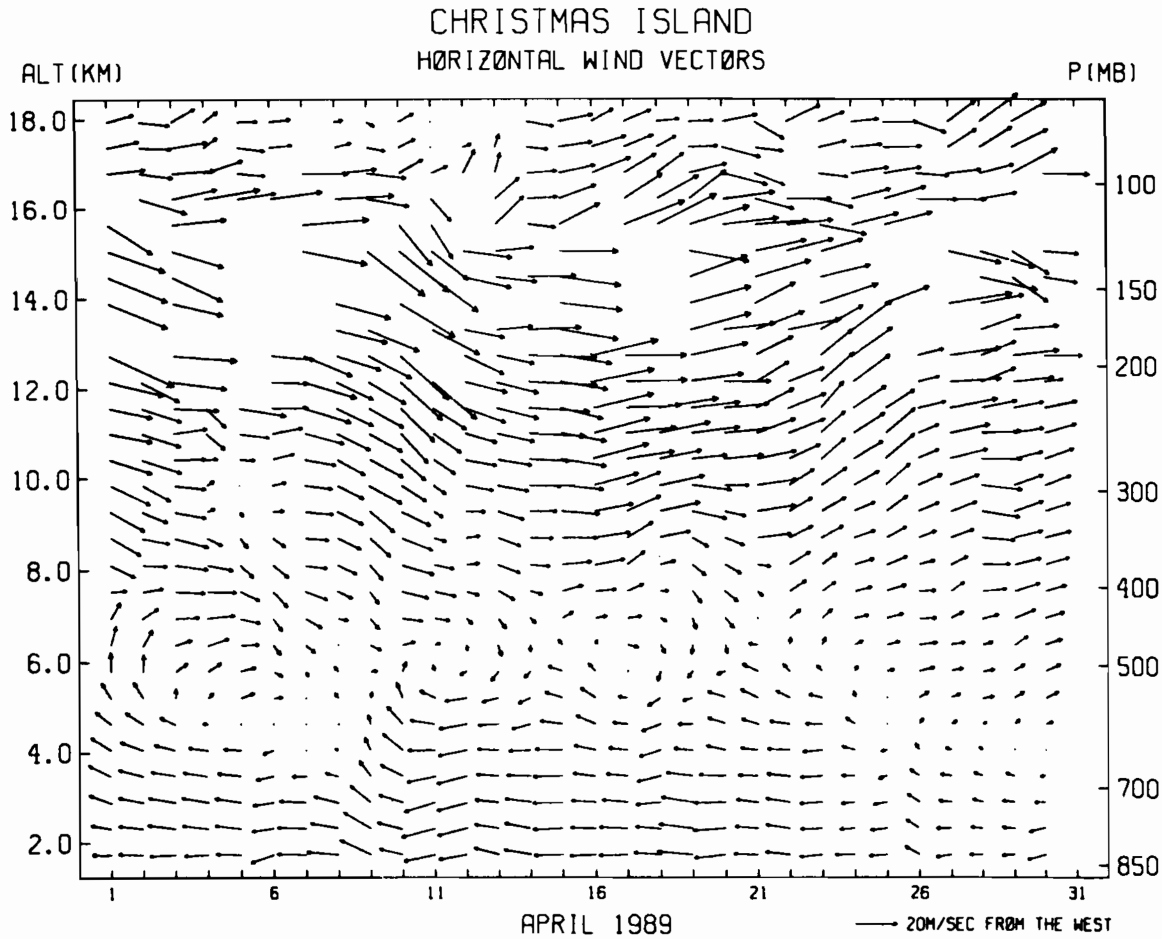

FIG.9. Monthly summary plot of Christmas Island wind vectors for April 1989.

4. A trans-Pacific network of wind profilers

As is well known, the atmosphere across the tropical Pacific is far from uniform. Sea surface temperatures are typically much warmer in the western Pacific than they are in the central and eastern Pacific. Convection tends to be concentrated over the warm water which normally resides in the western Pacific. As shown in Figure 12, large-scale ascent typically occurs centered over the western Pacific and Indonesian maritime continent. This zonal Walker Circulation is most pronounced during the anti-El Nino phase of the Southern Oscillation which represents the quasi periodic interannual variation of the Walker circulation (Rasmusson and Wallace, 1983).

The intraseasonal, seasonal, and interannual variations in tropical sea surface temperature, tropical convection and atmospheric circulation systems is a subject of much contemporary research. Variations in the longitudinal distribution of tropical convection are evident in patterns of outgoing long-wave radiation measured by satellite (Lau and Chan, 1985). Systematic patterns of low-level convergence and upper-level divergence are clearly associated with the regions of most intense convection (Weikmann, 1983). The influence of the non-uniform distribution of tropical convection across the Pacific basin is evident in the longitudinal variation of tropopause properties as discussed by Gage et al (1987). Recent diagnostic studies by Reid et al (1989) show

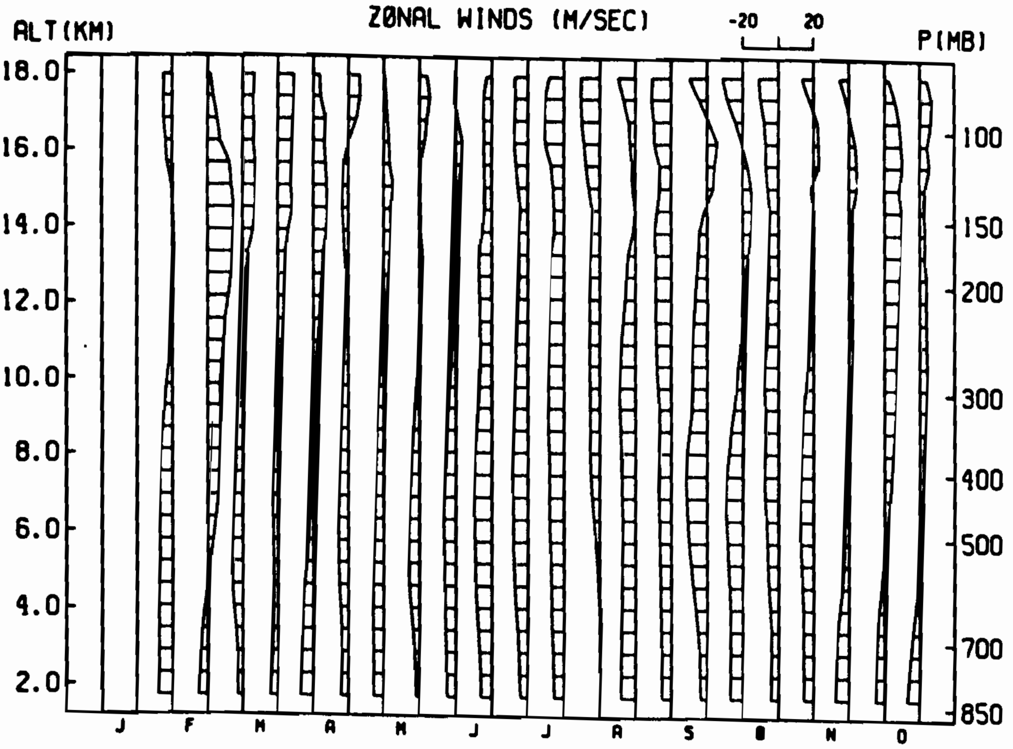

FIG.10. Annual summary of Christmas Island zonal winds for 1987.

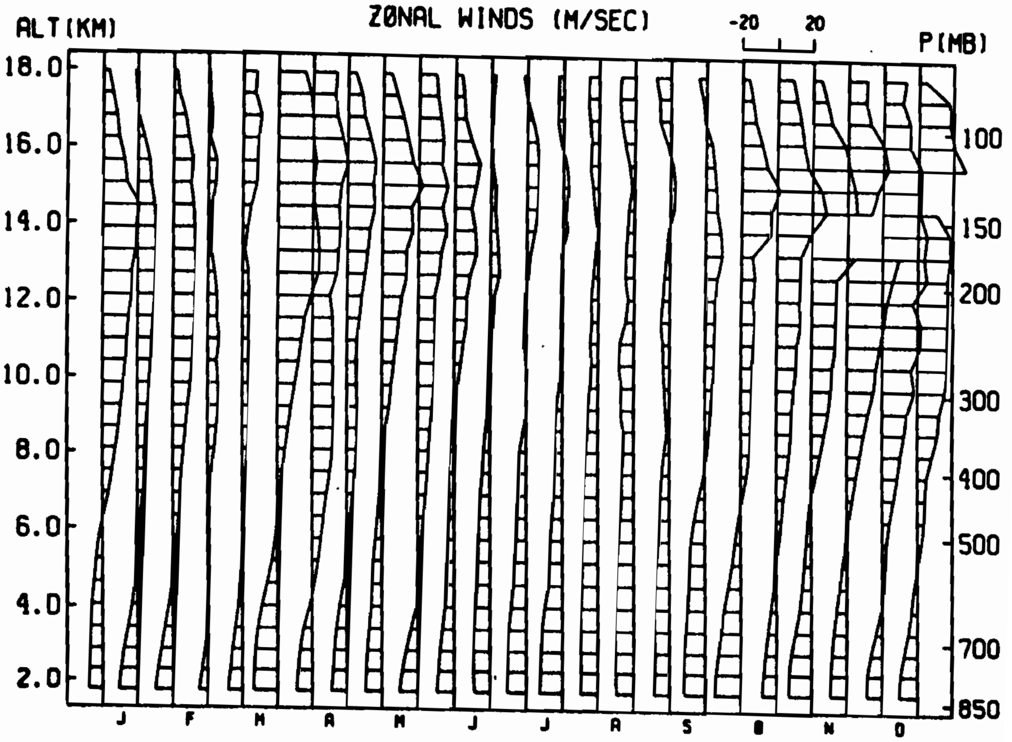

FIG.11. Annual summary of Christmas Island zonal winds for 1988.

that the influence of the ENSO signal can be seen at least into the lower stratosphere. It is thought that the influence of the varying tropical heating patterns create global teleconnections that influence weather around the globe (Horel and Wallace, 1981).

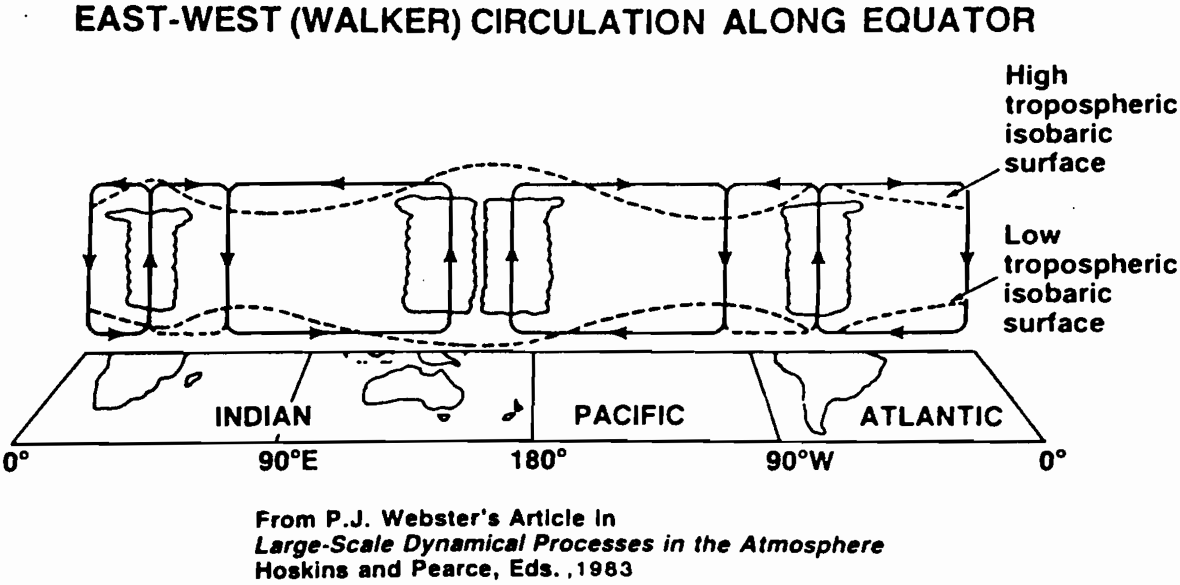

FIG.12. Walker circulation along the equator. (After Webster, 1983).

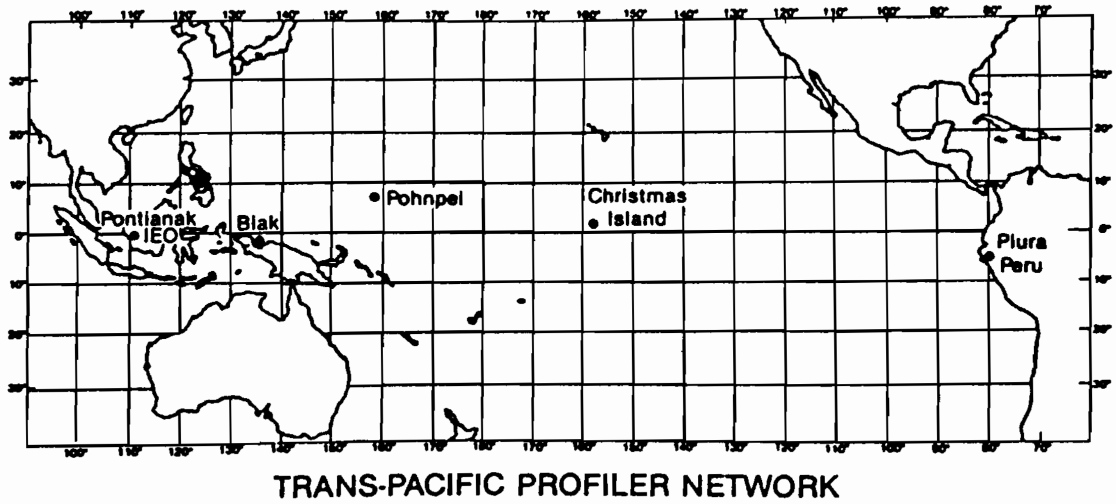

FIG.13. Planned trans-Pacific network of tropical wind profilers.

Clearly, an understanding of the coupled ocean atmosphere dynamics that governs the ENSO phenomena is of prime importance in making further progress in climate forecasting. The Tropical Ocean Global Atmosphere (TOGA) Program is an international program designed to develop an understanding of the coupled ocean atmosphere system over the tropics. An important part of the TOGA effort is an intensive ten-year monitoring program to observe the tropical oceans and atmosphere.

Evidence is accumulating that the western Pacific region plays a key role in the initiation of ENSO events (Lukas, 1988). Since the processes that give rise to the El Nino are so poorly understood, a coordinated effort is needed in the western Pacific to develop the requisite understanding to make further progress (Lukas and Webster, 1988). The TOGA Coupled Ocean Atmosphere Response Experiment (COARE) is planned for the early 1990's.

Figure 13 shows the Pacific ocean basin and the location of the proposed network of wind profilers. Profilers are already located at Pohnpei and Christmas Island. At the eastern end of the network a wind profiler is under construction at Piura, Peru. At the western end we plan to construct a wind profiler at Biak, Indonesia, in cooperation with the Indonesian National Institute of Aeronautics and Aerospace (LAPAN). When the planned International Equatorial Observatory (IEO) is taken into account, a truly international network of at least five wind profilers will eventually span the equatorial Pacific.

Wind observations from the proposed network should greatly aid the TOGA observational effort and provide a valuable new source of observations to explore a variety of dynamical phenomena in the tropics. The western stations should be well placed to be of use to the TOGA COARE experiment. The proximity of the network stations to the equator and the lack of other near equatorial stations will provide a new source of observations for the study of equatorial waves.

5. Concluding remarks

Consideration of the current base of wind observations that are used in contemporary operational global analyses and forecasts shows major deficiencies over the tropics. Furthermore, owing to the diversity of tropical circulation systems ranging from the scale of convection to the scale of the Walker and Hadley circulations, there is a need to better understand the scale interactions that take place in the tropical atmosphere. At the same time it is important to press forward on research aimed at better understanding of the coupled dynamics of the atmosphere and ocean.

A network of wind profilers spanning the tropical Pacific can contribute substantially to further progress in understanding the dynamics of the tropical atmosphere. Additionally, observations from the wind profilers could be used to overcome deficiencies in the global observation system. Furthermore, long continuous records of wind observations from these stations should prove invaluable in monitoring interannual variations in large-scale atmospheric circulation systems.

The wind profilers described here generally do not observe below about one kilometer. Because of the importance of the tropical boundary layer and the relative lack of observations that are currently available, an intensive effort should be made to complement the large wind profilers with smaller lower tropospheric wind profilers. A lower tropospheric profiler that meets this need has recently been developed (Ecklund et al, 1988). This lower tropospheric wind profiler can be deployed in networks at a fraction of the cost of larger wind profilers, suggesting that eventually nested grids of large and small profilers may be desirable. We are also working together with colleagues at NCAR to develop an Integrated Sounding System (ISS) that would combine surface observations with upper-level balloon soundings of wind and temperature and continuous wind observations using the lower tropospheric wind profiler. This development should satisfy the need for a sounding system capable of monitoring temperature and wind fields.

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