14.5 THE TRANS-PACIFIC PROFILER NETWORK: A COMPARISON OF PROFILER AND NCEP/NCAR REANALYSIS WINDS

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1. INTRODUCTION

We present a comparison of horizontal winds from the NCEP/NCAR reanalysis (National Center for Environmental Prediction and National Center for Atmospheric Research) and those measured using VHF (50 MHz) wind profilers over the tropical Pacific. Reanalysis winds and observations were compared at four sites, Darwin (Australia), Biak (Indonesia), Christmas Island (Republic of Kiribati), and Piura (Peru) (Figure 1). This work is described more completely in Schafer et al. (2003).

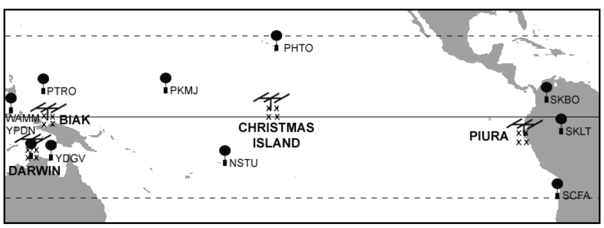

Fig 1. The Trans-Pacific Profiler Network. Antenna symbols mark the locations of wind profiling radars at Darwin, Biak, Christmas Island, and Piura. Balloon symbols mark the nearest rawinsonde launch sites. The crosses mark the closest four reanalysis grid points around the profiler site. A solid line marks the equator, while dashed lines mark the Tropic of Capricorn and the Tropic of Cancer.

Gage et al. 1988 examined the impact of incorporating Christmas Island wind profiler data in NMC analysis, and the ECMWF analysis (European Center for Medium-Range Weather Forecasts). Using 10 months of data (November 1986 to August 1987), they found that the assimilation of profiler data reduced the bias between observations and model analyses from about 1-3 m s^{-1} to 0.5 m s^{-1}. This directly showed the improvement in model analyses that can result by assimilating profiler observations. Our study builds on the Gage et al. (1988) analysis by comparing the NCEP/NCAR reanalysis winds with observations at each of the wind profiler sites across the tropical Pacific, and over a longer study period. Observations at Christmas Island are currently the only Trans-Pacific Profiler Network observations assimilated into the NCEP/NCAR Reanalysis.

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2. DATA AND TECHNIQUES

Profiler measurements have been made at Biak since 1992, at Darwin since 1990, at Christmas Island since 1986, and at Piura since 1991. For this comparison, wind profiler radial velocities were averaged using multiple averaging periods (1, 3, 6, 12, 24, and 48 hour), and a 3-hour sampling interval using a consensus averaging technique (Strauch et al. 1984). Vertical velocities were typically small compared to the mean radial velocities measured by the off-vertical beams. Gage et al. (1991) showed average vertical winds at Christmas Island with magnitudes less than several centimeters per second. Therefore, consistent with other studies, we assumed a zero mean vertical velocity. The average radial velocities were combined to form zonal and meridional winds. We limited the maximum height to 12 km, as low signal to noise ratios above this level often limit the quality of the measurements.

The NCEP/NCAR reanalysis takes an analysis/forecast model to perform data assimilation using data from 1957 through to the present (Kalnay et al. 1996). The assimilation output includes zonal and meridional winds on a global 2.5° latitude by 2.5° longitude grid (90° south to 90° north, and 0° east to 357.5° east). The data cover 17 pressure levels from 1000 hPa to 10 hPa corresponding to heights of about 0 km to 25 km above sea level.

Using geopotential height, the reanalysis zonal and meridional winds were interpolated to the wind profiler observation heights. The reanalysis data were also interpolated in longitude and latitude to match the locations of the wind profilers. Four reanalysis grid points forming the smallest box around the wind profiler location were used in the interpolation (Figure 1). This method produced a reanalysis data set of meridional and zonal winds with times, heights, and locations that correspond as closely as possible to the wind profiler data sets.

3. RESULTS

In this section we compare the profiler wind estimates to independent estimates from the NCEP/NCAR reanalysis. While the profiler winds are averaged using multiple averaging periods, the reanalysis winds are not. The multiple profiler averaging periods are compared directly to the original 6-hourly reanalysis. Comparison statistics, are created from both data sets using only times at which data points exist in both data sets. Missing values in the profiler data sets are also treated as missing values in the reanalysis data set. Sites are discussed, beginning on the western side of the Pacific at Darwin, to the eastern side of the Pacific at Piura.

3.1 *Darwin*

Mean statistics (not shown) suggested that the profiler and reanalysis winds at Darwin corresponded reasonably well. However a comparison of variances of the zonal winds highlighted some differences. Below 5 km, profiler observations with longer averaging periods (reduced variance) had variances that were closer to the reanalysis. Above 5 km, shorter profiler averaging periods gave variances that corresponded more closely to the reanalysis. The difference in variances, however, suggests that some atmospheric processes may not be fully resolved in both data sets.

The reanalysis seasonal zonal winds show a shallower layer of monsoon westerlies than the profiler winds, although the time of maximum strength does correspond to the maximum in the profiler westerlies (Figure 2). The trade wind flow appears to be well represented in the reanalysis, although the low-level easterlies appear weaker in the reanalysis. In contrast, maximums in the upper level westerlies are larger in the reanalysis. The reanalysis appears to capture the transition from break period to monsoon well, although the depth of the monsoon circulation is not well represented.

3.2 *Biak*

Westerlies are shown in the profiler zonal winds in the lower troposphere from November to May (Figure 3). The westerlies reach a maximum depth of 6 km in April and December. Above the westerlies, the easterly flow strengthens during December shifting downward the transition zone of easterly and westerly flow. The upper easterlies weaken from March to May, but strengthen again during the northern hemisphere summer monsoon. The pattern of profiler zonal winds is consistent with that of the reanalysis, although the lower level westerlies in the reanalysis are less deep and have a slightly later onset and earlier transition to easterly flow

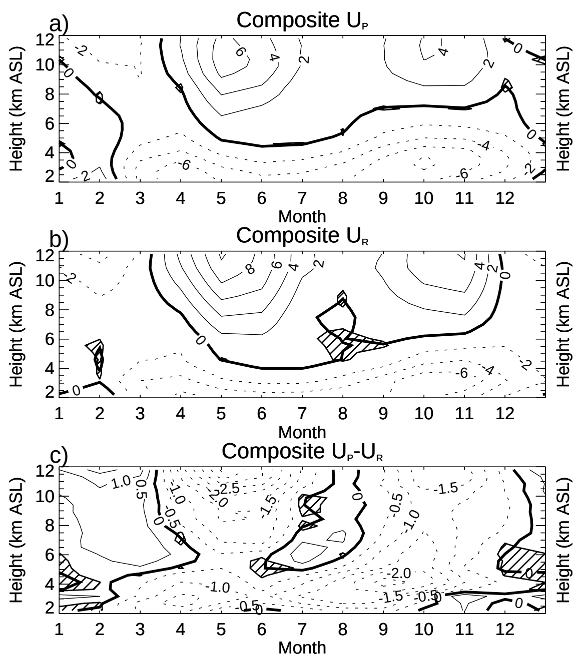

Fig. 2. Monthly time-height composites for Darwin describing, a) profiler mean zonal winds, b) reanalysis mean zonal winds, c) mean difference between the profiler and reanalysis zonal wind (UP-UN). The zero contours in each composite are shown as thick black lines. The region in each composite, where the 99 percent confidence interval includes zero is enclosed by line filled contours.

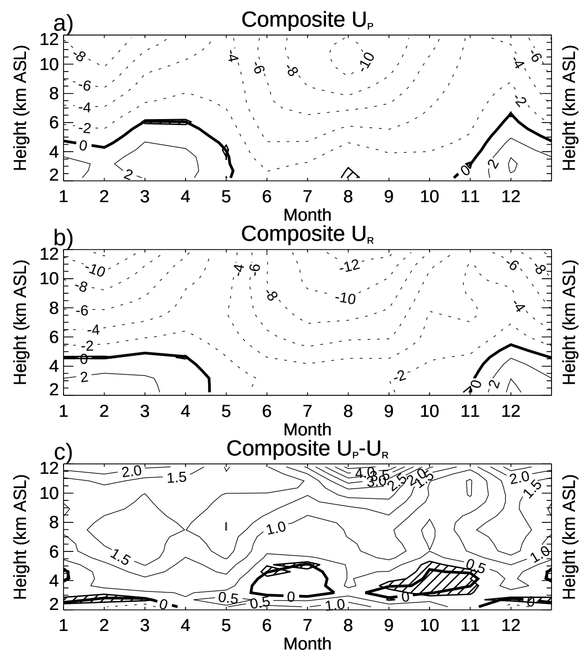

Fig. 3. As in Figure 2 but for Biak.

3.3 *Christmas Island*

The mean zonal wind profiles (not shown) showed a good agreement between the profiler and reanalysis, with easterlies below 9 km, and westerlies above. The mean meridional winds however showed less agreement.

The meridional wind composites for the profiler and zonal winds show some similarities in the circulation patterns, but the profiler circulation patterns are typically stronger (Figure 4). A relatively larger difference is associated with the two vertically stacked cores of northerly flow in the profiler data from May to October. Clearly the profiler observes a significant meridional circulation that is not well resolved in the reanalysis. The two cores of stronger northerlies may represent the deeper and shallower meridional overturning modes described by Trenbeth et al. (2000) in their study of the global monsoon.

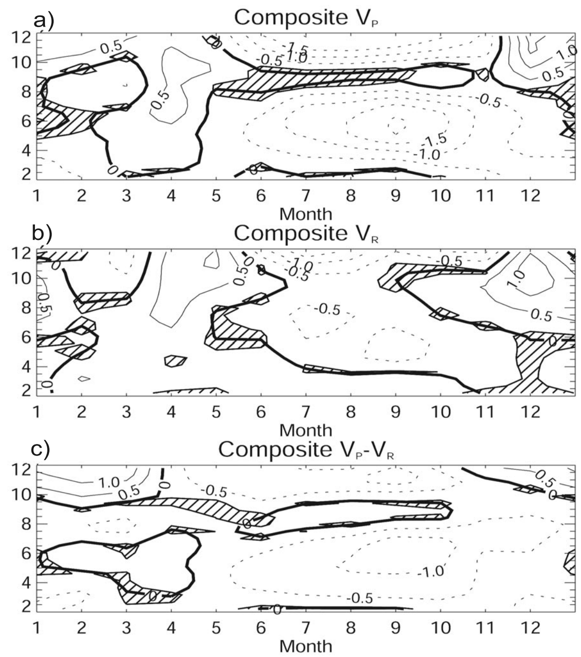

Fig. 4. As in Figure 2 but for meridional winds at Christmas Island. The contour interval is 0.5 ms^{-1} for the mean meridional winds and meridional wind differences.

3.4 *Piura*

The mean reanalysis easterlies at Piura (not shown) were stronger than the profiler easterlies below 6 km, but weaker above. The magnitude of the zonal mean differences is larger at Piura than at the other comparison sites

Seasonal contour plots for the zonal winds at Piura are shown Figure 5. The profiler zonal winds are consistently easterly although the strength varies through the year. The easterlies are weaker during the southern hemisphere summer, when heating over the tropical desert between the Andes and the Peruvian coast leads to convergence of the zonal flow. The profiler easterlies are also consistently weaker below about 3.5 km. The Andes rise to about 3.9 km to the east of Piura, and likely impede the easterly flow. The blocking of the easterly flow by the Andes as suggested by the weaker profiler easterlies in this layer is not evident in the reanalysis zonal winds.

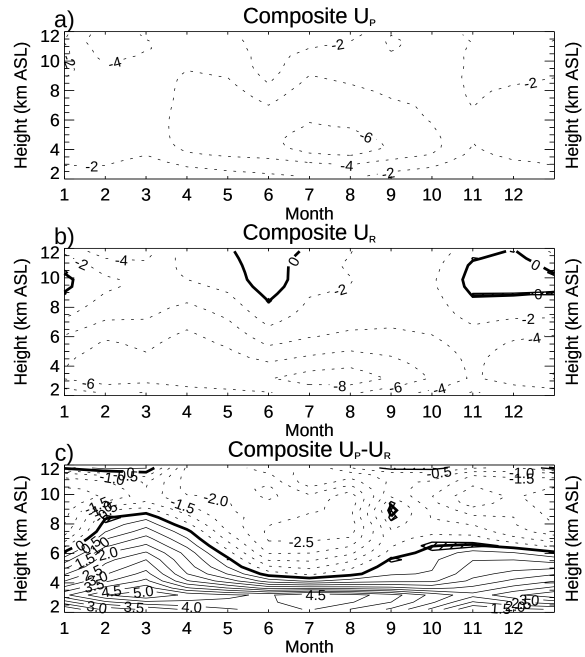

Fig. 5. As in Figure 2 but for Piura.

Figure 6 compares the surface topography in the reanalysis to the digital elevation model (DEM) of the USGS (United States Geological Survey) EROS (Earth Resources Observation Systems) data center. The reanalysis topography gives a maximum height of the Andes to the east of Piura of only 1.4 km, while the DEM indicates a maximum height of about 3.4 km. In addition, the reanalysis cannot resolve the 150 km stretch of low relatively flat topography from the Peruvian coast to the foot of the Andes. Since the topography near Piura is poorly resolved, the reduction in the strength of the easterlies may be an atmospheric process that cannot be resolved in the current 2.5º resolution of the reanalysis.

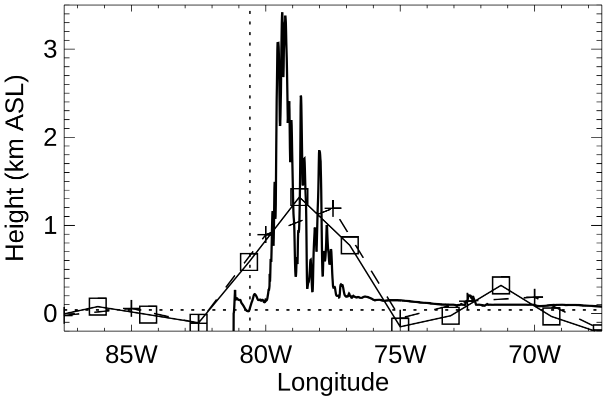

Fig. 6. Comparison of topography in the NCEP/NCAR reanalysis and topographic data from the USGS EROS data center as a function of longitude near Piura. The solid line shows USGS EROS topographic data. The square symbols show the reanalysis topography on the models approximately 1.9° longitudinally spaced Gaussian grid. The plus symbols show the reanalysis topography on the 2.5° uniform grid (output grid) interpolated to the exact latitude of the Piura profiler. Horizontal and vertical dotted lines mark the height and longitude of the profiler.

4. CONCLUSIONS

The profiler and reanalysis zonal winds show the closest agreement at Christmas Island. In contrast, the meridional winds at Christmas Island show a poor agreement. While the profiler meridional winds are available for assimilation into the reanalysis, they may be rejected if there is a large error of representativeness. We believe that the meridional circulation might not be resolvable by the 2.5º resolution of the reanalysis.

The poorest agreement between reanalysis and profiler winds was shown to occur at Piura. This poor agreement is expected, as the only rawinsonde observations are over 1300 km from Piura. In addition, the closest rawinsonde site is on the eastern side of the Andes. The blocking of the easterly flow by the Andes evidenced in the profiler zonal winds is not shown in the reanalysis winds. In addition to the lack of assimilated observations, this may be a result of the representation of the topography in the model.

Differences outlined in this study suggest that some significant atmospheric processes across the equatorial Pacific may be better represented in the reanalysis, if a finer spatial resolution is used, and if profiler winds where available are assimilated.

Acknowledgements
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