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VARIABILITY OF THE CROSS-EQUATORIAL FLOW OVER THE EASTERN PACIFIC OCEAN FROM 8 YEARS OF PILOT BALLOON OBSERVATIONS AT PIURA, PERU

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Abstract

Pilot balloon observations have been made at Piura, Peru since 1997 as part of the PACS–SONET project. This data set is the most complete set of observations from SONET, and illustrates the value of a single station's multi-year record for studies of interannual variability of the windfield near the equator.

1. INTRODUCTION

Pilot balloon observations have been made at Piura, Peru (~ 5.2˚S) since 1997 as part of the PACS-SONET project. These observations were begun as an effort to measure possible cross-equatorial flow variations that might be related to rainfall variations in Central America. Originally, observations were to have lasted for 6-months, but observations were extended because of the 1997-8 El Niño event, and then variously extended until the present. This data set is the most complete set of observations from SONET, with the only major gap in observations due to a period when a boundary layer wind profiler was operating at Piura (this profiler has a much more "gappy" record due to hardware failures).

The Piura location was suggested to us because the University of Piura, through the Insitituto Geofisico del Peru, had been operating a wind profiler at this site with support from the University of Colorado and NOAA. Thus, they had technical expertise and communications. The wind profiler was primarily designed for measurements of the upper troposphere, stratosphere, and higher, and no winds were being obtained below about 6 km. Thus the planned pilot balloon activities were not redundant with the profiler activities. Later, a boundary layer profiler (BLP) was established at the University of Piura, and this has functioned for a considerable period. However, it has had periods of failure, and because of its unreliability (without substantial financial support, which was not related to SONET) we opted for continuing pilot balloon observations. The only major gap in Piura pilot balloon observations occurred in 1999, when it appeared that the BLP was going to replace the pibal observations and observations were stopped. The BLP then failed. Thereafter, independent of the success of BLP operation we chose to continue to make the pibal observations.

The pilot balloon observations are made by an observer (or usually two) who inflates a pilot balloon of 30gm mass, which is filled correctly when it lifts a specified weight from the floor. This balloon is then released and tracked by an optical theodolite until lost due to cloud cover or poor visibility. Balloons are either red or "natural" color, to maximize visibility depending on sky conditions. The main uncertainty of the observation is the ascent rate of the balloon, which has been previously calibrated via numerous double-theodolite ascents under controlled conditions for the specific balloon and

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weight combination. These tests show that the ascent rate is very nearly constant, but this can vary with a standard deviation of about 3-5% of the assumed value.
The reason for use of pilot balloons is that they are quite inexpensive compared with radiosonde observations (~10%), the operations can be established rapidly (a few days training), and with low initial cost (spare theodolites/tripods are provided, gas cylinders are purchased as needed, and no inflation shelter needs to be constructed).

Piura is located some 40 km inland from the coast, on a relatively flat coastal plain (Fig. 1). The coastal plain is among the widest location anywhere along the coast of South America, being ~ 100km wide. The Piura location is actually very flat, with sand dunes and acacia trees forming the natural landscape on terrain away from the Piura River. The significant terrain is found to the east and north, and the flow from the southeast through west (nearly all observations show these directions in the lowest 500m) is essentially unaffected by topography. The foothills of the Andes begin about 60+ km to the east of Piura, with terrain 1500+m being found between 90 and 120 km to the northeast or east.

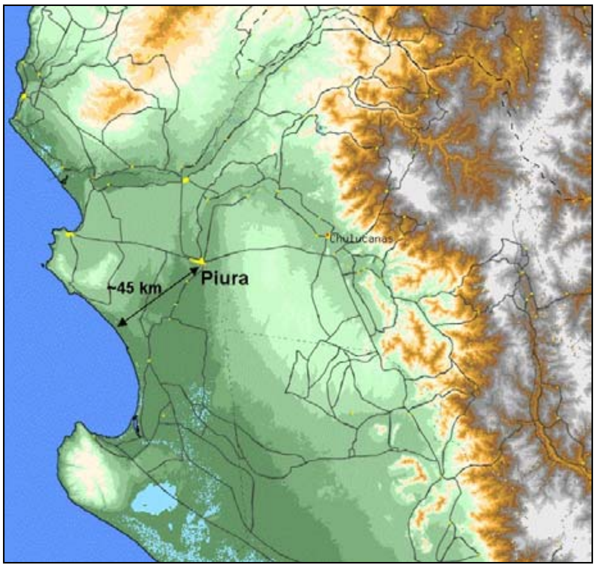


Fig. 1. Geography and topography of the Piura site. Highest terrain is about 3 km (white area). Shading interval is 100m near sea level.

The main problem with the Piura observations is the high frequency of low clouds that prevents most observations from reaching high levels. Initially, observations were made twice-daily, the results (Fig 2) showed that it was far more effective to make routine once-daily observations only in the afternoon. Even the afternoon hours are often cloudy, but the height-frequency statistics are much better than during the morning.

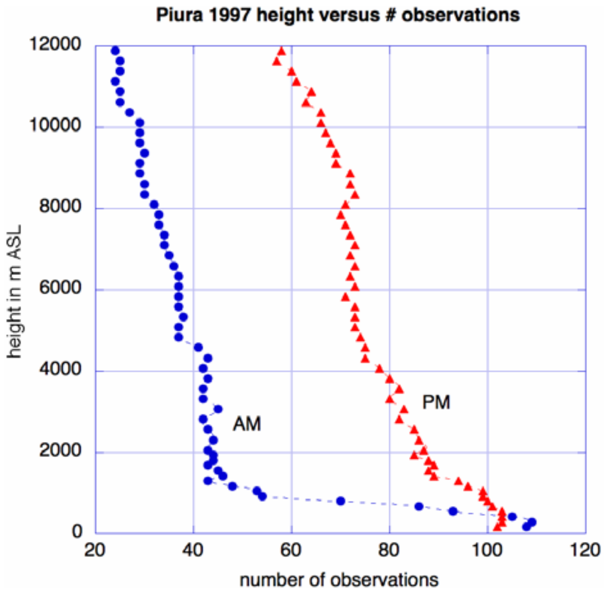
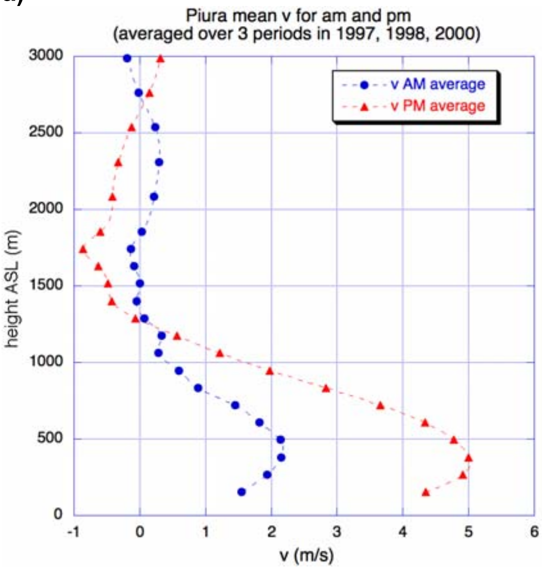


Fig. 2. The number of observations at Piura during a 4-month period during 1997 when observations were made twice-daily. Note the very rapid drop-off in observations during the AM due to a persistent low cloud layer present on most days. The cloud layer generally dissipated by the afternoon observation time. Above the low-cloud layer, the decrease in observations with height is similar in both morning and afternoon.

There is a strong sea-land breeze circulation at Piura; the 1997-8 cool season monthly mean observations show that this is a very regular feature. Using all available observations when both AM and PM observations were made, the 0000 UTC profiles show both a stronger onshore flow, and a stronger southerly flow (Fig. 3). From Fig. 3a, the PM profiles have about a 25% greater northward mass flux than the mean values, and almost 3 times the AM values.

a)



b)

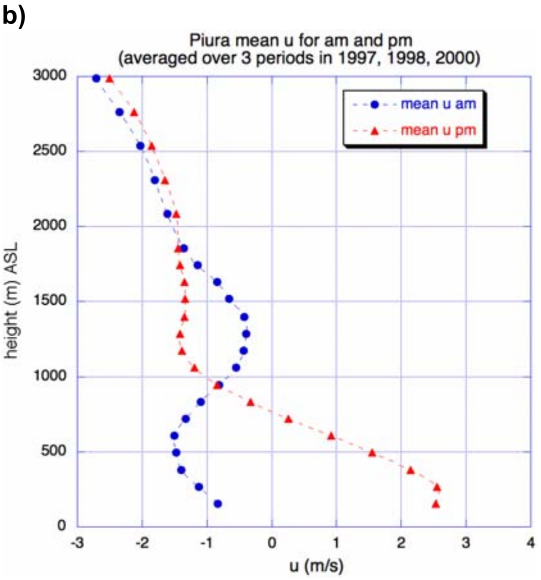


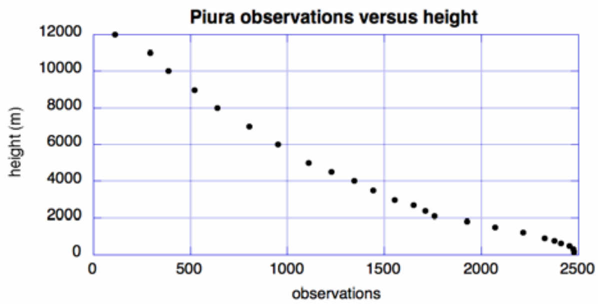
Fig. 3. a) Diurnal variation of meridional wind at Piura, based on all observations when months had am and pm soundings. b) same as a) but for zonal wind component.

In this paper we will show the variations of the meridional wind that are evident at Piura on synoptic to seasonal time scales. These variations can be compared with similar variations observed in observations made at a site in the Galapagos Islands during a shorter, and more intermittent period (to be shown in poster, not presented here). Our primary objective is to demonstrate the value of these simple observations for routine monitoring of climate (and even synoptic variations) in data poor regions.

2. DATA

All PACS-SONET pilot balloon data has been passed through an interactive quality control procedure where the raw angle information is displayed and examined for obvious and not-so-obvious errors. Erroneous angles are corrected and the corrected file is stored and winds are calculated from these. The Piura data processing was generally very good compared with other stations and most real-time observations were useable directly. However, all PACS-SONET observations have been subjected to the same quality control procedure using simple, but effective, interactive software designed for this procedure.

Using the more than 2900 observations from Piura, we have obtained monthly mean wind profiles for each month. However, because of the high frequency of low cloudiness at Piura, the monthly means are not reliable at higher levels. Figure 4 shows the number of observations versus height at Piura, based on the entire data set, and for cool season and warm season months. The effect of the low clouds is very apparent. Despite this, the results below will show that even with a reduced number of observations at higher levels it is possible to describe the mean wind profiles with moderately high confidence.



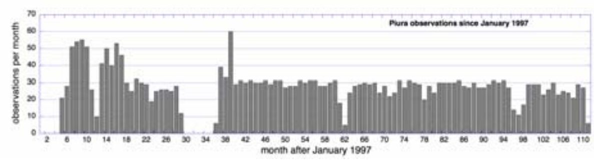


Fig. 4. Number of observations versus height (top) and number of observations per month (bottom) in Piura.

3. RESULTS

In this section we describe the mean profiles for Piura starting with the longest time averages, and describe successively higher frequency variations.

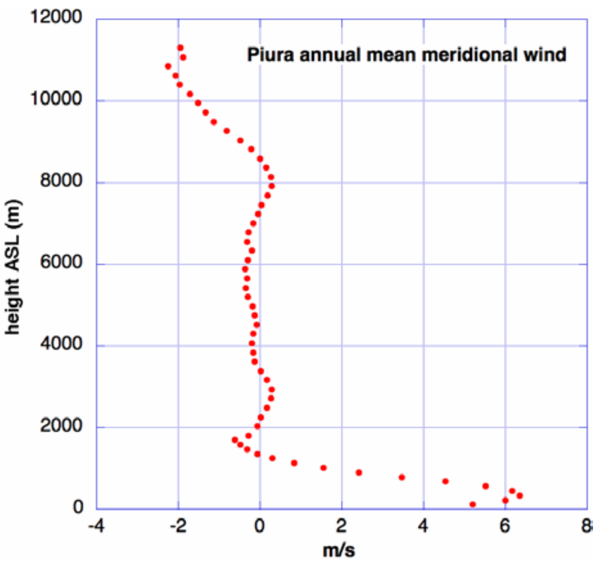


Fig. 5. Annual mean meridional wind profile, based on ~2900 observations at Piura from 1997 to 2006.

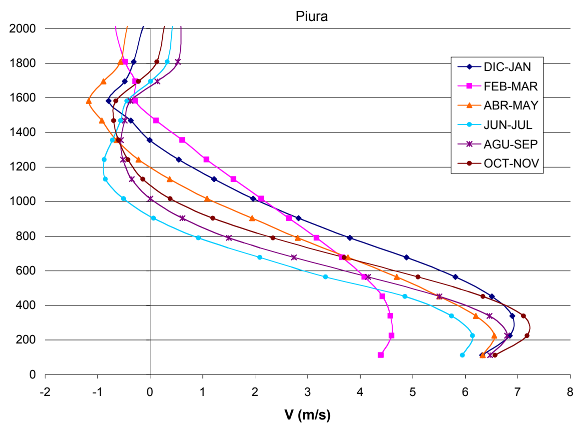
Annual mean profiles of meridional and zonal wind

The annual mean meridional wind at Piura (Fig. 5) shows very clearly the shallow northward flow that is inflow into the ITCZ, whose climatological position is north of the Equator. The inflow layer depth is about 1200m, with very little meridional flow between this level and 9000m. Above 9000m the northerly flow, increasing with height, is the outflow from the ITCZ. This layer is not well resolved by the pibal data, since few observations reached this level at Piura, and the last wind level is at ~11.5 km by agreement (52 minutes of tracking). This is beneath the average level of maximum outflow from the ITCZ, which is usually near 13-14km.

Seasonal and monthly evolution of the meridional flow

Because Piura lies close to the equator it does not show typical seasonality as in mid-latitudes. Rather, there is a very strong (by tropical standards) annual cycle to the sea surface temperatures in the far eastern tropical Pacific, which along the northern coast of Peru range from ~17˚C in September-November to 22˚C in February-March. However, local coastal upwelling can create minima near 14˚C and extreme El Niño events (1998) can be associated with SST's of up to 29˚C. Since the warmest water temperatures are in February-March and the coolest approximately in September-October we have chosen these to average.

a)



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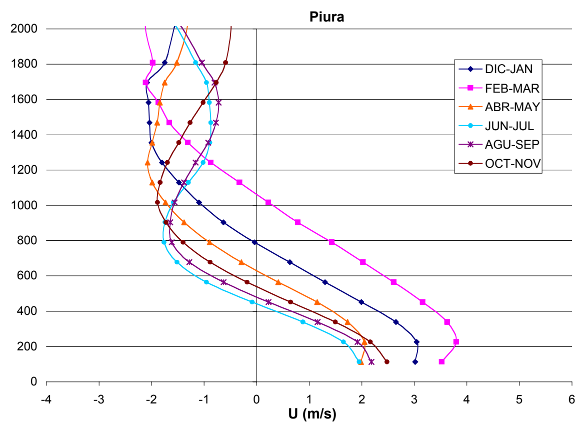
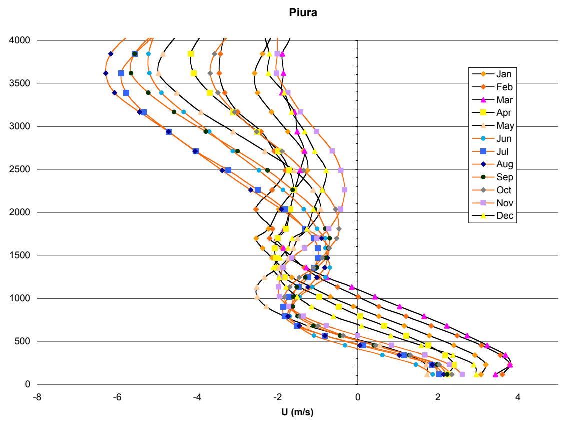


Fig. 6. Bi-monthly averaged wind profiles of the meridional(top) and zonal (bottom) wind components. Note the large differences between the warm months of Feb-March and most other profiles.

A comparison of the mean meridional wind profiles for each bi-monthly period (Fig. 6a) shows that February-March departs significantly from the rest of the months (the averaging was chosen to highlight this). The northward flux is deeper (~1500m) than other months, with the shallowest northward flow being found during June-July (~900m). However, because the

February-March flux is weaker below 500m (but not above), the February-March flux, integrated over the surface to zero wind level, is only about

a)



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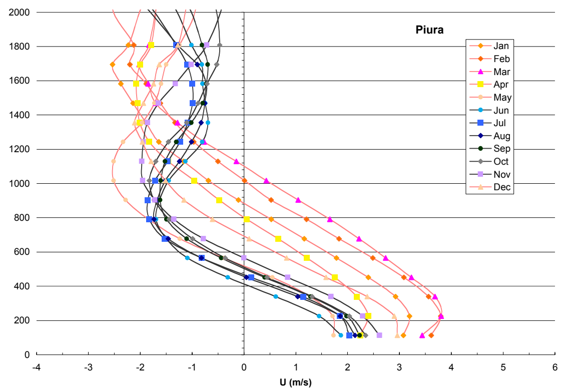

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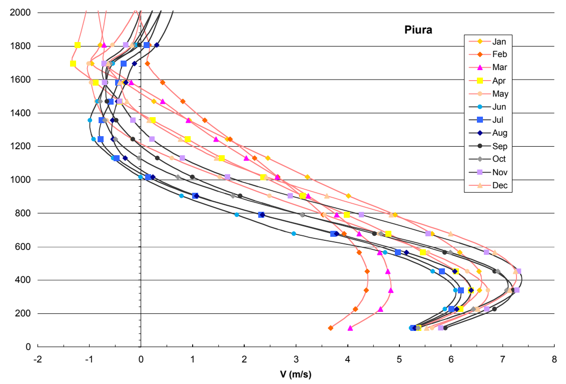

Fig. 7. Monthly mean profiles of zonal and meridional wind. Top and center are same zonal profiles, but different vertical scale. Bottom is monthly mean meridional wind profiles. Pink curves indicate warmer months, black curves cooler season months.

25% larger than that in June-July. Also evident, by inspection, is that the Dec-Jan flux is larger than that in Feb-Mar.

Comparing the extremes of the zonal wind means (Fig. 6b) for the different bi-monthly periods, we can see that the difference between the months with largest onshore flow (in the layer from the surface to zero zonal wind) is February-March, while the months with least are June-July (note not 6 months out-of-phase). The February-March flux is slightly more than 4 times the June-July flux.

Fig. 7 shows the monthly mean meridional and zonal wind profiles based upon all of the Piura observations. It is apparent in Fig. 7a that there is less time continuity to the evolution of the zonal wind profiles at higher levels, for this reason the lower portion is amplified in Fig. 7b. There is very good evolution of the profiles below 2 km, in the sense that the changes from one month to the next are smooth. It is apparent from these profiles that the months of February and March stand out as quite different from the other months, with weakest meridional winds and stronger zonal winds (Fig 7c.)

Another means of looking at the seasonal changes in the monthly mean winds at Piura is through time-height sections of the wind components. Fig. 8 shows such sections for both the zonal and meridional winds. The easterly winds are strongest near 4 km during the cool season, with weaker zonal flow in the warm season. At very high levels the data is so limited that no seasonal pattern can be identified. The meridional wind is much weaker above the boundary layer, with generally plausible, but weak, patterns. A closer view of the lower levels of Fig 8 is shown in Fig. 9, where the boundary layer details are evident. Notable is the asymmetry between the slow deepening and strengthening of the onshore flow prior to February and the relatively rapid weakening afterwards. As discussed previously, the shallowest and weakest zonal flow is seen in June, only 3-4 months after its maximum in February-March.

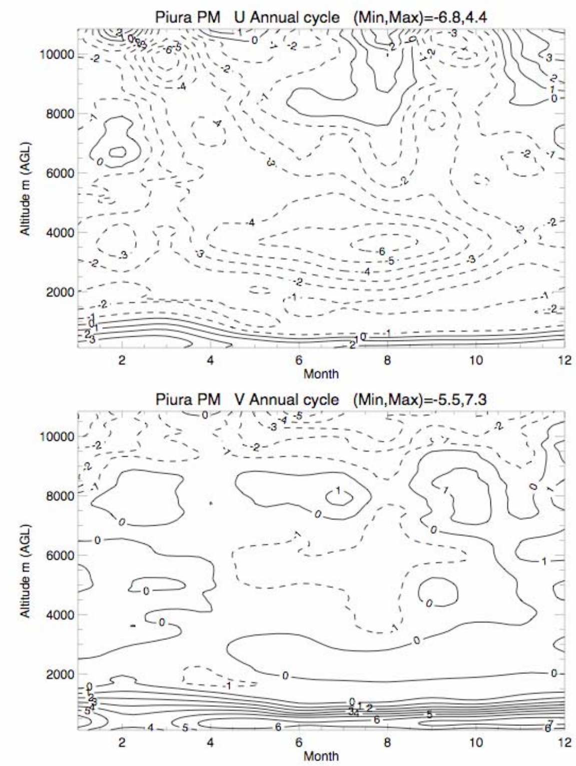

Fig. 8. Height-time sections of monthly mean zonal (top) and meridional (bottom) winds at Piura, averaged over all observations. Highest levels show noisy pattern, reflecting few observations.

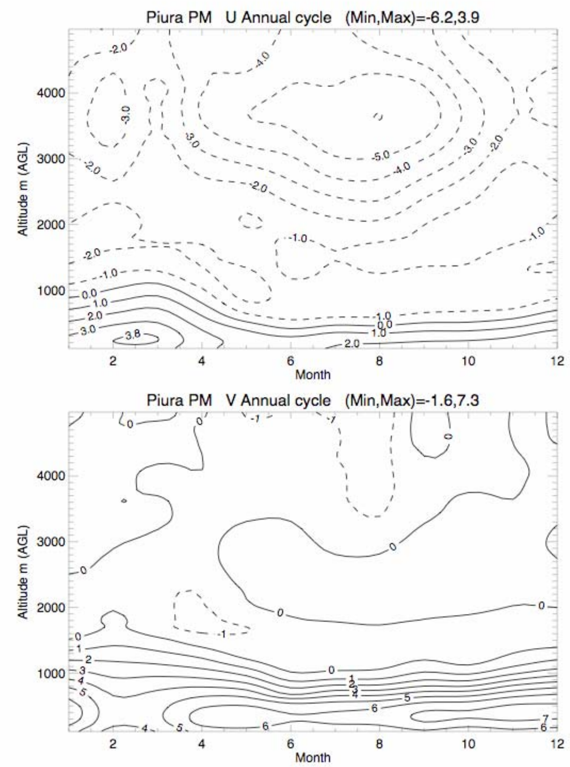

Fig. 9. Same as Fig. 8 except vertical scale now is maximum of 5000m to highlight annual cycle in lower troposphere.

3. Summary and implications of the results

The mean winds at Piura show that even with unfavorable cloudiness conditions it is possible to obtain monthly mean values of the wind that are sufficiently accurate to describe intraseasonal to interannual variations. The requirement is of course that the standard deviation of the winds about the mean be not excessively large compared with the variations which one seeks. The large signal associated with the 1998 El Niño event stands out as the most prominent feature of the 8-year record, although the cool year of 2005 showed a significant departure from the 8-year mean in the opposite sense.