P7R.1 Time-frequency analysis of UHF and VHF profiler observed winds over the central equatorial Pacific

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1. INTRODUCTION

Much of the precipitation over the equatorial Pacific is organize by atmospheric waves, but there are few detailed observations of the vertical structure of these waves (e.g. Takayabu 1994; Wheeler and Kiladis 1999). This study using three to seven years of wind observations from collocated UHF and VHF wind profilers in the central equatorial Pacific documents some of the dominant waves/ oscillations including mixed Rossby gravity waves, and the Quasi Biennial Oscillation, and their vertical structures. This paper begins with a comparison of the UHF and VHF wind profiler observations. This is followed by a time-frequency analysis of meridional winds with a study of mixed Rossby gravity waves and of vertical winds with a study of the Quasi Biennial Oscillation (QBO).

2. DATA AND TECHNIQUES

Three years (1998-2000) of UHF and VHF wind profiler data at Christmas Island are combined as 3 hour averages using a new processing technique (Coplanar Spectral Averaging; CSA) that gives an observation height range of about 0.3 to 18 km above sea level. This is the first time the UHF data have been analyzed in conjunction with the VHF data providing observations down into the boundary layer. CSA increases the detectability of the signal through averaging spectra over time from coplanar beams (e.g. east and west beams; Schafer et al. 2004). CSA improves the agreement between UHF and VHF profiler observations by reducing differences associated with spatial variability. To create spectra more representative of the larger pulse length of the VHF observations (1 km), UHF spectra are averaged over 500 m range bins approximating a 500 m pulse length.

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Fixed temporal signals such as the annual, seasonal and diurnal cycles are easily observed using power spectra of the entire CSA-processed time series. Other signals such as mixed Rossby gravity waves and Kelvin waves that occur more sporadically are better observed using time frequency analysis such as sliding spectra or wavelet analysis. After determining the dominant frequencies, the time series are filtered using a sliding Fourier transform to isolate specific frequency bands. A regression analysis of filtered time series at all heights is used to show the phase structure of that frequency band as a function of height.

3. COMPARISON OF VHF AND UHF WIND PROFILER OBSERVATIONS

After using CSA processing and averaging UHF spectra into effective 500 m pulse lengths, UHF and VHF wind time series were compared at their overlap range (2 km ASL). The bias and RMS difference between UHF and VHF wind components is shown in Table 1.

Table 1 RMS difference and bias between UHF and VHF profiler wind components at 2 km ASL for 30 minute CSA and 3 hour CSA (brackets).

	Bias (ms^{-1})	RMS (ms^{-1})
U	0.16 (0.01)	1.8 (1.4)
V	-0.13 (-0.05)	1.2 (1.2)
W	0.05 (0.04)	0.13 (0.08)

Periodograms of the 3-hour averaged zonal and vertical winds at 2 km are shown in Figure 1. Zonal spectra follow an approximate $F^{-\frac{5}{3}}$ dependence, while vertical velocity spectra follow an approximately $F^{-\frac{1}{2}}$ dependence. The vertical velocity spectra do not agree with theory that predicts a flat vertical velocity spectrum and may suggest some contamination of the vertical velocity by the zonal wind.

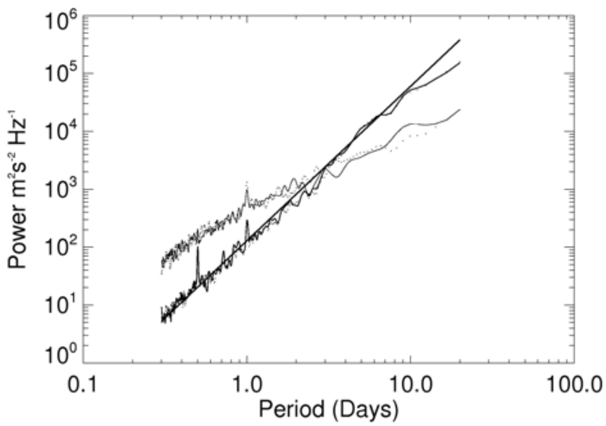

Figure 1 Comparison of Lomb-Scargle normalized periodograms UHF (solid) and VHF (dotted) of the Zonal (thick) and vertical (thin) 3-hour wind components. Also shown is the curve representing $P = CF^{-\frac{5}{3}}$ where *P* is power, *F* is frequency and *C* is a constant.

4. TIME-FREQUENCY ANALYSIS

In this section two oscillations will be analyzed, 1) the mixed Rossby gravity wave, and 2) the QBO.

4.1 Mixed Rossby Gravity Waves

Mixed Rossby gravity waves have a period between about 4 and 5 days (e.g. Liebman and Hendon, 1990; Wheeler et al. 2000). Over the central equatorial Pacific, these waves have a clear signal from July to November, and have a coherent signal over the full depth of the troposphere. A periodogram using 10 day segments of the meridional velocity time series at 2 km ASL indicates a signal near 4.5 days (not shown). To examine this signal, meridional wind time series were filtered using a sliding Fourier transform to suppress oscillations with periods outside the range of 3.5 to 6 days. A lagged-regression was then performed with the filtered time series at 6 km against filtered time series at all other observation heights. The results of the lagged regression are shown in Figure 2.

The mixed Rossby gravity waves show a positive slope (upward phase propagation) from the lowest observation level to about 12 km and a transition to a negative slope (downward phase propagation) above. This is consistent with results presented by Wheeler et al. (2000).

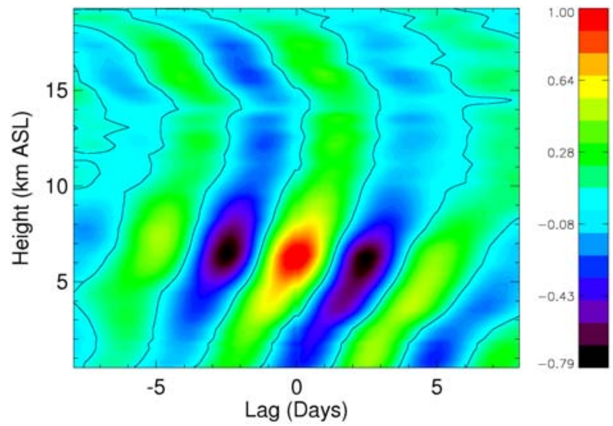

Figure 2 Correlation of a 3.5-6 day filtered meridional wind time series at 6 km with filtered meridional time series at all other observation heights as a function of lag in days.

4.2 Quasi Biennial Oscillation (QBO)

The height coverage (range of good signal return) for VHF wind profilers is typically best in the vertically directed beam rather than the oblique beams (directed about 15 degrees from zenith). This is because the distance to the altitude of interest is shorter (height=range) and specular reflection from atmospheric layers observed by the vertical beam are often stronger than Bragg scatter observed by the oblique beams. This study therefore uses seven years of 3-hour averaged vertical velocities from the VHF profiler to investigate the structure of the lower-stratospheric QBO. A periodogram of the vertical velocity time series at 20 km ASL indicates a strong signal near 740 days, suggesting that the wind profiler is observing the QBO (not shown).

Figure 3 shows the lagged regression for vertical velocities filtered to suppress oscillations with periods outside the range of 500 to 1000 days.

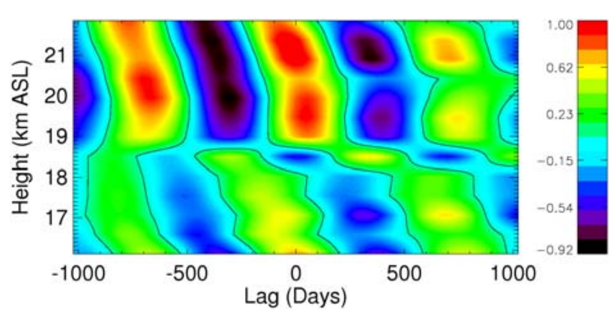

Figure 3 Correlation of a 500-1000 day filtered vertical wind time series at 21 km with filtered vertical time series at all other observation heights as a function of lag in days.

In the Central equatorial Pacific, the tropopause is at approximately 18 km ASL (based on wind profiler reflectivity measurements). The lagged regression shows a clear discontinuity in the phase of the QBO near the tropopause. Also shown is a downward phase progression over time consistent with other studies of the QBO.

5. CONCLUSION AND FURTHER WORK

This work has shown that UHF and VHF winds can be combined to provide wind observations that extend down into the boundary layer at Christmas Island. The zonal wind spectra from both profilers are similar and show a frequency dependence that agrees with theory. The vertical power spectra also agree with each other, but have a slope that suggests possible contamination by the zonal wind.

Periodograms created from sliding spectra, and the use of sliding Fourier transforms for filtering the time series has shown signals in the profiler data consistent with observed waves and those predicted by theory. Lagged regression can be used to show the vertical structure. Continuing work will include determining the frequency of occurrence of individual wave events and how well these events agree with the long time series statistics.

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