P5.2 A METHOD FOR IMPROVING UPPER-LEVEL WIND ESTIMATES FROM ARCHIVED WIND PROFILER VELOCITY SPECTRA.

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1. INTRODUCTION

Wind profiling radars operating at 915 MHz and 50 MHz are important tools for measuring horizontal and vertical winds in the boundary layer and troposphere. However, due to low signal to noise ratio the quality of wind measurements usually deteriorates above about 3 km for 915 MHz profilers, and above 10 km for 50 MHz profilers.

In the standard processing mode, the atmospheric signal return is sampled over time using many sample points for each beam and range gate. Time domain filtering in the form of a simple boxcar average reduces the number of sample points. A Fourier transform of the reduced series is then computed. This sample reduction and Fourier transform computation is repeated a number of times and the resulting spectra are averaged to produce mean spectra. These mean spectra and moments derived from them are archived.

A number of researchers have studied methods for improving the processing of the sampled signal. For example, Merritt (1995) used a statistical averaging approach to average spectra in a way that removed contamination from intermittent targets such as birds. Wilfong et al. (1999) combined statistical averaging in the spectral averaging phase with processing at the sampling stage to improve identification of the clear air peak in the presence of intermittent echoes and clutter. These methods were designed to improve the estimation of spectra from the sampled signal rather than from archived data where spectral averaging and time domain averaging have already occurred. These methods have not been used to enhance the detectability of a signal at altitudes where the signal to noise ratio is low.

In this paper we present a method for enhancing the clear air signal in archived upper-level wind profiler velocity spectra. The new method combines coplanar spectra, and averages spectra over time and spectral points. We call this method coplanar spectral averaging (COA). To develop COA, we use both simulated and real spectra.

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2. DATA AND TECHNIQUES

2.1 *Coplanar Averaging*

The coplanar spectral averaging method involves three steps: 1) Combining spectra from opposite coplanar beams (e.g. eastbeam and westbeam), 2) averaging the spectra over time, and 3) smoothing the spectra over spectral points. These steps are shown in Figure 1.

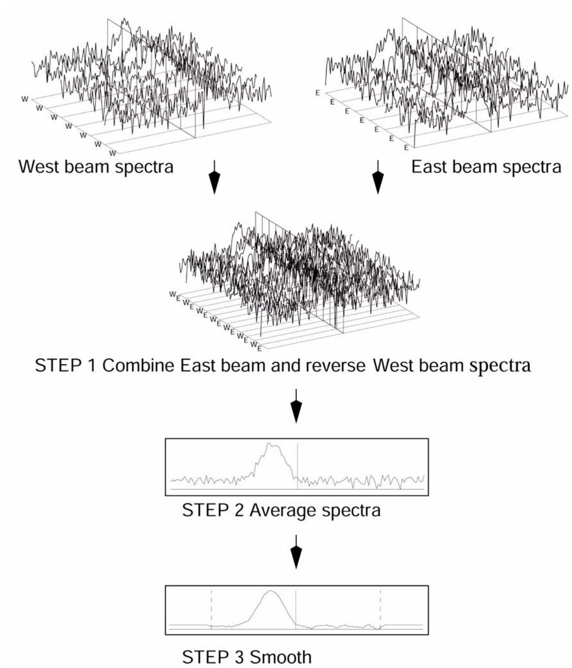

Figure 1 Steps used in the spectral processing method for the eastbeam and coplanar westbeam. The first step involves combining the east beam spectra and the reverse (flipped about zero velocity) westbeam spectra into a single array in order of ascending time. In the second step spectra are averaged over time. The final step is smoothing the spectra over spectral points.

If we assume that the horizontal wind field is homogeneous between two coplanar wind profiler beams and that the vertical velocity field is zero, then neglecting statistical fluctuations and noise, the spectrum in one beam (e.g. eastbeam) will be the same as the spectrum in the coplanar beam (westbeam), but reflected about zero wind speed. By averaging one beams spectra with the reverse of the corresponding coplanar beams spectra, the noise variability is reduced, increasing the signal detectability. If the horizontal wind field is only approximately uniform, then the coplanar spectra will overlap and averaging will result in a retrieval of the uniform component. However, if the wind field is significantly different between the beams and the spectra do not overlap, then two individual peaks may appear in the averaged spectrum representing the difference in the wind field.

A vertical velocity introduces a shift in the spectra. Because of the convention that velocity towards the radar is positive, a uniform positive (downward) vertical velocity will shift both the eastbeam spectra and westbeam spectra to the right. When combining the eastbeam spectra with the reverse of the westbeam spectra, a separation between the two clear air peaks is introduced, with a separation of twice the vertical velocity (projected on the beam declination). If the vertical velocity is small, then the peaks will overlap and averaging will remove the vertical velocity component.

Common methods used for combining multiple spectra into a single spectrum include: 1) taking the mean over time for each spectral point, 2) taking the median over time for each spectral point, and 3) using a statistical averaging method (SAM) (Merritt 1995). We found that these 3 methods performed about equally well and chose to use the median as it eliminates some outliers and requires significantly less processing time than the SAM method.

In the final step of COA, the spectra are smoothed over spectral points using a 3-point average. This smoothing eliminates multiple peaks from closely overlapping spectra.

The COA method assumes that: 1) there is signal in at least some of the velocity spectra, 2) the horizontal wind field is sufficiently uniform over time and between coplanar beams to allow individual spectra to overlap, and 3) the vertical velocity contribution to the spectra is small.

2.2 *Simulated Spectra*

To investigate the effect of vertical velocity on the retrieval of horizontal wind speed, we generated simulated eastbeam and westbeam spectra with known signal to noise ratio, noise level, spectral width, and radial velocity determined from a known horizontal and vertical velocity. Realistic statistical fluctuations and the effects of windowing and averaging spectra were added to our simulated spectra using a technique developed by Zrnic (1975). A 768 points long (6 multiples of 128 points) time series is created from the simulated spectra using an inverse FFT. The method of Zrnic (1975) is then applied to the time series to generate realistic statistical fluctuations. The time series are divided into 128-point sequences each of which is used to generate a 128-point spectrum (using a forward FFT). These 6 spectra are then averaged. This process simulated the averaged spectra typical in archived profiler data.

The parameters used in generating model spectra are shown in Table 1. Using these parameters, 480 unique parameter sets are produced. Each of the 480 parameter sets is used to generate 100 spectra each with different realizations of noise, windowing, and spectral averaging. These 100 realizations of each parameter set are treated as a time series with each realization spaced in increments of 10 minutes (similar to the time difference between same beam observations in profiler data). This simulation therefore produces a time series of 100 eastbeam and westbeam spectra for 480 different clear air signals.

TABLE 1. Parameters used for generating simulated eastbeam and westbeam spectra.

Parameter	Min	Max	Inc	# Par
SNR (dB)	-20	-5	5	4
Vertical Velocity (ms^{-1})	0	0.5	0.125	5
Horizontal Velocity (ms^{-1})	0	20	4	6
Spectral Width (ms^{-1})	0.5	2	0.5	4
Noise Level	100	100	N/A	1
Parameter Sets #				480

2.3 *Christmas Island 915 MHz and 50 MHz profilers*

Christmas Island is located in the central equatorial Pacific (157°W, 2°N). A 50 MHz profiler has operated at this site since 1986, and a 915 MHz profiler has operated at this site since 1990. Both profilers operate in a 5-beam mode, with a vertical beam and beams inclined about 14 degrees from the vertical to the North, South, East, and West. Average radial velocities are produced using a consensus-averaging technique (Strauch et al. 1984). Using the geometry of these beams and a suitable consensus-averaging period, vertical and horizontal velocities are calculated.

For this analysis, we selected two months of data (November 1999 and February 2000). These periods were chosen, as they occurred after maintenance and upgrades on the 50 MHz profiler in September 1999.

Since 50 MHz wind profilers are often the only source of upper tropospheric wind measurements in the Tropics, the primary objective of this new method is to improve the height coverage of 50 MHz profilers. However, to develop and evaluate COA we have applied the technique to 915 MHz profiler where archived consensus winds from a collocated 50 MHz profiler can be used as "Truth" in the relevant altitude range. While the collocated 50 MHz profiler provides the best possible comparison, Johnston et al. (2002) showed that significant differences in measured wind speed can occur as a result of the different pulse lengths use by 50 MHz and 915 MHz profilers. In addition, the 50 MHz consensus winds were calculated with the assumption of zero vertical velocity.

The comparison is made with 1) Archived 915 MHz consensus horizontal wind speed and direction, where a consensus threshold was used to determine if an average is accepted or treated as a missing value, and a vertical velocity correction was made using the vertical beam, 2) Archived consensus radial velocities where all radial velocities regardless of the number of observations forming the consensus average were used to calculate the horizontal wind and coplanar averages were used to correct for vertical velocity, and 3) Using COA.

In the next section, we first evaluate COA applied to simulated spectra, where a vertical velocity component is introduced. This is followed by an application of COA to 915 MHz archived spectra.

3. RESULTS

3.1 *Estimation using simulated spectra*

Using the technique outlined in section 2.2, time series of spectra were created for coplanar east and west beams. Three methods were then used to generate hourly spectra. These were 1) the COA method, 2) Spectral averaging using only one of the coplanar beams (eastbeam), and 3) Retrieval using only a single spectrum (eastbeam). Moments were calculated by fitting a gaussian function to the data about the maximum point in each spectrum. Note, since only a single beam is used in methods 2 and 3, there is no automatic correction for vertical velocity. This is consistent with the assumption of zero vertical velocity made in many studies using 50 MHz profilers, and with consensus estimates of horizontal velocity in the Christmas Island archive. In contrast, the COA method automatically removes the vertical velocity.

The results of the retrieval of the horizontal wind using these methods are presented in Table 2. Using COA, there is only a small decrease in the percentage of successful retrievals when vertical velocity increases. The impact however is larger when the coplanar spectra are not used. This reflects the impact of an uncorrected vertical velocity. The lowest percentage of successful retrievals, as expected, occurs when no spectra are averaged.

TABLE 2. Percentage of retrievals with absolute relative error in zonal wind speed less than 10% as a function of model vertical velocity. Shown are the retrieval percentages for the full COA method, the retrieval percentages using only spectral averaging over time (no coplanar averaging or correction for vertical velocity), and the retrieval percentages without any spectral averaging or correction for vertical velocity.

Vertical Velocity (ms^{-1}) (8800)	COA %	No coplanar averaging %	No spectral averaging %
0	71	64	29
0.125	71	58	27
0.25	70	45	23
0.375	69	31	18
0.5	68	17	14

3.2 *Estimation using archived spectra*

Archived consensus 50 MHz wind speed and direction were converted into zonal and meridional components and compared against averaged 915 MHz profiler zonal and meridional wind components. A vector difference was calculated by combining the component differences (matched in time and height to the 50 MHz consensus). Figures 2 and 3 show cumulative distributions of vector wind difference for November 1999 and

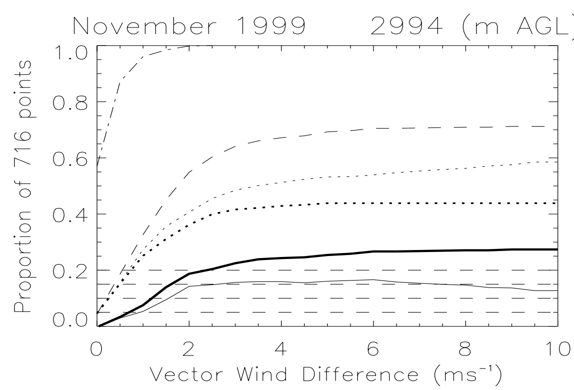

Fig. 2. Cumulative distribution of vector horizontal wind difference for November 1999 at an altitude of 3 km. Differences are calculated between standard 50 MHz archived consensus winds and 915 MHz hourly averages using: COA (dashed), Archived consensus speed and direction (thick dotted), Consensus radial velocities no threshold (thin dotted), 50 MHz consensus radial velocities no threshold (dash dotted). The differences in cumulative proportion are also shown: COA minus archived consensus (thick solid line), COA minus consensus radial velocities (thin solid line).

February 2000 respectively.The cumulative proportion is based on the total number of hours in the month.

If we select an acceptable difference limit for example 2 m s^{-1}, we can see that the COA method typically returns a greater number of good wind estimates (about 10-20 percent). It is also interesting to note that averages determined from consensus averaged, but not thresholded coplanar beams returned a greater number of good wind estimates than the standard consensus technique. This may be a result of the consensus threshold being too restrictive, or the standard consensus method using the vertical beam for vertical velocity correction rather than the off-vertical coplanar beam. A larger improvement in the number of good estimates using COA is shown in November 1999 (Figure 2). While the COA proportion of good values does not change significantly between November and February, the proportion of good values returned by the consensus methods does. The cause of this difference requires further investigation. Also shown in the figures is the difference between the 50 MHz standard wind consensus (no vertical velocity correction) and that calculated from off vertical coplanar beams with no thresholding. The difference is likely a result of inhomegeneity in the wind field across the coplanar beams and an uncorrected vertical velocity.

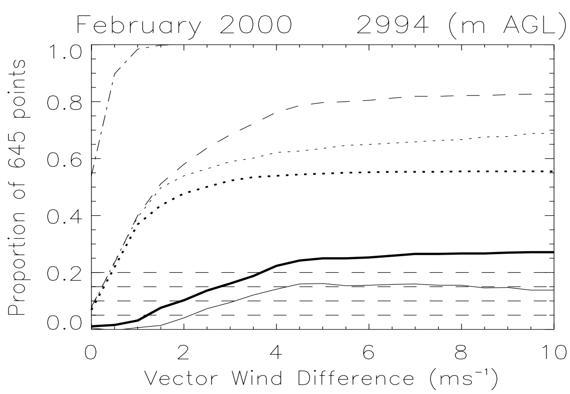

Fig. 3. As in Figure 2 but for February 2000.

4. CONCLUSIONS AND FURTHER WORK

This study has shown that for a 915 MHz profiler, the number of good horizontal wind estimates near the maximum observation height can be increased using the COA method. It also showed that the standard consensus method rejects too many observations. The increase in the number of good estimates using COA ranges from about 10-20 percent over the standard consensus technique. Many cases were noted in the COA processed spectra where a clear air peak was visible, but either clutter or a noise spike dominated and was selected in the peak fitting stage. A further improvement in the number of good wind estimates should therefore be possible by applying a better peak identification method e.g. a Fuzzy Logic approach (Cornman et al. 1998). Continuing work will involve applying the technique to 50 MHz archived data.

Acknowledgements
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