4.1.2 A COMPARISON OF VERTICAL VELOCITIES MEASURED FROM SPECULAR AND NONSPECULAR ECHOES BY A VHF RADAR

J. L. Green, W. L. Clark, J. M. Warnock

Aeronomy Laboratory
NOAA, Boulder, CO 80303

G. D. Nastrom

Control Data Corporation
Minneapolis, MN 55440

INTRODUCTION

One of the important and almost unique capabilities of the MST radar technique is the measurement of the vertical component of wind velocity. Measurements of vertical velocity are routinely made at many ST and MST radars both from scattering due to turbulence and quasi-specular reflection. Not only is the vertical velocity of great significance in itself, but as shown by CLARK et al. (1985), often the vertical velocity is required for accurate determinations of horizontal velocity.

However, for a number of years, there have been doubts about the accuracy of vertical velocities measured with quasi-specular reflections (GAGE and GREEN, 1978; ROTTGER, 1980, 1981). The concern has been that the layers producing the quasi-specular echoes might have small tilts as show in Figure 1a. Because of the quasi-specular reflection process, this hypothetical tilt would control the effective zenith angle of the radar antenna beam so that a small component of the horizontal velocity would be included in what was assumed to be a truly vertical beam. It is the purpose of the research reported here to test the hypothesis that there is an effect on the wind velocities measured on a vertical antenna beam due to a long-term tilting of the stable atmospheric layers that cause quasi-specular reflection.

Gravity waves have been observed to cause short-term tilting of turbulent layers (HOOKE and HARDY, 1975), and specularly reflecting layers (ECKLUND et al., 1981). In both cases, the effect was a wave-like deformation of atmospheric layers with a period of a few minutes. This geometry is shown in Figure 1b. Because of this influence of gravity waves, it was expected that there would be short-term variations in the vertical velocity.

EXPERIMENTAL METHOD

The Sunset radar (GREEN et al., 1986) was used for the experiments described here. This radar is located west of Boulder, CO, just 10 km from the Continental Divide as shown in Figure 2. Because of the mountain environment, there is frequent mountain lee wave activity above the radar. It was anticipated that the lee waves would exaggerate the tilting of the atmospheric layers causing a bias in the measured vertical velocities. It was also expected that the intense gravity wave associated with the mountain environment would increase the variance of the velocity measurements. The radial component of wind velocity was measured using five antenna beam positions, vertical and 15° from the vertical in the east, west, north and south. The geometry of the radar volumes is shown in Figure 3. An example of the radial velocity measured with the east and west slanted beams is shown in Figure 4. An estimate of the vertical component of wind velocity, W_{ew} can be derived from the two slant beams, assuming no gradients of horizontal velocity,

$$W_{ew} = (V_e + V_w)/\cos Z$$

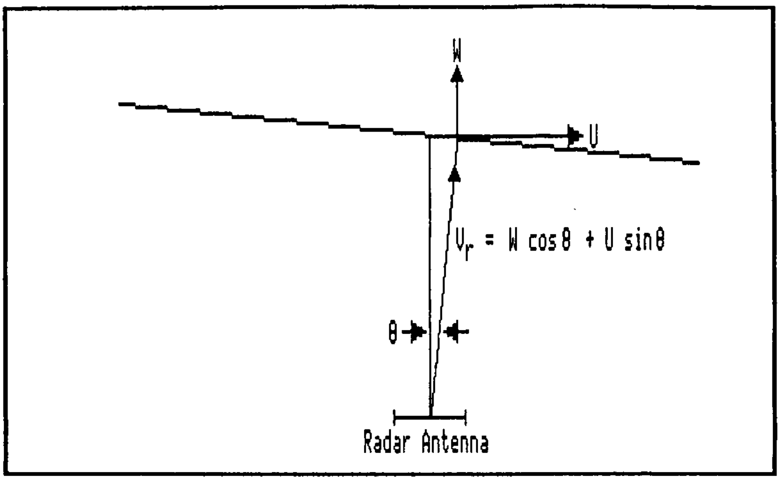

Figure 1a. Inclination of stable layer.

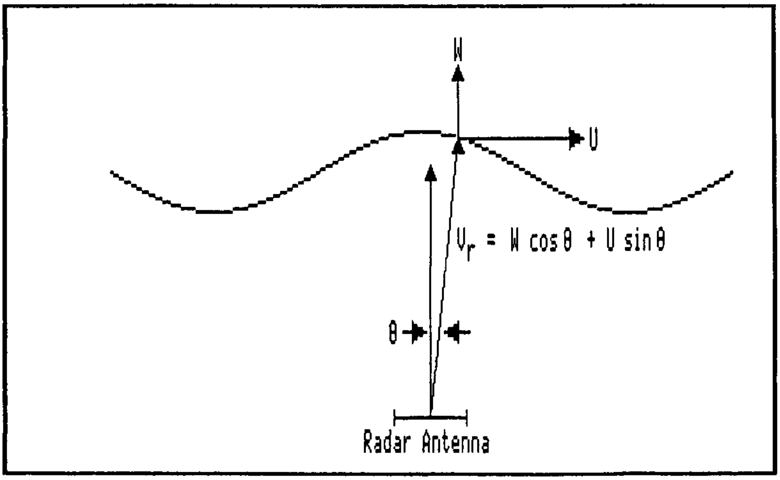

Figure 1b. Modulation of layers by gravity waves.

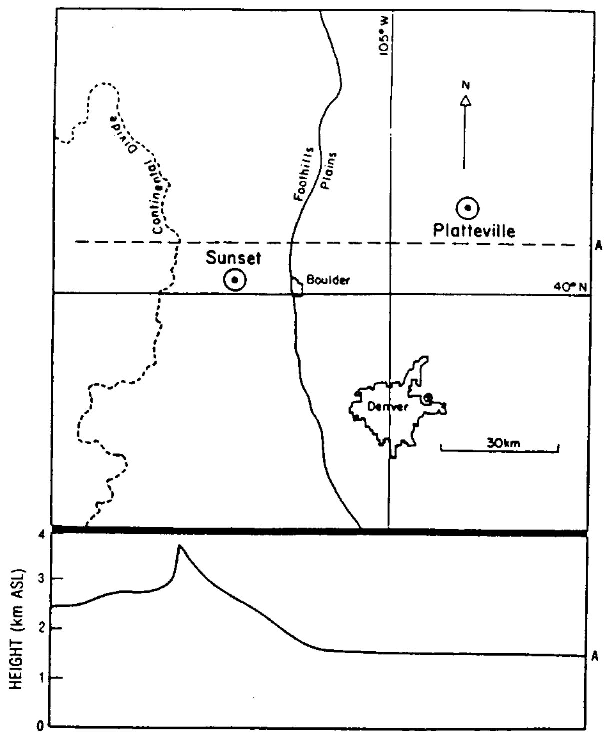

Figure 2. Location of Sunset radar.

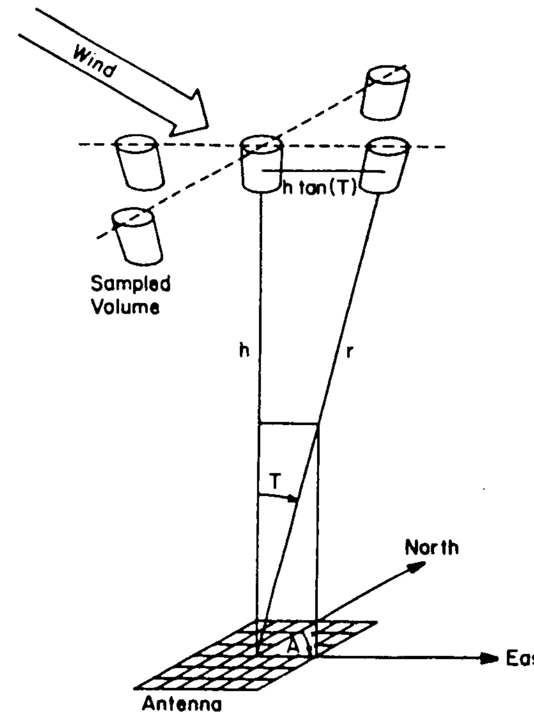

Figure 3. Antenna volume arrangement.

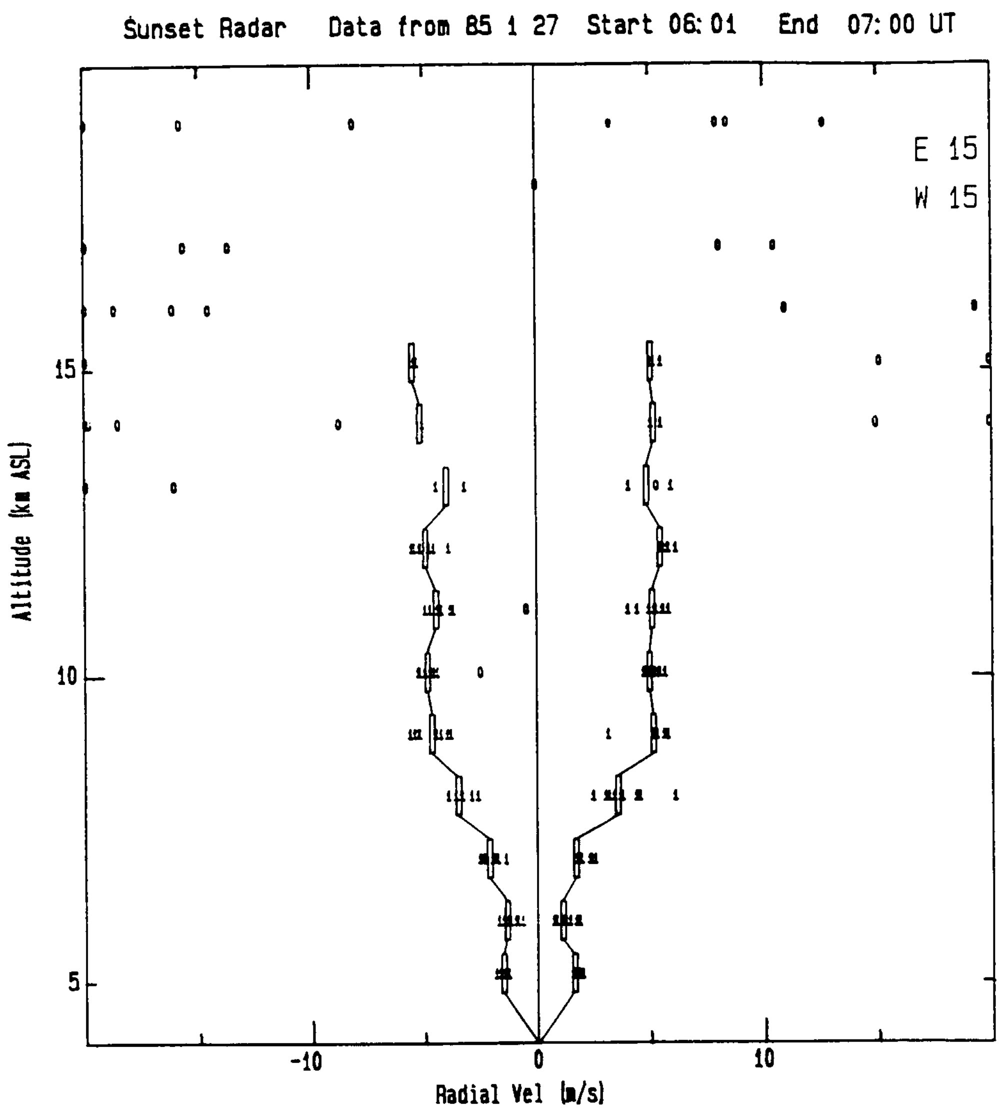

Figure 4. Example of radial velocity.

where Z is the angle from the zenith and V_e and V_w are the radial velocities measured on the antenna slanted to the east and west, respectively (VINCENT and REID, 1983). It has been established that echoes observed with antenna beams slanted away from the vertical are from turbulence scatter (VANZANDT et al., 1978). Therefore, W_{ew} can be always assumed to be measured from turbulence scatter. On the other hand, velocities measured with the vertical beam, W_{vert} can be from turbulence scatter or quasi-specular echoes, depending on the altitude and the time. Only the data from the antenna beam positions in the east-west vertical plane are presented here.

Figures 5-8 are XY plots comparing W_{vert} and W_{ew}. The range resolution was 1 km and the data were obtained from 5 - 15 km above sea level. The coordinates of each plotted point (W_{vert} and W_{ew}) were calculated from the medians of 9 - 12 individual radar records over one hour for each altitude and antenna beam direction. Only the measurements with valid data from the vertical beam and both slant beams are plotted. At a particular time and altitude, if the hourly median echo power from the vertical beam exceeded that of the slant beams by a factor of three, the data point was plotted as an "X" to signify that the echo from the vertical beam was quasi-specular, else it was plotted as an "O" to signify its origin in turbulence scatter. Each of these plots typically contains 24 hours of data. Before plotting, the entire data set was carefully hand-edited to eliminate echoes from aircraft.

To provide a measure of long-term bias, the median (W_{vert} - W_{ew}) for the cases when the echo on the vertical beam was quasi-specular, turbulence scatter and total cases inclusive are tabulated in the lower right-hand corner of each plot.

RESULTS

Figure 5 represents a day with very light winds and has the least scatter about the X = Y line of the four cases presented. Note that the scatter of the points where W_{vert} is from a quasi-specular echo is about equal to that of the points where W_{vert} is obtained from a turbulence echo and that the bias of the points associated with quasi-specular echoes is only 1 cm/s.

The winds were higher on the days represented by Figures 6-8, the range of W_{vert} associated with turbulent echoes is larger. Even so, the scatter of points about the X = Y line where W_{vert} is from quasi-specular or turbulent echoes is still about the same. However, the long-term W_{vert} - W_{ew} is about 10 cm/s for both turbulence scatter and quasi-specular reflection.

DISCUSSION

The following tentative conclusions can be drawn from the four examples presented:

1. The behavior of the vertical component of wind velocity measured with quasi-specular reflection or with turbulence scatter is not markedly different, either in the hourly median or the daily median (W_{vert} - W_{ew}). The similarity of the scatter of W_{vert} - W_{ew} when the vertical beam received a quasi-specular or a turbulence scatter echo puts a limit on the errors in the measurement of W_{vert} due to the tilting of stable layers by gravity waves. This similarity of behavior is also evidence that W_{vert}, measured with either type of echo is the vertical component of that wind velocity in agreement with WATKINS and JAYAWEERA (1985) and RIDDLE and BALSLEY (1985).

2. The daily median W_{vert} - W_{ew} for either type of echo is not more than a few cm/sec.

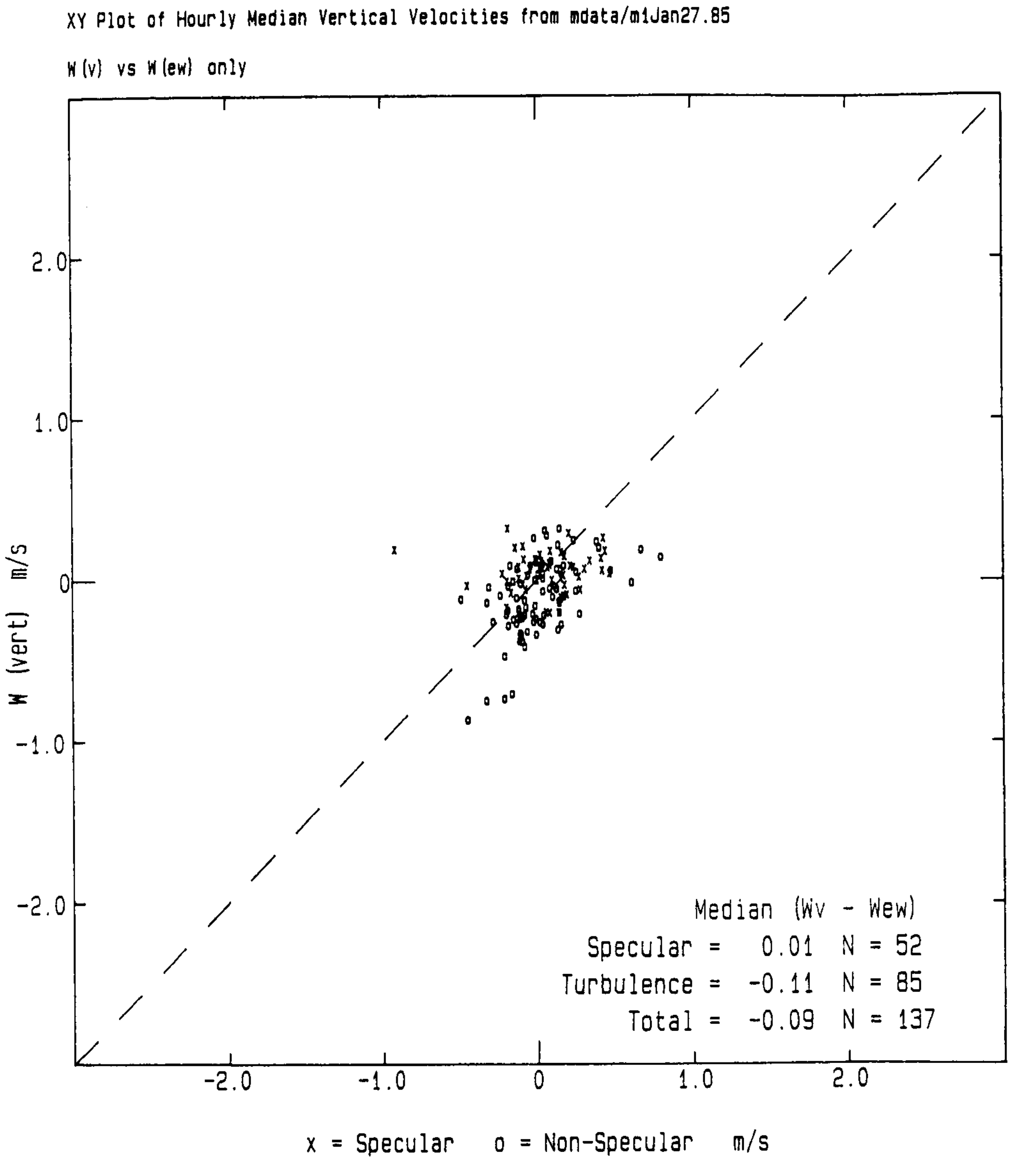

Figure 5. Plot of W_{vert} (vertical axis) vs W_{ew} (horizontal axis) January 27, 1985.

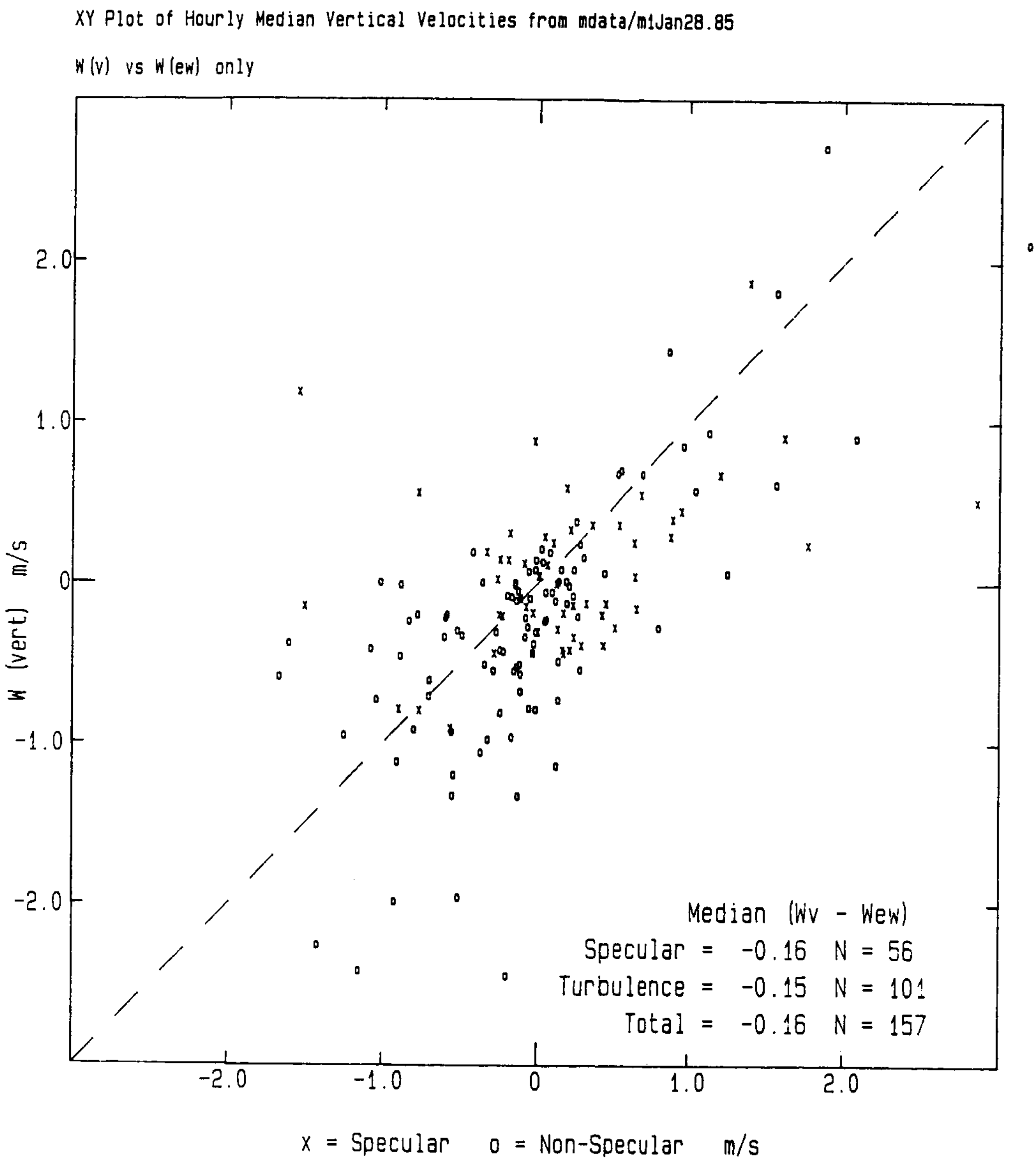

Figure 6. Plot of W_{vert} (vertical axis) vs W_{ew} (horizontal axis) January 28, 1985.

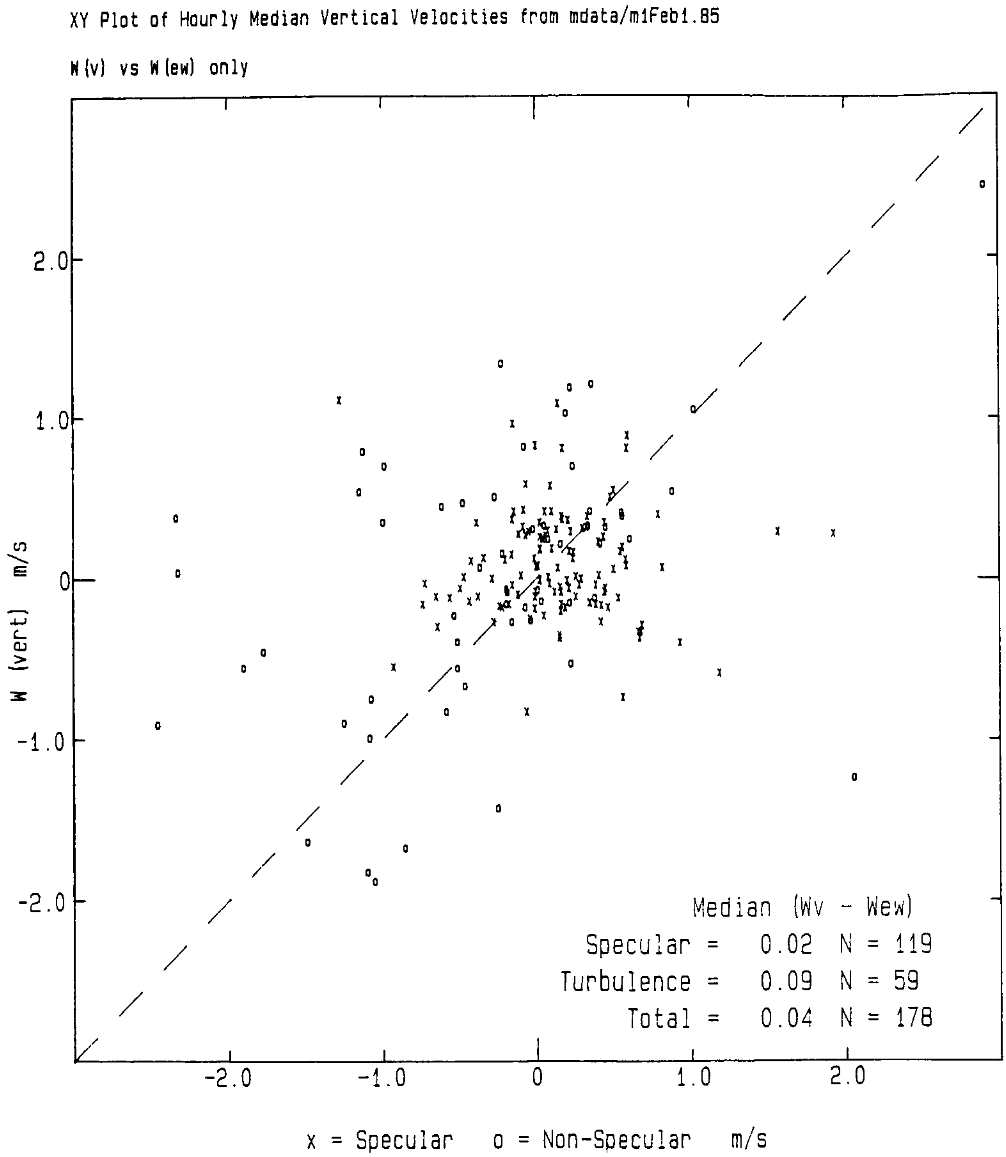

Figure 7. Plot of W_{vert} (vertical axis) vs W_{ew} (horizontal axis) February 1, 1985.

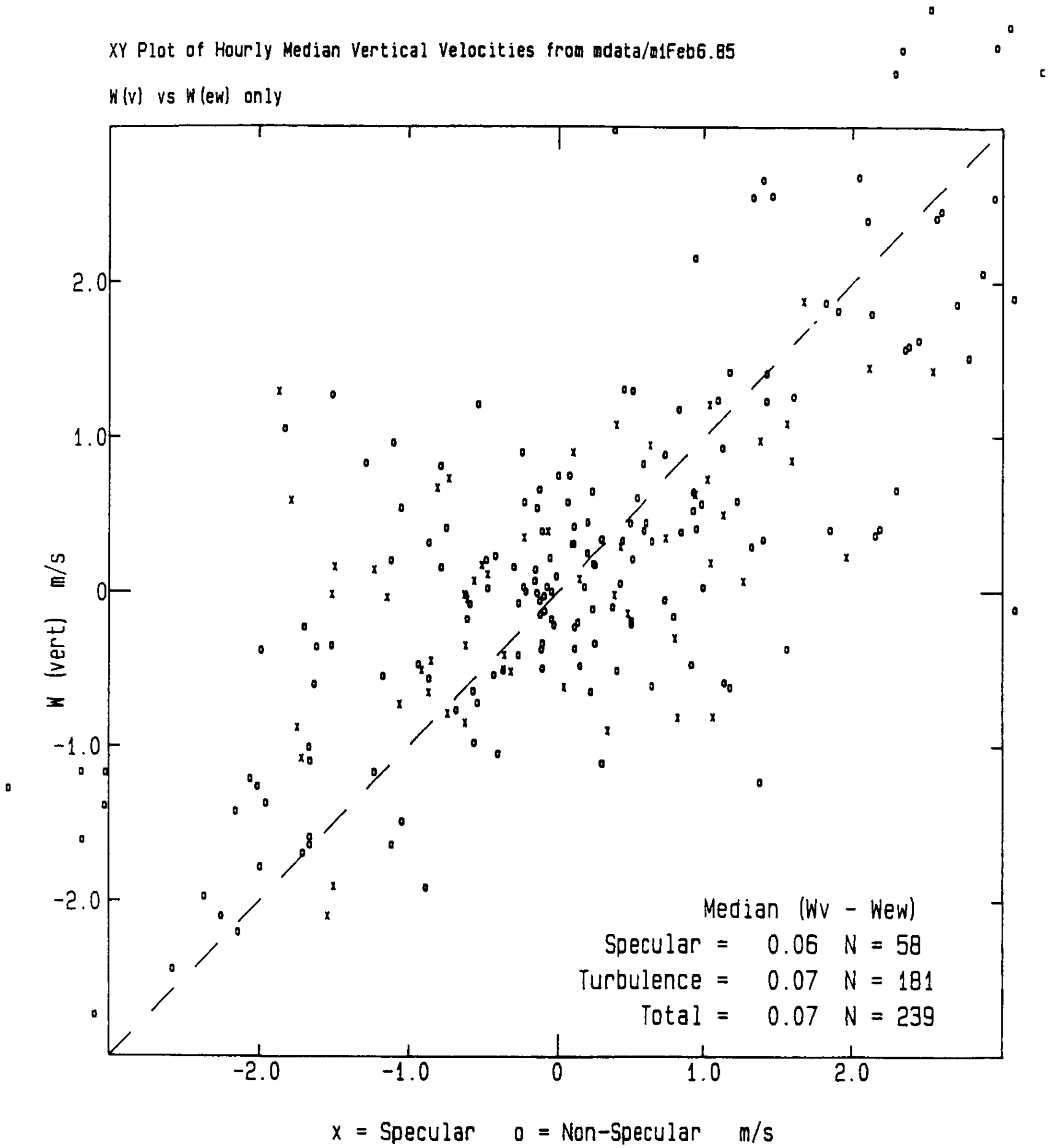

Figure 8. Plot of W_{vert} (vertical axis) vs W_{ew} (horizontal axis) February 6, 1985.

3. Even in the mountain environment, $W_{vert} - W_{ew}$, computed from hourly medians of radial velocity are typically less than ± 1 m/s. Roughly, the uncertainty in the computation of horizontal components of velocity using hourly medians, but uncorrected by the vertical velocity, would be W cos 15°/sin 15°, or typically less than ± 4 m/s. The observed scatter of the hourly medians of $W_{vert} - W_{ew}$ could be due to horizontal gradients of vertical velocity (CLARK et al., 1985) and/or by velocity perturbations due to gravity waves.

REFERENCES

Clark, W. L., J. L. Green, and J. M. Warnock (1985), Estimating meteorological wind vector components from monostatic Doppler radar measurements: A case study, Radio Sci., 20, 1207-1213.

Clark, W. L., J. L. GREEN, and J. M. Warnock (1986), Determination of U, V, and W from single Doppler radar radial velocities, this volume.

Ecklund, W. L., K. S. Gage, and A. C. Riddle (1981), Gravity wave activity in vertical wind observed by the Poker Flat MST radar, Geophys. Res. Lett., 8, 285-288.

Gage, K. S., and J. L. Green (1978), Evidence for specular reflection from monostatic VHF radar observations of the stratosphere, Radio Sci., 13, 991-1001.

Green, J. L., J. M. Warnock, W. L. Clark, and T. E. VanZandt (1986), Recent results at the Sunset radar, this volume.

Hooke, W. H., and K. R. Hardy (1975), Further studies of the gravity wave over the eastern seaboard on 18 March 1969, J. Appl. Meteorol., 14, 31-38.

Riddle, A. C., and B. B. Balsley (1985), Comment on "Comparisons of vertical winds measured with the Chatanika and Poker Flat radars, J. Geophys. Res., 90, 8160-8162.

Rottger, J. (1980), Reflection and scattering of VHF radar signals from atmospheric reflection structures, Radio Sci., 15, 259-276.

Rottger, J. (1981), Wind variability in the stratosphere deduced from spaced antenna VHF radar measurements, Proc. 20th Conf. Radar Meteorology, Boston, MA, Am. Meteorol. Soc., 22-29.

VanZandt, T. E., J. L. Green, K. S. Gage, and W. L. Clark (1978), Vertical profiles of refractivity turbulence structure constant: comparison of observations by the Sunset radar with a new theoretical model, Radio Sci., 13, 819-829.

Vincent, R. A., and I. M. Reid (1983), HF Doppler measurements of mesospheric gravity wave momentum fluxes, J. Atmos. Sci., 40, 1321-1333.

Watkins, B. J., and K. Jayaweera (1985), Comparisons of vertical winds measured with the Chatanika and Poker Flat radars, J. Geophys. Res., 90, 8143-8148.