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VERTICAL VELOCITY IN CIRRUS CASE OBTAINED FROM WIND PROFILER

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1. INTRODUCTION

Cirrus clouds play an important role in the climate and general circulation because they significantly modulate the radiation properties of the atmosphere. However understanding the processes that govern their presence is made difficult by their high altitude, variable thickness, complex microphysical structure, and relatively little knowledge of the vertical motion field.

In the FIRE II experiment, a 404MHz wind profiler was set up to provide continuous measurements of clear air wind field at Parsons, Kansas. Simultaneously, the NOAA wind profiler network supplied a wider spacial scale observation. On Nov. 26, 1991, we had the most significant cirrus cloud phenomena during the experiment with a jet streak at 250 Mb. Analyses of the vertical wind velocity are made by utilizing different methods based on wind profiler data, among them the direct measurements from CSU wind profiler and NOAA network wind profilers, VAD(Velocity Azimuth Display) technique and the kinematic method.

On Nov. 26, the Parsons' site was just at the cold exit region of the jet streak which is shown in Fig.1. According to the conceptual model of a jet streak by Mattocks and Bleck (1986) (MB) shown in Fig.2, the vertical velocity should have from ascent below to descent above the height of the maximum horizontal wind. An agreement between the observations in the cold exit area and the conceptual model is shown first time using high resolution wind profiler data.

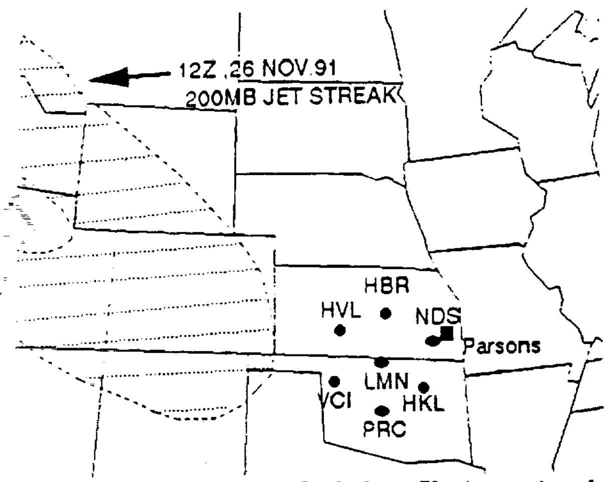

Figure 1.Location of CSU wind profiler(square) and some of the network stations(circle). The 1200Z jet streak is denoted by shaded area.

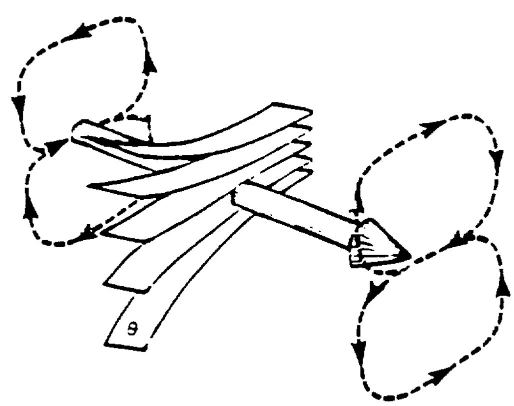

Figure 2.Three-dimensional schematic of the circulation induced by a jet streak. (from Mattocks and Bleck, 1986)

2. METHODS

2.1 Direct Doppler Method:

The CSU wind profiler was operated in a 10-minute cycle which consists of measurements along five directions: one pointing vertically with the other four beams tilted 15° from zenith toward east, north, west and south. The NOAA network radars had three directions of operation (one vertical, two tilted away from zenith toward east and north respectively) with a 6-minute cycle. The direct Doppler method deduces vertical velocities from the radial velocities of the vertical beam. In the past, several works (Larsen et al.,1991a,b; Yoe et al.,1992) have shown the uncertainties in direct measurements of vertical velocity and have also given some comparisons between these radar direct measurements and other data sources or other techniques based on radar data.

2.2 VAD Method:

The VAD method was originally derived to retrieve horizontal wind components from the radial velocities of a radar azimuth scan (Browning and Wexler 1972; Wilson and Miller 1972). By applying the mass continuity equation under assumption that air density is locally stationary and horizontally strtified, one can derive the vertical components of wind fields (Larsen et al. 1991; Doviak and Zrnic 1984). In our experiments, the CSU wind profiler's five-beam data was employed in a quasi-VAD technique.

The VAD sampling scheme is shown in Fig.3, U is the horizontal wind vector, and w is the vertical velocity. In ideal cases, which have a nearly linear horizontal wind field within the measurement circle so that the components u, v and w are well approximated by the zeroth- and first-order terms of a Taylor series, the measured radial velocity at sampling points will fit a sine curve as shown in the lower panel. Here, the offset C_0 at each height is equal to the average of radial velocities at all sampling points in one circle at that height and can also be expressed as equation(1) through a Taylor expansion (Larsen et al., 1991).

$$C_0 = [\, w + \frac{z}{2} \tan^2\theta(\nabla_h \cdot U)] \cos\theta \qquad (1)$$

By assuming the density is stationary in time locally and that the medium is horizontally stratified, we write the mass continuity equation:

$$\nabla_h \cdot \rho U = \rho \nabla_h \cdot U = -\frac{\partial}{\partial z}(\rho w) \qquad (2)$$

Combining the above equations and integrating the differential equation from an upper height boundary z_T by assuming zero w at z_T, we have equation (3):

$$-(\rho w)_z + \frac{2\cos\theta}{\sin^2\theta}\int_z^{z_T} \frac{\rho C_0}{z}dz - 2ctan^2\theta\int_z^{z_T} \frac{\rho w}{z}dz = 0 \qquad (3)$$

Eq.(3) can be solved numerically for w, the vertical velocity.

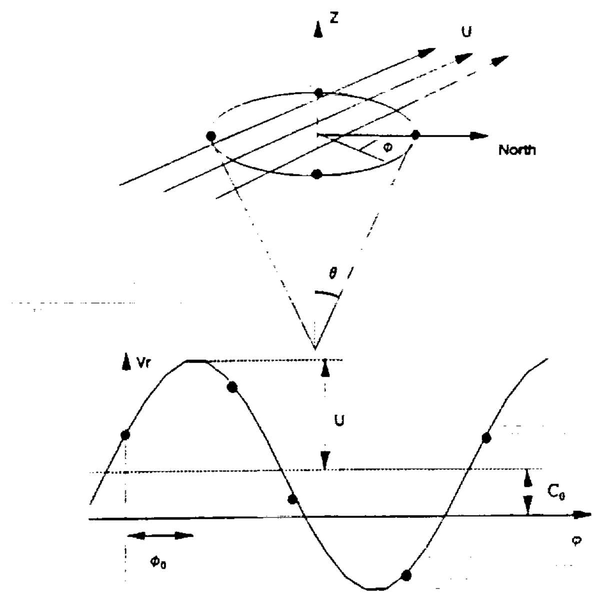

Figure 3.Schematic of the VAD sampling and sine curve fitted by the sample data.

2.3 Kinematic Method:

The kinematic method was carried out by Bellamy(1949) as an objective calculation of divergence and vertical velocity. In this method, we have an assumption that the wind field is a linear function of space between the observation points which are non-collinear located. Then the horizontal divergence can be calculated from the rate of change of the outflow through the unit vertical sides of the volume. The vertical velocity in height coordinates can be computed based on the known horizontal divergence and mass continuity equation by assuming incompressible air medium (cf. Bellamy,1949). In this study, we use NOAA network stationd NDS, HBR and LMN to form a triangular area(Fig.1).

3. RESULTS AND DISCUSSIONS

As described in the above section, three methods are used to derive vertical velocity. They are the direct doppler measurement, VAD and kinematic method. Figs.4, 5 and 6 are the 3-period averaged vertical velocities from the direct doppler measurements of the CSU and network wind profiler at NDS, and also the VAD calculation. The appearance of thin cirrus clouds was confirmed by lidar from about 1600Z, and after 1820Z, clouds became much thicker with

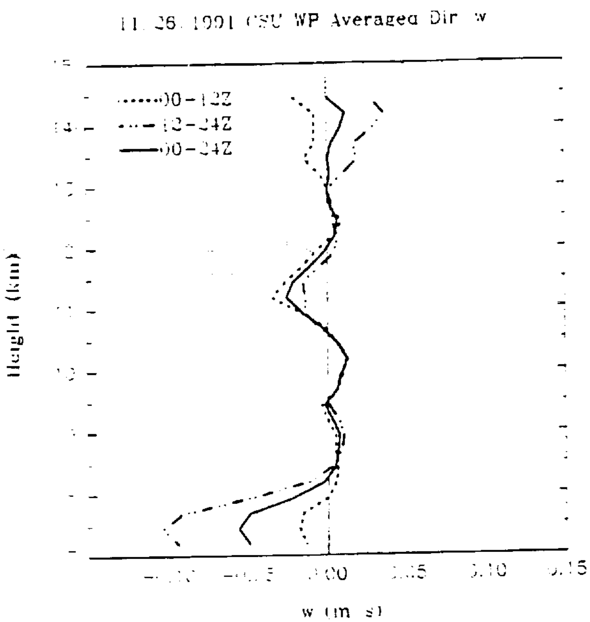

Figure 4. Profiles of averaged vertical velocity measured in the vertical beam of CSU wind profiler at Parsons on Nov. 26, 1991

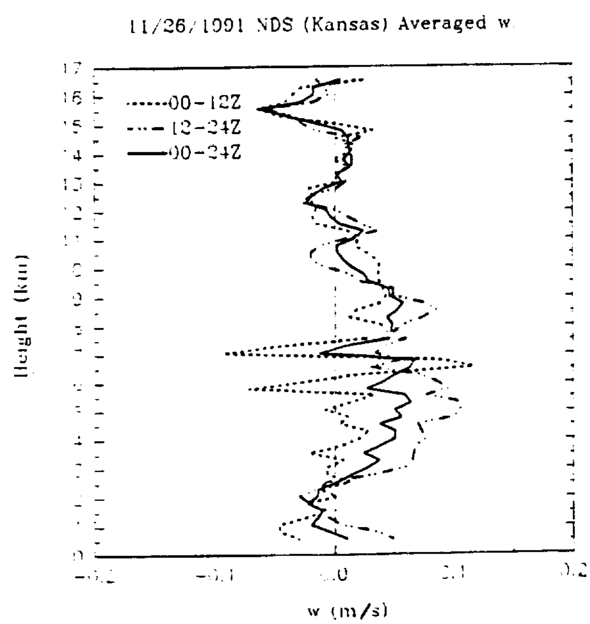

Figure 5. As same as Fig.4, but from network profiler at NDS.

cloud tops consistently at about 10km and bases down to 8km and even lower. All plots in Figs.4, 5 and 6 present the evidence of a continuously upward motion in this layer. Since both CSU and network wind profilers are operating at 404MHz, which corresponds to a wavelength of 75cm, ice particles are expected to be relatively transparent to the profiler radars.

Above the cloud, the 12-24Z averaged plots exhibit a change from upward motion to downward motion at slightly different locations: 10.7km for CSU direct measurement, and about 9.95km for both NDS direct measurement and CSU VAD calculation. In MB model, this reversal is expected to be close to the maximum horizontal wind level(Fig.2). A vertical cross section(from (30°N,110°W) to (45°N,90°W)) perpendicular to the jet streak indicates the maximum wind layer is located at 10.5km (Fig.7). The observations agree extremely well with the model study.

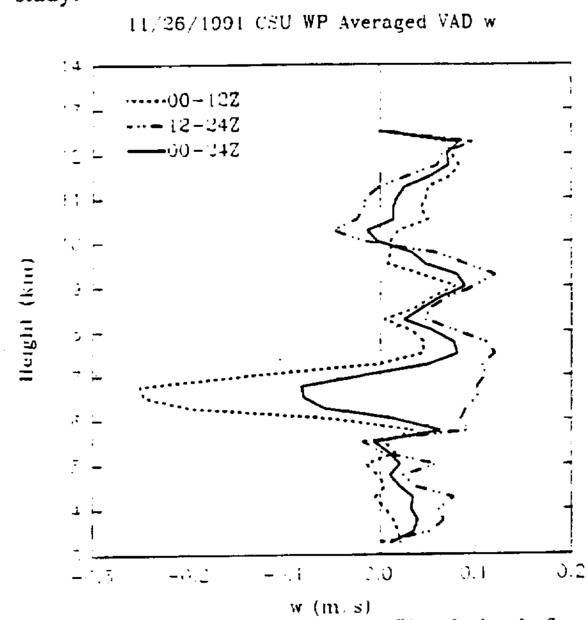

Figure 6. Vertical velocity profile derived from VAD. Parsons, Nov. 26, 1991.

Fig.8 presents the time-height contouring of the vertical velocity derived from the kinematic method. A very thick line which clearly separates the downward motion and upward motion is evident. The figure shows this change at cloud level starting from about 1400Z which was shortly before clouds were detected by the lidar. This reversal level settled at about 10km from 1700Z to 2000Z, which is what is expected according to the MB model. From 2000Z, this level dramatically dropped down to lower levels after the jet streak already passed over the area.

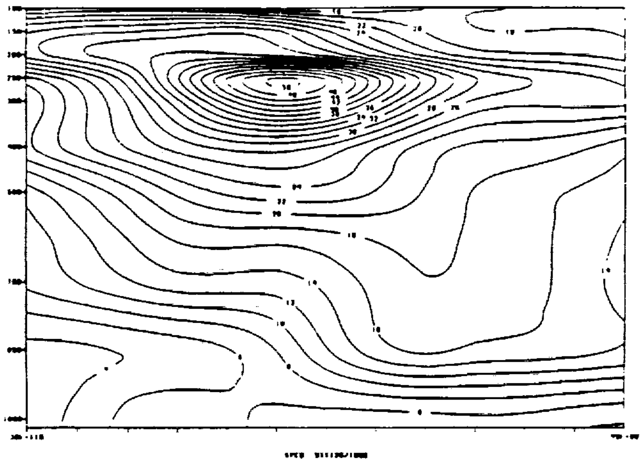

Figure 7. vertical velocity w(m/s) derived from the kinematic method on Nov.26,1991. Dash line is negative w; thin solid line is positive w; thick solid line is zero w.

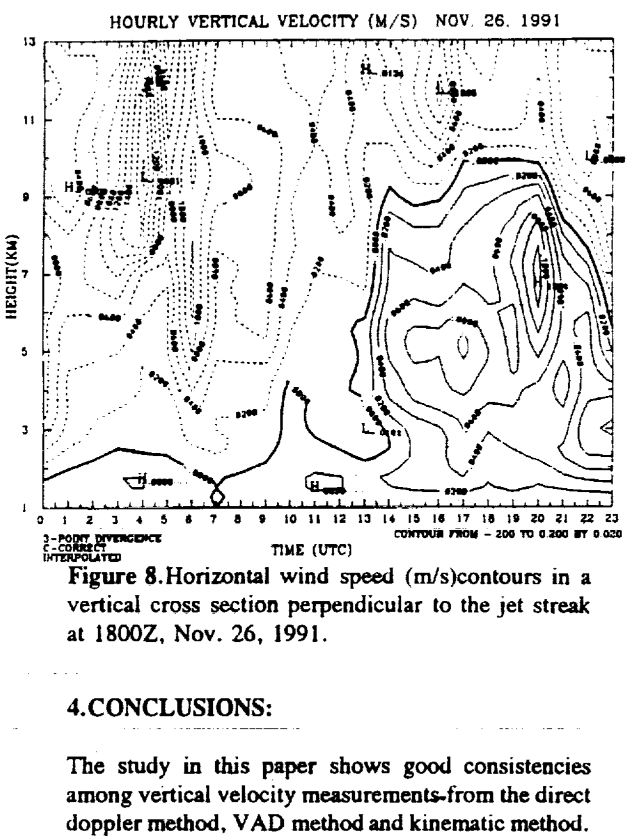

Figure 8. Horizontal wind speed (m/s)contours in a vertical cross section perpendicular to the jet streak at 1800Z, Nov. 26, 1991.

4.CONCLUSIONS:

The study in this paper shows good consistencies among vertical velocity measurements from the direct doppler method, VAD method and kinematic method. And the observation results agree very well with the theoretical model. Upward air motions exist at and below the cirrus cloud layer with weaker downward motions above. More confidence is gain for utilizing wind profiler data in our future researches.

5. ACKNOWLEDGEMENTS

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