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JAWS MICROBURSTS OCCURRING FROM OROGRAPHIC VORTEX STREETS

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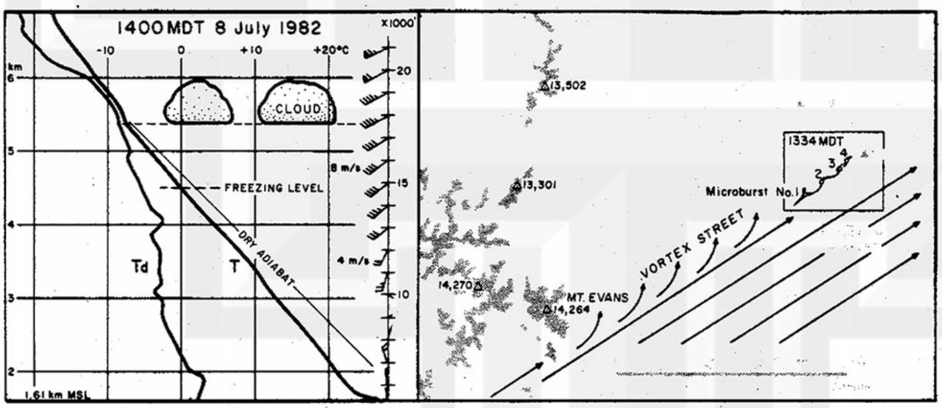

Fig. I. Statically stable Denver sounding (left) and anticipated orographically forced vortex street (Fujita, 1985).

1. INTRODUCTION

The first study to examine the parent cloud of a downburst was reported by Fujita (1977). Subsequent work inferred the existence of smaller scale downbursts which were denoted as microbursts (Fujita,1981) and examined the effects of rotation in microburst parent clouds (Fujita,1983). This paper presents a means to generate vorticity for a case during the JAWS project in which rotating clouds were harbingers to surface microbursts.

2. CASE PREFIGURATION

On 8 July 1982, a series of four dry microbursts occurred in the North Platte River Valley from four seperate high based, shallow clouds. As Fig. 1 illustrates, this family nearly falls on a line segment. Prevailing winds near the mountain apex and above are approximately the same velocity so vertical shear is small. Below this level there is considerable horizontal variation in the winds with a relatively quiescent region from 10-12,000 feet. The microburst family is almost parallel to prevailing winds at and above 13,000 ft. Extension of the line segment to the southwest reveals that the vortices appear to emanate from the southern end of Mount Logan (southern edge of gray area of 12,000 ft. + around Mt. Evans). This suggests the family is imbedded within a Von Karman-like vortex street.

3. THEORY

A Von Karman vortex street forms when a nearly incompressible fluid is forced to flow around a cylinder with a characteristic Reynolds number of at least 40. The street is denoted by two parallel rows of vortices rotating opposite to each other. As Re (Reynolds number) increases, the street and the vortices become more disorganized so that by Re of 10^6 the flow is chaotic. Within the regime of Re between 40 and 10^4 the fluid flow may be considered two-dimensional. For fluid flow that is three-dimensional at low Froude number (Fr), Smith (1979) has stated that periodic shedding of vortices may occur. It is the allowance of vertical deflections of upstream horizontal fluid planes that requires the third dimension. Shown qualitatively (Smith,1979) is the slight uplifting upstream with even greater sinking in the lee if Fr is large enough. A quanitative estimate is not given.

For the two or three-dimensional fluid flow to be considered Von Karman-like it should consist of a double row of vortices,each of comparable circulations. If they are also shed from each side of a body with a regular frequency the rate of vorticity discharged to the wake may be determined (Chopra,1973) as the product of the frequency and circulation. One may also determine the speed of eddy propagation as shown in Chopra (1973), that Von Karman theory predicts.

4. ANALYSIS AND RESULTS

In the center of fig. 2 a wavelike reflectivity pattern appears. Since the top of the page is north one can clearly see the northeast to southwest orientation of the echo returns. The echo in the upper right is the oldest and appeared similar to that in the center about 10 minutes earlier. The height of this scan is around 8,000 ft. As the left side of fig. 1 shows, the expected cloud base should be 16-17,000 ft. Since this is obviously below the actual cloud base the power returned to the radar is due primarily to virga, insects and dust. This also accounts for the relatively low reflectivity values.

Where returns were judged to be meaningful, Doppler velocities were calculated and are shown in fig. 3. The general flow field relative to the ground seems to be westerly. Around the boxed area the central echo appears to be acting as a barrier deflecting air around it. Velocities are within a vertical thickness of about 250m. with a center near 960m. Since the angles of CP2 and CP3 (4.8°) are small, the calculated velocities are plotted as horizontal velocities with negligible error.

Divergence was calculated using a first approximation finite difference scheme (fig. 5). Of particular note is that the hatched hole in the reflectivity has 0 divergence. The only large areas convergence exist on the north side of the short wave (10km., 245°) and a long band that skirts the southern end of the echo. The remaing area is diverging. This may mean that air is rising at this short wave to feed the cumulus aloft while descending motion prevails throughout the rest of the cloud.

To see the rotation in the enlarged area, the mean wind (3 m/s from the west) was subtracted from the dual-Doppler calculated winds. A well defined area is shown to exist in fig.5 with a center appearing to be just southeast of the 15 dBZ contour. Here it also appears as if an extension of the northern boundary may pick up an anticyclonic partner.

Divergence (fig. 6) analysis reveals convergence on the front edge of the short wave and the better resolution shows convergence at the right side of the cyclone center and divergence everywhere else.

Fig.7 shows the expected cyclonic vorticity at the vortex (misocyclone) center. The low value of vorticity associated with this center may be attributed to an area whose size is comparable to the spacing of the finite difference scheme being applied.

The trough behind the main echo appears to be a center of anticyclonic vorticity while the short wave in advance is cyclonic. The product of figs.6 and 7 appears as fig.8. For this one instance in time one may see where cyclonic vorticity increases. The largest increase in relative vorticity should occur at the crest behind the echo and the east side of the echo. Weakening is also predicted for the right side of the vortex. This should be expected since this is an Eulerian snapshot in a psuedo-Lagrangian system. However, fig.9 and fig.10 show CP2 reflectivity profiles, plotted on the CP3 grid for ease of comparison, that illustrate the formation of a protuberance 2.5 minutes and its' marked growth in the next 2.5 minutes. Also, the large hump that is the west side of the 1332 MDT echo has disappeared in the same 5 minute interval.

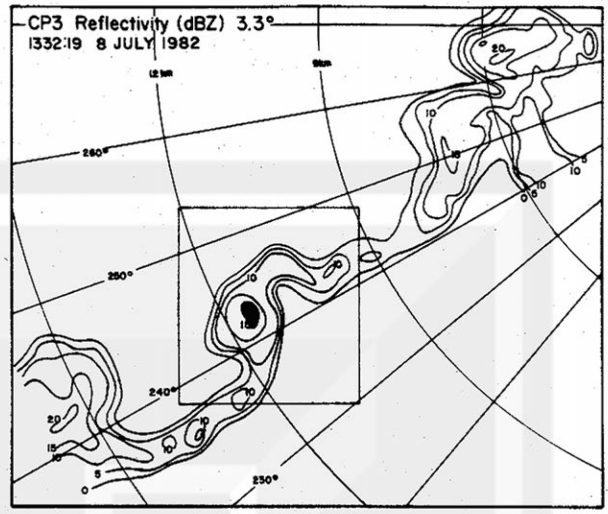

Fig. 2. CP3 Reflectivity with area to be enlarged outlined by box.

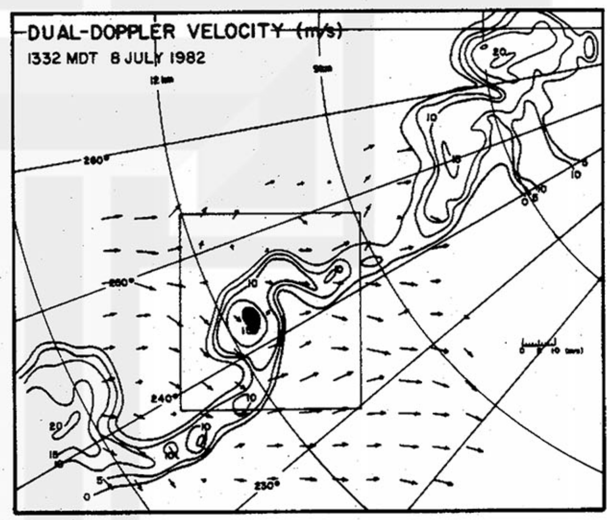

Fig. 3. CP2 & CP3 dual-Doppler velocity calculations.

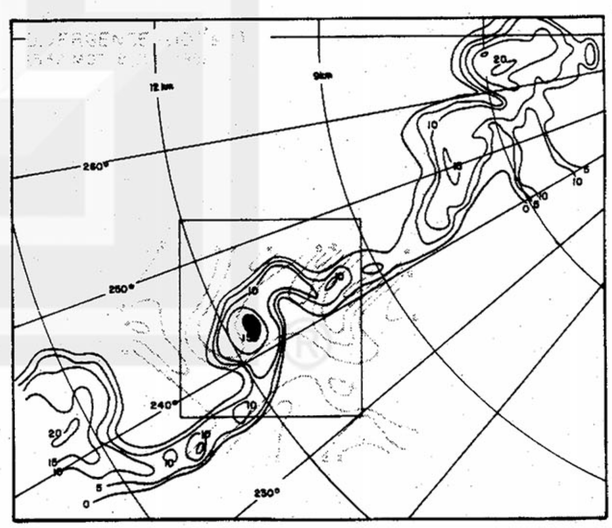

Fig. 4. Divergence analysis.

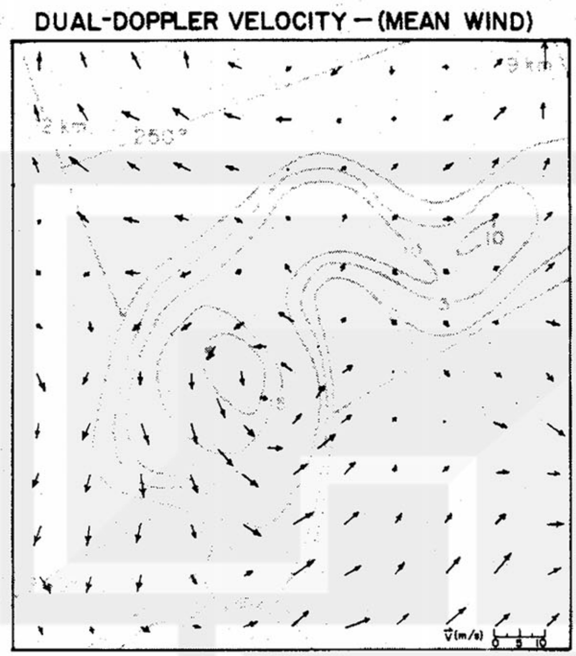

Fig.5 Dual-Doppler velocity with mean wind (3m/s from the west) subtracted out for the enlarged area.

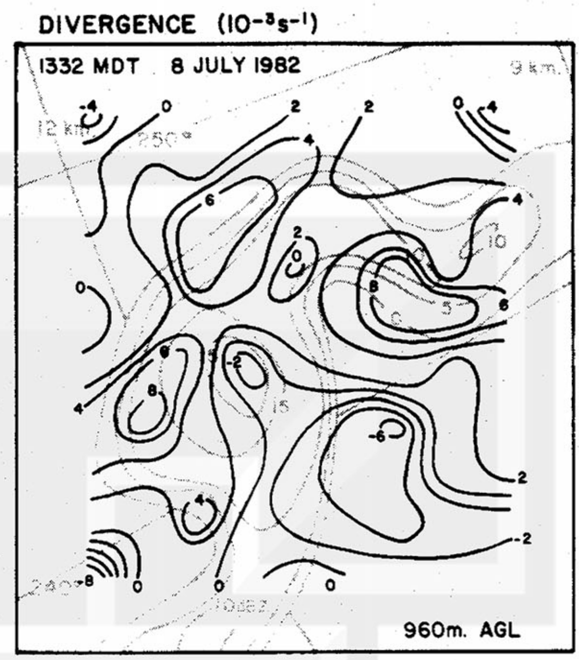

Fig.6 Divergence for the enlarged area.

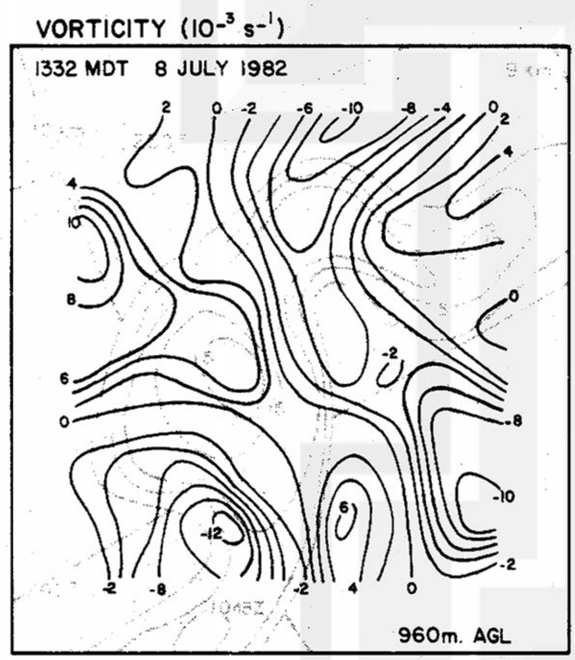

Fig.7 Vorticity for the enlarged area.

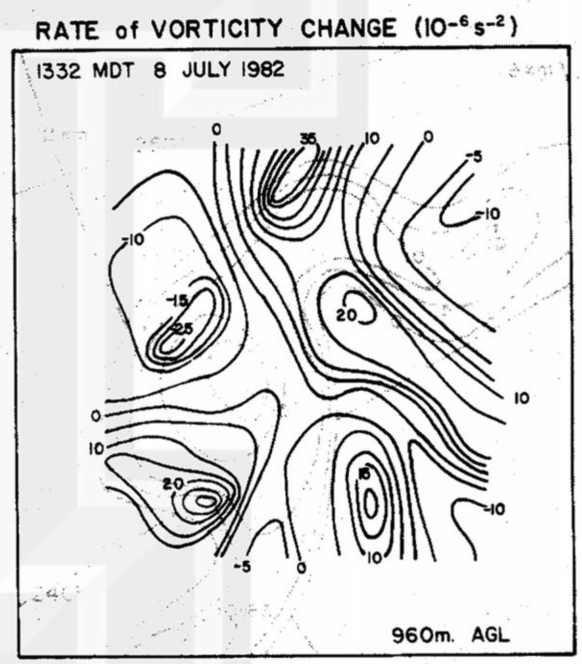

Fig.8 Rate of vorticity change for enlarged area.

Re for this case is on the order of 10^8 so that the two-dimensional vortex street approximation may not be valid. Fr is about 1 so that there is reason to believe that the three-dimensional theory might apply.

The frequency of these vortices shedding is about 1 per 1000 seconds or 1 every 17 minutes. Theory predicts 1 for every 12 minutes. Taking the upper level steering winds to be 6m/s theory predicts eddy propagation speed to be 5.5m/s. Actual data set value was nearer to 4m/s. Finally, the calculated rate of vorticity discharge in the wake is about $7100 m^2/s$.

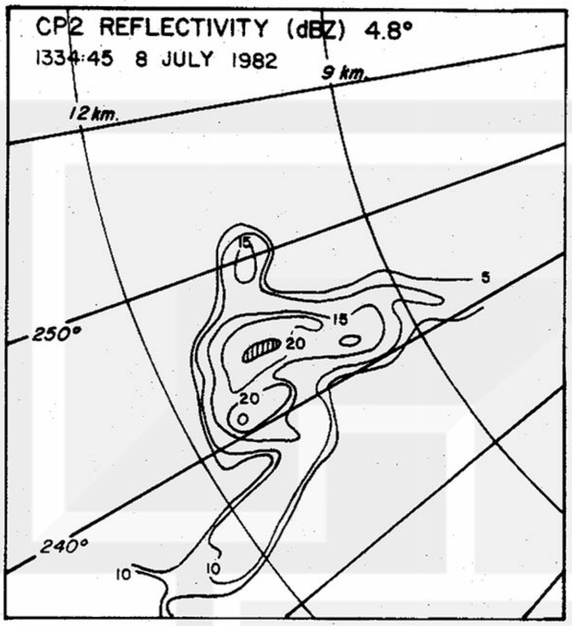

Fig.9 CP2 Reflectivity on CP3 base grid at 1334:45

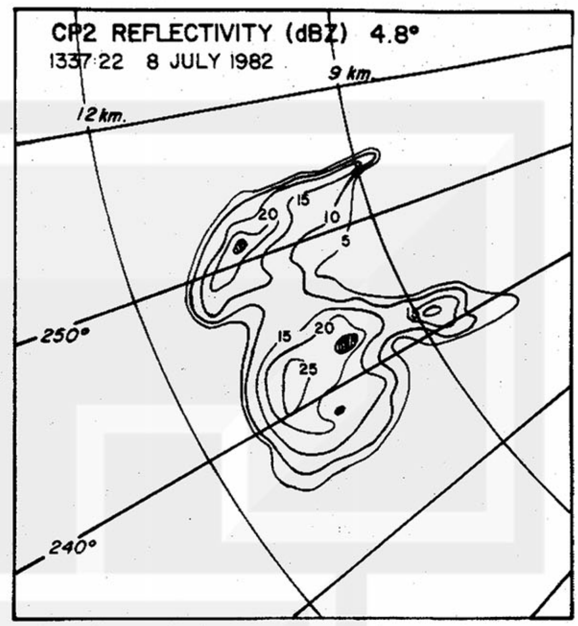

Fig.10 CP2 reflectivity on CP3 base grid at 1337:22

5. CONCLUSIONS

From the calculation of the speed of the reflectivity cores this particular vortex was found to be moving at rate of 4m/s towards the northeast. This was nearly along the axis of the line segment. The dual-Doppler velocities for the 960m. level had a mean component due east. This suggests that the vortex is being steered aloft with the winds of 10,000 ft. or greater. Since this layer of nearly uniform wind velocities is of a substantial thickness it seems reasonable to believe that these vortices are indeed Von Karman-like in strength and may make up a vortex street. The vertical deflections may even be determined to be a forcing mechanism for microbursts in some instances. To be honest, the generation of vorticity may be of a different type in this case.

Anticyclonic vortices were not obsereved in this particular case. This does not imply they were not there but rather if they were present they were not readily seen. Winant (1973) describes a process where vortex pair interaction allows for vortices to combine. These vortices are formed along the boundary of shear between two fluid layers with different velocities. The dominant circulation direction would be associated with the faster flow which in this case would be the air flowing past the southern end of Mount Logan and not around. This could easily set up a horizontal wind shear. The drawback of this method is that it applies to lower Re than is normally associated with the atmosphere. By adding the third dimension to flows similar to this might be fruitful. For in this case the vortices one observes could all be rotating in the same direction.

6. ACKNOWLEDGMENTS

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7. REFERENCES

Chopra,K.P.,1973:Atmospheric and Oceanic Flow Problems Introduced by Islands.Adv. in Geophys. 16,297-421.

Fujita,T.T.,1985:The Downburst.SMRP Research Paper No.210,p.122.

Fujita,T.T. and H.R.Byers,1977:Spearhead Echo and Downburst in the Crash of an Airliner. Mon. Wea. Rev.,105,129-146.

Fujita,T.T. and R.M.Wakimoto,1981:Five Scales of Airflow Associated with a Series of Downbursts on 16 July 1980.Mon.Wea.Rev.,109, 1438-1456.

Fujita,T.T. and R.M.Wakimoto,1983:JAWS Microbursts Revealed by Triple Doppler Radar,Aircraft, and PAM Data.Preprints,13th Conference on Severe Local Storms,Tulsa, Okla. Amer.Met. Soc.,Boston Ma.,97-100.

Smith,R.B.,1979:The Influence of Mountains on the Atmosphere.Adv. in Geophys.,21,87-230.

Winant,C.D. and F.K.Broward:Vortex Pairing: The Mechinism of Turbulent Mixing Layer Growth at Moderate Reynolds Number.J.Fluid Mech. 63,237-255.