# ATMO 445/545 PROBLEM SET 3 Due 18 April 2003

**Problem 1 - Doppler Radar and Microbursts**

**Consider the site of the WSR-88D relative to Tucson International Airport (TIA) - radar is 40 km southeast of TIA; radar is at 5,200 ft MSL elevation; TIA elevation is 2,400 ft MSL. There are two figures with this problem: top shows data from the JAWS research project and a typical vertical profile of velocities associated with microbursts is indicated; bottom figure shows idealized radial velocity fields associated with a microburst.**

**a)** How well can the WSR-88D detect microbursts in the vicinity of TIA? Explain your answer. How can data from the radar be used to help aircraft landing and taking off at TIA avoid microbursts?

**b)** The FAA decides to install a TDWR near TIA. How close to the end of the runway does the radar need to be to detect accurately the wind maxima associated with a typical microburst? Assume that detect accurately means that the beam center needs to be no higher than the height of the wind maxima. You can ignore the curvature of the earth. Remember that for the TDWR: wavelength is 5 cm, beam angular width is 1/2 degree, and the radar is allowed to scan at zero degree elevation angle. How tall should the radar tower be? If you make additional assumptions, please list them. It will be adequate to use simple geometry in parts b and c of this problem.

**c)** If it were acceptable to measure the maximum radial divergence to within 60% scanning at 0.5 degree elevation angle, how far away could the radar be sited, if tower height is same as in **b**?

**d)** Consider the idealized isotach pattern (i.e., Fig. 3.1, the contours of inbound and outbound speeds) for a microburst. If the isotach intervals are at 5 m/s, estimate the maximum value of radial divergence detected by a Doppler radar observing the microburst exactly as depicted in the figure.

**e)** The idealized microburst of Fig. 3.1 is located 2 km SE of the end of the runway at TIA. At distances beyond 5 km from the center of the microburst the wind is calm everywhere. An airplane approaching the runway from the SE flies directly through the center of the microburst. Wind speeds do not change in the vertical for the altitudes at which the plane is flying. The plane does not land but continues to the NW. Plot the airplane's air speed as a function of distance (out to radii of 6 km) from the center of the microburst. Assume that the pilot somehow maintains a constant ground speed of 140 knots. What is the greatest loss of airspeed that occurs, and over what period of time does this loss occur?

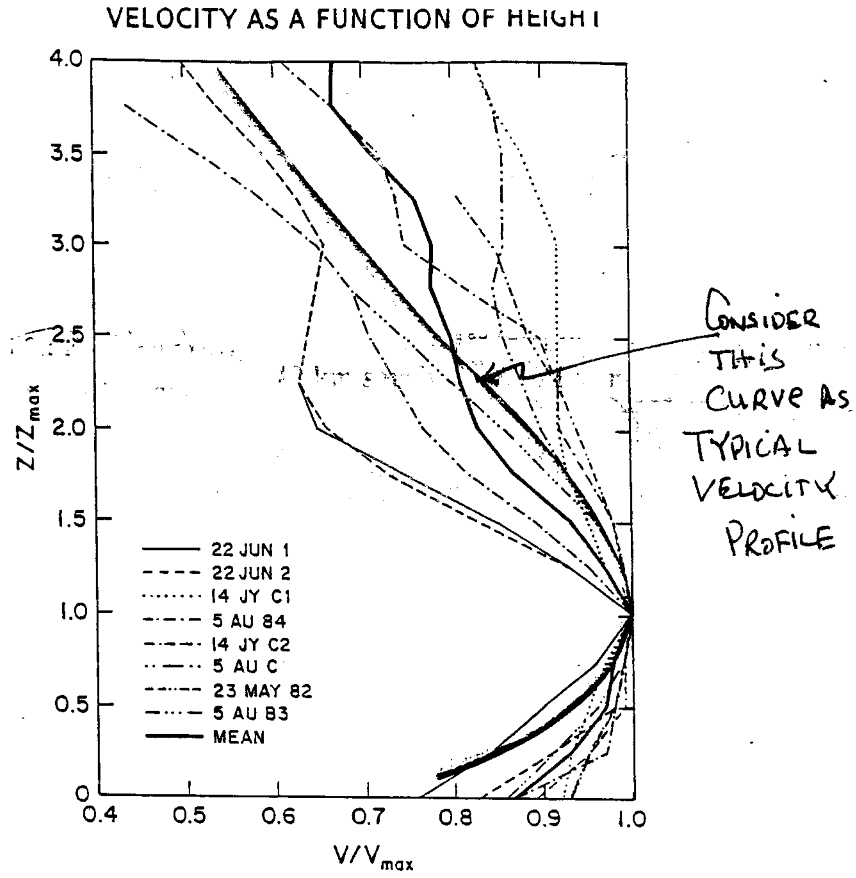



FIGURE 5.3. This figure plots velocity as a function of height through the center of a microburst velocity maximum. All velocities have been normalized to the maximum velocity found in the vertical. Eight microbursts make up the sample; all show very similar structure below the height of maximum velocity. But, as for the decay of $\Delta V_r$ after the maximum time and the change in diameter after the time of maximum $\Delta V_r$, these microbursts show markedly different profiles above the height of maximum velocity. The heavy dark line shows the mean for the eight cases plotted, and a velocity profile typical of an impinging wall jet is indicated by the wide grey line. The mean height of maximum outflow winds is 80 m, indicating that if a radar cannot view events very near the ground, there is no way of knowing how strong the event might be.

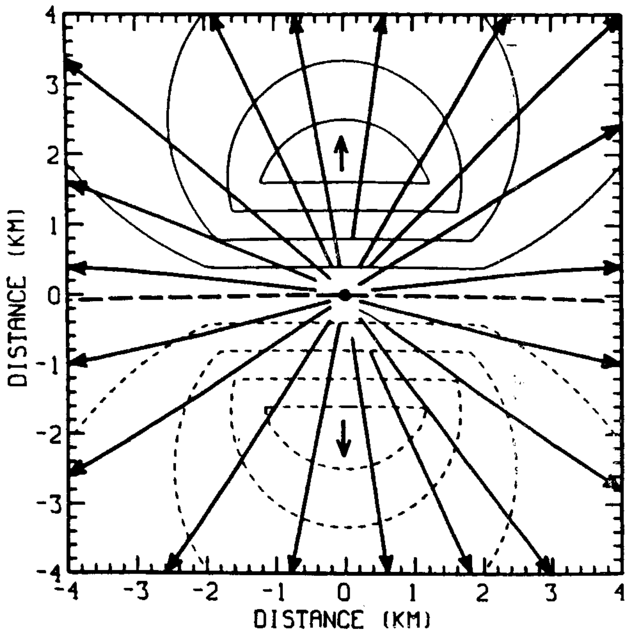



*Fig. 3.1 Single-Doppler signatures of (a) a vortex and (b) a divergence source. Heavy lines are true airflow; thin lines are radial velocity contours with dashes for inbound radial component; short arrows mark radial velocity maxima. (From Wood and Brown, 1983.)*

**Problem 2** - **The WSR-88D VAD Algorithm**

**There is one figure for this problem. It is a highly idealized VAD algorithm "fit" to radial velocity data measured at a radius of 20 km from the Doppler radar. The data points were measured at a beam height center of 1 km above a flat earth. You can assume that the 2-D horizontal wind direction at 1 km is everywhere uniform.**

**a)** From what direction is the 2-D horizontal wind blowing?

**b)** What is the horizontal 2-D wind speed at an azimuth of 90 degrees; at an azimuth of 45 degrees; at an azimuth of 225 degrees, and at an azimuth of 315 degrees?

**c)** What is the maximum radial divergence measured by the Doppler radar using data from any two radials separated by 180 degrees?

**d)** Compute the total divergence of the 1 km 2-D horizontal wind field present over the region within 20 km radius of the Doppler radar.

**Problem 3** - **The Reflectivity - Rainfall Rate Relation**

**a)** Derive the famous Marshall-Palmer Z/R relation using equations 1 through 3 from their 1948 paper.

**b)** List all the assumptions that have been made to allow this result.

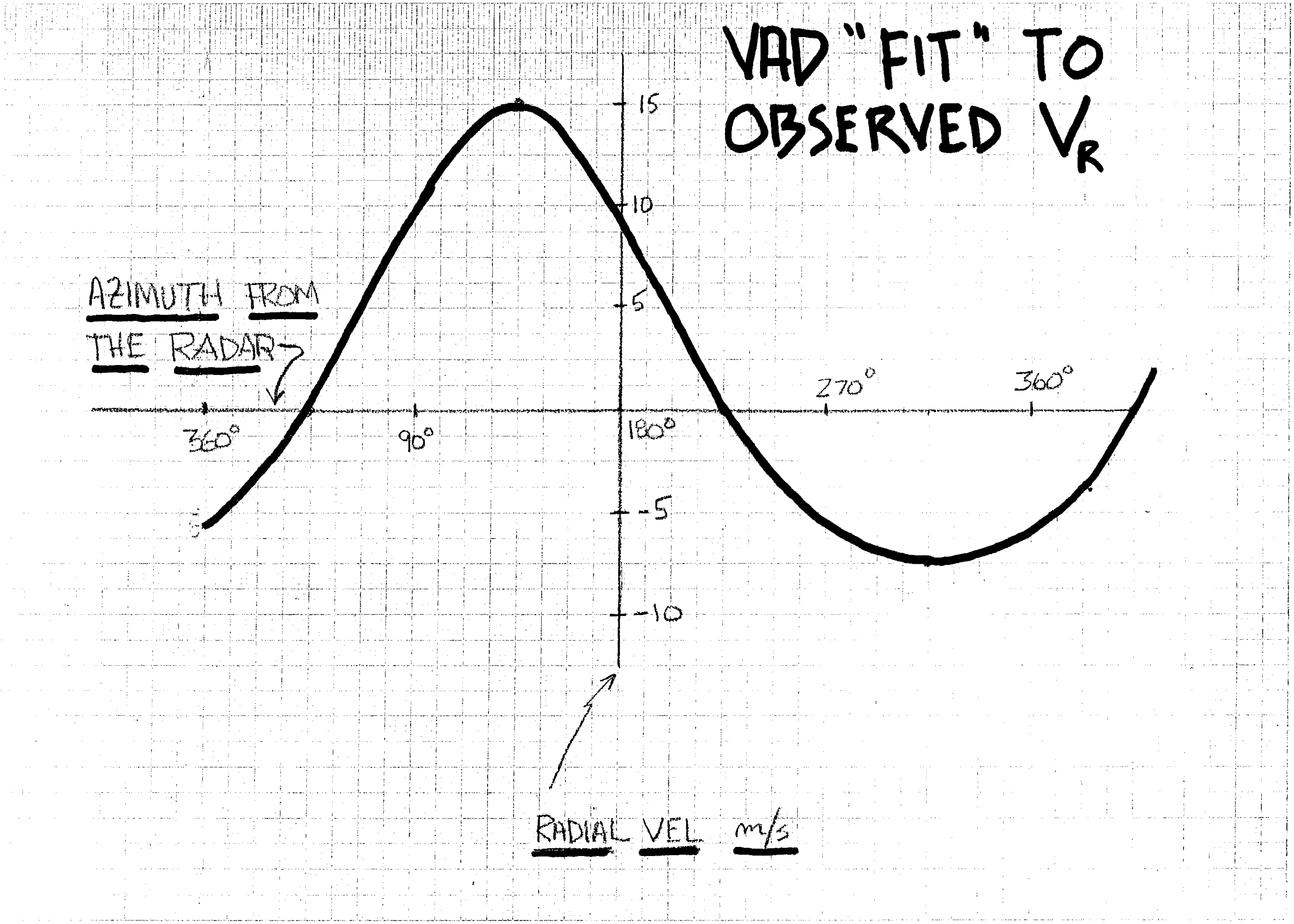
**c)** Which of these assumptions are most likely to be valid for precipitation events observed at low-levels by weather radars? Explain why.

**Problem 4** - **The Reflectivity - Rainfall Rate Relation**

Consider the following, simple, homogenous distribution of water drops within a volume of 1 cubic meter.

| Diameter (mm) | Number |
|---|---|
| 0.1 | 500 |
| 1.0 | 300 |
| 1.5 | 75 |
| 2.0 | 15 |
| 3.0 | 8 |
| 5.0 | 5 |

**NOTE:** The density of water is 1 gram per cubic cm and terminal velocity Vt of the drops can be approximated by D(mm) times 1000/s


VAD "FIT" TO OBSERVED $V_R$
15
10
5
-5
-10
360°
90°
180°
270°
360°
AZIMUTH FROM THE RADAR
RADIAL VEL m/s

**4 - Continued**

**a)** Calculate the rain rate in mm/hour for this drop size distribution in still air; in air that is sinking at 4 m/s; and in air that is rising at 3.0 m/s.

**b)** Compute the radar-estimated rain rate for this drop size distribution using the WSR-88D convective (default) Z-R relation. Assume that reflectivity is truncated at 53 dBZ in all allowed WSR-88D Z-R relations.

**c)** Compute the radar-estimated rain rate for this drop size distribution using the WSR-88D West-Cool Stratiform Z-R relation.

**d)** Discuss reasons for any differences between your answers in a, b, and c. Is this a sprinkle, a typical Arizona summer shower, or a "cats and dogs" storm?"

**<u>Problem 5</u> - The Reflectivity - Vertically Integrated Liquid Water (VIL)**

**a)** Give the relation that Greene and Clark derive for VIL and list the assumptions they made in deriving this relation.

**b)** Explain why "VIL" is a misnomer.

**c)** Discuss at least three reasons, related to how the data in the first tilt are extrapolated downward in the WSR-88D VIL algorithm, why computed values of VIL can be quite inaccurate in the western U.S.

**d)** Why do some forecasters prefer to use "VIL Density" in identifying potentially severe storms?

**e)** Consider the figure that follows, which is from the NWS on-site radar training course materials. This figure shows VIL values calculated for a single storm cell located at different ranges from a WSR-88D. One curve shows the VIL calculated when the radar operates in VCP-21 and the other when it operates in VCP-11. Explain and discuss the following two aspects of these plots: the strong cyclic high and low character of the VCP-21 curve; low values of VIL at short ranges. Finally, the curves show that VIL calculated when the radar is operating in VCP-21 can sometimes exceed the VCP-11 value by as much as 20 kg/square meter. How can this be? It may help to use diagrams to explain your answers.

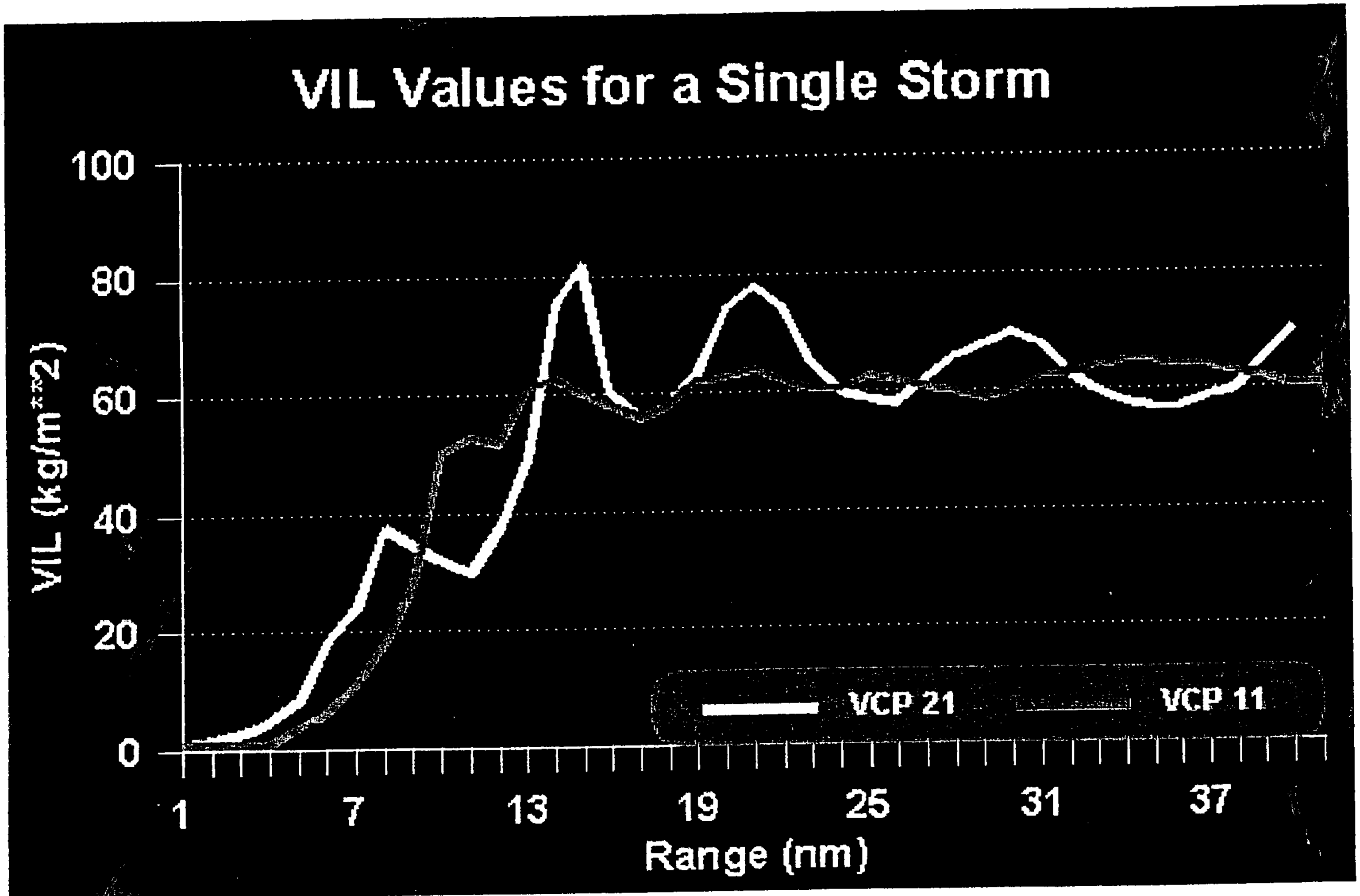



**Figure 3-5.** This study is from measurements of a single storm using two different volume coverage patterns.

## BOUNDARY CONDITIONS/GRADING

**Individual work efforts please.**

**All calculations and work pages must be attached to answer sheets.**

**Problems due at start of class on Friday April18th.**

**Late penalty 10 points per day lost.**

**Grading** 20 pts/question but Seniors can do either 3 or 4 at 40 pts

**Problem 1** Part
- a - 4
- b - 2
- c - 2
- d - 4
- e - 6

**Problem 2** Part
- a - 3
- b - 6
- c - 4
- d - 7

**Problem 3** Part
- a - 10 (20)
- b - 6 (12)
- c - 4 (8)

**Problem 4** Part
- a - 8 (16)
- b - 5 (10)
- c - 3 (6)
- d - 4 (8)

**Problem 5** Part
- a - 3
- b - 3
- c - 4
- d - 3
- e - 7