ATMO 489/689
Radar Meteorology

Laboratory #5
10/17/05 (Monday section) and 10/18/05 (Tuesday section)

Radar Reflectivity (Factor)
A radar measurement and a physical property of rainfall

Due: By beginning of lecture on Wednesday, 10/26/2005

Reading: Rinehart (2004) Chapter 5

Questions (100 points):

1. (40 points) The Distromet Joss-Waldvogel (J-W) disdrometer (http://www.distromet.com/default.htm and pictured below in Fig. 1) for raindrops is an instrument for measuring raindrop size distributions continuously and automatically.

Figure 1. Joss- Waldvogel (J-W) disdrometer signal processor/storage (left) and measuring unit (right).

It was developed because statistically meaningful samples of raindrops could not be measured previously without a prohibitive amount of work. The J-W instrument transforms the vertical momentum of an impacting drop into an electric pulse whose amplitude is a function of the drop diameter. A conventional pulse height analysis yields the size distribution of raindrops in 20 discrete bins. Drop size distribution (DSD) data is typically averaged over a 1 minute period.

The Texas A&M University Department of Atmospheric Sciences currently owns and operates three J-W disdrometers over southeastern Texas for the study of physical and radar meteorology. One of the instruments was installed by Dr. Courtney Schumacher and her research group at the old TI building in College Station, as shown in Fig. 2. The other two units are currently being installed in the downtown Houston area and along the Texas coast near Galveston.

The signal processor and PC, which process, store and displays the data, are housed in the custom designed enclosure shown in Fig. 2a. The J-W measuring unit sits on top of the enclosure (Fig. 2b). The unit runs continuously, recording the DSD of any rain events that pass overhead.

a. **b.**

Figure 2. Texas A&M University Joss-Waldvogel (J-W) disdrometer operated by Dr. Courtney Schumacher and her research group at the old TI building in College Station, TX. (Pictures courtesy of Dr. Schumacher)

One such rain event occurred on December 22, 2004 for about 5 hours with widespread light to heavy rain (Figure 3). This storm was associated with the passage of a cold front, which generated a strong temperature gradient. The widespread rain developed behind the front as the upper level low lagged the surface front.

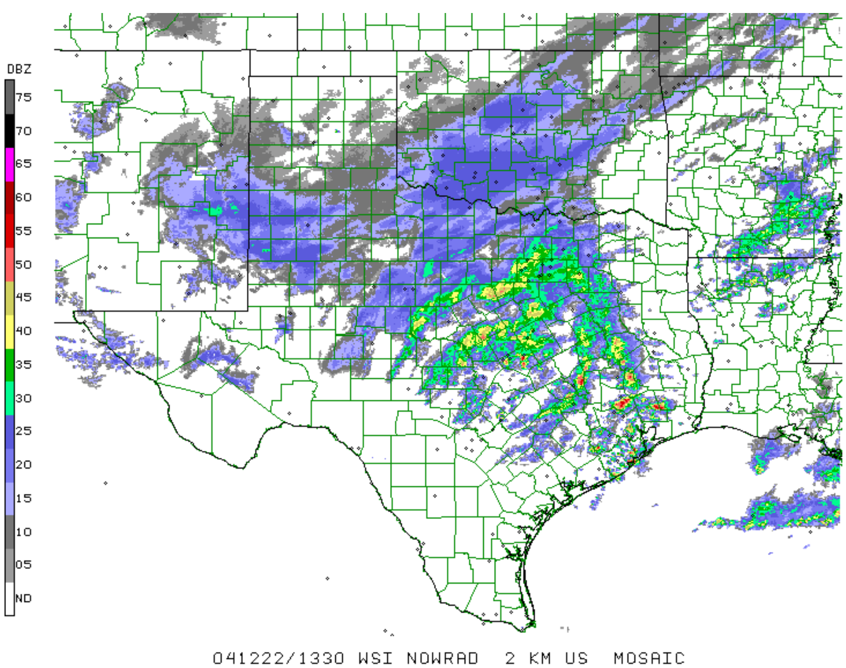

Figure 3. WSI NOWRAD mosaic of low level WSR-88D (Weather Surveillance Radar – 1988 Doppler) data over Texas and vicinity on December 22, 2004 at 1330 UTC.

Table 1. A twenty-six minute sample of one-minute averaged J-W DSD data from 1327 UTC to 1352 UTC on December 22, 2004.

Bin Center Diameter (D) [mm]	0.359	0.455	0.551	0.656	0.771	0.913	1.116	1.331	1.506	1.665	1.912	2.259	2.584	2.869	3.198	3.544	3.916	4.335	4.859	5.373
Bin Concentration per channel (#)	n01	n02	n03	n04	n05	n06	n07	n08	n09	n10	n11	n12	n13	n14	n15	n16	n17	n18	n19	n20
1327	0	0	0	0	0	0	0	0	0	2	11	5	1	0	0	0	0	0	0	0
1328	0	0	0	0	0	0	1	1	4	6	1	1	0	0	1	0	0	0	0	0
1329	0	0	0	0	0	0	1	4	6	8	17	15	7	5	1	4	1	0	0	0
1330	0	0	0	0	1	2	6	18	14	7	14	19	14	20	17	4	5	2	0	0
1331	0	0	0	2	3	6	17	12	10	9	53	45	12	8	5	3	1	0	0	0
1332	0	0	0	1	0	11	17	35	38	42	64	48	23	20	11	7	3	0	1	0
1333	0	0	0	0	1	10	29	34	38	21	70	45	23	9	11	10	10	3	0	0
1334	0	0	0	0	0	2	25	32	53	46	76	54	25	35	23	16	18	4	3	0
1335	0	0	0	0	0	4	27	32	49	53	78	59	25	21	30	17	4	5	3	0
1336	0	0	0	0	1	9	35	69	63	52	70	38	26	22	24	14	16	11	7	1
1337	0	0	0	1	0	6	52	62	43	51	91	58	27	40	26	12	9	10	4	0
1338	0	0	1	0	2	15	30	35	36	38	71	48	16	12	8	2	3	1	0	0
1339	0	0	0	0	0	4	21	41	39	39	46	74	34	28	14	14	5	2	0	0
1340	0	0	0	0	1	11	37	51	52	60	109	61	28	23	17	7	3	0	1	0
1341	0	0	0	0	0	10	56	66	62	61	80	32	13	6	3	0	0	0	0	0
1342	0	0	0	0	2	12	49	58	30	24	30	16	4	1	0	0	0	0	0	0
1343	0	0	0	0	0	15	49	37	18	14	8	0	1	1	0	0	0	0	0	0
1344	0	0	0	1	2	11	53	57	38	37	76	33	14	4	2	0	0	0	0	0
1345	0	0	0	0	2	12	81	76	40	41	51	19	7	8	0	0	0	0	0	0
1346	0	0	0	0	1	13	74	105	67	42	31	5	0	0	0	0	0	0	0	0
1347	0	0	0	0	4	15	43	22	3	0	0	0	0	0	0	0	0	0	0	0
1348	0	0	0	1	2	21	34	5	0	0	0	0	0	0	0	0	0	0	0	0
1349	0	0	0	0	1	19	12	11	9	7	0	0	0	0	0	0	0	0	0	0
1350	0	0	0	0	2	6	35	24	3	0	0	0	0	0	0	0	0	0	0	0
1351	0	0	0	0	0	6	7	0	0	0	0	0	0	0	0	0	0	0	0	0
1352	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Discrete 1-minute average rain drop size distribution (DSD) data in 20 size bins measured by a J-W disdrometer are given in Table 1 and in the associated space-delimited data file (disdrom_data.prn) or the tab-delimited data file (disdrom_data.txt). The DSD data is presented as rain drop concentration per bin during a 26 minute period beginning at 1327 UTC and ending at 1352 UTC. The bin center diameter (mm) for each bin is provided at the top of the table and data file.

The following expression is the definition of radar reflectivity factor (z, $mm^6\ m^{-3}$) as measured by discrete data from a J-W disdrometer,

$$z = \sum_{i=1}^{M} \frac{N(D_i) \bullet D_i^6}{T \bullet A \bullet v_i(D_i)} \qquad [1]$$

where i is the bin (or channel) number, $N(D_i)$ is the concentration (i.e., #) of drops per D_i bin, M is the total number of bins, D_i is the i^{th} diameter size (mm), T is the sampling time (seconds), A is the sample area (m^2), and v_i is the terminal fall speed of rain drops ($m\ s^{-1}$). For the J-W disdrometer, T = 1 minute and A = 50 cm^2. We will use the following expression for the terminal fall speed of raindrops: $\nu(D_i) = 386.6 \bullet D_i^{0.67}$ [$m\ s^{-1}$], where D_i is in meters (m) (Atlas and Ulbrich 1977).

a. (35 points) Using the data in Table 1 and the definition in equation [1], calculate and plot a time series of radar reflectivity factor (z, $mm^6\ m^{-3}$) and Z (dBZ). You are encouraged to use either a computer programming language or a spreadsheet program of your choice to solve this problem. Several options are available on the LINUX PC's in Rm 1201.

b. (5 points) Based on the given definition and your results above, discuss whether concentration or size typically dominates the radar reflectivity factor.

2. (15 points) Calculate the *equivalent* radar reflectivity factor (z_e, $mm^6\ m^{-3}$ and Z_e, dBZ) for beam filling precipitation targets described by the following

a. (3 points) A monodisperse raindrop size distribution with a diameter of 300 μm and a concentration of 1 l^{-1}.
b. (7 points) An inverse exponential raindrop size distribution, $N(D) = N_0 \exp(-\lambda D)$, where $N_0 = 4.67 \times 10^4\ m^{-3}\ mm^{-1}$ and $\lambda = 3.33\ mm^{-1}$. (*Hint*: Assume D varies from 0 to ∞).
c. (5 points) Ice aggregates (i.e., snow) characterized by melted drop diameters that have the same size distribution as in part a) above. For size distributions of ice particles expressed in terms of melted drop diameters, note that $|K_i|^2 = 0.208$.

3. (30 points) The following table contains the approximate specifications for the operational WSR-88D and research NOAA WP-3 tail radars. Answer the questions below using these specifications and the assumptions listed beneath the table. Be attentive to units in your calculations!

Parameter	NOAA WP-3 TAIL RADAR	WSR-88D RADAR
Wavelength (λ)	3.2 cm	10.7 cm
Pulse Duration (τ)	0.5 μs	1.57 μs (short pulse)
Half-power Beamwidth	Horizontal = 1.35° Vertical = 1.9°	1°
Peak Power	60 kW	1000 kW
Antenna Gain (G)	40 dB	45 dB
Minimum Detectable Signal (MDS)	-111 dBm	-113 dBm

For both radars, assume that the system noise power, P_n, equals the minimum detectable signal (P_n = MDS). Also, assume that the attenuation loss factor equals -3 dB (l = -3 dB) for both radars. Assume that both radars transmit at the peak power. Assume the hydrometeors are water.

a. (8 points) What is the signal to noise ratio (SNR, dB) for each radar at a range of 20 nm (nm=nautical miles) if the reflectivity factor is 0 dBZ? What about 55 dBZ?

b. (8 points) For each radar, what is the minimum detectable reflectivity (factor), or MDR, at a range of 20 nm if the system performance specifications require the SNR = 0 dB?

c. (7 points) What happens to the MDR at 20 nm if we require the SNR to be 1 dB for each radar?

d. (7 points) If the dynamic range of the WSR-88D radar is 93 dB, what is the saturation (or maximum) reflectivity (in dBZ) that is detectable at 20 nm by the WSR-88D?

4. (15 points) You are a radar meteorologist planning to study boundary layer wind transport in the precipitation clear-air (i.e., insects with radar reflectivity factor ranging from -20 dBZ < Z < 20 dBZ) for an air quality field experiment in Houston using the CHILL radar. Using the logarithmic form of the radar range equation and the information provided in Appendix D of Rinehart (2004), graph the minimum detectable reflectivity (MDR) (dBZ) as a function of range (km) for the CHILL radar. Discuss the implications of this graph for your proposed field experiment.