

ATMO 489
Radar Meteorology

Laboratory #7
10/23/06

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

Due: Wednesday, Nov 1, 2006 at the beginning of lecture. No late labs will be accepted.

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 (CLL), 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.

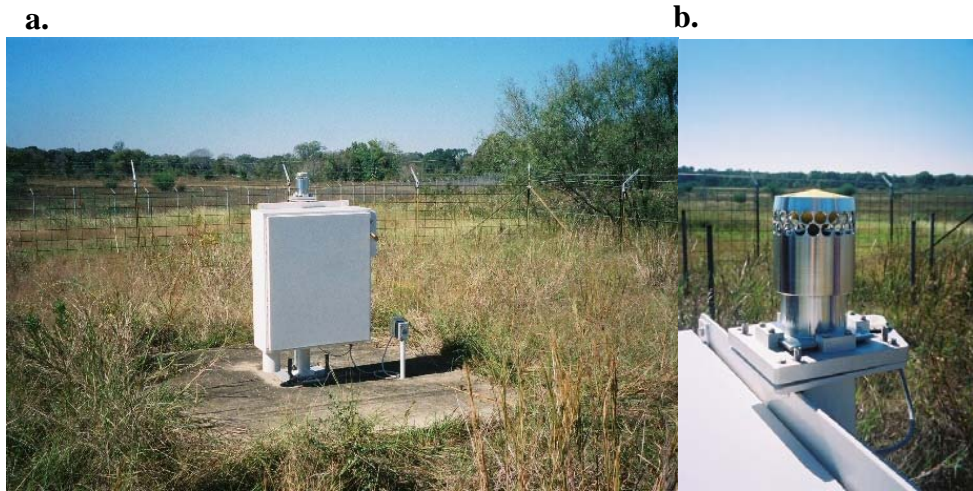


Figure 2. Texas A&M University Joss-Waldvogel (J-W) disdrometer operated by Dr. Courtney Schumacher and her research group at the old TI building in College Station, TX. (Pictures courtesy of Dr. Schumacher)

One such rain event occurred on October 31, 2005 associated with a mesoscale convective system (MCS) that was characterized by a leading convective line and trailing stratiform regions (Figs. 3a,b).

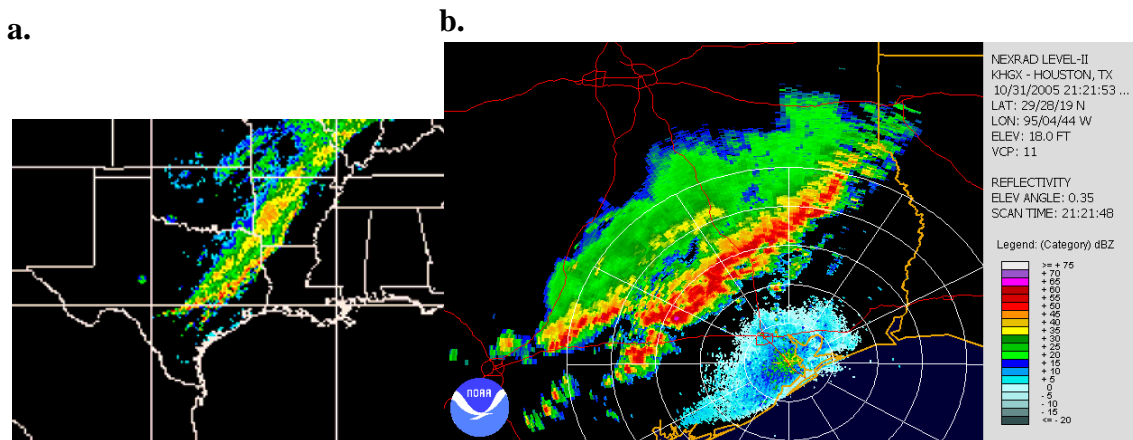


Figure 3. WSR-88D data of CLL rainfall event. a) Zoomed in WSI NOWRAD mosaic of low level WSR-88D (Weather Surveillance Radar – 1988 Doppler) data over Texas and vicinity on October 31, 2005 at 15:00 CST (21:00 UTC). b) WSR-88D KHGX (League City, TX) 0.35° elevation angle PPI at 21:21:53 UTC (1522 CST). Note CST=UTC-6 hours.

Table 1. A twenty-one minute sample of ten second averaged J-W DSD data from 15:13:00 to 15:34:00 CST on October 31, 2005.

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	
10/31/2005	15:13:00	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0
10/31/2005	15:13:10	0	0	0	1	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
10/31/2005	15:13:20	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2	0	0
10/31/2005	15:13:30	0	0	0	0	0	0	0	0	0	1	1	0	2	0	0	1	1	1	2	2	2
10/31/2005	15:13:40	0	0	0	0	0	0	2	1	0	1	1	1	0	1	0	0	2	4	1	1	1
10/31/2005	15:13:50	0	0	0	0	0	0	1	0	4	1	3	2	1	0	0	0	3	1	3	0	0
10/31/2005	15:14:00	0	0	0	0	0	0	1	2	1	0	0	2	0	1	1	1	1	0	4	2	2
10/31/2005	15:14:10	0	0	0	0	2	1	0	0	0	0	1	4	0	0	1	0	1	1	1	1	0
10/31/2005	15:14:20	0	0	0	0	0	0	1	0	2	2	12	7	1	0	2	4	1	4	0	0	0
10/31/2005	15:14:30	0	0	0	0	0	2	3	2	3	2	5	6	4	3	0	0	1	0	2	0	0
10/31/2005	15:14:40	0	0	0	0	0	0	2	1	3	2	1	5	3	3	1	4	7	3	2	0	0
10/31/2005	15:14:50	0	0	0	0	0	0	0	3	0	2	2	3	3	4	1	2	3	3	1	1	1
10/31/2005	15:15:00	0	0	0	0	0	0	2	5	2	3	6	2	2	4	6	3	3	0	1	3	3
10/31/2005	15:15:10	0	0	0	0	0	2	3	3	3	1	5	4	3	1	1	2	4	3	1	0	0
10/31/2005	15:15:20	0	0	0	0	0	1	6	3	4	3	6	1	4	2	5	0	3	0	1	0	0
10/31/2005	15:15:30	0	0	0	0	0	6	5	2	3	4	12	15	3	8	10	5	2	2	1	0	0
10/31/2005	15:15:40	0	0	0	0	0	2	11	8	8	6	16	6	7	9	10	8	0	1	0	0	0
10/31/2005	15:15:50	0	0	0	0	1	2	6	8	10	10	13	8	10	2	2	2	2	1	0	0	0
10/31/2005	15:16:00	0	0	0	0	0	0	7	5	7	4	16	12	9	7	6	1	3	1	0	0	0
10/31/2005	15:16:10	0	0	0	0	0	2	6	4	11	9	15	16	13	6	7	9	6	3	2	0	0
10/31/2005	15:16:20	0	0	0	0	0	0	10	10	3	7	14	7	6	10	9	10	3	3	0	0	0
10/31/2005	15:16:30	0	0	0	0	0	2	6	12	14	13	18	19	12	10	10	6	3	1	0	0	0
10/31/2005	15:16:40	0	0	0	0	0	4	14	18	16	13	22	27	11	11	7	2	1	0	0	0	0
10/31/2005	15:16:50	0	0	0	0	0	7	10	8	7	8	14	27	10	7	6	3	5	1	0	0	0
10/31/2005	15:17:00	0	0	0	0	0	3	12	13	15	16	33	20	12	7	5	4	4	1	1	0	0
10/31/2005	15:17:10	0	0	0	0	3	5	13	13	12	9	26	13	9	2	8	4	3	1	0	1	1
10/31/2005	15:17:20	0	0	0	0	2	3	12	4	8	6	16	17	9	9	8	6	4	1	2	1	1
10/31/2005	15:17:30	0	0	0	2	0	1	9	9	3	7	12	19	10	13	9	4	4	1	1	0	0
10/31/2005	15:17:40	0	0	0	0	1	3	17	9	8	8	16	26	11	3	7	2	5	2	0	0	0
10/31/2005	15:17:50	0	0	0	0	2	5	18	13	4	2	13	25	6	5	6	3	0	3	1	1	1
10/31/2005	15:18:00	0	0	0	0	0	1	9	7	14	7	19	15	7	4	3	2	2	2	0	0	0

10/31/2005	15:18:10	0	0	0	1	2	7	19	12	12	9	21	20	9	6	5	3	1	1	1	0
10/31/2005	15:18:20	0	0	0	0	1	5	14	14	9	10	24	15	6	6	4	0	1	0	0	0
10/31/2005	15:18:30	0	0	0	0	2	5	11	14	16	22	26	18	7	5	4	5	1	0	0	0
10/31/2005	15:18:40	0	0	0	0	2	8	13	13	12	14	30	13	9	7	7	1	4	0	0	0
10/31/2005	15:18:50	0	0	0	2	1	11	28	13	14	12	22	13	10	9	6	4	2	1	0	0
10/31/2005	15:19:00	0	0	0	1	1	6	14	13	19	12	11	16	7	11	6	1	1	0	0	0
10/31/2005	15:19:10	0	0	0	0	0	7	10	10	11	17	16	11	5	6	5	2	0	1	0	0
10/31/2005	15:19:20	0	0	1	0	2	3	9	15	11	11	20	13	9	7	7	3	2	0	0	0
10/31/2005	15:19:30	0	0	0	0	5	10	25	10	10	13	14	15	7	6	6	2	4	0	0	0
10/31/2005	15:19:40	0	0	0	1	1	4	18	13	12	11	13	18	7	7	6	4	3	1	1	0
10/31/2005	15:19:50	0	0	0	0	2	4	11	11	6	5	18	6	5	3	7	2	0	2	0	0
10/31/2005	15:20:00	0	0	0	0	0	8	11	21	11	8	11	11	5	7	5	3	2	2	1	0
10/31/2005	15:20:10	0	0	0	0	0	1	13	12	11	13	17	23	7	8	7	6	6	1	0	0
10/31/2005	15:20:20	0	0	0	0	2	1	12	15	8	15	25	21	19	9	15	2	2	1	2	0
10/31/2005	15:20:30	0	0	0	0	0	7	25	20	12	22	28	32	20	17	12	7	1	1	0	0
10/31/2005	15:20:40	0	0	0	0	0	1	18	26	31	19	44	34	26	18	15	2	3	1	0	1
10/31/2005	15:20:50	0	0	0	0	1	12	31	18	19	23	36	20	20	11	4	3	0	0	0	0
10/31/2005	15:21:00	0	0	0	0	0	6	16	16	14	14	30	16	11	9	4	3	1	0	0	0
10/31/2005	15:21:10	0	0	0	0	1	2	22	25	17	26	42	26	10	6	6	5	2	1	0	0
10/31/2005	15:21:20	0	0	1	0	0	5	37	21	31	18	29	30	17	5	8	5	0	0	0	0
10/31/2005	15:21:30	0	0	0	2	1	4	17	26	14	17	21	15	11	9	5	3	0	0	1	0
10/31/2005	15:21:40	0	0	0	1	0	12	18	30	12	8	20	15	15	9	5	3	1	0	0	0
10/31/2005	15:21:50	0	0	0	0	1	4	23	27	17	15	38	29	19	6	6	4	0	0	0	0
10/31/2005	15:22:00	0	0	0	0	2	12	22	30	16	8	26	22	9	9	7	2	1	0	0	0
10/31/2005	15:22:10	0	0	1	1	1	13	34	31	12	16	33	24	17	6	5	5	4	0	1	0
10/31/2005	15:22:20	0	0	0	0	4	9	23	24	21	13	26	21	7	4	1	1	1	0	0	0
10/31/2005	15:22:30	0	0	0	0	2	12	23	22	13	14	23	16	14	5	7	2	0	0	0	0
10/31/2005	15:22:40	0	0	0	0	1	4	18	15	17	16	19	17	8	8	7	2	3	0	0	0
10/31/2005	15:22:50	0	0	0	1	4	5	18	22	14	13	31	17	3	13	5	1	1	0	0	0
10/31/2005	15:23:00	0	0	2	1	3	4	21	10	10	9	15	14	8	3	1	0	0	0	0	0
10/31/2005	15:23:10	0	0	0	0	3	9	18	17	15	15	20	13	4	0	1	0	0	0	0	0
10/31/2005	15:23:20	0	0	0	2	5	13	20	23	17	14	16	25	6	2	1	0	0	0	0	0
10/31/2005	15:23:30	0	0	0	2	4	14	15	17	17	8	24	14	5	2	0	0	0	0	0	0
10/31/2005	15:23:40	0	1	0	2	4	11	27	16	14	9	24	9	2	0	0	0	0	0	0	0
10/31/2005	15:23:50	0	0	0	3	9	14	24	35	20	13	22	11	1	1	0	0	0	0	0	0
10/31/2005	15:24:00	0	0	0	2	3	9	18	20	18	12	14	20	1	0	1	0	0	0	0	0
10/31/2005	15:24:10	0	0	0	2	6	17	23	25	11	13	24	10	3	0	0	0	0	0	0	0

10/31/2005	15:24:20	0	0	1	4	5	13	21	27	22	12	18	5	1	0	0	0	0	0	0	0
10/31/2005	15:24:30	0	0	0	1	3	15	27	22	18	9	19	3	1	1	0	0	0	0	0	0
10/31/2005	15:24:40	0	0	0	1	1	7	14	11	11	10	17	1	0	0	0	0	1	0	0	0
10/31/2005	15:24:50	0	0	0	0	2	10	8	23	18	13	14	4	0	0	0	0	0	0	0	0
10/31/2005	15:25:00	0	0	1	4	1	16	18	16	24	12	12	4	1	0	0	0	0	0	0	0
10/31/2005	15:25:10	0	0	0	1	5	7	18	22	15	10	10	5	1	0	0	0	0	0	0	0
10/31/2005	15:25:20	0	0	0	1	5	13	14	17	10	7	8	2	0	0	0	0	0	0	0	0
10/31/2005	15:25:30	0	0	0	3	6	10	15	19	8	7	7	9	3	0	0	1	0	0	0	0
10/31/2005	15:25:40	0	0	1	4	8	9	23	18	9	6	8	2	2	1	0	0	0	0	0	0
10/31/2005	15:25:50	0	0	0	0	4	12	26	24	19	10	5	8	1	1	2	0	0	0	0	0
10/31/2005	15:26:00	0	0	1	1	7	7	18	18	27	7	9	11	4	3	3	0	0	0	0	0
10/31/2005	15:26:10	0	1	0	0	1	8	22	19	9	6	17	19	4	2	1	0	0	0	0	0
10/31/2005	15:26:20	0	0	0	2	3	7	21	13	1	8	10	10	5	2	2	0	0	0	0	0
10/31/2005	15:26:30	0	0	0	0	0	7	21	16	5	4	10	15	10	3	0	2	0	0	0	0
10/31/2005	15:26:40	0	0	0	0	1	5	14	17	11	6	11	9	4	0	2	1	0	0	0	0
10/31/2005	15:26:50	0	0	0	2	4	8	15	22	9	7	20	10	4	3	6	0	1	0	0	0
10/31/2005	15:27:00	0	0	0	1	1	8	17	26	15	12	14	16	2	6	2	0	0	0	0	0
10/31/2005	15:27:10	0	0	0	1	4	13	24	20	3	13	23	6	3	5	1	1	0	0	0	0
10/31/2005	15:27:20	0	0	1	3	4	8	15	12	10	9	26	11	3	1	2	0	0	0	0	0
10/31/2005	15:27:30	0	0	0	0	4	8	15	21	20	5	28	8	7	2	0	0	1	0	0	0
10/31/2005	15:27:40	0	0	0	1	2	5	23	19	14	8	18	15	7	1	0	1	0	0	0	0
10/31/2005	15:27:50	0	0	0	1	3	12	23	12	15	5	28	11	7	5	1	0	0	0	0	0
10/31/2005	15:28:00	0	0	0	2	1	9	15	23	18	9	12	3	3	1	1	0	0	1	0	0
10/31/2005	15:28:10	0	0	1	1	4	9	17	13	16	12	13	4	2	1	1	0	0	0	0	0
10/31/2005	15:28:20	0	0	0	0	9	6	19	22	12	8	8	2	2	0	3	0	1	0	0	0
10/31/2005	15:28:30	0	0	1	0	0	12	18	34	16	6	7	4	1	3	0	1	0	0	0	0
10/31/2005	15:28:40	0	0	0	2	2	8	18	21	12	8	11	6	0	2	2	1	0	0	0	0
10/31/2005	15:28:50	0	0	1	1	1	10	21	14	21	6	8	3	0	1	0	2	1	0	0	0
10/31/2005	15:29:00	0	0	0	1	2	5	19	24	5	7	8	2	0	0	3	0	0	0	0	0
10/31/2005	15:29:10	0	0	2	4	5	9	21	16	6	4	6	5	0	2	0	0	0	0	0	0
10/31/2005	15:29:20	0	0	0	6	1	8	8	6	7	2	2	0	0	0	0	0	0	0	0	0
10/31/2005	15:29:30	0	0	1	7	7	11	20	15	6	7	2	2	0	0	0	0	0	0	0	0
10/31/2005	15:29:40	0	0	1	5	4	14	26	26	10	7	3	0	0	2	0	0	0	0	0	0
10/31/2005	15:29:50	0	0	0	6	5	11	21	13	16	3	2	0	1	0	0	0	0	0	0	0
10/31/2005	15:30:00	0	0	1	1	5	8	30	15	8	1	1	0	0	0	0	0	0	0	0	0
10/31/2005	15:30:10	0	0	1	4	3	9	15	13	4	3	2	0	0	0	0	0	0	0	0	0
10/31/2005	15:30:20	0	1	0	3	6	17	27	15	3	2	6	0	0	0	0	0	0	0	0	0

10/31/2005	15:30:30	0	0	0	5	6	9	27	17	10	4	3	0	0	0	1	0	0	0	0	0
10/31/2005	15:30:40	0	0	0	4	5	9	21	14	4	4	7	0	0	0	1	0	0	0	0	0
10/31/2005	15:30:50	0	0	0	1	2	18	21	19	16	9	6	2	0	1	0	0	0	0	1	0
10/31/2005	15:31:00	0	0	1	1	2	11	16	30	16	13	9	0	0	0	0	0	0	0	0	0
10/31/2005	15:31:10	0	0	2	6	3	11	25	18	8	6	5	0	0	0	0	0	0	0	0	0
10/31/2005	15:31:20	0	0	2	6	6	9	10	9	4	2	2	0	0	0	0	0	0	0	0	0
10/31/2005	15:31:30	0	0	0	3	8	16	6	16	4	0	0	0	0	0	0	0	0	0	0	0
10/31/2005	15:31:40	0	1	1	4	3	10	10	15	6	7	2	0	0	0	0	0	0	0	0	0
10/31/2005	15:31:50	0	0	2	2	4	7	19	16	5	5	2	0	0	0	0	0	0	0	0	0
10/31/2005	15:32:00	0	0	0	2	13	14	11	9	3	3	2	0	0	0	0	0	0	0	0	0
10/31/2005	15:32:10	0	0	1	3	5	11	6	5	2	1	0	0	0	0	0	0	0	0	0	0
10/31/2005	15:32:20	0	0	1	3	8	11	5	0	0	0	0	0	0	0	0	0	0	0	0	0
10/31/2005	15:32:30	0	0	2	5	2	7	2	0	0	0	0	0	0	0	0	0	0	0	0	0
10/31/2005	15:32:40	0	0	0	3	4	6	4	0	0	0	0	0	0	0	0	0	0	0	0	0
10/31/2005	15:32:50	0	0	0	2	6	9	0	0	0	1	0	0	0	0	0	0	0	0	0	0
10/31/2005	15:33:00	0	0	1	5	4	12	3	1	0	0	0	0	0	0	0	0	0	0	0	0
10/31/2005	15:33:10	0	0	0	0	1	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0
10/31/2005	15:33:20	0	0	0	2	1	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0
10/31/2005	15:33:30	0	0	1	3	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
10/31/2005	15:33:40	0	0	0	7	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10/31/2005	15:33:50	0	0	0	1	4	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0
10/31/2005	15:34:00	0	0	2	2	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Discrete 10-second 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 21 minute period beginning at 1513 CST and ending at 1534 CST. 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 , $\text{mm}^6 \text{m}^{-3}$) as measured by discrete data from a J-W disdrometer,

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

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, $T = 10$ seconds and $A = 50 \text{ cm}^2$. We will use the following expression for the terminal fall speed of raindrops: $v(D_i) = 386.6 \cdot D_i^{0.67} [\text{m s}^{-1}]$, 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 , $\text{mm}^6 \text{m}^{-3}$) 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 , $\text{mm}^6 \text{m}^{-3}$ 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 $900 \mu\text{m}$ and a concentration of $1 \Gamma^{-1}$.
 - b. (7 points) An inverse exponential raindrop size distribution, $N(D) = N_0 \exp(-\Lambda D)$, where $N_0 = 8.0 \times 10^3 \text{ m}^{-3} \text{ mm}^{-1}$ and $\Lambda = 1.65 \text{ mm}^{-1}$. (*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 Weather Surveillance Radar – 1988 Doppler (WSR-88D) and Aggie Doppler Radar (ADRAD). Answer the questions below using these specifications and the assumptions listed beneath the table. Be attentive to units in your calculations!

Parameter	WSR-88D	ADRAD
Wavelength (λ)	10.7 cm	10.56 cm
Pulse Duration (τ)	1.57 μ s (short pulse)	0.8 μ s (short pulse)
Half-power Beamwidth	1°	1.52°
Peak Power	1000 kW	1000 kW
Antenna Gain (G)	45 dB	40.3 dB
Minimum Detectable Signal (MDS)	-113 dBm	-110 dBm

For both radars, assume that the system noise power, P_n , equals the minimum detectable signal ($P_n = \text{MDS}$). 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.

- (8 points) What is the signal to noise ratio (SNR, dB) for each radar at a range of 30 km if the reflectivity factor is 0 dBZ? What about 55 dBZ?
- (8 points) For each radar, what is the minimum detectable reflectivity (factor), or MDR, at a range of 30 km if the system performance specifications require the SNR = 0 dB?
- (7 points) What happens to the MDR at 30 km if we require the SNR to be 1 dB for each radar?
- (7 points) If the dynamic range of the WSR-88D (ADRAD) radar is 93 (84) dB, what is the saturation or maximum reflectivity (in dBZ) that is detectable at 30 km by the WSR-88D (ADRAD)?

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 $-20 \text{ dBZ} < Z < 20 \text{ dBZ}$) 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.