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WORKSHOP ON CLOUD PHYSICS AND CLIMATE

23 November - 20 December 1985

CLOUD AND PRECIPITATION PROCESSES
Part IV

HIGHPLAINS CONVECTION

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LECTURE 4 HIGH PLAINS CONVECTION

North Central US, East of Rocky Mountains
Summertime rain is low, hailstorms frequent.
Cool, dry air — high cloud bases +5 to 0°C.
Continental airmasses — narrow cloud droplet spectra.

Evidence for precipitation development via graupel growth:
- First echoes form at ~ −12°C
- No supercooled drops >100 μm observed.
- Precipitation-sized (>500 μm) particles are rimed crystals
- Non-rimed crystals form at T < −15°C in concentrations of >1 per liter, often reaching >100 per liter.
- Time of echo formation coincides with in-situ observation of small graupel.

References: J. Atm. Sci., 1974 pp 2142 - 2159 Parts I, II, IV
Cooper 1978 - AMS Cld Phys. Conference, I Magua, p. 347.

Examples (not the best ones)
19 July, 1981 Sailplane ascent — single cell
6 Aug 1981 Multicell storm

Summary:
Ice particles 1 - 100 ℓ^{-1} in clouds which develop precipitation
Large drops ~ 1 m^{-3} i.e. 10^3 or 10^4 fewer than ice particles
(but, 10% of hailstones have drop centers)
In unmixed updrafts ice concentration is low: 0.1 ℓ^{-1} at −15°C.
LWC of 1-2 $g\,m^{-3}$ provide rapid growth of graupel.
Secondary processes contribute to development of ice.

HIPLEX seeding experiment:
Small Cu con (tops −12 to −15°C) seeded at temp > −10°C.
Decay of LWC reduces graupel growth time — inefficient precipitation production, but reduced seeding potential.
Seeding effect evident in early stages.
Ref.: Cooper & Lawson, J. Climate & Appl. Meteor. 1984, p 523

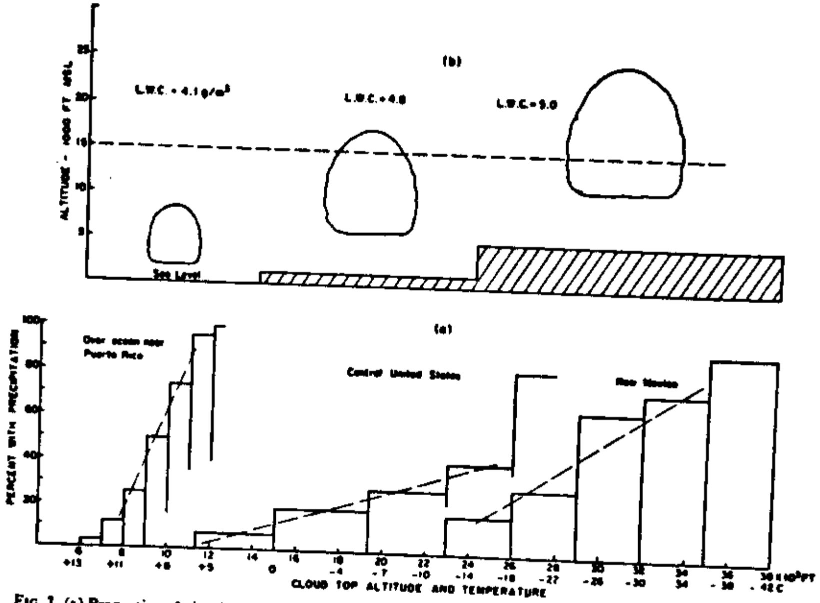


FIG. 7. (a) Proportion of visually observed clouds that yielded a radar echo and so were assumed to be precipitating, plotted against height above sea level and a temperature scale adjusted to be representative in all regions. (b) Size and calculated maximum liquid water content of that class of cloud of which 20 percent yielded radar echoes (from Battan, Byers, and Braham, 1955).

Table 1. Cloud depths related to the frequency occurrence of radar echoes.

Caribbean Sea (warm clouds) (after Byers and Hall)		New Mexico (after Braham et al)	
Cloud depth (ft)	Per cent of clouds with echoes	Cloud depth (ft)	Per cent of clouds with echoes
3,500—4,000	2	> 5,000—8,000	0
4,000—4,500	4		
4,500—5,000	11		
5,000—5,500	13		
5,500—6,000	23		
6,000—6,500	28		
6,500—7,000	53		
7,000—7,500	47		
7,500—8,000	73		
8,000—8,500	74		
8,500—9,000	83	> 8,000—11,000	16
9 000 and up	100	> 11,000—14,000	30

Tellus X (1958), 1

complete the sample, we have [illegible] cloud base temperatures [illegible] 1978 from the climb-out sounding by the King Air.

Fig. 2.1 is a histogram of cloud base temperature for 70 days in 1978-1980 on which CuCg clouds were studied. (Only days from June and

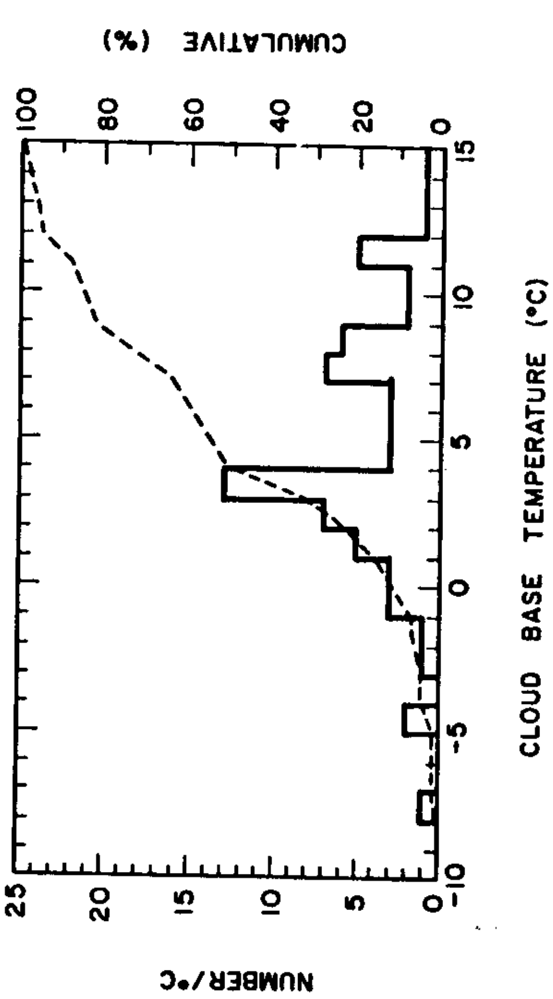


Fig. 2.1: Differential (solid line) and cumulative (dashed line) frequency distributions for the measured cloud base temperatures from 70 days in June and July, 1978-80, on which research flights were conducted in the Miles City area.

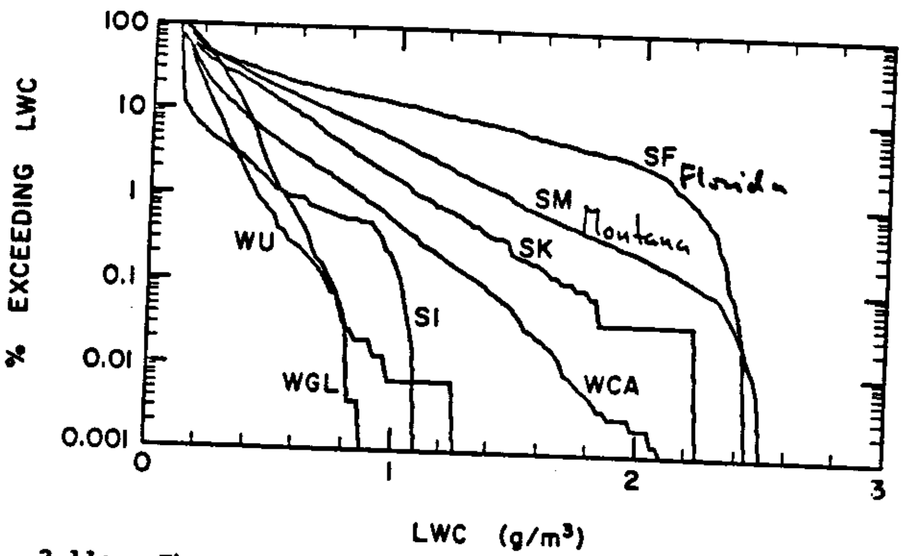


Fig. 2.11: The percentage of the JW measurements of liquid water content which exceeded various values. The areas were: (SM) summertime, Montana HIPLEX; (SF) summertime, Florida, (SK) springtime, Kansas; (WCA) wintertime, California; (SI) summertime, Illinois; (WU) wintertime, Utah; and (WGL) wintertime, Great Lakes.

Fig. 2.12 shows the percentage of regions in which the liquid water content, when averaged over the indicated distance ...

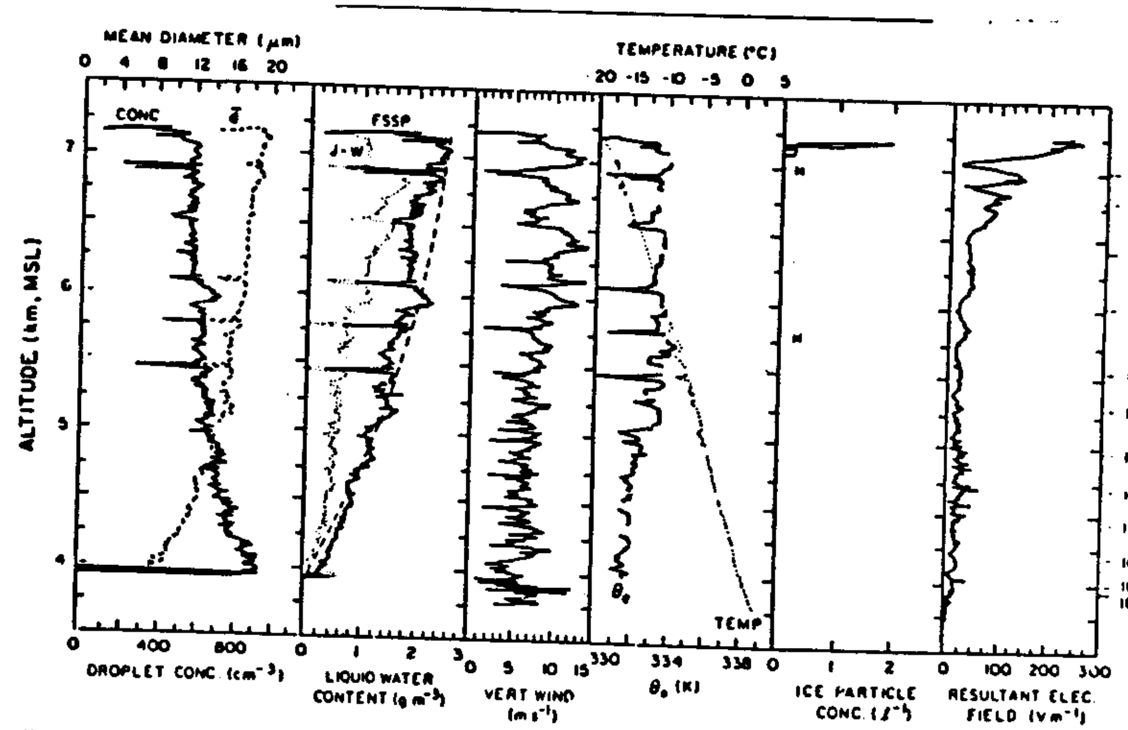
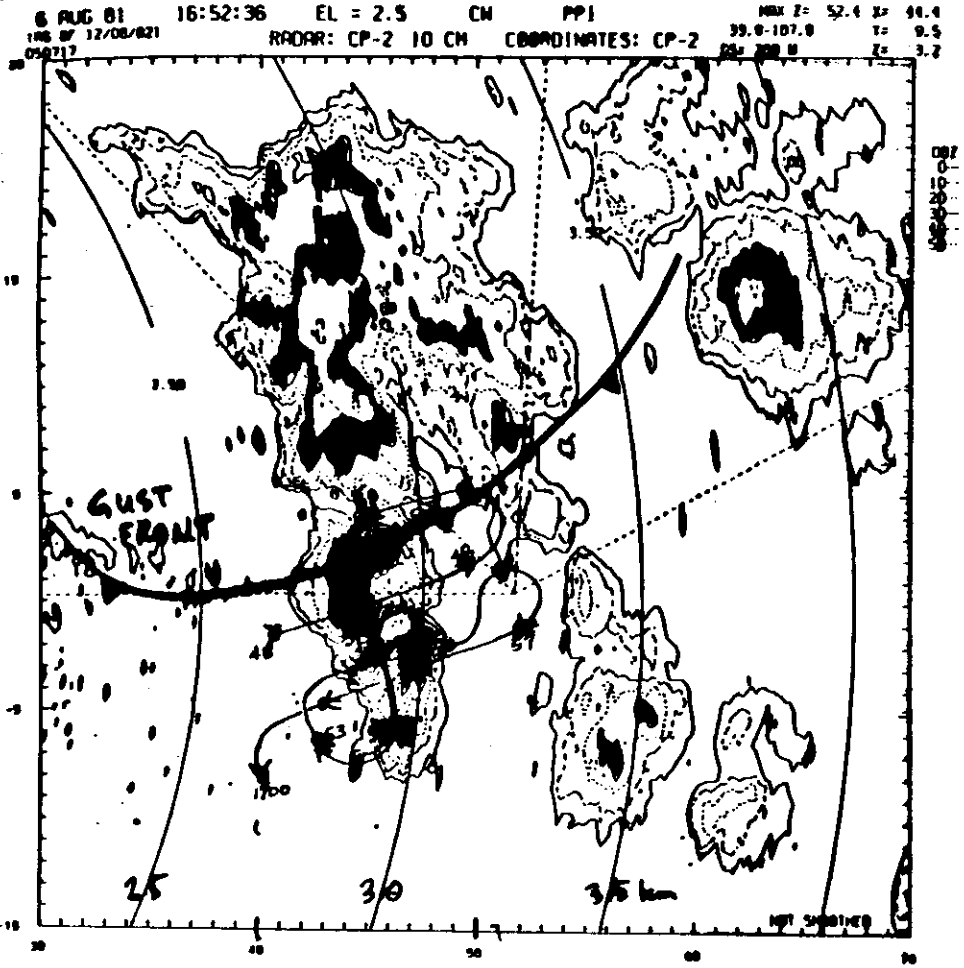


Figure 1: Measurements from the sailplane as it ascended from cloud base to 7.2 km.

19 July 1982.

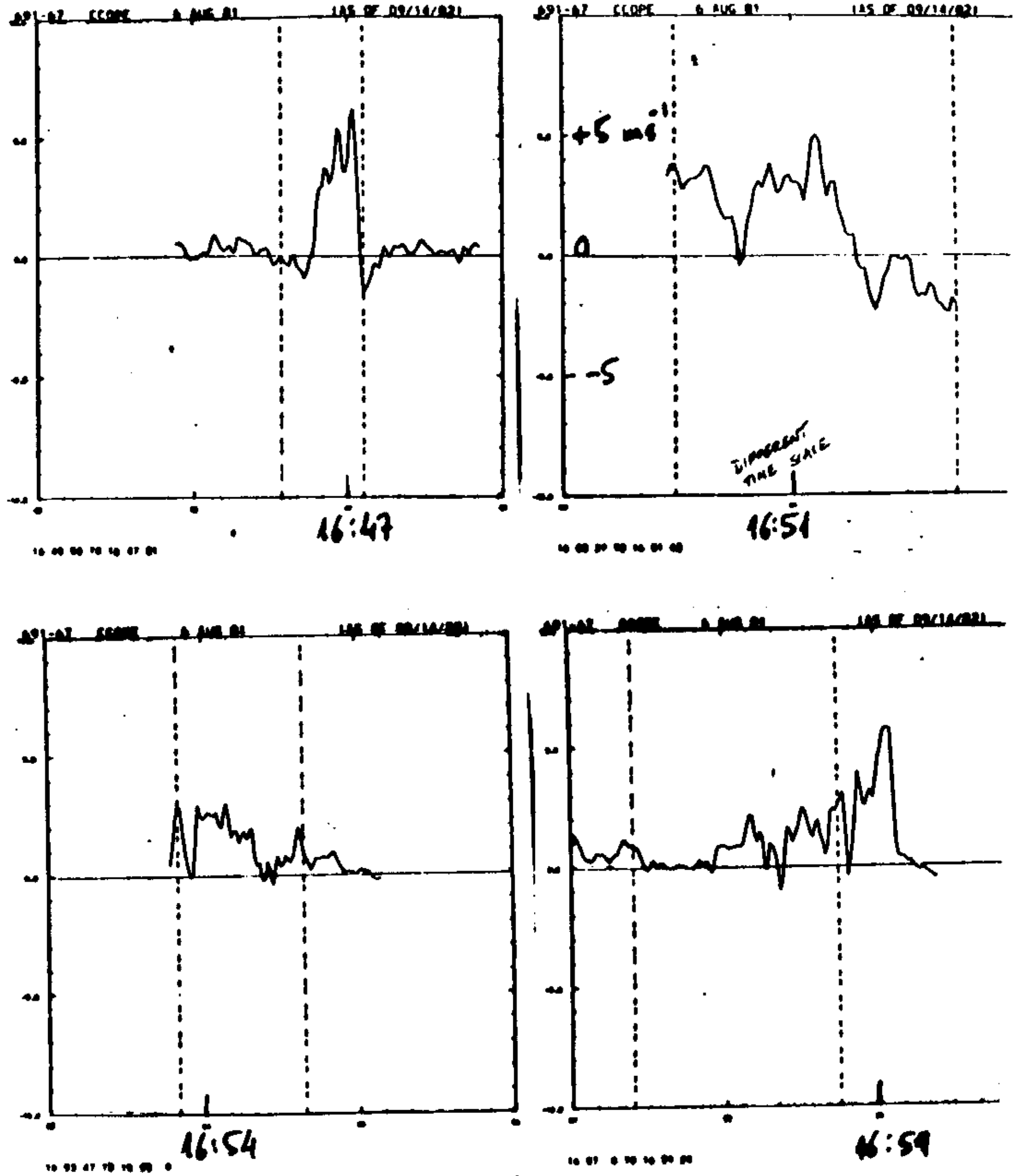
Grandliner, 1985 Ice Conf.
Example of ascent of sailplane in near-adiabatic core of Cu con.

CASE STUDY – 6 Aug 1981

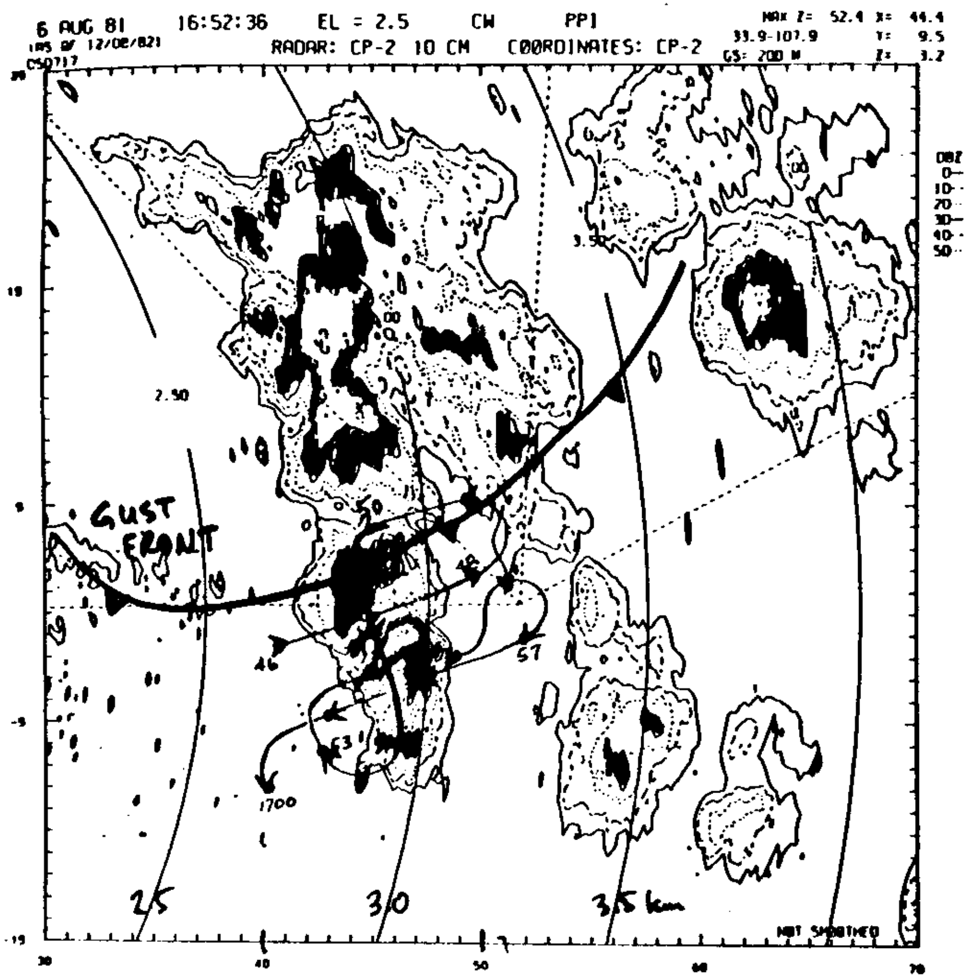


← 10 km →

306 D TRACK

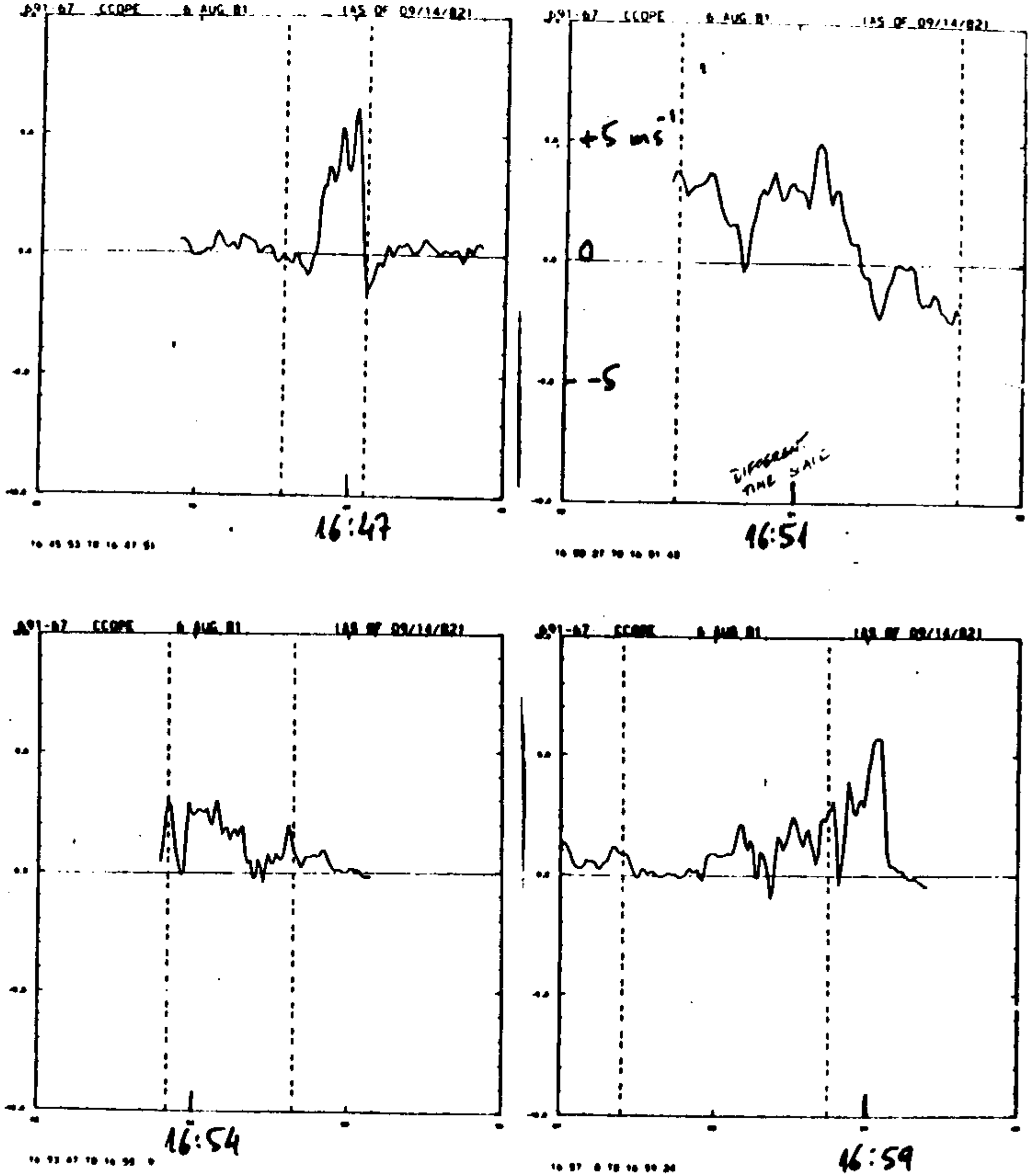


CASE STUDY – 6 Aug 1981.



← 10 km →

306 D TRACK



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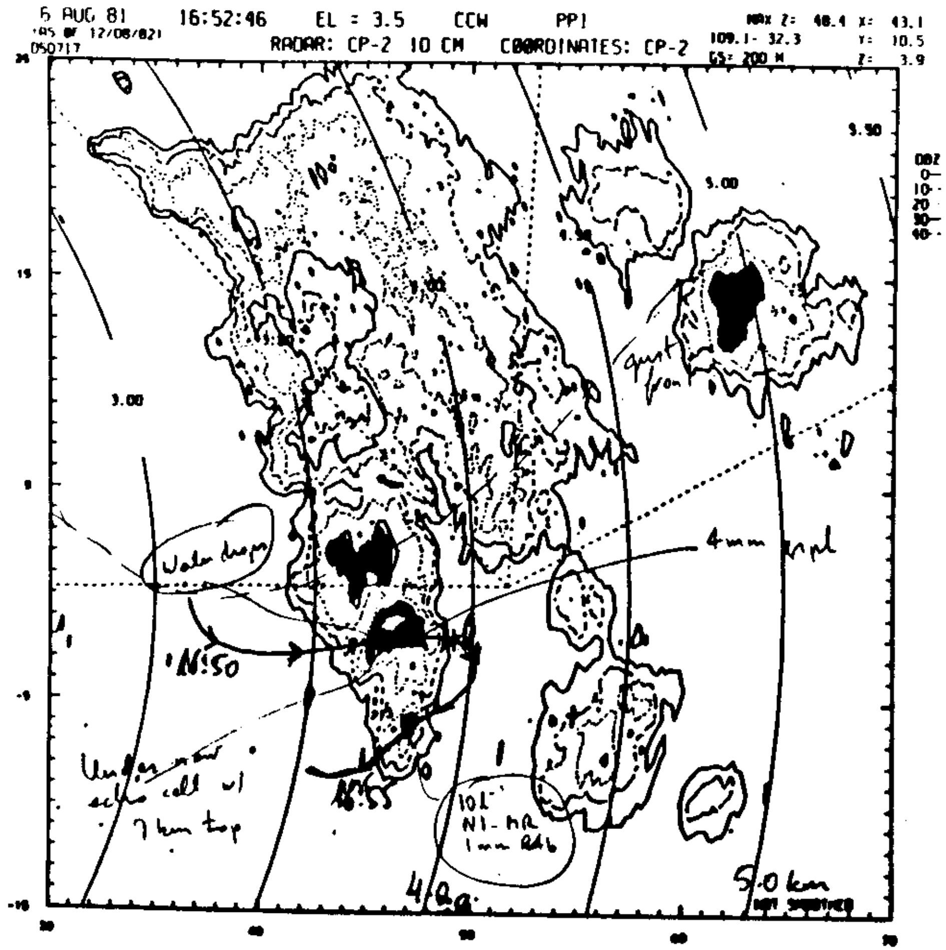
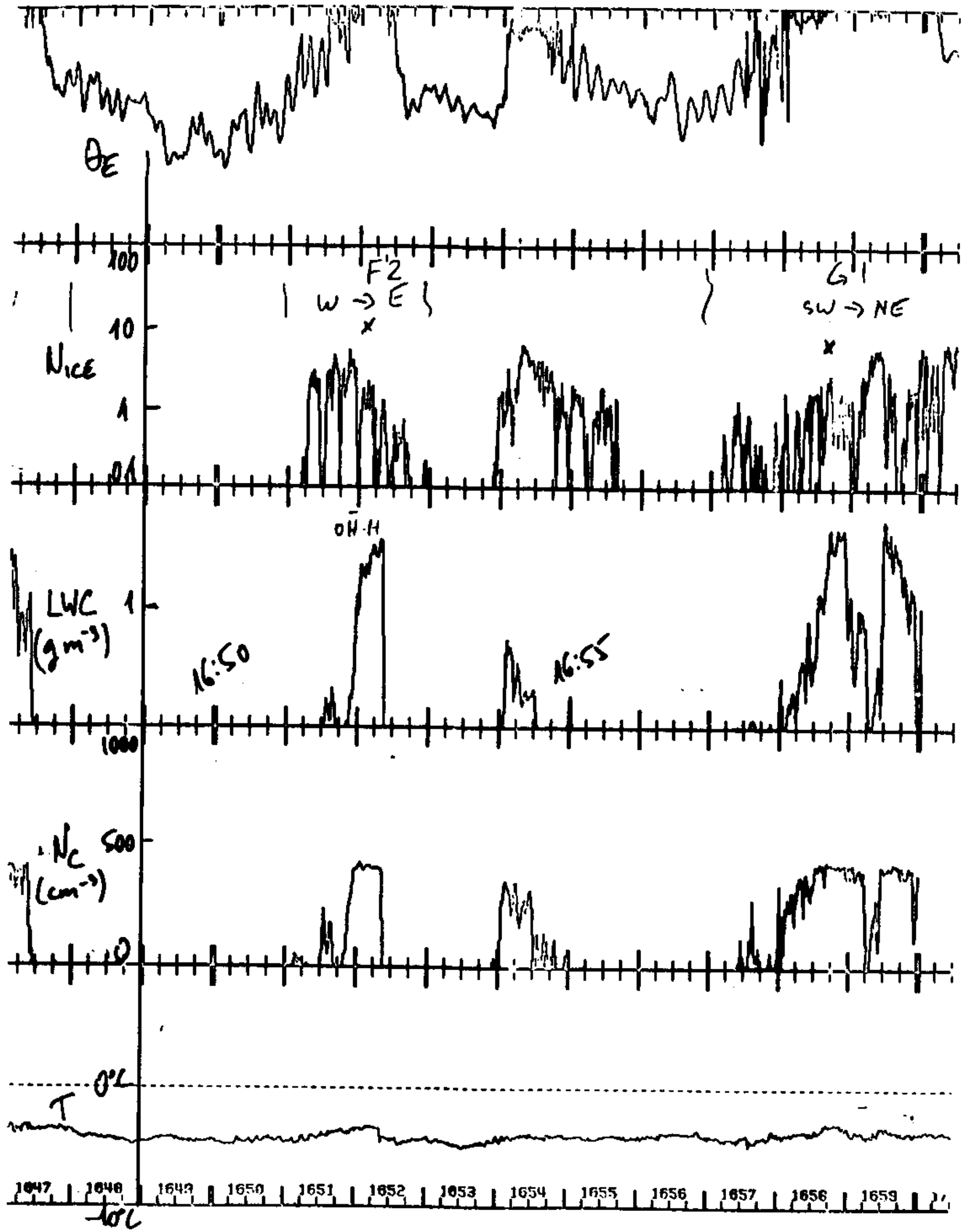
F2


6 AUG 81 16:52:46 EL = 3.5 CCW PPI
RADAR: CP-2 10 CM COORDINATES: CP-2
MAX Z: 48.4 X: 43.1
Y: 10.5
Z: 3.9
GS: 200 M
DBZ
0
10
20
30
40
3.00
5.00
5.50
Water drops
4mm ppl
16:50
16:55
Under new echo cell w/ 7 km top
10L
N1-HR
1mm RdG
5.0 km
NOT SMOOTHED
30
40
50
60
70


θ_E
100
10
1
0.1
F2
W → E
G1
SW → NE
N_{ICE}
LWC
$(g\,m^{-3})$
1
16:50
16:55
1000
500
0
N_C
(cm^{-3})
0°C
T
1647
1648
1649
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1652
1653
1654
1655
1656
1657
1658
1659
-10°C

6

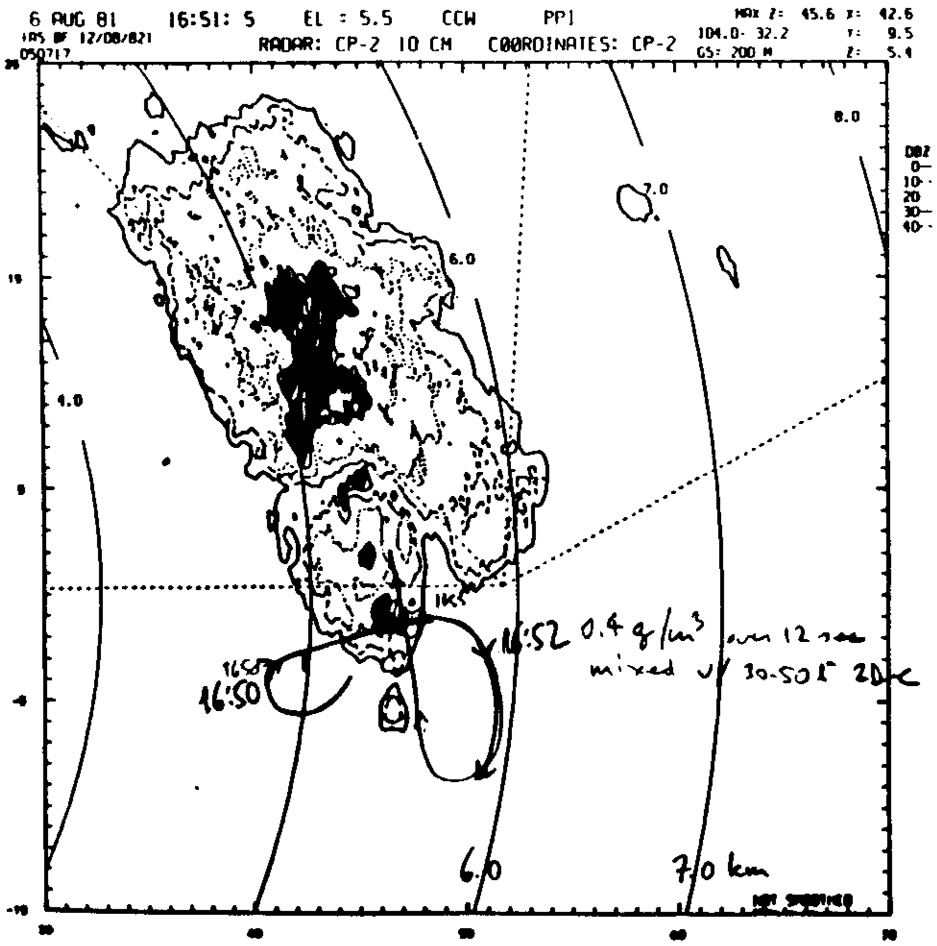
RTIME	CONCT	CONCC	CONCU	CONCW	CONCI	T-MASS	T-PR	SVOL	REC	OL	FT	SIZEI	SIZEW	SIZEU
165207	8.84	5.80	1.11	1.11	3.59	503.05	3.09	3.6	1.17	0	2	920.0	431.3	112.5
165208	6.19	1.36	.84	.28	.84	8.03	.02	3.6	.06	0	1	700.0	250.0	33.3
165209	10.00	4.21	1.36	0.00	2.24	217.92	1.13	3.6	.79	0	2	662.5	0.0	[illegible]
165210	[illegible]	4.74	2.23	.56	1.95	124.59	.00	3.6	.79	0	2	720.0	512.5	137.5
165211	12.00	4.93	1.32	.27	2.74	148.58	.00	3.6	.98	1	4	892.5	550.0	183.6
165212	.53	0.00	0.00	0.00	0.00	0.00	0.00	3.7	.99	1	0	0.0	0.0	0.0
165213	7.34	2.18	1.05	.26	.79	14929.00	215.18	3.8	1.90	1	15	4150.0	350.0	150.0
165217	.26	.26	0.00	0.00	.26	.42	.00	3.8	0.00	0	0	400.0	0.0	0.0
165218	2.00	.79	.52	0.00	.26	20.73	.06	3.8	.27	0	1	2000.0	0.0	75.0
165219	0.63	2.00	1.31	.52	1.05	100.02	1.05	3.8	.05	0	3	600.0	550.0	135.0
165220	10.24	2.89	.79	0.00	2.10	168.11	.08	3.8	.92	0	2	1012.5	0.0	91.7
165221	5.25	1.31	.26	0.00	1.05	107.65	.50	3.8	.46	0	3	787.5	0.0	175.0
165222	3.15	.52	.26	0.00	.26	85.90	.44	3.8	.26	0	0	1400.0	0.0	25.0

N18UW DATA COLLECTED ON 910806 - PROCESSED ON 000624 AT 155005

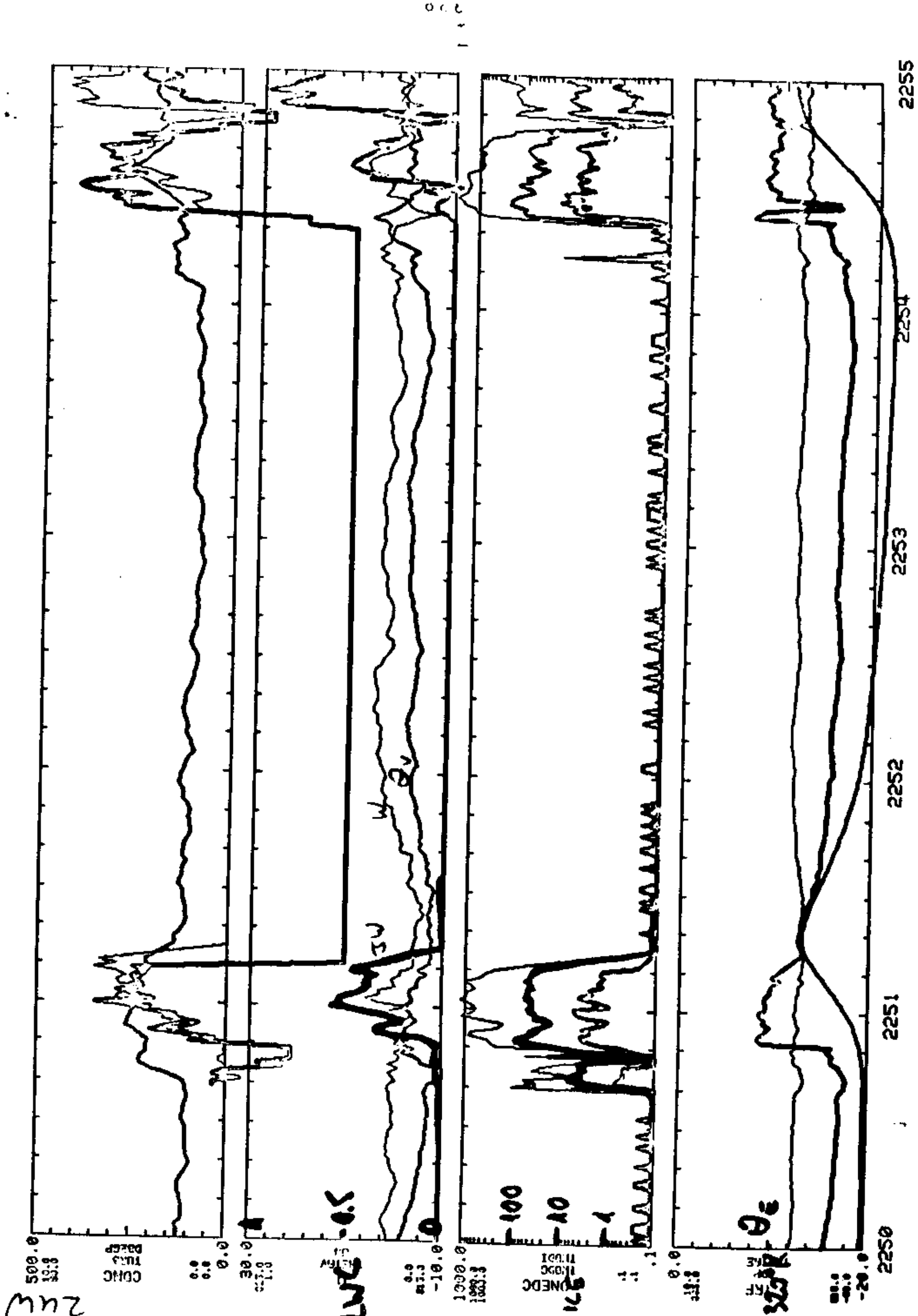
RTIME	CONCT	CONCC	CONCU	CONCW	CONCI	T-MASS	T-PR	SVOL	REC	OL	FT	SIZEI	SIZEW	SIZEU
165109	.60	0.00	0.00	0.00	0.00	0.00	0.00	3.3	.01	0	0	0.0	0.0	0.0
165112	.30	.30	.30	0.00	0.00	.04	.00	3.3	0.00	0	0	0.0	0.0	50.0
165113	.30	0.00	0.00	0.00	0.00	0.00	0.00	3.3	0.00	0	0	0.0	0.0	0.0
165114	.30	.30	0.00	.30	0.00	2.44	.01	3.3	0.00	0	0	0.0	250.0	0.0
165116	2.39	1.00	1.90	.30	0.00	3.23	.01	3.3	.14	0	0	0.0	250.0	95.0
165117	6.03	4.52	2.41	.60	1.51	22.98	.05	3.3	.76	0	0	275.0	237.5	115.6
165118	8.44	5.73	4.22	.30	1.21	8.95	.03	3.3	1.17	0	1	375.0	300.0	89.3
165119	10.85	7.84	6.03	.30	1.51	42.30	.41	3.3	.58	0	0	260.0	575.0	126.3
165120	5.96	4.77	3.57	0.00	1.19	5.31	.01	3.4	.28	0	0	260.0	0.0	102.1
165121	10.13	8.94	7.45	.60	.89	32.29	.18	3.4	.45	0	1	400.0	350.0	96.8
165122	6.55	5.36	3.87	.60	.89	12.46	.05	3.4	.32	0	1	475.0	287.5	90.4
165123	6.05	3.74	3.17	.29	.29	5.40	.01	3.5	.29	0	0	400.0	225.0	120.5
165124	8.06	6.33	4.32	.86	1.15	79.89	.76	3.5	.41	0	1	331.3	450.0	86.7
165125	7.20	6.33	4.32	.29	1.73	41.48	.27	3.5	.36	0	1	333.3	500.0	88.3
165126	1.14	.57	0.00	0.00	.57	55.76	.20	3.5	.03	0	0	625.0	0.0	0.0
165131	.86	.86	.57	0.00	.29	7.62	.02	3.5	.03	0	0	375.0	0.0	100.0
165132	12.57	7.54	5.03	.28	2.24	26.84	.07	3.6	1.42	0	0	515.6	275.0	90.3
165133	11.66	8.05	5.27	1.67	1.11	69.72	.23	3.6	.61	0	1	493.8	266.7	94.7
165134	16.14	9.83	6.29	.55	2.19	73.34	.54	3.7	.95	0	2	362.5	437.5	83.7
165135	7.11	4.92	3.28	.55	1.09	922.69	7.24	3.7	.60	0	2	1537.5	600.0	72.9
165136	4.65	1.92	1.37	0.00	.55	2.05	.01	3.7	.23	0	0	412.5	0.0	60.0
165137	13.82	7.20	3.05	.83	3.32	3543.00	41.62	3.6	1.10	0	2	997.9	400.0	120.5
165138	25.82	15.82	8.88	1.39	5.55	250.82	1.41	3.6	1.84	0	4	616.3	395.0	103.9
165139	18.70	12.62	9.25	.28	3.08	985.32	6.22	3.6	1.27	0	2	1084.1	350.0	99.2
165140	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

7

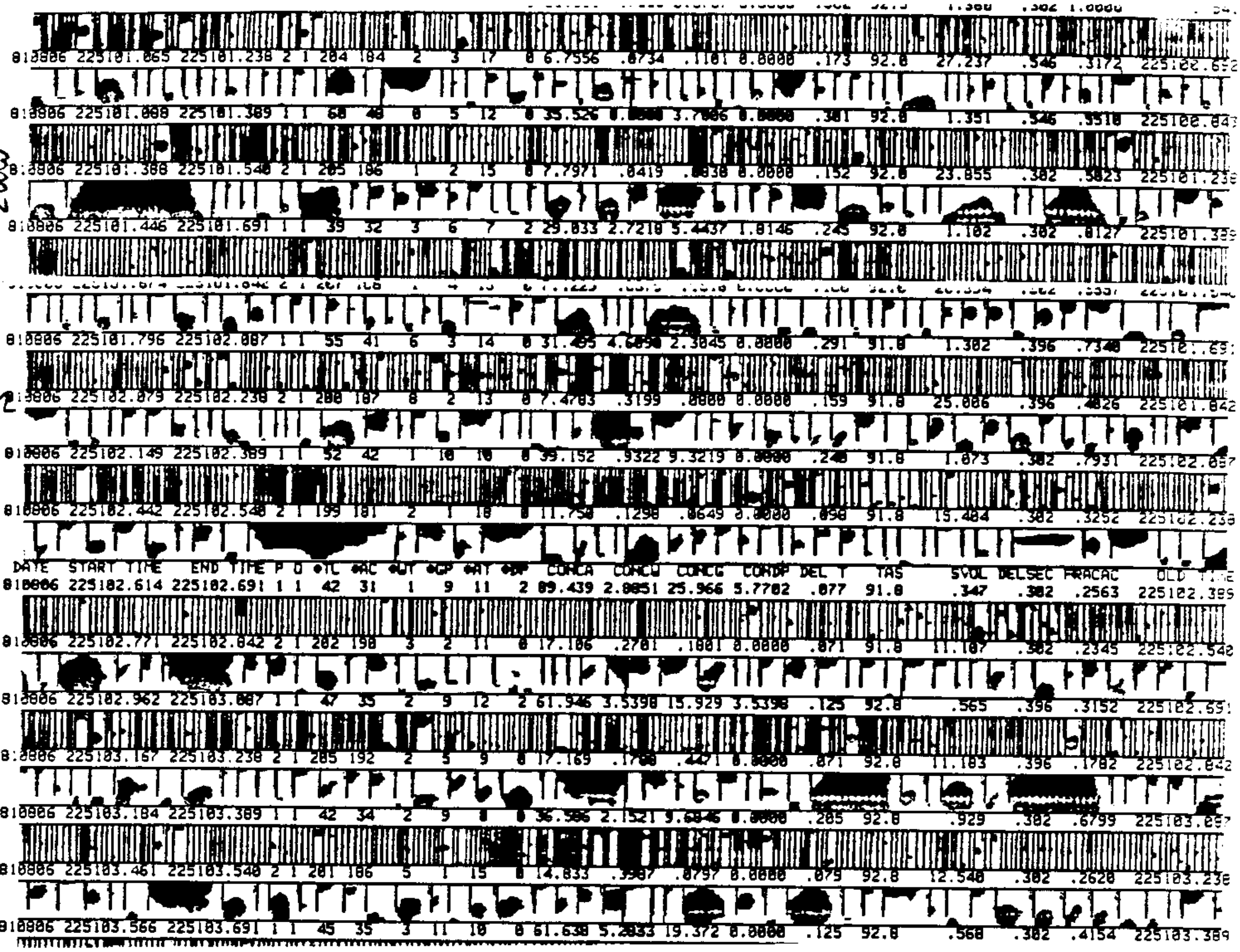
2uw



810306

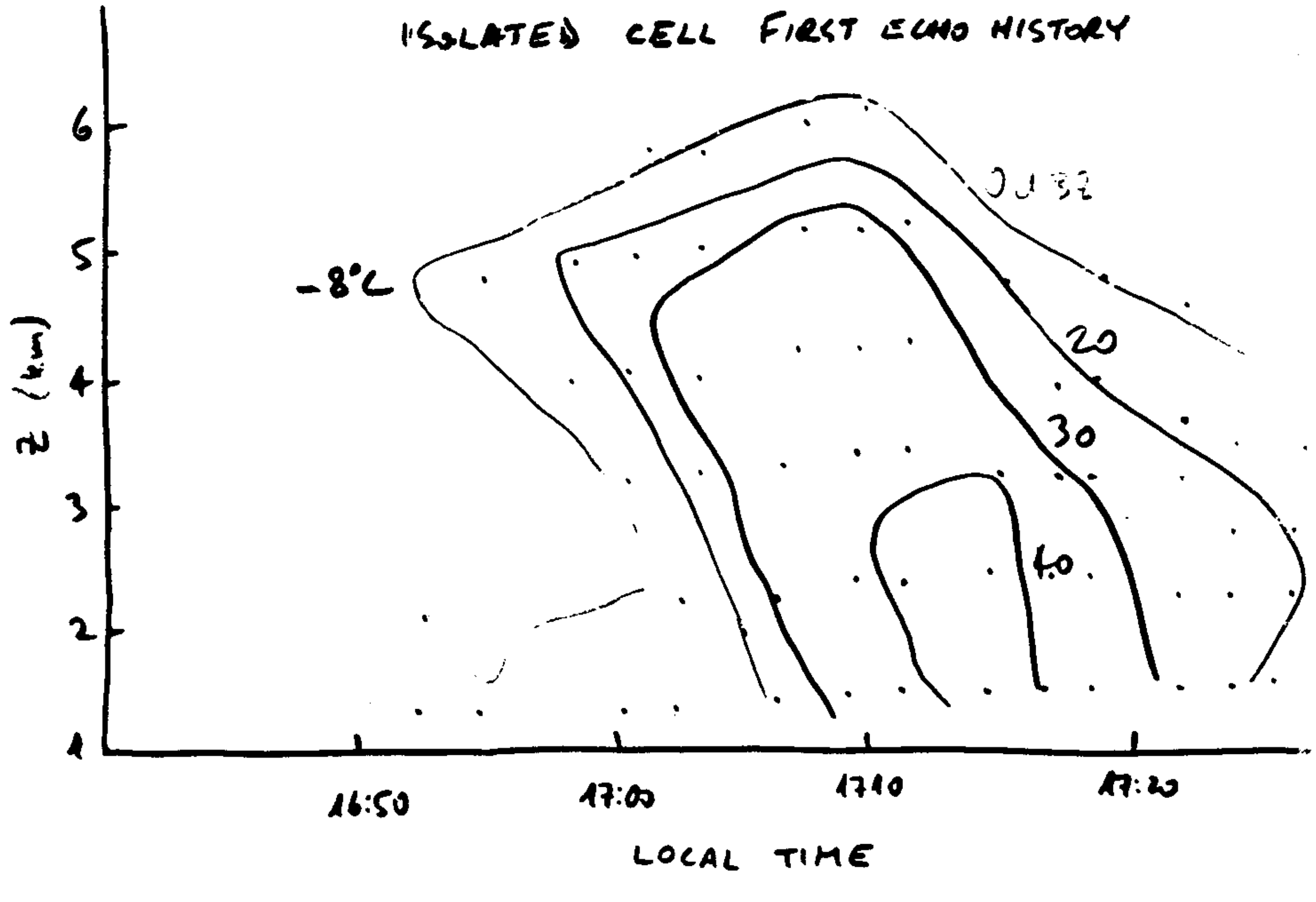


2uw

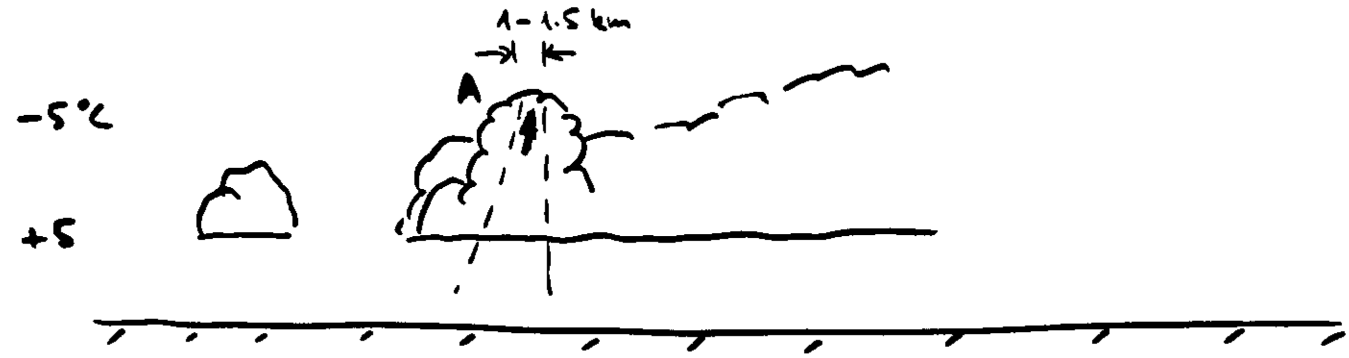


6 AUG 1.81

ISOLATED CELL FIRST ECHO HISTORY



A: $\theta_E = 326°K$
LWC ~ 1 g m^{-3}
~2 lit^{-1} graupel (R4)
to 400 μm over
½ of updraft

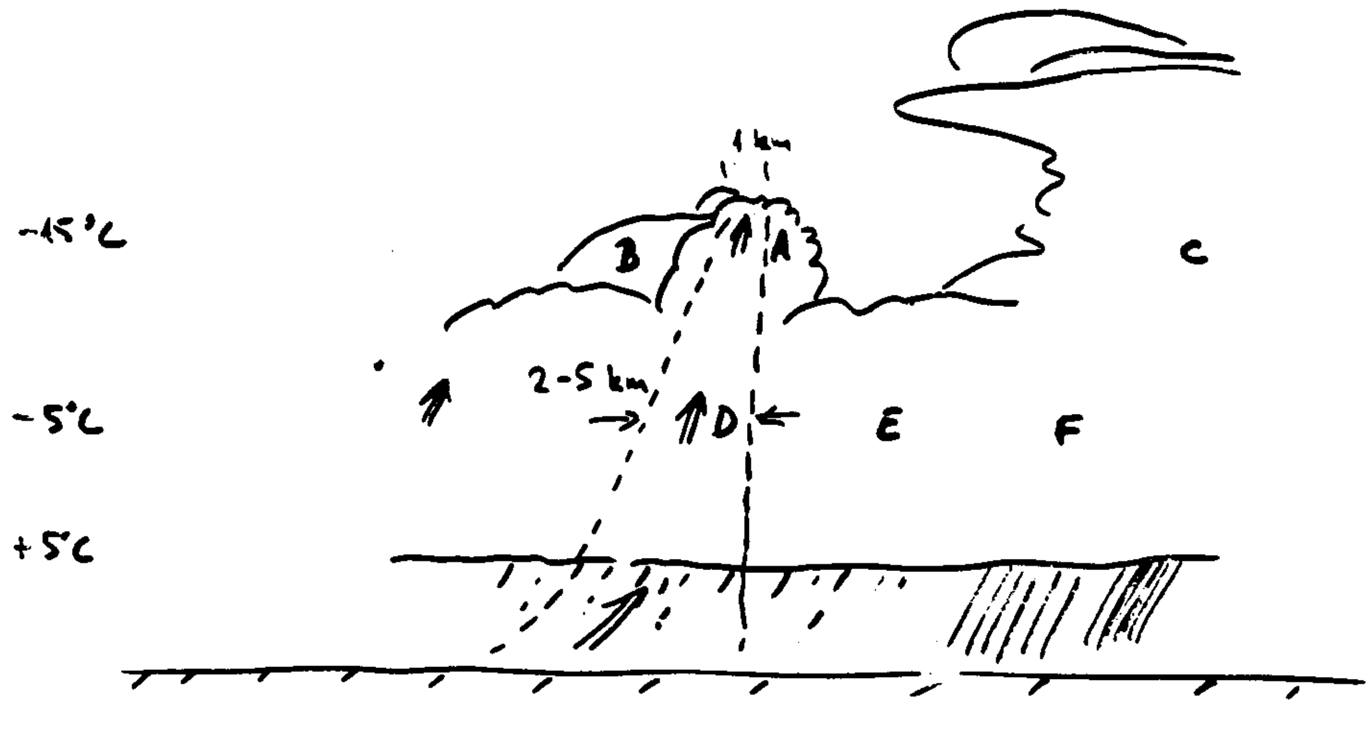


10

B: 1 lit^{-1} P1, CP1, R4
< 300 μm

A: $(\theta_E)_{max} = 322°K$
w = 5 m s^{-1}
LWC = 1.5 g m^{-3}

C: to 100 lit^{-1} R4
and aggregates



D: $(\theta_E)_{max} = 326°K$
LWC = 1.2 g m^{-3}

E: LWC = 0
10-20 L^{-1} R4
< 1 mm

F: LWC = 0
100 L^{-1} N1, < 1 mm
20 L^{-1} R4 < 2 mm
R ≈ 20 mm hr^{-1}

HIPLEX

STEP BY STEP HYPOTHESIS

QUALIFYING PENETRATION : 2-8 km a -8°C
SEEDING BY A/C TOP > -20°C
MONITORED EVOLUTION 1 g m^{-3}

STATISTICAL TESTS FOR
RESPONSE VARIABLES
PHYSICAL INTERPRETATION

-11

HIPLEX RESULTS

FIG. 3. Examples of ice crystals collected on an oil-coated slide 2 min after seeding.

was intentionally quite marginal. Ice crystals generally require almost 5 min of growth before the threshold for riming is reached, as can be deduced from the growth rates measured by Ryan *et al.* (1976) and the riming thresholds calculated by Pitter (1977) and Schlamp *et al.* (1975). CCR5 thus provided a stringent test that accretional growth was beginning as expected. Figure 5 shows the cumulative distributions of CCR5 for seeded and unseeded cases, and Fig. 6 shows some of the ice crystals collected on slide samples from a seeded plume 5 min after seeding. The seeded clouds had substantially higher concentrations of rimed crystals than the unseeded clouds, and the crystals in Fig. 6 indicate that light riming was beginning after 5 min as expected. The crystals have appropriate habits for growth near the observation level, and have sizes consistent with an origin at the time of seeding.

c. The growth to precipitation embryos

The response variable PIC8 also was chosen to provide a critical test. PIC8 represents the concentration of hydrometeors larger than 600 μm in maximum dimension, evaluated 8 min after treatment. Since 8 min is not sufficient time for growth to 600 μm at −5°C by diffusional growth alone, growth by either accretion or aggregation is required if hydrometeors produced by seeding are to reach the required size. Figure 7 shows the cumulative distributions for PIC8. This figure provides the first indication that the hypothesized precipitation development did not proceed as expected. Although the effect is in the correct direction, the separation between seeded and unseeded cases is clearly not as strong as for the preceding variables. Furthermore, the two-dimensional images recorded about 8 min after seeding showed that, when precipitation elements were present in unseeded clouds, they were

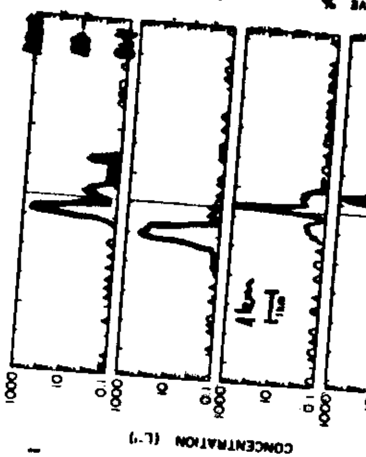


FIG. 4. Examples of the [illegible] ice crystal concentration as a function of time for passes by the King Air through the ice crystal plumes produced by seeding 2 min earlier. The target location in cloud corresponds to the vertical line in the center of each plot. Concentrations were measured by a 2DC probe.

FIG. 5. Cumulative distributions for the concentrations of rimed ice crystals measured on slide samples collected 5 min after treatment (seeding or "placebo") in the HIPLEX-1 clouds.

FIG. 6. Examples of ice crystals collected on a [illegible] (22 July 1979, HIPLEX [illegible]

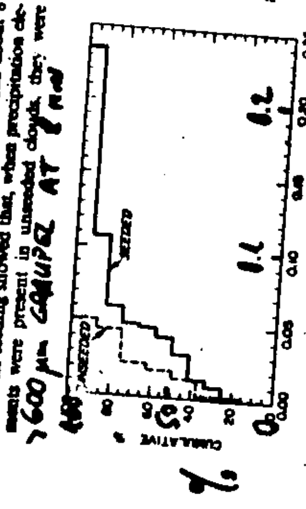


FIG. 7. Cumulative distributions for the response variable PIC8, representing the concentration of precipitating ice hydrometeors (at least 600 μm in longest dimension) in the HIPLEX-1 clouds 8 min after treatment.

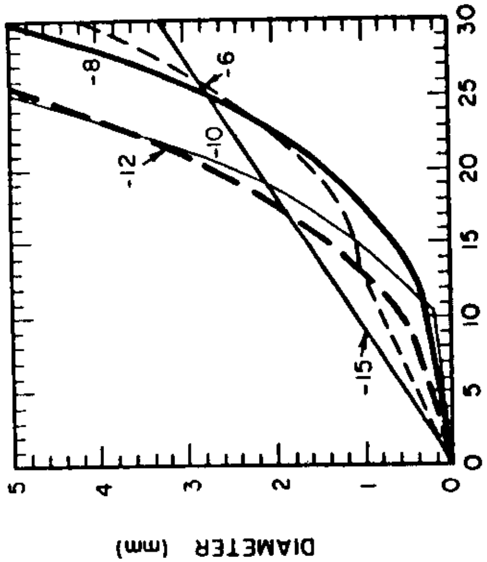


Fig. 3.17: Graupel particle diameter as a function of time for the various indicated temperatures. All calculations were for a pressure of 500 mb, a liquid water content of 1 g/m^3, and a cloud droplet diameter of 20 μm.

temperature of the graupel (Macklin, 1962). In these calculations, the most important factor controlling the development was the fall speed of the graupel, which was reflected in the droplet

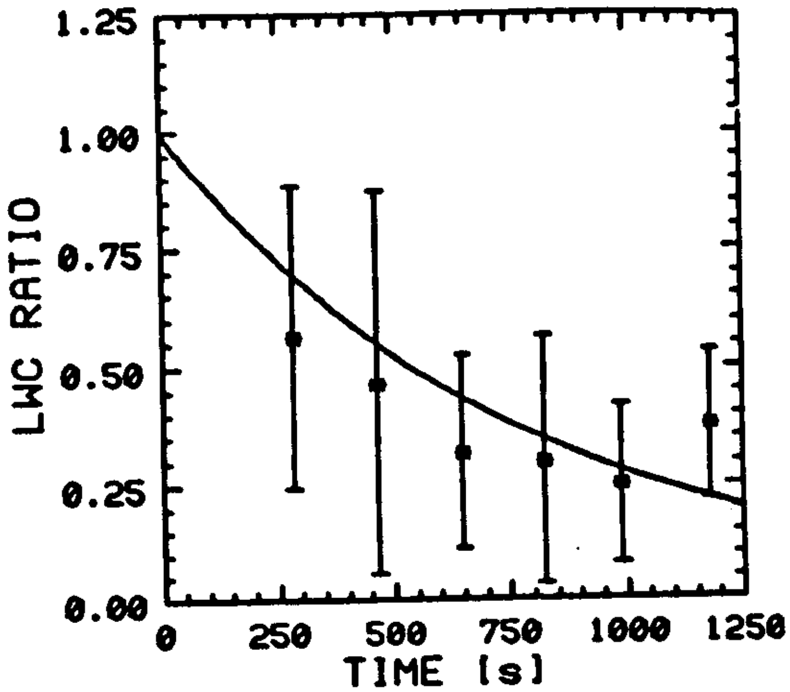


FIG. 1. Average values of the ratio R_i as a function of time after the first pass. The error bars indicate sample standard deviations, and the exponential curve represents the best-fit decay with a decay constant of 780 s.

The measurements of exactly zero were not included in these averages. Most such measurements were due to descent of the cloud below the flight level prescribed

s; this can be consi
these zero values
the cloud. Althou
than the value of
substantially long
by ST.

This method h
CL method of fit
observations. The
necessary, and ave
values with small
fitted curve.

3. Nature of the

Some of the ev
was presented in
indicate that the
beled.) Figure 1 a
nonlinear. The χ
to the mean LW
from standard de
5 degrees of freed
decay was about
m^{-3} min^{-1} the χ
nential form is c

Figure 2 elab