MANCHESTER
1824

The University of Manchester

Modelling and Measurements of the interactions between aerosols and clouds during ACTIVE

P. Connolly♣, G. Vaughan♣, K. Bower♣, T. W. Choularton♣, M. W. Gallagher♣, M. Flynn♣, G. Allen♣.

A.Heymsfield♥, A. Bansemer♥.

♣School of Earth,Atmospheric and Environmental Sciences,
The University of Manchester.
♥NCAR, USA

Campaign 1

Nov

13 ED			**16ED GF**	17	18	19 D GF
20	21	22	23 D GF	24 D	25	26
27	28 D F	29 GF	**30ED GF(2)**	1 ED	2	3 E
		6 E	7	8 E	9 E	10 E

This study

Dec

Test Survey Hector Mixed survey/Hector

Single-cellular Hector

Multi-cellular Hector

Mini-monsoon

Campaign 2

This study

Jan	16	17			20ED	21
22ED T	23 E T	24	25 E PT	D	27 ED PT	28
29	30 D	31 E	1 ED		3 ED	4
5	6 ED PT			D T	10ED PT	11
12 ED PT	13 E	1 ED	15 E	16	17	Feb

Test Survey Hector Monsoon Aged anvil Lidar

Westerly Monsoon

Monsoon trough

Inactive Monsoon

Single-cellular Hector

Multi-cellular Hector

Summary

- Around 30 flights with each aircraft in and around tropical convection
- Inflow conditions change from polluted early in November (smoke from biomass burning) to very clean in Jan/Feb
- Hectors observed in polluted and clean regimes
- Monsoon convection observed in the second half of January

Question

- Can we observe the thermodynamic indirect effect? AND How important is it?

MANCHESTER 1824

The University of Manchester

LEM Model framework

Large eddy model

- Island heat fluxes and roughness length - MODIS.
- Droplet activation – Twomey 1959: $N=Cs^k$
  - Maritime: $C=240cm^{-3}$, Continental: $C=720cm^{-3}$.
- 2-moment bulk microphysical scheme.
- 3-moment graupel scheme-density of graupel.
- Radiation code – LW, SW.

MANCHESTER 1824

The University of Manchester

Heterogeneous freezing of rain

$$\left.\frac{dN_R}{dt}\right|_{fr} = -N_R \times V \times J_{het}(T)$$

Bigg 1953

$$\left.\frac{dq_R}{dt}\right|_{fr} = \left.\frac{dN_R}{dt}\right|_{fr} \times \overline{q}_R$$

Important to predict number of activated droplets and raindrops

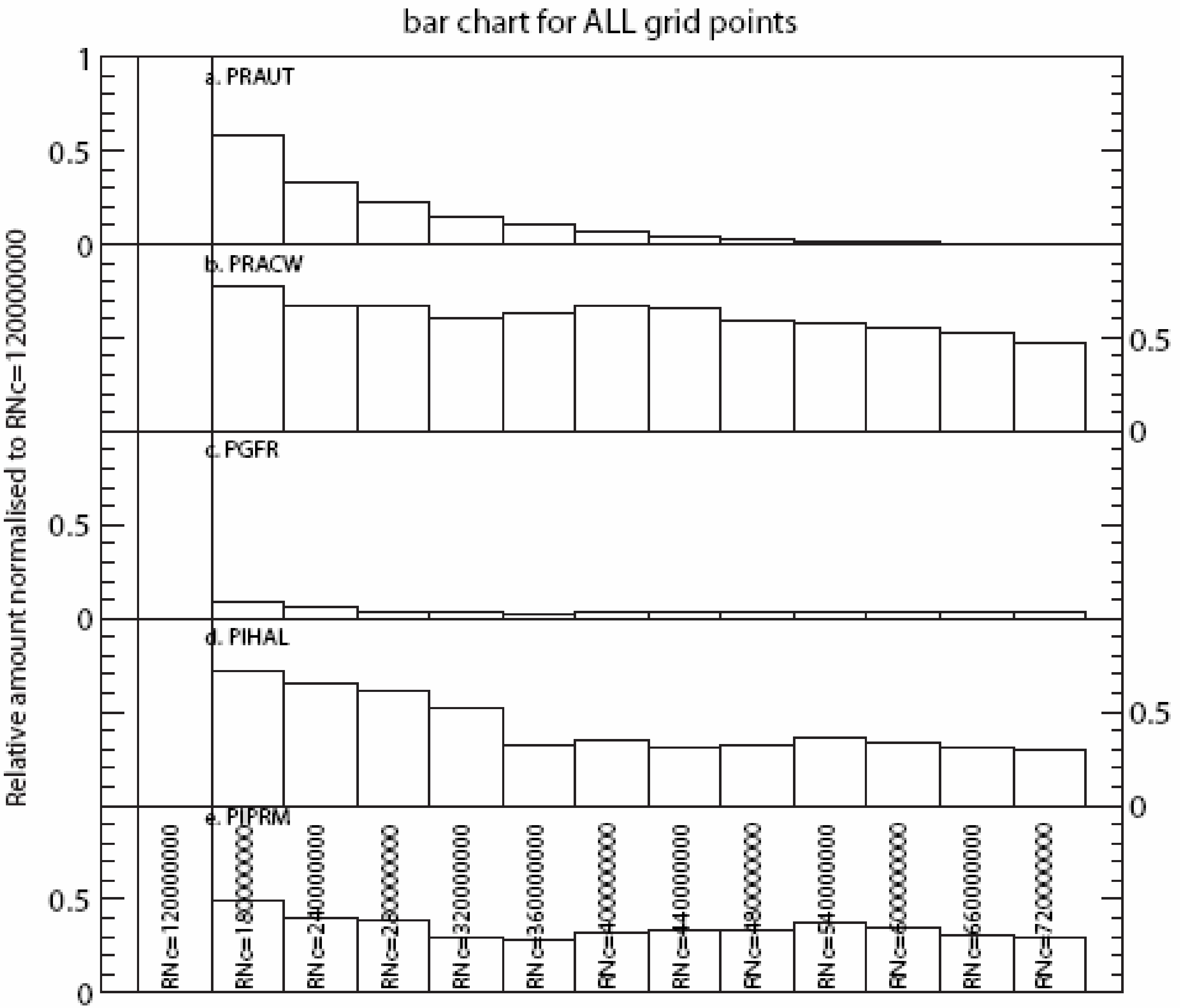
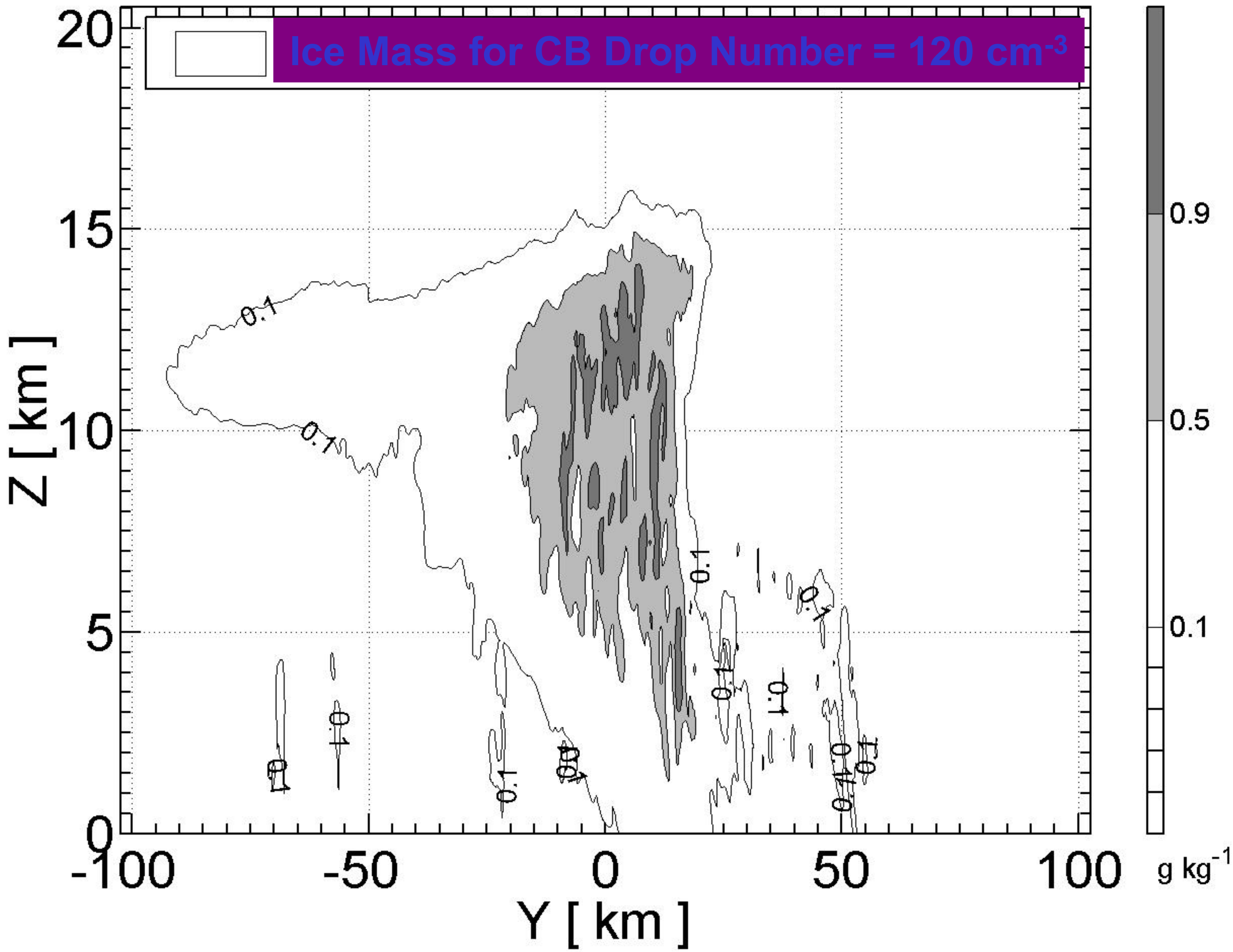
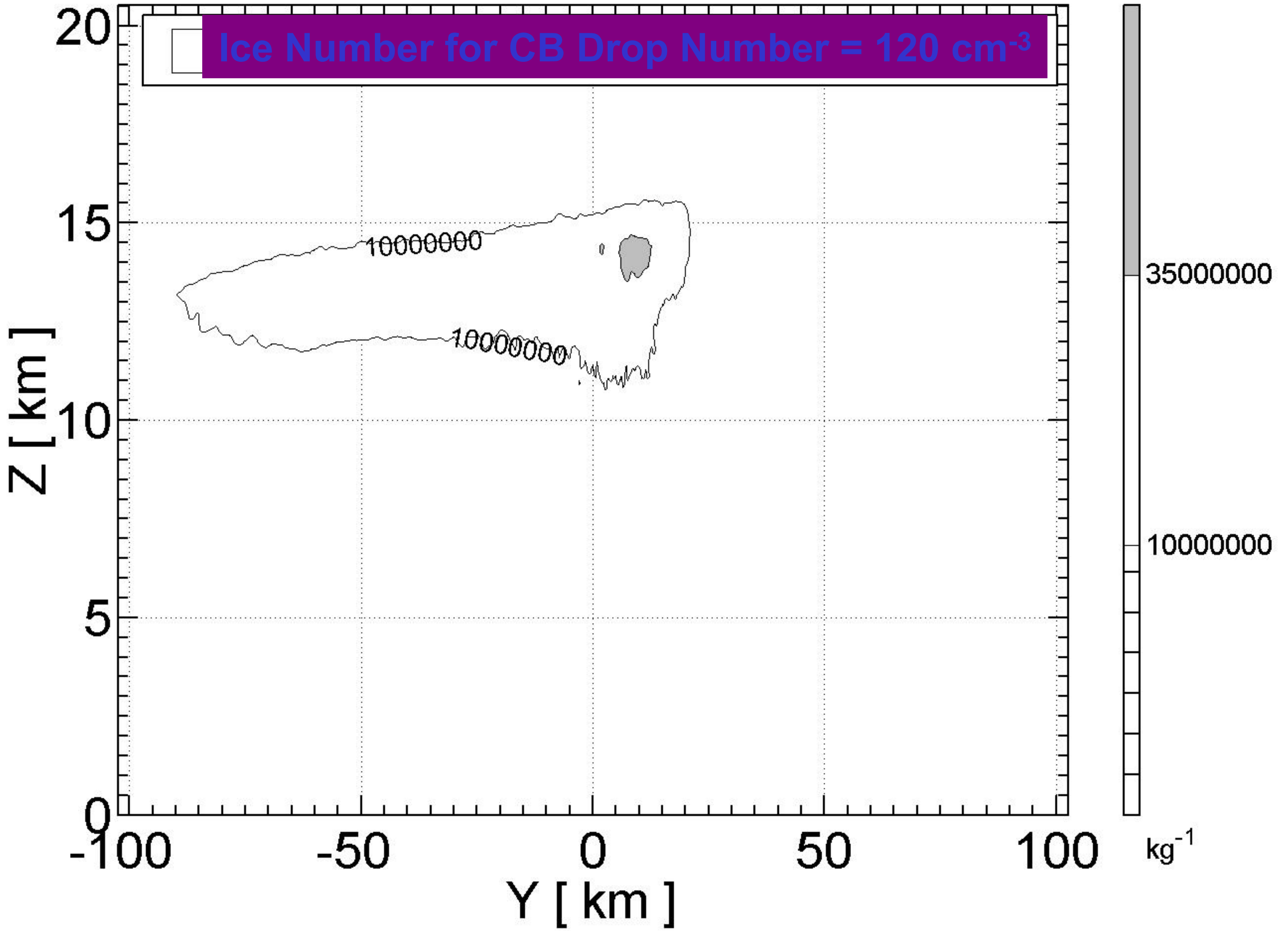


Figure 5. Source terms for CRM Droplet number sensitivity. (a) shows the autoconversion of cloud water to rain, (b) accretion of cloud water by rain, (c) probabilistic freezing of rain, (d) the Hallett-Mossop process, (e) the production of primary ice crystals. All rates are scaled to the first run ($RNc = 120000000\ \mathrm{m}^{-3}$)

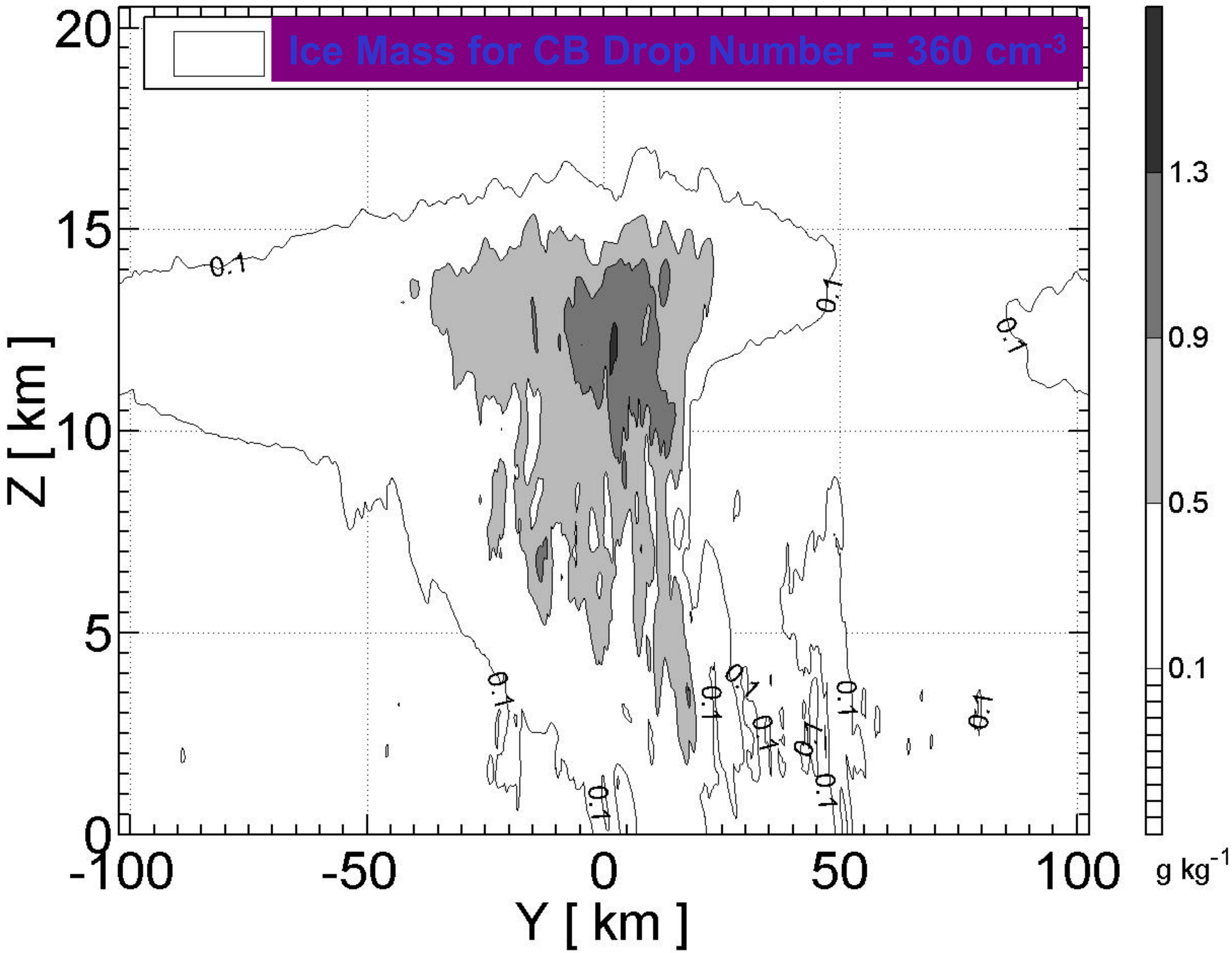


Ice Mass for CB Drop Number = 120 cm-3
Z [km]
Y [km]
0.1
0.9
0.5
0.1
g kg-1

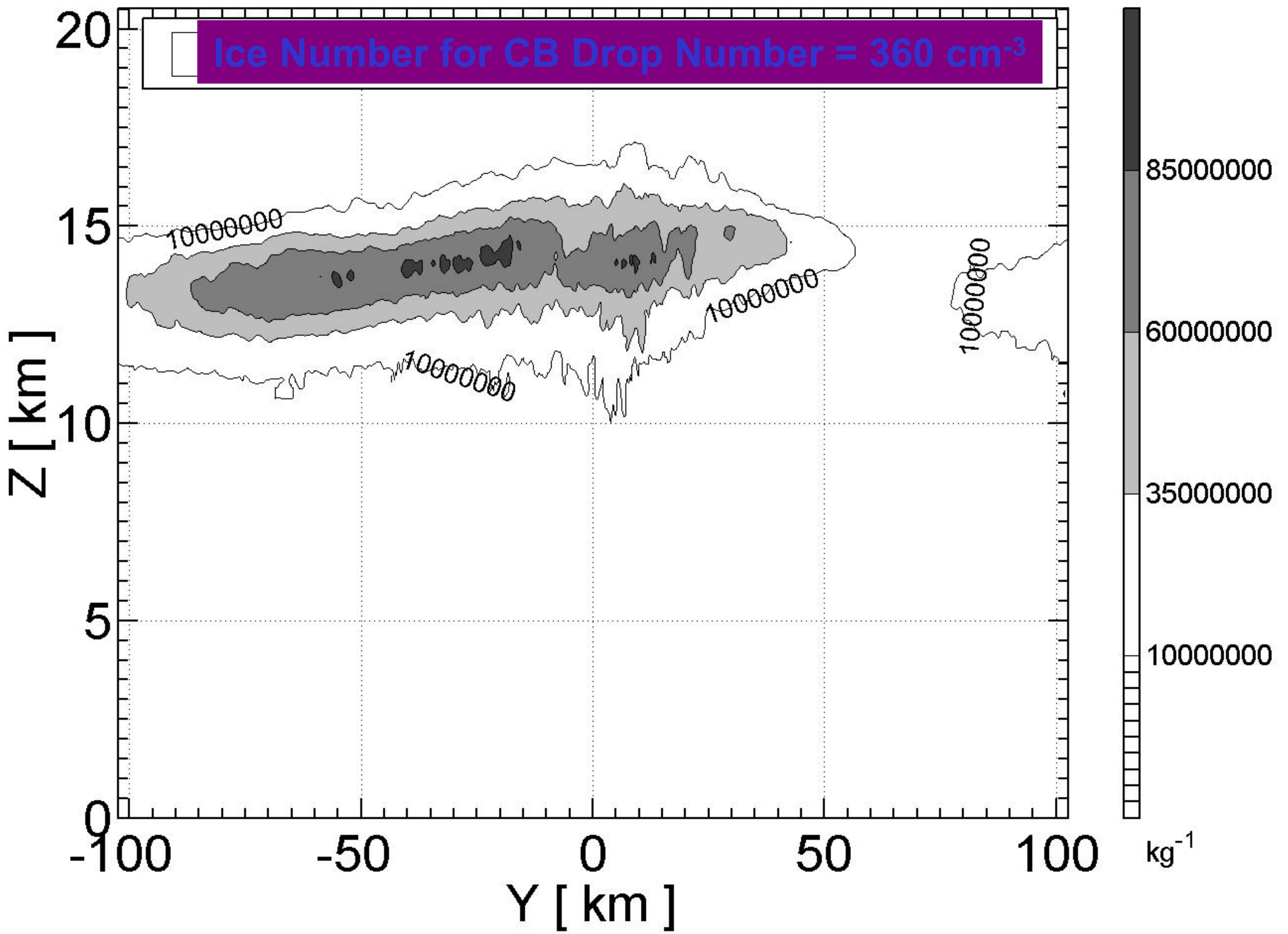
MANCHESTER 1824

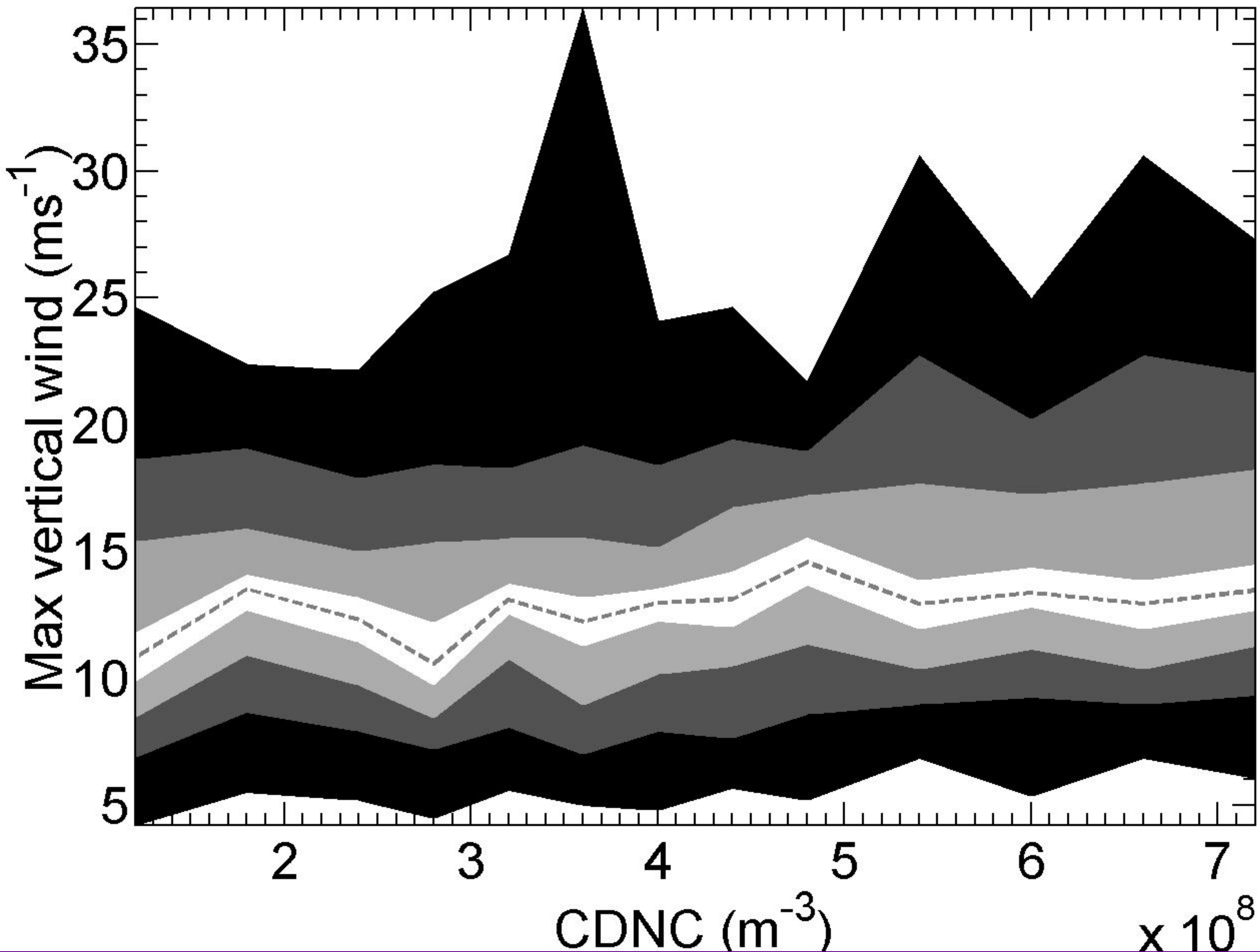


MANCHESTER
1824



MANCHESTER 1824




Max vertical wind (ms-1)
35
30
25
20
15
10
5
2
3
4
5
6
7
CDNC (m-3)
x 10^8

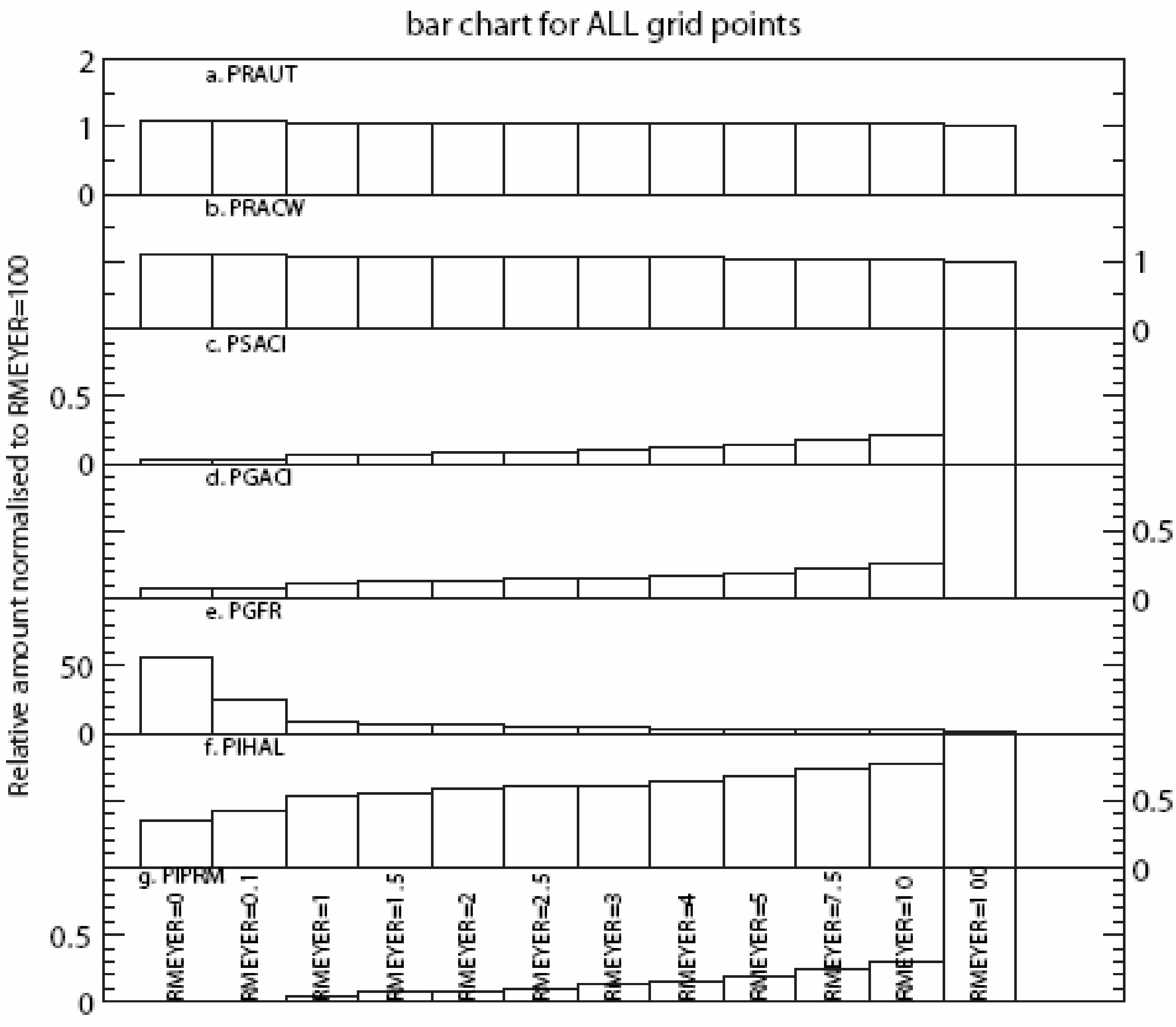
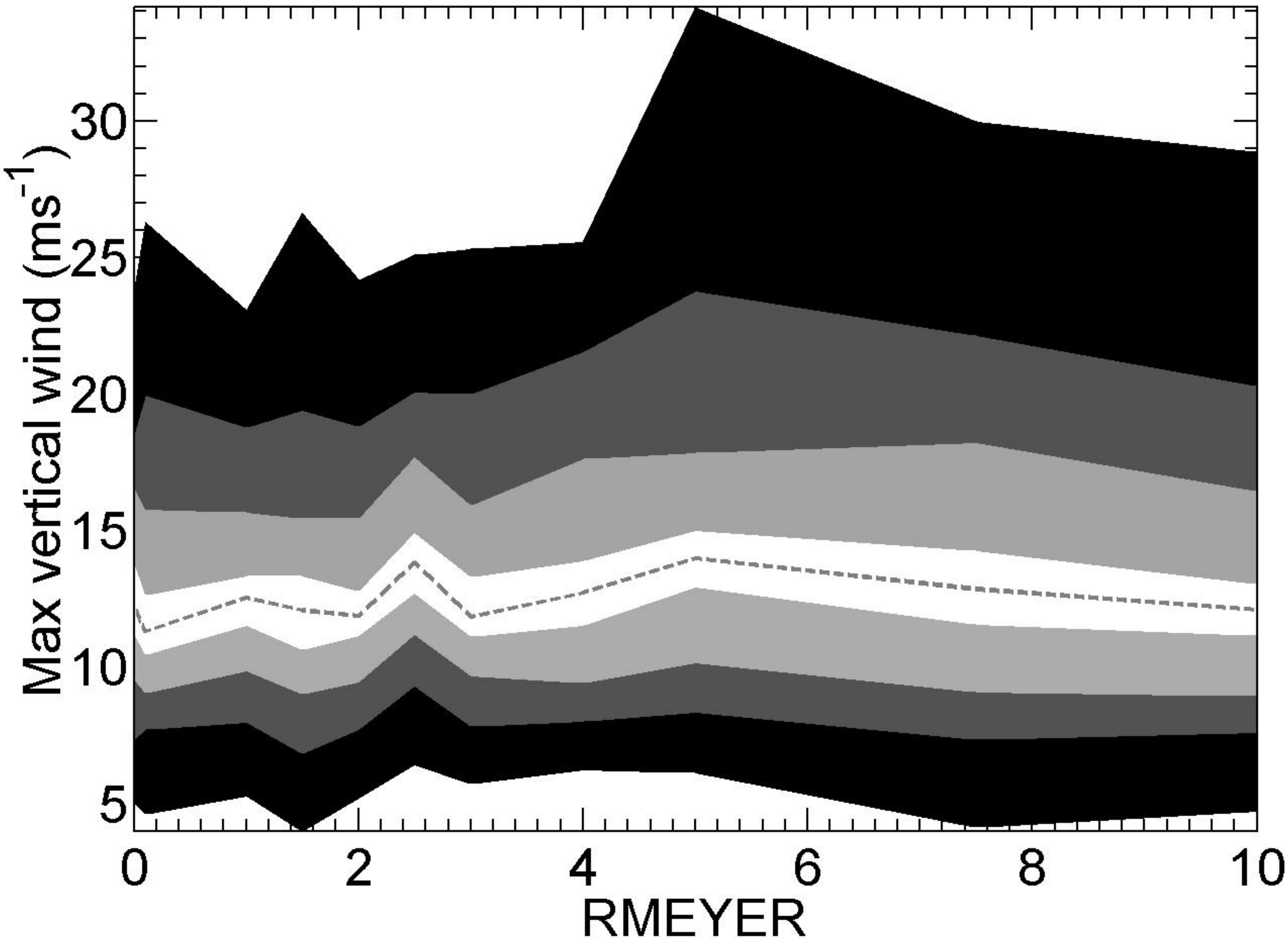
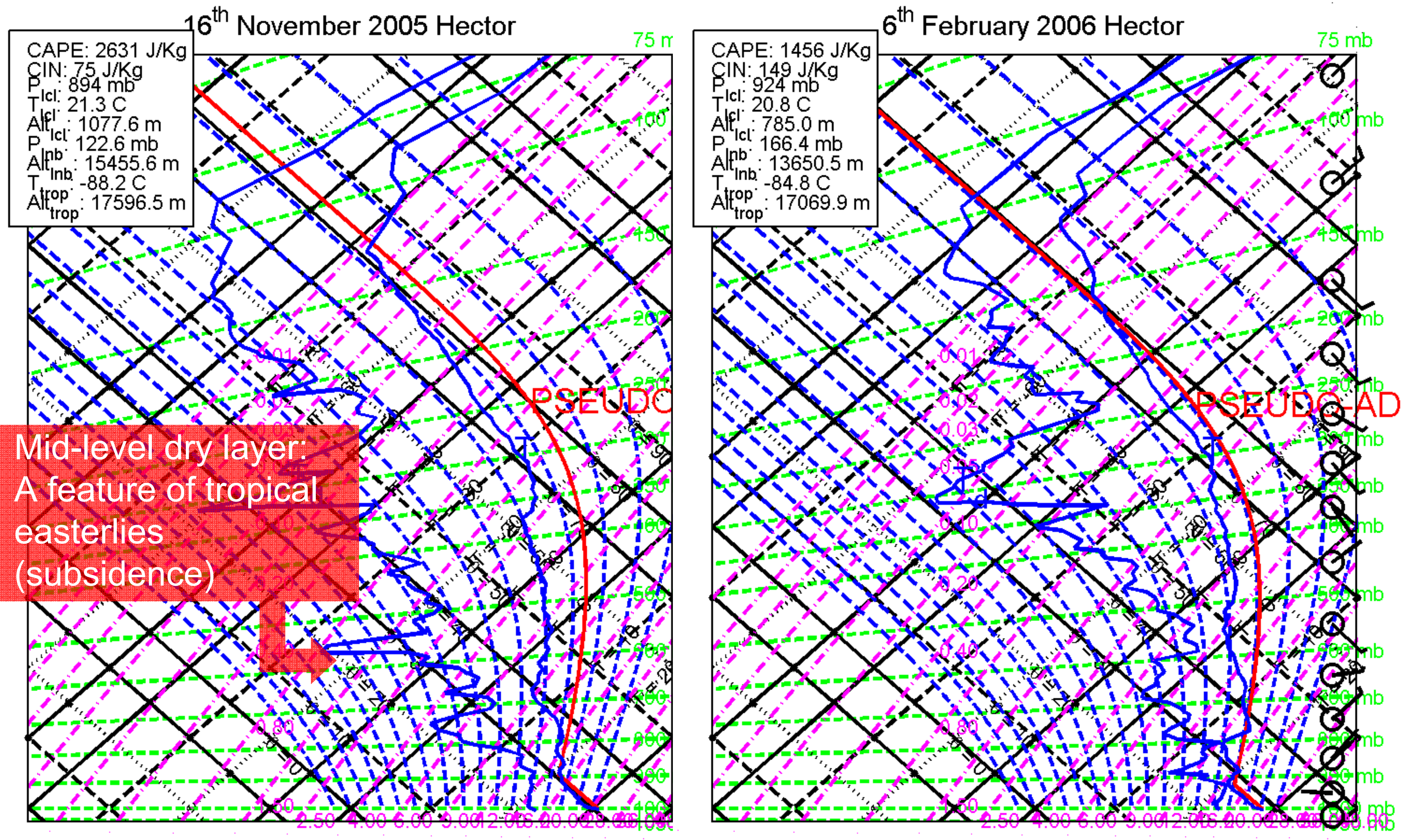


Figure 8. Source terms for CRM primary ice sensitivity. (a) shows the autoconversion of cloud water to rain, (b) accretion of cloud water by rain, (c) accretion of cloud ice by snow, (d) accretion of cloud ice by graupel, (e) probabilistic freezing of rain, (f) the Hallett-Mossop process, (g) the production of primary ice crystals. All rates are scaled to the last run ($RMEYER = 100$)

MANCHESTER 1824



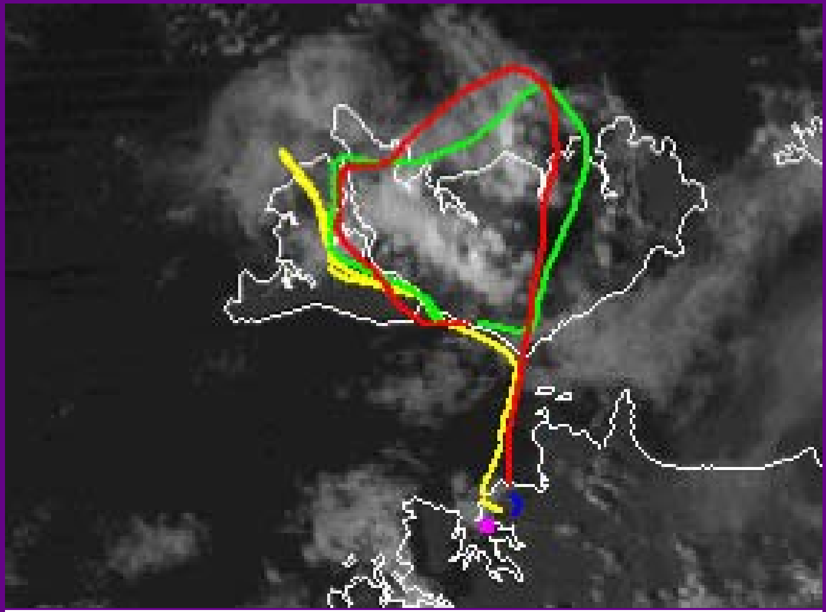
Two Hectors… Data – Peter May

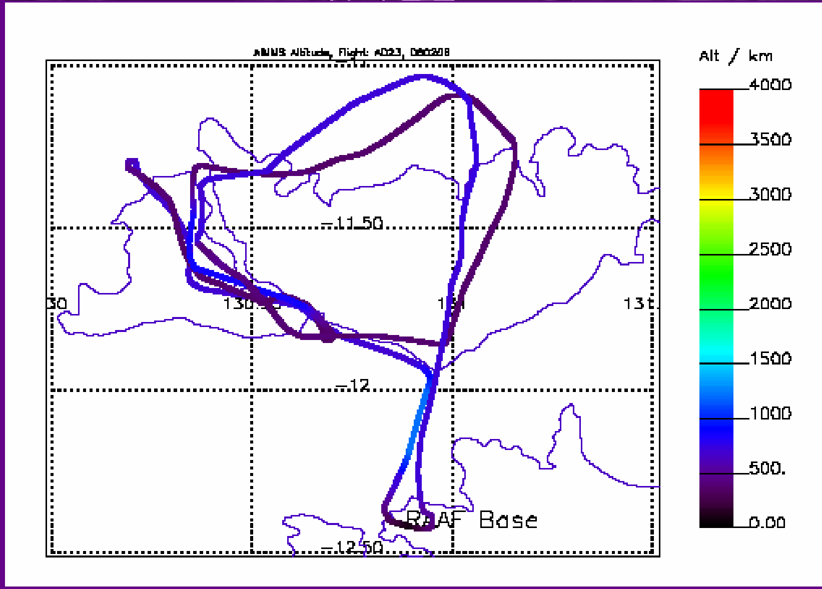


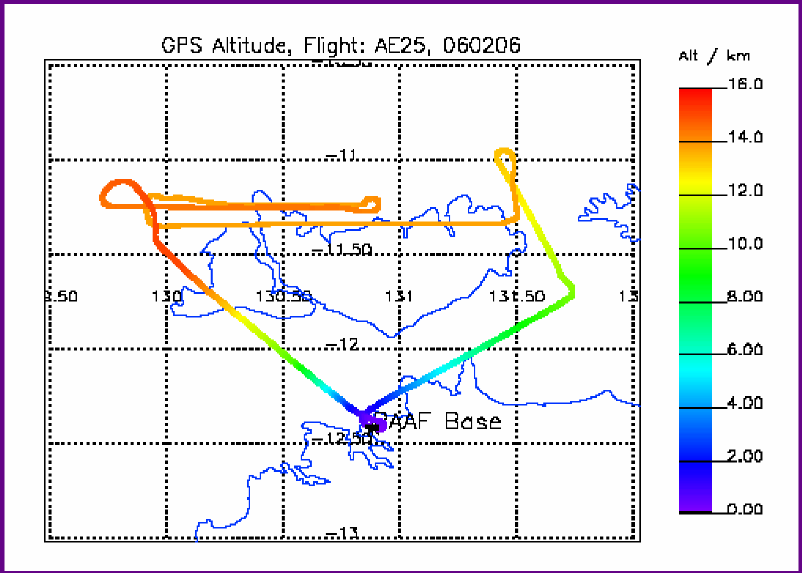
MANCHESTER 1824

The University of Manchester

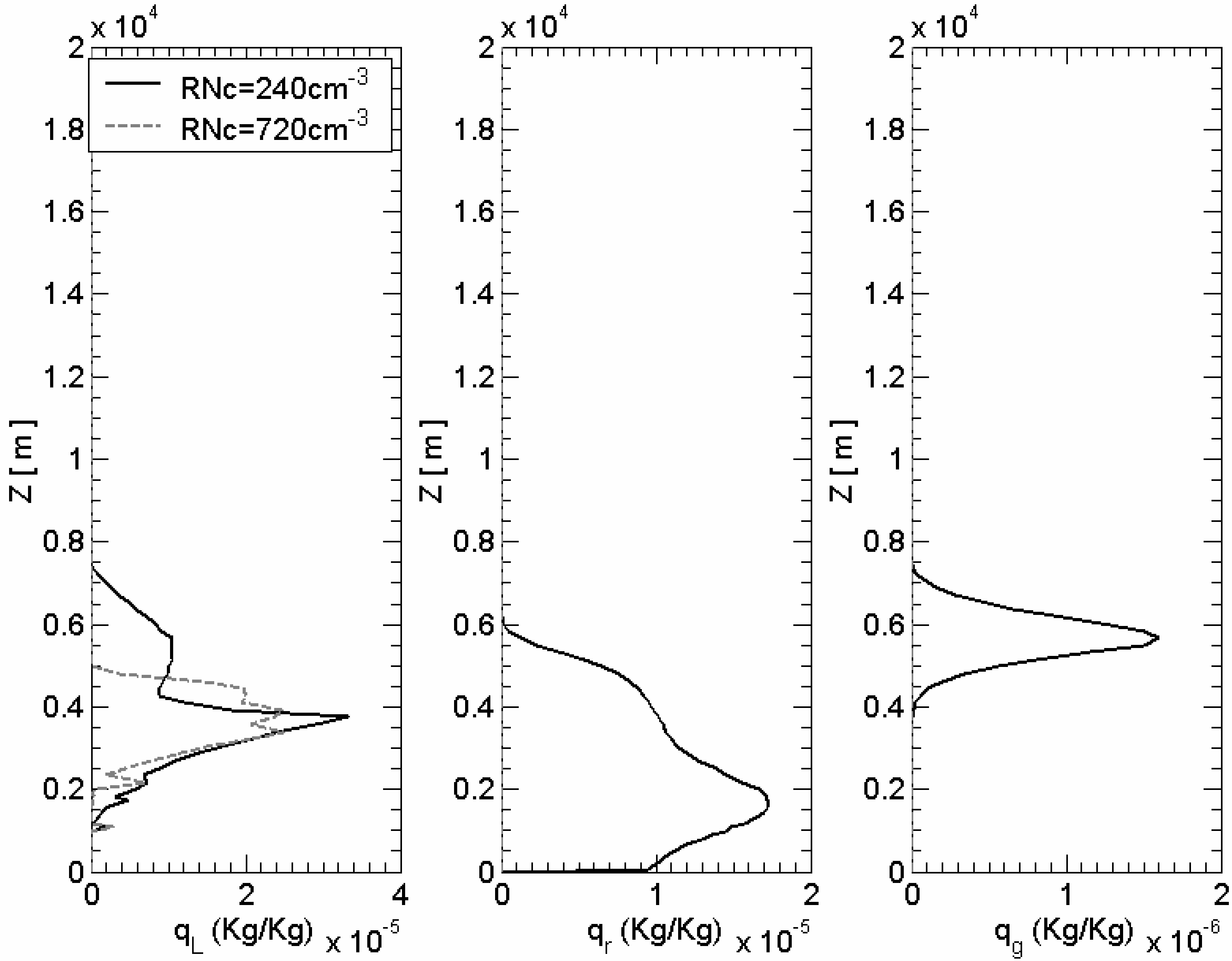
6 Feb 2006 -clean



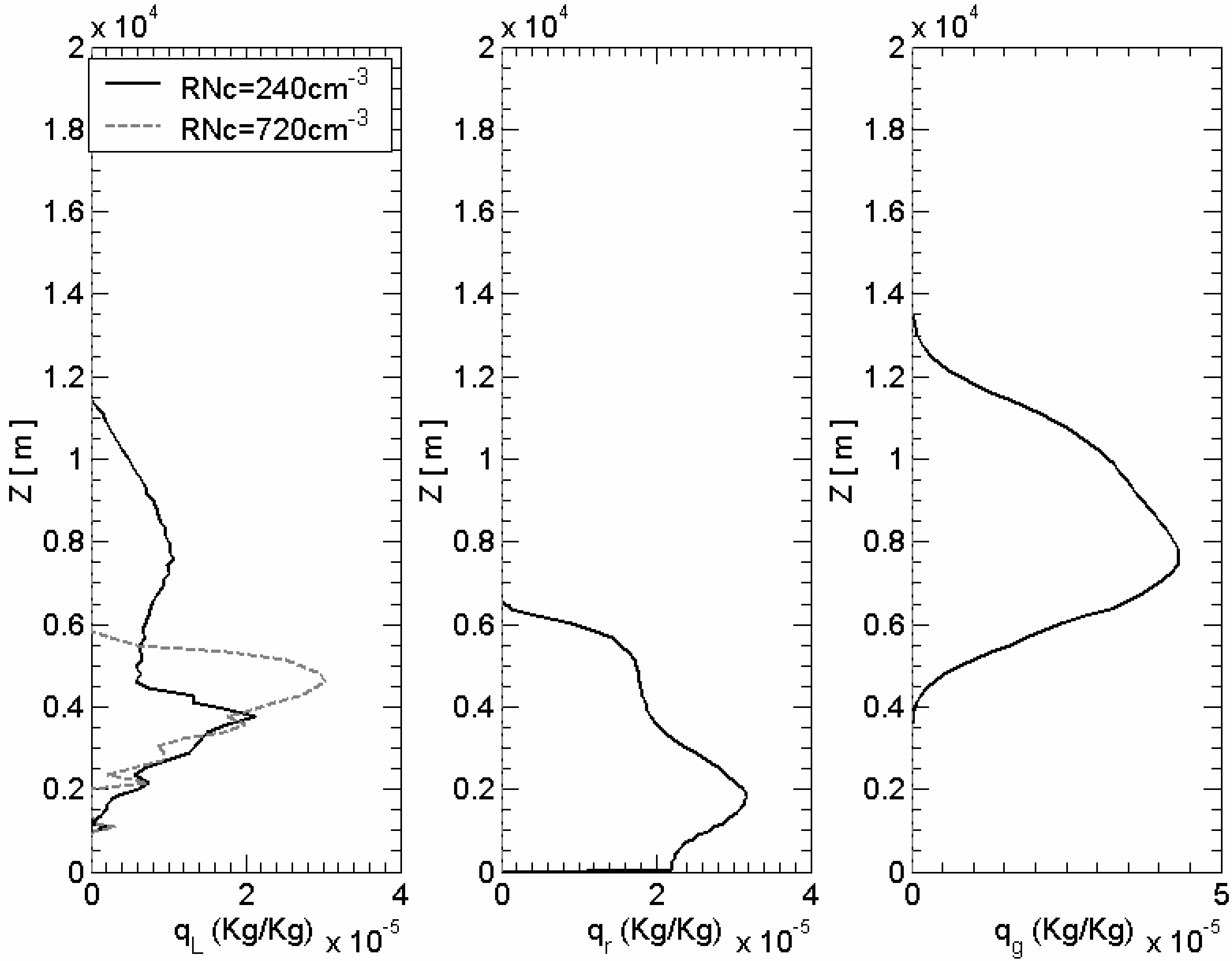


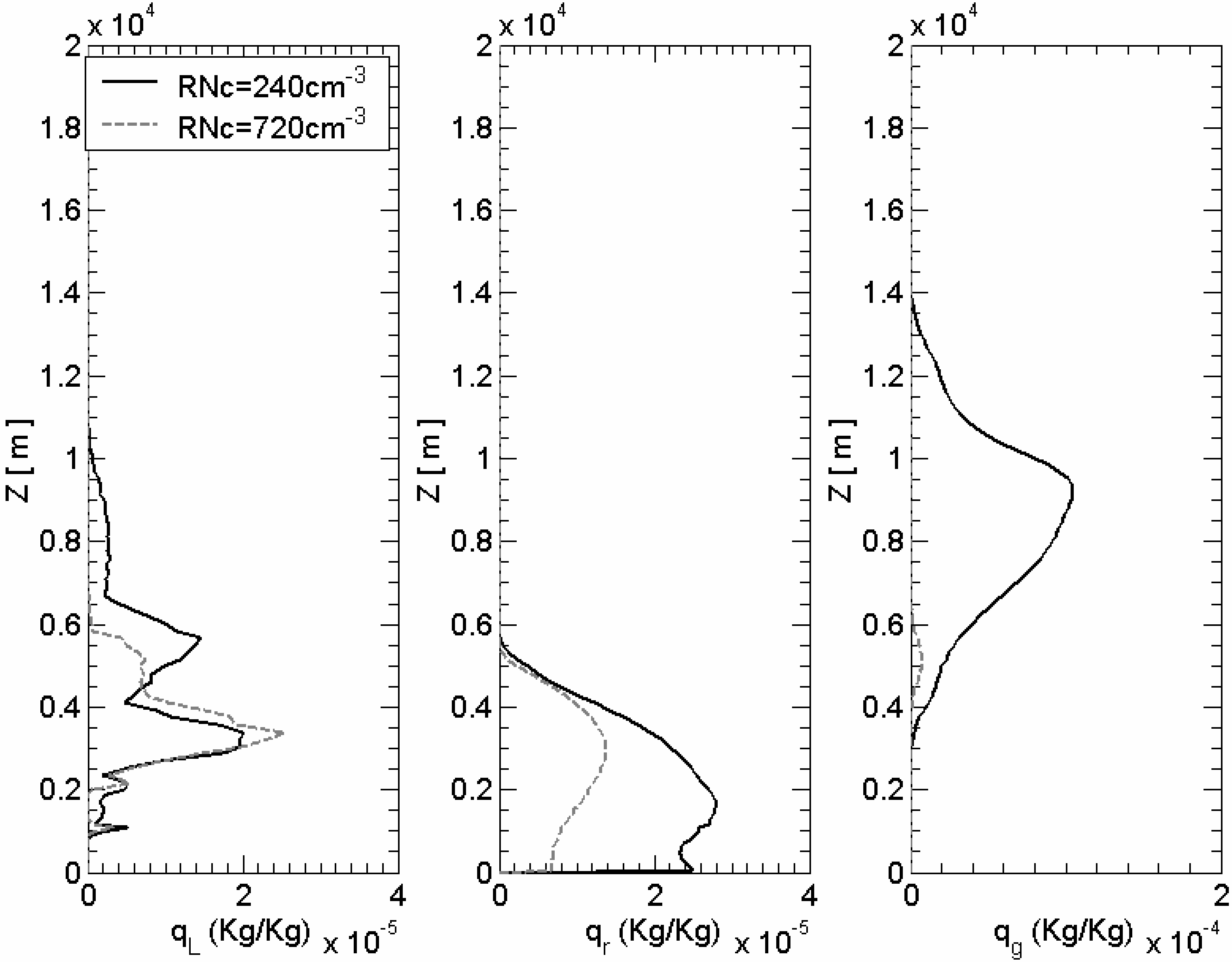


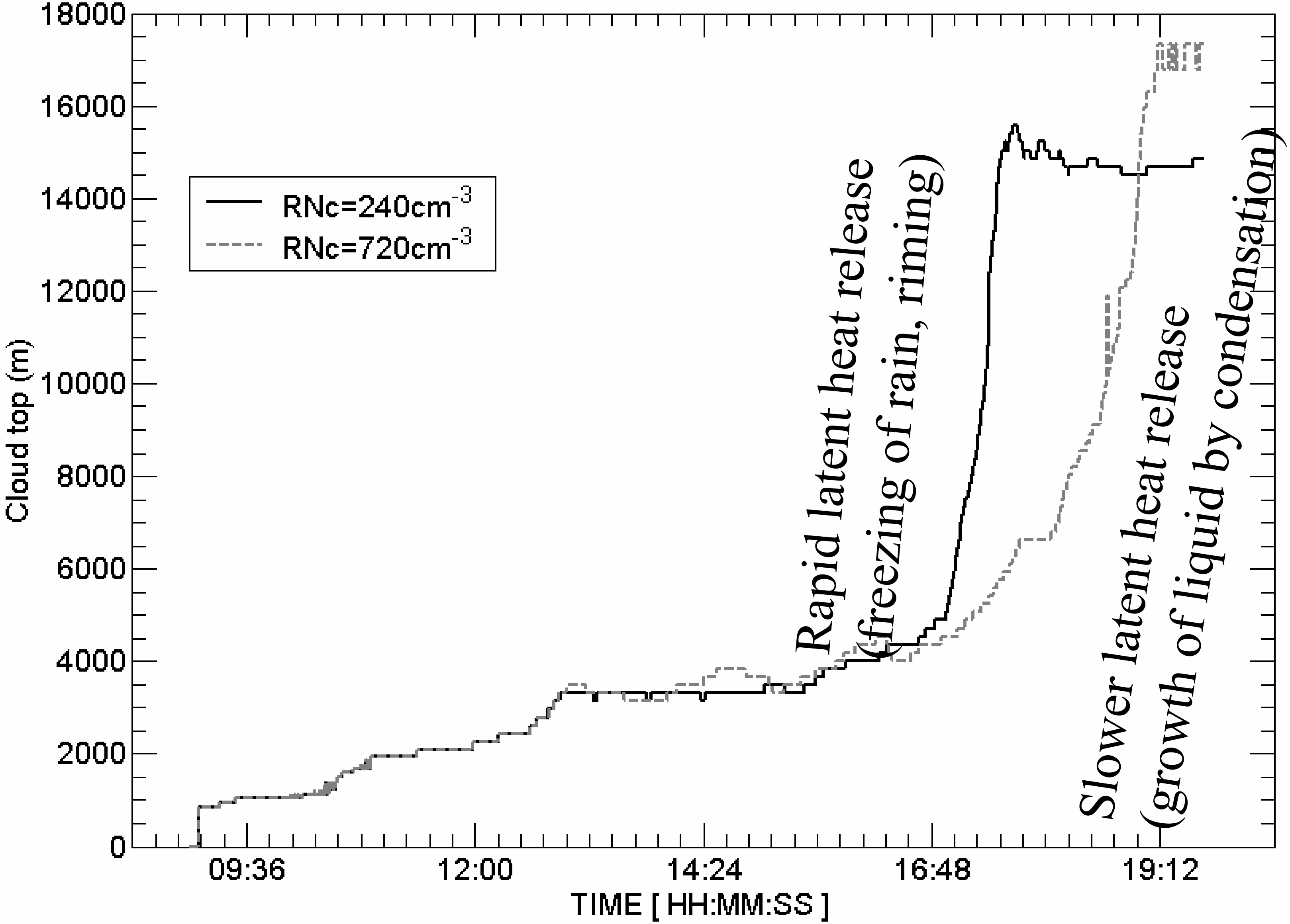
Satellite data from BoM, aircraft tracks by G. Allen



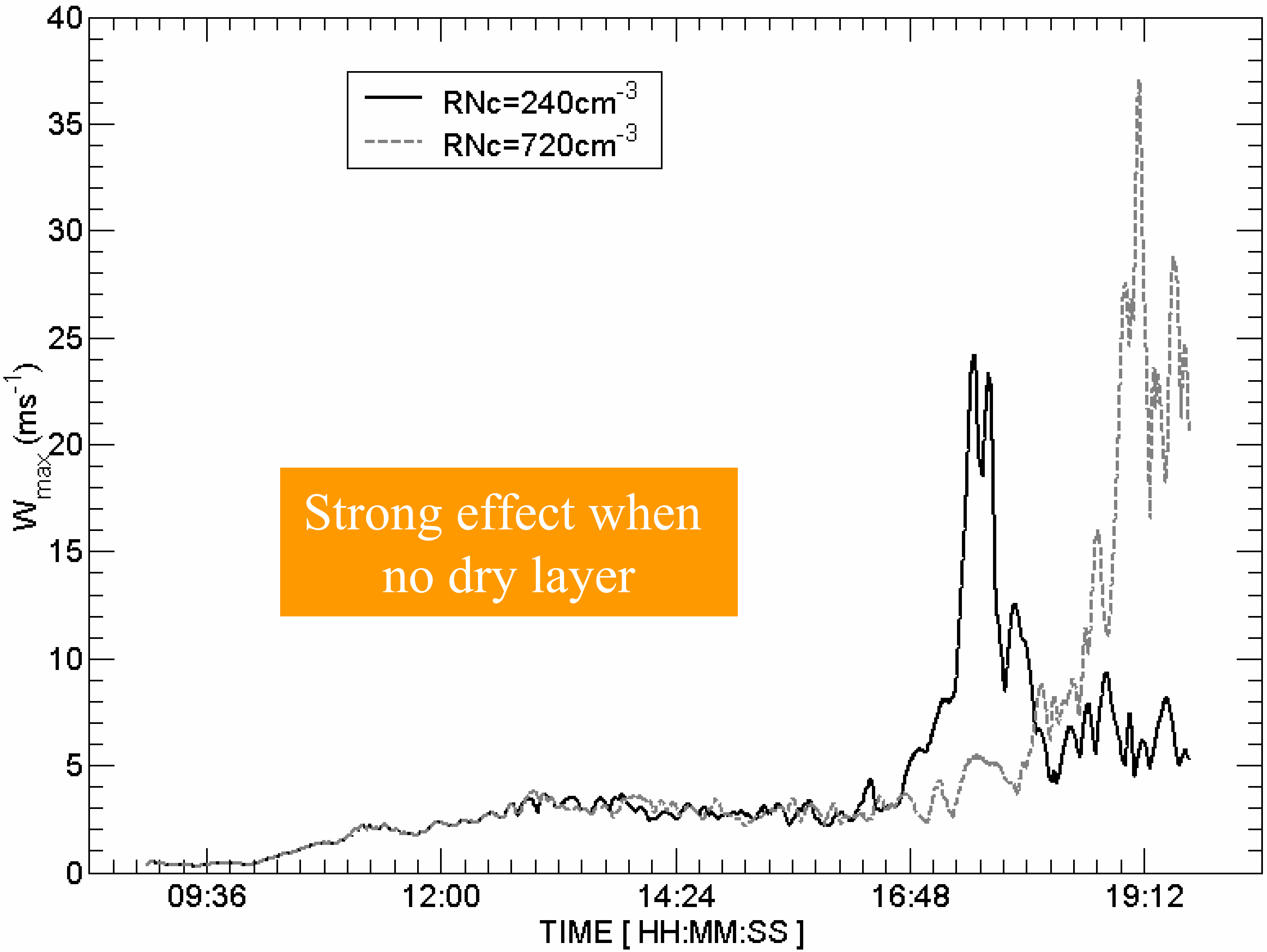
x 10^4
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Z [m]
RNc=240cm^-3
RNc=720cm^-3
0
2
4
q_L (Kg/Kg)
x 10^-5
x 10^4
Z [m]
0
1
2
q_r (Kg/Kg)
x 10^-5
x 10^4
Z [m]
0
1
2
q_g (Kg/Kg)
x 10^-6


x 10^4
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Z [m]
RNc=240cm^-3
RNc=720cm^-3
0
2
4
q_L (Kg/Kg)
x 10^-5
q_r (Kg/Kg)
5
q_g (Kg/Kg)


x 10^4
RNc=240cm^-3
RNc=720cm^-3
Z [m]
q_L (Kg/Kg) x 10^-5
q_r (Kg/Kg) x 10^-5
q_g (Kg/Kg) x 10^-4

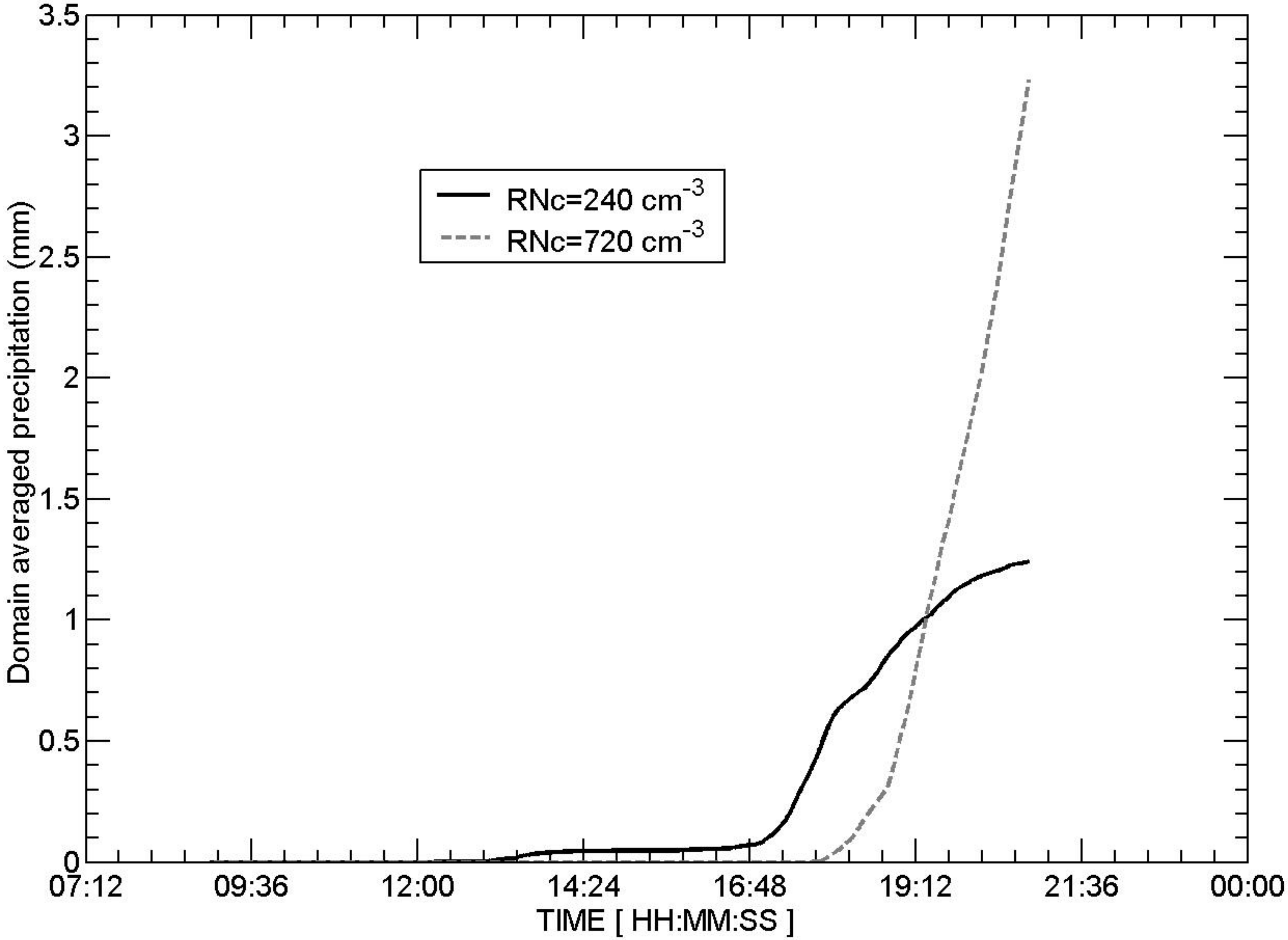


18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Cloud top (m)
09:36
12:00
14:24
16:48
19:12
TIME [HH:MM:SS]
RNc=240cm^{-3}
RNc=720cm^{-3}
Rapid latent heat release
(freezing of rain, riming)
Slower latent heat release
(growth of liquid by condensation)

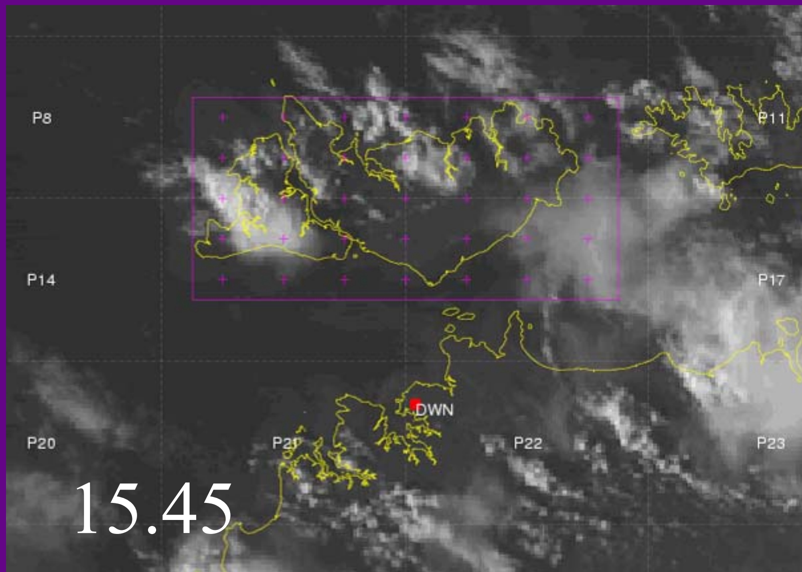


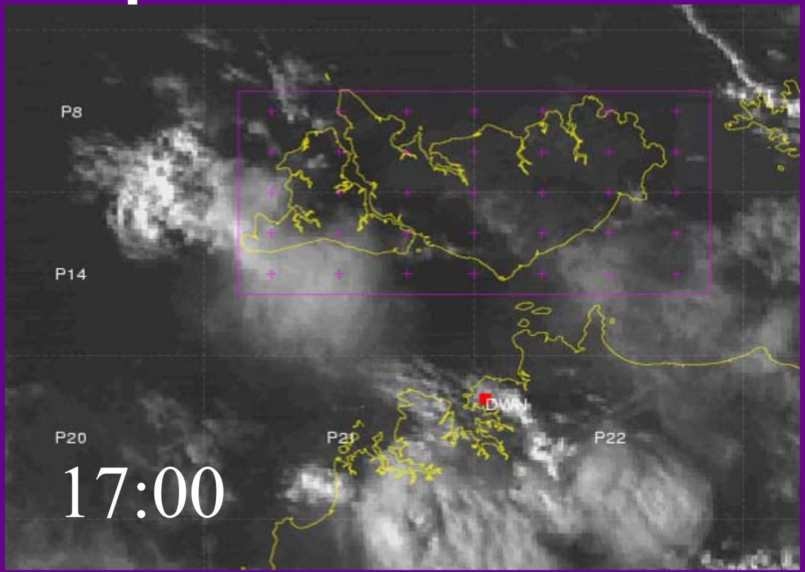
Strong effect when no dry layer

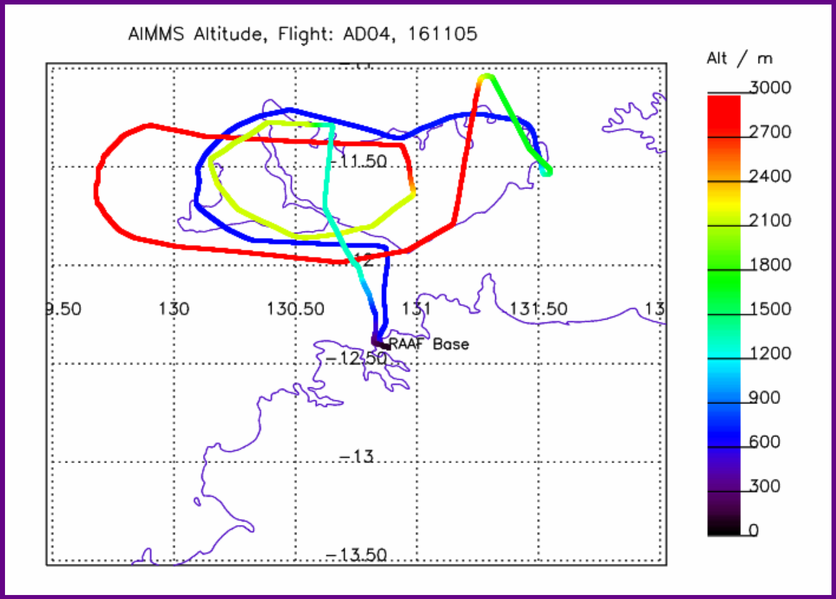
MANCHESTER
1824

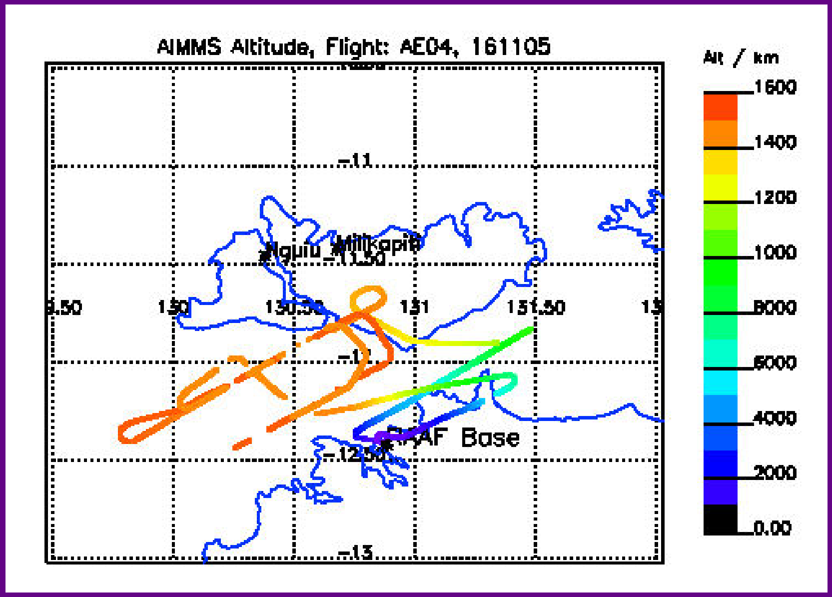


16 Nov 2005 - polluted

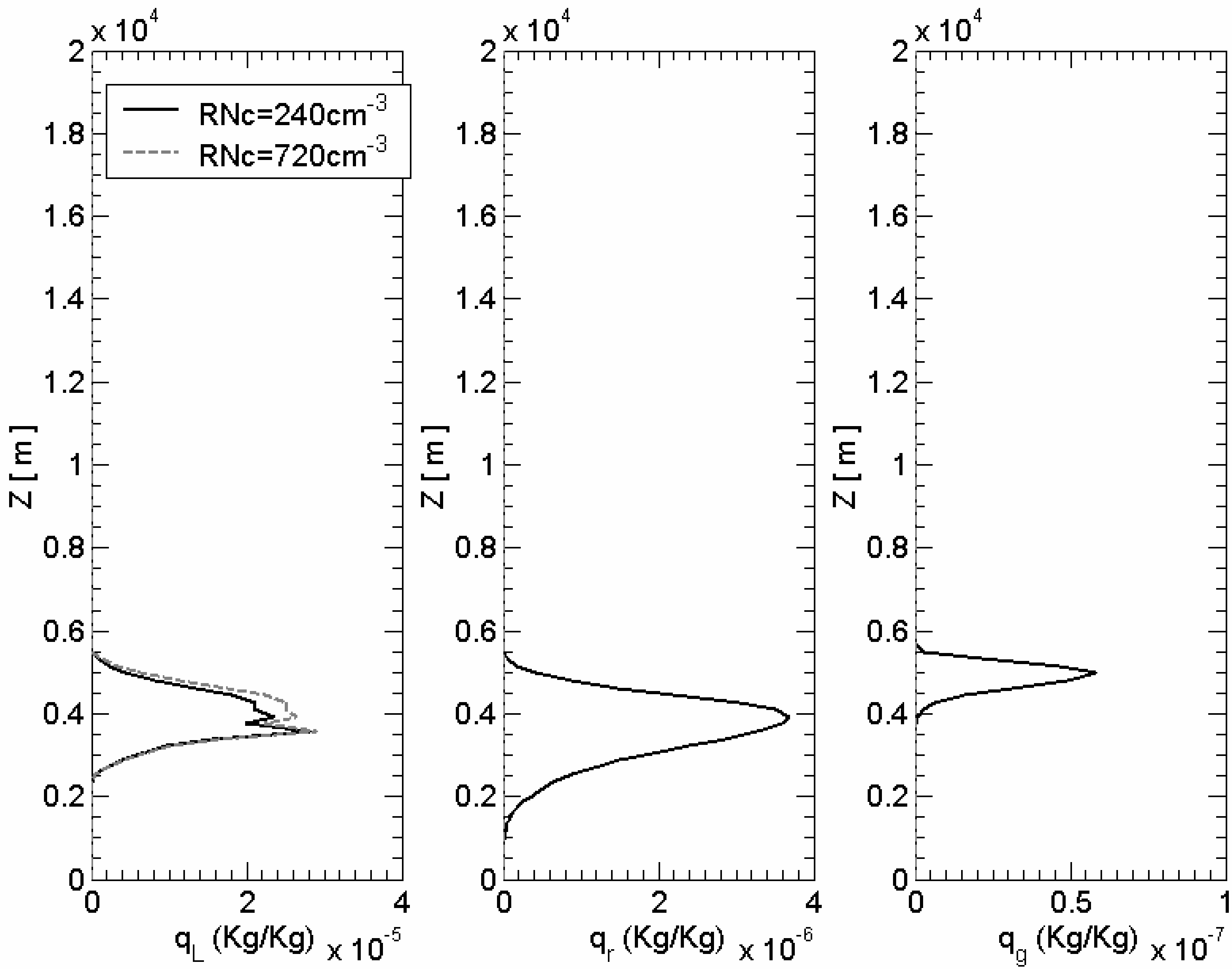


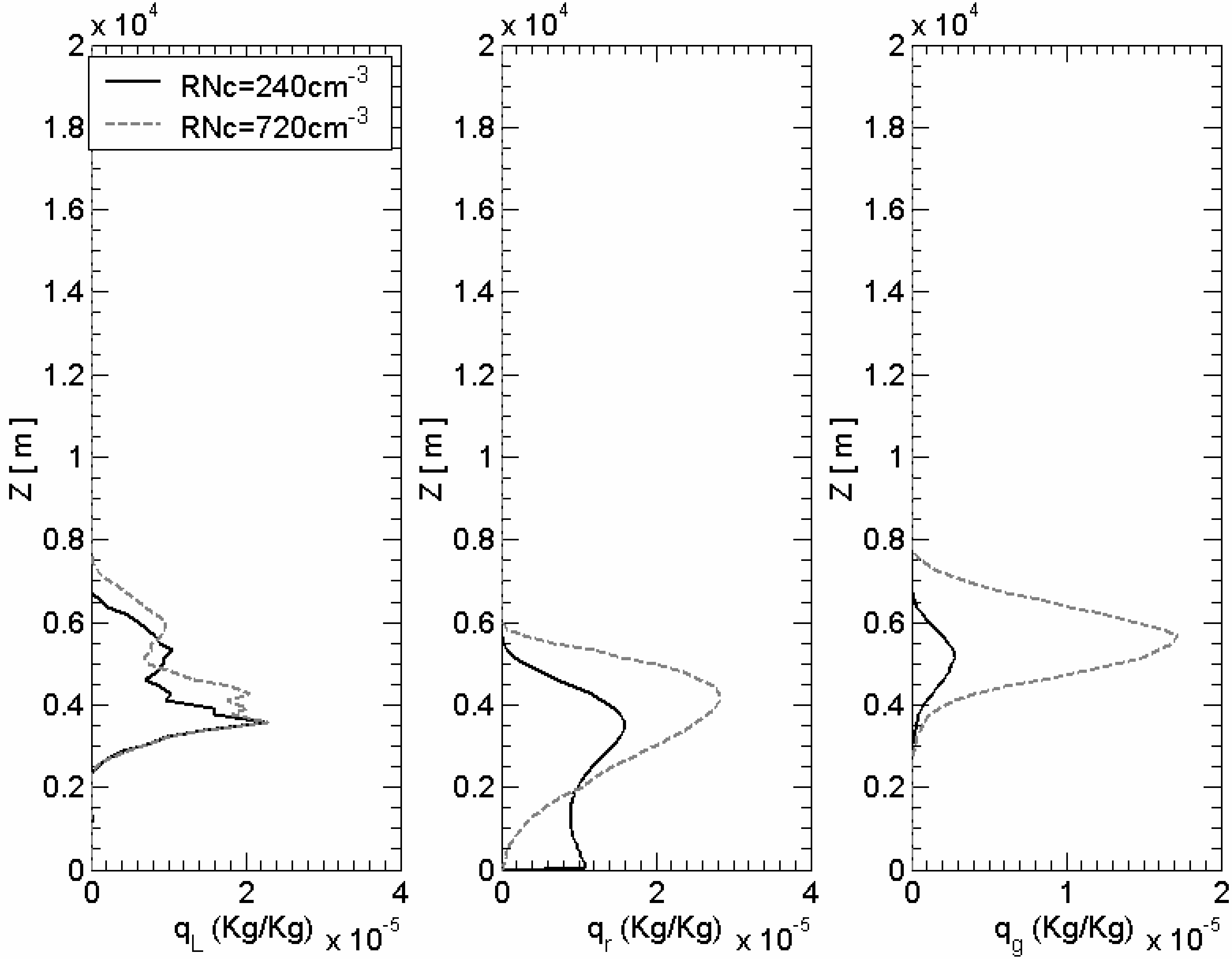


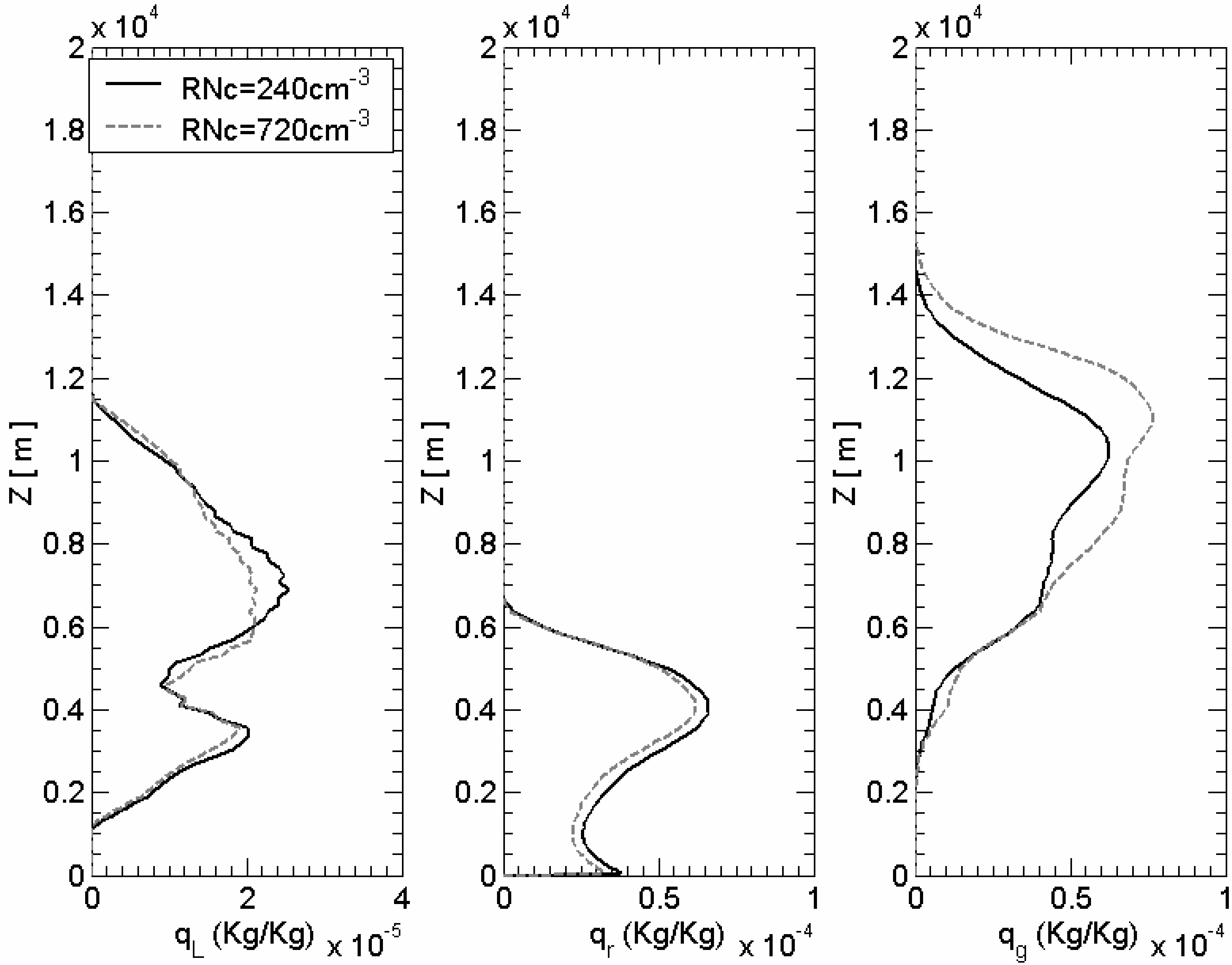




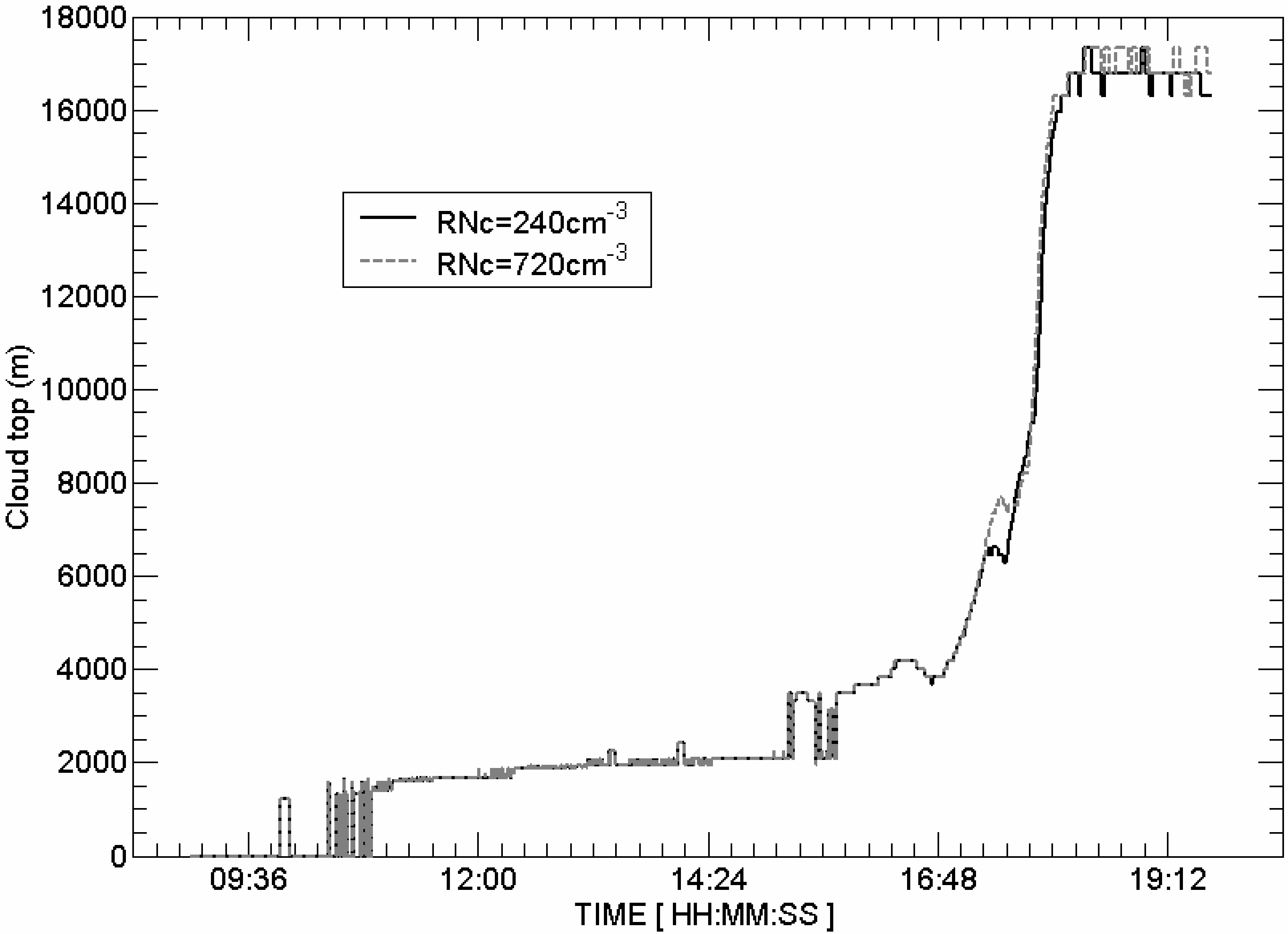
Satellite data from BoM, aircraft tracks by G. Allen


x 10^4
RNc=240cm^-3
RNc=720cm^-3
Z [m]
q_L (Kg/Kg) x 10^-5
q_r (Kg/Kg) x 10^-6
q_g (Kg/Kg) x 10^-7


x 10^4
RNc=240cm^-3
RNc=720cm^-3
Z [m]
q_L (Kg/Kg)
x 10^-5
q_r (Kg/Kg)
q_g (Kg/Kg)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
4

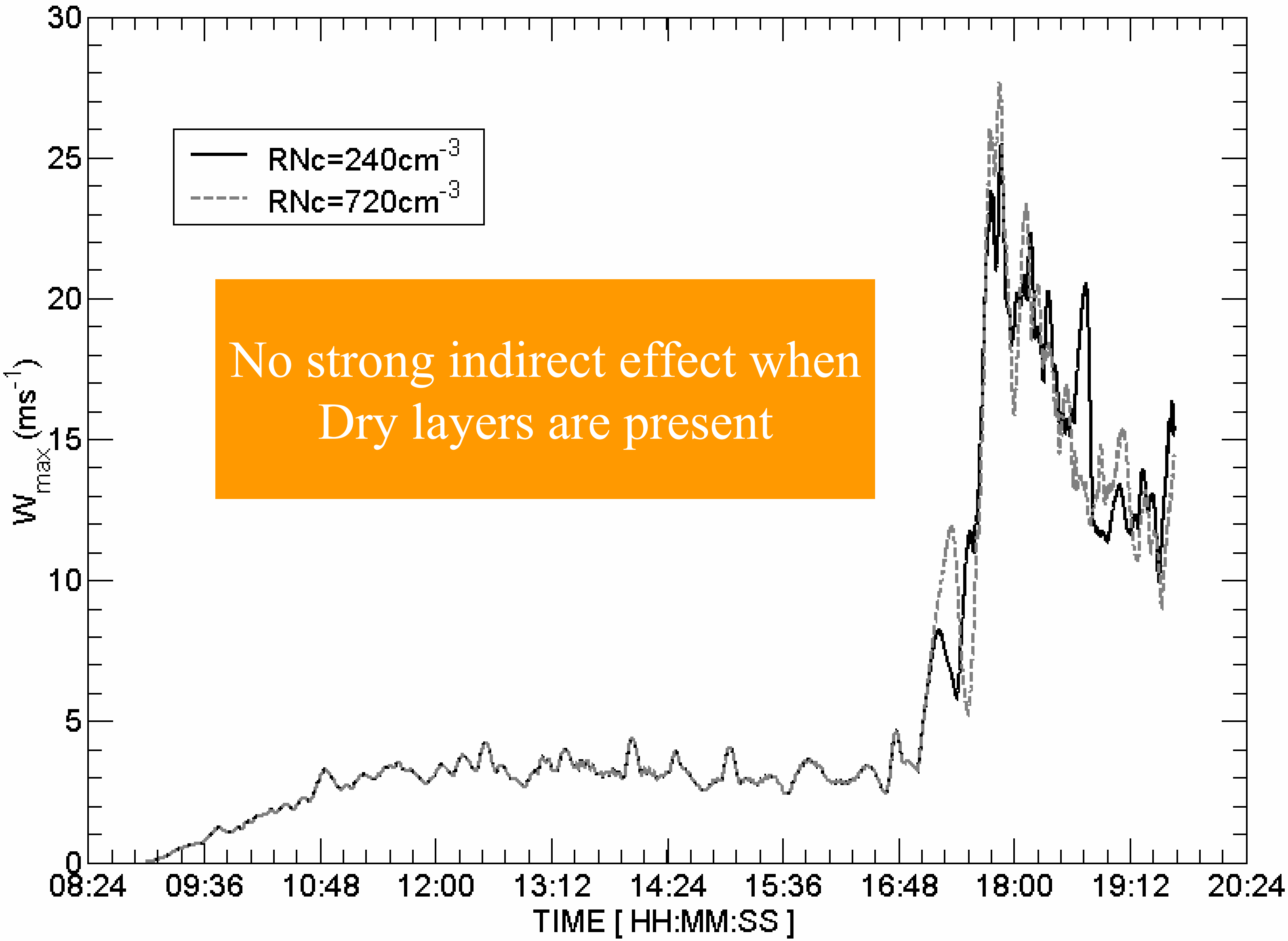


x 10^4
RNc=240cm^-3
RNc=720cm^-3
Z [m]
q_L (Kg/Kg) x 10^-5
q_r (Kg/Kg) x 10^-4
q_g (Kg/Kg) x 10^-4
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0.5
4

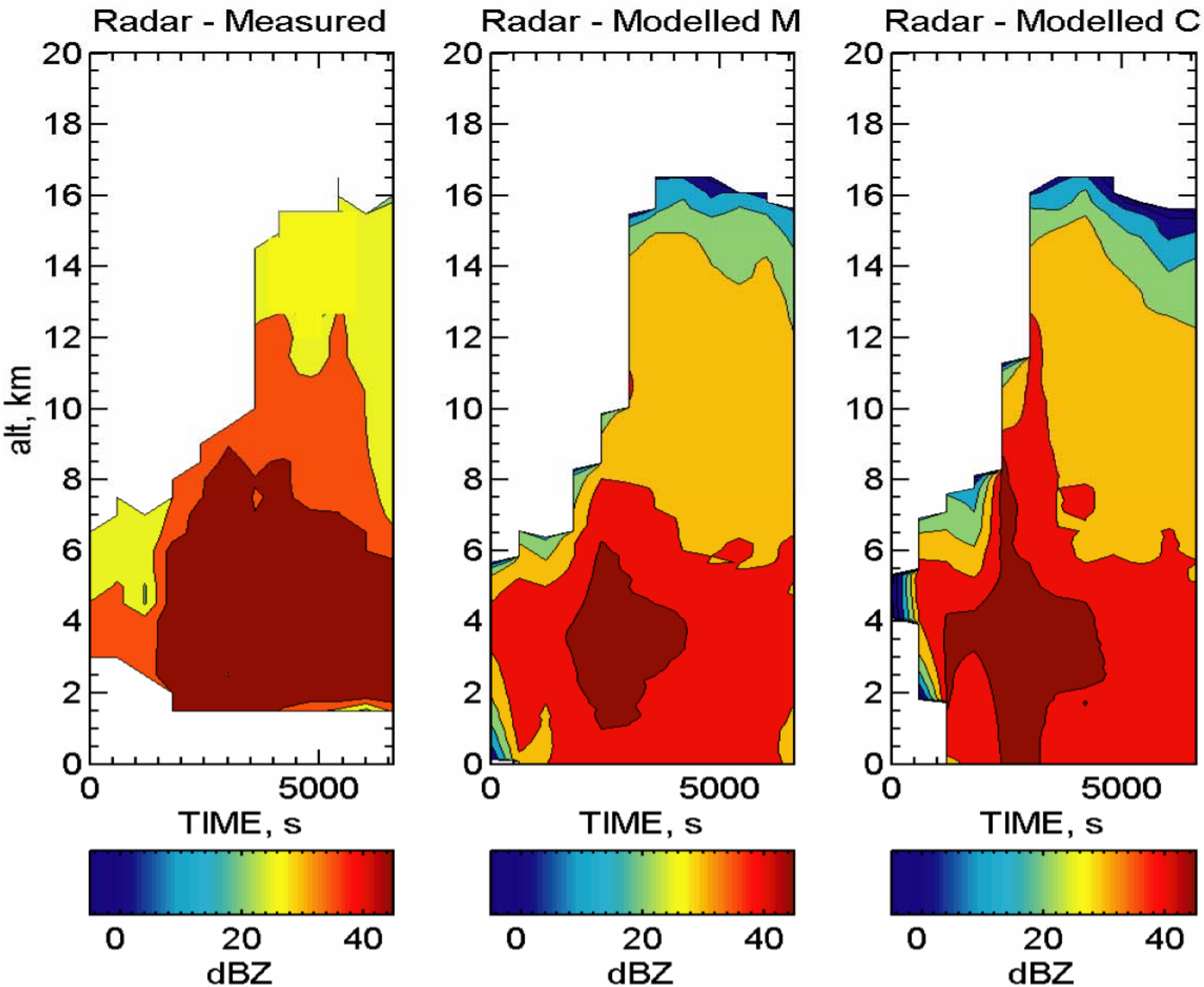


18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Cloud top (m)
RNc=240cm-3
RNc=720cm-3
09:36
12:00
14:24
16:48
19:12
TIME [HH:MM:SS]

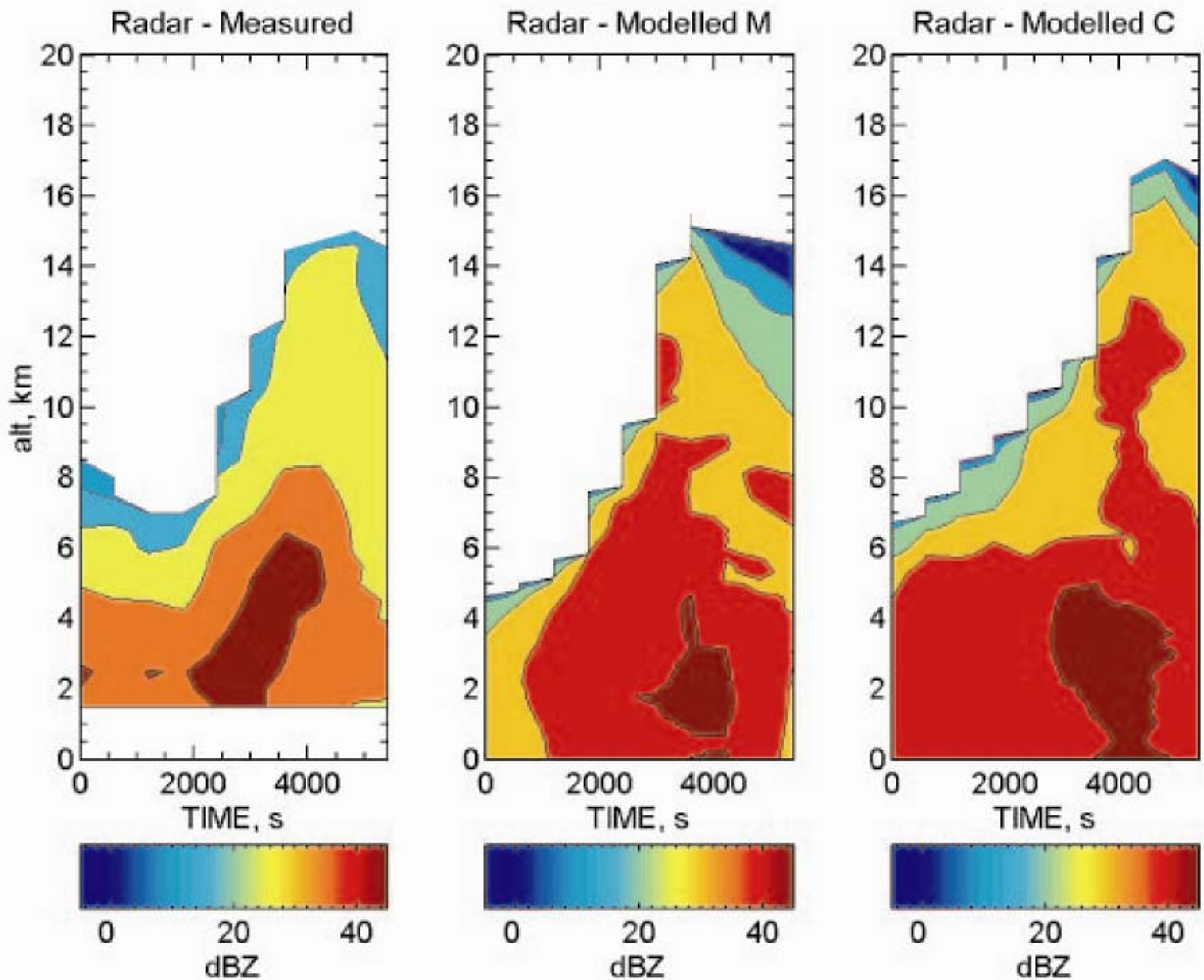
No strong indirect effect when Dry layers are present



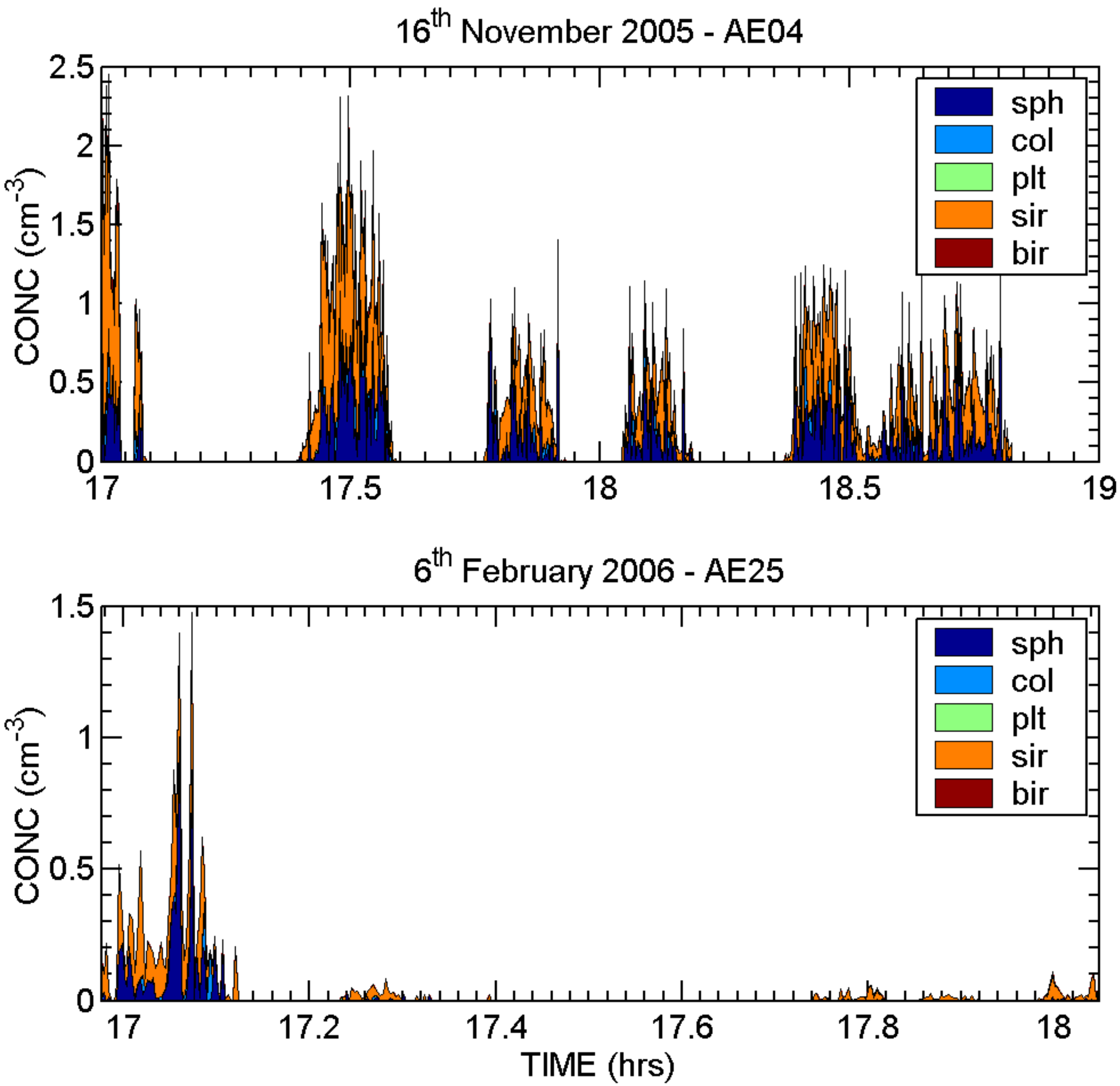
16 Nov (polluted)



6 Feb (clean)

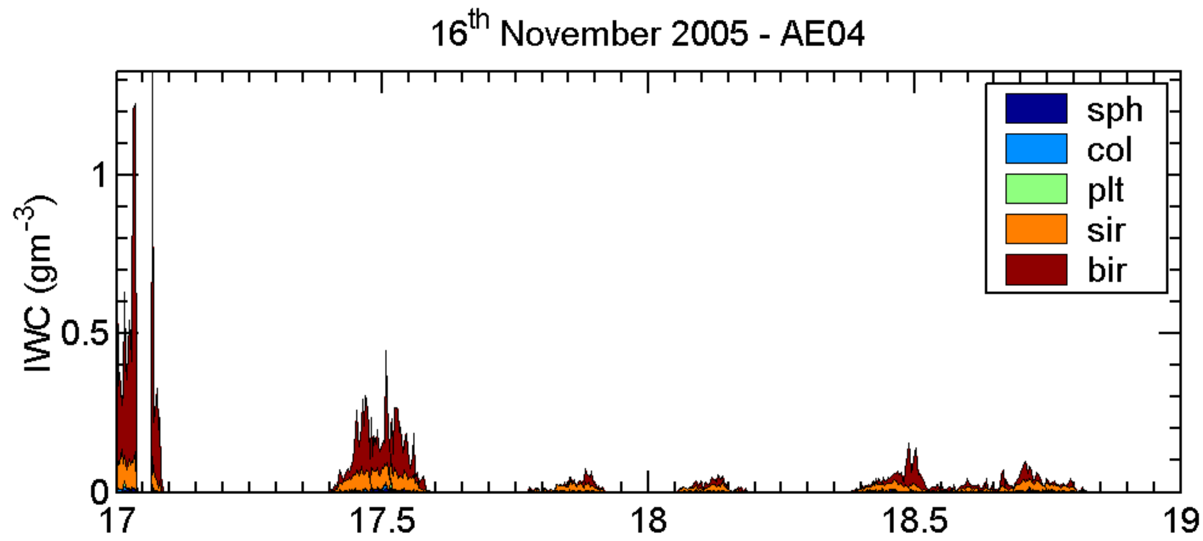


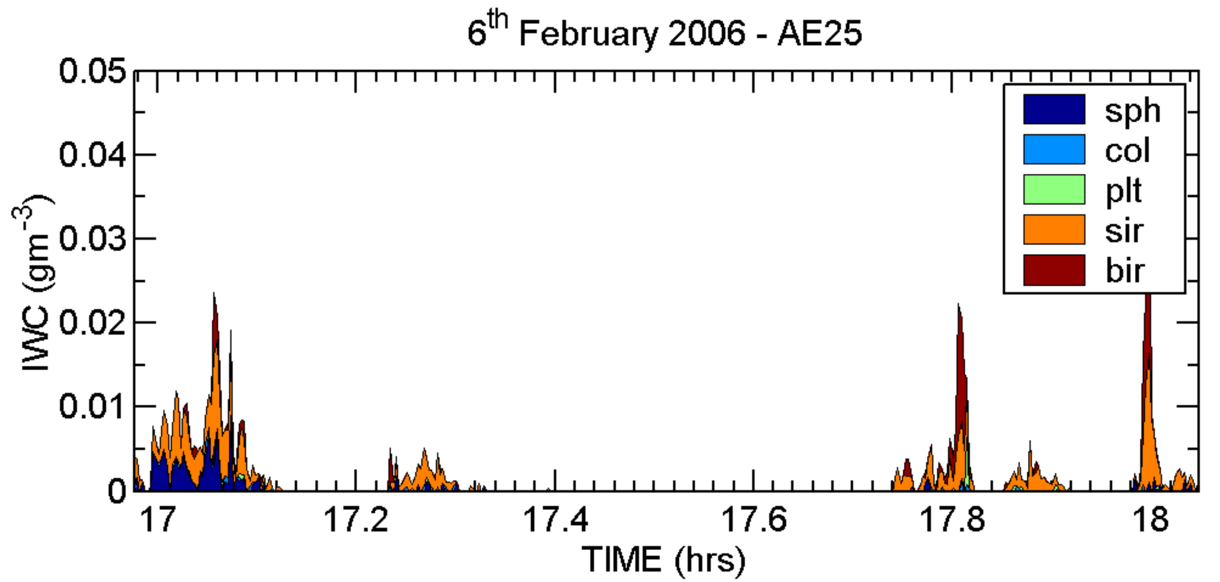
Radar - Measured
Radar - Modelled M
Radar - Modelled C
alt, km
20
18
16
14
12
10
8
6
4
2
0
0
2000
4000
TIME, s
0
20
40
dBZ


16th November 2005 - AE04
CONC (cm-3)
2.5
2
1.5
1
0.5
0
17
17.5
18
18.5
19
sph
col
plt
sir
bir
6th February 2006 - AE25
CONC (cm-3)
1.5
1
0.5
0
17
17.2
17.4
17.6
17.8
18
TIME (hrs)
sph
col
plt
sir
bir

MANCHESTER
1824

The University of Manchester





Conclusion

- Two case studies are consistent with high aerosol concentrations pre-monsoon and low post monsoon.
- The thermodynamic indirect effect is strongly dependent on the dryness of the sounding below the melting level.
- For deep convective clouds, the presence of rain above the freezing level is vital to the indirect effects.
- It is vital to accurately predict the droplet number concentration in order to ascertain these effects.

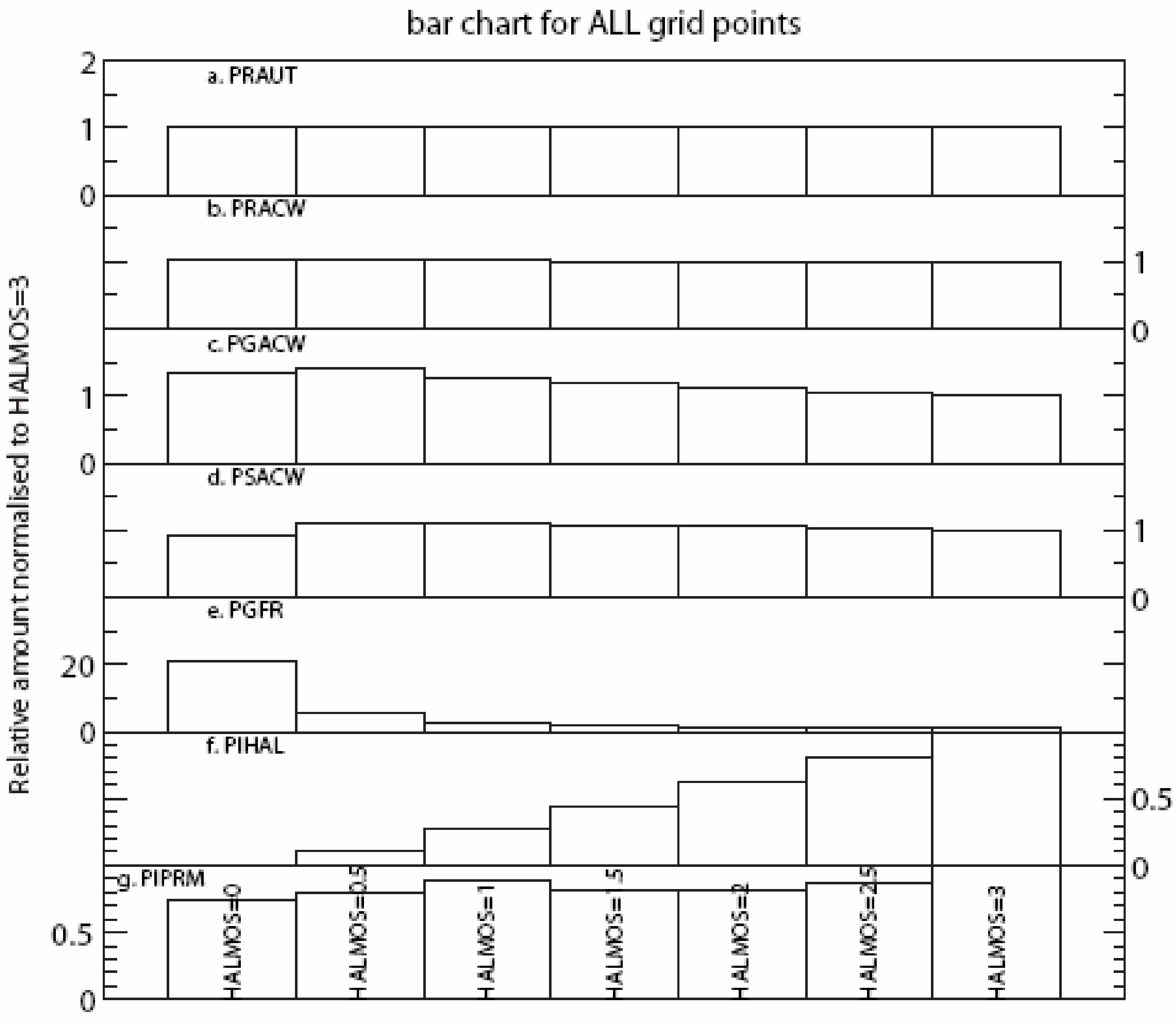


Figure 11. Source terms for CRM Hallett-Mossop sensitivity. (a) shows the autoconversion of cloud water to rain, (b) accretion of cloud water by rain, (c) accretion of cloud water by graupel, (d) accretion of cloud water by snow, (e) probabilistic freezing of rain, (f) the Hallett-Mossop process, (g) the production of primary ice crystals. All rates are scaled to the last run ($HALMOS = 3.0$)

MANCHESTER
1824

Egrett payload

Basic Meteorology and position	Pressure, temperature, wind (1 Hz), GPS
DMT Single Particle Soot Photometer (SP-2) †	Aerosol particle size distribution (0.2 – 1.0 μm), light absorbing fraction (LAP), carbon mass, metal
2 x TSI-3010 Condensation Particle Counter (CPC)	Total condensation particles > 40 nm & > 80 nm
DMT Cloud, Aerosol & Precipitation Spectrometer (CAPS)	Cloud Droplet *psd*, aerosol/small particle assymetry, aerosol refractive index,large ice *psd*, ($0.3<D_p<3{,}200$ μm), Total Liquid Water Content
DMT Cloud Droplet Probe (CDP)	Particle Size Distribution ($2< D_p<60$ μm)
SPEC Cloud Particle Imager CPI-230	Cloud particle/ice CCD images, ($30 < D_p< 2{,}300$ μm)
Buck Research CR-2 frost point hygrometer	Temperature, dew/ice point, 20 s, ± 0.1°
2X Tunable diode laser Hygrometer (SpectraSensors)	Water vapour, 2 Hz, ± 0.005 ppmv precision
Julich CO analyser	High precision (± 2 ppb), fast response (10 Hz) CO
Cambridge Miniature Gas-Chromatograph	Halocarbons (Cl, Br, I), 3-6 min, ± 5%
TE-49C UV Ozone sensor	Ozone concentration (± 1 ppbv, 10 seconds)
Adsorbent tube carbon trap	C4-C9 aliphatics, acetone, monoterpenes
NO and NO_2 chemiluminescent detector †	± 200 ppt @ 10 Hz; ± 30 ppt @ 4 s integration

† alternates

Aerosol (white) **Chemistry** (orange) **Met/Position** (purple)

Humidity (cyan) **Cloud Physics** (green)

MANCHESTER 1824

The University of Manchester

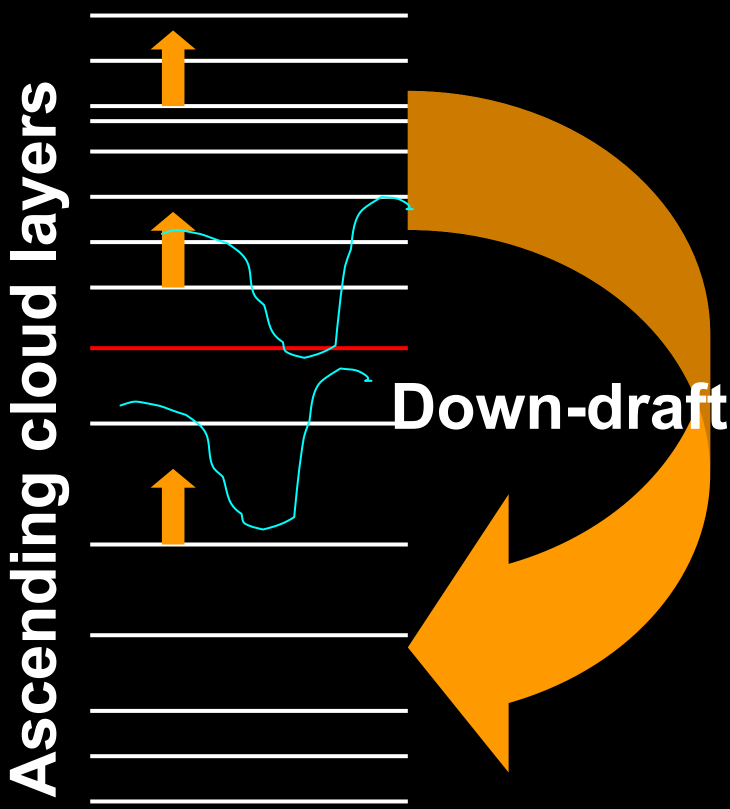
Dornier payload

Basic meteorology	Aventech probe	ARSF/Manchester
Position/Timing	GPS	ARSF
Aerosol Mass Spectrometer	Aerosol compositionn, 30 – 2000 nm	Manchester
Condensation particle counter	Aerosol concentration > 10 nm	Manchester
Grimm Optical Particle Counter	Aerosol size distribution, 0.5 – 20 μm	Manchester
Ultra high sensitivity aerosol spectrometer	Aerosol size distribution 50 nm – 0.8 μm	Manchester
Aerosol spectrometer probe	Aerosol size dist^n, 0.1 – 1 μm	Manchester
FSSP	Aerosol, size (2- 47 μm)	Manchester
Filters	Coarse aerosol composition	Manchester
Ozone	UV absorption, 2B	York
CO	AL5003	York
VOC	Adsorbent tubes	York
NO/NO_x	Chemiluminescence/catalysis	York
Halocarbons	DIRAC gas chromatograph	Cambridge
Black Carbon	PSAP	DLR

Aerosol (white) Chemistry (orange) Met/Position (purple)

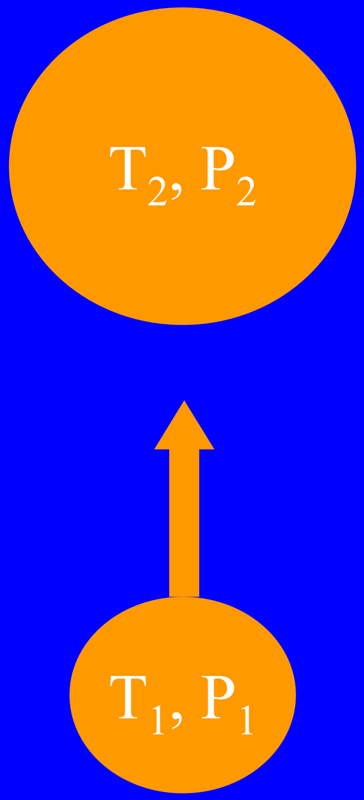
Modelling mixed phase clouds

EMM



Lagrangian tracking of precipitation

Parcel model – detailed sectional microphysics



CRM –

- Bulk 2-moment microphysics.
- Explicit ice density.
- Broad-band radiation module.
- Eulerian grid.