Heterogeneous freezing on desert dust

Paul Connolly

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Work on aerosol-cloud interactions

- AIDA – heterogeneous freezing of desert dust samples (O. Moehler) – ACPIM.
- ICEPIC – ice initiation in cumulus clouds in the UK (Alan Blyth – Leeds University) – ACPIM.
- APPRAISE work – aerosol cloud interactions in frontal systems and altocumulus in the UK (Tom Choularton – University of Manchester)
- ACTIVE – Anvil properties in deep convection in differing aerosol regimes (G. Vaughan – University of Manchester)

Motivation

GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 12, 1633, doi:10.1029/2003GL017371, 2003

Saharan dust storms and indirect aerosol effects on clouds: CRYSTAL-FACE results

Kenneth Sassen,[1] Paul J. DeMott,[2] Joseph M. Prospero,[3] and Michael R. Poellot[4]

[1] A recent field experiment in southern Florida using aircraft and polarization lidar shows that mineral dust particles transported from Saharan Africa are effective ice nuclei, apparently capable of glaciating a mildly supercooled (−5.2° to −8.8°C) altocumulus cloud. These results are similar to those from Asian dust storm particles observed over the western US, suggesting that in the northern hemisphere major dust storms play a role in modulating climate through the indirect aerosol effect on cloud properties. If this is true of desert dusts in general, then even minor aeolian emissions could have an effect on regional weather and climate. *INDEX TERMS:* 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 0345 Atmospheric Composition and Structure: Pollution—urban and regional (0305); 3360 Meteorology and Atmospheric Dynamics: Remote sensing. **Citation:** Sassen, K., P. J. DeMott, J. M. Prospero, and M. R. Poellot, Saharan dust storms and indirect aerosol effects on clouds: CRYSTAL-FACE results, *Geophys. Res. Lett.*, *30*(12), 1633, doi:10.1029/2003GL017371, 2003.

Part 1 – AIDA studies

$$\frac{dN_i}{dt} = N_d A J$$

Nucleation rate formulation

$$J(t) = \frac{dN_i}{dt} \Big/ N_d A$$

Defined from data from the chamber. But J(T) cannot be defined as it depends on pumping rate.

$$n_s(T_{\min}) = \int_{t_1}^{t_2} J(t)dt$$

The important parameter for a singular process is the number of germs per unit area of sample (units $\#m^{-2}$).

$$J = \frac{dn_s(T)}{dT}\frac{dT}{dt}$$

We can use this to define J in our equation.

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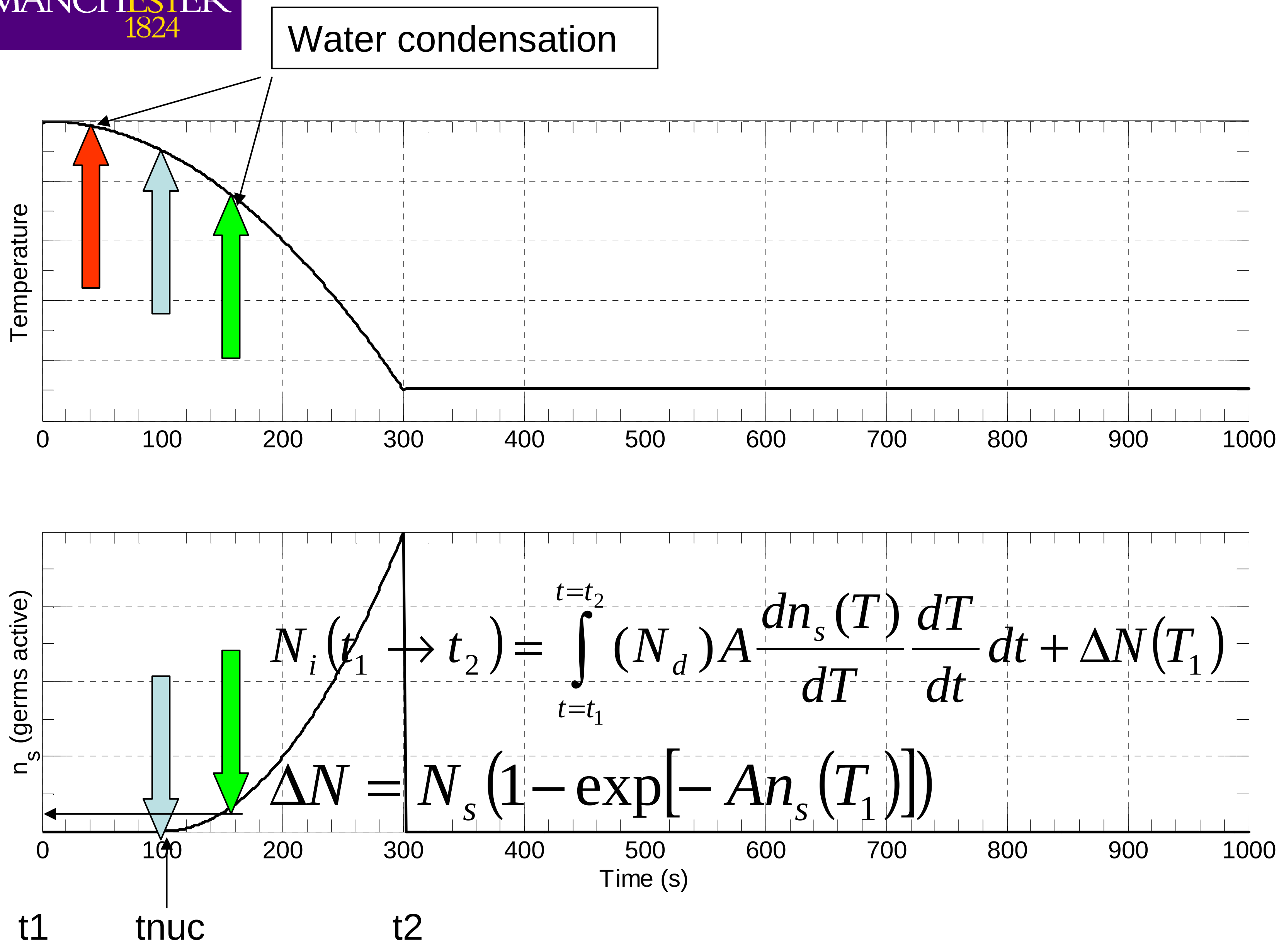

$$N_i(t_1 \to t_2) = \int_{t=t_1}^{t=t_2} (N_d) A \frac{dn_s(T)}{dT}\frac{dT}{dt}\,dt + \Delta N(T_1)$$

$$\Delta N = N_s\left(1-\exp\left[-An_s(T_1)\right]\right)$$

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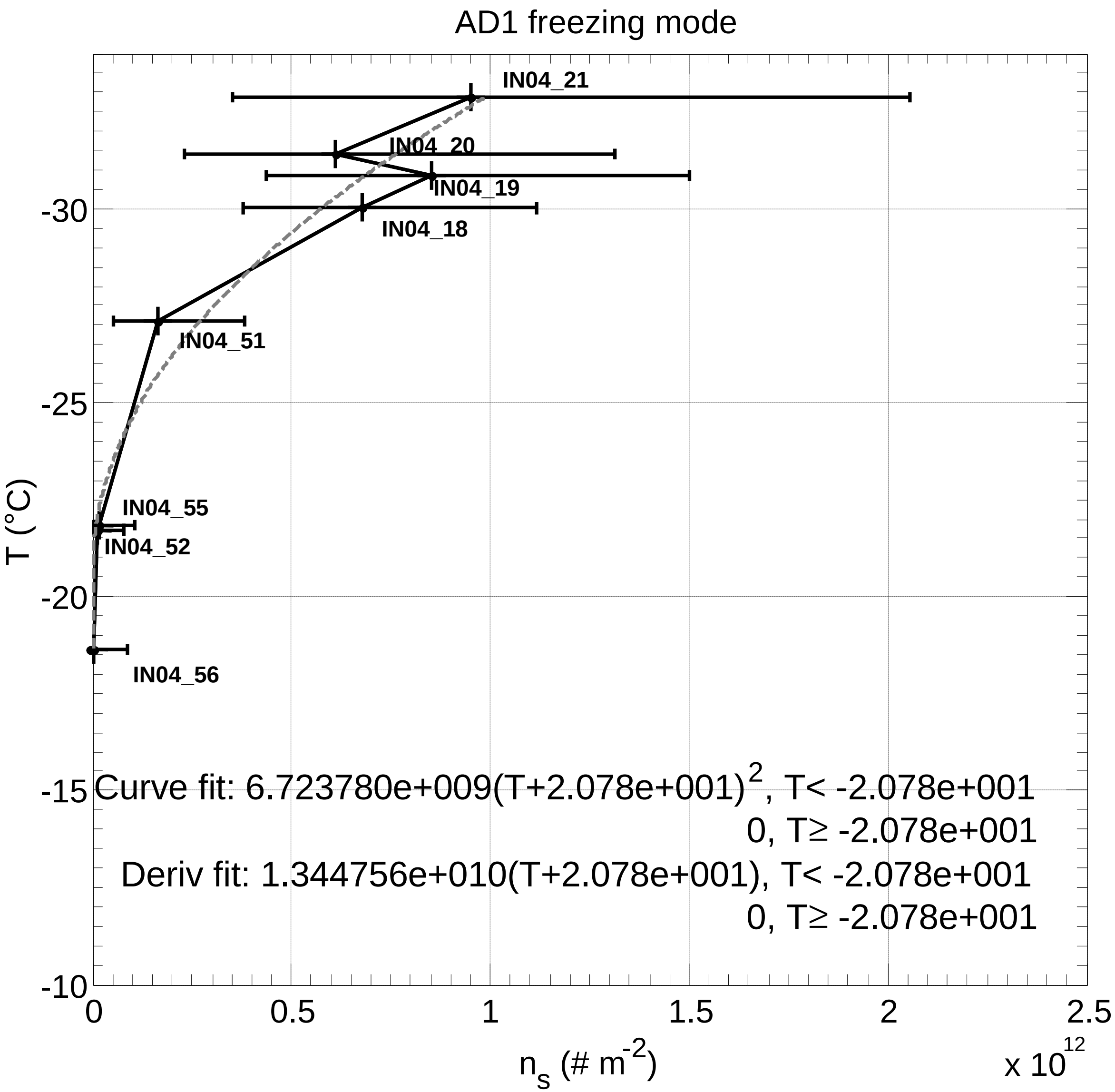
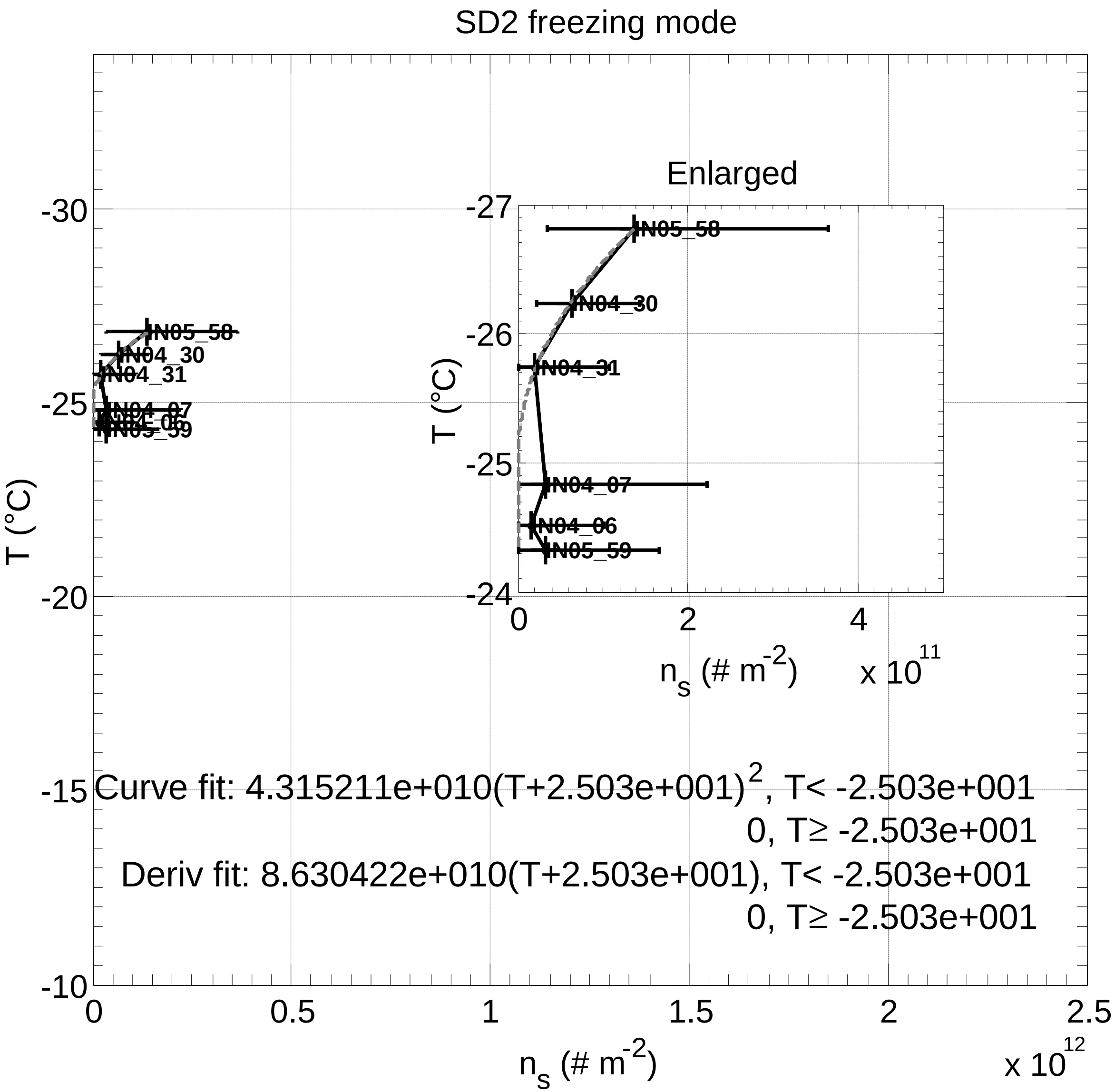
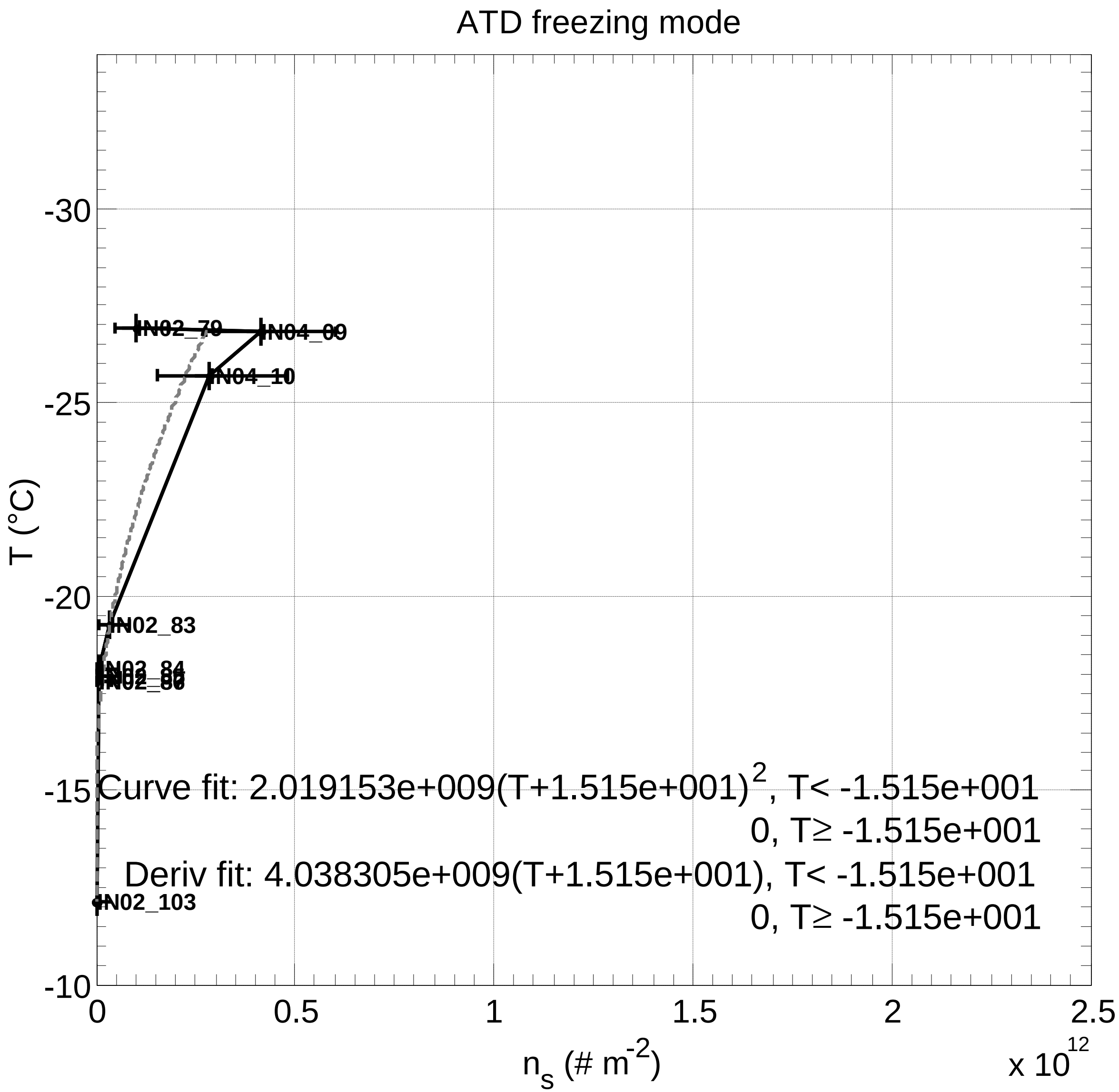
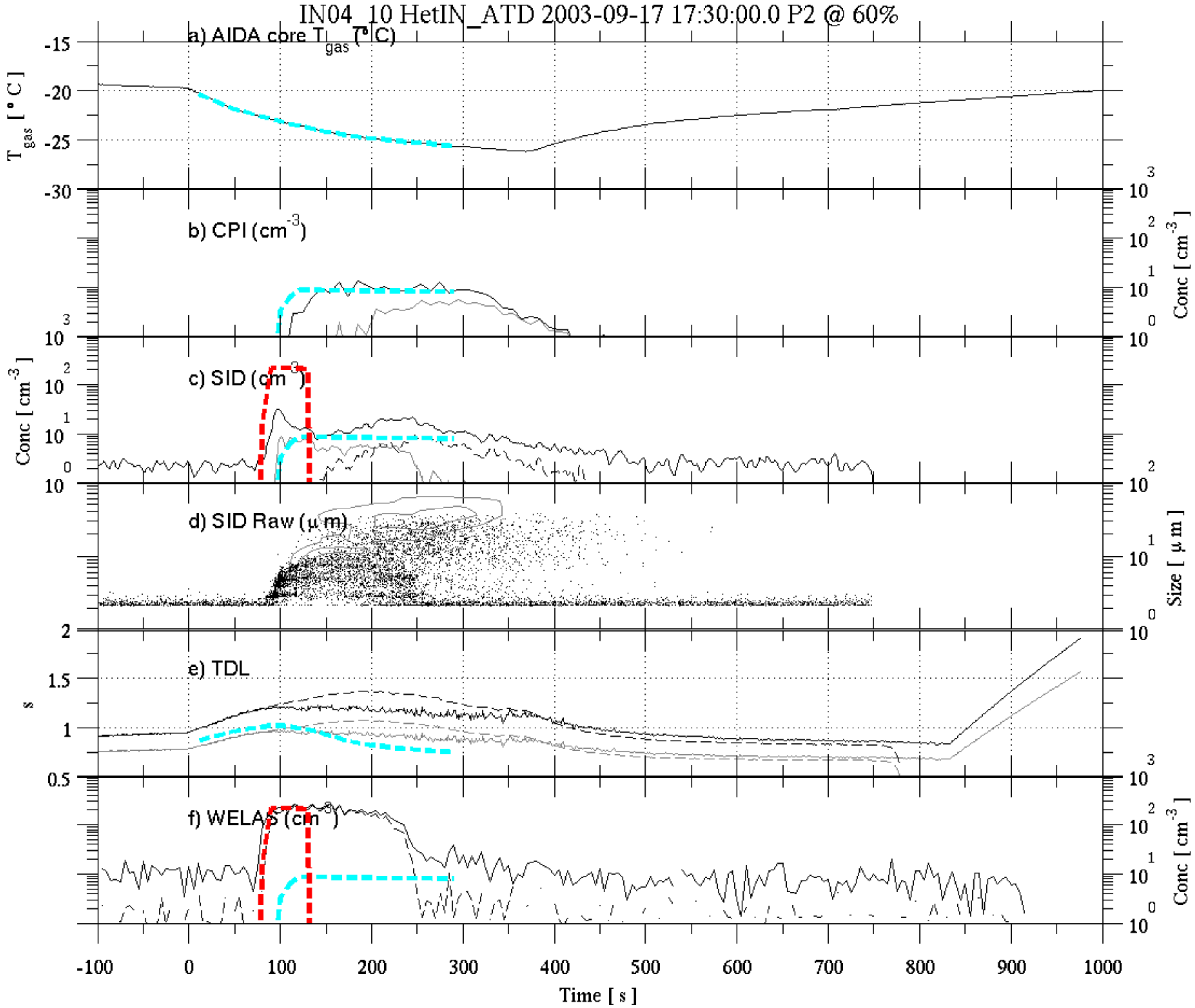



SD2 freezing mode
Enlarged
IN05_58
IN04_30
IN04_31
IN04_07
IN04_06
IN05_59
T (°C)
n_s (# m^-2) x 10^11
n_s (# m^-2) x 10^12
Curve fit: 4.315211e+010(T+2.503e+001)^2, T< -2.503e+001
0, T≥ -2.503e+001
Deriv fit: 8.630422e+010(T+2.503e+001), T< -2.503e+001
0, T≥ -2.503e+001


ATD freezing mode
T (°C)
-30
-25
-20
-15
-10
0
0.5
1
1.5
2
2.5
n_s (# m^{-2})
x 10^{12}
N02_79
N04_09
N04_10
N02_83
N02_84
N02_103
Curve fit: 2.019153e+009(T+1.515e+001)^2, T< -1.515e+001
0, T≥ -1.515e+001
Deriv fit: 4.038305e+009(T+1.515e+001), T< -1.515e+001
0, T≥ -1.515e+001


IN04_10 HetIN_ATD 2003-09-17 17:30:00.0 P2 @ 60%
a) AIDA core T_gas (°C)
b) CPI (cm^-3)
c) SID (cm^-3)
d) SID Raw (μ m)
e) TDL
f) WELAS (cm^-3)
T_gas [°C]
Conc [cm^-3]
Size [μ m]
s
Time [s]

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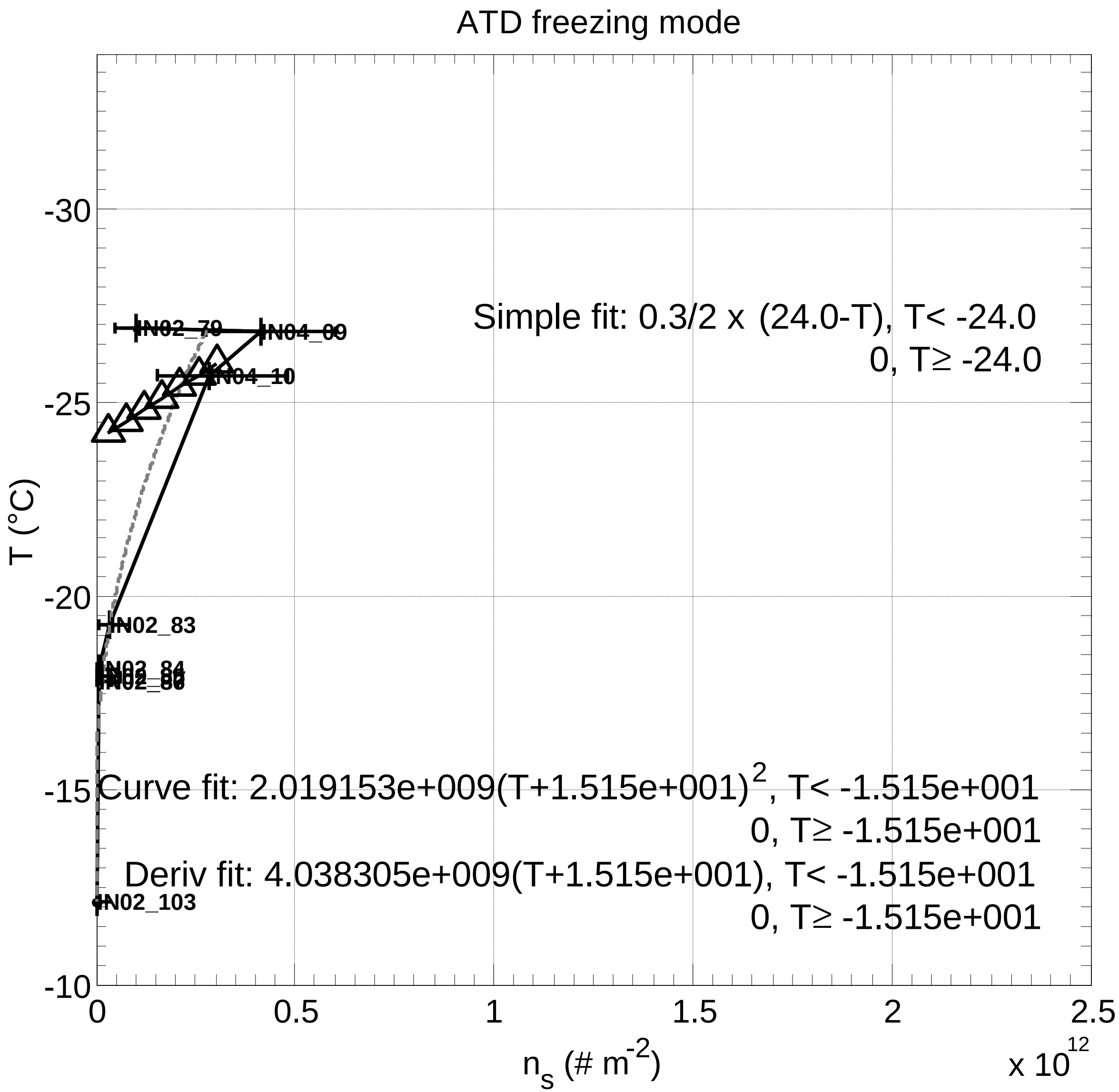

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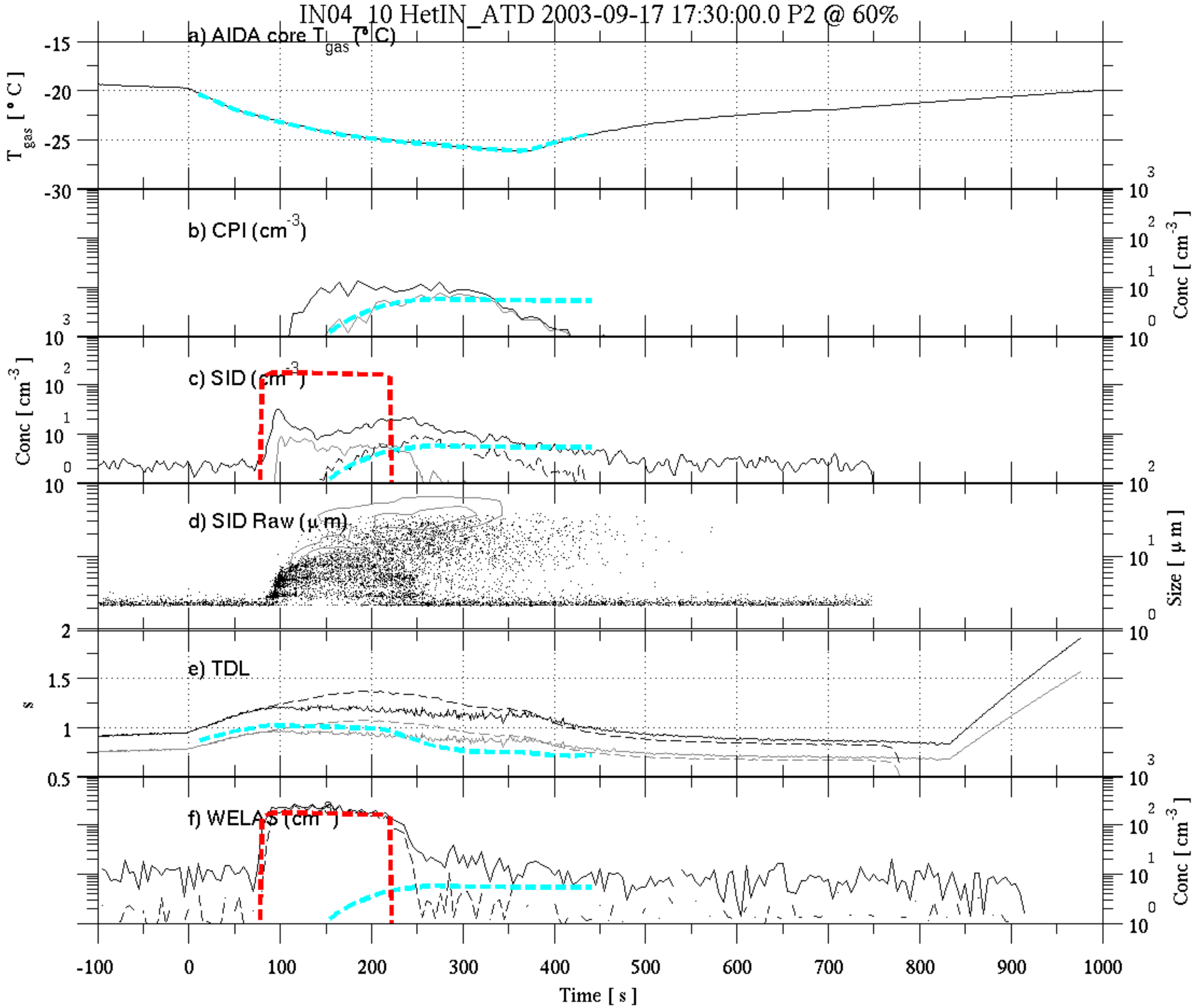

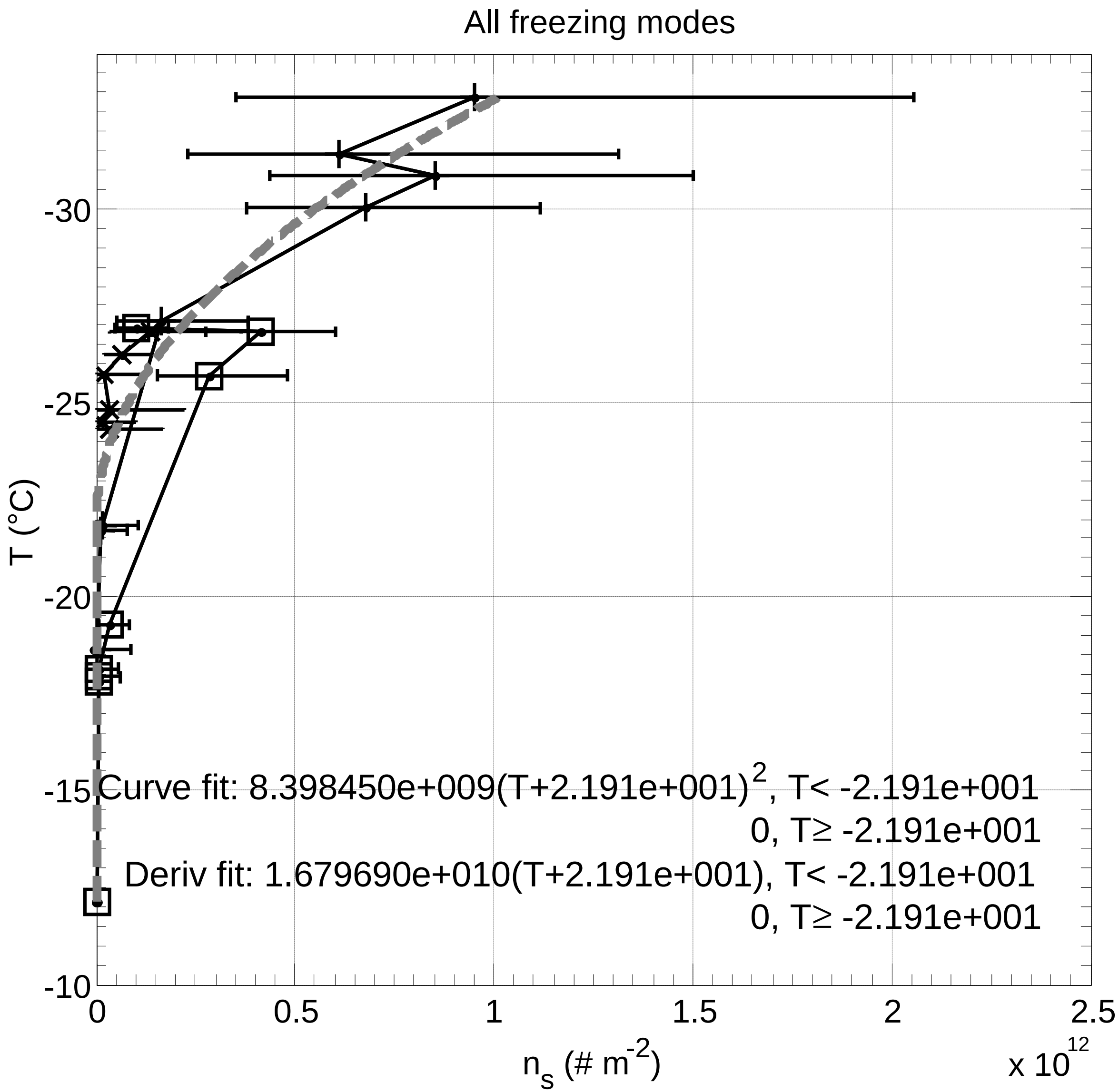

All freezing modes
Curve fit: 8.398450e+009(T+2.191e+001)^2, T< -2.191e+001
0, T≥ -2.191e+001
Deriv fit: 1.679690e+010(T+2.191e+001), T< -2.191e+001
0, T≥ -2.191e+001
T (°C)
-30
-25
-20
-15
-10
0
0.5
1
1.5
2
2.5
n_s (# m^-2)
x 10^12

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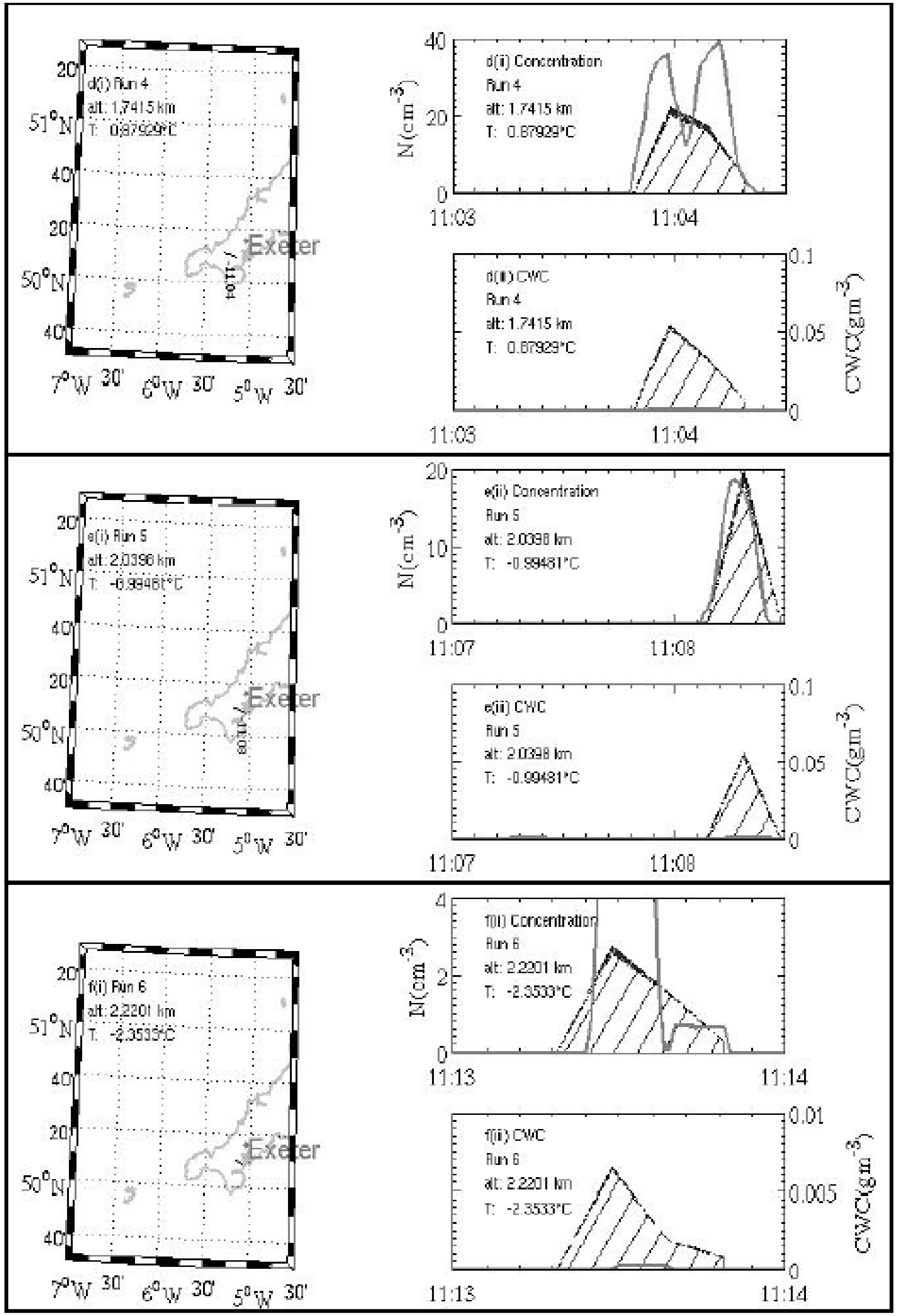
Part 2 – ICEPIC studies

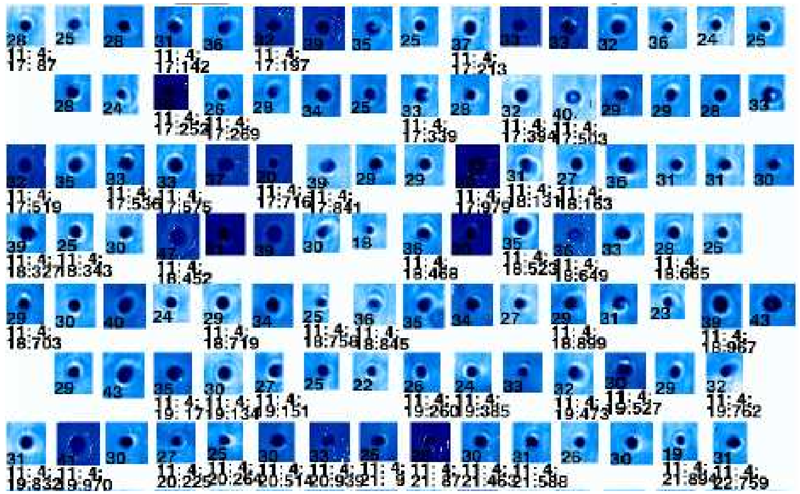
- ICEPIC fly through the tops of cumuli over the UK as they develop.
- In cumulus clouds one argument is that large raindrops freeze at -15 to -20C and these fall into the region between -2.5 and -7.5 C.
- These frozen raindrops then rime and splinters are produced.
- Lets look at an example…

+1 C

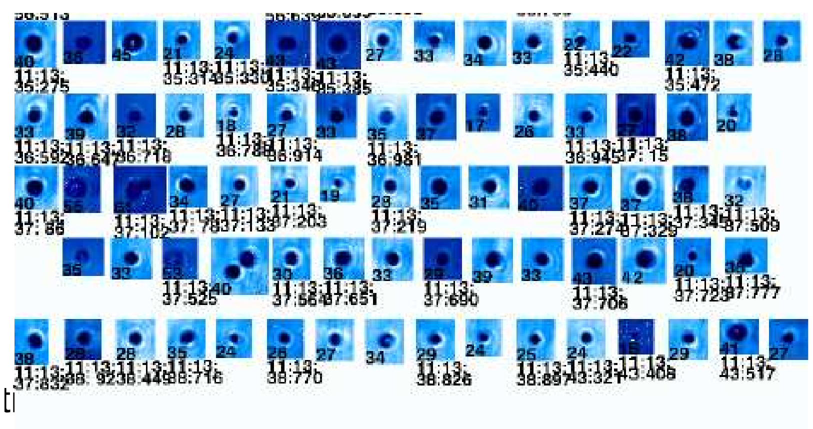
-1 C

-2.3 C





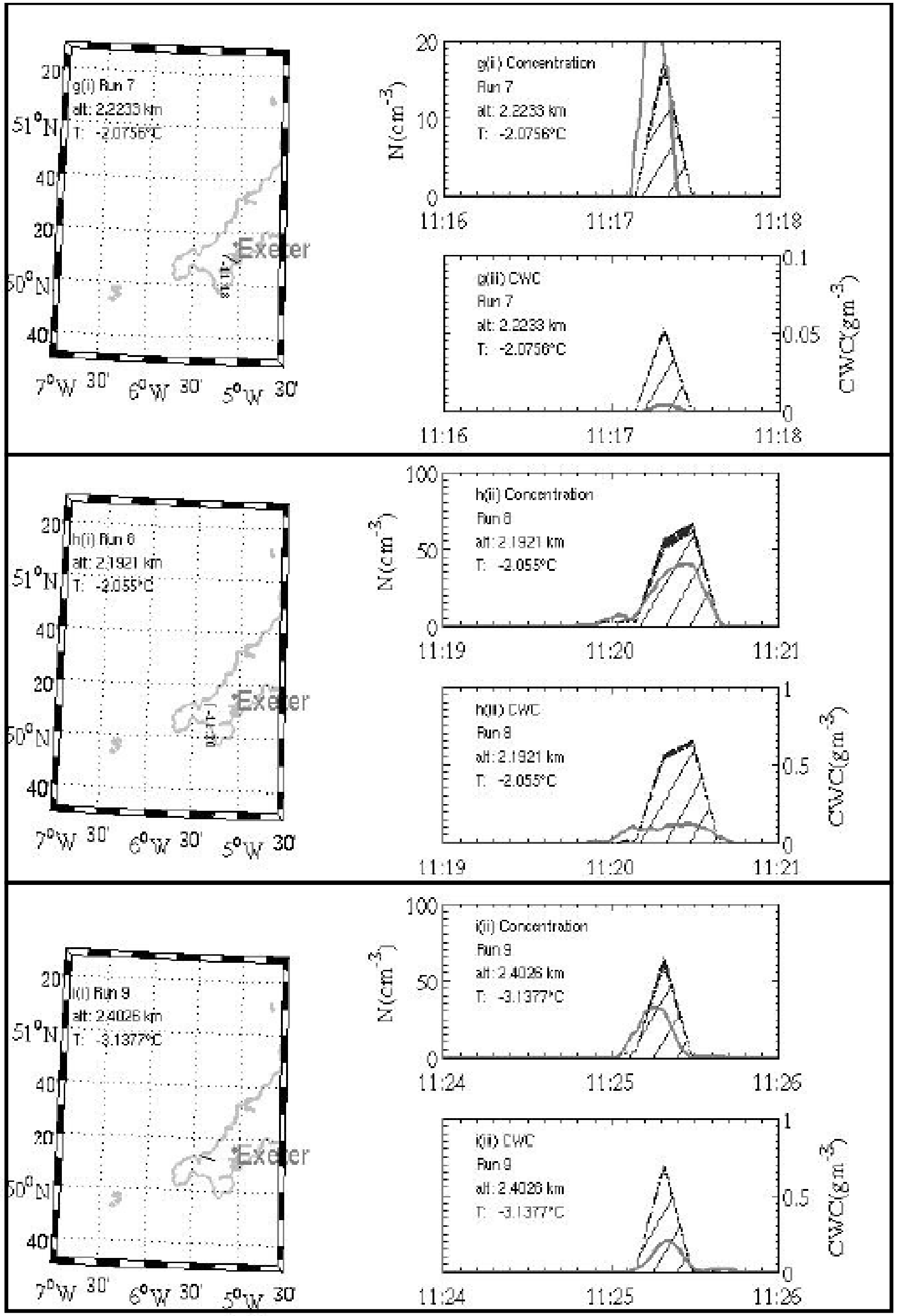
All drops



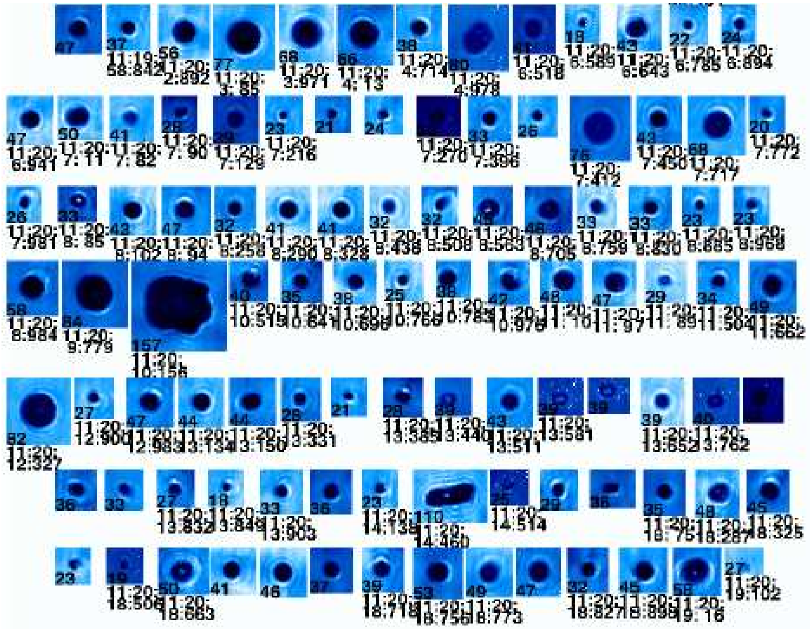
-2 C

-2.2 C

-3.1 C



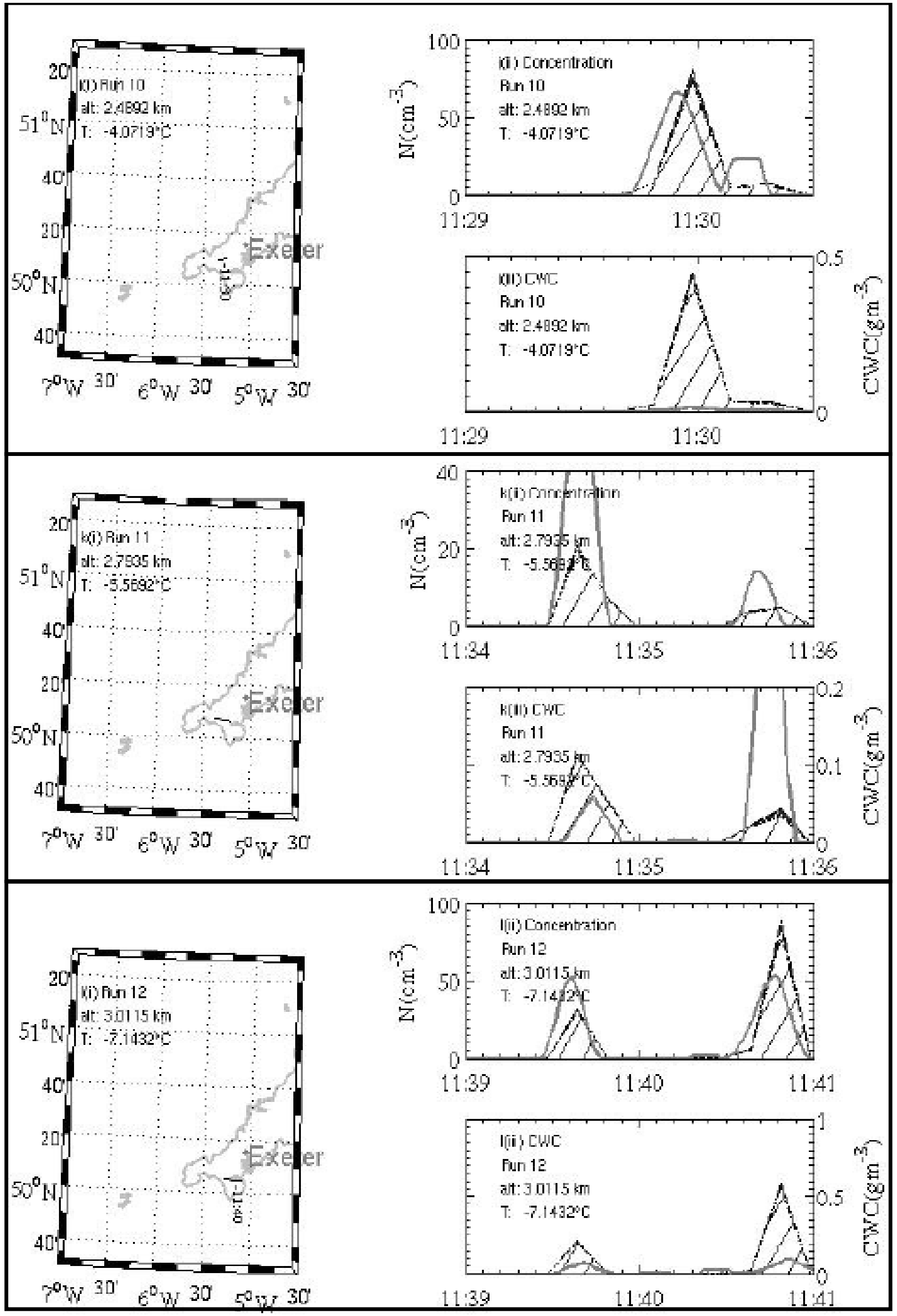
Mostly drops, but a few ice crystals picked out.

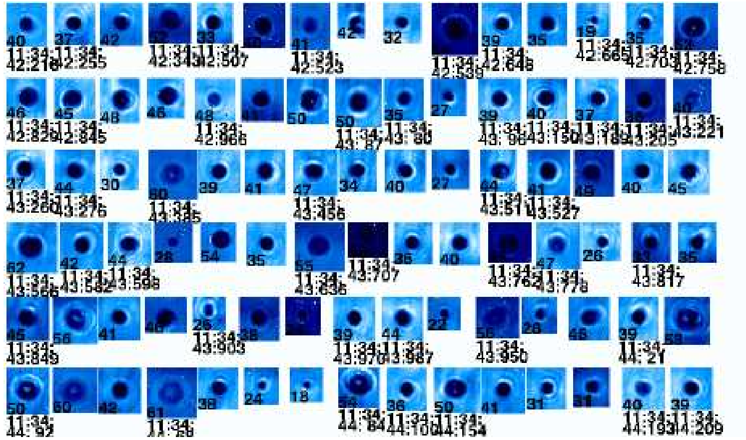


-4 C

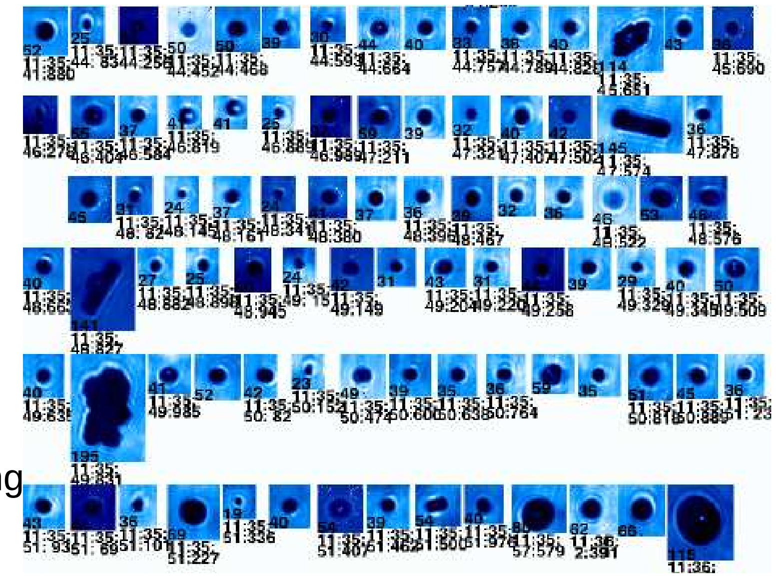
-5.5 C

-7 C





Small amount of ice at -7C



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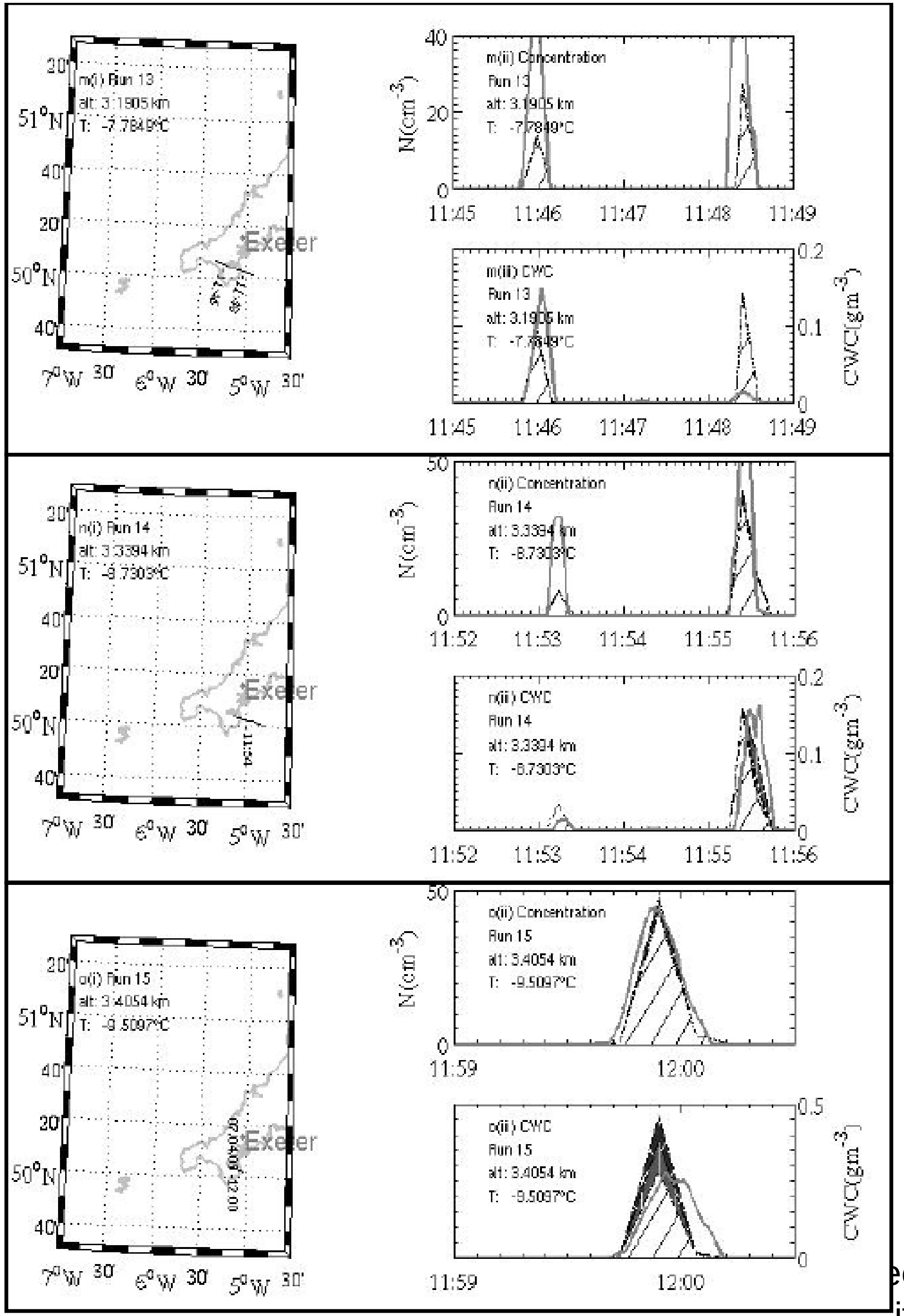
-7.8 C

-8.7 C

-9.5 C



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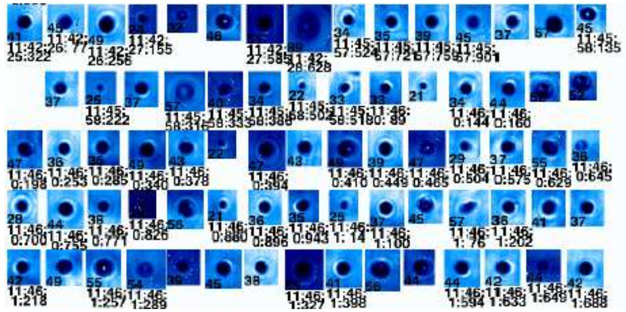
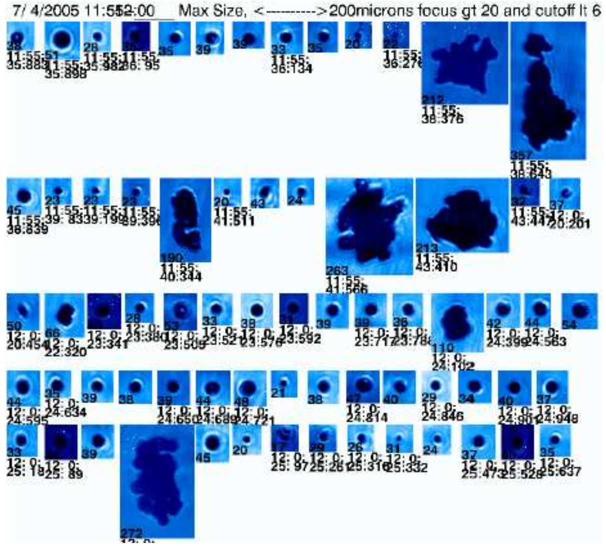
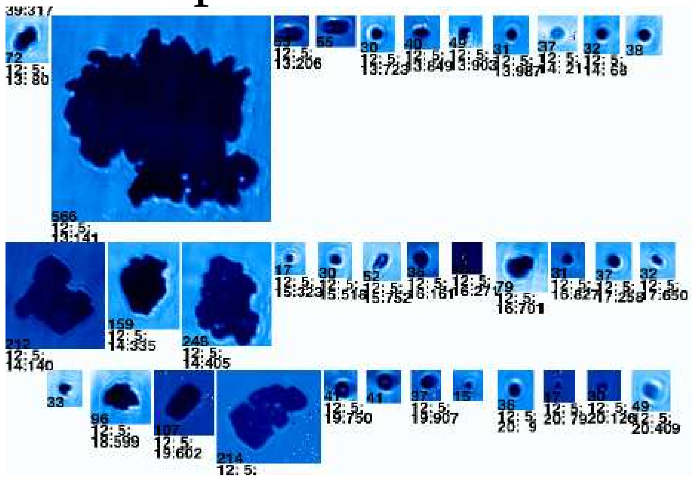




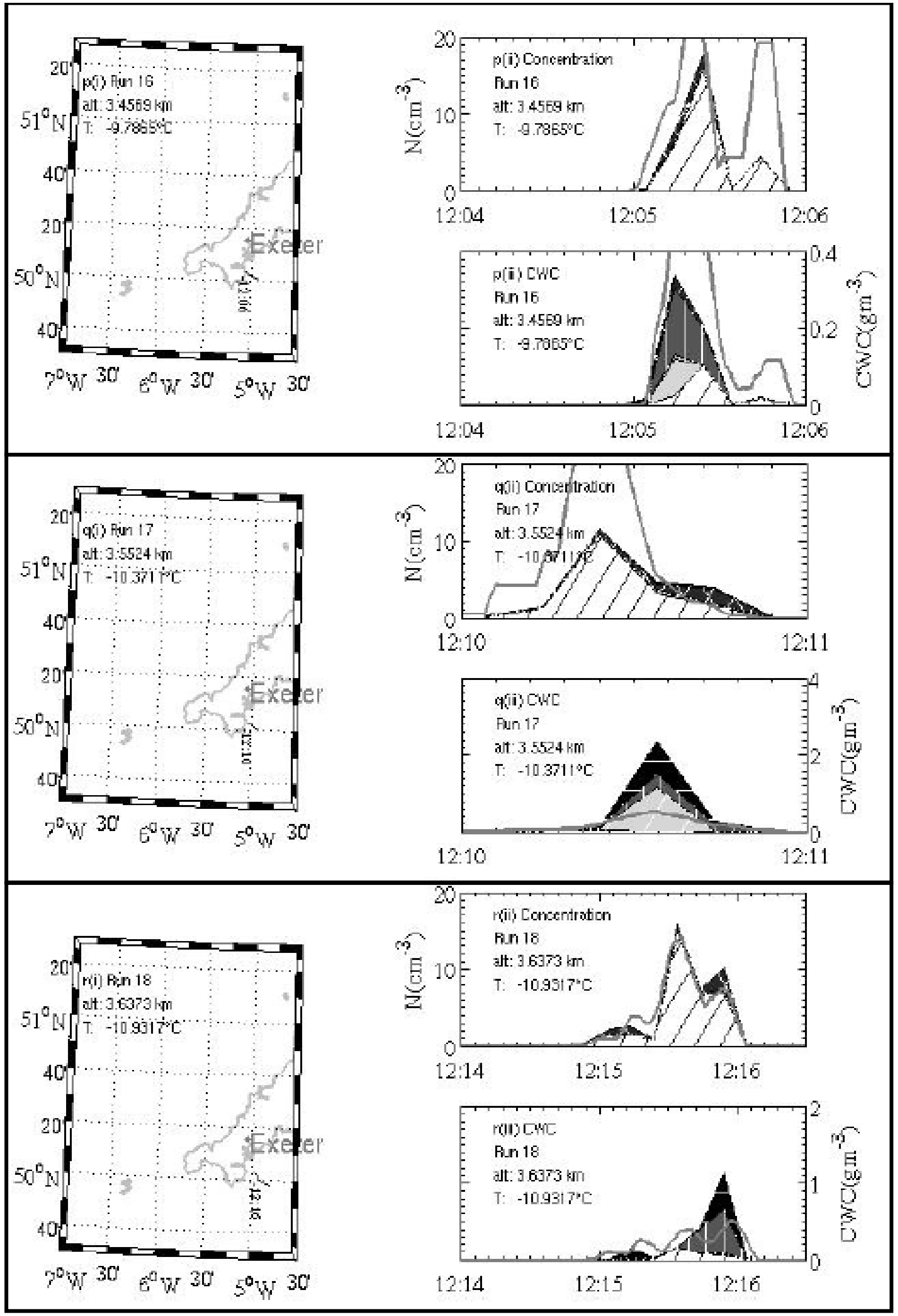
Mixed phase cloud at -9C

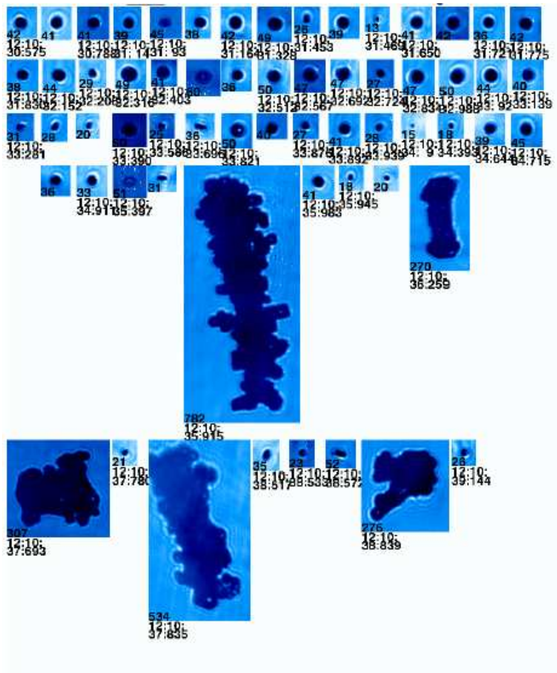


-9.7 C

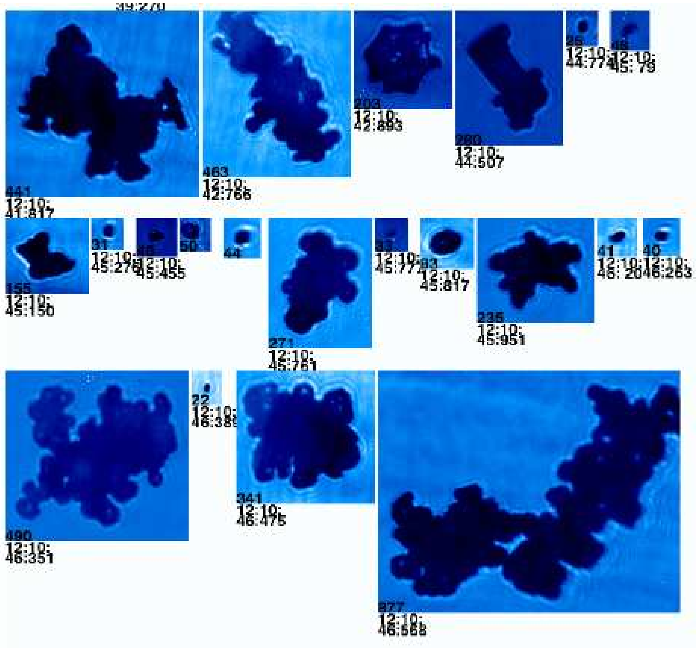
10.3 C

11 C





Glaciating cloud at -10 C



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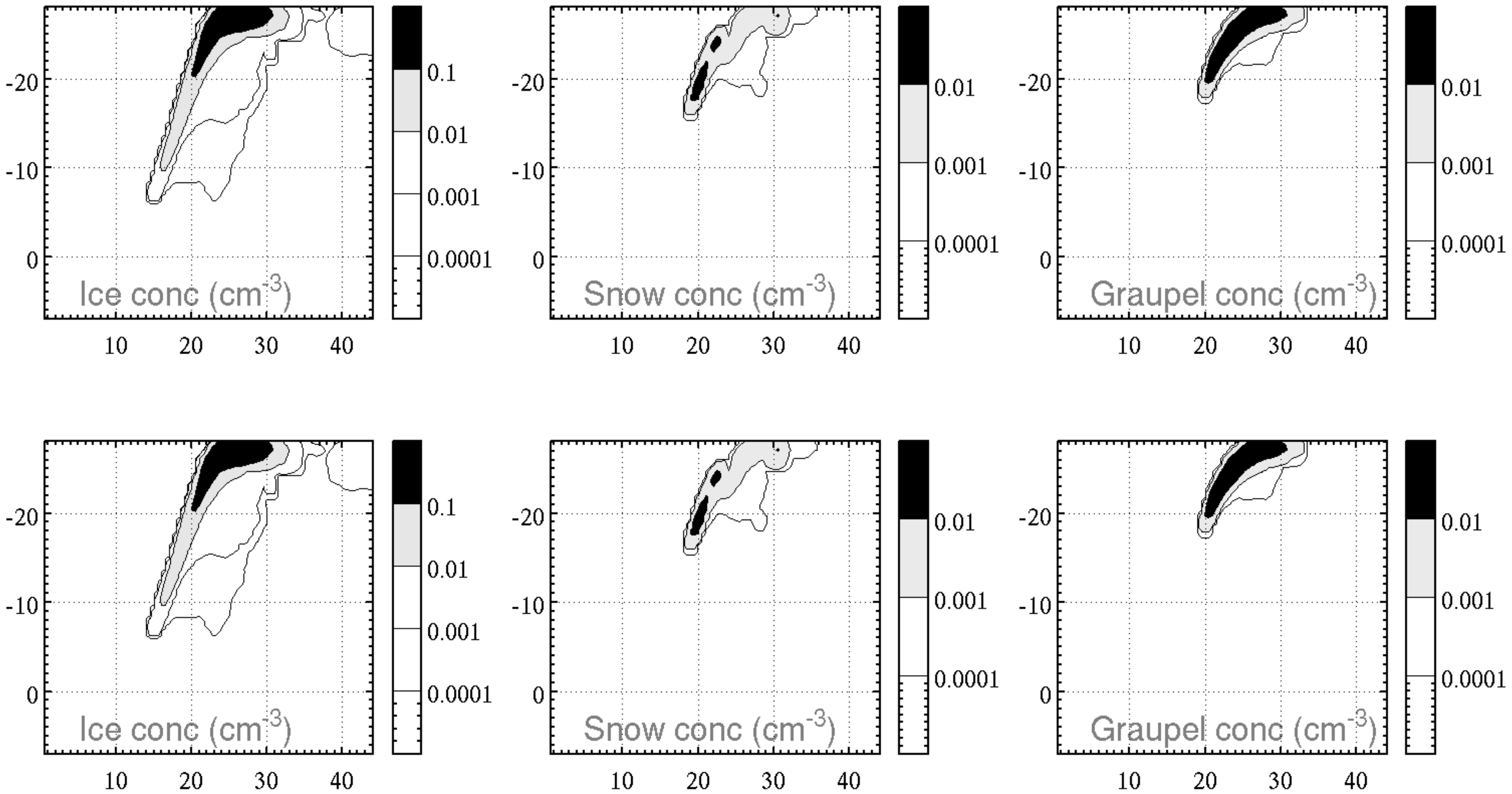
Explicit Microphysics Modelling



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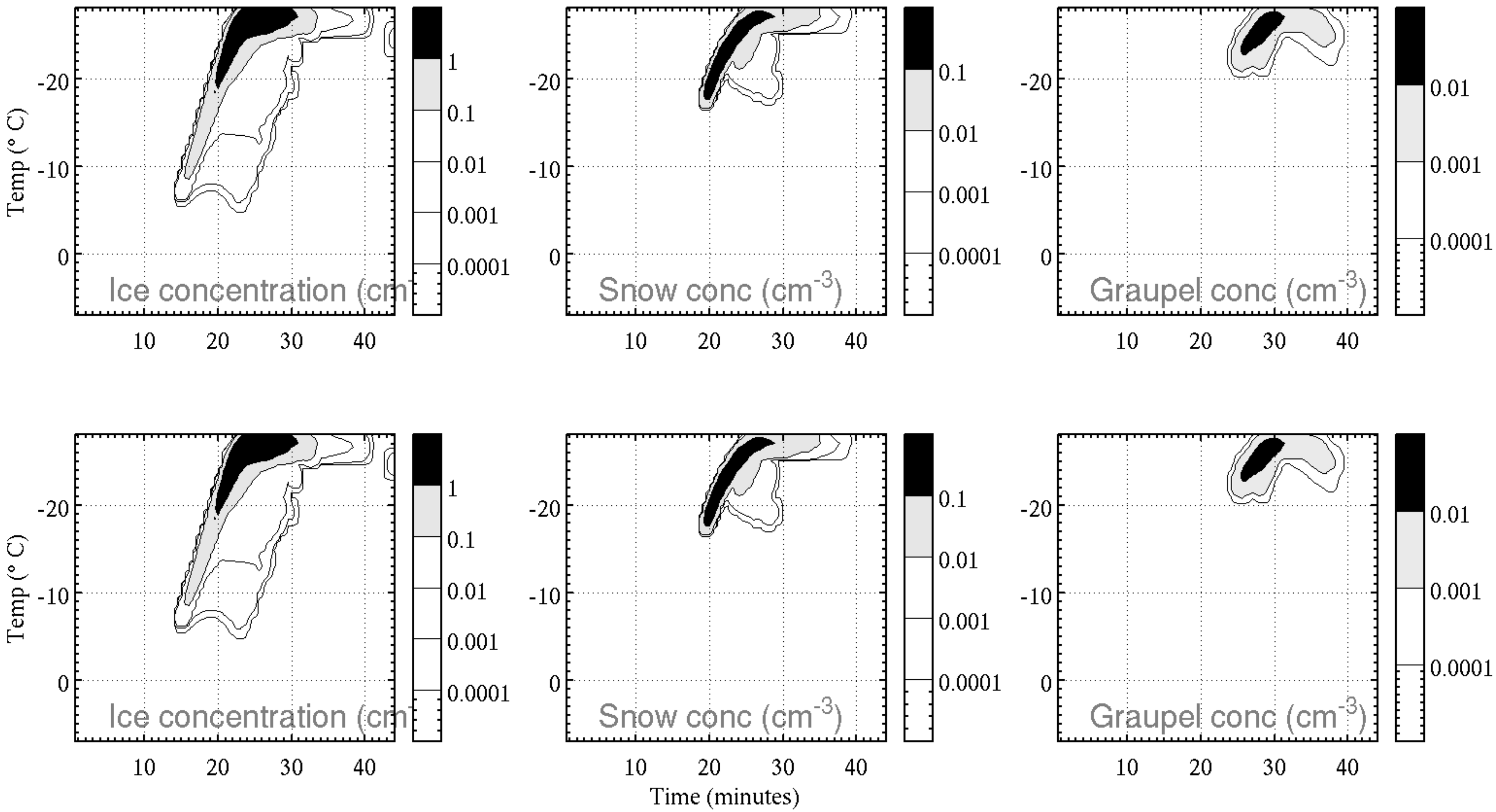
15 x Meyers scheme



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Summary

- We were able to parameterise the nucleation behaviour in the freezing mode by assuming the singular hypothesis
- The ATD exhibited strong deposition behaviour as well at temperatures colder than -24C.
- The results cannot explain numerous observations of ice at warmer temperatures – like the study of Sassen et al (or ICEPIC).
- In ICEPIC case study graupel apparently does not have time to fall into the H-M region.

- Are the ice nucleation properties different is contact nucleation important? How can we study this?

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Other examples