Using Field Measurements and Numerical Simulations to Constrain Mechanisms of Ice Formation During the M-PACE IOP

Ann Fridlind and Andy Ackerman, NASA GISS

DOE ARM Science Team Meeting

Albuquerque, New Mexico, 29 March 2006

Observations

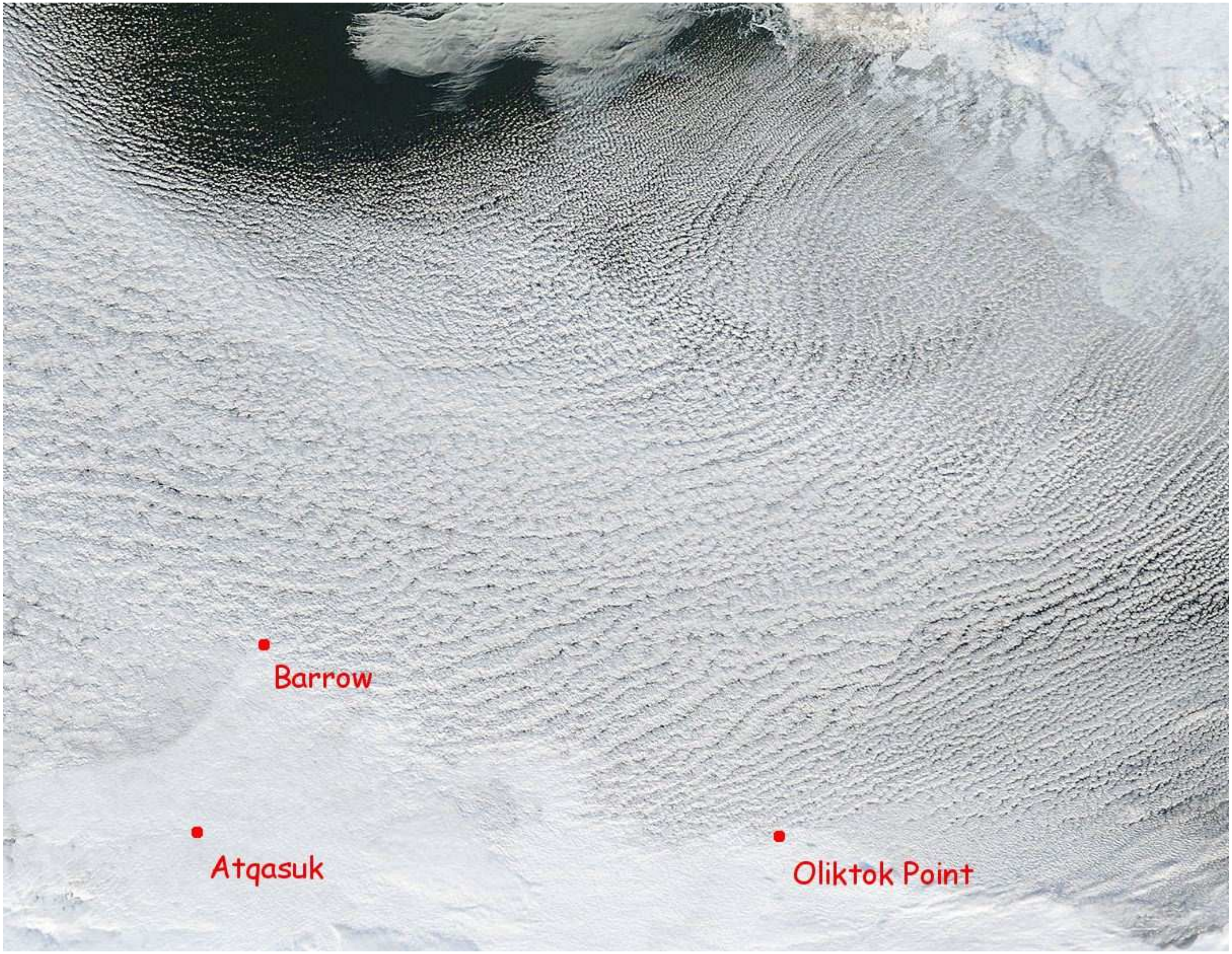
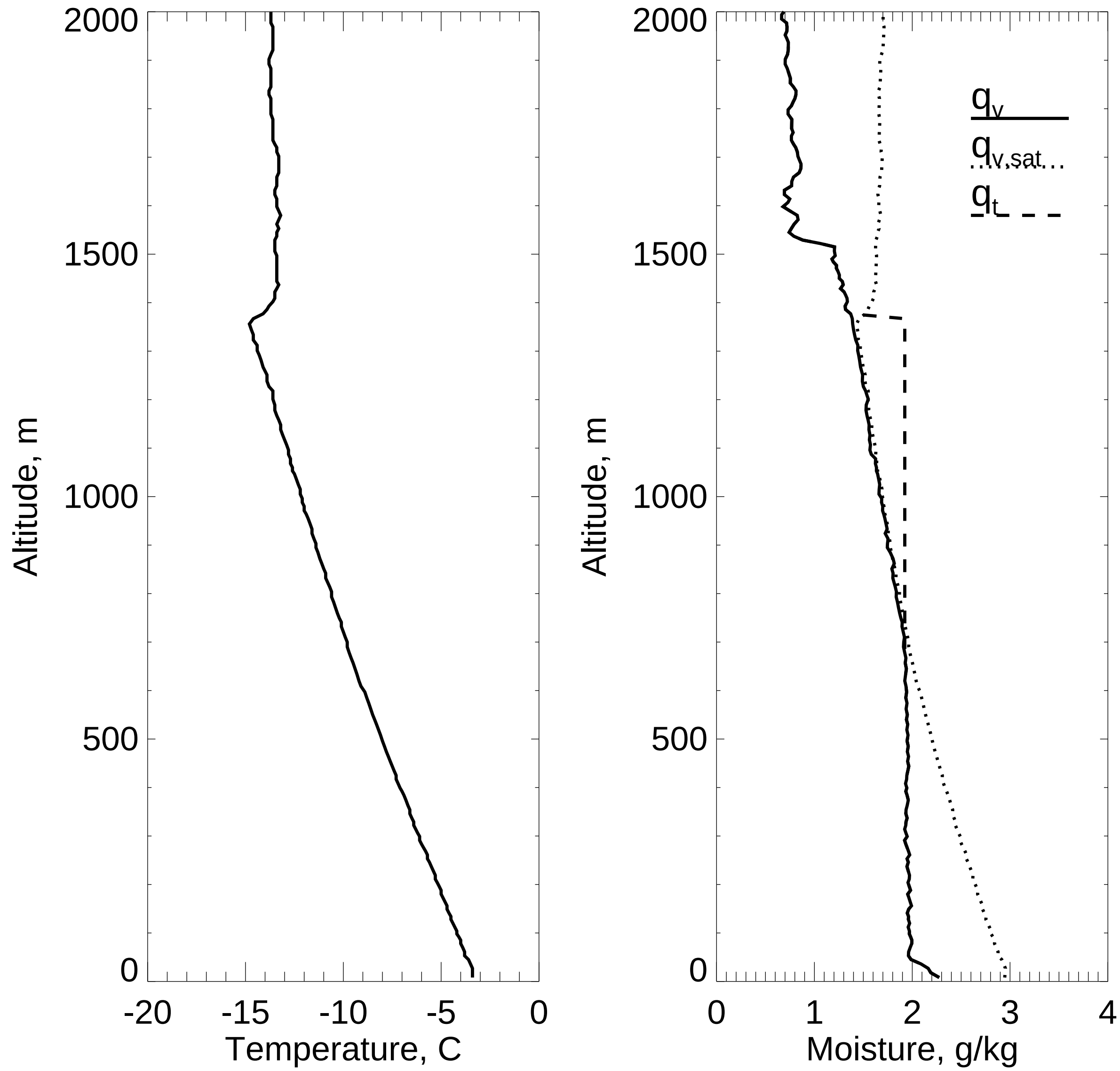


Image source: AVHRR, Pennsylvania State University M-PACE website

Observations



Data source: Hans Verlinde, ARM Archive

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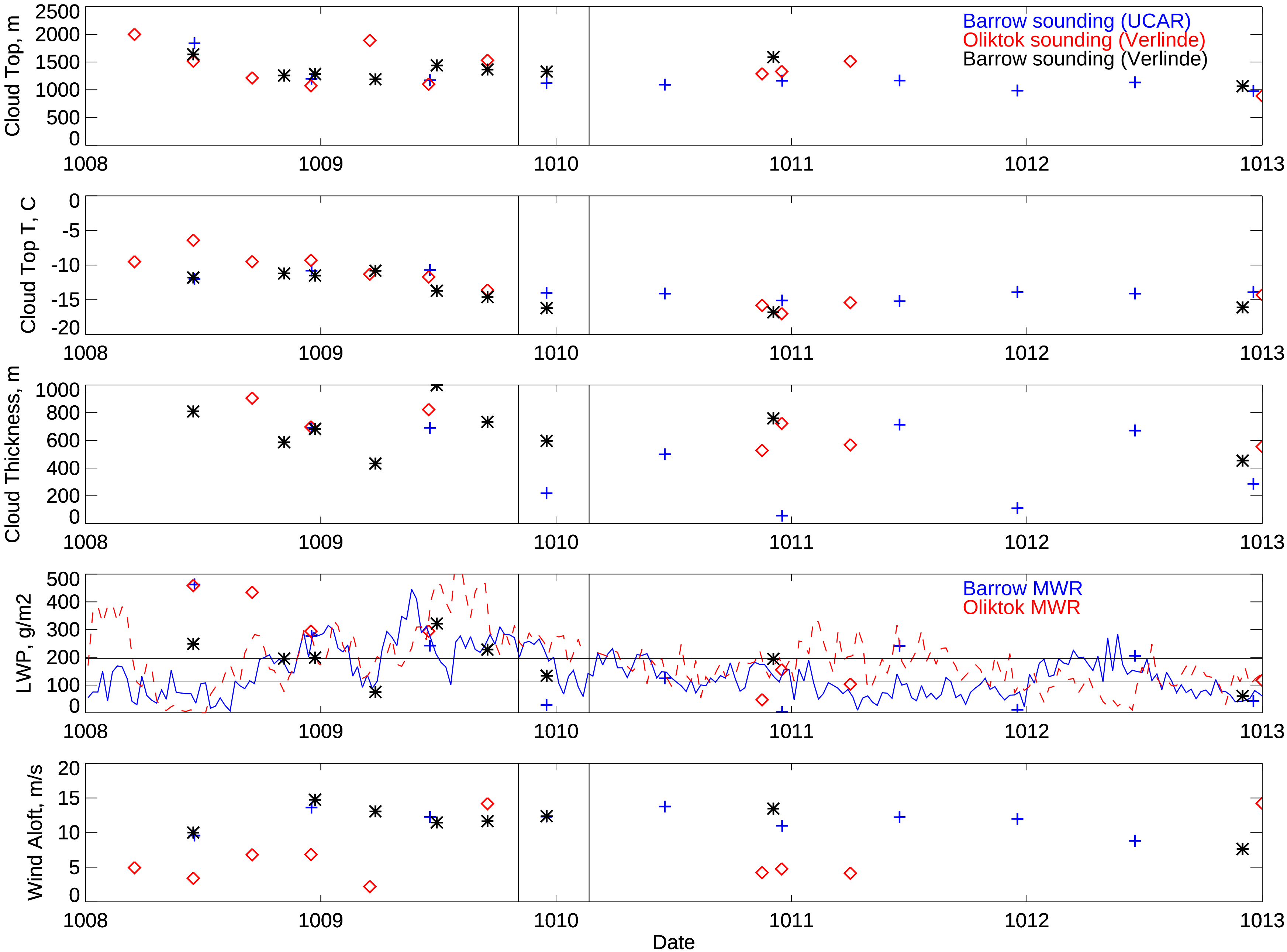

Data sources: UCAR/NWS, Hans Verlinde, Jim Mather, ARM Archive

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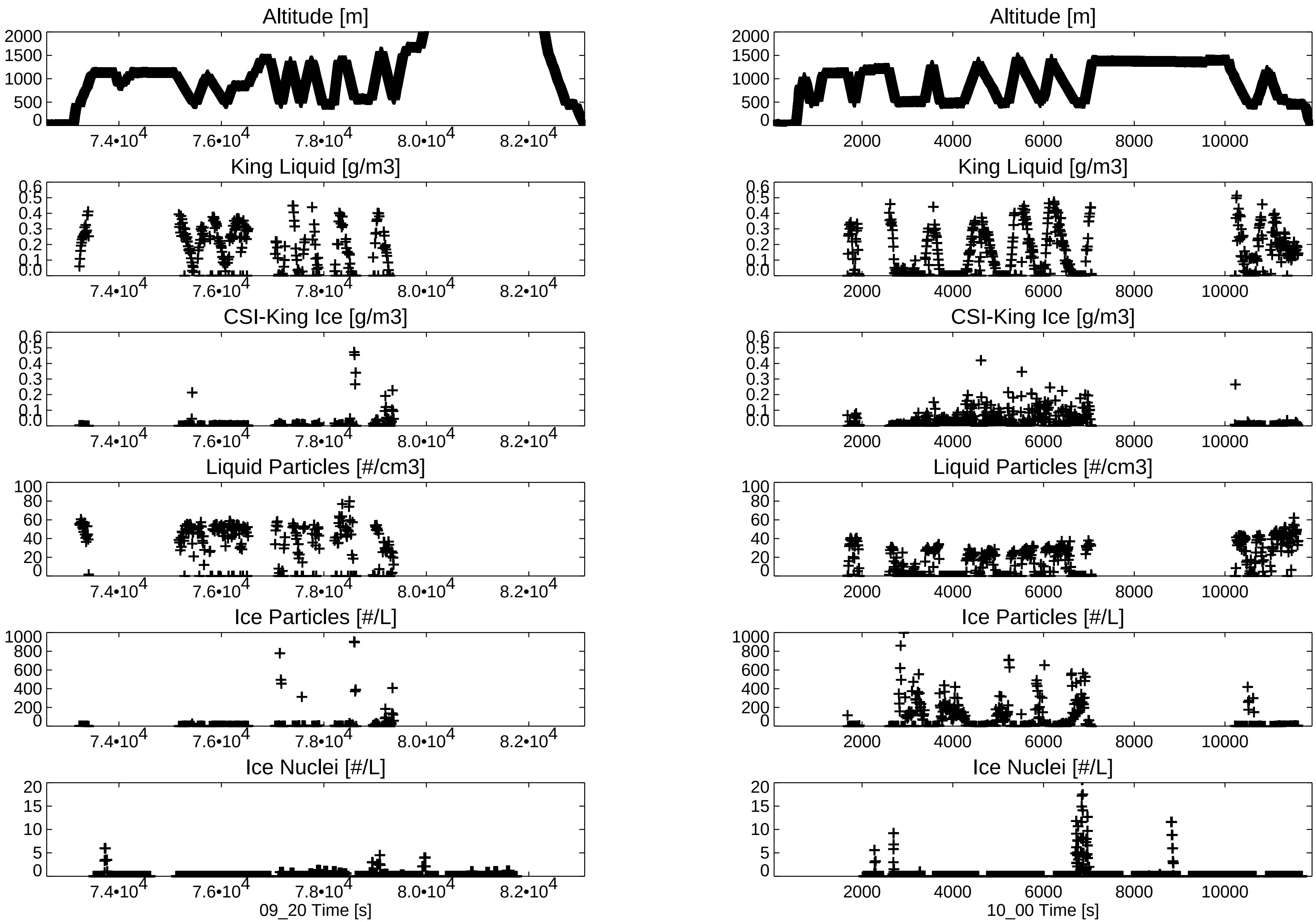

Data sources: Greg McFarquhar, Mike Poellot, Tony Prenni, Paul DeMott

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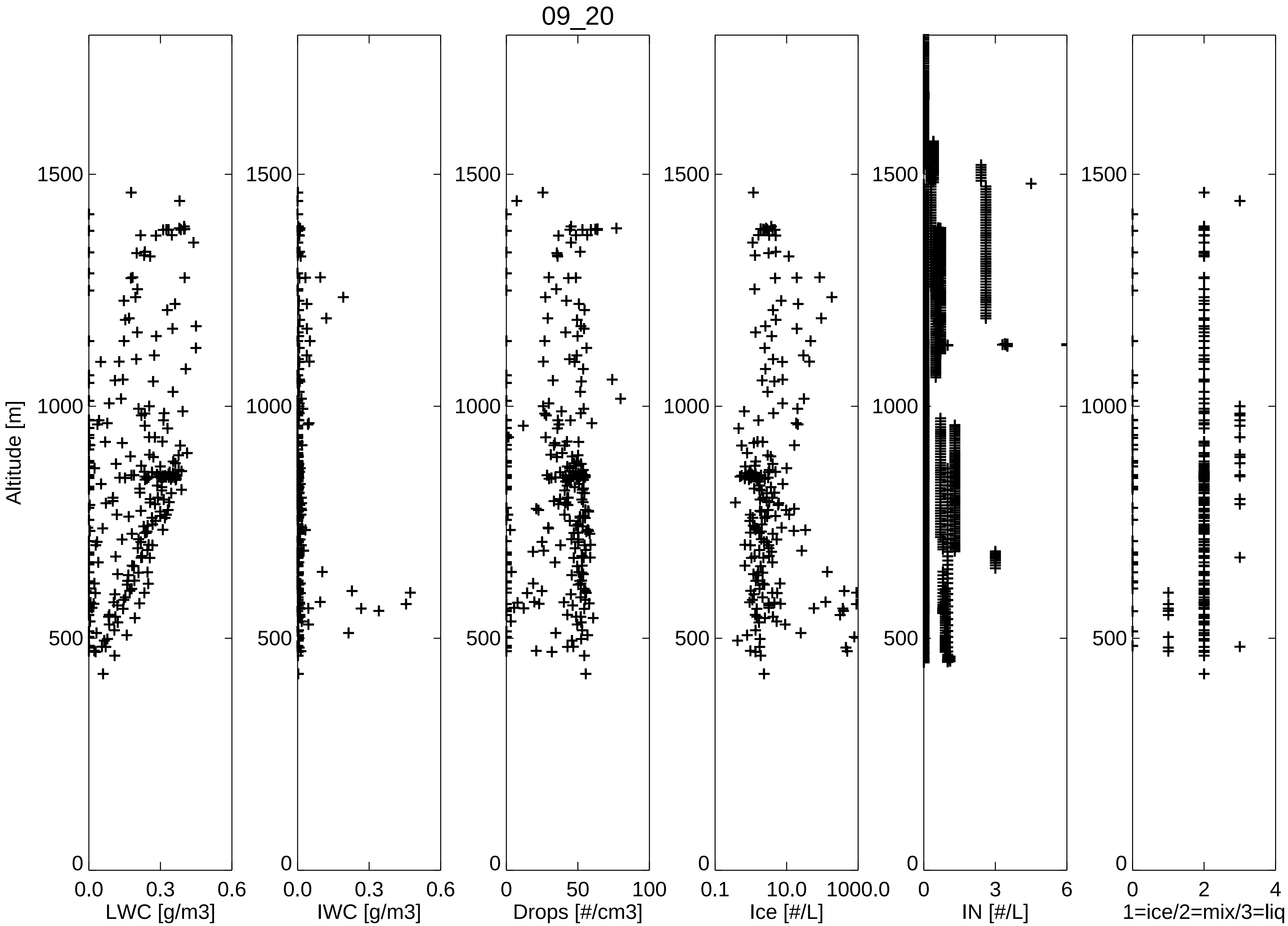

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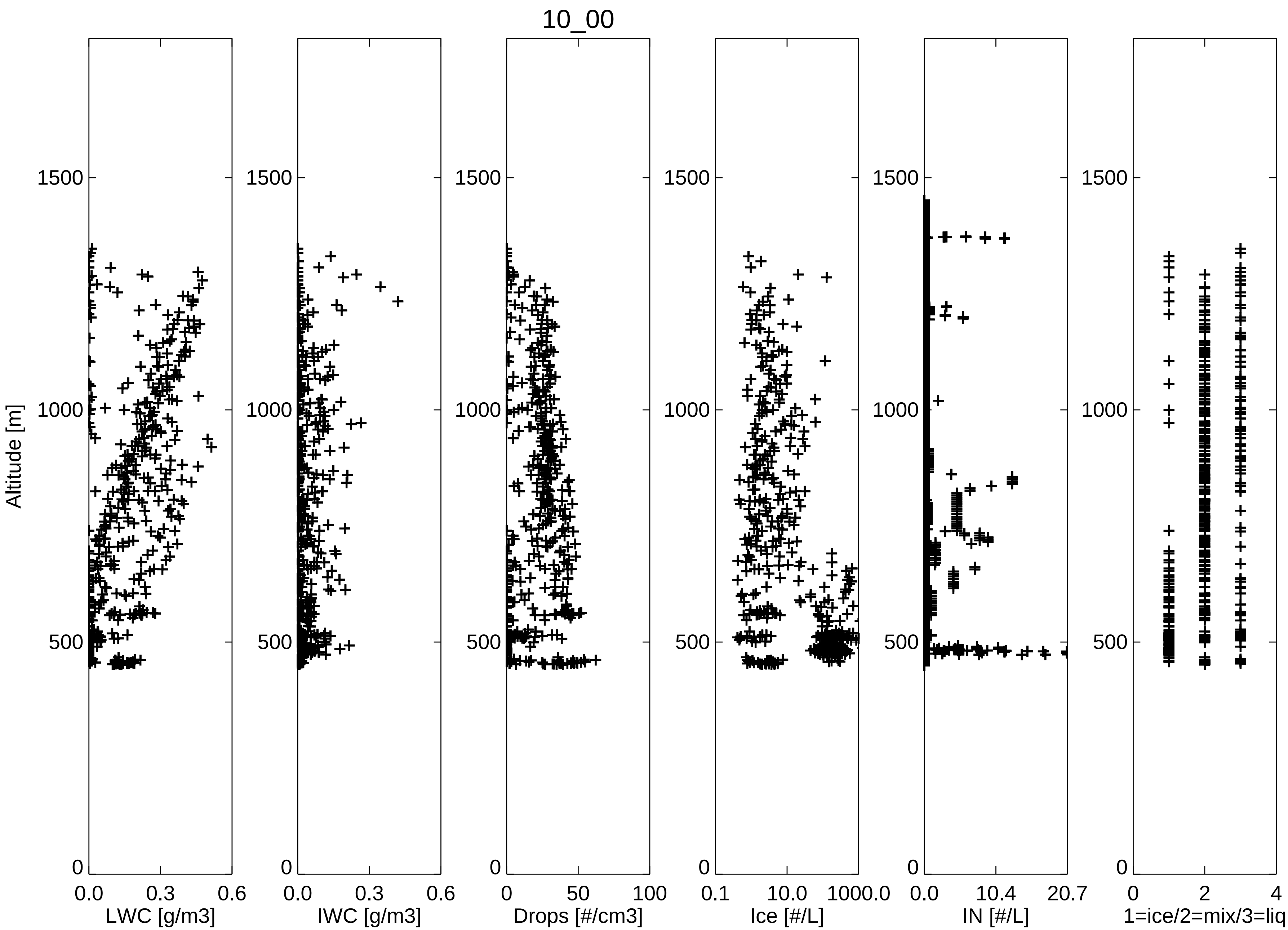

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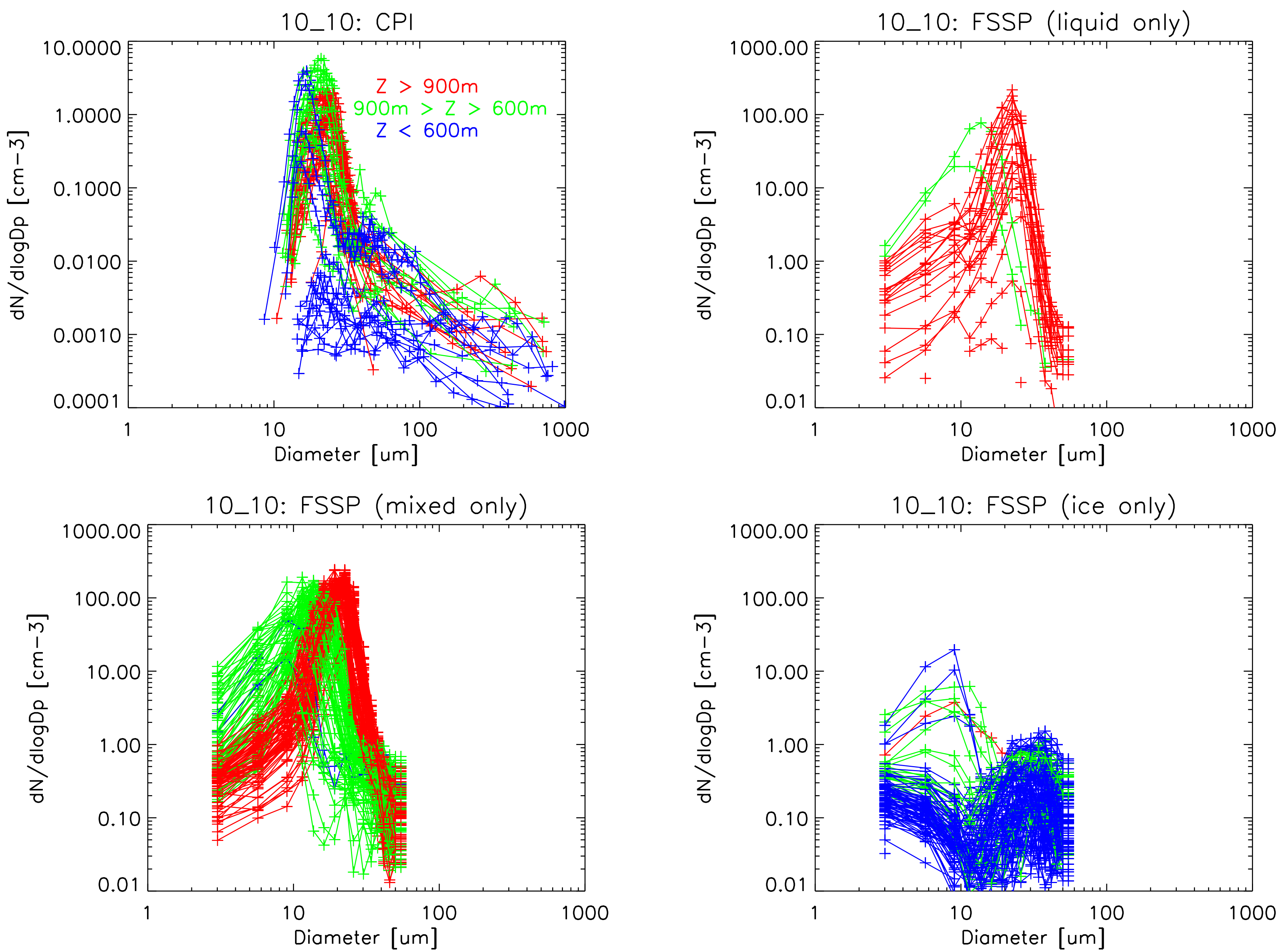

Data sources: Greg McFarquhar, Andy Heymsfield

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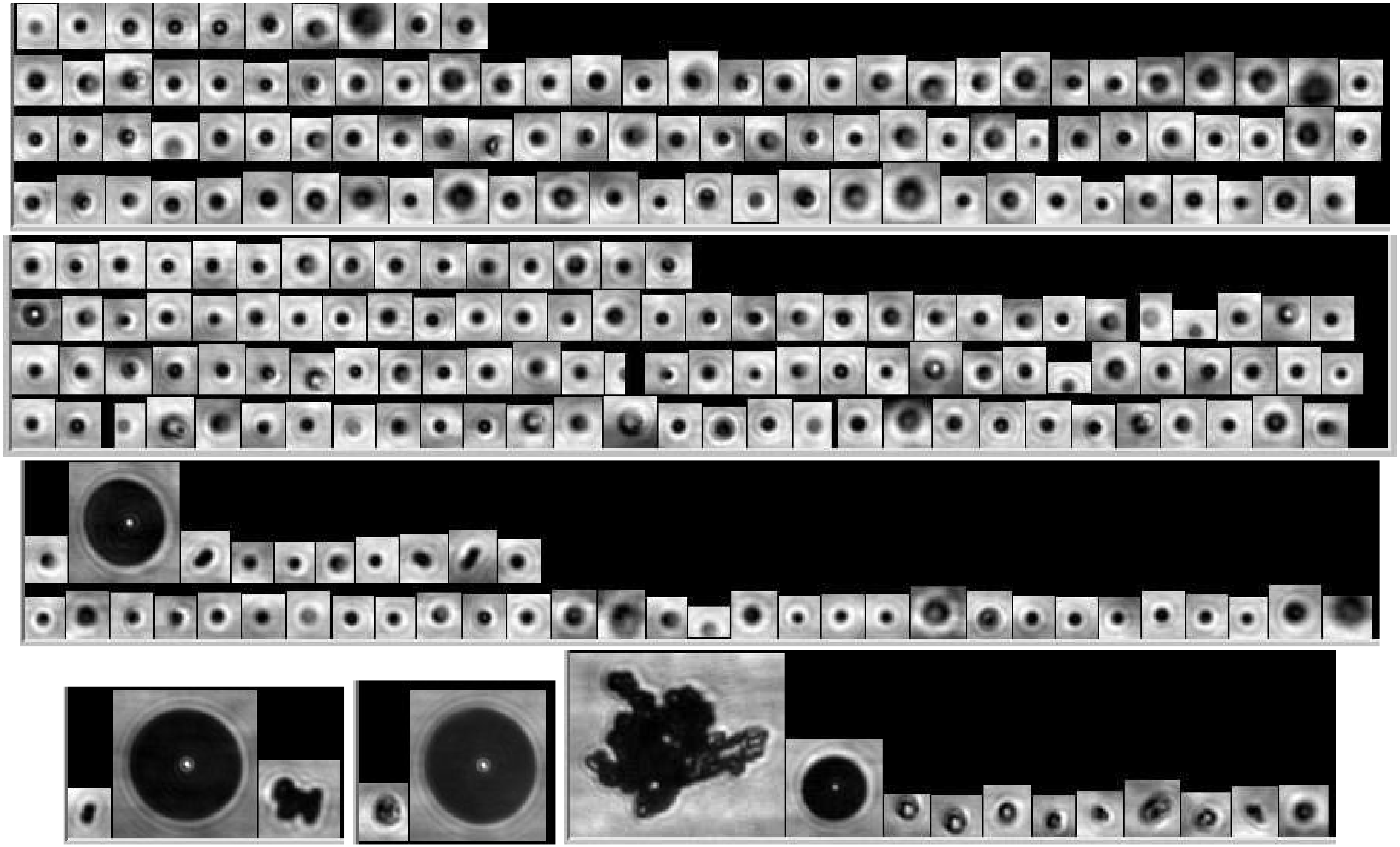

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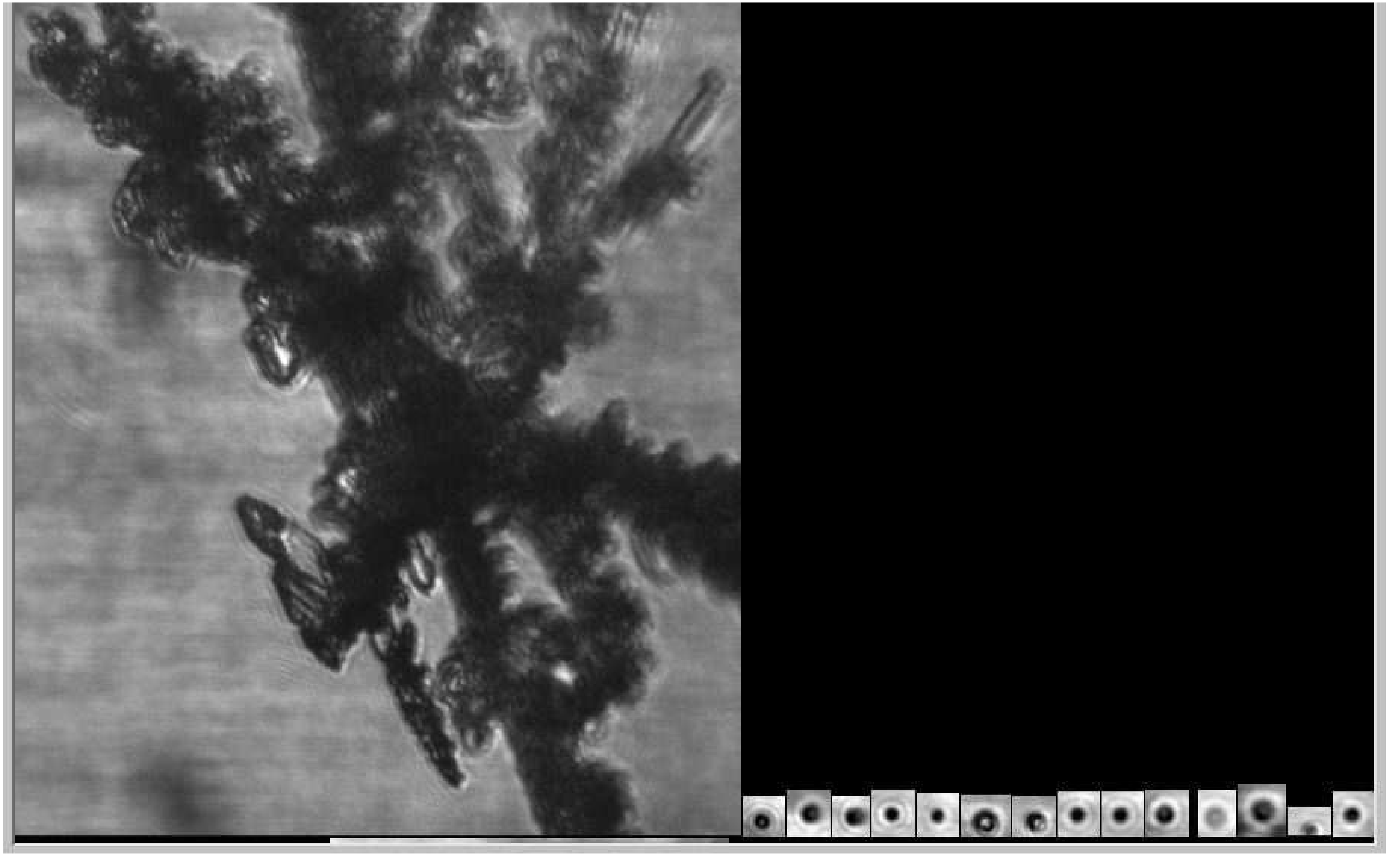

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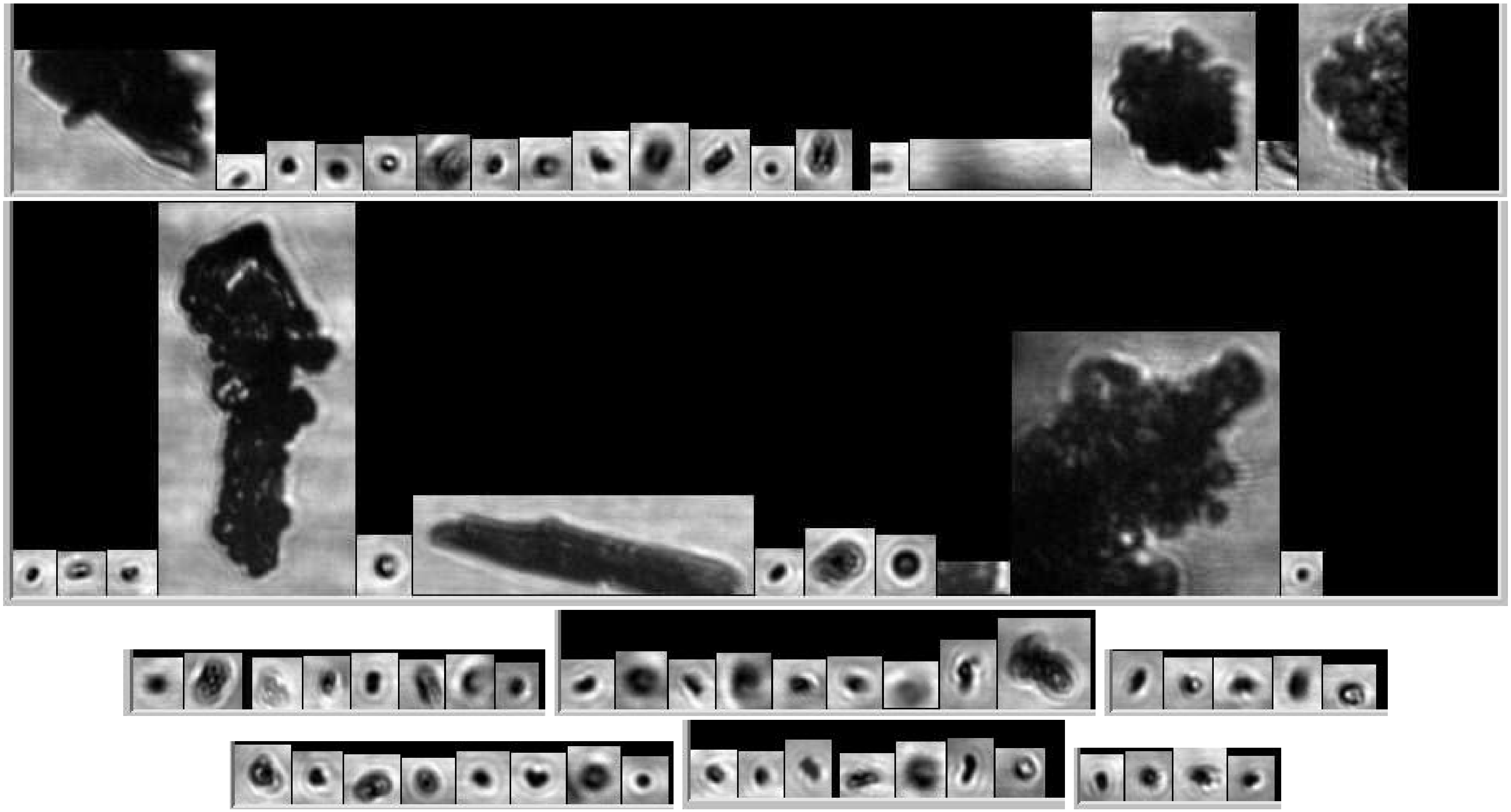

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Laboratory Results

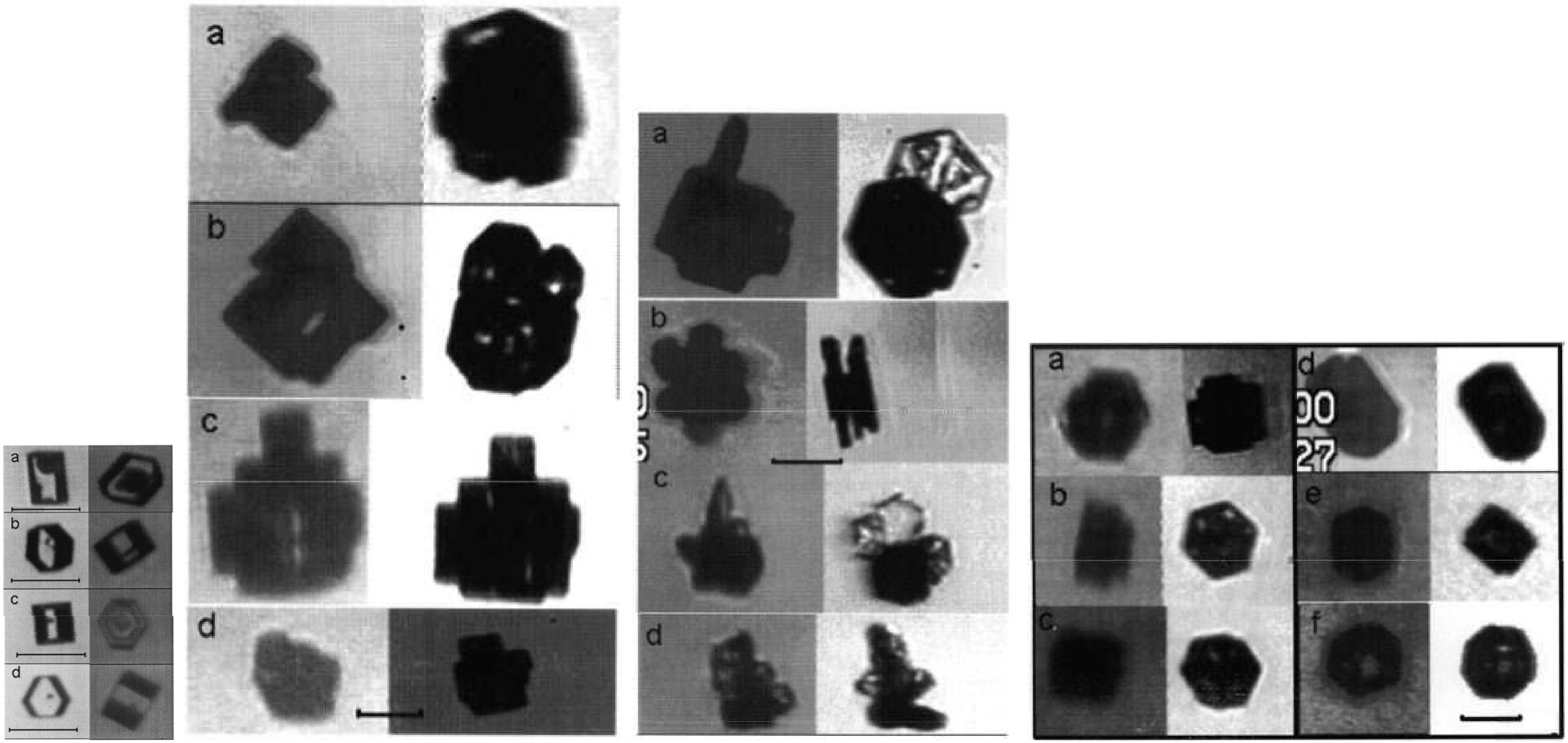

Image source: Bacon et al, Initial stages in the morphological evolution
of vapour-grown ice crystals: A laboratory investigation, QJRMS 129:1903, 2003

Literature Survey

- 'clouds having large liquid-water drops rapidly form high concentrations of ice particles regardless of the concentrations of foreign ice-forming nuclei' [Koenig, 1963]
- ice enhancement may be associated with 'the partial evaporation and freezing of a small fraction ($\approx$0.1%) of the droplets approximately $>$20 μm in diameter' and 'contact nucleation might be responsible' [Hobbs and Rangno, 1985]
- 'the fraction of evaporated cloud droplets producing a transient population of sorption IFN was estimated between 10^{-5} and 10^{-4}' [Rosinski and Morgan, 1991]
- 'one potential process at cloud top (or in downdrafts) is the creation of "evaporation ice nuclei" from a small fraction of the residue of cloud droplets' [Beard, 1992]
- electroscavenging 'provides a pathway for contact ice nucleation when charged aerosol particles from evaporated charged droplets collide with supercooled droplets' over a charge loss timescale of 10^2–10^3 seconds [Tinsley et al., 2000]
- 'freezing probability can be enhanced by the electrical collection' and 'particularly so in the case of small ($<$20 μm) supercooled drops' [Tripathi and Harrison, 2002]
- 'most of the ice nucleation must occur at a critical time during evaporation of the liquid droplets in the downdraught' and thermophoretically-enhanced rates of contact nucleation 'are too low' [Cotton and Field, 2002]

Literature Survey

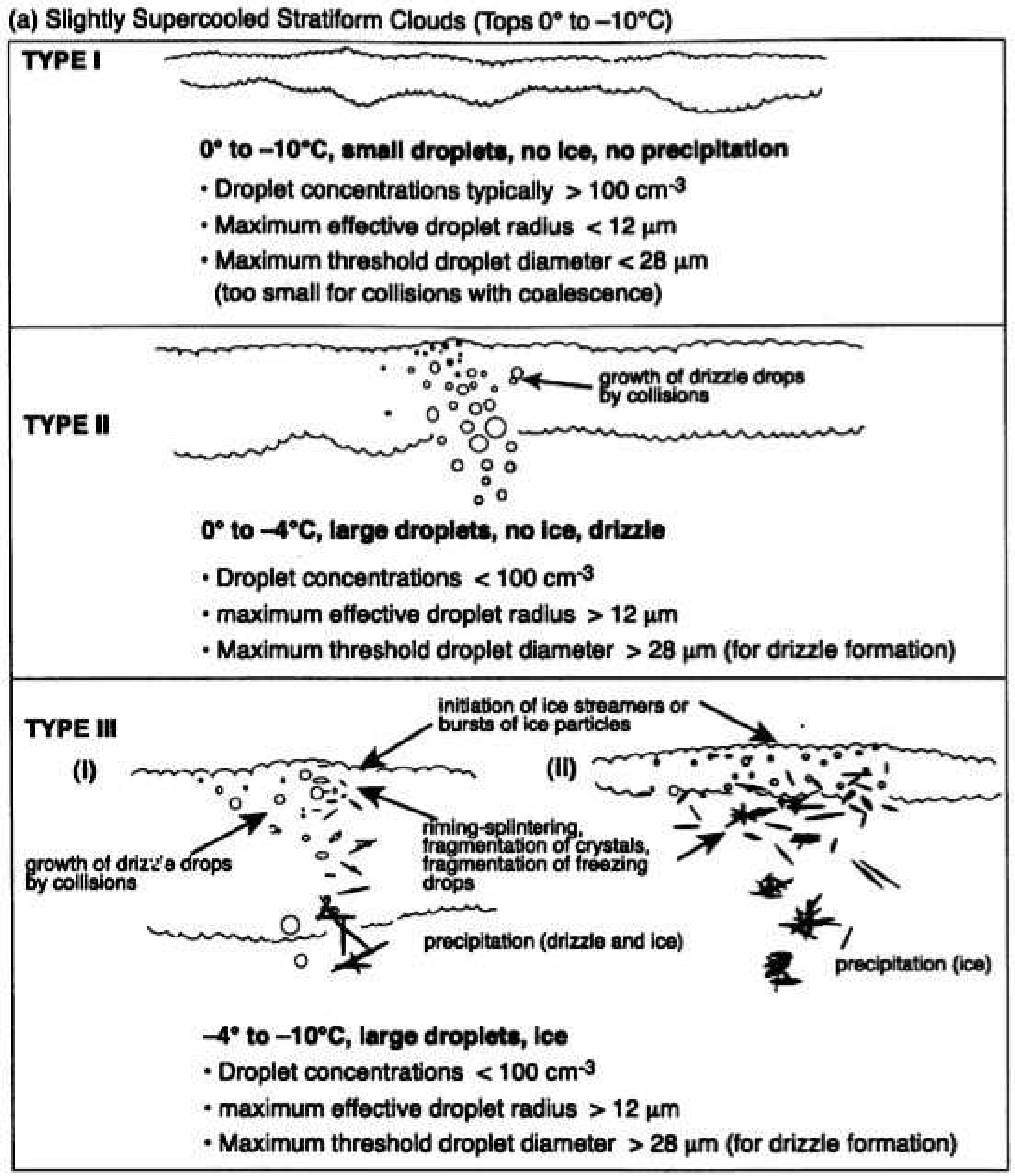

Image source: Rangno and Hobbs, Ice particles in stratiform clouds in the Arctic and possible mechanisms for the production of high ice concentrations, JGR 106:15,065, 2001

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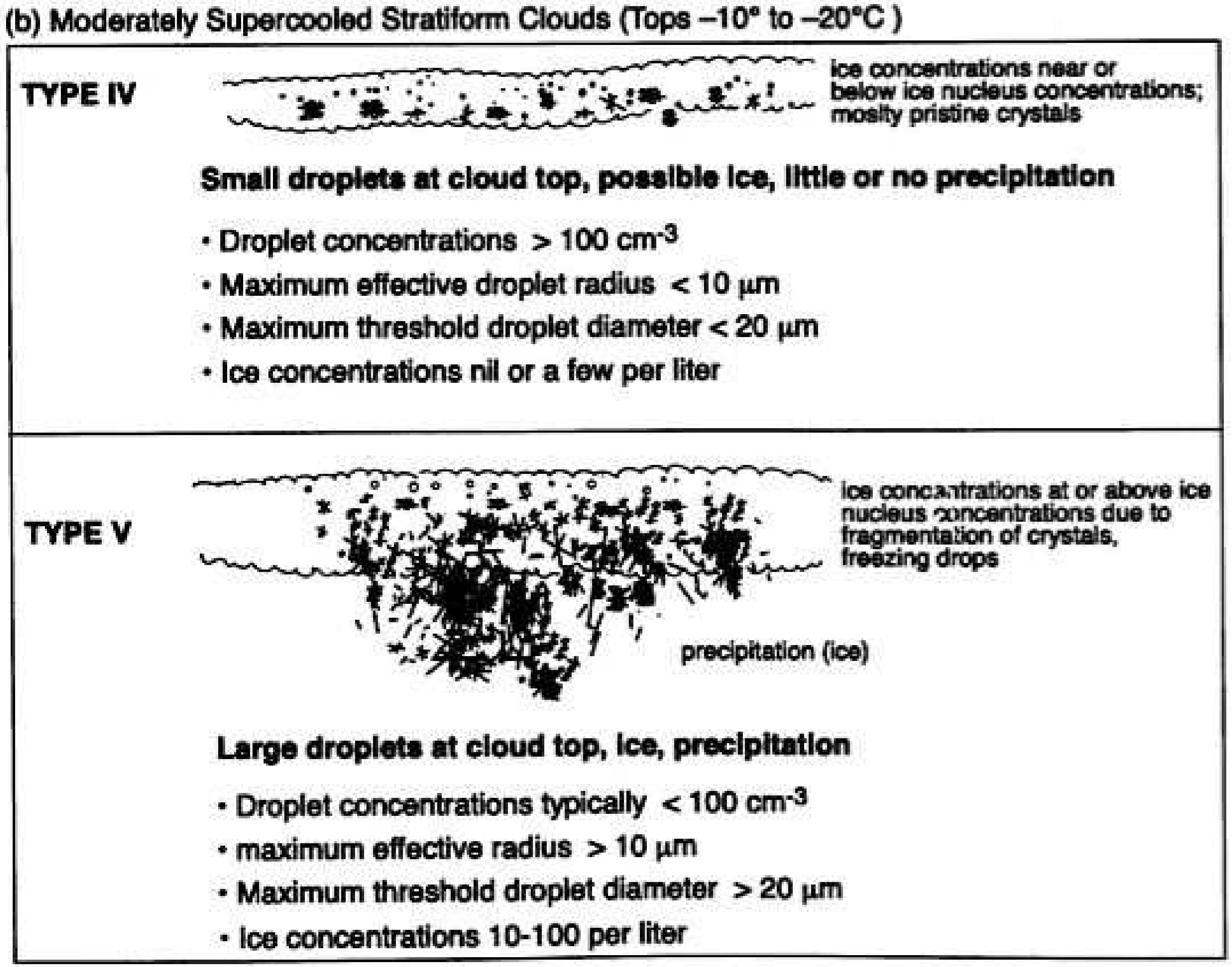

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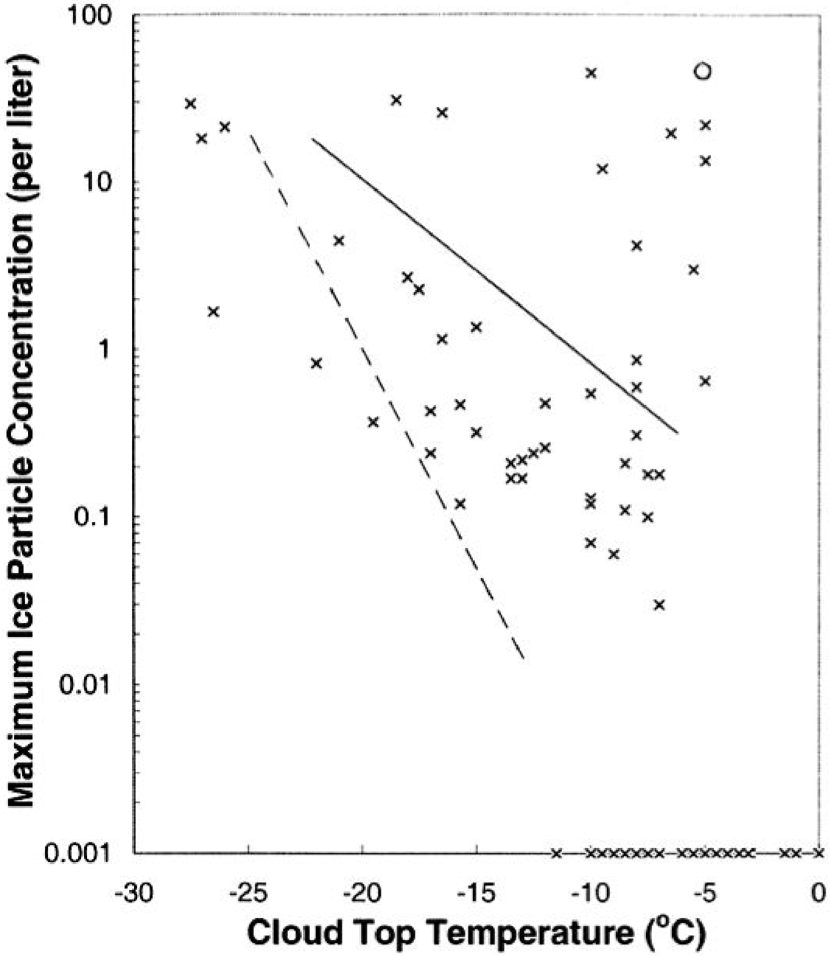
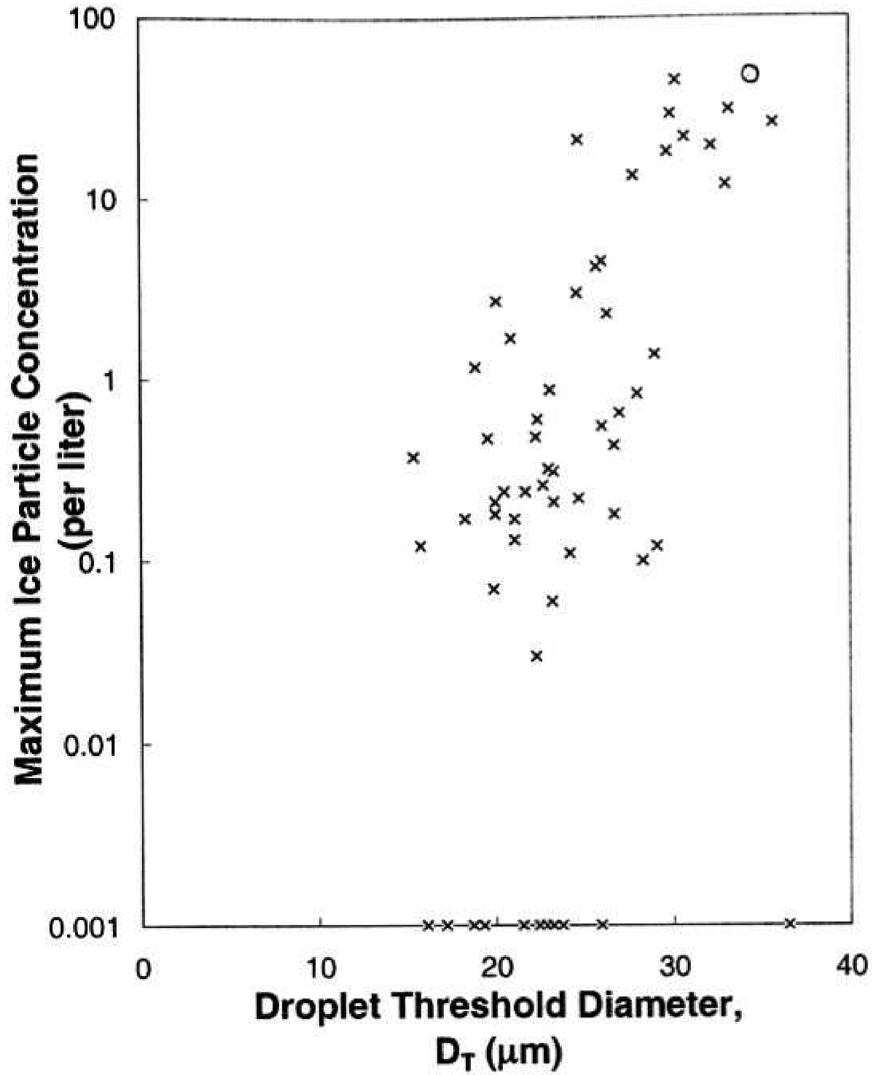




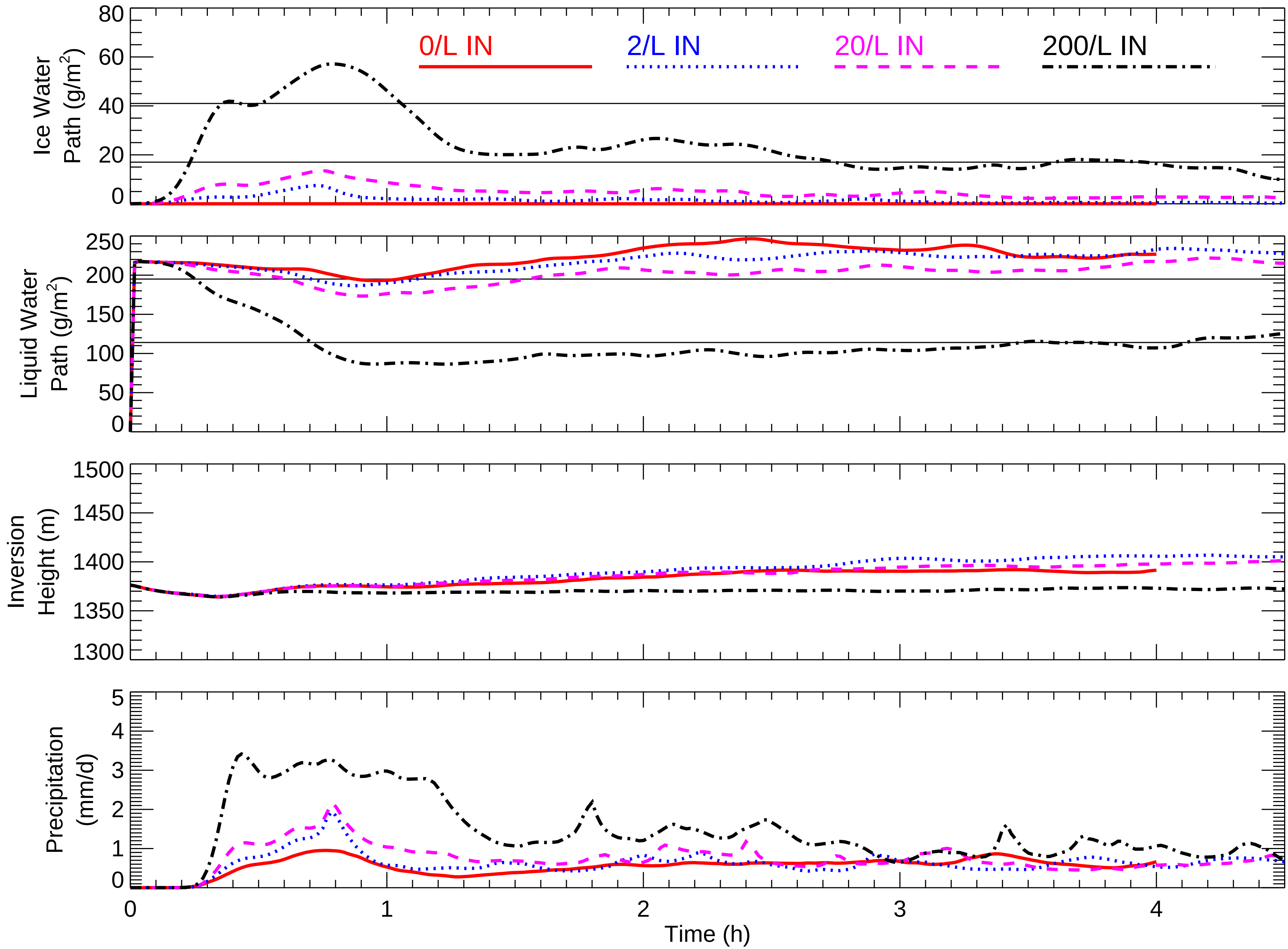
Model Description

- Dynamics framework
  - large-eddy simulation [Stevens and Bretherton, 1997]
  - dynamic Smagorinsky subgrid model [Kirkpatrick et al., 2006]
  - 2-stream radiative transfer at 44 wavelength bands [Toon et al., 1989]
  - 3.2 x 3.2 x 2.5 km domain, doubly periodic
  - 64 x 64 x 96 mesh, uniform horizontal and vertical
  - specified SST, advective flux and subsidence profiles
- Size-resolved microphysics [Jensen et al., 1994; Ackerman et al., 1995]
  - diagnostic CCN: 20 bins, 10 nm–1 μm diameter
  - liquid: 20 bins, 2 μm–2 mm
  - ice: 20 bins, 2 μm–5 mm
  - prognostic IN: 10 bins, most to least easily nucleated

Model Description

Mechanism	Temp, C	Supersat	Dependence	Description
Primary modes				
contact	-4 to -14	—	$f_{lin}(T)$	drop + $\mathrm{IN}_{aer} \rightarrow$ ice
condensation	-8 to -22	$S > S_w$	$f_{lin}(T)$	$\mathrm{IN}_{aer} \rightarrow$ ice
deposition	$T < -10$	$S > S_i$	$f_{exp}(S)$	$\mathrm{IN}_{aer} \rightarrow$ ice
immersion	-10 to -24	—	$f_{lin}(T)$	drop + $\mathrm{IN}_{drop} \rightarrow$ ice
Multiplication				
rime-splinter	-3 to -8	—	$f_{lin}(T)$	one crystal per 250 collisions
drop shatter	$T < 0$	—	$D_{drop} > 50\ \mu$m	multiplication factor = 2

Model Results



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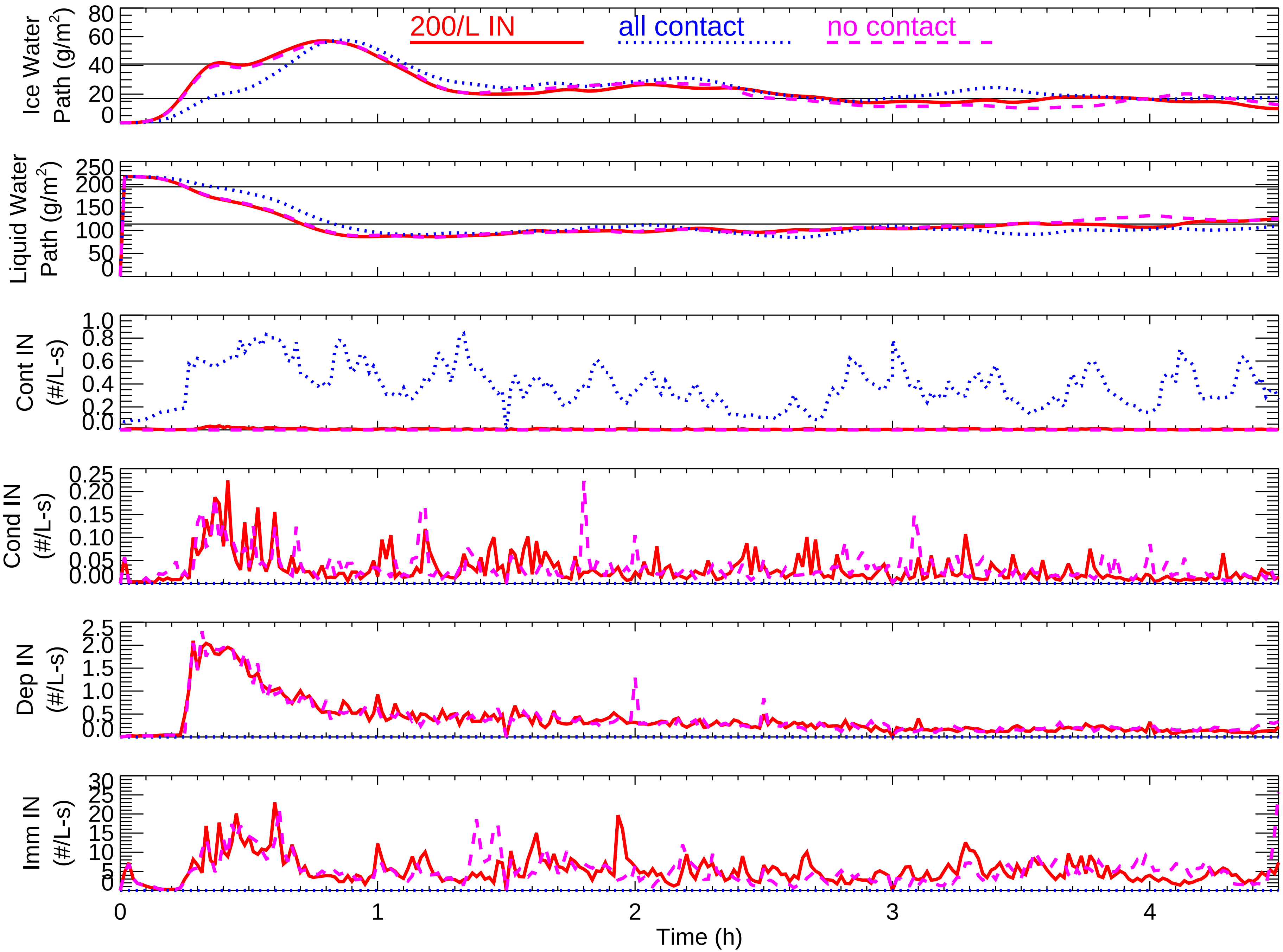

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Multiplication				
rime-splinter	-3 to -8	—	$f_{lin}(T)$	one crystal per 250 collisions
drop shatter	T < 0	—	D$_{drop}$ $>$ 50 μm	multiplication factor = 2

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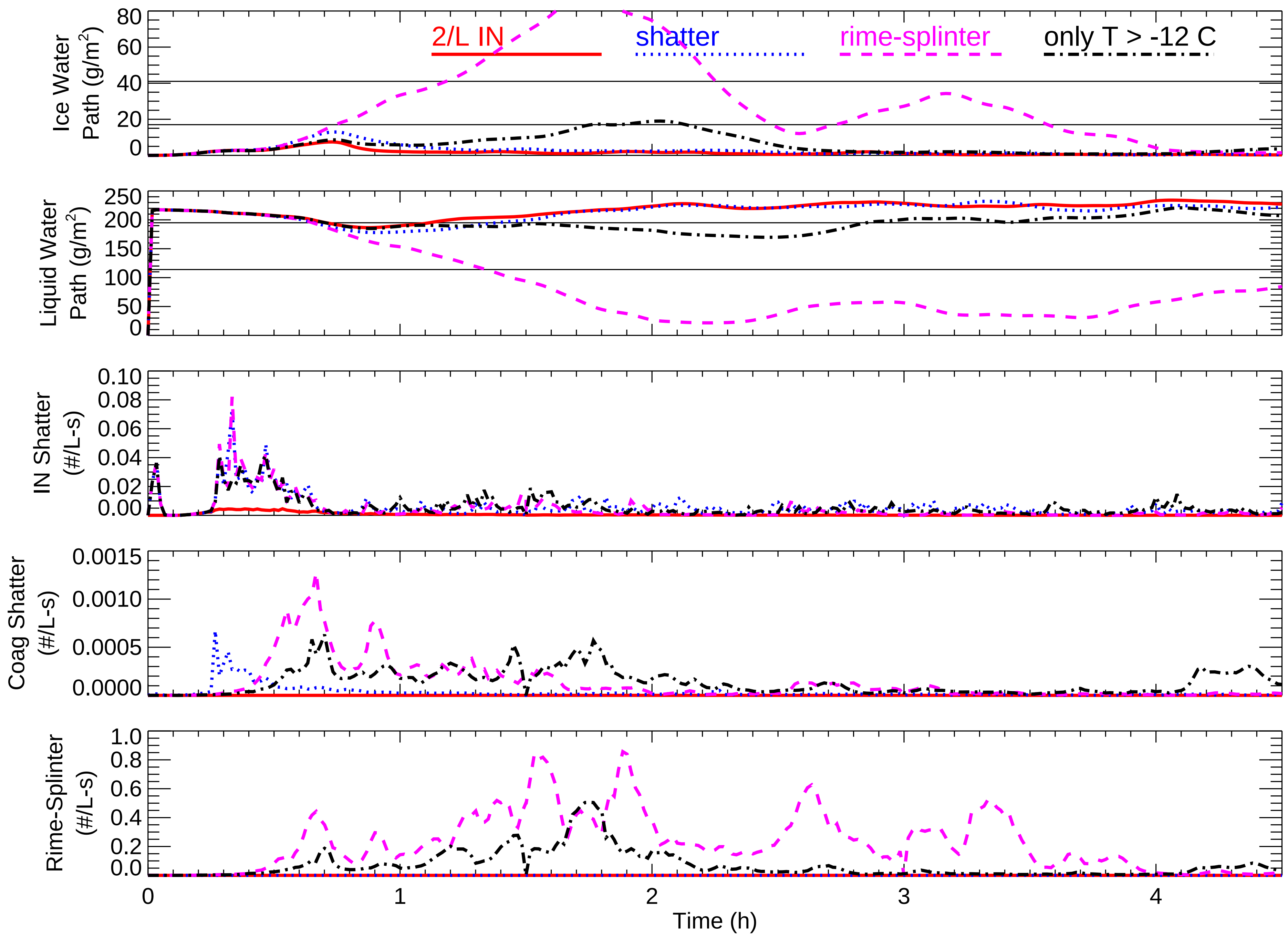

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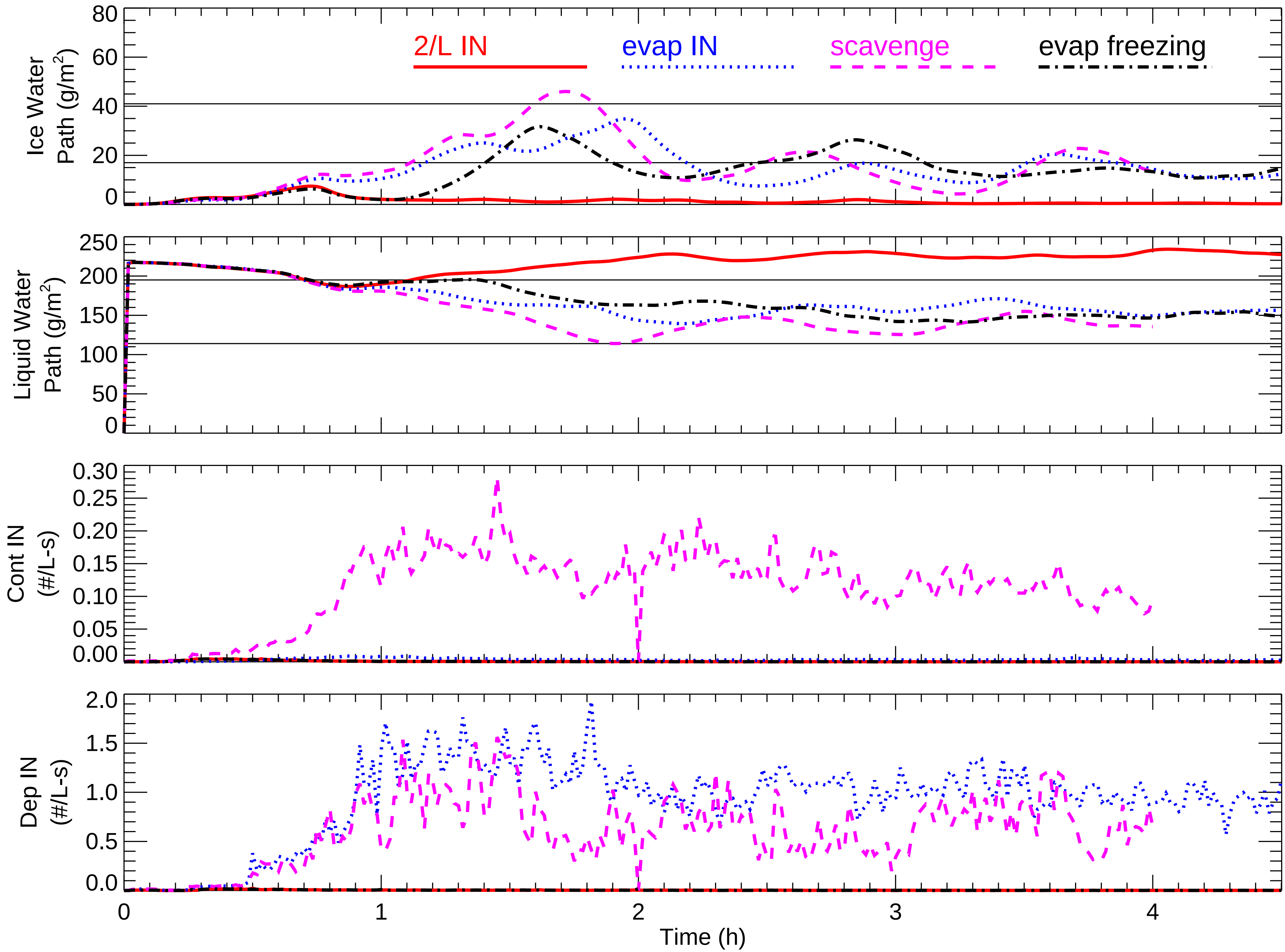
Multiplication				
rime-splinter	-3 to -8	—	$f_{lin}(T)$	one crystal per 250 collisions
drop shatter	$T < 0$	—	$D_{drop} > 50\ \mu$m	multiplication factor = 2
Other processes				
evaporation nuclei	$T < 0$	$S < S_w$	—	evaporated drop $\rightarrow IN_{aer}$
charge enhancement	$T < 0$	—	$f(t)$	evaporated drop retains charge
evaporation freezing	$T < 0$	$S < S_w$	—	evaporating drop 'just freezes'
ice preactivation	$T < 0$	$S < S_i$	—	evaporated ice $\rightarrow IN_{aer}$

Model Results



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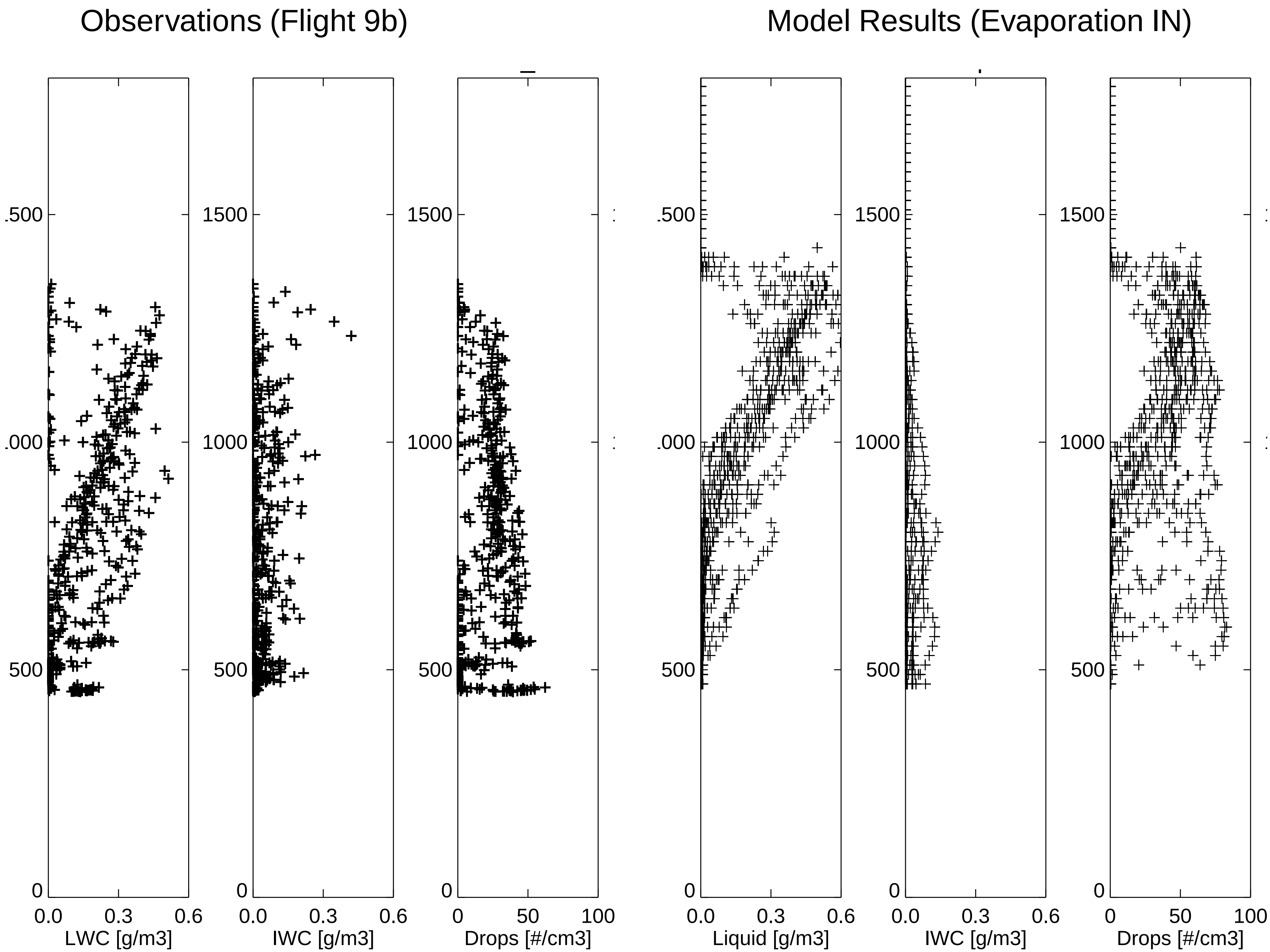

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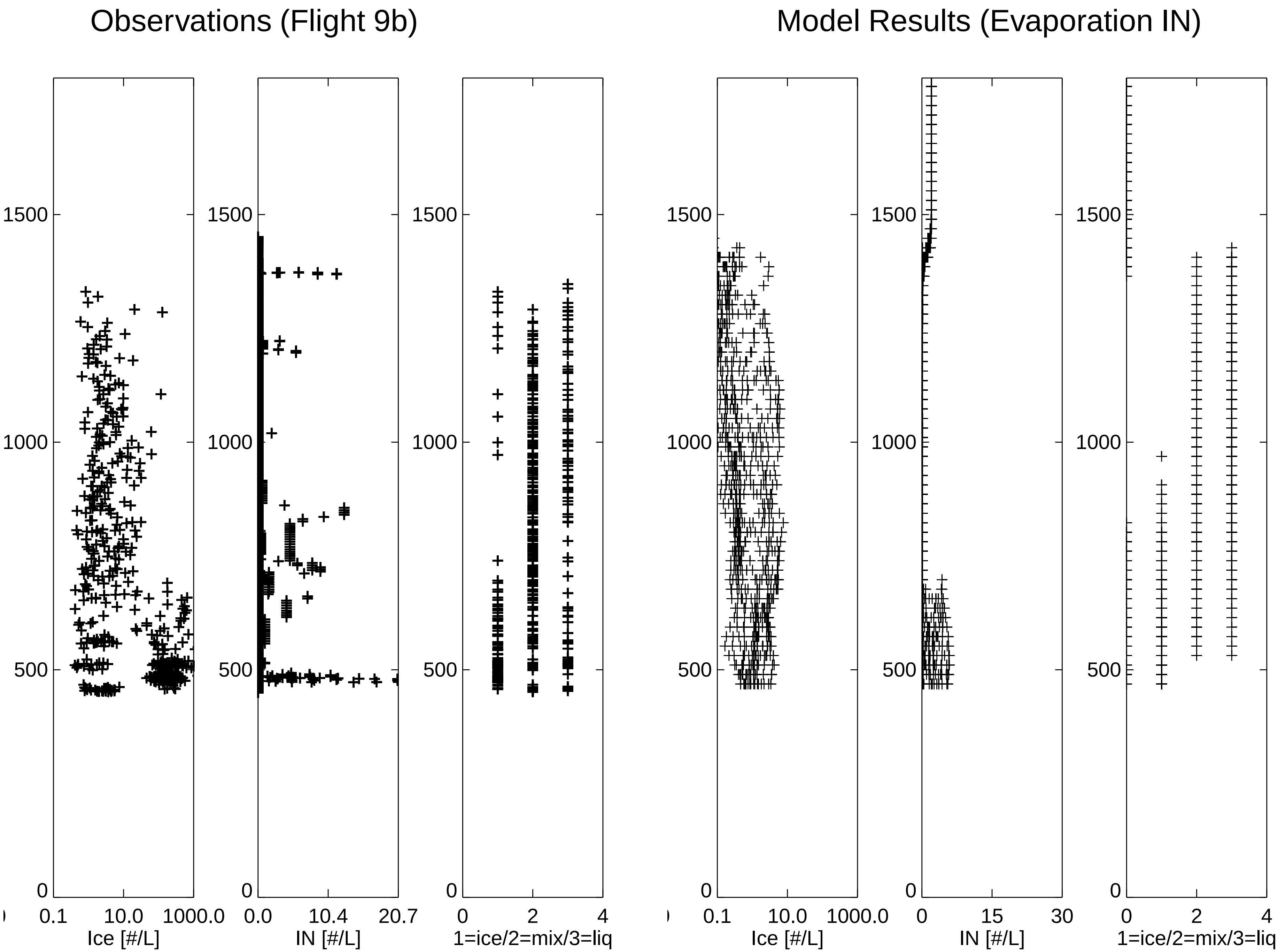

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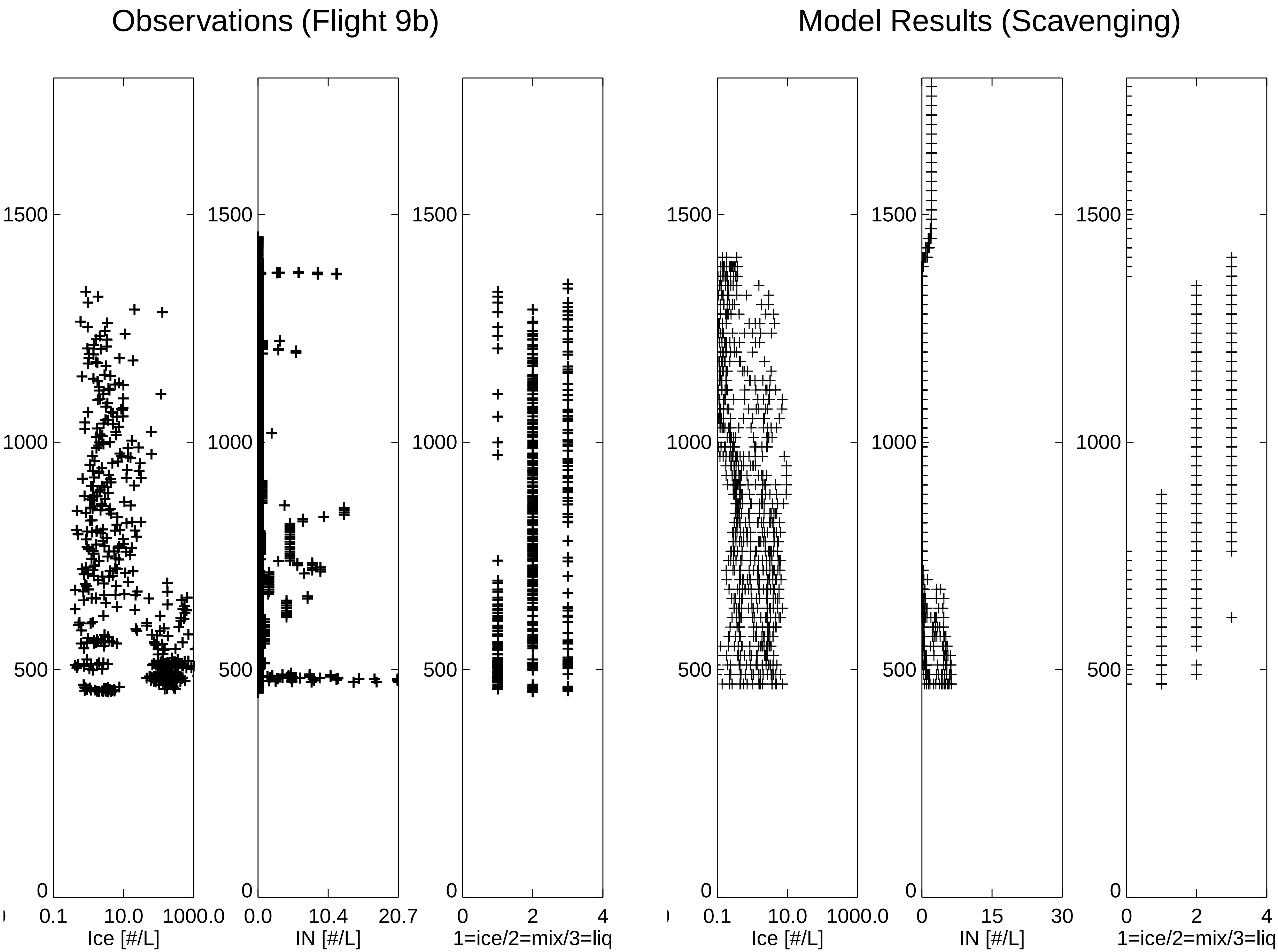

Summary

- Ice mass and number far exceeds that predicted from ice nuclei
- Multiplication mechanisms appear too weak to explain the difference
- Other processes during drop evaporation appear most consistent with the observations and model results thus far

Acknowledgments

- Funding
  - DOE Atmospheric Radiation Measurement Program
  - NASA Radiation Sciences Program
  - NASA Advanced Supercomputing Division
- Data and collaboration
  - Shaocheng Xie, Steve Klein, Hugh Morrison
  - Greg McFarquhar, Andy Heymsfield, Mike Poellot, Tony Prenni, Paul DeMott
  - PSU Group quicklooks, Pat Minnis Group flight track overlays