Ice formation closure during ISDAC: Flight 31 as a first modeling study

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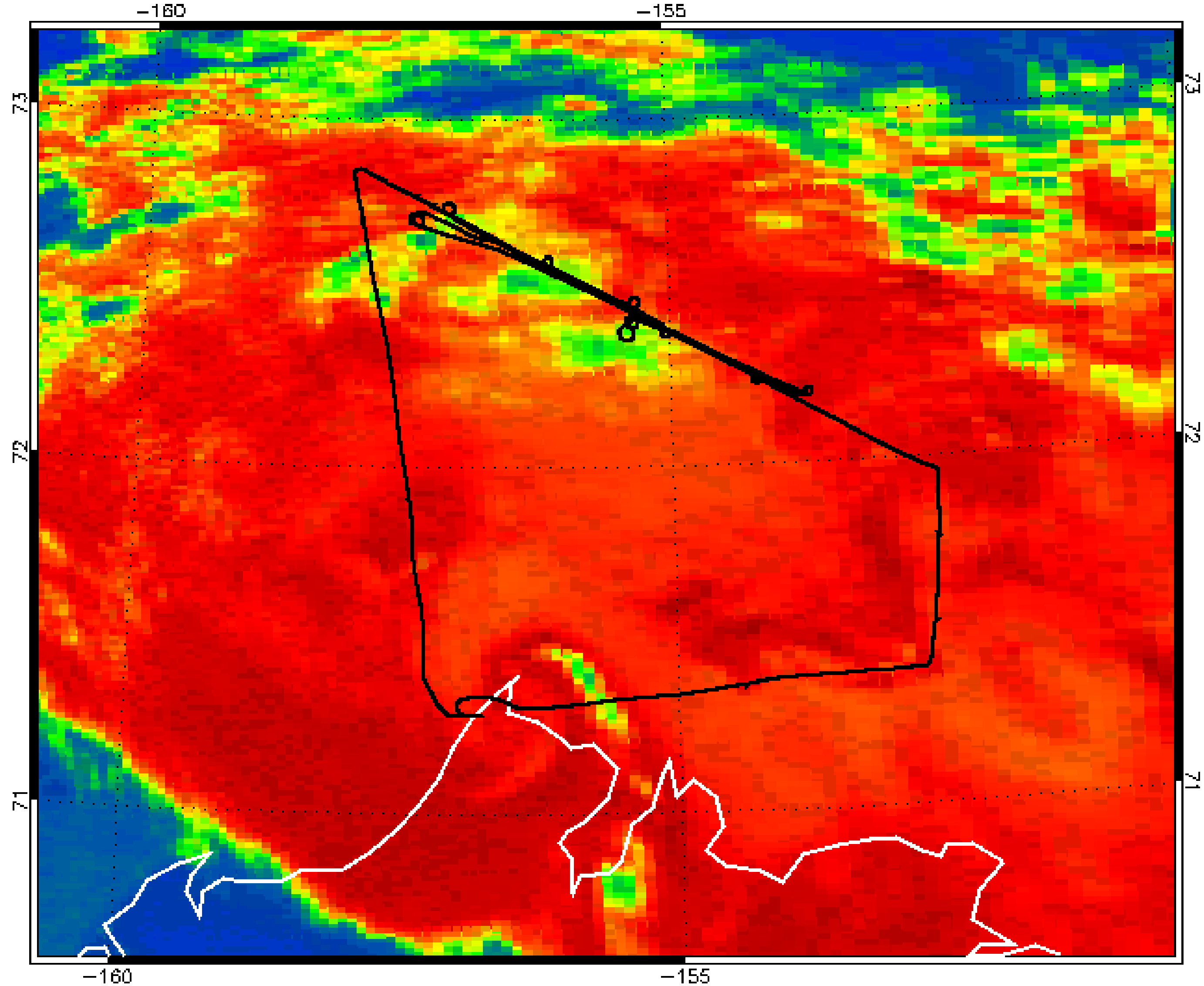
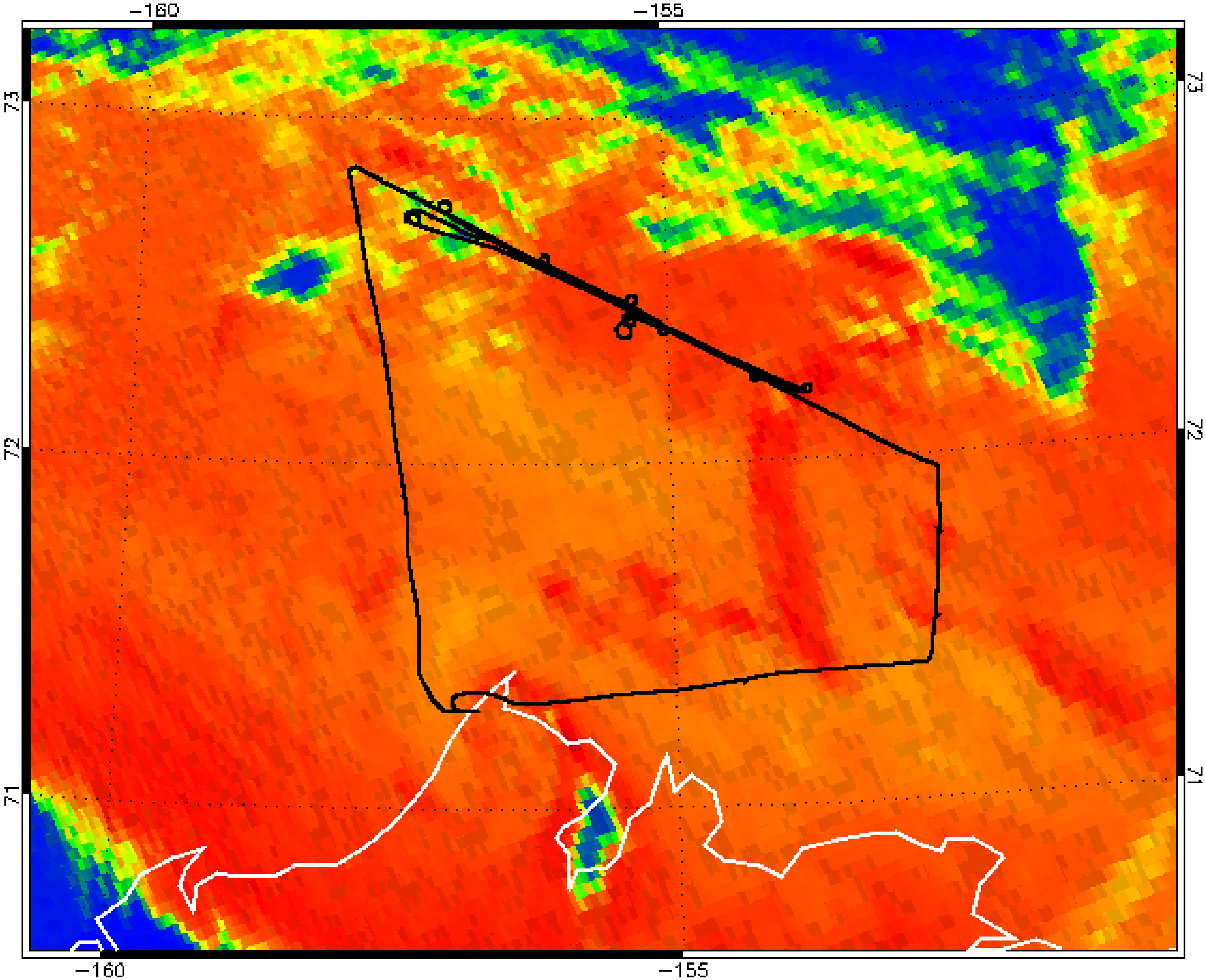
Objectives

- Ice formation – can "conventional" ice nucleation mechanisms explain observed ice concentrations?
- Ice crystal habit – even given one habit (dendrites), how do variations in capacitance, mass- and area-size (maximum length) influence simulated cloud microphysics?

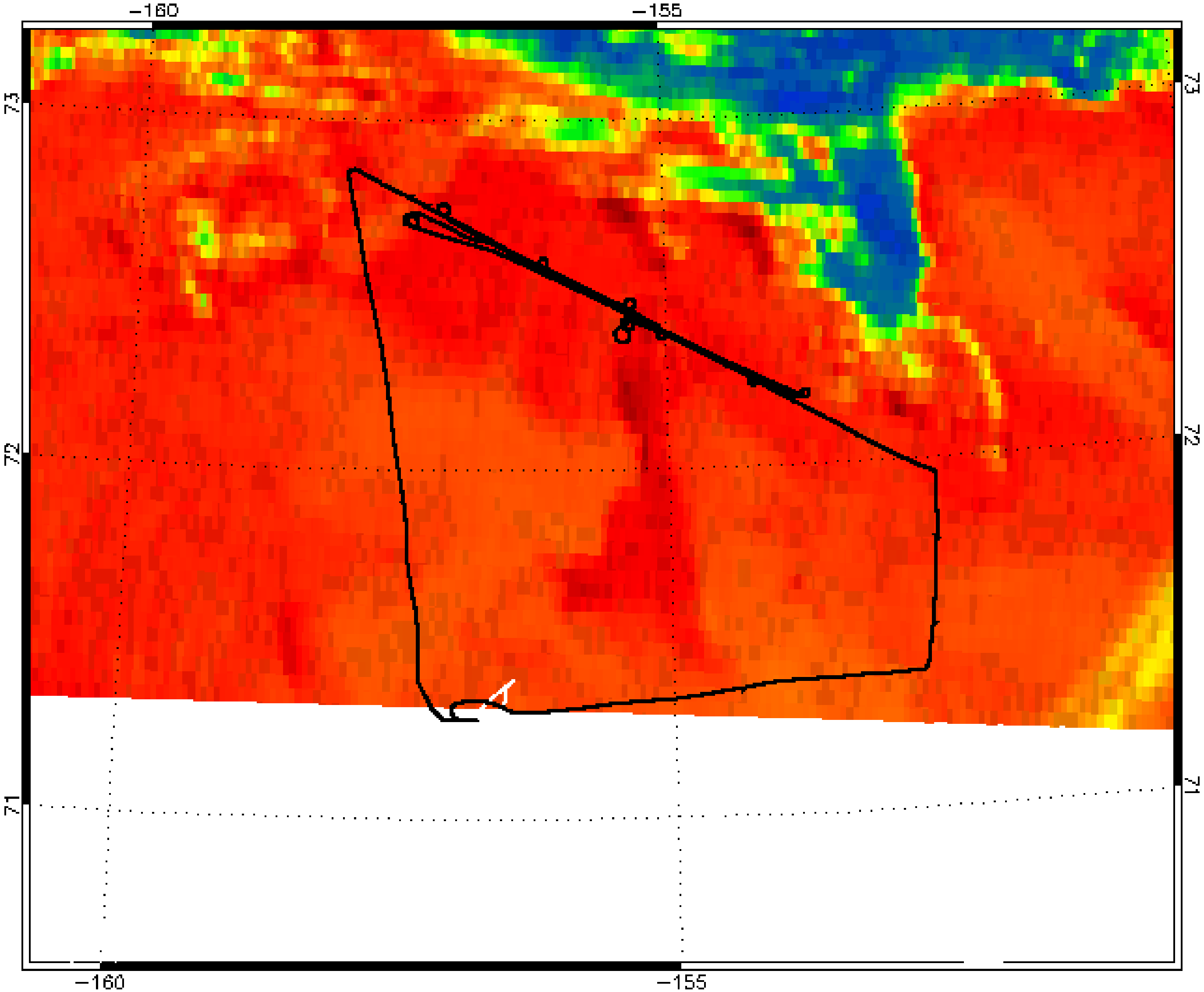
MODIS 3.7 um at 00:05 UTC

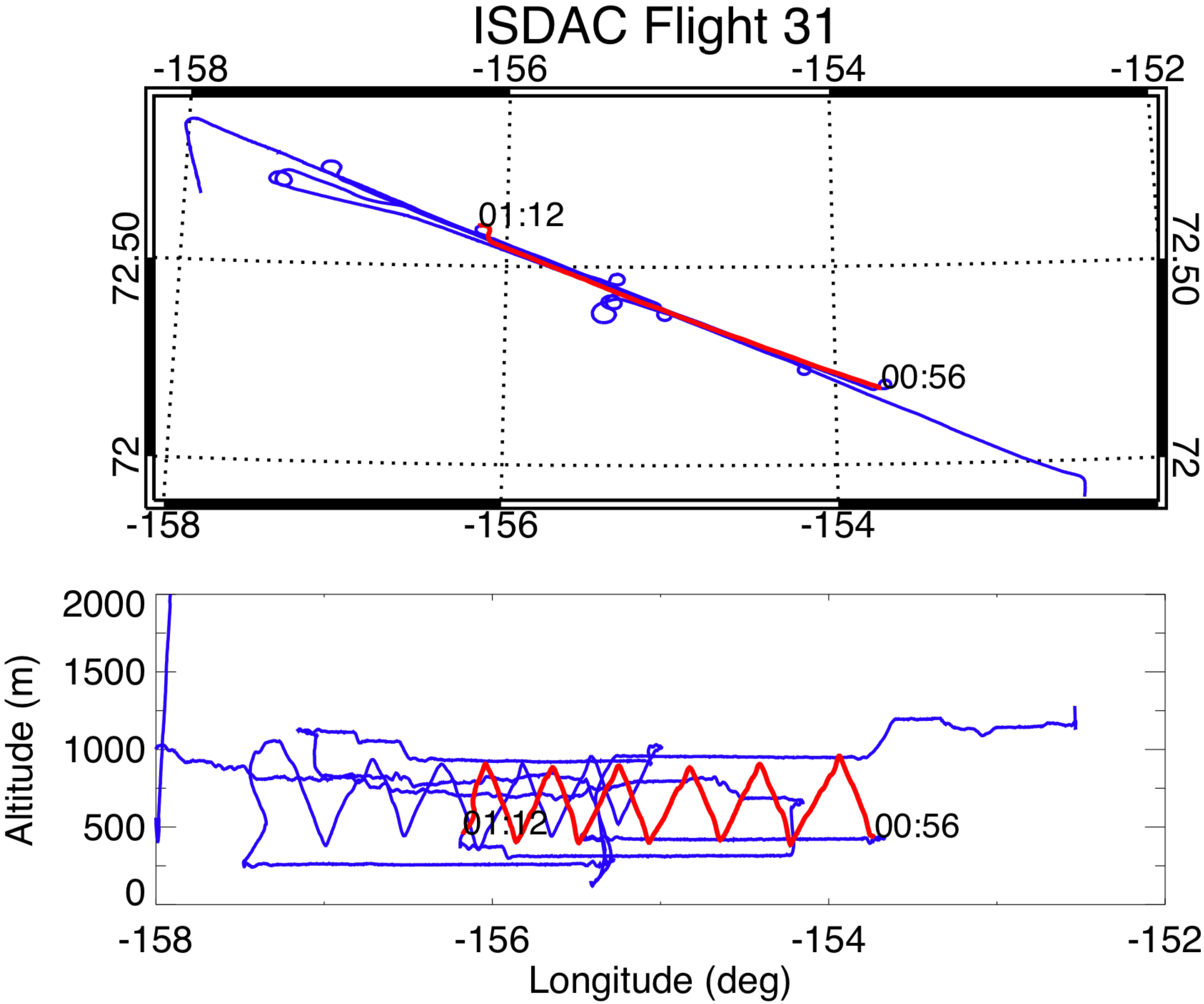


MODIS 3.7 um 01:25 UTC



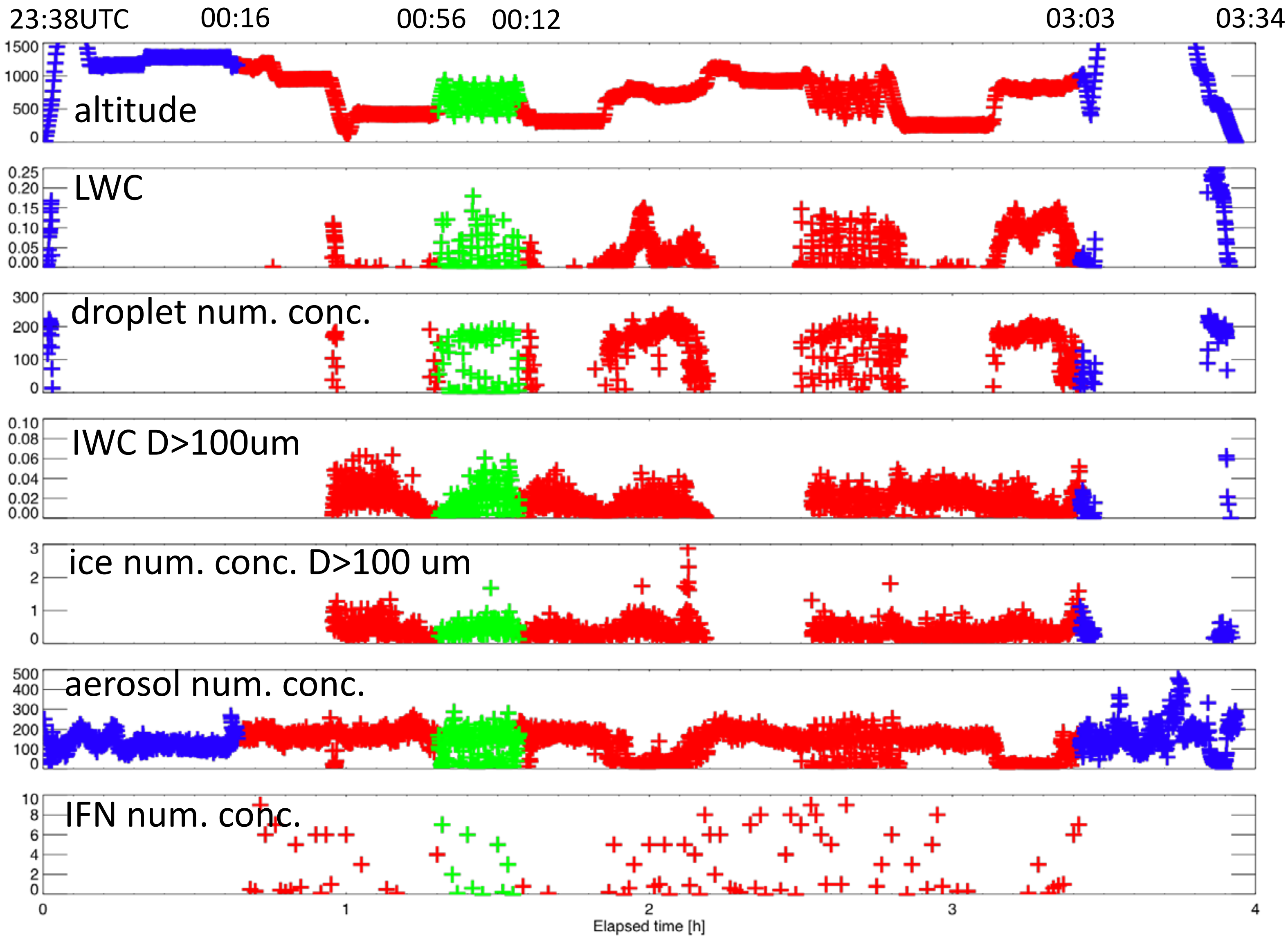
MODIS 3.7 um 03:00 UTC



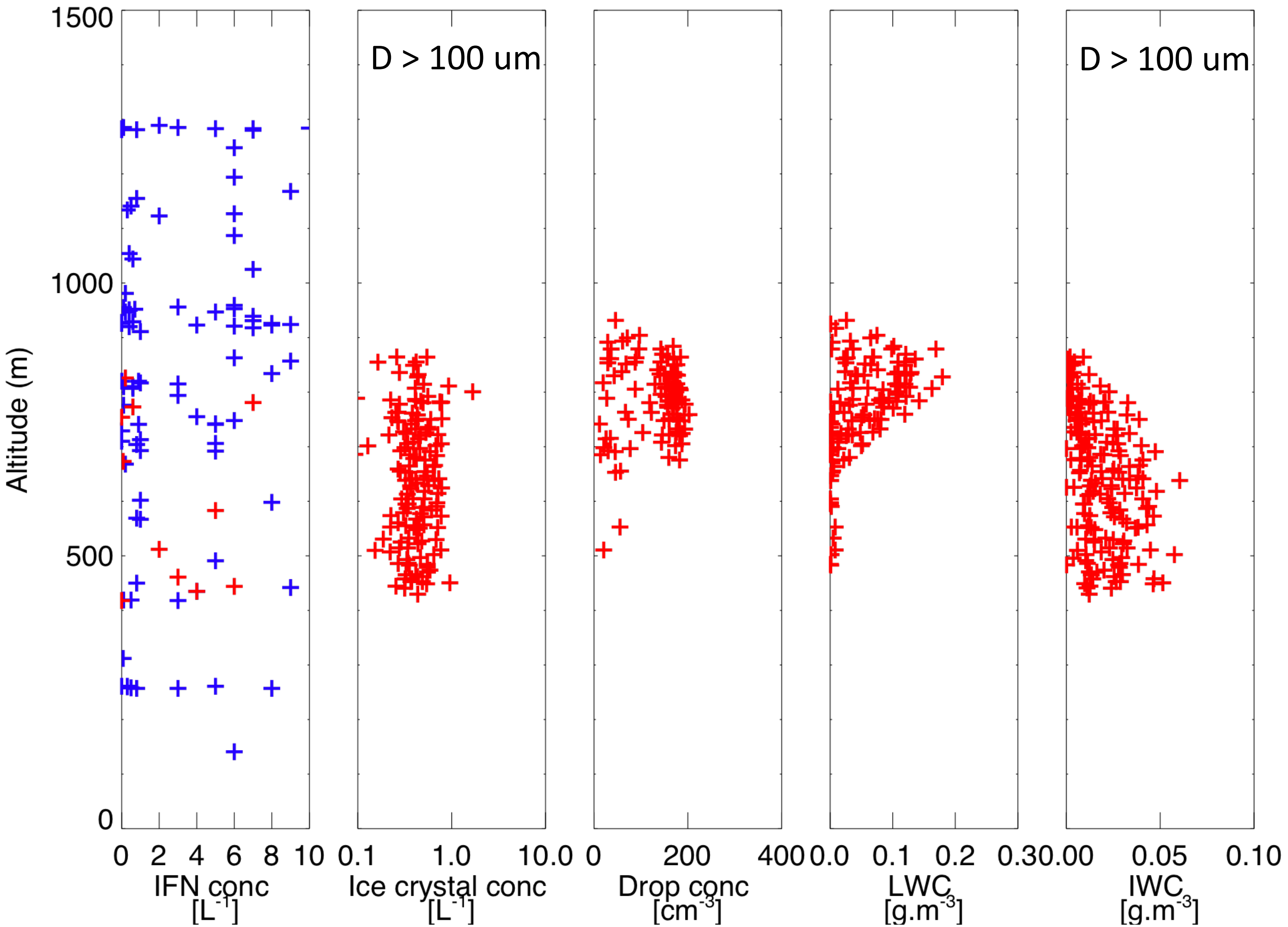


ISDAC Flight 31
-158
-156
-154
-152
72.50
72
01:12
00:56
2000
1500
1000
500
0
Altitude (m)
Longitude (deg)

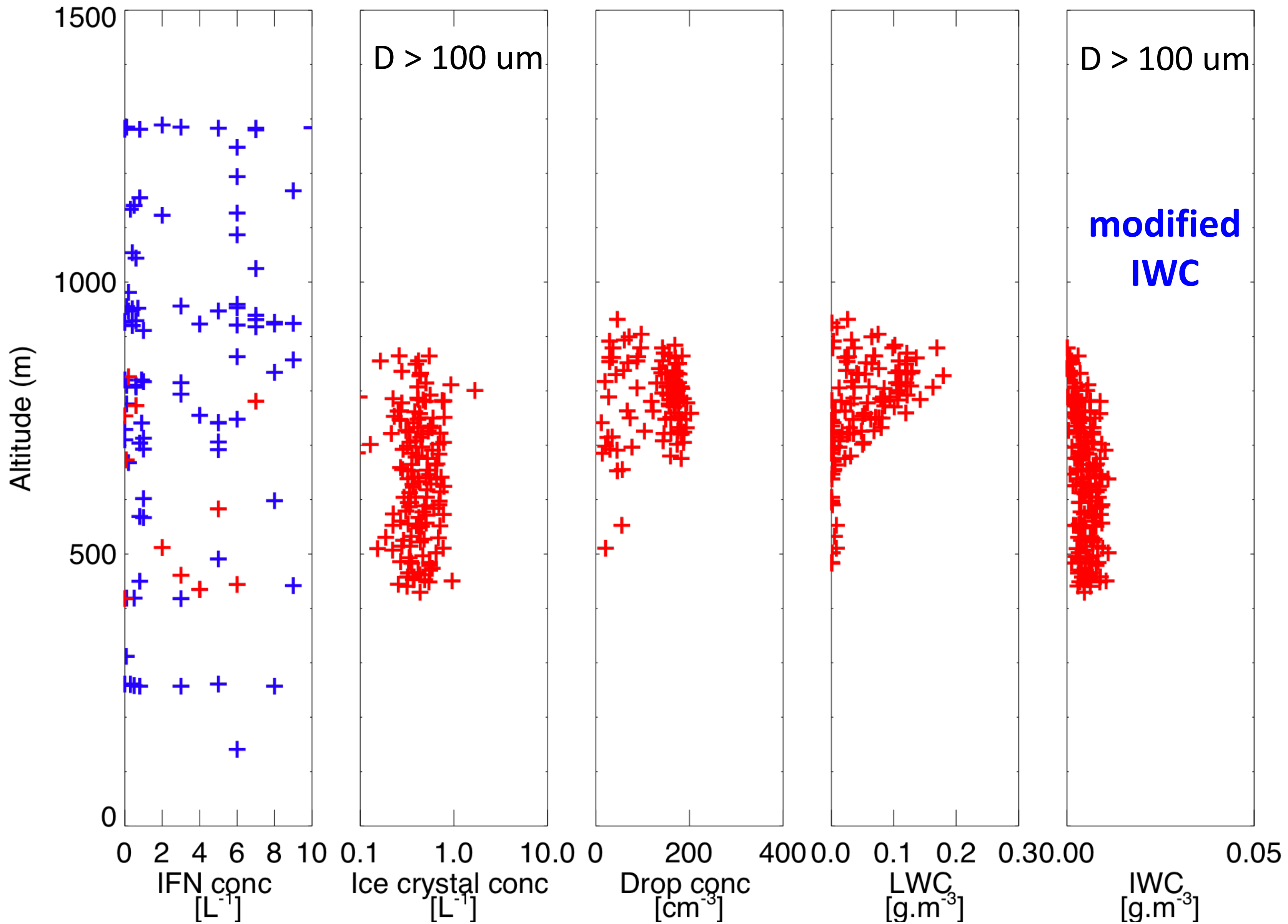
Aircraft observations: Flight 31



Aircraft observations: Flight 31



Aircraft observations: Flight 31



Model Description: Dynamics

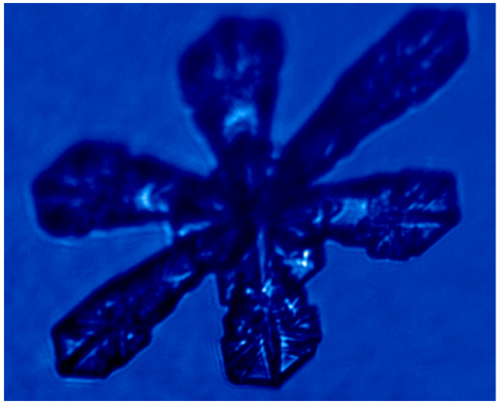
- 3.2 x 3.2 x 1.5 km, doubly periodic BCs
- 64 x 64 x 100 mesh, 50 m x 50 x 15 m uniform grid
- LES code [Stevens and Bretherton, 1997]
- dynamic Smagorinsky subgrid model [Kirkpatrick et al., 2006]
- domain translation with mean winds
- fixed surface temperature, similarity sensible and latent heat fluxes
- advective flux and subsidence profiles from ECMWF
- 2-stream radiative transfer, 44 wavelength bands [Toon et al., 1989]

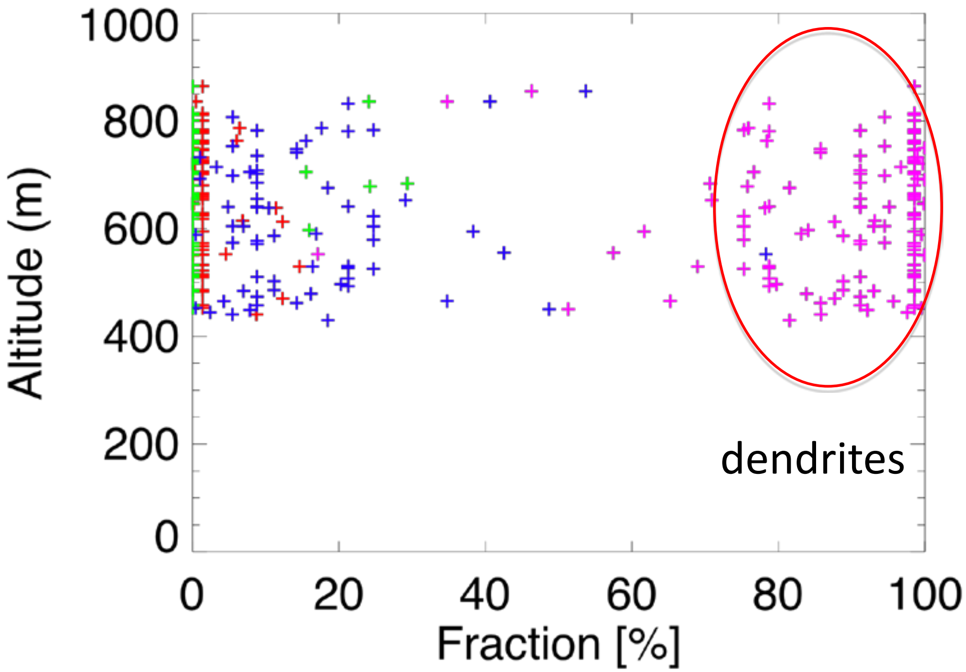
Model Description: Microphysics

- size resolving, bin scheme [Jensen et al., 1994; Ackerman et al., 1995; Fridlind et al., 2007]
- diagnostic aerosols: 32 bins, D = 20 nm–1 µm
- liquid: 32 bins, D = 1.5 µm–2.8 mm
- ice: 32 bins, D_{max} = 2 µm–9 cm
- also keep track of aerosols embedded in drops and ice
- processes: drop activation, heterogeneous ice formation, sedimentation, collision-coalescence
- ice fall speeds and collision-coalescence efficiencies based on mass, maximum dimension, projected area, and aspect ratio relations [Böhm, 1989, 1992a-c, 1994, 1999, 2004]

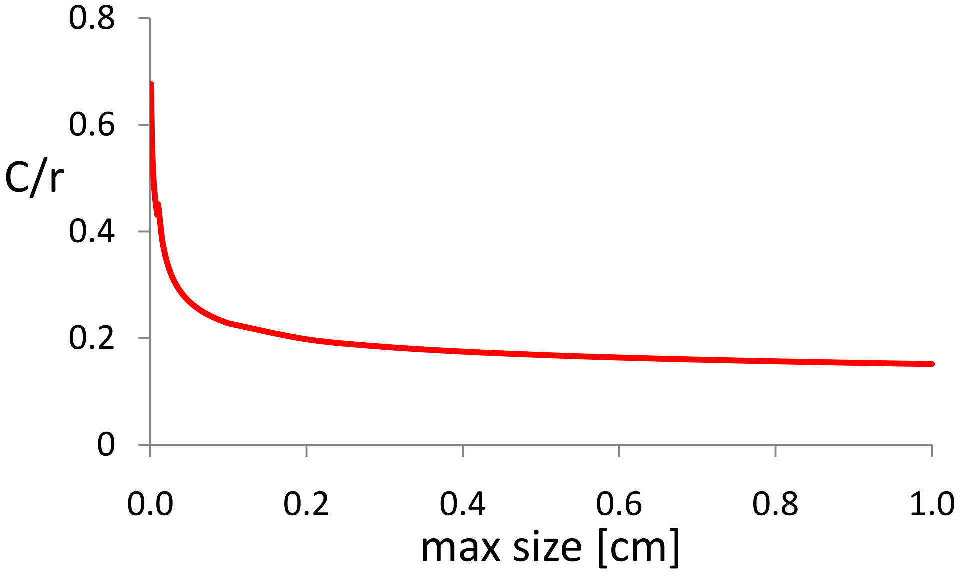
Ice crystal habit parameterization

Very pristine case (compared to M-PACE), dendritic shapes predominate at all heights



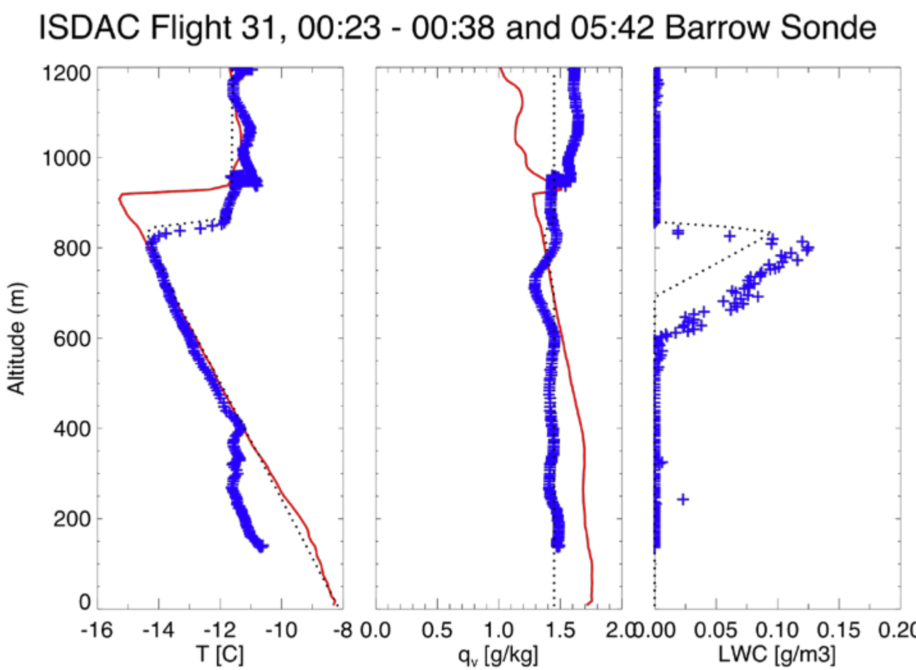


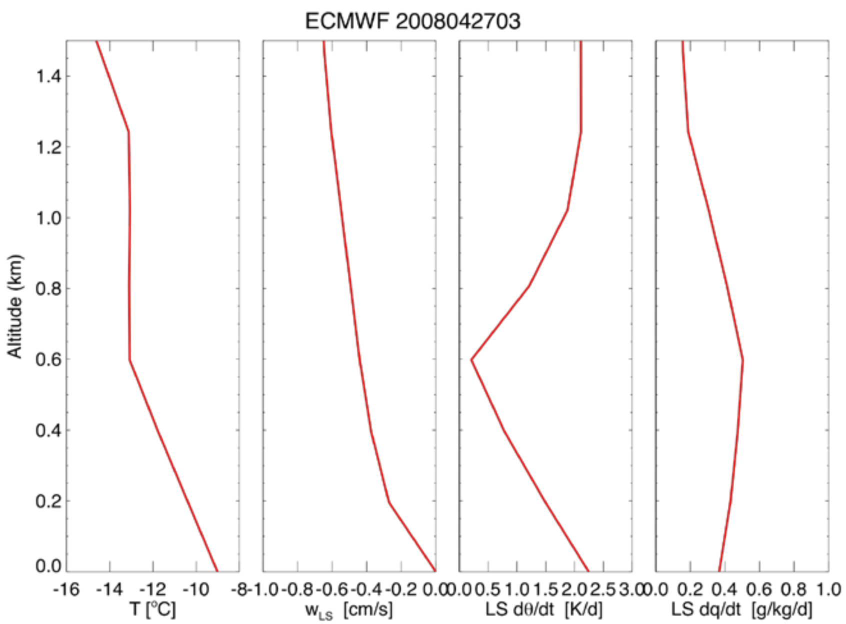
- M-D, A-D relations from Mitchell (1996); P1d crystal
- aspect ratio derived from Mitchell relations assuming constant ice density
- shape factor (C/r) – theoretical formulation for oblate spheroids

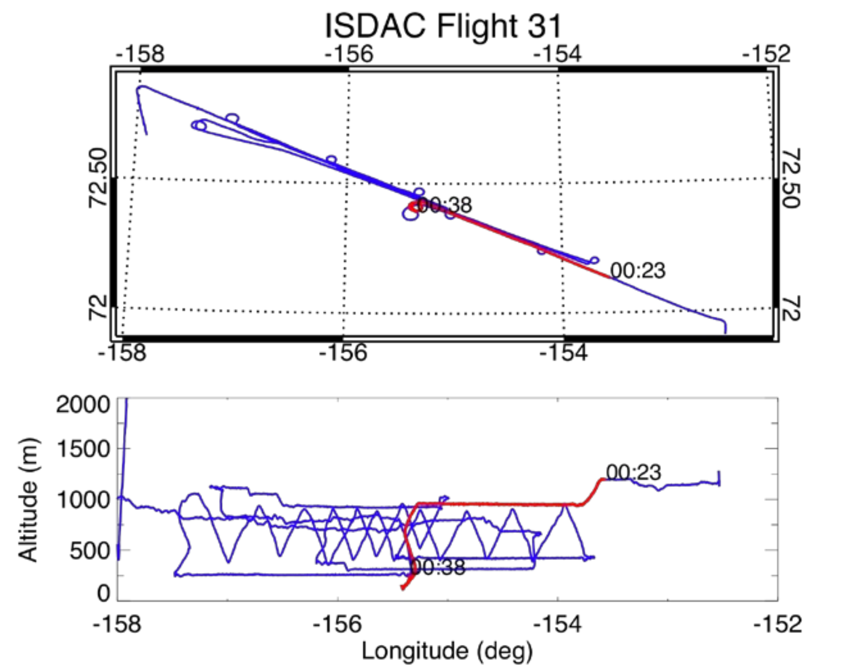


Model initialization

- idealized sounding derived from aircraft observations and ARM sounding data
- ECMWF derived LS forcing (S. Xie)







Simulation design

Different treatments of ice nuclei in separate runs:

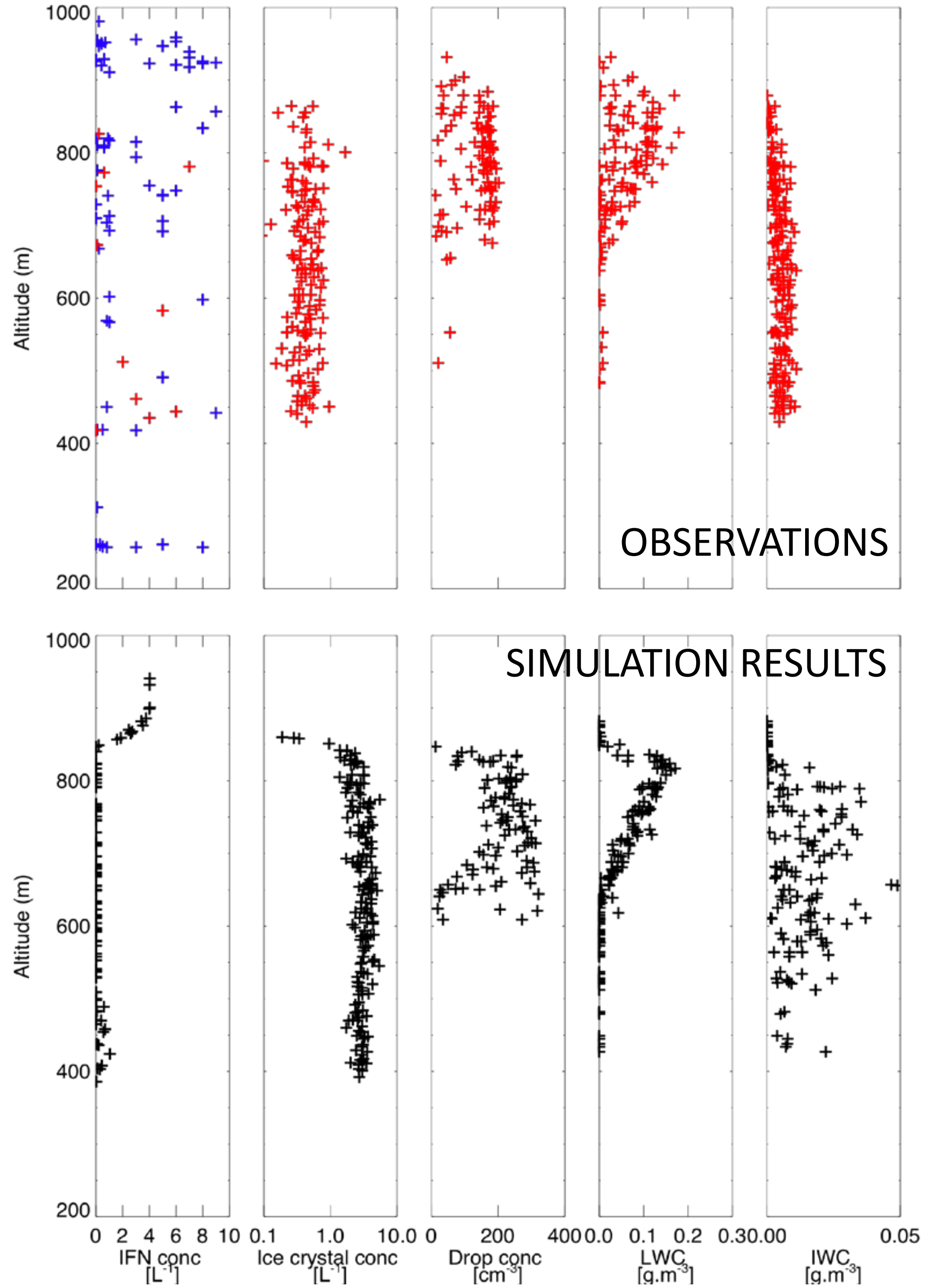
- diagnostic ice nuclei in deposition mode only (Morrison and Zuidema, 2008), all IN easily activated
- prognostic ice nuclei in deposition, condensation, contact, and immersion modes: 10 bins, most to least easily nucleated

$4L^{-1}$ diagnostic IN

Analysis: randomly sample (in horizontal space and time) model domain using altitudes of airborne measurements

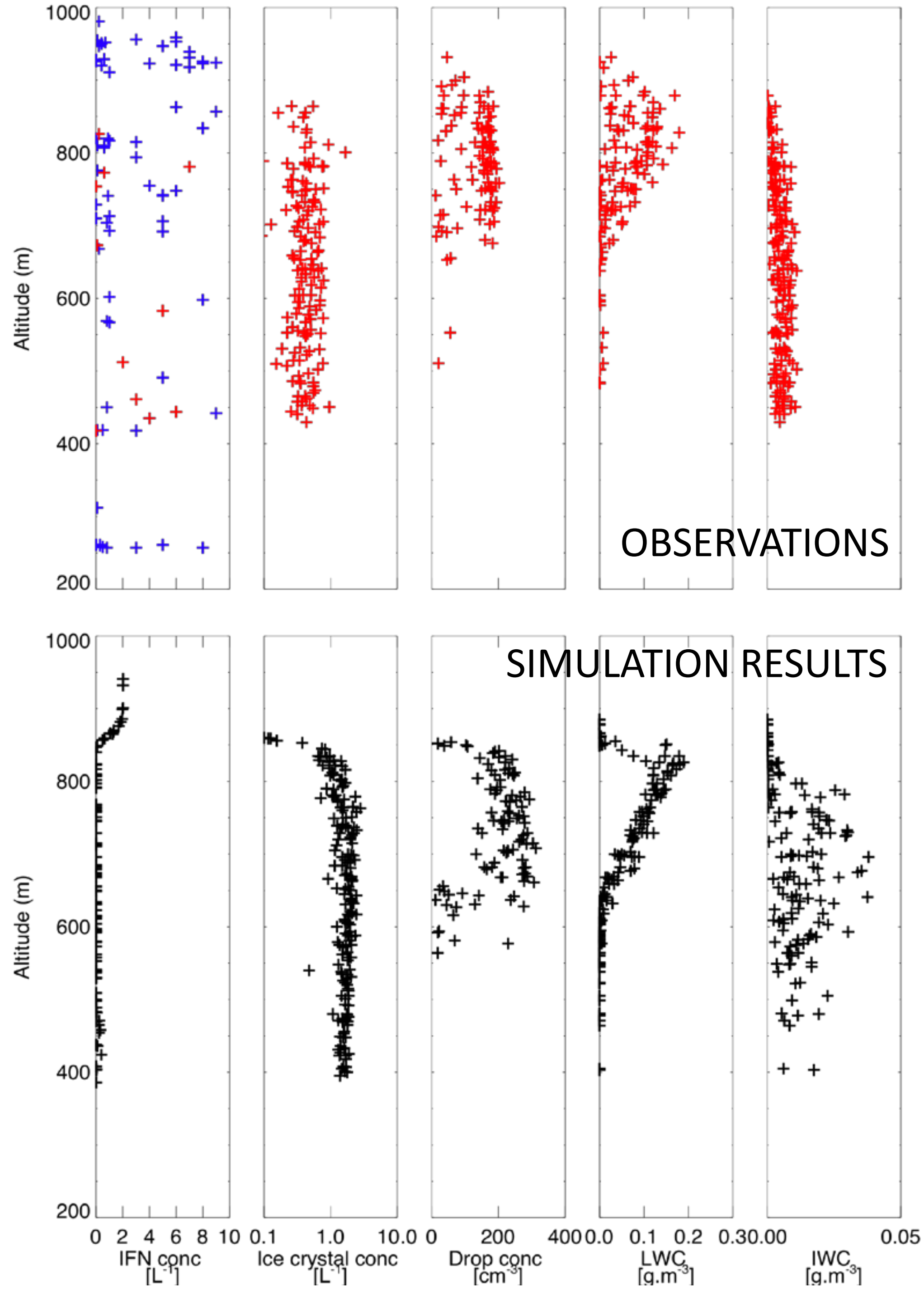
Summary:
- Ice number concentration too great
- Ice water contents also too great
- LWC and drop conc. about right

=> decrease IN concentration



2L^{-1} diagnostic IN

Summary:
- Ice number concentration still too great
- Ice water contents also
- LWC and drop conc. slightly increase



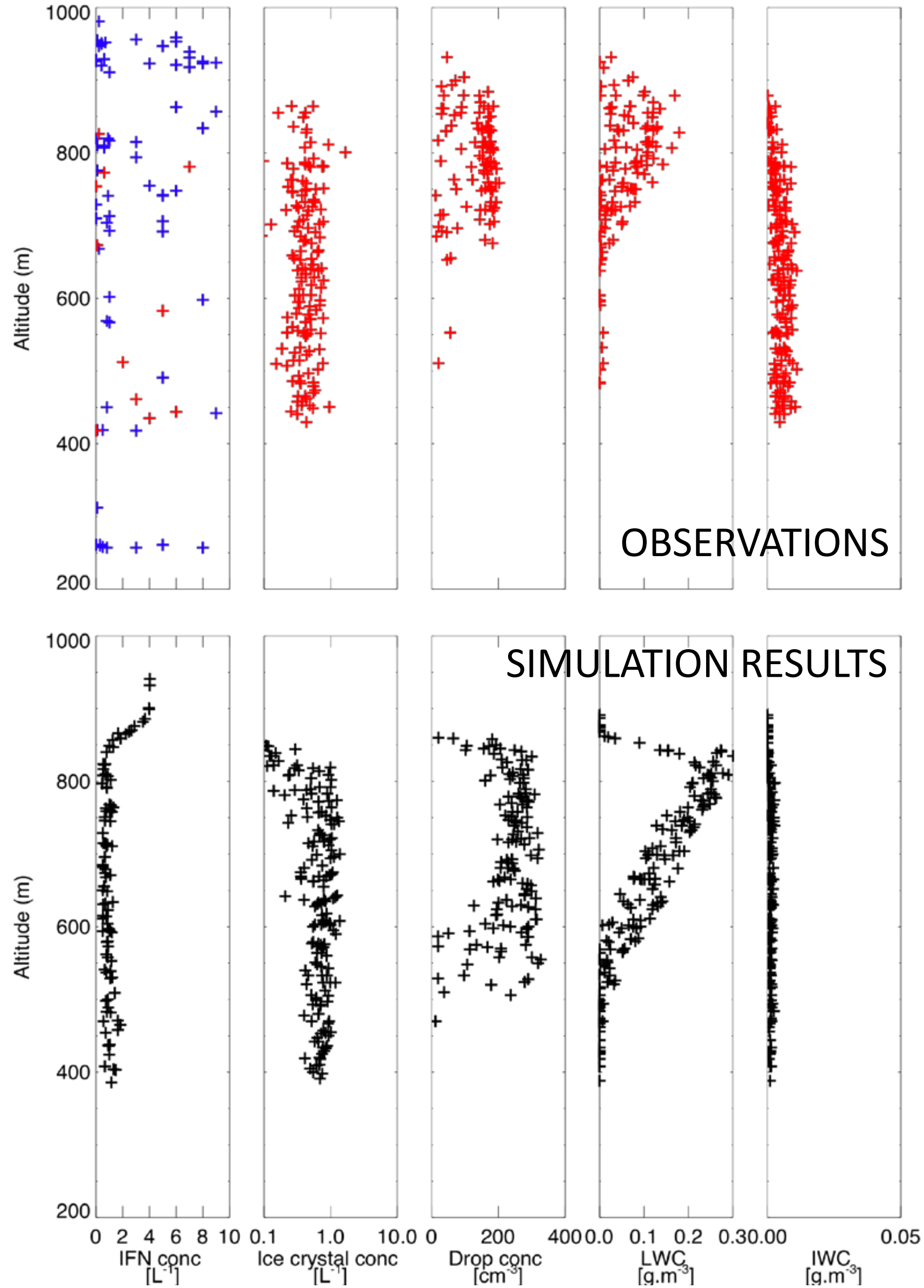
Prognostic IN treatment

- $4L^{-1}$ IN
- Ice-liquid collisions have surprisingly large impact on LWC and ice concentrations, but CPI images do not show any significant riming, so for now we turn off ice-liquid and ice-ice collisions entirely.

Summary:

- ice number concentrations about right
- ice crystals fall speed too small; full BL depletion in > 1 day
- IWC too small
- droplet concentration and LWC too great

=> increase ice growth – go back to fixed shape factor



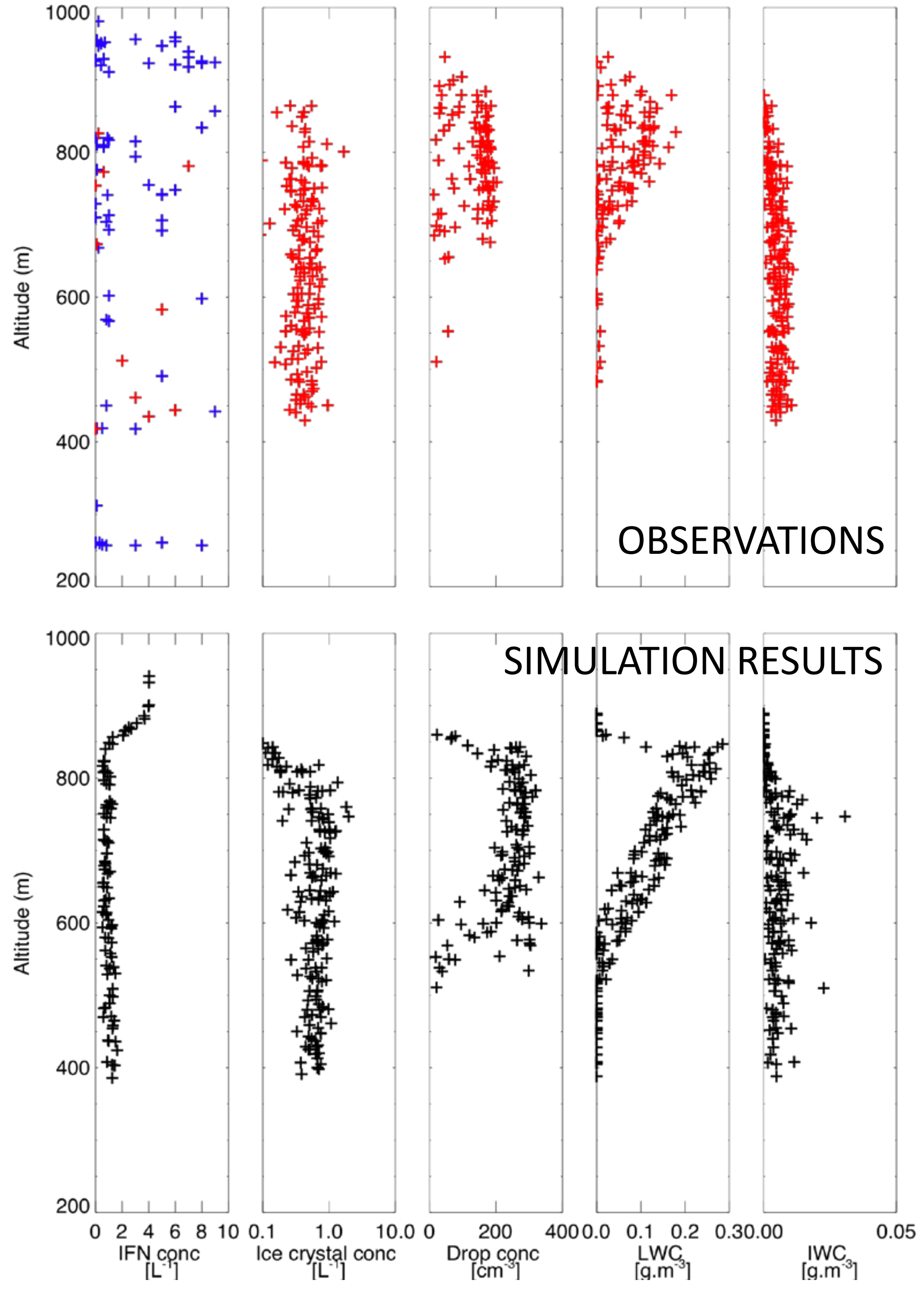
Prognostic IN treatment

- $4L^{-1}$ IN
- no ice-liquid and ice-ice collisions
- C/r fixed at 0.5 (Westbrook, 2008)

Summary:

- ice number concentration and IWC about right
- drop concentration and LWC still too great

=> decrease LS moisture advection



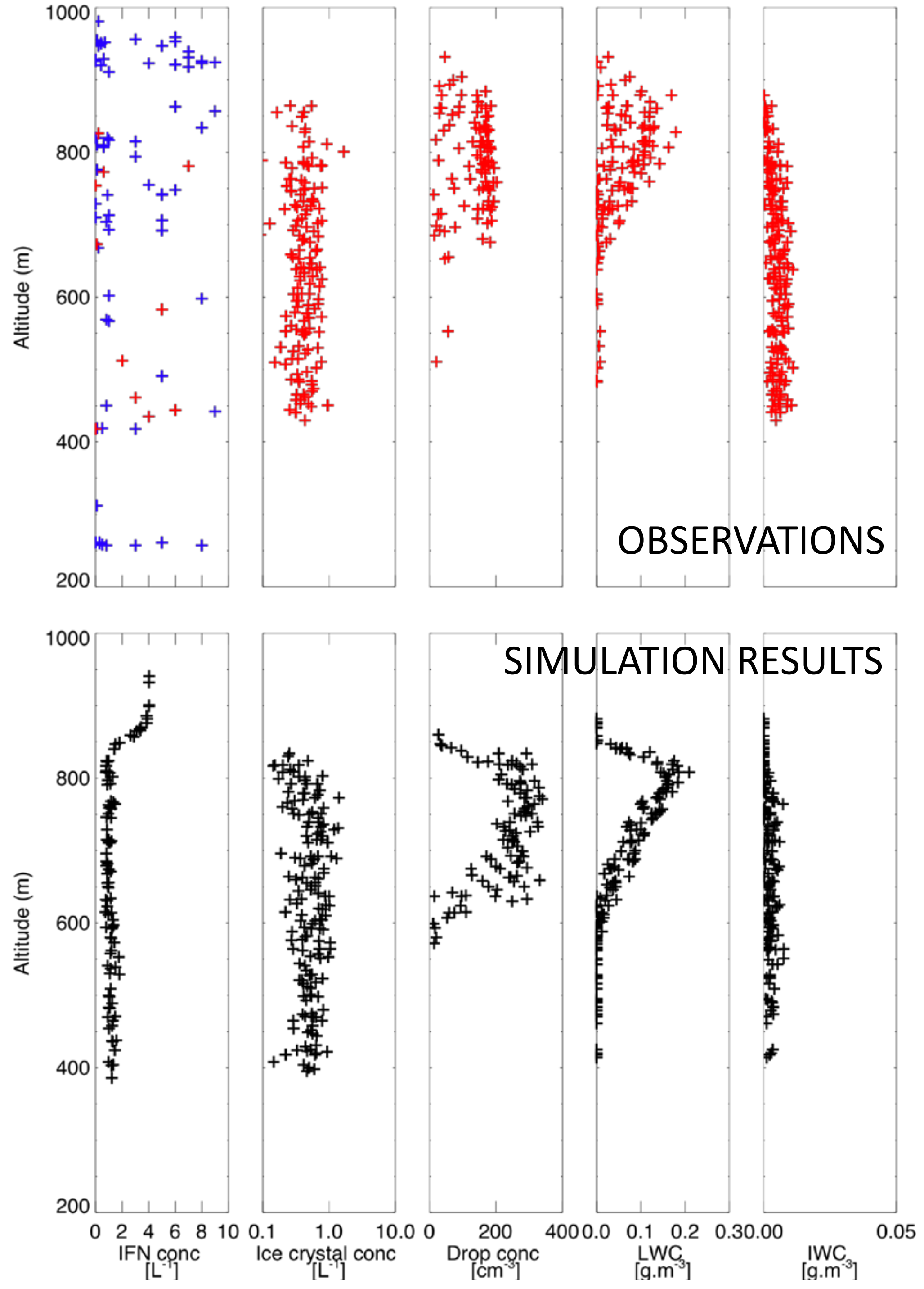
Prognostic IN treatment

- $4L^{-1}$ IN
- no ice-liquid and ice-ice collisions
- C/r fixed at 0.5 (Westbrook, 2008)
- no LS moisture advection

Summary:

- ice number concentration and IWC about right
- drop concentration and LWC also very close to the observed

=> RIGHT ANSWER?

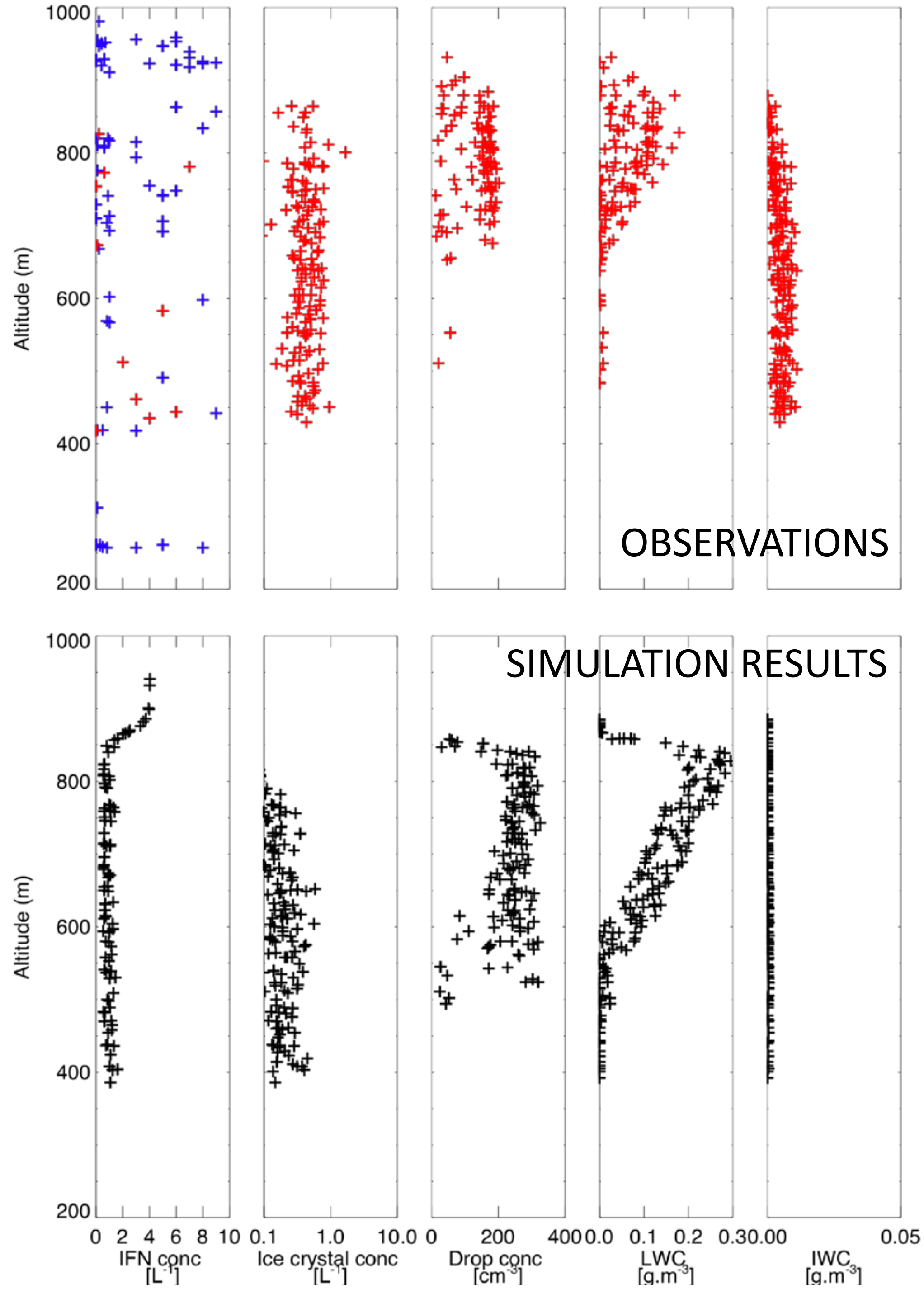


Concluding remarks

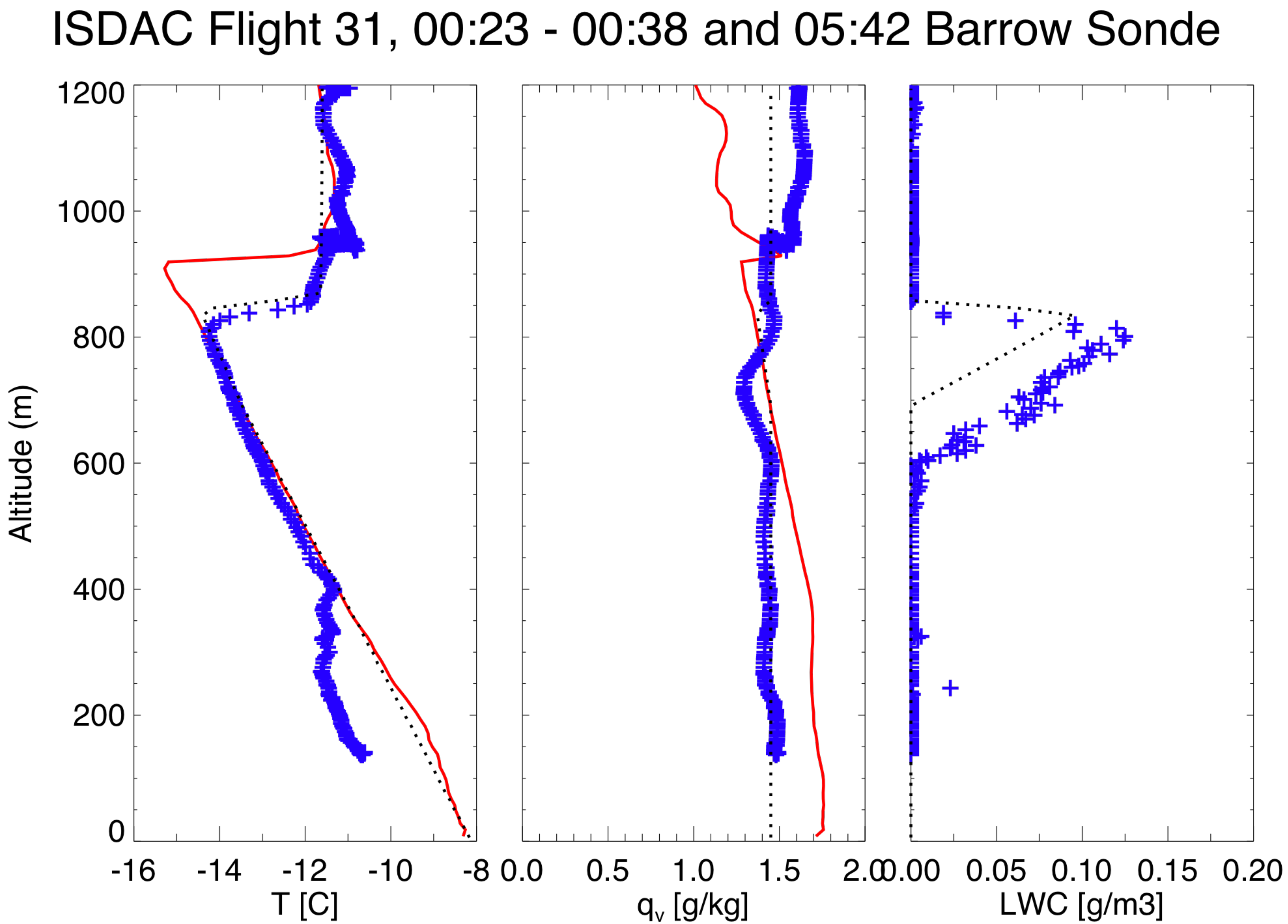
- Haven't used particle spectra yet – "right" answer for wrong reasons? What about D<100 um?
- Flight 31: pristine case, predominantly dendrites (small fall speeds), high IN concentrations => most favorable conditions for models to match the observed ice concentrations. If they cannot, then what? Uncertainties in IN measurements? Alternative IN sources or ice nucleation mechanisms?
- Comparisons with radar observations – not only constraining fall speeds but also comparing simulated and observed cloud structure: correlations between dynamics and microphysics. How different is the cloud over Barrow hours after the aircraft observations were taken?

Additional slides

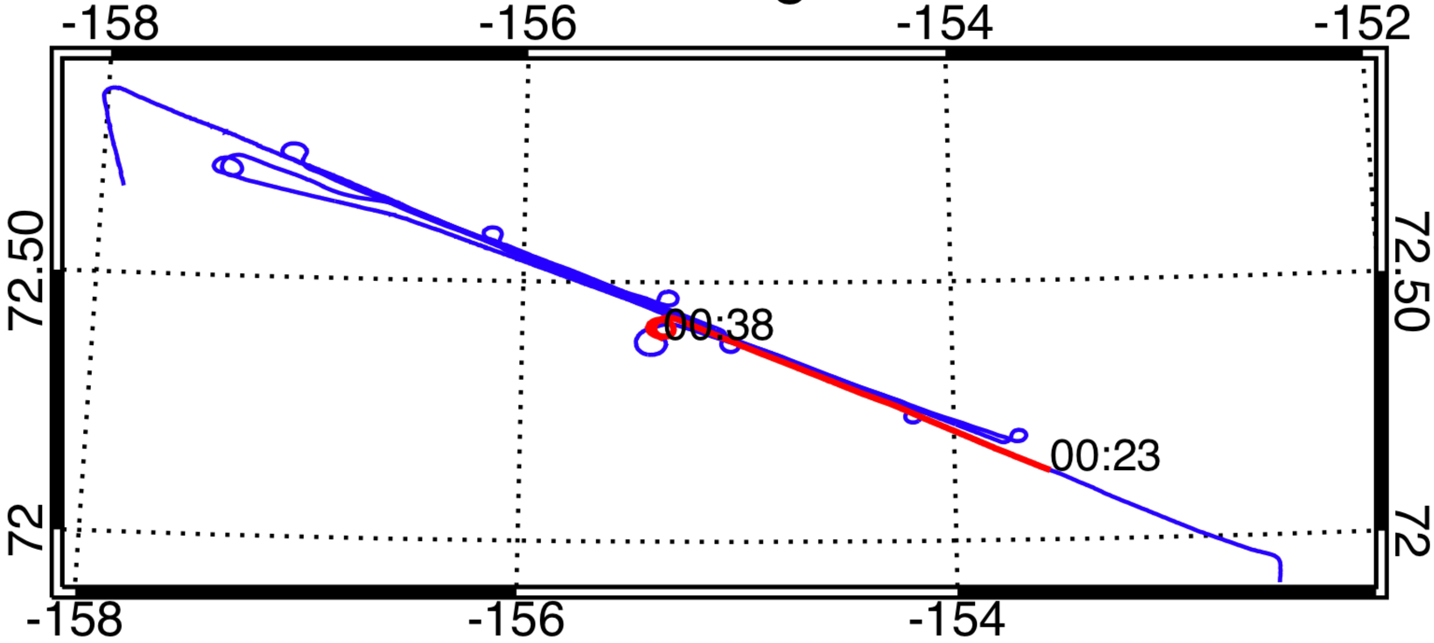
- Diagnostic IN treatment
  - 2L^{-1} IN
  - 4L^{-1} IN
  - 2L^{-1} IN; no ice-ice and ice-liquid collisions
  - 4L^{-1} IN; no ice-ice and ice-liquid collisions
  - Prognostic IN treatment
  - 4L^{-1} IN
  - 4L^{-1} IN; no ice-ice and ice-liquid collisions
  - 4L^{-1} IN; no ice-ice and ice-liquid collisions; S fixed
  - 4L^{-1} IN; no ice-ice and ice-liquid collisions; no LS moisture advection
  - 4L^{-1} IN; no ice-ice and ice-liquid collisions; no LS moisture advection; fixed S
  - 4L^{-1} IN; no ice-ice and ice-liquid collisions; spheres

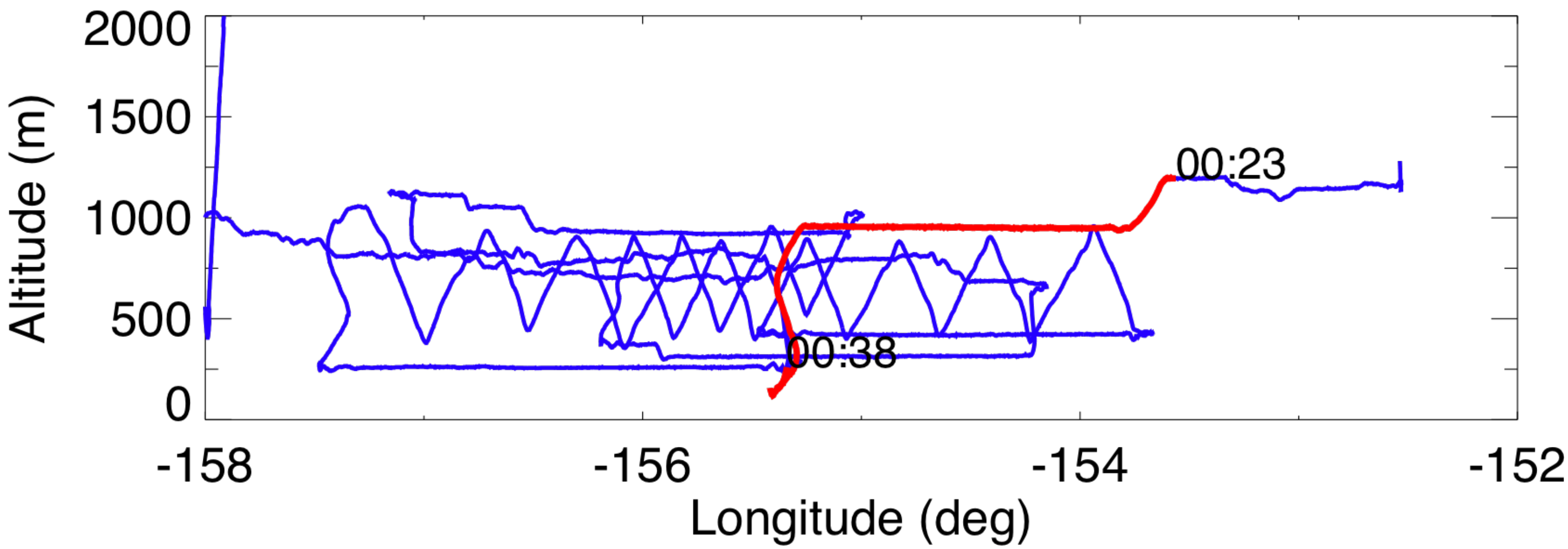


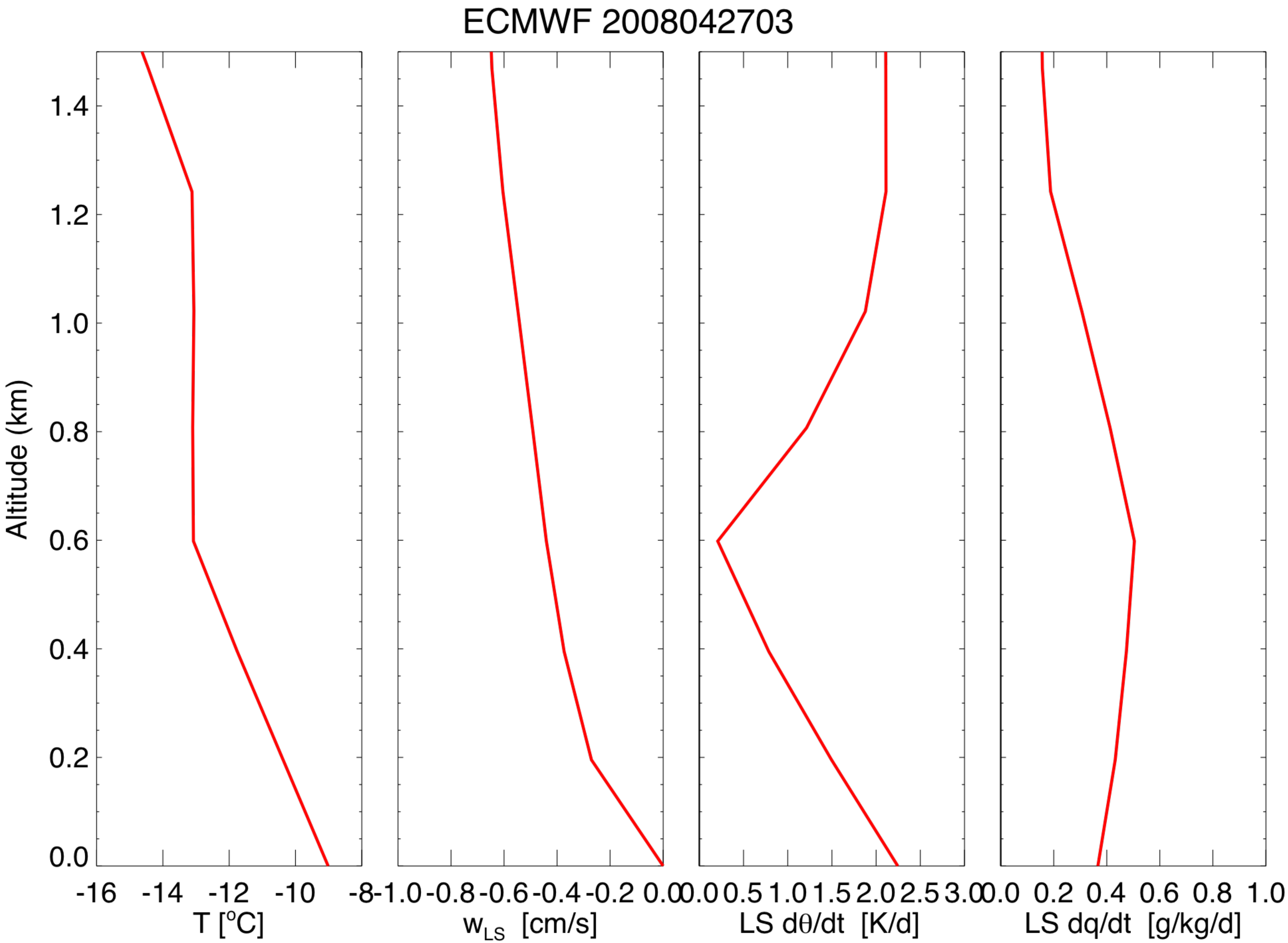
Mechanism	Temp	Supersat	Dependence	Description
Primary modes				
contact	-4 > T > -14	-	$f_{lin}(T)$	drop + IN_{aer} -> ice
condensation	-8 > T > -22	$0 < S_w$	$f_{lin}(T)$	In_{aer} -> ice
deposition	-10 > T	$0 < S_i < 0.2$	$f_{exp}(T)$	In_{aer} -> ice
immersion	-10 > T > -24	-	$f_{lin}(T)$	drop + In_{drop} -> ice
Multiplication				
rime-splintering	-3 > T > -8	-	$f_{lin}(T)$	crystal per 250 collisions
drop shattering	0 > T	-	D_{drop}> 50 um	multiplication factor = 2
ice fragmentation	0 > T	-	$f_{lin}(\Delta mom^2)$	up to 20-60 fragments
Other processes				
evaporation nuclei	0 > T	$S < S_w$	-	$1/10^4$ drops -> IN_{aer}
charge enhancement	0 > T	-	$f(D_{drop})$	evaporate retains charge
evaporation freezing	0 > T	$S < S_w$	-	“some” drops just “freeze”


ISDAC Flight 31, 00:23 - 00:38 and 05:42 Barrow Sonde
Altitude (m)
1200
1000
800
600
400
200
0
-16
-14
-12
-10
-8
T [C]
0.0
0.5
1.0
1.5
2.0
q_v [g/kg]
0.00
0.05
0.10
0.15
0.20
LWC [g/m3]

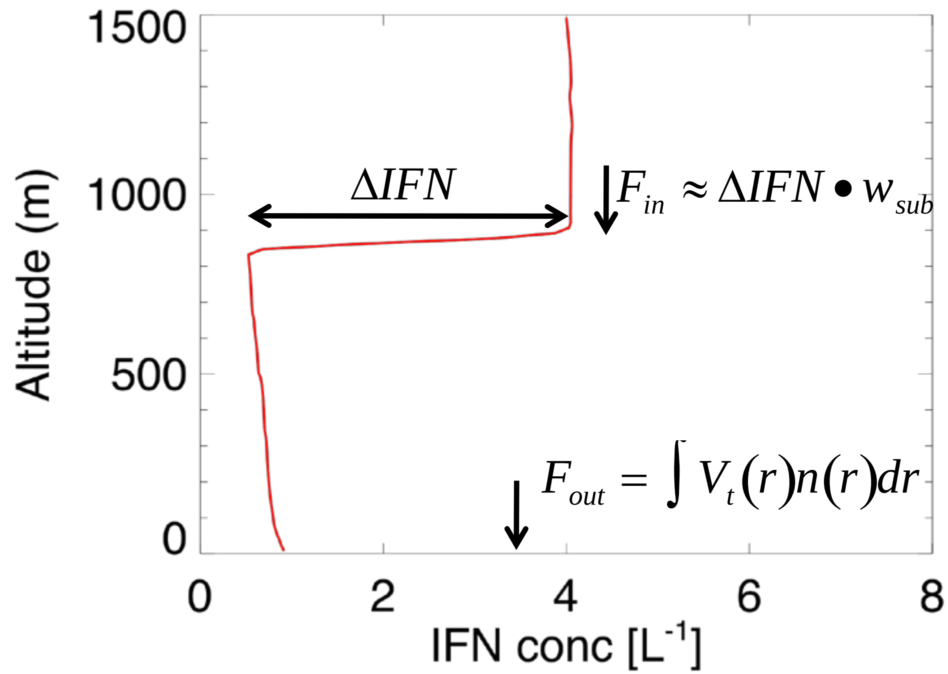
ISDAC Flight 31







ECMWF 2008042703
Altitude (km)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
-16
-14
-12
-10
-8
T [°C]
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
w_LS [cm/s]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
LS dθ/dt [K/d]
0.0
0.2
0.4
0.6
0.8
1.0
LS dq/dt [g/kg/d]



1500
1000
500
0
Altitude (m)
0
2
4
6
8
IFN conc [L^-1]
ΔIFN
F_in ≈ ΔIFN • w_sub
F_out = ∫ V_t(r)n(r)dr