Towards ice formation closure in mixed-phase boundary layer clouds during ISDAC

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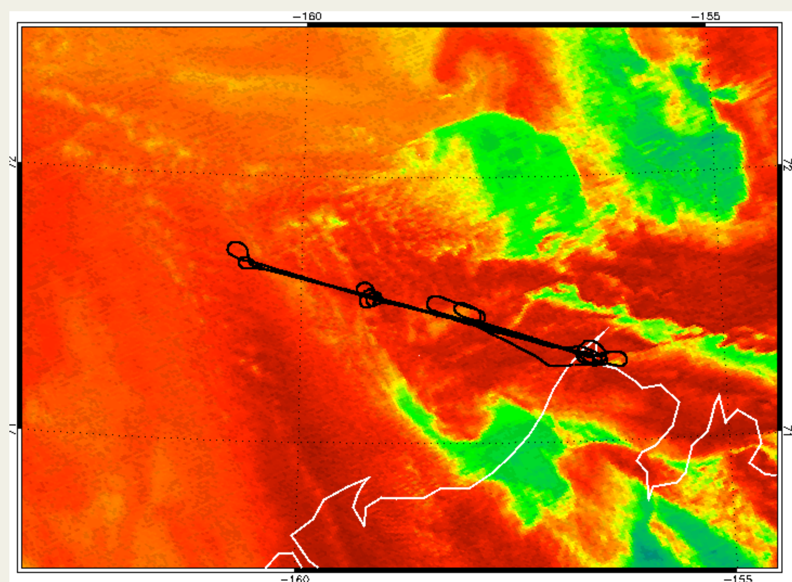
Objectives:

➢ Ice formation – can "conventional" ice nucleation mechanisms explain observed ice concentrations?

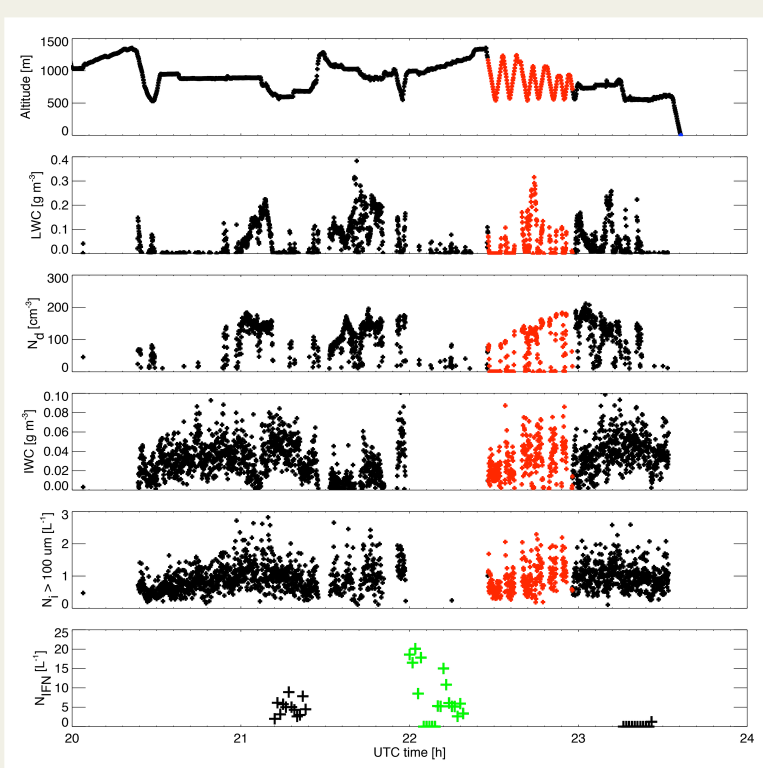
➢ Use in-situ and radar observations to constrain model simulations

Case description
April 8, 2008 – Flight 16

- Single layer mixed-phase stratus cloud
- Aircraft measurements taken near and over Barrow allow comparisons with ground-based remote sensing data
- CPI images indicate predominance of dendritic ice shapes at all levels – most favorable case for "conventional" nucleation mechanisms (high IN concentrations, too)



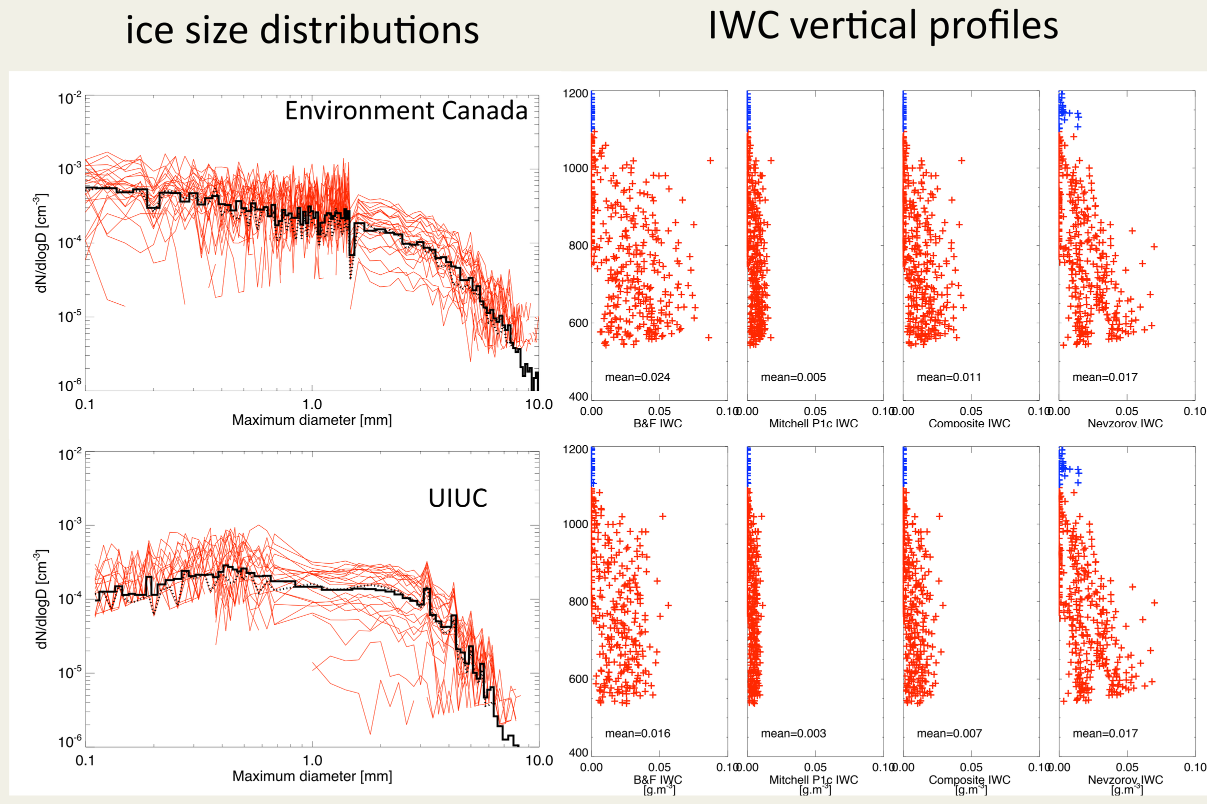
3.7-um radiances at 22.40Z with flight track overlaid



Time series of in-situ measurements

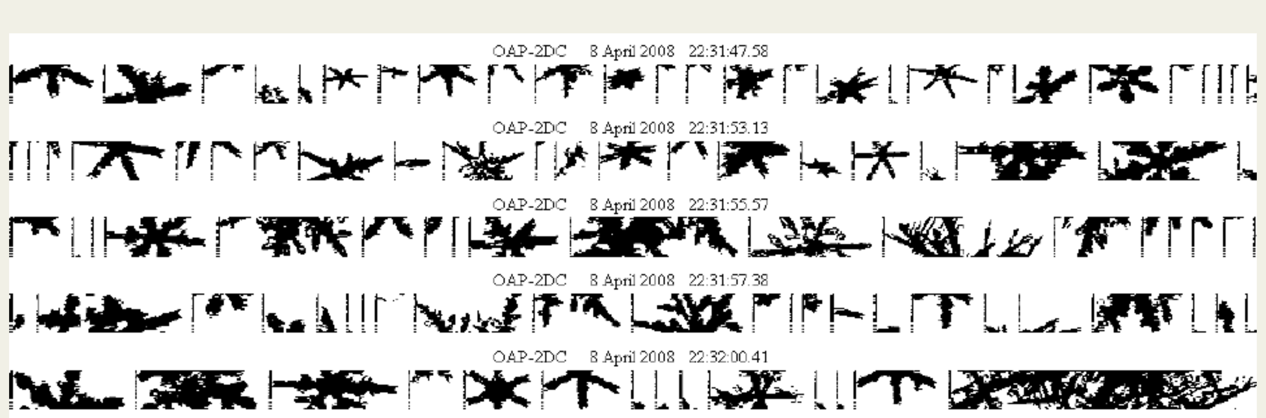
- mean IFN concentrations above cloud layer ~ $10 L^{-1}$
- mean ice crystal concentrations ~ $1 L^{-1}$

ice size distributions IWC vertical profiles

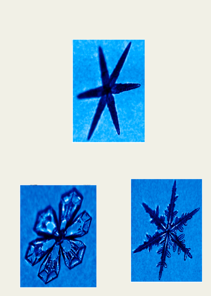


IWC derived from ice PSD and assumed M-D relation

- pristine dendrites do not provide good match with total ice water probe
- better match obtained if a gradual shift to aggregates at size 2-5 mm is assumed (1-4 mm, much better yet)



Representative 2DC images



Representative CPI images (D~200 um)

Model description and setup

3.2 x 3.2 x 1.5 km, doubly periodic BCs, 50 x 50 x 15 m uniform mesh

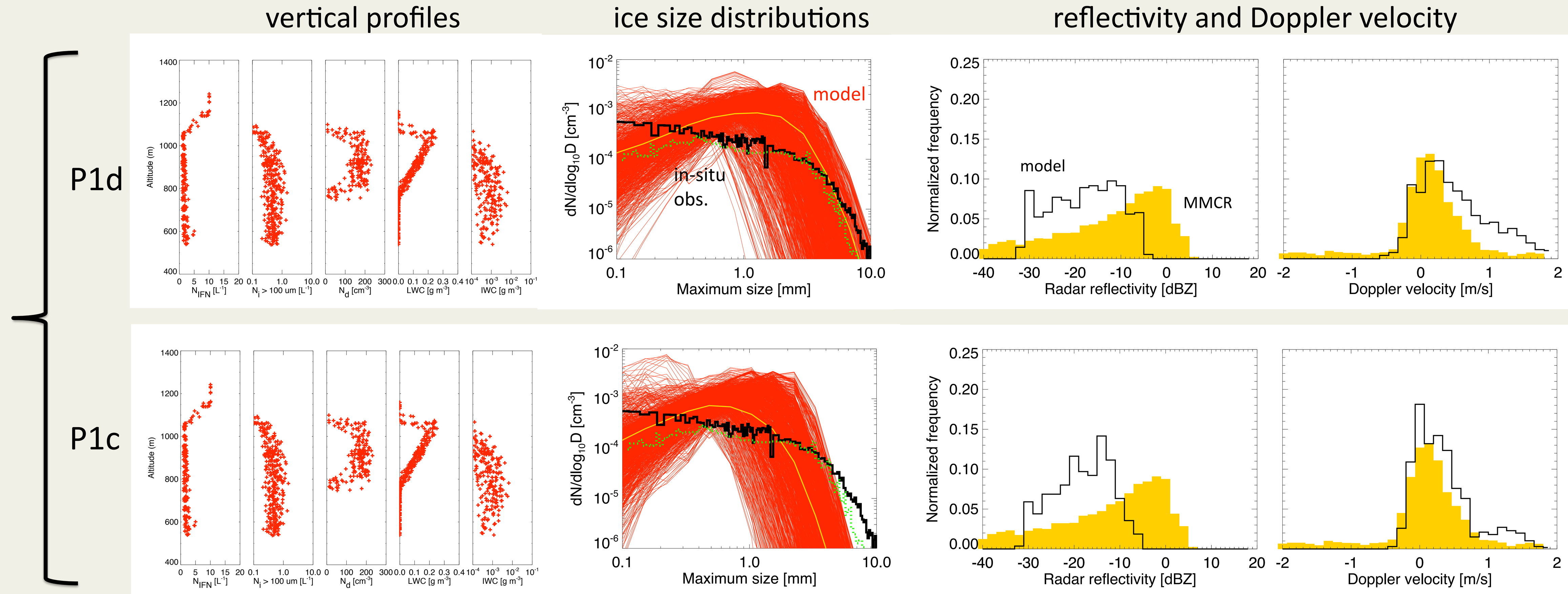
- LES code [Stevens and Bretherton, 1997]; dynamic Smagorinsky subgrid model [Kirkpatrick et al., 2006]
- 2-stream radiative transfer, 44 wavelength bands [Toon et al., 1989]
- fixed surface temperature, similarity sensible and latent heat fluxes
- large-scale subsidence from NCEP reanalysis
- size resolving, bin scheme [Jensen et al., 1994; Ackerman et al., 1995; Fridlind et al., 2007]
- diagnostic aerosols: 32 bins, D = 20 nm–1 μm
- prognostic IN: 10 activation bins
- liquid: 32 bins, D = 1.5 μm–2.8 mm
- ice: 32 bins, dendrites D_{max} = 2 μm–9 cm, optional aggregates: 32 bins, D_{max} = 2 μm–5 cm
- also keeps 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 Mitchell [1996], [Böhm, 1989, 1992a-c, 1994, 1999, 2004]

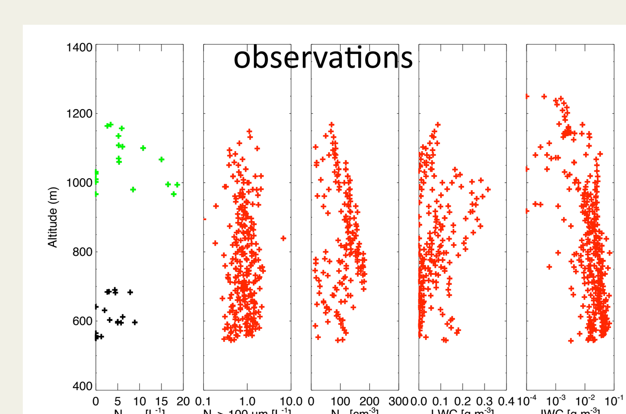
Results

$10 L^{-1}$ prognostic IN, dendritic habits: P1d (stellar crystal) and P1c (broad-armed dendrite)

- enhanced ice depositional growth (fixed shape factor S=0.6)
- ice number concentrations similar to observed (shown below)
- ice size distributions somewhat similar to observed
- simulated Doppler velocities show very good agreement with MMCR observations
- but, simulated reflectivities ~ 10-15 dBz too low

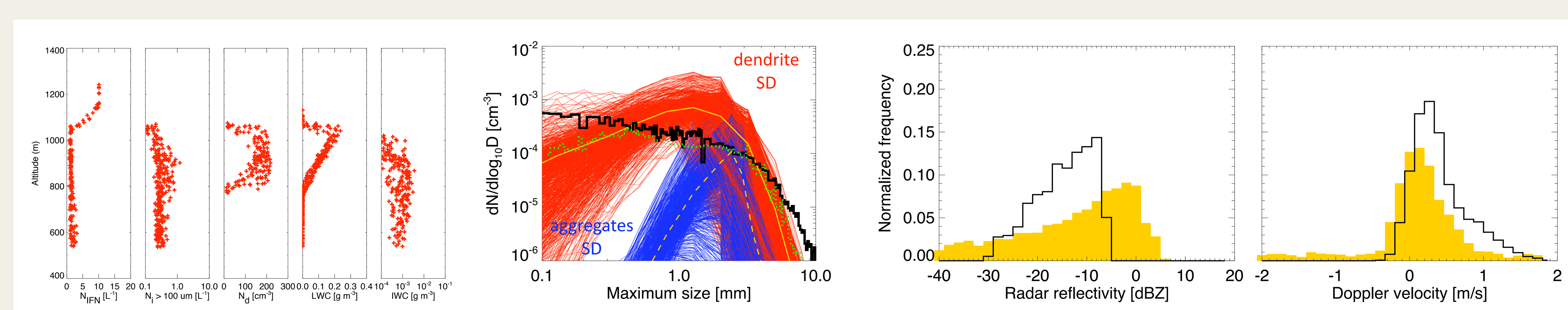
vertical profiles ice size distributions reflectivity and Doppler velocity





$10 L^{-1}$ prognostic IN, stellar dendrite P1d and aggregates of dendrites

- more realistic ice depositional growth S=S(α,D)
- ice number concentrations similar to observed
- ice size distributions also similar to observed
- simulated Doppler velocities match observed
- simulated reflectivities closer to MMCR values, still too low



Summary

➢ 2D-C and 2D-P data and consistency check with Nevzorov IWC help to constrain habit and M-D relation choice.

➢ Simulations using pristine dendrites provide very good match to MMCR Doppler velocities and acceptable agreement with measured ice concentrations. Simulated IWC and radar reflectivity, however, are too low.

➢ Including second ice category of aggregates leads to better agreement with observations quantities. Further refinement is needed.