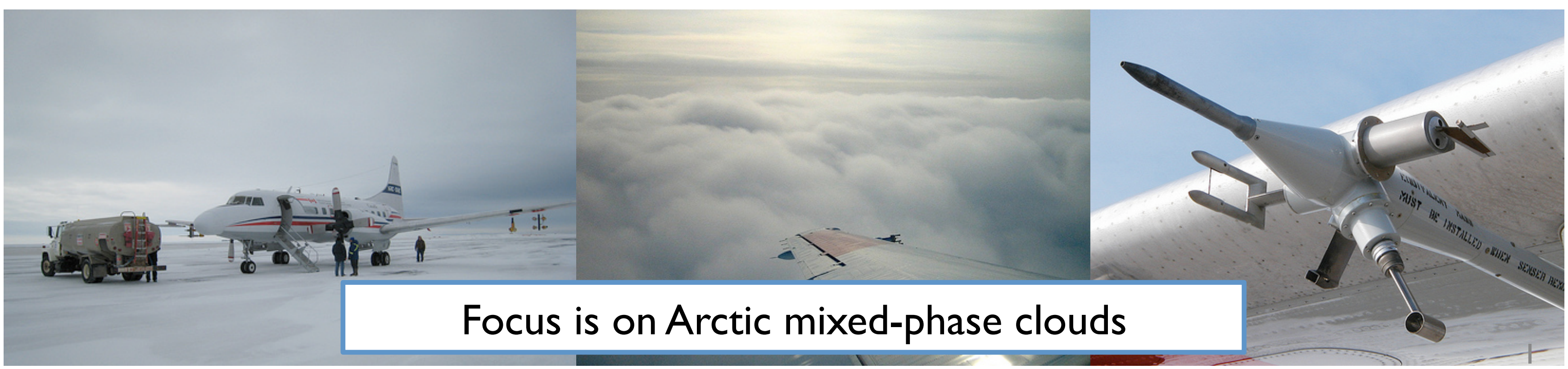
Implementation and testing of an ice nucleation scheme in SAM

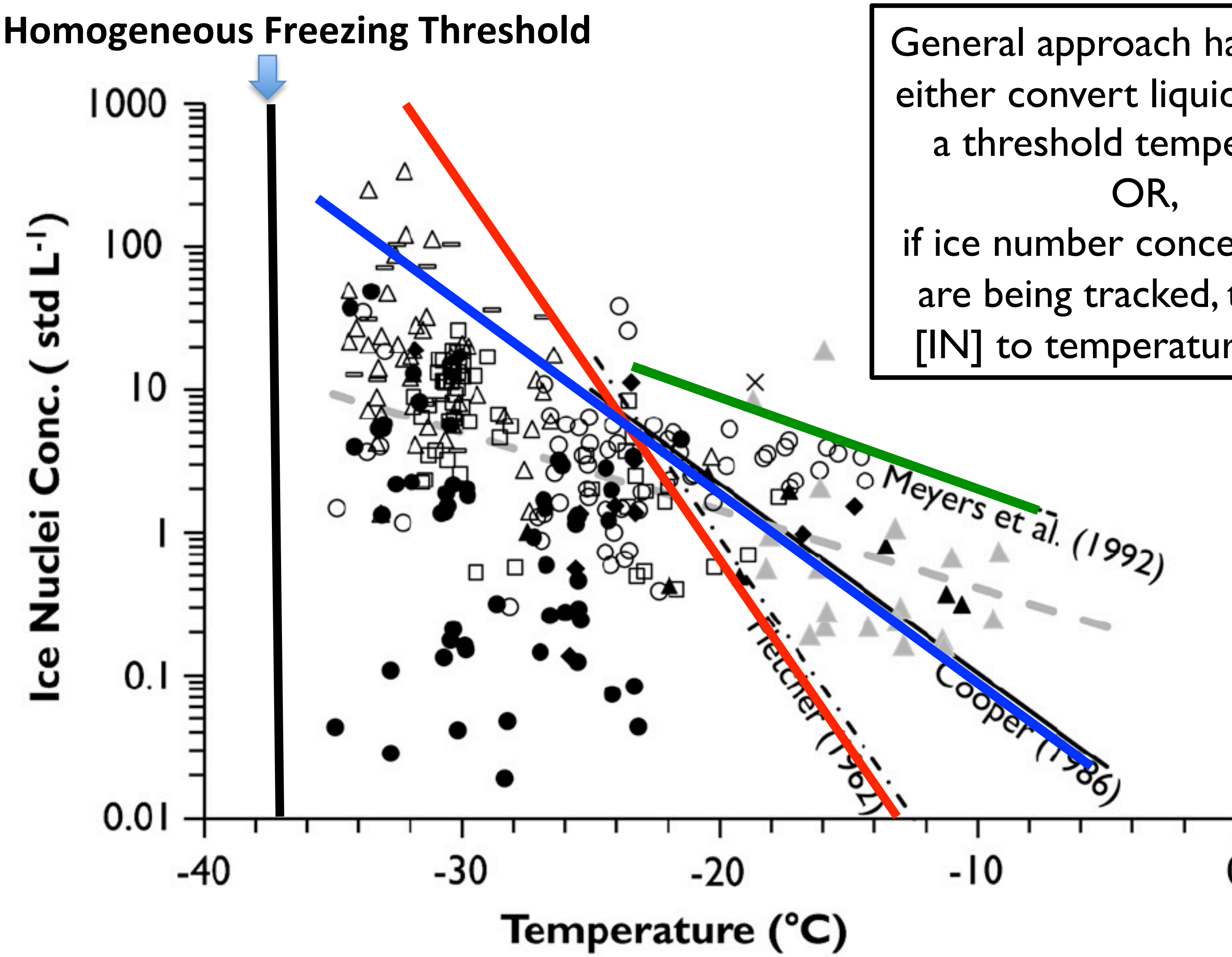
James Carpenter (successful M.S. defense 12/12/12)
Sonia Kreidenweis, Paul DeMott, Mark Branson

(also, thanks to CMMAP for support, and
to Dave Randall, Richard Eykholt, and Kelley Wittmeyer)



Focus is on Arctic mixed-phase clouds

Describing [IN] in models



General approach has been to either convert liquid → ice at a threshold temperature, OR, if ice number concentrations are being tracked, to relate [IN] to temperature ONLY

After DeMott et al., 2010

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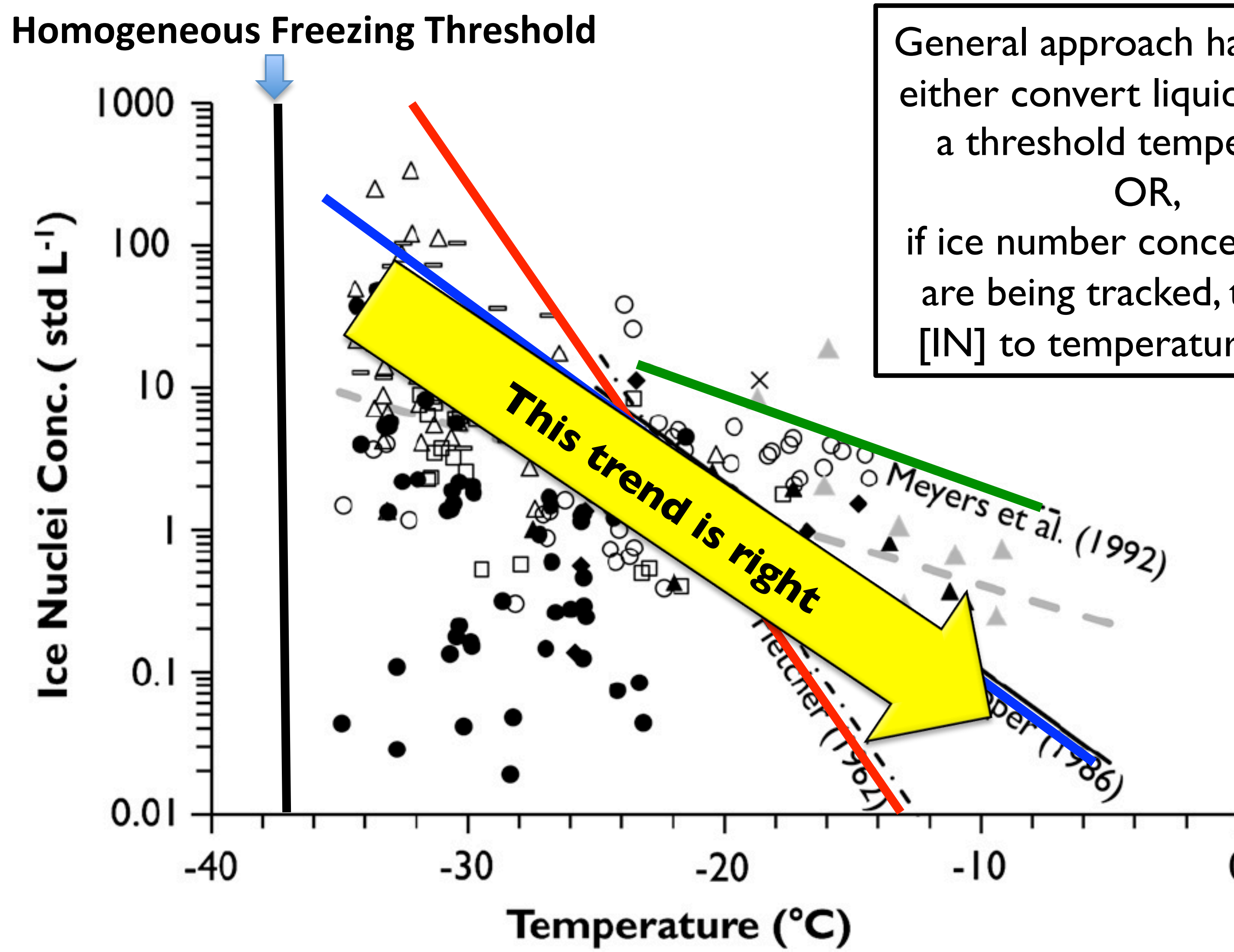

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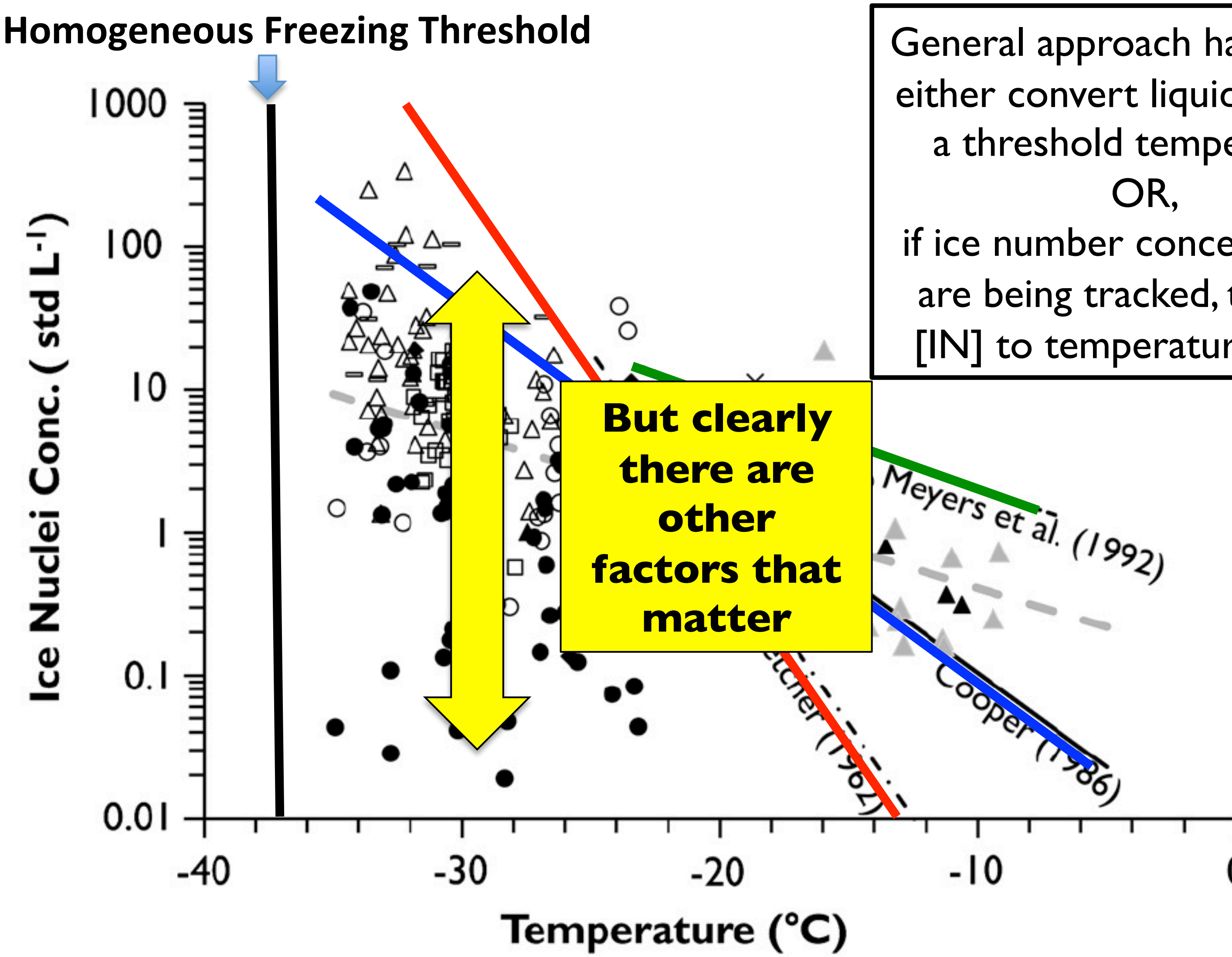

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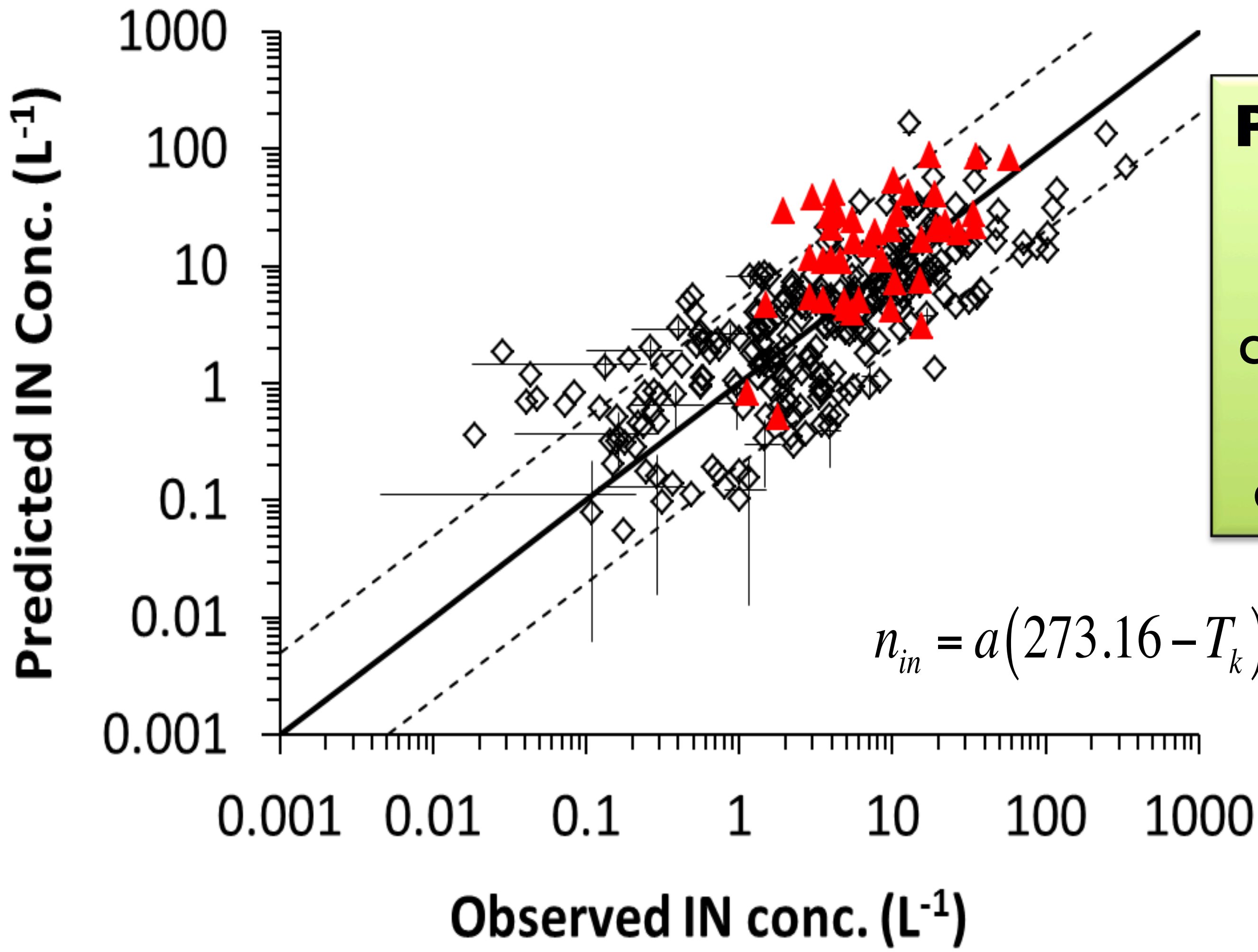
Aerosol-linked parameterization of [IN]



Predicted [IN] are computed from measured concentrations of all particles with diameter > 500 nm

$$n_{in} = a\left(273.16 - T_k\right)^b \left(n_{aer,0.5}\right)^{\left(c(273.16 - T_k)+d\right)}$$

Adapted from DeMott et al., 2010

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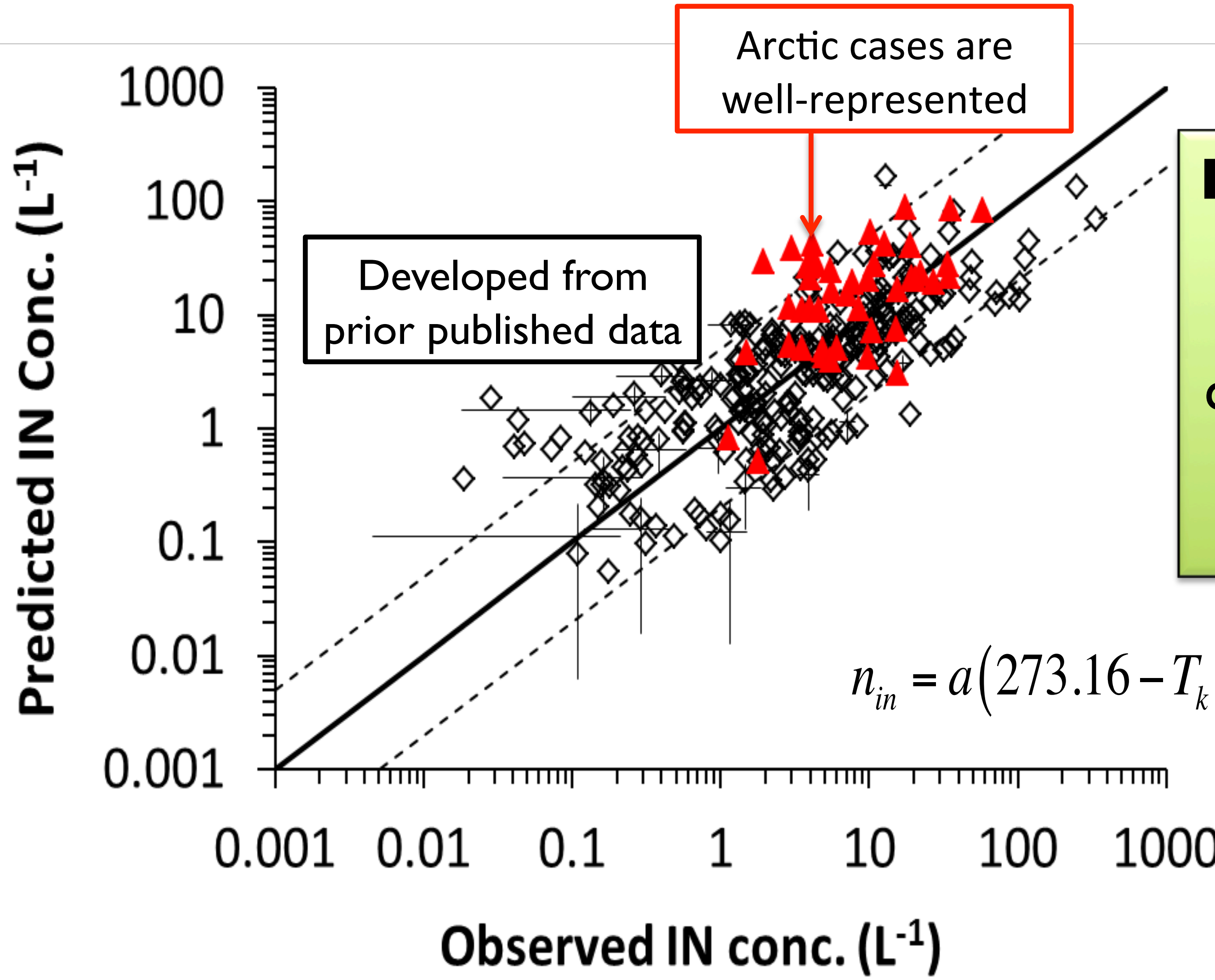

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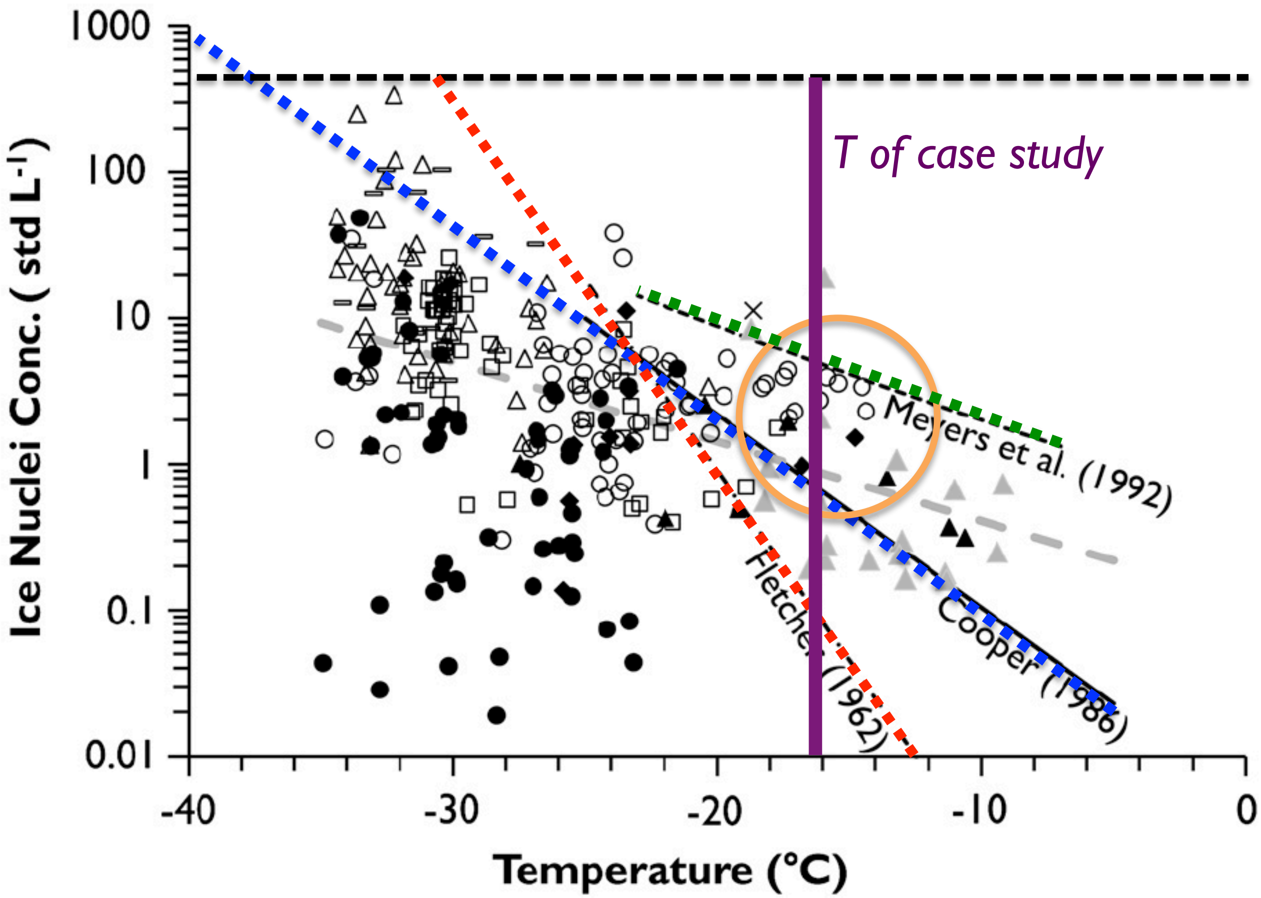
QUESTION:

Does linking ice formation to observed aerosol (and thus to IN) improve our ability to simulate a long-lived, mixed-phase cloud?

Three treatments for ice nucleation



1. CONTROL (model default): no explicit IN; ice nucleated according to Cooper scheme ($500\ L^{-1}$ cap, shown as black line)

2. DIAGNOSTIC: IN are predicted from DeMott et al. parameterization, but no IN budget is applied

→ Represents observed IN well

3. PROGNOSTIC ("IN budget"): same as diagnostic, but IN are depleted when ice nucleates and regenerated if the crystal evaporates **(SINGLE BIN APPROACH)**

After DeMott et al., 2010

Case Studies

ISDAC (APR 2008)

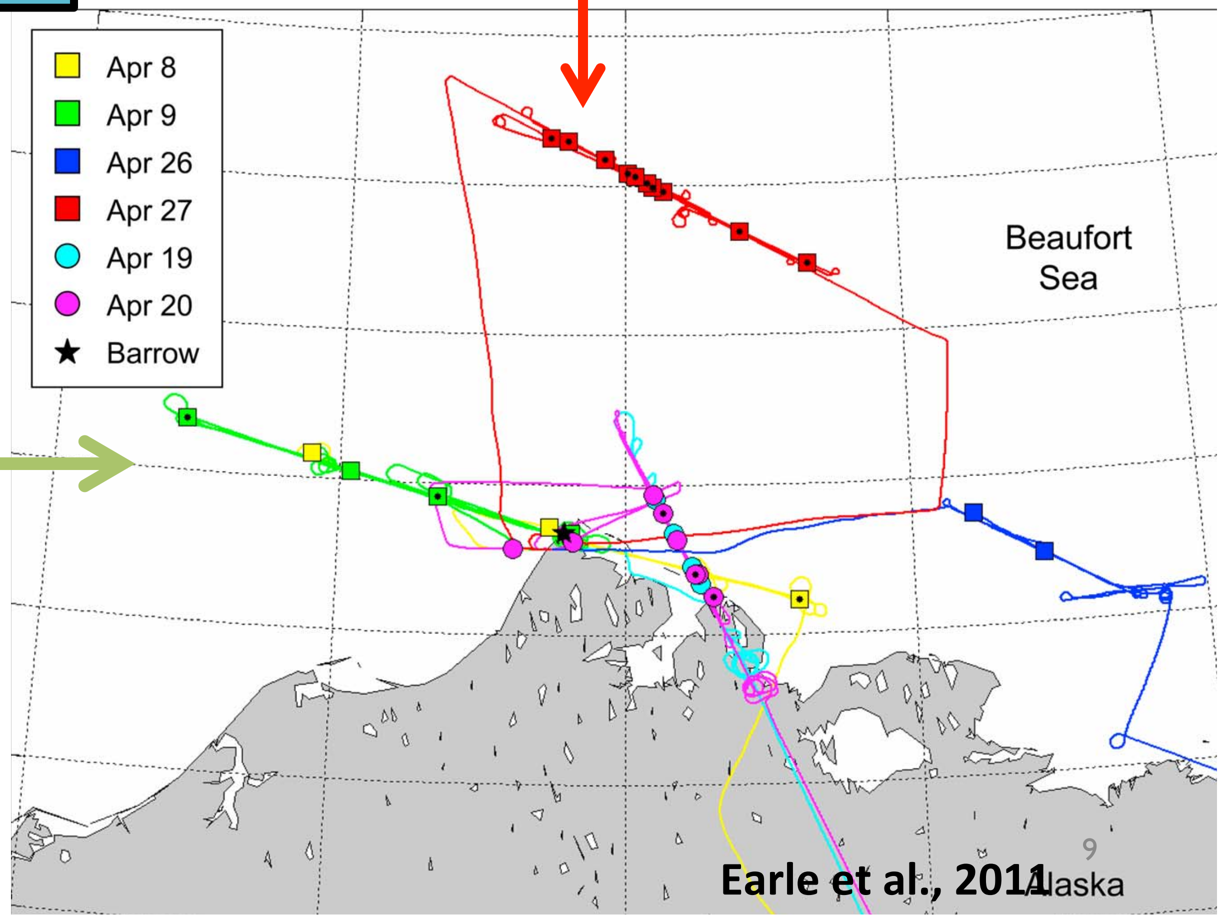
- **Spring cloud**
- **Transition to polluted regime**
- **High sea-ice extent**
  - **Lower surface fluxes**

FLIGHT 31 (26 APR)

- Oceanic air mass
- Observed [IN] ~1 L^{-1}
- Observed ice ~0.1-1 L^{-1}
- ~15 hour lifetime

FLIGHT 16 (8 APR)

- Continental air mass
- Observed [IN] <0.1-10 L^{-1}
- Observed ice ~0.1-1 L^{-1}
- ~24 hour lifetime



Earle et al., 2011

OTHER STUDIES:

Liu et al., 2011 (16, 31)

Avramov et al., 2011 (16)

Ovchinnikov et al., 2011 (31)

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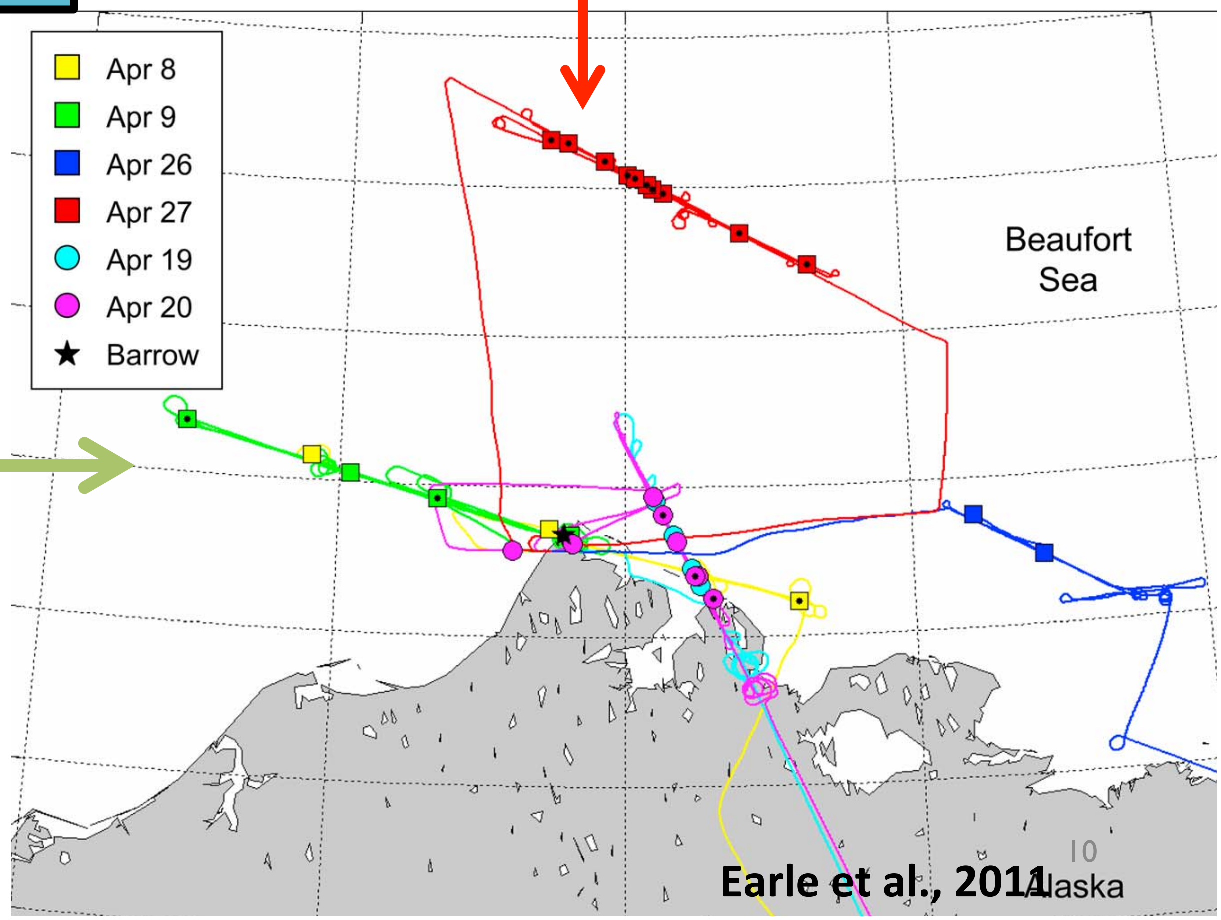

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Prior Conclusions about Simulations of Flight 16 Clouds

Avramov et al., 2011:

- DHARMA: Large-eddy simulations, using a size-resolved bin microphysics model, prognostic IN in 10 bins
- [IN] specified on basis of 10 per liter active at cloud top T (-17C). This [IN] was actually measured at -23C, and represents 10x DeMott et al. prediction.
- "**Reasonable agreement with the observed ice number concentrations** and size distributions, but radar reflectivities and ice water content were underestimated"
  - LWC overestimated
- Adjusting to low density dendrites and aggregates provided a better match to radar reflectivities, for two assumptions about IN:
  - IN concentrations increased fourfold
  - IN concentrations initialized with a vertically uniform profile, and mixed in slowly from below cloud
- Ability to "explain" cloud properties and persistence was in contrast to previous studies of Arctic mixed-phase clouds, which typically showed a large discrepancy when observed IN concentrations were used and treated prognostically
  - Missing process or missing [IN] source invoked

Simulations

DIAGNOSTIC

1. **CTRL – Cooper Scheme (F16)**
2. **DEMOTT – [IN] Parameterization (F16, F31)**
3. **10x DM – [IN] Param. X10 (F16)**
4. **0.1x DM – [IN] Param. x0.1 (F16)**

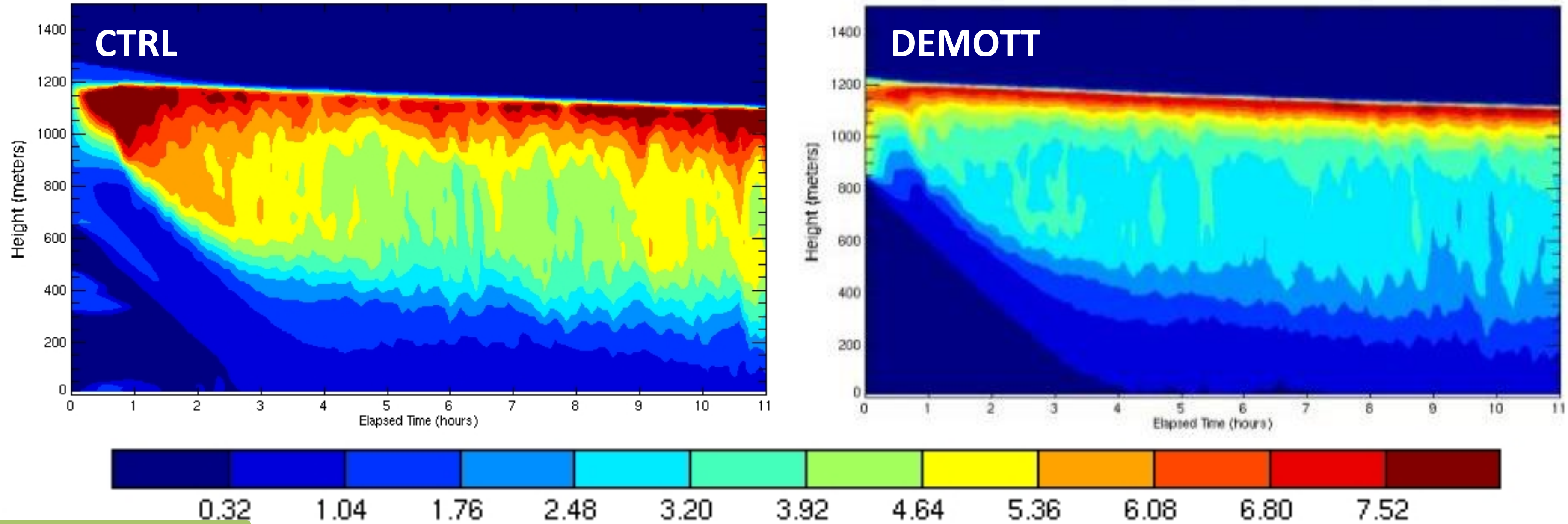
PROGNOSTIC

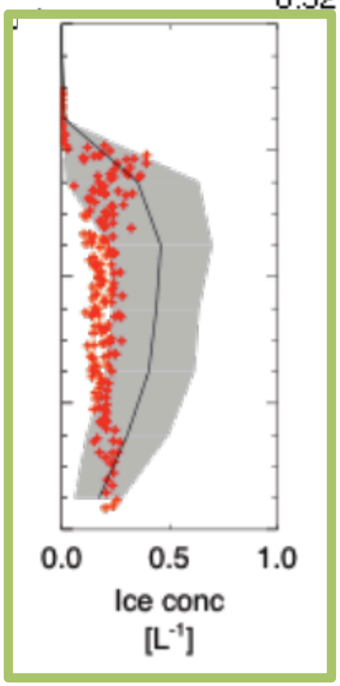
1. **No sublimation (F16, F31)**
2. Snow sublimation
3. Snow sublimation (dry lowest 200 m)
4. **All sublimation (F16, F31)**
5. **All sublimation (dry lowest 200 m) (F16)**
6. All sublimation (5x DeMott instead of 10x)

	ISDAC Flight 16	ISDAC Flight 31
Domain [km]	3x3	3x3
Simulated Time [hrs]	12	12
Grid boxes	300x300	300x300
Δx [m]	10	10
Δz [m]	10	10
Δt [s]	1	1
Aerosol Mode 1 Geometric Mean Radius [μm]	0.1	0.1
Aerosol Mode 1 σ	1.43	1.5
Aerosol Mode 1 N [cm-3]	171.7	200
Aerosol Mode 2 Geometric Mean Radius [μm]	0.55	0.75
Aerosol Mode 2 σ	2.35	2
Aerosol Mode 2 N [cm-3]	5	2

F16 – Diagnostic - Ice number concentration ($cm^{-3} * 10^{-4}$)

8 APR 2008





Observed N_i: 0.4 L^{-1} (Peak 0.8-1 L^{-1})

CTRL N_i: 0.5 L^{-1} (>0.75 L^{-1})

DEMOTT N_i: 0.35 L^{-1} (0.7 L^{-1})

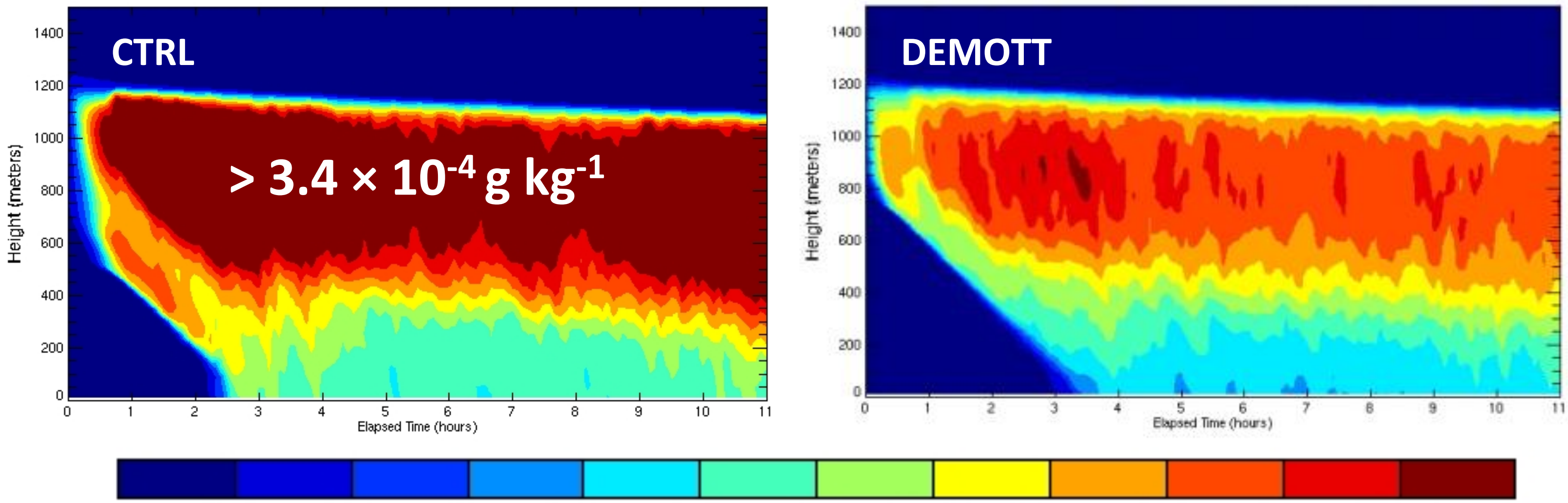
Avramov N_i: 0.25 L^{-1} (0.4 L^{-1})

Ice number concentrations are OK

Avramov et al., 2011 (Observations in grey)

F16 – Diagnostic - Cloud ice (g kg^{-1} * 10^{-4})

8 APR 2008



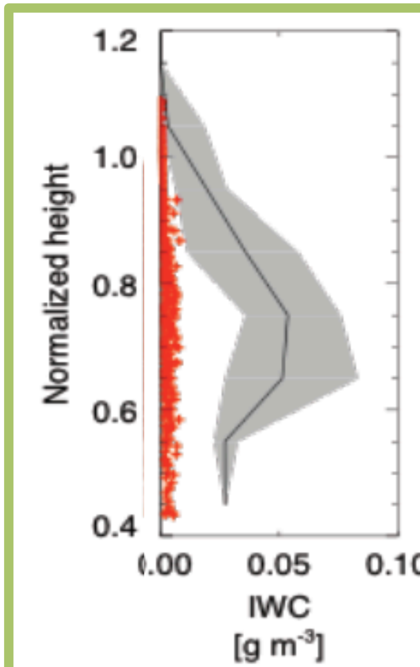
Oct 18, 2012

Observed IWC: 0.05 g m^{-3}

CTRL IWC: >0.00034 g m^{-3}

DEMOTT IWC: 0.00029 g m^{-3}

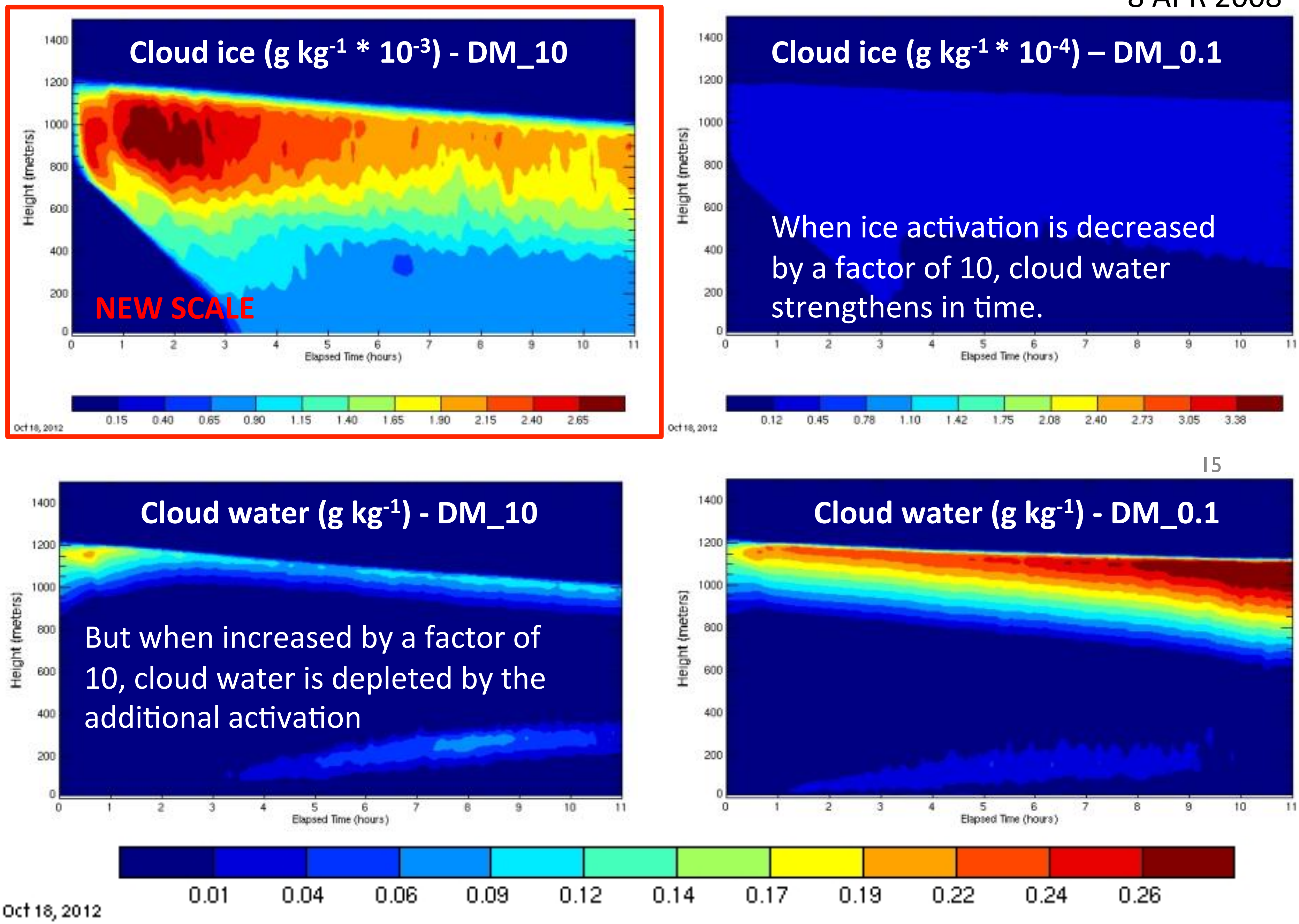
Similar issues as past studies with too little ice mass calculated



Avramov et al., 2011 (Observations in grey)

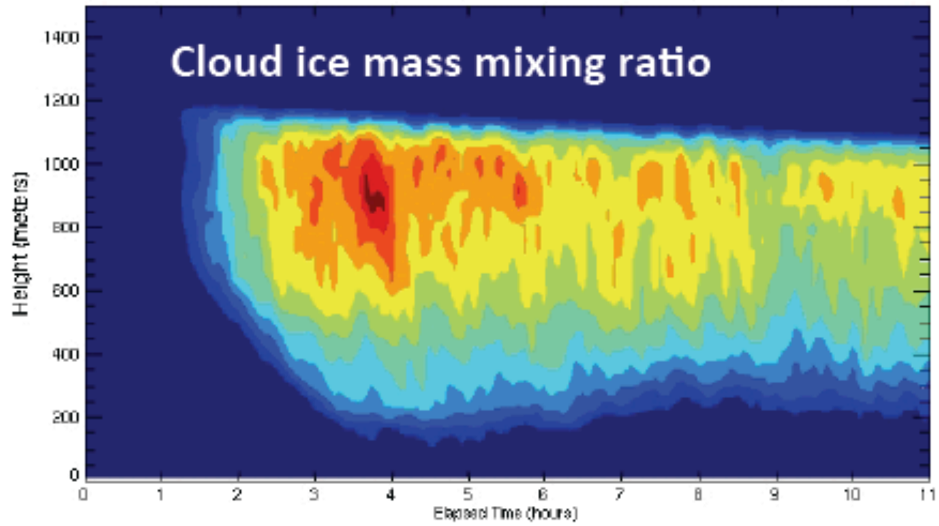
Effects of changing IN Concentrations (F16)

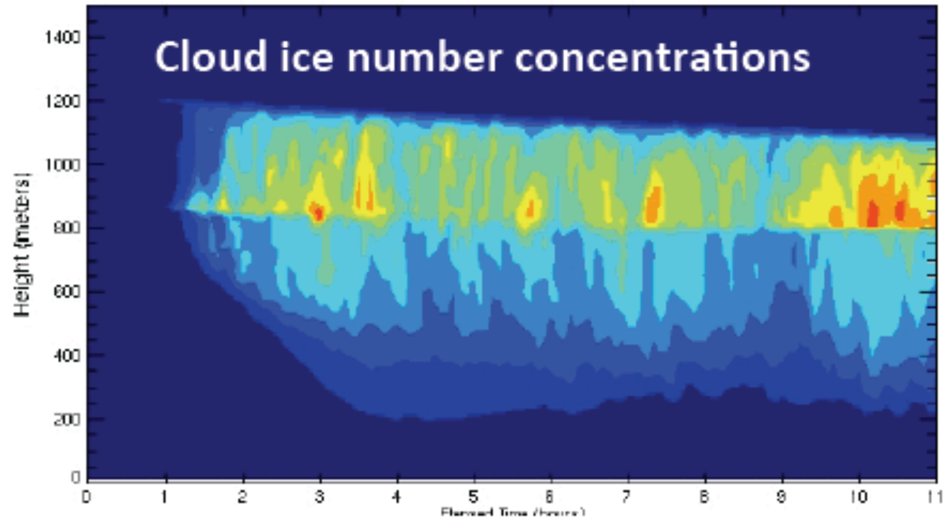
8 APR 2008

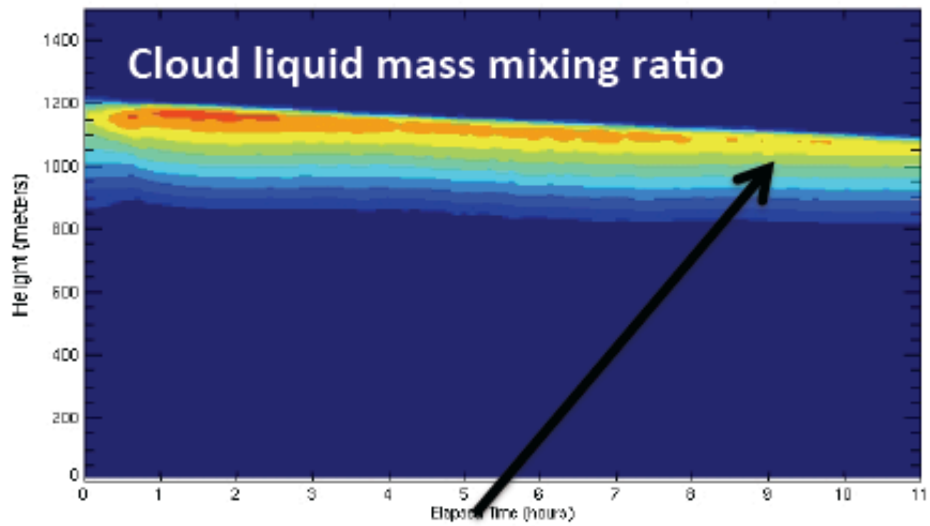


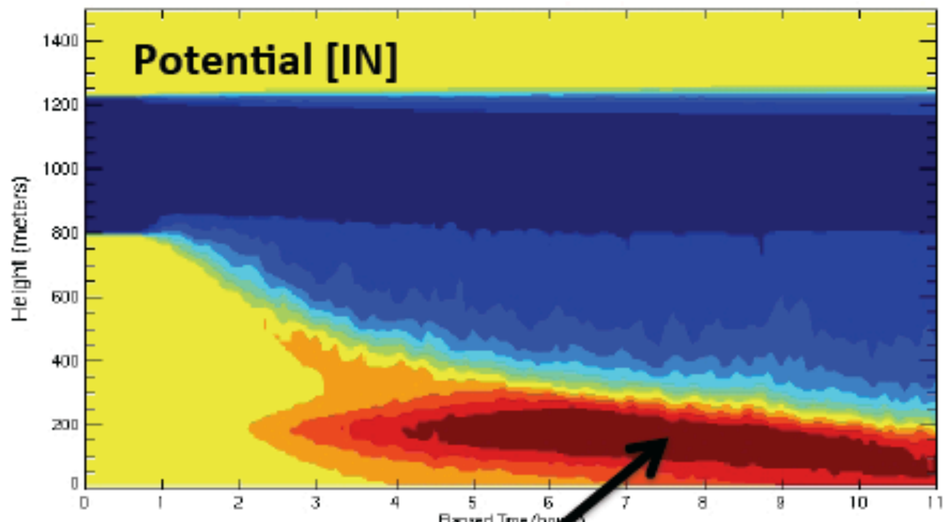
F16 – Prognostic – Drying Lowest 200 m

8 APR 2008









Stronger depletion of LWC – entrainment of dry air, additional ice loading

[IN] > 12.75 L^{-1}

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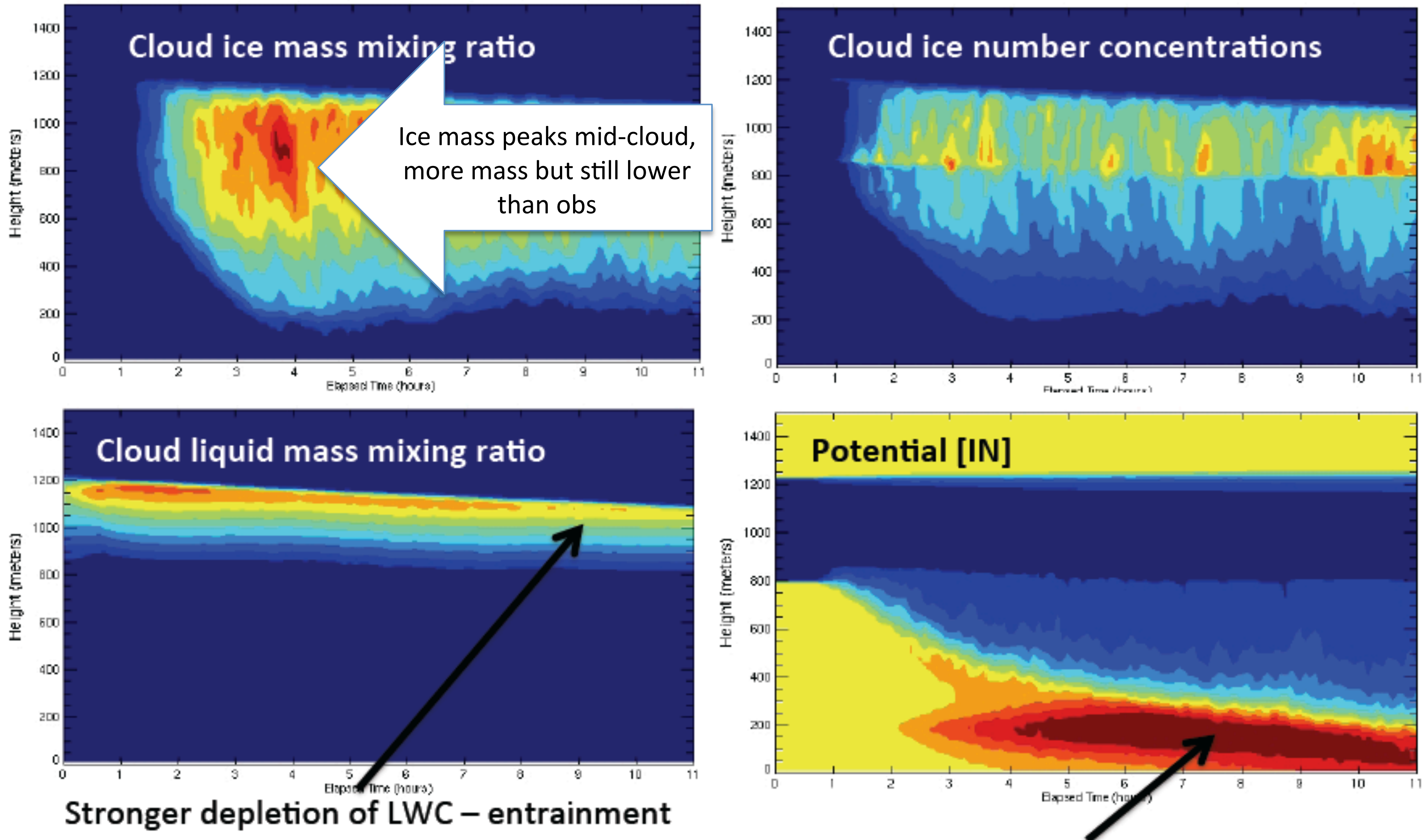

Stronger depletion of LWC – entrainment of dry air, additional ice loading

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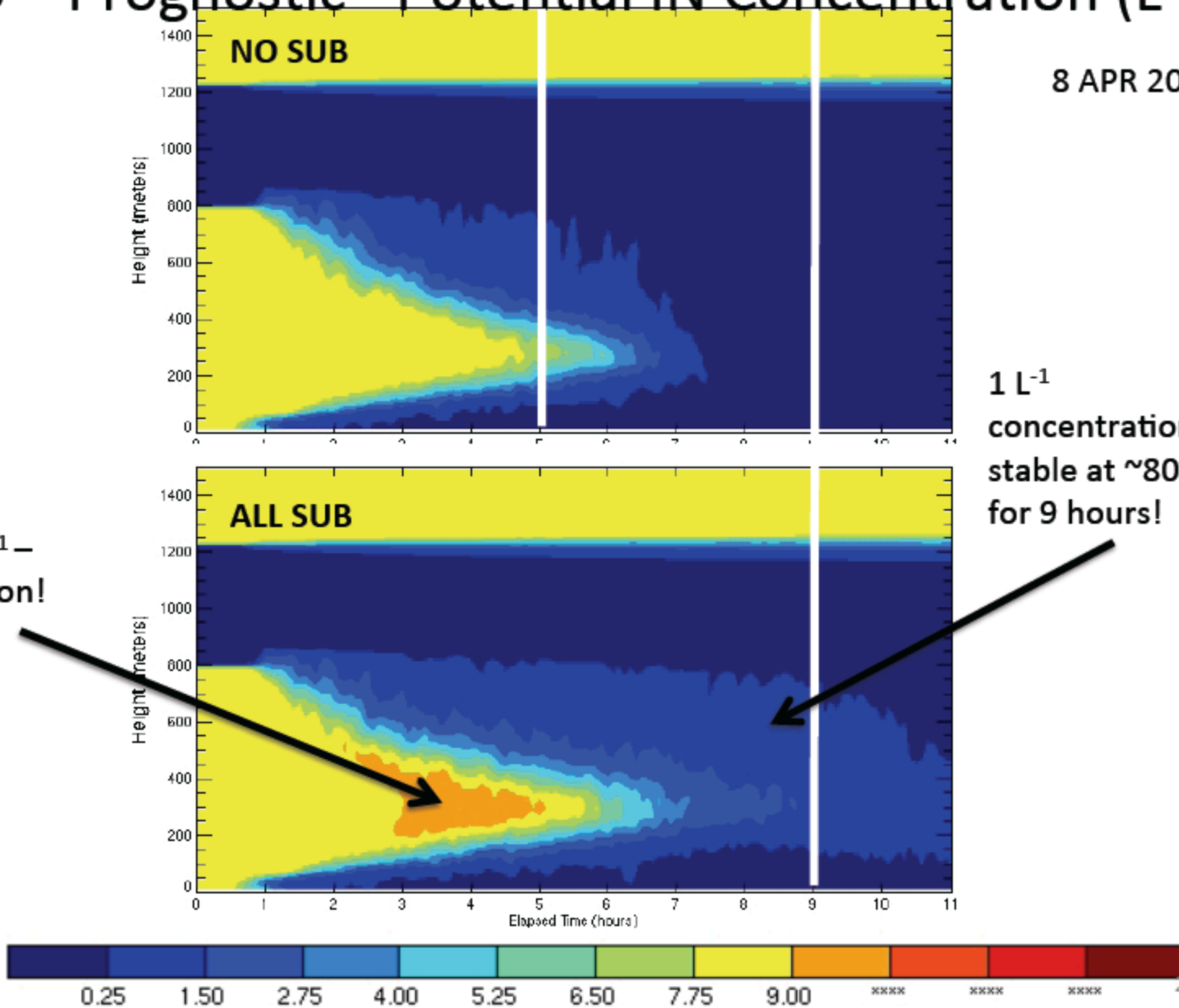
F16 – Prognostic - Potential IN Concentration (L^{-1})

8 APR 2008



[IN] > 9 L^{-1} – Sublimation!

1 L^{-1} concentration stable at ~800 m for 9 hours!

Conclusions

- Diagnostic IN, linked to aerosol measurements via the DeMott parameterization, reasonably represented both IN and ice crystal number concentrations and persistent mixed-phase cloud
  - True also for coarser resolution modeling (100 m horizontal)
  - But hard to get split between LWC and ice mass correct, as also found in other studies
- Prognostic IN are scavenged effectively and lead to short lifetimes
  - Allowing for sublimation and return of IN helps extend lifetime
  - Also need to constrain fluxes of IN into domain
- Conclude that the ISDAC case as hard to explain as other Arctic cases that have been attempted
  - Avramov et al. used [IN] at high end of observations, not consistent with most observations nor the T regime of the clouds
  - Need to improve the model's ice microphysics – right now, spherical ice assumed
  - Cloud microphysical measurements should be improved to offer better constraints as well