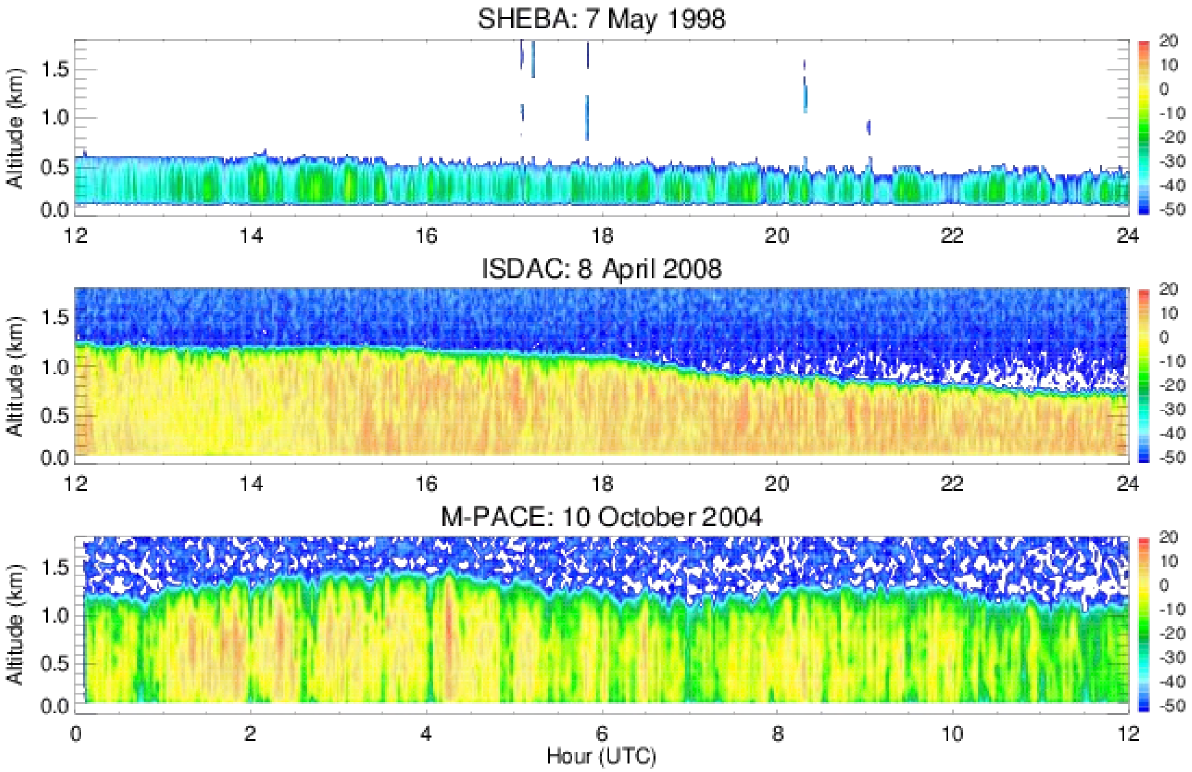
Time-dependent versus singular ice nucleation schemes: Estimated impact on mixed-phase stratiform clouds in ModelE3



Fridlind et al.
Poster 88 Wed@3:30

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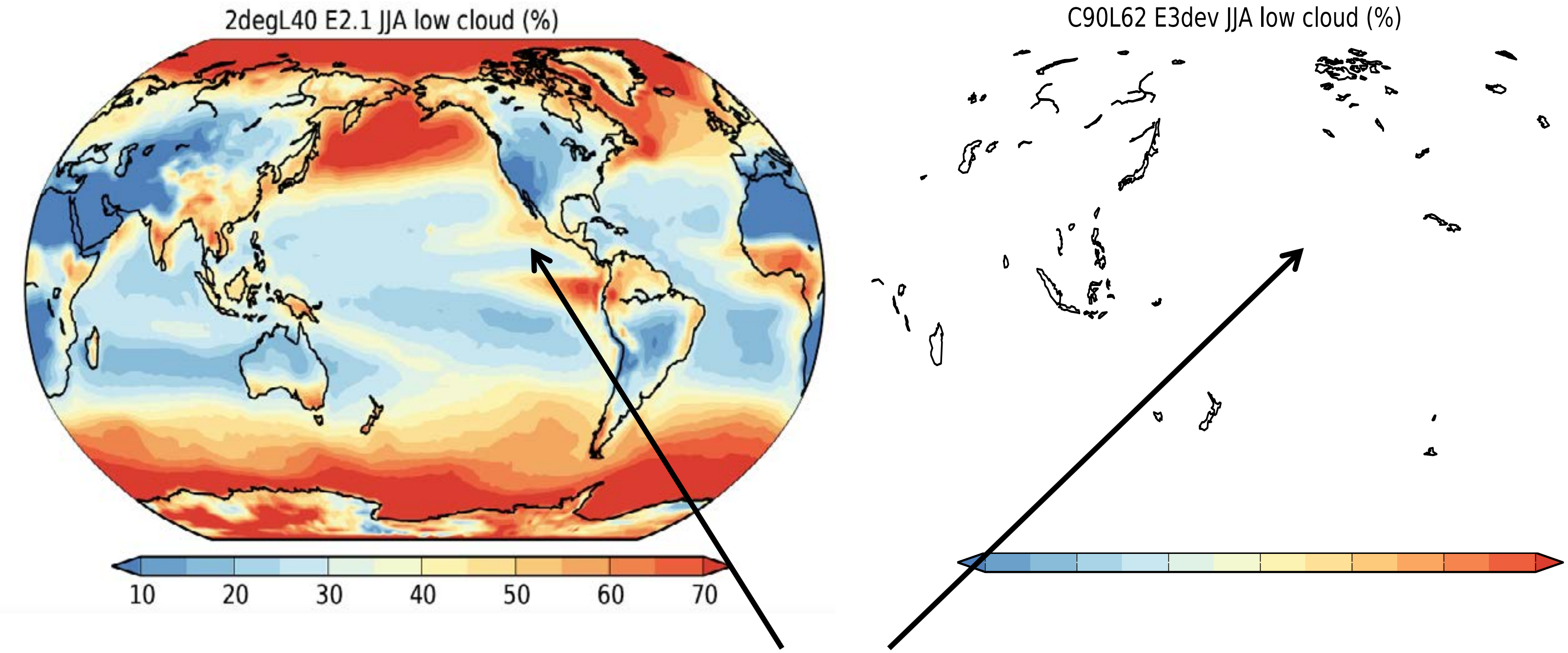
NASA Radiation Sciences Program

Liquid-phase low cloud fraction

- Preliminary version of ModelE3 (Ackerman, Cheng, Del Genio, Kelley)
  - turbulent mixing [Bretherton and Park 2009]
  - large-scale cloud fraction for liquid [Smith 1990], ice [1999]
  - large-scale two-moment microphysics [Gettelman and Morrison 2015]

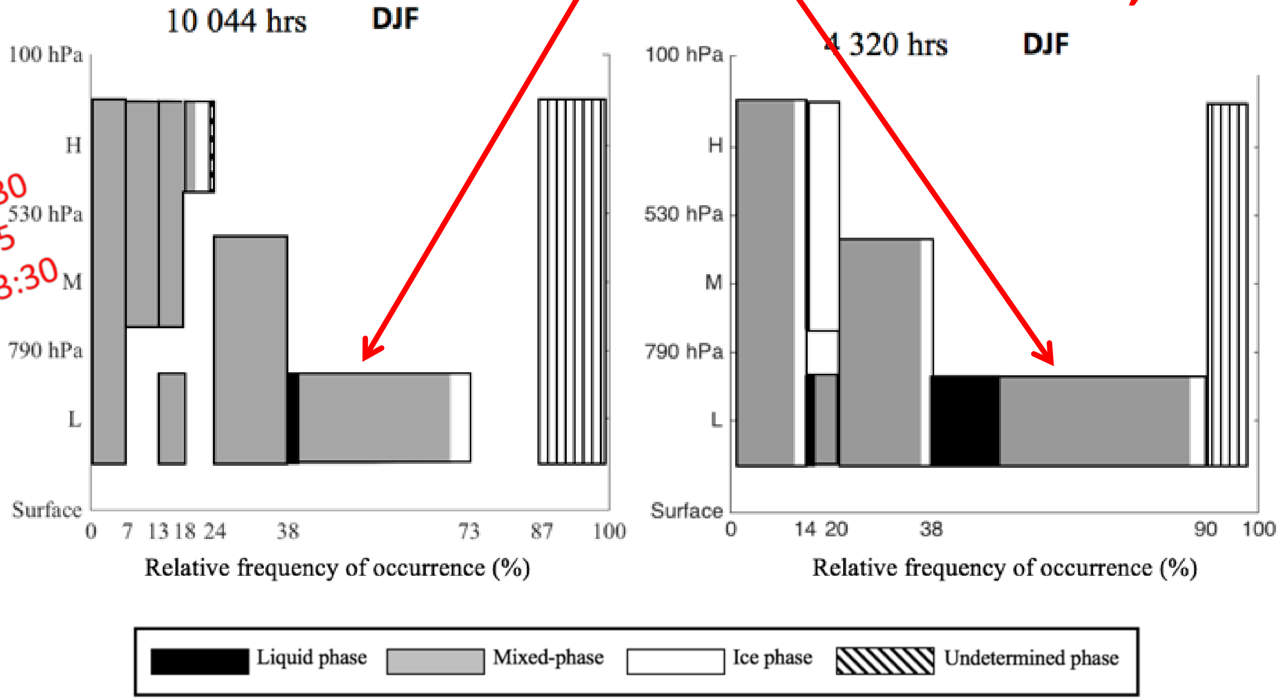
ModelE2.1, 2x2.5x40L **ModelE3, C90x62L**



liquid-phase stratiform clouds

Mixed-phase low cloud occurrence frequency at NSA

- Preliminary version of ModelE3
    - immersion freezing [Bigg 1953] of cloud and rain drops
    - contact freezing [Young 1974] of cloud drops
    - aerosol freezing with prescribed cloud ice concentration (100/L) and RHI$_{crit}$ following Karcher and Lohmann [2002]
    - convective detrainment glaciated at 0°C



NSA Obs

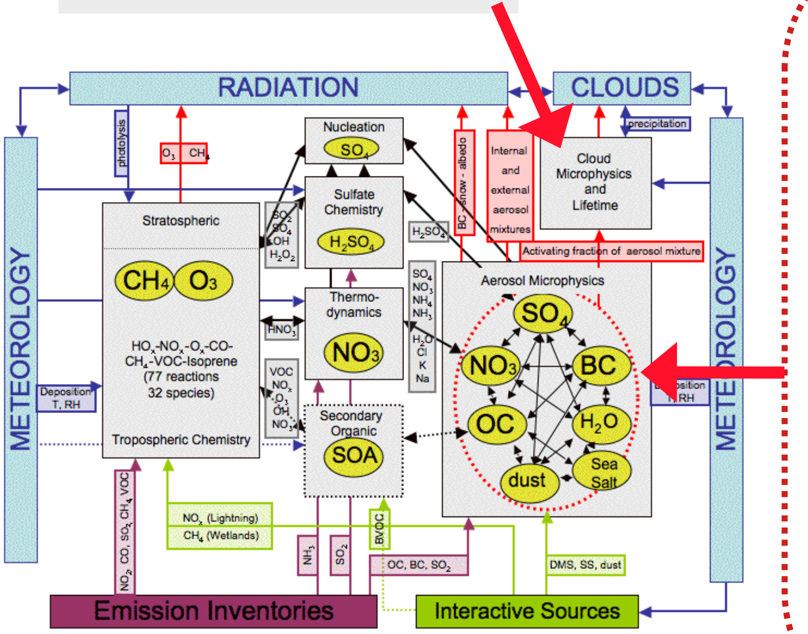
mixed-phase stratiform clouds

ModelE3, 62L

LAMER ET AL. [IN PREP.]
POSTER 192 WED@3:30
VIRT IOPS THU@10:45
IN BREAKOUT THU@3:30

ModelE3 gas and aerosol-phase chemistry

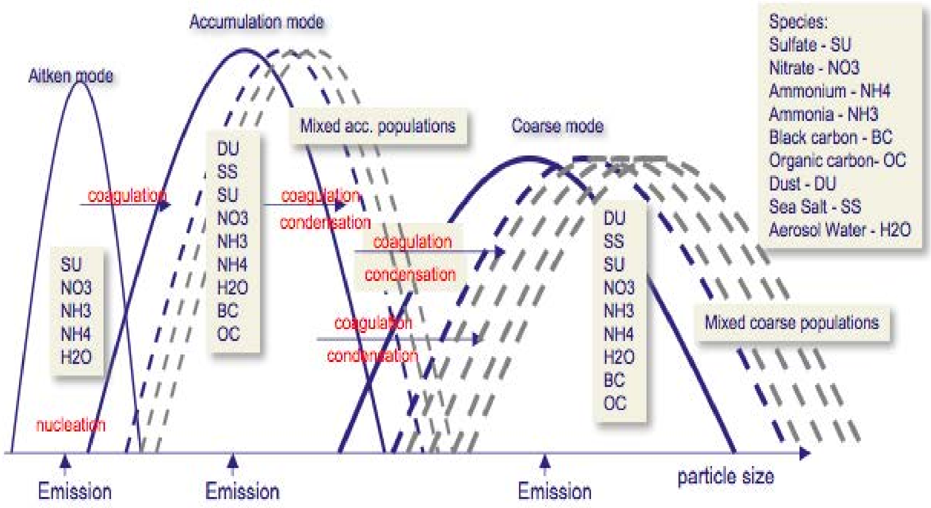
Droplet activation following
Adbul-Razzak et al. (1998)
and Abdul-Razzak and Ghan (2000)



MATRIX

Aerosol Microphysical Model based on the Methods of Moments

Bauer et al. ACP 2008



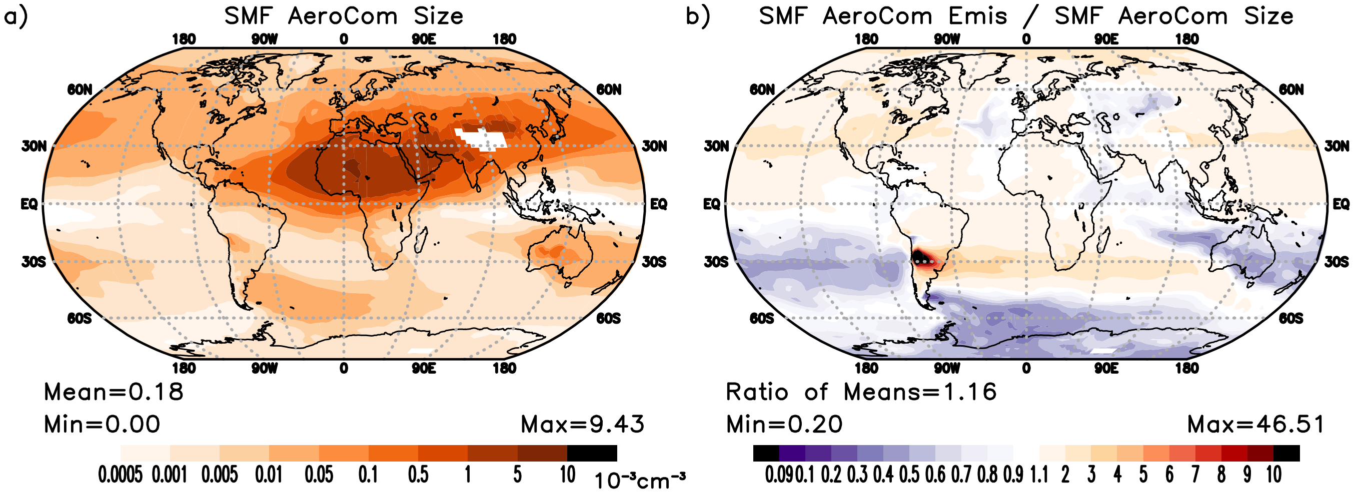
Bauer et al., Atmos. Chem. Phys. 8, 6603-6635, 2008
Bauer et al., Atmos. Chem. Phys., 10, 7439-7456, 2010
Gao et al. Geosci. Model Dev., 10, 751-764, 2017

ModelE3 off-line INP calculations

- feldspar $N_{INP}(T)$ @ 600 mb using an active site scheme [cf. Atkinson et al. 2013]
- inform MATRIX single dust type

CHARNAWSKAS ET AL.
POSTER 143 TUES@3:30
PERLWITZ ET AL. [IN PREP.]

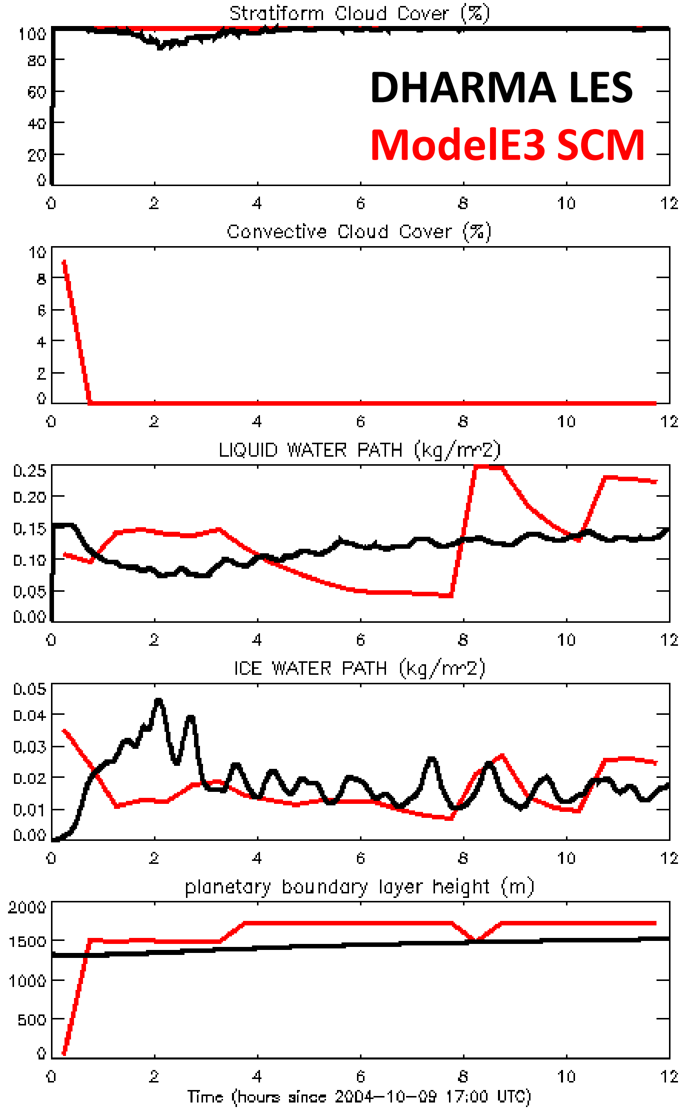
ModelE2.1, 40L



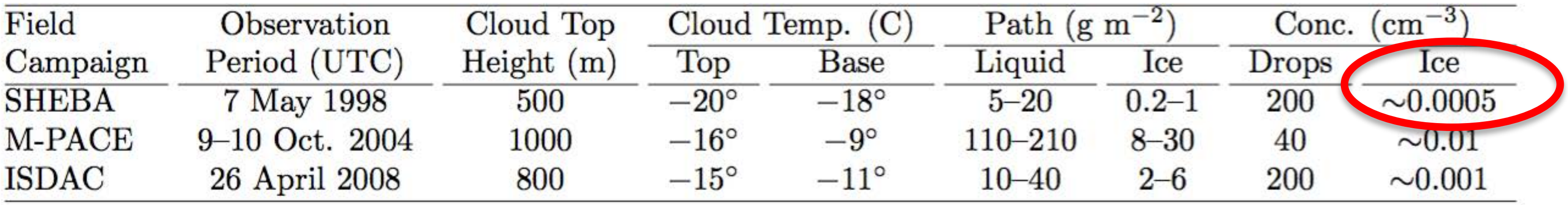
ModelE3 SCM versus LES

- M-PACE case [Klein et al. 2009]
  - reasonable behavior
  - liquid-phase boundary layer is big challenge
    - **can we make a simple model to test likely response to differing ice nucleation schemes?**
    - **e.g. Vali and Snider [2015] parcel model**

ModelE3, 62L

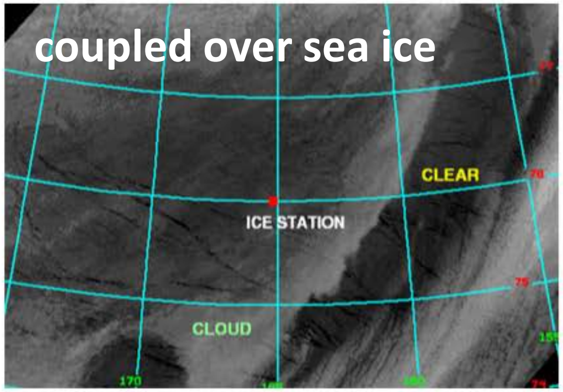


Simplest mixed-phase stratiform cloud?



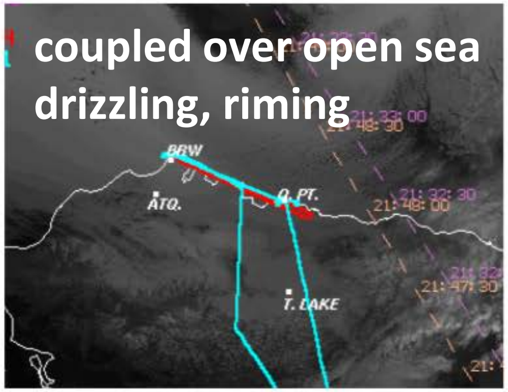
Field	Observation	Cloud Top	Cloud Temp. (C)		Path (g m^{-2})		Conc. (cm^{-3})	
Campaign	Period (UTC)	Height (m)	Top	Base	Liquid	Ice	Drops	Ice
SHEBA	7 May 1998	500	−20°	−18°	5–20	0.2–1	200	∼0.0005
M-PACE	9–10 Oct. 2004	1000	−16°	−9°	110–210	8–30	40	∼0.01
ISDAC	26 April 2008	800	−15°	−11°	10–40	2–6	200	∼0.001

SHEBA



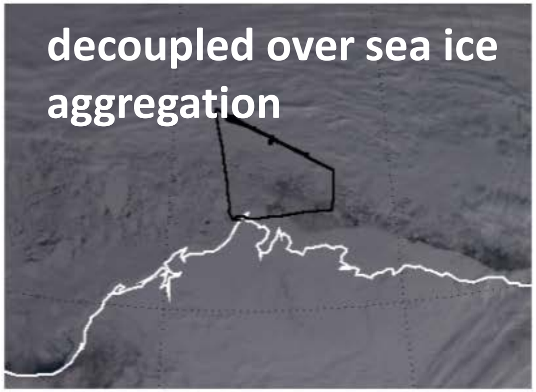
coupled over sea ice

M-PACE



coupled over open sea
drizzling, riming

ISDAC

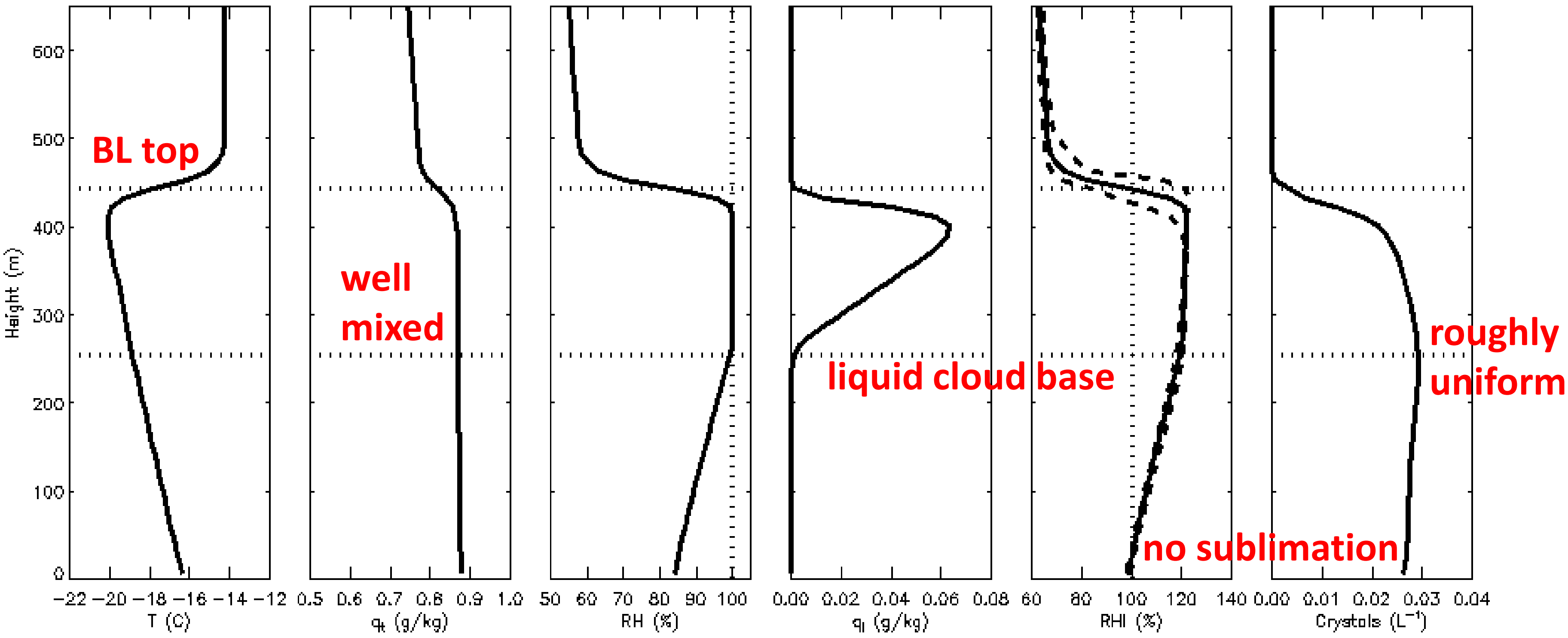


decoupled over sea ice
aggregation

Source: Fridlind and Ackerman [submitted chapter, Ed. C. Andronache]

Simplest mixed-phase stratiform cloud?

- **1D model with only N_i and INP properties evolving**
  - quasi-stationary well-mixed BL
  - liquid-phase not strongly desiccated by ice present
    - ice approximately independent of liquid [cf. Yang et al. 2014]
  - quasi-stationary ice size distribution [Fridlind et al. 2012]



DHARMA LES

BL top

well mixed

liquid cloud base

no sublimation

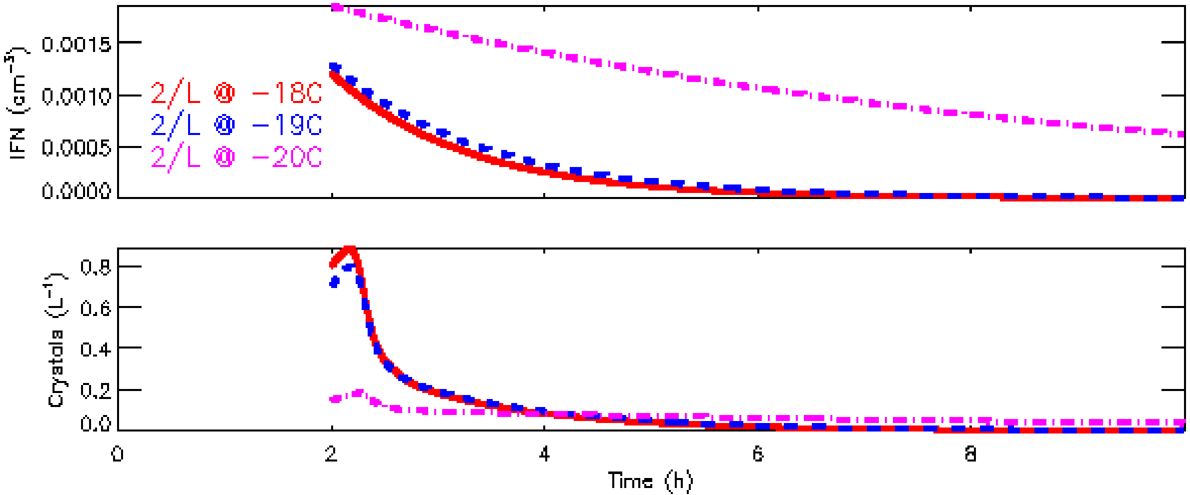
roughly uniform

Fridlind et al. [2012] SHEBA case study

2 L^{-1} singular immersion INP [cf. Fridlind et al. 2012]

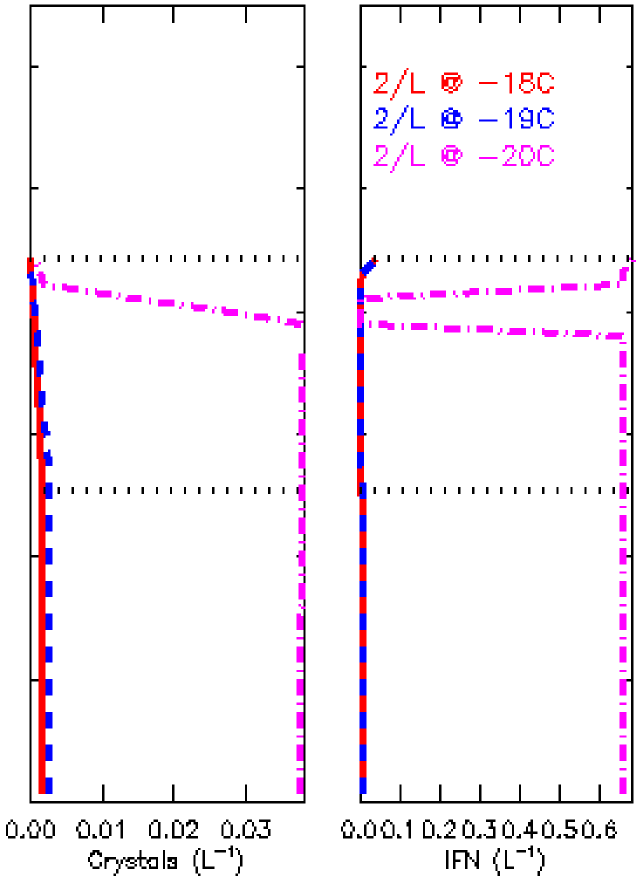
- **1D model with only N_i and INP properties evolving**
  - initialize INP properties profile (size distribution, activation parameters)
  - predict INP activation, turbulent mixing, cloud top entrainment
  - predict N_i formation, sedimentation, turbulent mixing

rapid loss of INP [cf. Harrington and Olsson 2001]



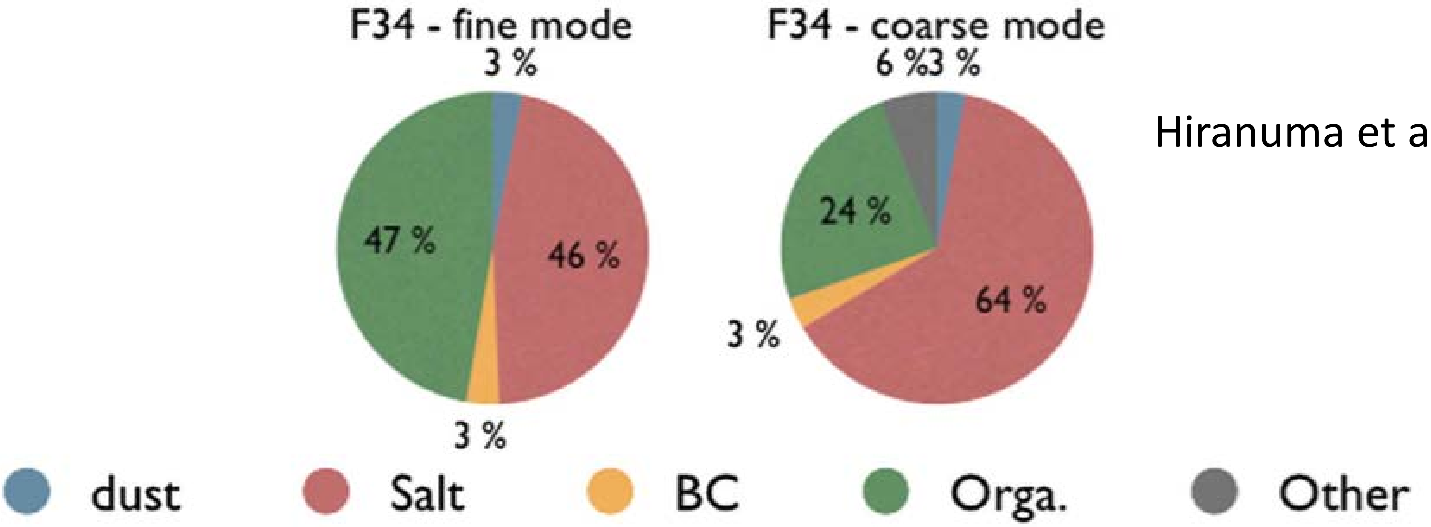
weakly sustained ice formation [cf. Fridlind et al. 2012]

1D model @ 10 h



~10 cm^{-3} following classical nucleation theory

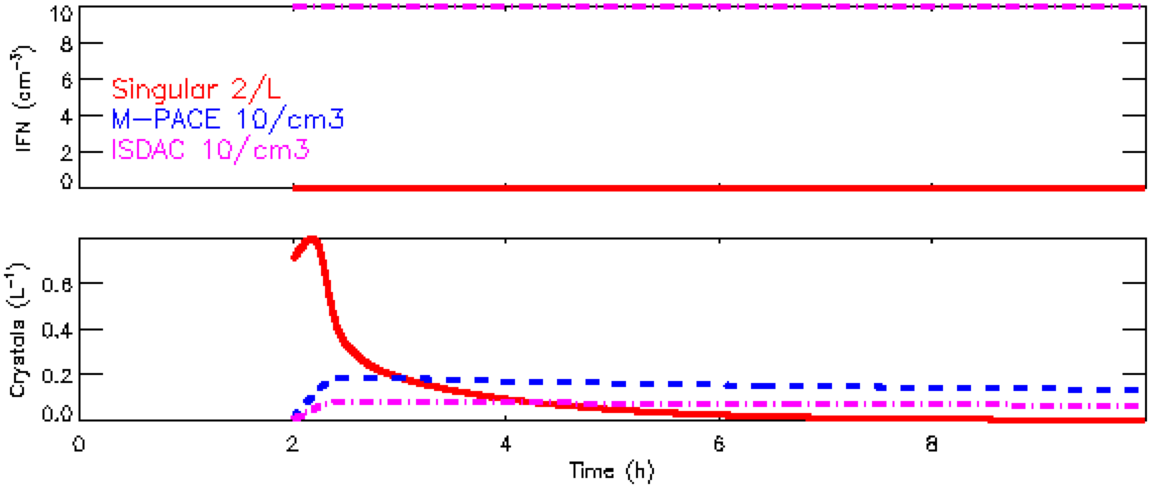
- **Classical nucleation theory-based model [Savre and Ekman 2015]**
  - evolving PDF of contact angles (initially Gaussian, one θ and J(θ) per particle)
  - inputs derived from aerosol single-particle data rather than Counter-Flow Diffusion Chamber (CFDC)



Hiranuma et al. [2013]

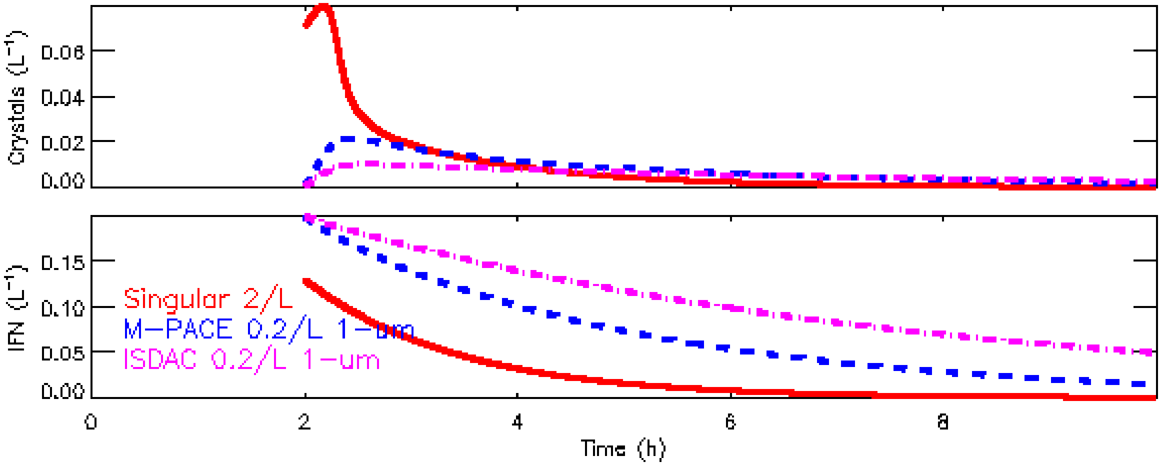
10 cm^{-3} following classical nucleation theory

- **compared with Savre and Ekman [2015]**
  - ABIFM immersion INP model [Knopf and Alpert 2013]
    - fit to CFDC measurements from M-PACE, ISDAC
  - slow sustained ice formation [cf. Morrison et al. 2005]
  - negligible loss of INP [cf. Westbrook and Illingworth 2013]
  - recycling would be negligible [cf. Solomon et al. 2015]



0.2 L^{-1} following classical nucleation theory

- **compared with Savre and Ekman [2015]**
  - 0.2/L 1-um-diameter INPs (like singular)
  - consistent with CFDC measurements (but not single-particle measurements?)
  - weaker ice formation, substantial loss of INP [cf. Fridlind et al. 2012]

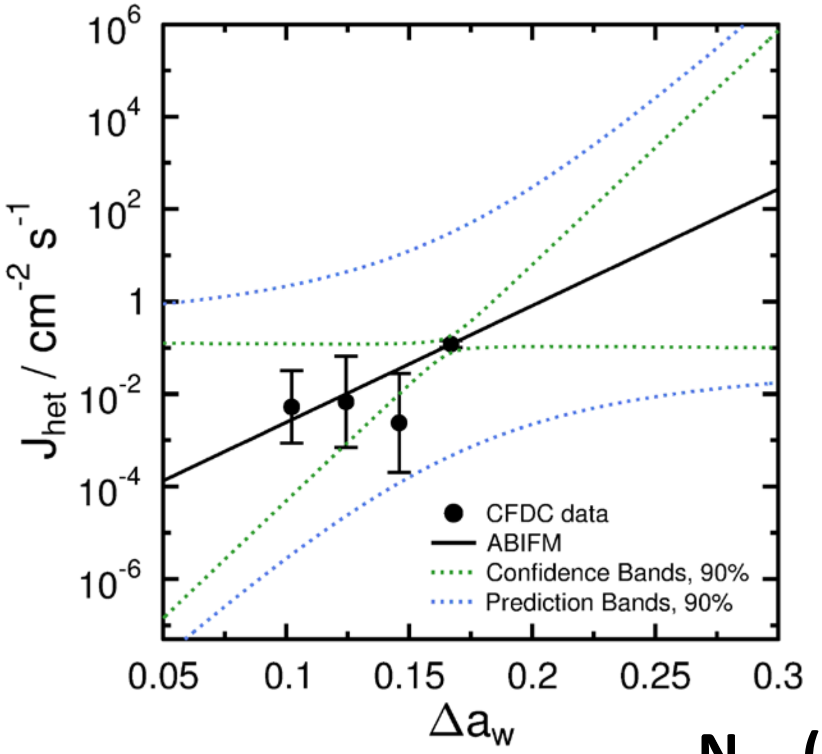


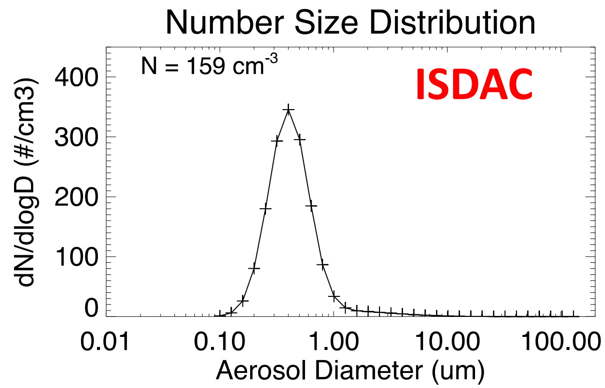
Summary

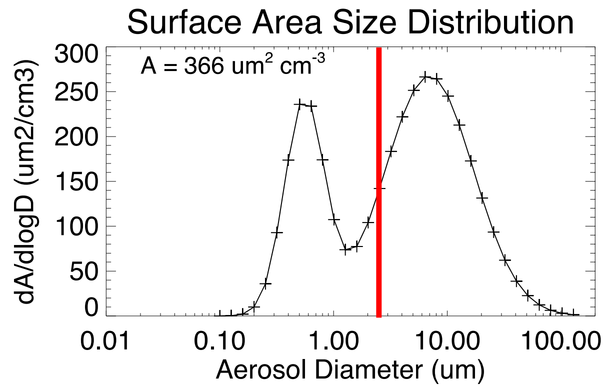
- Simple 1D model of mixed-phase BL cloud
  - tool to predict ModelE3 N_i and INP evolution to first order
    - contrast to Vali et al. [2015], Field et al. [2014]
  - rigorous constraint of time-dependent schemes requires
    - known size distributed INP surface area and properties
    - merging disparate lab and field measurement data
    - closure study?
- Future work
  - add MATRIX aerosol parameter initiation and evolution
  - study potential ice nucleation treatments
  - cirrus

What is the INP size distribution?

- need to assume INP types, size distributions to constrain with Counter-Flow Diffusion Chamber (CFDC) field measurements







$$\frac{N_{INP}(t)}{N_{INP}} = \text{Froz. Frac.} = 1 - e^{-J_{het}\, SA_{tot}\, t_{CFDC}}$$

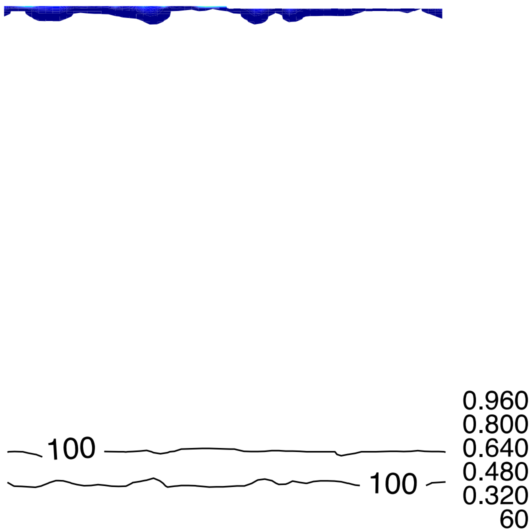
$$J_{het}(RH,T) = m\, \Delta a_w(RH,T) + c$$

Fridlind, Alpert, Knopf, DeMott, Brooks et al. [in preparation]

LES results

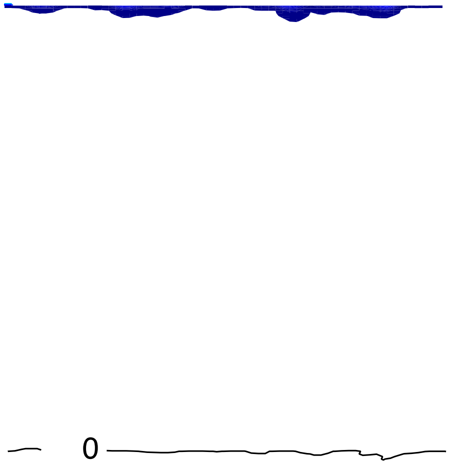
Singular immersion

Droplets (cm^{-3})



Slow contact

Droplets (cm^{-3})



Time-dependent immersion (ABIFM)

Droplets (cm^{-3})