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Time-dependent versus singular ice nucleation schemes: Application of a 1D model to estimate impacts on mixed-phase stratiform clouds in ModelE

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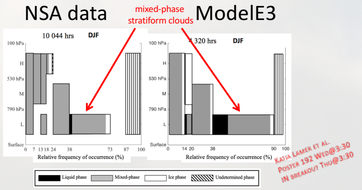
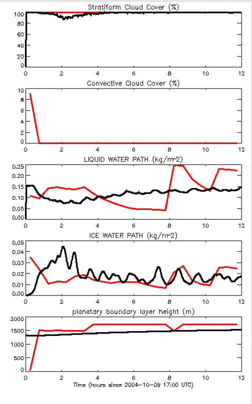
1. Motivation

○ mixed-phase stratiform clouds are common at high latitudes in many seasons and their proper representation has been tied to GCM climate sensitivity [Tan et al. 2016]



○ Klein et al. (2009) intercomparison case mixed-phase stratiform cloud looks pretty good in ModelE3's SCM (roughly similar to observed)



○ biggest challenge for ModelE3 is the liquid-phase boundary layer (weakly desiccated)

○ next step: make ice nucleation prognostic

○ can we make a simpler model to test likely response of ModelE3 mixed-phase stratiform cloud layers to differing ice nucleation schemes?

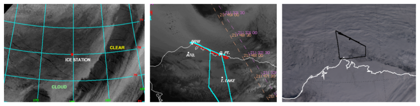
○ what makes such cloud layers unique?

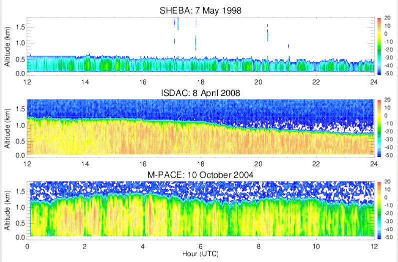
- liquid-topped layers
- precipitating ice continuously
- long-lived in Eulerian and Lagrangian
- overlying air is continuously entrained
- layers tend to be well-mixed
- commonly coupled and also decoupled from the surface
- no parcels can be considered "glaciated" in the conventional sense (contrast to Field et al. 2014)

2. Case study

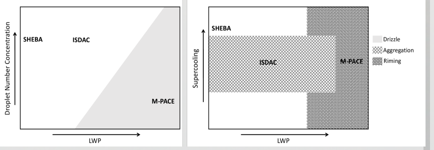
○ well-observed and widely simulated case studies offer guidance

Field Campaign	Observation Period (UTC)	Cloud Top Height (m)	Cloud Temp. (C)		Path ($g\ m^{-2}$)		Conc. (cm^{-3})	
			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



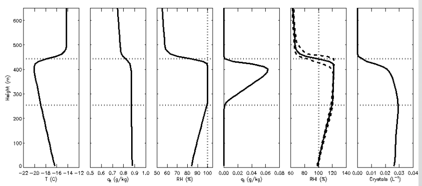


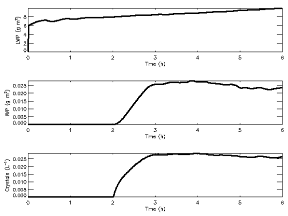
○ liquid- and ice-phase microphysical processes differ among the cases



○ choose the simplest case study from the standpoint of microphysics and dynamics: SHEBA

○ add ABIFM model (Knopf and Alpert 2014) to Fridlind et al. (2012) LES case study





3. 1D model

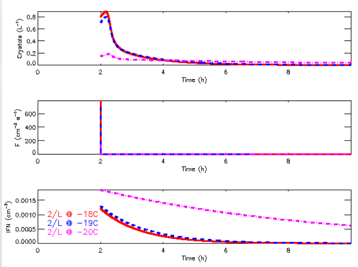
○ read in soundings from LES (assumed constant)

○ prognose ice number concentration (Ni) and ice nucleus (IN) number size distribution profiles

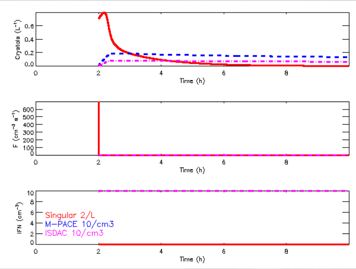
○ calculate IN activation rate profile, IN size-distributed loss rate profile, cloud-top entrainment rates, and Ni sedimentation rate profile (using fixed number-weighted fall speed from LES)

○ first assume a conventional singular IN scheme as in Fridlind et al. (2012) constrained by Counterflow Diffusion Chamber (CFDC) measurements under cloud top conditions

○ as long as IN are not active in a very thin layer at cloud top (coldest activation temperature assumed), IN consumption is rapid, consistent with Fridlind et al. (2012)



○ next assume a time-dependent scheme (ABIFM) fit to CFDC measurements assuming 10/cm3 IFN as Savre and Ekman (2015) assumed based on ISDAC SPLAT measurements, size distributed consistent with observed modes and fit to CFDC using only surface area where diameter less than 1.5 µm

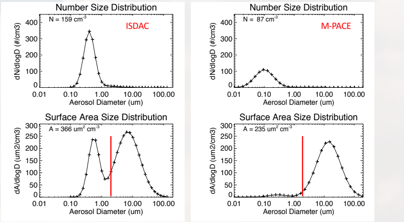


○ here IN are weakly active and scarcely consumed in 8 hours, differing from Savre and Ekman (2015) in that their properties are uniform rather than evolving in efficiency

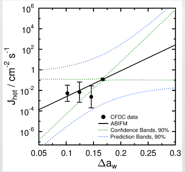
○ the initial reservoir of IN is now long lasting

4. Results

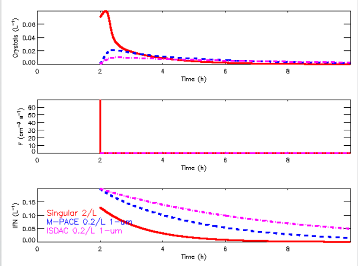
○ initial rate fitting to ISDAC and M-PACE CFDC data (used in the SHEBA case study, where data are no longer considered most reliable) indicates that 2/L IN rates differ if the IN are assumed to large (e.g. 1-µm diameter, roughly largest measured by CFDC) or distributed similar to the aerosol population (as in Savre and Ekman 2015)



○ for this work we derive a nucleation rate Jhet(T,RH) based on an arbitrary aerosol surface area for M-PACE and ISDAC case studies, and then scale it to assumed IN properties (size and number concentration)



○ if IN are scarce (e.g., near the CFDC detection limit) and large, the time-dependent scheme behavior tends towards a singular scheme



Acknowledgments

○ ***Funding***—2016-2019 ASR Grant, NASA RSP

○ ***Observations***—ARM data archive

○ ***Computations***—DOE NERSC, NASA HEC/SMD