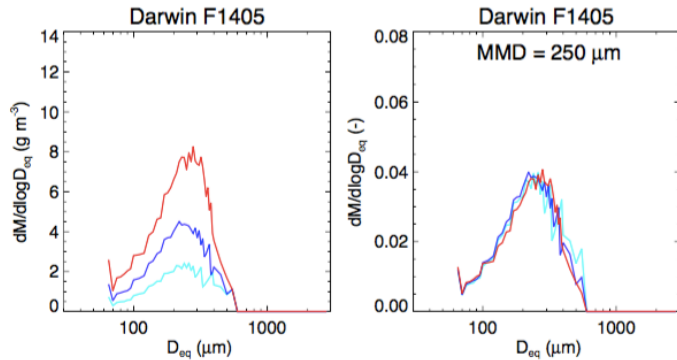
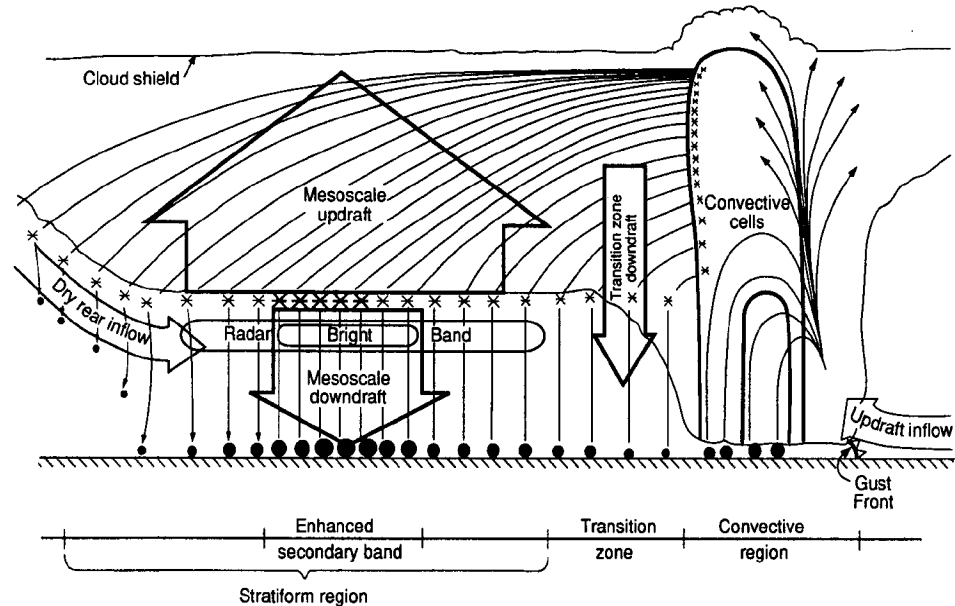
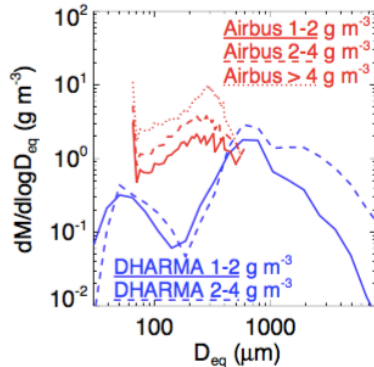
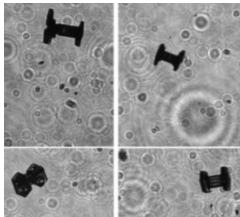


Advancing observational constraints on high-latitude cloud processes

Ann Fridlind, NASA GISS
giss.nasa.gov/staff/afridlind.html



Fridlind et al. [ACP, 2016]
 at -43°C near Cayenne (Airbus)
 Ackerman et al. [ACP, 2016]



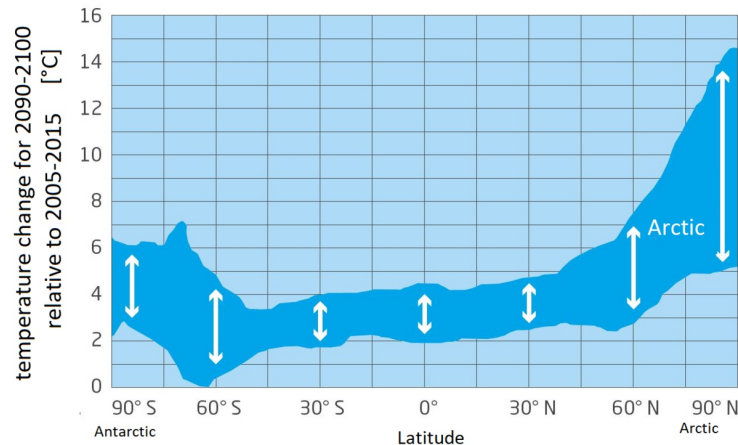
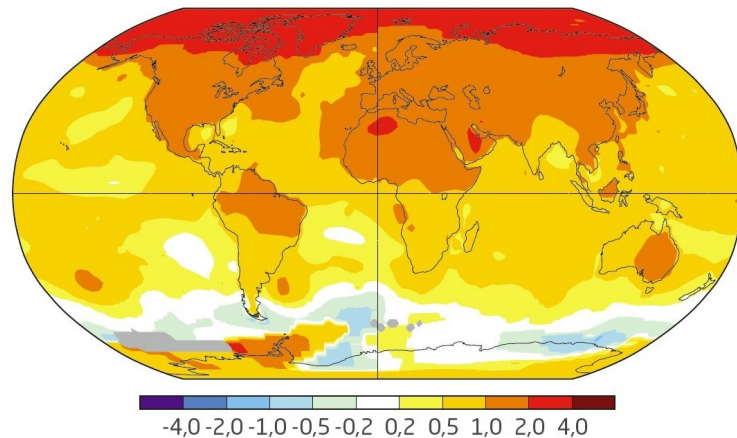
Biggerstaff and Houze [1993]



Motivation

- uncertainty in GCM predictions of polar amplification
- supercooled cloud water plays an outside role in polar surface energy budgets, GCM predictions
 - Zuidema, Intrieri, Curry et al. papers using SHEBA ice camp observations
 - Tan, Storelvmo, Kay et al. papers using climate models and CALIPSO observations

GISSTEMP 1970–2017 near-surface warming (K)



<https://www.mosaic-expedition.org/>

SHEBA Arctic survey

(a) Slightly Supercooled Stratiform Clouds (Tops 0° to -10°C)

TYPE I

0° to -10°C, small droplets, no ice, no precipitation

- Droplet concentrations typically > 100 cm⁻³
- Maximum effective droplet radius < 12 μm
- Maximum threshold droplet diameter < 28 μm (too small for collisions with coalescence)

TYPE II

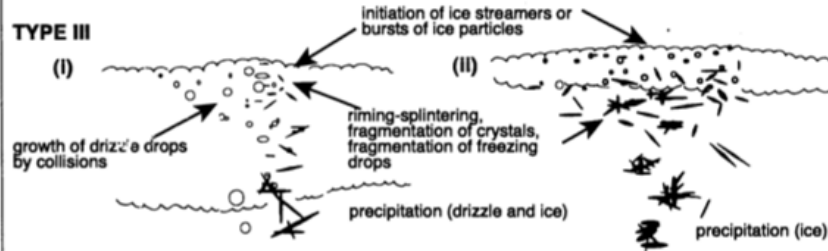
0° to -4°C, large droplets, no ice, drizzle

- Droplet concentrations < 100 cm⁻³
- maximum effective droplet radius > 12 μm
- Maximum threshold droplet diameter > 28 μm (for drizzle formation)

TYPE III

-4° to -10°C, large droplets, ice

- Droplet concentrations < 100 cm⁻³
- maximum effective droplet radius > 12 μm
- Maximum threshold droplet diameter > 28 μm (for drizzle formation)



(b) Moderately Supercooled Stratiform Clouds (Tops -10° to -20°C)

TYPE IV



ice concentrations near or below ice nucleus concentrations; mostly pristine crystals

Small droplets at cloud top, possible ice, little or no precipitation

- Droplet concentrations > 100 cm⁻³
- Maximum effective droplet radius < 10 μm
- Maximum threshold droplet diameter < 20 μm
- Ice concentrations nil or a few per liter

TYPE V



ice concentrations at or above ice nucleus concentrations due to fragmentation of crystals, freezing drops

precipitation (ice)

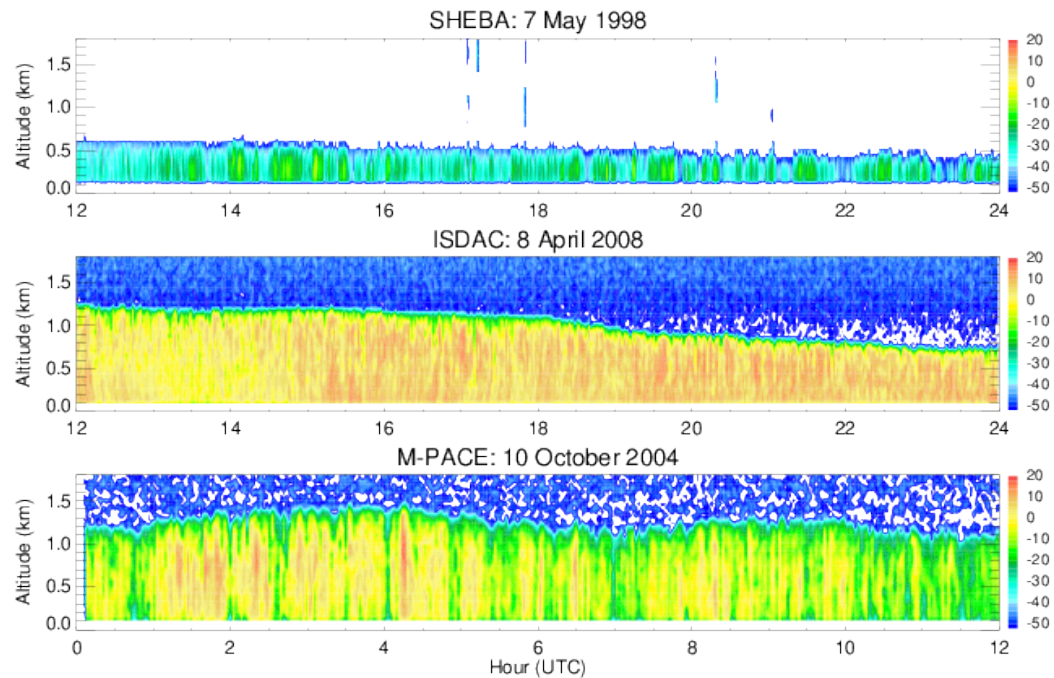
Large droplets at cloud top, ice, precipitation

- Droplet concentrations typically < 100 cm⁻³
- maximum effective radius > 10 μm
- Maximum threshold droplet diameter > 20 μm
- Ice concentrations 10-100 per liter

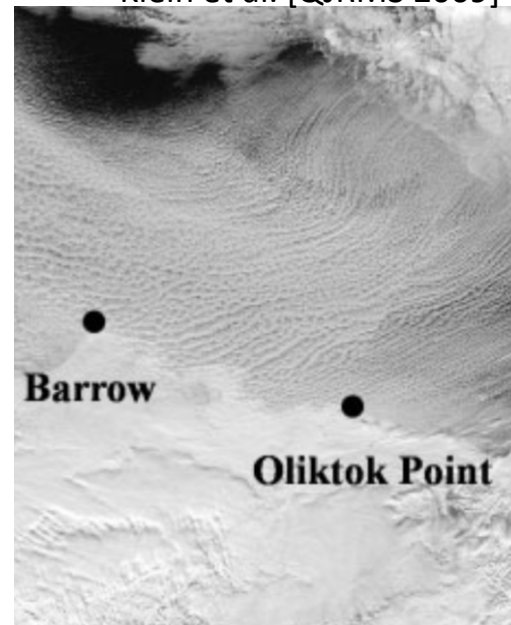
Rangno and Hobbs [JGR 2001]
following Hobbs and Rangno [1998]

Continuous ice precipitation

Vertically pointing mm-wavelength radar



Klein et al. [QJRM 2009]

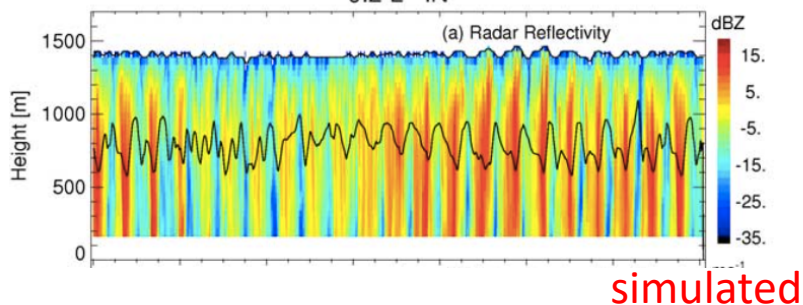
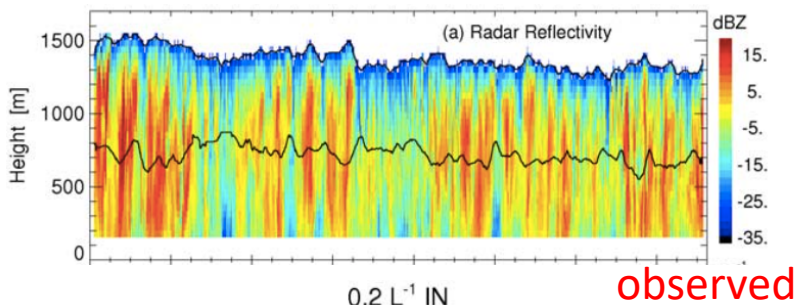


Fridlind and Ackerman [Simulations of Arctic mixed-phase boundary layer clouds: Advances in understanding and outstanding questions, Ch. 7 in *Mixed-Phase Clouds: Observations and Modeling*, Ed. C. Andronache, 2018]

Well-defined liquid cloud base

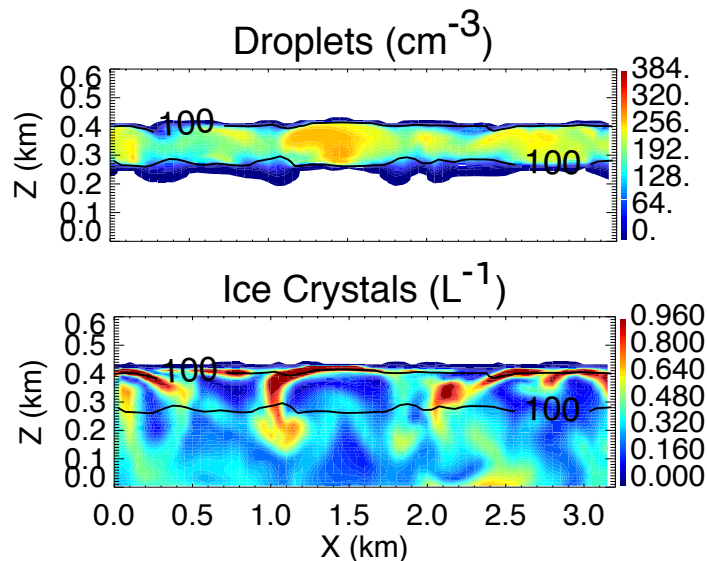
~~glaciated patches?~~

M-PACE radar reflectivity and lidar cloud base



van Dierenhoven et al. [JGR 2009]

SHEBA simulation

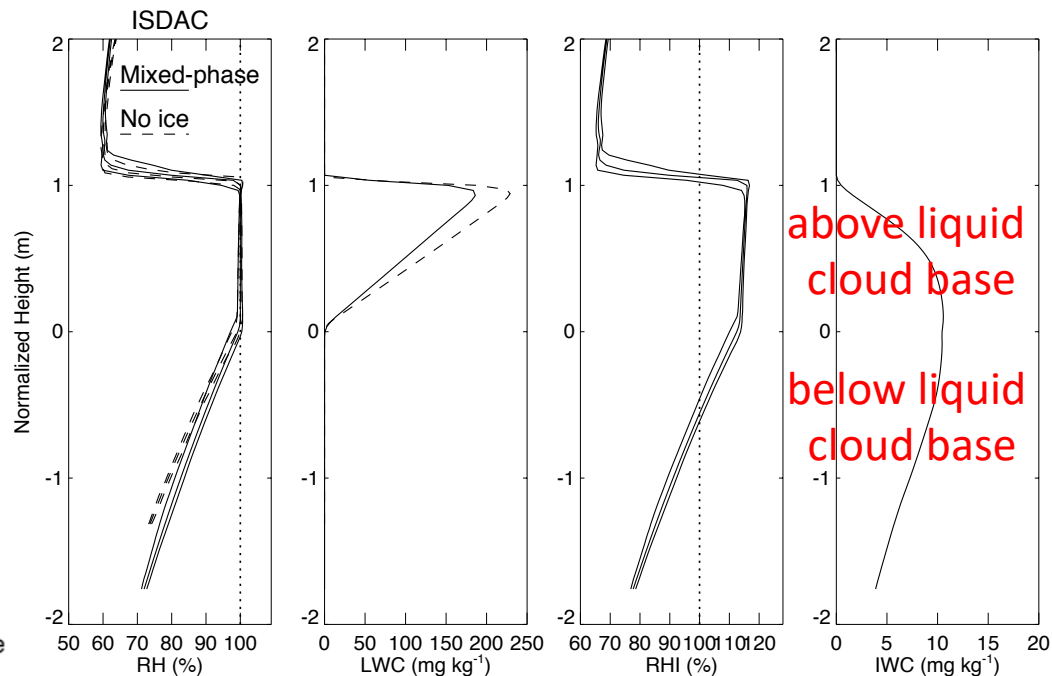
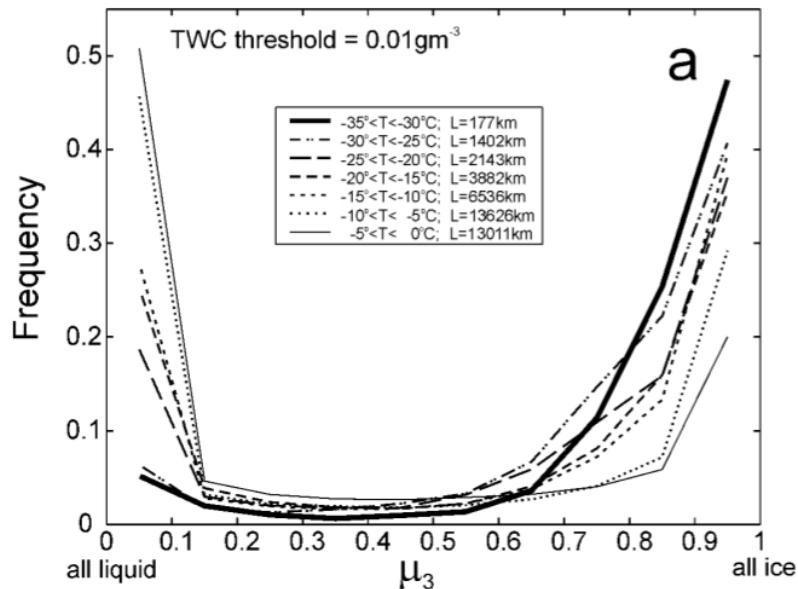


Fridlind et al. [JAS 2012]

Big data

Avramov et al. [JGR 2011]

Korolev et al. [QJRMS 2003]



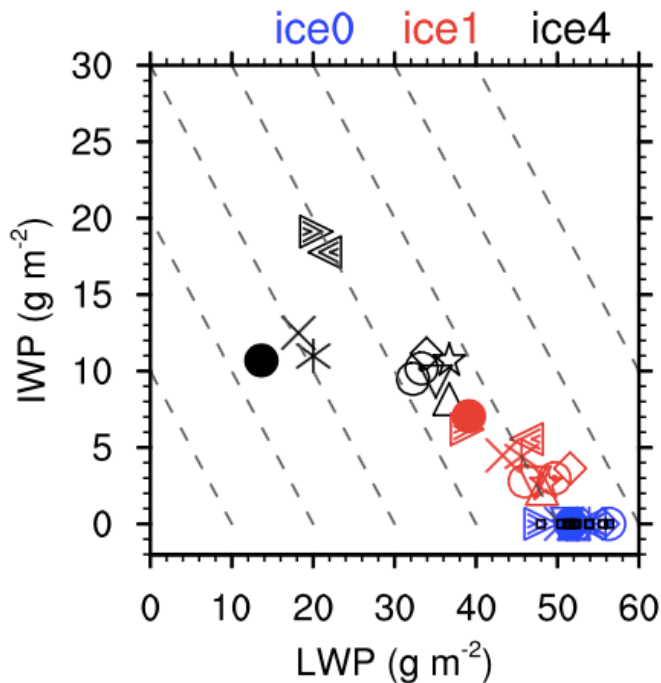
~ 100 m (1 s) averaging

N ~ 0.5 million

see also e.g. McFarquhar et al. [JGR 2004], Jackson et al. [JGR 2012]



ISDAC intercomparison



- \triangle DHARMA-2M
- ∇ SAM-2M
- \bullet METO
- $*$ COSMO
- \odot UCLALES
- \times UCLALES-SB
- \diamond RAMS
- \circ WRFLES
- \star WRFLES-PSU
- \triangleleft DHARMA-bin
- \triangleright SAM-bin

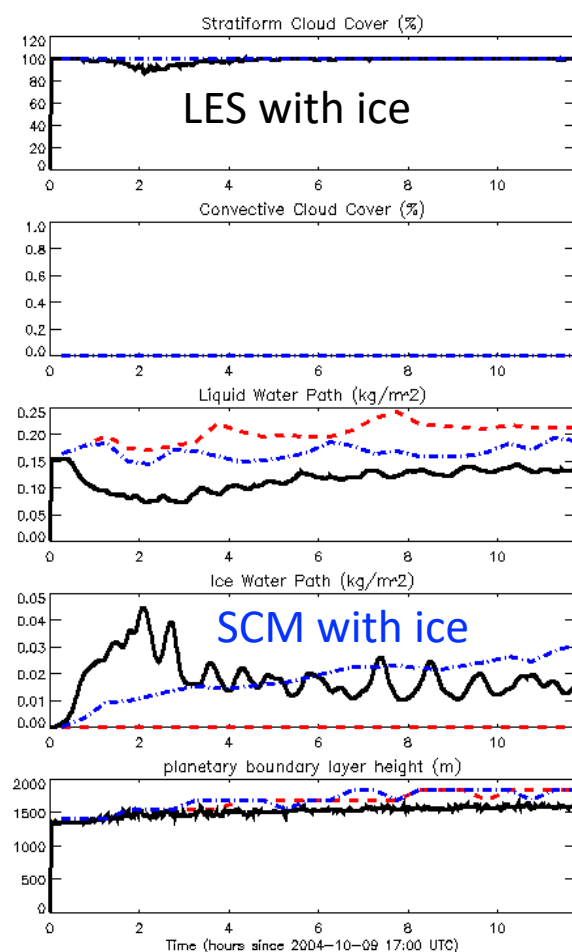
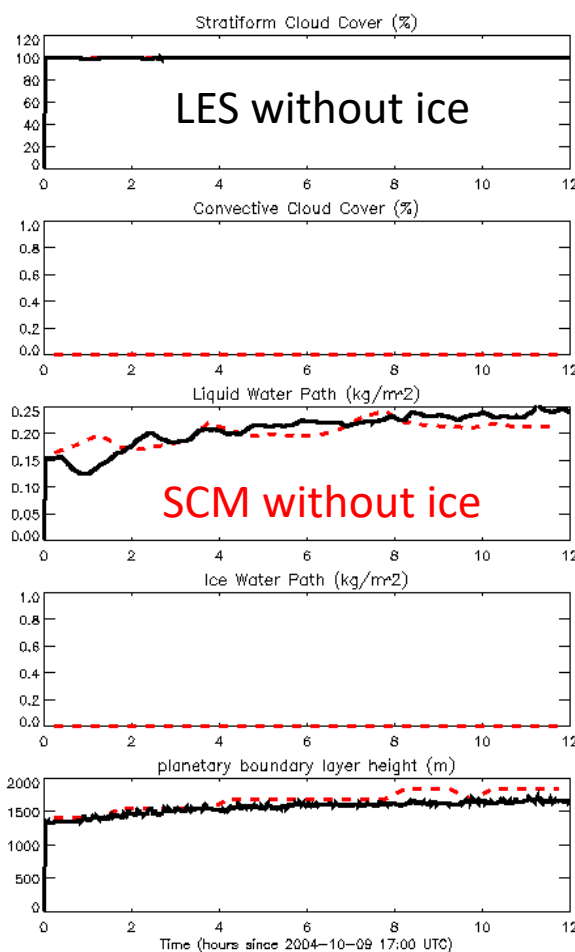
~~*persistence
remarkable?*~~

Ovchinnikov et al. [2014]

GCM in SCM mode

- M-PACE intercomparison case [Klein et al. QJRM 2009]
- GISS ModelE3 single-column model (Andy Ackerman)
 - moist turbulence scheme [Bretherton and Park 2009]
 - two-moment microphysics with prognostic precipitation [Gettelman and Morrison 2015]

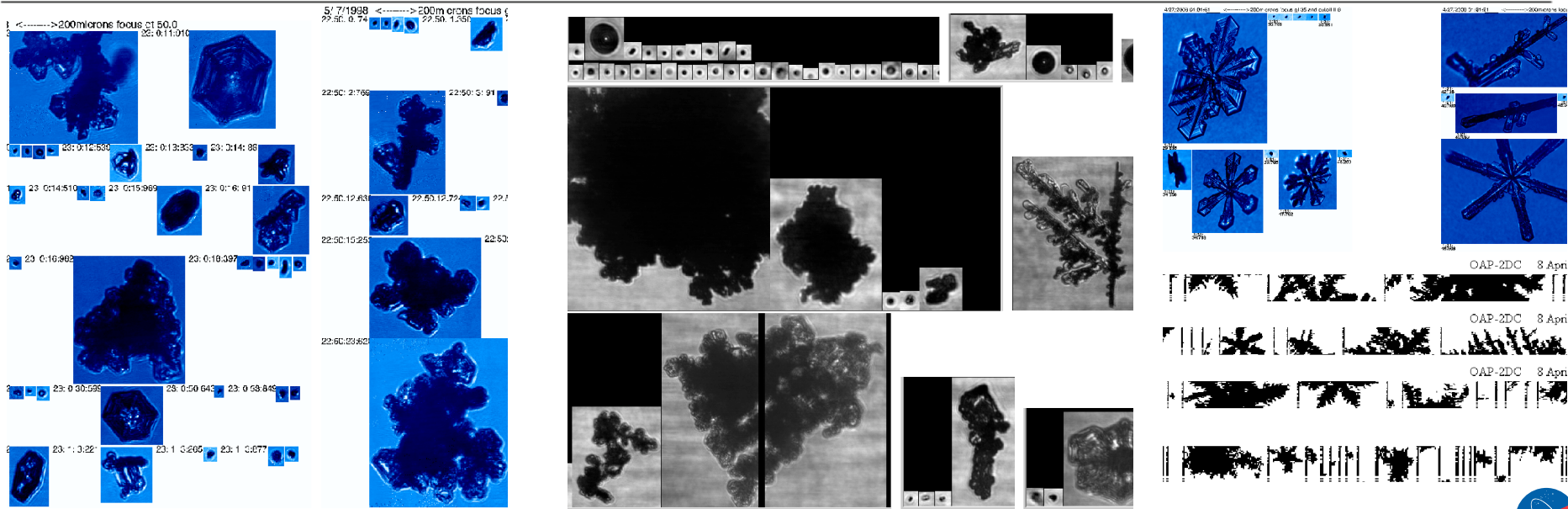
GCM $\Delta z \sim 100$ m
LES $\Delta z \sim 30$ m



Mixed-phase Sc LES case studies

Fridlind and Ackerman
[Elsevier 2018]

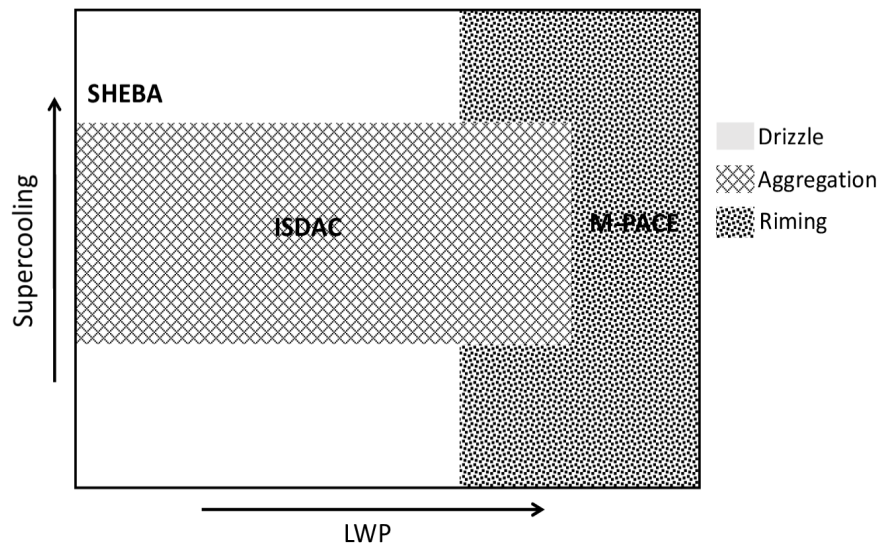
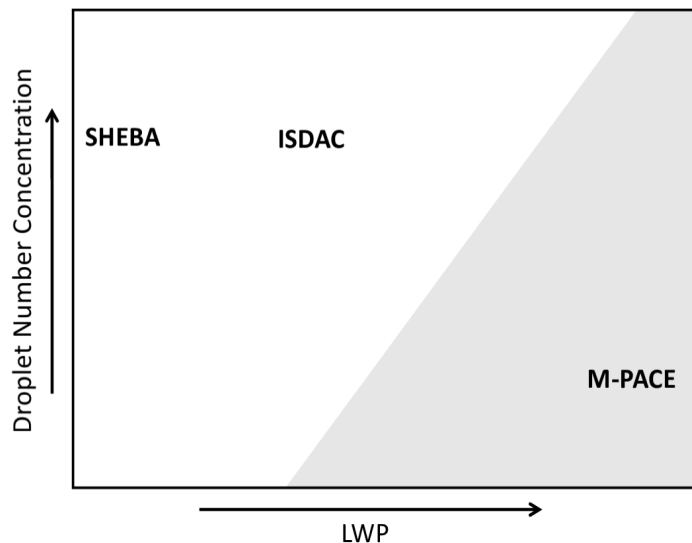
Field Campaign	Observation Period (UTC)	Cloud Top Height (m)	Cloud Temp. (C)		Path (g m^{-2})		Conc. (cm^{-3})	
			Top	Base	Liquid	Ice	Drops	Ice
SHEBA	7 May 1998	500	-20°	-18°	5-20	0.2-1	200	~0.0005
M-PACE	9-10 Oct. 2004	1000	-16°	-9°	110-210	8-30	40	~0.01
ISDAC	26 April 2008	800	-15°	-11°	10-40	2-6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



Mixed-phase Sc LES case studies

Fridlind and Ackerman
[Elsevier 2018]

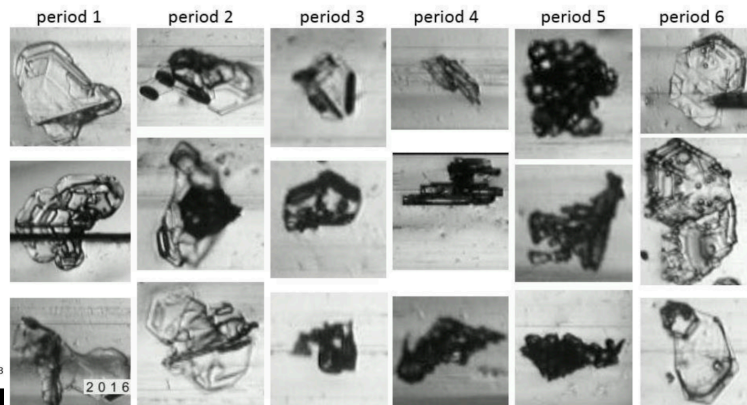
Field Campaign	Observation Period (UTC)	Cloud Top Height (m)	Cloud Temp. (C)		Path (g m^{-2})		Conc. (cm^{-3})	
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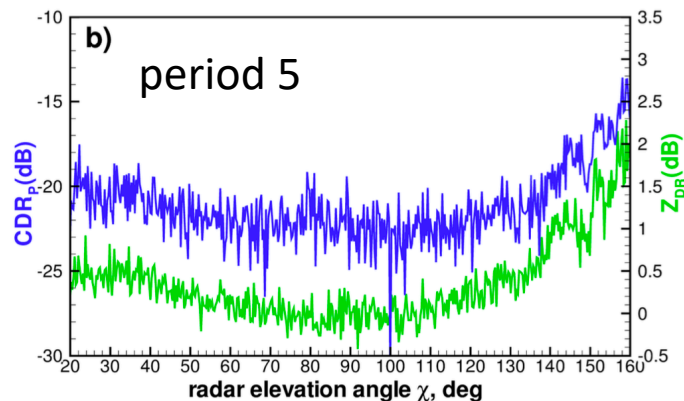
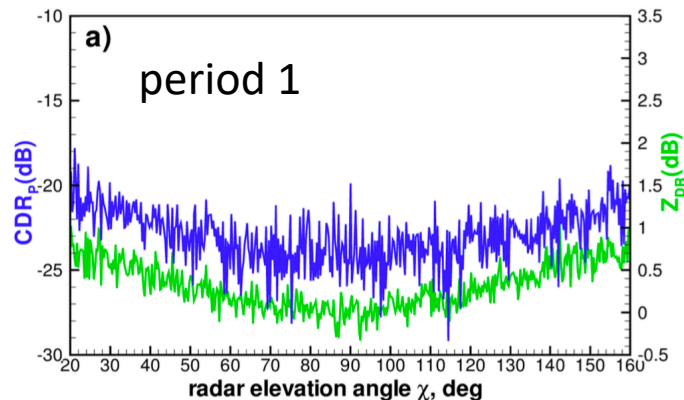
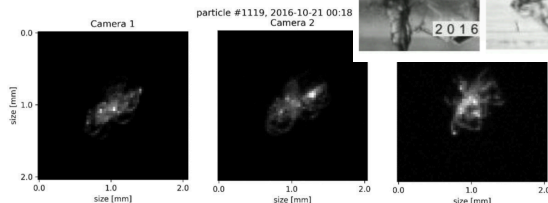
Reflectivity-weighted aspect ratio

- Matrosov et al. [JAOT 2017]
 - SACR Ka-band
 - circulation depolarization ratio (CDR) proxy

VIPS in situ
0.2–0.5 km

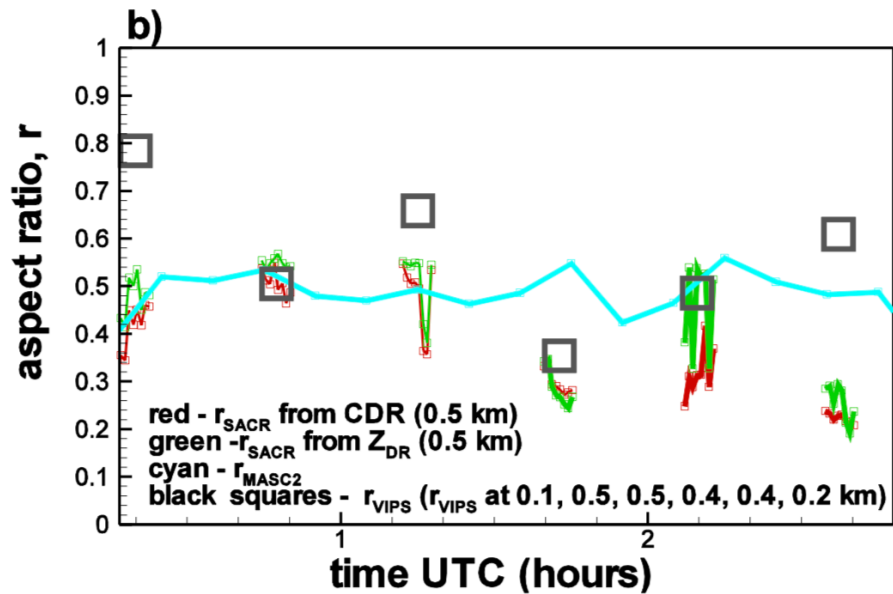


MASC period 1
stereo images



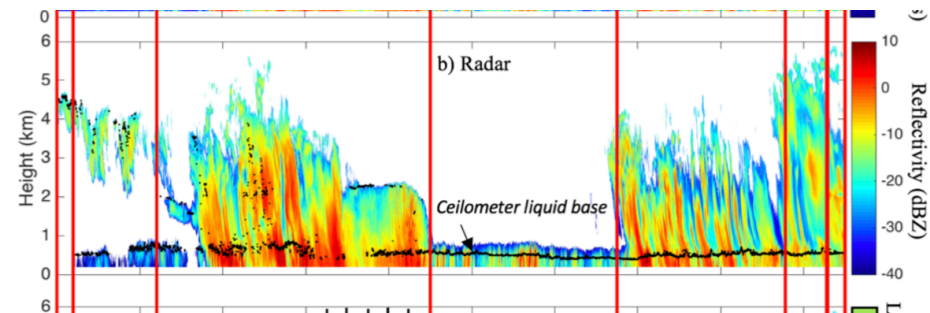
Reflectivity-weighted aspect ratio

- Matrosov et al. [JAOT 2017]
 - 40° CDR proxy or Zdr-based
 - characteristic size from dual-frequency reflectivity ratio (DFR) or dual Doppler velocity (for smaller particles)
 - uncertainty of 0.1–0.15
 - RHI scans averaged over 2° around 40° and 140°

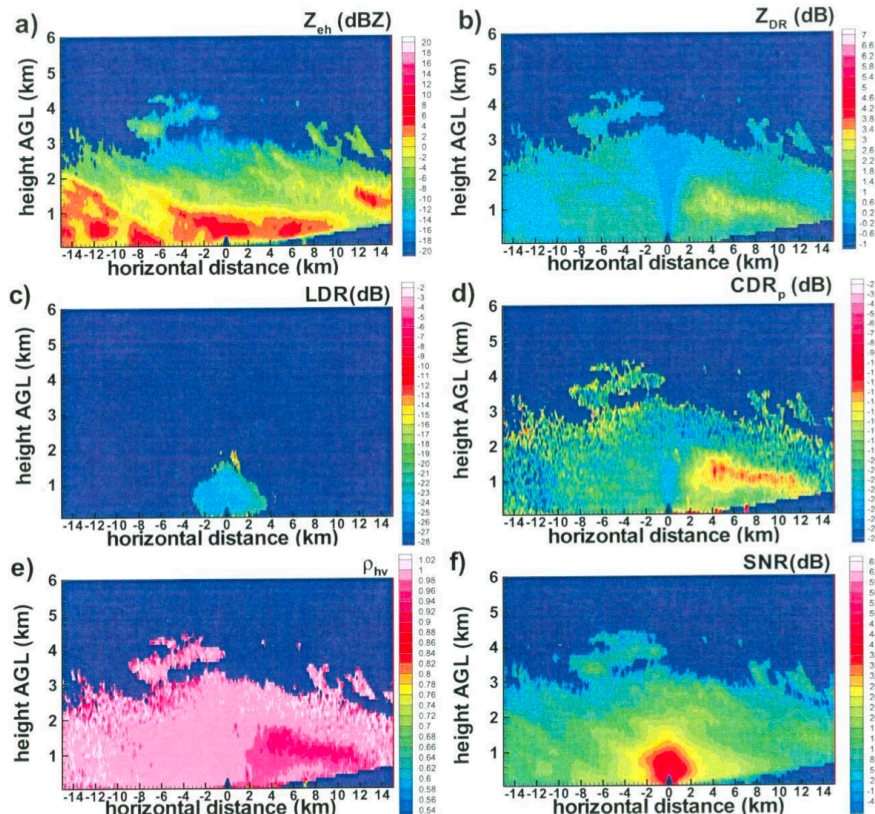


Cloud structure, too

- cloud structure deconvolution from vertically pointing or QVP: is it even robustly possible?
- if there is not a very substantial gain from QVP, RHI is preferable



Lamer [2017] NSA KAZR and ceilometer



Matrosov et al. [2017]