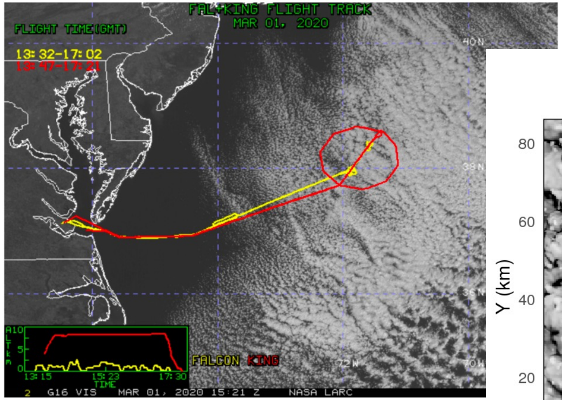
ModelE3 development approach

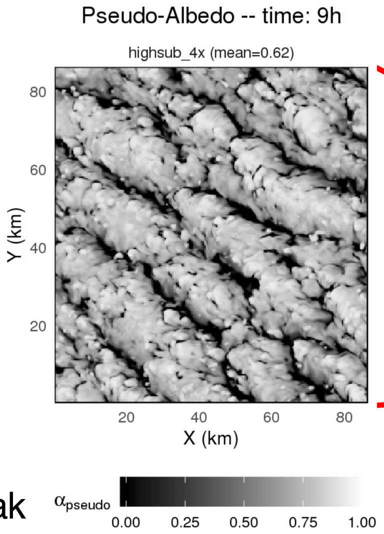
Global data → ESM tuning

Field campaigns → LES → SCM

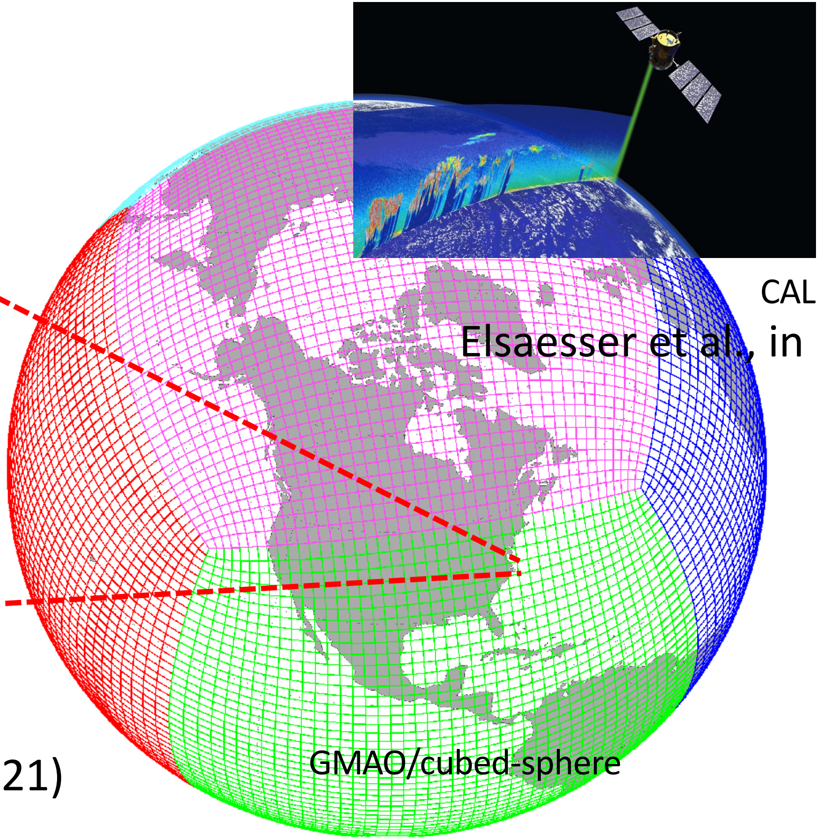


From https://satcorps.larc.nasa.go

ACTIVATE Flight RF13
1 March 2020
mixed-phase cold-air outbreak



Tornow et al. (ACP 2021)



CALIPSO

Elsaesser et al., in prep.

GMAO/cubed-sphere

Field campaigns —> LES —> Single-column model (SCM)

Conditions	Case study	Aerosol aware?
dry convective boundary layer	idealized [Bretherton and Park 2009]	—
dry stable boundary layer	GABLS1 [Cuxart et al. 2006]	—
marine stratocumulus	DYCOMS-II RF02 [Ackerman et al. 2009]	observed (2 modes)
marine trade cumulus (shallow)	BOMEX [Siebesma et al. 2003]	no
marine trade cumulus (deep, raining)	RICO [van Zanten et al. 2011]	no
marine stratocumulus-to-cumulus *	SCT [Sandu and Stevens 2011]	no
continental cumulus ^	RACORO [Vogelmann et al. 2015]	observed profile (3 modes)
Arctic mixed-phase stratus	M-PACE [Klein et al. 2009]	observed (2 modes)
Antarctic mixed-phase stratus *	AWARE [Silber et al. 2019, 2021, 2022]	estimated (1 mode)
tropical deep convection	TWP-ICE [Fridlind et al. 2012]	observed profile (3 modes)
mid-latitude synoptic cirrus *	SPARTICUS [cf. Mühlbauer et al. 2014]	no
mid-latitude cold-air outbreak *^	ACTIVATE [Tornow et al., 2021, 2022, in prep.]	observed profile (3 modes)
high-latitude cold-air outbreak *^	COMBLE [Tornow et al., in prep.]	observed/estimated profiles (3 modes w/INP)
marine cumulus and congestus *^	CAMP2Ex [Stanford et al., in prep.]	observed profiles (3 modes)
subtropical marine deep convection *^	SEAC4RS [Stanford et al., in prep.]	observed profiles (TBD)
continental sea breeze convection *^	TRACER [Matsui et al., in prep.]	observed profiles (TBD)

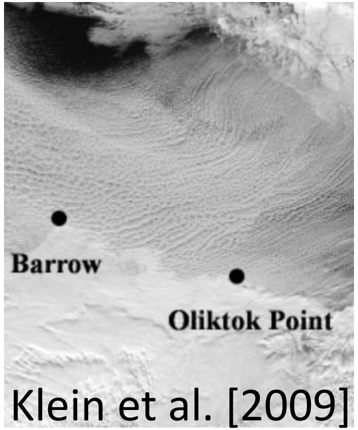
*Lagrangian (cf. Neggers JAMES 2015, Pithan et al. NatGeo 2019)

^ensemble (cf. Neggers et al. JAMES 2019)

Ice formation approach

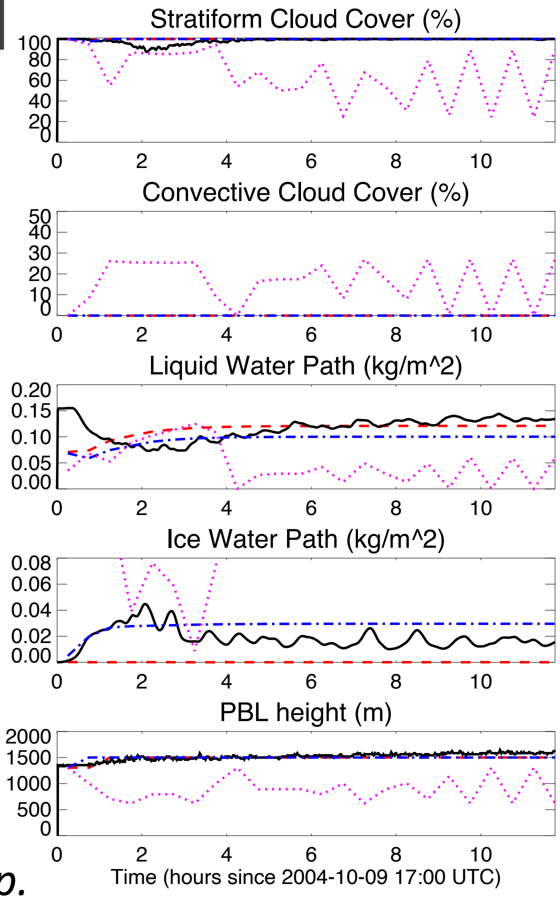
- Only physically-based mechanisms and parameterizations
- Avoid unnecessary complexity
- Each mechanism should be demonstrably active in observed case studies
- Heterogeneous freezing mechanisms should be linkable to aerosol properties
- But start with diagnostic INP, e.g. immersion mode
  - DeMott et al. 2010 * f_{scale_iifn}
  - $f_{scale\_iifn} < 1$ can crudely account for efficient precipitation scavenging (Fridlind et al. JAS 2012)

M-PACE

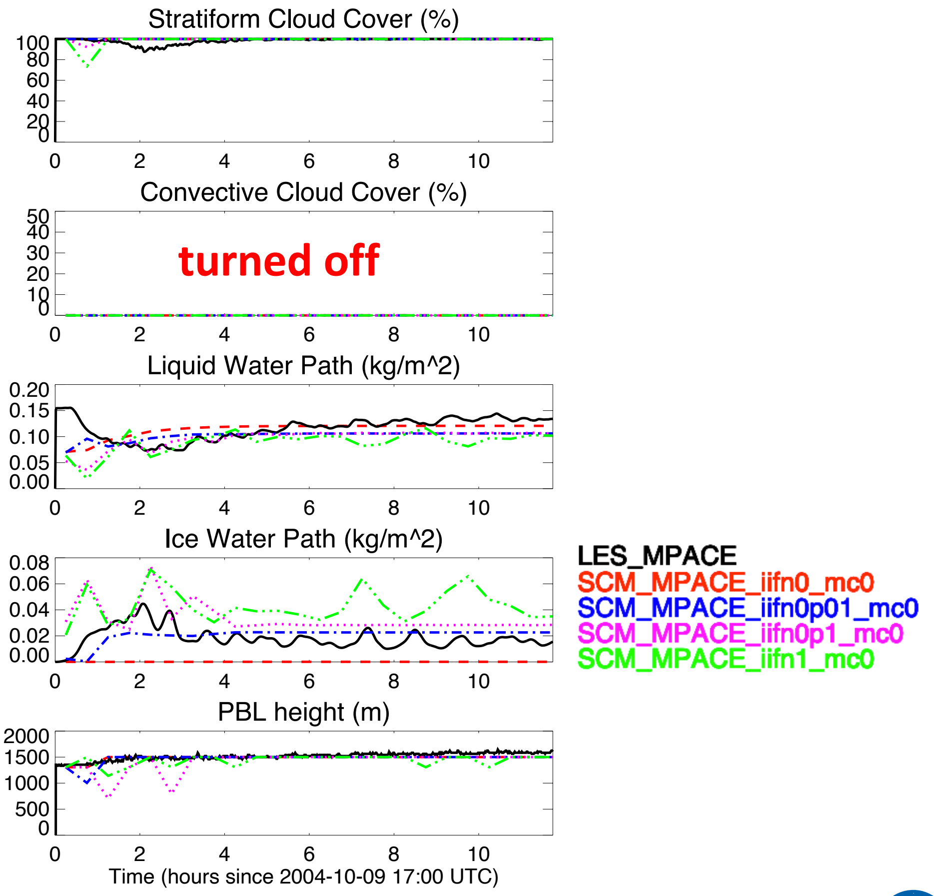


Klein et al. [2009]

fixed N_{ic}



N_{ic} = f * DeMott et al. [2010]

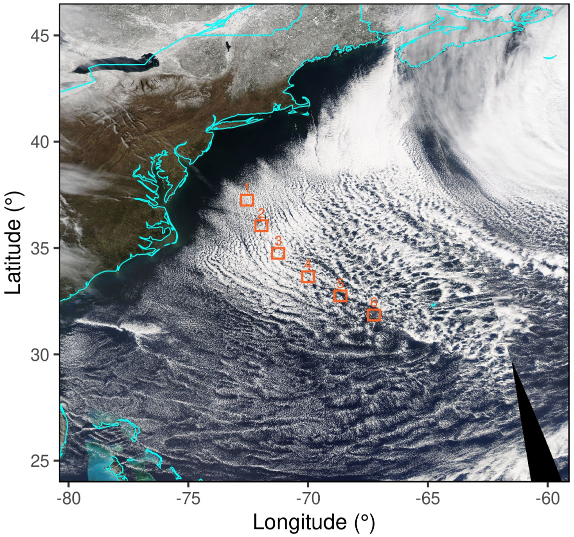


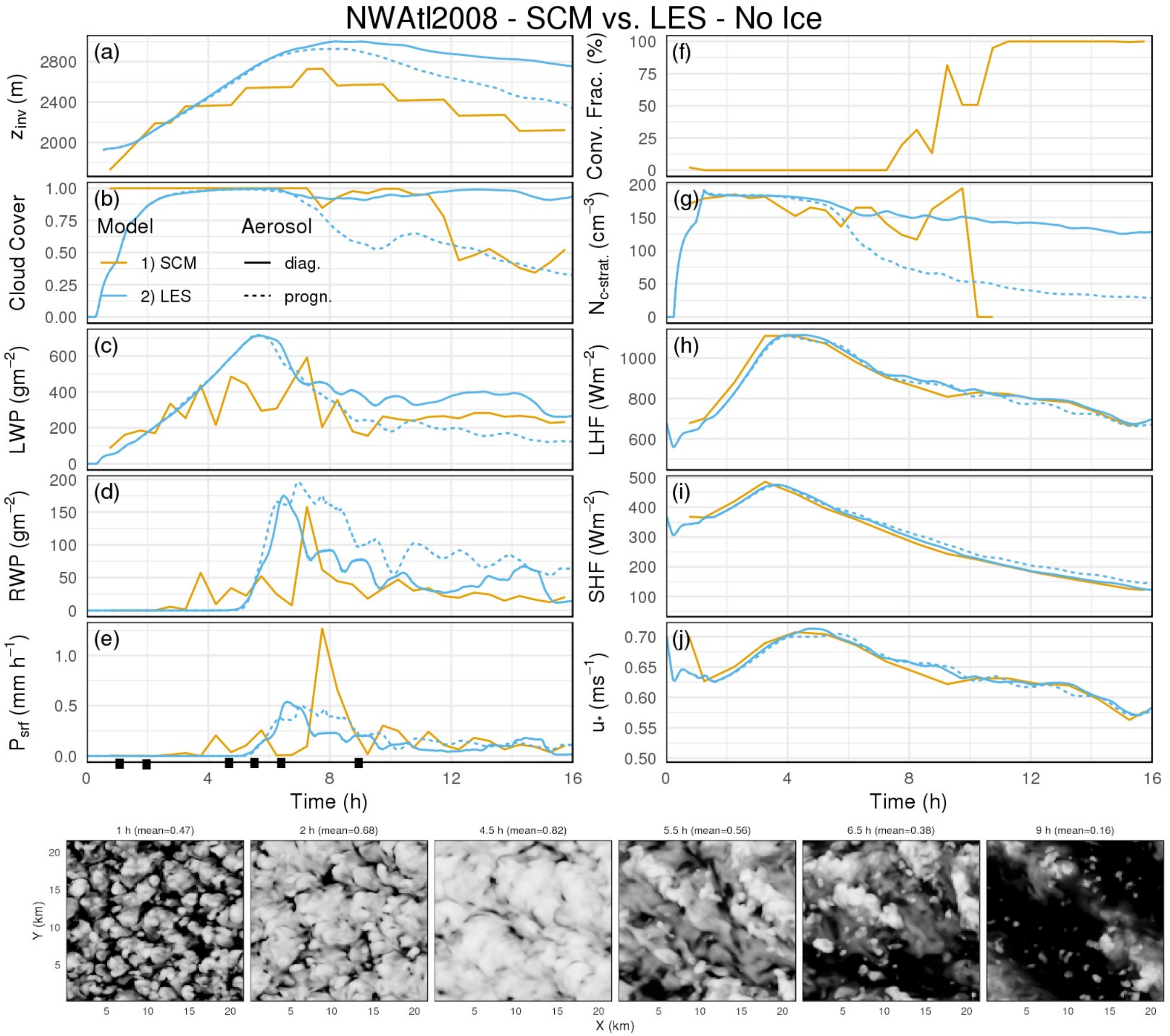
manuscript in prep.

NASA ACTIVATE

- riming consumes CCN [Tornow et al. ACP 2021]
- applicable to grey zone [de Roode et al. 2019]

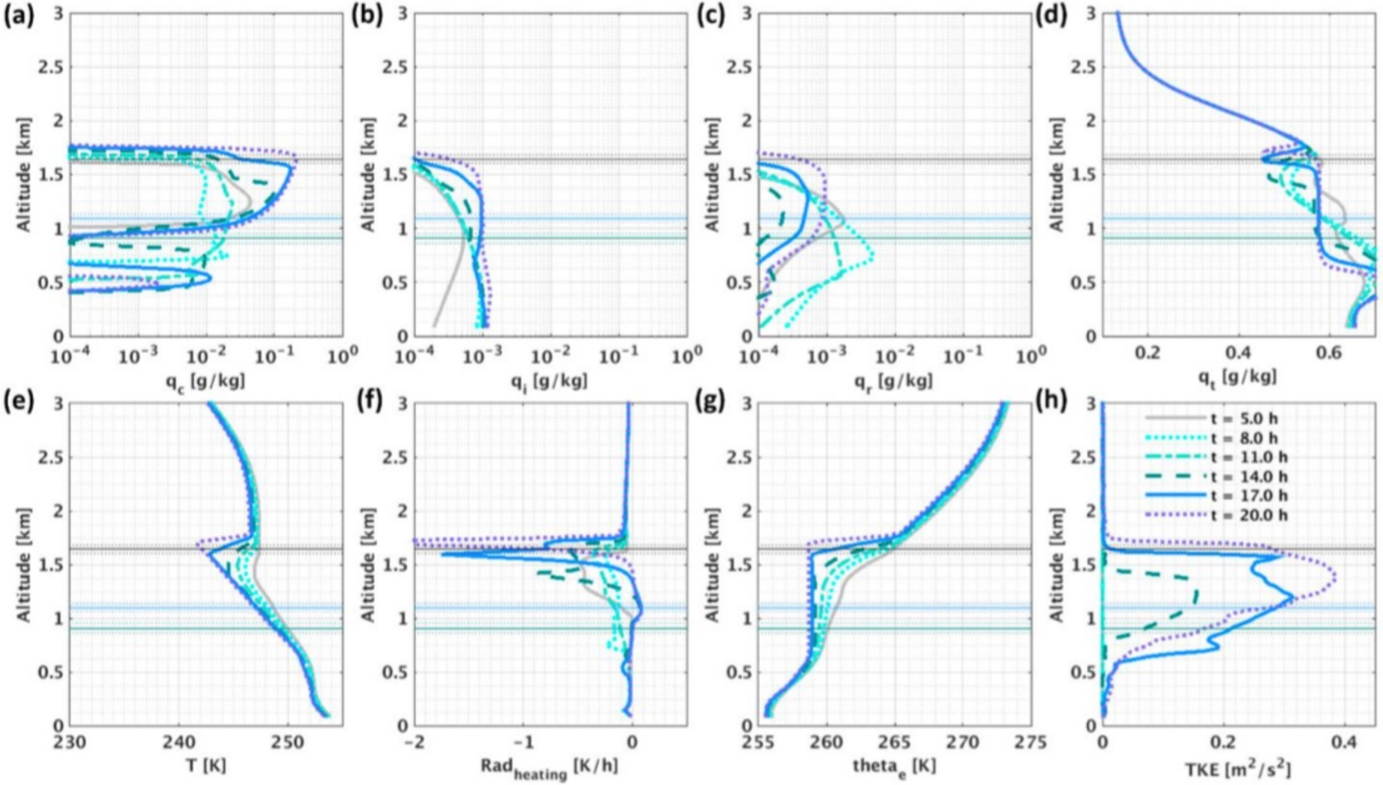
MODIS Aqua Imagery





Highly supercooled drizzle over Antarctica

- CTT ≈ –25°C
- initially stable atmosphere
- large-scale ascent —> thin supercooled cloud layer
- LW cooling —> thickening turbulent layer
- $N_c \approx 20/\text{cm3}$, $N_i \approx 0.1/\text{L}$

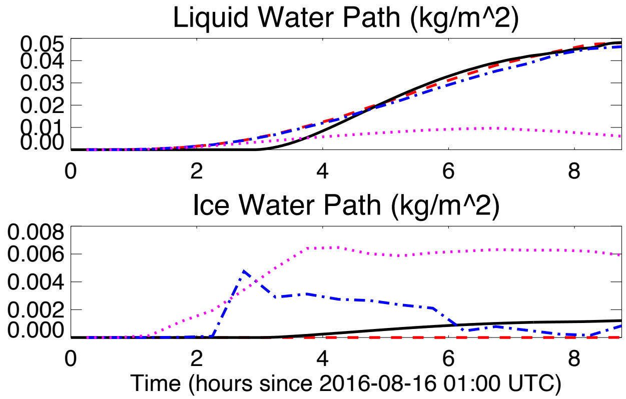


AWARE campaign case study (Silber et al. JGR 2019)

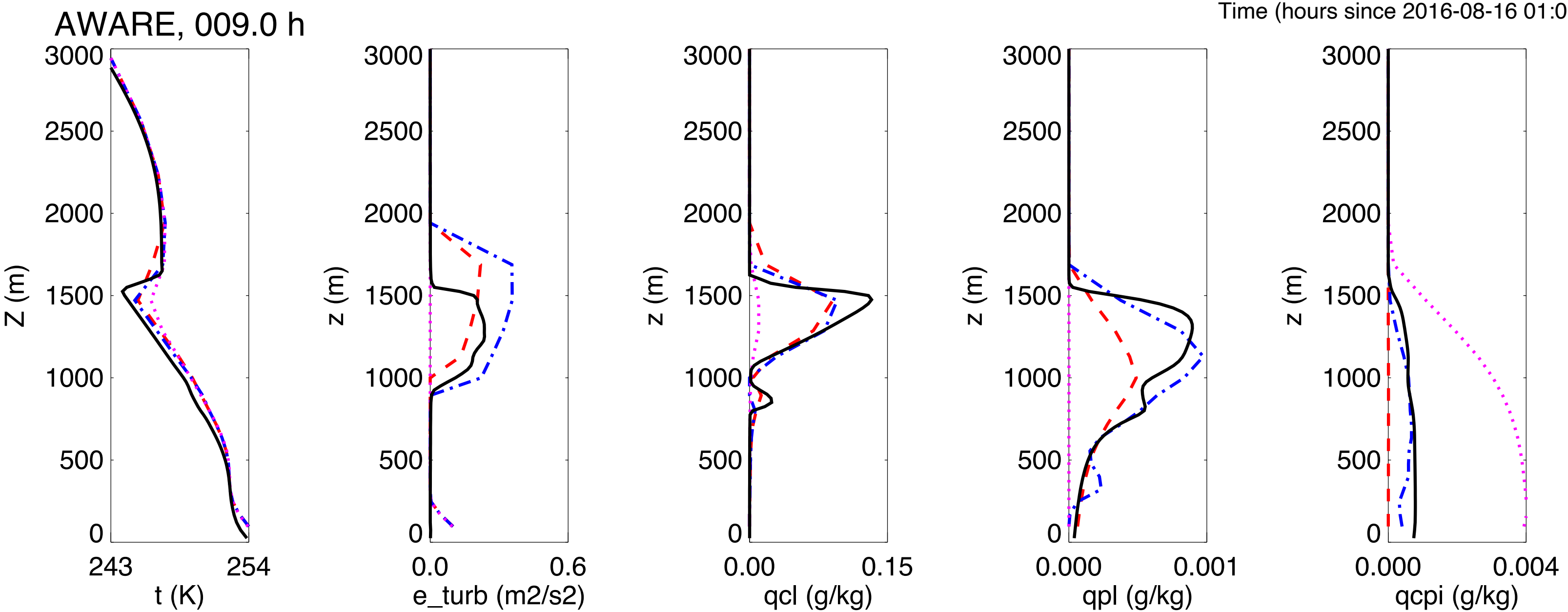
AWARE case study

- SCM performs quite well
- stable conditions common
  (Silber et al. ACP 2020; GRL 2021)

LES_AWARE
SCM_AWARE_iifn0
SCM_AWARE_iifn0p1
SCM_AWARE_iifn1



see Silber et al. [GMD 2021]



Tuning Protocol

- scale_iifn is one of 45 parameters taken to be poorly constrained
- LES/SCM used to estimate parameter ranges
- satellite dataset uncertainties are specified

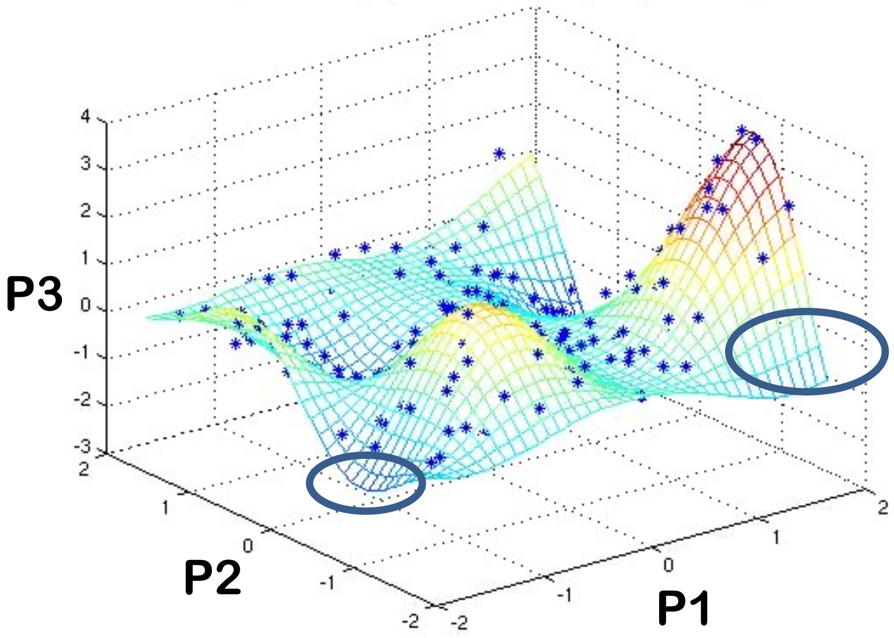
source: Greg Elsaesser

Metrics (36 in total)	Data Source
Radiation (Longwave [LW], Shortwave [SW])	CERES-EBAF-Ed4.1
Cloud Radiative Forcing (LWcrf, SWcrf)	CERES-EBAF-Ed4.1
Column Water Vapor (CWV)	*Obs4MIPS RSS, G-VAP
Specific Humidity profiles (qv)	*Obs4MIPS AIRS, MLS
Temperature profiles (T)	*Obs4MIPS AIRS, MLS, GNSS-RO
Total Liquid Water Path (TLWP)	*MAC-LWP, GPM/TRMM
Total Ice Water Path (TIWP)	*CloudSat, MODIS
Total Precipitation (Pr)	*GPCP, GPM/TRMM
Convective Precipitation (Prc)	GPM/TRMM
Total Cloud Cover (TCC)	CloudSat/CALIPSO, ISCCP
Low (Shallow Cu, StratoCu) Cloud Cover	CloudSat/CALIPSO
Cloudtop Droplet Number Concentration	*MODIS (Bennartz, Grosvenor)
Surface Wind (W)	*WindSat, QuikSCAT
Liquid-to-ice transition Temperature/Height	CALIPSO

ModelE3 emulator based on 450 1-year atmosphere runs

Latin Hypercube sampling in a 45-dimensional parameter state space. Lots of empty state space; emulator (neural network) fills in the gaps.

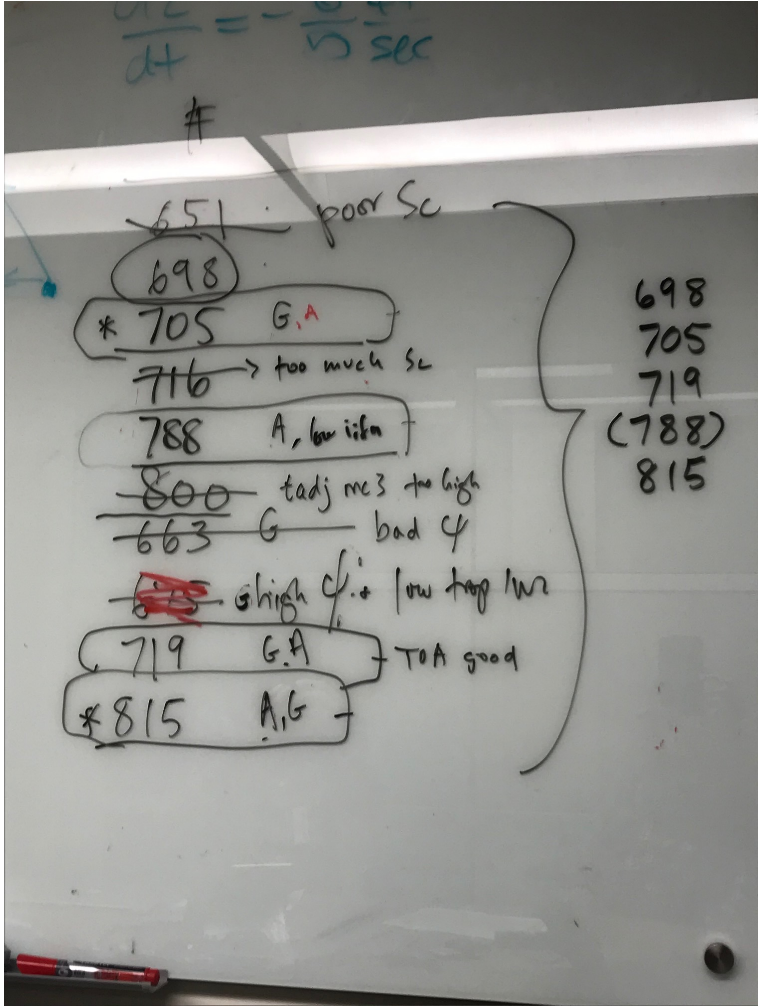
Example Penalty State Space Transect for any given model metric



source: Marcus van Lier-Walqui

After The Machine

- photo of white board at GISS

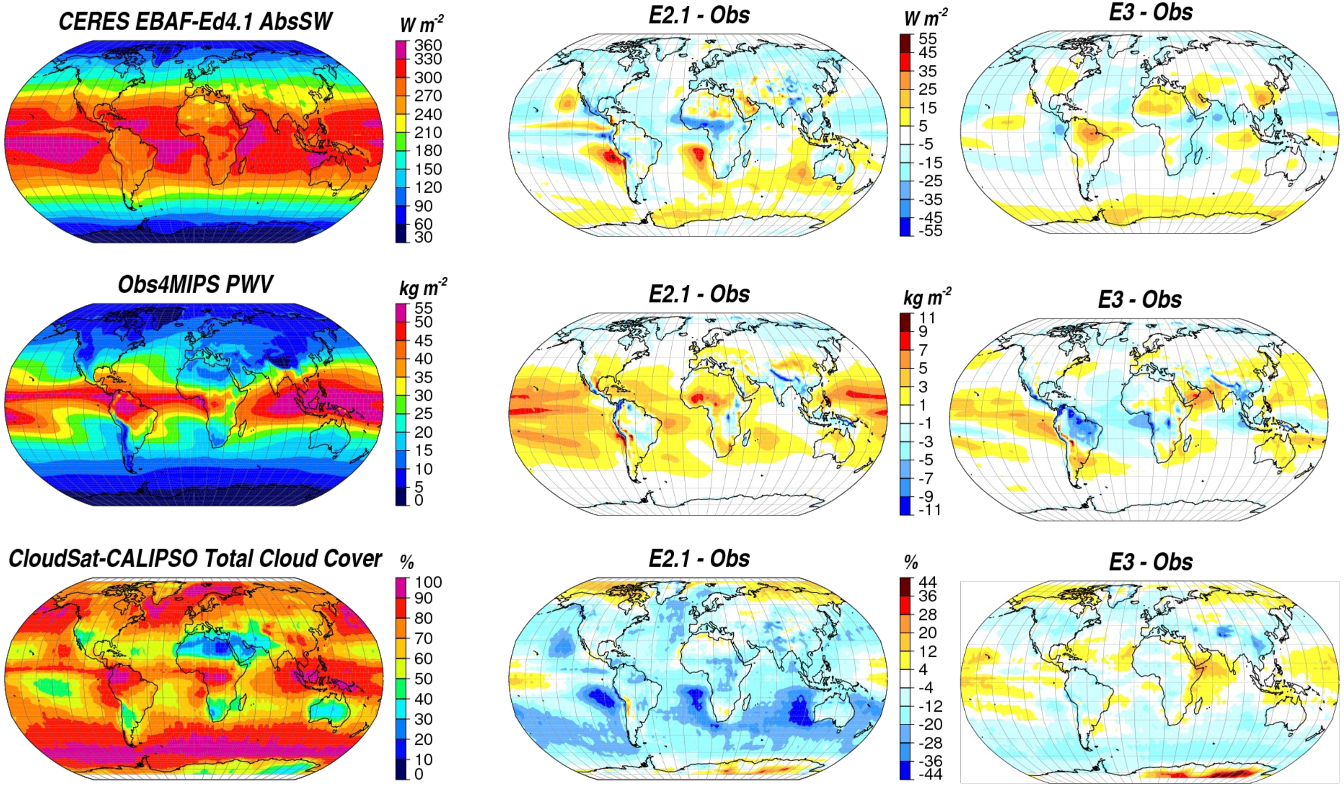


Obs **E2.1 – Obs** **E3.tun2 – Obs**

AbsSW

PWV

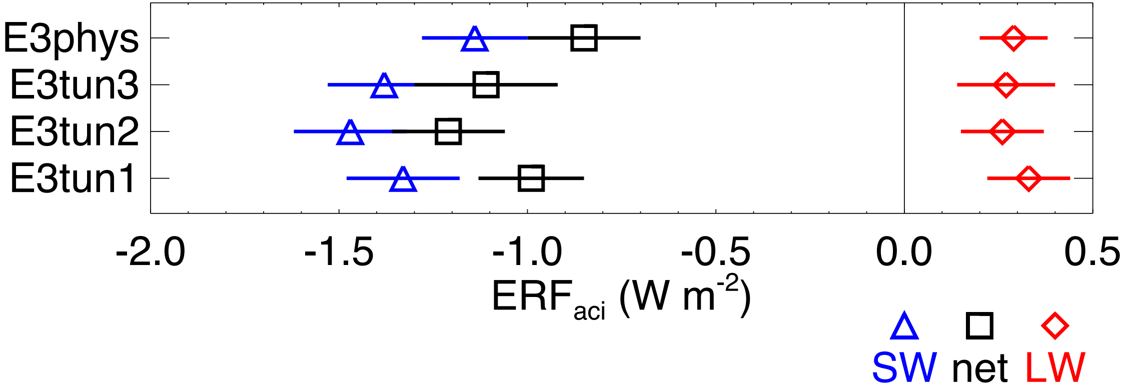
TCC

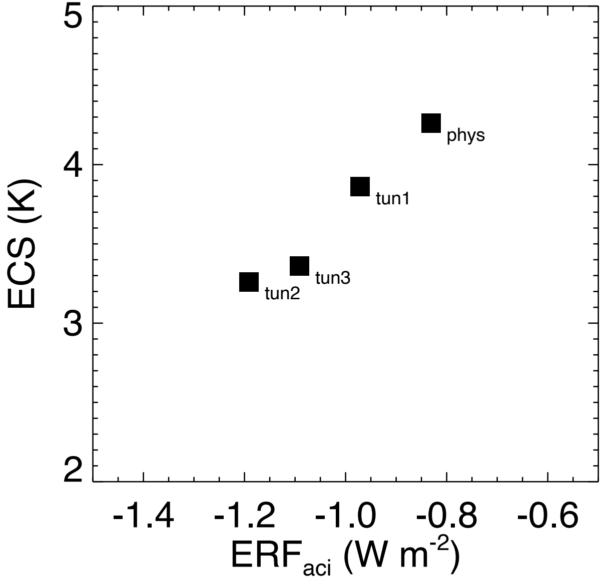


source: Greg Elsaesser

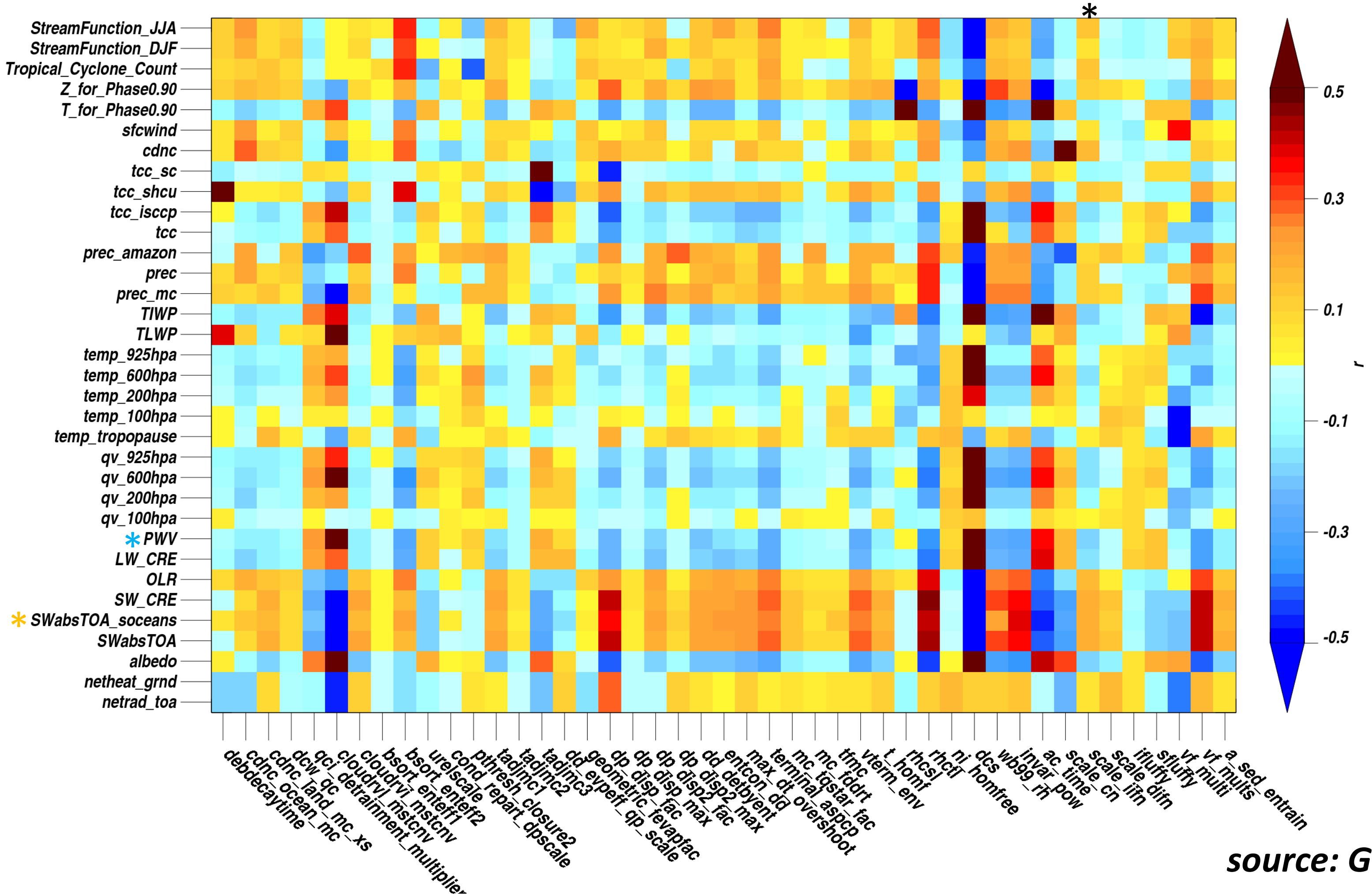
Aerosol indirect effect and ECS from E3 candidates

- AIE from 2000-2010 AMIP runs, PD minus PI offline aerosol for droplet activation only
- ECS from 30-year Q-flux PI runs





source: Andy Ackerman

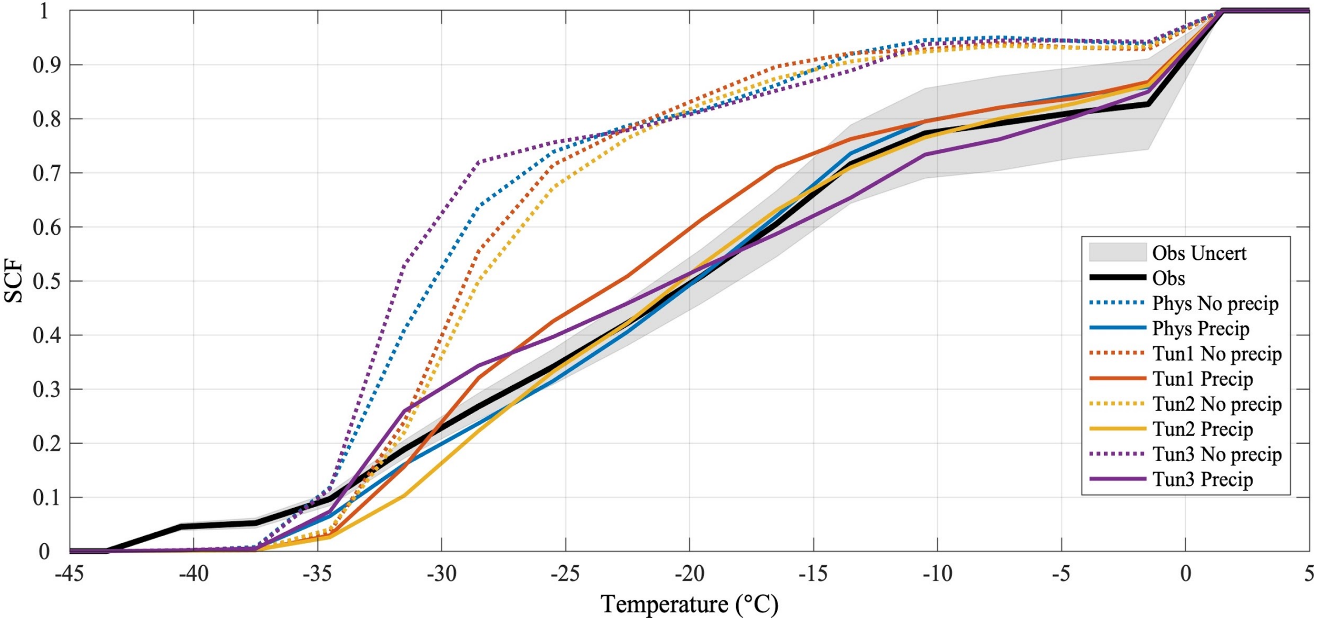


correlation with mean of obs metrics

source: Greg Elsaesser

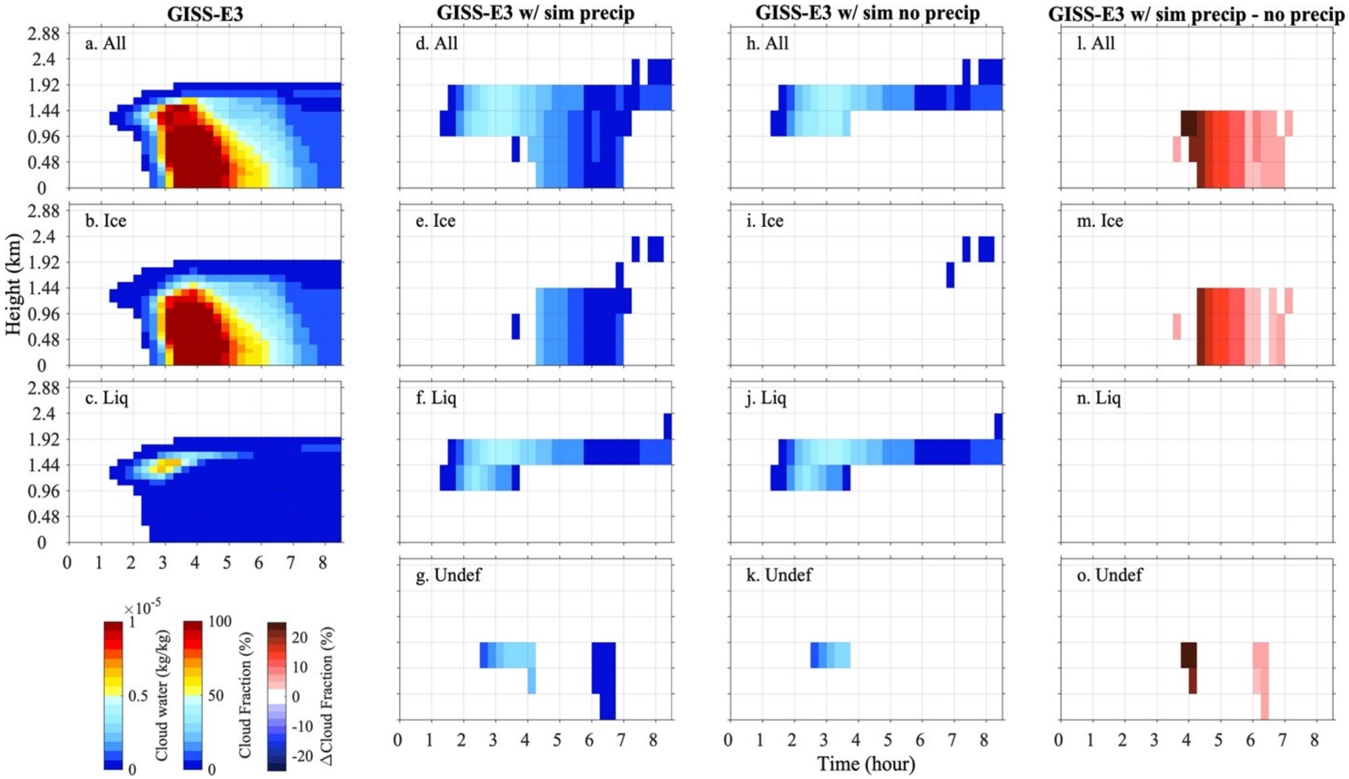
ModelE3 supercooled cloud fraction vs CALIPSO

- COSP simulator modified to see ”precipitation”
- note: cloud ice is continuous with precipitating ice (e.g., Fridlind et al. JAS 2012)
- ”precipitation” also affects cloud feedbacks across ModelE3s



Cesana et al. (GRL 2021, Fig. S6)

COSP simulator revision tested on SCM AWARE case

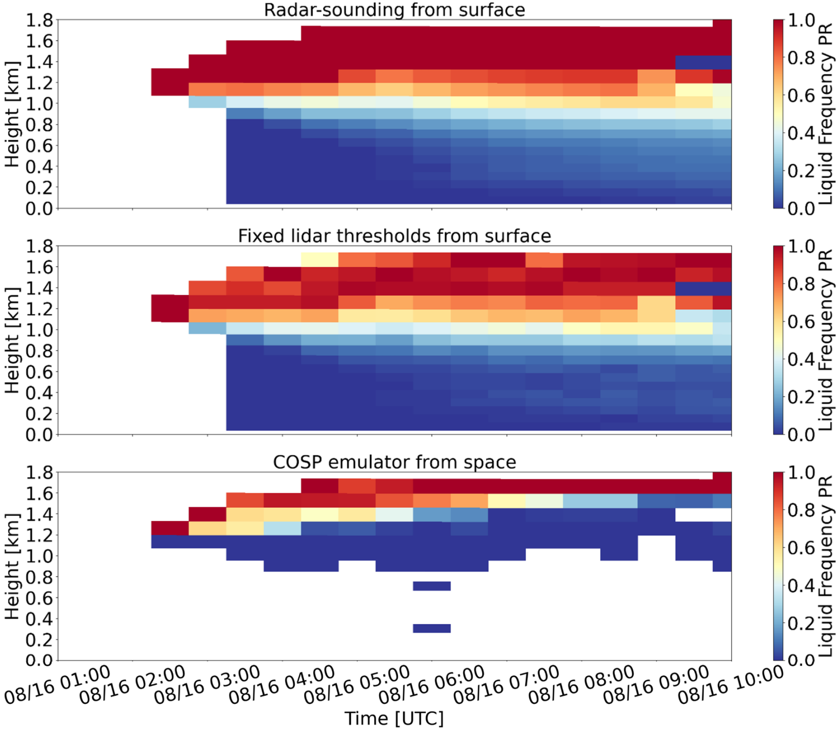


Cesana et al. (GRL 2021, Fig. S1)

A new ground-based lidar/radar simulator: EMC²

- Earth Model Column Collaboratory
- Python open source, community code base
- tool to evaluate supercooled cloud fraction, cloud base and surface precipitation, ...

***EMC²* microphysics**



from surface: sounding approach

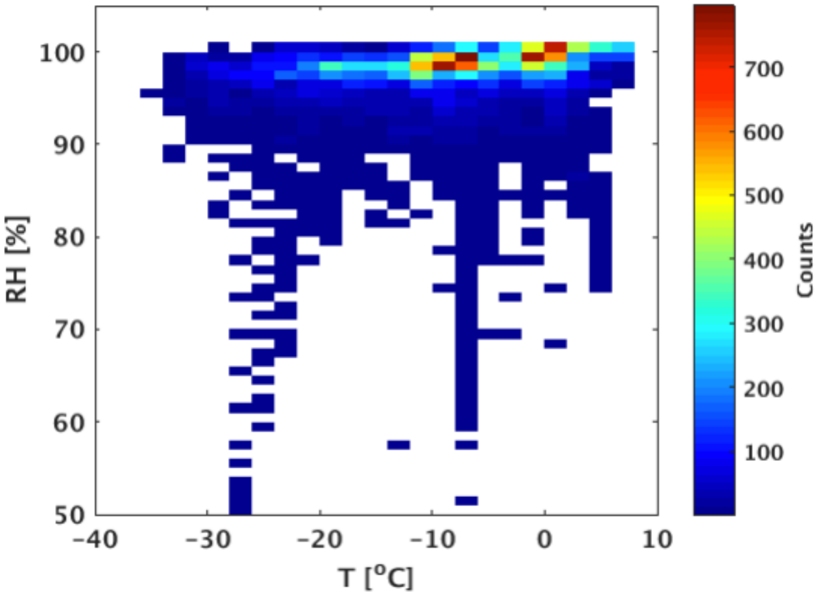
from surface: lidar approach

from space

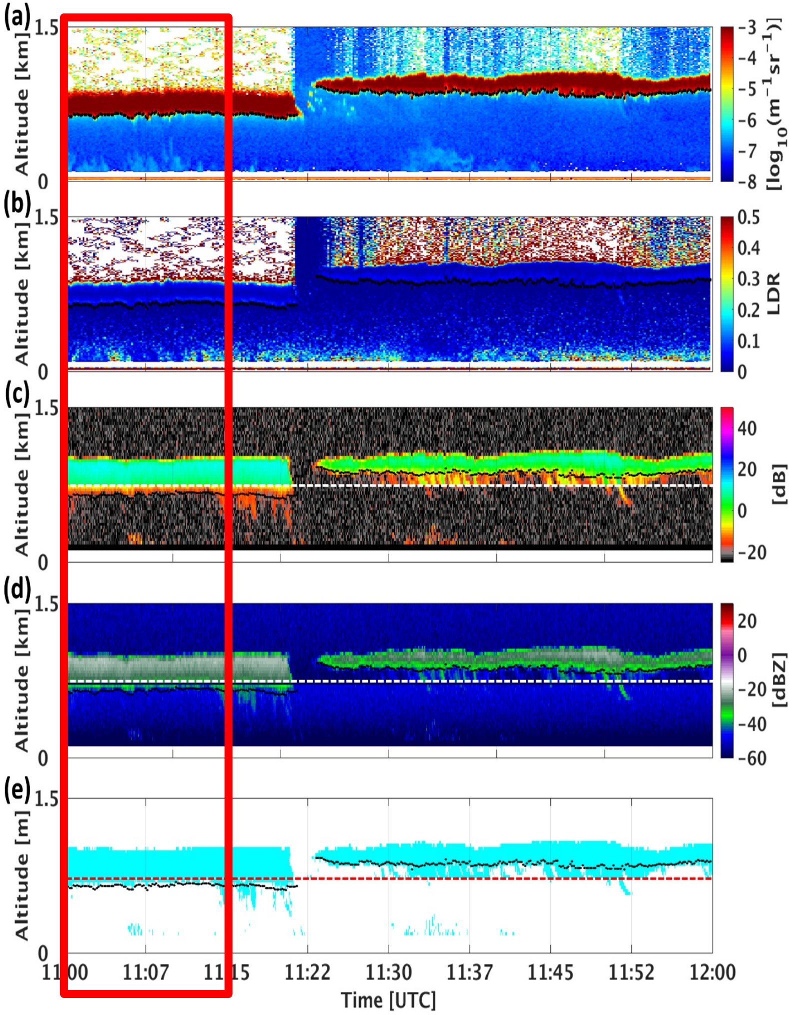
Silber, Jackson, Collis et al. (GMD, 2021)

Observing supercooled layers

- lidar attenuated? use soundings
- colocated radar reflectivity identifies precipitation at sounding cloud bases



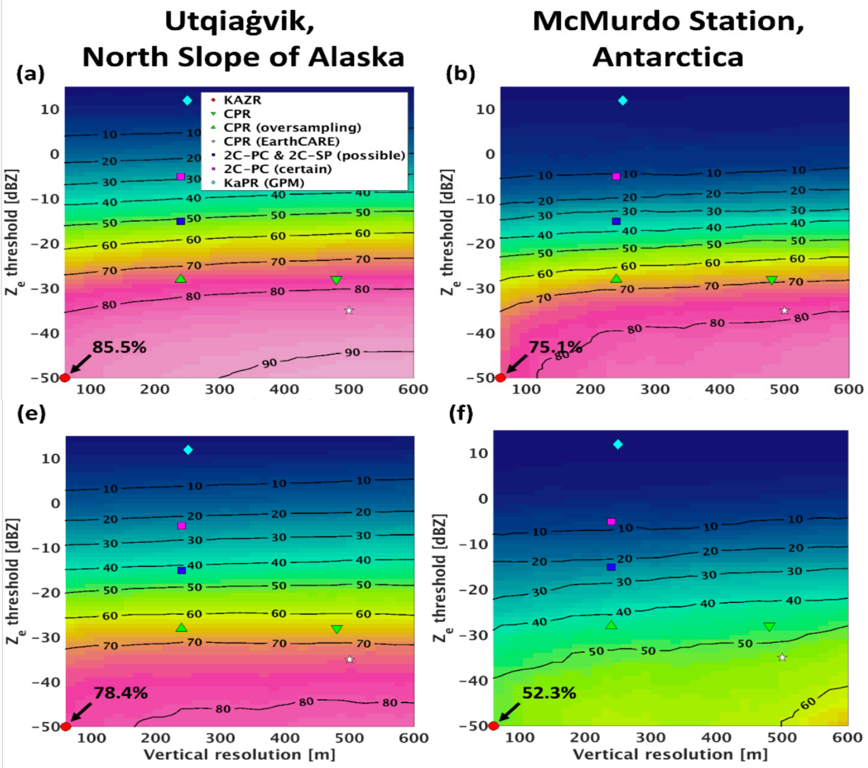
Silber et al. (ACP, 2021)



Precipitation from supercooled clouds

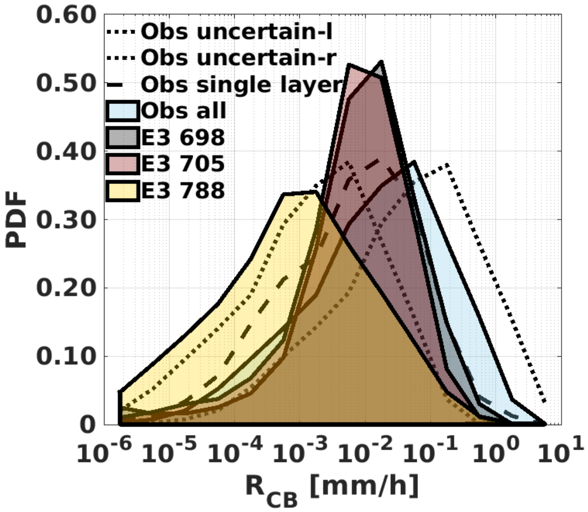
at cloud base

at surface



Silber et al. (ACP, 2021)

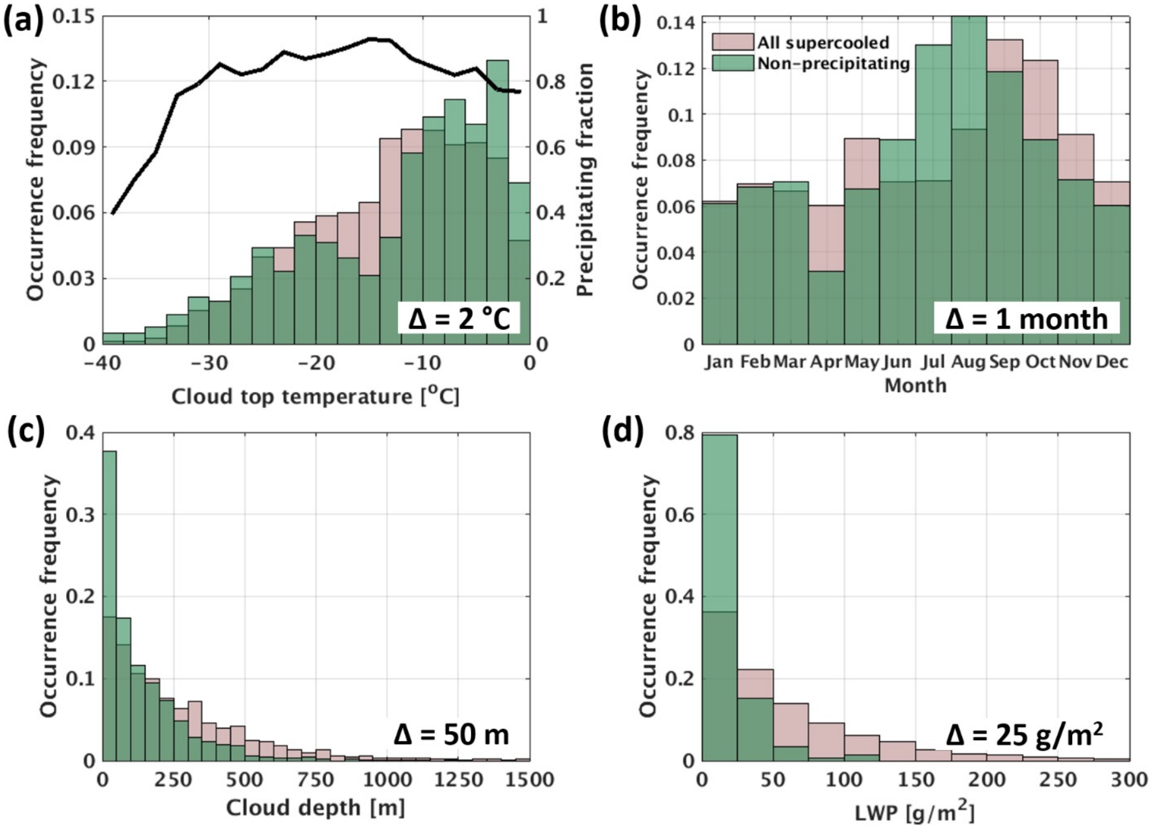
ModelE3 vs retrieved cloud base precipitation rate



source: Israel Silber, using EMC^2

Which Arctic supercooled clouds are *not* precipitating?

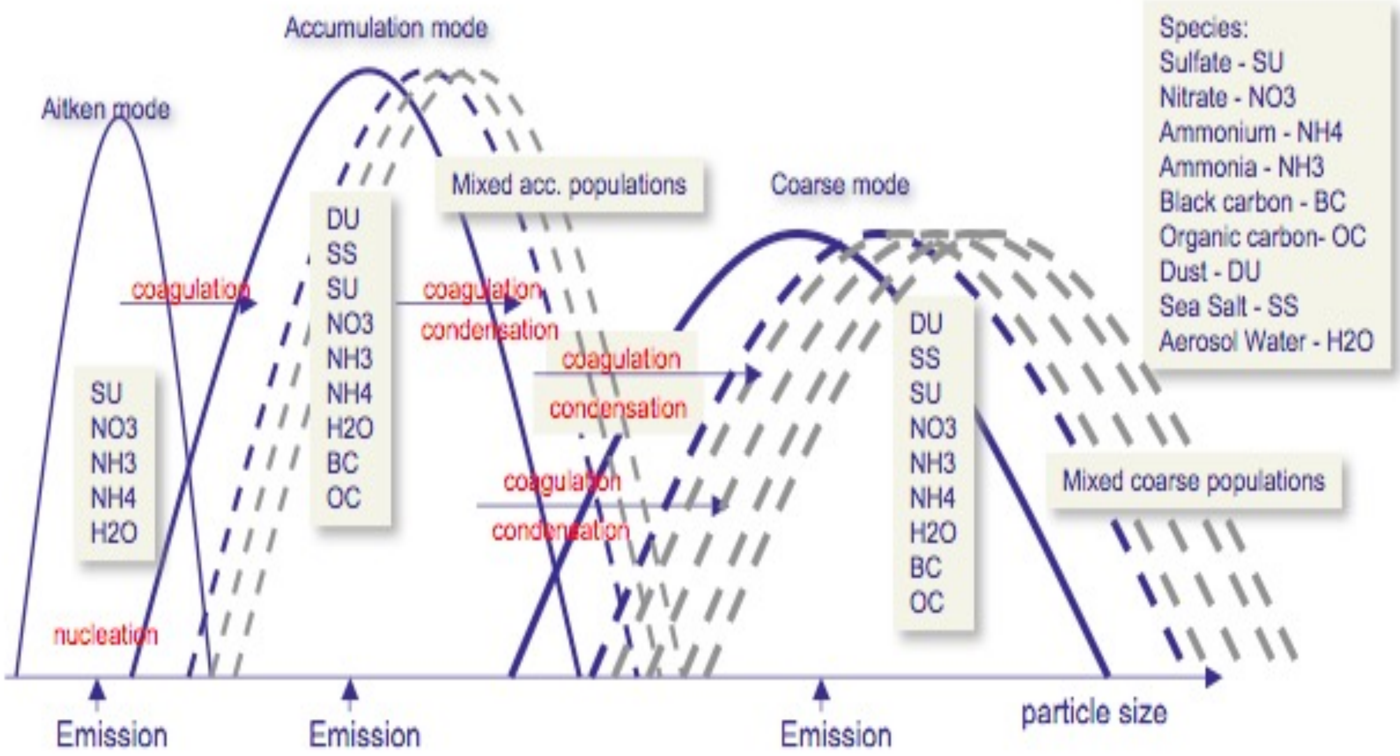
- >7 years of DOE ARM data over North Slope of Alaska
- >80% of detected cloud layers are precipitating at most cloud top temperatures
- similar statistics when excluding layers receiving ice from aloft
- non-precipitating tend to be
  - warmer at cloud top
  - thinner cloud layers
  - lower liquid water paths
  - non-turbulent



Silber et al. [ACP, 2021, Figure 2]

MATRIX scheme

Bauer et al. [ACP 2008, 2010]
Gao et al. [GMD 2017]



Stony Brook University
School *of* Marine and
Atmospheric Sciences

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6

AEROICESTUDY: An ARM Southern Great Plains Pilot Study to Assess a Field-Observational Approach to Conduct Aerosol-Ice Formation Closure

Knopf, D. A., Barry, K. R., Brubaker, T. A.,
Jahl, L. G., Jankowski, K. A., Li, J., Lu, Y., Monroe, L. W., Moore, K. A., Rivera-Adorno, F. A., Sauceda, K. A., Shi, Y., Tomlin, J. M.,
Vepuri, H. S. K., Wang, P., Lata, N. N.,
Levin, E. J. T., Creamean, J. M., Hill, T. C. J., China, S., Alpert, P. A., Moffet, R. C., Hiranuma, N., Sullivan, R. C., Fridlind, A. M., West, M., Riemer, N., Laskin, A., DeMott, P. J., Liu, X.

U.S. DEPARTMENT OF ENERGY

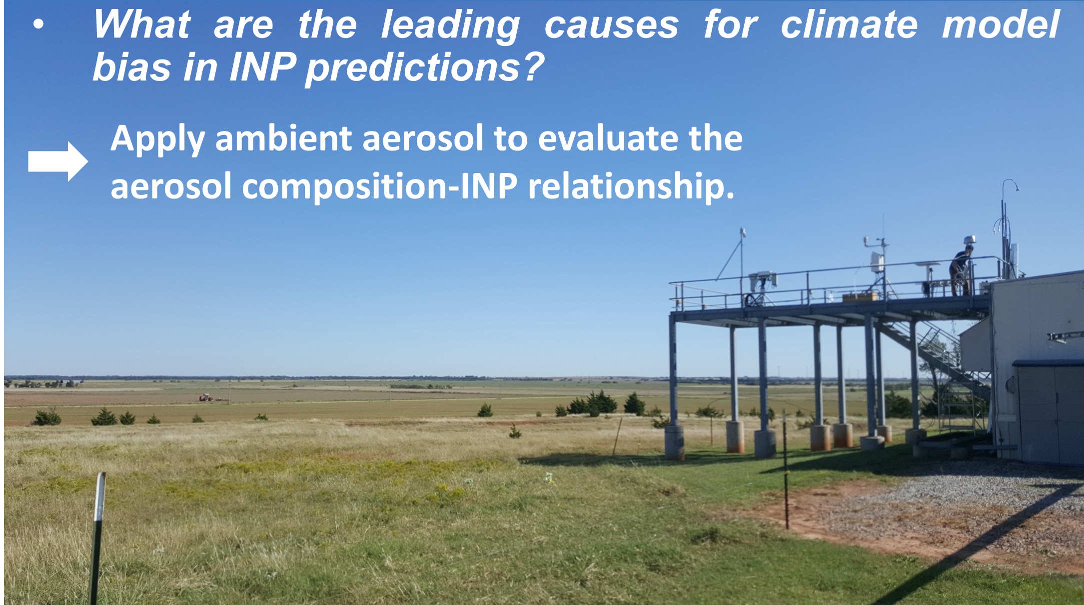
Knopf et al. (BAMS 2021)

ASR Atmospheric System Research

Goals and Objectives

- *Identify ice nucleation parameterizations that produce the most robust predictions of INP number concentrations.*
- *What are the crucial aerosol physicochemical properties to guide ice nucleation representations in models and long-term INP measurements?*
- *What level of parameter details needs to be known to achieve aerosol-INP closure?*
- *What are the leading causes for climate model bias in INP predictions?*

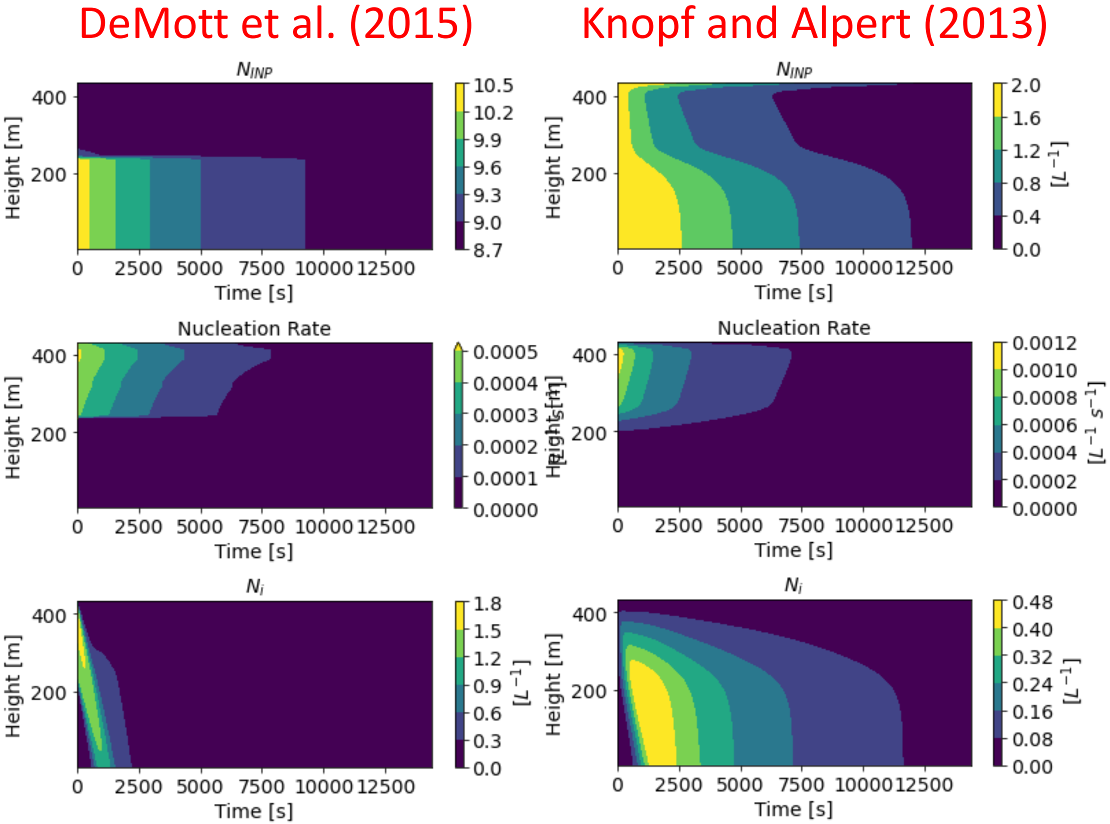
➡ **Apply ambient aerosol to evaluate the aerosol composition-INP relationship.**



INP reservoir dynamics in SHEBA case study

- 1D Python model prognosing INP, N_{ice}
- if INP are rapidly activated in mixed-phase clouds, loss to precipitation will be important (cf. Fridlind et al. 2012)
- if an INP scheme introduces INP diversity within a modal class, tracking loss adds complexity

Manuscript in prep.



- primary and secondary ice formation

\+ rain formation and mesoscale structure

\+ gravity waves, surface fluxes, ice properties,
aerosol-cloud interactions, ...

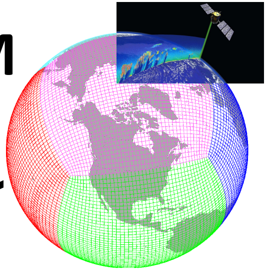
PARCEL + 1D

development

AEROICESTUDY

KIT laboratory SIP

ESM

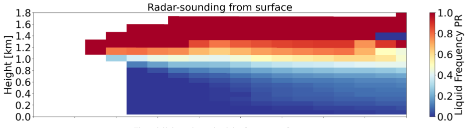


calibration

satellite + COSP

long-term ground + EMC^2

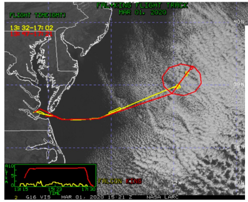
SCM



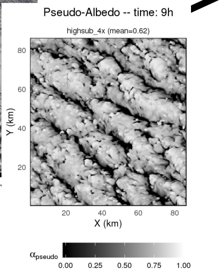
- ESM development workhorse
- pre-calibration tool
- simulator testbed
- cloud feedback analysis tool
- LES-SCM-MIP for CMIP7?

development

LES



From https://satcorps.larc.nasa.go



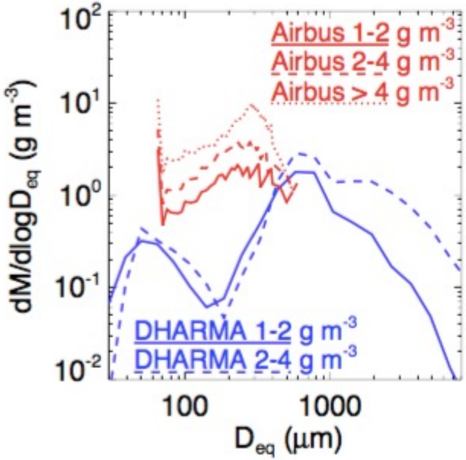
aircraft field campaigns

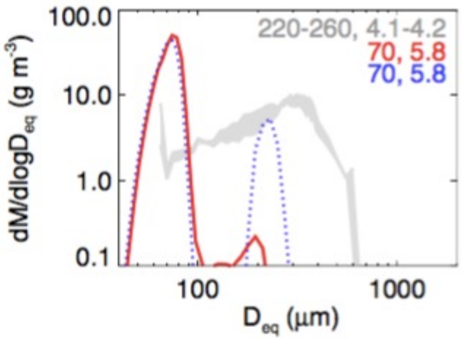
long-term ground

Tropical deep convection (TWP-ICE)

- How do you make a mass size distribution peak at D_{eq}≈300 µm?
  - ≈1 cm^{-3} ice crystals warmer than –10°C [cf. Lawson et al. 2015, ICE-T]

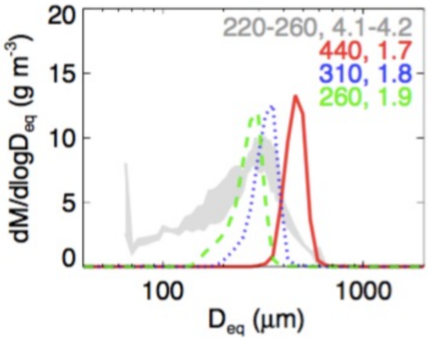
3D DHARMA simulations of TWP-ICE at –43°C





immersion INPs
“pseudo-Hallet-Mossop”

DHARMA sedimenting parcel simulations at –40°C

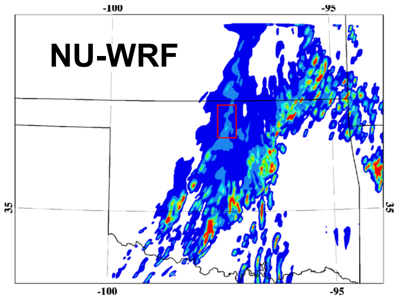


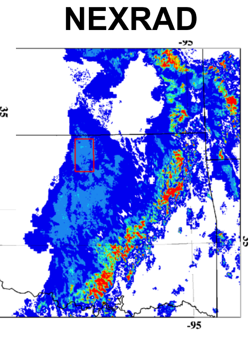
pseudo-Hallet-Mossop
1 cm^3
2 cm^3
3 cm^3

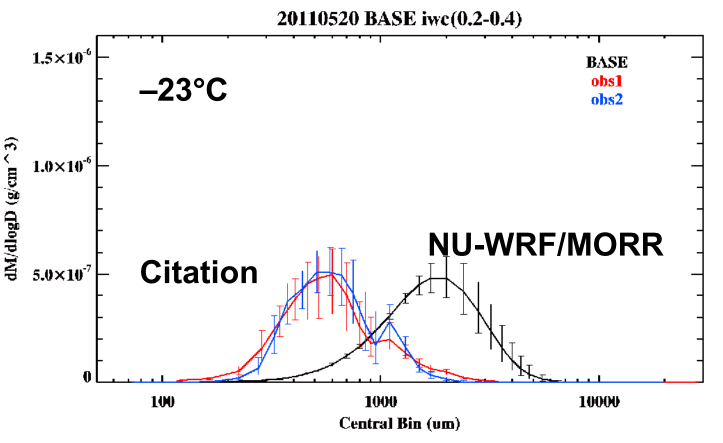
Ackerman et al. [ACP, 2016]

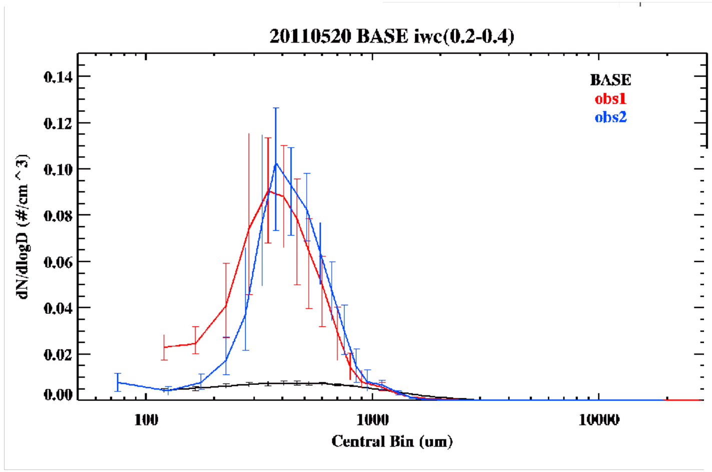
Springtime in Oklahoma during MC3E

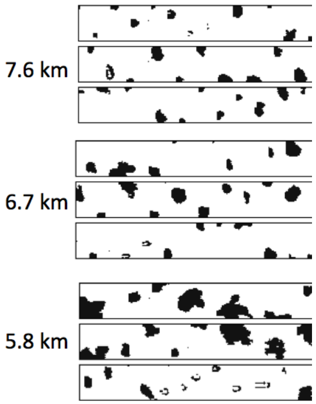
- similar conditions as HAIC/HIWC
- despite grossly differing updraft strength
- unknown multiplication mechanism(s)







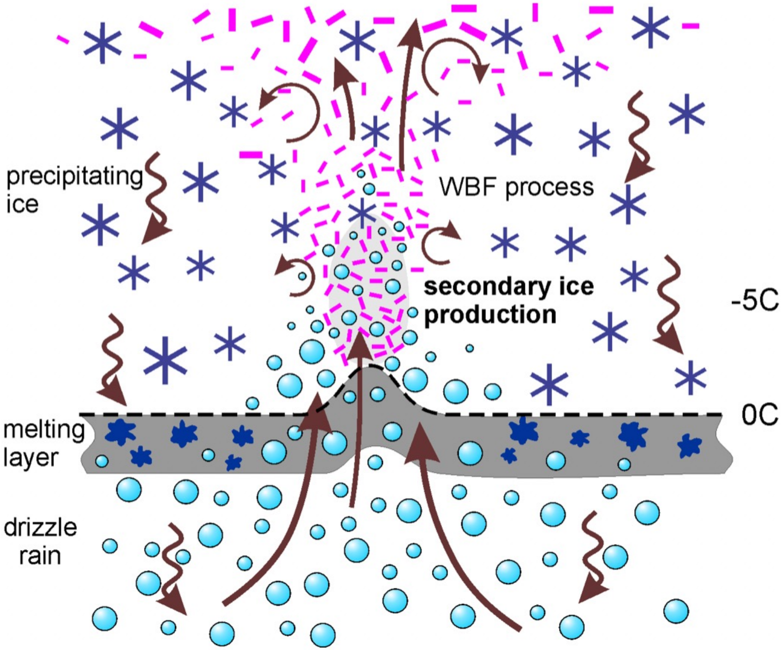


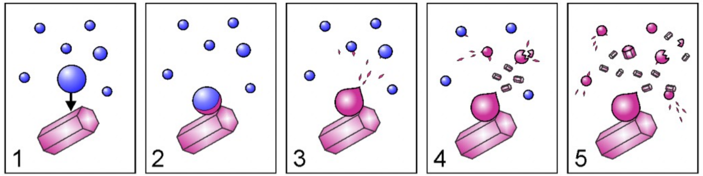


Fridlind et al. [ACP 2017]

Tropical deep convection (MCS conditions)

- Korolev et al. [ACP 2020]
  - examined flight legs at –15 < T < 0°C
  - state-of-the-art instrumentation
  - pristine faceted crystals D < 60 μm
    - best estimate N_i >> INP
    - drops D > 40 μm necessary but not sufficient
    - graupel or rimed particles often missing
  - points to drop shattering [e.g., Lauber et al. 2018]





Takeaways

- Foundations of model development using machine learning
  - NU-WRF/LES/SCM library of observation-based cases (field campaigns)
    - adding Lagrangian case study ensembles with realistic aerosol
    - focus on understanding key process-level knowledge gaps (may require additional laboratory data, new instruments)
      - e.g., GCCN, ice < 100–200 um, detailed aerosol and INP, GWs, ...
    - improving use of machine learning to define allowable phase space
  - global data sets for global tuning (relies on well-defined uncertainty)
- Site-based process-oriented model evaluation
  - focus on key process-level performance (e.g., supercooled cloud precip, morphology, cloud regimes, GWs, ...)
  - improving coordination with satellite obs, scratching the surface so far