GISS's Modeling Efforts to better understand Cloud Transitions in Cold Air Outbreaks

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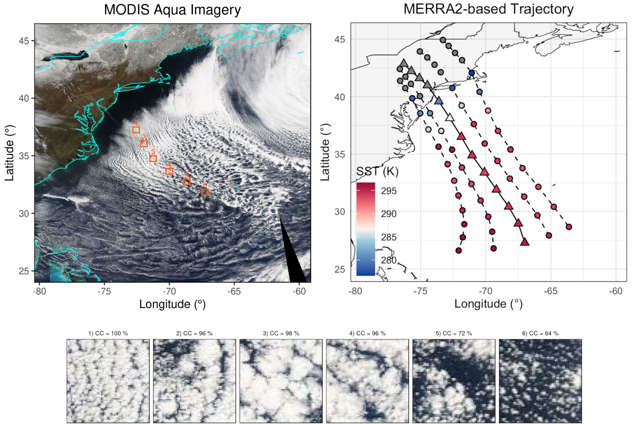
GISS - Modeling Concept for Cold Air Outbreaks



MODIS Aqua imagery of a 2008 cold air outbreak in the NW Atlantic (left), selected $(0.5°)^2$ regions (bottom), and quasi-Lagrangian trajectories generated from MERRA-2 (right)

General Focus

- improve cloud-aerosol-radiation interactions connected to cold air outbreaks (CAOs) in ModelE3 (latest gen. GISS climate model)
- follow a bottom-up roadmap:
  1) use ACTIVATE in-situ and remote-sensing observations
  2) understand factors controlling the observed cases and their evolution using large-eddy simulations (LES)
  3) evaluate column physics of ModelE3 using its single-column model (SCM) version

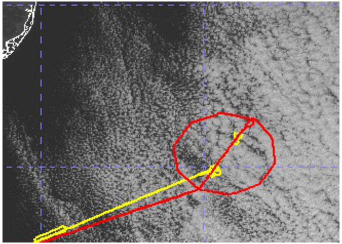
A Quasi-Lagrangian Framework

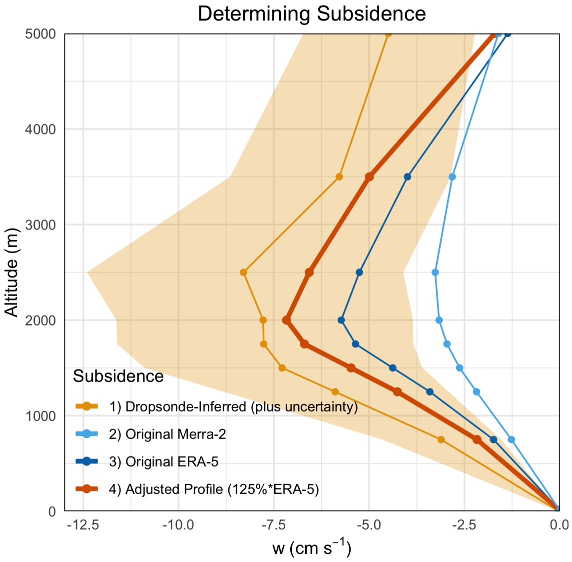
- CAOs with rapid advection, covering distances O(10^3 km) from cloud formation to cloud dissipation
- instead of simulating the entire area, we use a domain O(10^1-10^2 km) moving with the boundary layer flow

March 1st 2020: LES Setup guided by observations

Notes

- dropsondes used to infer subsidence
  also helped constrain inversion
  → adjusted reanalysis





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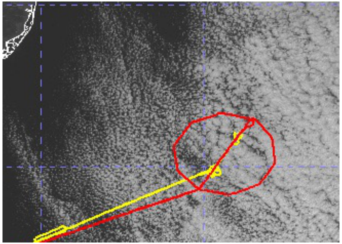

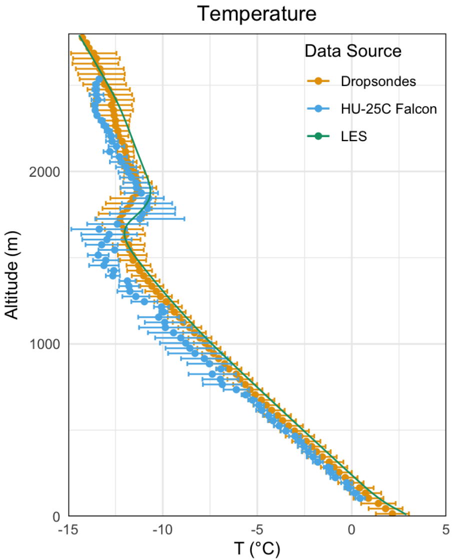

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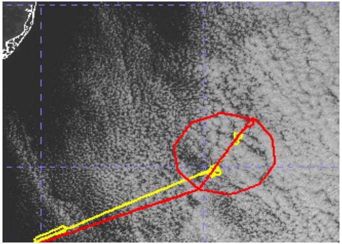

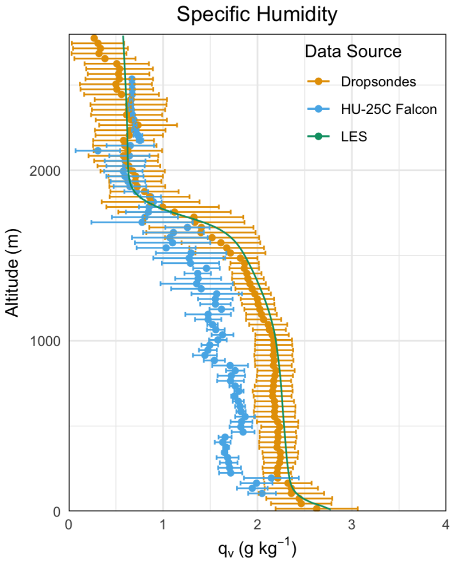

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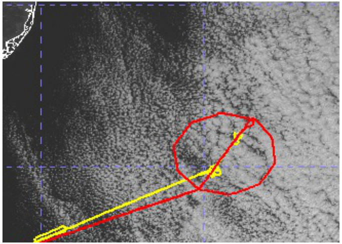
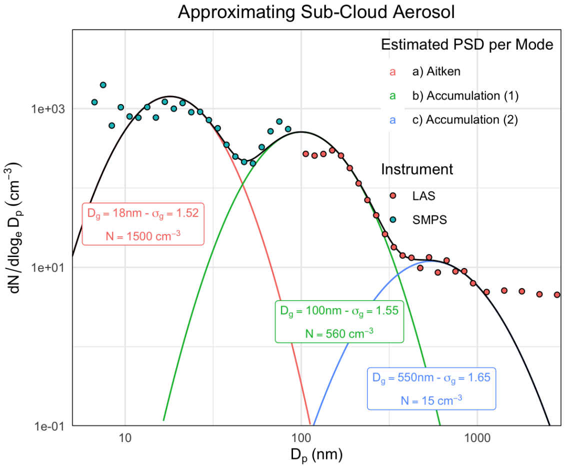
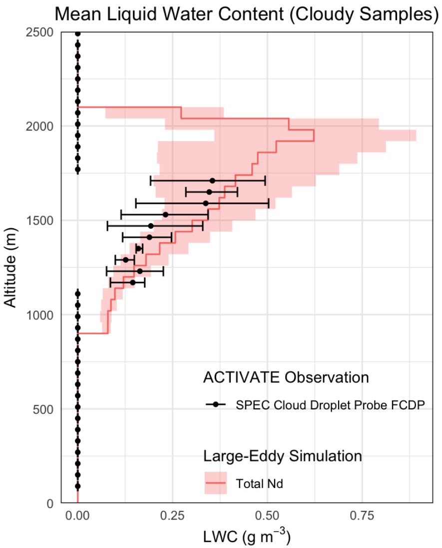
- realistic BL and FT vertical structure in simulations (3h after start)
- high concentrations of below-cloud CCN and presence of large coarse mode particles (>1.5 μm)





March 1st 2020: Realistic Cloud Properties



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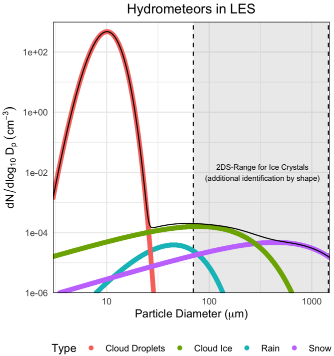

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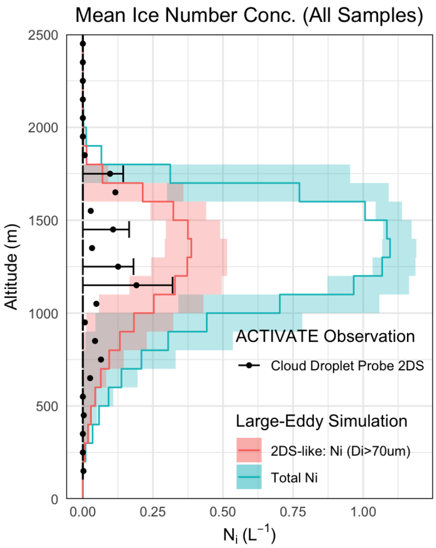

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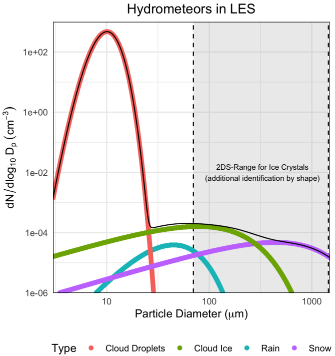

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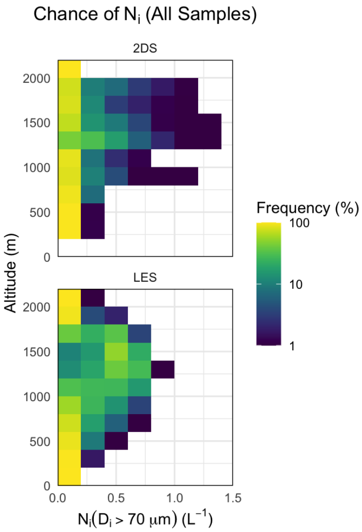

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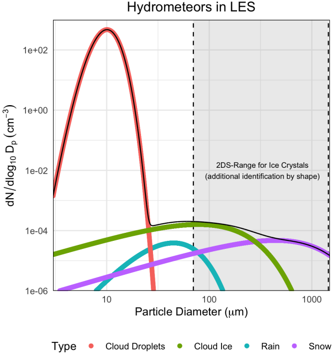
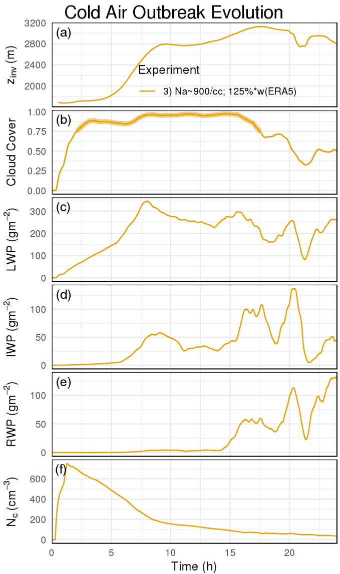
- overly simplified ice formation results in less variability in N_i than observed



March 1st 2020: Realistic Cloud Breakup



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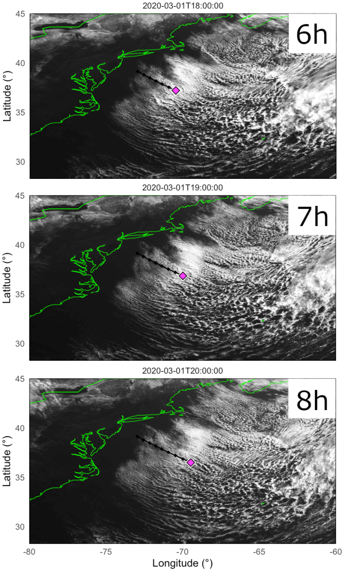
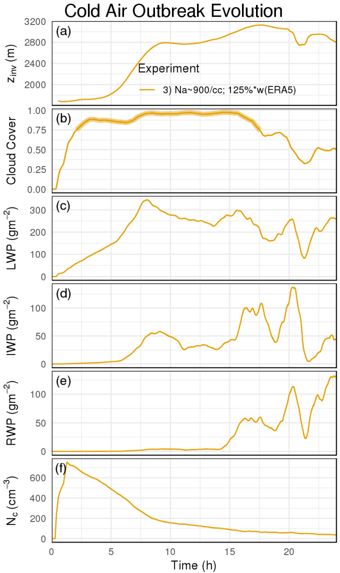
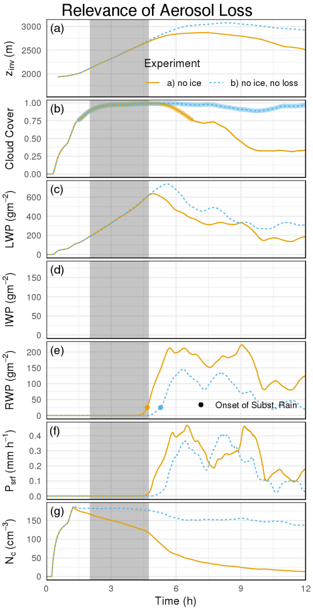




Impact of Ice on CAO Evolution

Findings

- CCN loss is integral part of the transition



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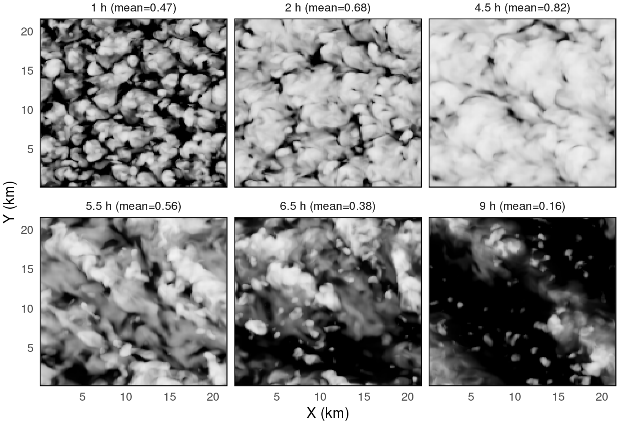

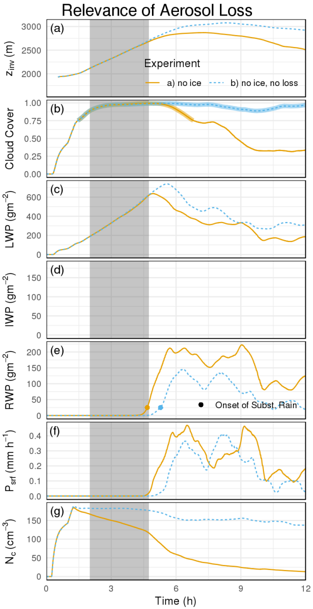

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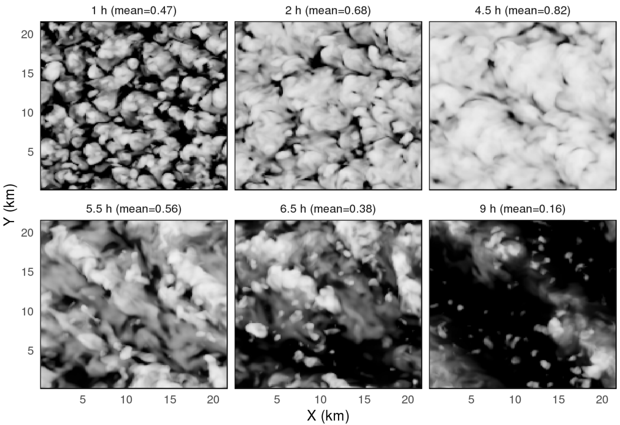

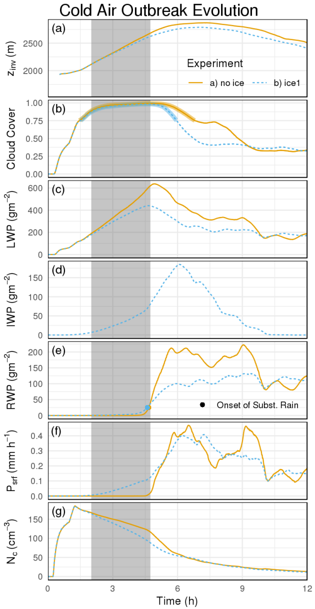

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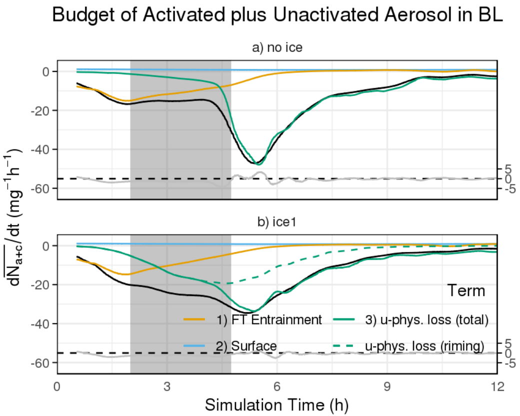

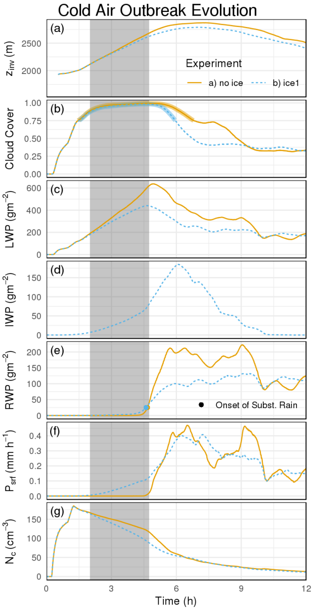

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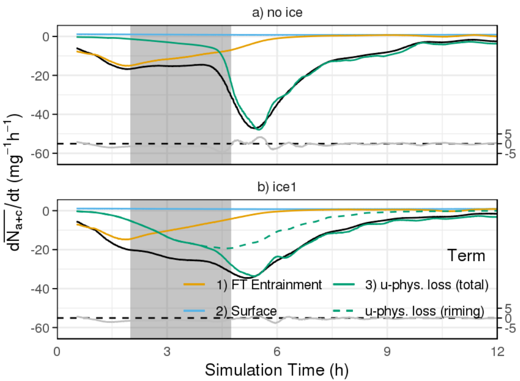
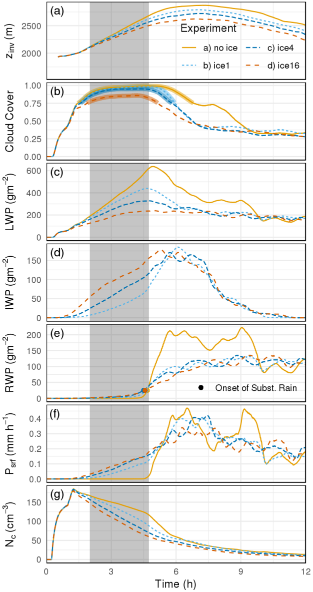
Budget of Activated plus Unactivated Aerosol in BL



Cold Air Outbreak Evolution



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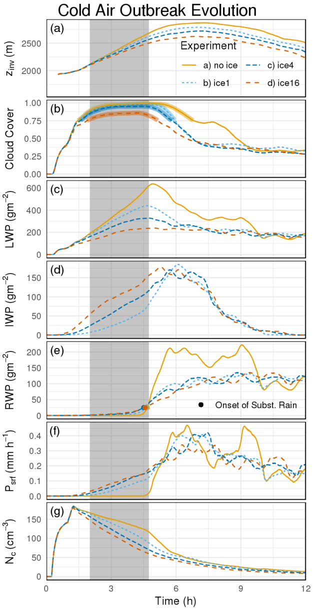
Role of Riming (Tornow et al., ACP, 2021)

- frozen hydrometeors affect CAO transition primarily through riming-related processes
  (1) frozen hydrometeors reduce LWP
  (2) more rapid N_c reduction
  (3) earlier precipitation of riming-grown crystals and cooling-moistening of sub-cloud layer
- acting prior to rain onset, we describe the combination as *preconditioning by riming*

Discussion

- this mechanism should comprise another negative cloud feedback in a warming climate
- ACTIVATE has the potential to observationally assess riming through in-situ observations



Supplementary Material

LES and SCM in a Lagrangian Framework

General Setup

- similar to de Roode et al. (2019) and as motivated by Pithan et al. (2018) use quasi-Lagrangian domain
- nudging ($\tau = 1$ h):
  - imposing $w_{sub}(z, t)$
  - $\langle T \rangle(z, t)$ and $\langle q_v \rangle(z, t)$ in FT
  - $\langle u \rangle(z, t)$ and $\langle v \rangle(z, t)$ above 500m
- diagnostic immersion N_{inp} (Ovchinnikov et al., 2014)

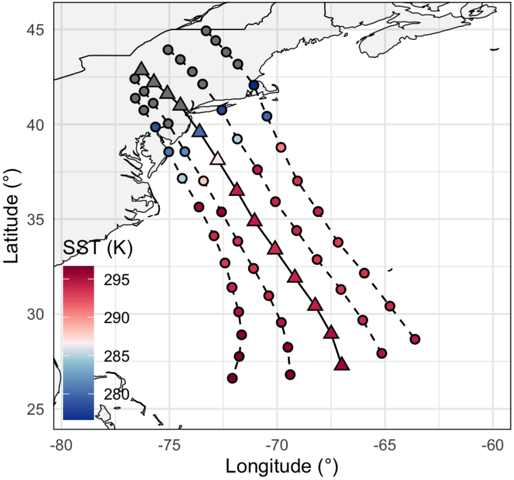
DHARMA Large-Eddy Simulations

- mixed-phase 2-moment microphysics (following Morrison et al., 2009)
- diagnostic or prognostic aerosol (1-moment)

Single Column Model of NASA's ModelE3

- Bretherton and Park (2009) PBL scheme
- 2-moment cloud microphysics (following Gettelman and Morrison, 2015)
- diagnostic aerosol (near-future prognostic)

MERRA2-based Trajectory

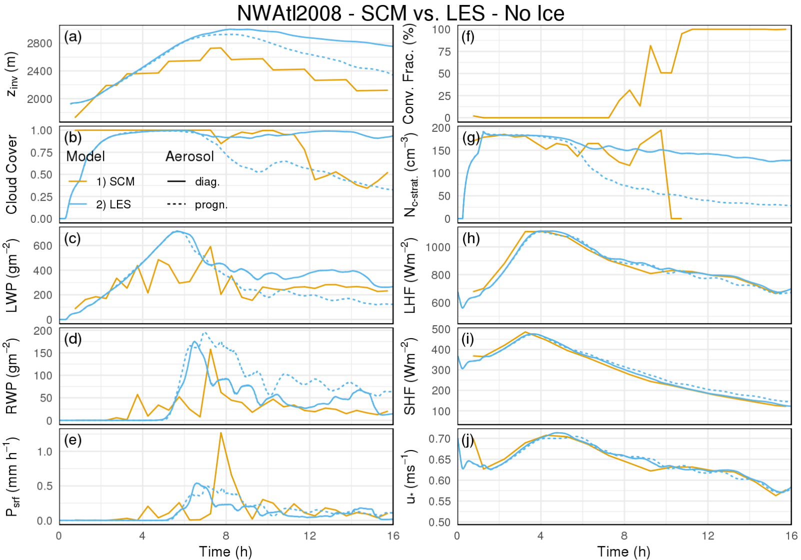


Comparison with ModelE3's SCM - in progress

Note:

(1) **SCM utilizes LES surface fluxes to avoid initially found flux discrepancies (!)**

(2) **for intercomparison, SCM and LES with simplified radiation using Beer's law**



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SCM vs. LES

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- shallower MBL and smaller peak LWP
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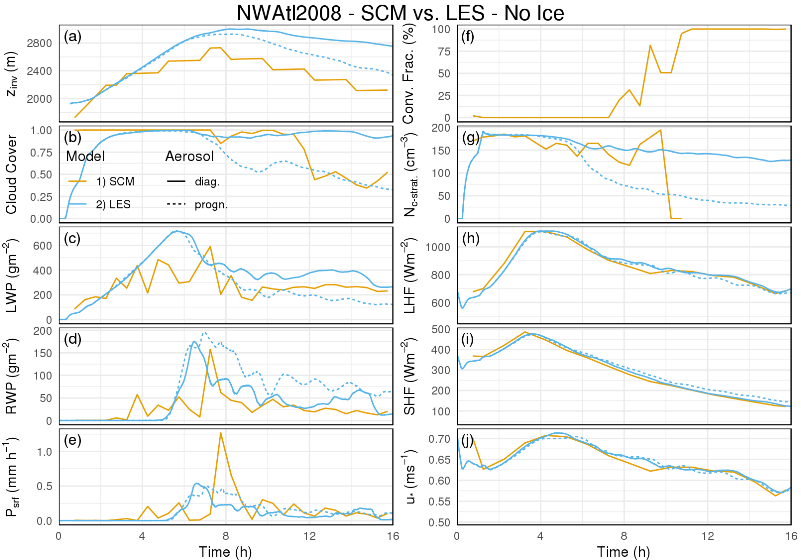

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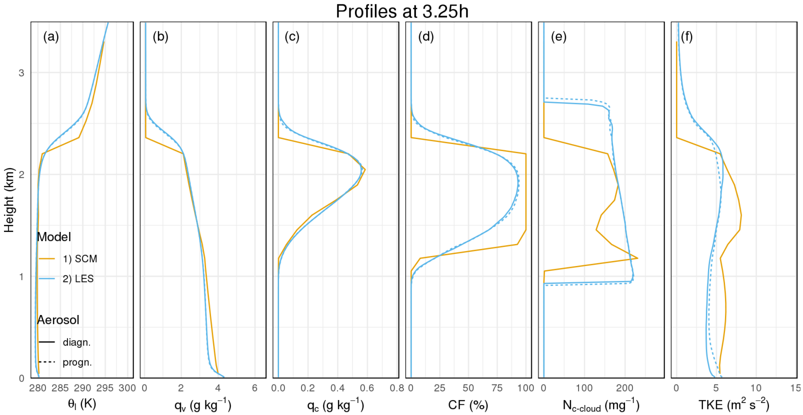

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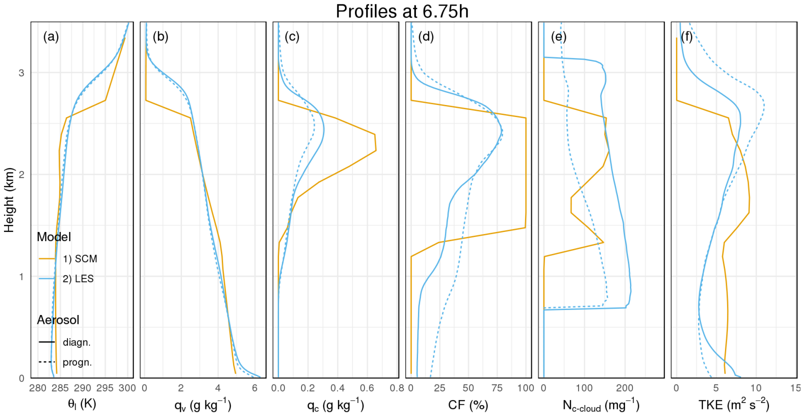

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Next Steps

- remove crutches:
  - reconcile differences in surface fluxes
- prognostic aerosol in SCM
- sensitivity to warm and cold precip. formation