Dissipation of Mixed-Phase Arctic Clouds and Its Relationship to Aerosol Properties

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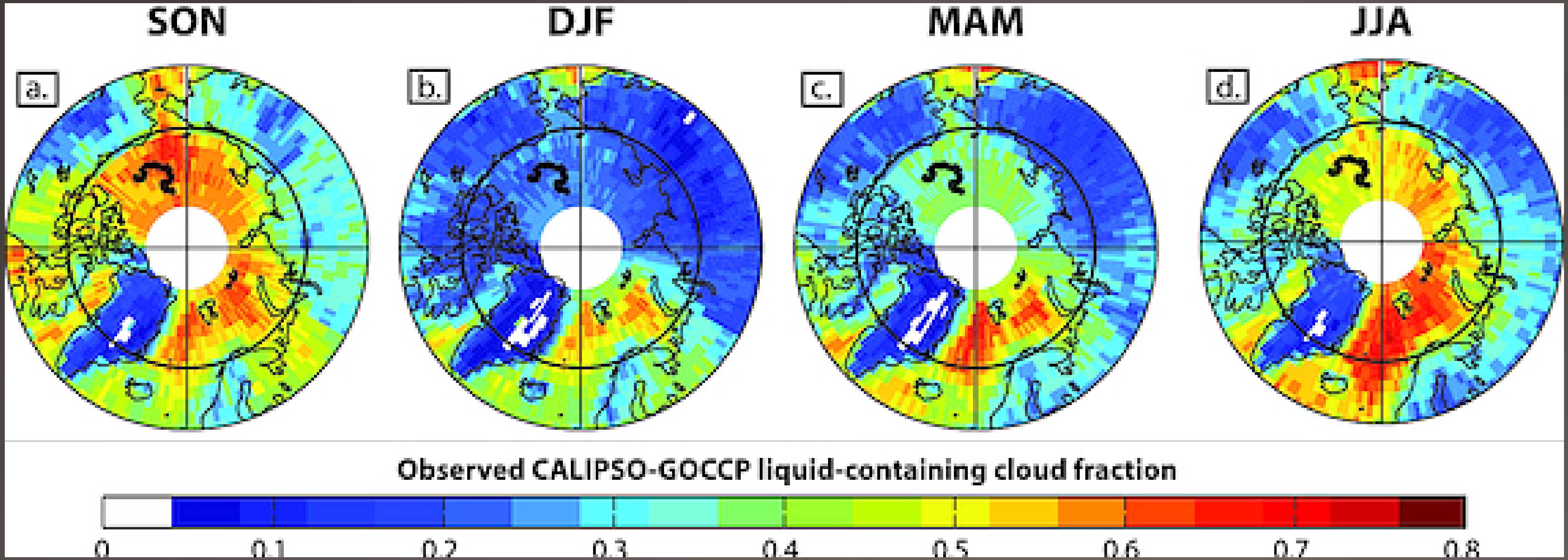
ASR
Atmospheric
System Research

Arctic Low-Level Clouds

- Persistent low-level, liquid containing clouds in the Arctic

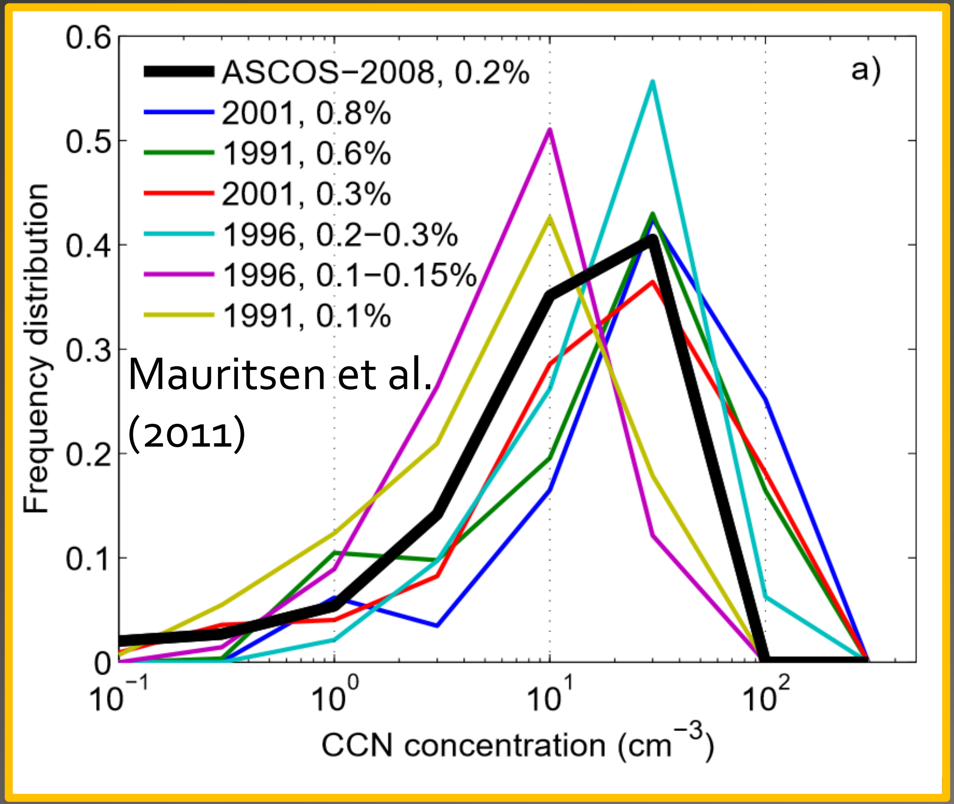


Cesana et al 2012

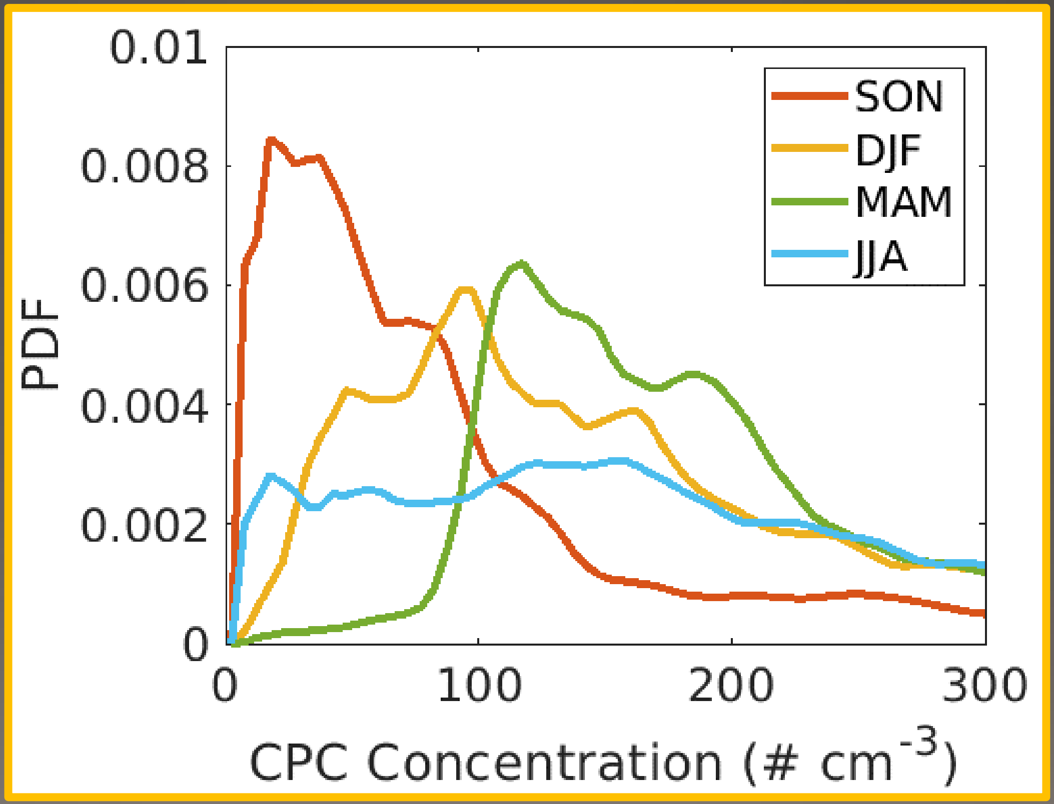
Arctic Aerosol Concentrations

- CCN concentrations at the surface in the high Arctic are frequently < 10 / cc, particularly in late summer and fall

High Arctic Summer CCN



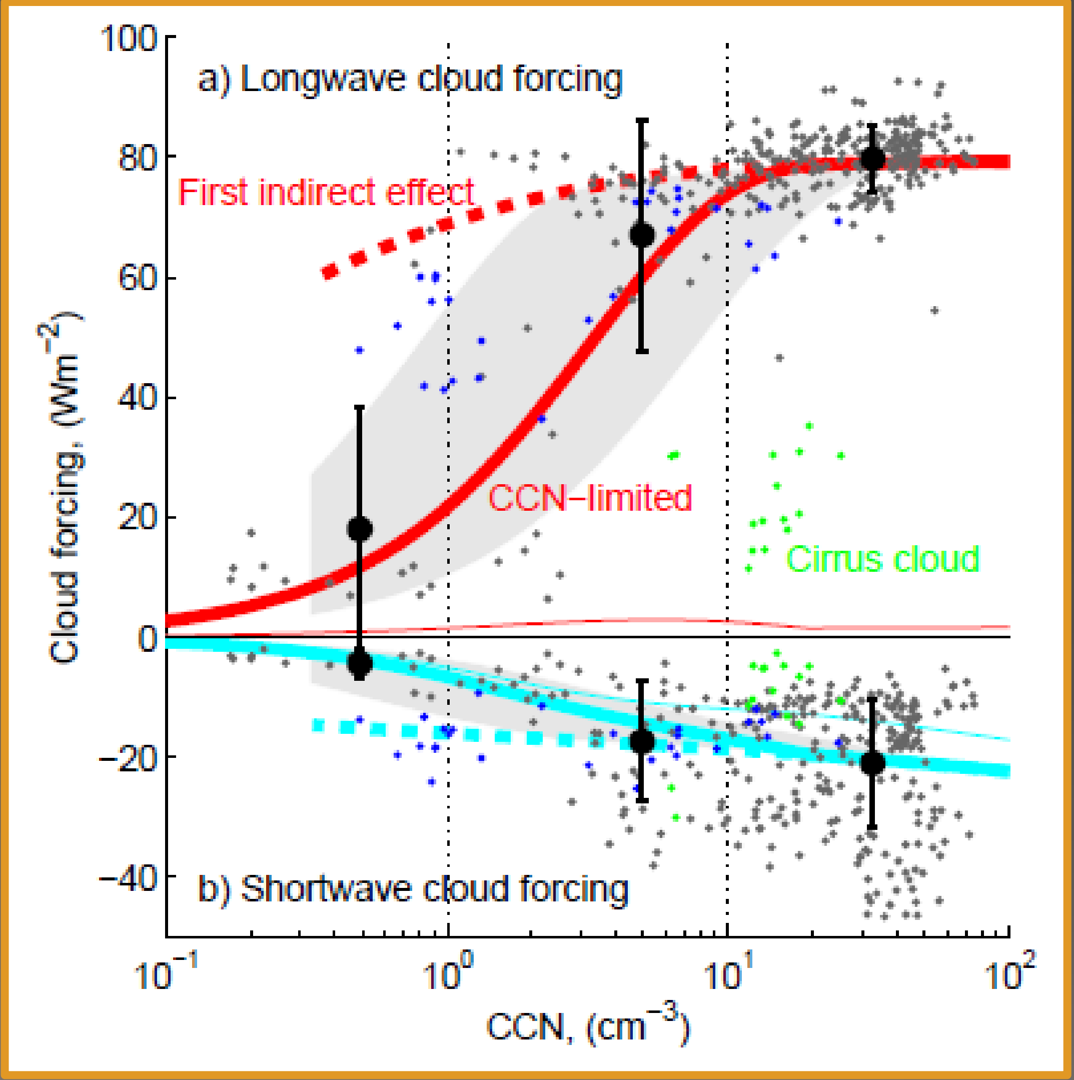
MOSAIC UF CPC



Arctic Aerosol Concentrations

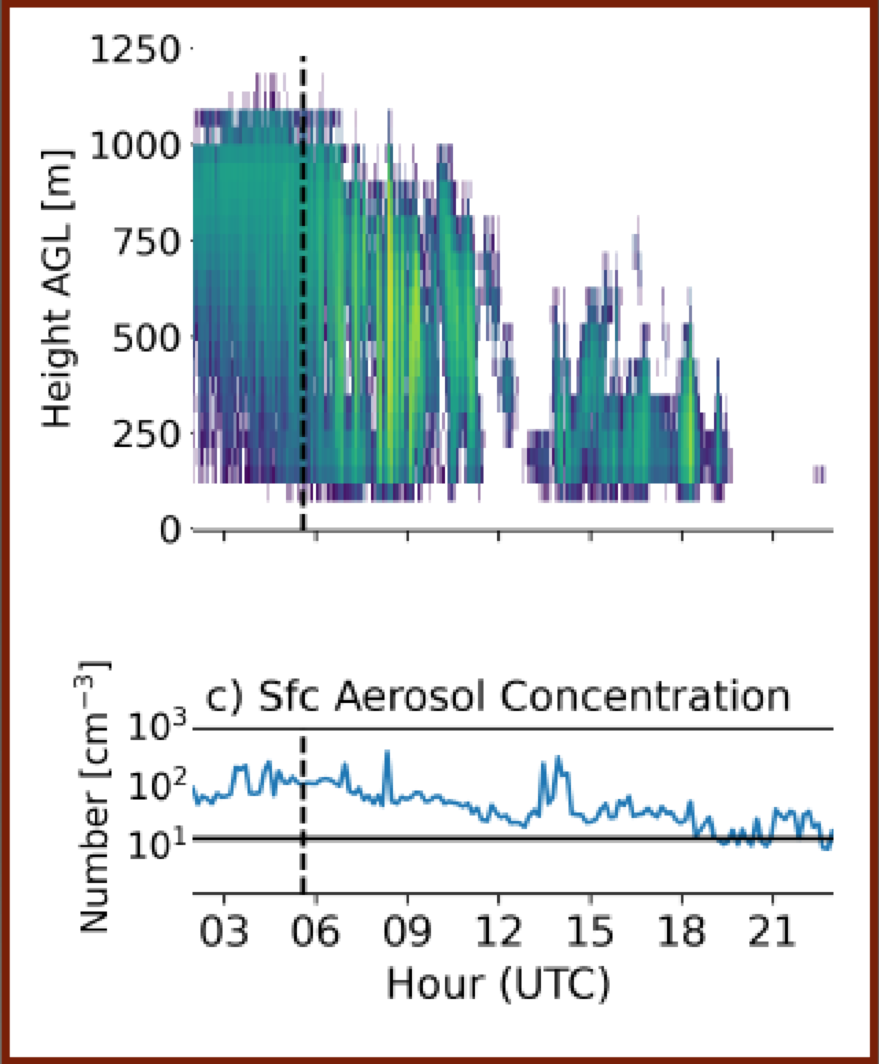
- "Tenuous" cloud regime (Mauritsen et al. 2011)
- Changes to CCN have large impacts on liquid water

- In turn, these changes impact the shortwave and longwave cloud forcing
  - Longwave forcing at the surface is important for sea ice melt



Aerosol-Limited Dissipation

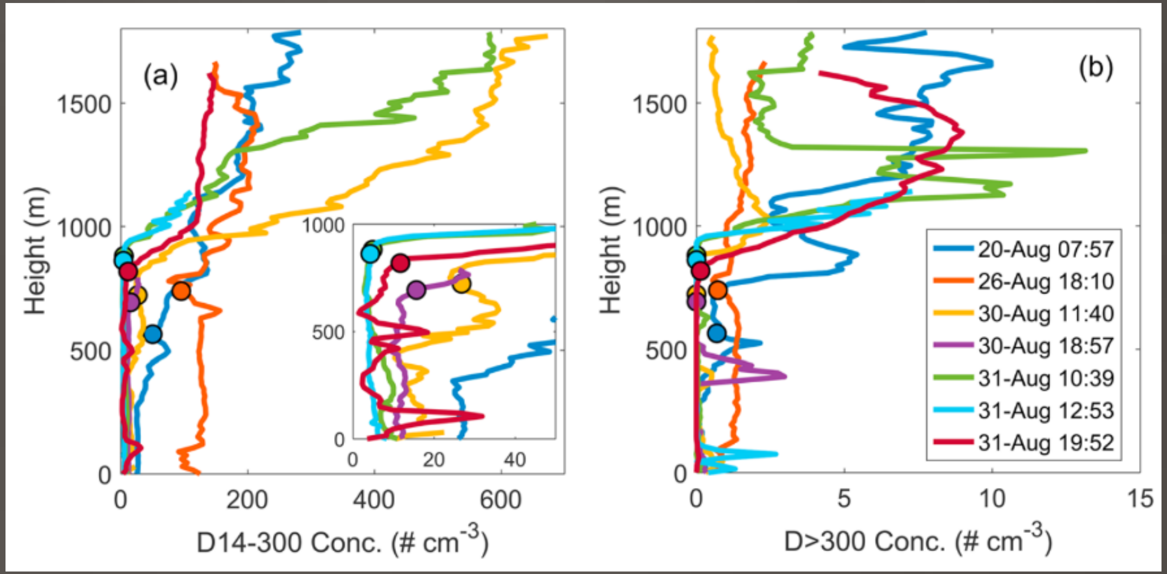
- This ASCOS case generated speculation that cloud dissipation was due to a lack of aerosol particles
- Loewe et al. 2017: low aerosol concentration was the most likely cause of dissipation
- Stevens et al. 2017: 3/cc was sufficient to maintain a cloud
- Extremely low aerosol concentrations may also influence the transition from non-turbulent to turbulent liquid bearing clouds (Silber et al. 2020)



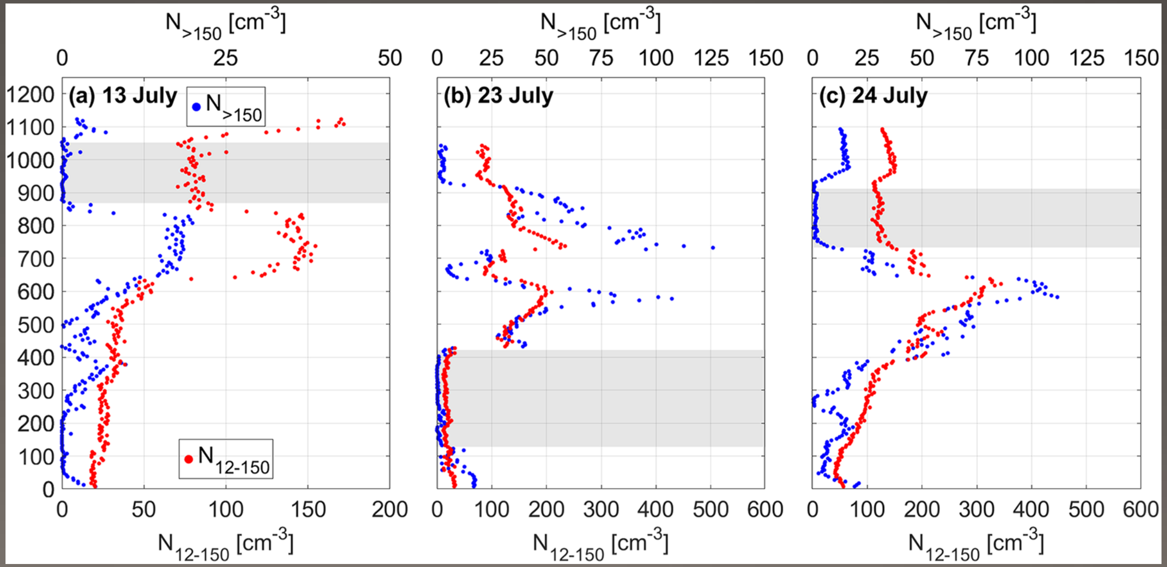
Surface Aerosol Concentrations

- Arctic low-level clouds are frequently decoupled from the surface
- Surface aerosol concentrations are perhaps not representative of conditions in clouds
- Concentrations above cloud top may be substantially higher

ASCOS: Igel et al. 2017



MOSAIC: Lonardi et al. 2022



Project Questions

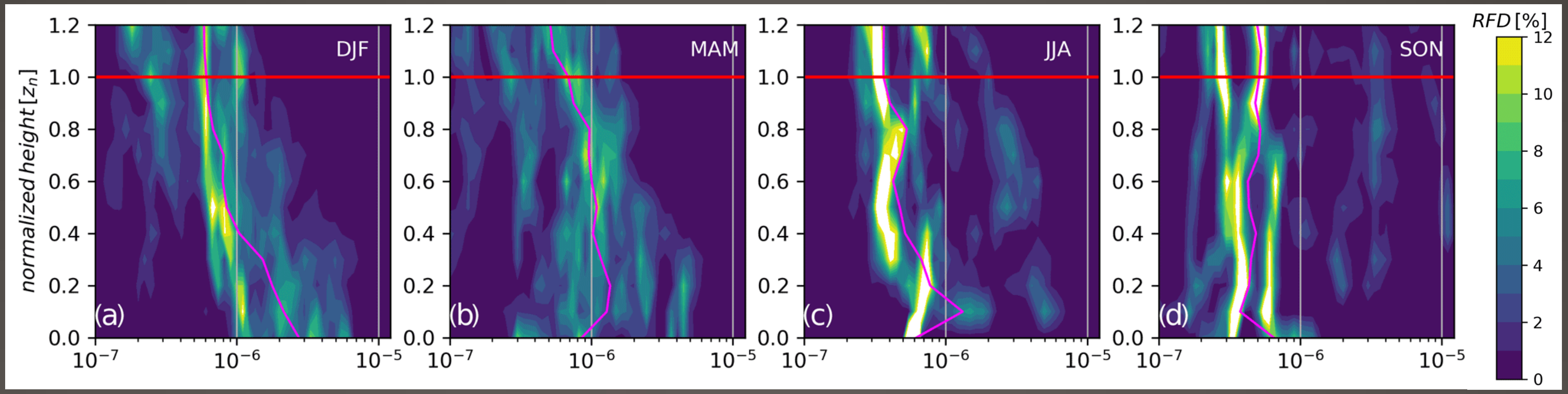
1. What are the characteristics of aerosol vertical profiles relative to the boundary layer top in the Arctic?
2. How often are cloud dissipation events associated with and caused by low aerosol concentrations?
3. What microphysical processes lead to the dissipation of low-level mixed-phase Arctic clouds?
4. What are the respective roles of sub-cloud and above-cloud aerosol properties in dissipation events?


c/o ASCOS science team

Q1: Aerosol Vertical Profiles

- In the climatological mean, no increase in aerosol backscatter above cloud top
- Doesn't matter if we look at the beginning or the end of a clear period

Aerosol backscatter profiles relative to cloud top for clear sky periods

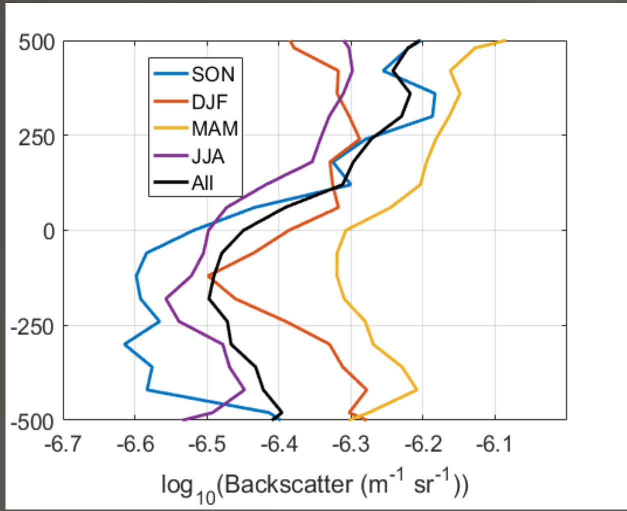


Sedlar et al. 2021

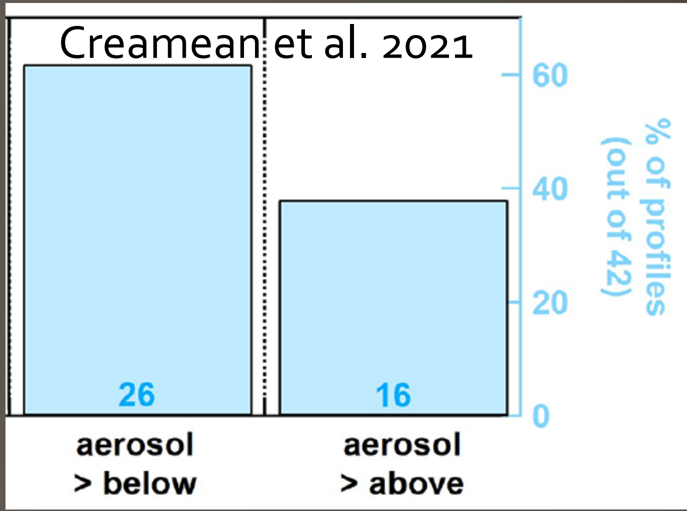
Q1: Aerosol Vertical Profiles

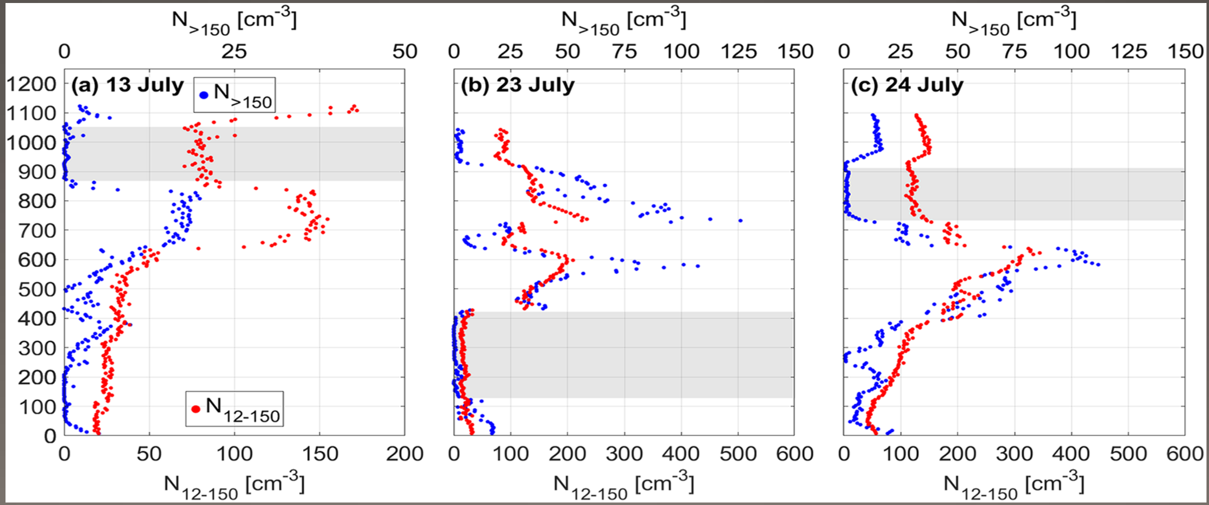
- Certainly, cases of increasing backscatter above BL top can be found
- OLI tethered balloon analysis shows that aerosol concentrations below cloud base are more frequently greater than above cloud top
- Regardless, surface aerosol concentrations are likely frequently unrepresentative of cloud conditions

Aerosol backscatter profiles relative to cloud top for clear sky periods



OLI tethered balloon aerosol concentrations

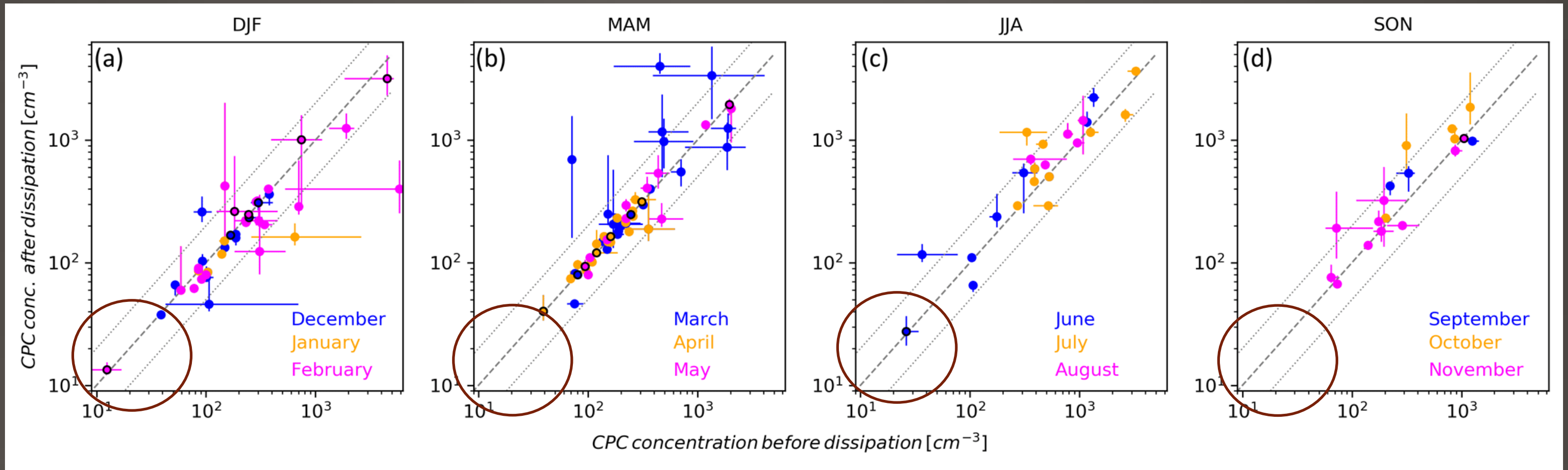




MOSAIC: Lonardi et al. 2022

Q2: Aerosol-Limited Dissipation Frequency

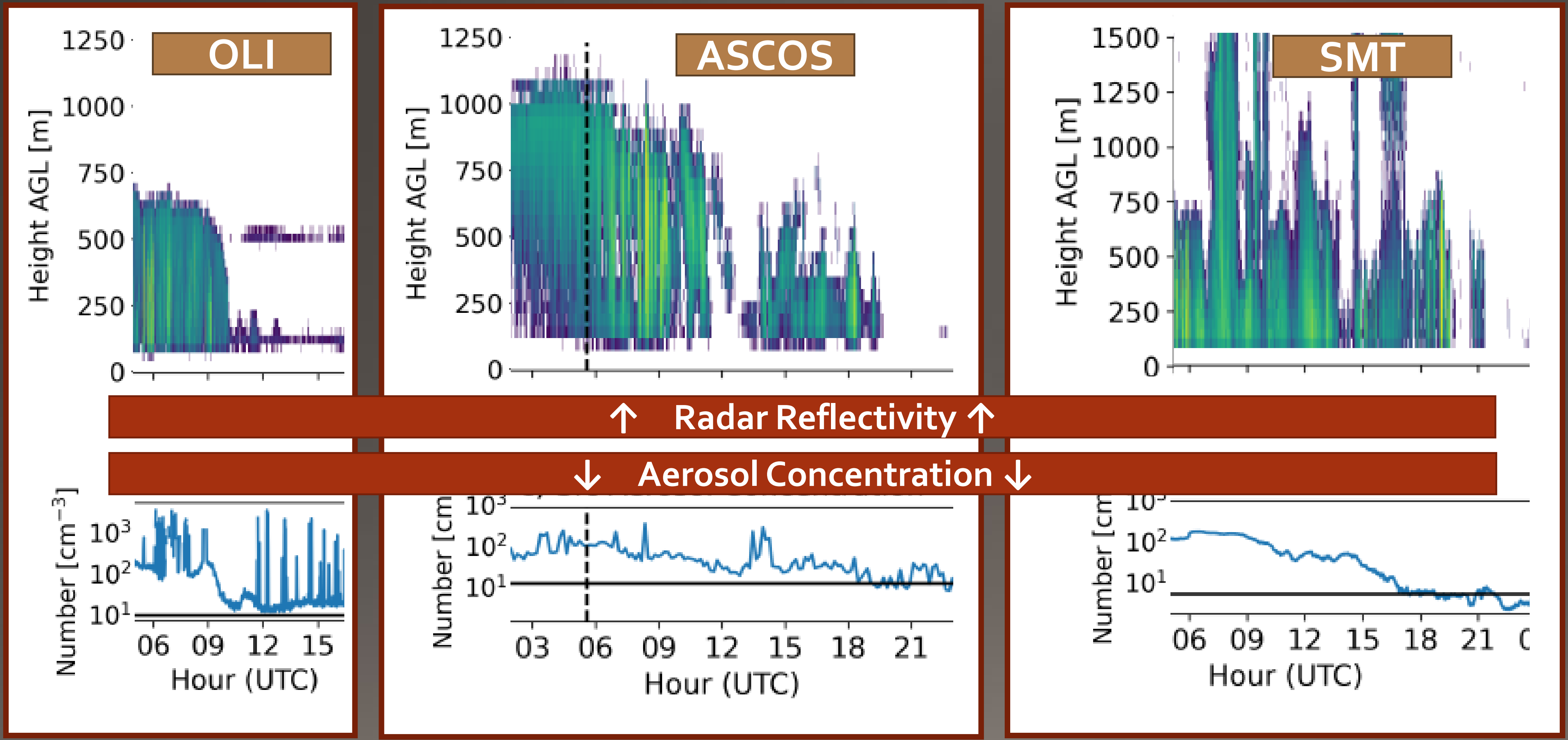
- Likely never at NSA
- Very difficult to find likely cases at either NSA or OLI



Sedlar et al. 2021

Q2: Aerosol-Limited Dissipation Frequency

Sterzinger et al, 2022



Q2: Aerosol-Limited Dissipation Frequency

LES simulations, RAMS

Three Cases: OLI, ASCOS, SMT

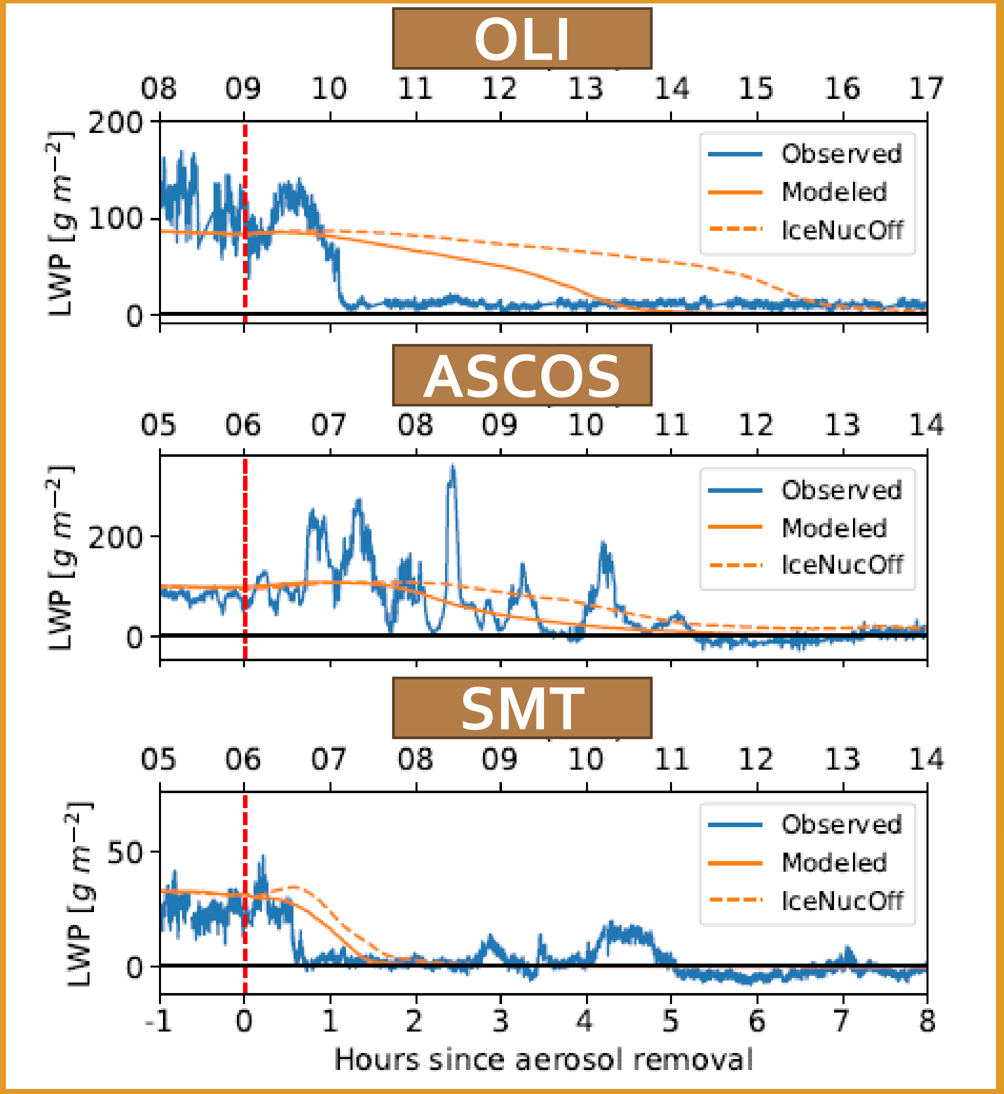
Double-moment cloud and aerosol physics

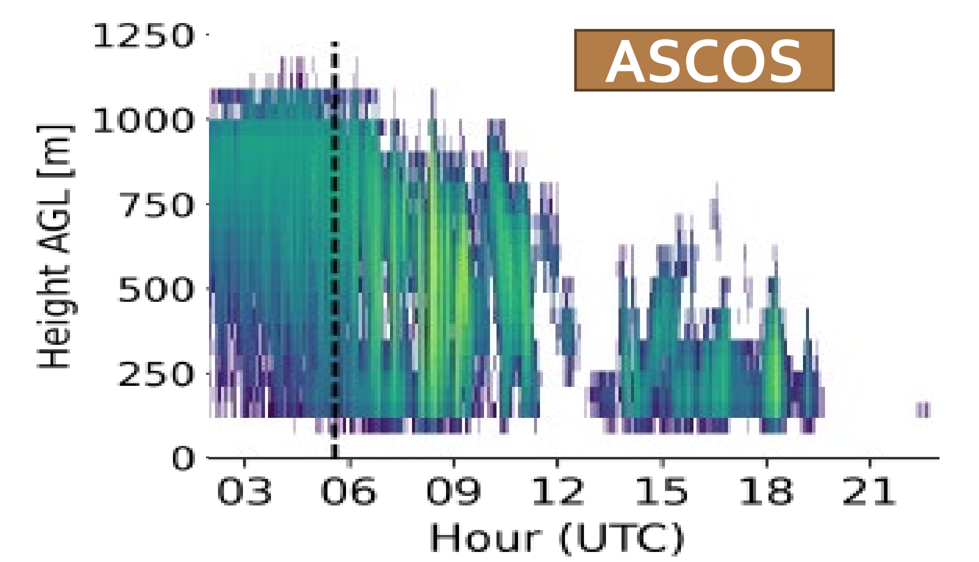
Removed all aerosol after cloud spin up

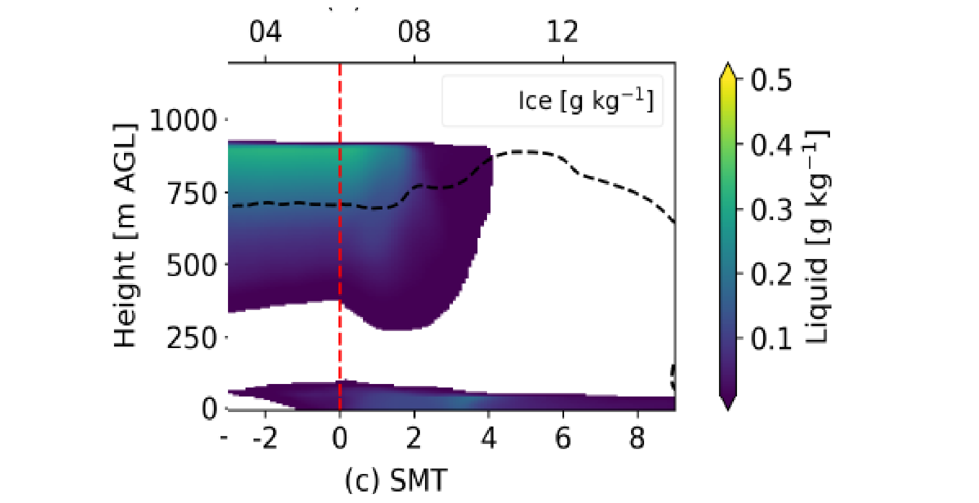
Gives us the fastest possible cloud dissipation time

Sterzinger et al. 2022

Q2: Aerosol-Limited Dissipation Frequency





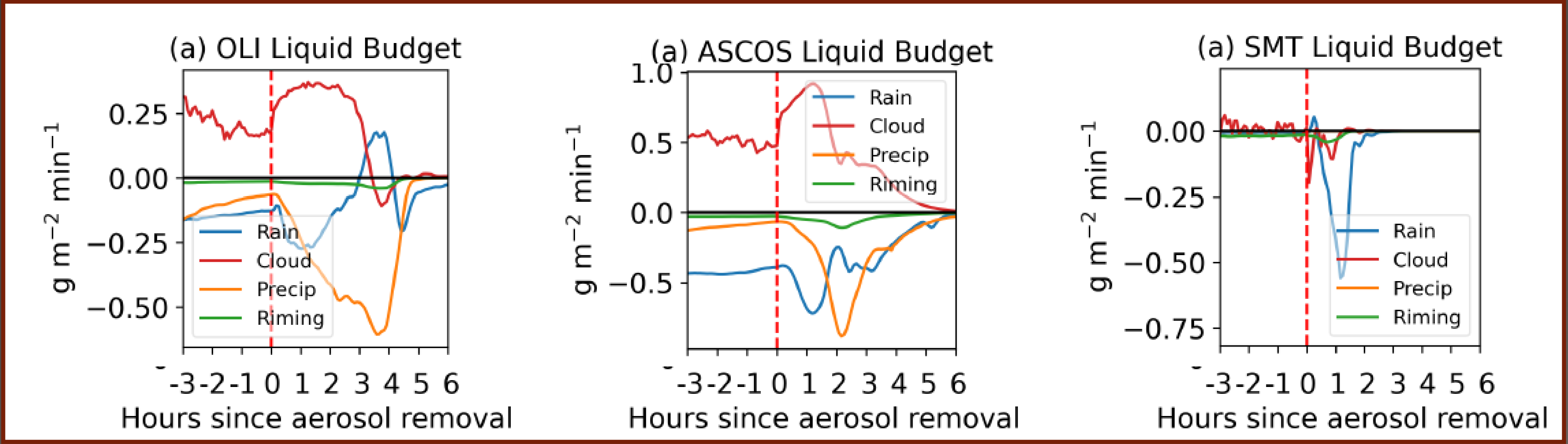


- Simulated dissipation is about 2-6 hours
- Simulated dissipation is slower than observed for OLI and SMT
- In ASCOS, where simulated and observed LWP dissipation is similar, cloud structures differ

Sterzinger et al. 2022

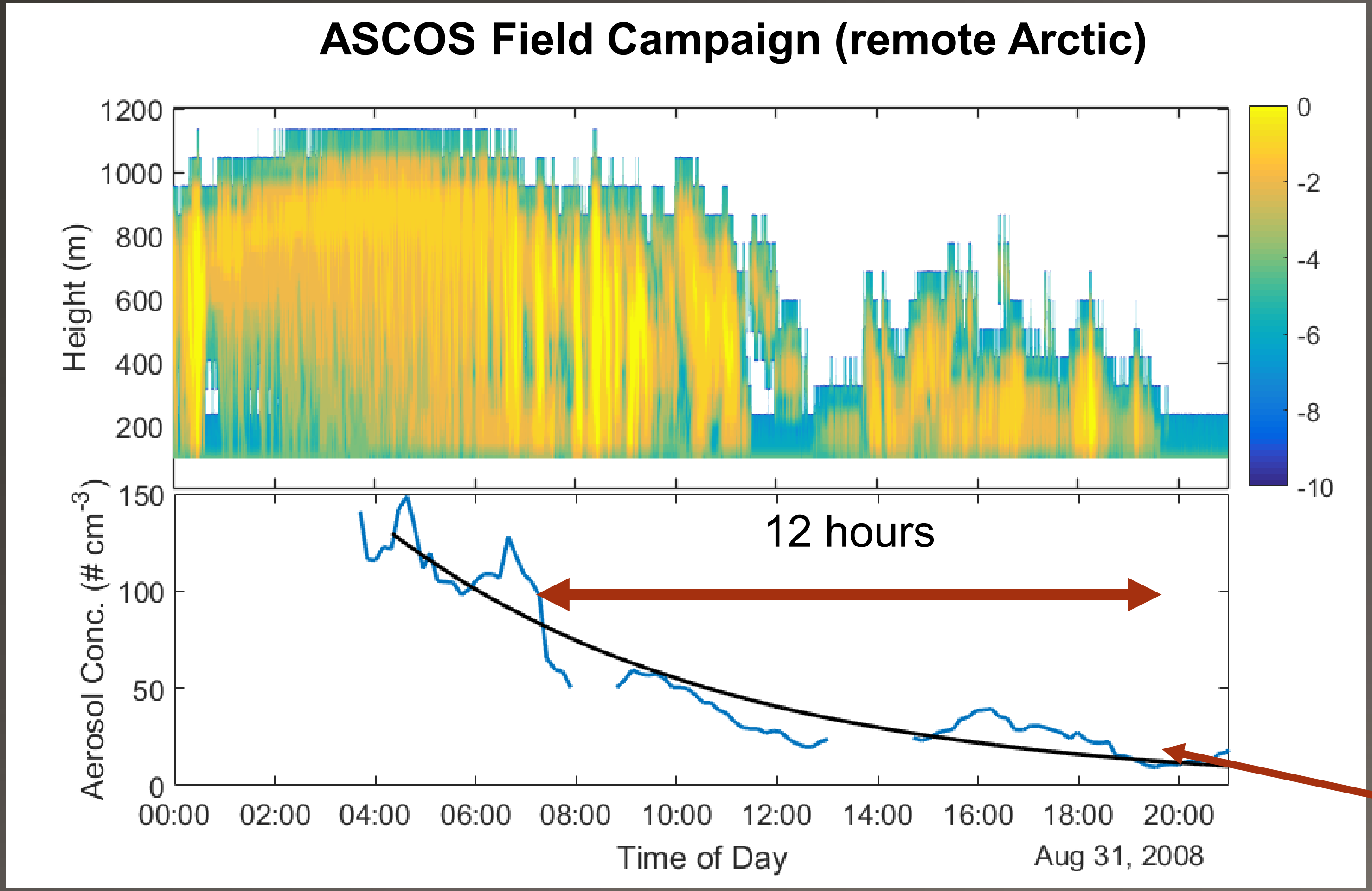
Q3: Cloud Dissipation Mechanisms

Dissipation in all cases is driven primarily by rain formation and subsequent evaporation, not glaciation.



Sterzinger et al. 2022

Q4: Roles of above- and below-cloud aerosol



- Slightly more realistic situation: aerosol concentration decreases at the observed rate
- Two tests:
  - Decrease only in BL
  - Decrease in both BL and FT
- Aerosol decrease is only forced outside of clouds

3-800 nm aerosol conc. drops to 10/cm^3

50-800 nm aerosol conc. drops to 2/cm^3

Q4: Roles of above- and below-cloud aerosol

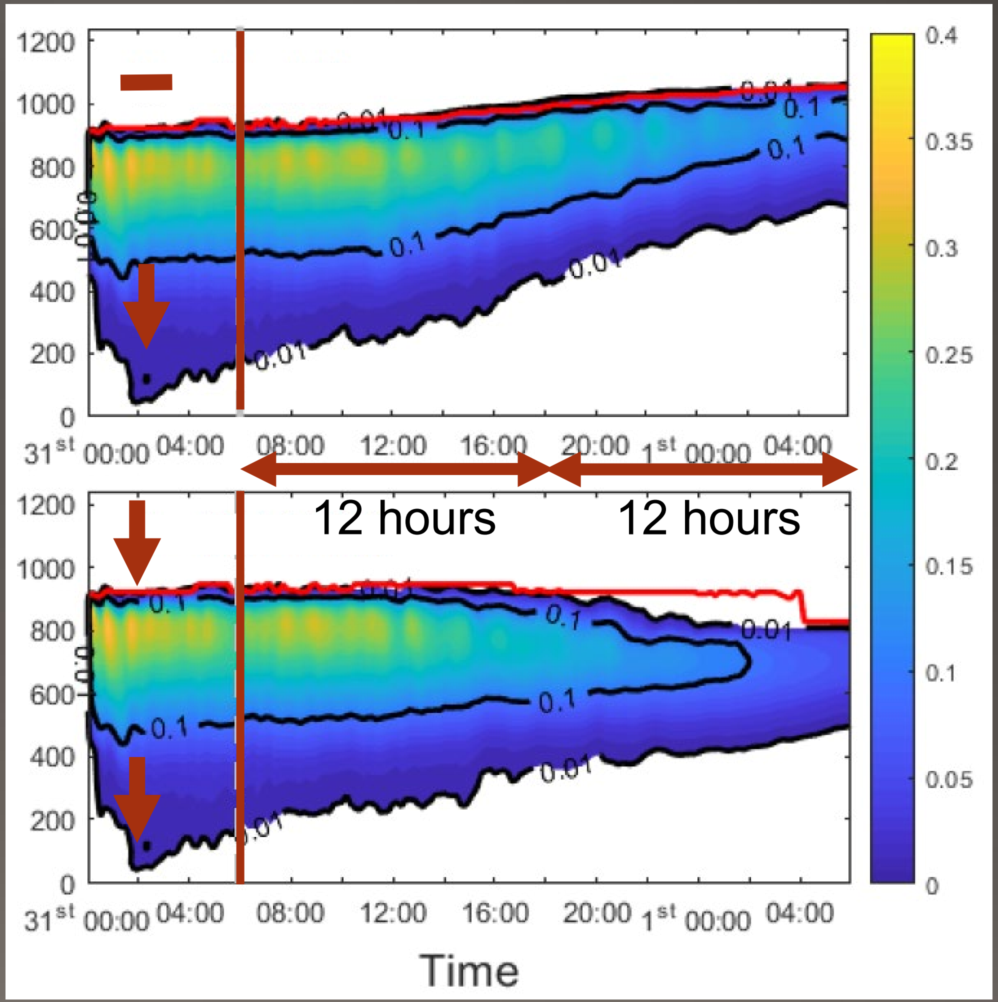
- Slightly more realistic situation: aerosol concentration decreases at the observed rate

- The cloud does not dissipate as was observed
- Treatment of FT aerosol does impact cloud evolution
  - Maintaining high FT aerosol leads to cloud top rise and higher LWP

ASCOS case

Aerosol decreases in the boundary layer only

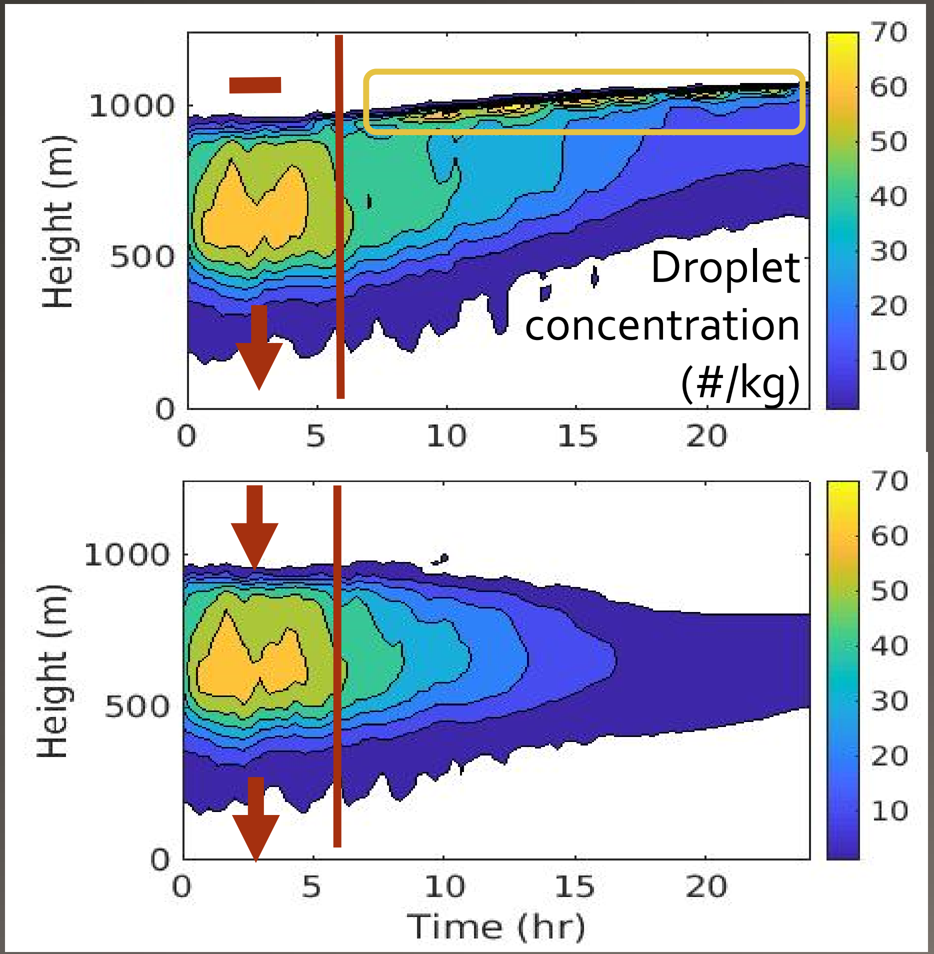
Aerosol decreases everywhere



Tong 2019, MS Thesis

Q4: Roles of above- and below-cloud aerosol

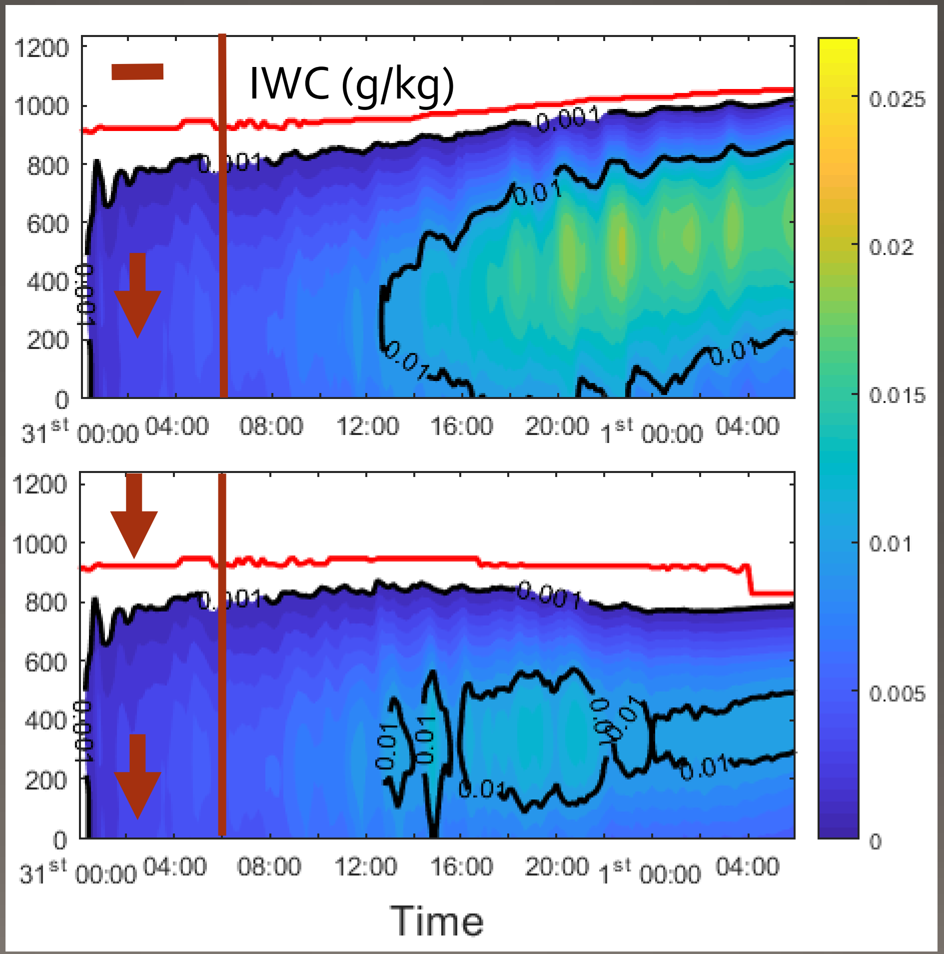
- Droplet concentration initially similar except at cloud top



Aerosol decreases in the boundary layer only

Aerosol decreases everywhere

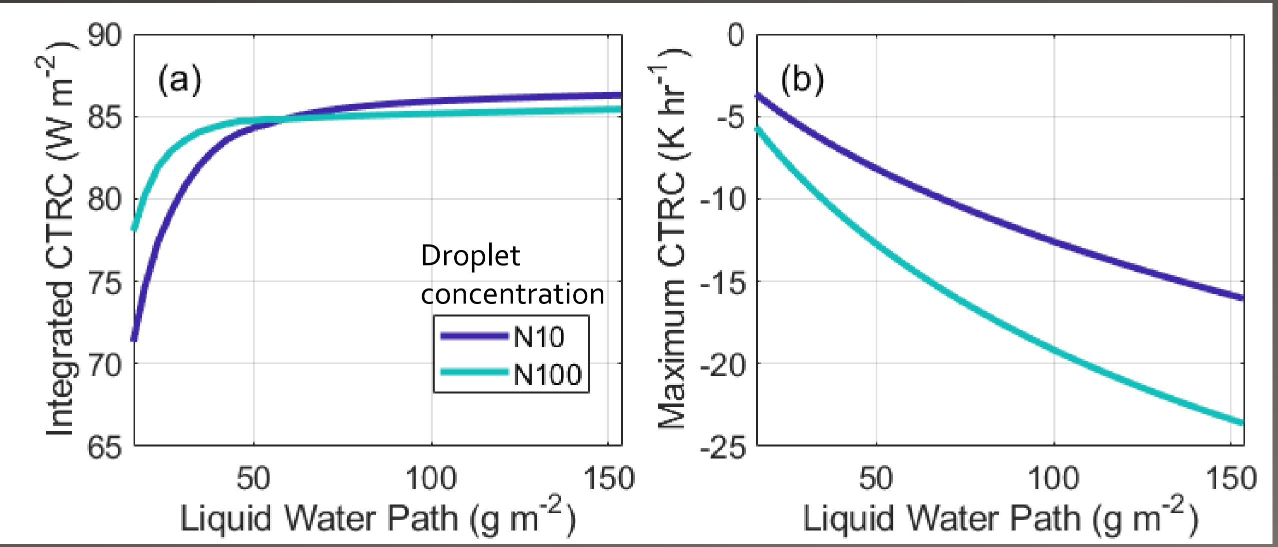
- Substantially more ice when FT aerosol is maintained



Tong 2019, MS Thesis

Q4: Roles of above- and below-cloud aerosol

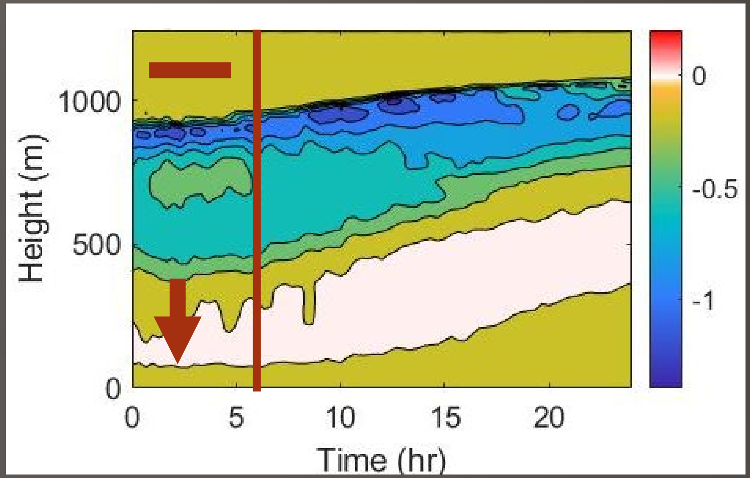
- High FT aerosol concentration may be important for maintaining droplet concentration at cloud top and therefore also high local radiative cooling rates
- Local droplet properties always modulate maximum local radiative cooling rates



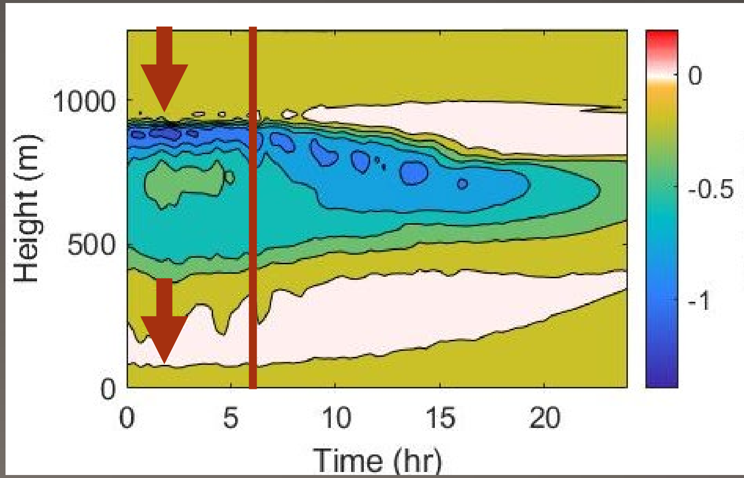
Williams and Igel 2021

Radiative cooling rate (K/hr)

Aerosol decreases in the boundary layer only



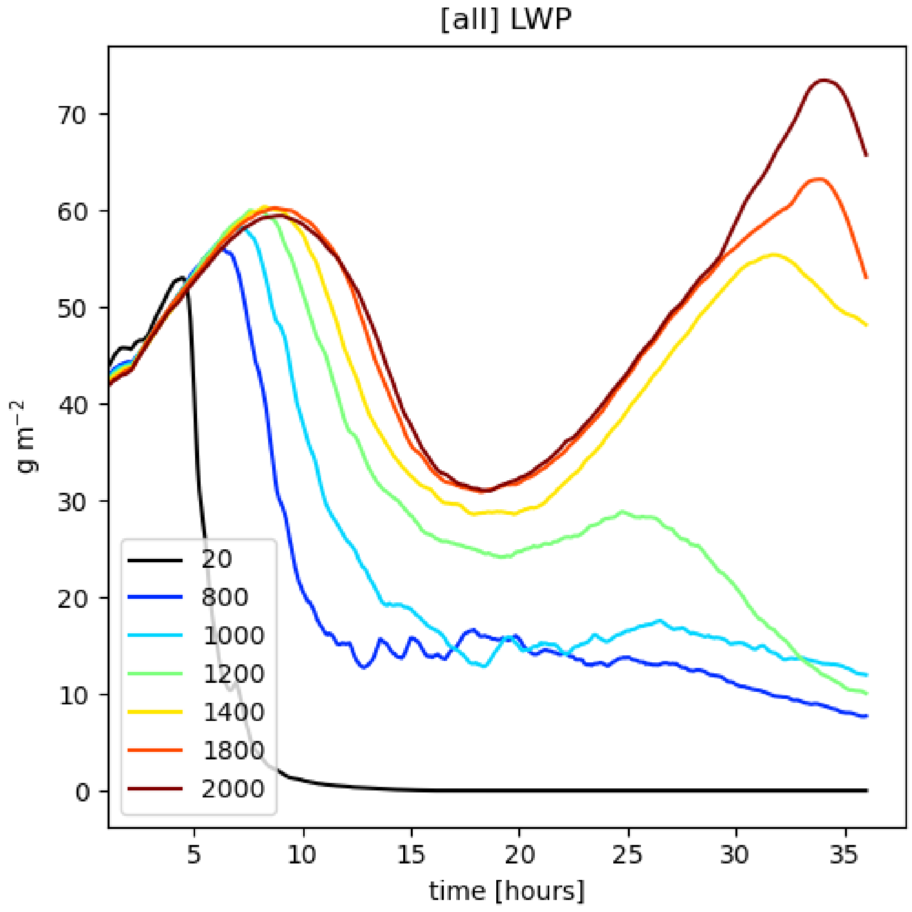
Aerosol decreases everywhere



Tong 2019, MS Thesis

Q4: Roles of above- and below-cloud aerosol

- Now simply specify FT aerosol concentration separately from the BL concentration
- FT aerosol concentration dictates whether the cloud evolves to
  - A) a high LWP state that oscillates with the diurnal cycle
  - B) a low LWP state that is in equilibrium
- Investigation ongoing, modulation of radiative cooling and heating likely important



Conclusions

1. What are the characteristics of aerosol vertical profiles relative to the boundary layer top in the Arctic?
   - Decreasing aerosol above BL top appears to be more common than increasing, but aerosol inversions do occur frequently
2. How often are cloud dissipation events associated with and caused by low aerosol concentrations?
   - Seems unlikely to be common, but clouds are very sensitive to low aerosol concentrations
3. What microphysical processes lead to the dissipation of low-level mixed-phase Arctic clouds?
   - Appears to be driven primarily by drizzle production, not glaciation
4. What are the respective roles of sub-cloud and above-cloud aerosol properties in dissipation events?
   - BL aerosol sets mean in-cloud droplet concentrations
   - FT aerosol modulates cloud top droplet concentration, may have important feedbacks to cloud dynamics through feedbacks to radiative cooling rates

Sedlar, Igel, Telg, 2021, ACP

Sterzinger, Sedlar, Guy, Neely III, Igel, 2022, ACP

Tong 2019, UCD Theses

Williams and Igel 2021, GRL