UC DAVIS
UNIVERSITY OF CALIFORNIA

U.S. DEPARTMENT OF ENERGY | Office of Science

Do Arctic Mixed-Phase Clouds Sometimes Dissipate due to Insufficient Aerosol?

Evidence from Idealized Large Eddy Simulations

Lucas Sterzinger, Joseph Sedlar, Heather Guy, Ryan Neely III, Adele Igel

EGU22 AS3.2 - Clouds, Aerosols, Radiation and Precipitation (General Session)

Thursday May 26, 2022

Arctic Cloud Persistence

- Important climate regulators, but poorly represented in models
- Often mixed-phase
  - Microphysically unstable
- Persistent (10s – 100s of hours) despite low surface heat/moisture fluxes
- Can dissipate without changes in large scale environment

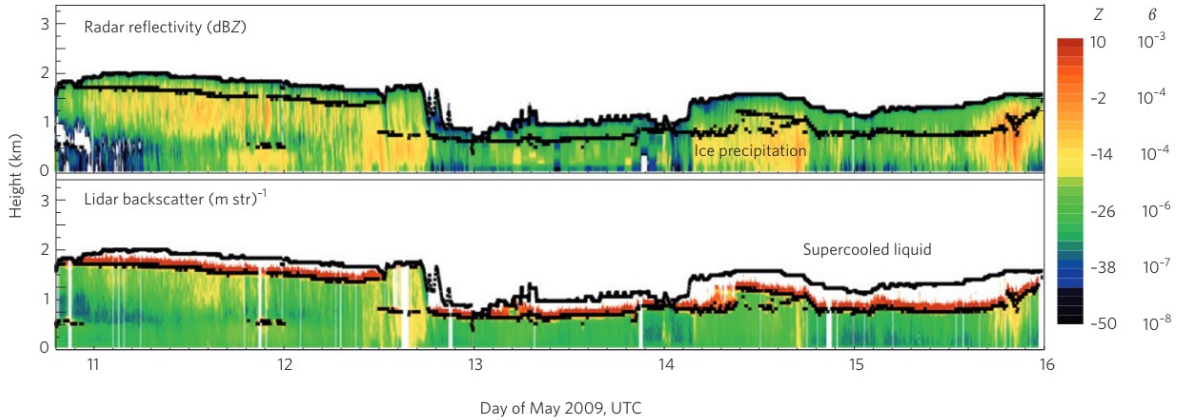


Figure 1 | Cloud radar and lidar indicating the characteristic structure of long-lived Arctic mixed-phase stratiform clouds. In this example, supercooled liquid water perseveres for more than 5 days despite a near-continual loss of mass owing to ice precipitation. Cloud radar reflectivity (top), Z, is dominated by the relatively large ice crystals that form in, and fall from, supercooled liquid cloud layers. Lidar backscatter (bottom), β, is dominated by the much smaller, yet more numerous, droplets found in liquid layers. The lidar signal is attenuated within the supercooled liquid layer, whose boundaries are defined by the black contour. UTC, coordinated universal time.

Morrison et al. (2012)

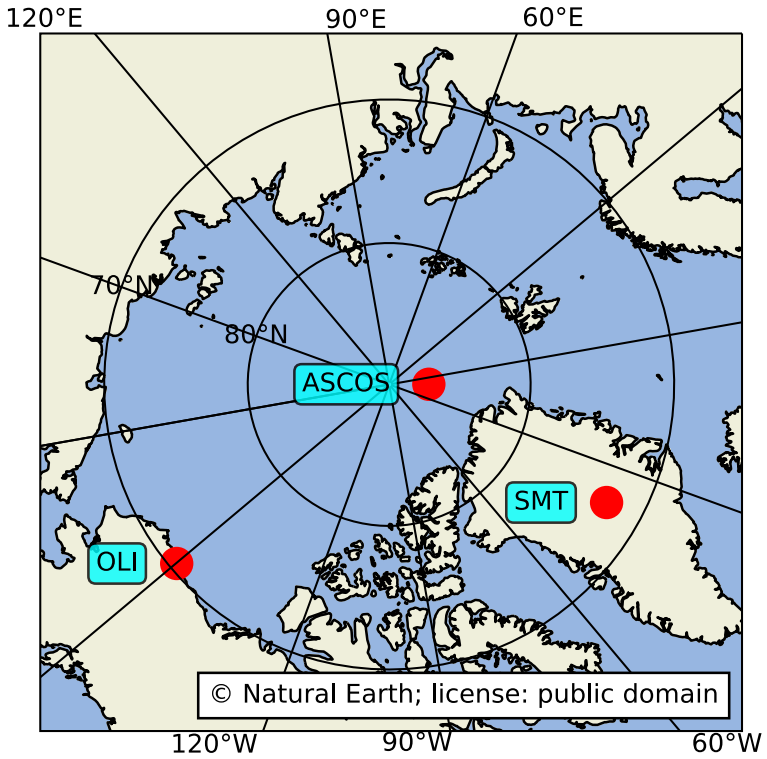
Question and Methods

Do Arctic clouds dissipate because there is insufficient aerosol concentration?

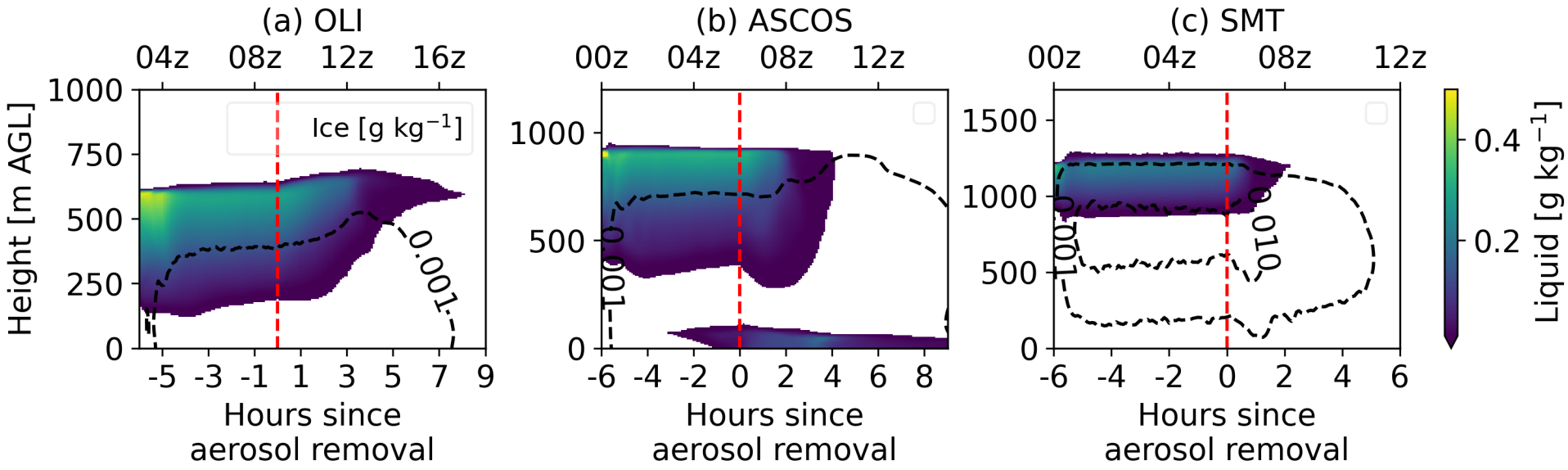
- Use observations to find periods in which an Arctic boundary-layer cloud dissipated coincidentally with a drop in surface aerosol concentration.
- Use idealized LES to test whether dissipation was caused by a lack of available aerosol
- Create “Worse case scenario” simulations in which all aerosol are removed from the environment instantaneously
- Compare simulated response to observations

Case Selection

- Oliktok Point, AK (OLI)
  - 2017-05-12
- ASCOS Field Campaign
  - 2008-08-31
- Summit Station, Greenland (SMT)
  - 2019-07-02
  - 3,200 meter elevation



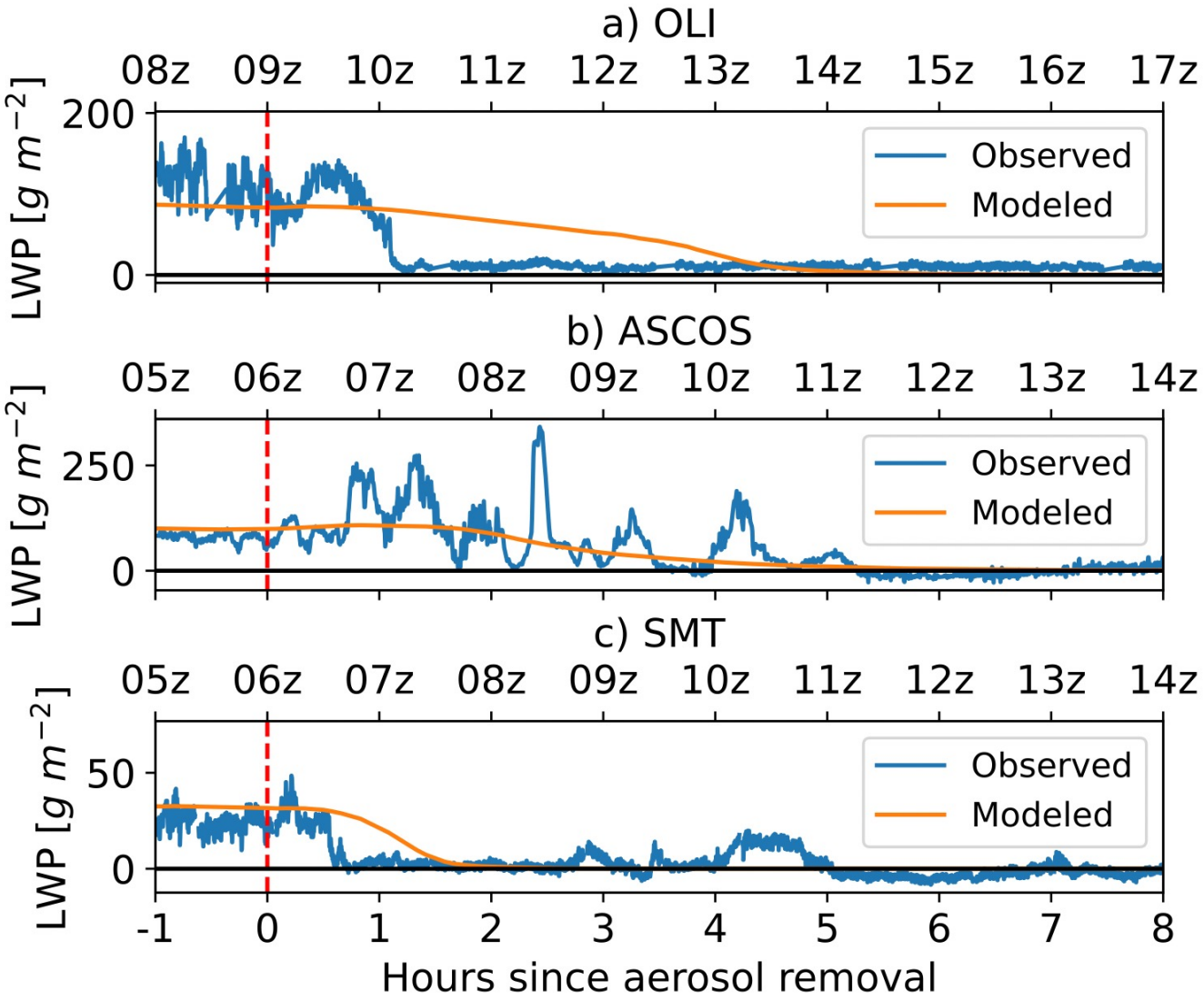
2D Cloud Contours



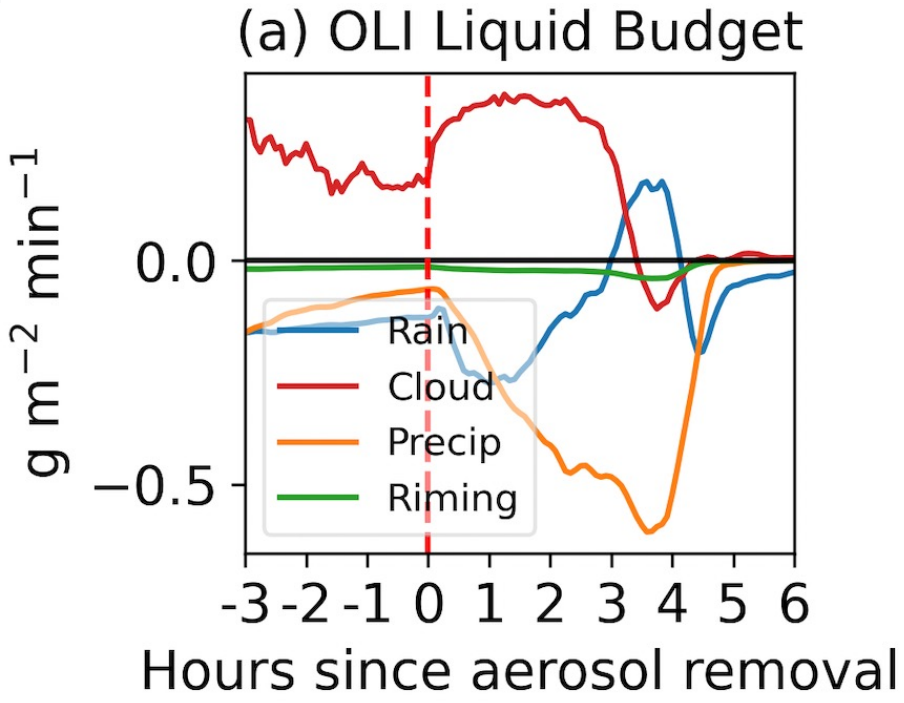
- Remove all aerosol from the environment at time denoted by red line
- ”Worst case scenario” (fastest theoretical timescale) for aerosol-limited dissipation

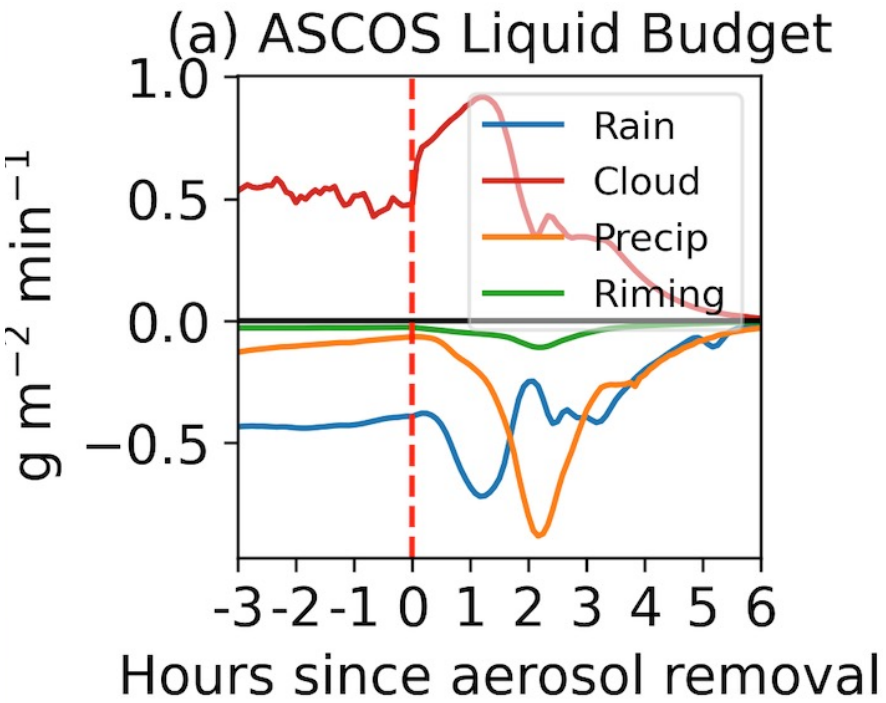
LWP Comparison

- Compare LWP to observations as a measure of dissipation timescale
- If modeled dissipation is slower than observed, probably not caused by lack of aerosol
  - Observed cloud at OLI dissipated significantly faster than modeled
  - ASCOS and SMT less certain



Vertically Integrated Budget - Liquid

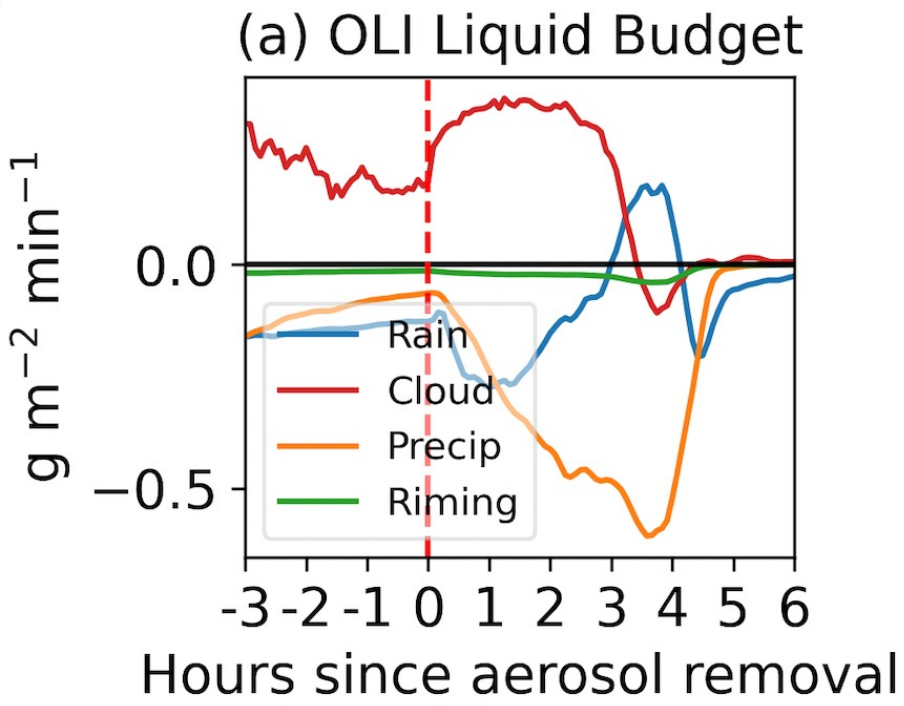


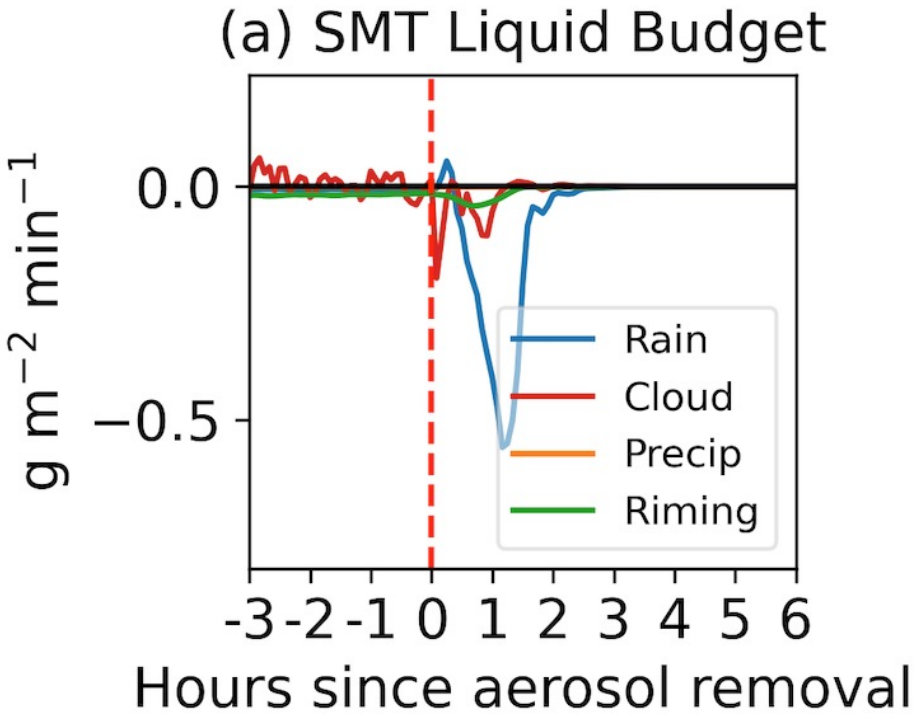


Red–Cloud Droplet Growth
Orange – Surface Precipitation

Blue – Rain Droplet Growth
Green – Riming

Vertically Integrated Budget - Liquid





Red–Cloud Droplet Growth
Orange – Surface Precipitation

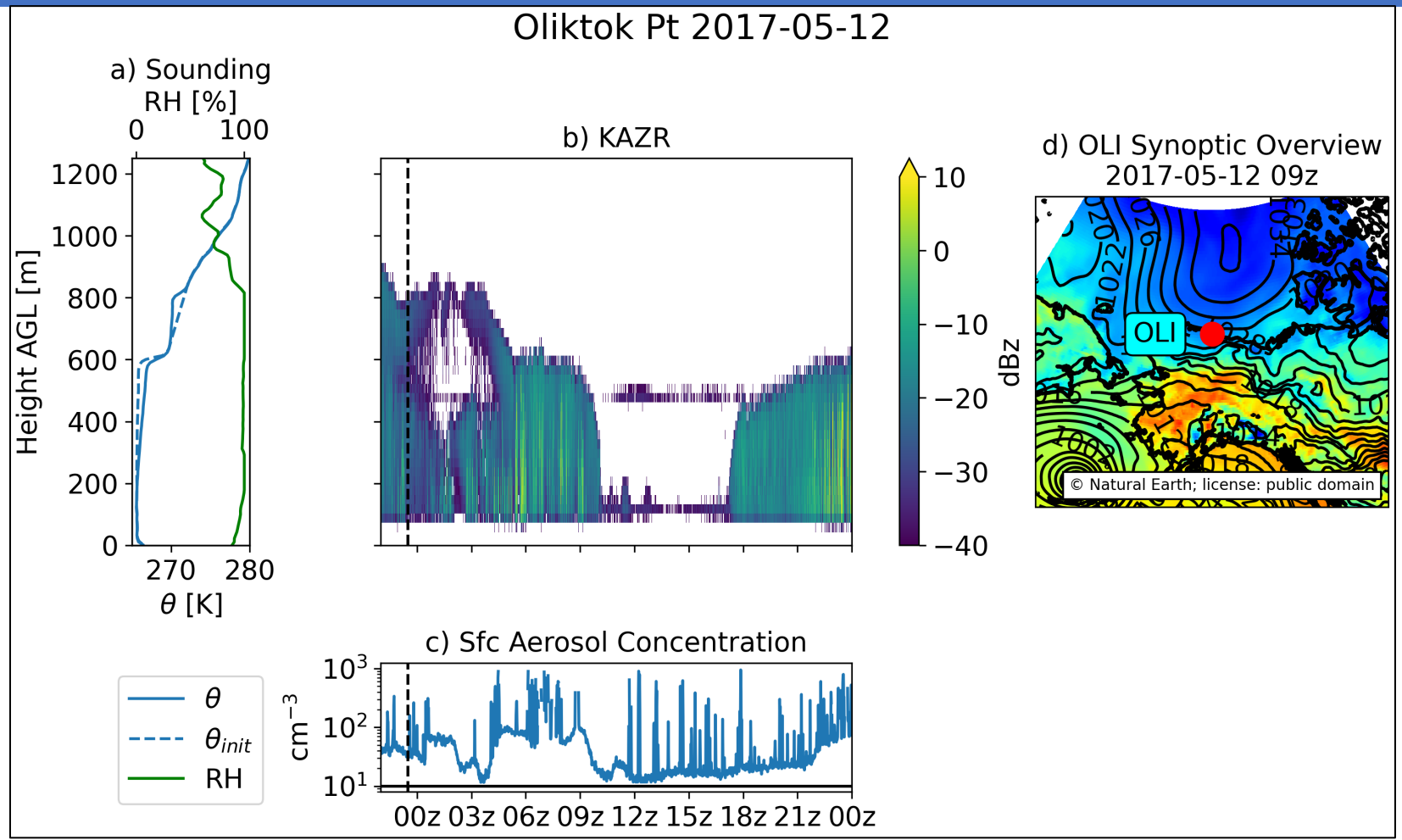
Blue – Rain Droplet Growth
Green – Riming

Main Takeaways

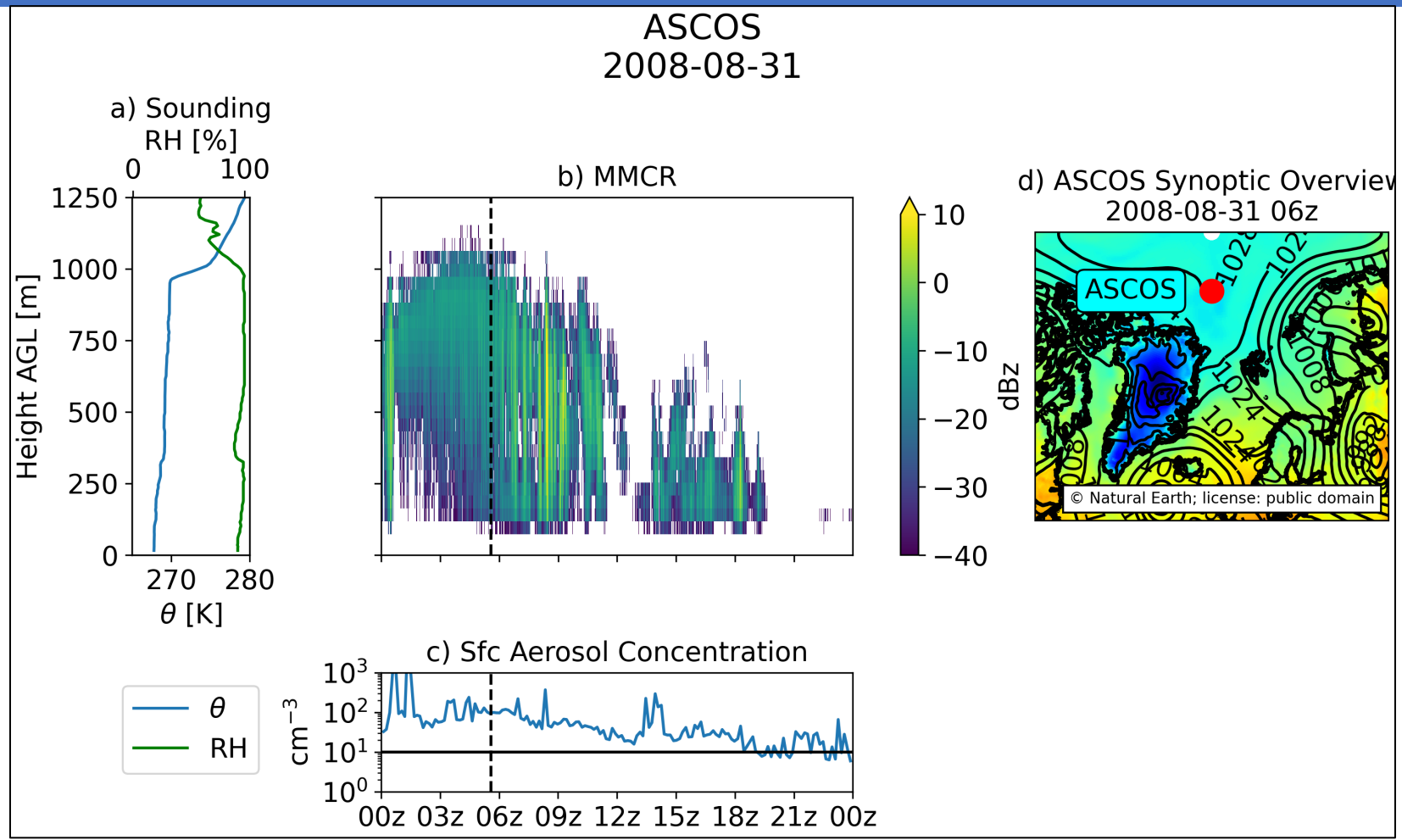
- Able to rule out OLI as a case of aerosol-limited dissipation
  - ASCOS and SMT more likely, but more investigation required (more realistic aerosol treatment)
- Response to aerosol removal varies by case
  - Cases with precipitating liquid layer dissipate via precipitation enhancement
  - Non-liquid precipitating case dissipated via glaciation
- More detail included in slides uploaded to the EGU22 website
- Watch out for our paper, currently in review in ACP
  - https://acp.copernicus.org/preprints/acp-2022-36/

Additional slides

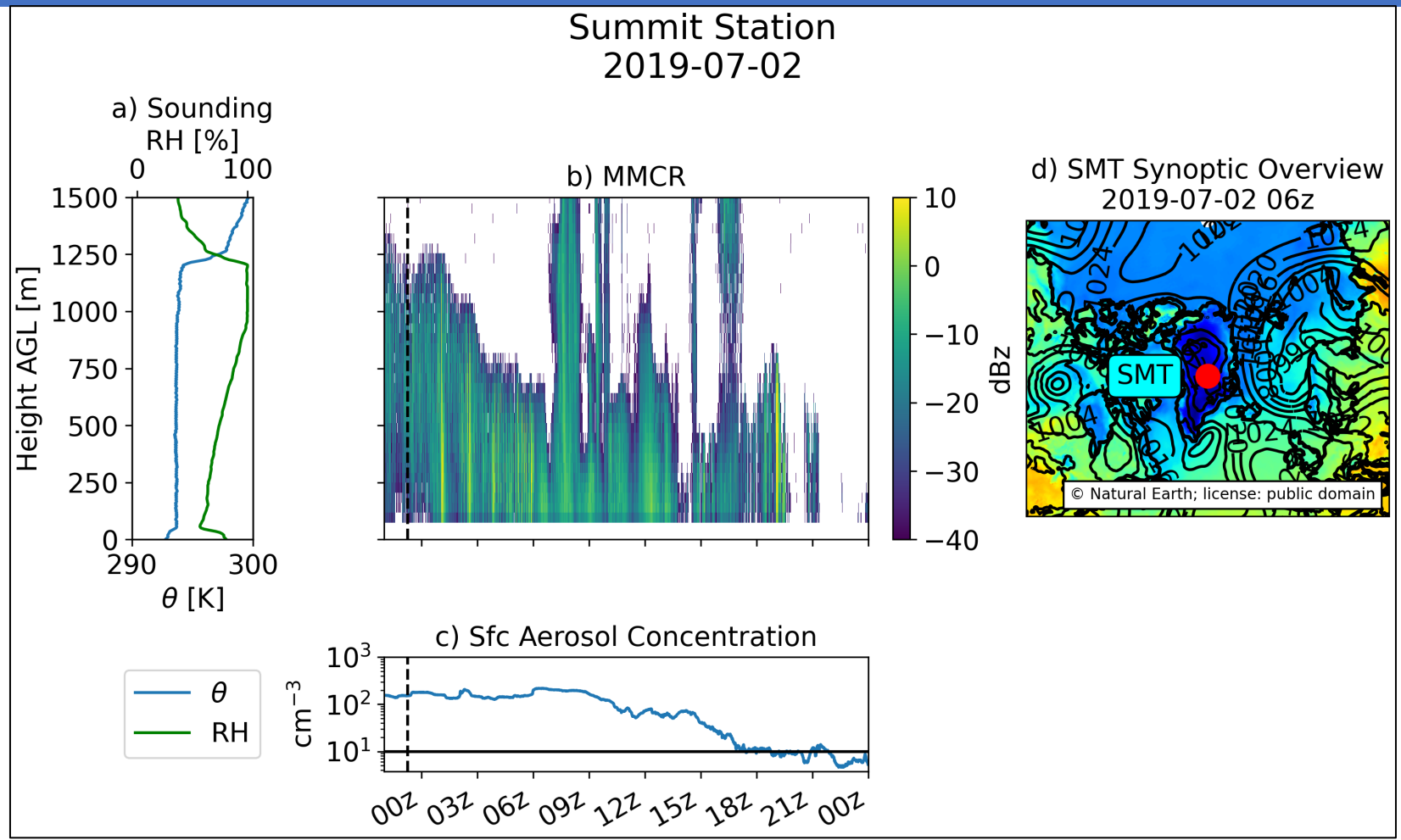
Cases - OLI


Oliktok Pt 2017-05-12
a) Sounding
RH [%]
0
100
1200
1000
800
600
400
200
0
Height AGL [m]
270
280
θ [K]
b) KAZR
10
0
−10
−20
−30
−40
dBz
d) OLI Synoptic Overview
2017-05-12 09z
OLI
© Natural Earth; license: public domain
c) Sfc Aerosol Concentration
10^3
10^2
10^1
cm^{-3}
00z 03z 06z 09z 12z 15z 18z 21z 00z
θ
$θ_{init}$
RH

Cases - ASCOS

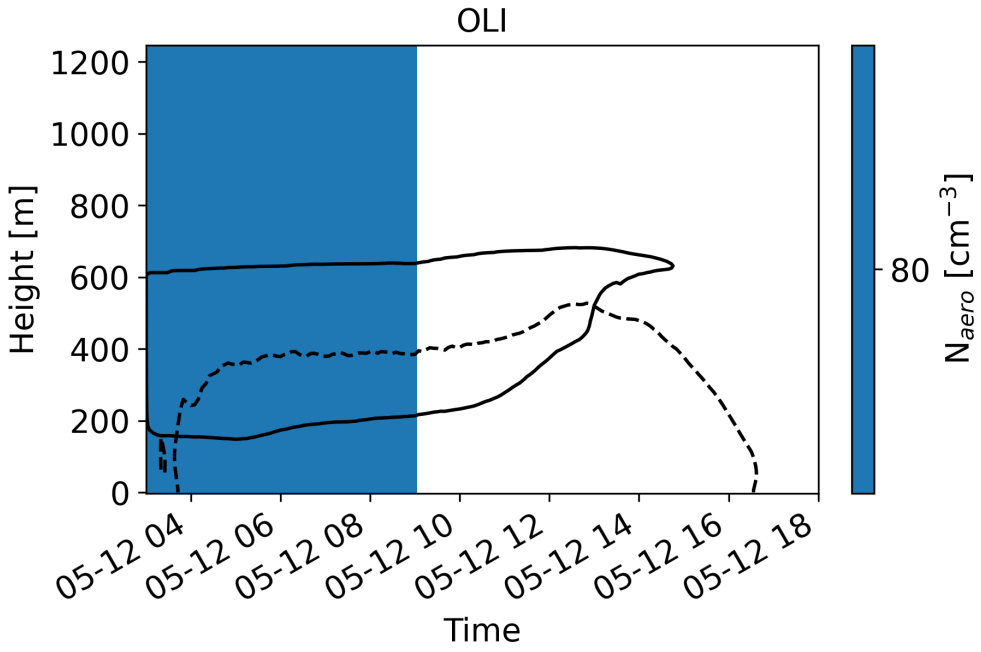

ASCOS
2008-08-31
a) Sounding
RH [%]
0
100
1250
1000
750
500
250
0
Height AGL [m]
270
280
θ [K]
θ
RH
b) MMCR
10
0
−10
−20
−30
−40
dBz
c) Sfc Aerosol Concentration
10^3
10^2
10^1
10^0
cm^{-3}
00z 03z 06z 09z 12z 15z 18z 21z 00z
d) ASCOS Synoptic Overview
2008-08-31 06z
ASCOS
© Natural Earth; license: public domain

Cases – SMT


Summit Station
2019-07-02
a) Sounding
RH [%]
0
100
1500
1250
1000
750
500
250
0
Height AGL [m]
290
300
θ [K]
θ
RH
b) MMCR
10
0
−10
−20
−30
−40
dBz
c) Sfc Aerosol Concentration
10^3
10^2
10^1
cm^{-3}
00z
03z
06z
09z
12z
15z
18z
21z
00z
d) SMT Synoptic Overview
2019-07-02 06z
SMT
© Natural Earth; license: public domain

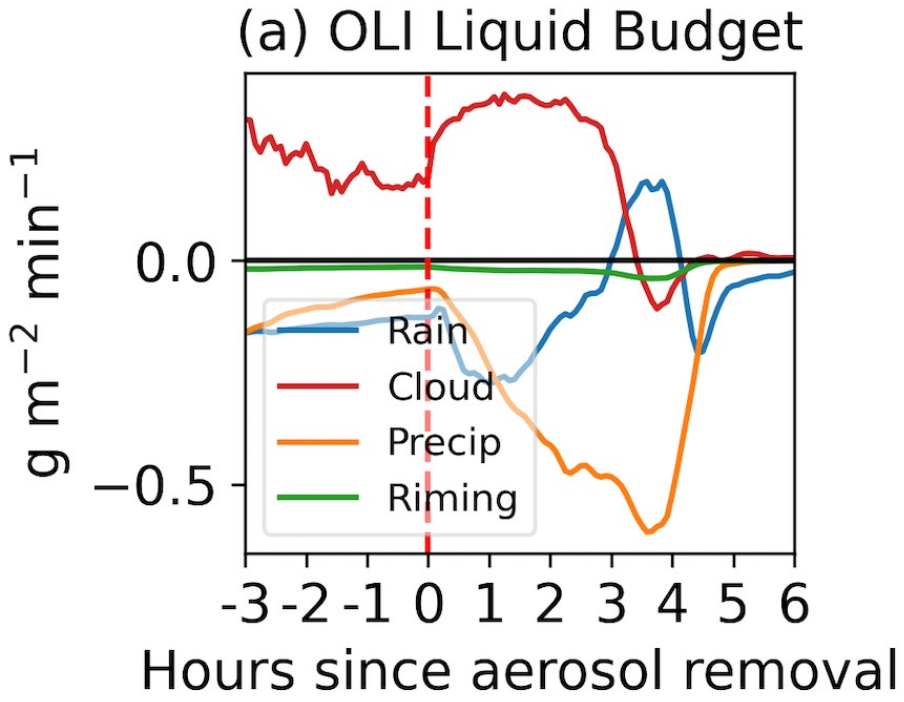
Modeling Setup

- Data from cases used to initialize Regional Atmospheric Modeling System (RAMS) in an LES setup
  - dx/dy = 62.5 m | dz = 6.25m
  - 2-Moment bulk microphysics
- Fixed aerosol concentration with no removal on activation
  - (upper limit on # of activated droplets)
- Spin-up the model for a few hours, then immediately remove all aerosol
- “Worst Case Scenario” for aerosol-limited dissipation



Aerosol concentration (blue), liquid outline (solid, 0.01 g/kg), ice outline (dashed, 0.001 g/kg)

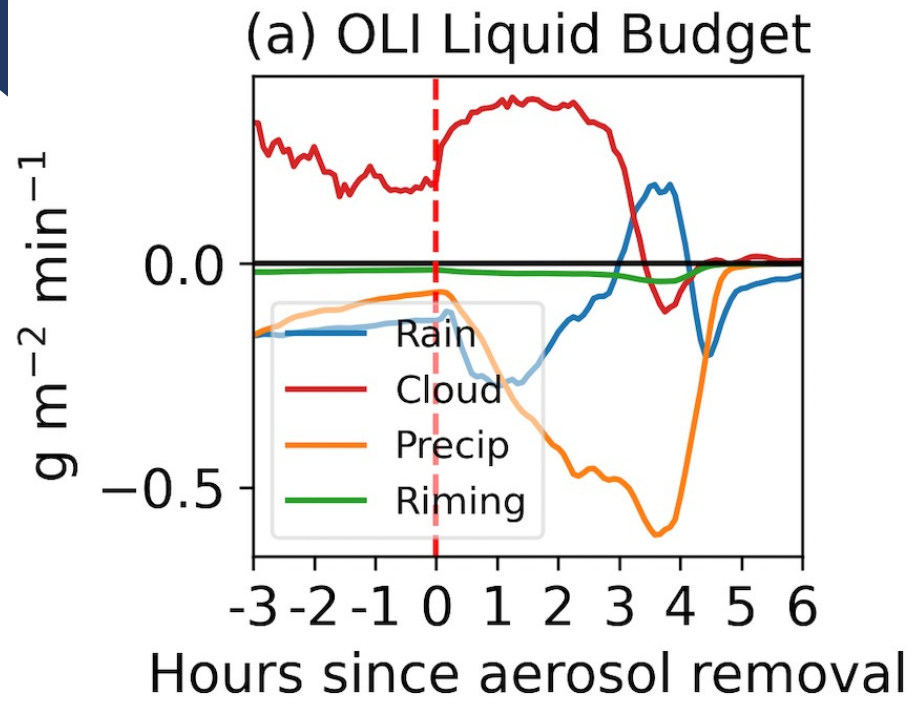
Vertically Integrated Budget - Liquid

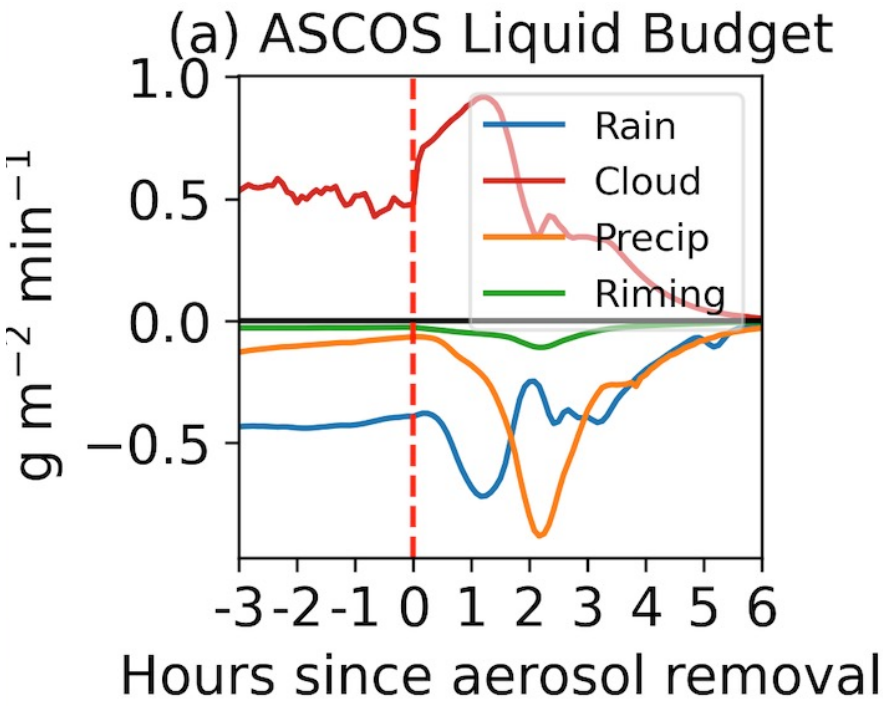


- Pre-removal
  - Constant cloud droplet growth
  - Surface liquid precipitation
- Post-removal
  - Increased cloud droplet growth
  - Increased Precipitation
- Cloud dissipated via precipitation enhancement

Red–Cloud Droplet Growth
Orange – Surface Precipitation
Blue – Rain Droplet Growth
Green – Riming

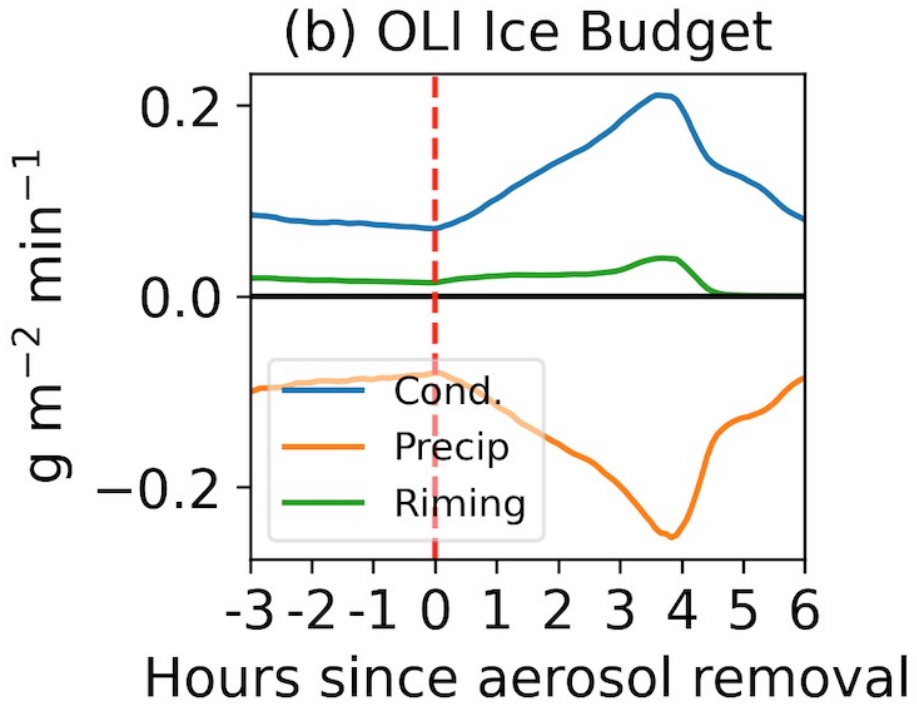
Vertically Integrated Budget - Liquid





Very similar structure pre- and post-removal

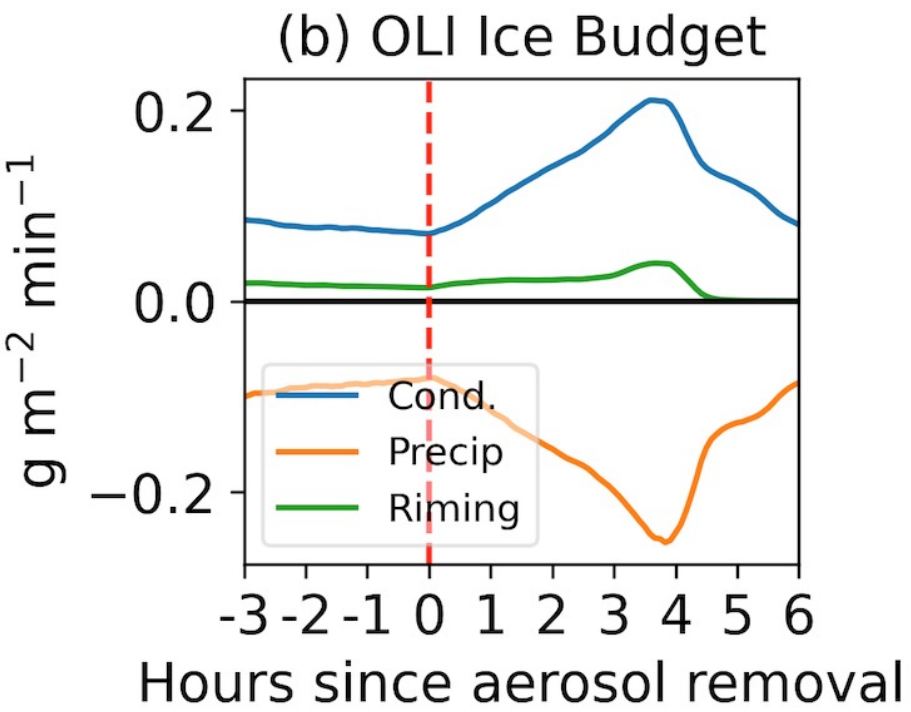
Vertically Integrated Budget - Ice

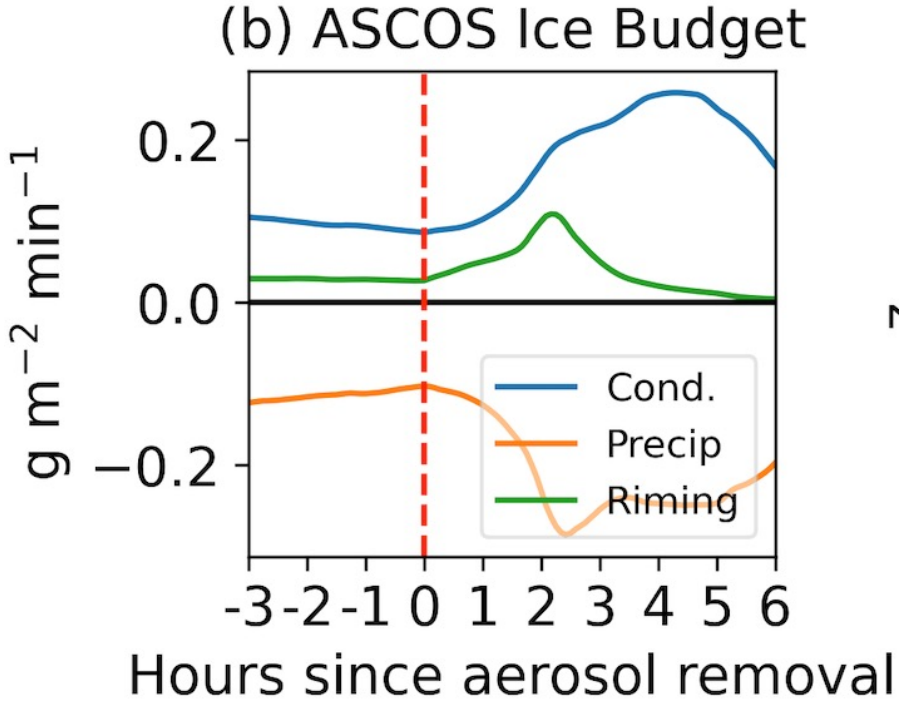


- Pre-removal
  - Constant ice crystal growth
  - Surface liquid precipitation
- Post-removal
  - Increased ice crystal growth
  - Increased Precipitation

Blue – Ice Growth Orange – Surface Precipitation Green – Riming

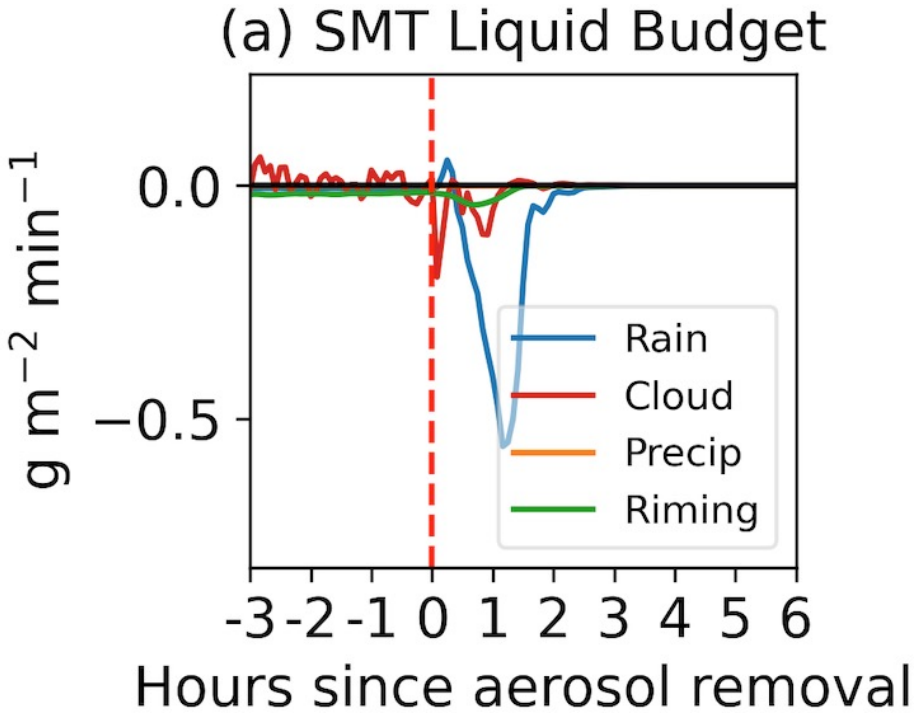
Vertically Integrated Budget - Ice





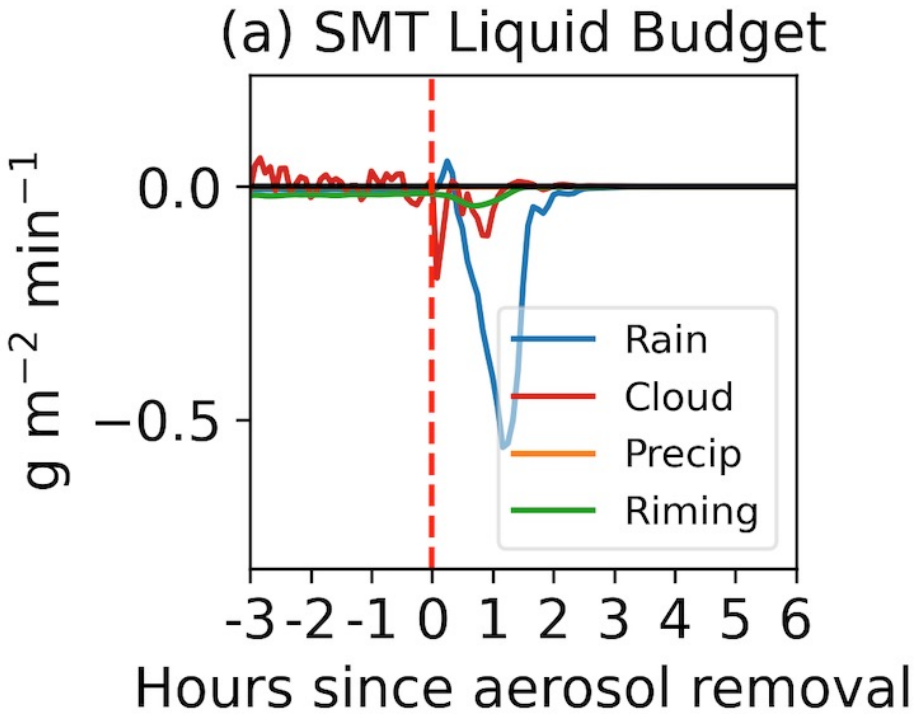
Blue – Ice Growth Orange – Surface Precipitation Green – Riming

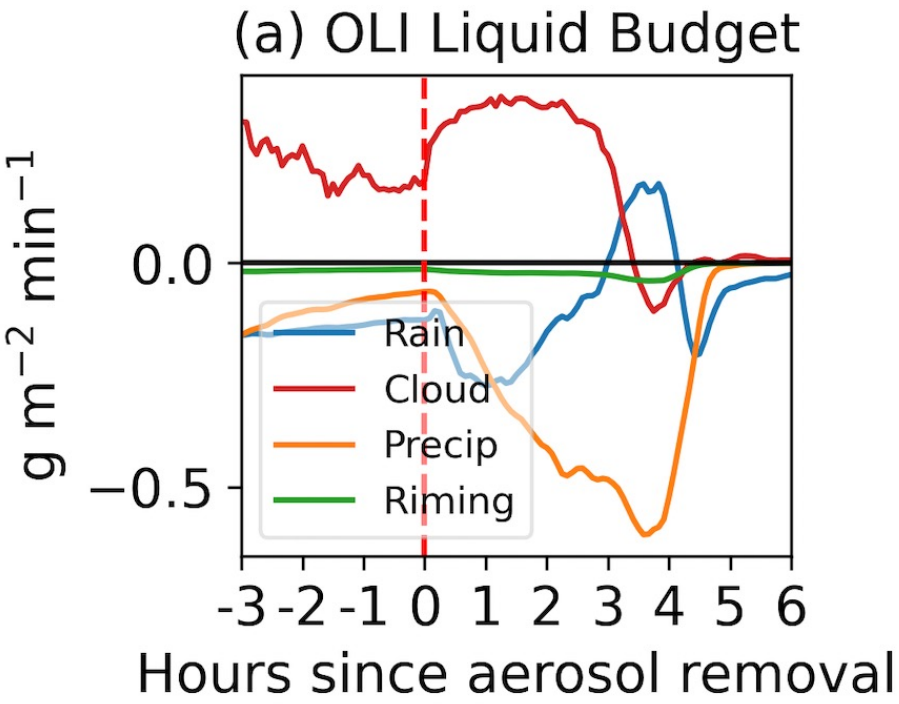
Vertically Integrated Budget - Summit



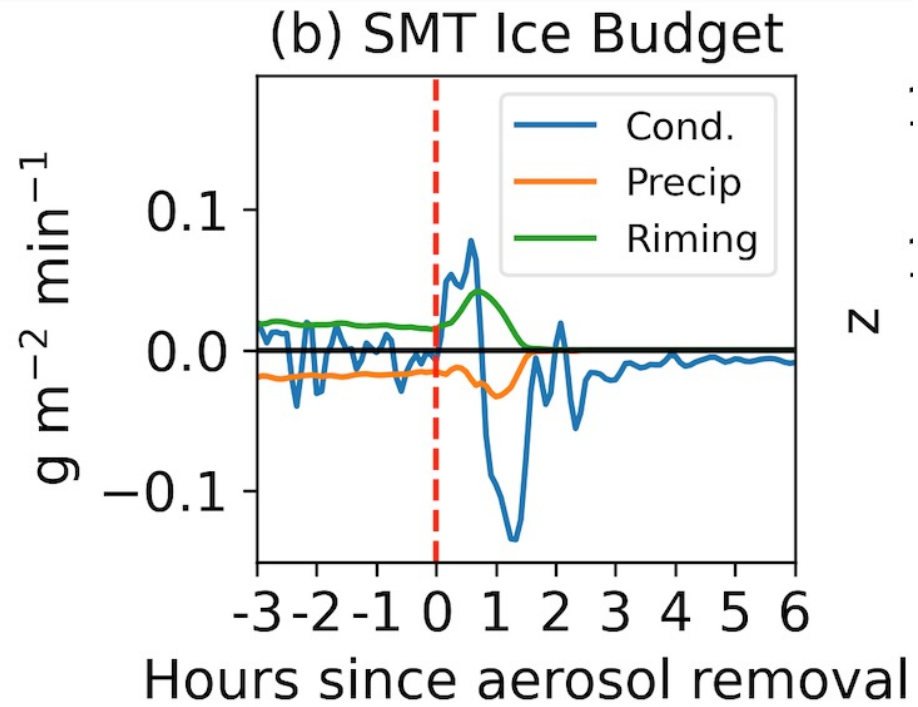
- Pre-removal
  - Near-zero integrated cloud and rain growth
  - No liquid surface precipitation
- Post-removal
  - Both liquid species evaporate

Vertically Integrated Budget - Summit



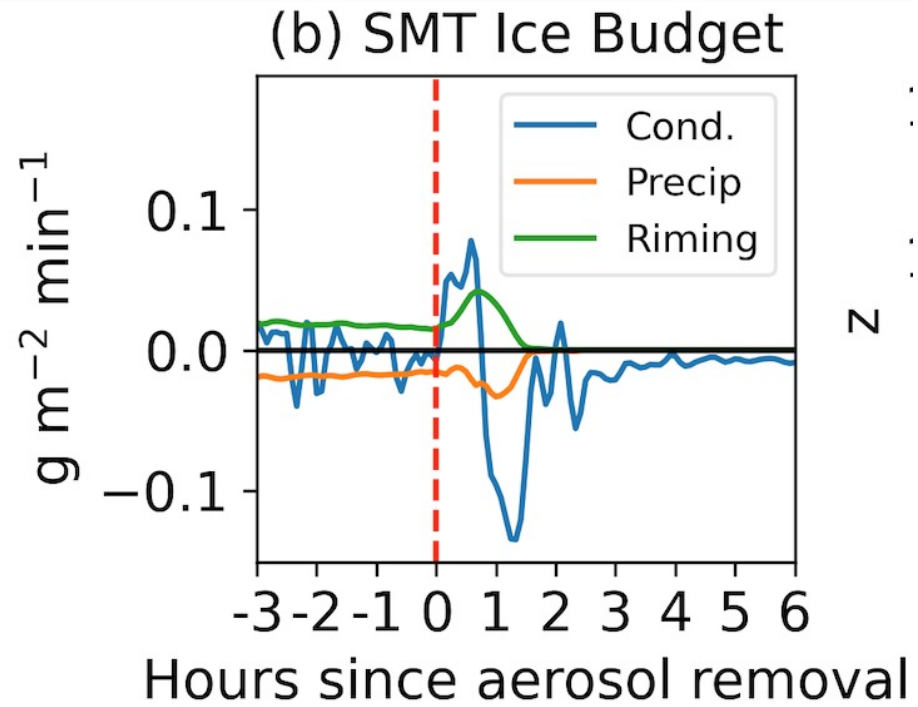


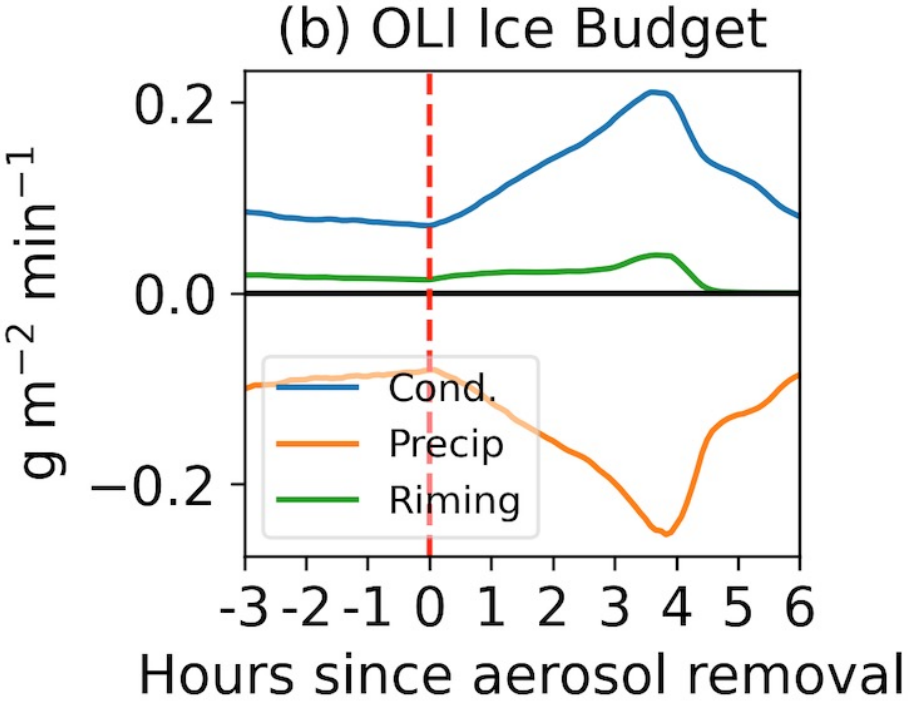
Vertically Integrated Budget - Summit



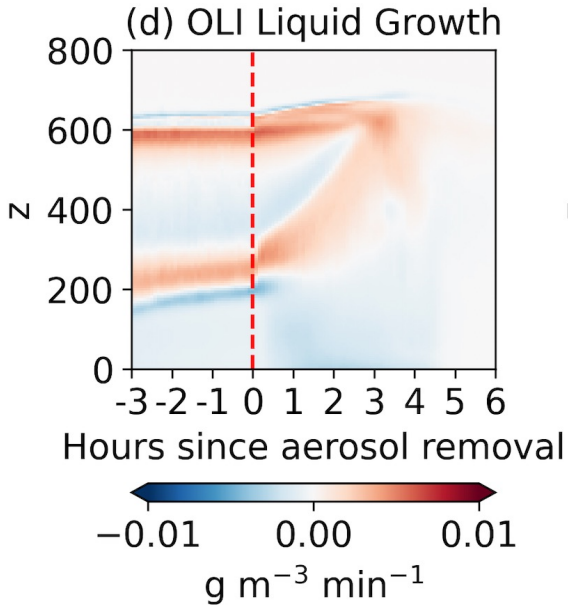
- Pre-removal
  - Slight ice precipitation
  - Near-zero ice growth
- Post-removal
  - Short period (< 1 h) of ice growth, followed by sublimation

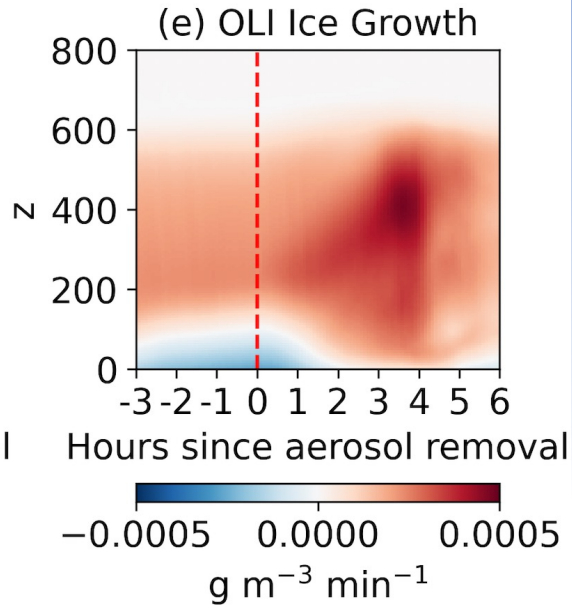
Vertically Integrated Budget - Summit

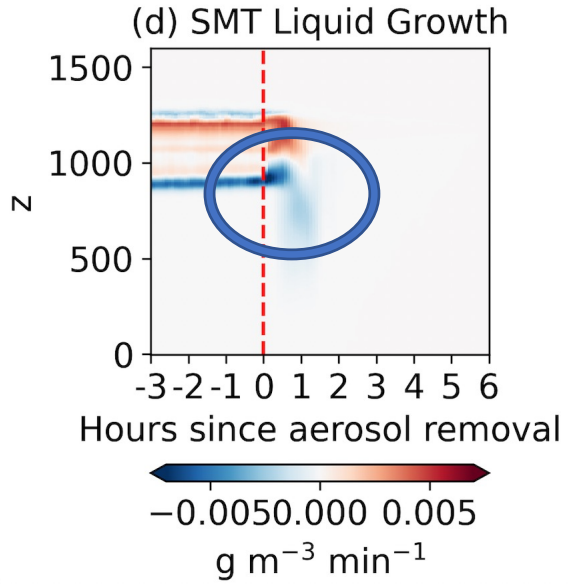


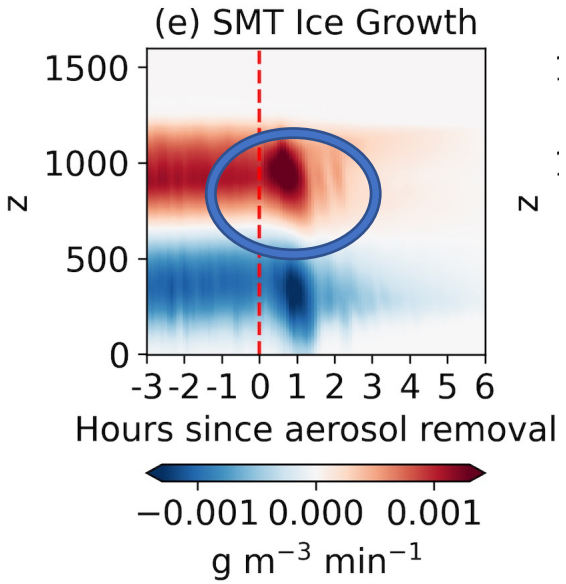


2D Growth - Summit









2D Growth - Summit

- WBF Process (ice growing at expense of liquid) seems to be active
  - May also explain high evaporation rates at cloud base pre-removal
- Could explain why SMT LWP dissipated faster