Overshooting convections seen by satellites

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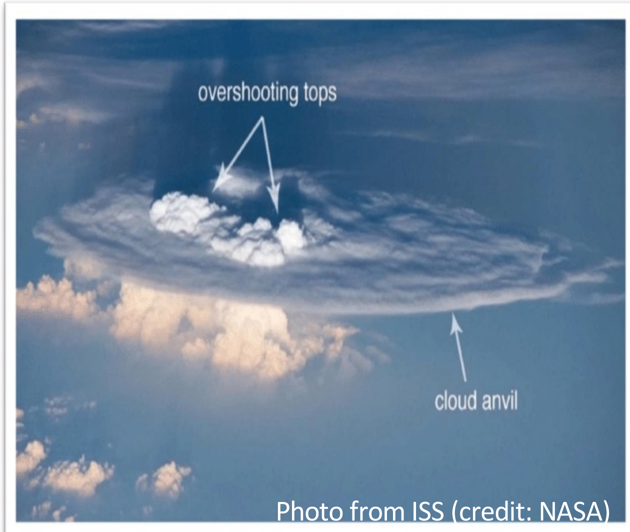
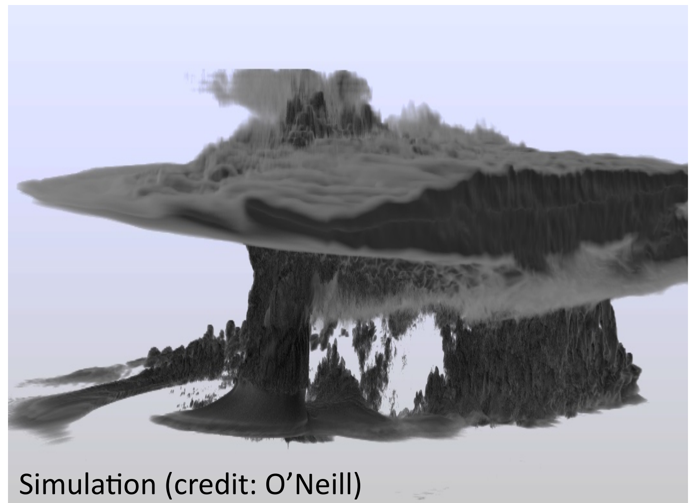
Funding acknowledgements:

GEWEX UTCC PROES meeting
IPSL/Sorbonne U, Paris
2025-05-21

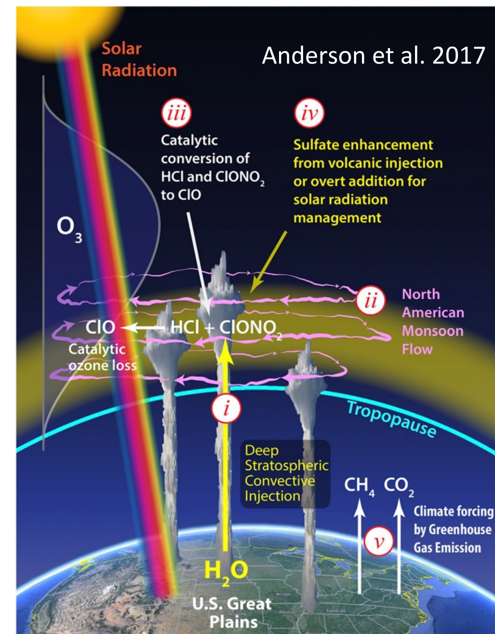
What and why do we care?



- Weather: extreme weather



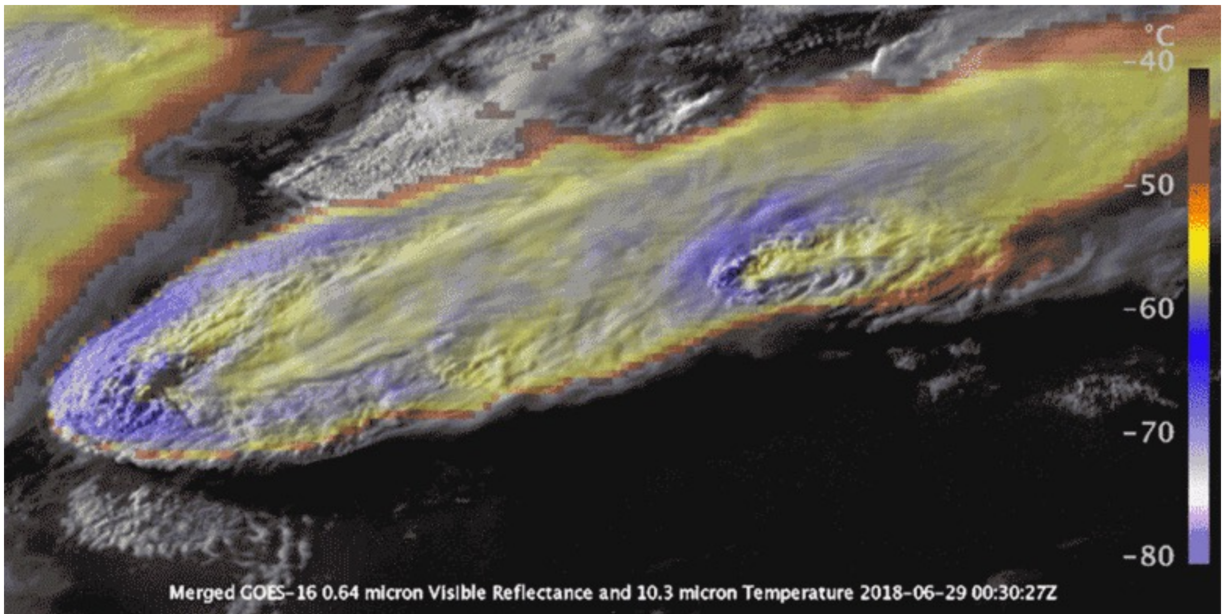
- Climate: atmospheric compositional, chemical and radiative impacts



PASSIVE SENSOR VIEW

Passive sensors

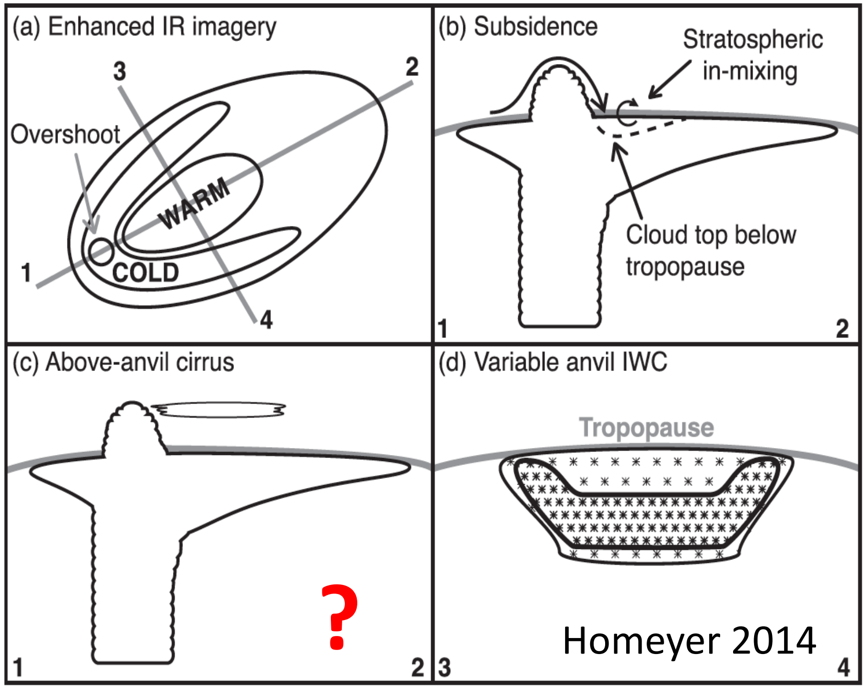
Geostationary imagery (IR)



Cold-V feature
(Heymsfield et al. 1983, Setvak et al. 2010, Homeyer 2014, Liang & Huang 2025, ...)

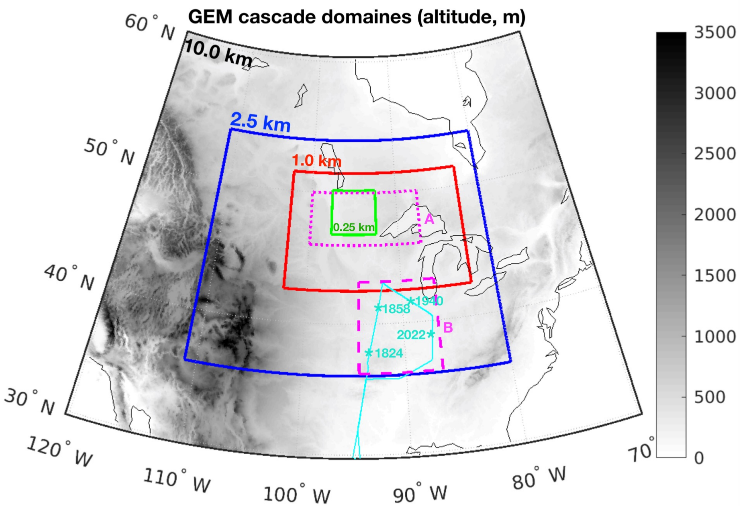
ISS photo (Visible)

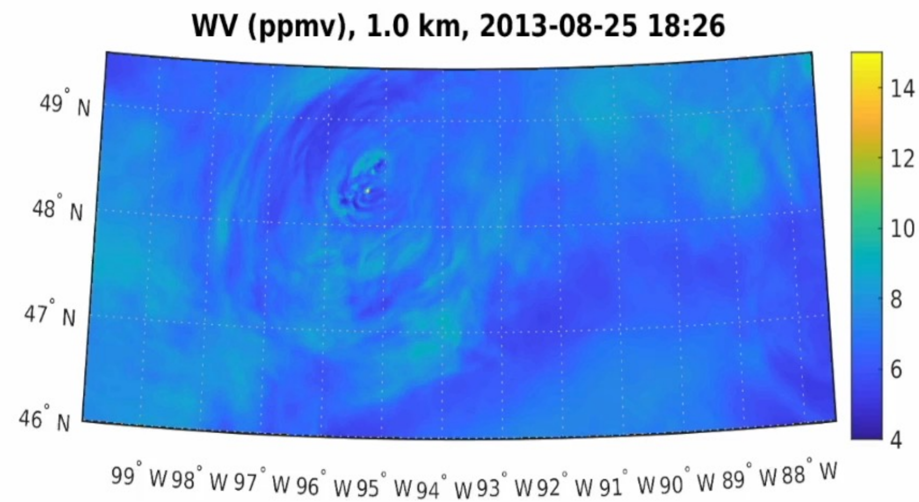
Cold-V mechanism



- Cause of cold-V
  - Subsidence (🚫)
  - Ice variation (🚫)
  - Above anvil cirrus (AAC) (🤔)

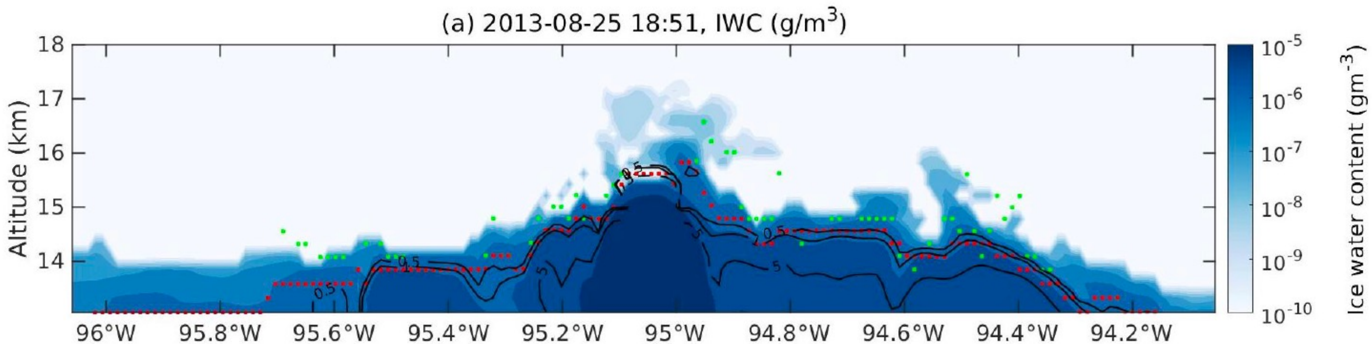
Testing of AAC hypothesis

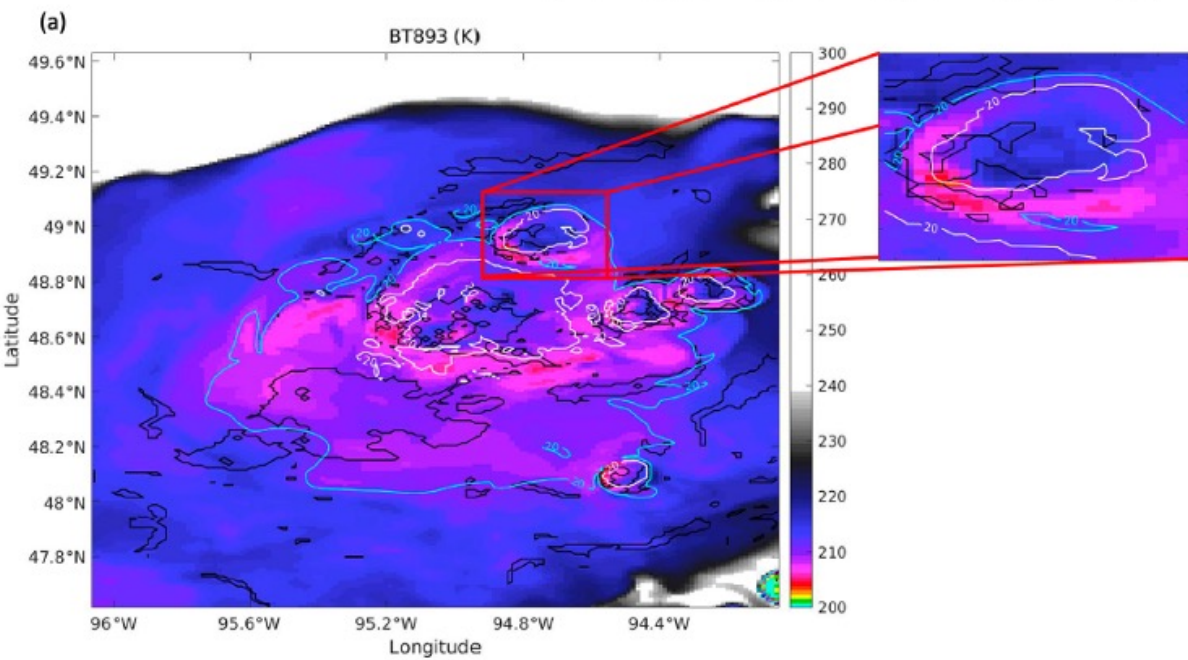




Nested simulation using the Global Environmental Multiscale (GEM) model (Qu et al. 2020; Wang et al. 2023; Liang & Huang 2025)
Resolution: 10, 2.5, 1, 0.25 km
Case: Aug 25-27, 2013

Simulated OC and cold-V



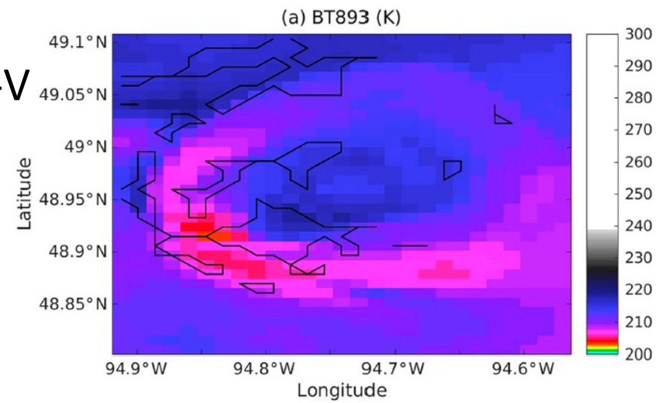


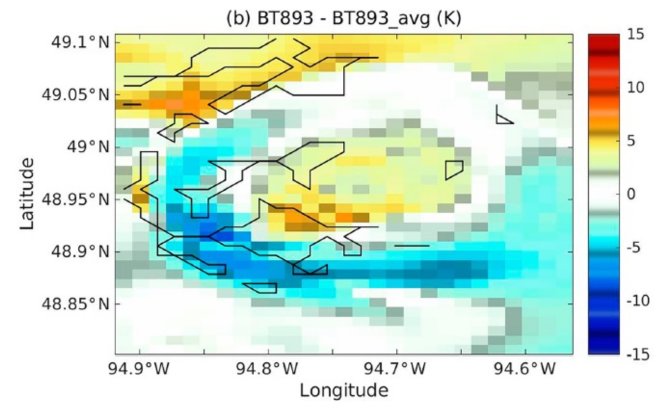
- The simulation well reproduces various features of overshooting including AAC (jumping cirrus) and cold-V.

Liang & Huang 2025, following Qu et al. 2020 and Wang et al. 2023

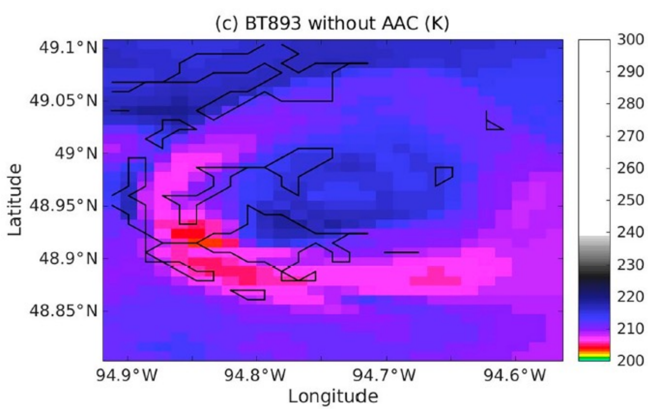
Mechanism denial experiments

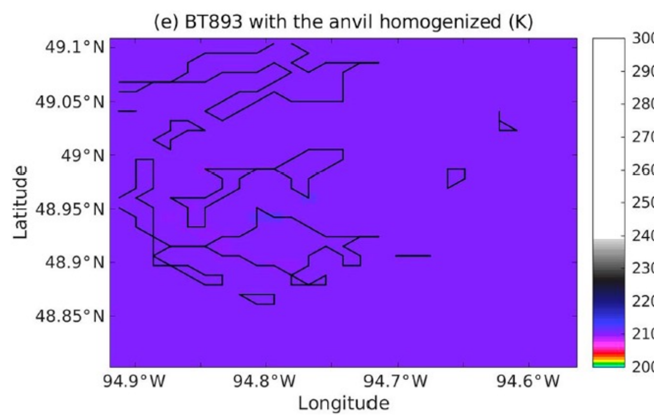
- Control : Cold-V reproduced





- Denial : Testing if AAC is a necessary condition

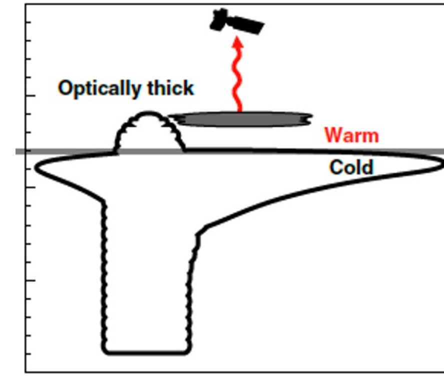




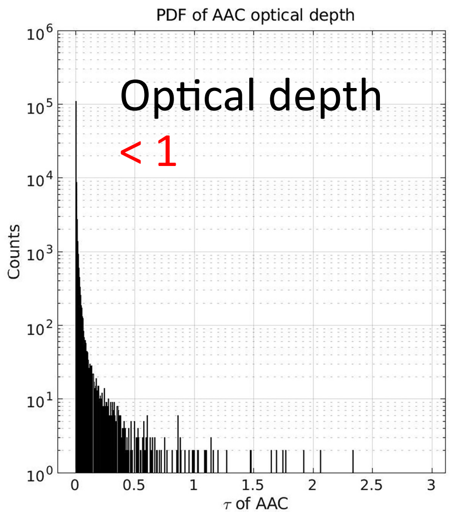
Removing AAC

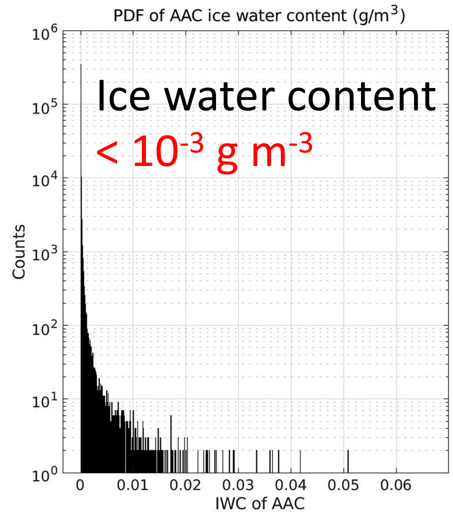
Homogenizing anvil temperature

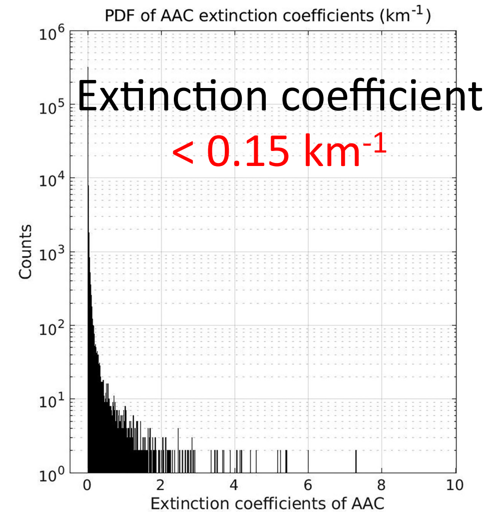
Radiative transfer explanation



$$\mathrm{BT} = T_a(1-\varepsilon) + T_c\varepsilon,$$
$$\mathrm{BT}_{\mathrm{AAC}} - \mathrm{BT}_{\mathrm{non\text{-}AAC}} = (T_c - T_a)\varepsilon.$$

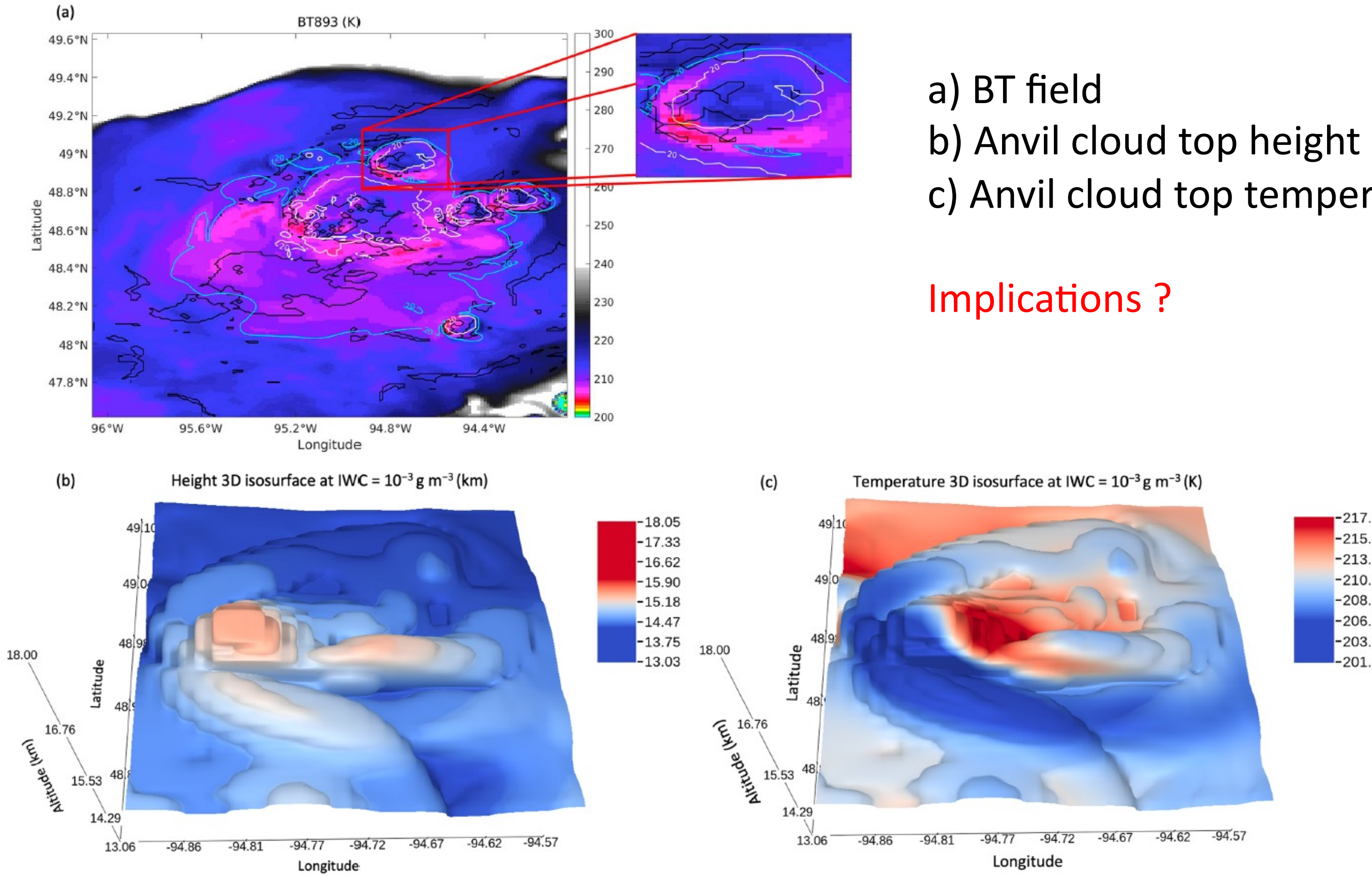






- AACs are optically too thin to cause significant BT anomalies!

Cold-V reflects anvil temperatures!

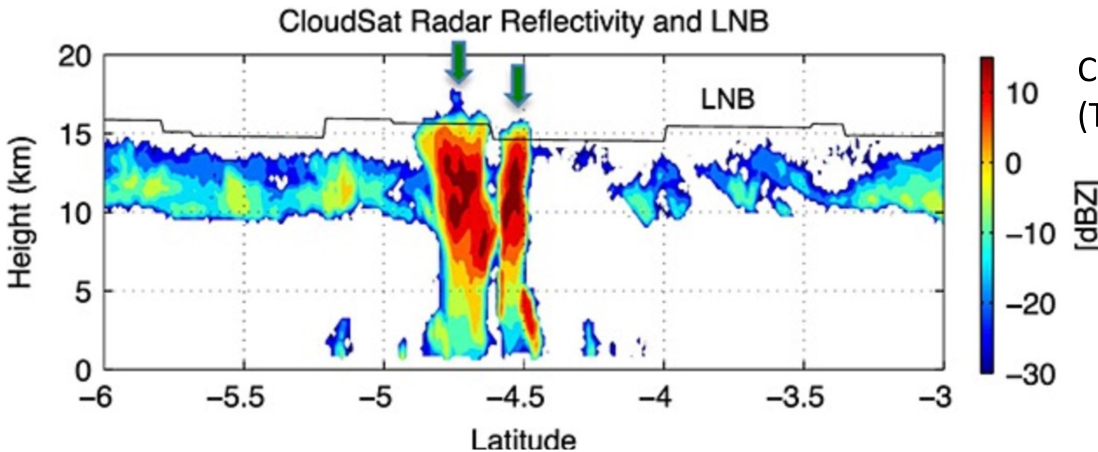


a) BT field
b) Anvil cloud top height
c) Anvil cloud top temperature

Implications ?

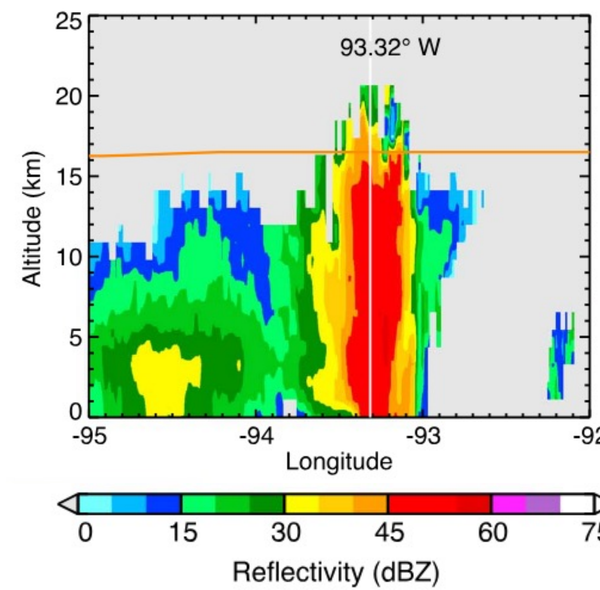
ACTIVE SENSOR VIEW

Active sensors

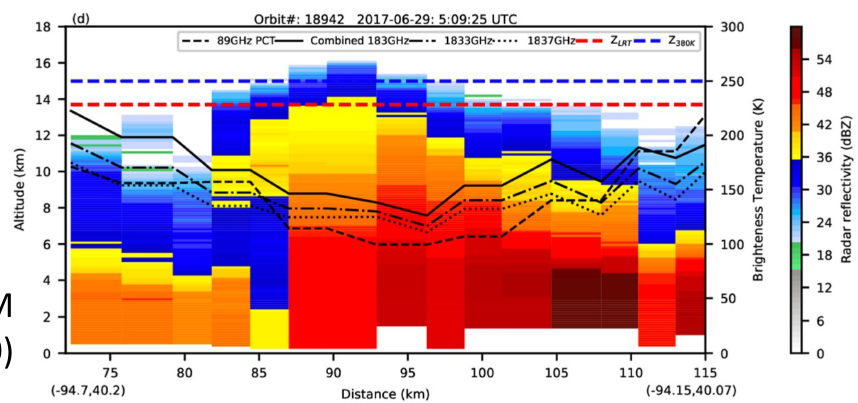


CloudSat
(Takahashi & Luo 2013)

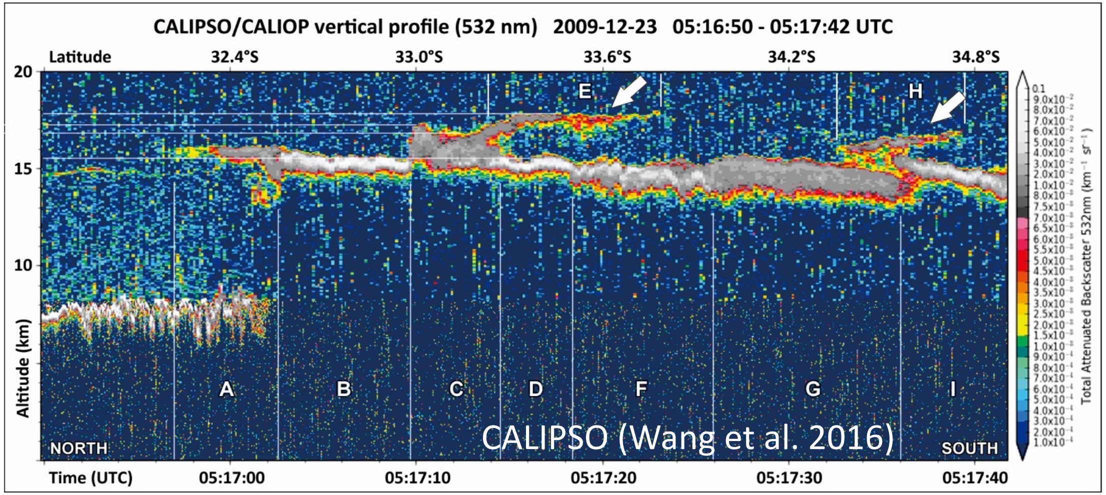
NEXRAD
(Cooney et al. 2018)



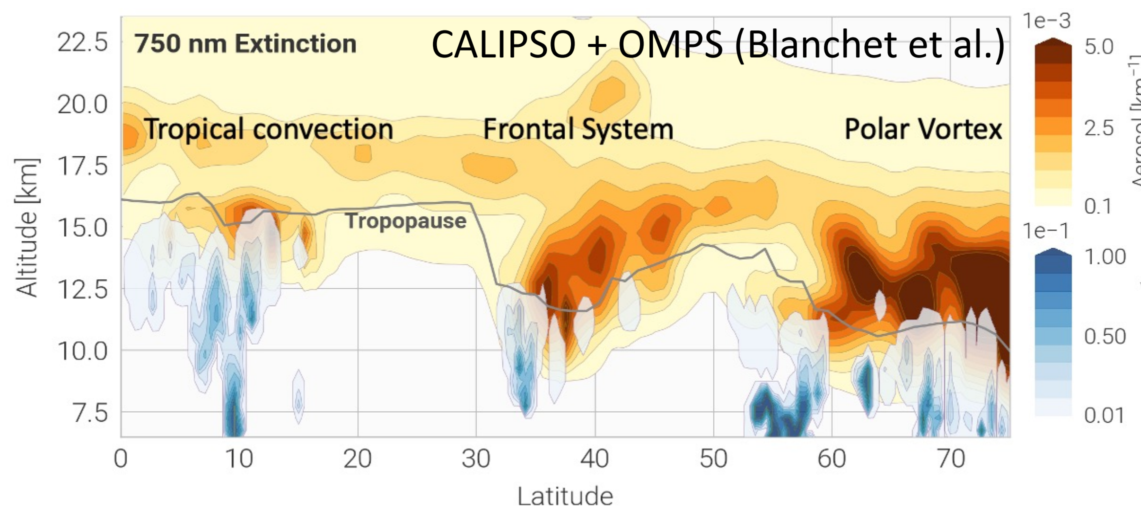
GPM
(Liu et al. 2020)



Deep convective transport

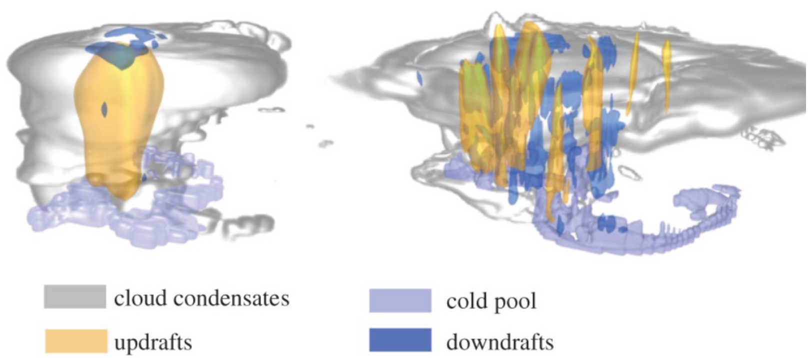


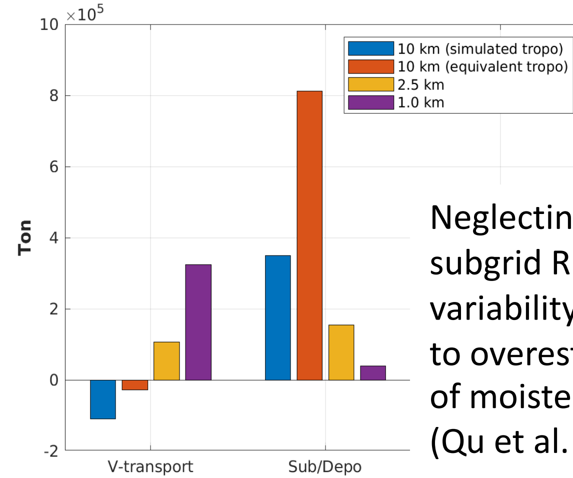
- "Jumping" cirrus: breaking of gravity waves, mixing and transport (?)



Potential impacts and challenges to model them

Finer resolution => stronger updraft (Prein et al. 2021)





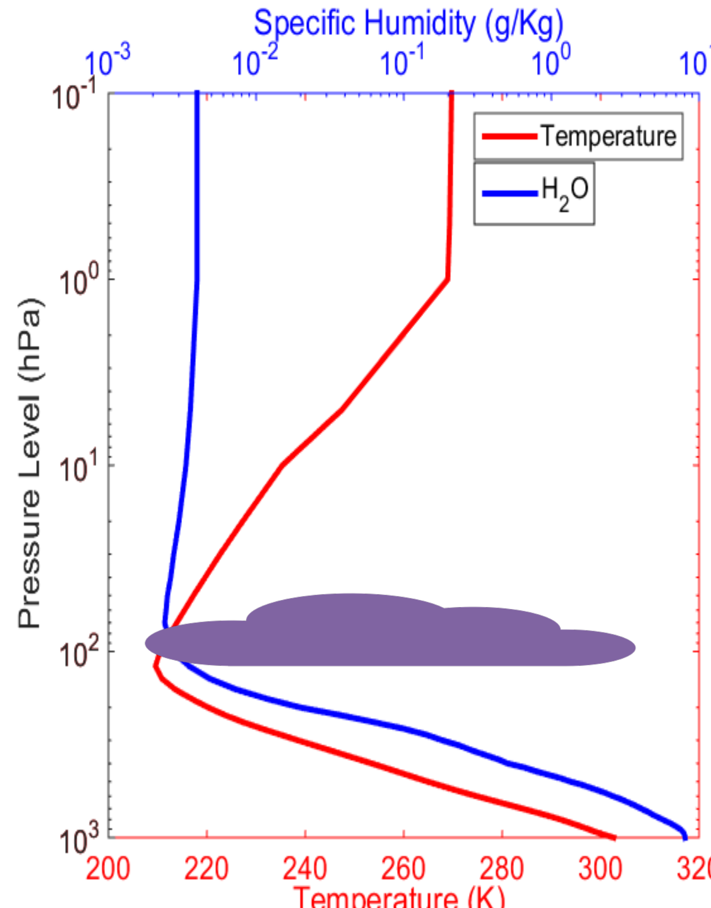
Neglecting subgrid RH variability leads to overestimate of moistening (Qu et al. 2020)

- LES model: higher resolution (stronger/better updraft) ≠ more transport!
- Implications: thermodynamics and microphysics!
  - Precondition: hydration vs dehydration (Jensen et al. 2007)
  - Subgrid variability (Qu et al. 2020)
- Need to observe thermodynamic fields!

Nadir passive retrieval: challenges

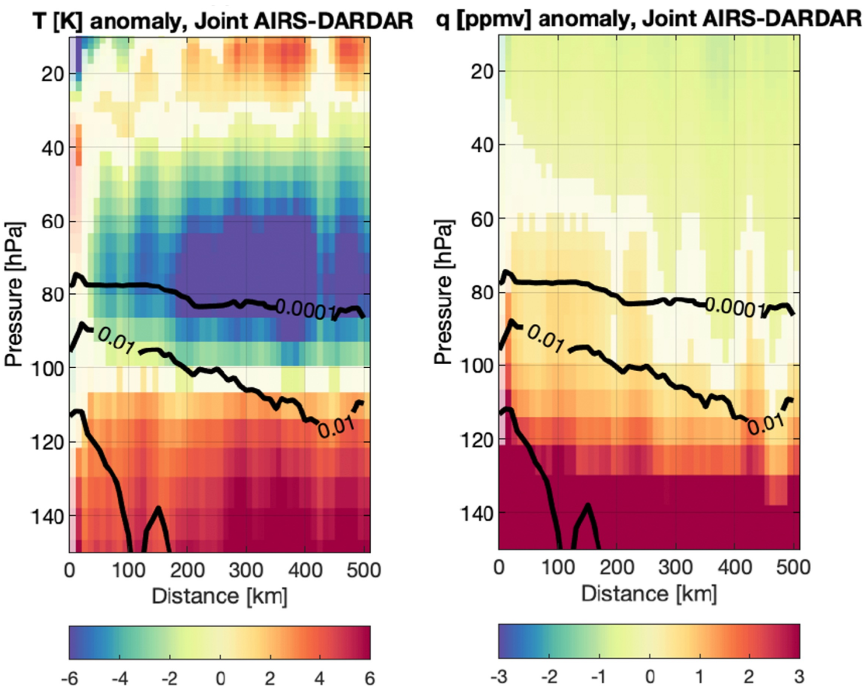
- Two fundamental challenges for retrieving stratospheric water vapor
  - Much lower WV concentration in stratosphere than in troposphere: noise from its tropospheric variability may be aliased as its stratospheric variation signal due to the smoothing effect of averaging kernel.
  - Non-monotonic temperature variation across tropopause – difficulty to relate radiance signal to WV anomaly.
- A dense cloud layer at tropopause reduces both adverse effects!

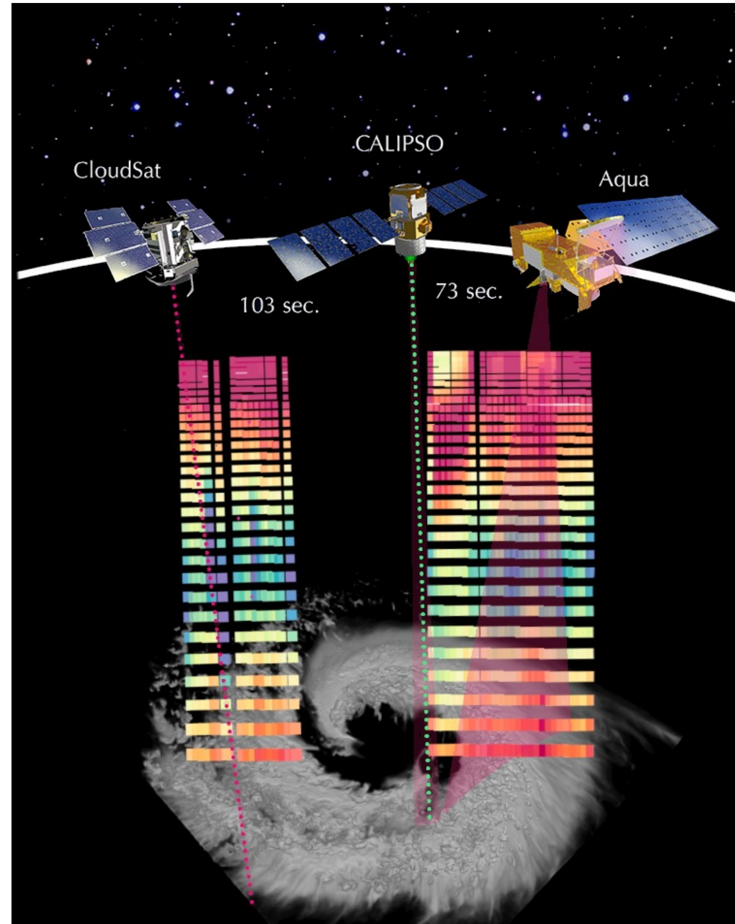
=> Cloud-assisted retrieval!



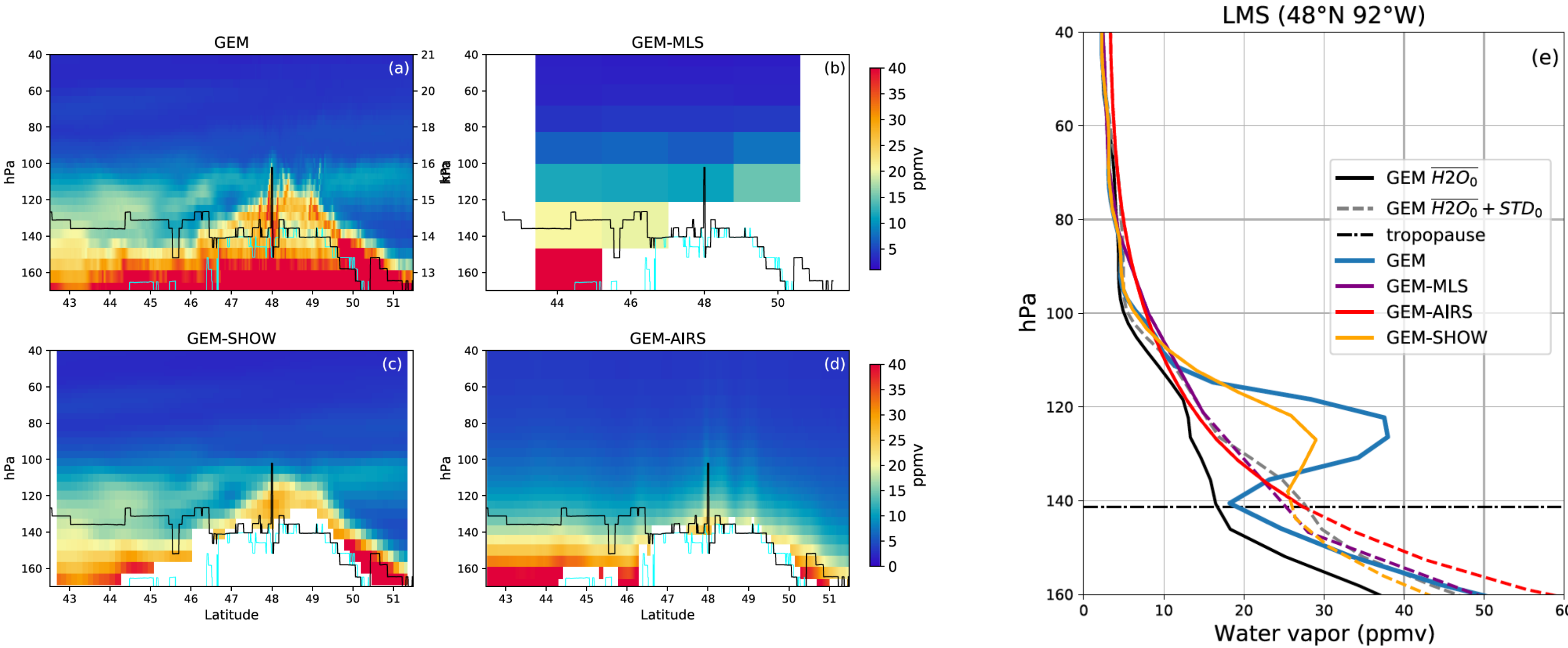
Cloud-assisted retrieval

- IR (AIRS) + active sensors (CloudSat-Calipso) (Feng & Huang 2018, 2020, 2021)
  - Forward model: MODTRAN
  - Inverse method: Optimal estimation



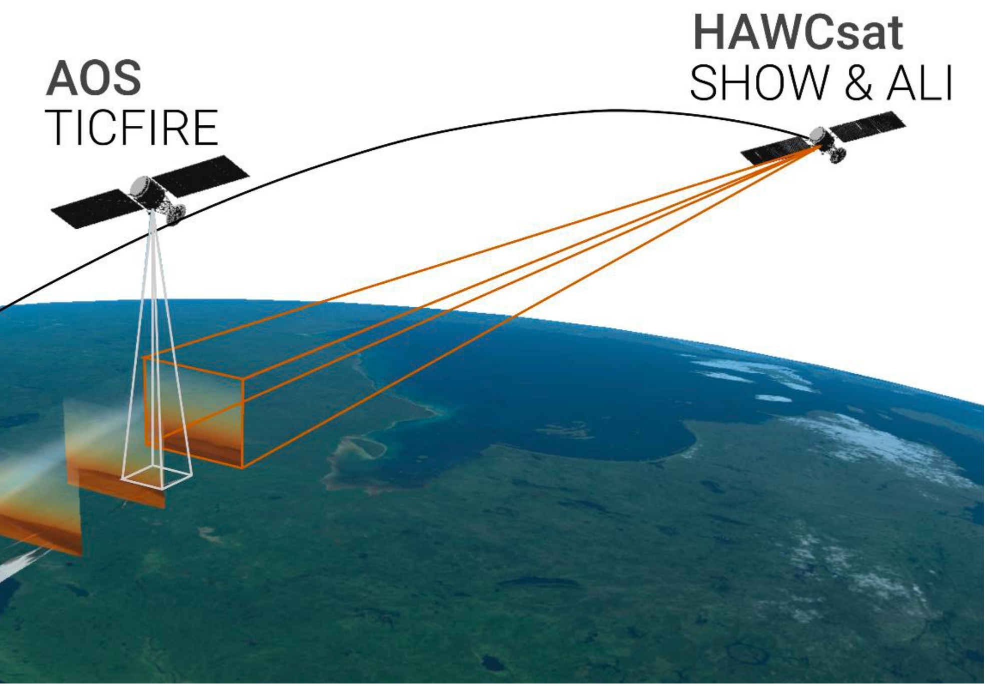


OSSE assessment: Observing convective impacts

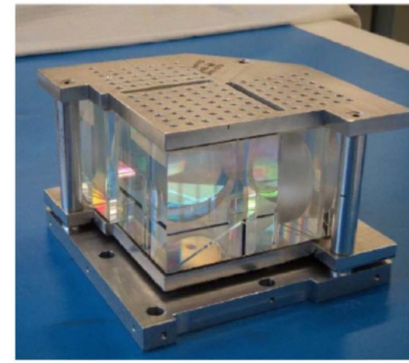


GEM "truth" vs simulated retrievals of MLS, AIRS (cloud-assisted technique) and SHOW (Wang et al. 2023)

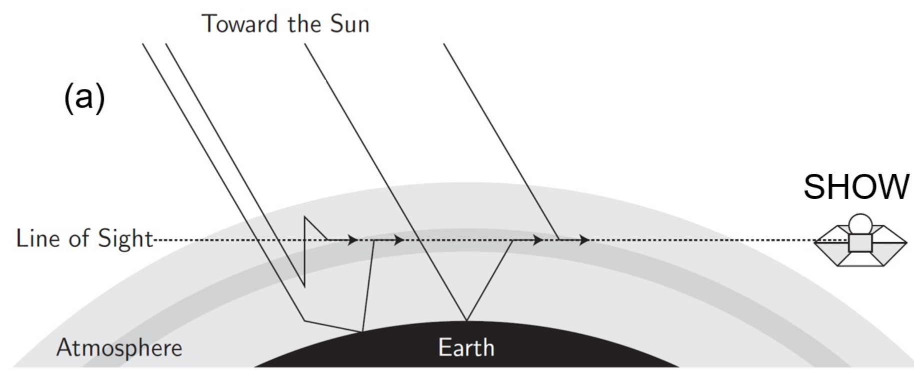
High-altitude Aerosols, Water Vapour and Clouds (HAWC)



Spatial Heterodyne Observations of Water (SHOW)
1362.00 – 1368.32 nm wavelength range, 0.25 km vertical resolution



Credit: A. Bourassa, D. Degenstein



(Langille et al. 2025)

Summary

- Existing
  - Hydrometeor detection, cloud system characterization, ...
- Lacking
  - Thermodynamics: T, q, besides droplet microphysics, ...
- Implications
  - For example, heating rate uncertainty resulting from the T/q variability inside and around clouds?