Dynamical responses of a mixed-phase cloud to ice seeding

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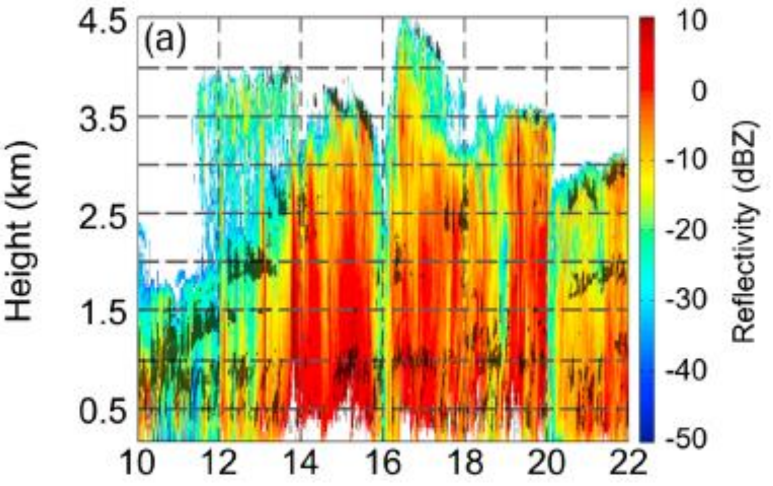
ARM CLIMATE RESEARCH FACILITY

ASR Atmospheric System Research

Motivation

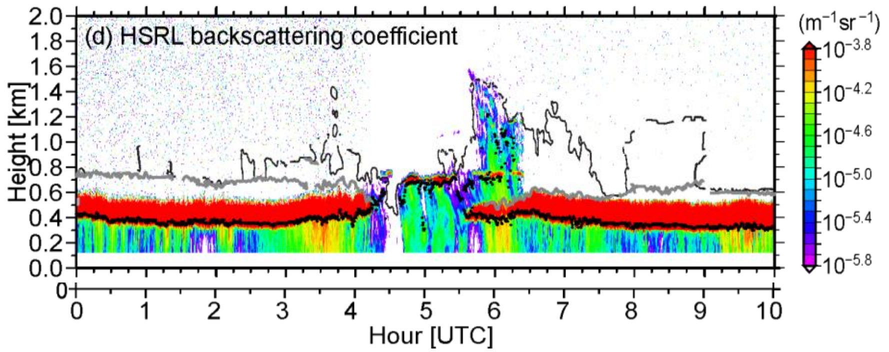
- Multi-layered mixed-phase clouds in Arctic
  - Both in summer and transition season
    - Jayaweera and Ohtake (1973); Curry et al. (1988); Pinto et al. (2001); Intrieri et al. (2002); Shupe et al. (2006); Shupe (2011); Verlinde et al. (2013)
  - Lower level cloud often embedded in ice shower from above
- When ice falls into supercooled liquid layer
  - Compete with liquid for vapor
  - Riming
  - Secondary ice production
  - Leading to loss of liquid
- What happens when ice particles fall into the liquid layer and open a gap in the liquid cloud deck?

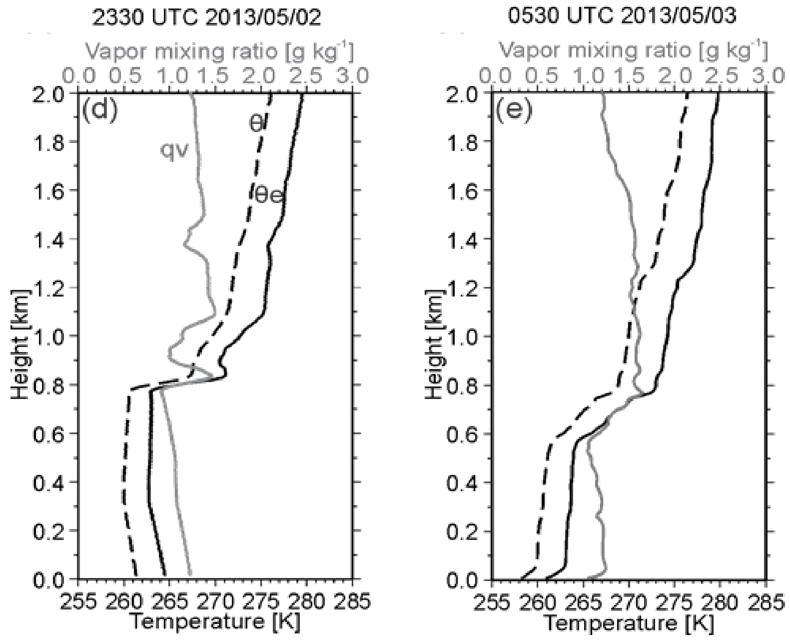


Verlinde et al. (2013)

Motivation

- An case observed on 2013.05.03 at NSA
  - A gap in the liquid cloud deck
  - KAZR reflectivity suggests ice precipitation from above
  - Warming in upper liquid layer and cooling in sub-cloud layer is similar to the outcome from the glaciation of liquid layer and precipitation of ice? (Harrington et al. 1999)
  - Is it possible that this is a gap left from ice precipitation?





Oue et al. (2017) in prep.

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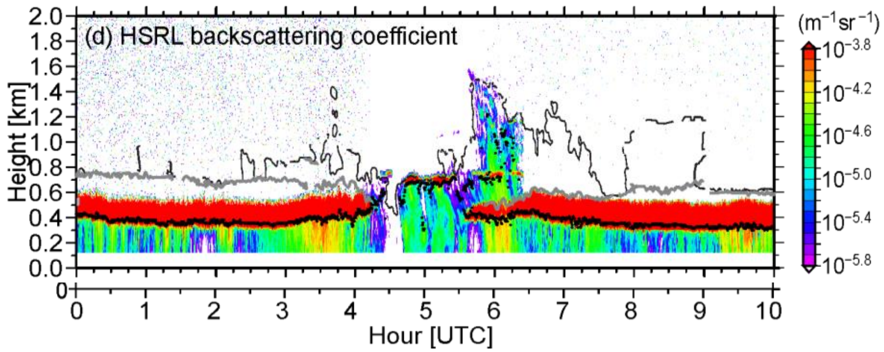

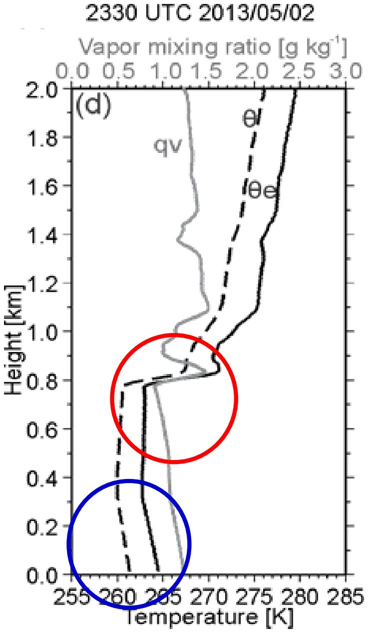

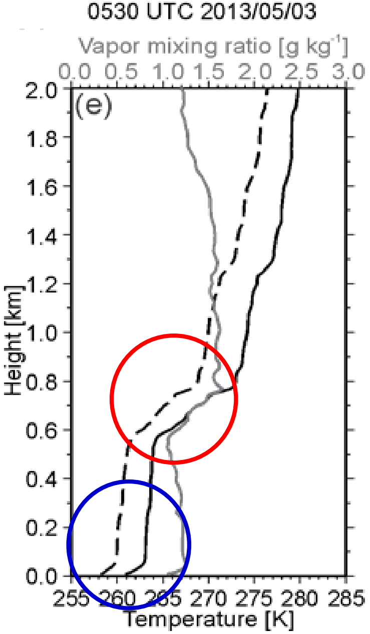

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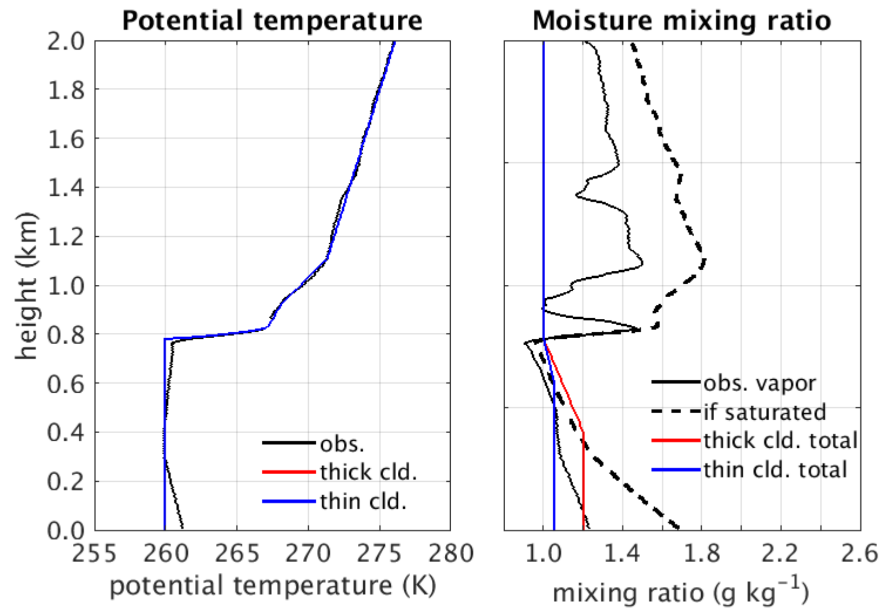
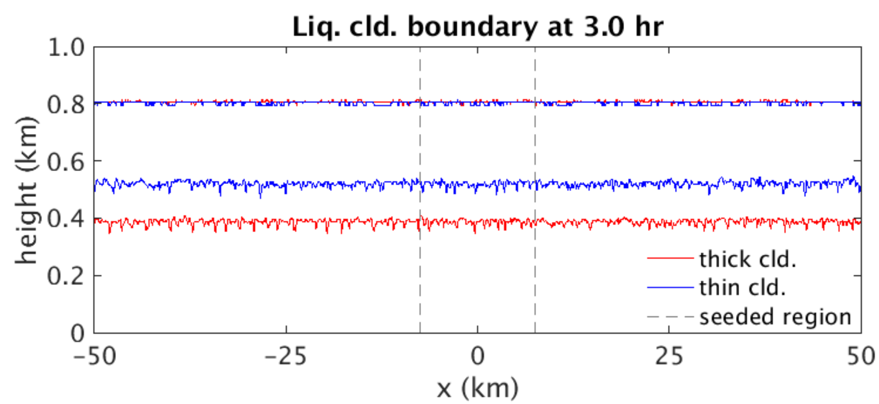
Simulation

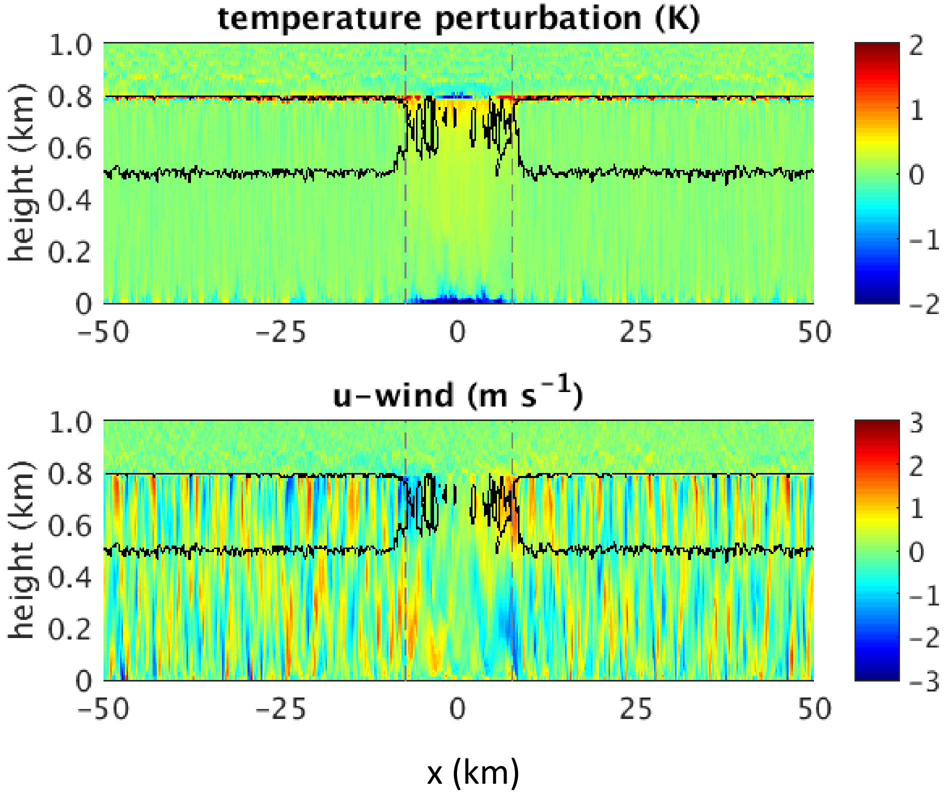
- Model
  - RAMSLES, 2-moment bulk microphysics
  - Ice growth from vapor only
- Base run
  - 2D domain 100 km by 2 km
  - Grid resolution 50 m by 10 m
  - Idealized sounding based on NWS sounding from 2013.05.02 23Z
  - Thick vs. thin clouds
- Seeding method
  - 0.5/1.0 mm/day; 1 ice L^{-1} per 30 sec
  - Over 15 km domain at liquid cloud top
  - Starts from the end of 3-hr spin-up, continues for the rest of the simulation





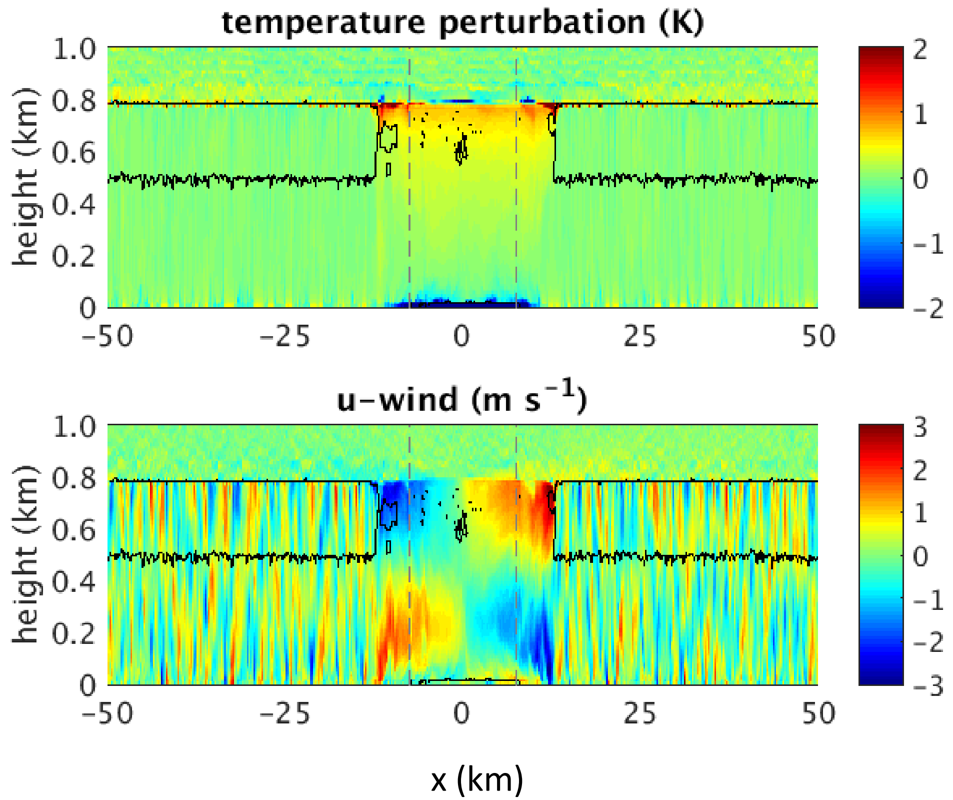
Results

- 0.5 mm/day thin cloud at 6.0 hr
  - Ice particles deplete the liquid in seeded region
  - Continue to take up vapor as they fall through the layer saturated w.r.t. ice
  - Sublimate near surface
  - Releases/Absorbs heat
  - Creates a gap in the liquid cloud deck



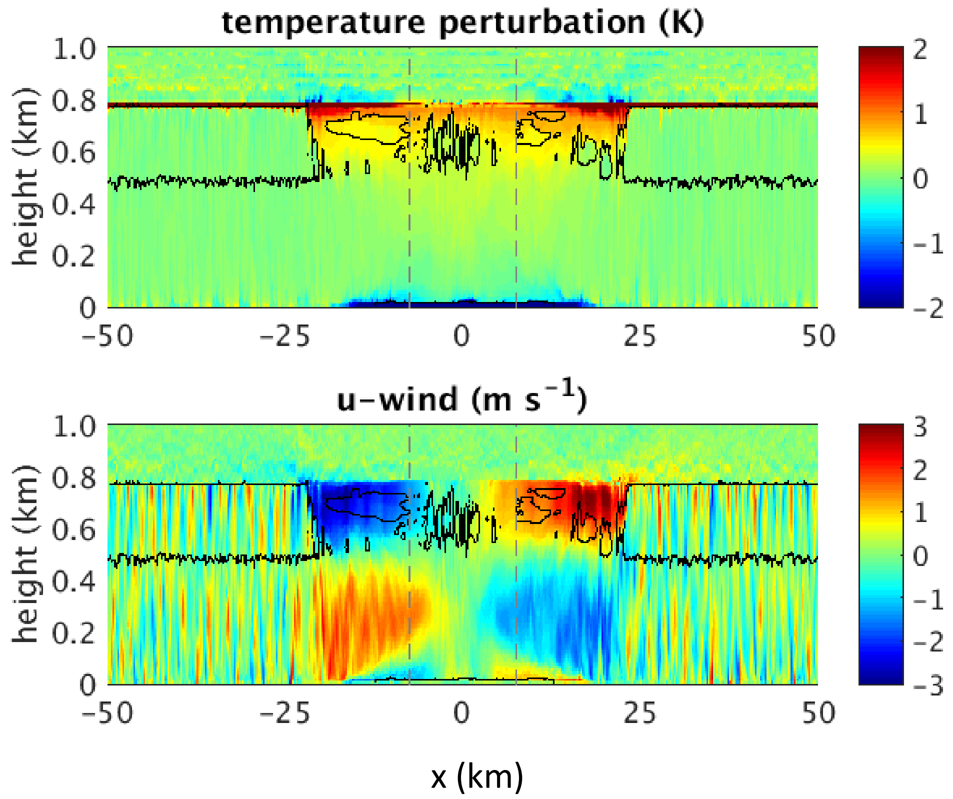
Results

- 0.5 mm/day thin cloud at 7.5 hr
  - The warm air in the seeded region expands
  - Drives mesoscale cloud layer divergence and subcloud convergence
  - Gap grows beyond seeded region



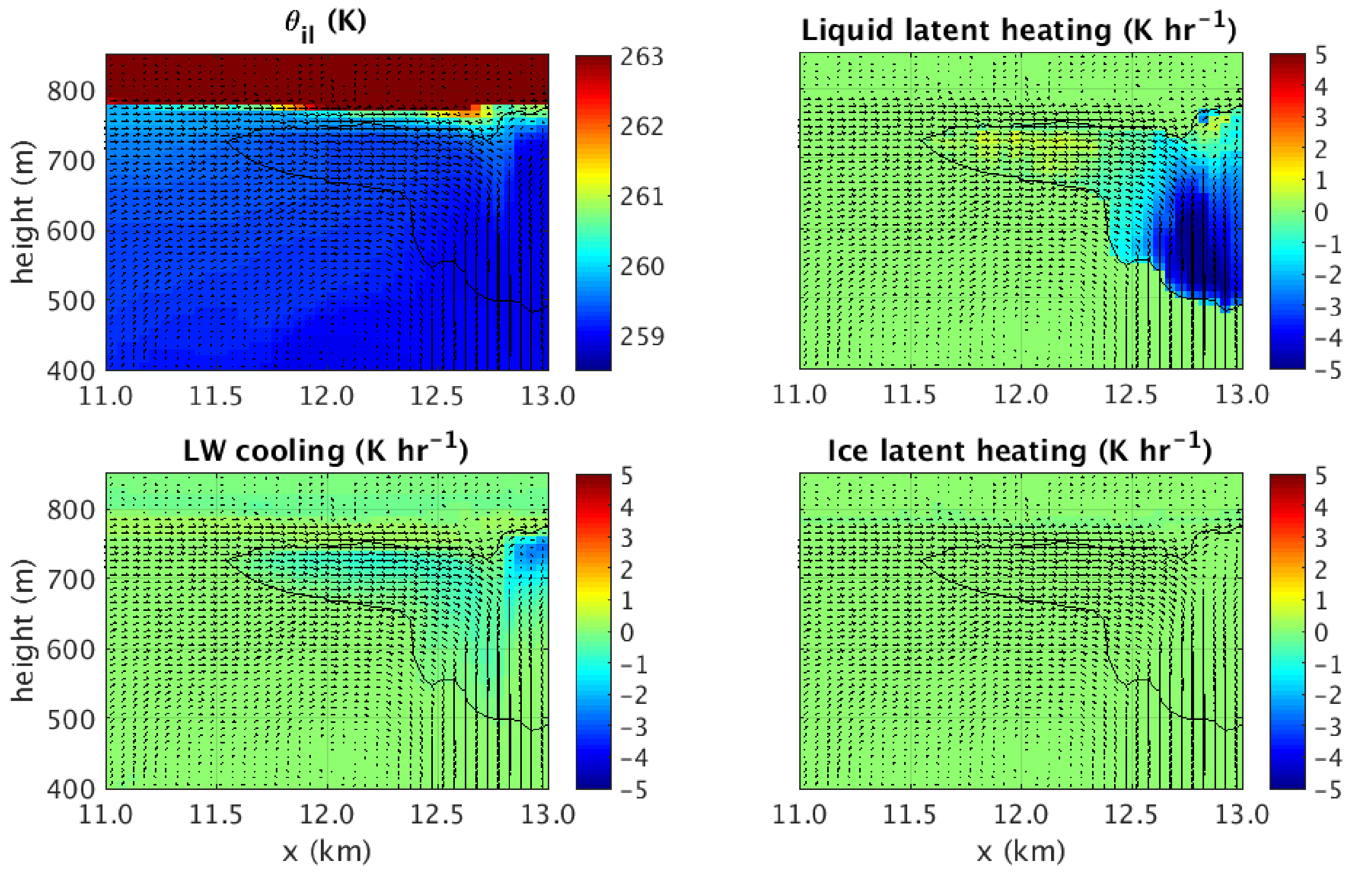
Results

- 0.5 mm/day thin cloud at 9.0 hr
  - Gap grows wider
  - Strong horizontal diverging flow
  - Temperature in the top of the clear region warms up due to mixing with warm air above



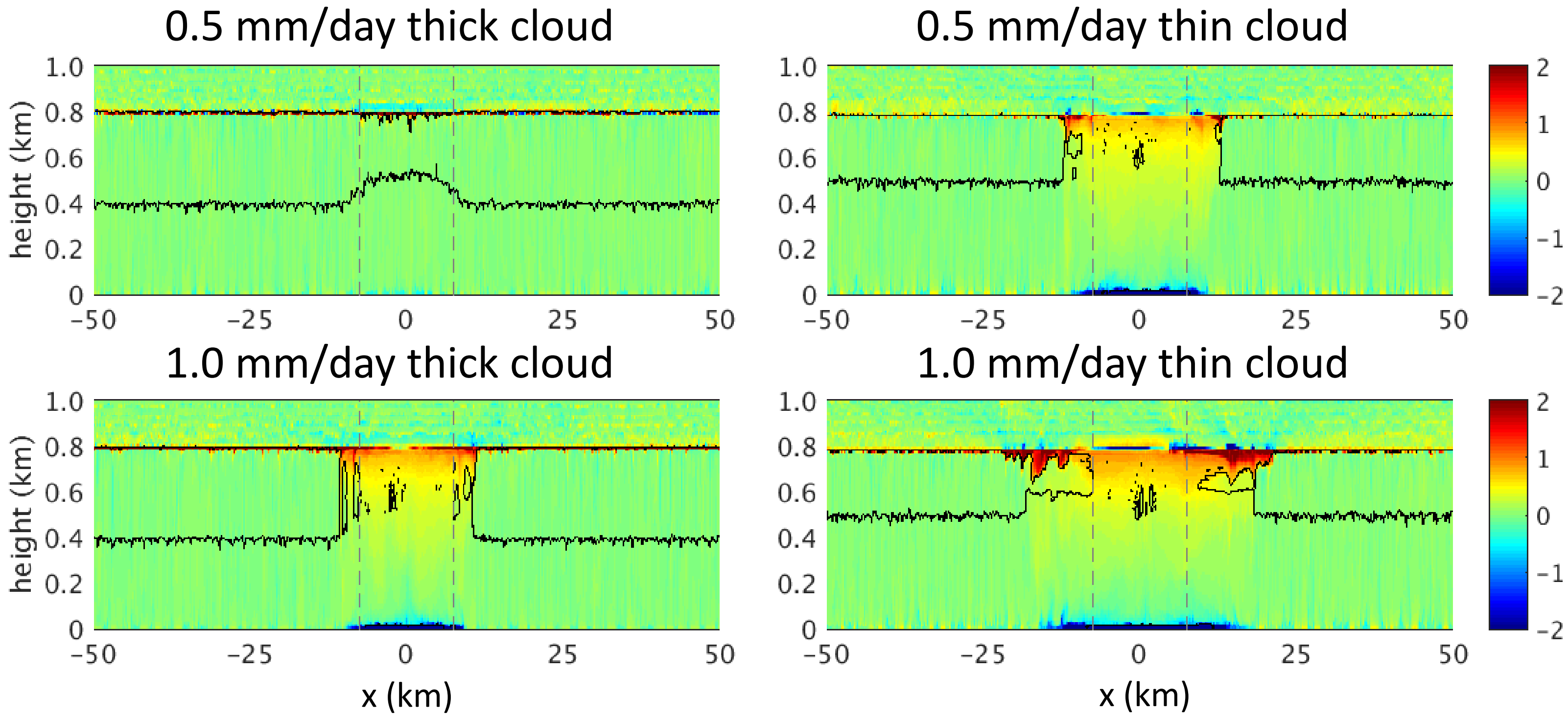
Results

- 0.5 mm/day thin cloud at 7.45 hr, zoomed in
  - Strong downdraft dissipates liquid cloud
  - Latent heat associated with ice drives the circulation but is less important near cloud edge



Results

- Development of the gap at 7.5 hr
  - Similar development among different configurations
  - Different rate depending on amount of seeding and liquid



Color shading: temperature perturbation in K; black contour: liquid cloud boundary; gray dash: seeded region

Summary

- Perturb a mixed-phase cloud with prescribed ice flux
  - Reasonable ice flux can open up a gap in thin cloud deck
  - Some similarities between the simulation and the observations
  - The mesoscale circulation driven by latent heat from ice microphysics
  - Downdraft near liquid cloud edge further dissipates liquid cloud
  - Gap grows to much beyond the seeded region
- Next step
  - Prove in details the hypothesized mechanism behind the dynamical response
  - Include more ice microphysics to create different ice heating profile