The Sensitivity of Springtime Arctic Mixed-Phase Stratocumulus Clouds to Surface Layer and Cloud-Top Inversion Layer Moisture and Ice Nuclei Sources

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In collaboration with
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Talk Outline

Large-Eddy Simulations

Case Study: ISDAC "Golden Day" 8 April 2008

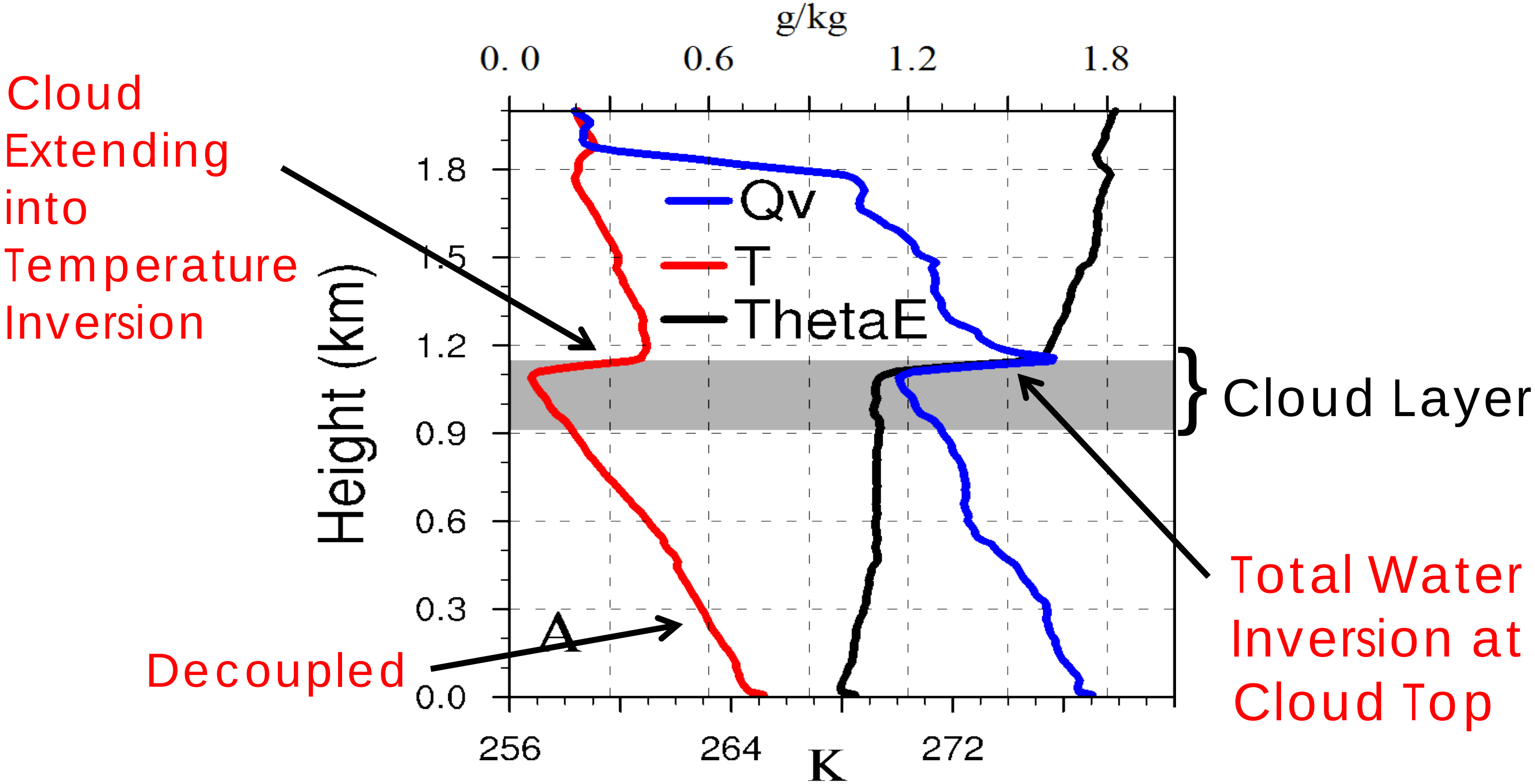
1) Role of surface layer and cloud-top inversion layer sources of moisture in maintaining decoupled Arctic mixed-phase stratocumulus (diagnostic ice nuclei)

2) Including a prognostic equation for ice nuclei (IN) to investigate sources and sinks of IN

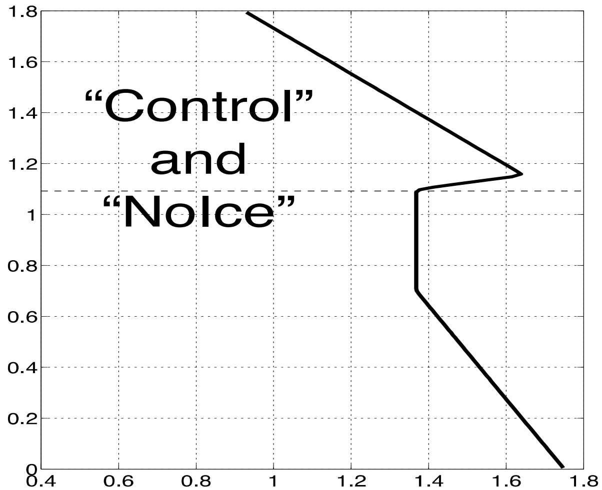
   ---Focus on recycling, surface layer sources, cloud-top entrainment, and turbulent mixing

Large-Eddy Simulation Configuration:

- WRFV3.3.1 in LES mode
- Vertical resolution = 10m, Horizontal resolution = 50m
- Morrison Microphysics -- 2-moment liquid and ice
- Surface fluxes set to zero
- CAM LW Radiation Scheme, SW=0
- Subsidence at and above inversion = -0.39 cm/s
- Initialized with Barrow, Alaska 17Z 8 April 2008 Sounding



ISDAC LES Sensitivity Studies:



Impact of Sedimentation in "NoIce"

Removing Sedimentation:

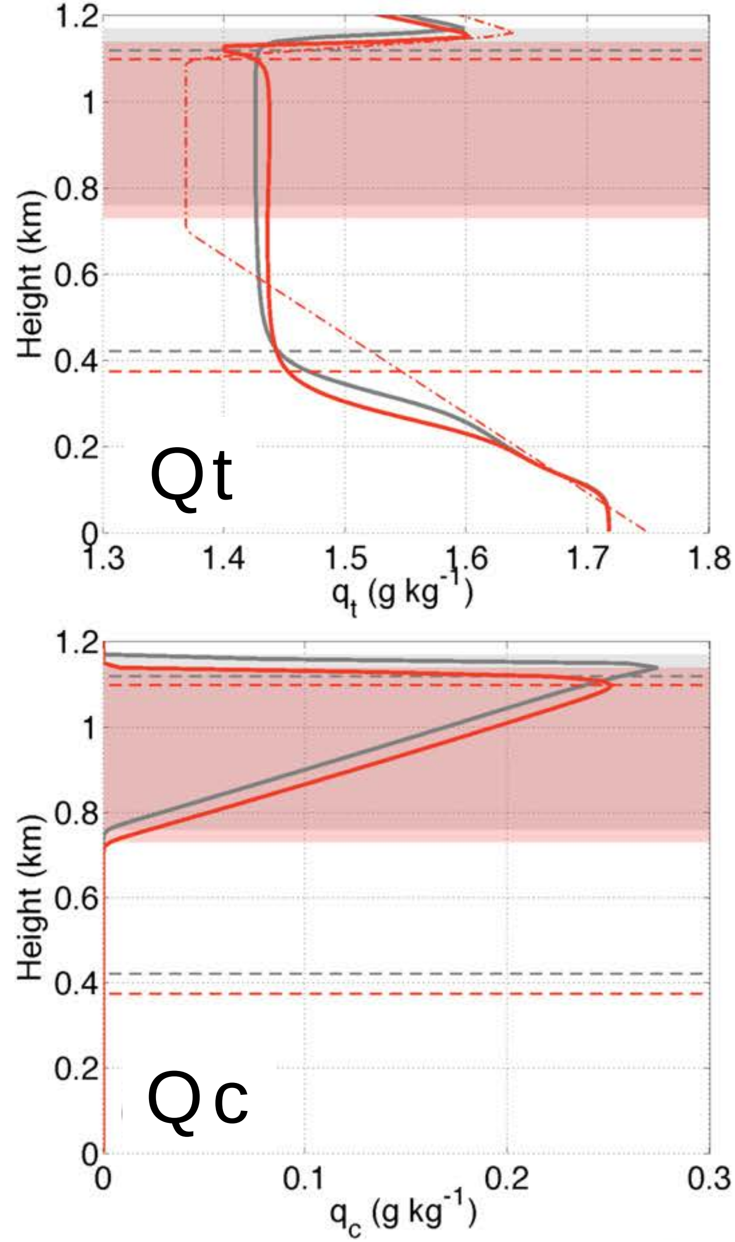
⟶Removes the q_t minima just above the mixed-layer top

⟶ Increases the LWP

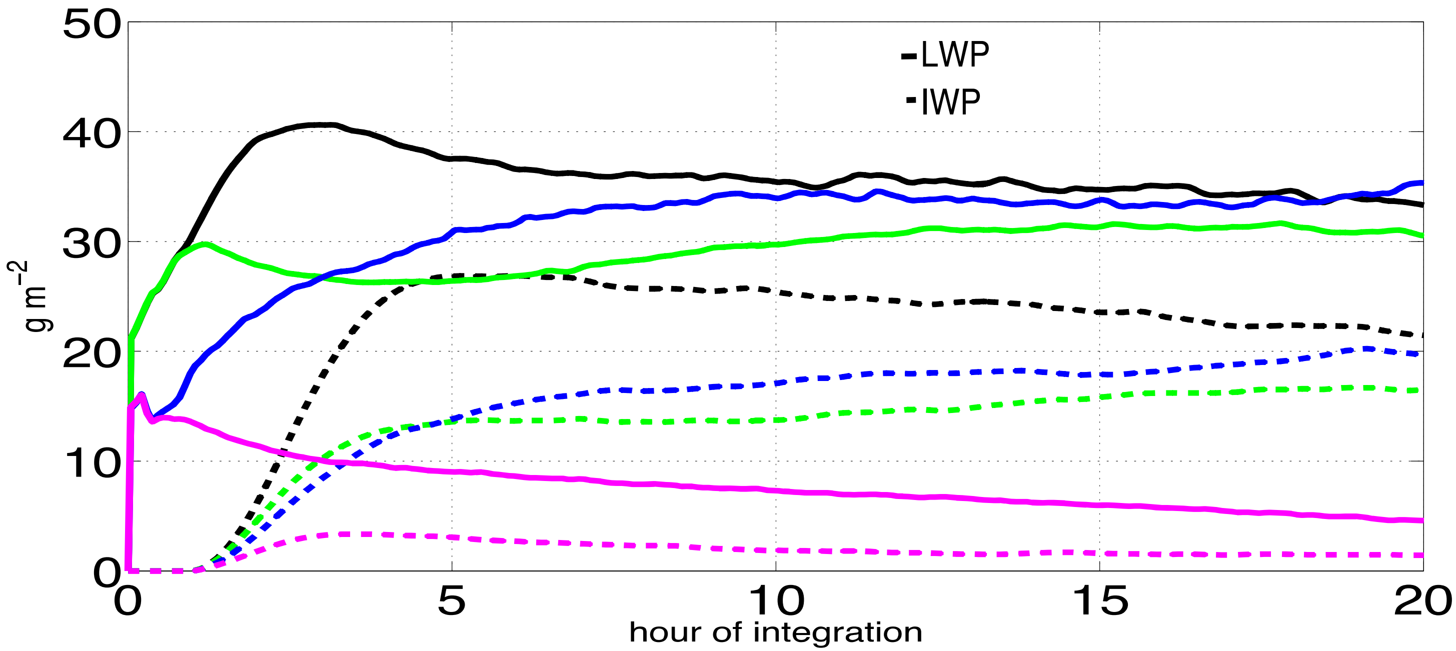
⟶Moves the cloud top higher into the inversion

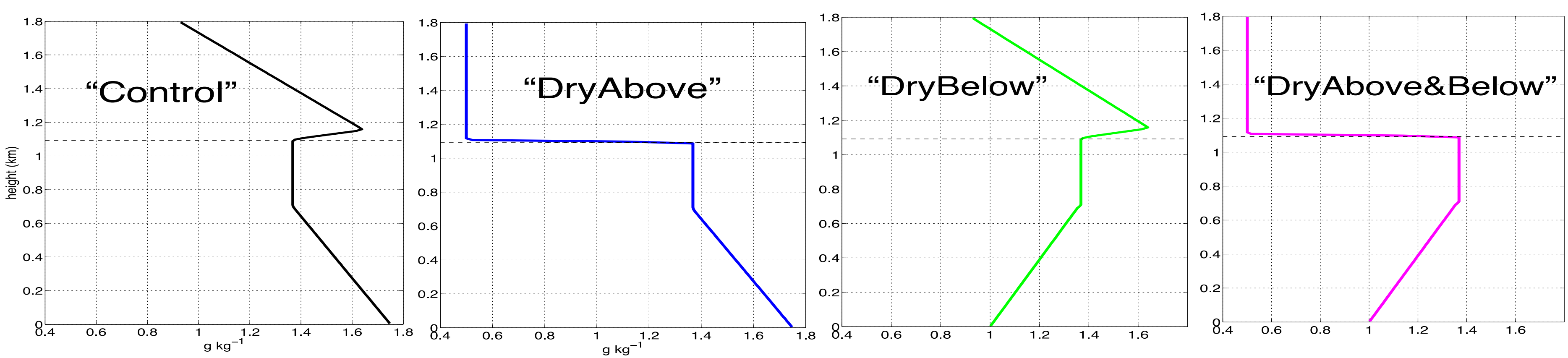
⟶The increase in radiative cooling occurs within the transition layer between cloud top and mixed-layer top

  ⟶Causing TKE and MSE tendencies to decrease in the mixed layer relative to NoIce



Sensitivity to Moisture Sources:





Impact of Removing Humidity Inversion:

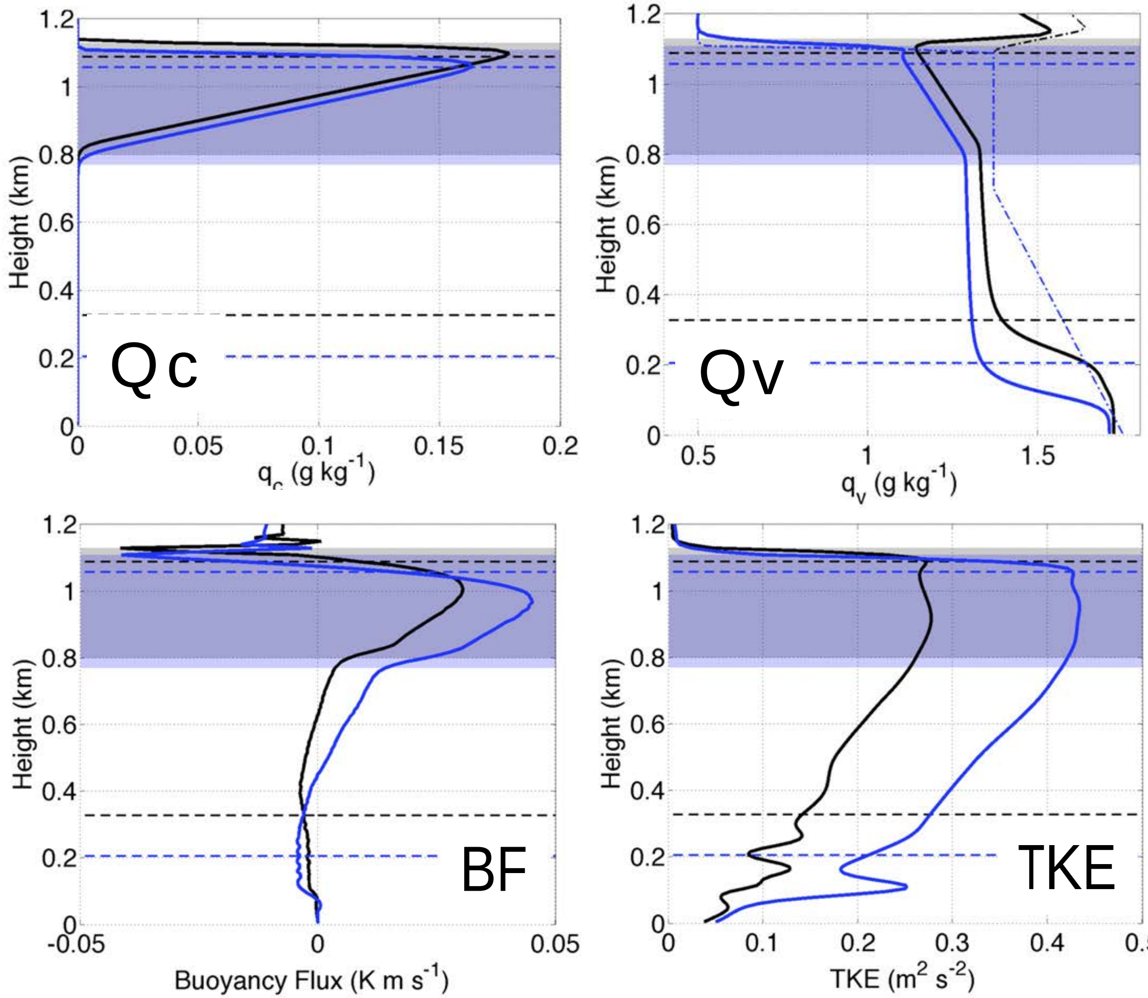
Comparison at Hour 9-10 (Quasi-Equilibrium State)

Cloud layer extends into inversion and above mixed layer top even though air above is dry

LWP decreases by 5%

Buoyancy fluxes larger in lower cloud layer and subcloud layer

Cloud layer and mixed layer descend faster



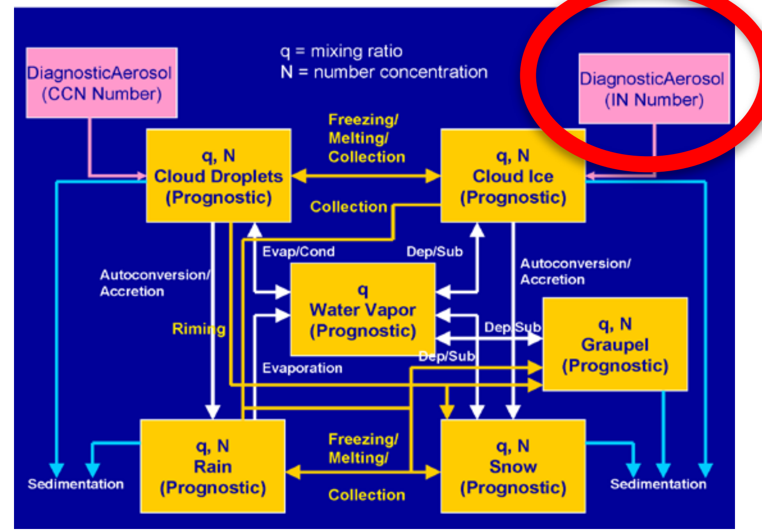
Qv in cloud layer decreases faster-- Faster cooling rate

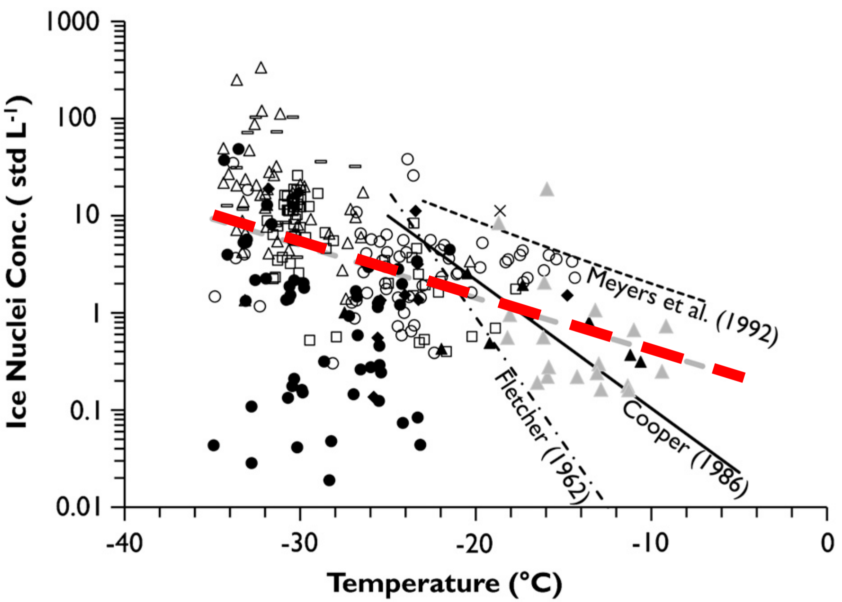
Qv below mixed layer depleted more rapidly

TKE ~60% larger (even though LWP is less)

Including IN Sources and Sinks:

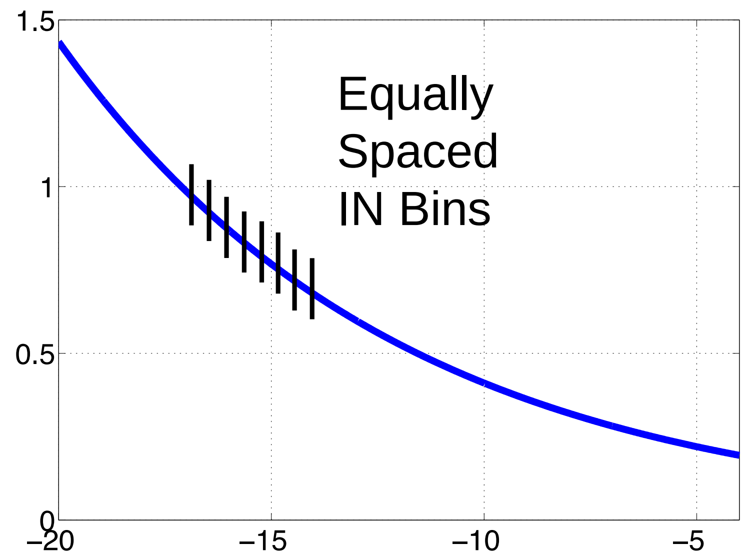
$$\frac{\partial IN}{\partial t} = \frac{\partial IN_{advection}}{\partial t} + \frac{\partial IN_{subsidence}}{\partial t} + \frac{\partial IN_{diffusion}}{\partial t} + \frac{\partial IN_{immersion}}{\partial t} + \frac{\partial IN_{recycling}}{\partial t}$$



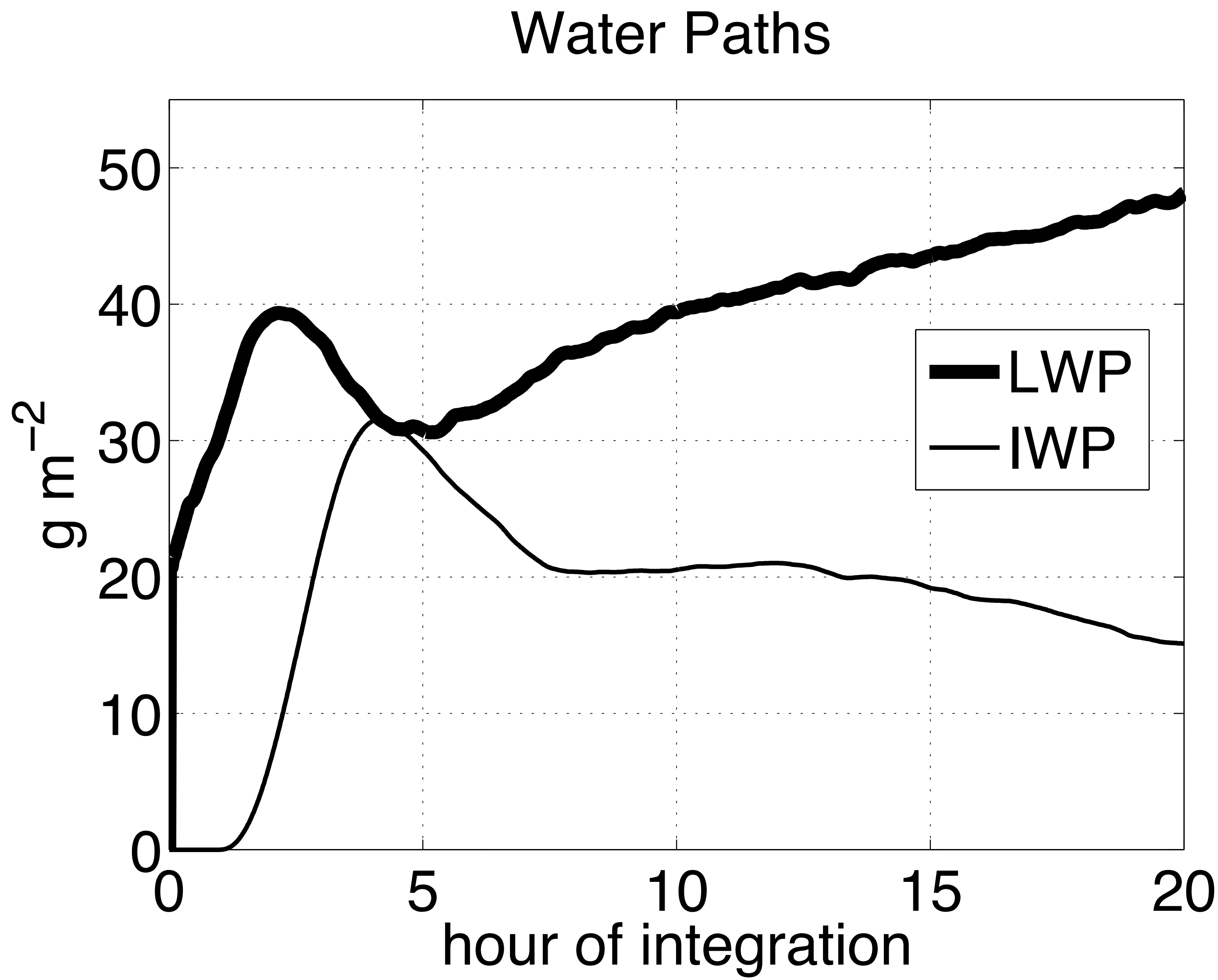


(DeMott et al 2010)

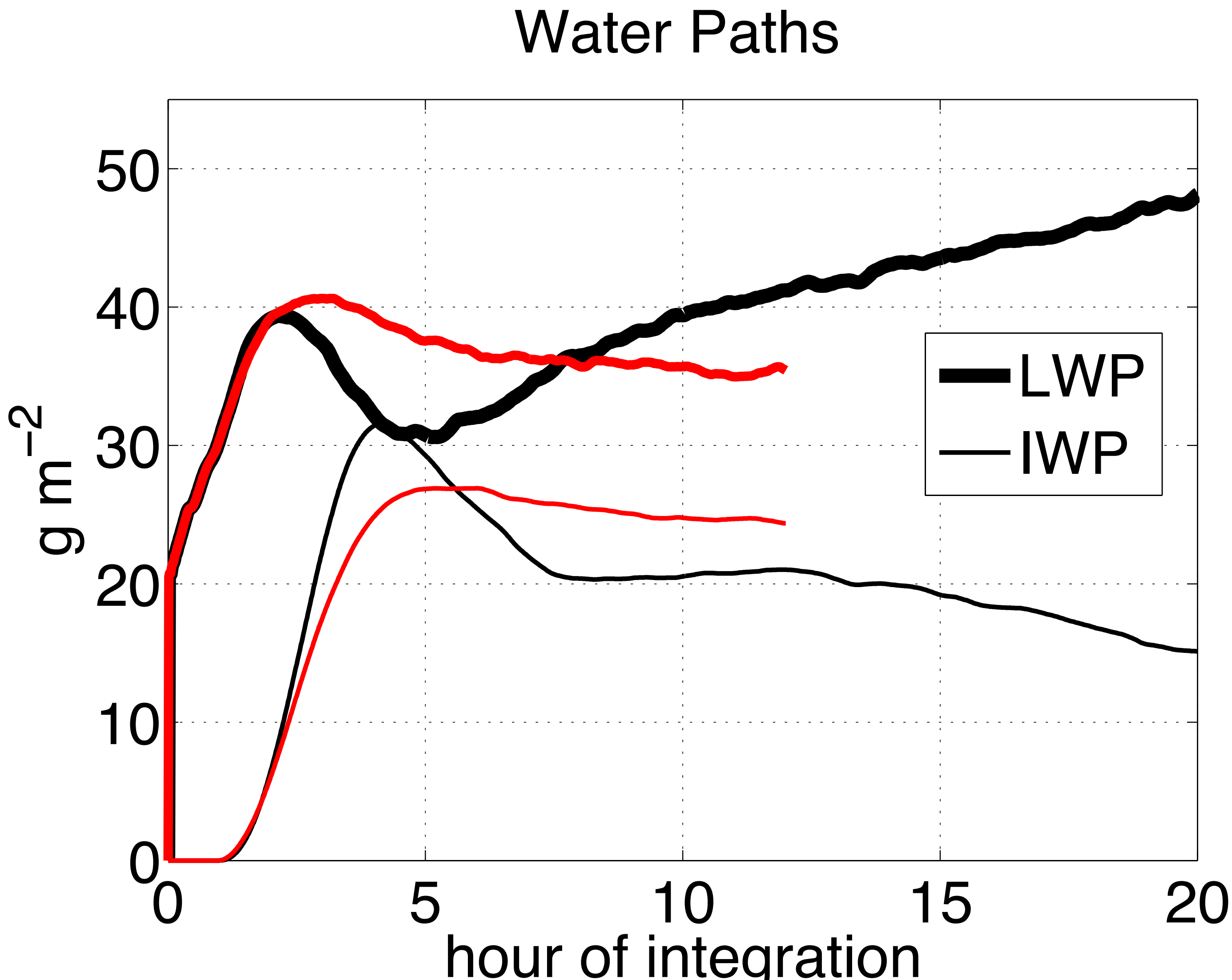
IN Concentration Active at Water Saturation



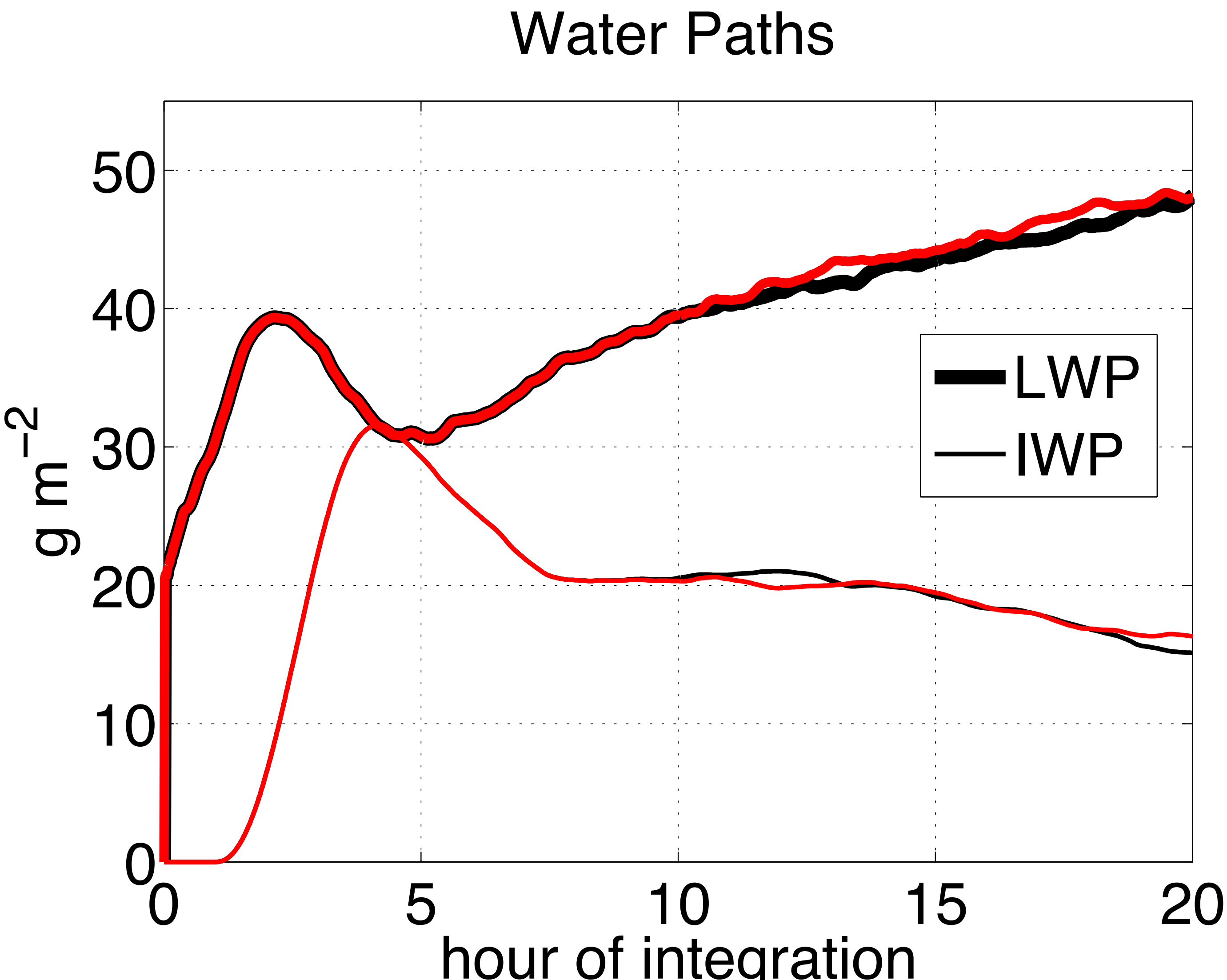
Prognostic IN: IN Initialized with 4x DeMott Curve



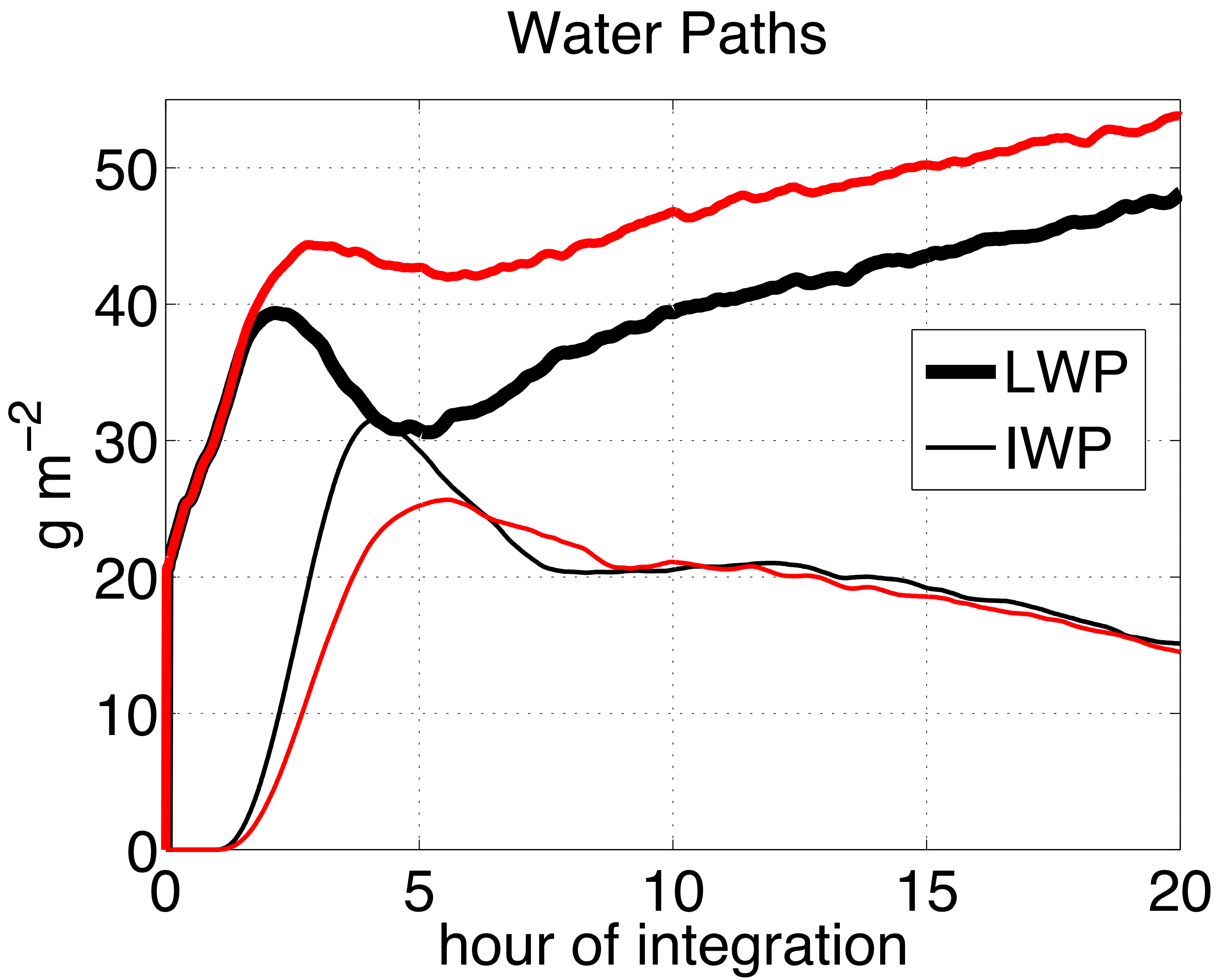
Prognostic IN vs. Diagnostic IN:



Prognostic IN: Excluding Cloud-Top Entrainment
(Initializing IN Below Inversion Base Only)

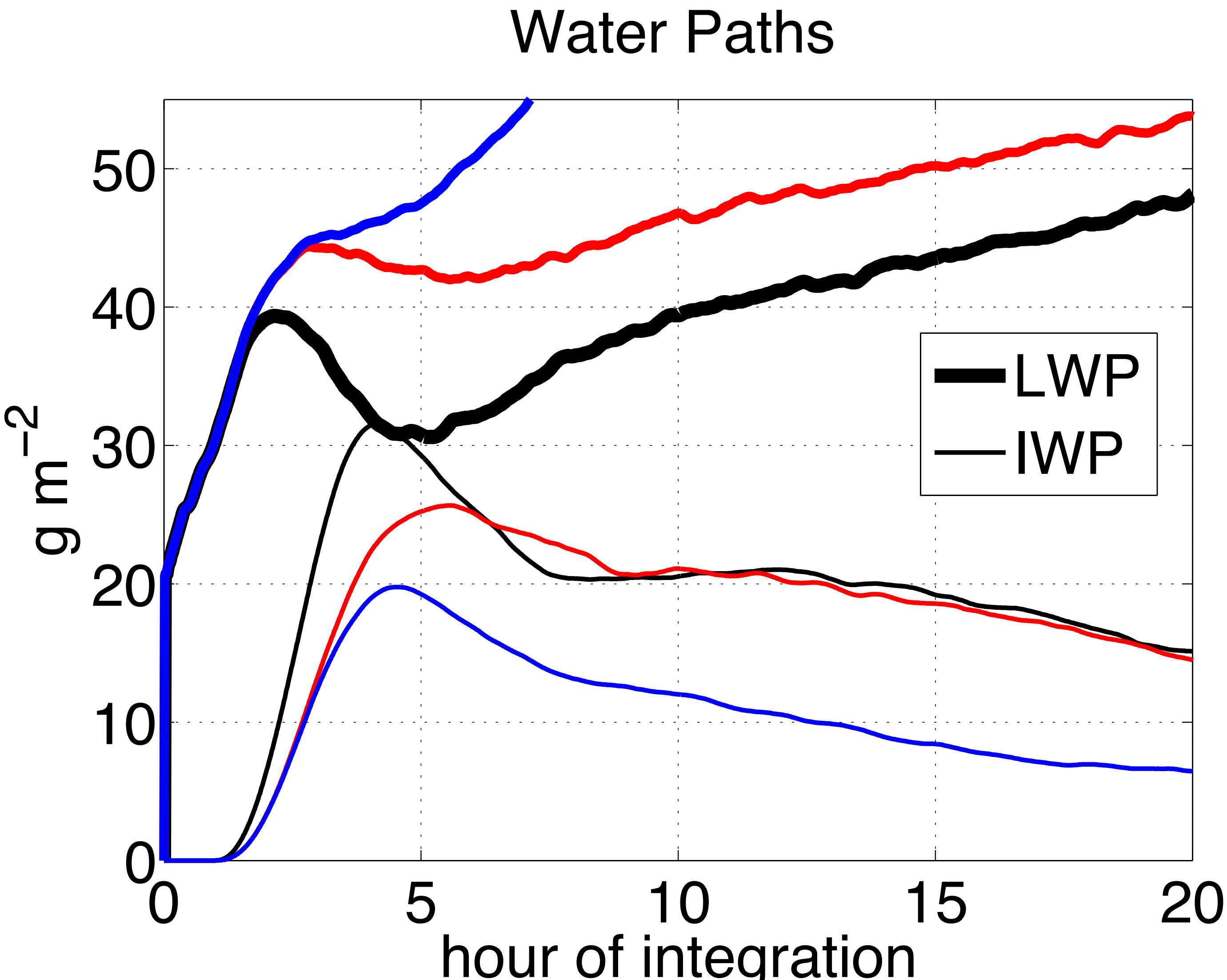


Prognostic IN: Role of Entrainment at Mixed-Layer Base
(IN initialized below 700m only)

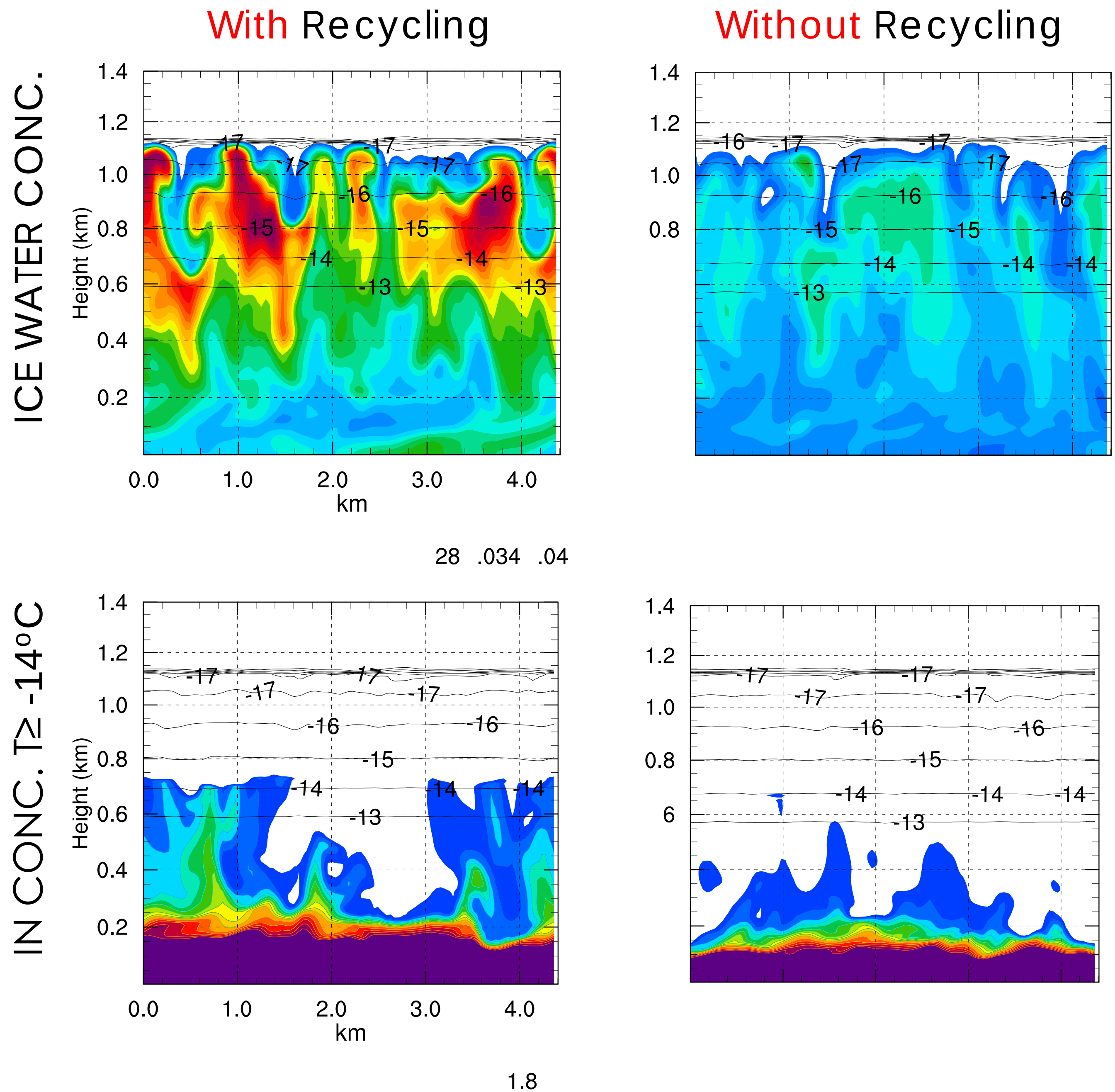


Prognostic IN: Role of Entrainment at Mixed-Layer Base

With Recycling and Without Recycling



IN Initialized Below 700m



Summary:

With or without ice, with or without a humidity inversion, the cloud layer extends into the temperature inversion (above the mixed layer top) producing a precipitation flux into the mixed layer.

The cloud layer is remarkably insensitive to changes in moisture source:

- When the overlying air is initially dried, radiative cooling and turbulent entrainment increase moisture import from the surface layer
- When the surface layer is initially dried, reduction in mixed-layer water vapor and a moistening of the surface layer evolve to reduce the loss of water through precipitation and entrainment

As a result, the total condensed water is found to be similar for all three cases. Only when moisture is cut off both above and below the mixed layer does the cloud layer consistently decay without reaching a quasi-equilibrium state.

Allowing for prognostic IN demonstrates that:

- Entrainment of IN at cloud-top plays a limited role
- IN is entrained into the mixed layer by a continuous deepening of the cloud-driven mixed layer
- Recycling increases mixed-layer IN by ~50%

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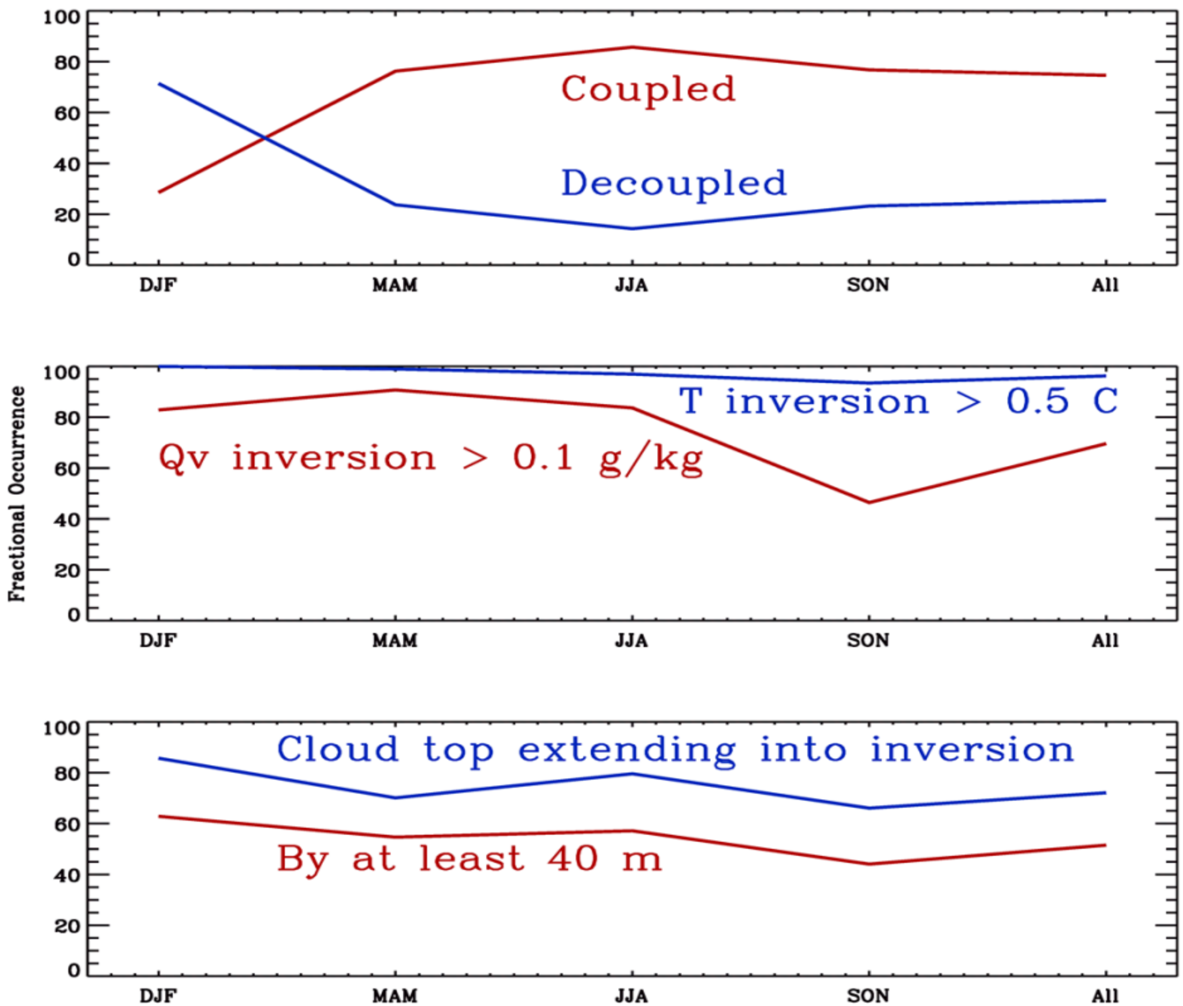
Statistics of Mixed-Phase Stratocumulus at Barrow



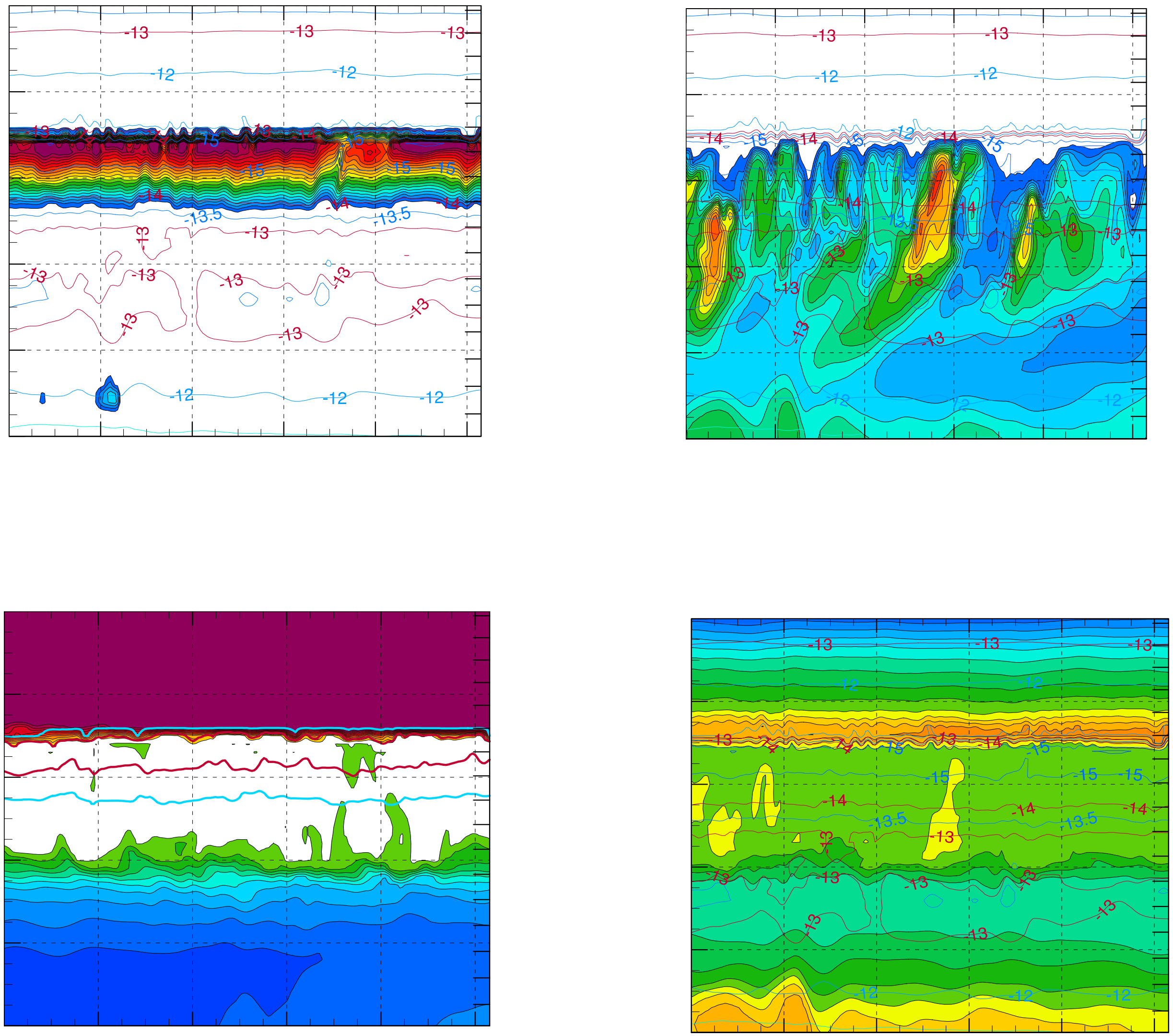
- Coupled cloud layers are most common most of the year
- Decoupling occurs 25% of the time
- Humidity inversions occur >70% of the time except in autumn
- More than ½ the time the cloud top extends into the temperature inversion

(Shupe et al. 2012)

- Cloud top extending into the inversion is coincident with a humidity inversion for 94% of the cases

(Sedlar et al. 2012)

Boundary Layer Structure Along Mean Mixed-Layer Winds:



Solomon et al. (2011)