# 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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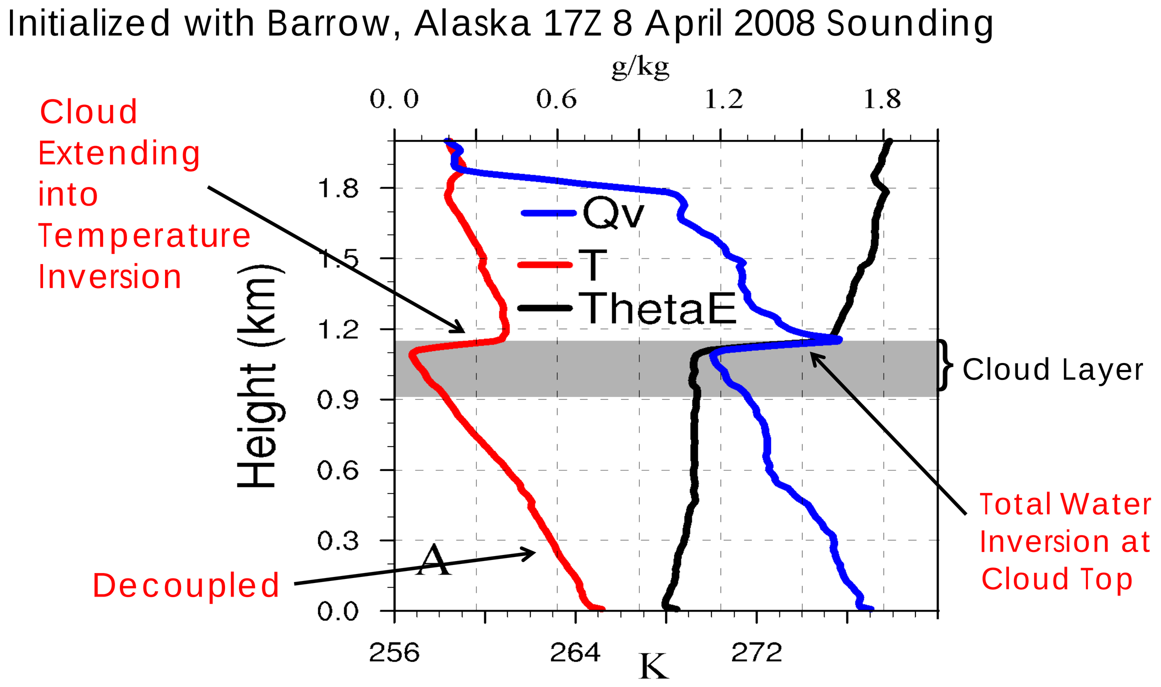
## Motivation

Observations indicate that the processes that maintain subtropical and Arctic stratocumulus (Sc) differ, due to the different environments in which they occur. For example, specific humidity inversions (specific humidity increasing with height) are frequently observed to occur coincident with temperature inversions in the Arctic (e.g., Curry et al. 1996, Tjernström et al. 2004, Sedlar and Tjernström 2009). In a recent study, Sedlar et al. (2011) surveyed data from SHEBA, ASCOS and at Barrow, Alaska, to find that specific humidity inversions occurred 75-80% of the time when low-level clouds were present. In addition, this study found a significant relationship between the existence of specific humidity inversions and Arctic Mixed-Phase Stratocumulus (AMPS) that extended into the temperature inversion, highlighting the difference between AMPS and subtropical stratocumulus where the entrainment of dry air aloft prevents cloud liquid water from forming in the temperature inversion. Other important differences between warm Sc and AMPS are more effective cloud top radiative cooling due to cold, dry overlying Arctic free troposphere, and vapor diffusion onto ice (Bergeron process) which acts as a potentially large sink of water vapor for AMPS even when there is limited liquid water. In warm Sc drizzle grows by collision-coalescence of droplets, so as liquid water in warm Sc decreases, drizzle will shut off.

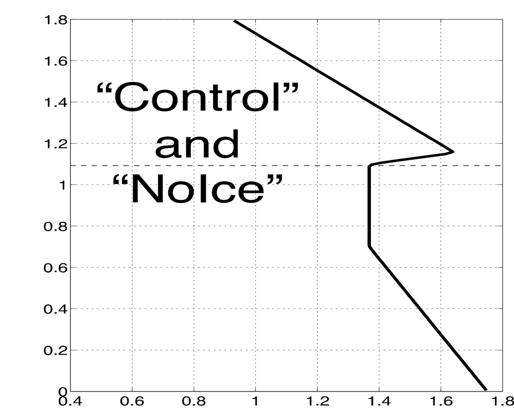
In this study we focus on quantifying the relative impact of cloud-top and sub-cloud layer sources of moisture and ice nuclei on the microphysical-radiative-dynamical feedbacks in an AMPS cloud system in LESs of the Department of Energy Atmospheric System Research Indirect and Semi-Direct Aerosol Campaign (ISDAC) "Golden Day" 8 April 2008.

## Setup of LES Simulations:

- 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

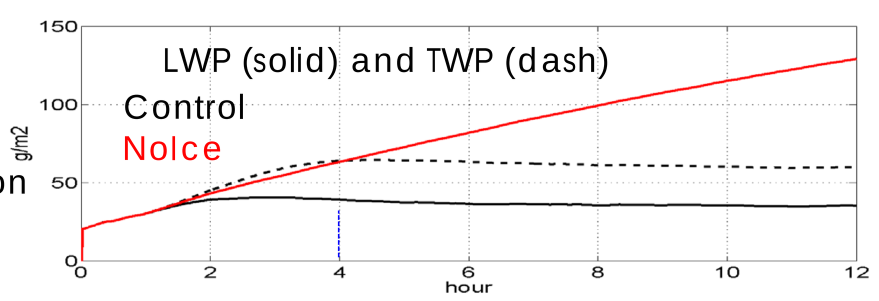



## Initial Total Water Profiles for Sensitivity Studies

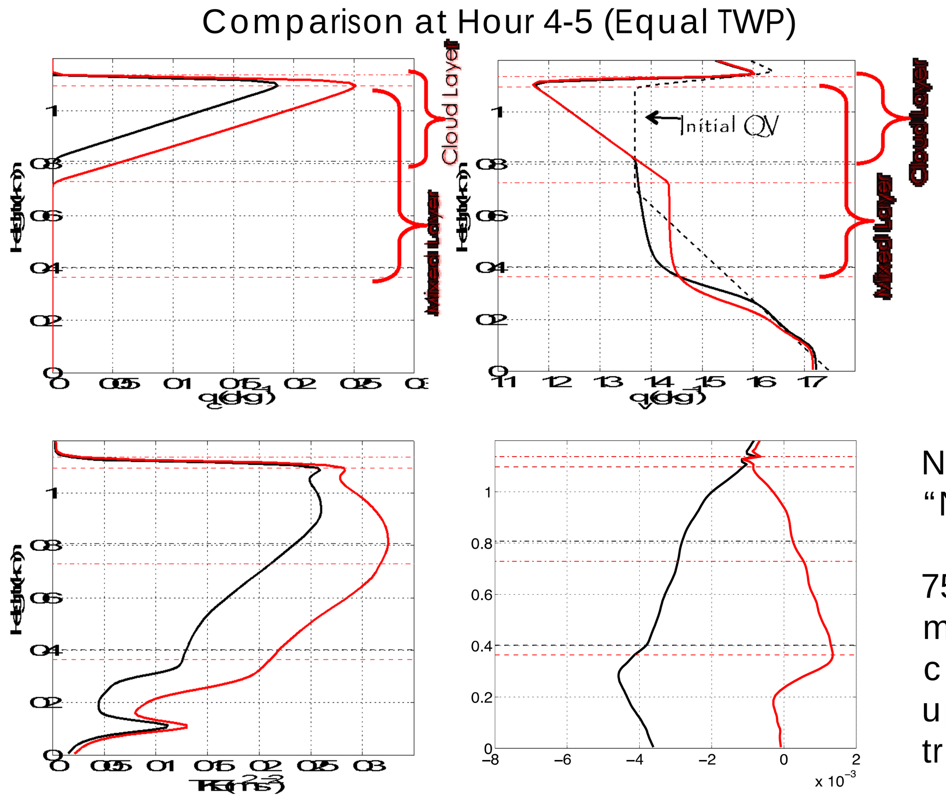



## Impact of Ice: "Control" vs. "NoIce"

Both runs: Cloud extends into the inversion and above the mixed layer top. Max LWC just below inversion base.




Comparison at Hour 4-5 (Equal TWP)




Ice reduces LWP by 50%

Cloud base descends more slowly

Same QV in cloud layer— Same cooling rate

Ice redistributes QV, increasing QV below mixed layer

Ice decreases TKE by 50%

No $q_t$ sinks in "NoIce" mixed layer

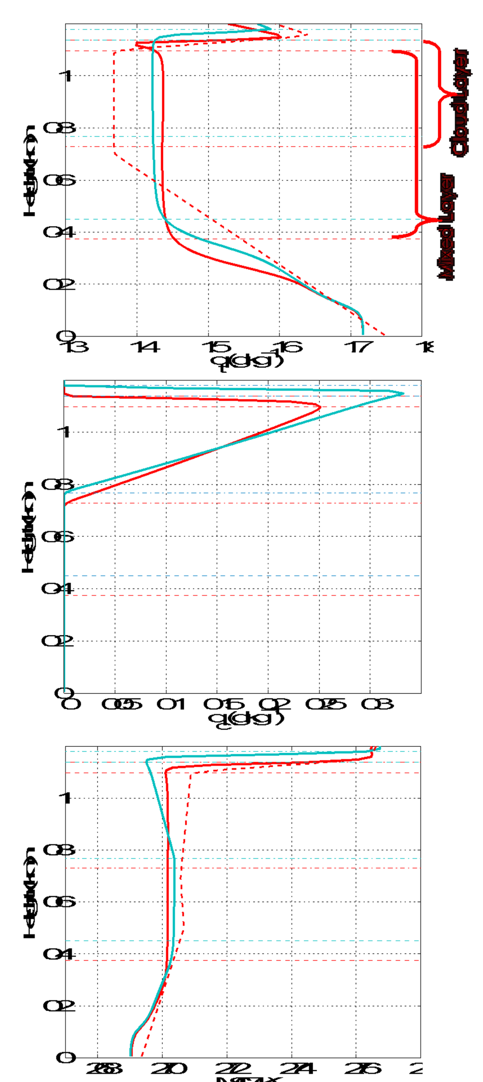
75% of precip flux at mixed layer top compensated by upward turbulent transport

## Impact of Sedimentation and Latent Heating in "NoIce"

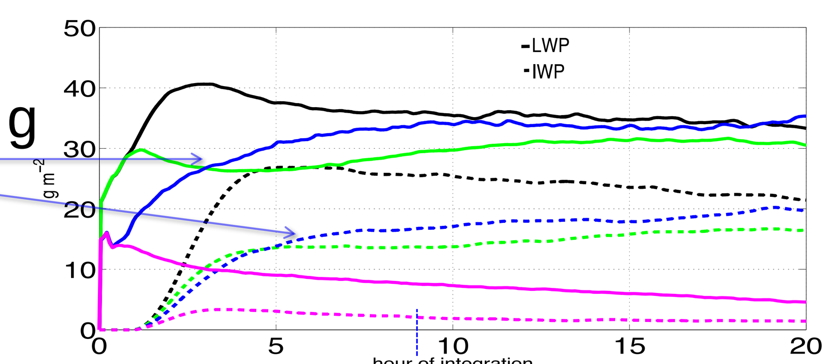
Removing sedimentation removes the $q_t$ minima just above the mixed-layer top, increases the LWP and moving the cloud top higher into the inversion.

The increase in LWP increases the longwave radiative cooling rates. However, the increase in radiative cooling occurs within the transition layer between cloud top and mixed-layer top, with radiative cooling rates actually decreasing at the top of the mixed layer relative to NoIce. This causes TKE and MSE tendencies to decrease in the mixed layer relative to NoIce.

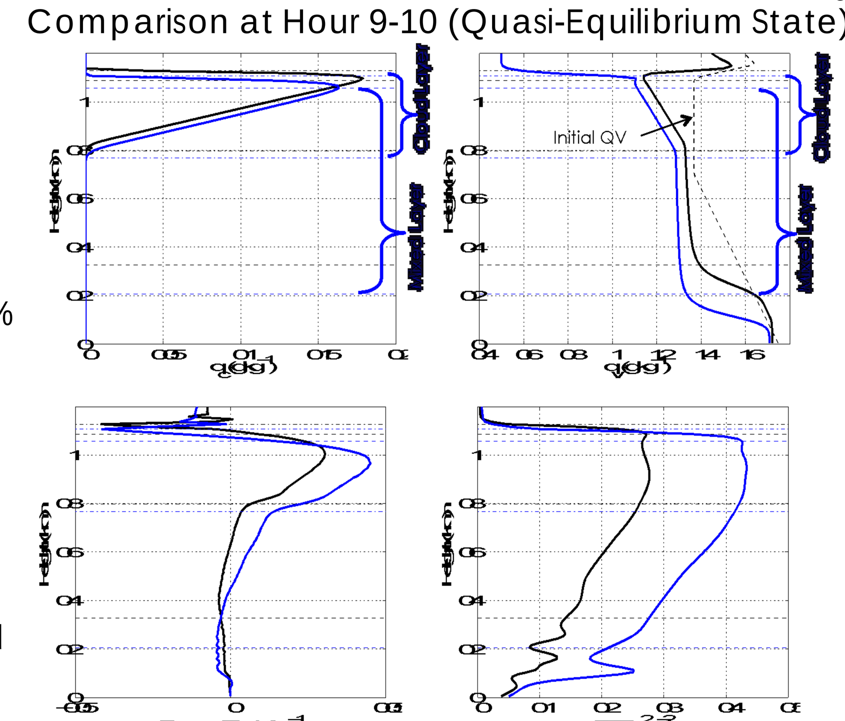
In the absence of latent heating potential temperature is the conserved and well-mixed field in the mixed layer, as opposed to equivalent potential temperature when latent heating is allowed. This causes temperatures to be colder in the cloud layer, which reduces the saturation vapor pressure, reducing the water vapor mixing ratio and increasing the cloud water mixing ratio. The cloud layer shows no sign of collapsing without latent heating.




## Impact of Removing Humidity Inversion: Focusing on "DryAbove" Simulation




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

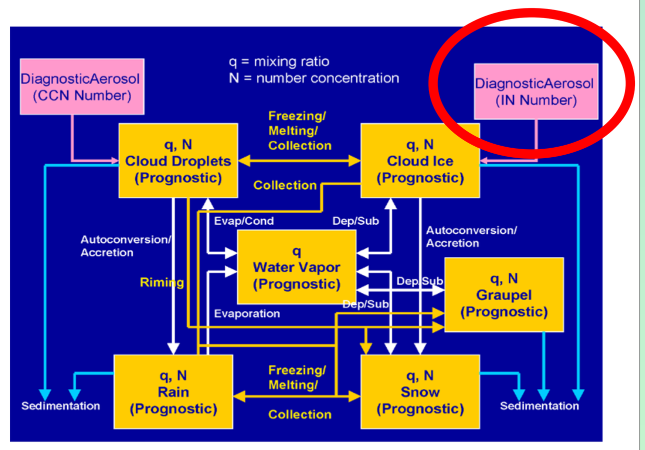
QV in cloud layer decreases faster-- Faster cooling rate

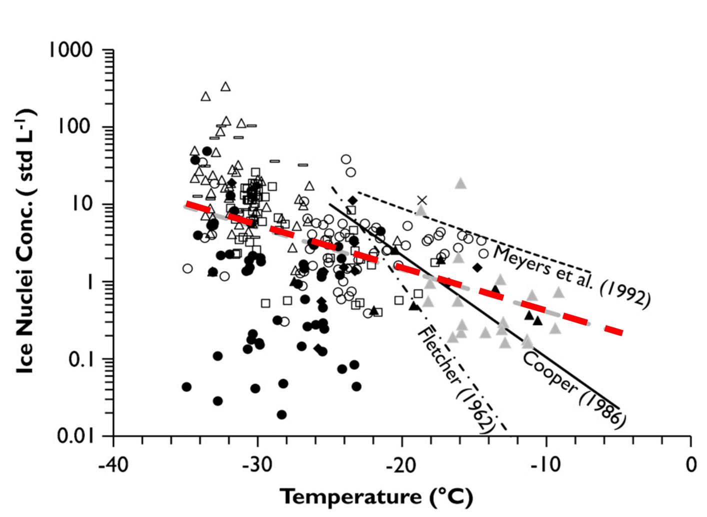
QV below mixed layer depleted more rapidly

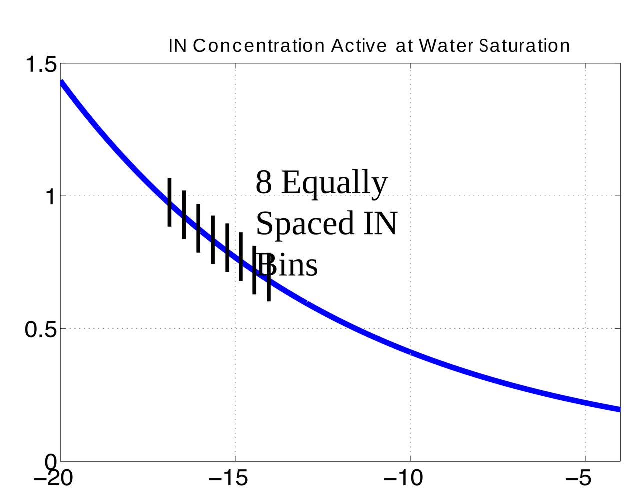
TKE ~60% larger (even though LWP is less)

## Including IN Sources and Sinks:

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

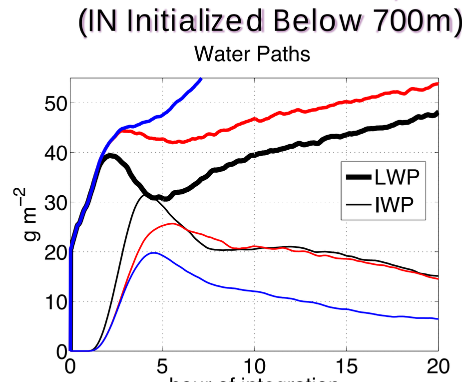


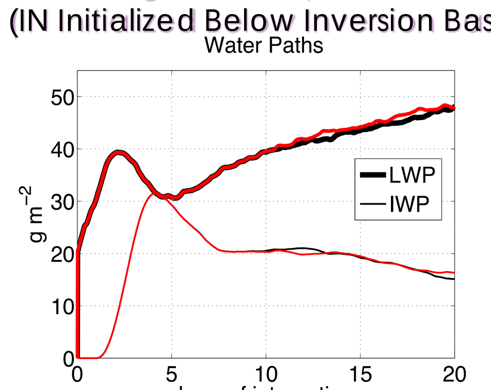




## Prognostic IN: Role of Cloud-top and Mixed-Layer Base Entrainment

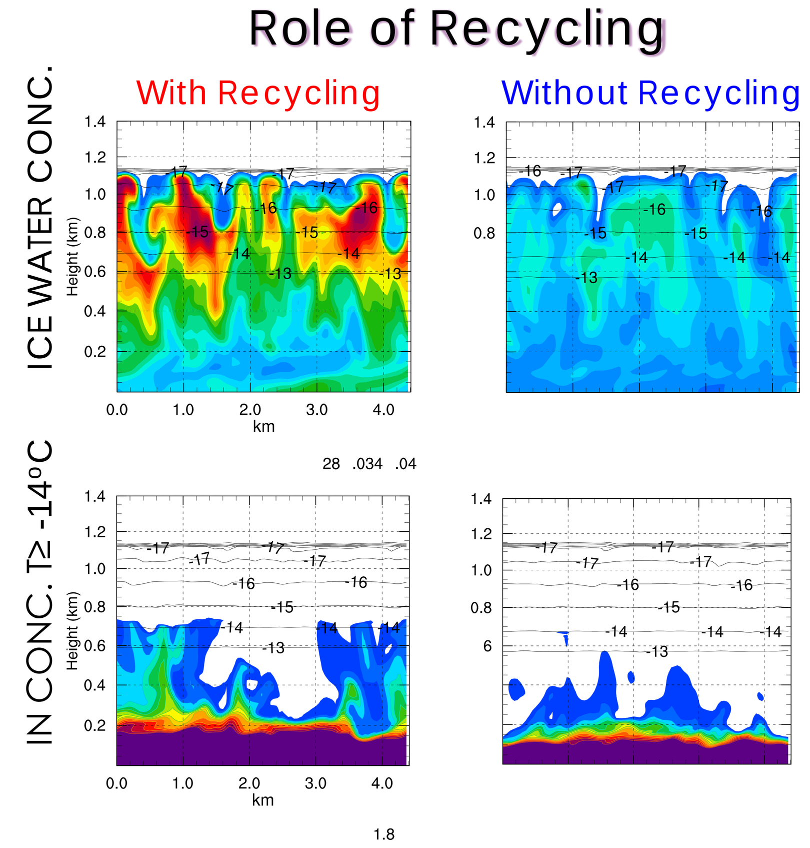
Role of Mixed-Layer Base Entrainment With and Without Recycling (IN Initialized Below 700m)




Excluding Cloud-Top Entrainment (IN Initialized Below Inversion Base)




### Role of Recycling




## Conclusions

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%


Reference: Solomon, A., M.D. Shupe, P.O.G. Persson, H. Morrison, T. Yamaguchi, P.M. Caldwell, and G. de Boer, 2014: The sensitivity of springtime Arctic mixed-phase stratocumulus clouds to surface layer and cloud-top inversion layer moisture. J. Atmos. Sci., doi:10.1175/JAS-D-13-0179.1.



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