Dynamical and Microphysical Characteristics and Interactions in Arctic Mixed-phase Clouds

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Observations

In this analysis we use multi-sensor observations from ground-based Arctic Atmospheric Observatories at multiple locations and time periods. These include observations at sea-ice, ice sheet, coastal and complex terrain sites, which represent the diverse environmental conditions encountered in the Arctic, with unique atmospheric and surface characteristics that can impact cloud formation.

- •Barrow, Alaska, USA: (Coastal W. Arctic)
- •SHEBA in the Beaufort Sea: (Arctic Ocean sea-ice)
- •Eureka, Nunavut, Canada: (Complex terrain)
- •Summit Station, Greenland: (High altitude ice sheet)

Retrieval Methods

Cloud Boundaries –Cloud top identified using radar, cloud base identified using high spectral resolution lidar or ceilometer.

Phase Classification – Uses phase-specific signatures from radar, lidar, microwave radiometer, and radiosonde measurements (Shupe, GRL 2007).

Ice Microphysics (IWC and IWP) – Empirical radar reflectivity power law relationship and assumptions about particle size dist'n and mass-size relationship (Shupe et al., JAM 2005).

Liquid Microphysics (LWC and LWP) – Adiabatic liquid water profile using cloud boundaries and temperature profiles, scaled using a liquid water path derived from combined microwave radiometer and AERI measurements (Turner, JGR 2007).

Vertical Velocity (W) – From cloud radar Doppler spectra, assuming liquid water droplets are tracers for air motions (Shupe et al., JTECH 2008).

Turbulent Dissipation Rate (ε) – From time-variance of radar mean Doppler velocity measurements (e.g., Shupe et al., JTECH 2008).

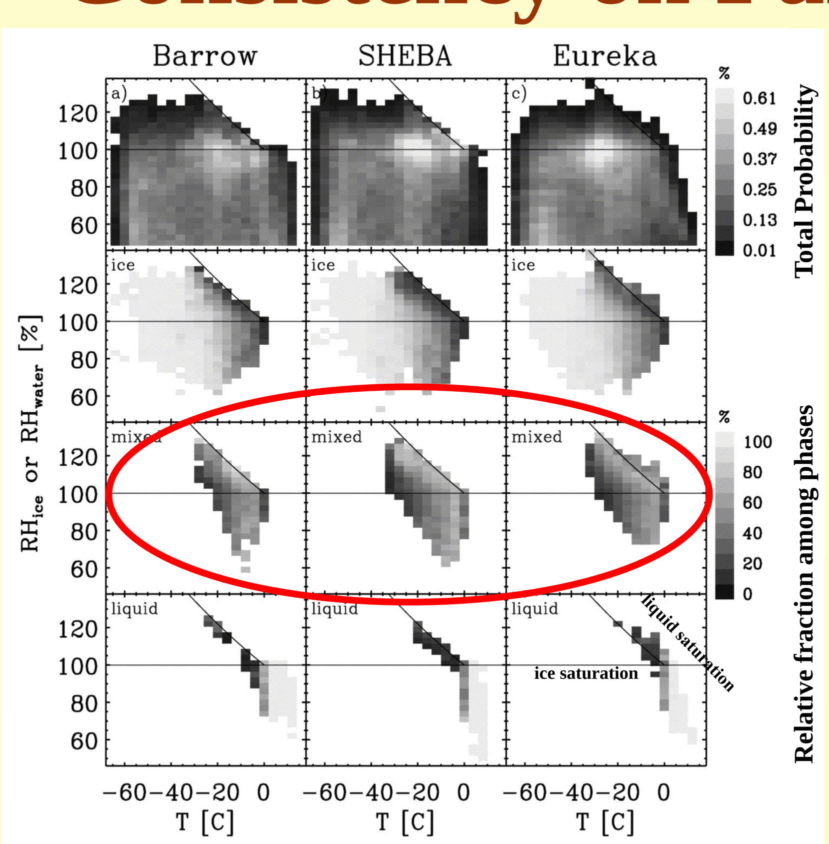
Summary

❖ Arctic stratocumulus persist in many different conditions and maintain relatively similar macrophysical qualities.

❖In the simplest case, the cloud is DECOUPLED from the surface and therefore does not benefit from energy or moisture from below. Yet, decoupled clouds still persist due to in-cloud processes that promote and maintain liquid water formation.

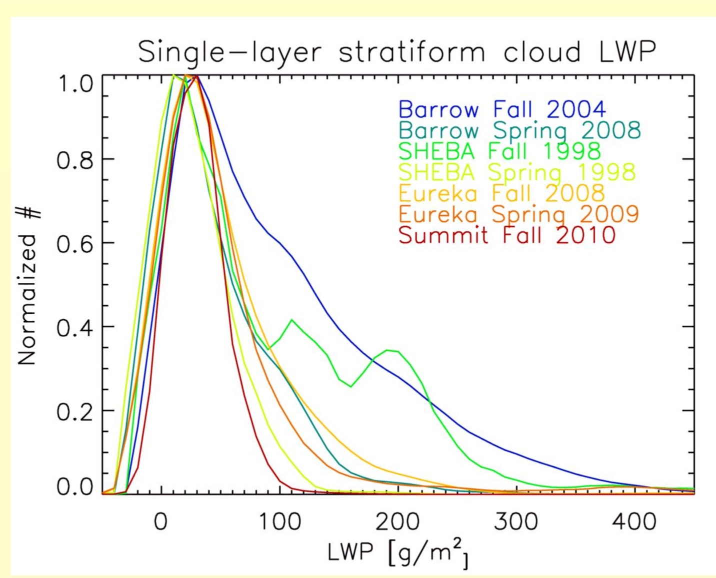
❖Mechanism for coupling vs. decoupling between the surface and cloud are not well understood, but are related to the magnitude of surface fluxes, the magnitude of cloud top radiative cooling, and the depth and height of the cloud mixed-layer.

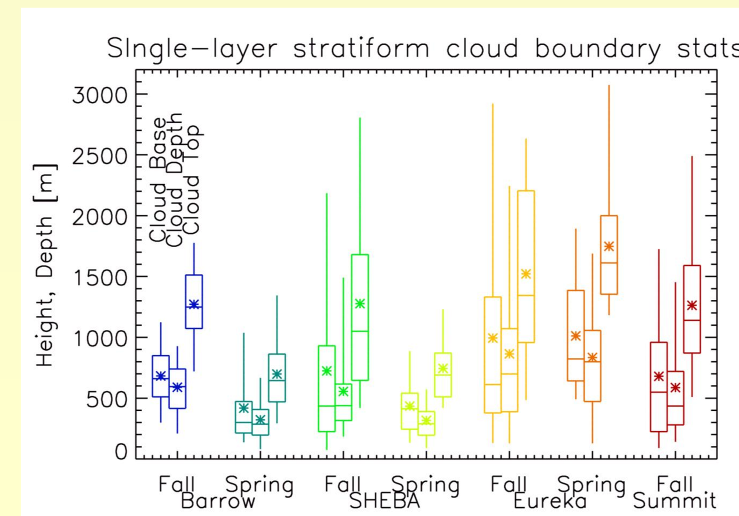
Consistency on Pan-Arctic scales



Clouds at Arctic Atmospheric Observatories

In terms of simple occurrence, mixed-phase clouds (and all cloud types) occur over similar ranges of temperature and RH, independent of Arctic location. Differences in fractional occurrence are thus due to differences in T-RH meteorology.





Single-layer stratiform clouds

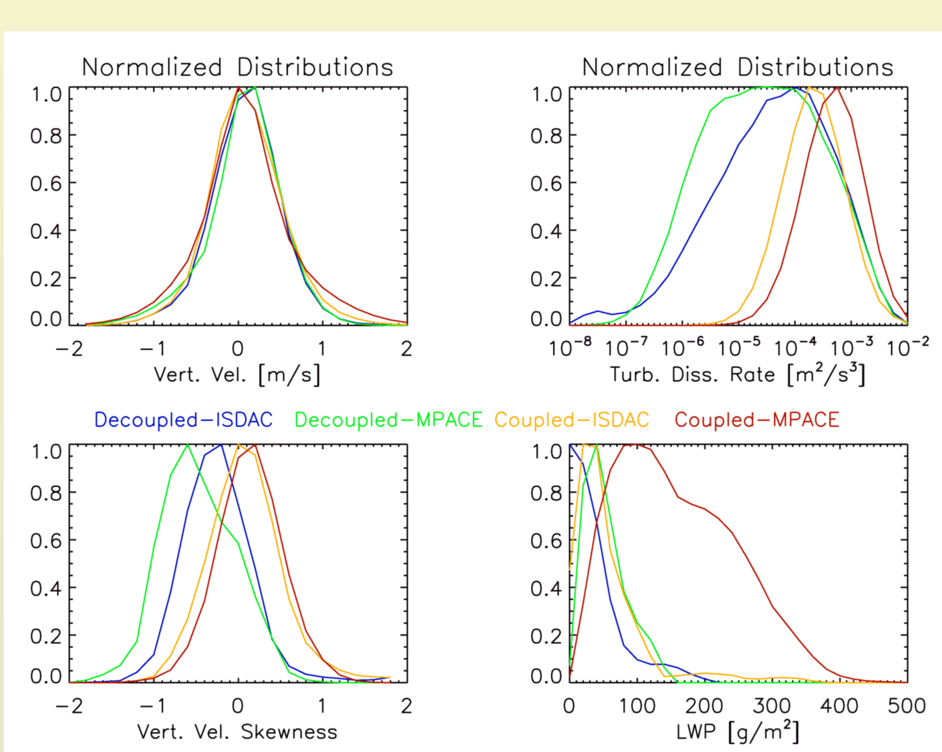
•At this collection of Arctic observatories, single-layer stratiform clouds are generally thicker and higher in the fall relative to the spring, except for at Eureka, Canada where they are similar in both seasons.

•Most clouds have LWP<100 g/m^2. Clouds have more liquid water in fall relative to spring.

•Clouds at Summit, Greenland have less liquid water than elsewhere.

Coupled vs. Decoupled

The coupling state is important for Arctic stratiform clouds as it determines whether the clouds are gaining energy and/or moisture from the surface. In either state, internal cloud processes also play a key role in maintaining the cloud.



Thermodynamically Coupled State

•Stronger turbulence and the profile is nearly constant from the surface to the cloud top.

•Wider distribution of vertical velocity, with stronger updrafts.

•Vertical velocity skewness distribution showing both positive and negative values (i.e., motions forced from the cloud and the surface).

•Larger cloud LWP due to added moisture from below.

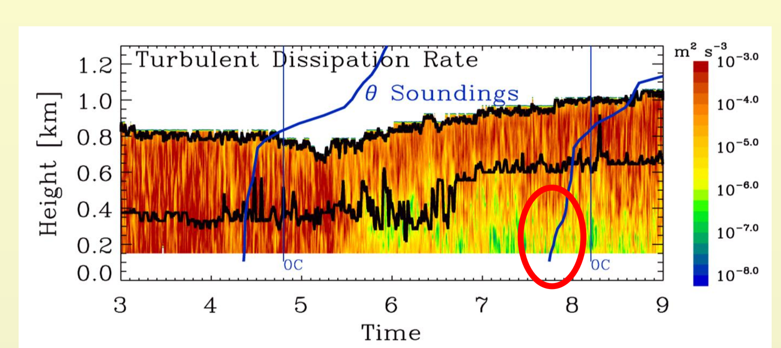
Thermodynamically De-coupled State

•Weaker turbulence, with a maximum in cloud and diminishing below cloud.

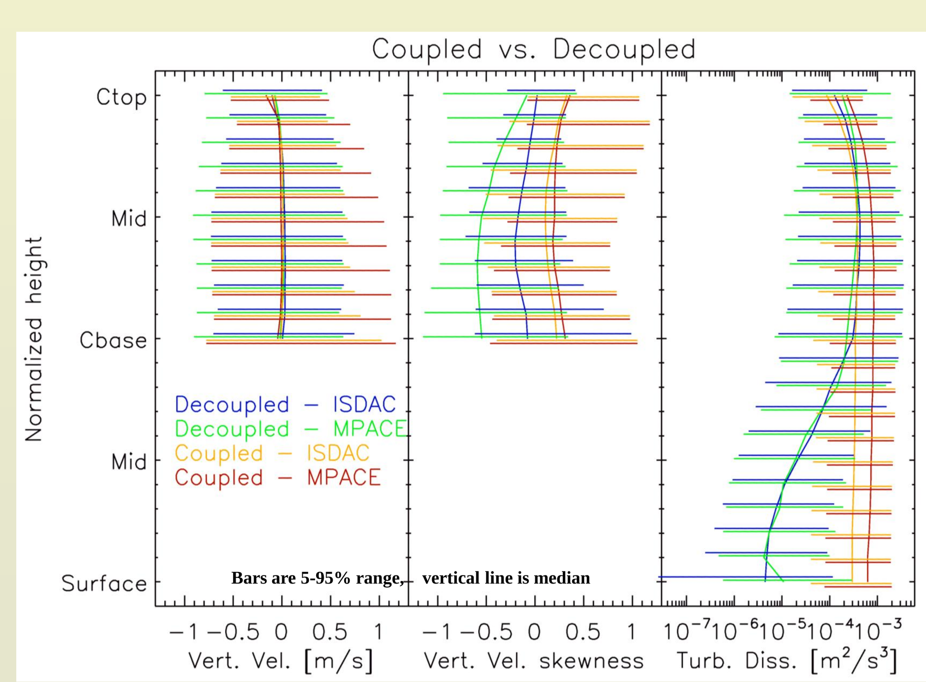
•Vertical velocity skewness distribution dominated by negative values (i.e., motions forced from within the cloud itself).

•Smaller cloud LWP.

Note: Differences between states are larger in the fall (MPACE) relative to the spring (ISDAC), probably due to stronger surface fluxes in fall.



Example: Transition from coupled to decoupled state as cloud layer lifts. Stable layer forms between cloud and surface, and cloud modifies thermodynamics within the lifting cloud layer.



Anatomy of Decoupled Arctic Mixed-Phase Stratocumulus

T and q inversions play a key role

1) Cloud liquid above inversion base:
Speculation: Condensation forced by radiative cooling

2) Cloud liquid below inversion base:
Condensation due to buoyant overturning

3) Entrainment moistens mixed-layer

Microphysical responses to turbulence

1) Little time variability in LWP:
Speculation: Liquid continually condenses above inversion base and moist air is entrained in downdrafts.

2) Ice increases in updrafts and occurs near cloud top:
Speculation: Ice preferentially nucleates in updrafts due to liquid DSD conditions, then grows in vapor-rich environment.

3) Ice evaporates below ML:
Due to dry, decoupled layer

Cloud-driven turbulent mixed-layer

1) Radiative cooling in cloud:
Forces strong, narrow downdrafts and weaker, broad updrafts

2) Cell aspect ratio: L/H = 2

3) Cloud-forced mixed-layer is decoupled from surface