The radiative and dynamical impact of aerosols on mixed-phase clouds observed during ISDAC and M-PACE

Amy Solomon, Matt Shupe, Ola Persson
(CIRES/University of Colorado and ESRL/NOAA)
Hugh Morrison (MMM/NCAR)

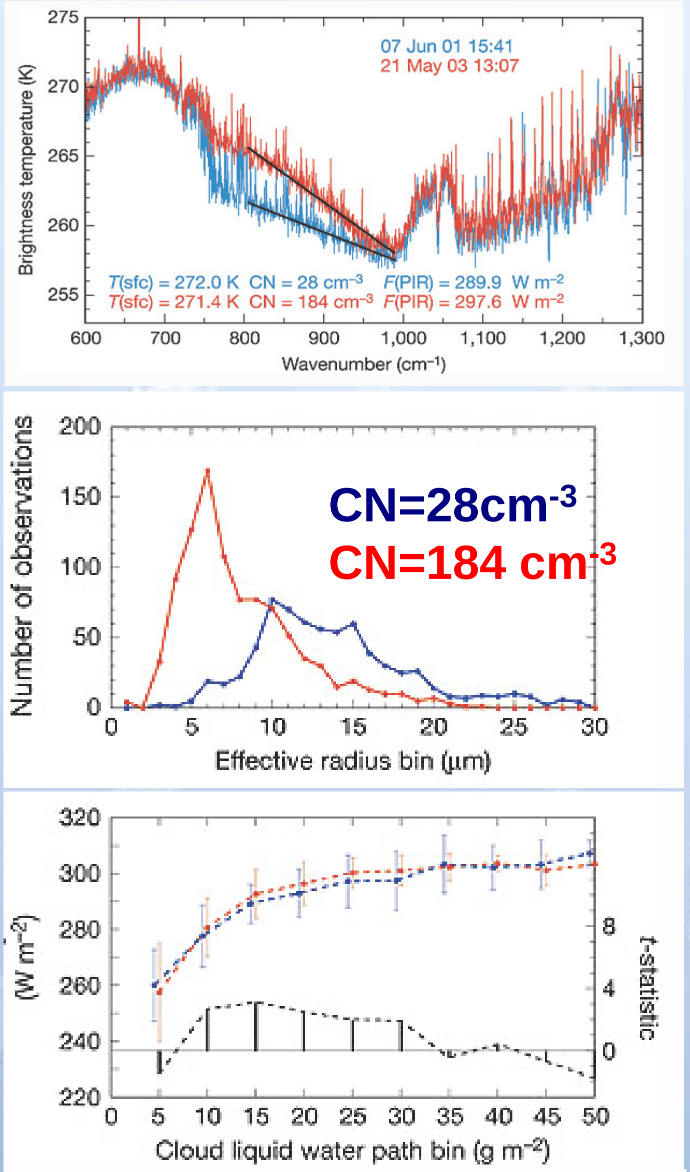
Joint Meeting of the DOE ARM Cloud Modeling and Aerosol WGs 1 October 2009

Indirect Effect of Arctic Aerosols

Elevated haze levels have been shown to increase cloud longwave emissivity---under a greybody cloud.
(Lubin and Vogelmann, 2006; Garrett and Zhao, 2006)

- How does weak or strong surface forcing change the indirect effect of aerosols? For example, are stratocumulus formed by cloud-top cooling less sensitive to changes in aerosols?

- What is the impact of elevated haze levels when cloud water paths > 50 gm^{-2} (typical values observed during ISDAC and M-PACE) and when the cloud is mixed phase?



(Lubin and Vogelmann, Nature 2006)

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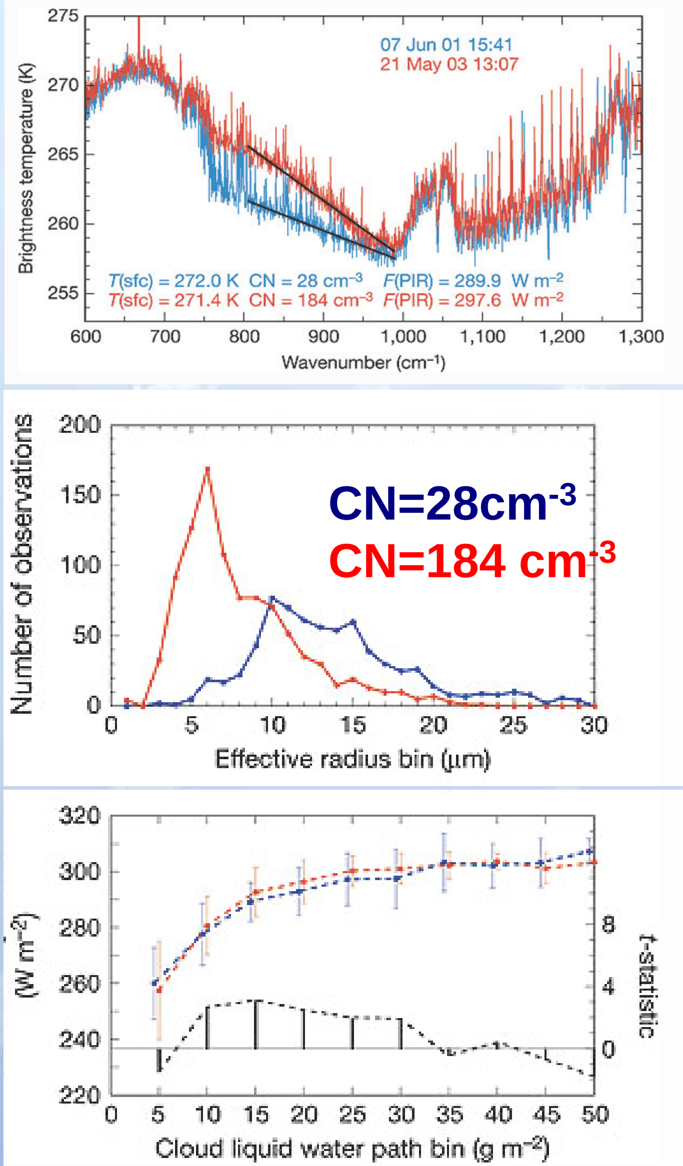

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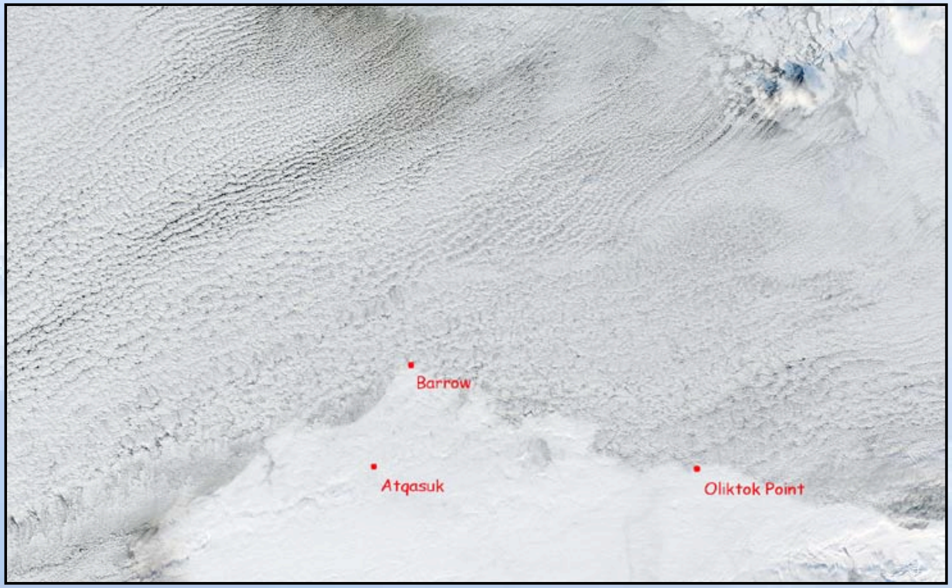
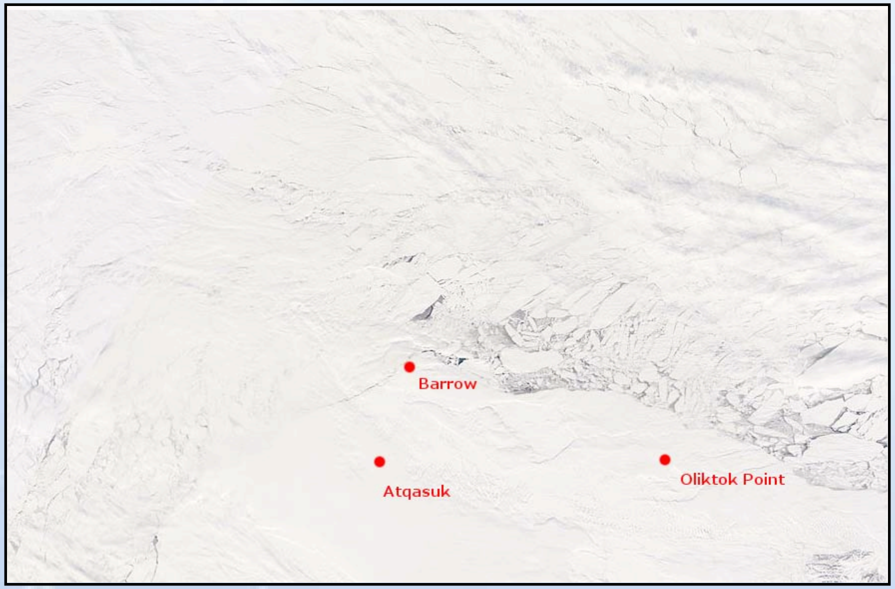
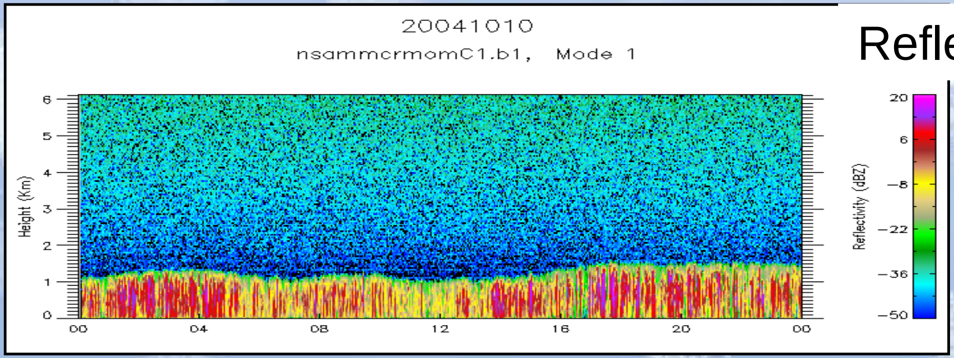
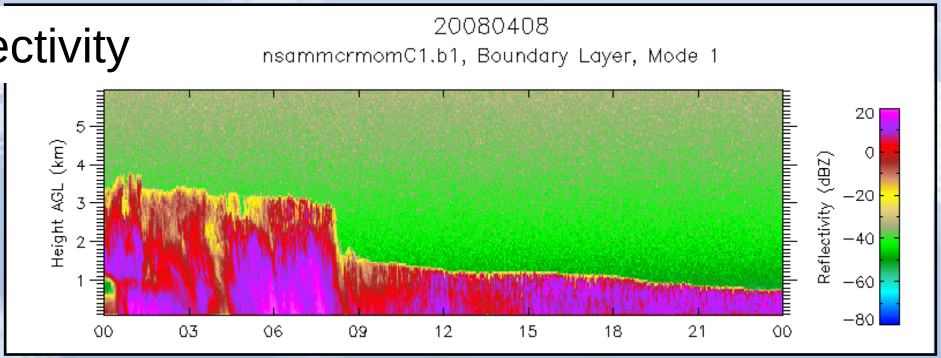
M-PACE (10 Oct 2004) vs. ISDAC (8 Apr 2008)





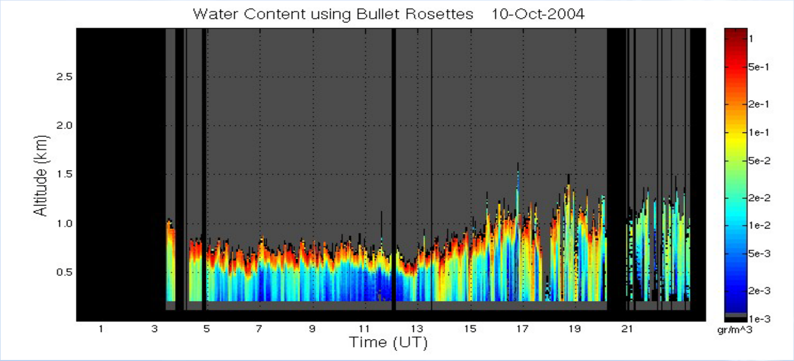
Reflectivity

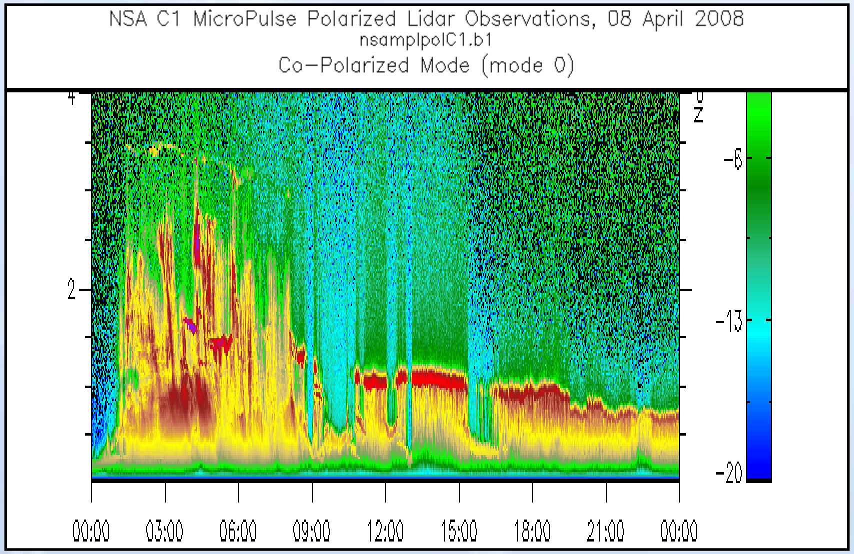


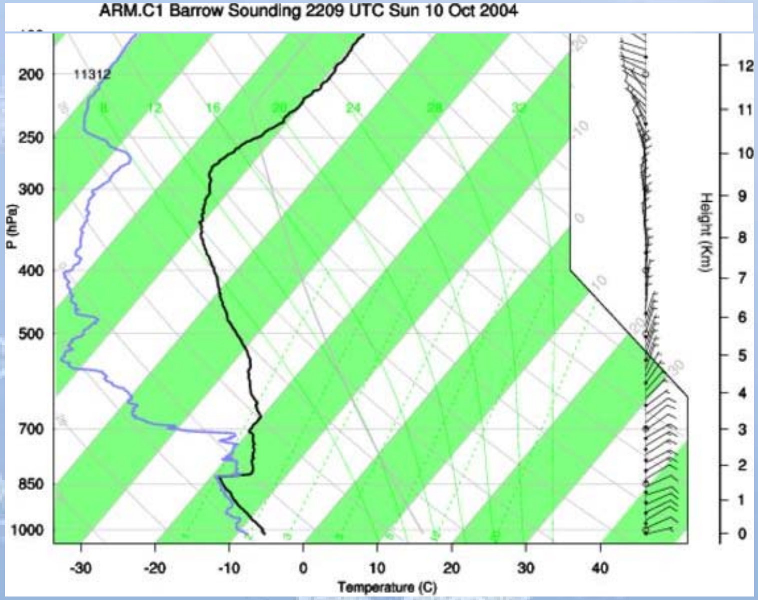


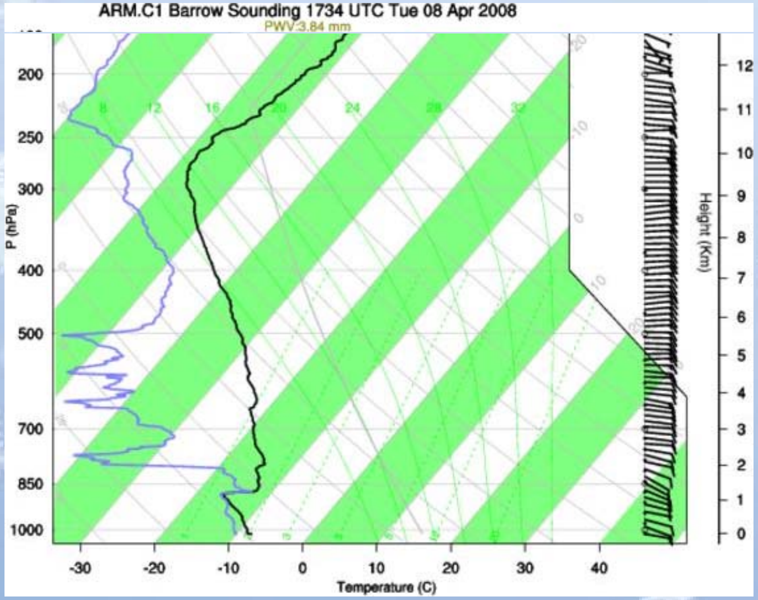
M-PACE (10 Oct 2004) vs. ISDAC (8 Apr 2008)

Water content









WRF Model Configuration

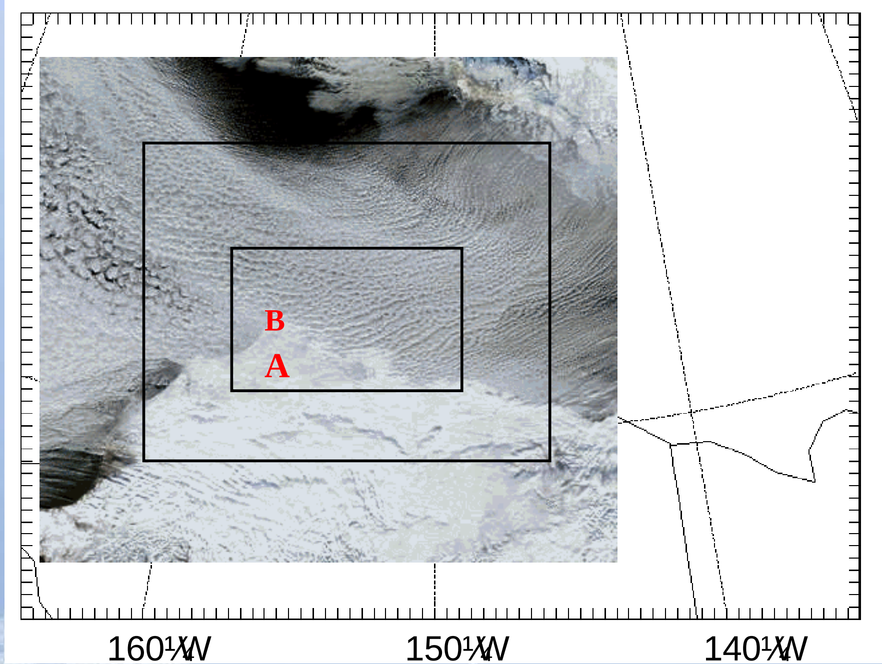
Weather Research Forecast Model V3.1

Nested 15/5/1 km horizontal grids

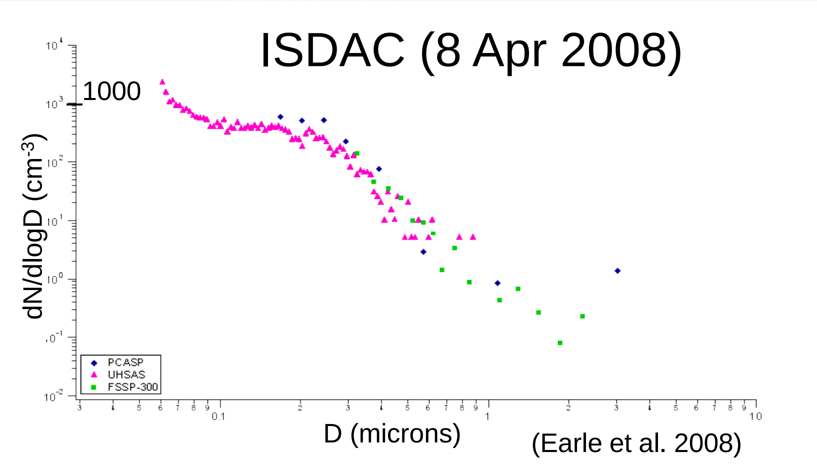
50 vertical levels (20 levels below 800 hPa).

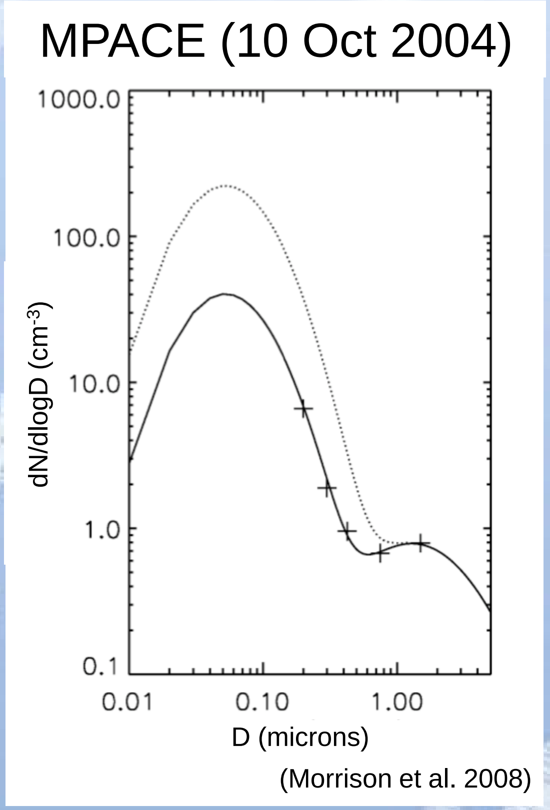
Morrison microphysics, RRTM/Goddard Radiation, NOAH LSM, Two-way feedbacks between grids,3D PBL mixing in the 1km grid (YSU in 18/6 km)

Liquid effective radius calculated in microphysics code is passed into the radiation code



Parameterization of Aerosols





A bimodal lognormal aerosol distribution is specified as a function of each modes standard deviation, geometric mean, and total number concentration

Potential number of droplets activated is a function of the CCN activity spectrum and the effective vertical velocity following Morrison and Pinto (2005)

CCN activity spectrum is calculated as a function of the aerosol size, number concentration, and composition following Khvorostyanov and Curry (1999)

The subgrid vertical velocity is a function of the predicted TKE following Morrison and Pinto (2005)

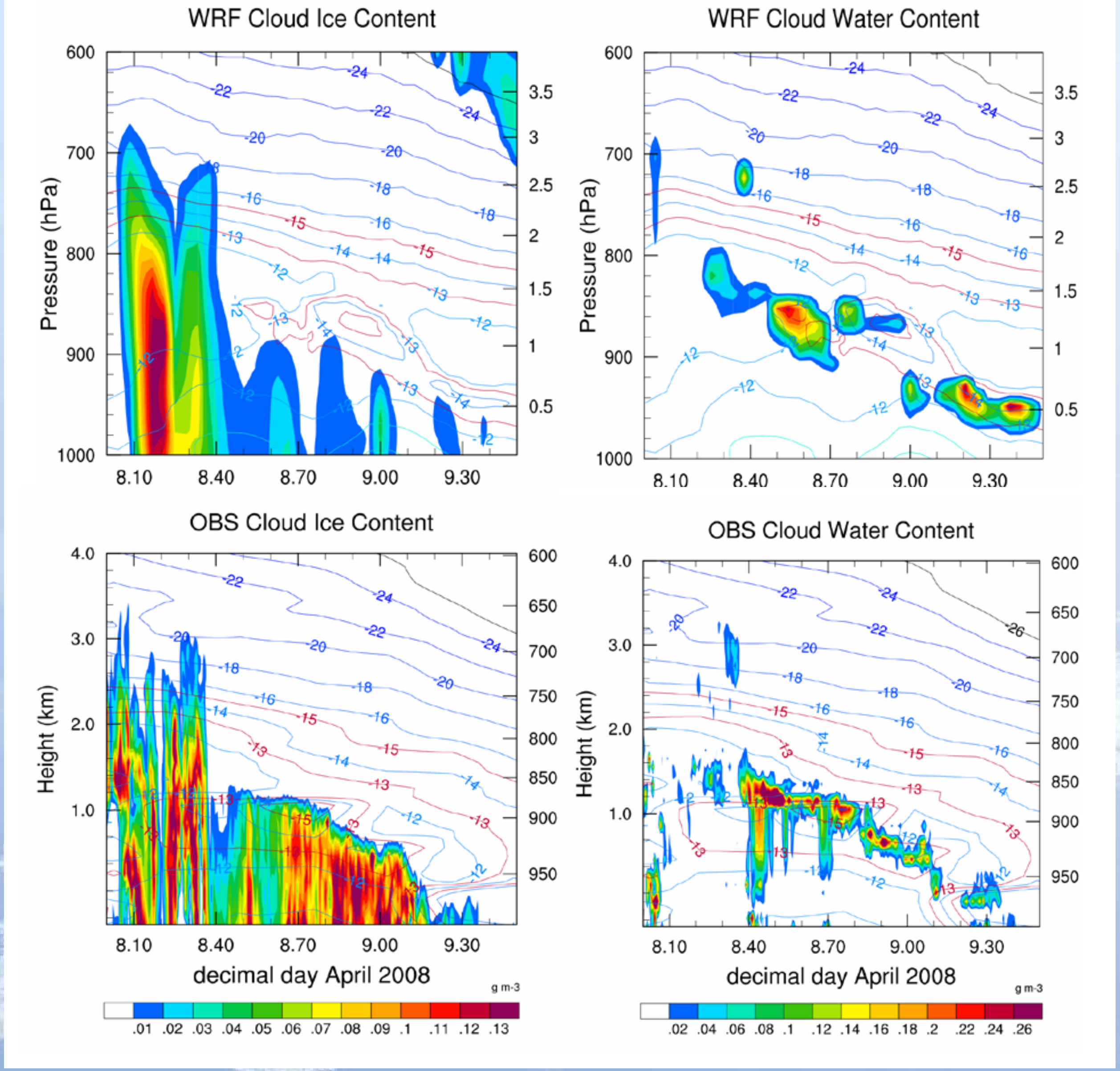
Experiment Design

1) Sensitivity to surface forcing
2) Sensitivity to small mode aerosol concentrations
3) Focus on IN activation mechanisms

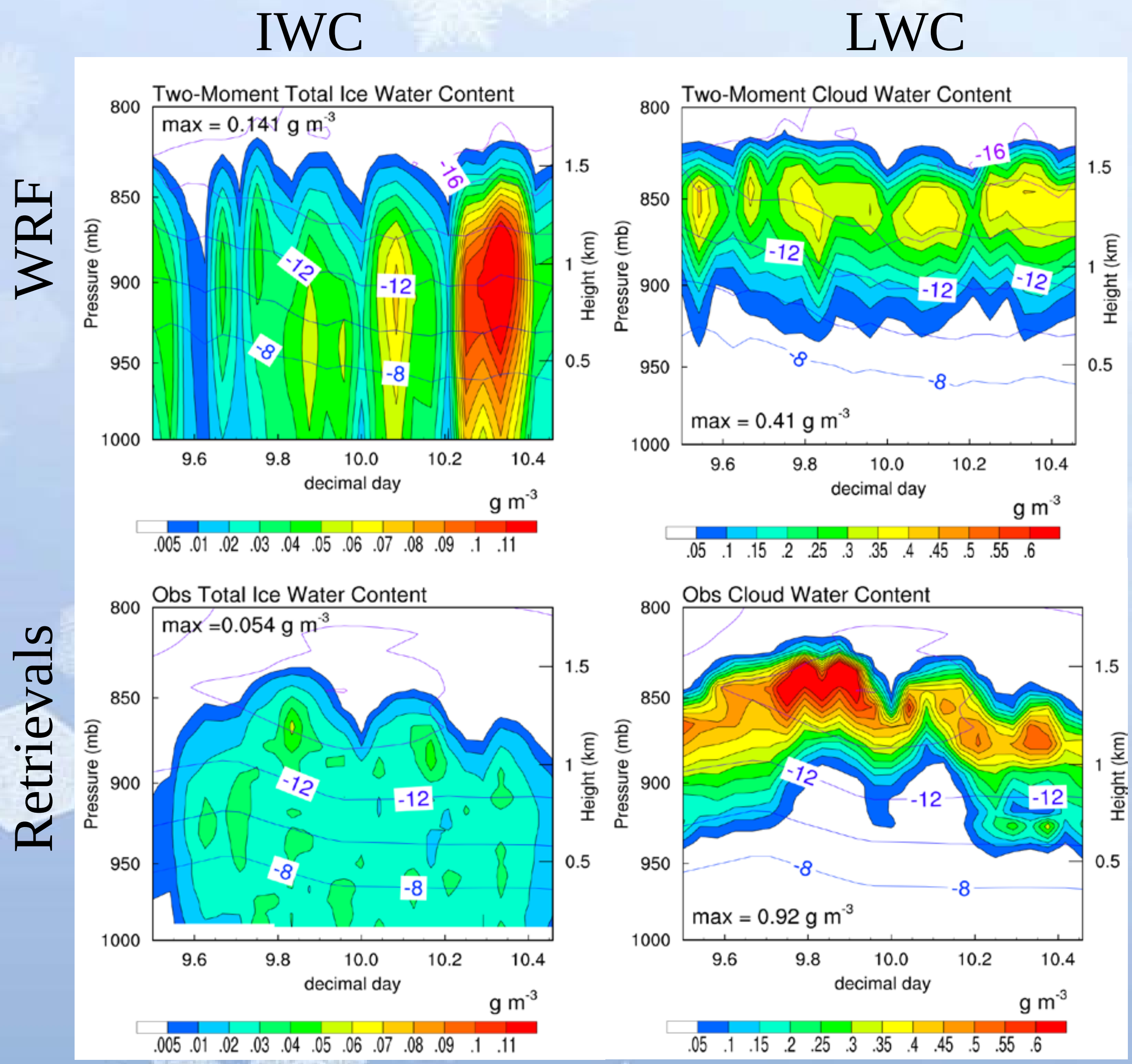
Model Validation for ISDAC at NSA Site

✓Model captures the IWC that extends up to 3km and descends below 1km after 10Z as a warm front moves in (but the ice-cloud does not persist throughout the day)

✓Model simulates the inversion that develops after 10Z and the mixed-phase cloud 10-24Z

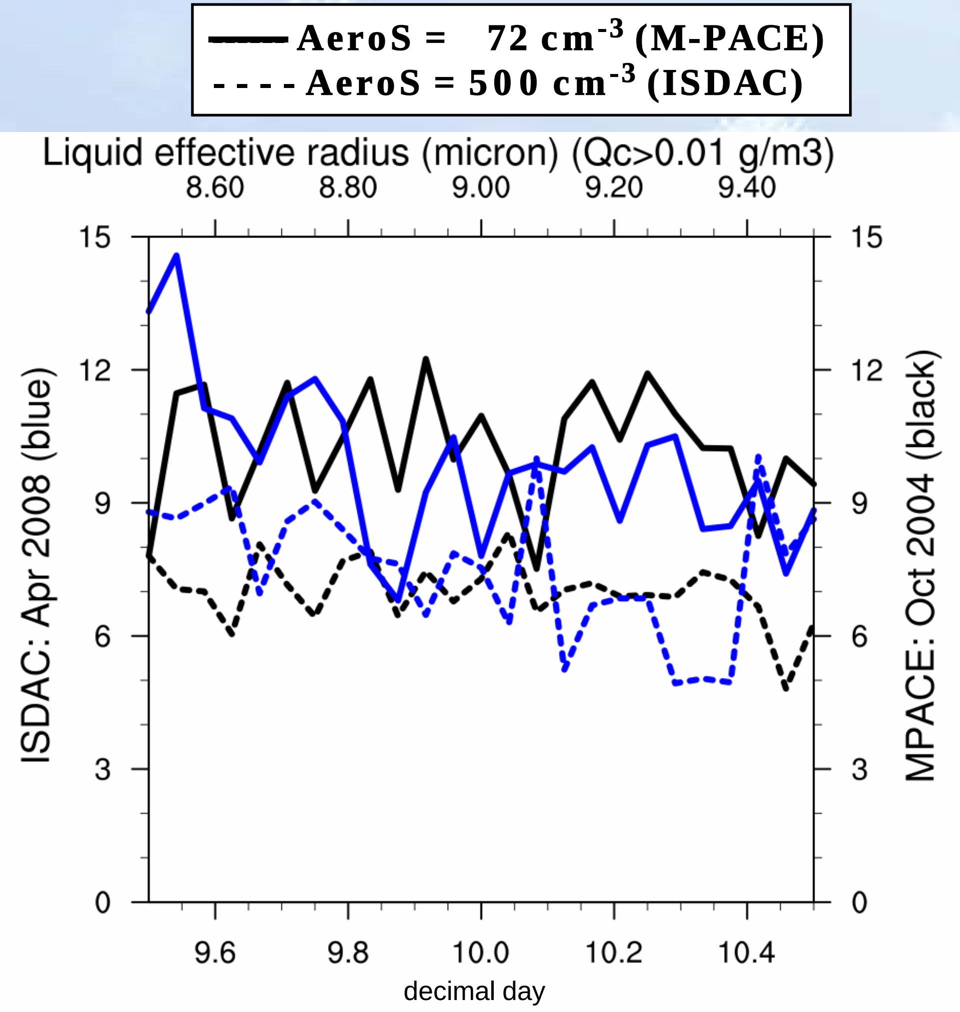


Model Validation for M-PACE at NSA Site



Impact of Aerosols at Barrow, AK: Strong vs. Weak Surface Forcing: Liquid Effective Radius

ISDAC BCs
M-PACE BCs

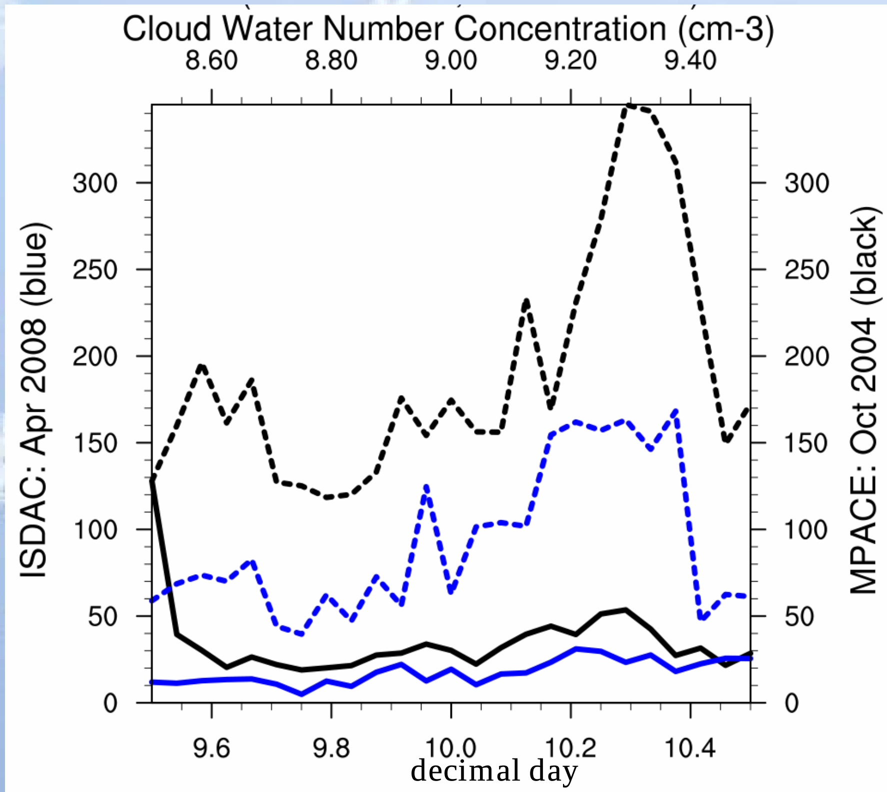


Impact of Aerosols at Barrow, AK: Strong vs. Weak Surface Forcing: Cloud Water Number Concentration and Liquid Water Path

ISDAC BCs
M-PACE BCs

—— AeroS = 72 cm^{-3} (M-PACE)
- - - - AeroS = 500 cm^{-3} (ISDAC)

37.8 ——
30.0 - - -
207.6 ——
223.8 - - -



Liquid Water Path (g/m2)

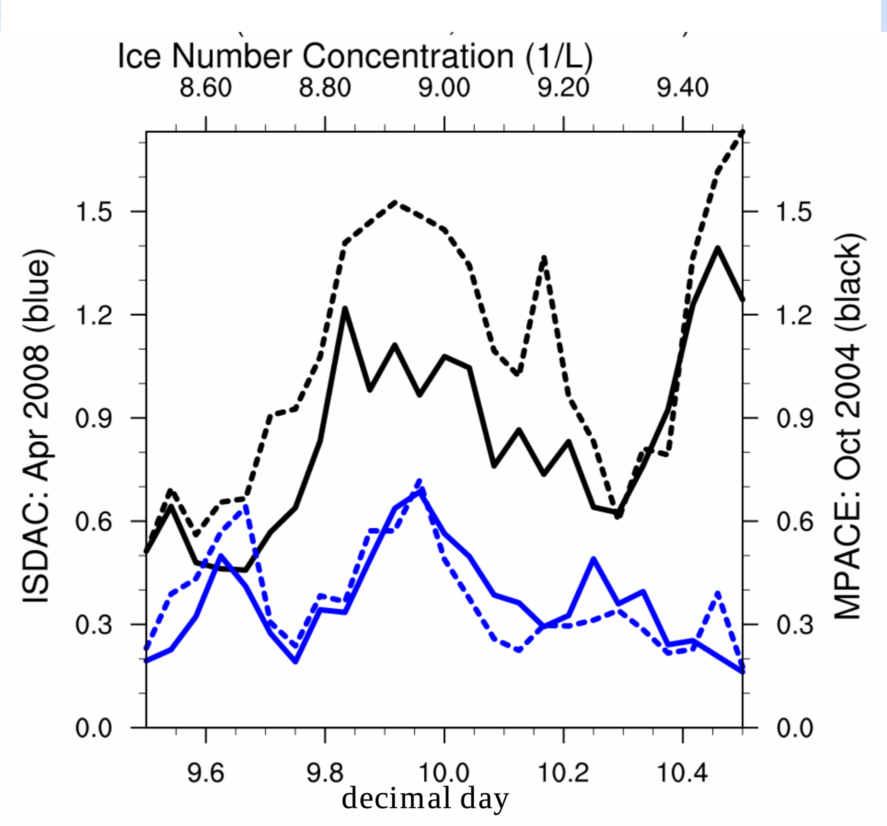
decimal day

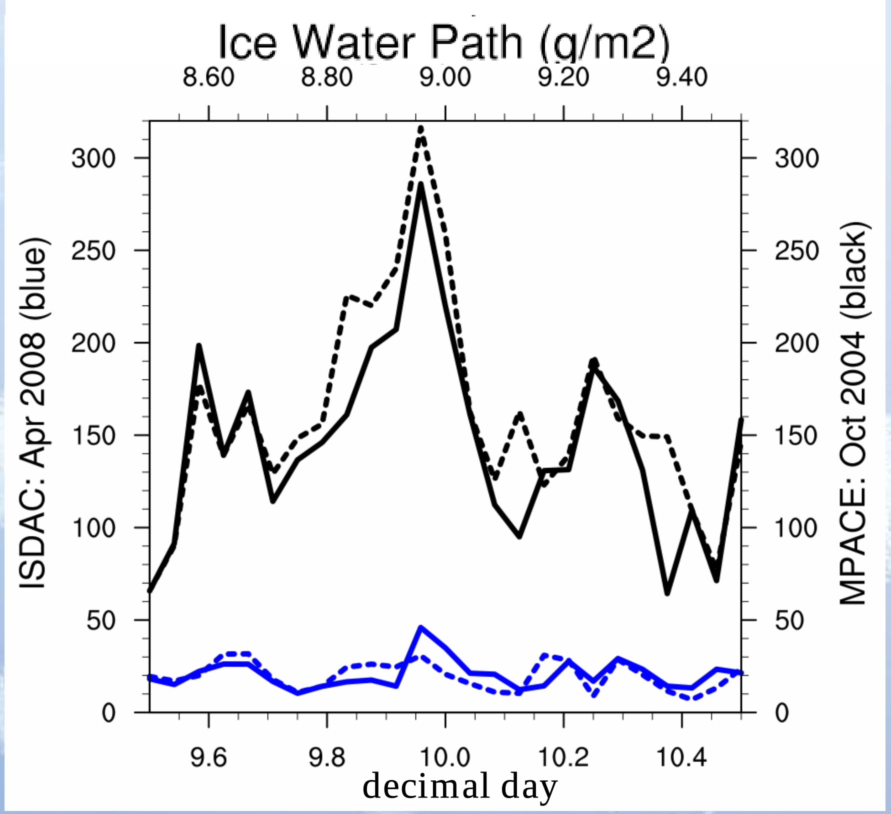
Impact of Aerosols at Barrow, AK: Strong vs. Weak Surface Forcing: Ice Number Concentration and Ice Water Path

ISDAC BCs
M-PACE BCs

—— AeroS = 72 cm^{-3} (M-PACE)
- - - - AeroS = 500 cm^{-3} (ISDAC)

20.6 ——
20.0 - - -
146.3 ——
161.2 - -





Impact of Aerosols at Barrow, AK: Strong vs. Weak Surface Forcing: Surface Radiation

ISDAC BCs
M-PACE BCs

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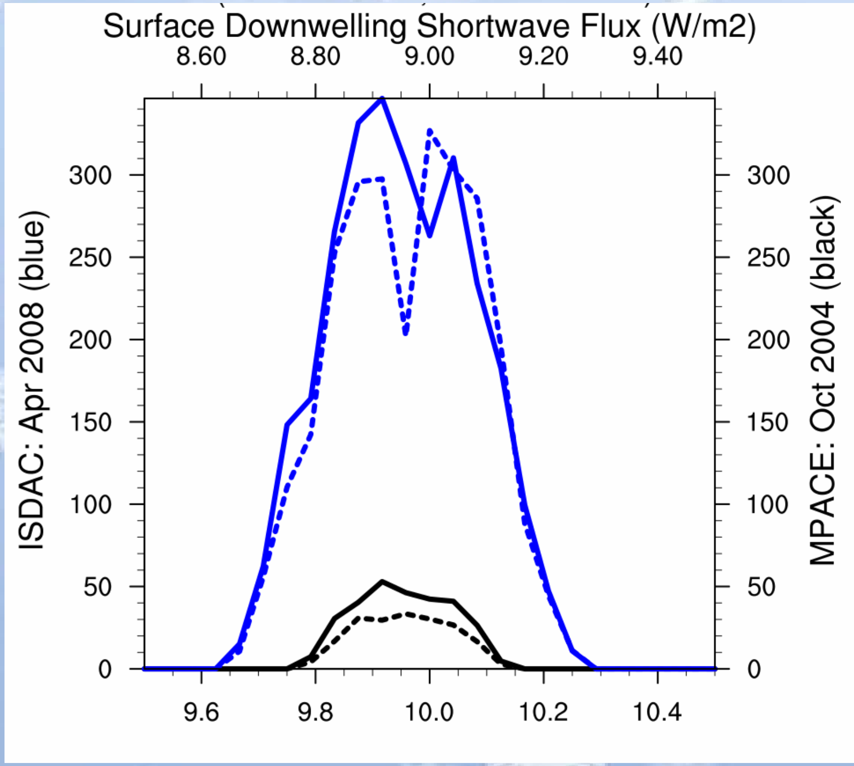
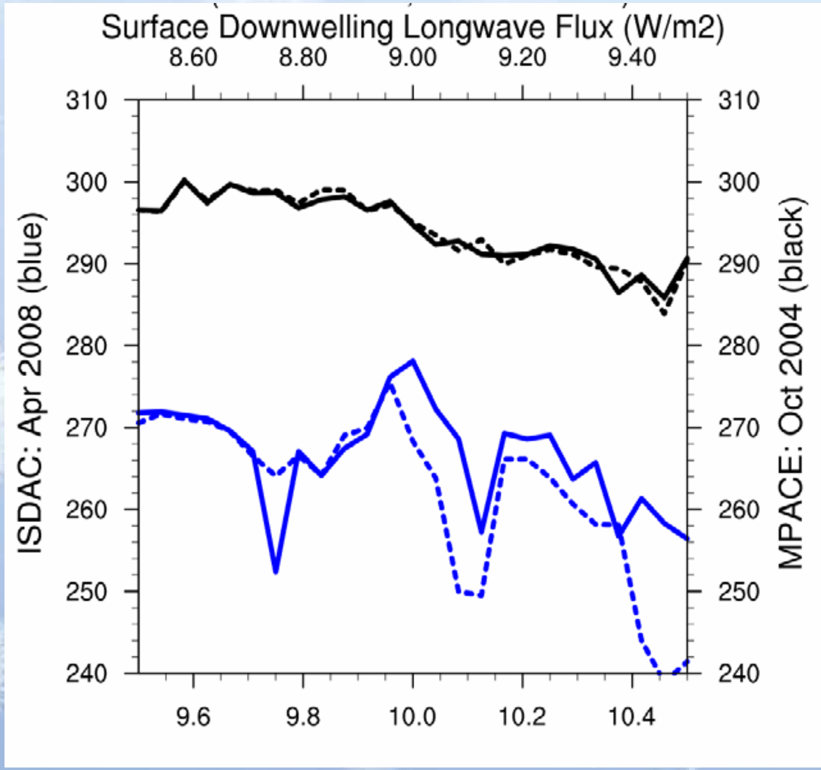
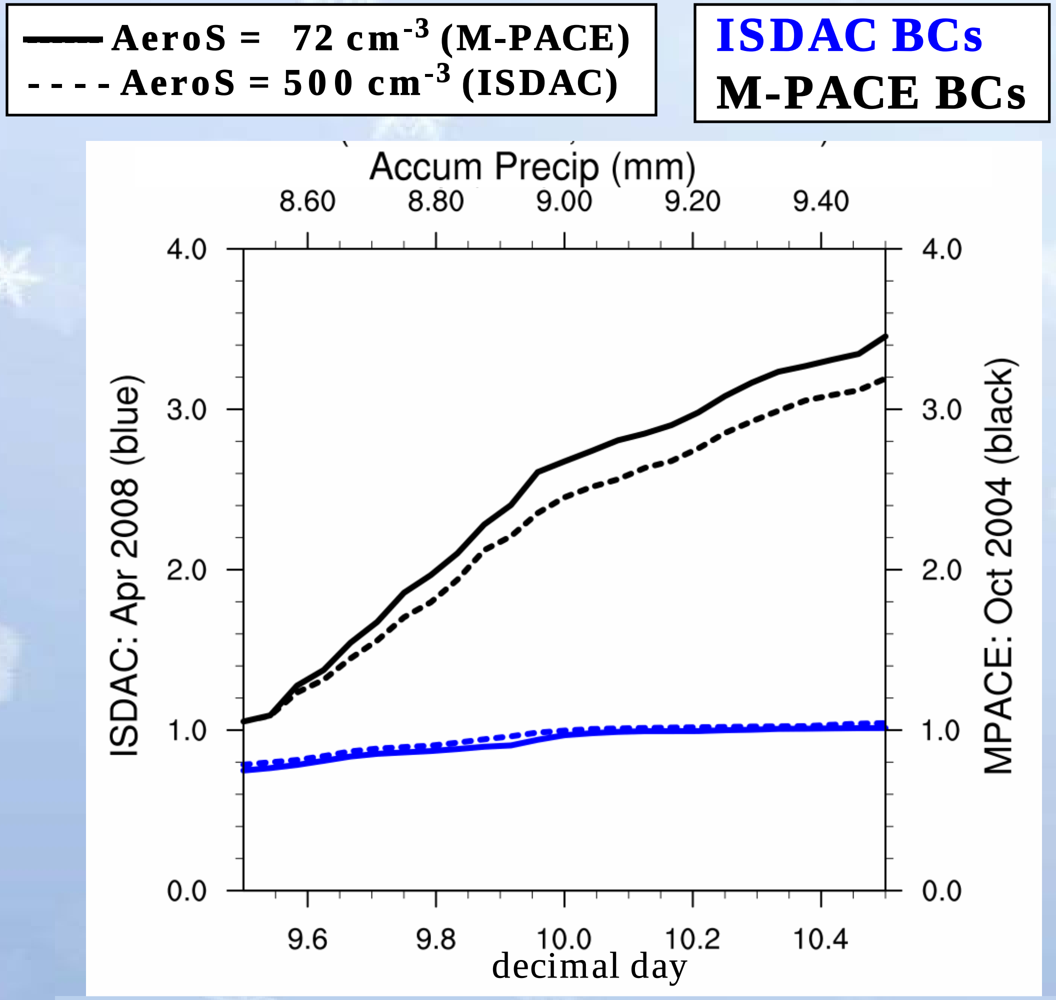




Impact of Aerosols at Barrow, AK: Strong vs. Weak Surface Forcing: Precipitation



Strong surface forcing: Glaciation suppressed

Weak surface forcing: Glaciation unchanged

Conclusions

Impact of increased aerosol concentration:

- ❖ Decrease in cloud droplet size-- for both strong and weak surface forcing

….which primarily results from increased droplet number concentration

However,

1) Ice number concentration and IWP increase only under strong surface forcing conditions
2) LWP decreases under weak surface forcing conditions
3) Glaciation is only suppressed under strong surface forcing conditions

⇒ *These results are due to the strengthening (weakening) of vertical circulations under strong (weak) surface forcing when aerosols are increased*

Microphysical Scheme

Prognostic variables include mixing ratios and number concentrations of cloud ice, cloud droplets, snow, graupel, and rain

Hydrometeors have the form of a complete gamma size distribution:

$f(D) = N_0 D^{Pc} e^{-\lambda D}$

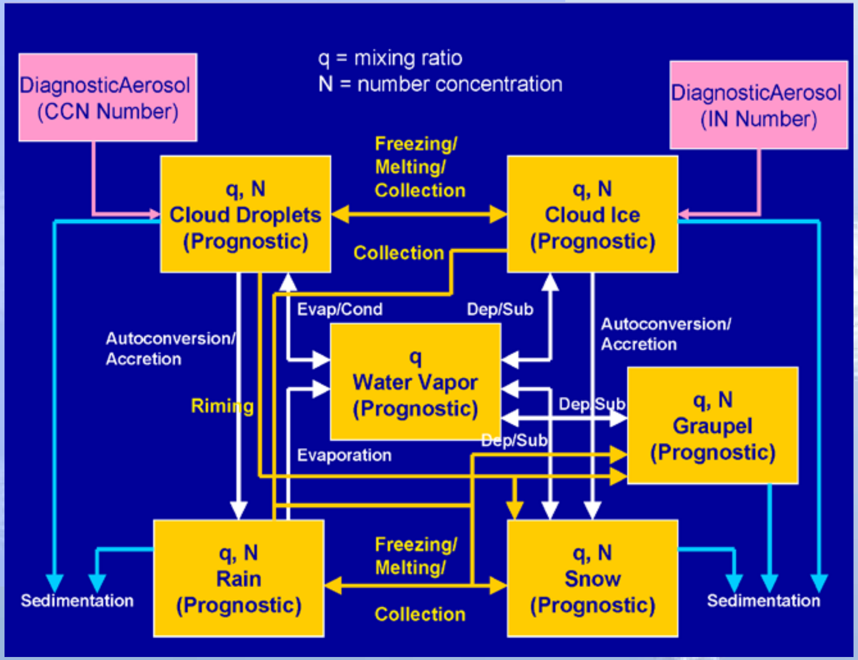
$$\lambda = \left[\frac{cN\Gamma(P_c + d + 1)}{q\Gamma(P_c + 1)} \right]^{1/d}$$

= the Slope Parameter

$N_0 = N\lambda^{Pc+1}$ is the Intercept Parameter

Pc is the Spectral Parameter
(Pc=0 for ice, snow, rain, graupel)

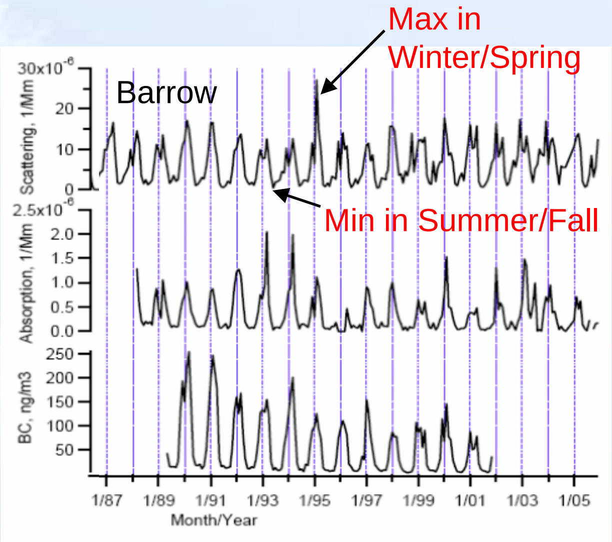
Bulk density of ice = 0.5 g cm^{-3}
Bulk density of snow = 0.1 g cm^{-3}

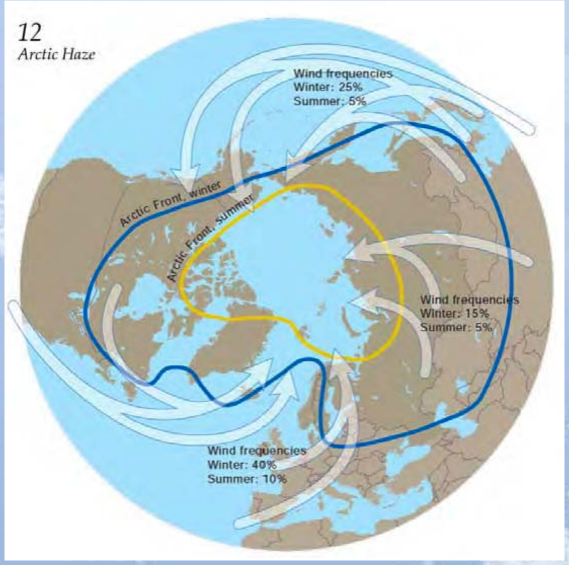


Seasonal Variations in Arctic Aerosols

Aerosol properties show a pronounced seasonal cycle in size, composition, mass loading, and number concentration throughout the Arctic

**Aerosols are primarily anthropogenic during the time of maximum mass concentration—the late winter and early spring
(Quinn et al. 2007)**





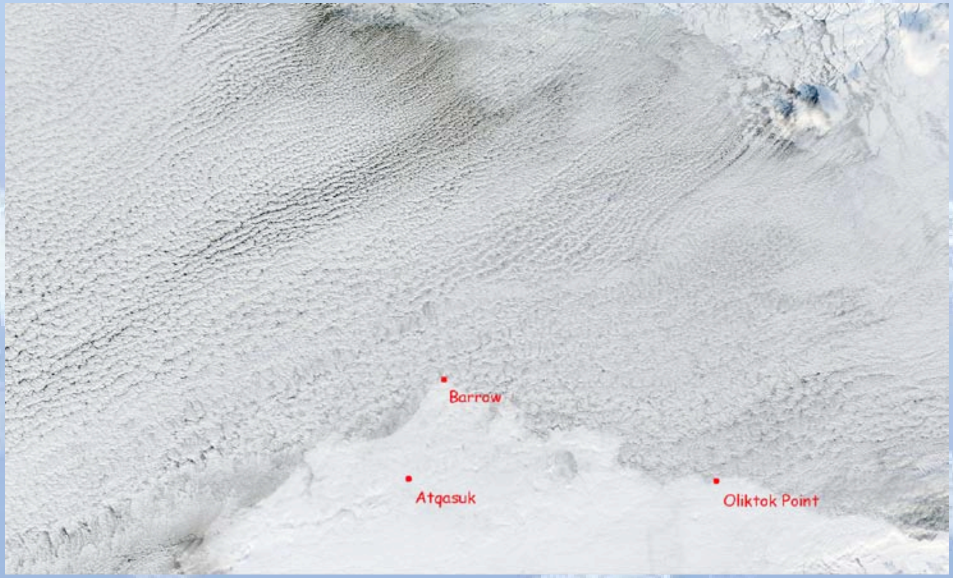
The dominant sources of the springtime surface aerosol maximum are seen to lie poleward of the Arctic front.

The largest contributions are believed to come from industrial sources in northern Europe and the Russian Arctic (Sharma et al., 2006; Stohl, 2006)

October Case Study:
Mixed-Phase Arctic Cloud Experiment (M-PACE)

Intensive Observations 6-11 Oct 2004:
Measurements at DOE ARM NSA Site
+ High Spectral Resolution Lidar
+ Atmospheric Emitted Radiance Interferometer
+ Radiosonde launches
+ Two Instrumented Aircraft with a Compliment of Cloud Physics Probes

MODIS visible image 10 Oct 0Z 2004



- A strengthening high-pressure system north of Alaska
- Caused air to flow from pack ice over the open Beaufort Sea to the North Slope of Alaska
- Forcing roll clouds that extended from the pack ice to the North Slope of Alaska
- These clouds are aligned closely to the direction of the boundary layer winds
- With wavelength of 10-15km and a PBL 1km over the ocean and <1km inland
- These clouds were mixed phase with total water content dominated by liquid hydrometeors throughout the cloud layer

April Case Study:
Indirect and Semi-Direct Aerosol Campaign (ISDAC)

Intensive Observations taken 1-29 Apr 2008:
Measurements at DOE ARM NSA Site
+ Atmospheric Emitted Radiance Interferometer
+ Radiosonde launches

Canadian NRC In-situ Measurements
+ Aerosol properties
+ Atmospheric state
+ Cloud microphysics
+ Visible and infrared radiation.

Flights were coordinated with NASA's B-200 King Air, DC-8, P-3 and NOAA's P-3 when possible.

First "Golden Day" 8 Apr 2008:

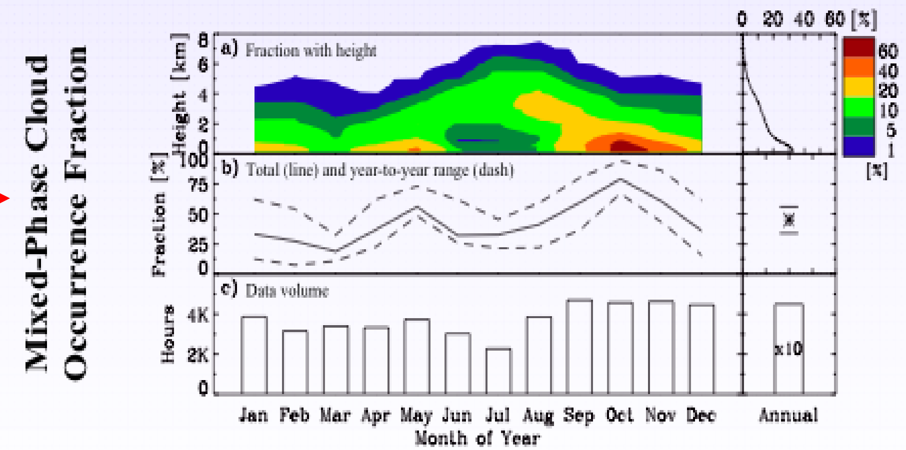
Distinct stratus deck and multiple Arctic haze layers

Observations of Mixed-Phase Arctic Stratocumulus

➢Mixed-phase clouds dominate the low-cloud fraction within the Arctic during the colder three-quarters of the year (Curry et al. 2000; Intrieri et al. 2002; Uttal et al. 2002; Wang et al. 2005), **peaking in the spring and fall transition seasons**

➢Arctic low-level mixed-phase clouds tend to be long-lived and are not observed to glaciate quickly due to the Bergeron process (Pinto 1998; Hobbs and Rangno 1998; Curry et al. 2000)

➢Mixed-phase clouds are observed to occur in regions of both strong and weak surface forcing, indicating that the cause of these cold, ice-precipitating clouds is microphysical in nature (Harrington et al. 1999; Morrison et al. 2005)



Cloud Occurrence. Mixed-phase clouds occur 45% +/- 10% of the time per year at the NSA site. There is a marked increase in mixed-phase cloudiness in the spring and fall transition seasons, mostly at heights below about 1 km.

(After Shupe et al. 2006)

Key Questions Addressed in this Study

• Why do mixed-phase clouds with similar structure form in both spring and fall when surface and radiative conditions differ?

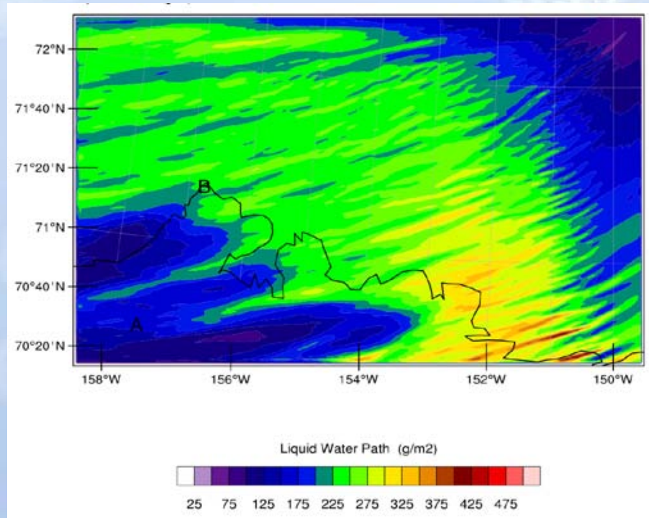
• To what extent do the different properties of Arctic aerosols in April and October produce differences in the microphysical and macrophysical properties of clouds and the surface energy balance?

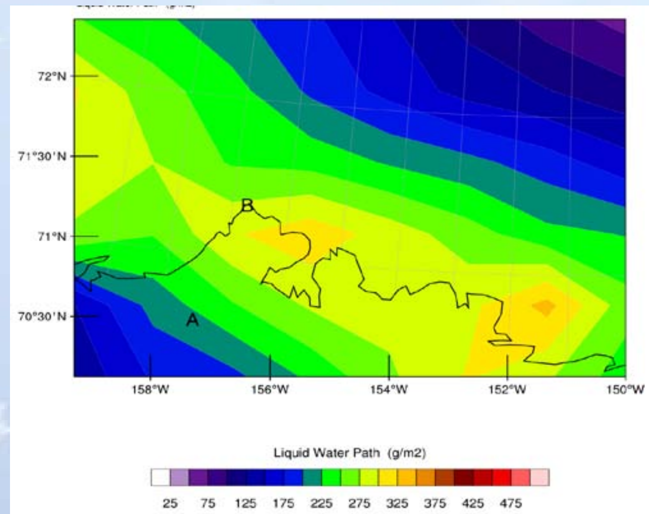
• How well can cloud parameterizations in mesoscale models simulate the sensitivity of Arctic clouds and the surface energy budget to the differences in aerosols between April and October?

Impact of Horizontal Resolution on the Maintenance of Liquid Water

1 KM | 50 KM

24-hour average





1-hour average