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

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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 and cloud models simulate the sensitivity of Arctic clouds and the surface energy budget to the differences in aerosols between April and October?

October Case Study

M-PACE: *Mixed-Phase Arctic Cloud Experiment*

6-11 Oct 2004:
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

April Case Study

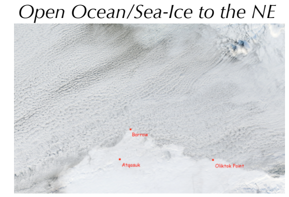
ISDAC: *Indirect and Semi-Direct Aerosol Campaign*

1-29 Apr 2008:
Same measurements at DOE ARM NSA Site
+ 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

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

Surface conditions

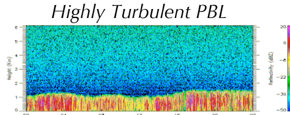
Open Ocean/Sea-Ice to the NE



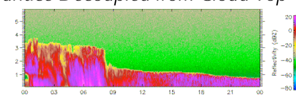
Uniform Sea-ice

PBL

Highly Turbulent PBL

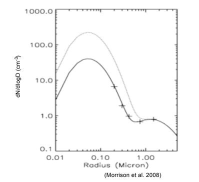


Surface Decoupled from Cloud Top

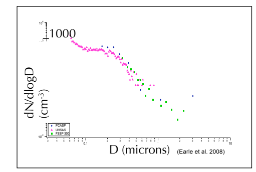


Aerosol concentrations

Pristine: Aero<72cm^{-3}

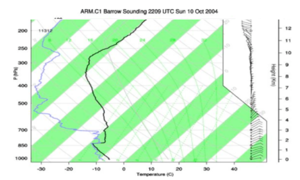


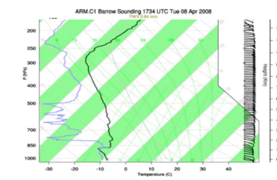
Arctic Haze: Aero>1000cm^{-3}



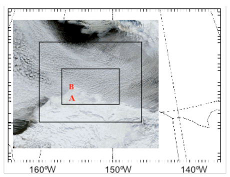
But Similar Surface Temp, PBL Height and Inversion Temp

Atmospheric structure





Experiment Design



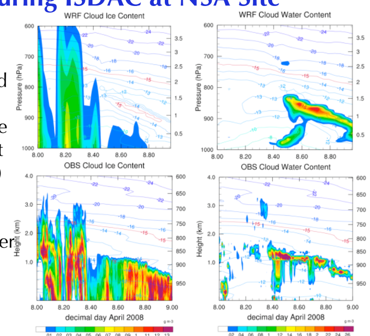
Using the regional WRF model with 18/6/1km grids, two-moment microphysics, and effective radius and droplet size varied separately to isolate the indirect effects of aerosols

Separating the influence of different boundary conditions from different aerosol concentrations:
– M-PACE aerosol and boundary conditions
– M-PACE aerosol and ISDAC boundary conditions
– ISDAC aerosol and M-PACE boundary conditions
– ISDAC aerosol and boundary conditions.

Model Validation during ISDAC at NSA Site

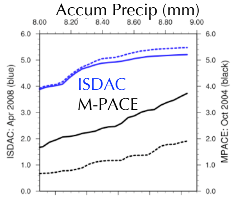
✓Model capture the IWC that extends up to 3km and descends below 1km after 10Z (but produces too little and the ice-cloud does not persist throughout the day)

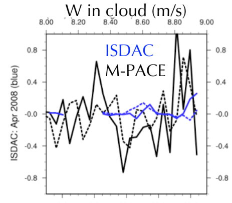
✓Model simulates the inversion that develops after 10Z and the mixed-phase cloud 10-24Z



Impact of Varying MPACE/ISDAC BCs (ER=10μm)

—— AeroS = 72 cm^{-3} (M-PACE)
······ AeroS = 1000 cm^{-3} (ISDAC)

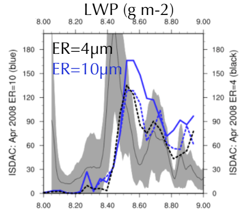


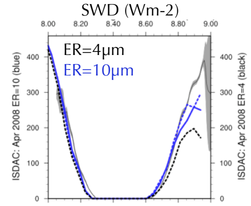


Strong surface forcing:
Glaciation *suppressed* by droplet size reduction
Weak surface forcing:
Glaciation *increased* by more efficient immersion freezing

Impact on Microphysics and Radiation (ISDAC BCs)

—— AeroS = 72 cm^{-3} (M-PACE)
······ AeroS = 1000 cm^{-3} (ISDAC)
▬ surface based measurements





With ISDAC BCS, increasing Aerosol concentration:
Microphysical feedbacks: *Decreased LWP* (and increased SWD)
Radiative feedbacks: *Decreased SWD* (and unchanged LWP)

Conclusions

Increased aerosol concentration:
1) Reduces droplet size, increasing the reflectivity of the clouds, and thereby reducing the amount of shortwave radiation that reaches the surface--the first indirect aerosol effect
2) Reduces the amount of liquid water that is maintained in the cloud (increasing the downwelling surface shortwave radiation)
3a) Under weak surface forcing conditions, glaciation in increased
3b) Under strong surface forcing conditions, glaciation is supressed (vertical motions are damped?)

The net impact of these effects depends on the strength of the surface forcing and the magnitude of the LWP

Morrison, H., J.O. Pinto, J.A. Curry, and G.M. McFarquhar, 2008: Sensitivity of modeled arctic mixed-phase stratocumulus to cloud condensation and ice nuclei over regionally-varying surface conditions. *J. Geophys. Res.*

Solomon, A., H. Morrison, O. Persson, M.D. Shupe and J.-W.Bao, 2009: Investigation of Microphysical Parameterizations of Snow and Ice in Arctic Clouds During M-PACE through Model-Observation Comparisons, *MWR*, in press.