Satellites Show Aerosol's Impact on Summer Arctic Cloud Freezing

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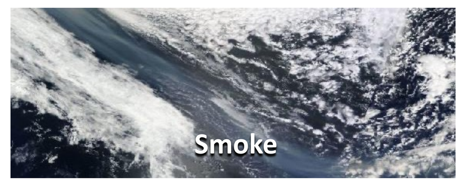
Background

Arctic aerosols affect cloud properties and climate, and others have shown Arctic aerosols are associated with cloud glaciation[1,2,3]. However, the magnitudes and mechanisms are uncertain, as are how aerosol-cloud relationships might change in a rapidly warming environment. We assessed some of the complex relationships between aerosols, surface, and meteorology in the relatively pristine summertime Arctic and quantified resulting impacts on clouds.

METHODS

We used CloudSat/CALIPSO data, AIRS RH and T, plus MERRA-2 aerosol and meteorological reanalysis products. These resources provide immense amounts of long-term vertically-resolved information that we can stratify into fine meteorological bins to:

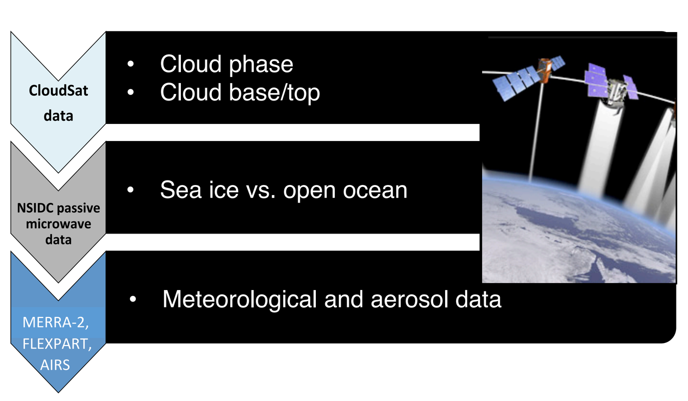


Control for co-varying meteorology

Isolate roles of surface and meteorology

Identify role of aerosol subtype

Images: NASA Worldview



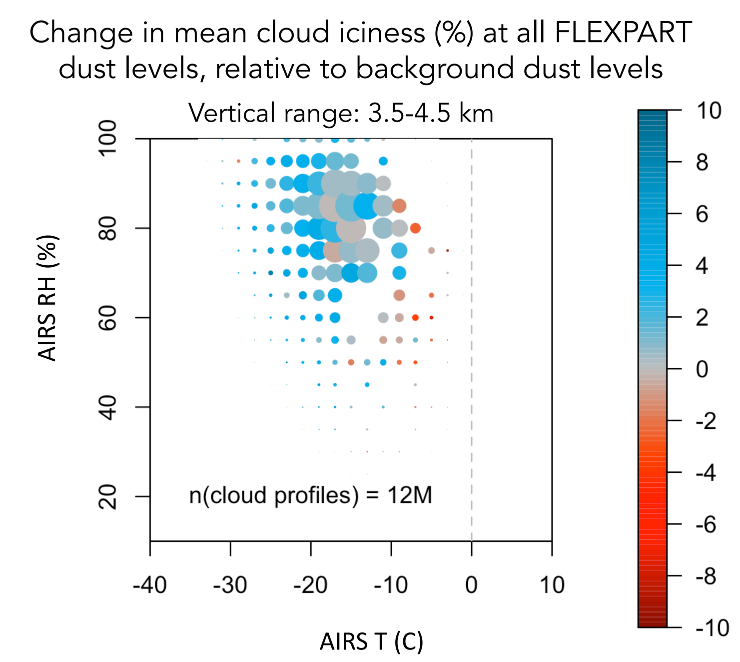
Cloud observation criteria:
- Cloud base > 0.6 km
- Clean clouds: lower 25% of aerosol data in top 5 km

Cloud "iciness" scale:
- 100% for icy clouds
- 50% for mixed phase
- 0% for liquid clouds

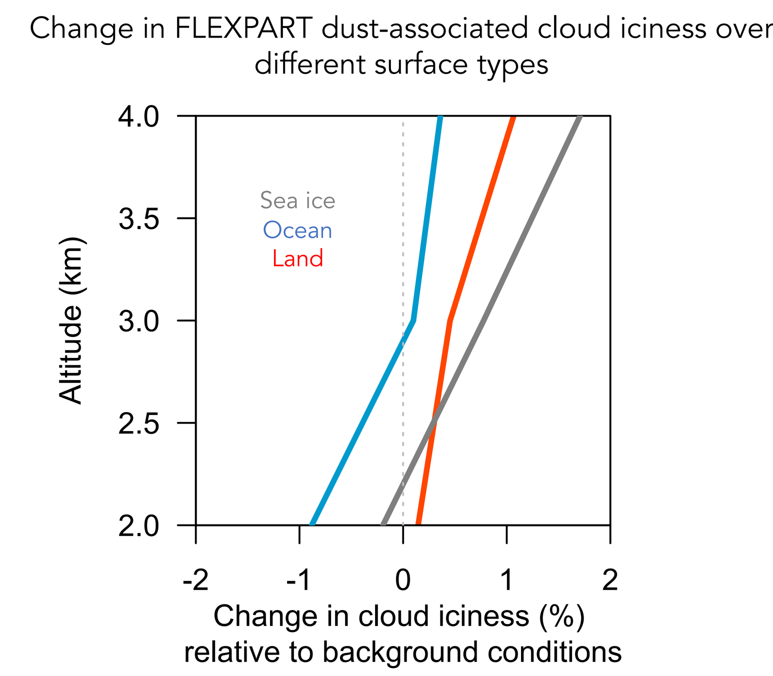
The CLDCLASS-LIDAR V5 product provides cloud phase, prevalence, and thickness. Phase is based on ECMWF cloud base and top temperatures, lidar attenuation magnitude and slope, and radar reflectivity.

MERRA-2 black carbon (BC), organic carbon (OC), and mineral dust aerosols were validated in Zamora et al., 2022. Model dust correlates poorly with CALIPSO dust below 1 km in FLEXPART and below 4 km in MERRA-2.

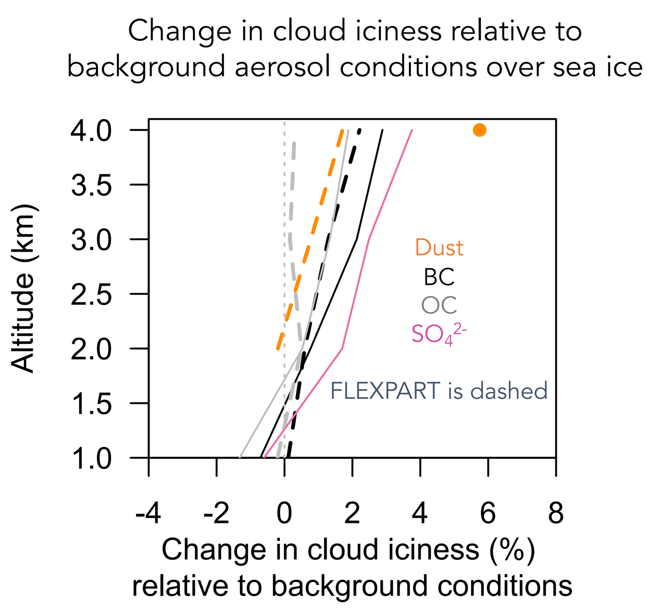
Preliminary Results



Data are binned into similar meteorological groups



FLEXPART dust aerosols are associated with icier clouds at some altitudes; effects vary with surface type

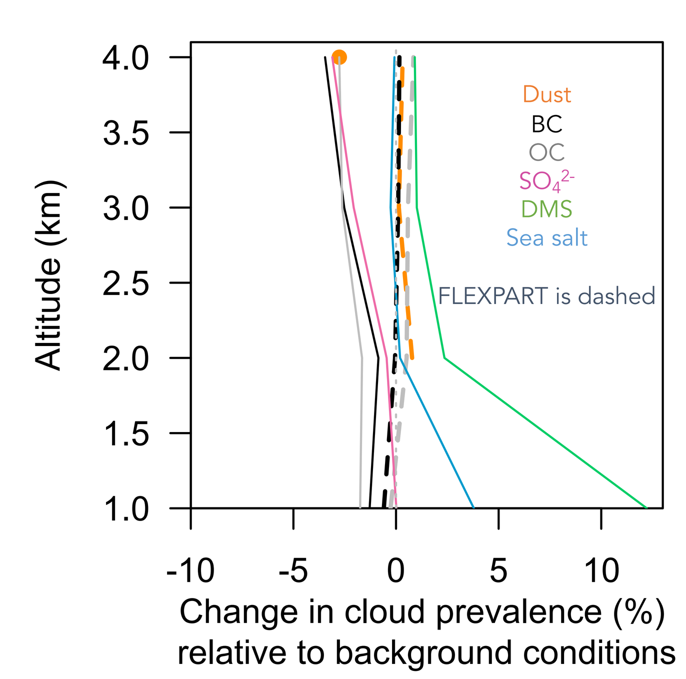


Other aerosol types are also associated with icier clouds. Large disagreement between modeled aerosols leads to uncertainty in aerosol effects

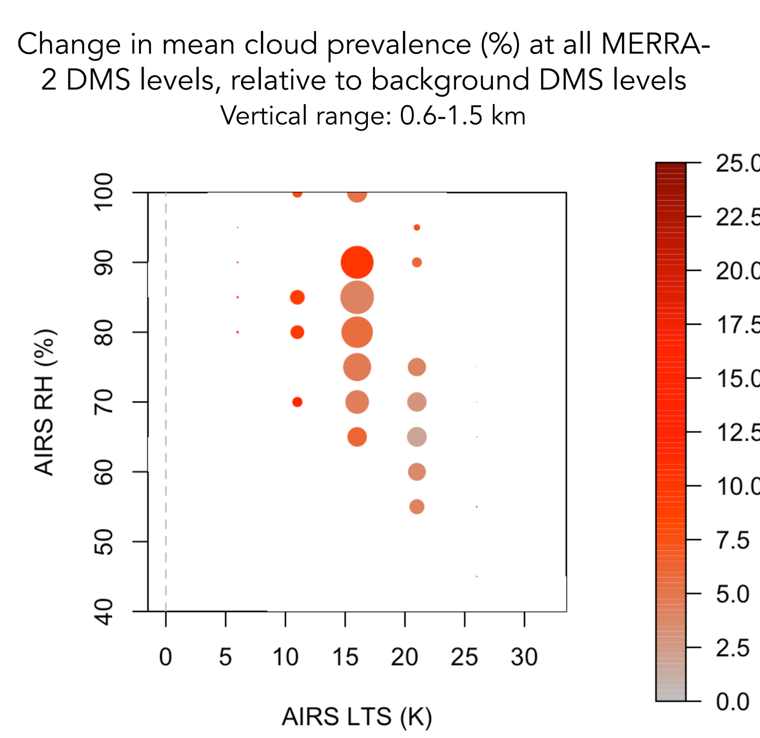
Top left: Cloud data are binned into RH, T, and lower tropospheric stability (LTS) groups (flattened to just show RH and T here). Cloud differences between average conditions and background dust aerosol conditions vary with meteorological factors, e.g., T. Blue points indicate that clouds with elevated aerosols are more likely be in mixed or ice phases than clouds in background conditions. Dot sizes are related to sample number in the bin; points with Wilcoxon rank test p>0.05 (i.e., low confidence) not shown.

Top middle: On average, dust aerosols are associated with changes in cloud iciness, based on the weighted mean of cloud differences from background in each meteorological bin, also weighted by how commonly each condition occurs. Effects are somewhat different over sea ice, open ocean, and land.

Top right: Results depend on aerosol type, and on aerosol model used.



MERRA-2 DMS gas is associated with more prevalent clouds near the surface



As might be expected if small particles were acting as CCN, DMS-related cloud prevalence effects appear to be higher in less stable and more humid environments

Preliminary Conclusions

In line with previous studies, dust aerosol layers over the summertime Arctic sea ice are associated with icier clouds, at least between 2.5-4.5 km; at cold conditions present at 3.5-4.5 km, up to ~6% clouds transition to an icier phase when dust levels are elevated relative to background levels. However, summertime dust-associated cloud glaciation is uncommon at temperatures > -10 °C and not likely at lower altitudes in the summer.

We use DMS concentrations as a proxy for marine new particle formation. When DMS is elevated, open ocean clouds near the surface (0.6-1.5 km) are up to 12% more prevalent.

Note: the system is very noisy; results only apply to statistically large samples, and not necessarily to individual clouds. Work is ongoing and will benefit from further aerosol model validation and improvement.

These findings allow us to make some educated guesses about where key processes are occurring, such as ice nucleation from dust, and to more effectively prioritize aircraft targeting in future field campaigns, such as ARCSIX.

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