Oliktok Point Site Science: Aerosol-cloud interactions

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Introduction

- Cloud condensation nuclei (CCN) and ice nucleating particle (INP) modulation of cloud microphysics is one of the least understood atmospheric processes.
- Due to limited observations, aerosol-cloud interactions in the Arctic are especially not well constrained.
- The Oliktok Point Site Science team has several research projects associated with improving understanding of Arctic aerosol-cloud interactions at the ARM facilities in northern Alaska.

Using balloon-borne measurements for evaluation of aerosol-cloud interactions

Motivation: Vertical profiling of aerosols, especially in the Arctic, is very limited. To improve understanding of aerosol-cloud interactions, measurements of aerosols at the ground and aloft are needed.

Data set: Evaluation of aerosol size distributions via tethered balloon during the Inaugural Campaigns for ARM Research using Unmanned Systems (ICARUS). Several case studies are under evaluation to shed light on aerosol sources and resulting implications for cloud formation through observational and modelling approaches. __See poster #17 by de Boer et al. for initial results.__

Parameterizing CCN and INP as a Single Population

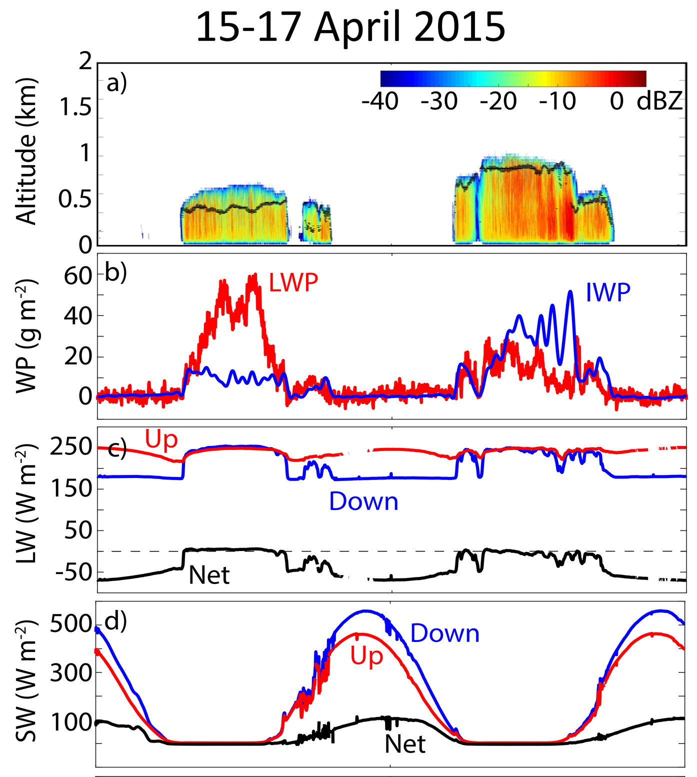
$$\frac{\partial N_{CCN}}{\partial t} + ADV + DIFF = \frac{\partial N_{CCN}}{\partial t}\Big|_{subsidence} + \frac{\partial N_{CCN}}{\partial t}\Big|_{activation} + \frac{\partial N_{CCN}}{\partial t}\Big|_{evaporation}$$

$$N_{INP} = I * N_{NC} * 4.0\times10^{-7} * S(t)$$

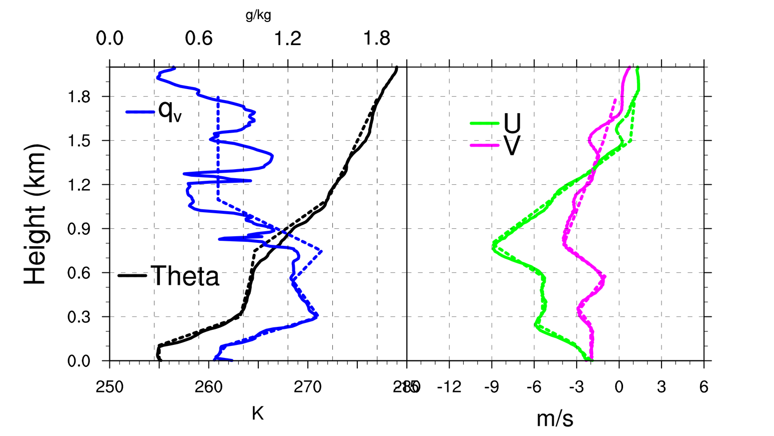
Model used: WRFLESV3.3.1

Initial Aerosol Concentrations:
Wintertime, 1/8X Control CCN ~20 cm^{-3}
Springtime, Control CCN ~130 cm^{-3}
Polluted, 8X Control CCN ~1000 cm^{-3}

Measurements at Oliktok Point, AK
15-17 April 2015

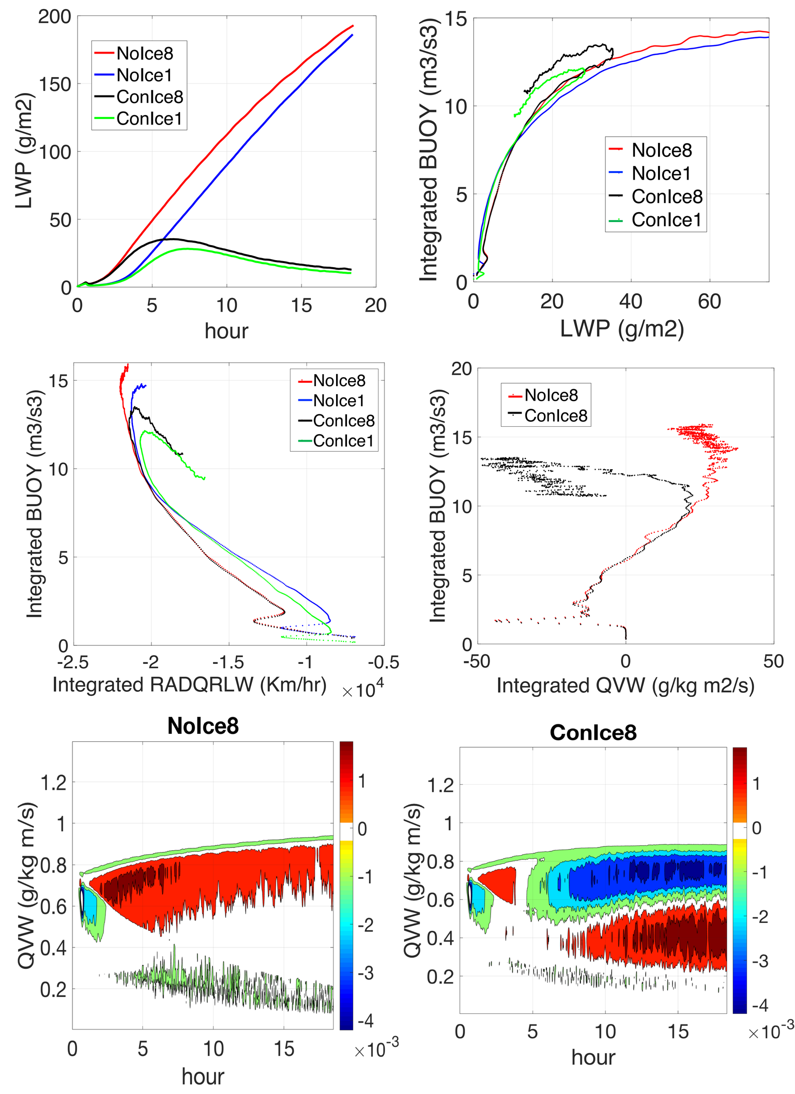


Initial State: 0 UTC 17 April 2015
Sounding (solid) Initial profiles used in the WRFLES experiments (dashed)

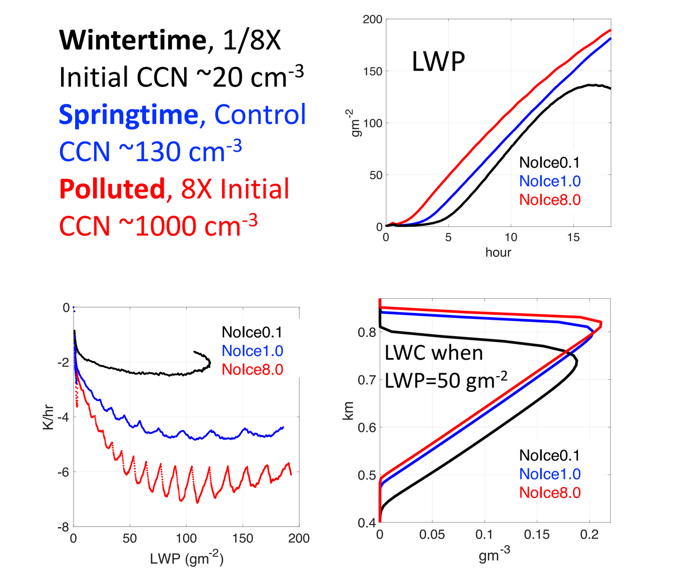


Left: water vapor mixing ratio (q_v) and potential temperature (theta), in units of g kg^{-1}, and Kelvin respectively. Right: zonal wind (U) and meridional wind (V), in units of m s^{-1}. The dashed line overlying water vapor mixing ratio is the initial profile for the total water mixing ratio.

Sensitivity to Ice Formation
Constant Ice Runs (IN=A/CCN):
Ice formation (1) depletes water vapor BUT increases vertical water vapor flux, maintaining TKE with less LWP
(2) reduces LWP causing larger sensitivity to aerosol perturbations



No Ice Runs: CCN perturbations impact cloud structure through LW emissivity (sharper cloud top for increased CCN)
--impacts persist even when the cloud is a blackbody.

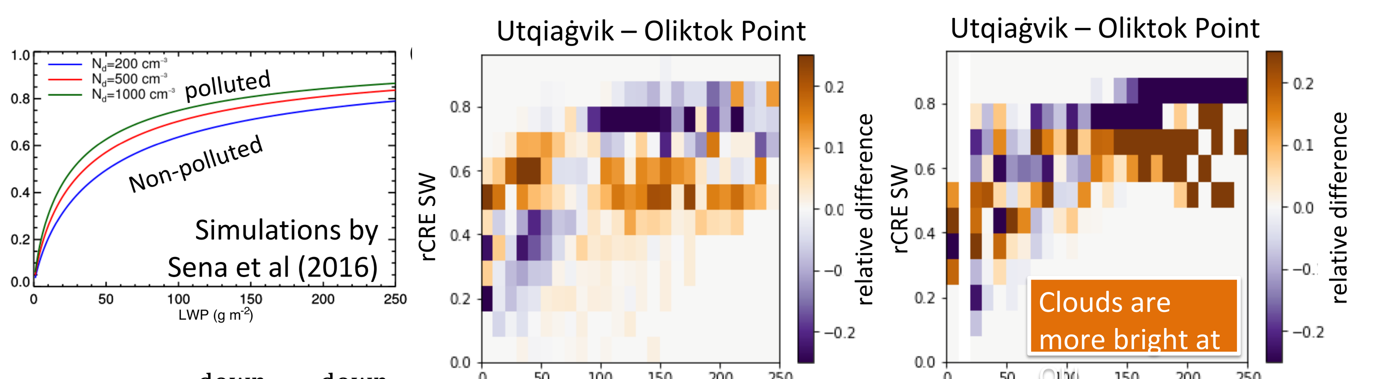


Anthropogenic pollution and cloud properties at the North Slope of Alaska

Motivation: Oliktok Point (OLI) and Utqiaġvik/Barrow (NSA) have similar synoptic forcing, but different aerosol backgrounds, because Oliktok Point is at the edge of the Prudhoe Bay oilfield -> Together, they form a natural laboratory for studying aerosol cloud interaction.

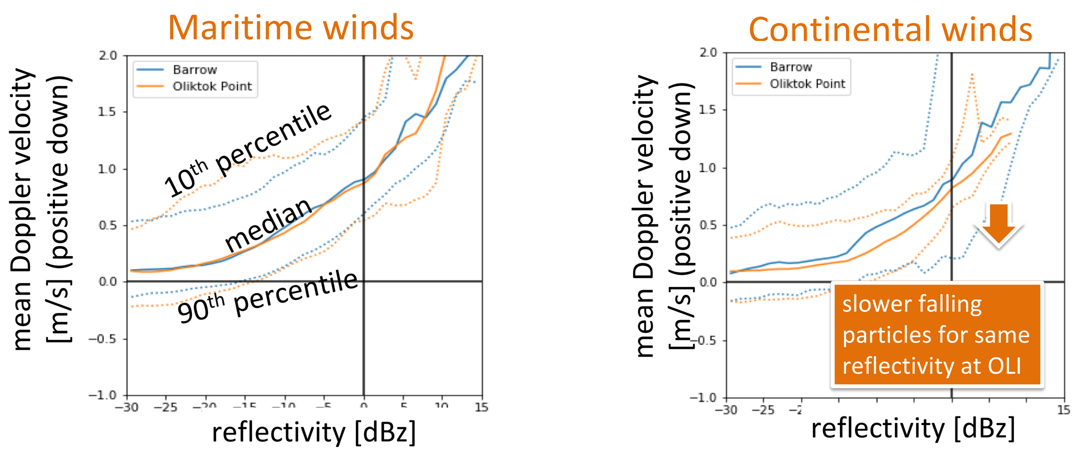
Data set: We use data from the two ARM sites of summer 2016. Analysis is limited to warm shallow clouds. For both sites, we compare continental (i.e. potentially polluted) and maritime (i.e. potentially pristine) air masses.

Radiation perspective: polluted clouds are brighter as expected using the shortwave relative cloud radiative effect. This quantity does not depend on surface albedo and less on solar zenith angle, but on LWP and droplet number concentration.

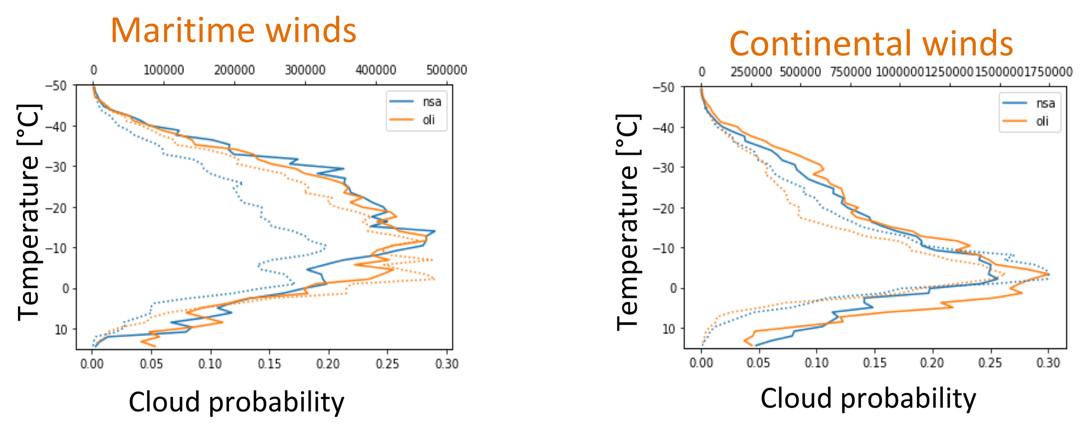


$$rCRE = \frac{F^{down}_{clear} - F^{down}_{all}}{F^{down}_{clear}}$$

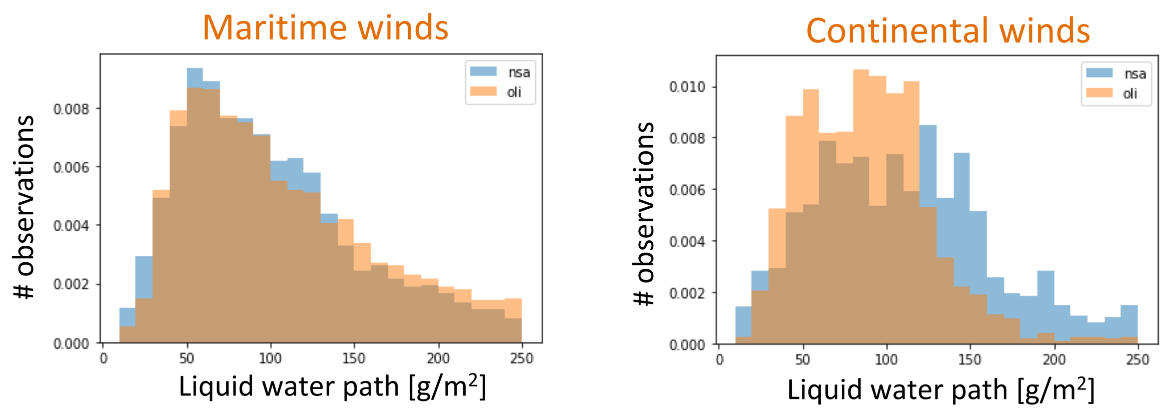
Radar perspective: The generation of drizzle is suppressed at Oliktok Point in comparison to Utqiaġvik/Barrow. When comparing median values for the whole data set, the mean Doppler velocity is reduced for the same radar reflectivity.



Radar perspective: The probability to observe a cloud with radar as a function of temperature (solid line, proxy for season and height) is increased at Oliktok Point for -5 to 5°C. Is that related to cloud life time?



MWR perspective: Interestingly, the continental clouds have higher LWP for Barrow in comparison to the maritime ones, but there is only little change for Oliktok Point.



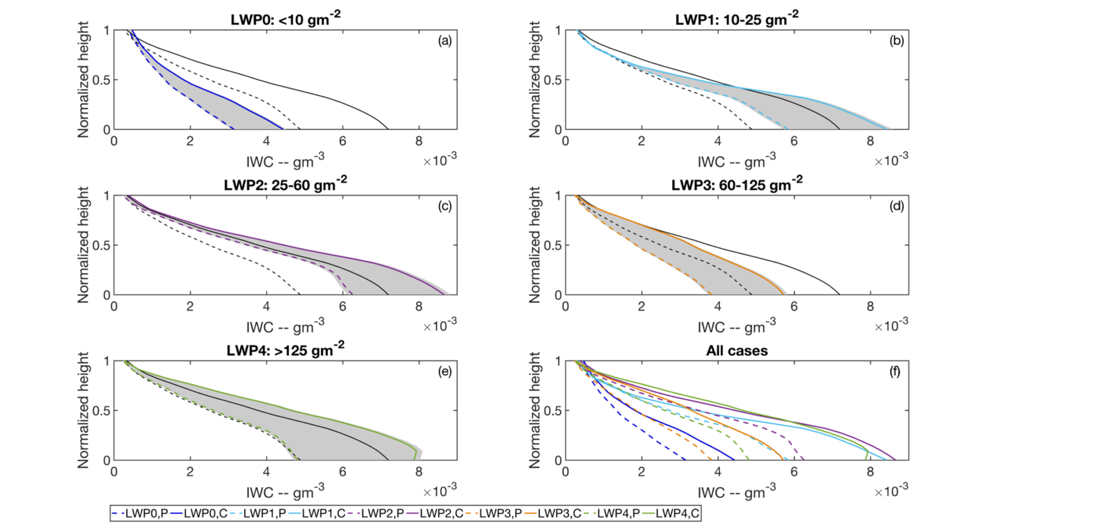
Only radar cloud base & top > 0°C

Suppression of cloud ice due to aerosols at Utqiaġvik

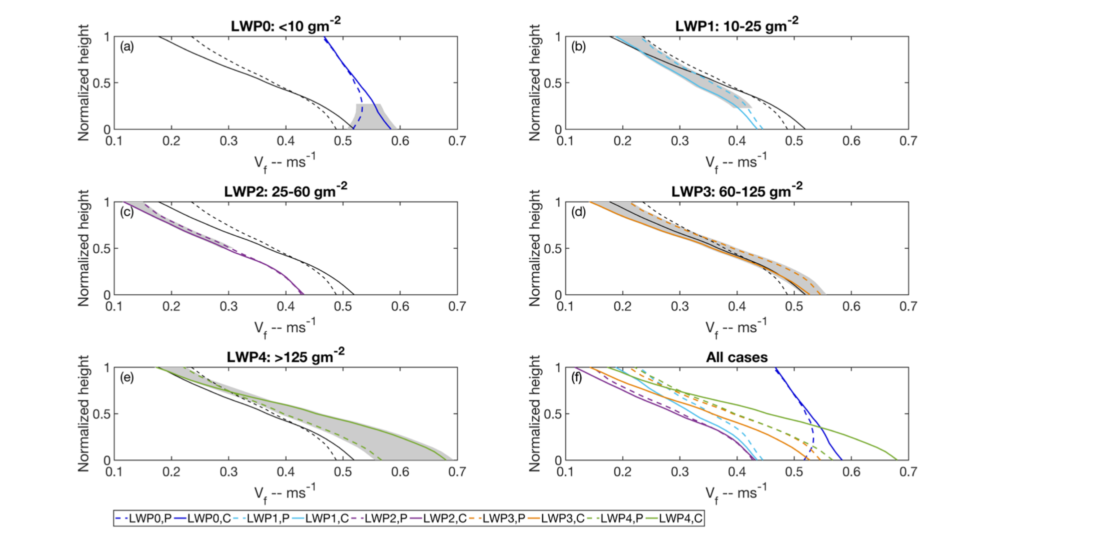
Motivation: Determining aerosol effects on mixed-phase cloud ice production is difficult because we have limited in cloud observations of liquid and ice properties.

Data set: We use a 9-year record of surface aerosol scattering coefficients and radar derived cloud ice water content (IWC) profiles to determine the effect of high and low aerosol concentrations on the levels of IWC in cloud layers. This understanding is an initial step in determining how aerosol effects (e.g. ice nuclei availability, freezing point depression, etc.) sum to influence the IWC production in these clouds.

IWC profiles: Shown within the mixed-phase cloud layer under 5 different liquid water path regimes. For each case, clean clouds have significantly higher IWC at cloud base than clouds found in polluted conditions. At cloud top, IWC levels are comparable.



Hydrometeor fall speeds: Indicate the presence of smaller sized ice crystals in clean clouds at cloud top. Given the similar IWC values in this upper region of the cloud, the implication is that there are fewer, but larger, ice crystals produced at cloud top in polluted clouds. Therefore, the best explanation of the high IWC values observed by cloud base in clean clouds, is more efficient secondary ice production (e.g. ice deposition and riming). We suspect that clean clouds have high depositional efficiency because ice crystal number is elevated, and riming efficiency is high due to the larger average size of the liquid droplets present in the cloud layer.



References

Norgren, M. S., de Boer, G., and Shupe, M. D.: Observed aerosol suppression of cloud ice in low-level Arctic mixed-phase clouds, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2017-1191, in review, 2018.

Sena, E. T., A. McComiskey, and G. Feingold, 2016: A long-term study of aerosol–cloud interactions and their radiative effect at the Southern Great Plains using ground-based measurements. Atmos. Chem. Phys., 16, 11301–11318, http://dx.doi.org/10.5194/acp-16-11301-2016.

Solomon, A., G. de Boer, C. Cox, J. Creamean, A. McComiskey. And M. Shupe, 2018: The relative impact of perturbations in cloud condensation nuclei and ice nucleating particle concentrations on the longwave forcing of Arctic Mixed-Phase Stratocumulus Clouds. ACP. In prep.

Acknowledgments

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