How can the Cold-Air Outbreak Experiment in the Sub-Arctic Region (CAESAR) contribute to larger goals of improved understanding & prediction of mixed-phase processes and cloud morphology?

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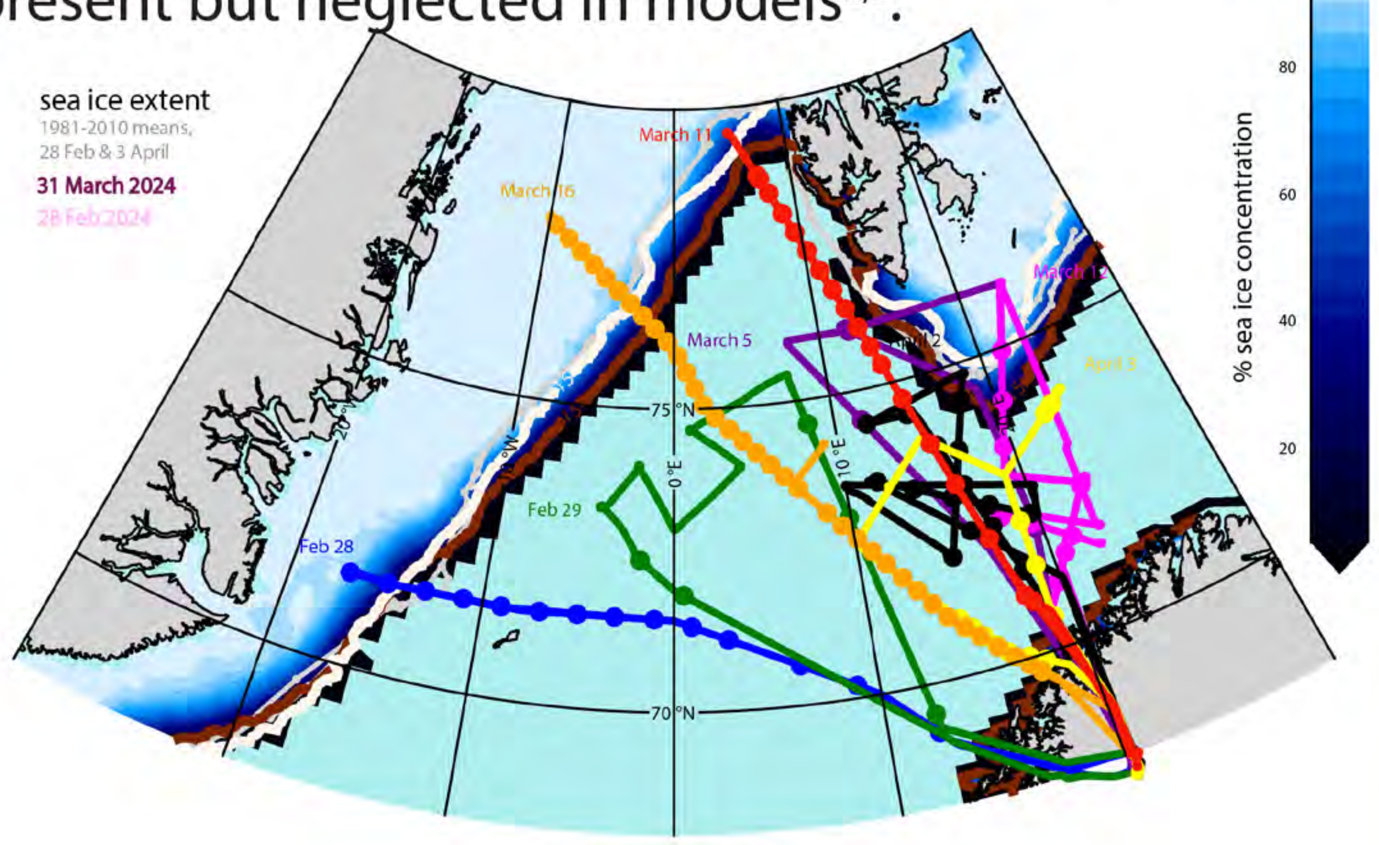
Field Campaign Motivation

- An Arctic warming 2-4 times the global mean motivates drive to better understand and depict cold-air outbreaks (CAOs) flowing off the sea-ice from both a weather and climate perspective. As sea ice retreats, the fetch over open water increases fueling more precip development downstream[1]. The proper representation of mixed-phase processes is also important for top-of-atmosphere radiation and climate prediction. While primary ice nucleation is overestimated by traditional parameterizations, secondary ice production processes are typically present but neglected in models[2,3].



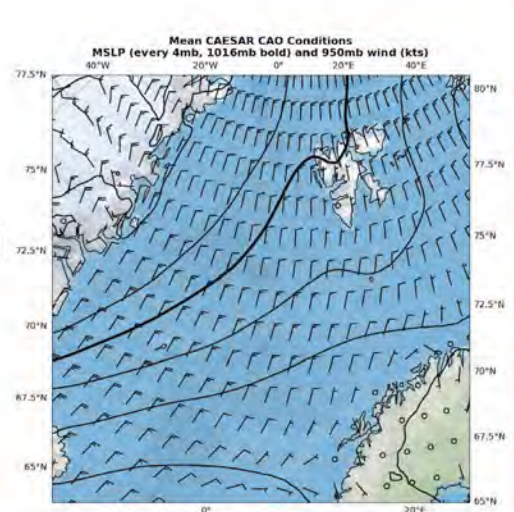


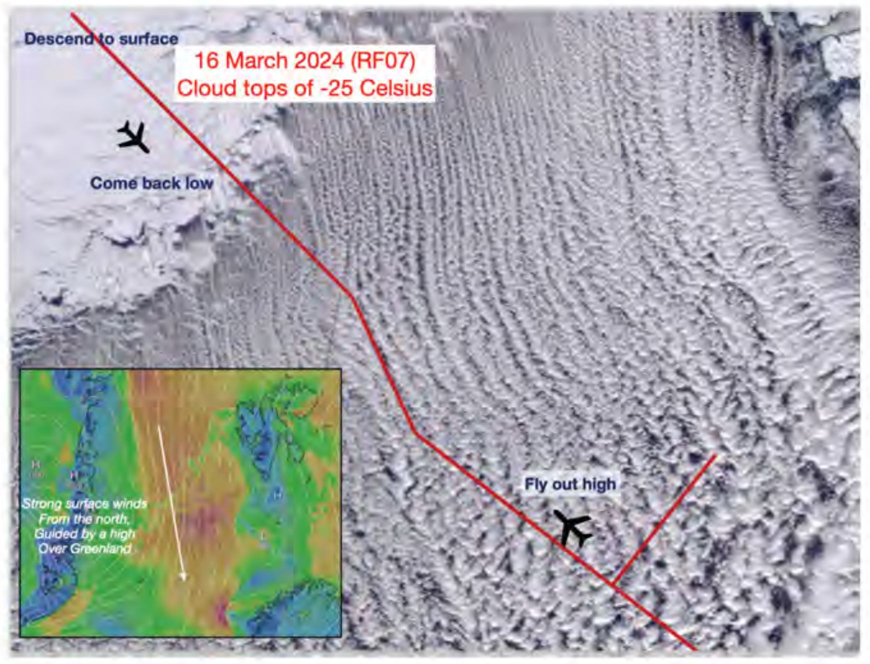
Fig. 1: The sea ice extent on March 31, 2024 (maroon line) was larger than on Feb. 28, 2024 (pink line) because of anomalously high CAO activity in March, bringing this spring's sea ice extent close to (and exceeding in places) climatological values. Multi-year averages show spring sea ice retreating off of eastern Greenland since 1981 (not shown). Data from NSIDC.

The CAESAR Field Campaign

NSF supported the deployment of the NCAR C-130 aircraft to Kiruna, Sweden, with 8 research flights spanning 28 Feb. to 3 April of 2024 (Fig. 1). The plane was well-equipped with both remote and in-situ sensors.

Fig. 2: A strength of CAESAR was its comprehensive suite of instruments. Not shown are the aerosol sensorss (CCN, UHSAS, SP2) and trace gas sensors (CO, O3, H2O isotopes). Photo credits: Sarah Woods (left), Zhien Wang (right).

What can we achieve with this dataset?



CAESAR sampled CAO conditions on every flight. Microphysics were preferentially collected at colder in-cloud temps than sampled recently in the winter northwest Atlantic[4] and southern Oceans[5] (Fig. 3).

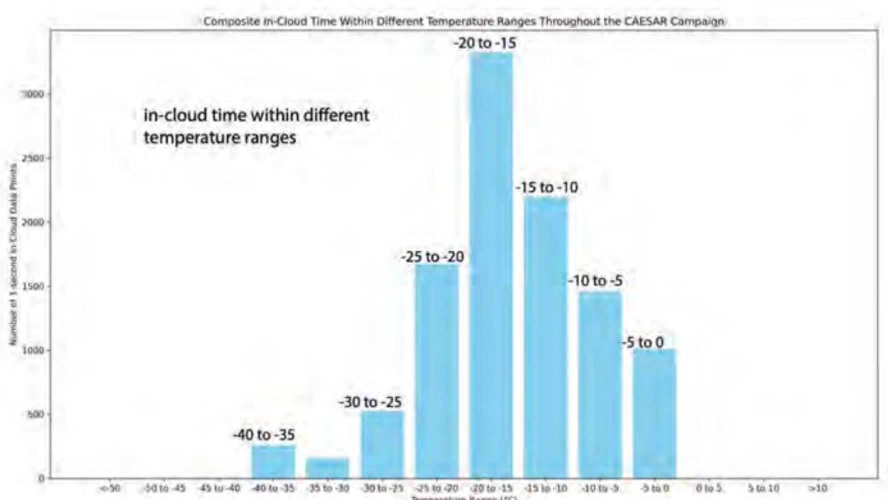
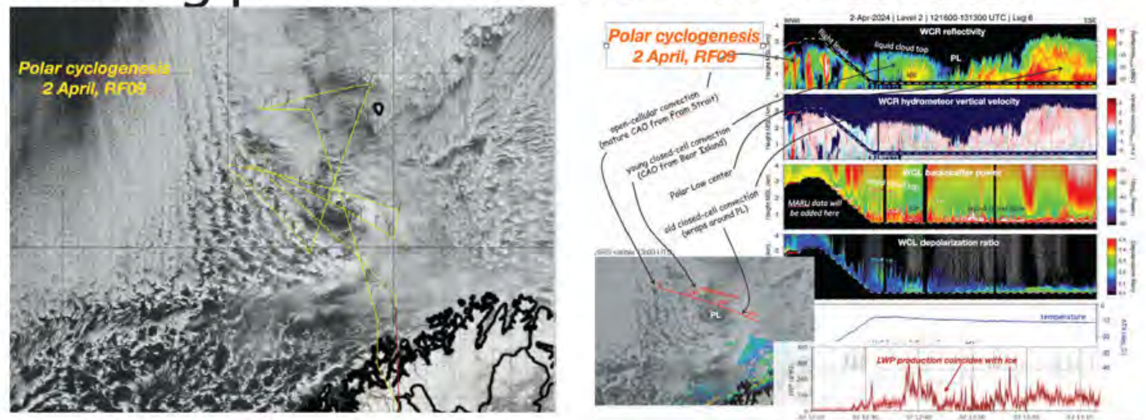
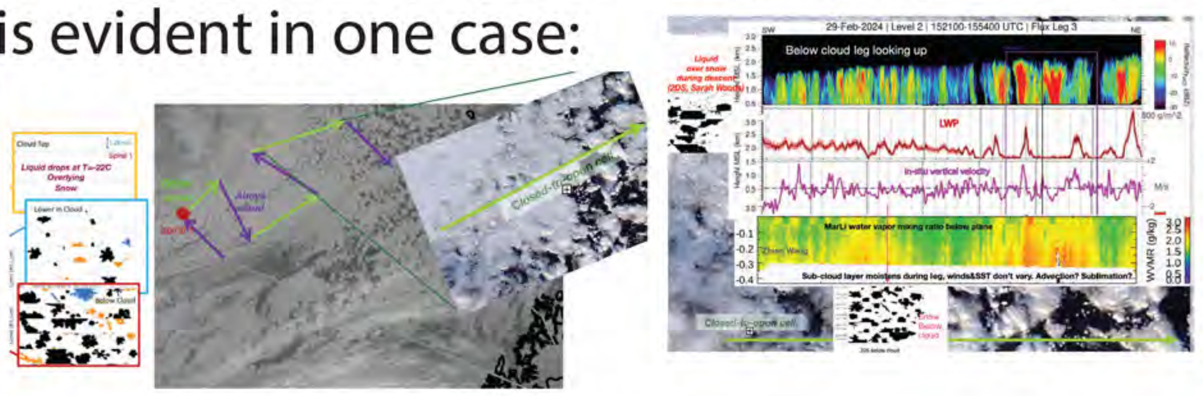


Fig. 3: In-cloud temperatures were most commonly between -15C to -20C. Plot by Nick Amundsen.

1): "golden case": a coastal polar low near Kiruna was well-documented and now becoming the basis of a focused modeling study. such efforts can uncover missing processes/model deficiencies.



2): Micro2Macro: most CAOs were organized into cloud streets, suggesting mean wind shear is more important to organizing the cloud structure than precipitation/cold pools. this relationship is underexplored. the transition of closed- to open-celled clouds is evident in one case:



3): forecasts->reanalysis/observations: AROME-Arctic forecasts at 2.5 km grid res., initialized by ECMWF & using similar model physics, combined with ECMWF forecasts/reanalyses at ~31km grid res., combined with obs. provide a hierarchical approach to discerning model bias origins in microphysics/turbulence.

[1]Bailey, H., A. Hubbard, E. S. Klein, K.-R. Mustonen, P. D. Akers, H. Marttila, and J. M. Welker, 2021: Arctic sea-ice loss fuels extreme European snowfall. Nat. Geosci., 14, 283–288, doi:10.1038/s41561-021-00719-y. [2]Atlas, R. L., C. S. Bretherton, M. F. Khairoutdinov, and P. N. Blossey, 2022: Hallett-Mossop rime splintering dims cumulus clouds over the southern ocean: New insight from nudged global storm-resolving simulations. AGU Adv., 3, e2021AV000454, doi.:10.1029/2021AV000454, [3]McCluskey, C. S., and Coauthors, 2018: Observations of ice nucleating particles over southern ocean waters. Geophys. Res. Lett., 45, 11 989–11 997, doi:10.1029/2018GL079981. [4]Seethala, C., P. Zuidema, S. Kirschler, C. Voigt, B. Cairns, E. C. Crosbie, R. Ferrare, J. Hair, D. Painemal, T. Shingler, M. Shook, K. L.Thornhill,F. Tornow, A. Sorooshian, 2024: Microphysical evolution in mixed-phase mid-latitudemarine cold-air outbreaks. J. Atmos. Sci., 81, pp. 1725-1747, doi:10.1175/JAS-D-23-0203.1. [5]D'Alessandro, J. J., McFarquhar, G. M., Wu, W., Stith, J. L., Jensen, J. B., & Rauber, R. M., 2021: Characterizing the occurrence and spatial heterogeneity of liquid, ice and mixed phase low-level clouds over the Southern Ocean using in situ observations acquired during SOCRATES. J. Geophys. Res., 126, e2020JD034482. doi:10.1029/2020JD034482
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