An isotopic approach for evaluating ice particle growth in mixed phase-clouds

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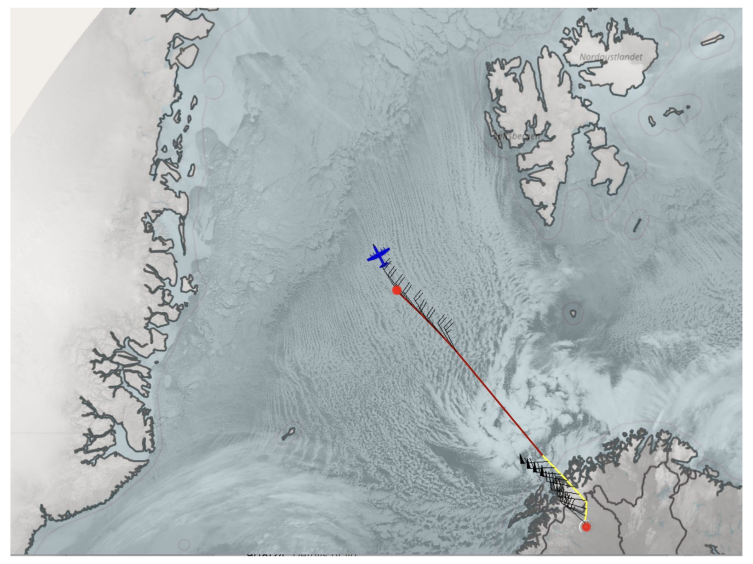
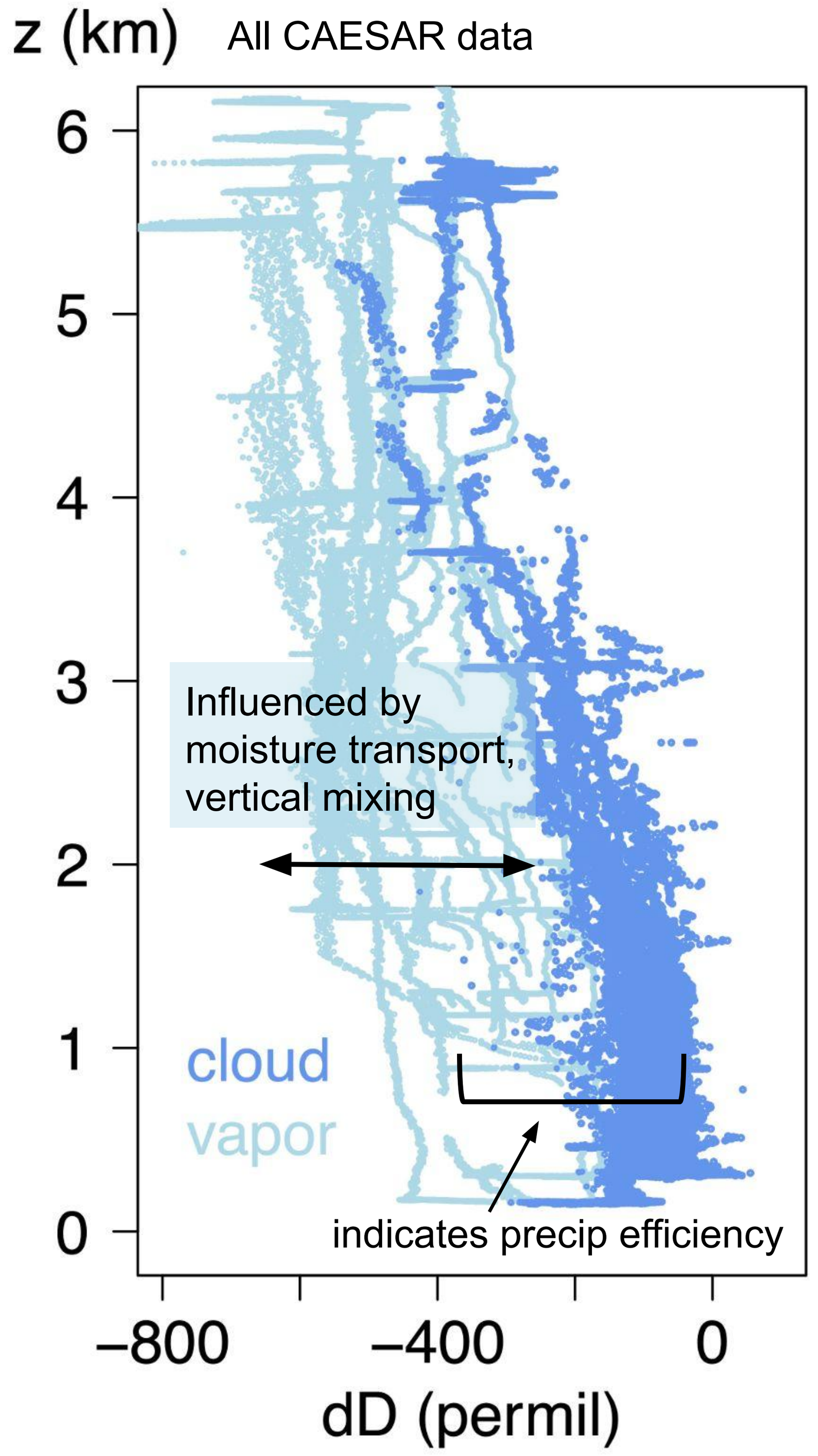
CAESAR—the Cold-Air Outbreak Experiment in the Sub-Arctic Region—set out to study the links between large-scale dynamics, regional evaporative fluxes, and microphysics, as well as their influence on cloud patterns and precipitation. Measurements of water's isotope ratios were made in cloud and vapor (total water) to trace the origin of moisture in the Arctic atmosphere and to help evaluate the efficiency of ice growth and precipitation formation. Here, we consider opportunities to use such measurements to distinguish cloud particle growth by riming vs. vapor deposition.



Cloud streets streaming off the sea ice edge in the Norwegian Sea are typical of cold-air outbreaks. CAESAR flights sampled these clouds by flying with the predominant flow.

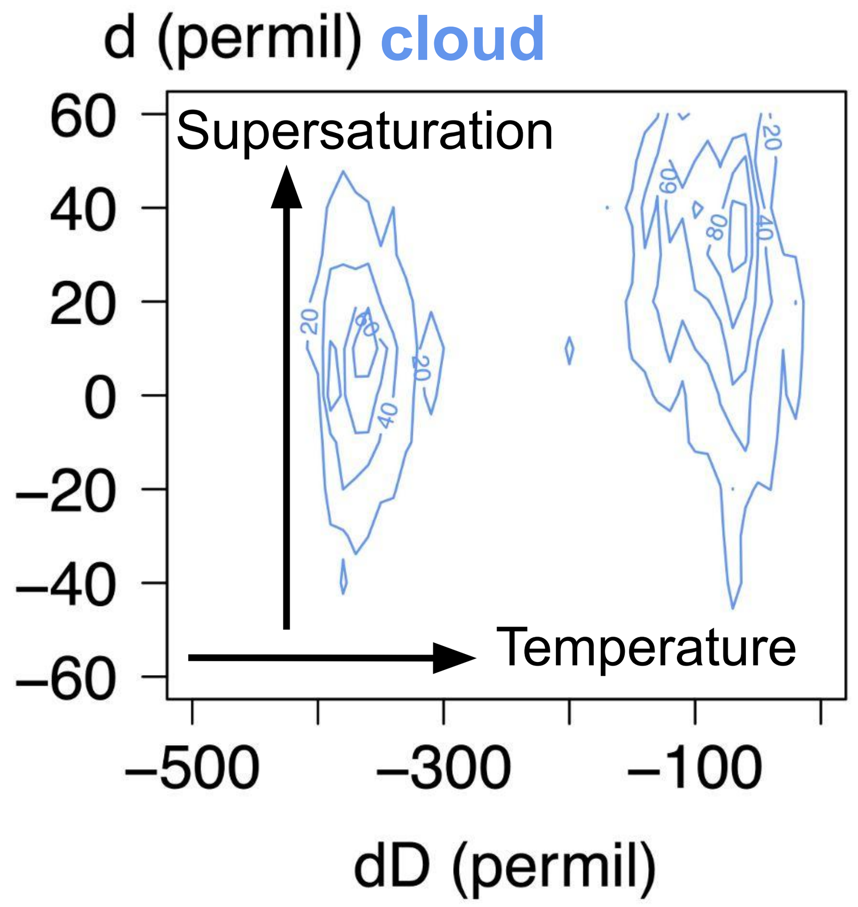
The NSF-NCAR C-130 was outfitted with remote sensors and in-situ instruments. Eight full-length research flights were flown between February and April 2024.

The Counterflow Virtual Impactor (CVI, inlet shown above) separates cloud particles from vapor and aerosol, making it possible to sample isotope ratios in condensate.

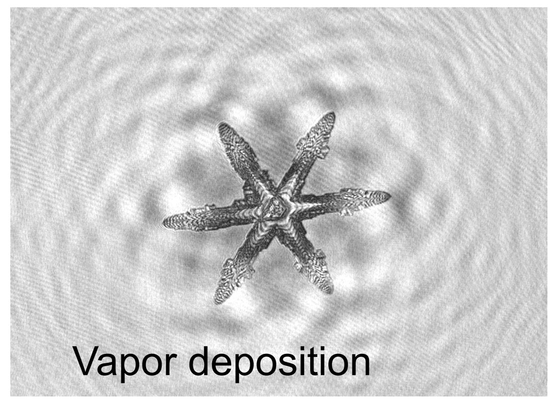


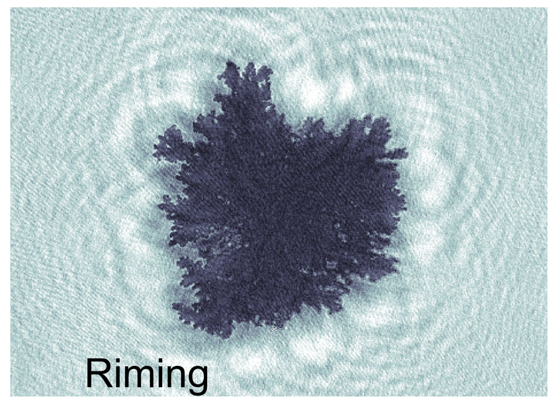
$H_2{}^{16}O$, HDO, $H_2{}^{18}O$ change phase and diffuse with different efficiencies depending on temperature and relative humidity. Their ratios **(dD, d^{18}O)** provide integrated records of the moist processes that define characteristic moisture transport paths. Deuterium excess **(d) = dD - 8 × d^{18}O is influenced by diffusive exchange**, which should be especially prominent when ice particles grow by vapor deposition.

During CAESAR, water vapor isotope ratios were measured to evaluate the relative contributions of local and remote moisture sources to Arctic clouds. Cloud condensate isotope ratios were measured to evaluate ice growth and precipitation efficiency.

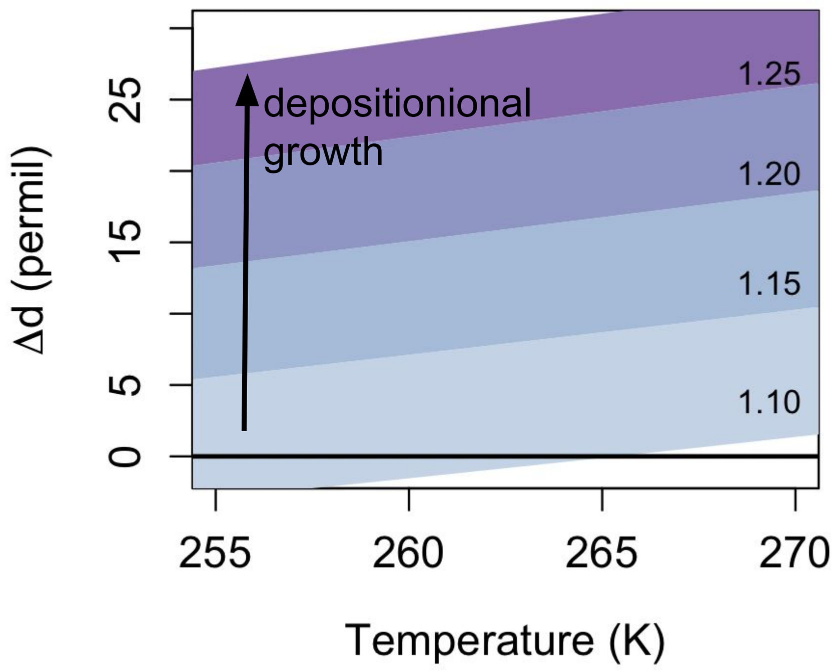


How should we interpret the CAESAR cloud isotopic data?





Expected deuterium-excess differences (Δd) for ice particles grown by deposition vs. riming

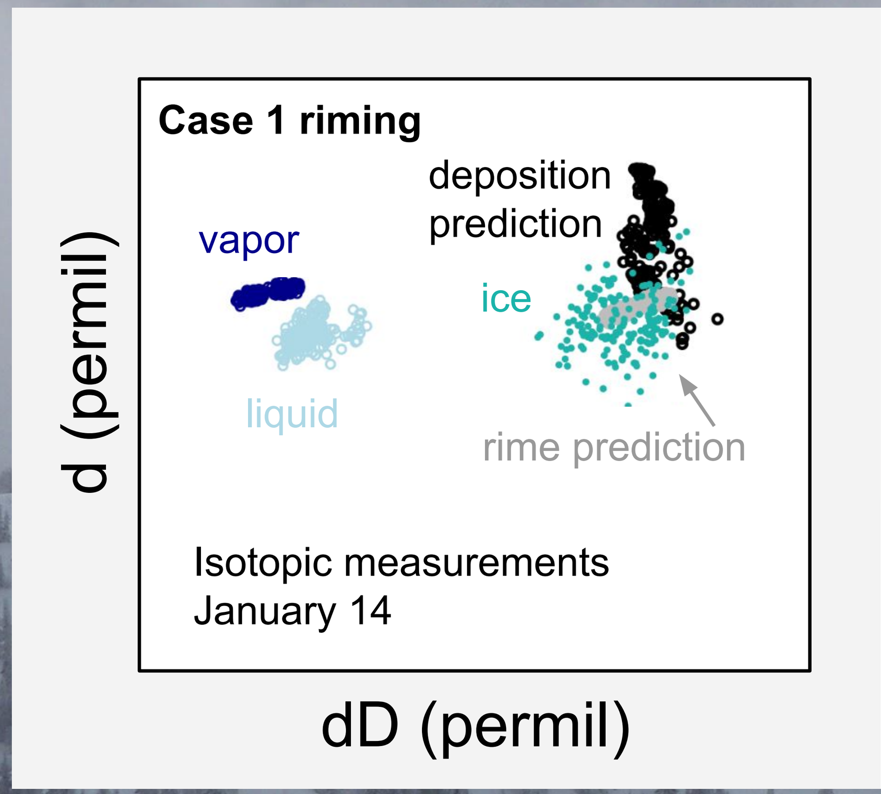


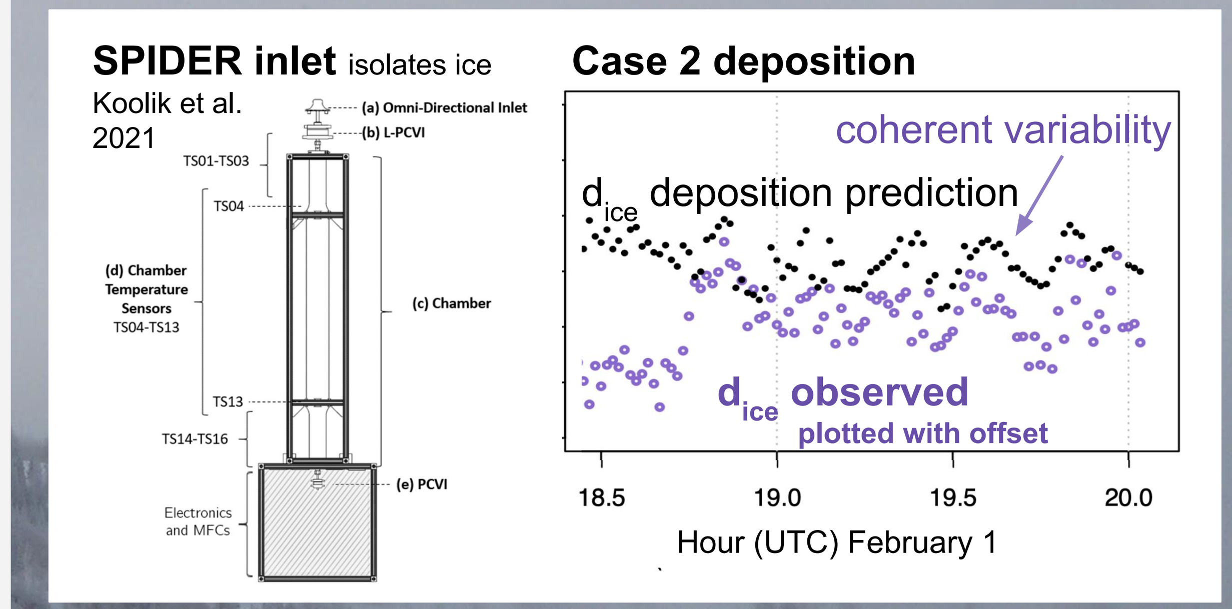
The expected d-difference is larger as the saturation ratio (filled contours, labeled) and temperature increase.

Condensate isotope ratios will have higher deuterium-excess if

- ice particles grow by deposition
- ice water content greatly exceeds liquid water content

2022 Storm Peak Laboratory experiment—measurements of isotope ratios in mixed-phase clouds tested our ability to detect expected differences between riming and deposition. Unlike in CAESAR, the measurements from Colorado utilized a novel 3-phase separating inlet (SPIDER, below) that allowed us to sample ice, supercooled liquid droplets, and vapor separately. Cases of riming (1) and deposition (2) are shown below.





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