Observed Ambient Conditions in Winter Storm Cloud Sandwiches

NC STATE

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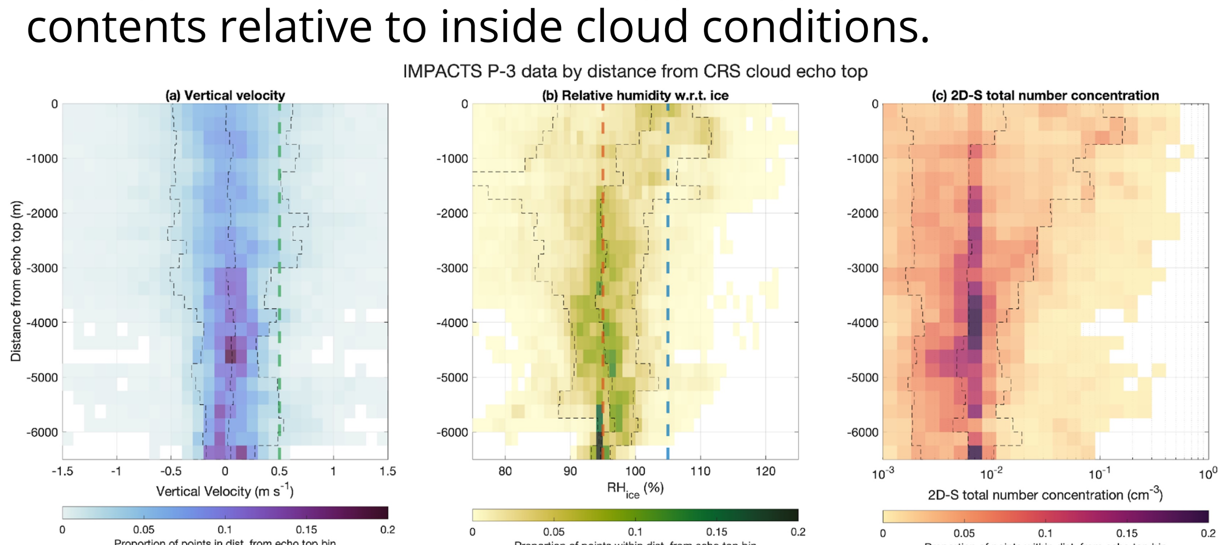
Motivation

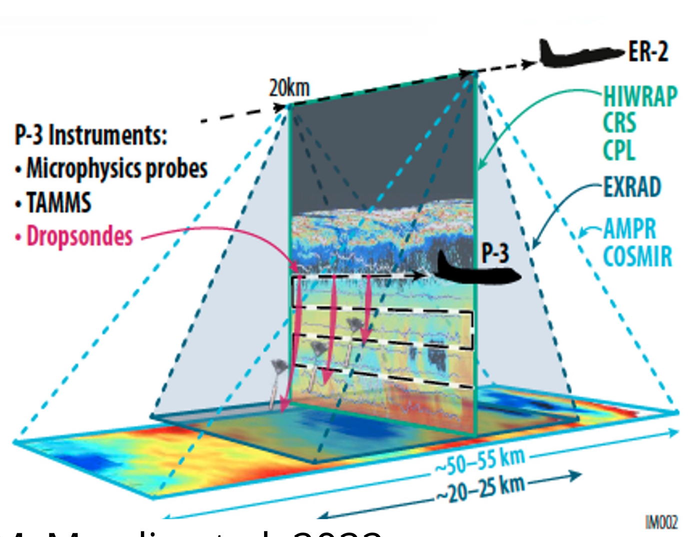
Aircraft in situ observations show that non-orographic winter storms have few updrafts sufficient to loft precipitation-size ice (Allen et al, 2025). Stronger updrafts are more common within layers of generating cells near cloud top. As the snow particles descend toward the surface they pass through varying conditions of temperature and relative humidity. It not uncommon for **cloud sandwiches** – clear layers between two layers of visible clouds – to occur in winter storms. We examine conditions within cloud sandwiches to better understand their potential role in reducing precipitation-ice water contents relative to inside cloud conditions.



2D histograms depicting 100-m horizontal scale (a) in situ vertical velocity, (b) RHice, and (c) 2D-S particle concentration relative to distance from cloud echo tops from IMPACTS data (Allen et al, 2025).

Data and Methods

The NASA Investigation of Microphysics and Precipitation for Atlantic-Coast Threatening Snowstorms (IMPACTS) campaign flew two research aircraft equipped with weather instruments into storms over three winter seasons. The NASA ER-2 aircraft flew at 20 km altitude and had downward-looking sensors including a cloud radar (CRS). The NASA P-3 aircraft flew at lower altitudes and collected in situ measurements and video observations along the flight track. Missions were designed so that many ER-2 and P-3 flight legs were time-coordinated with the P-3 flying under the ER-2.



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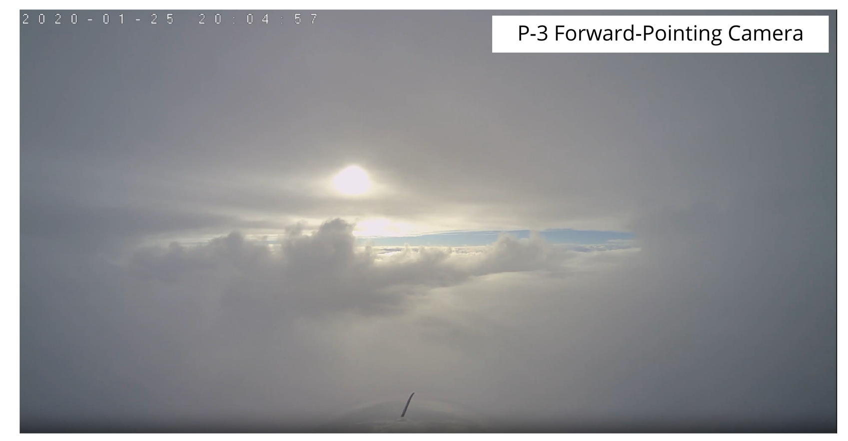
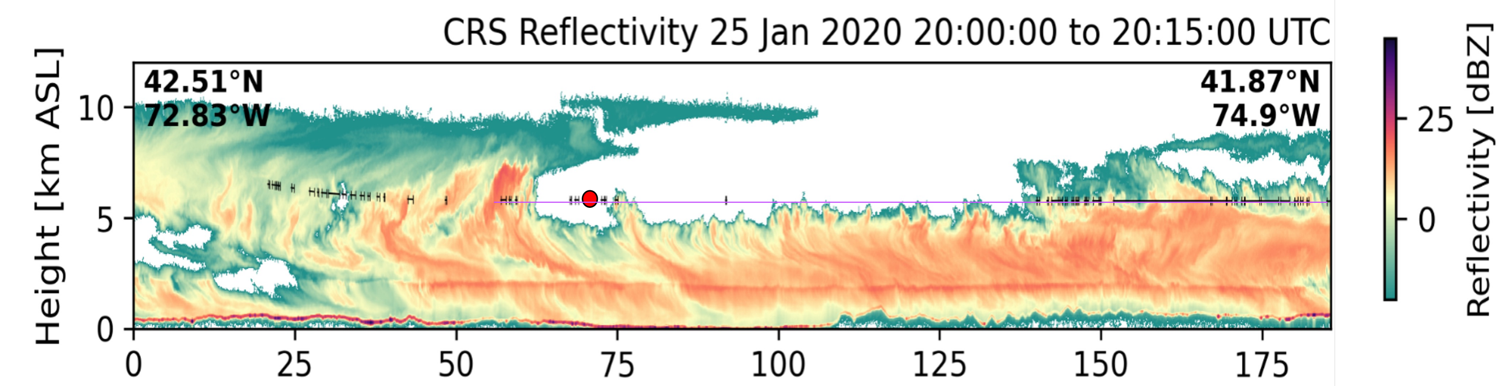
Using visual inspection, we examined the videos from all the IMPACTS daylight flight legs and found 57 leg segments, each ≈15 minutes in length, that contained a prominent cloud sandwich.

We used the in situ data from the P-3 aircraft as well as CRS data from the ER-2 aircraft to characterize conditions in each individual cloud sandwich leg. Information from time series of relative humidity with respect to both water and ice, 2D-S particle concentrations and vertical air motions are combined with cloud radar reflectivity along the flight leg and screen captures from the P-3 videos of the cloud sandwiches.

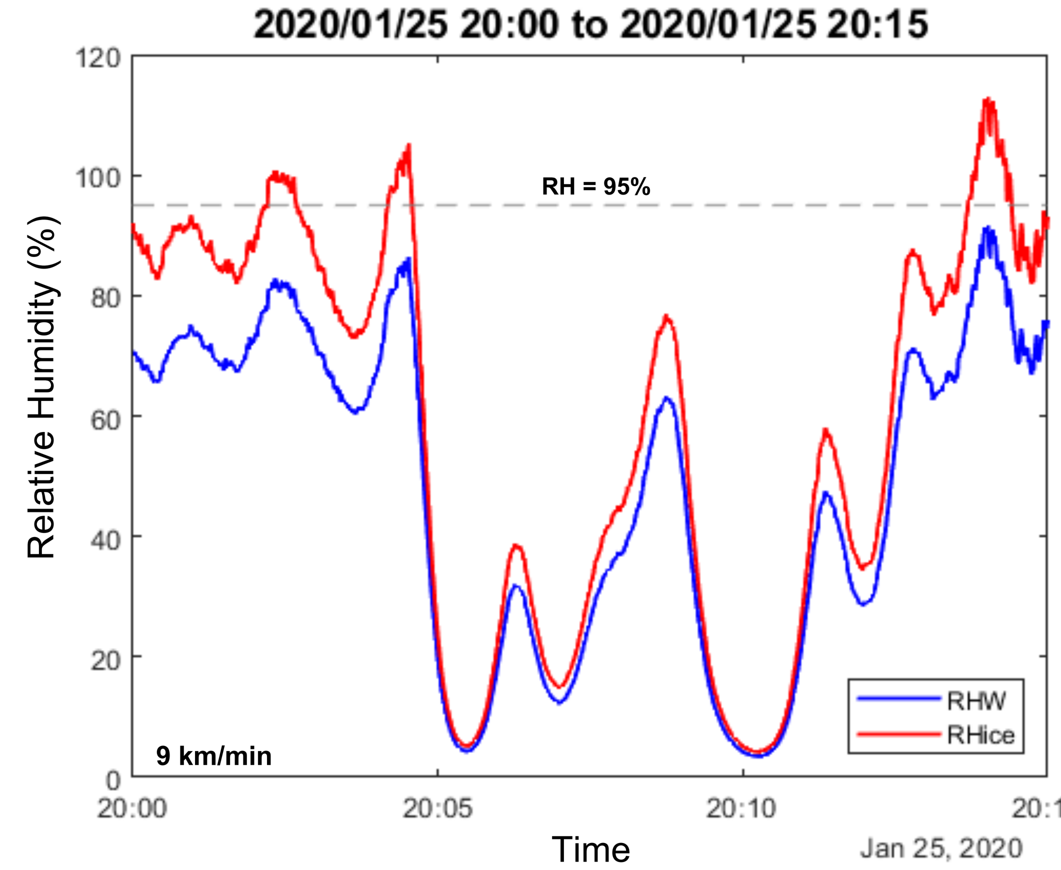
20200125 - 20:00 to 20:15 UTC Flight Leg



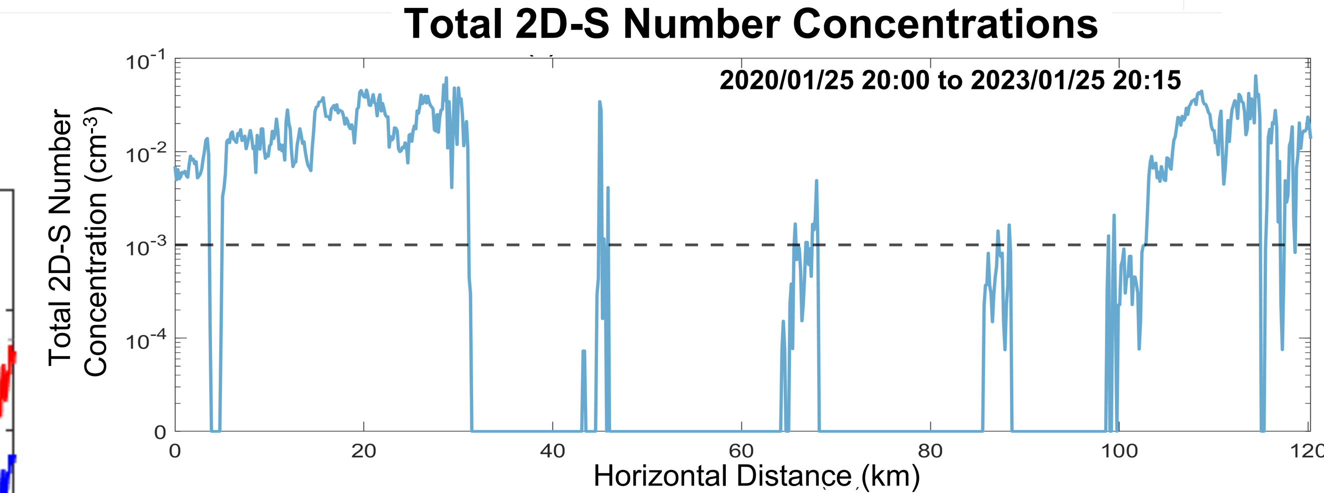


● shows position of aircraft on cloud radar plot

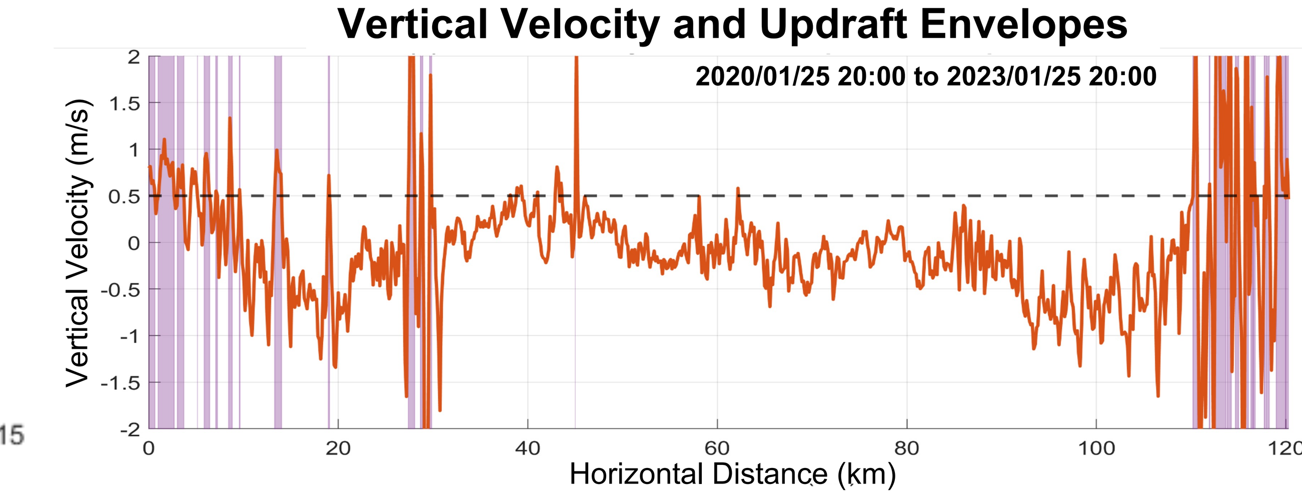
RH_W and RH_{ice} Time Series
2020/01/25 20:00 to 2020/01/25 20:15



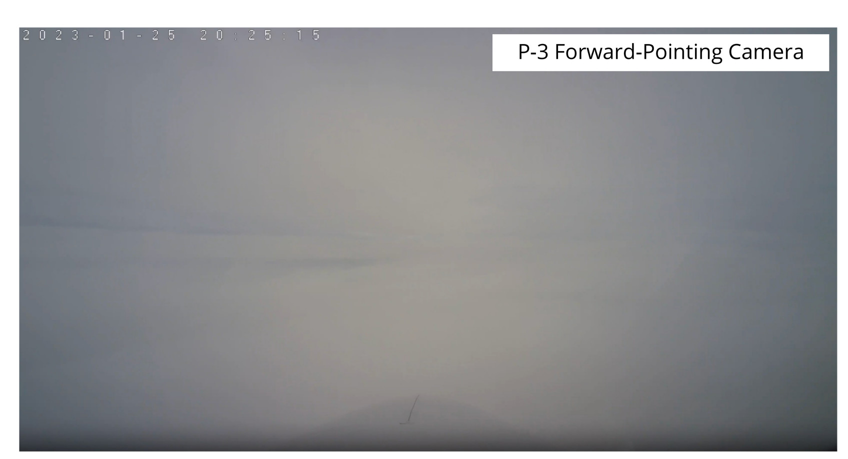
Total 2D-S Number Concentrations

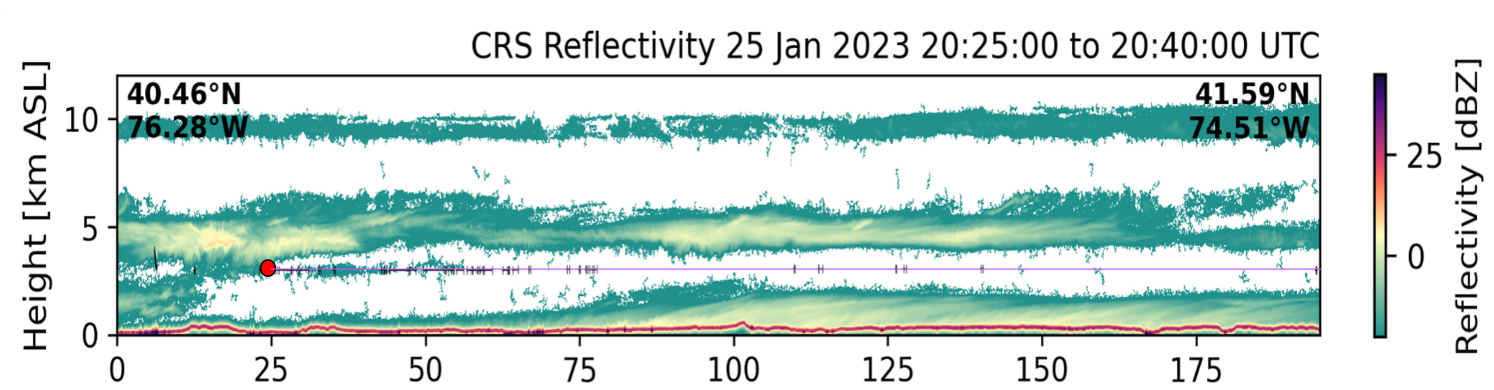


Vertical Velocity and Updraft Envelopes



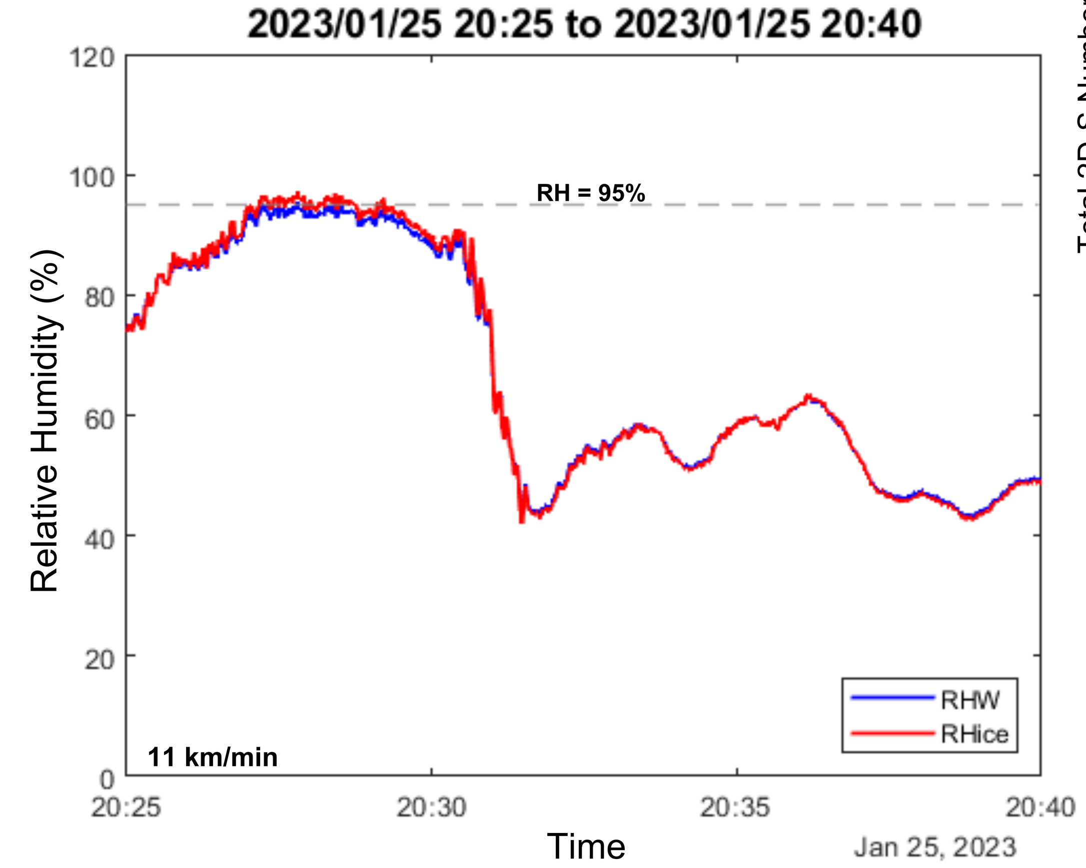
20230125 - 20:25 to 20:40 UTC Flight Leg



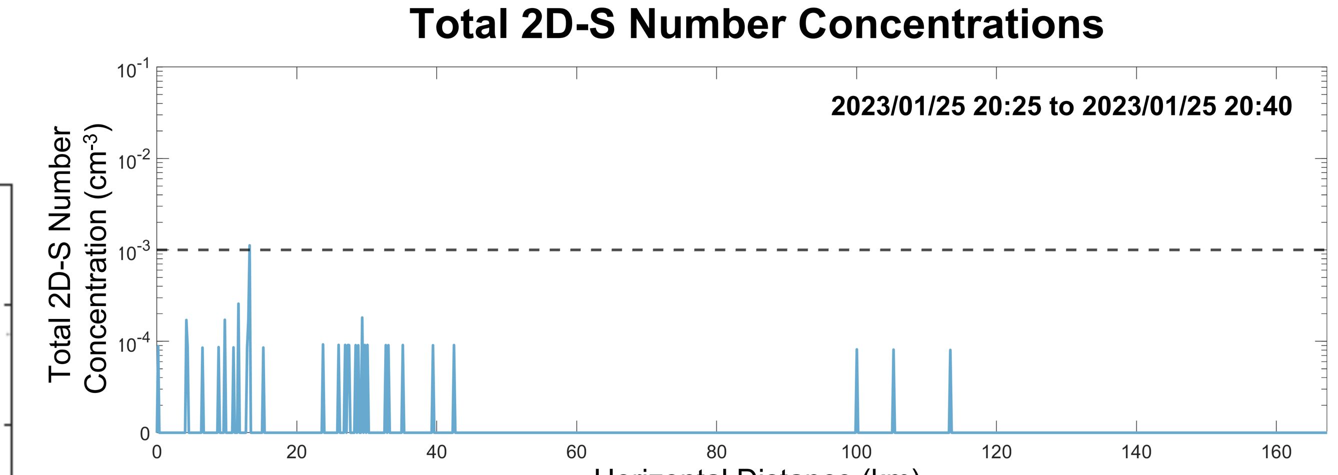


● shows position of aircraft on cloud radar plot

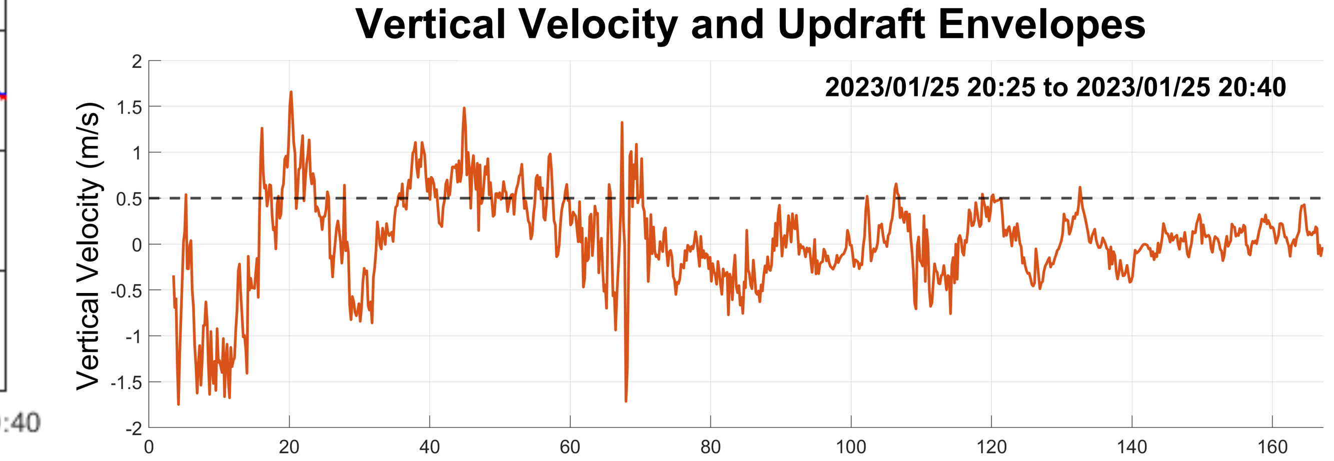
RH_W and RH_{ice} Time Series
2023/01/25 20:25 to 2023/01/25 20:40



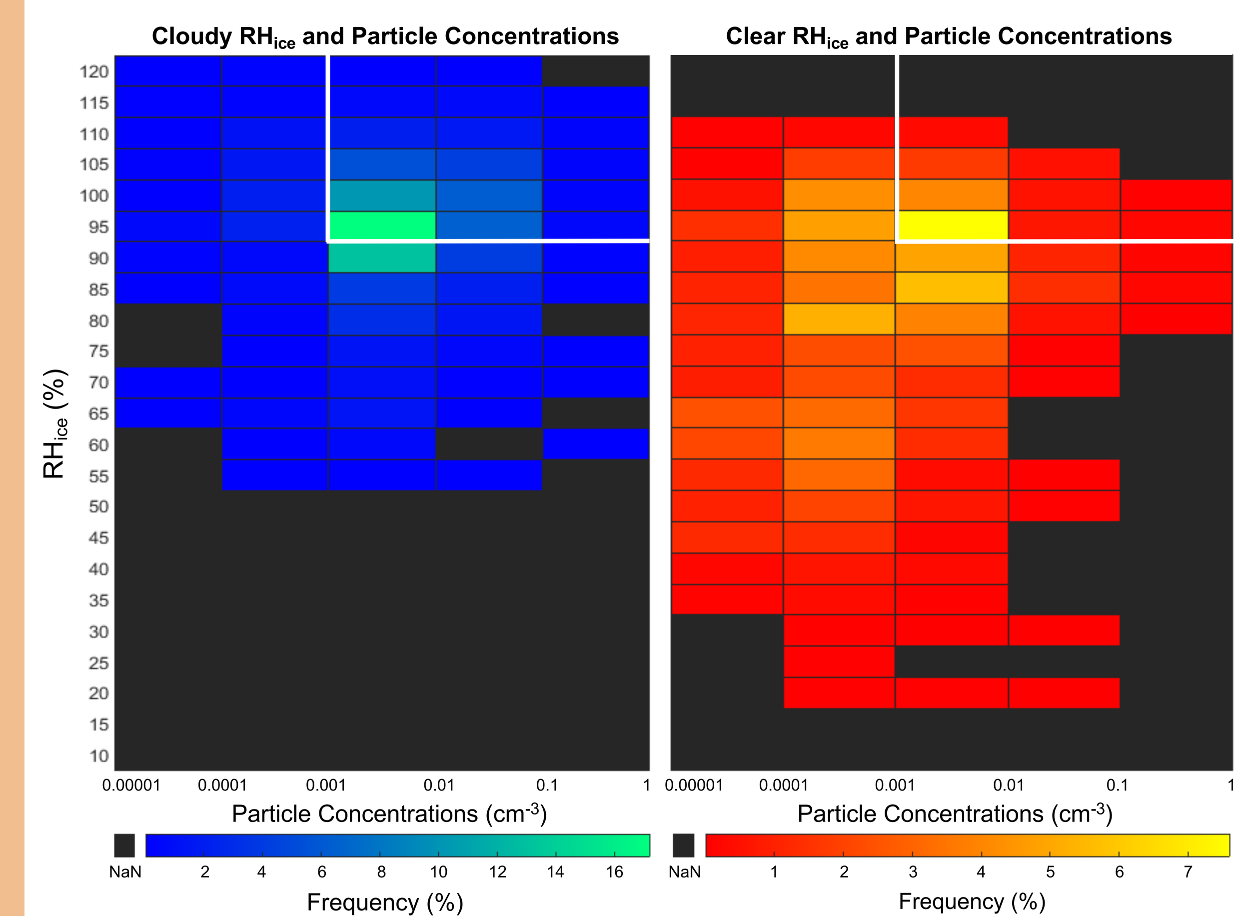
Total 2D-S Number Concentrations



Vertical Velocity and Updraft Envelopes



2D-S and RH_{ice} Data from Cloud Sandwich Legs



2D histograms plotting frequencies of concurrent 100-m horizontal scale RH_{ice} and 2D-S concentration data (100-2000 μm diameter) during 21 cloud sandwich legs. The data from the legs were divided into times that were visually cloudy and clear using the P-3 video observations. The white lines outline the region of RH_{ice} ≥ 95% and 2D-S concentrations ≥ 0.001 cm^{-3}.

Summary

- The coordinated flight legs between the ER-2 and P-3 planes from NASA IMPACTS provide a large sample size of conditions within non-orographic winter storms.
- Based on a sample of 21 legs, the distributions of in situ conditions in cloudy and clear visual portions of cloud sandwiches have the same mode. Cloudy visual portions have narrower distributions of RH_{ice} and number concentration values compared to clear visual portions.
- RH_{ice} and 2D-S concentrations can spike up for short intervals within visually clear periods.
- Local variations in RH_{ice} are an important constraint on microphysical pathways.
- Feedbacks within cloud sandwiches are complex since the local RH_{ice} will increase as snow particles sublimate, which then will decrease the sublimation rate.
- Sublimation will preferentially remove smaller ice particles (decreasing concentrations) and decrease the mass of larger ice particles. Reduced concentrations can modify the seeder-feeder mechanisms in the lower cloud layers.

References and Acknowledgements

Allen, L. R.,et al., 2024: In-cloud characteristics observed in US Northeast and Midwest non-orographic winter storms with implications for ice particle mass growth and residence time *Atmos. Chem, Phys, Disc.*., submitted 12/2024.

McMurdie L. M. et al. 2022: Chasing Snowstorms: The Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) Campaign NASA IMPACTS. https://espo.nasa.gov/impacts/content/IMPACTS

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