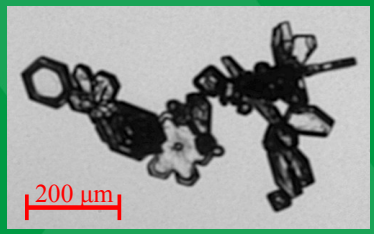
UNIVERSITY OF NORTH DAKOTA

Chain Aggregates Observations during Recent Field Campaigns



David Delene, Christian Nairy, Marwa Majdi, Andrew Detwiler, Shawn Wagner, and Youngsuk Oh

Busan IAMAS-IACS-IAPSO Joint Assembly 2025 (BACO-25), M04, C101-C102, July 22/23 - Cloud-Precipitation-Aerosol Studies Symposium, 14:45-1500 Tuesday 22 July 2025 in Convention Hall 1F, C101 – 102, Busan, Republic of Korea

I am glad to be here to talk about chain aggregates that were observed during two recent field campaigns.

I am representing the University of North Dakota Team that includes, (list authors and titles).

Additionally, the team collaborates with many people outside of the University, which are not listed. We are always willing to work with new collaborators.

Motivation for Research

- Cloud aggregation is a fundamental process important for precipitation.
- Chain aggregates are long, linear aggregates that are made of similar sized monomers crystals.
- Not well understood.
  - Where and How? Importance of electrical forces?
    - Inconsistencies exists between cloud chamber experiments and aircraft observations.

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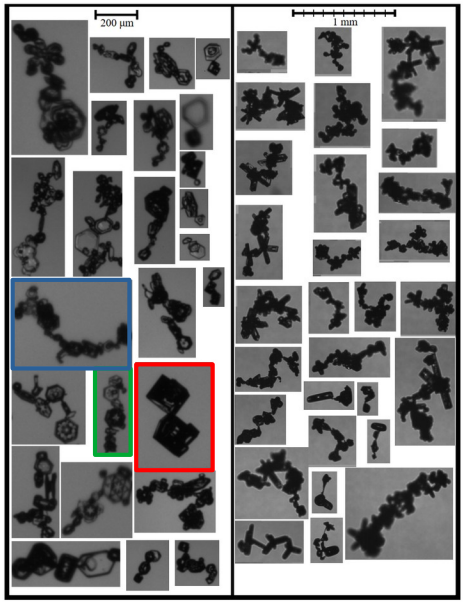


Aggregation is a fundamental process in clouds.

- **Ice particle aggregation in the atmosphere is attributed to aerodynamic, inertial, and gravitational forces, which are applied constantly during ice crystal interactions (Finnegan & Pitter, 1988).**

Chain aggregates are long, linear aggregates that are made of several, similar sized monomers crystals.

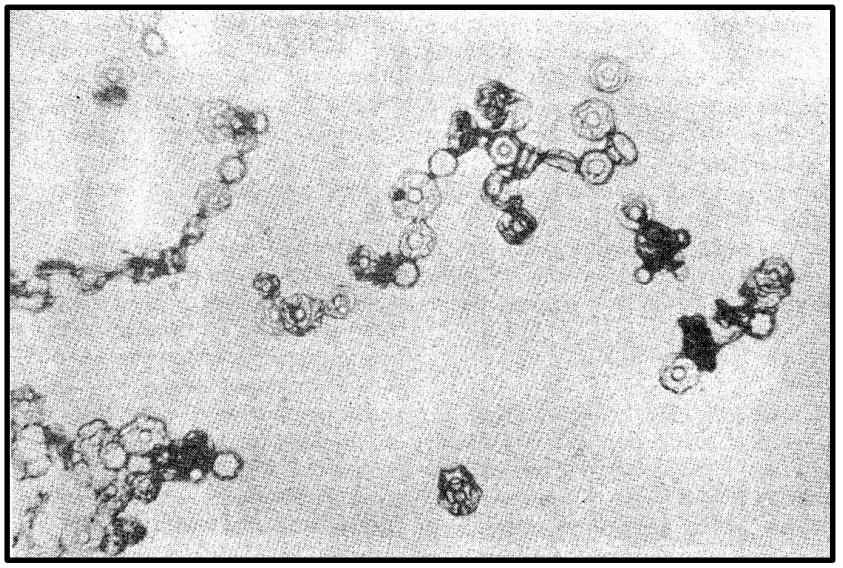
It is uncertain where chain aggregation occurring?

What electric field strength is requires?

How electric field strength and temperature are related to aggregation efficiency?

Laboratory Observations of Chain Aggregates

- In High Electric Fields
- Ice Crystal Concentrations Between 3 and 4 x 10^6 m^{-3}
- Chain aggregation seems to require a minimum field.
  - 60 kV m^{-1}
- Chain aggregation found to be temperature dependent.
  - Maximum efficiency found at ~ -8 °C



Chain Aggregates on form var slides that were generated in a cloud chamber. Adapted from Saunders and Wahab, 1975.

Laboratory experiments are helpful for understand the chain aggregation process.

New cloud chamber facilities, include facilities in South Korea, could be really helpful for understanding the chain aggregation process.

Observational Research Objectives

- Understand the context of where and when chain aggregates are observed in terms of the time evolution of cloud systems to provide information related to possible formation processes.
  - Machine Learning methods are a critical tool for identifying the millions of aggregate images obtained during a single research flight.
- Place chain aggregate observations into context with other measurements and relate them to the storm's life cycle.

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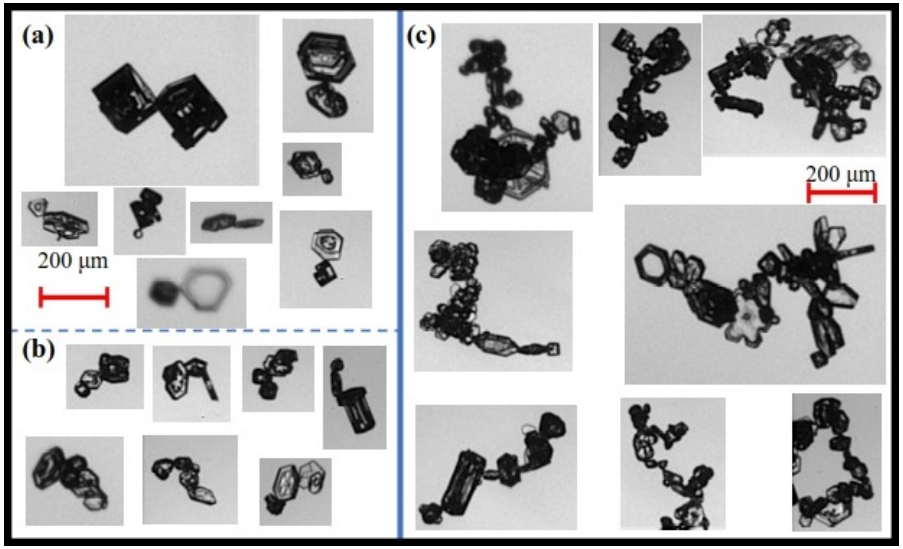
Using all available observations are necessary to understand chain aggregation processes and how things change with location and time.

Aircraft Observations of Chain Aggregates

- PHIPS images of chain aggregates (a and b) comprised of ice crystals found in Florida cirrus anvil clouds produced by summertime convection observed during the CapeEx19 field campaign.
- CPI images of chain aggregates (c) found near convective band associated with wintertime convection off the New England coast.



Nairy, C. M., D. J. Delene, A. G. Detwiler, J. M. Schmidt, P. R. Harasti, M. Schnaiter, E. Järvinen, T. D. Walker, Ice Crystal Chain Aggregates in Florida Cirrus Cloud Anvils – 3 August 2019 Case Study. Journal of Geophysical Research: Atmospheres. In Review, 2025.

Nairy, Christian M., David J. Delene, Joseph A. Finlon, John E. Yorks, Emma Järvinen, Martin Schnaiter, Andrew J. Heymsfield, Andrew G. Detwiler, Lynn A. McMurdie, Unveiling In-situ Observations of Ice Crystal Chain Aggregates in Winter Storms. Journal of Geophysical Research Letter, In Review, 2025`

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High resolution images are important to observing chain aggregates.

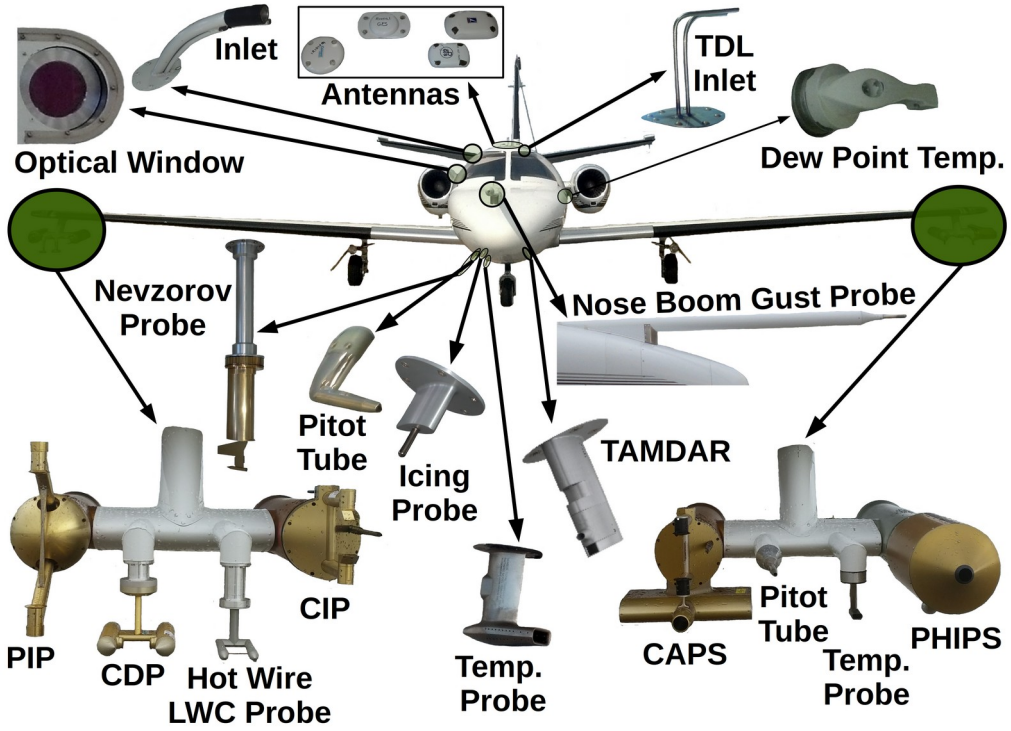
Today, I would like to give overview of chain aggregate observation from two field project, CapeEX19 and IMPACTS.

Details are available in two papers, we have under review.

CapeEx19 Dataset and Instrumentation

12 Flights

2019/7/22
2019/7/24
2019/7/25
2019/7/26
2019/7/29
2019/7/30
2019/7/31
2019/8/01
2019/8/2a
2019/8/2b
2019/8/3a
2019/8/3b



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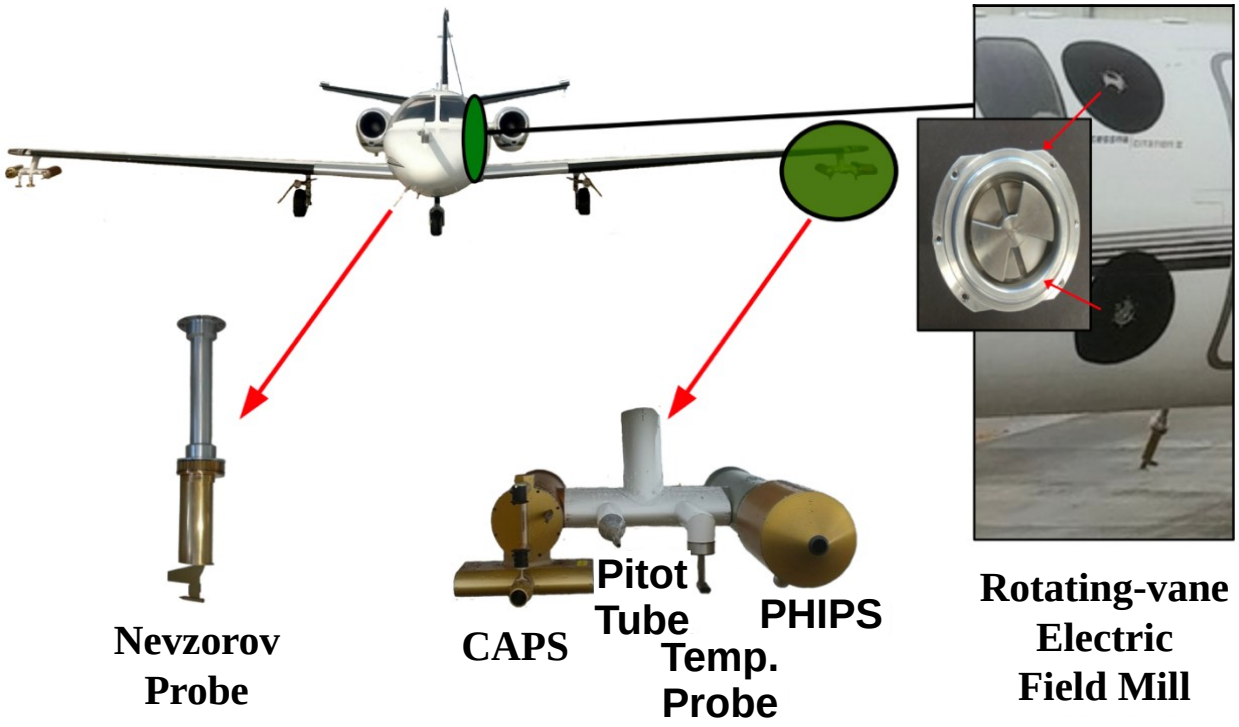
The Navy sponsored CapeEx19 project sampling cirrus anvils from summer time convection in Florida using the North Dakota Citation Research Aircraft with a full set of cloud physics instruments.

CapeEx19 Unique Measurements

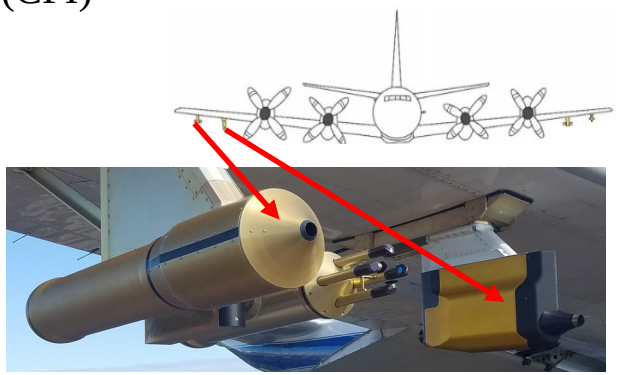


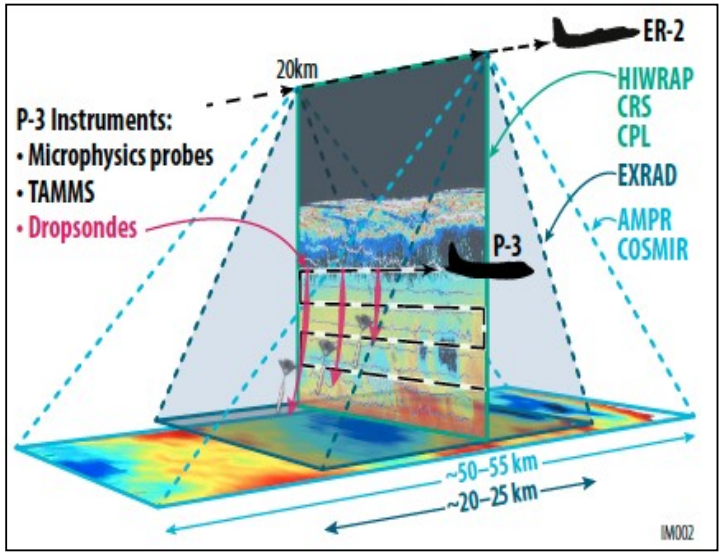
The CapeEx19 project deployed the PHIPS instruments, along with Electric field mills.

Mention that the rotating-vane Electric Field Mill are a unique instrument that is not often deployed to measure electric fields.

IMPACTS Field Project and Instrumentation

- **I**nvestigation of **M**icrophysics and **P**recipitation for **A**tlantic **C**oast-**T**hreatening **S**nowstorms (IMPACTS).
- NASA P-3 Orion Research Aircraft
  - Particle Habit Imaging and Polar Scattering probe (PHIPS)
  - Hawkeye-Cloud Particle Imaging (CPI)





Adapted from the NASA IMPACTS executive summary (https://espo.nasa.gov/impacts/).

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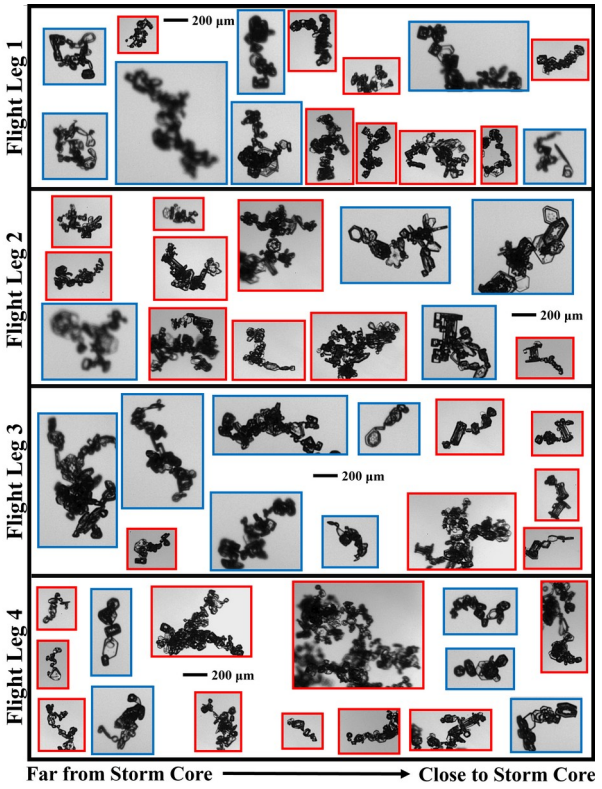
The NASA IMPACTS project deployed a PHIPS and a CIP for obtaining high resolution images.

However, no in cloud electric field observations, only **electric field mills on the ER-2** flying high above the storms

CapeEx19
Chain Aggregates

- Illustration showing representative chain aggregate images observed during the CapeEx19 field campaign grouped by Flight Leg obtained while sampling anvil cirrus clouds.
- The flight legs are at 10 km AGL from 2019/08/03a research flight, and images are group from far way from the convective storm core to close to the convective storm core.



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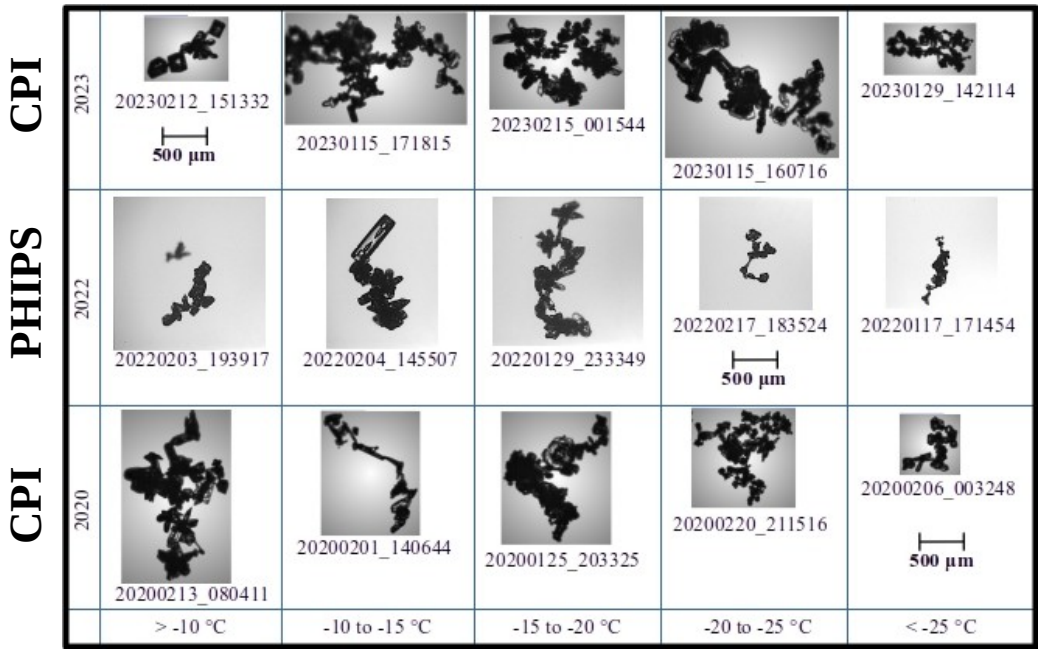
Observations show lots of interesting chain aggregates.

IMPACTS Representative Chain Aggregates



Representative chain aggregate images observed during IMPACTS grouped by temperature and deployment year.

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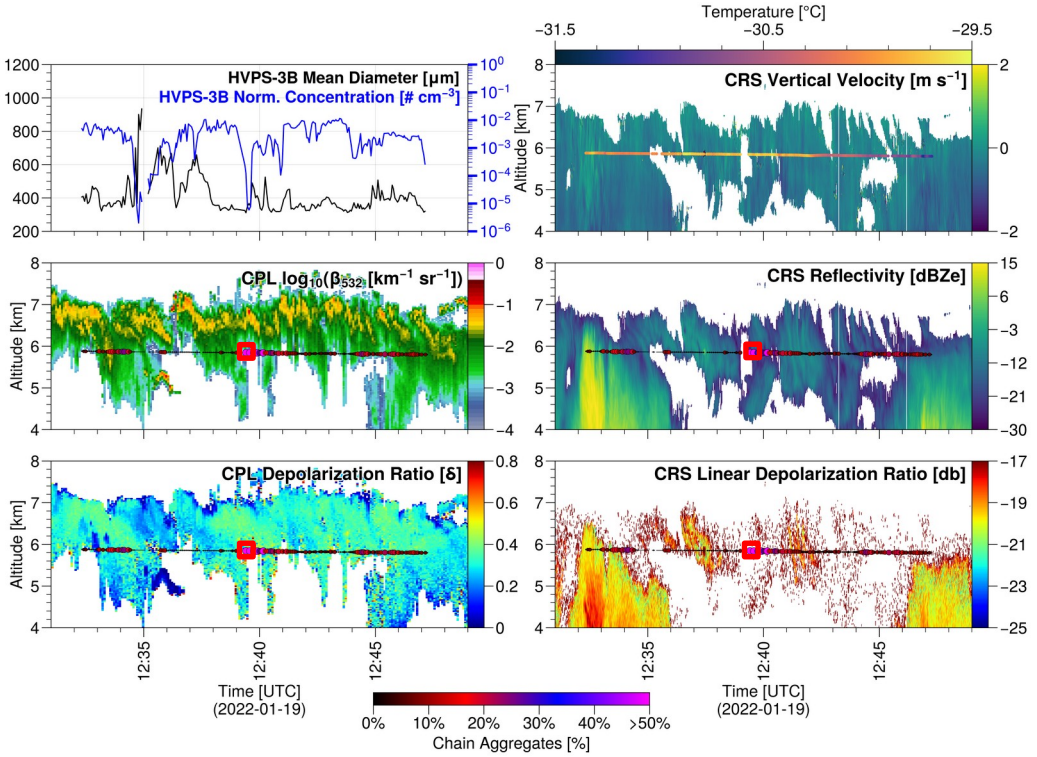
Illustration showing representative chain aggregate images observed during the NASA IMPACTS field campaign grouped by deployment year and temperature intervals.

The image labels give the UTC date and time. The 2023 and 2020 rows contain Hawkeye Cloud Particle Imager (CPI) images, while the 2022 row contains PHIPS probe images.

Contextualization of Chain Aggregate Observations

The collocated in-situ and remote sensing observations obtained by the NASA P-3 and ER-2 on 19 January 2022.

The Red Box highlights an area of high chain aggregates percentage.



Remote sensing data is necessary to put the in-situ observatory chain aggregates into context since only have one point in time and space.

Need both type of measurements since there is not a clear remote sensing observations related to the chain aggregates such as reflectivity or depolarization ratio.

Crystal Habit Classifications

- 5 Flight Segments Classified:
  - *Total Time Coverage:*

    1hr 40m 49s
  - *Temperature Range:*

    -36 to -5 ºC
- Total # of Particles Classified (after QA/QC):

  24,786
- # of Chain Aggregates Classified (after QA/QC):

  1,357

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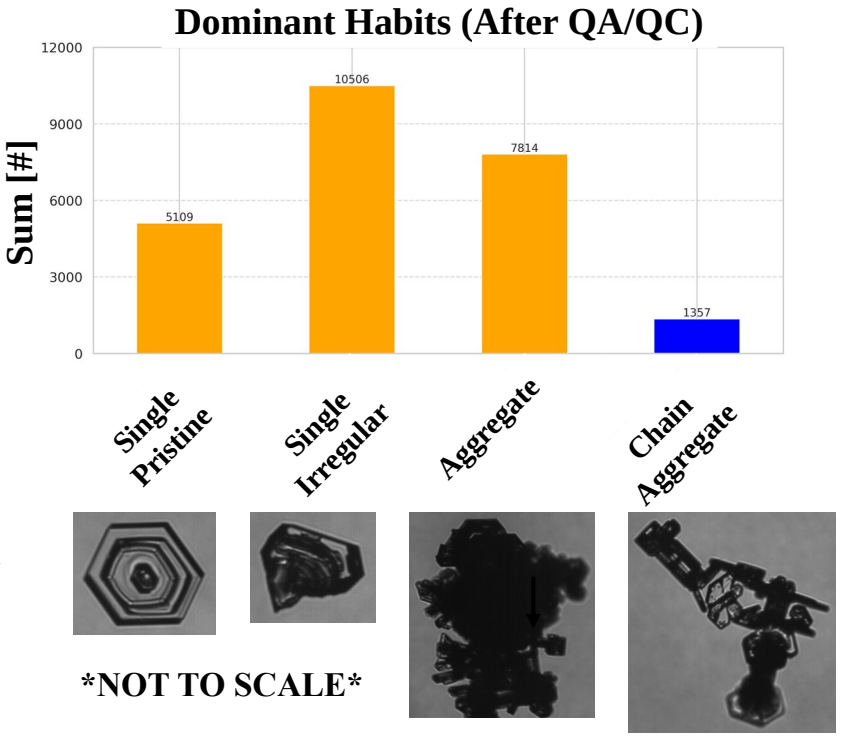
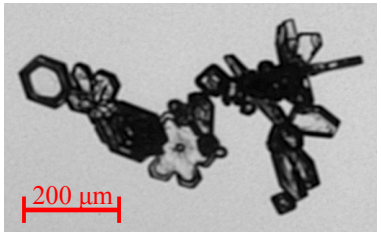


Need the in-situ observations, which have lots of images.

Manually classifying images is not possible to look at enough data to combine with remote sensing data to conceptualize the chain aggregate process.

Conclusions



- First high-resolution observations of ice crystal chain aggregates in winter storms.
- Chain aggregates observed in winter storms show similar characteristics to chain aggregates observed in upper-level clouds associated with summertime convective storms.
- Formation process are uncertain, which can be improved with the localization of chain aggregates in relationship to in-cloud electric field and remote sensing measurements.

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Conclusions from the two field project's chain aggregate observations are ..

Publications, References, and Acknowledgments

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Nairy, Christian, David J. Delene, Joseph Finlon, John E. Yorks, K. Lee Thornhill, Applying and Evaluating Random Forest Classification to Identify Ice Crystal Chain Aggregates During the IMPACTS Field Campaign, Talk presentation given on Wednesday 15 January 2025 at 8:45-9:00 AM in Room 224 at American Meteorological Society's Second Symposium on Cloud Physics at the 105th AMS Annual Meeting, from January 12 - 16, 2025 in New Orleans, LA.

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This research was supported by a NASA research grant to the University of North Dakota. Grant #: 80NSSC19K0328. The IMPACTS dataset is publicly available at the NASA GHRC http://dx.doi.org/10.5067/IMPACTS/DATA101. We would also like to thank Andrew Heymsfield, Stephen Nicholls, Mircea Grecu, Andrew Detwiler, & Patrick Britt for their added expertise in this work.

Here are list of publications and references discussed.

I would like to acknowledge this work's research support by the NASA IMPACTS project.

Forth Coming Publications

Nairy, C. M., D. J. Delene, A. G. Detwiler, J. M. Schmidt, P. R. Harasti, M. Schnaiter, E. Järvinen, T. D. Walker, Ice Crystal Chain Aggregates in Florida Cirrus Cloud Anvils - 3 August 2019 Case Study. Journal of Geophysical Research: Atmospheres. In Review, 2025.

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Future Work (NASA Grant 80NSSC25K7971)

- Apply Machine Learning (XGBoost, Random Forest, Convolutional Neural Network) across all research flights conducted during the IMPACTS field campaign.
- Contextualize chain aggregates within storm life-cycles for improved understanding in the chain aggregation process.

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There are two publications related to this research under review.

We are starting a new project where we plan to published two papers.