UNIVERSITY OF NORTH DAKOTA

ATMOSPHERIC SCIENCES

Christian Nairy's Thesis Committee Meeting

2021/06/01

Committee Members:

Dr. David Delene (Chair)

Prof. Michael Poellot

Dr. Jerome Schmidt

Dr. Paul Harasti

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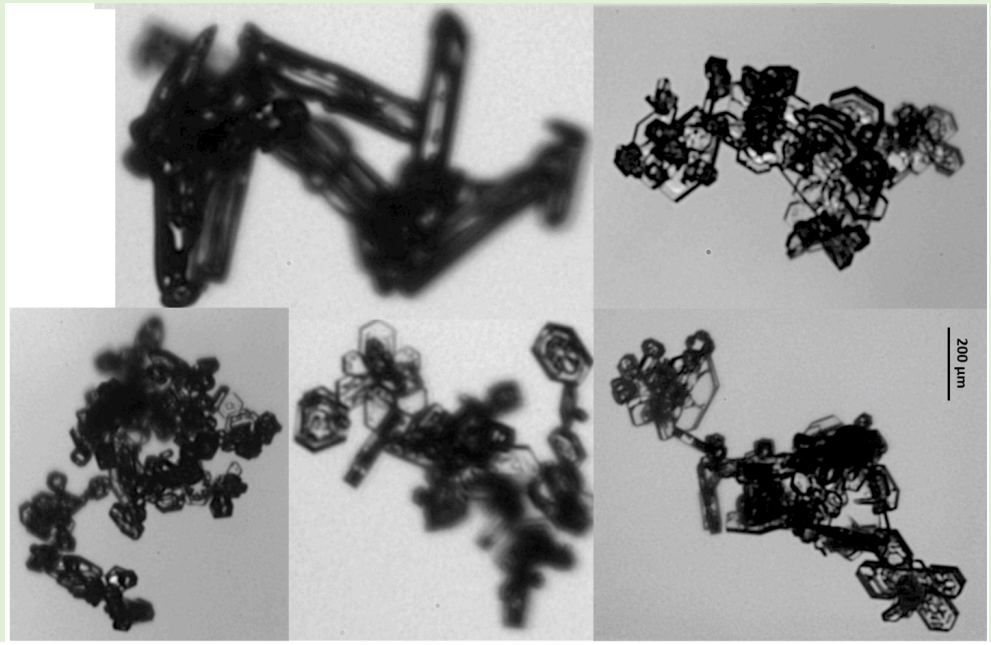
Review from Last Committee Meeting

- Reviewed the AGU poster and oral presentations.
  - Presentations are on the UND Wiki page:
    - wiki.atmos.und.edu/doku.php?id=atmos:citation:research:agu_presentation
- Completed the Thesis Plan of Study form.

Thesis Topic Proposal

Title: **Microphysical Observations of Chain Aggregates in Florida Cirrus Cloud Anvils on 3 August 2019**



Thesis Topic Proposal - Introduction

- Evidence since the 1960's has shown that electric fields have an influence on aggregation.

Previous Cloud Chamber Experiments:

- Latham and Saunders (1970): Small ice crystals collection efficiencies substantially increased in the presence of electric fields.
- Crowther and Saunders (1973): Tested aggregation and fragmentation of ice crystals in the presence of electric fields (10^5 V m^{-1}).
  - Observed aggregates not in clumps, but in an elongated, quasi-linear, chain-like orientation occasionally containing 10 or more ice crystal elements.
- Saunders and Wahab (1975): Tested aggregation and fragmentation of ice crystals in the presence of electric fields (10^5 V m^{-1}) but using more realistic ice crystal concentrations (than previous cloud chamber work).

Thesis Topic Proposal - Introduction

- Saunders and Wahab, 1975:

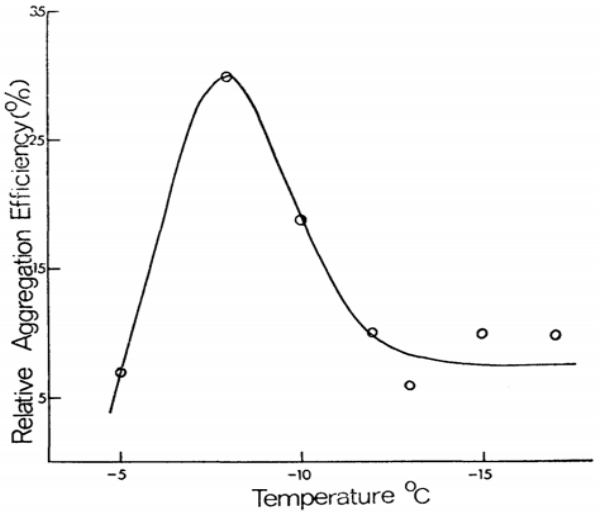


Fig. 2. The relative aggregation efficiency as a function of temperature for an electric field strength of 2×10^5 Vm^{-1} and ice crystal concentration between 3 and $4 \times 10^6 m^{-3}$. Typical ice crystal dimension, 50μ.

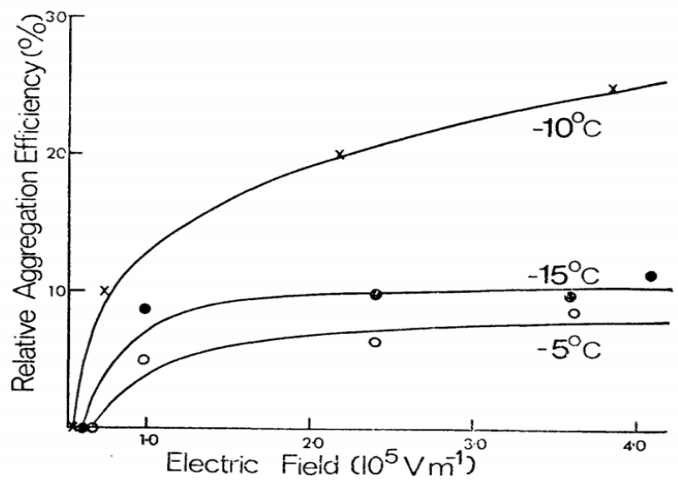


Fig. 3. The relative aggregation efficiency as a function of electric field for three values of temperature and ice crystal concentration between 3 and $4 \times 10^6 m^{-3}$. Typical ice crystal dimension, 50μ.

Thesis Topic Proposal – Introduction
Saunders and Wahab, 1975:

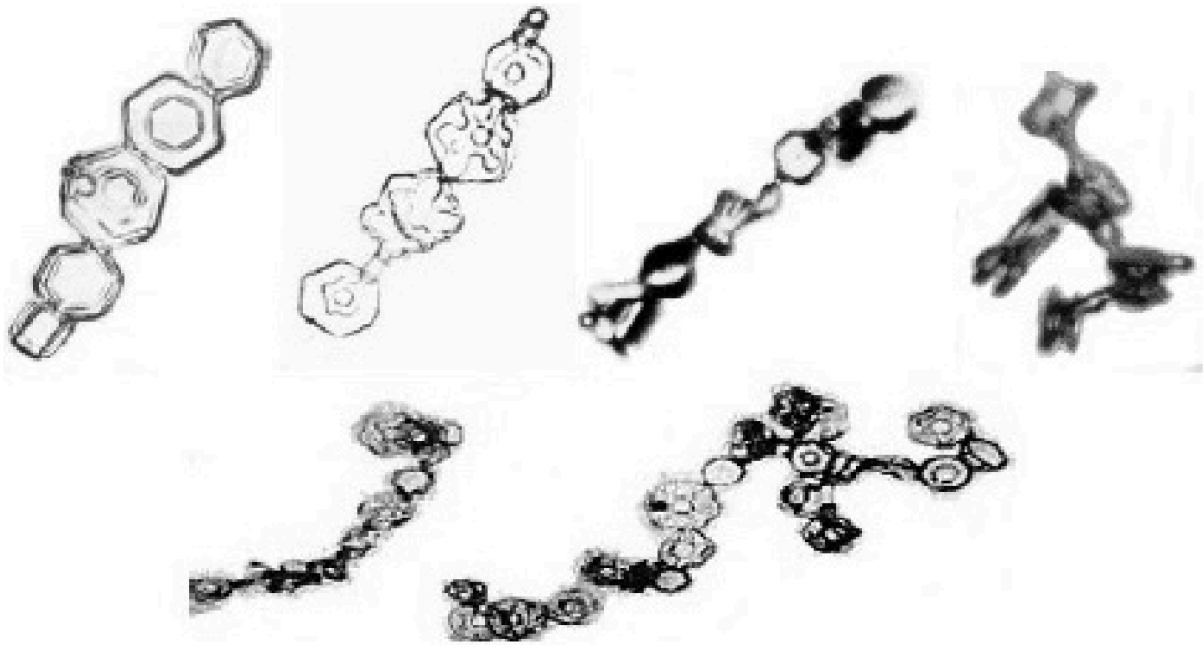


Figure 1. Examples of linear and branched chain aggregates of plates generated in the laboratory by the influence of electric fields. Top: field $-\mathrm{E} = 0.5\times10^5$ V m^{-1}, temperature $T = 11$ °C, from Wahab (1974); bottom: $-\mathrm{E} = 1.0\times10^5$ V m^{-1}, $T = -12$ °C, (Saunders and Wahab 1975). Individual plate sizes vary from 30 to 50 μm.

Thesis Topic Proposal - Introduction

- Recent field campaigns (aircraft in-situ sampling that observed chain aggregates):
  - Stith et al. 2002, 2004, 2014; Lawson et al. 2003; Whiteaway et al. 2004; Connolly et al. 2005; Garret et al. 2005; Gayet et al. 2012.

- Higher concentrations of chain aggregates have been observed in cirrus anvils produced by continental convection than maritime convection.

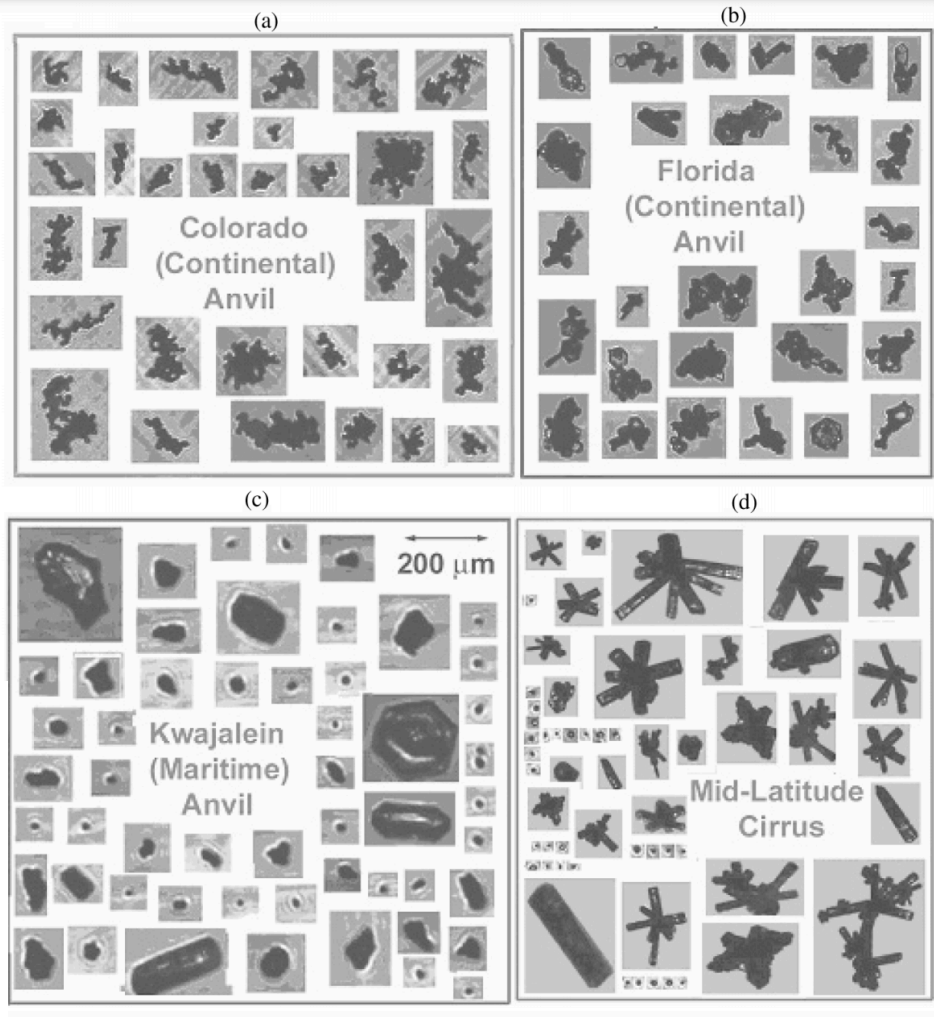
- Chain Aggregates produced from continental convection:
  - Found in colder temperature regimes.
  - Chain aggregates (rimed and unrimed) found at ~ -8°C in Florida thunderstorms during the CRYSTAL-FACE field campaign.

Thesis Topic Proposal – Introduction - Field Campaigns

- Data presented by Connolly et al. 2005:
- Comparison between continental and maritime anvils where chain aggregates were observed
- Case study for the EMERALD-II field campaign.

Storm type	Location	No. of particles examined	Aggregates	Chain-like aggregates	Temperature
Continental	Colorado	8600	28%	5.5%	−47 °C
Maritime	Kwajalein	5600	0.5%	0%	−40 to −60 °C

Figure 3. Adaptation of figure from Lawson *et al.* (2003) showing examples of ice crystals imaged by the CPI in outflow regions of continental thunderstorms investigated in (a) Colorado by the SPEC Learjet, and (b) Florida by the NASA WB-57F during the CRYSTAL-FACE project, and (c) in maritime convective storms investigated by the NASA DC-8 during the TRMM KWAJEX project. (d) Examples of CPI images of mostly rosette-type ice particles typically observed in midlatitude cirrus (cirrus images adapted from Sassen *et al.* (2001)). Also shown (below) are results of a visual examination of the percentages of aggregates and chain-like aggregates in the Colorado (continental) and Kwajalein (maritime) outflows.



Thesis Topic Proposal – Introduction
Connolly et al. 2005

- Case study for the EMERALD-II Field Campaign
  - Island forced convection over the Tiwi Islands.
  - Sampled cirrus outflow from tropical multi-cell convection.
- Hector is not actually strictly continental; the aerosol inflow tends to be from continental Australia and so it is classed as continental.

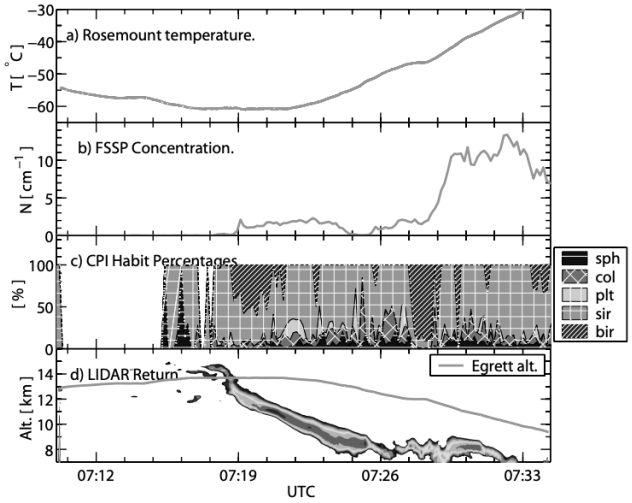


Figure 5. *In situ* data during a descent into the anvil of Hector from the EMERALD-II case-study on the 2 December 2002. (a) Temperature from a Rosemount temperature probe on the Egrett; (b) number concentration from the Forward Scattering Spectrometer Probe; (c) the contribution from each of the automatically classified habits to the total of habits imaged by the Cloud Particle Imager. 'sph' = spheres, 'col' = columns, 'plt' = plates, 'sir' = small irregular, 'bir' = big irregular. (d) Data from a LIDAR mounted on a King Air aircraft, which was flown directly below the Egrett (the corresponding Egrett altitude is shown).

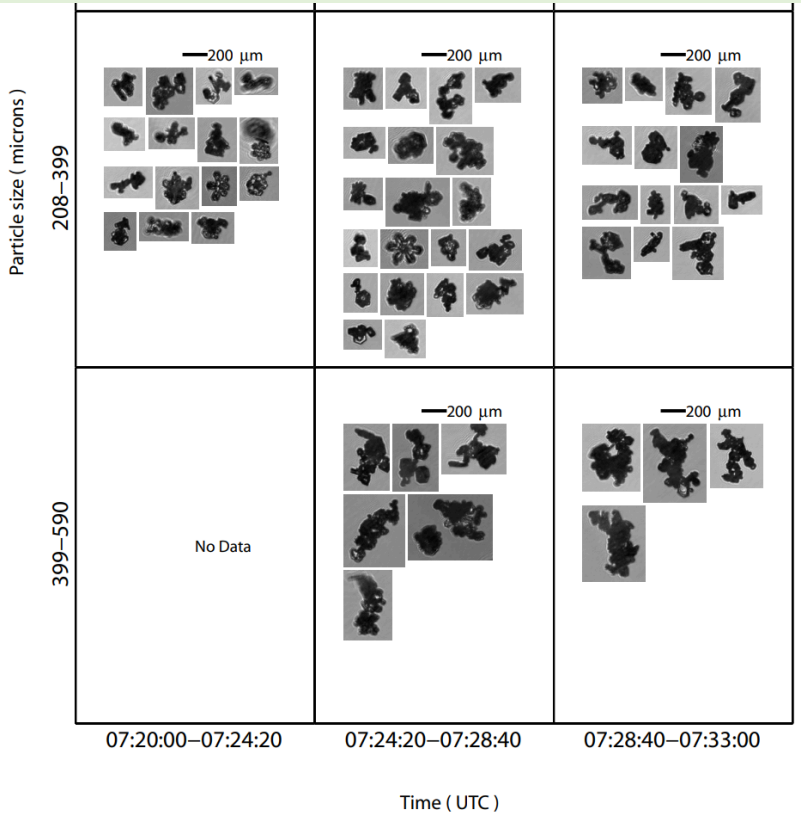


Figure 6. Cloud Particle Imager images from the EMERALD-II case-study on the 2 December 2002. Images correspond to the period 0720 to 0733 UTC (see Fig. 5). Note the appearance of chains of ice crystals from 0724 to 0729 UTC.

Thesis Topic Proposal – Introduction
Connolly et al. 2005

- Ice-crystal chains were found in the highest frequencies near the anvil base (continental).
  - Sedimentation and/or other mechanisms.
- No direct measurements of electric fields were made.
- Possible that the aggregates originated higher in the mixed-phase updraught region?
- Distinct lack of riming on the crystal aggregate chains observed in the outflow (Tiwi Island convection)
  - Gives some evidence to support the idea that the majority of the chains in the dataset formed in fully glaciated regions below approximately −37°C.

Thesis Topic Proposal – Introduction

- Due to the minimal amount of in-situ observations in thunderstorms, the processes involved in **chain aggregate formation are not well understood.**

- To further our understanding of the chain aggregation process, the recent CapeEx19 field campaign provides an additional dataset where chain aggregation was observed via in-situ sampling.

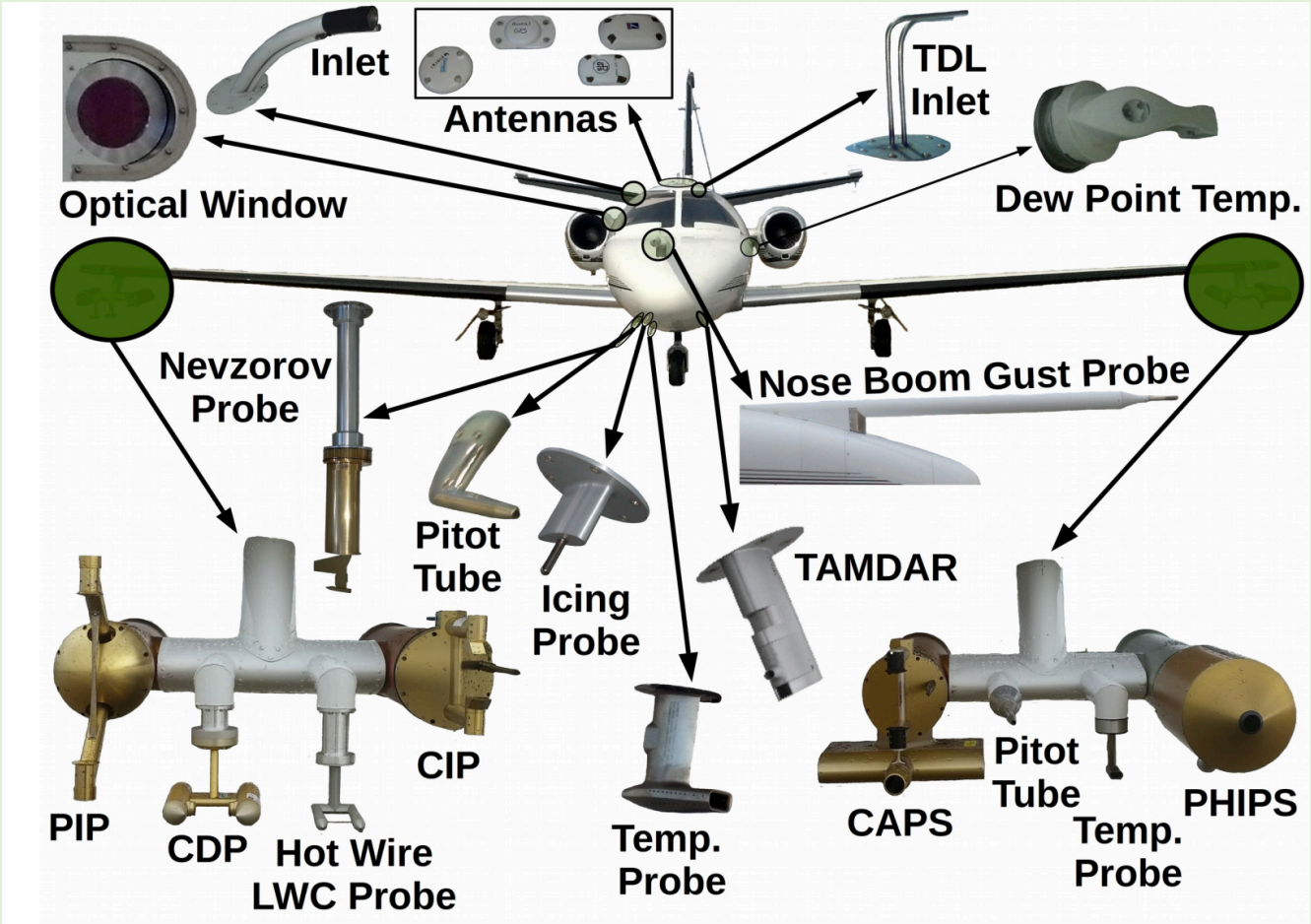
- During the CapeEx19 field campaign, the North Dakota Citation II Research Aircraft obtain in-situ observations in tropical-continental cirrus anvils initiated by sea-breeze convection over Florida.

Thesis Topic Proposal - Methodology

- **<u>CapeEx19 Field Campaign</u>**
- Location: Cape Canaveral, Florida
- Time Frame: Late July 2019 – Early August 2019
- Field Campaign Objectives:
  - **Continue improvements to both cirrus cloud modeling and radar interpretation by utilizing aircraft observations to enhance our understanding of Florida convection.**
  - **Understanding the various processes that result in chain aggregate formation**.

Thesis Topic Proposal - Methodology

North Dakota Citation II Research Aircraft

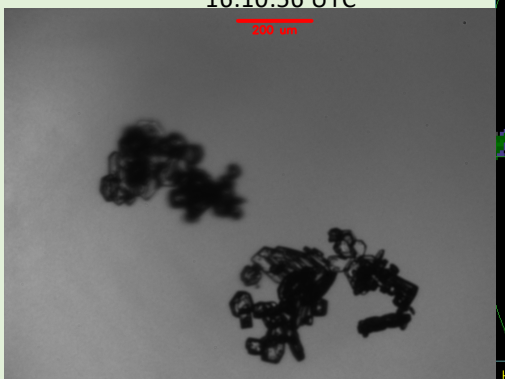


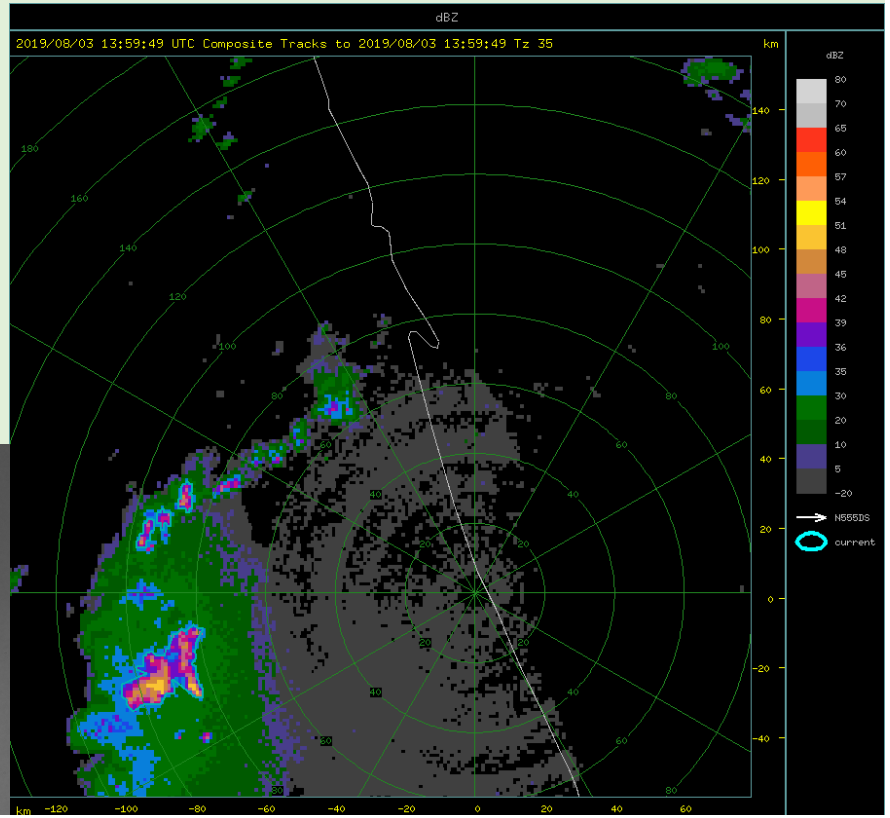
Thesis Topic Proposal – Methodology

- **Case study** on the 3 August 2019 flight (20190803a) during the CapeEx19 field Campaign
- Sea-breeze induced convection over western Florida. Later enhanced by convergence zone west of Cape Canaveral, Florida.
  - 14:24:00 – 17:26:00 UTC
  - North Dakota Citation II Research Aircraft sampled through the cirrus anvil regions (9.5 – 11.5 km above ground level).
    - Chain Aggregates observed

15:54:16 UTC

16:10:56 UTC





Thesis Topic Proposal – Methodology

- **Question:** Is chain aggregation occurring in the cirrus anvil region of Florida thunderstorms?

- Utilize CapeEx19 dataset and characterize the observed chain aggregates in cirrus anvil region.
  - Microphysical properties
  - Environmental properties (where the particles were sampled).
  - Properties based on distance from convective cores.

- Compare data to the Saunders and Wahab (1975) criteria. Is the cirrus anvil environment conducive for chain aggregation?

- Comparisons from previous field campaigns and other flights during the CapeEx19 field campaign to provide context as to what is typical/atypical from the case study.

Thesis Topic Proposal – Methodology
Key Instrumentation/Datasets

- On Aircraft

- Particle Habit Imaging Polar Scattering (PHIPS) Probe
  - Depiction of the individual chain aggregate size, orientation, and the individual number of elements.
  - Characterizing the different or similar individual crystal-type habits that make up the chain aggregate in its entirety.
  - Depict if the chain aggregate experienced any riming and during its existence up until the time of sampling.
  - Analyze the various phase changes the chain aggregate may have possibly experienced up until the time of sampling (in combination with the environmental probes).
- Nezorov Probe
  - Utilize for inner-cloud threshold, LWC, and TWC.
- Cloud Imaging Probe (CIP)
  - Provide information regarding the number concentrations of particles and the size distribution of those particles sampled during flight.
  - Utilize to see if inner-cloud particle concentrations meet the criteria necessary for chain aggregation based in Saunders & Wahab, 1975
- (6) Rotating-Vane Electric Field Mills
  - Utilize to distinguish if the electric field is sufficient for chain aggregation in the cirrus anvil region based in Saunders & Wahab, 1975

Thesis Topic Proposal – Methodology
Key Instrumentation/Datasets

- On Aircraft

- Melbourne, FL National Weather Service WSR-88D Radar (KMLB)
  - S-band radar data.
- Cloud Precipitation Radar – Hydrometeor Detection (CPR-HD)
  - C-band radar data.
- National Lightning Detection Network (NLDN)
  - Provide insight into the electrical activity of the sampled storm(s).
- Kennedy Space Center Lightning Mapping Array (KSCLMA)
  - Provide insight to inner-cloud electric charge regions & intensity.

Thesis Topic Proposal – Objective

- Provide a quantification of aggregation in the cirrus anvil region for the formation of chain-like aggregates.
  - **Is chain aggregation occurring in the cirrus anvil or not?**

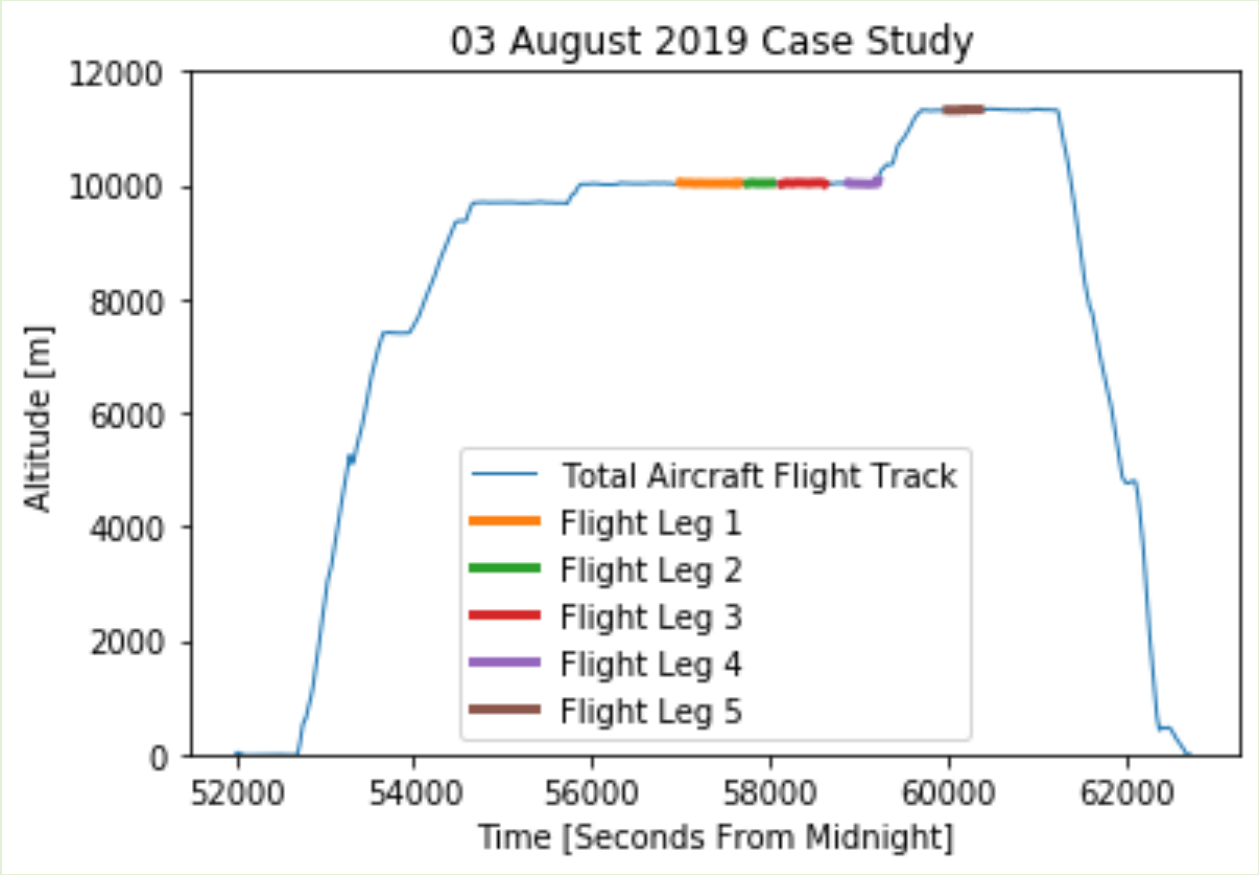
Thesis Topic Proposal – Expected Results

- Answer our main objective (previous slide)
- Allow for better interpretation of radar data.
- Provide microphysical data and characteristics about chain aggregates observed in Florida cirrus anvils which may inevitably enable models to predict their occurrence.
  - Implementation of chain aggregates in models will improve the accuracy of the radiative impacts of cirrus anvils.
  - Chain aggregation in models will lead to more accurate and efficient supersonic projectile travel.
    - Hypersonic collisions with relatively large and irregular ice crystals may cause cratering on supersonic vehicle's nose cones, which can alter the vehicle's aerodynamics (Meng and Ludema 1995, Barnes Jr. 1982).

Questions/Comments on Topic Proposal?

Brief Results

- 20190803a Flight Legs (FL)
- Lightning Activity - NLDN
- PHIPS Images
  - Observed Chain Aggregates & Levels of Confidence
- PHIPS Data
  - Maximum Diameter of Observed Chain Aggregates (FL1-5)
  - Chain Aggregates vs. Distance from Storm Core (Reflectivity Centroid)
- CIP Particle Concentrations
- Electric Field Measurements

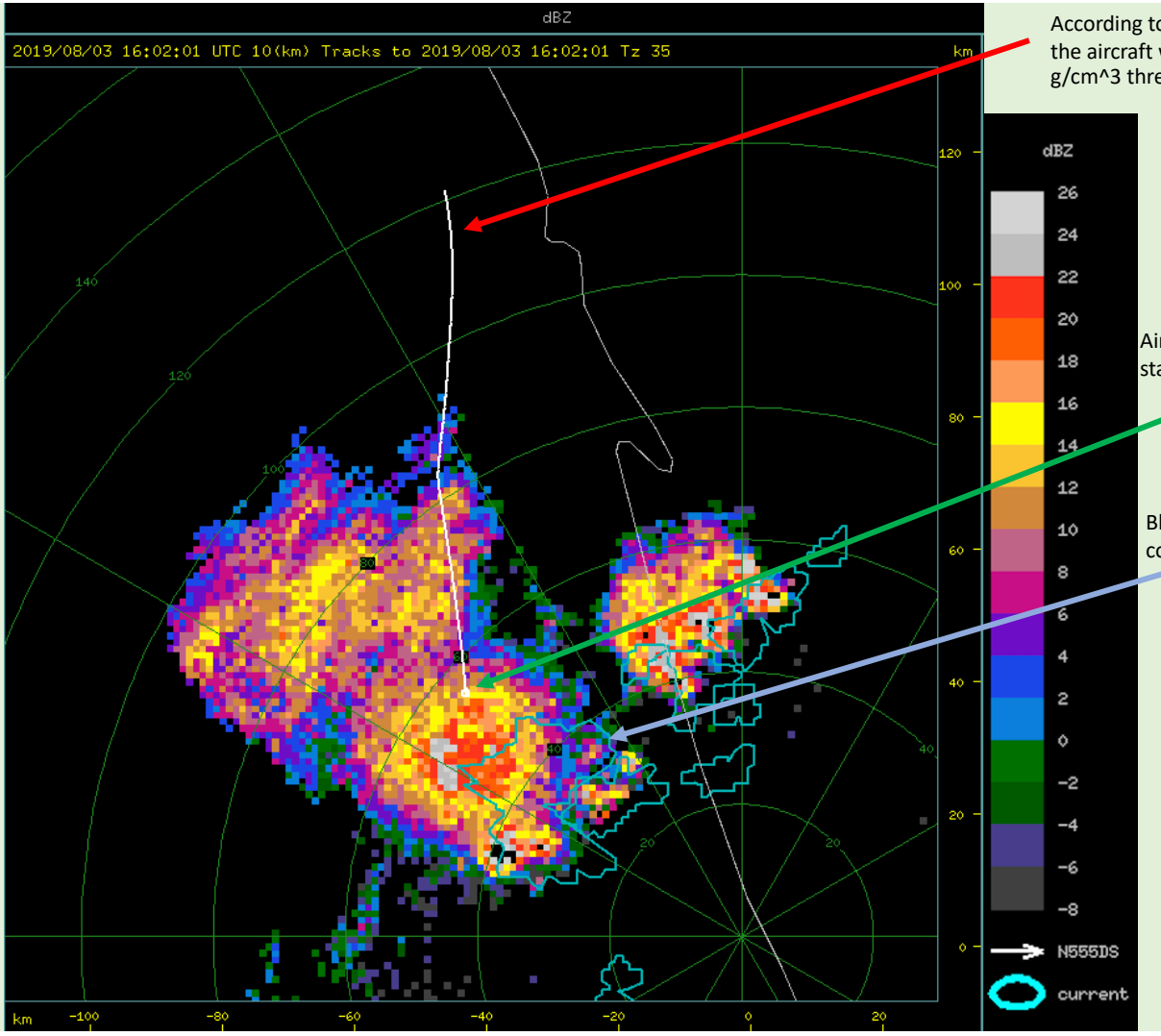


In order to provide consistency when analyzing the data, individual flight legs are defined during the 3 August 2019 flight where the aircraft was sampling without sharp maneuvers, **heading toward**, **away**, and **parallel** to the convective thunderstorm cores.

Flight Leg 1:

15:51:15 – 16:01:00 UTC

Radar Scan: 16:02:01 UTC
10 km CAPPI



According to the Nev. TWC probe, the aircraft was above the 0.005 g/cm^3 threshold = in cloud

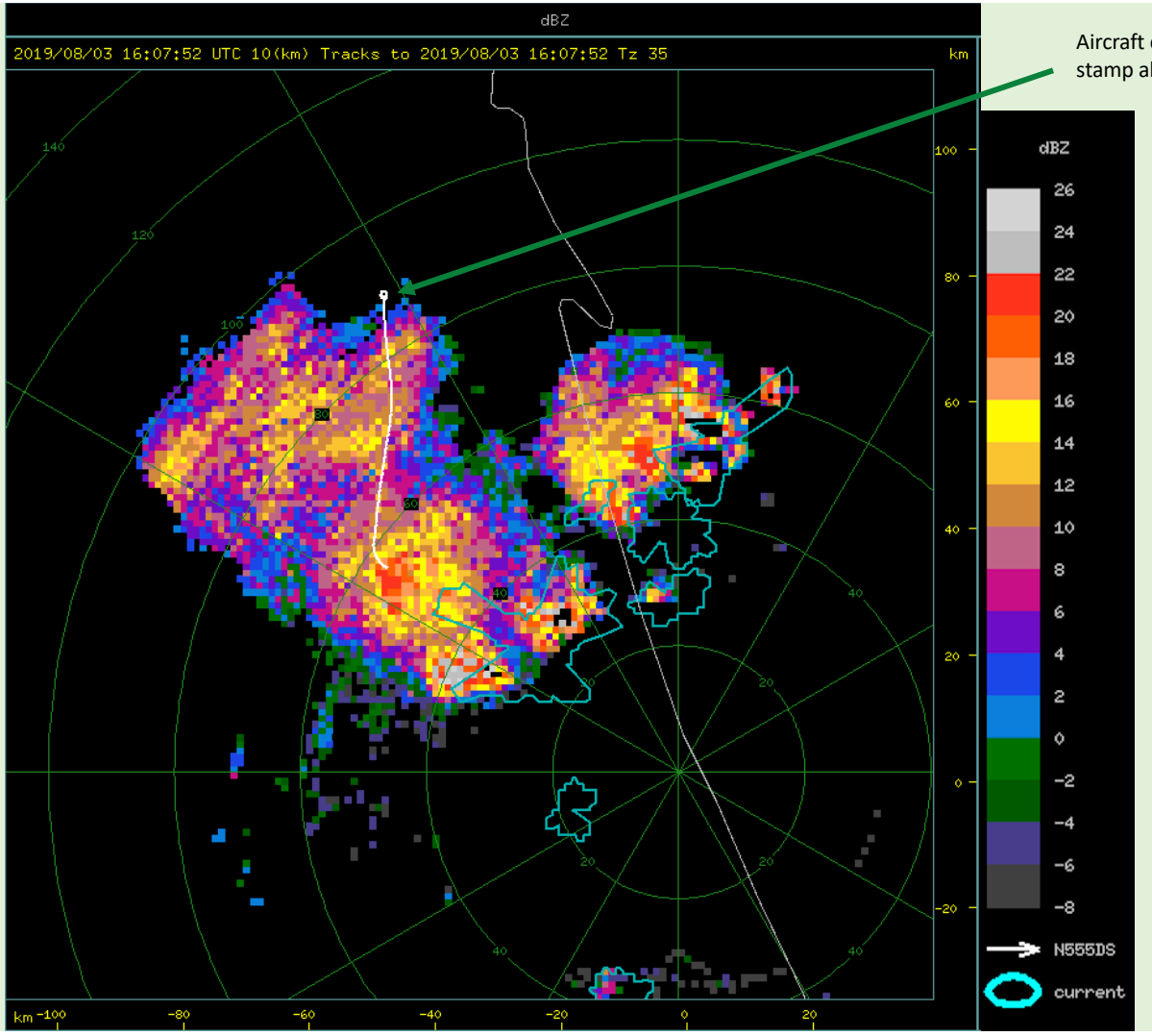
Aircraft current position at time-stamp above.

Blue circles indicating convective cores. (35 dBZ threshold)

Flight Leg 2:

16:02:00 – 16:07:00 UTC

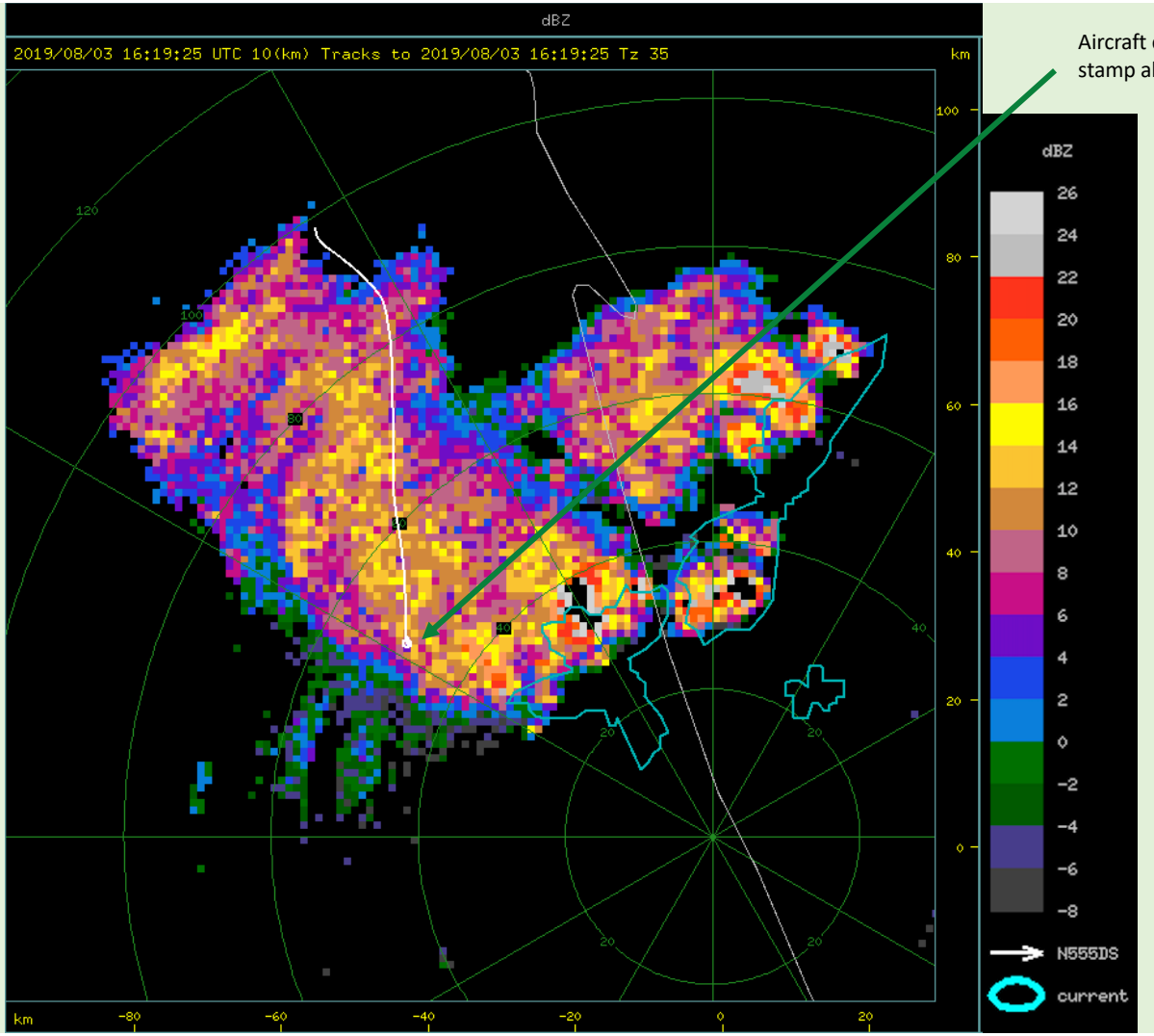
Radar Scan: 16:07:52 UTC
10 km CAPPI



Flight Leg 3:

16:09:00 – 16:17:00 UTC

Radar Scan: 16:19:25 UTC
10 km CAPPI

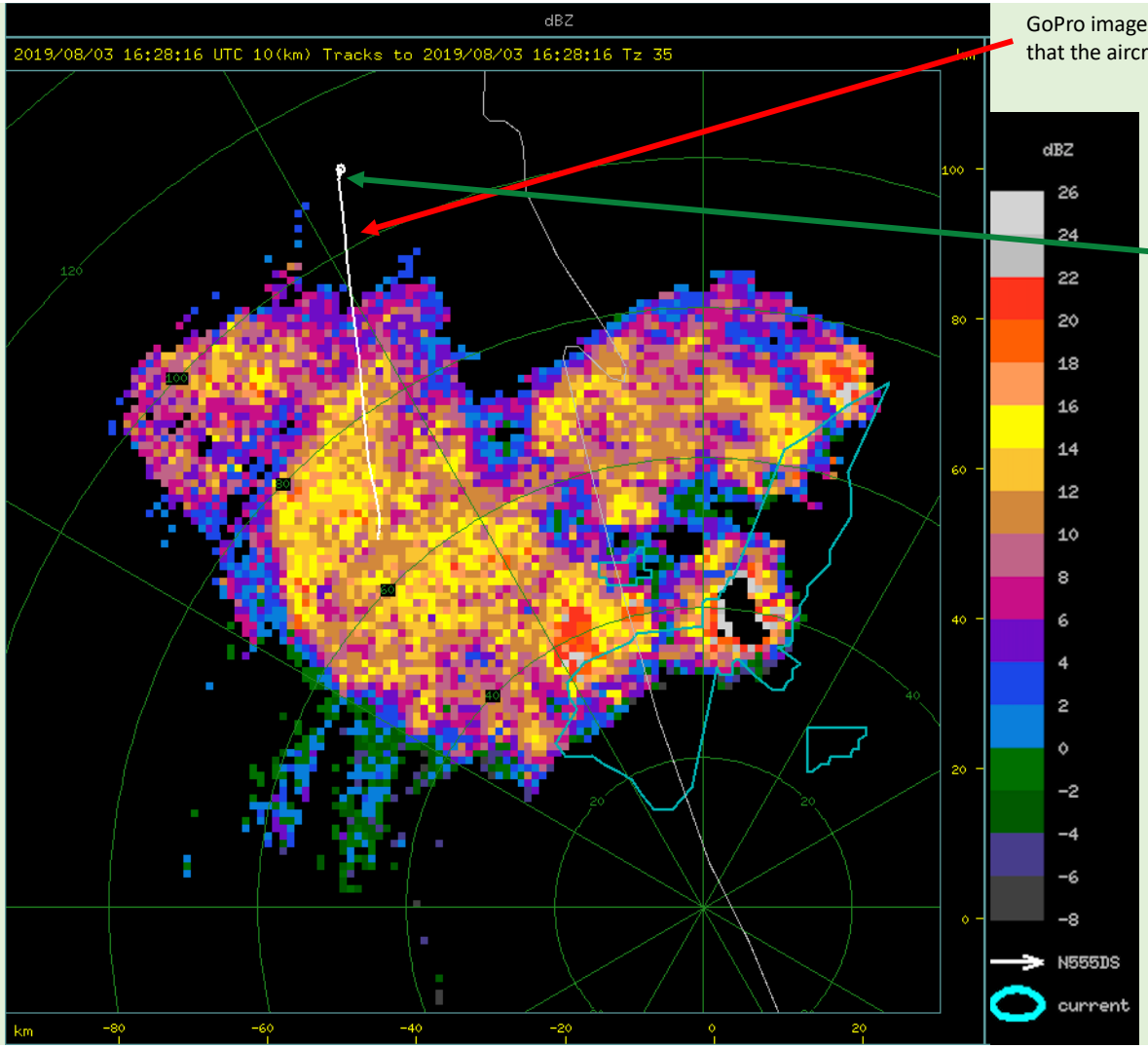


Aircraft current position at time-stamp above.

Flight Leg 4:

16:21:30 – 16:27:00 UTC

Radar Scan: 16:28:16 UTC
10 km CAPPI



GoPro images and TWC probe indicate that the aircraft was still in cloud

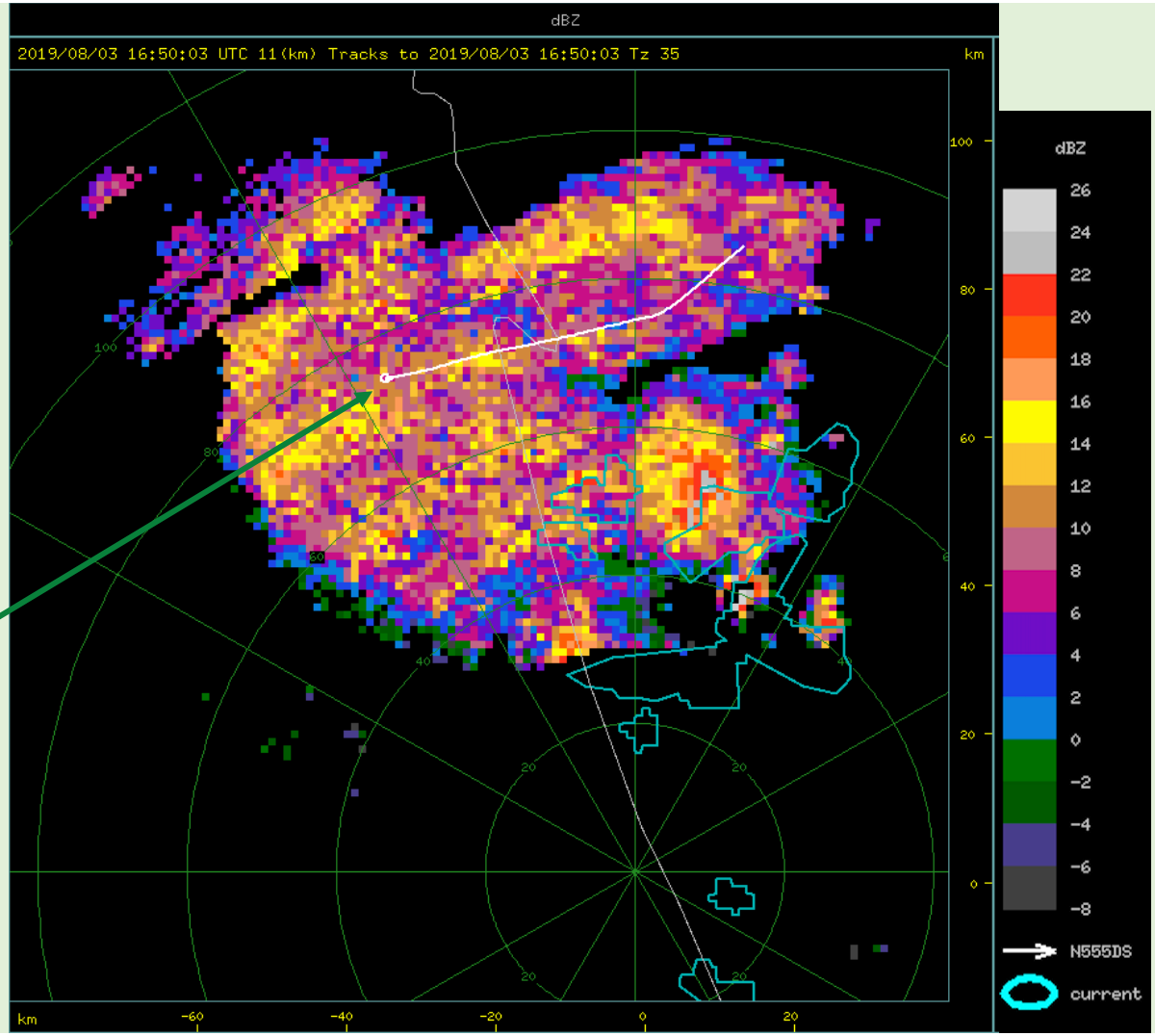
Aircraft current position at time-stamp above.

Flight Leg 5:

16:40:00 – 16:46:00 UTC

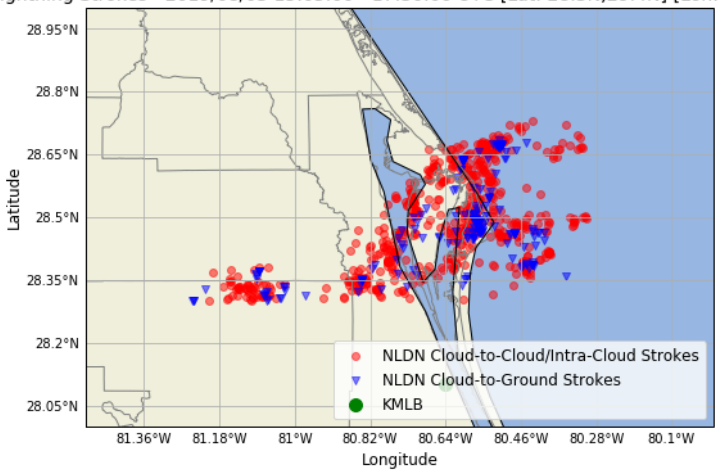
Radar Scan: 16:50:03 UTC
11 km CAPPI

Aircraft current position at time-stamp above.



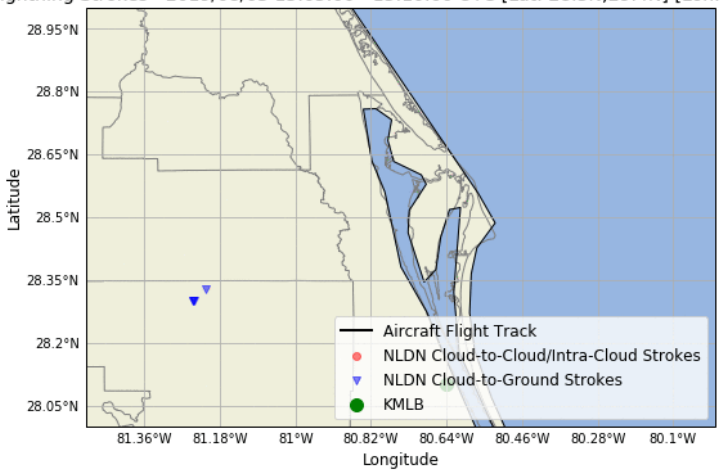
NLDN Data

NLDN Lightning Strokes - 2019/08/03 15:05:00 - 17:30:00 UTC [Lat: 28.3N;29.4N] [Lon: -81.5W;-80.3W]

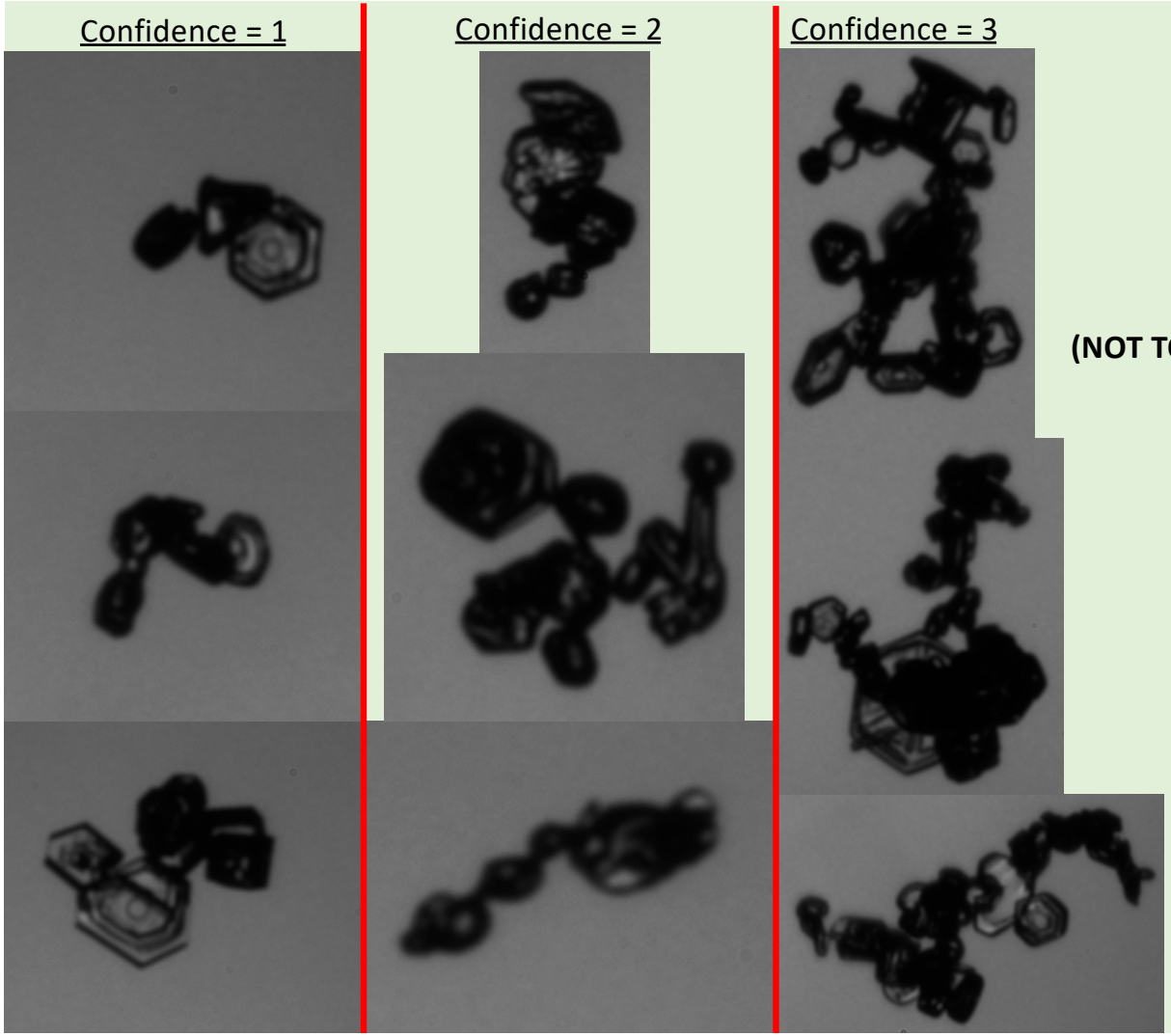


Total # of Cloud-to-Ground Strokes = 195
Total # of Cloud-to-Cloud/Intra-Cloud Strokes = 605

NLDN Lightning Strokes - 2019/08/03 15:05:00 - 15:10:00 UTC [Lat: 28.3N;29.4N] [Lon: -81.5W;-80.3W]



Total # of Cloud-to-Ground Strokes = 4
Total # of Cloud-to-Cloud/Intra-Cloud Strokes = 0



(NOT TO SCALE)

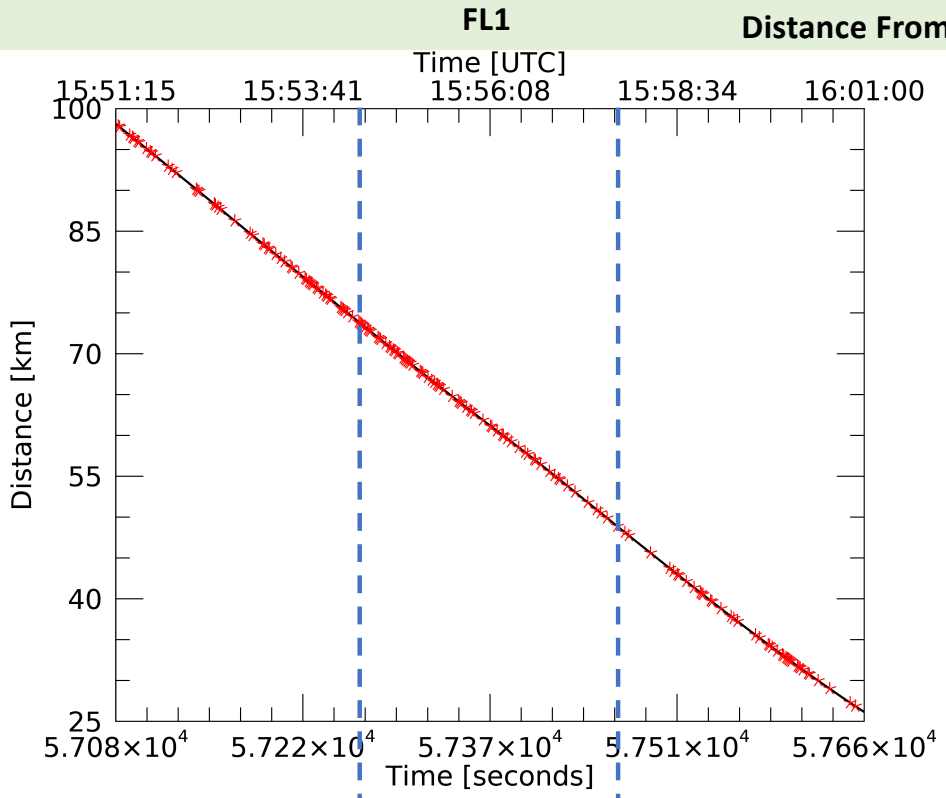
Chain aggregates were **defined** by:

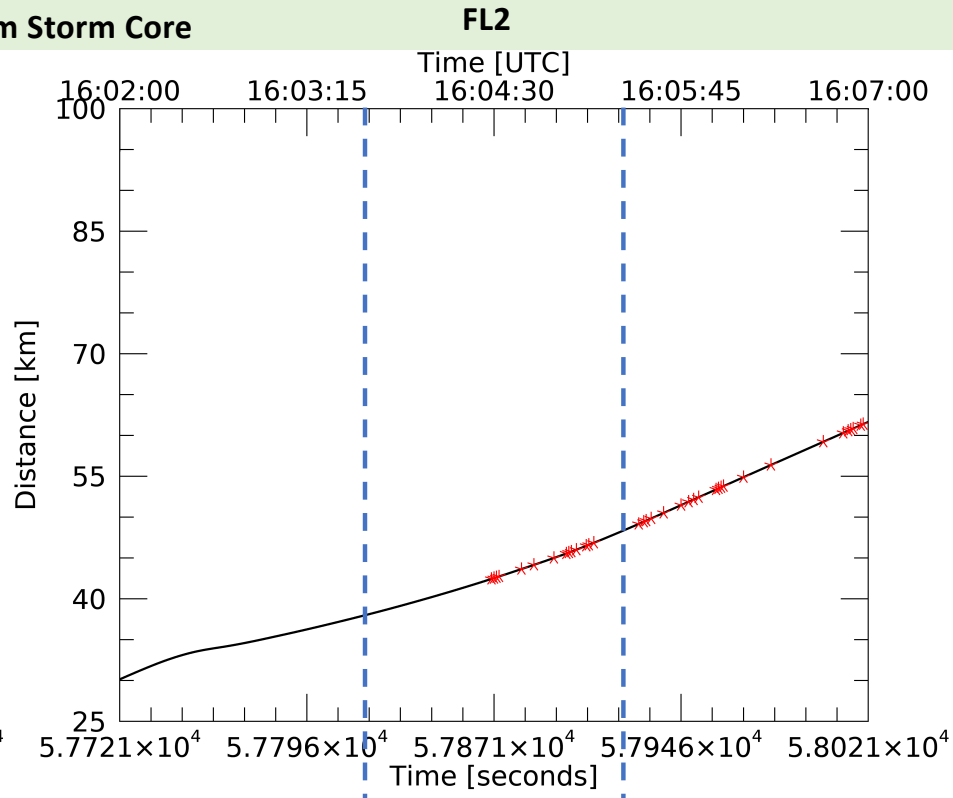
- 3 or more particles oriented in a linear fashion and/or...
- Multiple particles joined by small joints and/or…
- Elongated

Confidence was determined by the classifier:

1. Lowest Confidence (1): One of the three definitions observed.
2. Moderate Confidence (2): Two of the three definitions observed.
3. Highest Confidence (3): All three definitions observed.

Distance From Storm Core





1st 1/3 of FL1
# of Chains = 68
# of PHIPS Images = 435
15.6%
mean distance = 84.0 km
median distance = 82.9 km

2nd 1/3 of FL1
# of Chains = 73
# of PHIPS Images = 398
18.3%
mean distance = 63.7 km
median distance = 64.7 km

3rd 1/3 of FL1
# of Chains = 44
# of PHIPS Images = 389
11.3%
mean distance = 36.5 km
median distance = 34.8 km

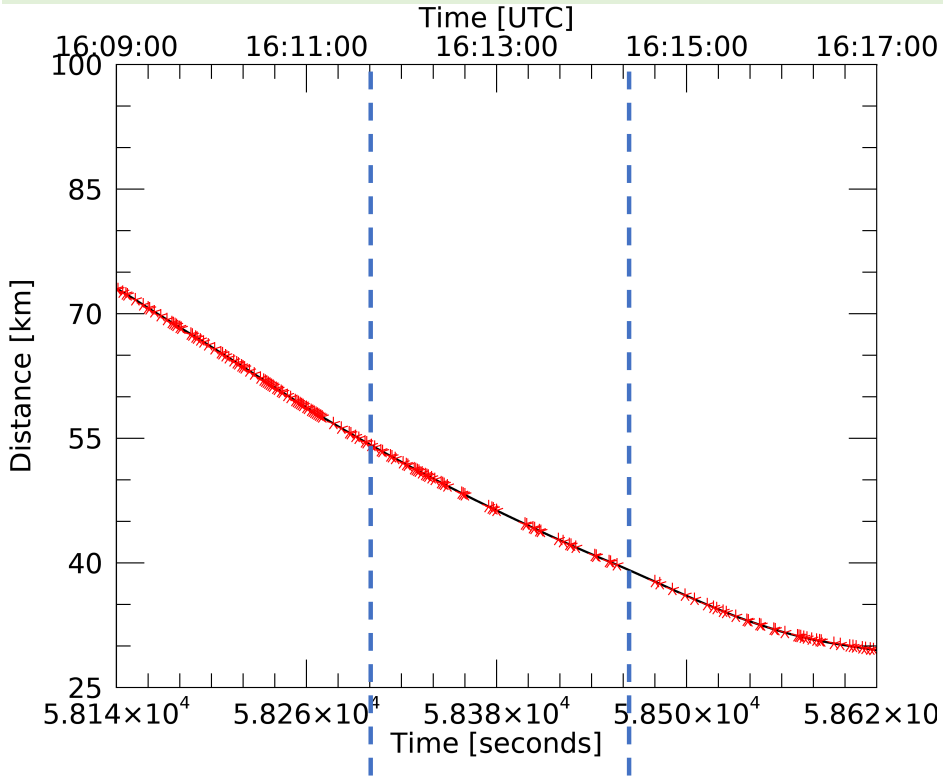
1st 1/3 of FL2
# of Chains = 0
# of PHIPS Images = 1
0%
mean distance = N/A
median distance = N/A

2nd 1/3 of FL2
# of Chains = 17
# of PHIPS Images = 103
16.5%
mean distance = 44.7 km
median distance = 45.2 km

3rd 1/3 of FL2
# of Chains = 24
# of PHIPS Images = 252
9.5%
mean distance = 54.8 km
median distance = 53.5 km

Distance From Storm Core

FL3

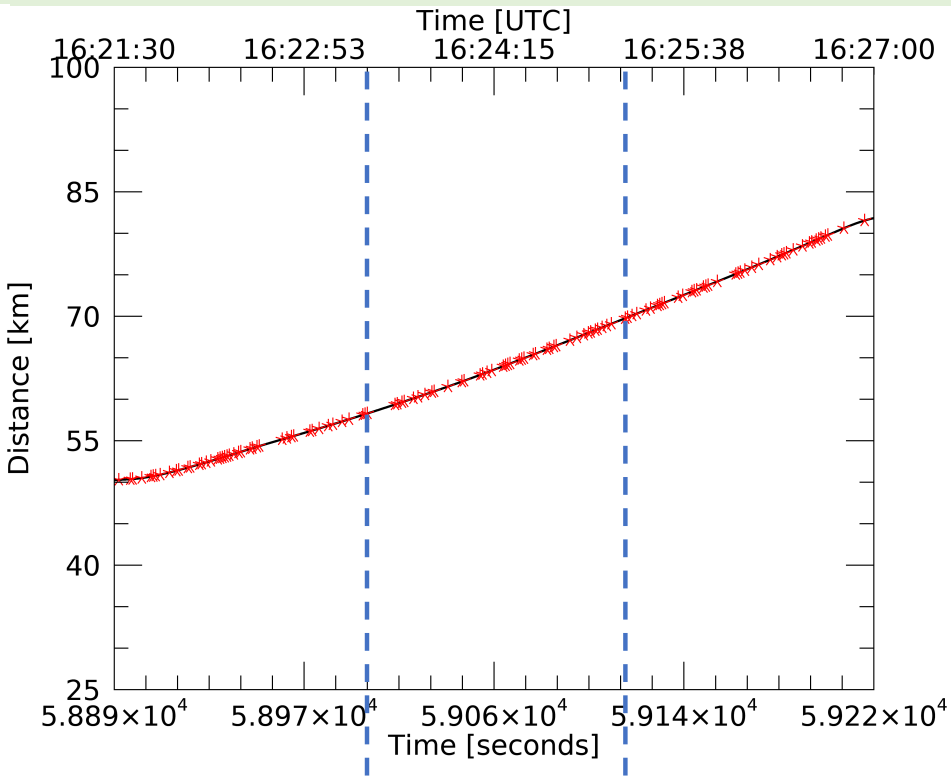


1st 1/3 of FL3
# of Chains = 95
# of PHIPS Images = 421
22.5%
mean distance = 63.2 km
median distance = 62.4 km

2nd 1/3 of FL3
# of Chains = 53
# of PHIPS Images = 484
10.9%
mean distance = 47.7 km
median distance = 49.2 km

3rd 1/3 of FL3
# of Chains = 46
# of PHIPS Images = 592
7.7%
mean distance = 32.3 km
median distance = 31.4 km

FL4

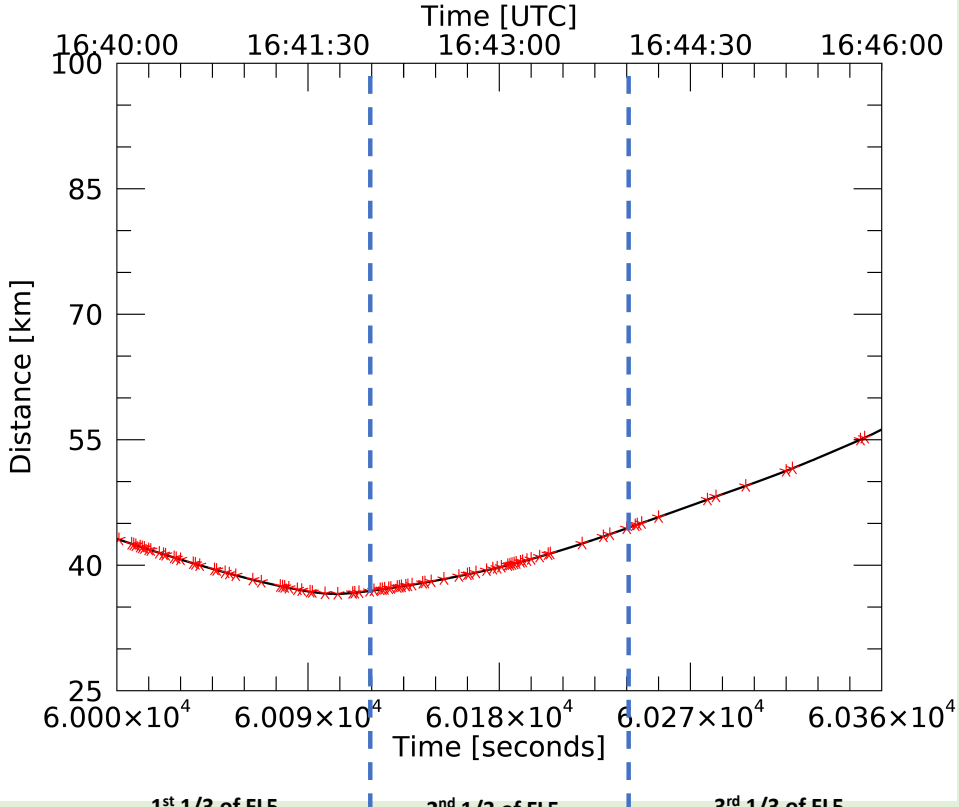


1st 1/3 of FL4
# of Chains = 49
# of PHIPS Images = 191
25.6%
mean distance = 53.5 km
median distance = 53.1 km

2nd 1/3 of FL4
# of Chains = 47
# of PHIPS Images = 291
16.1%
mean distance = 64.1 km
median distance = 64.2 km

3rd 1/3 of FL4
# of Chains = 47
# of PHIPS Images = 332
14.1%
mean distance = 75.1 km
median distance = 75.2 km

Distance From Storm Core
FL5



1st 1/3 of FL5
# of Chains = 41
# of PHIPS Images = 161
25.4%
mean distance = 39.4 km
median distance = 39.4 km

2nd 1/3 of FL5
# of Chains = 46
# of PHIPS Images = 202
22.7%
mean distance = 39.2 km
median distance = 39.1 km

3rd 1/3 of FL5
# of Chains = 12
# of PHIPS Images = 119
10.0%
mean distance = 48.6 km
median distance = 48.0 km

NOTE:

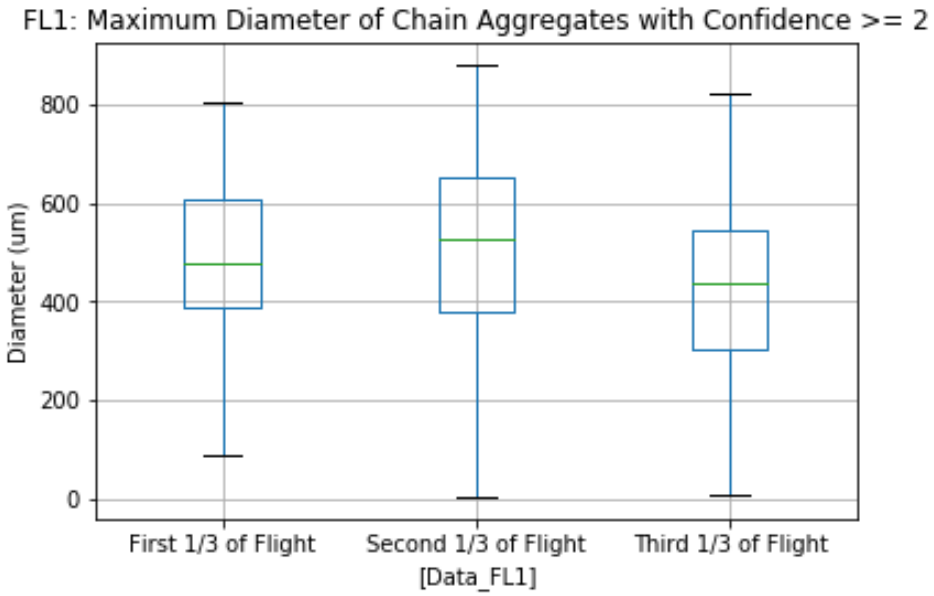
- In FL5 the Citation was flying at an average altitude of 11,321 m, while in FL1-4 the Citation was flying a the 10,014 – 10,053 m range.
- Also, in FL5 the Citation was flying nearly parallel to the storm core, while in FL1-4 the Citation was heading towards or away from the storm core.

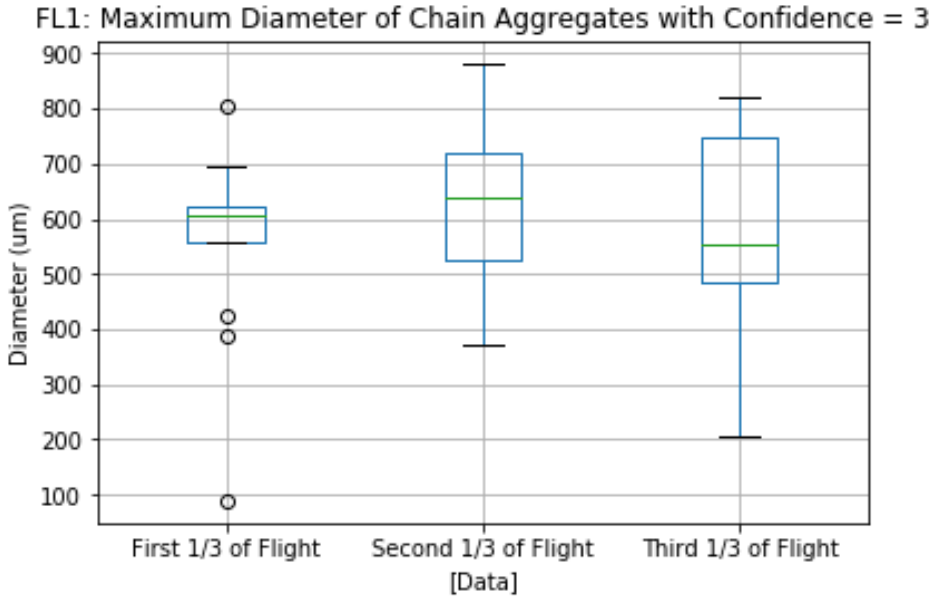
Discussion

- Distance from storm core range: 70 – 100 km
  - 141 Chain Aggregates / 876 PHIPS Images = **16.1%**
- Distance from storm core range: 40 – 70 km
  - 378 Chain Aggregates / 2,348 PHIPS Images = **16.1%**
- Distance from storm core range: 10 – 40 km
  - 141 Chain Aggregates / 1,208 PHIPS Images = **11.7%**
- No clear correlation between the amount of chain aggregates with respect to distance from storm core.

***Altitude Range: 10 – 11 km AGL**

PHIPS: Maximum Diameter of Chains in FL1 Intervals

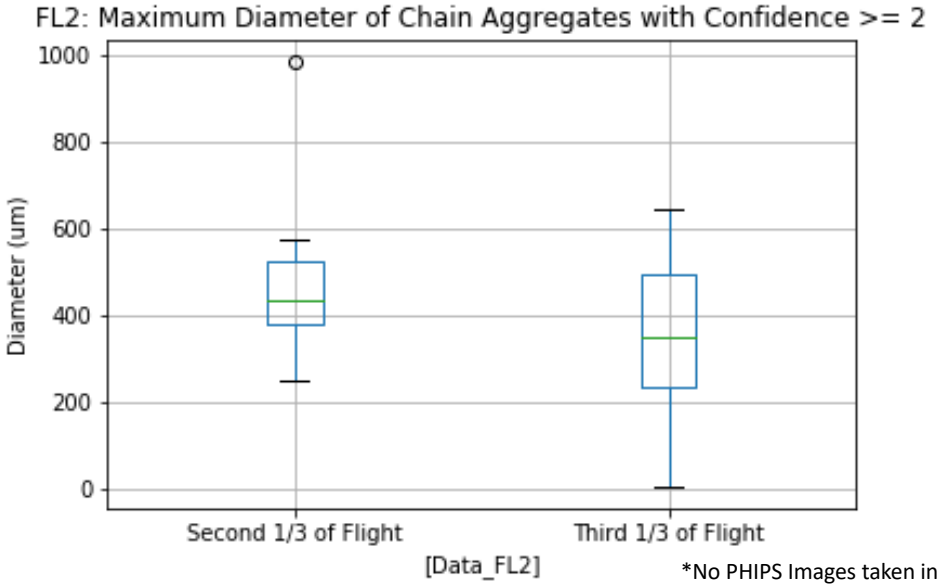


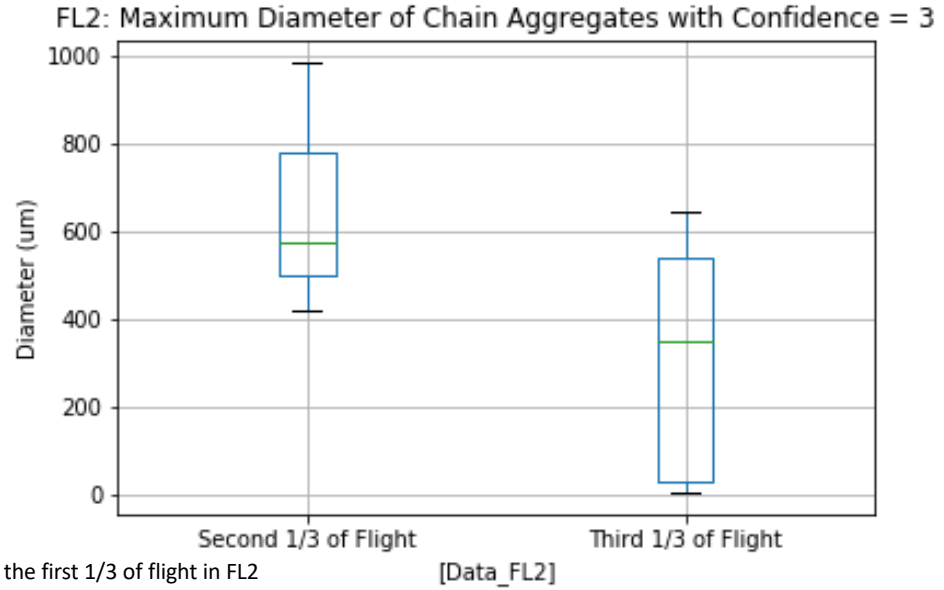


Aircraft Heading Toward Storm Core (N to S)

Aircraft Heading Toward Storm Core (N to S)

PHIPS: Maximum Diameter of Chains in FL2 Intervals



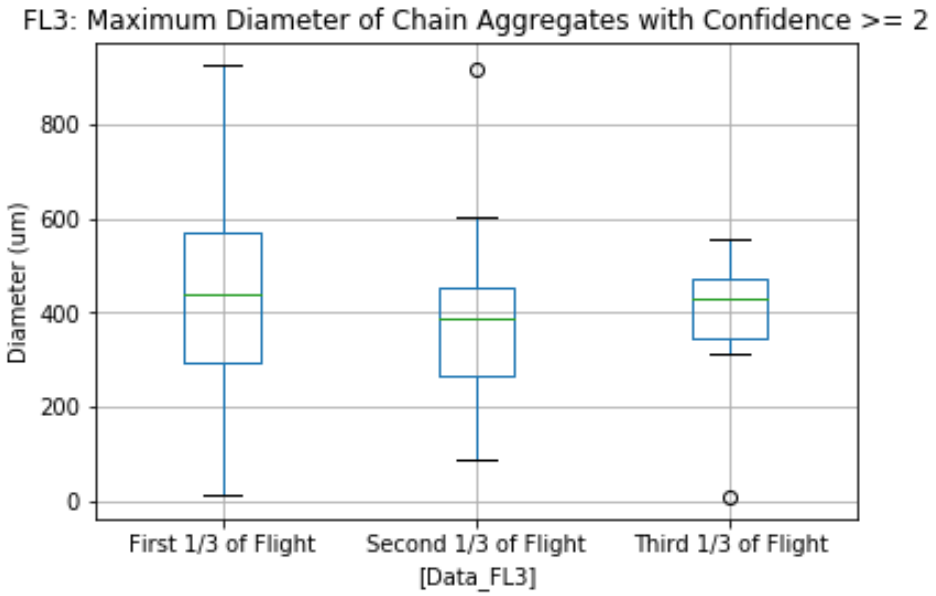


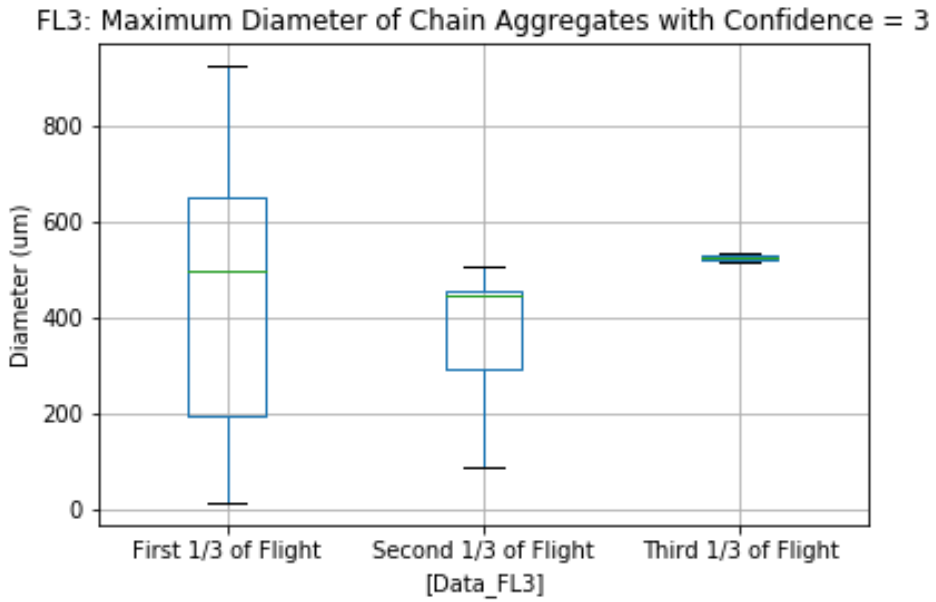
*No PHIPS Images taken in the first 1/3 of flight in FL2

Aircraft Heading Away From Storm Core (S to N)

Aircraft Heading Away From Storm Core (S to N)

PHIPS: Maximum Diameter of Chains in FL3 Intervals

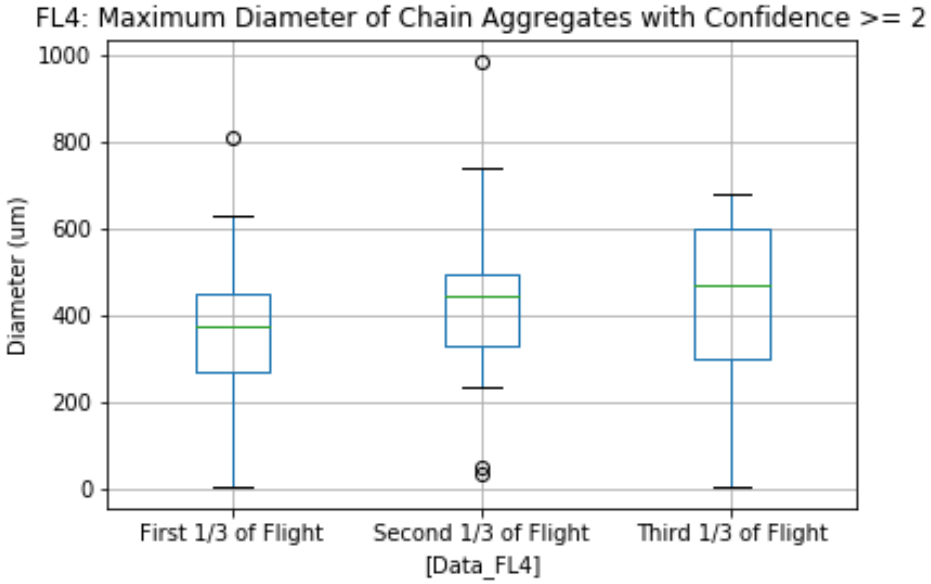


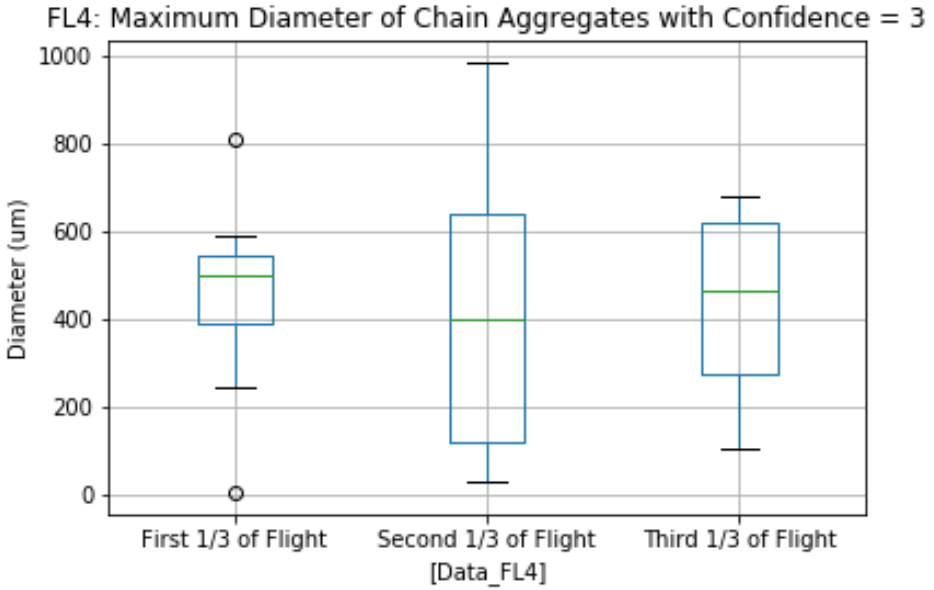


Aircraft Heading Toward Storm Core (N to S)

Aircraft Heading Toward Storm Core (N to S)

PHIPS: Maximum Diameter of Chains in FL4 Intervals

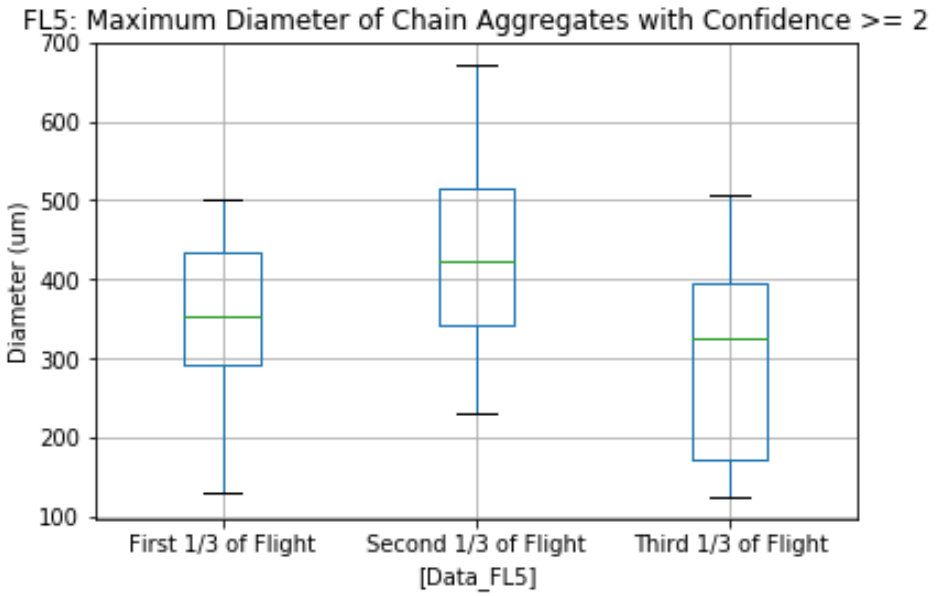




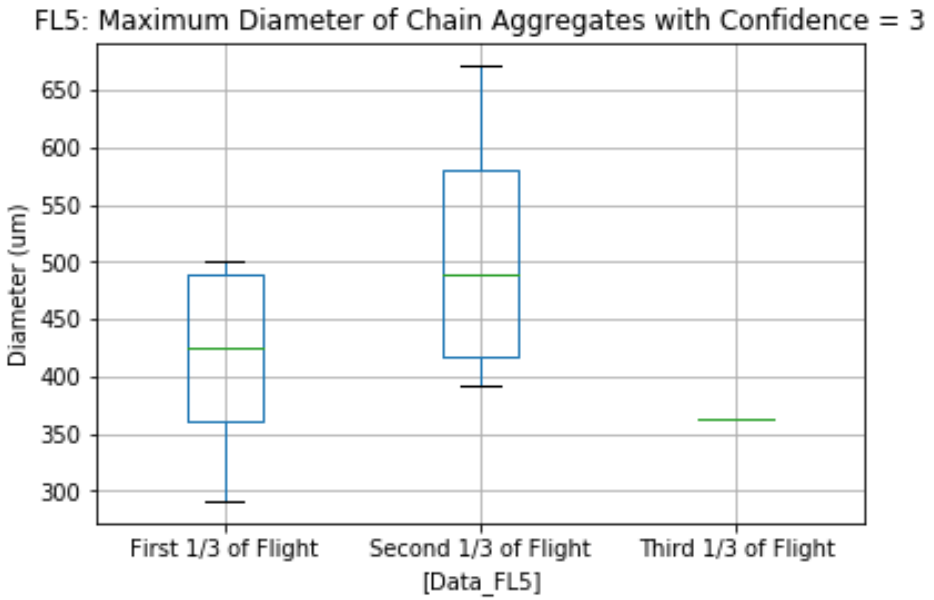
Aircraft Heading Away From Storm Core (S to N)

Aircraft Heading Away From Storm Core (S to N)

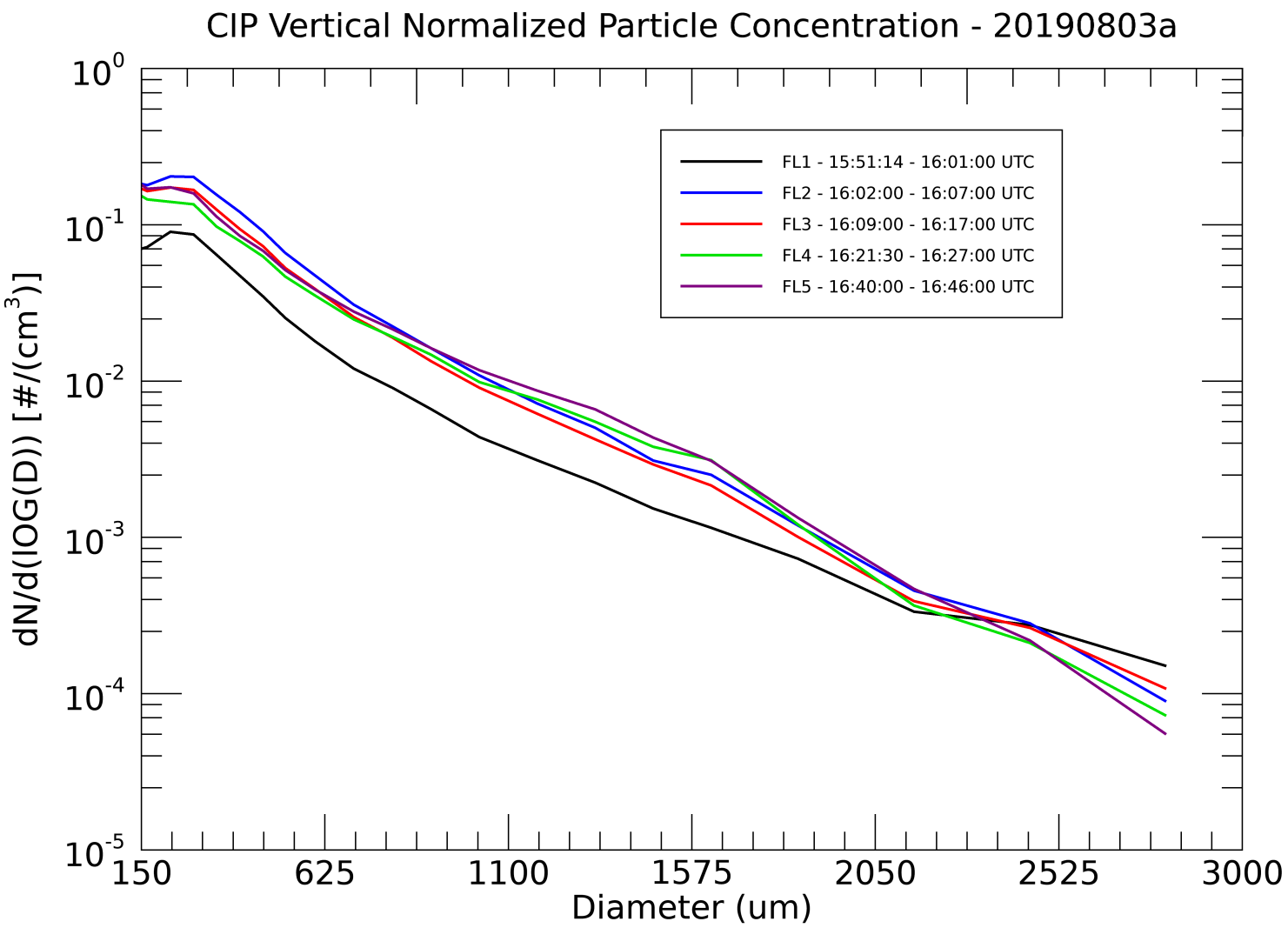
PHIPS: Maximum Diameter of Chains in FL5 Intervals



Aircraft Parallel to Storm Core (E to W)



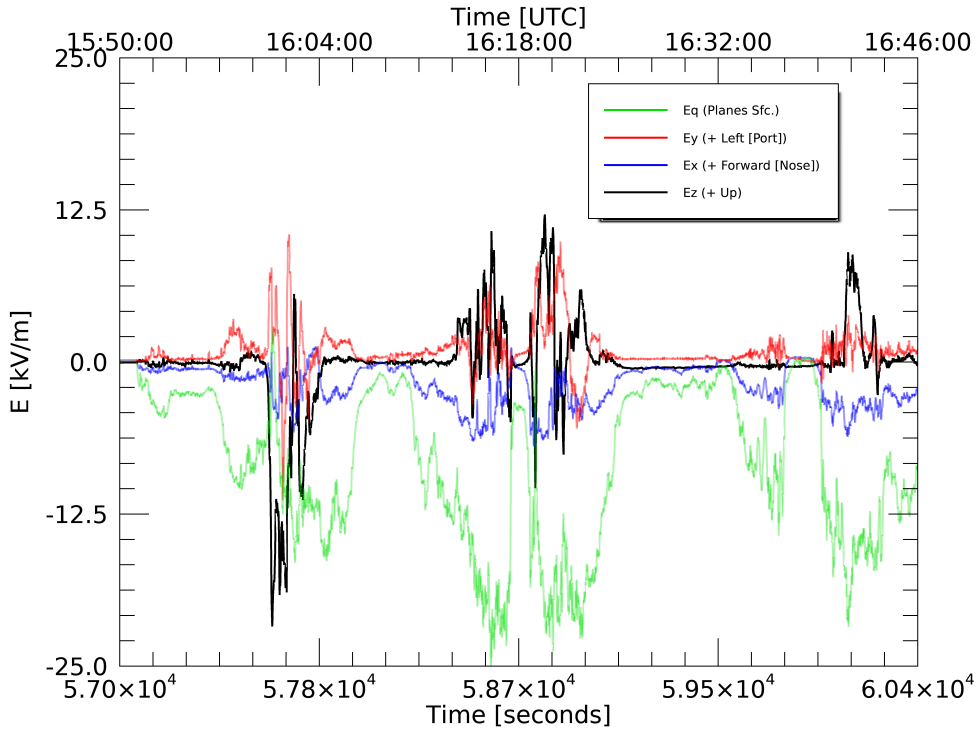
Aircraft Parallel to Storm Core (E to W)


CIP Vertical Normalized Particle Concentration - 20190803a
dN/d(log(D)) [#/(cm3)]
Diameter (um)
FL1 - 15:51:14 - 16:01:00 UTC
FL2 - 16:02:00 - 16:07:00 UTC
FL3 - 16:09:00 - 16:17:00 UTC
FL4 - 16:21:30 - 16:27:00 UTC
FL5 - 16:40:00 - 16:46:00 UTC
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
150
625
1100
1575
2050
2525
3000

Electric Field Data FL1-5

- During the Flight Legs, the Ex, Ey, and Ez do not meet the minimum E-field criteria as tested (60 kV/m) by Saunders and Wahab, 1975

- Further evidence for higher rates of chain aggregation closer to the mixed-phase region of the storm?
  - *Aircraft never was directly over the storm core*.



Current Plan

- Send out semi-final form of topic proposal to all committee members to review and make comments.
  - Submit for graduate school approval by the end of June.
- Starting June 7th, I will be starting the NRIEP (NRL internship in Monterey, CA).
  - 10-week duration (First 5 weeks are remote, last 5 weeks in person).
  - Driving to Monterey, CA on July 7th -> arriving late July 9th or early July 10th
  - Internship ends August 13th
- Resume my thesis work.
  - Start writing my thesis.
    - All done with classes.
    - Taking two hours every morning (increasing the duration every week) to solely focus on writing.
    - Concurrently taking time to finalize my results and making publish worthy figures.
    - During (or before) writing, I'll be creating a thesis defense PowerPoint.
- Graduation planned for December 2021.

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