Committee Meeting

5 April 2022

Christian Nairy

Updates

- Participated in the 2022 IMPACTS field campaign
- Current writing and preparing for defense (this summer)

Refresher

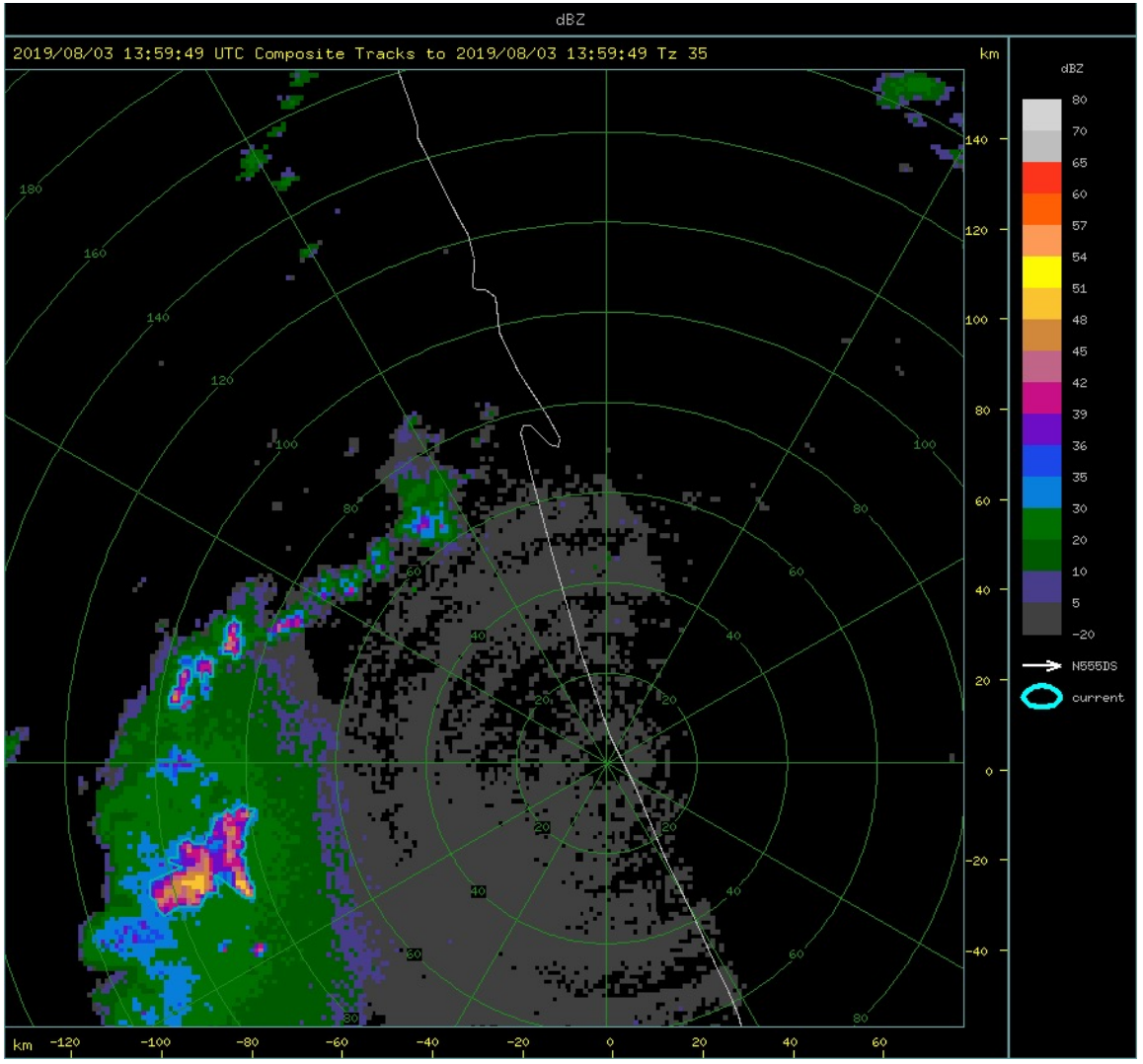
- Thesis Title:
  - **OBSERVATIONS OF CHAIN AGGREGATES IN FLORIDA CIRRUS CLOUD ANVILS ON 3 AUGUST 2019 DURING CAPEEX19**
- Objective:
  - To answer: Is chain aggregation occurring within the cirrus anvil region?

- Methods:
  - Characterizing and analyzing observed chain aggregates with respect to distance from Florida thunderstorm cores from in-situ microphysical probes via aircraft.
  - Compare to microphysics to in-situ electric field observations and radar data from the CapeEx19 data set.

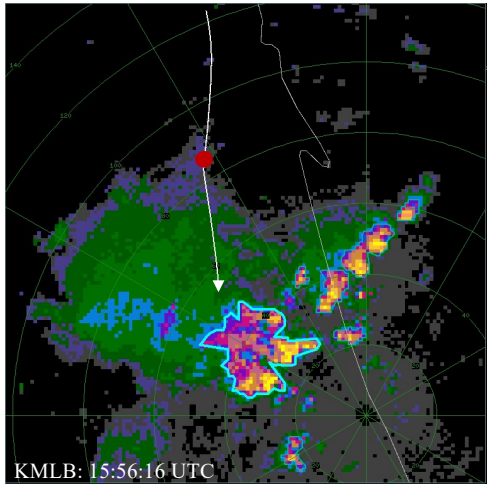
- Expected Results:
  - Provide insight into the overall clouds processes responsible for creating chain-like crystals to enable improvement of cloud models.

Latest data and Results

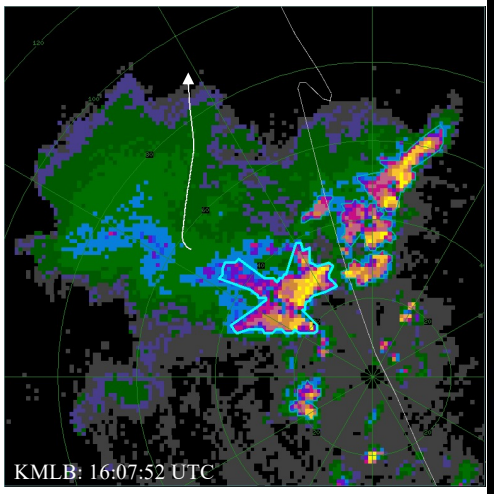
Messy & unorganized convection.



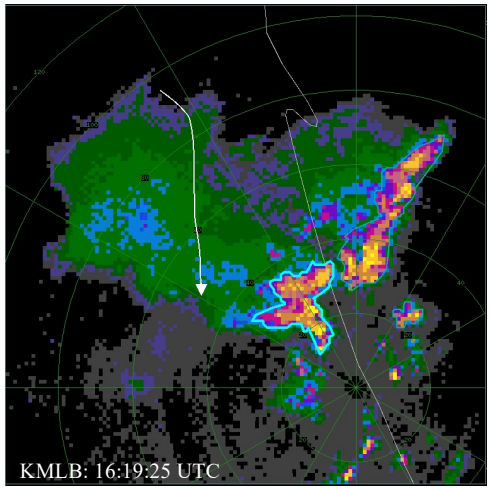
(a) – FL1: 15:51:15 - 16:01:00 UTC



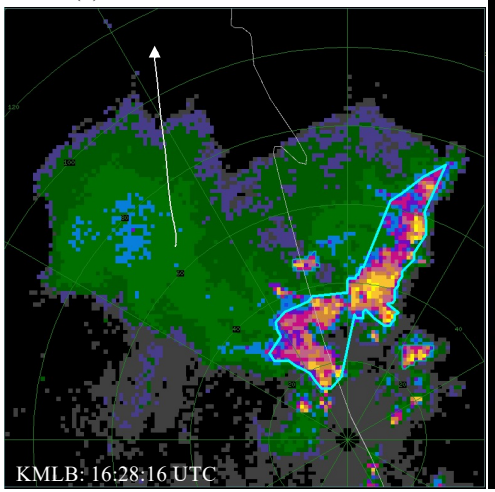
(b) – FL2: 16:02:00 - 16:07:00 UTC

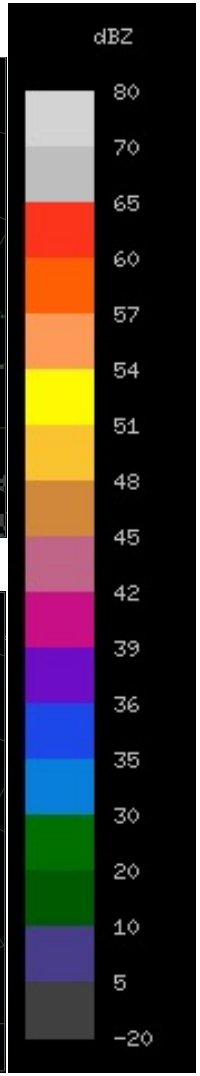


(c) – FL3: 16:09:00 - 16:17:00 UTC



(d) – FL4: 16:21:30 - 16:27:00 UTC



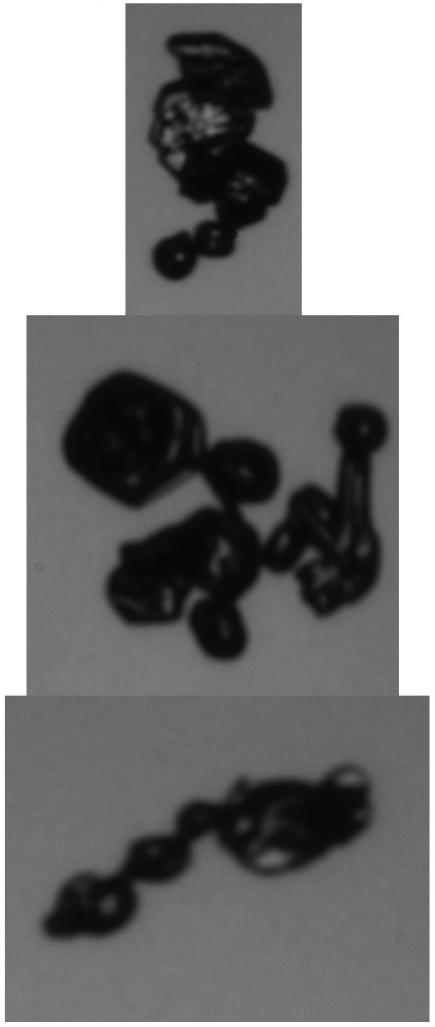


Omit FL5

FL1 – Other convective cells to the WNW and may have an influence on the in-situ data.

Confidence = 1

Confidence = 2



Confidence = 3

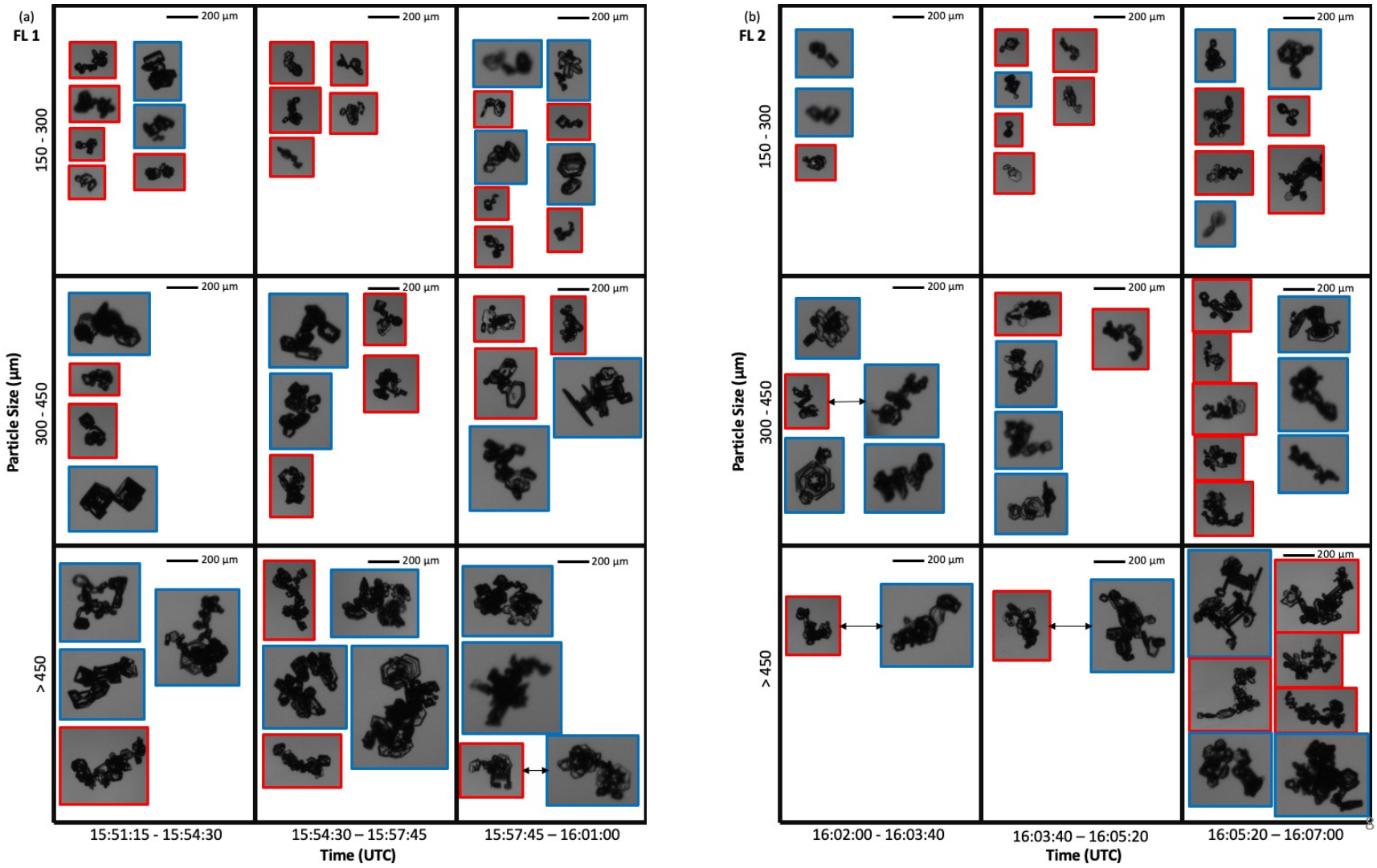
(NOT TO SCALE)

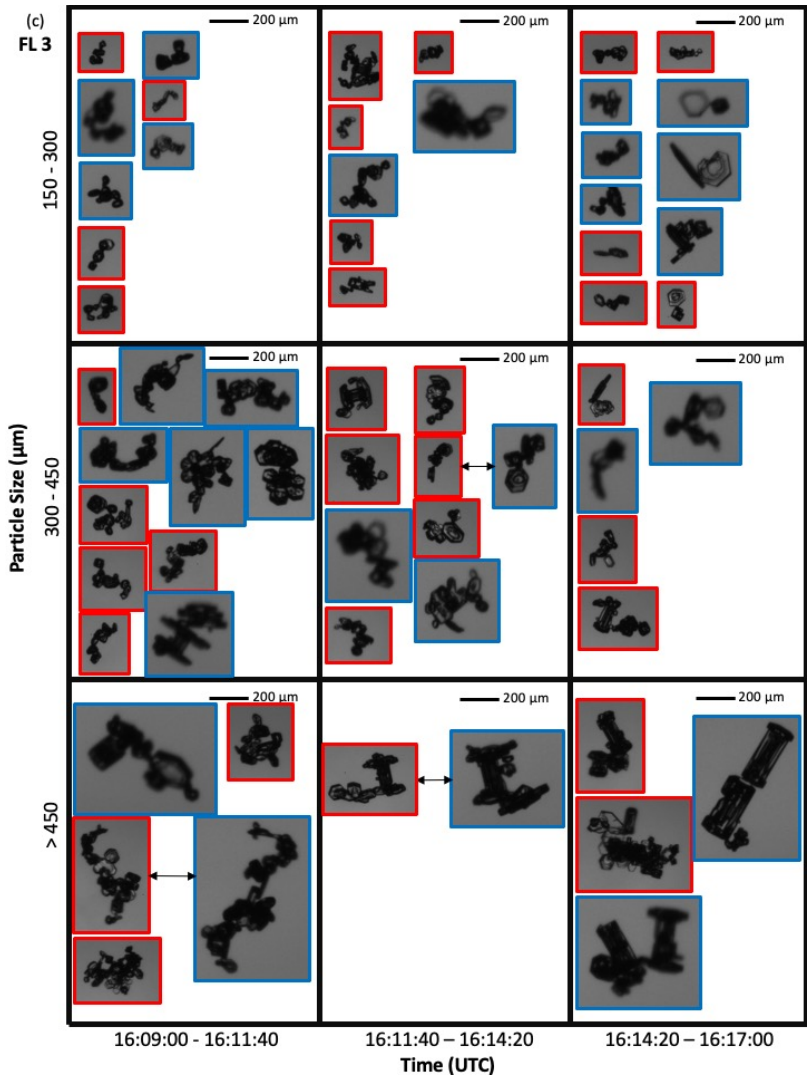
Chain aggregates were **defined** by:

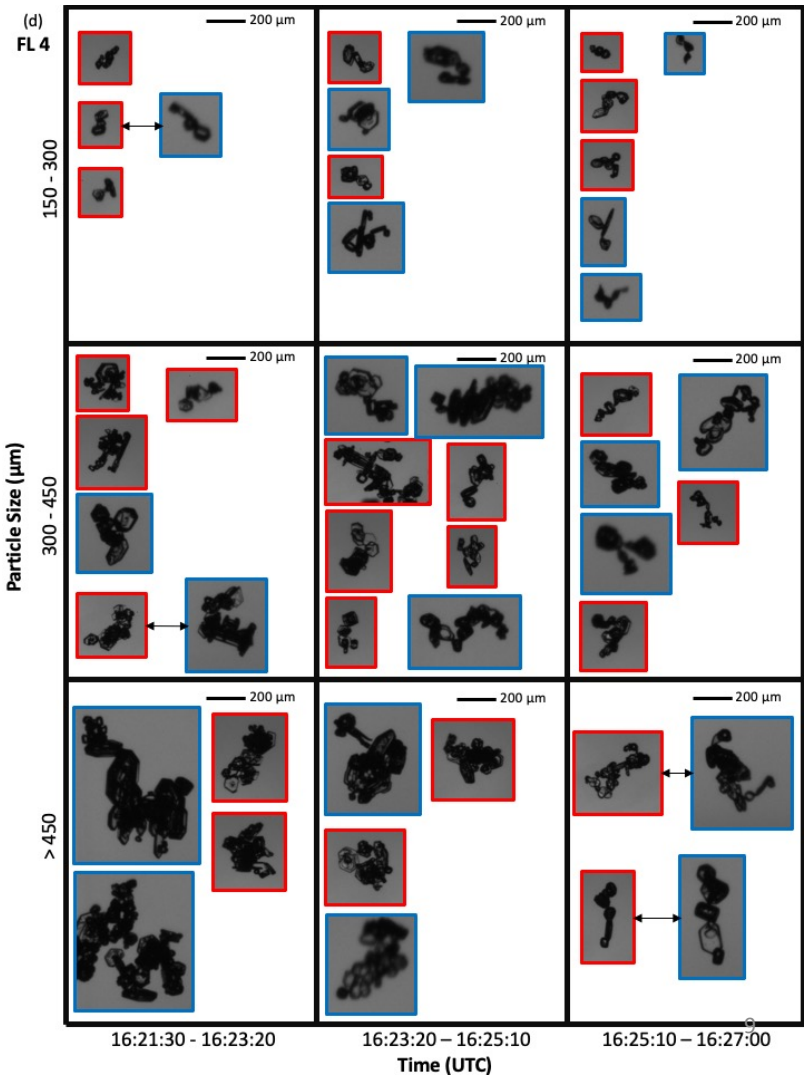
- 3 or more discernable particles oriented in a quasi-linear fashion and/or…
- Particles joined together by small joints and/or…
- Links of particles that are unusually elongated

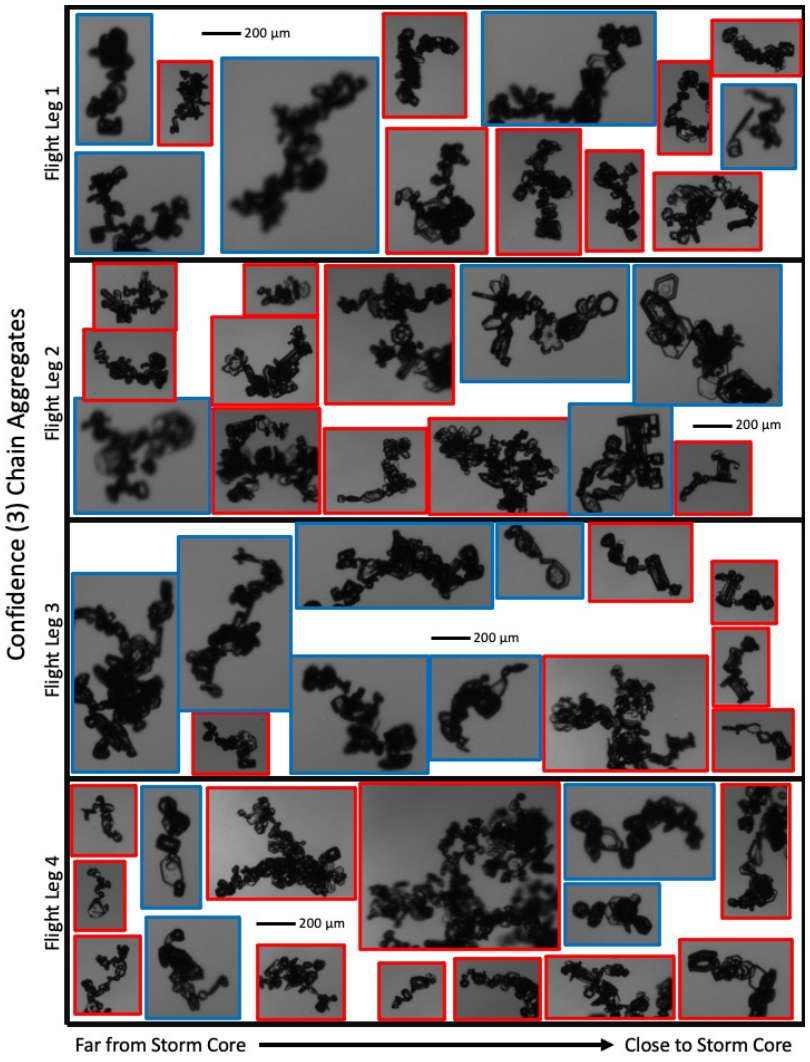
Confidence was determined by the classifier:

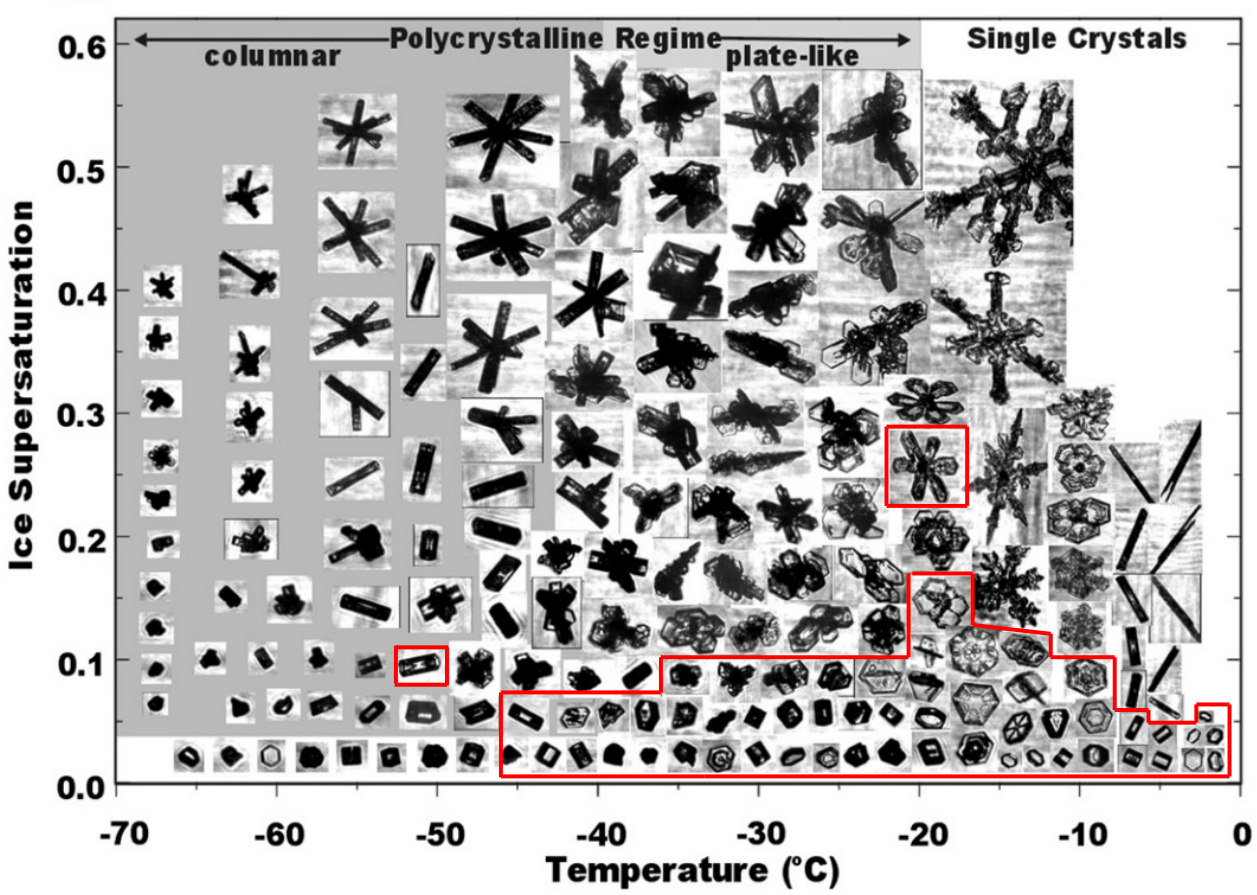
1. Lowest Confidence (1): One of the three definitions observed.
2. Moderate Confidence (2): Two of the three definitions observed.
3. Highest Confidence (3): All three definitions observed.


(a)
FL 1
(b)
FL 2
Particle Size (µm)
150 - 300
300 - 450
> 450
200 µm
15:51:15 - 15:54:30
15:54:30 – 15:57:45
15:57:45 – 16:01:00
16:02:00 - 16:03:40
16:03:40 – 16:05:20
16:05:20 – 16:07:00
Time (UTC)


(c)
FL 3
Particle Size (µm)
150 - 300
300 - 450
> 450
200 µm
16:09:00 - 16:11:40
16:11:40 – 16:14:20
16:14:20 – 16:17:00
Time (UTC)


(d)
FL 4
Particle Size (µm)
150 - 300
300 - 450
> 450
200 µm
16:21:30 - 16:23:20
16:23:20 – 16:25:10
16:25:10 – 16:27:00
Time (UTC)


Confidence (3) Chain Aggregates
Flight Leg 1
Flight Leg 2
Flight Leg 3
Flight Leg 4
200 µm
200 µm
200 µm
200 µm
Far from Storm Core
Close to Storm Core

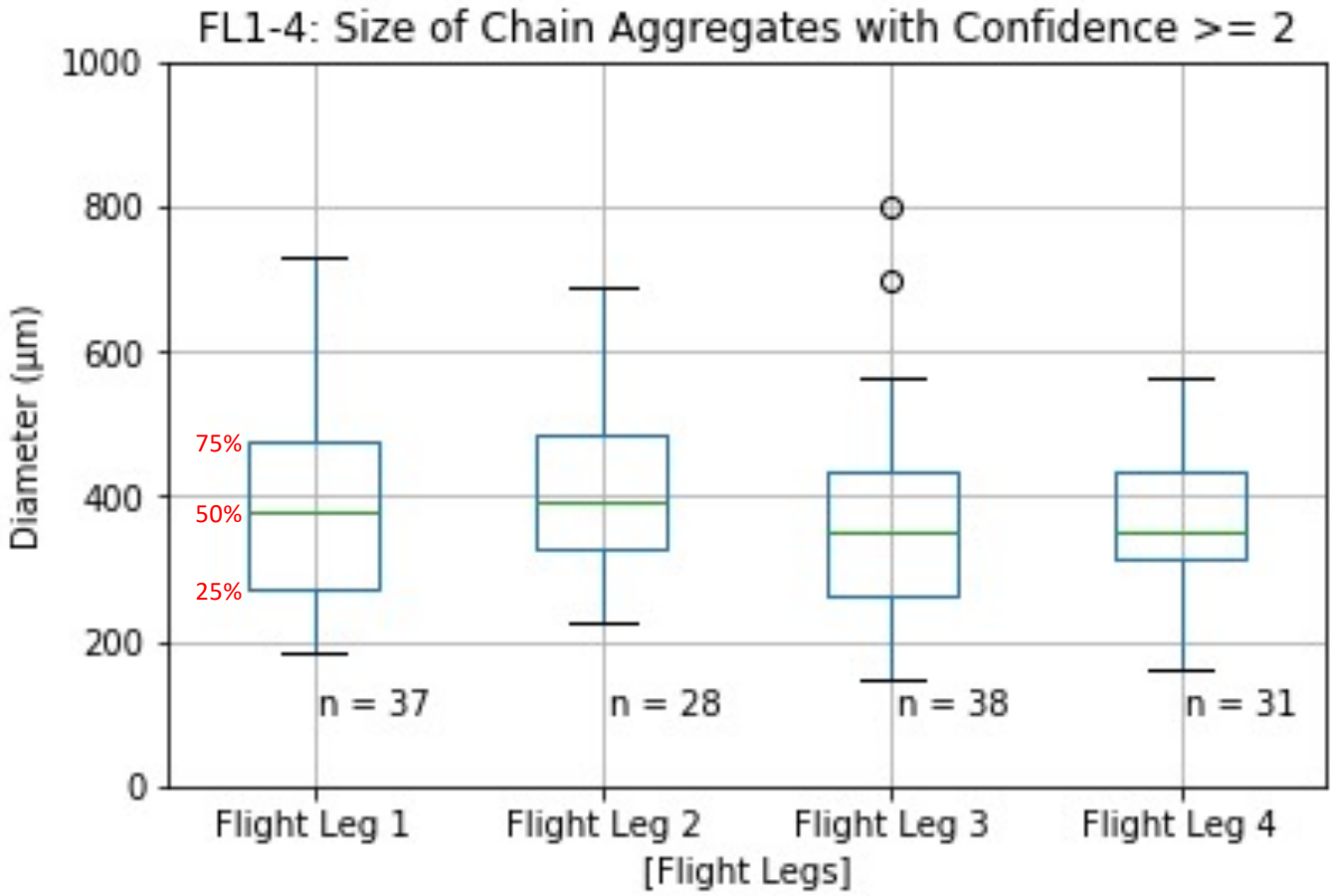

columnar
Polycrystalline Regime
plate-like
Single Crystals
Ice Supersaturation
0.0
0.1
0.2
0.3
0.4
0.5
0.6
-70
-60
-50
-40
-30
-20
-10
0
Temperature (°C)

Legs	Total # of Chains	Total # of Images	Confidence = 1	Confidence = 2	Confidence = 3
FL1	218	1,507	69	80	69
	14.5 ± 0.6%		**4.6 ± 0.4%**	**5.3 ± 0.5%**	**4.6 ± 0.4%**
FL2	118	917	39	48	31
	12.9 ± 0.8%		**4.3 ± 0.5%**	**5.2 ± 0.6%**	**3.4 ± 0.5%**
FL3	191	1,375	64	89	38
	13.9 ± 0.6%		**4.7 ± 0.5%**	**6.5 ± 0.5%**	**2.8 ± 0.4%**
FL4	141	855	33	67	41
	16.5 ± 0.8%		**4.0 ± 0.5%**	**7.7 ± 0.7%**	**4.8 ± 0.6%**
TOTAL	**668**	**4,654**	**205**	**284**	**179**
	14.4 ± 0.3%		**4.4 ± 0.2%**	**6.1 ± 0.3%**	**3.8 ± 0.2%**

PHIPS Data

	70 – 100 km from Storm Core		40 – 70 km from Storm Core		10 – 40 km from Storm Core	
Legs	# of Chains	# of Images	# of Chains	# of Images	# of Chains	# of Images
FL1	58	510	124	631	36	366
	11.4 ± 1.0%		**19.7 ± 1.0%**		**9.8 ± 1.1%**	
FL2	N/A	N/A	78	520	40	397
	N/A		**15.0 ± 1.0%**		**10.1 ± 1.1%**	
FL3	18	55	121	800	52	520
	32.7 ± 3.3%		**15.1 ± 0.8%**		**10.0 ± 1.0%**	
FL4	44	178	97	677	N/A	N/A
	24.7 ± 1.9%		**14.3 ± 0.9%**		**N/A**	
Total	120	743	420	2628	128	1283
	16.2 ± 0.9%		**16.0 ± 0.5%**		**10.0 ± 0.6%**	

PHIPS Data



Using ‘all in’ PHIPS images

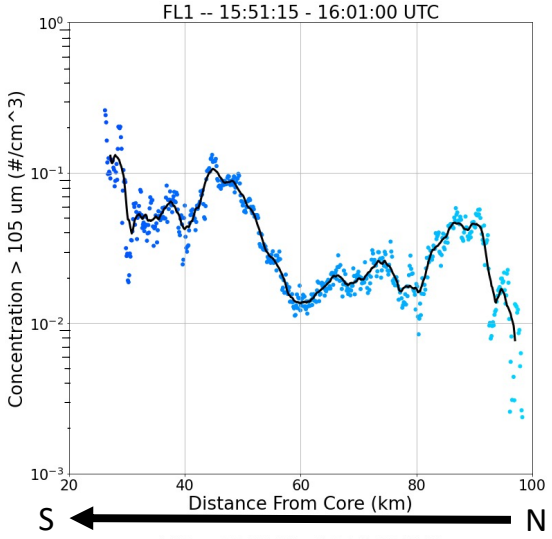
PHIPS Image Data of Particles with a Sizing (D_{max}) Attribute > 495 um

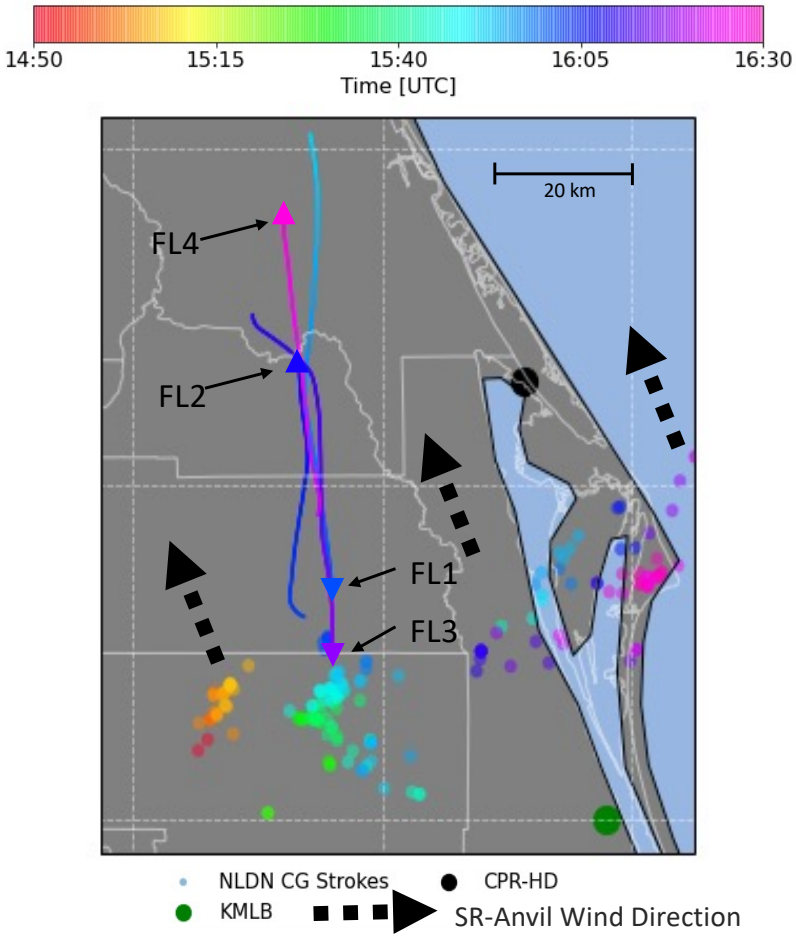
Legs	Particles > 495 µm (#)	Chains > 495 µm (#)	$\frac{\#\ of\ Chains > 495\ \mu m}{\#\ of\ Particles > 495\ \mu m}$	Avg. confidence of chains > 495 µm
FL1	7	7	100%	2.71
FL2	11	8	73%	2.38
FL3	8	7	88%	2
FL4	10	8	80%	1.88
TOTAL	**36**	**30**	**83%**	**2.2425**

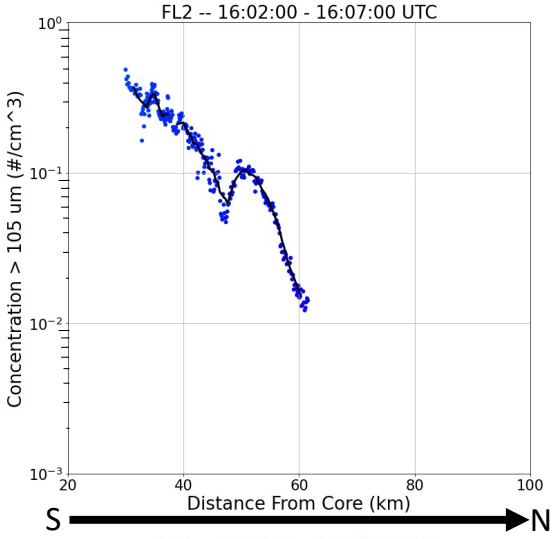
- This give confidence to look at the CIP data (which has a higher sampling volume than the PHIPS) and pull the concentration of particles > 495 micro-meters.

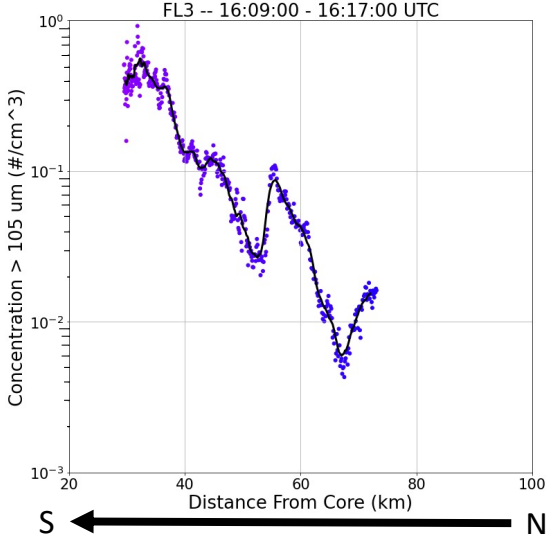
- **Chain aggregates = CIP particle concentrations > 495 um; non-chain aggregates = CIP particle concentrations between 105 – 315 um; Particle buffer zone = CIP particle concentrations between 315 – 495 um.**

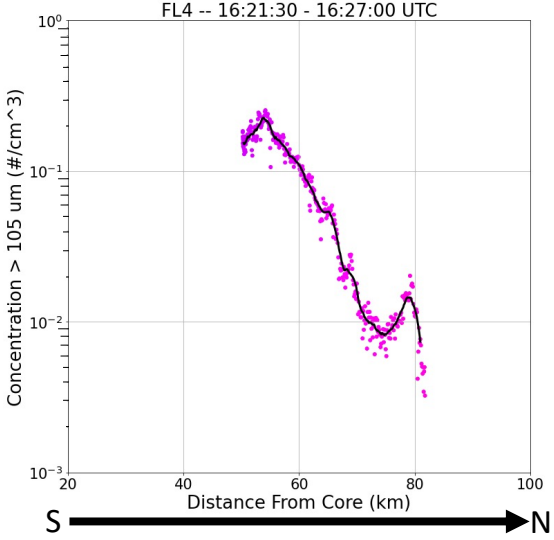
Total Particle Concentration



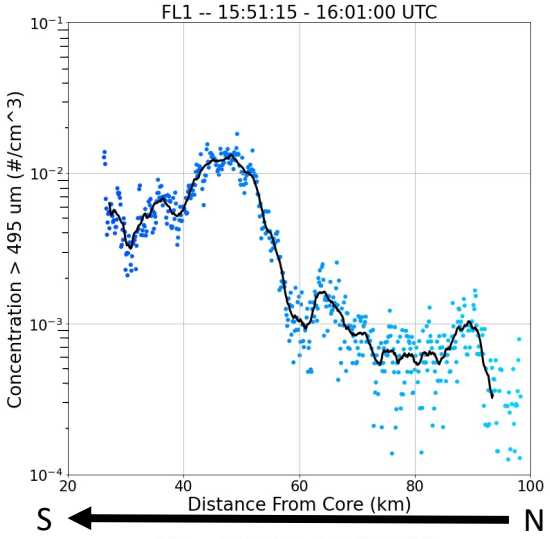


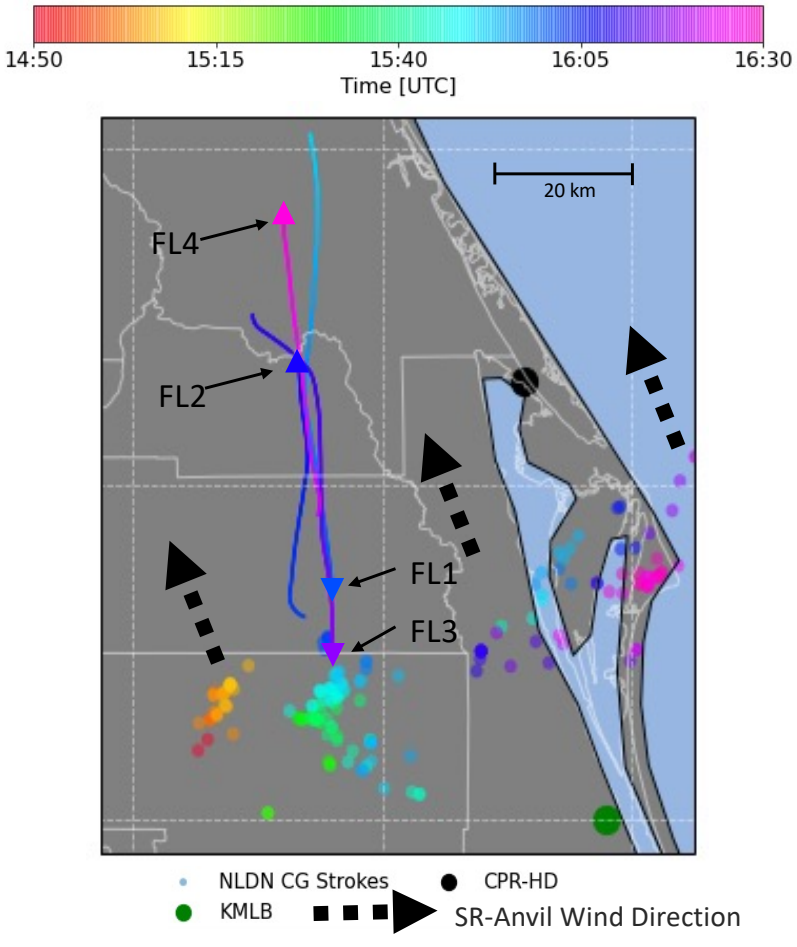


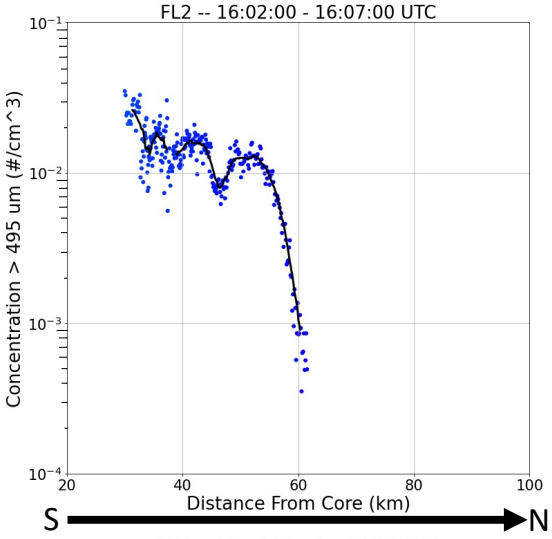


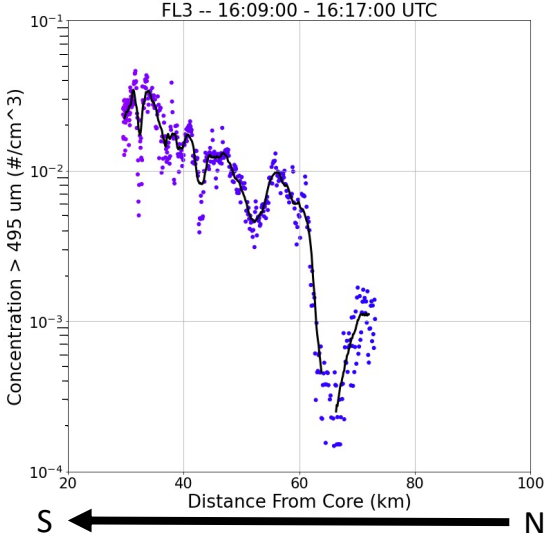


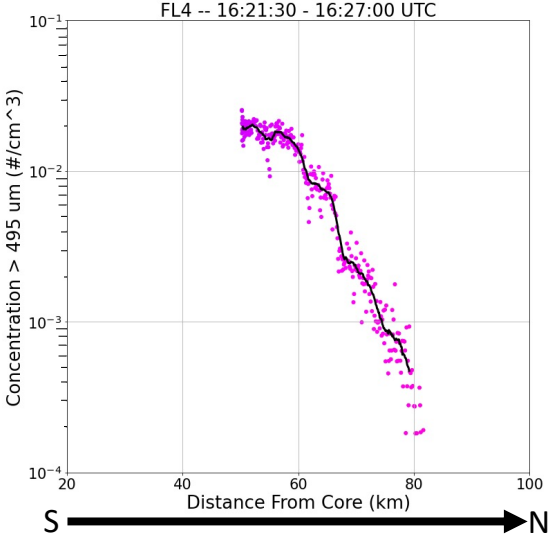
Chain Aggregate Concentration

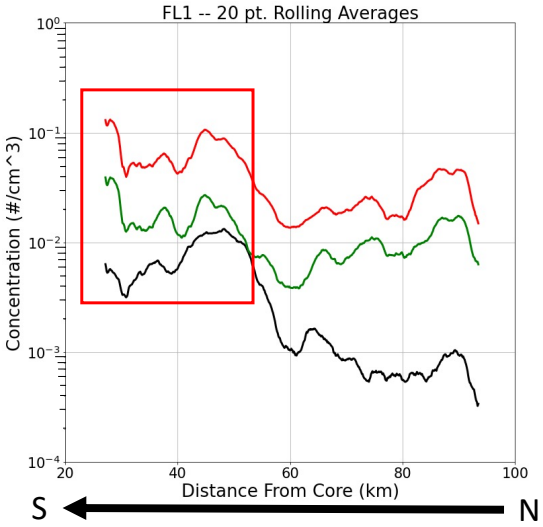


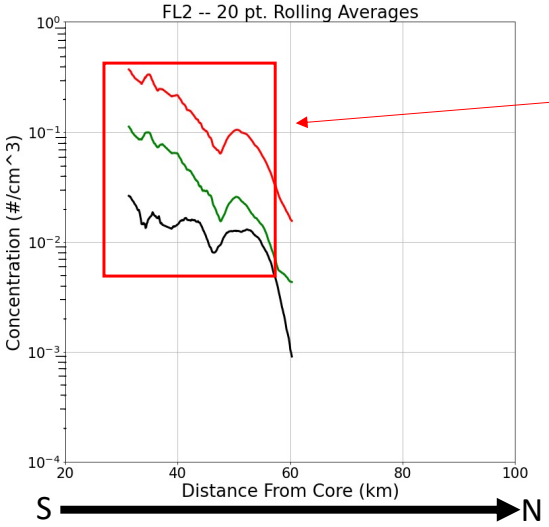




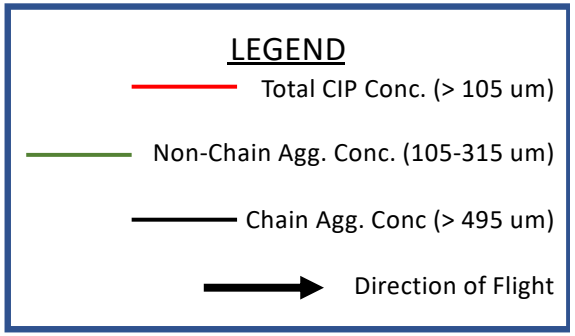


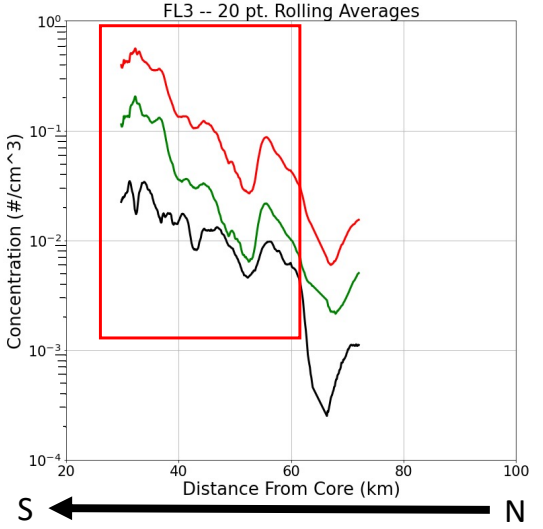


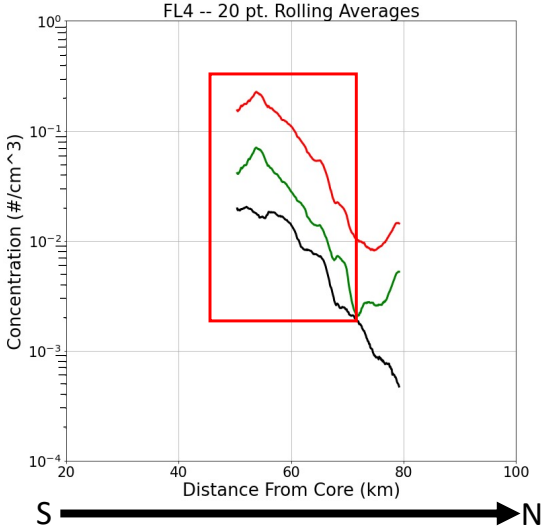




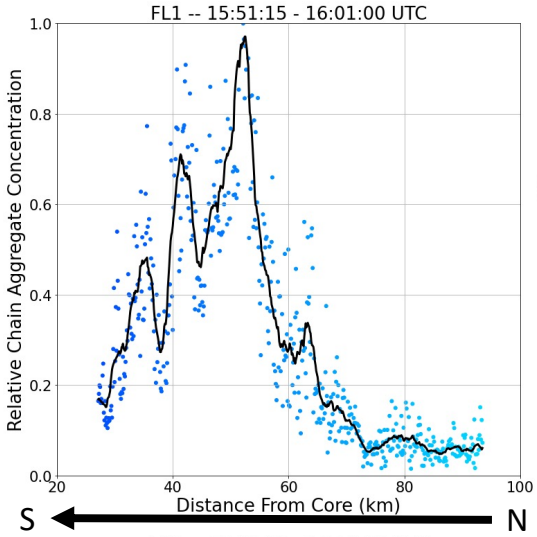
Convergence between the non-chain and chain Aggregate concentration (heading away from storm core

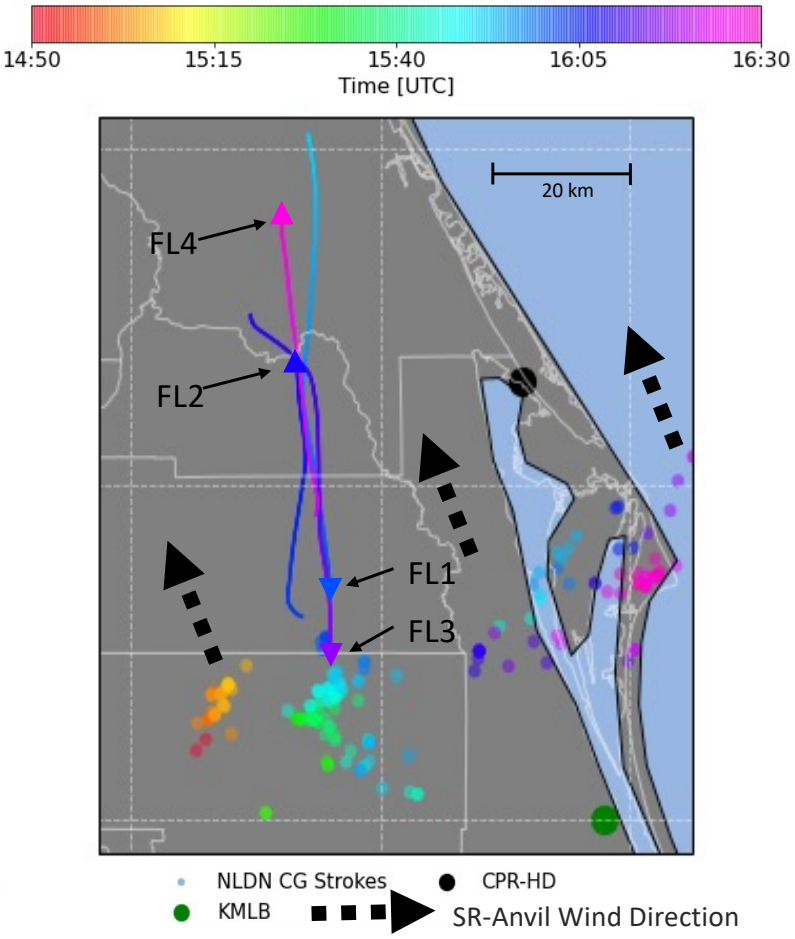


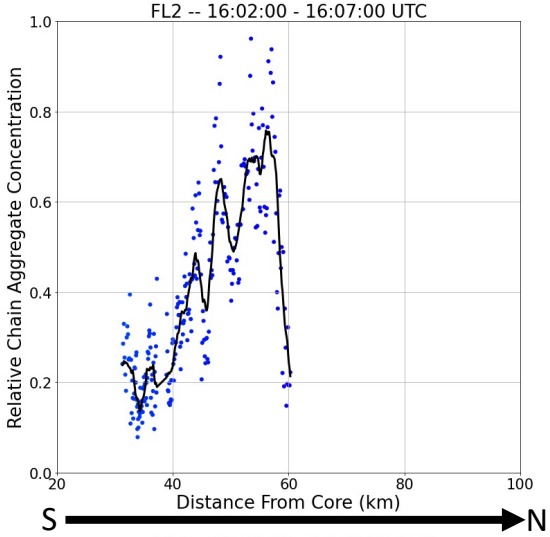


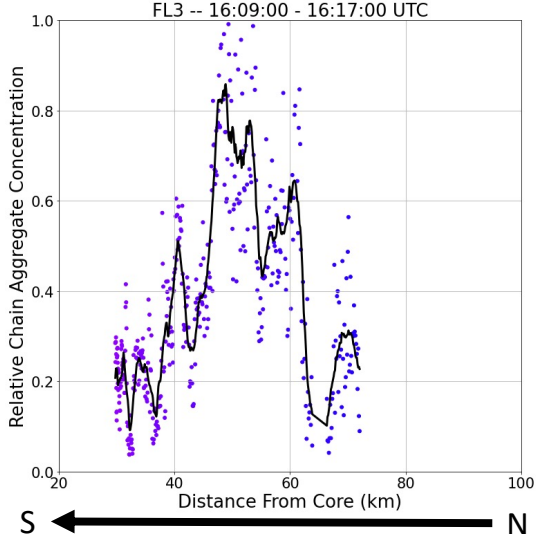


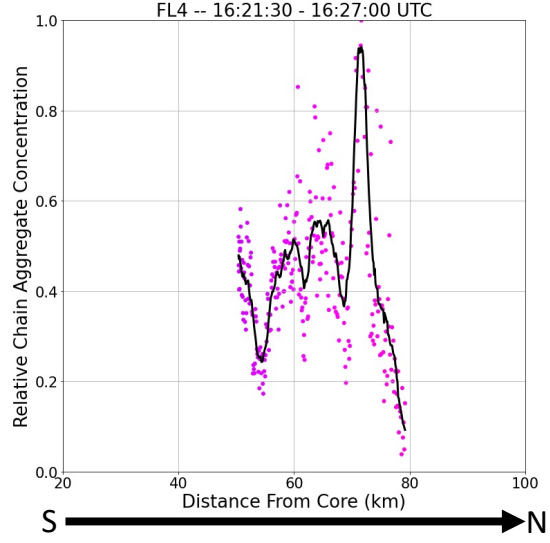
Relative Chain Aggregate Concentration

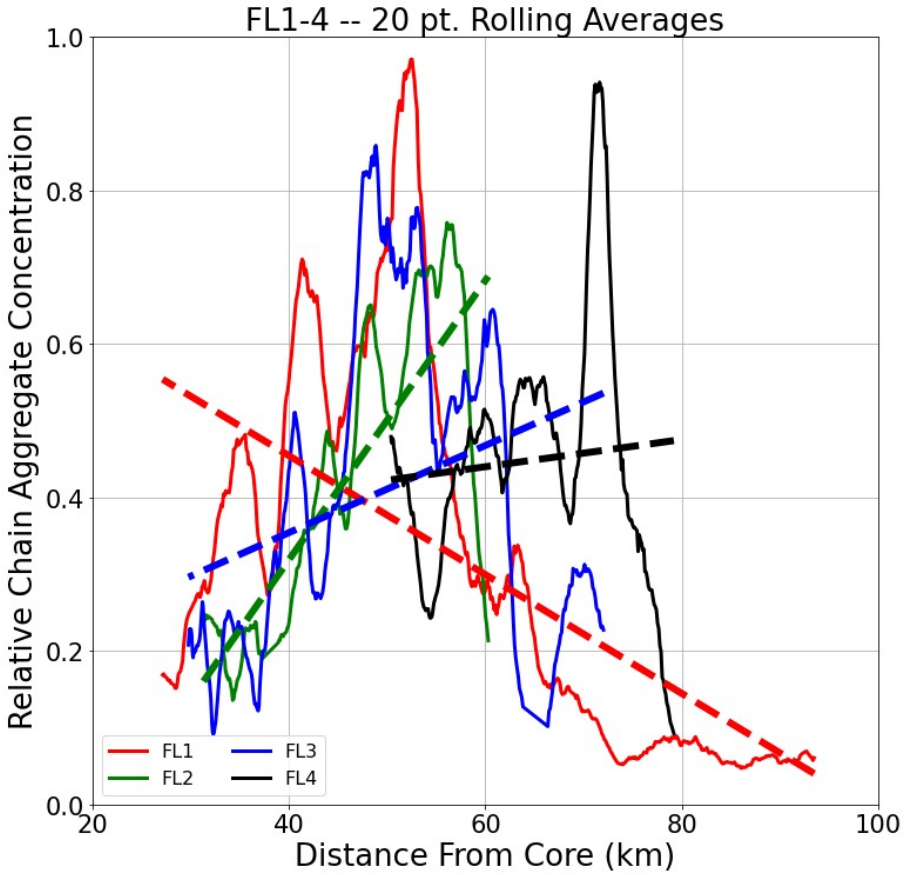


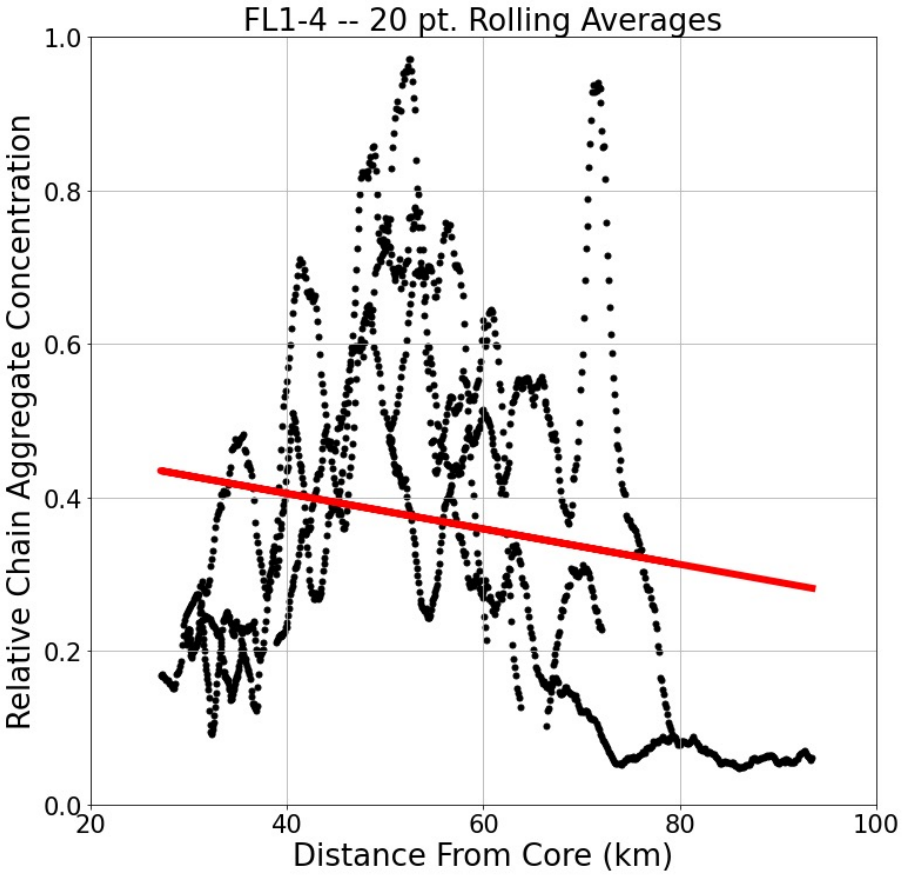









FL1-4 -- 20 pt. Rolling Averages
Relative Chain Aggregate Concentration
Distance From Core (km)
FL1
FL2
FL3
FL4
0.0
0.2
0.4
0.6
0.8
1.0
20
40
60
80
100


FL1-4 -- 20 pt. Rolling Averages
Relative Chain Aggregate Concentration
Distance From Core (km)
0.0
0.2
0.4
0.6
0.8
1.0
20
40
60
80
100

Conclusions

- Observed chain aggregates contain particles from different temperature regimes.
  - Lack of rimed ice.
- The general trend for chain and non-chain aggregate concentrations decrease with distance from core.
- There is an increase in the relative chain aggregate concentration heading away from the core (to a certain distance – varies per flight leg).
- Peaks in the relative chain aggregate concentration are never when the aircraft was closest to the core.
- Periodicities in the relative chain aggregate concentration are observed.

Summary/Discussion

- The lack of rimed ice and individual ice particles of different habits give confidence that chain aggregation may be occurring in colder regions of the storm.

- Are the fluctuations in the particle sizes the product of storm convective growth and decay?

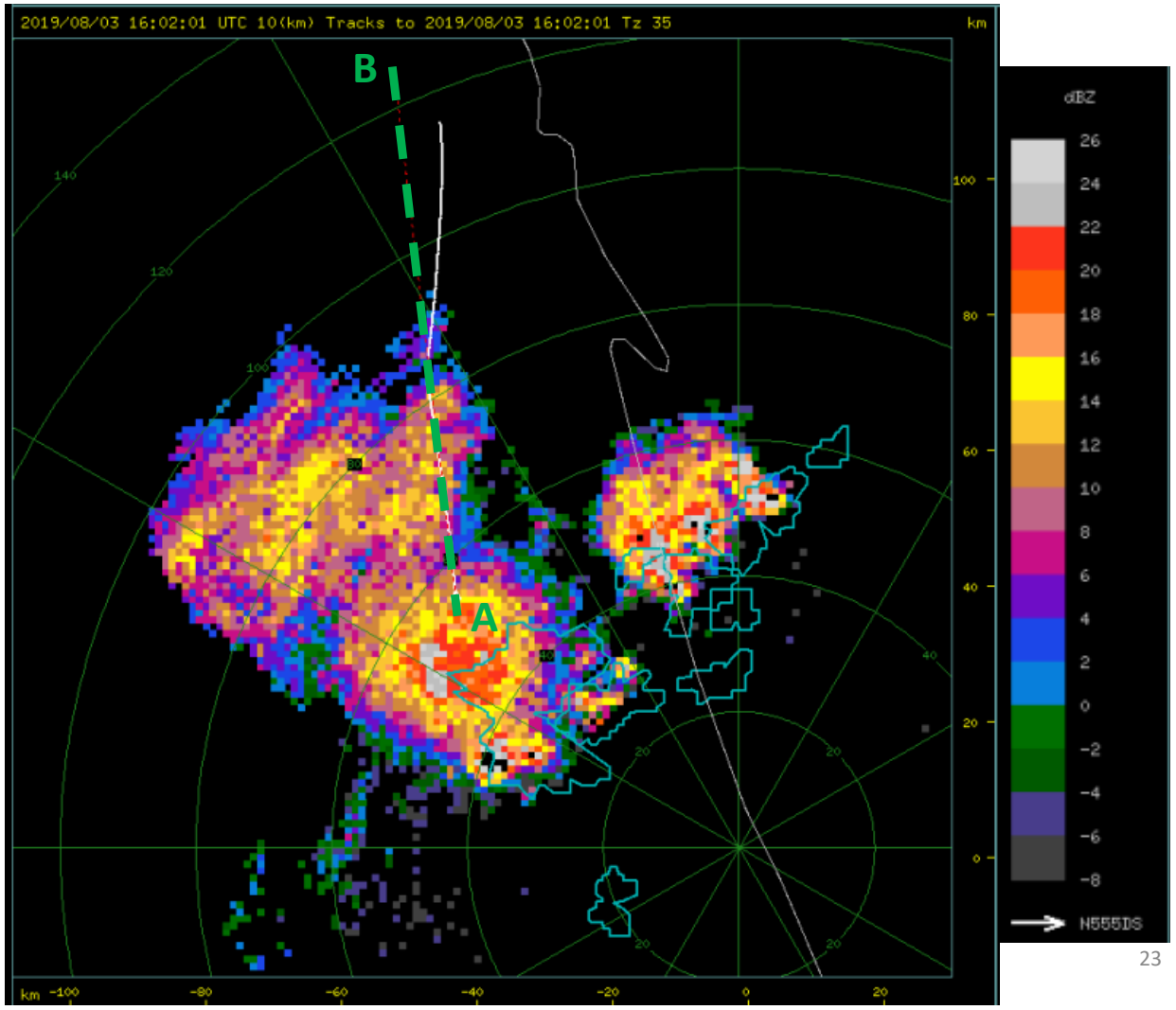
- Possible interpretations of relative chain aggregate concentration increases:
  - (1) The smaller particles are taking part in the chain aggregation process allowing for less smaller particles and more larger particles.
  - (2) More of the non-chains are falling out, sublimating, and/or climbing within the cirrus anvil away from where the aircraft was sampling from.

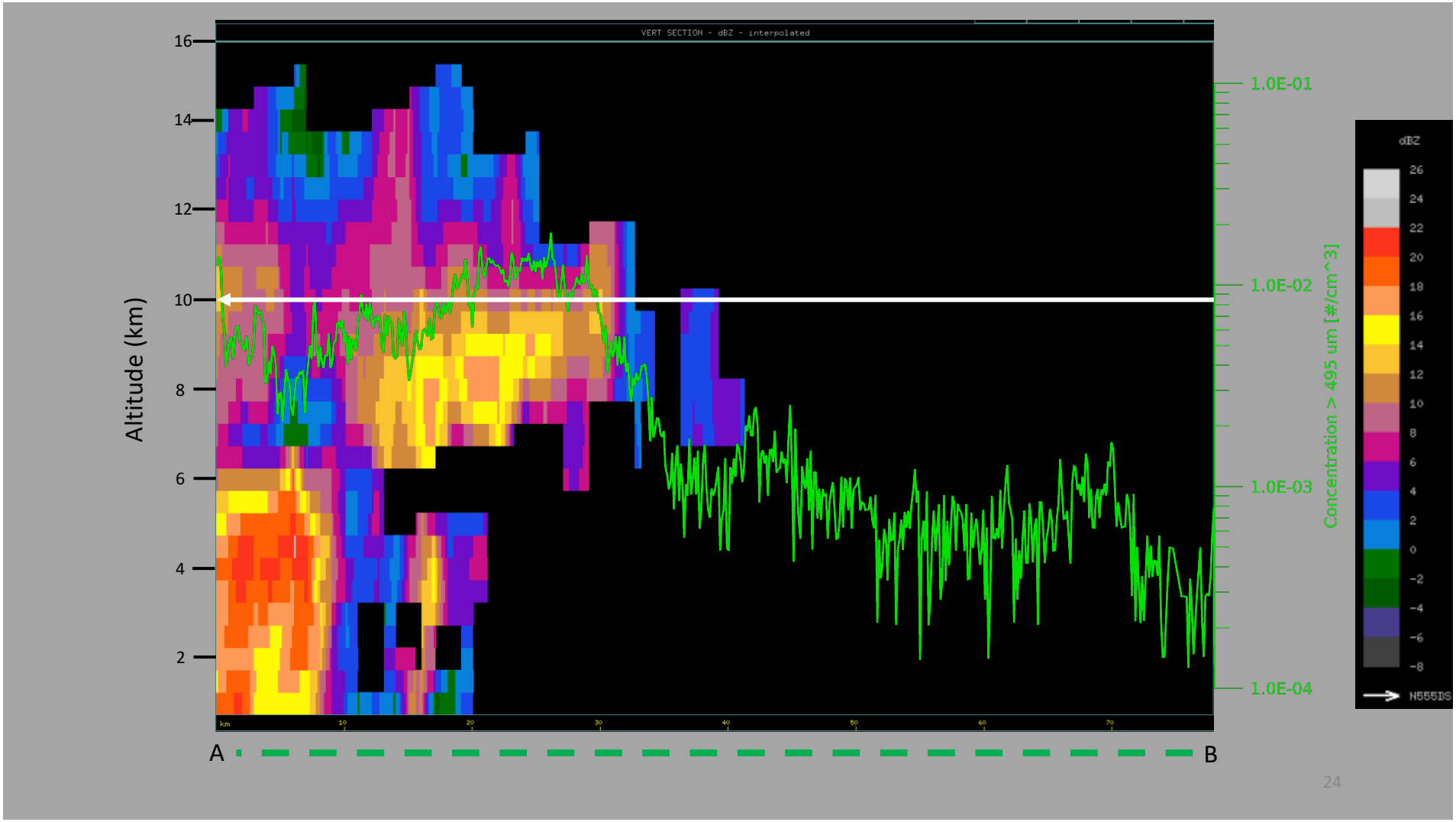
Flight Leg 1 (FL1)

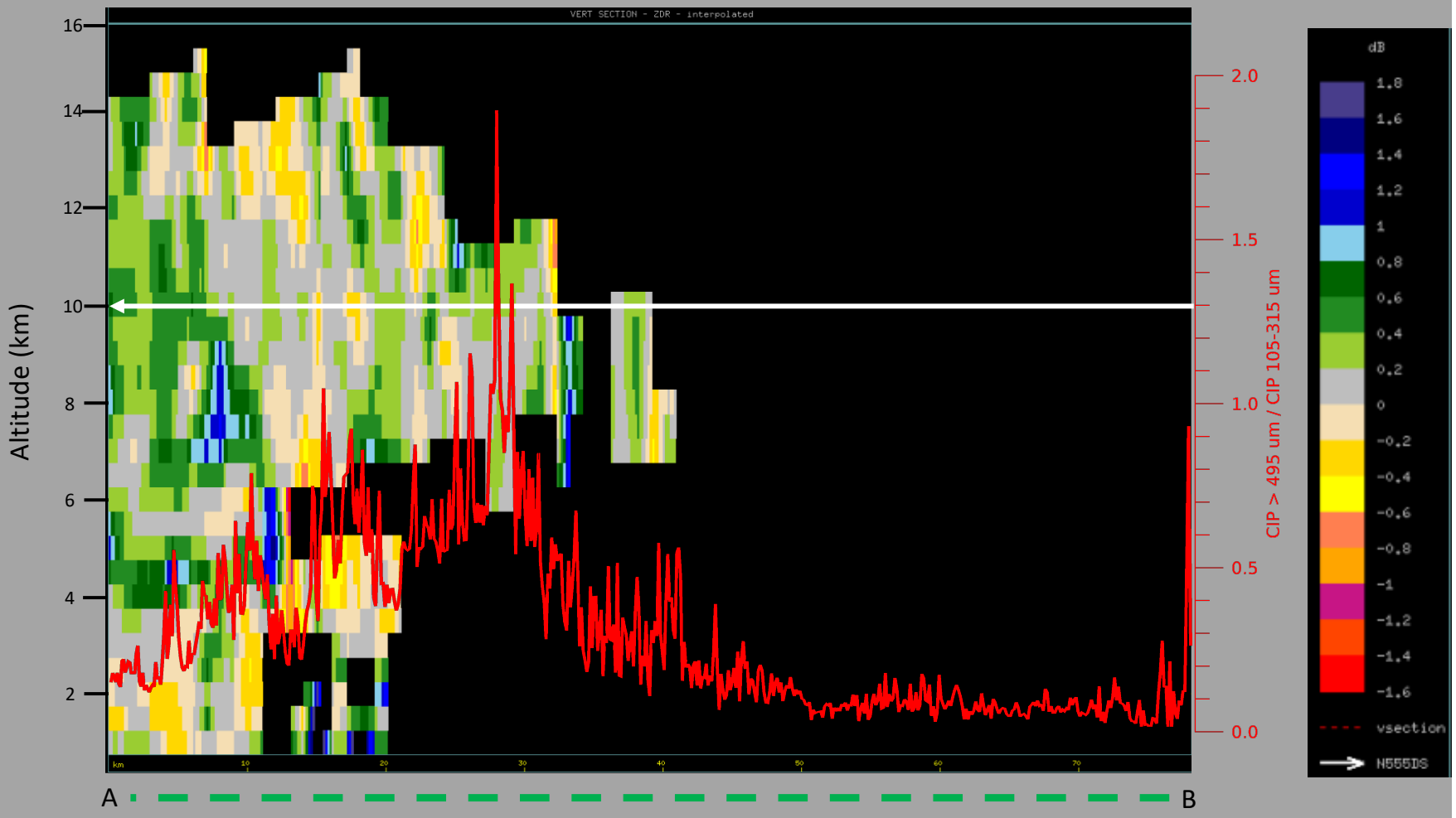
15:51:15 – 16:01:00

KMLB Vol Scan: 16:02:01

10 km CAPPI




VERT SECTION - dBZ - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
km
10
20
30
40
50
60
70
A
B
1.0E-01
1.0E-02
1.0E-03
1.0E-04
Concentration > 495 um [#/cm^3]
dBZ
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
N555DS

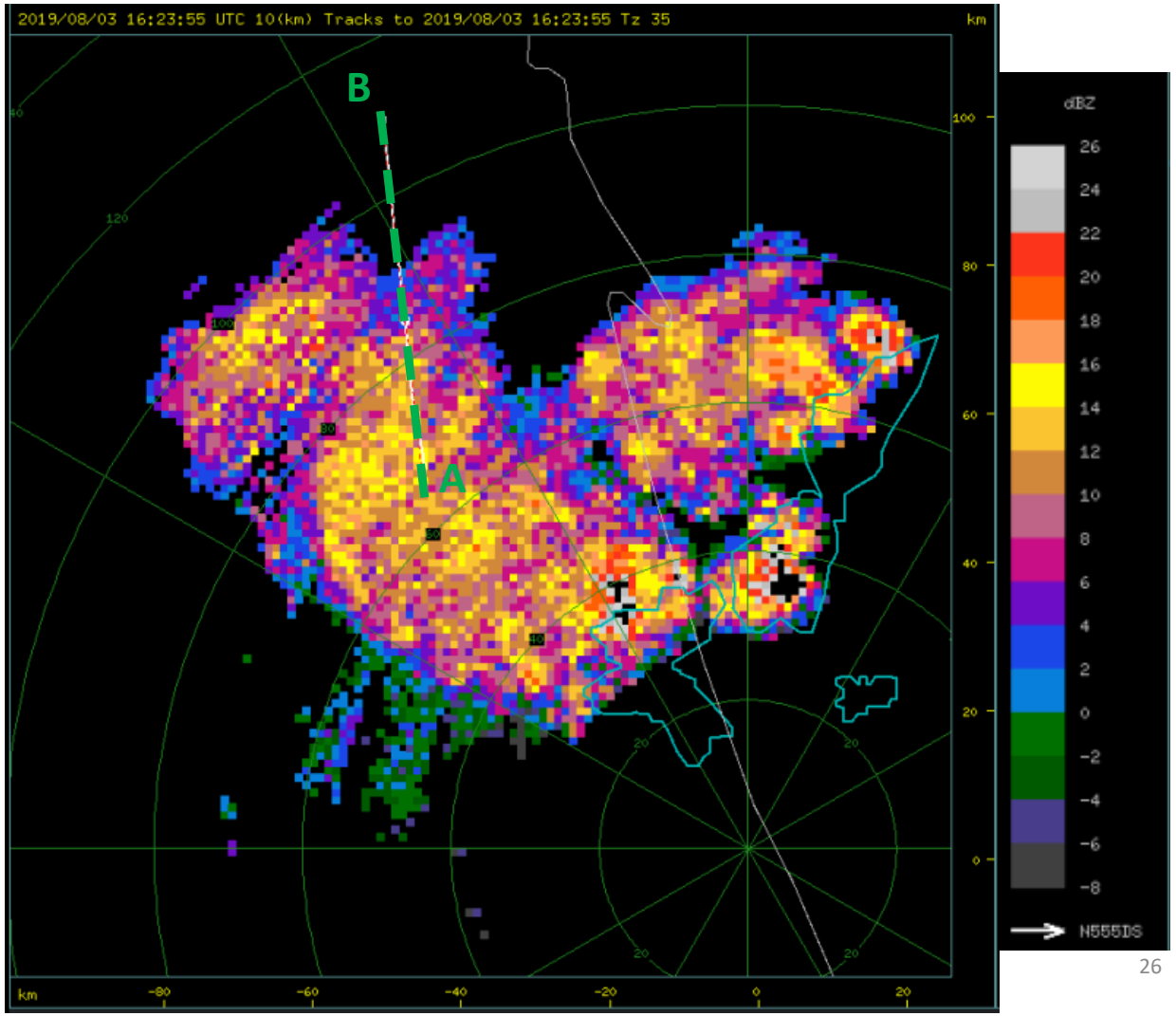

VERT SECTION - ZDR - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
km
10
20
30
40
50
60
70
A
B
2.0
1.5
1.0
0.5
0.0
CIP > 495 um / CIP 105-315 um
dB
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
vsection
N555DS

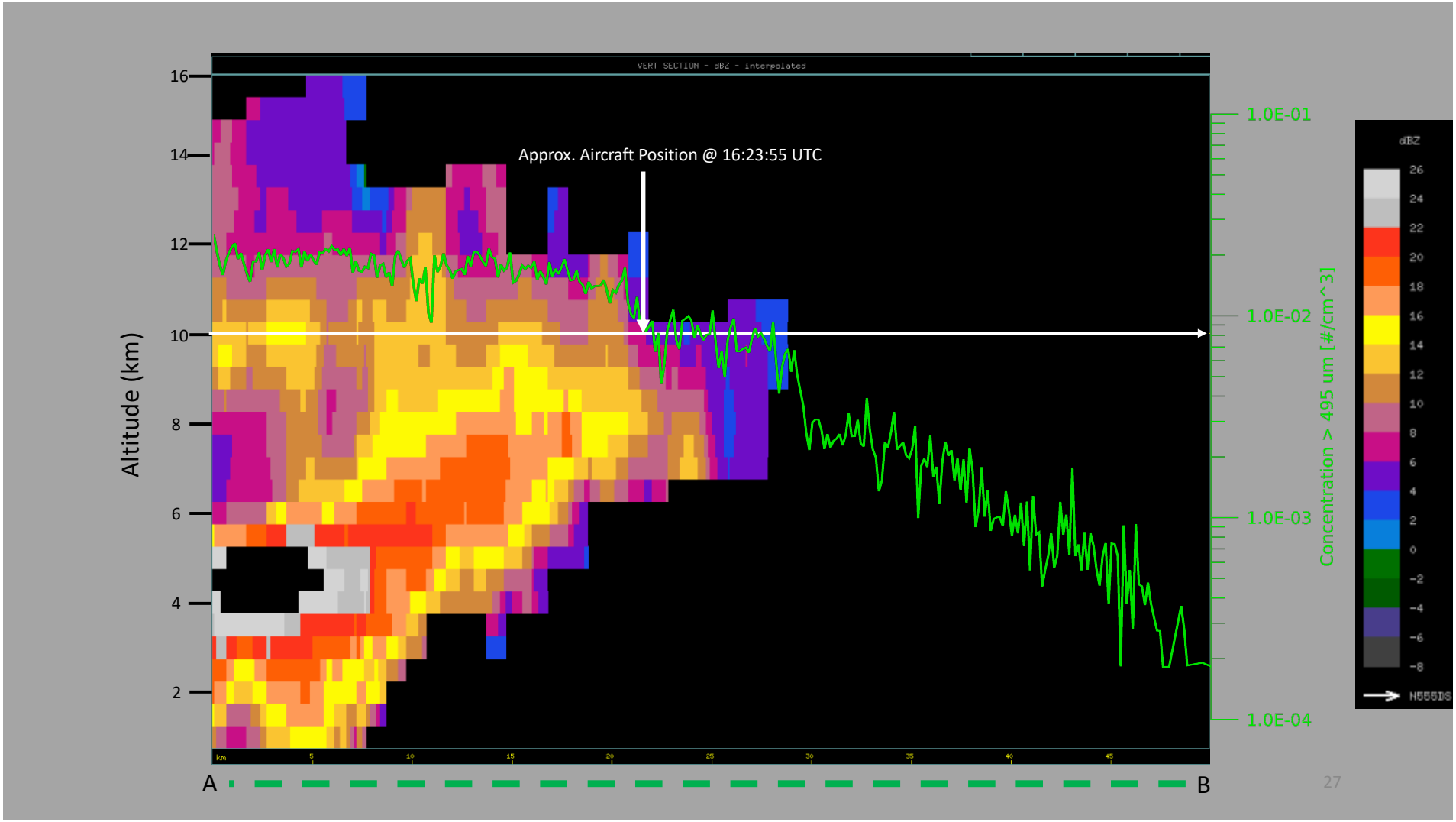
Flight Leg 4 (FL4)

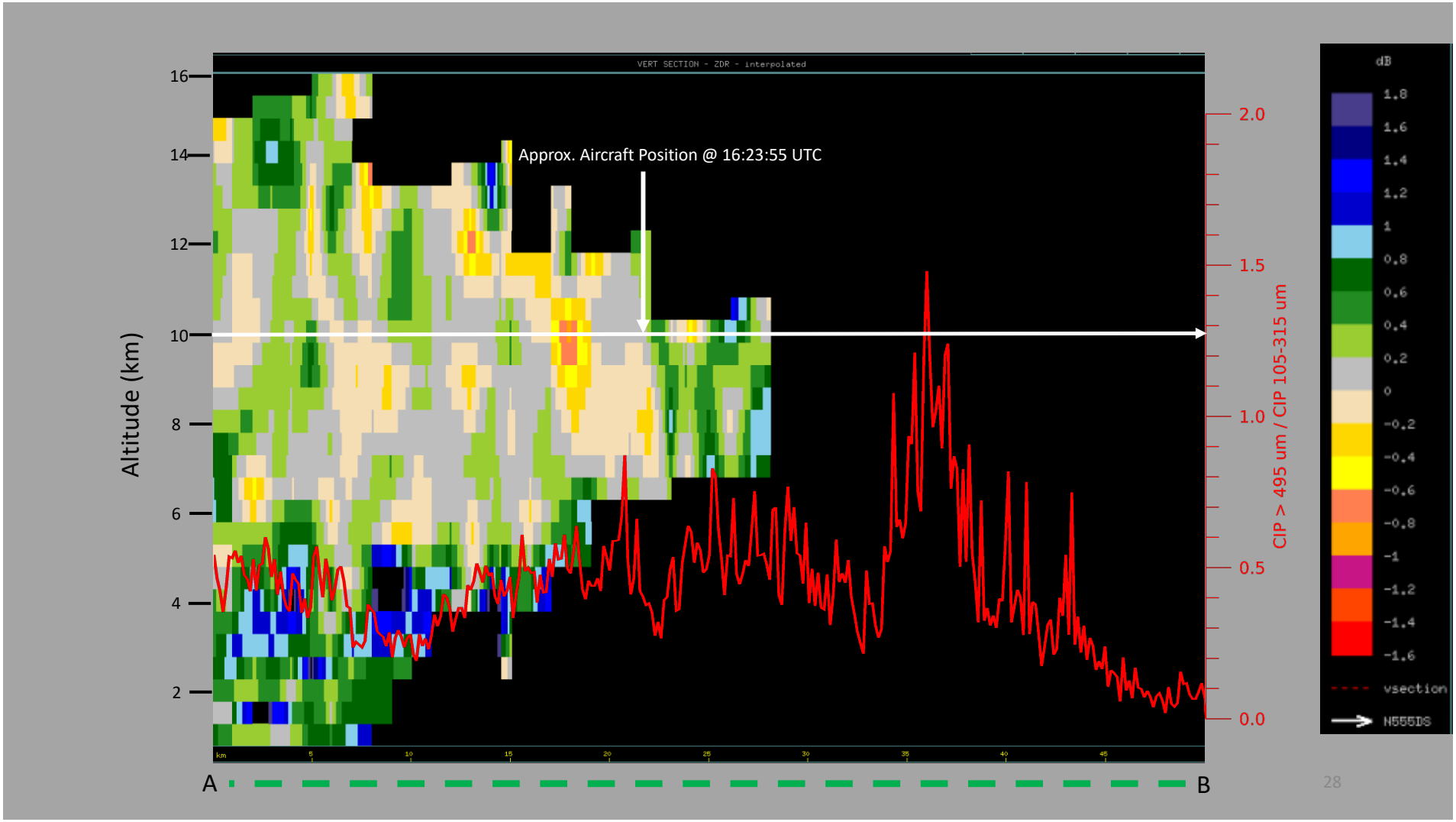
16:21:30 – 16:27:00

KMLB Vol Scan: 16:23:55

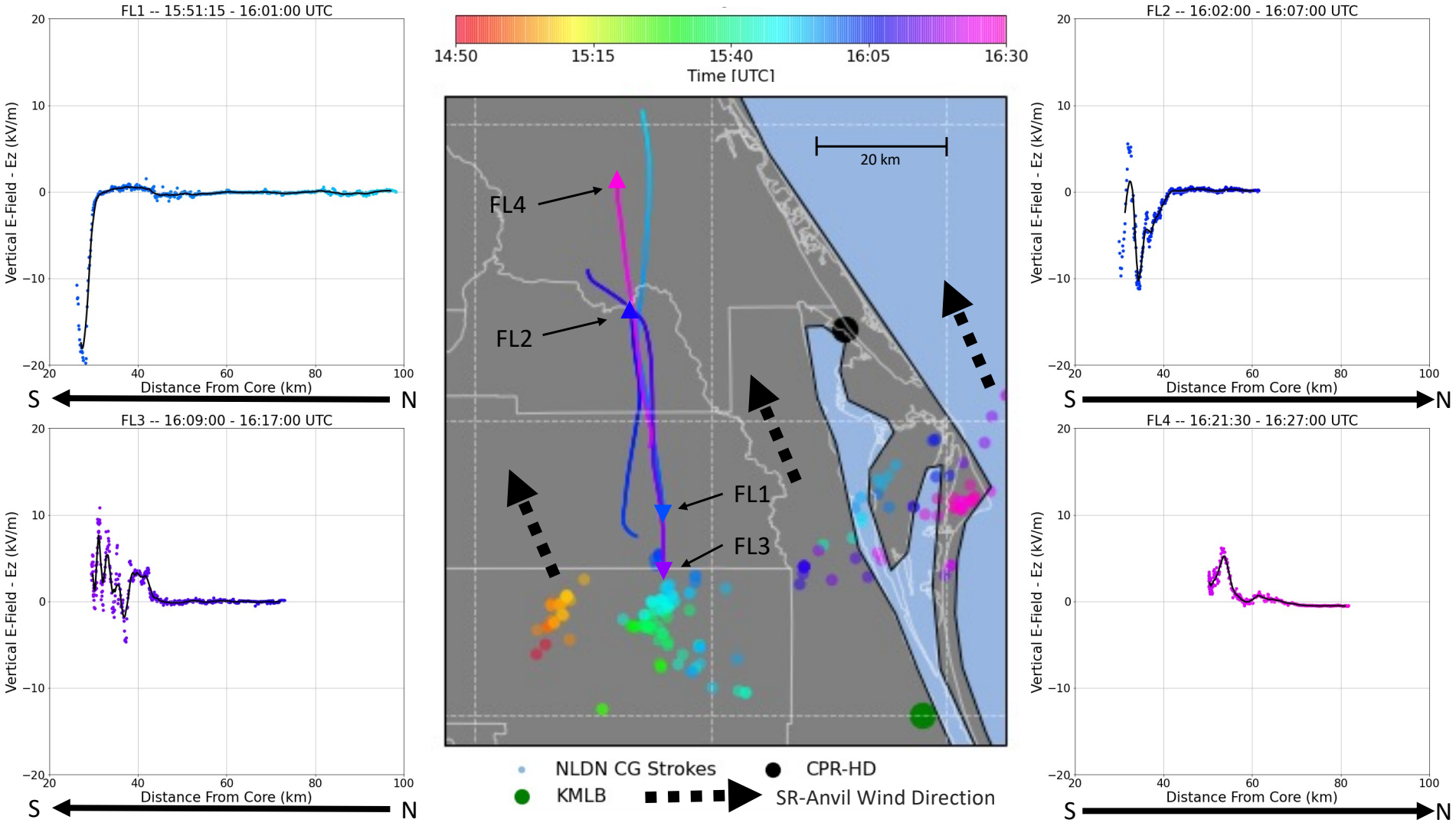
10 km CAPPI



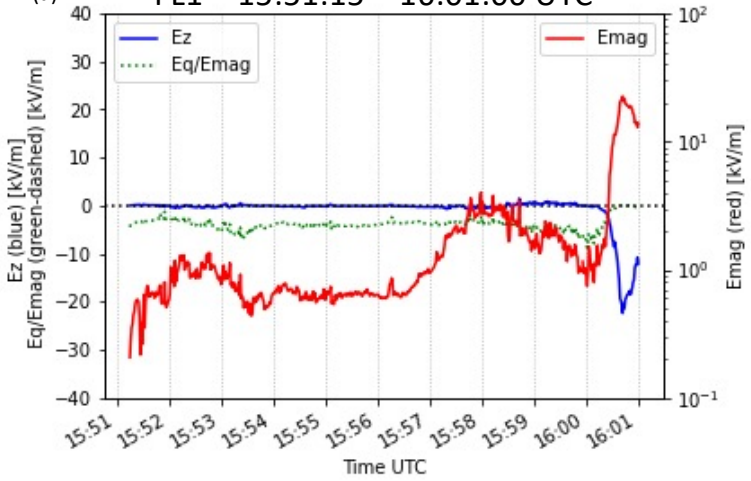

VERT SECTION - dBZ - interpolated
Approx. Aircraft Position @ 16:23:55 UTC
Altitude (km)
16
14
12
10
8
6
4
2
1.0E-01
1.0E-02
1.0E-03
1.0E-04
Concentration > 495 um [#/cm^3]
dBZ
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
N555DS
km
5
10
15
20
25
30
35
40
45
A
B


VERT SECTION - ZDR - interpolated
Approx. Aircraft Position @ 16:23:55 UTC
Altitude (km)
16
14
12
10
8
6
4
2
2.0
1.5
1.0
0.5
0.0
CIP > 495 um / CIP 105-315 um
km
5
10
15
20
25
30
35
40
45
A
B
dB
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
vsection
N555DS

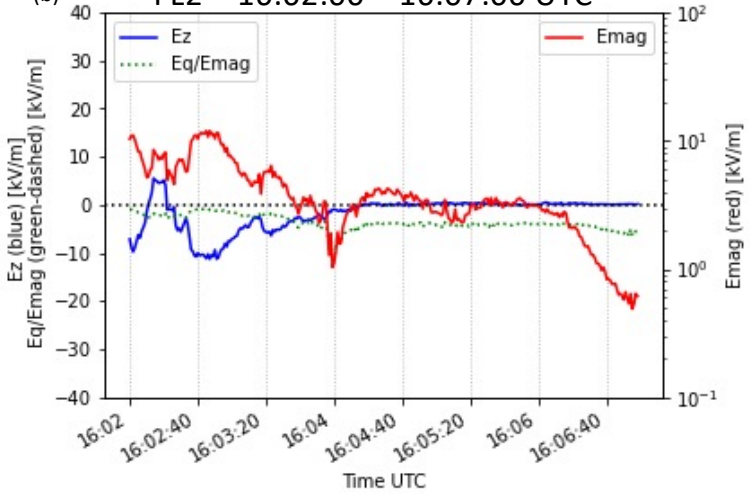
ELECTRIC FIELD DATA & KSCLMA ANALYSIS


FL1 -- 15:51:15 - 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
Vertical E-Field - Ez (kV/m)
Distance From Core (km)
S
N
14:50
15:15
15:40
16:05
16:30
Time [UTC]
20 km
FL4
FL2
FL1
FL3
NLDN CG Strokes
CPR-HD
KMLB
SR-Anvil Wind Direction

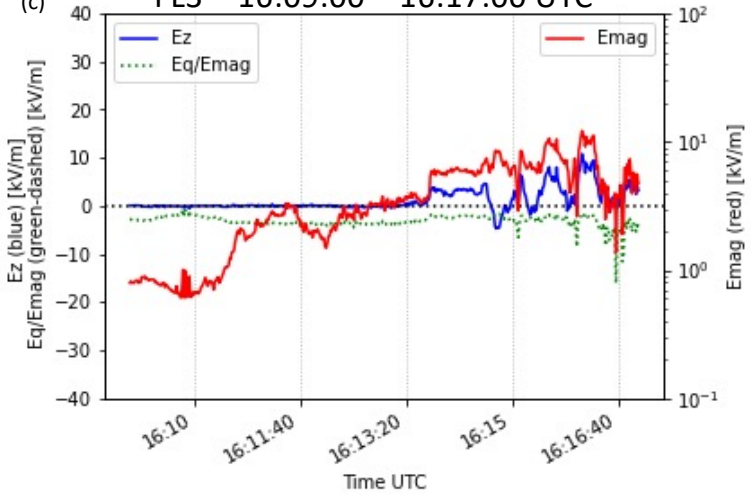
(a) FL1 – 15:51:15 – 16:01:00 UTC



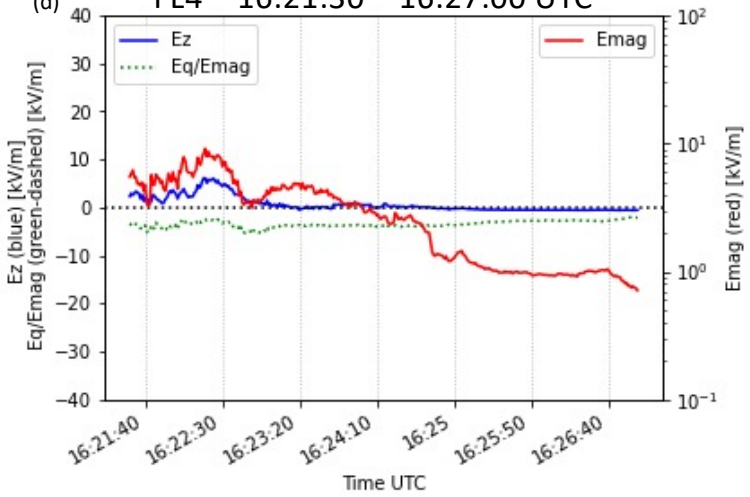
(b) FL2 – 16:02:00 – 16:07:00 UTC



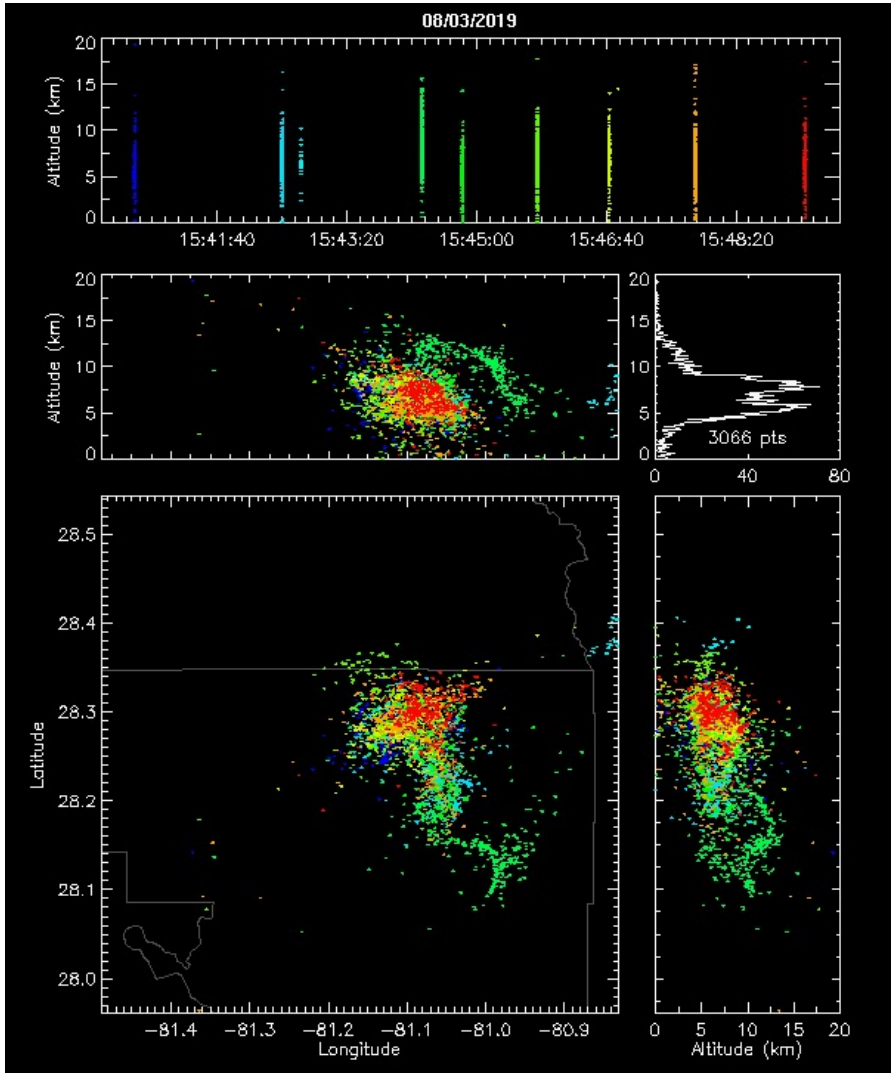
(c) FL3 – 16:09:00 – 16:17:00 UTC

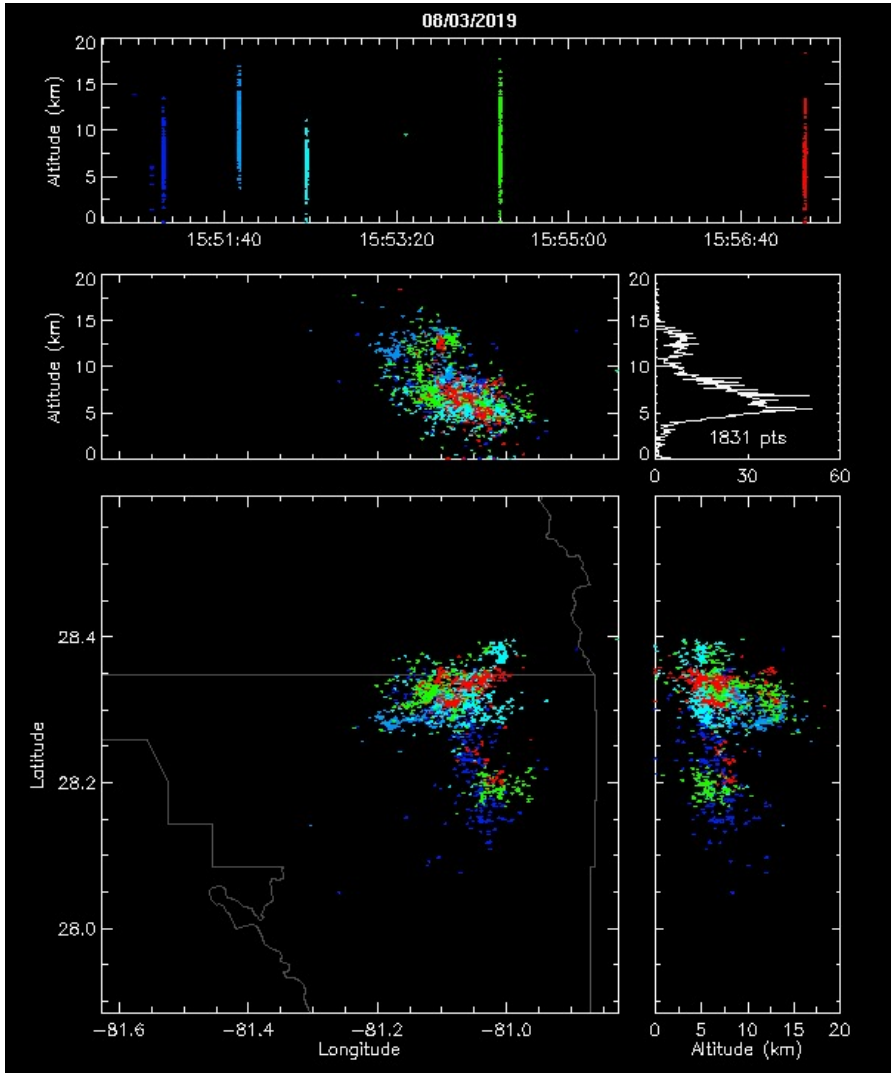


(d) FL4 – 16:21:30 – 16:27:00 UTC



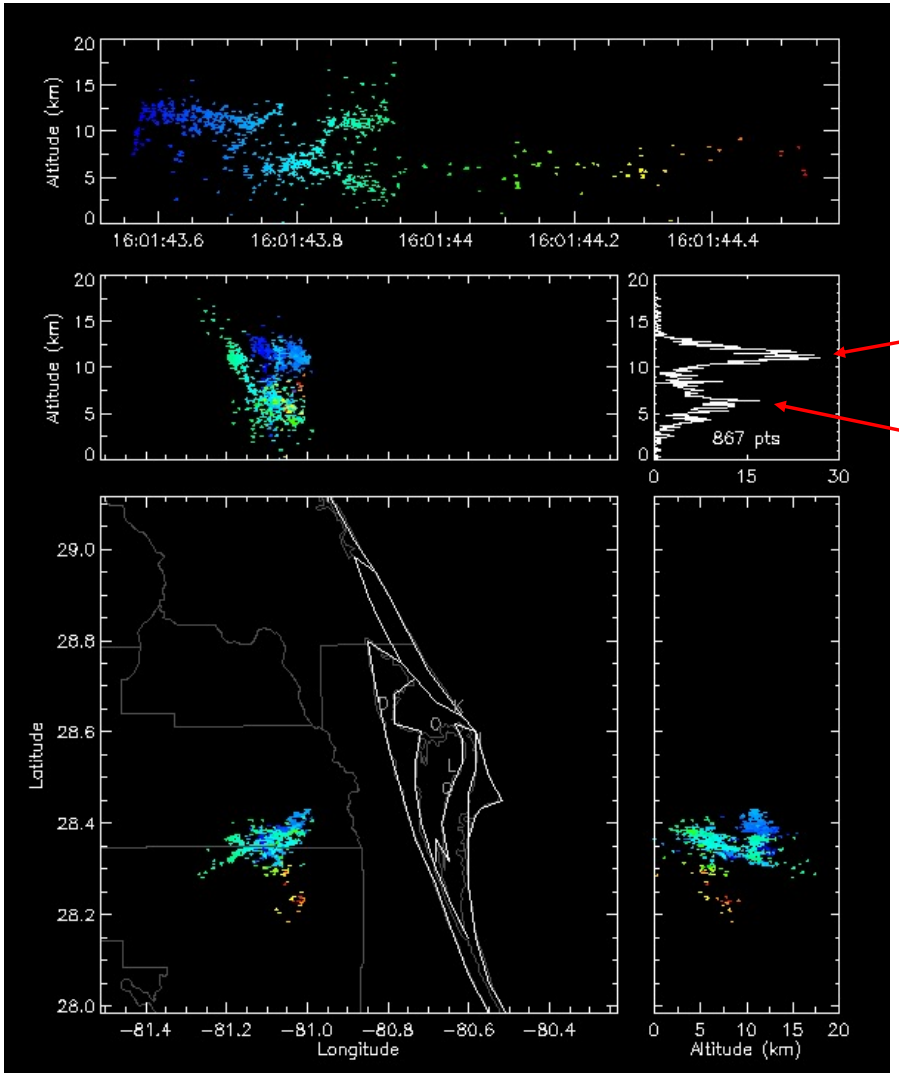
Flight Legs	Time [UTC]	Ex - Range [kV/m]	Ex - Mean [kV/m]	Ey - Range [kV/m]	Ey - Mean [kV/m]	Ez - Range [kV/m]	Ez - Mean [kV/m]
FL1	15:51:15 - 16:01:00	[-4.01, 0.17]	-0.89	[-0.16, 8.04]	0.93	[-22.37, 1.50]	-0.87
FL2	16:02:00 - 16:07:00	[-5.63, 1.52]	-1.96	[-4.93, 6.42]	0.78	[-11.22, 5.53]	-1.76
FL3	16:09:00 - 16:17:00	[-6.59, -0.21]	-2.95	[-3.43, 6.67]	1.05	[-4.70, 10.80]	1.15
FL4	16:21:30 - 16:27:00	[-4.86, -0.40]	-2.36	[-5.86, 4.28]	-0.11	[-0.58, 6.15]	0.68


08/03/2019
Altitude (km)
15:41:40
15:43:20
15:45:00
15:46:40
15:48:20
3066 pts
Latitude
Longitude
Altitude (km)


08/03/2019
Altitude (km)
15:51:40
15:53:20
15:55:00
15:56:40
1831 pts
Latitude
Longitude
Altitude (km)

Lightning Strike @ 16:01:43 UTC

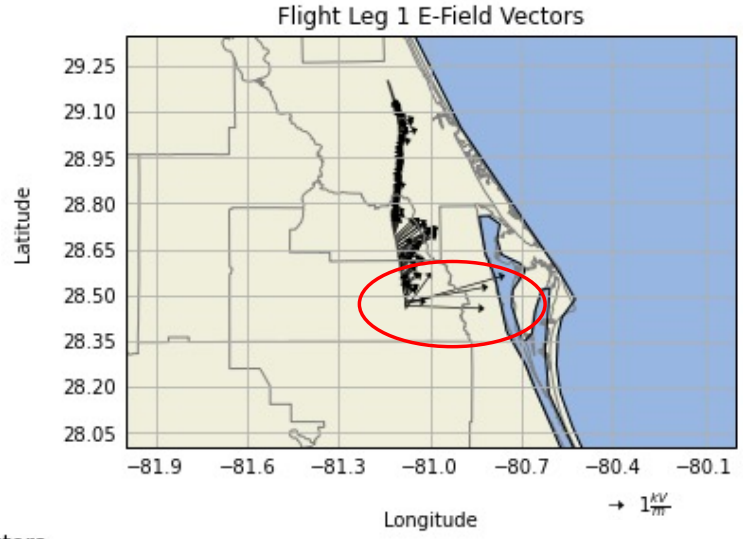
NOTE: According to NLDN data This was the last lightning strike associated with our storm of Interest.

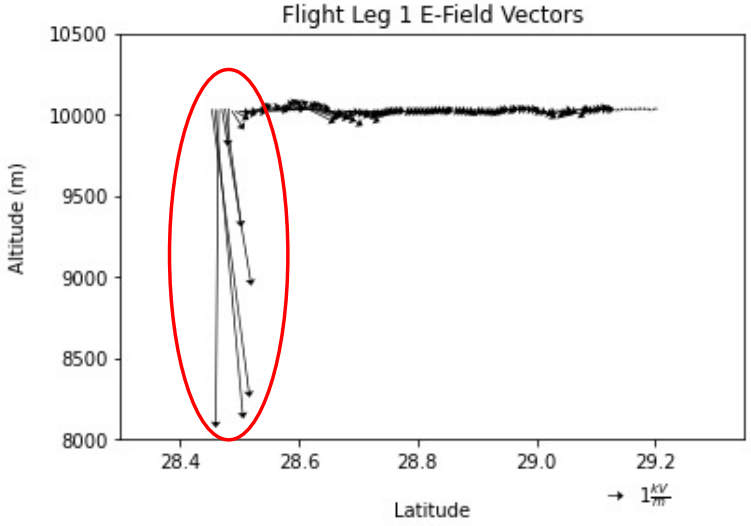


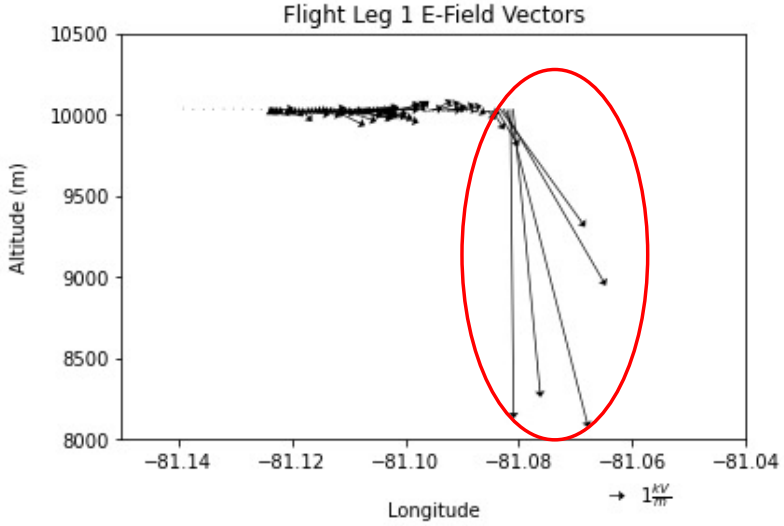
Upper + Charge Region

Lower - Charge Region

- By the divergence of downward-pointing vectors near the end of Flight-leg-1 there is clearly a compact center of positive charge above the aircraft.
- There is agreement in polarity in the LMA plot of the 16:01 UTC lightning event suggesting a layer of positive charge just above the aircraft.







Conclusions

- The largest sources of electric fields are when the aircraft is in close proximity to the storm core.

- Near the storm core the vertical electric field values are mainly on the order of 10^0 kV/m for each FL.
  - Although, there is a strong E_z signal during the end of FL1 where E_z reached -22.37 kV/m, which is an order of magnitude higher than what is typically observed.

  - The temporal span (electric build-up) of this peak is on the order of seconds, and detection of electric discharges are on the order of micro – seconds, thus it is believed that this peak in electric field is due to the aircraft entering in a 'high' electric charge region and not by lightning.

- The electric field magnitude (E_{mag}) for all flight legs peaked on the order of 10^1 kV/m.

Discussion

- Based on the KSCLMA/E-field data, upper positive region seems to be the culprit for fluctuations in E_z.

- The E_{mag} values are the same order of magnitude to what was used in cloud chamber experiments performed by Saunders and Wahab (1975).
  - However, in the cloud chamber experiments, chain aggregates were only generated while using an electric field greater than or equal to 60 kV/m.

- Is the E-Field threshold smaller than previously tested?
  - Evidence from previous research (Dye *et al.* 2007) coupled with these results -> can propose that yes it may?

Overall Conclusions and Comments

- PHIPS observations show chain aggregates throughout the anvil region, with different individual particle habit, and lack rimed ice
- Relative chain aggregate concentrations suggest that in the cirrus anvil:
  - (1) The smaller particles are taking part in the chain aggregation process allowing for less smaller particles and more larger particles.
  - (2) More of the non-chains are falling out, sublimating, and/or climbing within the cirrus anvil away from where the aircraft was sampling from.
- The fluctuations in the particle sizes cloud be the product of storm convective growth and decay.
  - Further radar analysis needed.
- The E_{mag} values are the same order of magnitude to what was used in cloud chamber experiments performed by Saunders and Wahab (1975).
  - Similar values to other field projects where chain aggregates were also observed.
  - E-Field thresholds for chain aggregation in the cirrus anvil may be less than 60 kV/m.

Is Chain Aggregation Occurring in the Cirrus Anvil during FL4?

Secondary Aggregation Sources?

- Main support for yes:
  1. Chains contain particles from different temperature regimes.
     - Lack of rimed ice.
  2. There is an increase in the relative chain aggregate concentration heading away from the core (to a certain distance – varies per flight leg).
     - Peaks in the relative chain aggregate concentration are never when the aircraft was closest to the core.
  3. The E_{mag} values are the same order of magnitude to what was used in cloud chamber experiments performed by Saunders and Wahab (1975).
     - 'Relatively' close to the core
- Main support for no:
  1. Cross-convection cirrus anvil contamination – **MAJOR INFLUENCE**
     - Periodicies in the relative chain aggregate concentration may be due to storm cycles or different sources of convection.

Request

- The scanning capabilities of the S-band NWS radar is extremely limited (especially during the 3 August 2019 flight).

- With the scanning capabilities of the MCR (CPR-HD), the data will be extremely beneficial when comparing to the in-situ microphysical data.

- The MCR (CPR-HD) data will be used to see if chain aggregation is occurring within the convection – induced, cirrus anvil region.

- Due to FL4 being more oriented to the SR-anvil wind direction and occurring when there is only one CLEAR main source of convection, **it is proposed to obtain the MCR (CPR-HD) data or flight leg 4 [16:21:30 – 16:27:00 UTC] for further radar analysis.**

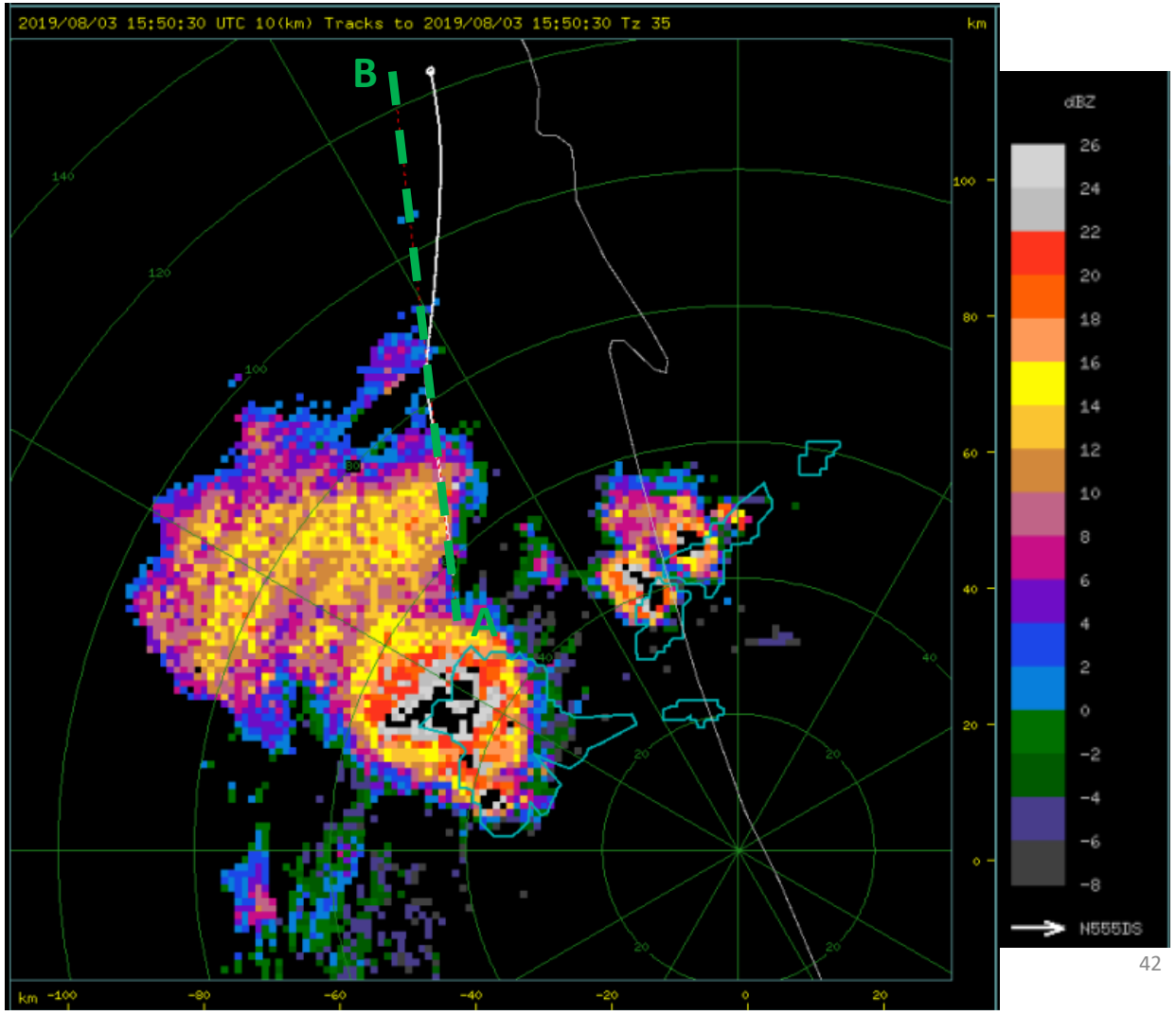
Extra Slides

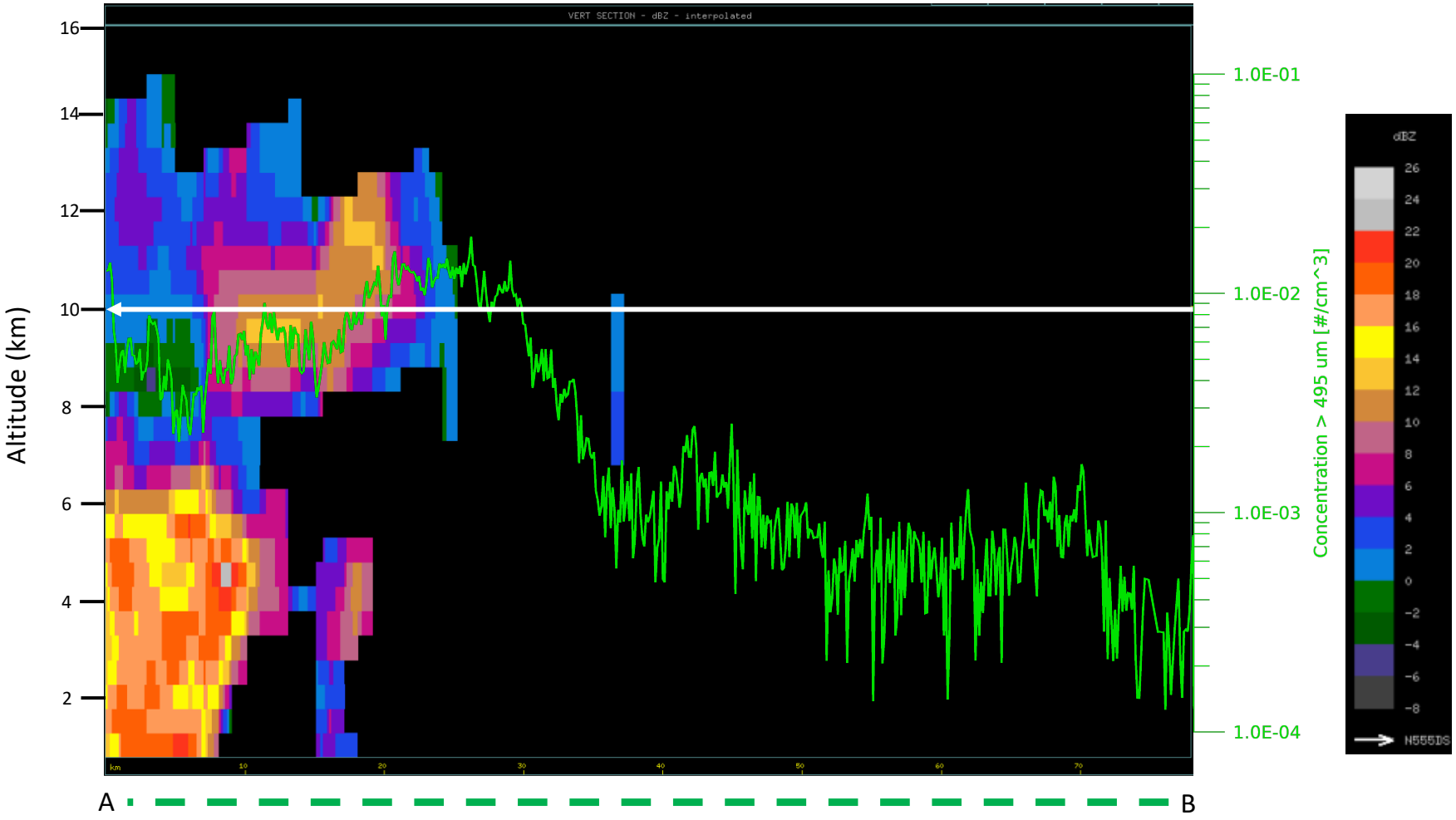
Flight Leg 1 (FL1)

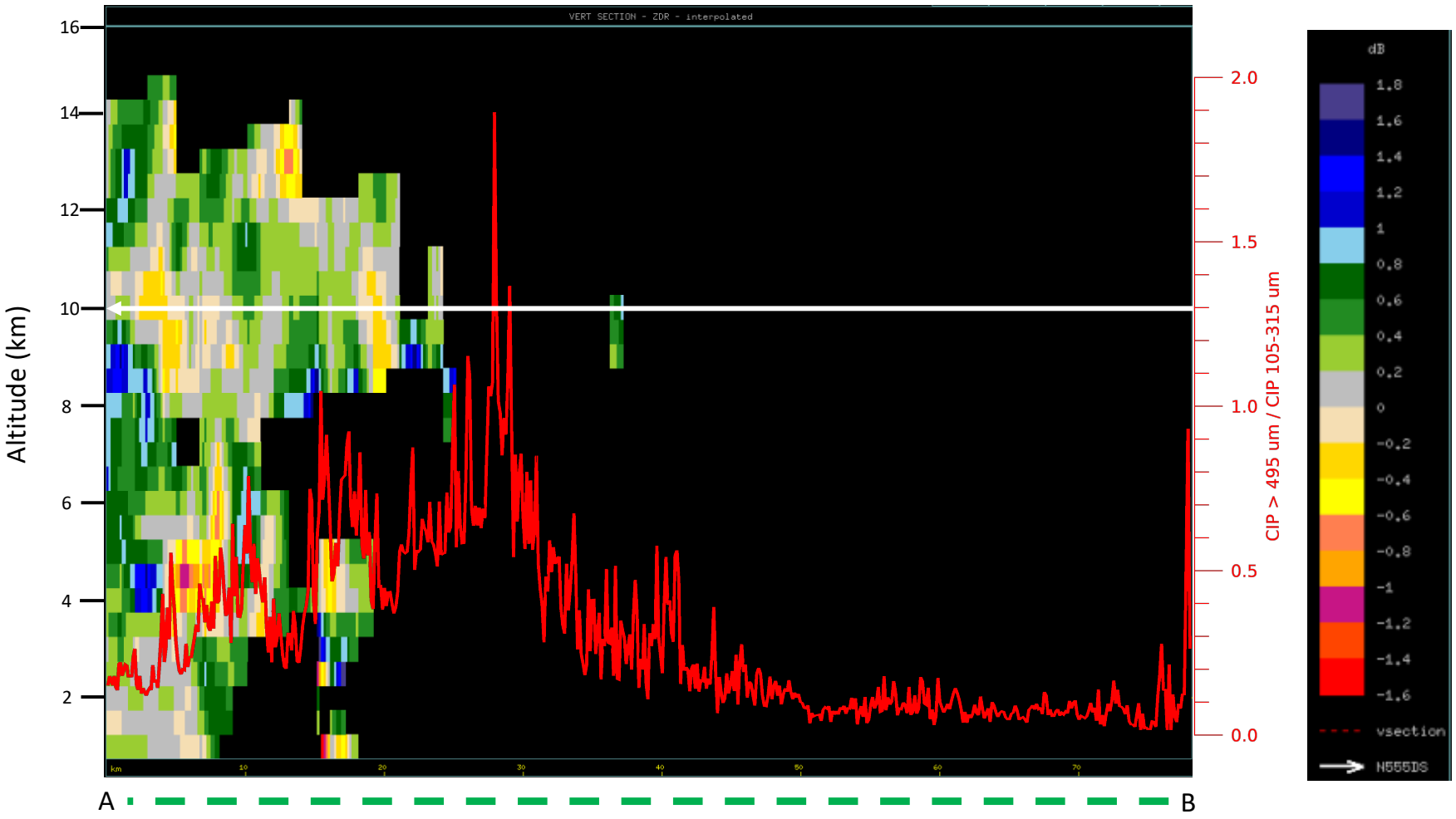
15:51:15 – 16:01:00

KMLB Vol Scan: 15:50:30

10 km CAPPI




VERT SECTION - dBZ - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
km
10
20
30
40
50
60
70
1.0E-01
1.0E-02
1.0E-03
1.0E-04
Concentration > 495 um [#/cm^3]
dBZ
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
N555DS
A
B

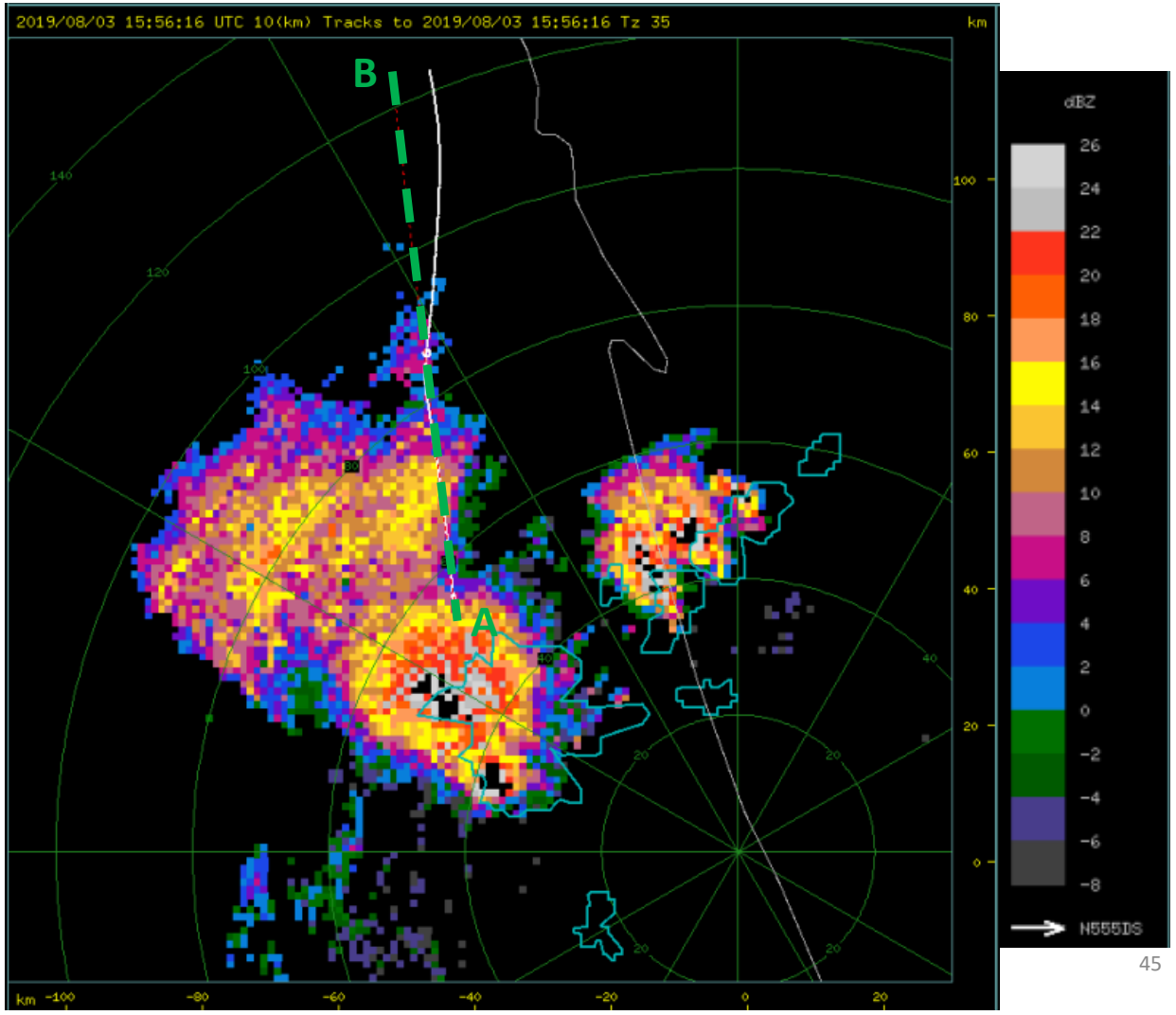

VERT SECTION - ZDR - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
km
10
20
30
40
50
60
70
2.0
1.5
1.0
0.5
0.0
CIP > 495 um / CIP 105-315 um
dB
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
vsection
N555DS
A
B

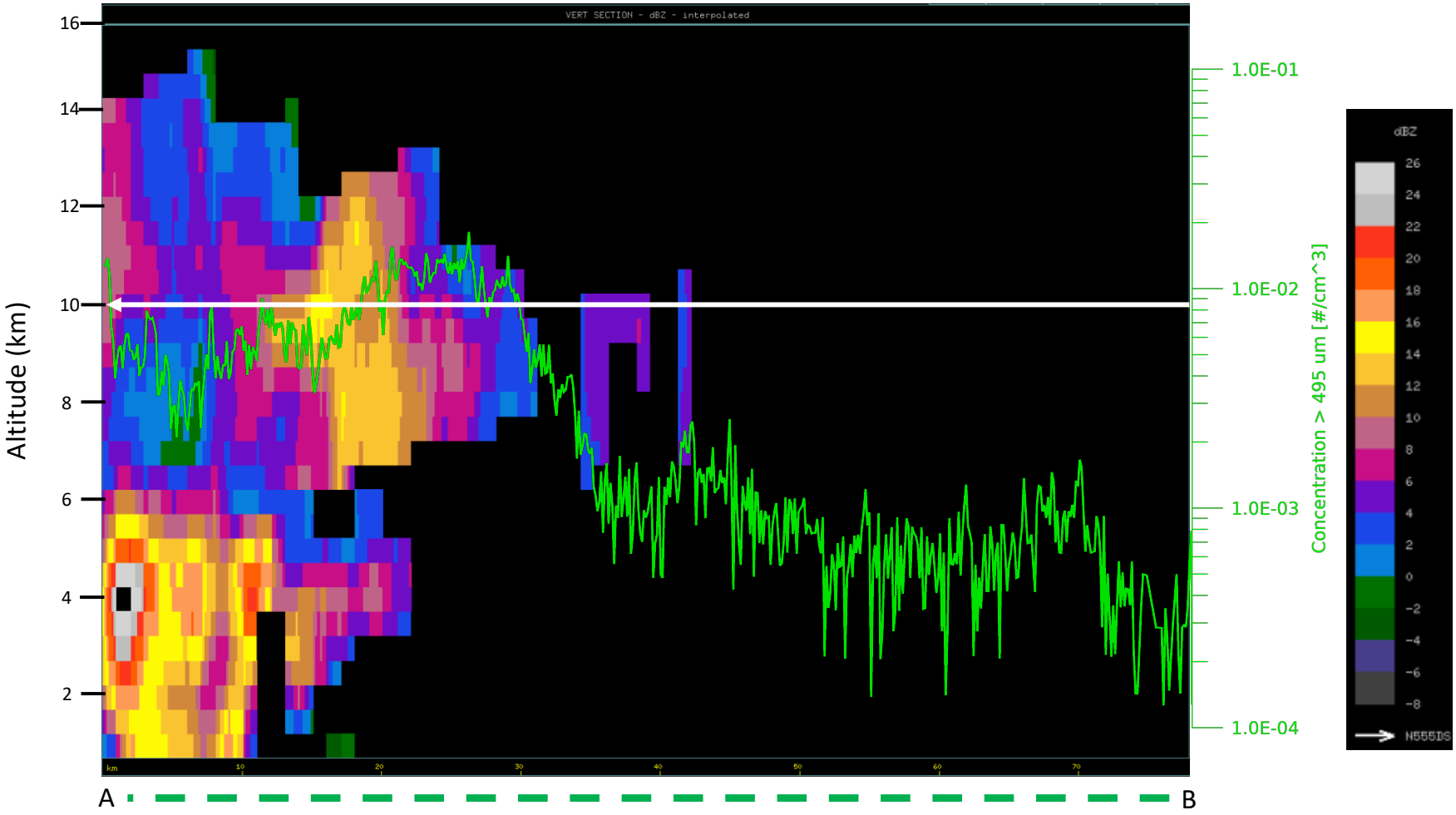
Flight Leg 1 (FL1)

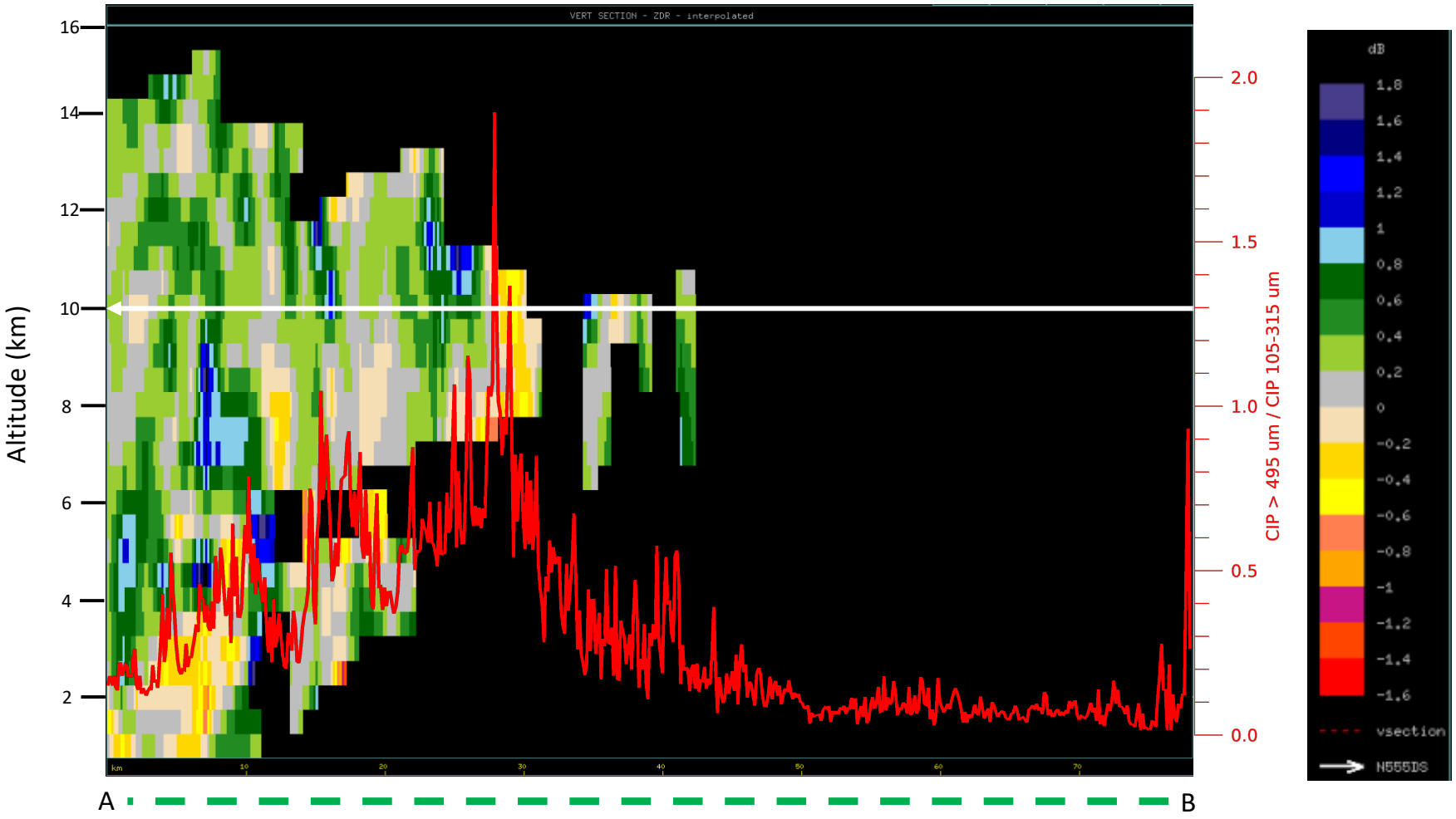
15:51:15 – 16:01:00

KMLB Vol Scan: 15:56:16

10 km CAPPI




VERT SECTION - dBZ - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
km
10
20
30
40
50
60
70
A
B
1.0E-01
1.0E-02
1.0E-03
1.0E-04
Concentration > 495 um [#/cm^3]
dBZ
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
N555DS

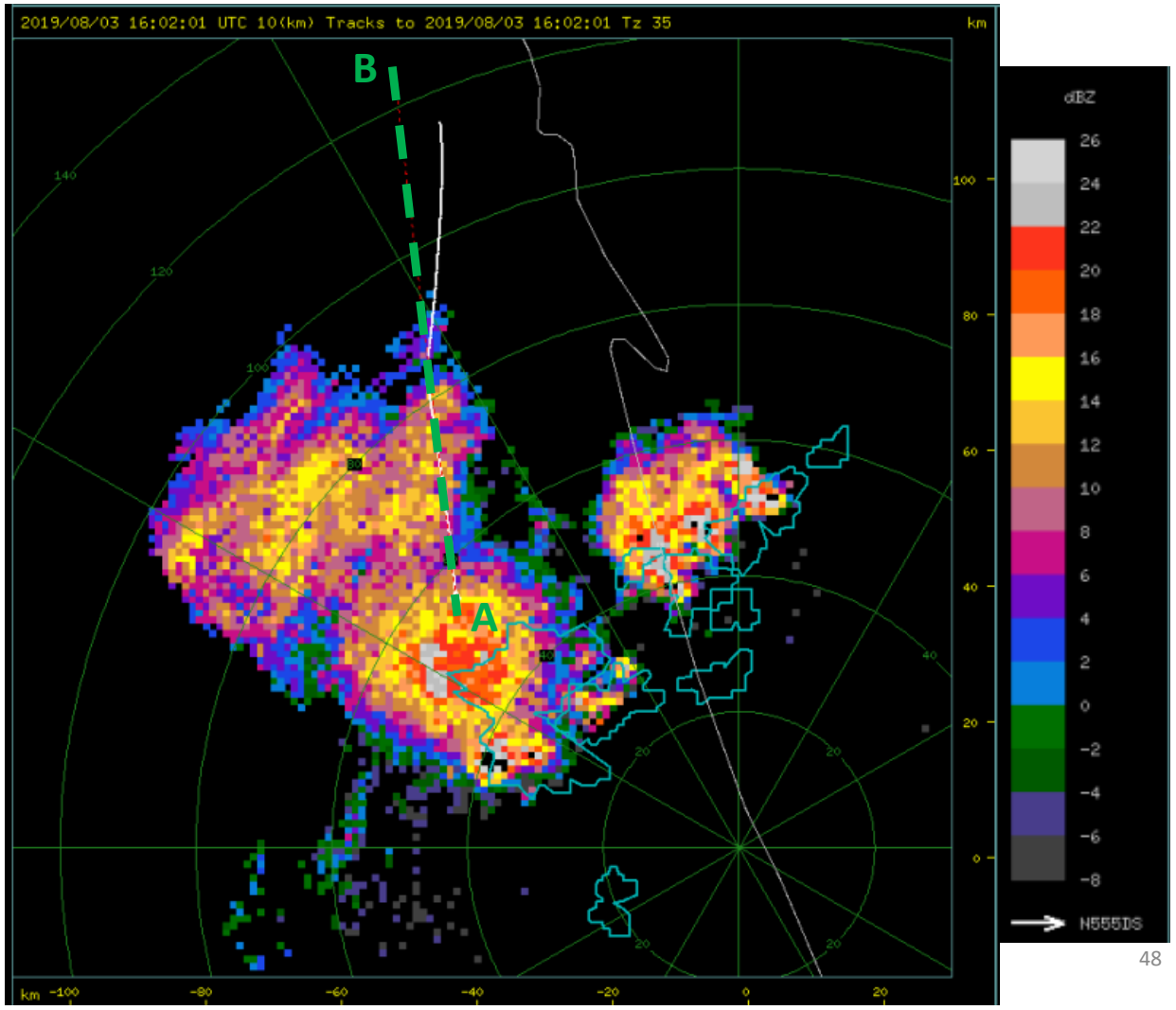

VERT SECTION - ZDR - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
2.0
1.5
1.0
0.5
0.0
CIP > 495 um / CIP 105-315 um
dB
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
vsection
N555DS
km
10
20
30
40
50
60
70
A
B

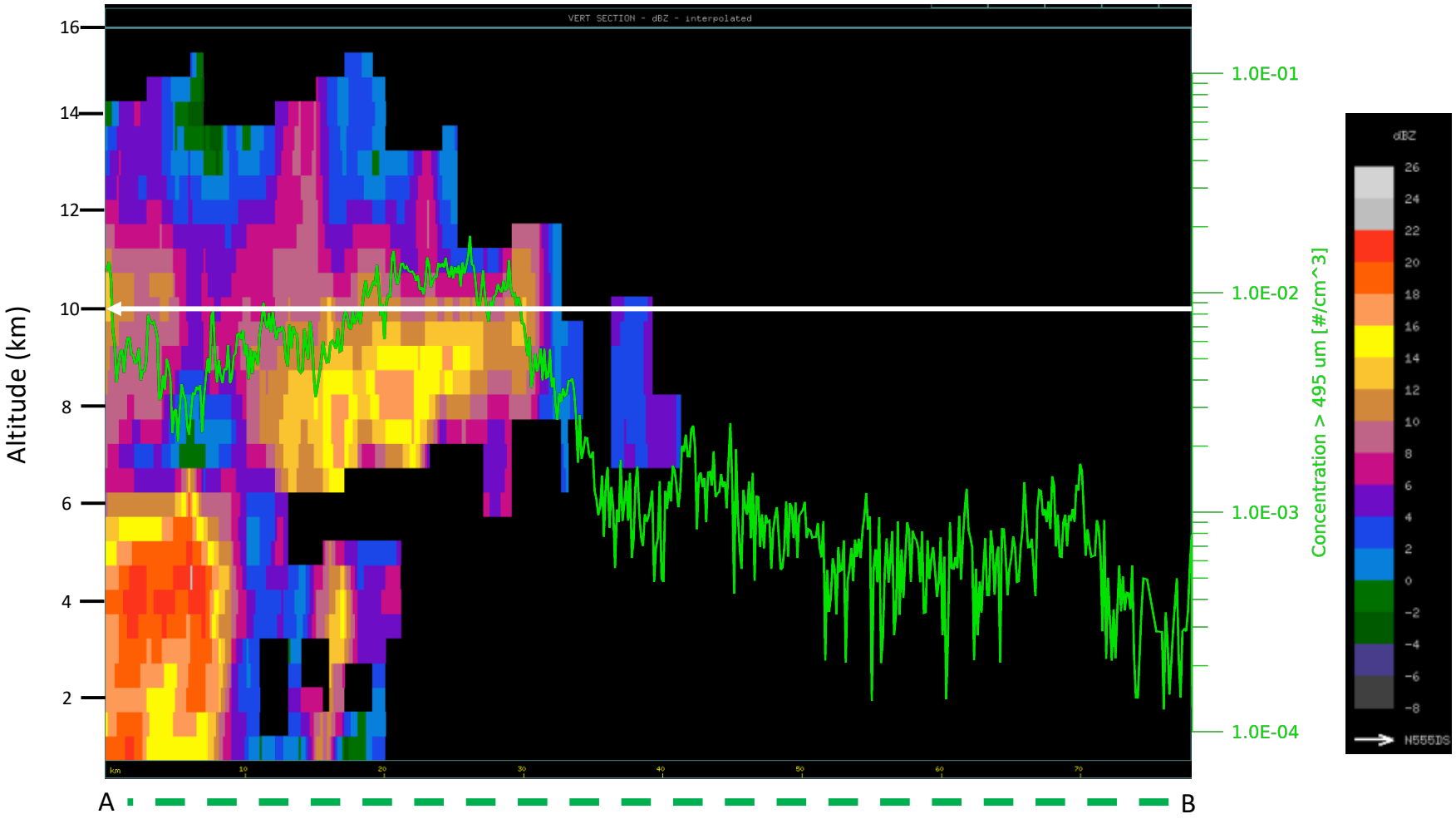
Flight Leg 1 (FL1)

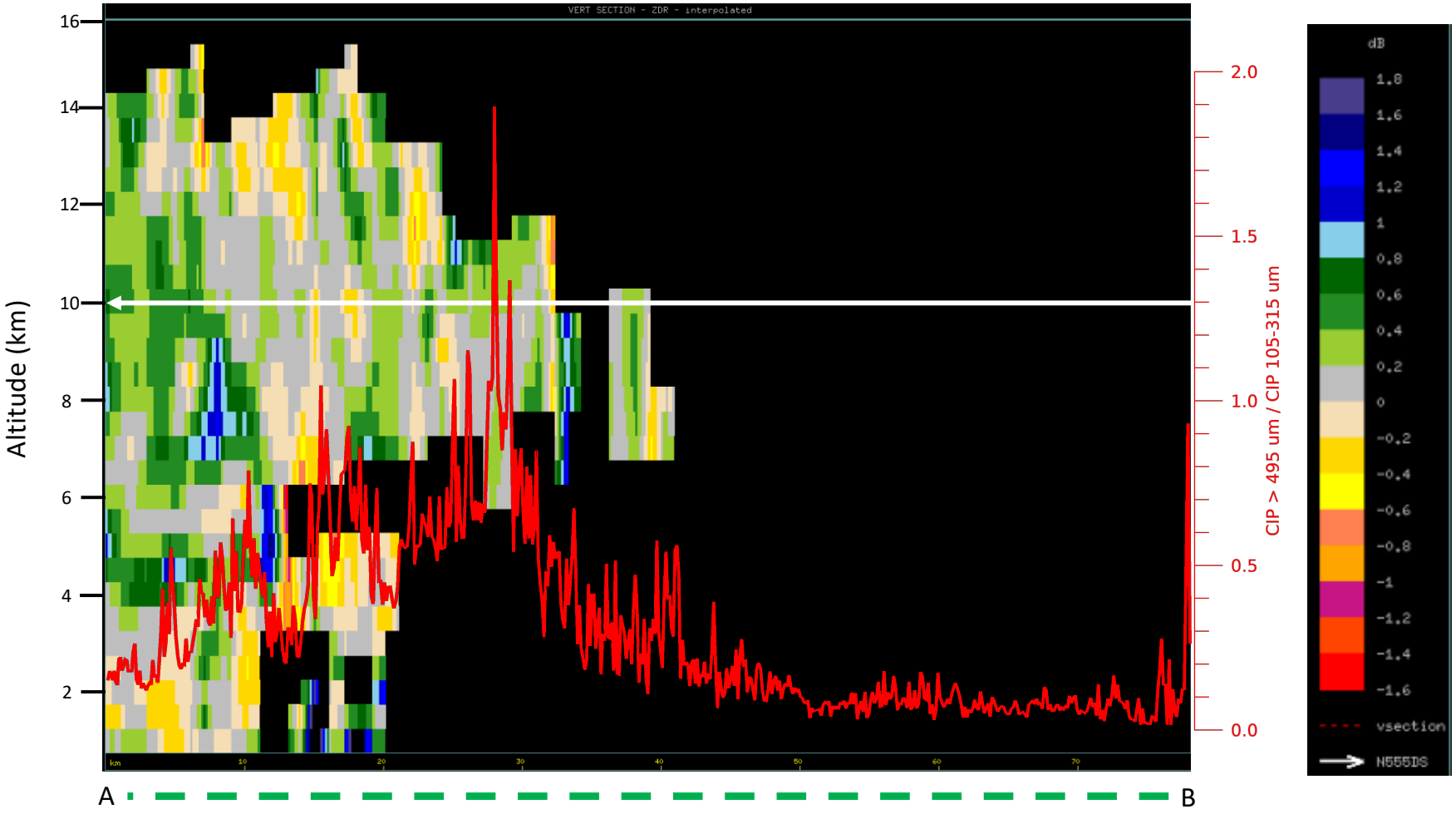
15:51:15 – 16:01:00

KMLB Vol Scan: 16:02:01

10 km CAPPI




VERT SECTION - dBZ - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
km
10
20
30
40
50
60
70
A
B
1.0E-01
1.0E-02
1.0E-03
1.0E-04
Concentration > 495 um [#/cm^3]
dBZ
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
N555DS

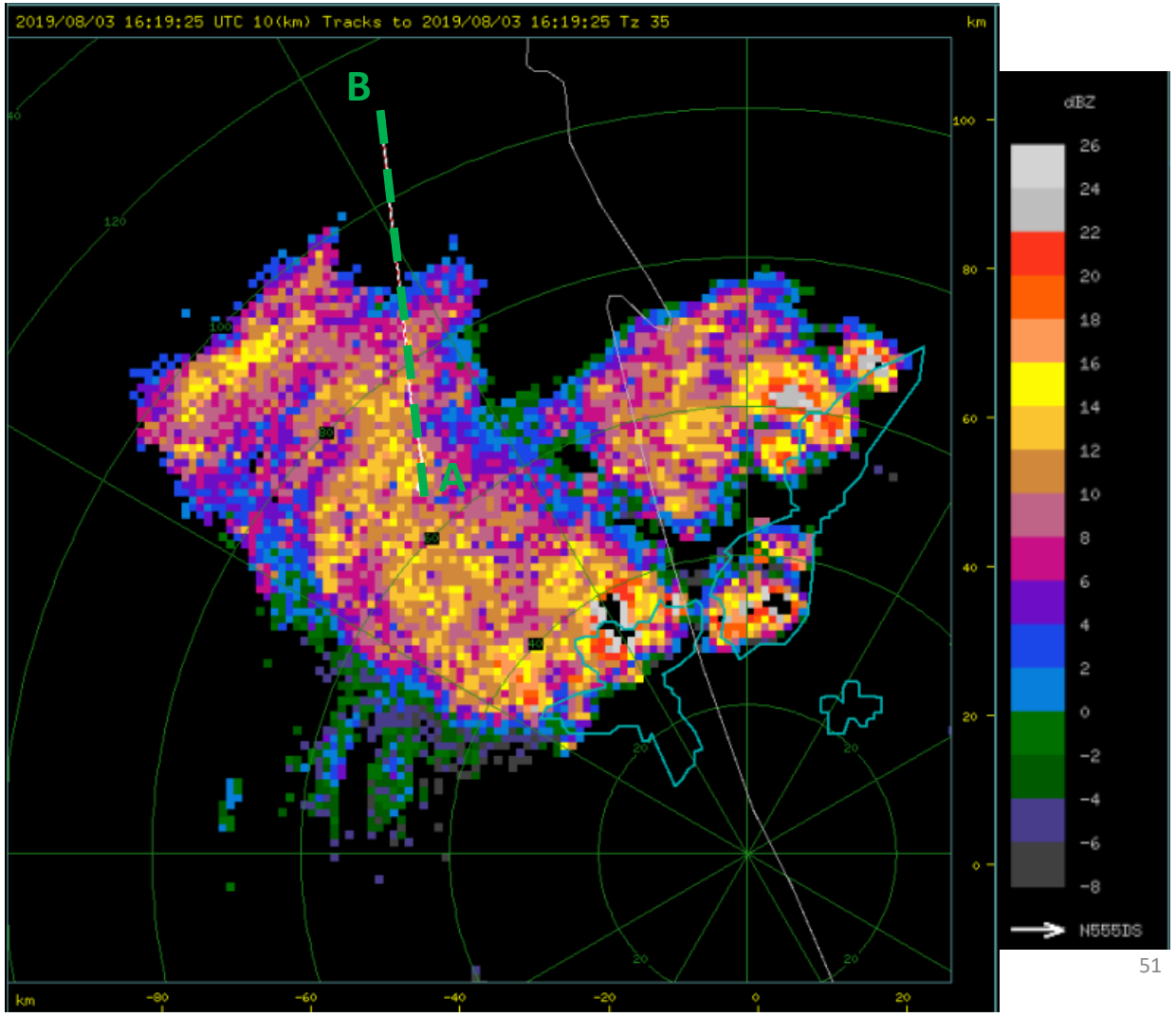

VERT SECTION - ZDR - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
km
10
20
30
40
50
60
70
2.0
1.5
1.0
0.5
0.0
CIP > 495 um / CIP 105-315 um
dB
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
vsection
N555DS
A
B

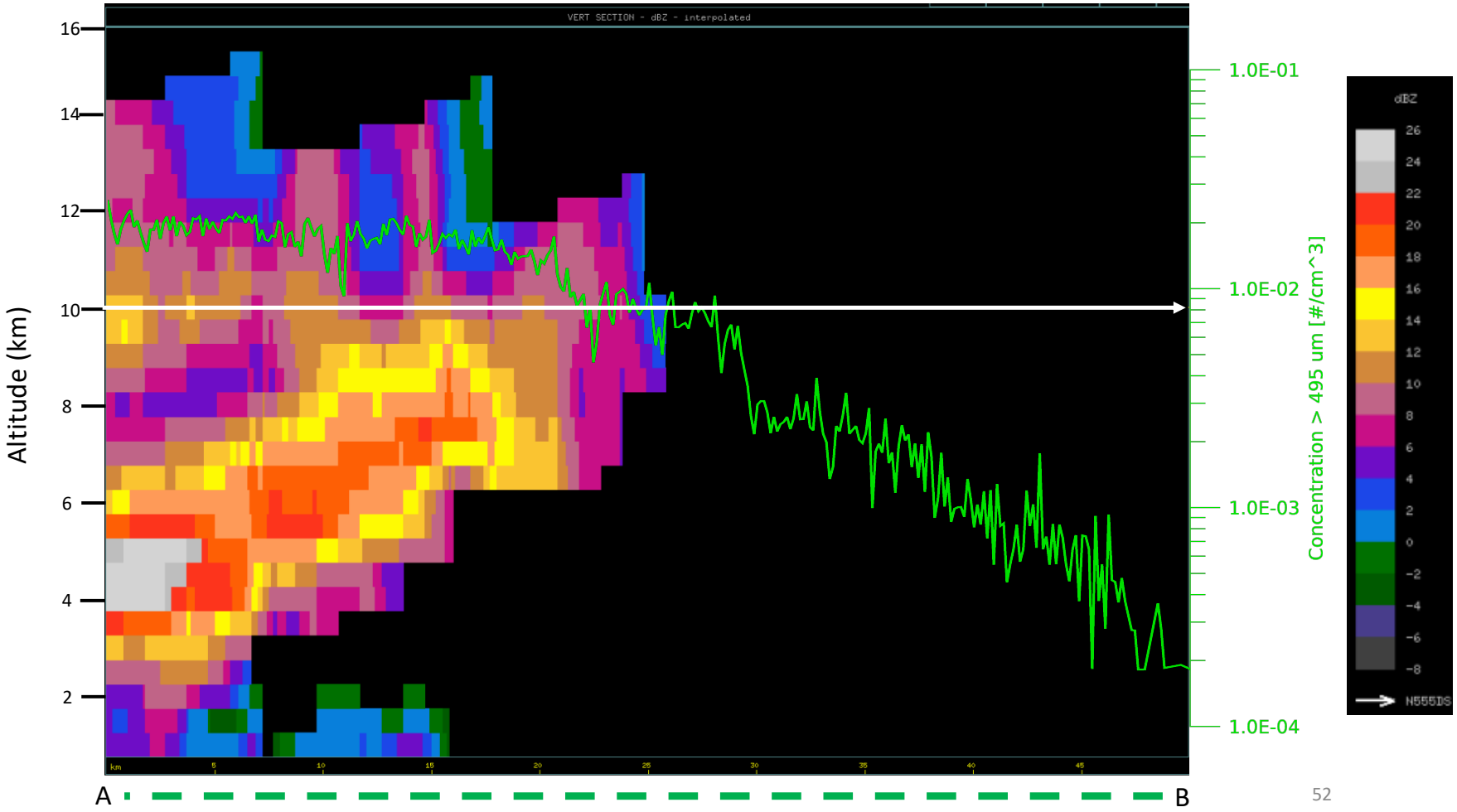
Flight Leg 4 (FL4)

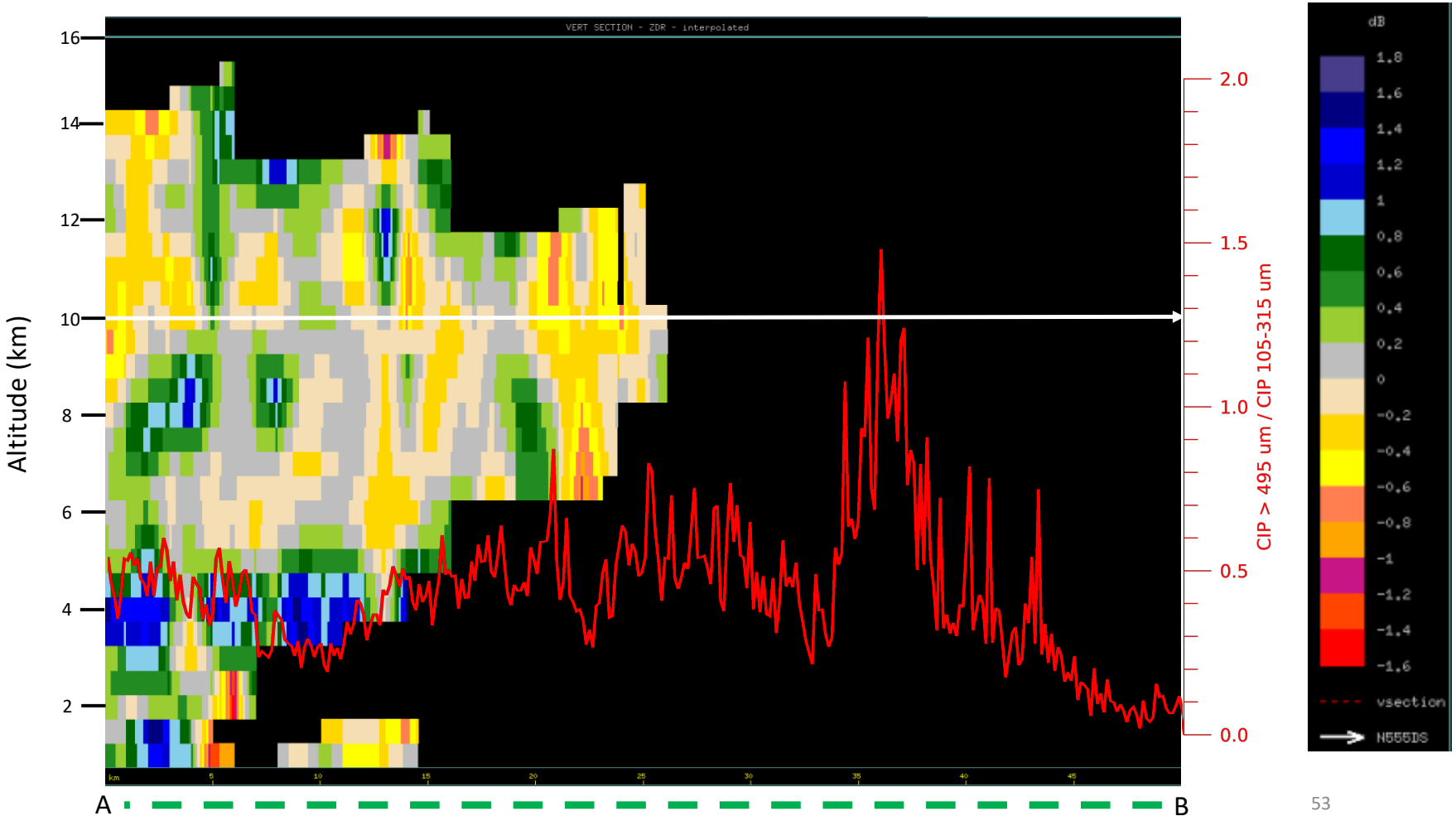
16:21:30 – 16:27:00

KMLB Vol Scan: 16:19:25

10 km CAPPI




VERT SECTION - dBZ - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
1.0E-01
1.0E-02
1.0E-03
1.0E-04
Concentration > 495 um [#/cm^3]
dBZ
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
N555DS
km
5
10
15
20
25
30
35
40
45
A
B

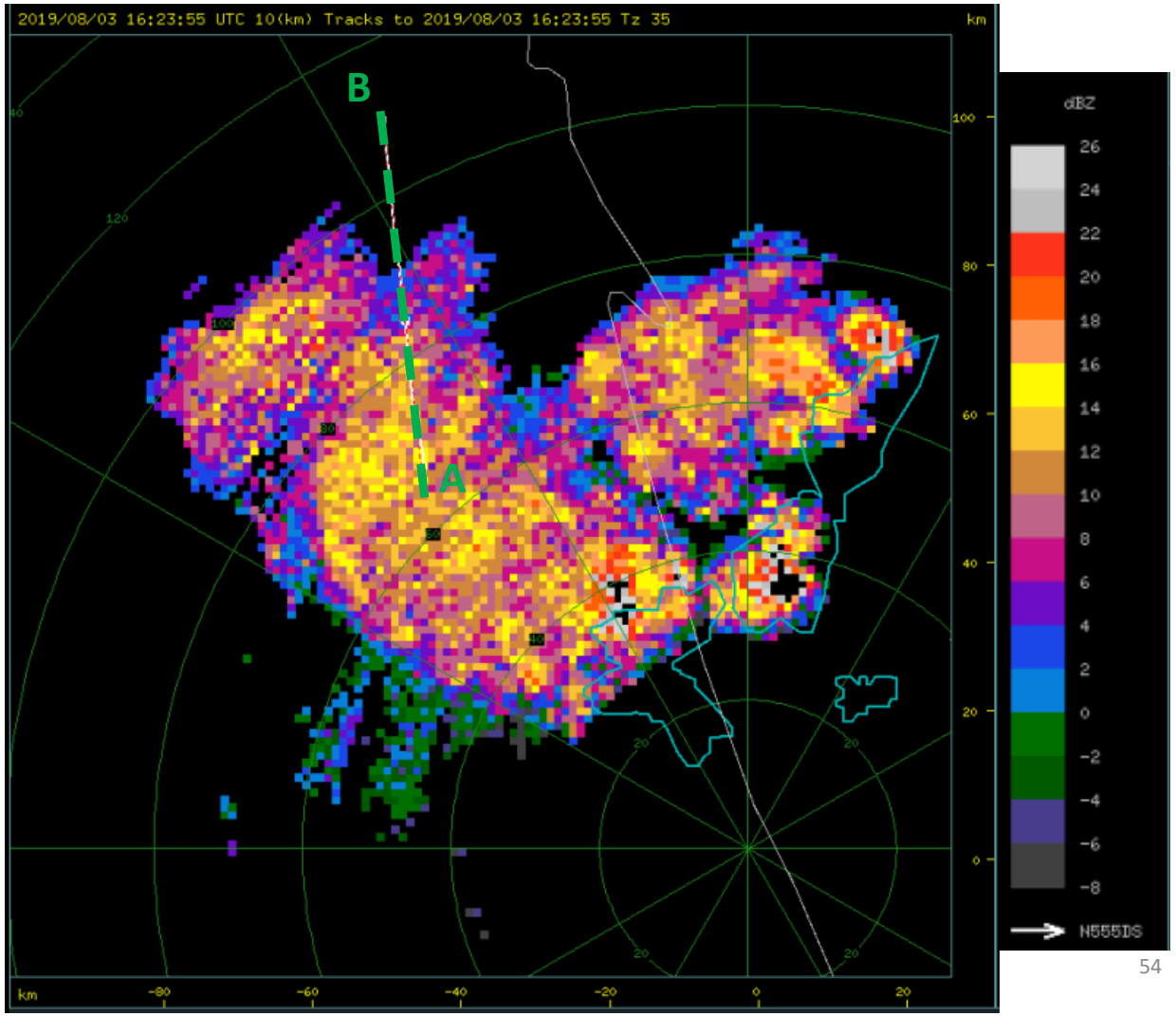

VERT SECTION - ZDR - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
2.0
1.5
1.0
0.5
0.0
CIP > 495 um / CIP 105-315 um
dB
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
vsection
N555DS
km
5
10
15
20
25
30
35
40
45
A
B

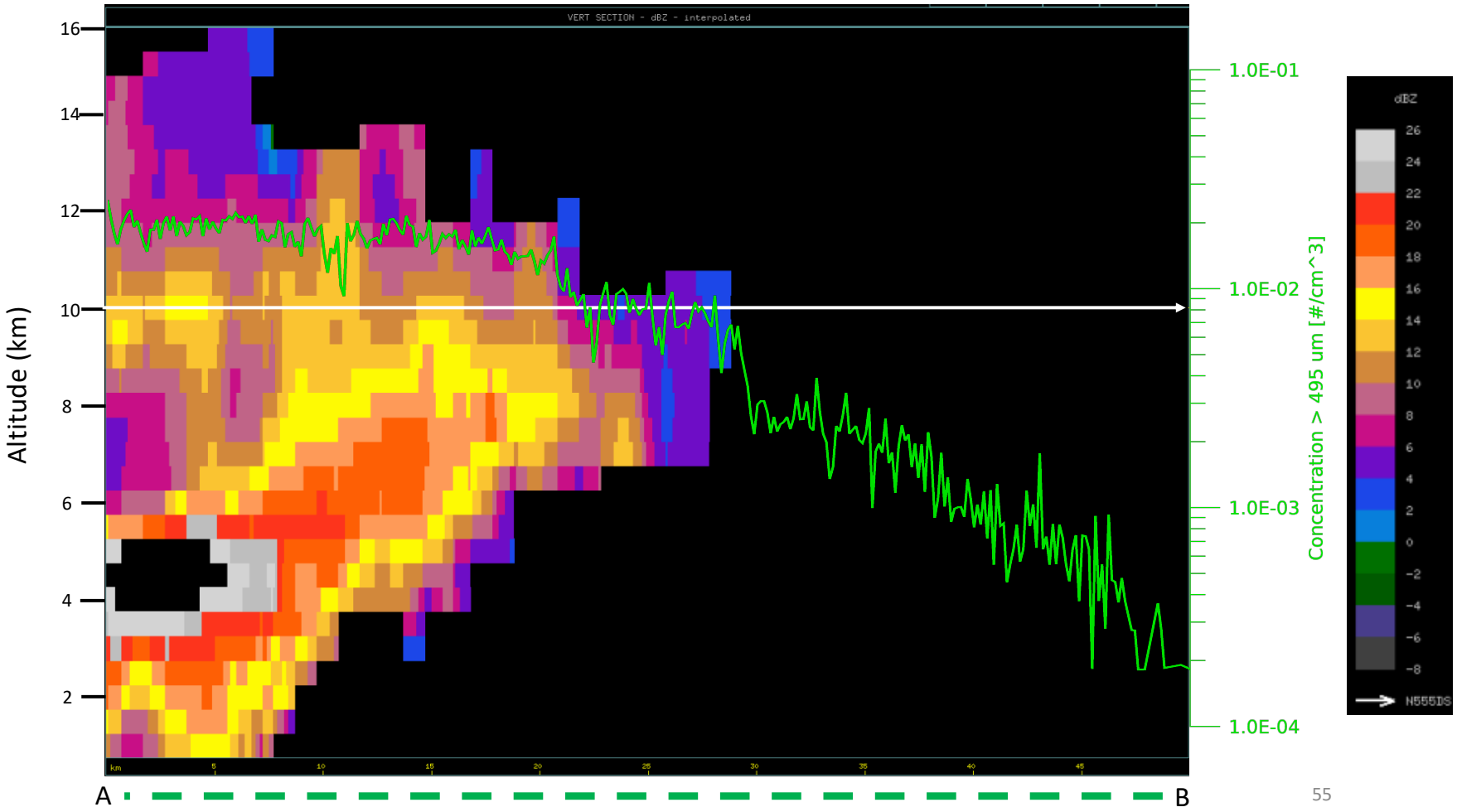
Flight Leg 4 (FL4)

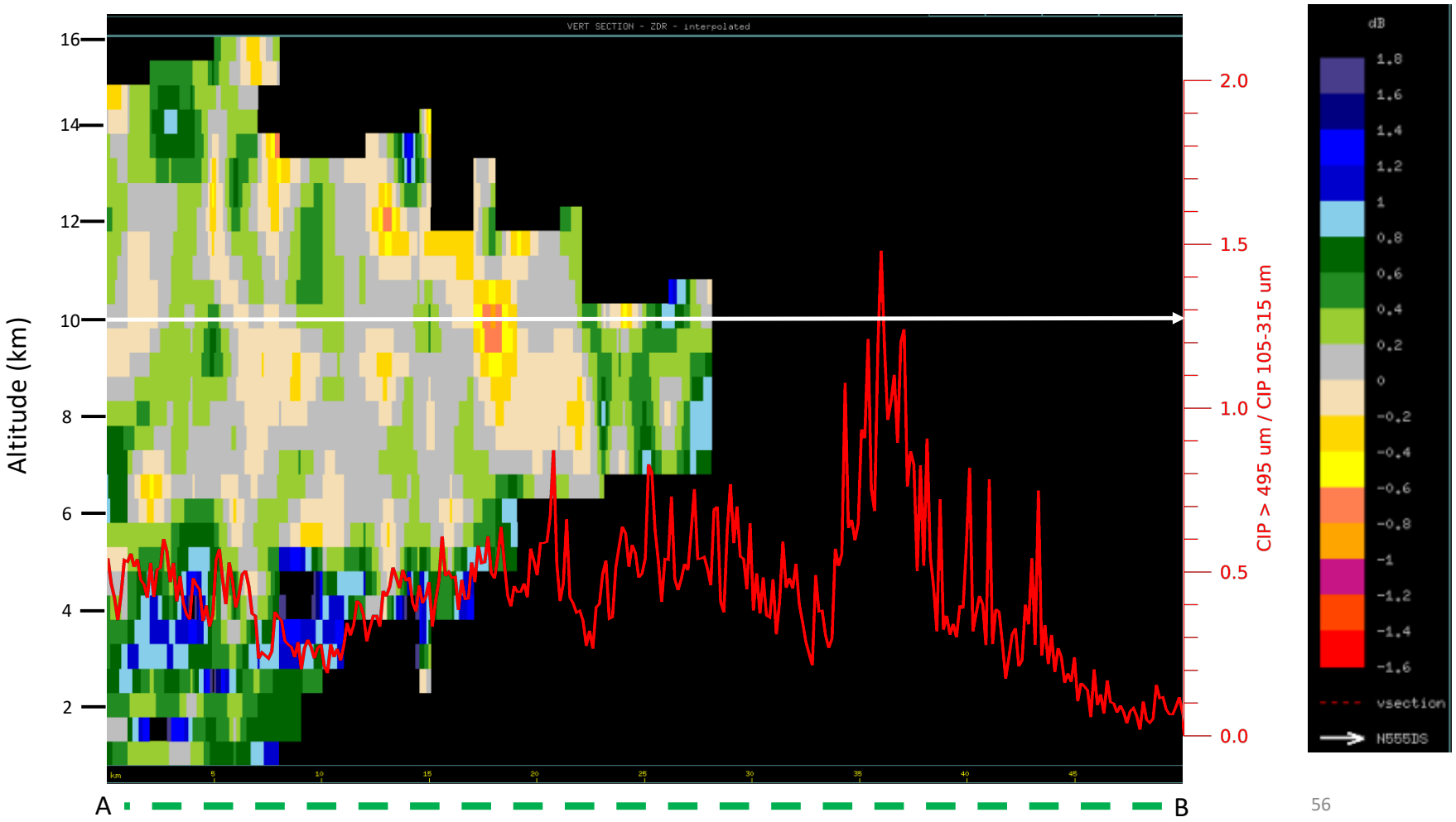
16:21:30 – 16:27:00

KMLB Vol Scan: 16:23:55

10 km CAPPI




VERT SECTION - dBZ - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
km
5
10
15
20
25
30
35
40
45
1.0E-01
1.0E-02
1.0E-03
1.0E-04
Concentration > 495 um [#/cm^3]
dBZ
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
N555DS
A
B

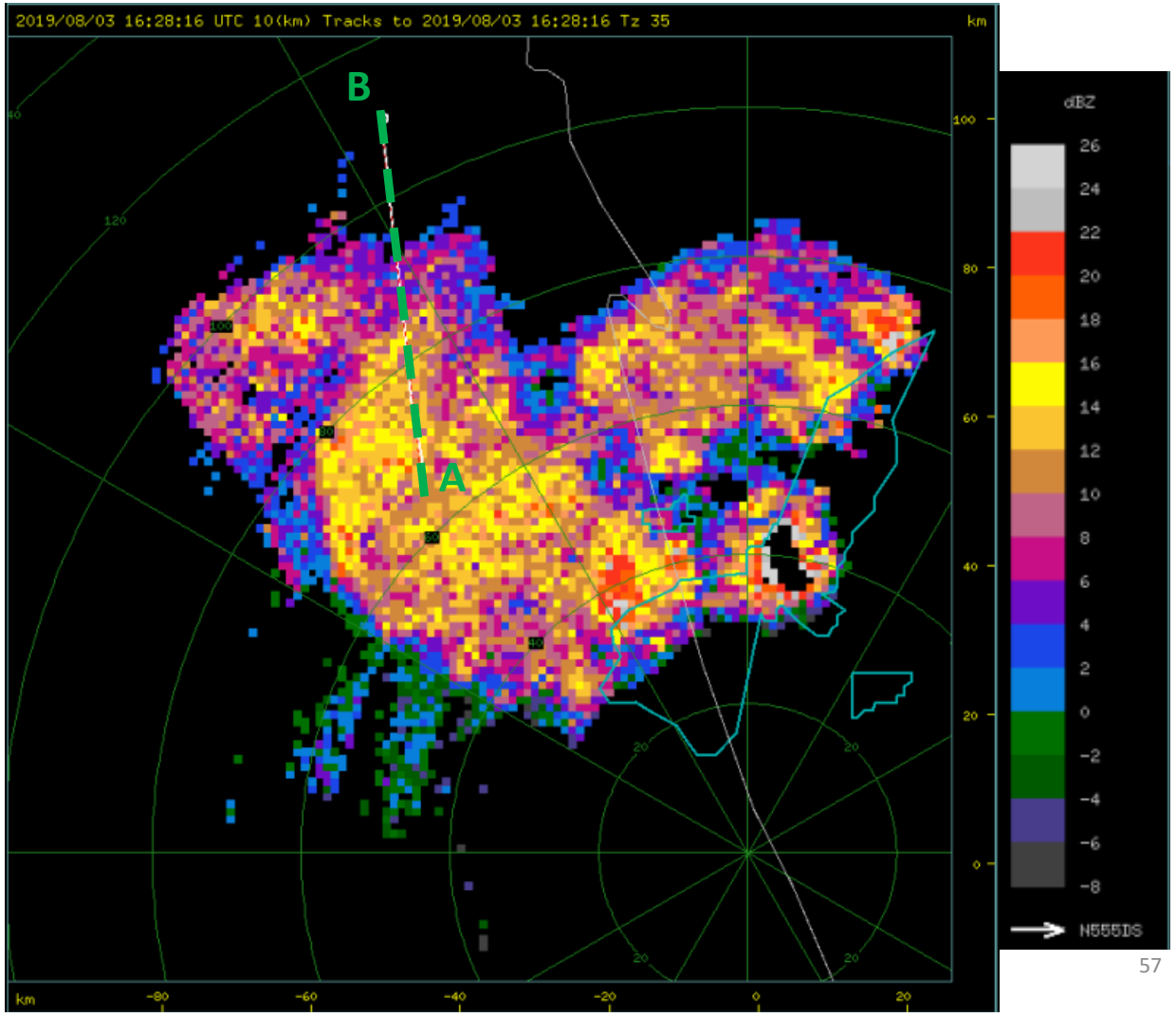

VERT SECTION - ZDR - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
2.0
1.5
1.0
0.5
0.0
CIP > 495 um / CIP 105-315 um
dB
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
vsection
N555DS
km
5
10
15
20
25
30
35
40
45
A
B

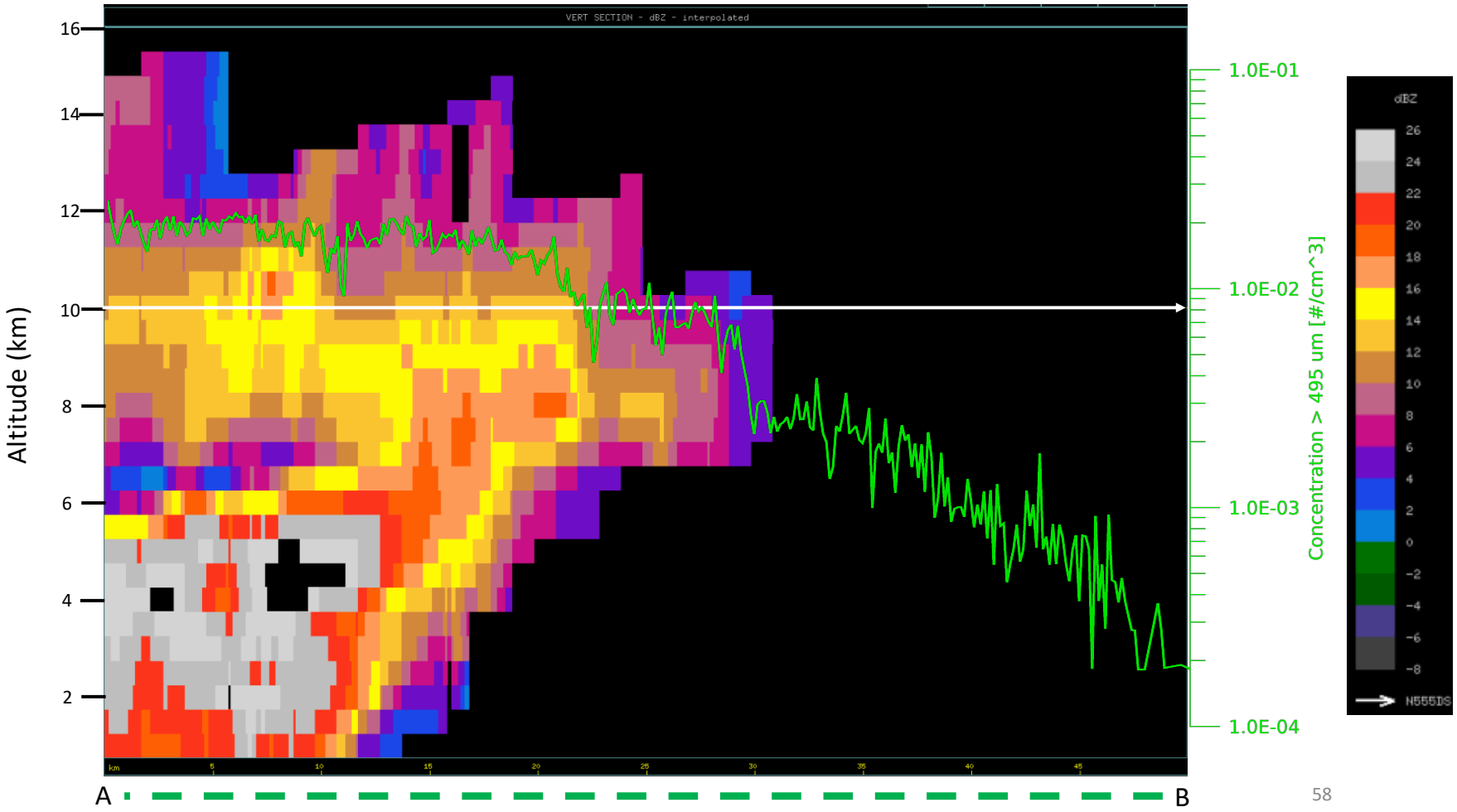
Flight Leg 4 (FL4)

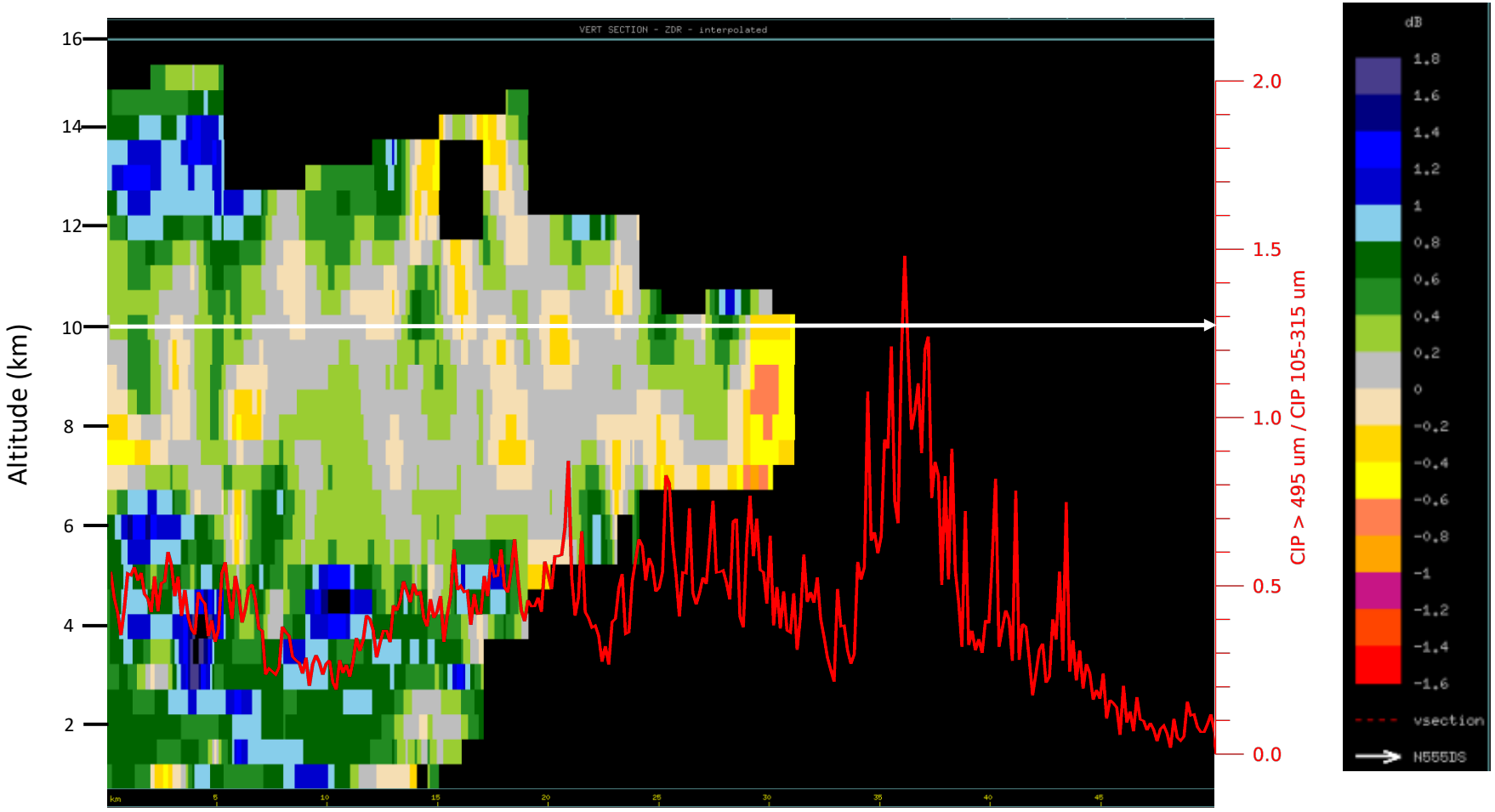
16:21:30 – 16:27:00

KMLB Vol Scan: 16:28:16

10 km CAPPI




VERT SECTION - dBZ - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
km
5
10
15
20
25
30
35
40
45
A
B
1.0E-01
1.0E-02
1.0E-03
1.0E-04
Concentration > 495 um [#/cm^3]
dBZ
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
N555DS


VERT SECTION - ZDR - interpolated
Altitude (km)
16
14
12
10
8
6
4
2
2.0
1.5
1.0
0.5
0.0
CIP > 495 um / CIP 105-315 um
dB
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
vsection
N555DS