Summary of the NASA/FAA High Ice Water Content and Aerosols Flight Campaign (HIWC-2022)

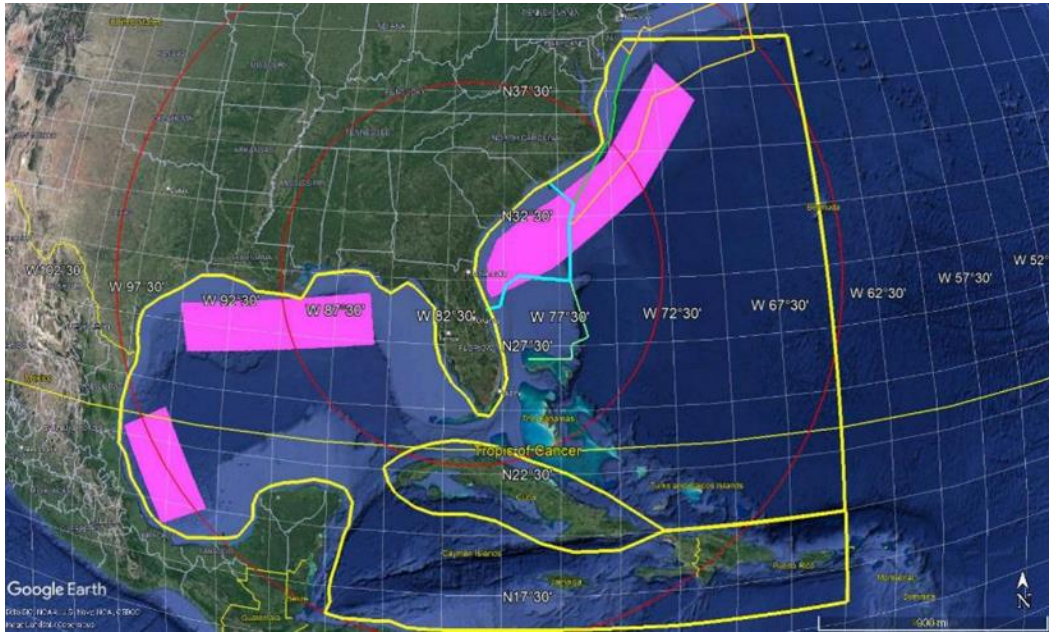
Tom Ratvasky

HIWC-2022 Special Topics Meeting

November 29-30, 2023 – Boulder, CO

HIWC-2022 Flight Campaign Overview:

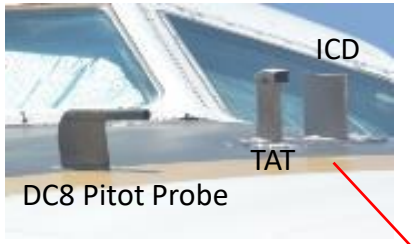
- 4-week campaign, Cecil Airport, Jacksonville, FL
  - Jul 05-Aug 01, 2022
- NASA DC-8 Airborne Science Laboratory
  - Used previously for HIWC research and aerosol measurement campaigns
- Operating Area: Off coasts of Virginia, Carolinas, Gulf of Mexico and Caribbean
  - 5-year climatology indicated:
    - » average of 6.5 flights during the operation period to fly in MCS with moderate-high aerosol in this region
    - » MCSs tend to be short lived (~6 hours)
    - » Suitable clouds tended to be more intense and more frequent in night-time hours
  - Areas defined to facilitate discussions with ATC and country clearances

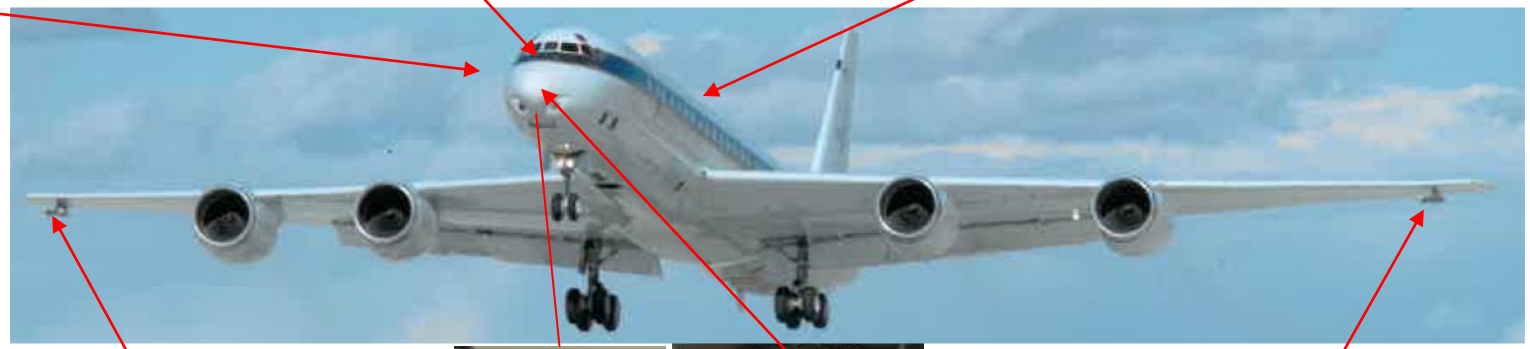


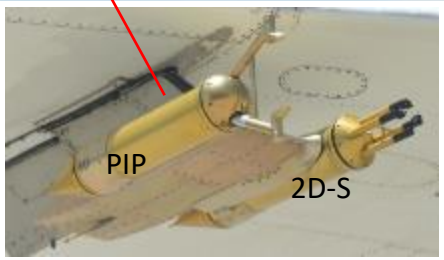
Yellow outline defined operating area. Pink regions indicating areas identified by climatology study for MCS with moderate-high aerosol.
Range rings: 450 and 900 Nm respectively from Jacksonville.

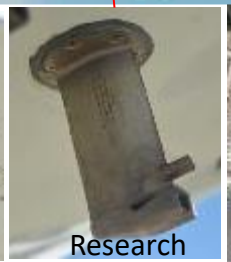
NASA DC-8 with HIWC & Aerosol Instrumentation

Clarke Inlet for aerosol instruments

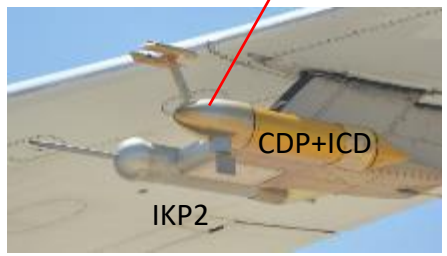








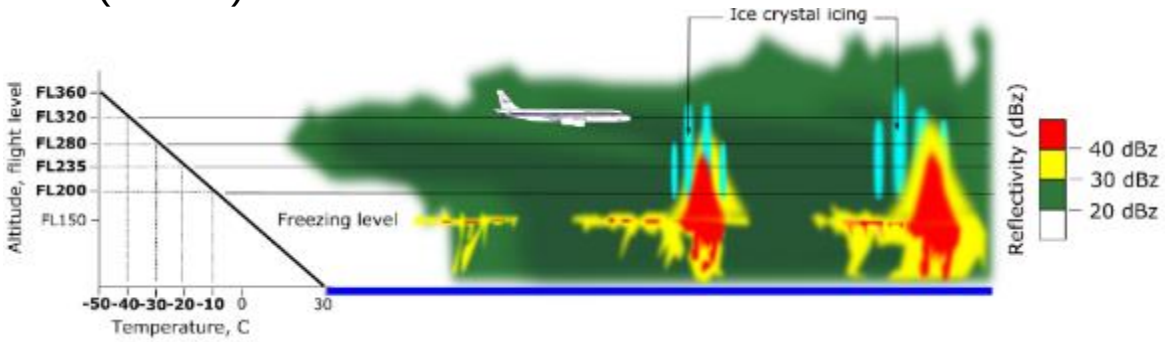
Modified Honeywell RDR-4000



- Cloud Water Content: IKP2, SEA ICD
- Cloud particle spectra: CDP-2, 2D-S, PIP
- RDR-4000 Wx Radar
- Background water vapor: Diode Laser Hygrometer, Licor/WVSS2
- Aerosol instruments: PCASP-100X, CCN-200, SMPS, CPC, OPC, Impactor

Flight Sampling Strategies

- Target large convective clouds (mesoscale convective systems – MCSs) greater than 60 Nm in diameter over the ocean, and in locations with expected high concentration of aerosols on day of flight
- For regulatory objectives:
  - straight-level transects/survey patterns in and/or near active cells were critical;
  - target temperature level: -40C (FL340)



- For science objectives:
  - Investigate smaller (~< 10 Nm diameter) cumulonimbus (Cbs) and/or towering cumulous (TCu) clouds forming in same atmosphere as MCSs before fully mature stage, to document early precipitation development (including warm rain)
  - Sample cloud-free air below cloud, and sample in cloud below and above freezing level (e.g. approx. altitudes: 5kft, 10kft, 15kft)

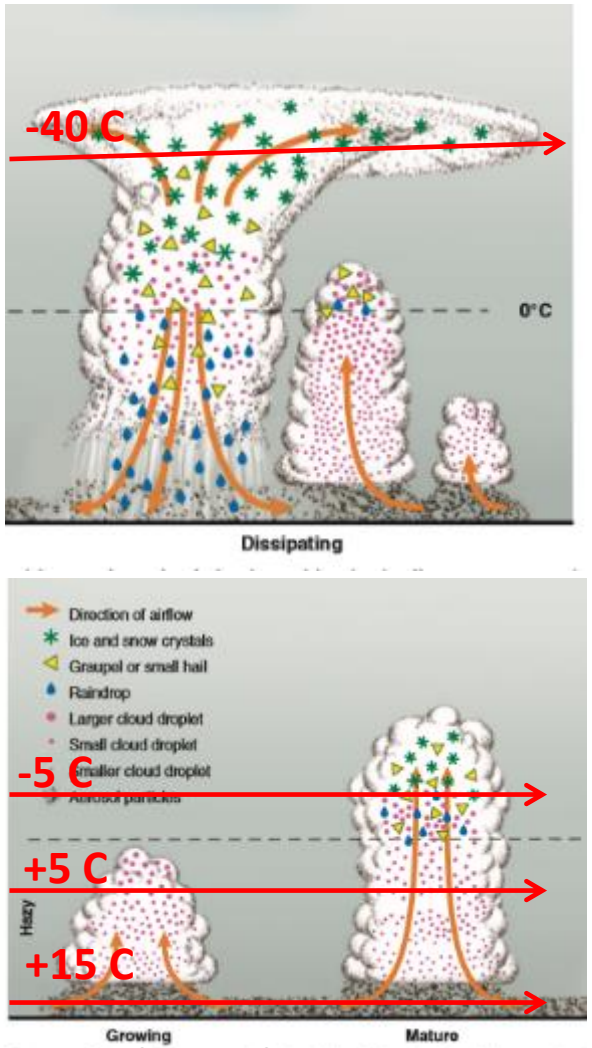
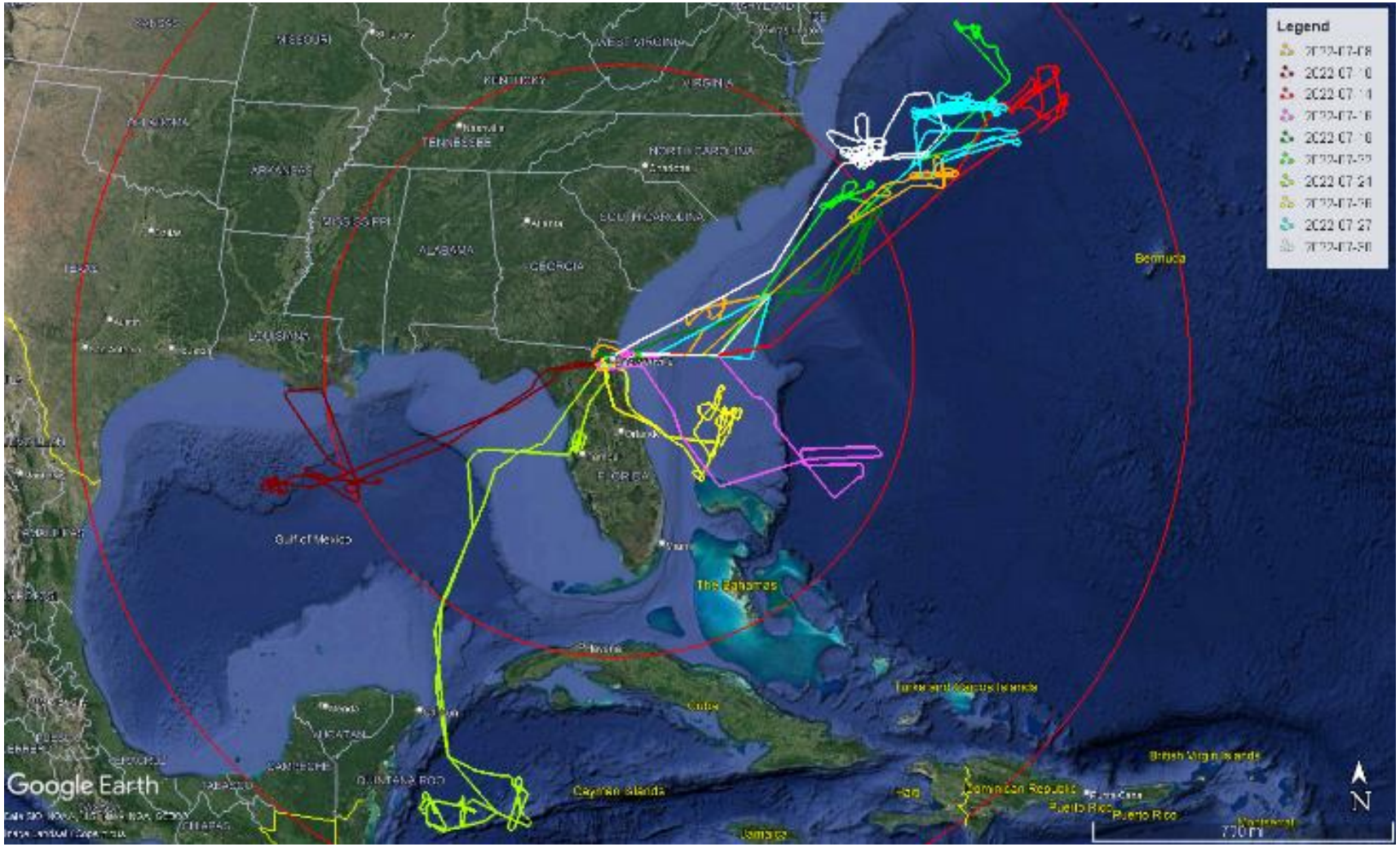


Figure adapted from Rosenfeld et al., *Flood or Drought: How Do Aerosols Affect Precipitation,* Sep 2008 doi:10.1126/science.1160606. Reprinted with permission from AAAS

HIWC-2022 Flight Campaign Summary

- Completed 10 research flights
  - 8 low-mod aerosol MCS flights
  - 1 high aerosol MCS flight
    - » 30 July 2022
  - 1 flight dedicated to aerosol effects on TCu, to augment other TCu measurements
    - » 26 July 2022
  - All daytime flights; counter to climatology expectations



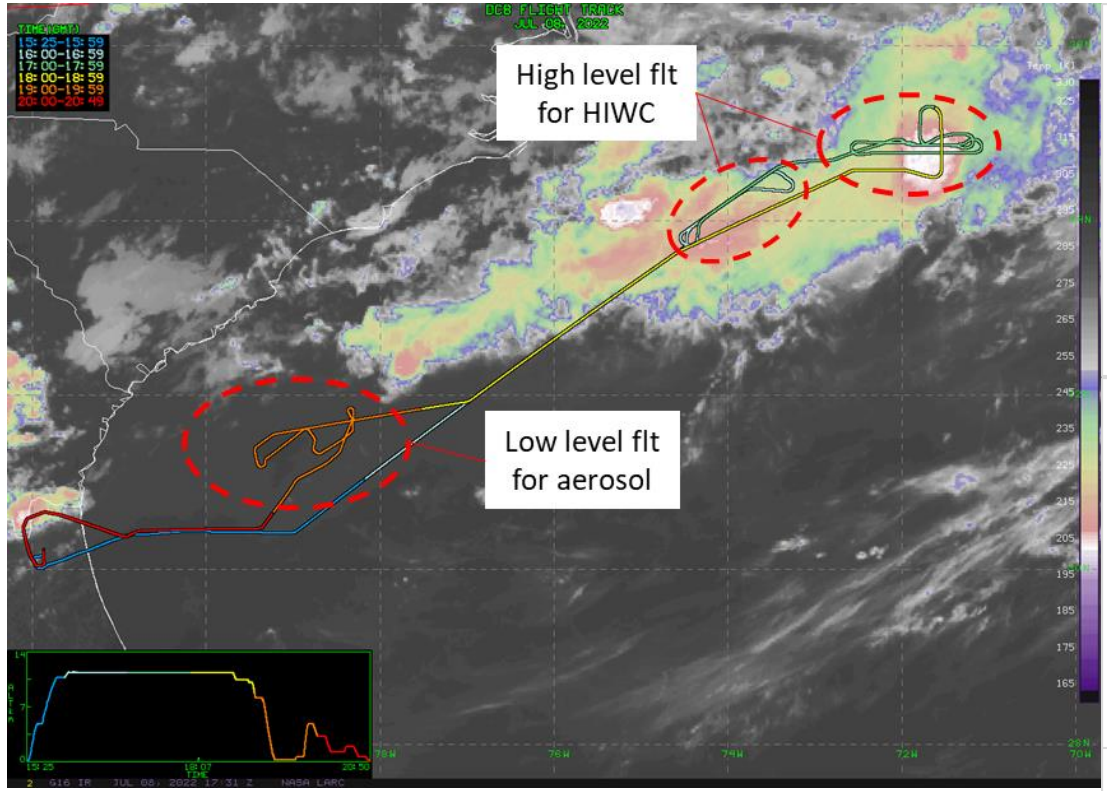
HIWC-2022 Flight Campaign Summary

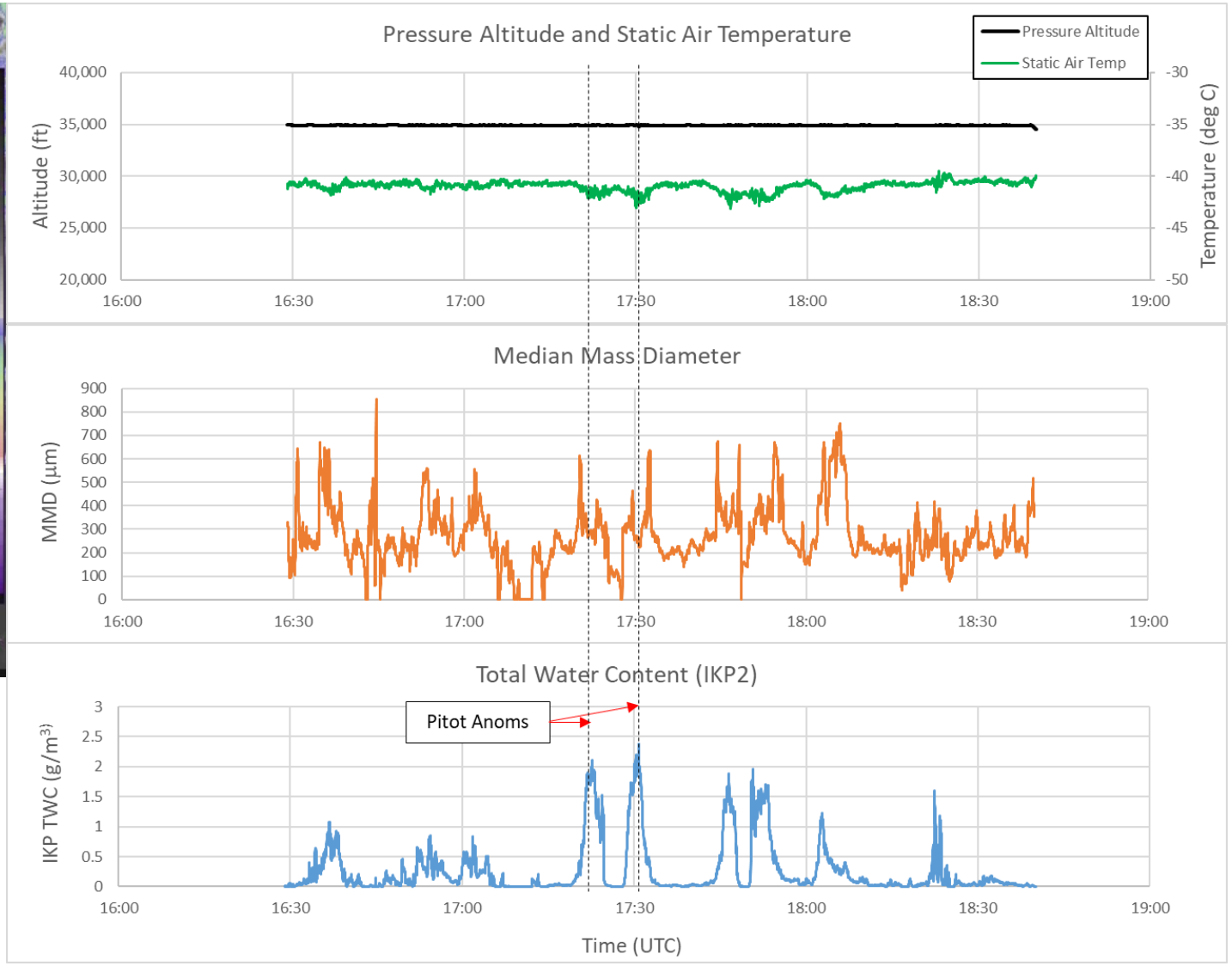
Flight Date	HIWC Flt No.	Takeoff (UTC)	Landing (UTC)	Flight Time	Region	HIWC	Aerosol	Comments/Observations
2022-06-15	1	16:11	19:47	3.6	off CA coast	N/A	N/A	Instrument check flight
2022-07-05	2	15:59	20:18	4.3	CA to FL	N/A	N/A	Ferry flt from Palmdale (PMD) to Jacksonville (Cecil VQQ).
2022-07-08	3	15:25	20:49	5.4	off mid-Atlantic coast	8 runs at 34kft (-41C). Peak IWC_{max}: 2.37 g/m^3 Time in cloud>1.0 g/m^3: 11.9 min	Moderate PCASP: 235	ADC1 pitot anomalies at two time periods (17:22 and 17:30)
2022-07-10	4	16:10	22:18	6.1	Central Gulf	7 runs at 34kft (-38C) 1 runs at 30kft (-28C) Peak IWC_{max}: 3.70 g/m^3 Time in cloud>1.0 g/m^3: 25.1 min	low-mod PCASP: 160	ADC1 and ADC2 pitot anomalies at two time periods (17:10 and 19:14. ADC1 brief glitch at 18:56. Lightning strike about 17:51. Graupel damage to ICDs
2022-07-14	5	13:50	20:43	6.9	off mid-Atlantic coast	9 runs at 34kft (-41C). Peak IWC_{max}: 1.67 g/m^3 Time in cloud>1.0 g/m^3: 9.0 min	Moderate PCASP: 85	Good low alt. measurements and limited Tcu, lowest aerosol. Lower CAPE
2022-07-16	6	14:02	18:21	4.3	north of Bahamas	4 runs at 30kft (-33C). Peak IWC_{max}: 2.04 g/m^3 Time in cloud>1.0 g/m^3:14.1 min	No low level flights	Lower altitude than previous flights due to ATC/air traffic. Lightning strike about 16:07. Flight terminated early
2022-07-18	7	16:06	21:14	5.1	off N-S Carolina coasts	7 runs at 34kft (-41C). Peak IWC_{max}: 2.29 g/m^3 Time in cloud>1.0 g/m^3: 12.3 min	No low level flights	Flight terminated early due to cabin pressure control issue

HIWC-2022 Flight Campaign Summary

Flight Date	HIWC Flt No.	Takeoff (UTC)	Landing (UTC)	Flight Time	Region	HIWC	Aerosol	Comments/Observations
2022-07-22	8	12:01	18:36	6.6	off NC-Virginia coasts	3 runs at 34kft (-41C) 2 runs at 32kft (-35C) Peak IWC_{max}: 2.60 g/m^3 Time in cloud>1.0 g/m^3: 16.4 min		Low level flight 350 NM to NE of high level flight
2022-07-24	9	11:35	18:59	7.4	east of Yucatan Pen / south of Cuba	1 run at 35kft (-44C) 1 run at 34kft (-41C) 2 runs at 33kft (-38C) 1 run at 30kft (-30C) Peak IWC_{max}: 2.34 g/m^3 Time in cloud>1.0 g/m^3: 2.4 min		Low level flight in TCu and below cloud base Least amount of time in HIWC
2022-07-26	10	11:33	15:15	3.7	off east coast of Florida	N/A	TCu and aerosol flight	Dedicated flight to TCu and aerosol
2022-07-27	11	9:58	19:10	9.2	off coast of Virginia	9 runs at 34kft (-41C). Peak IWC_{max}: 2.62 g/m^3 Time in cloud>1.0 g/m^3: 44.8 min	High-Mod PCASP: 150	High level flights before and after low level flight for aerosol. First high level flight directly over low level on north side of storm. Second high level on south side of storm
2022-07-30	12	13:43	20:36	6.9	off Carolina Coast	2 runs at 34kft (-40C). Peak IWC_{max}: 2.02 g/m^3 Time in cloud>1.0 g/m^3: 12.7 min	High-Mod PCASP: 840	Attempted runs at 39kft, but cabin pressure control could not be maintained. Flight terminated somewhat early.
2022-08-01	13	13:53	17:48	3.9	FL to CA	Ferry flight		Ferry flt from Jacksonville (Cecil VQQ) to Palmdale (PMD)

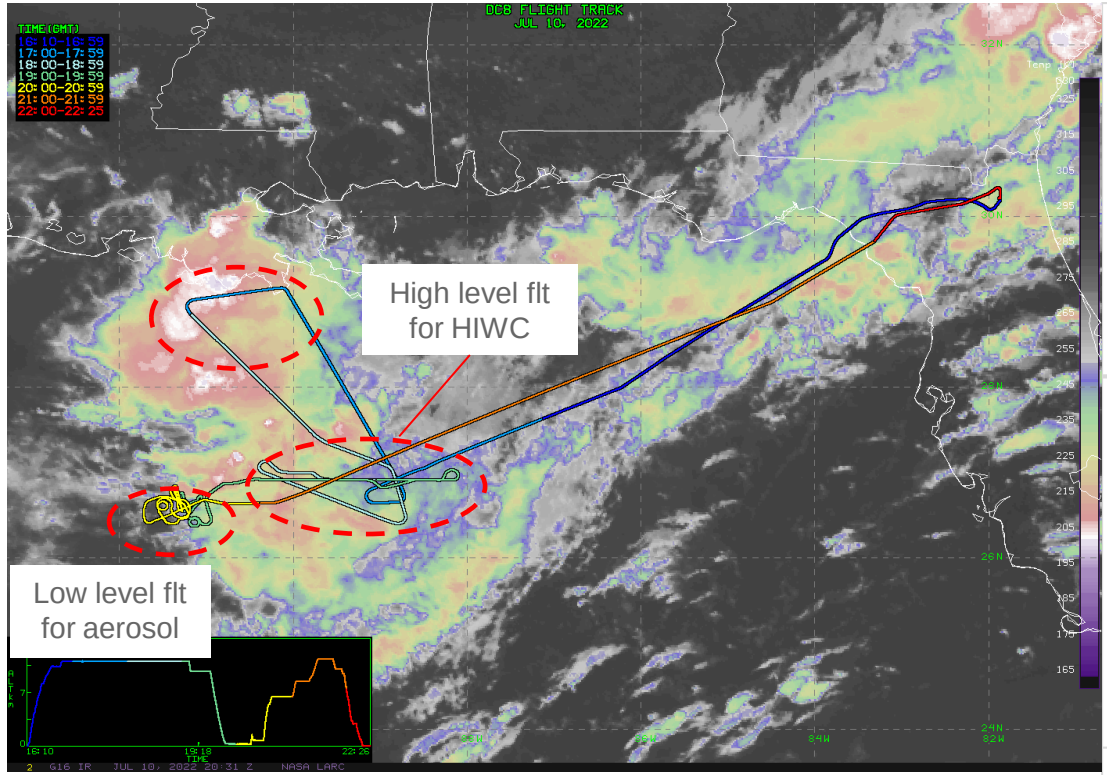
08 July 2022

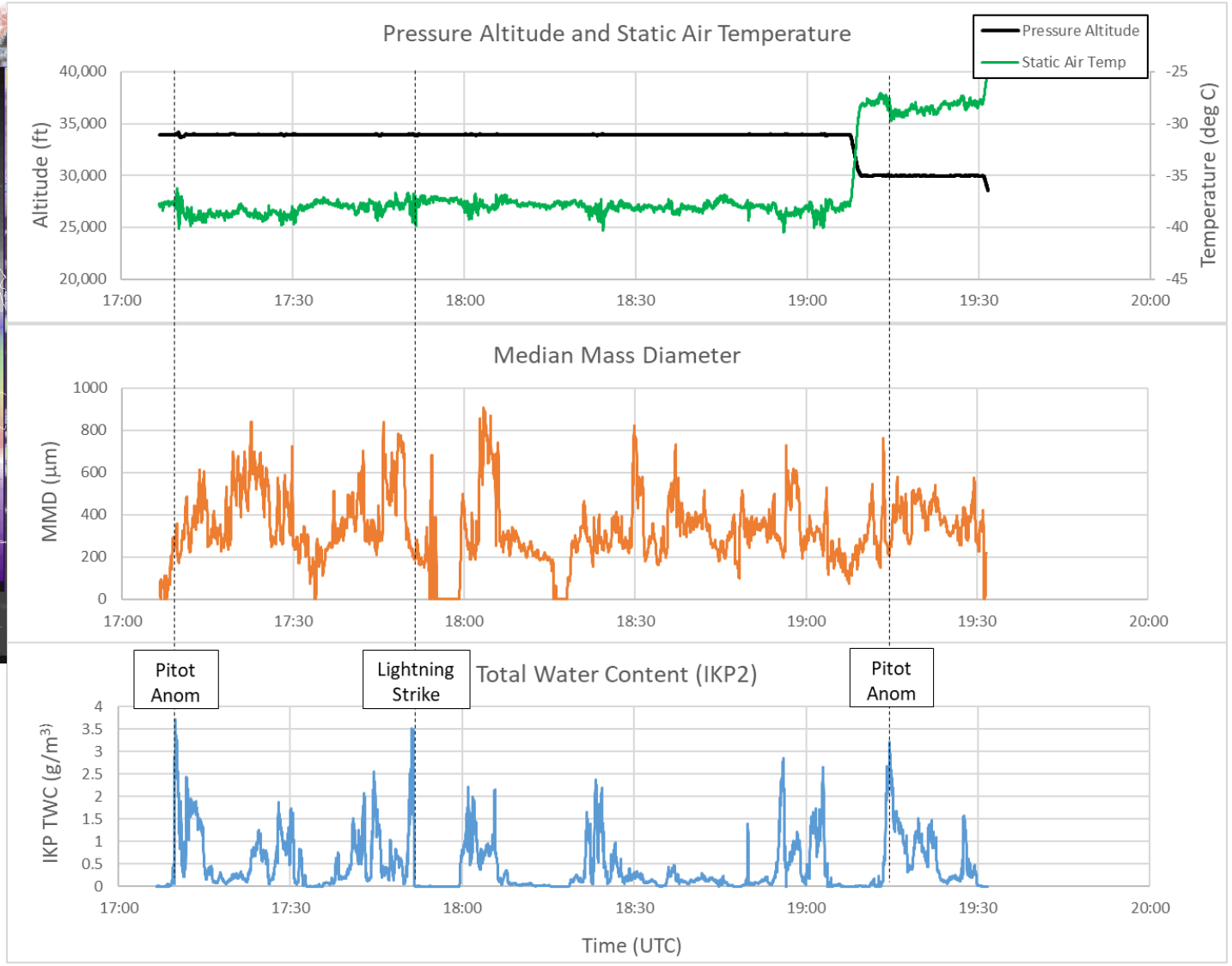




- Isolated deep convection, but low level measurements remote
- ADC1 pitot anoms. Graupel?

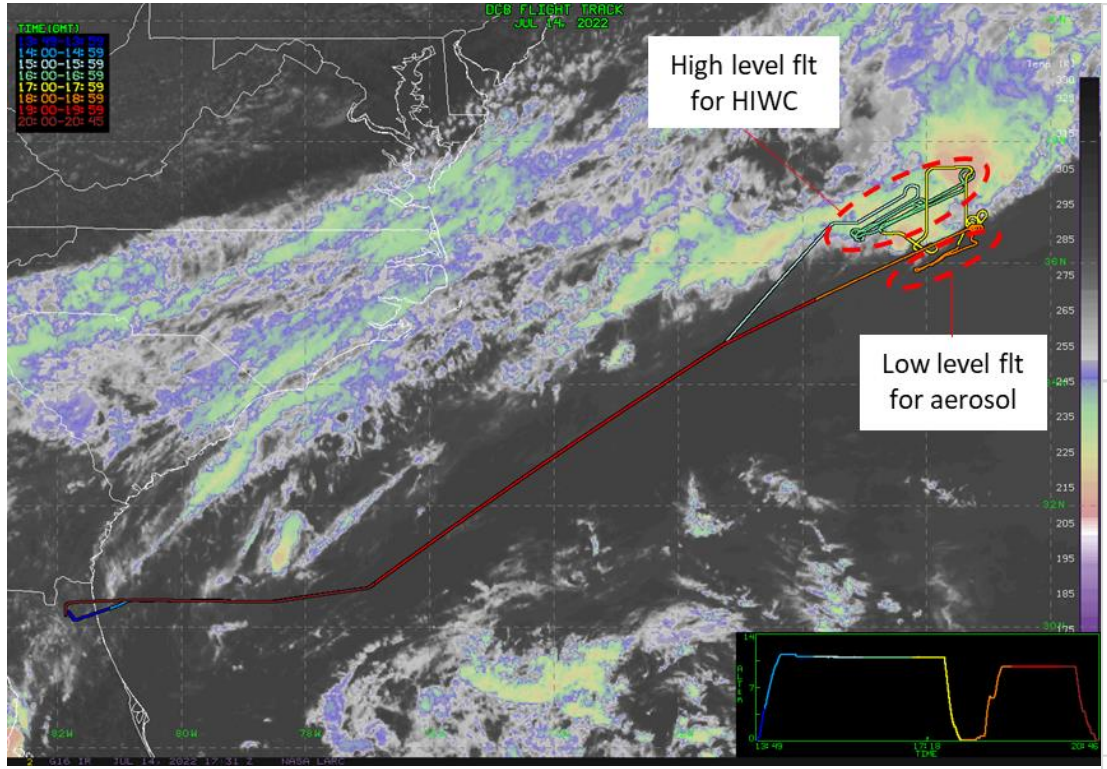
10 July 2022

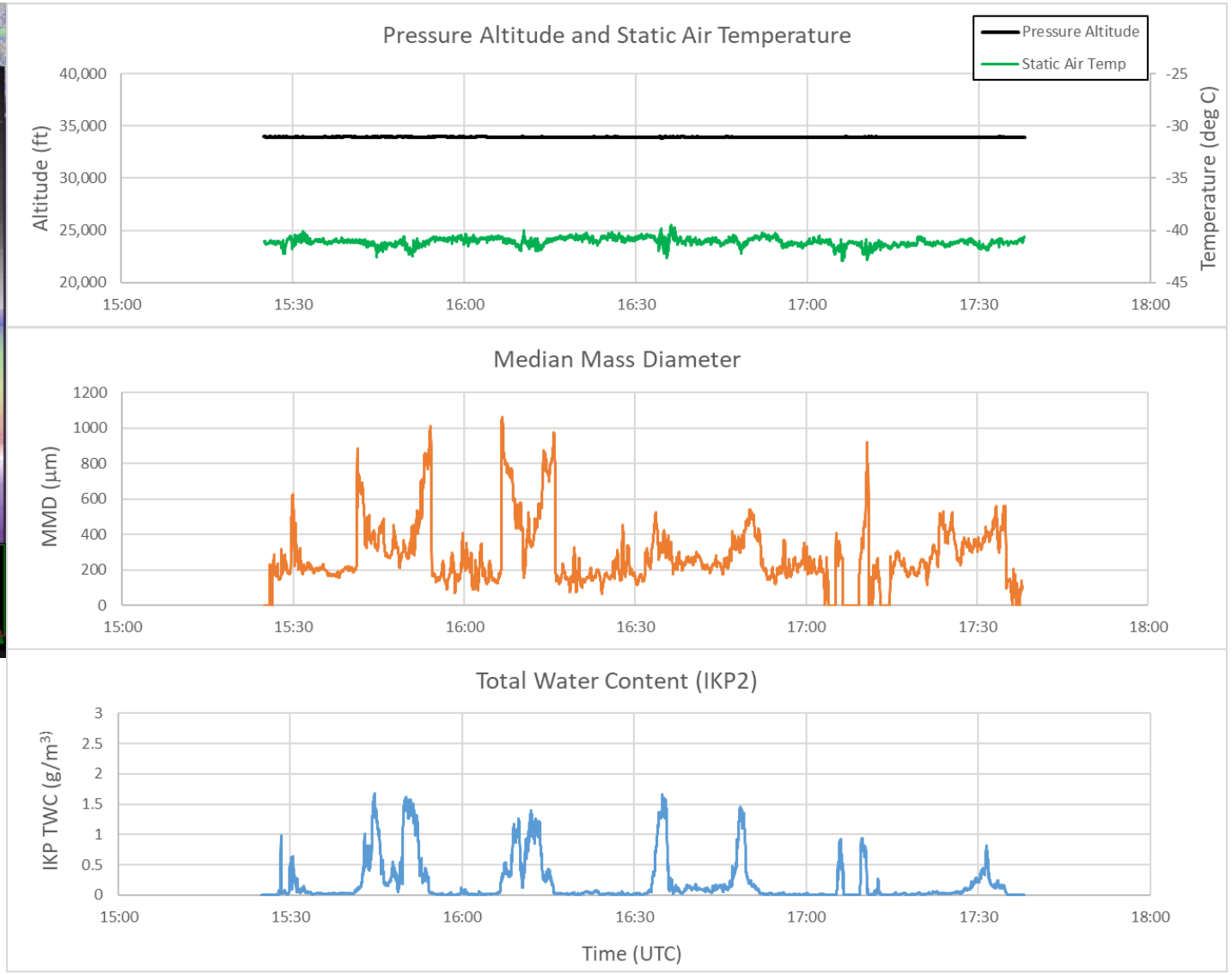




- Highest IWC during initial run
- ADC1, 2 pitot anoms. Graupel 2-4 mm; ICDs damaged
- Lightning strike

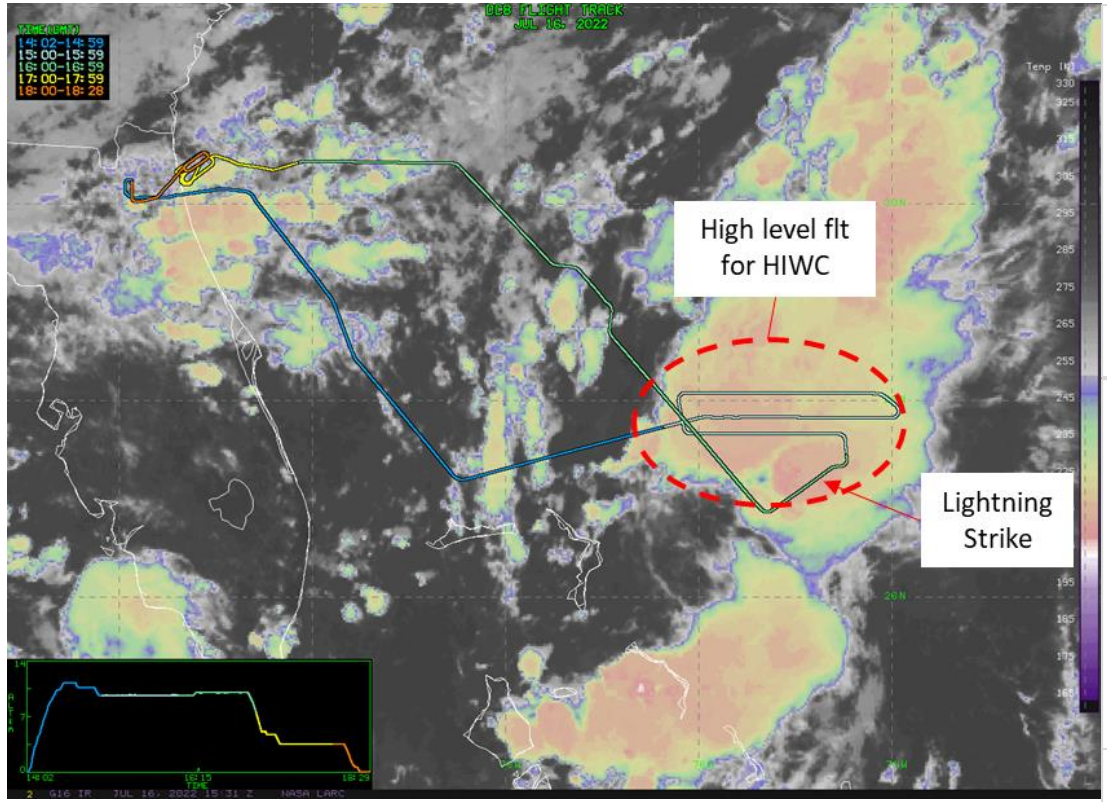
14 July 2022

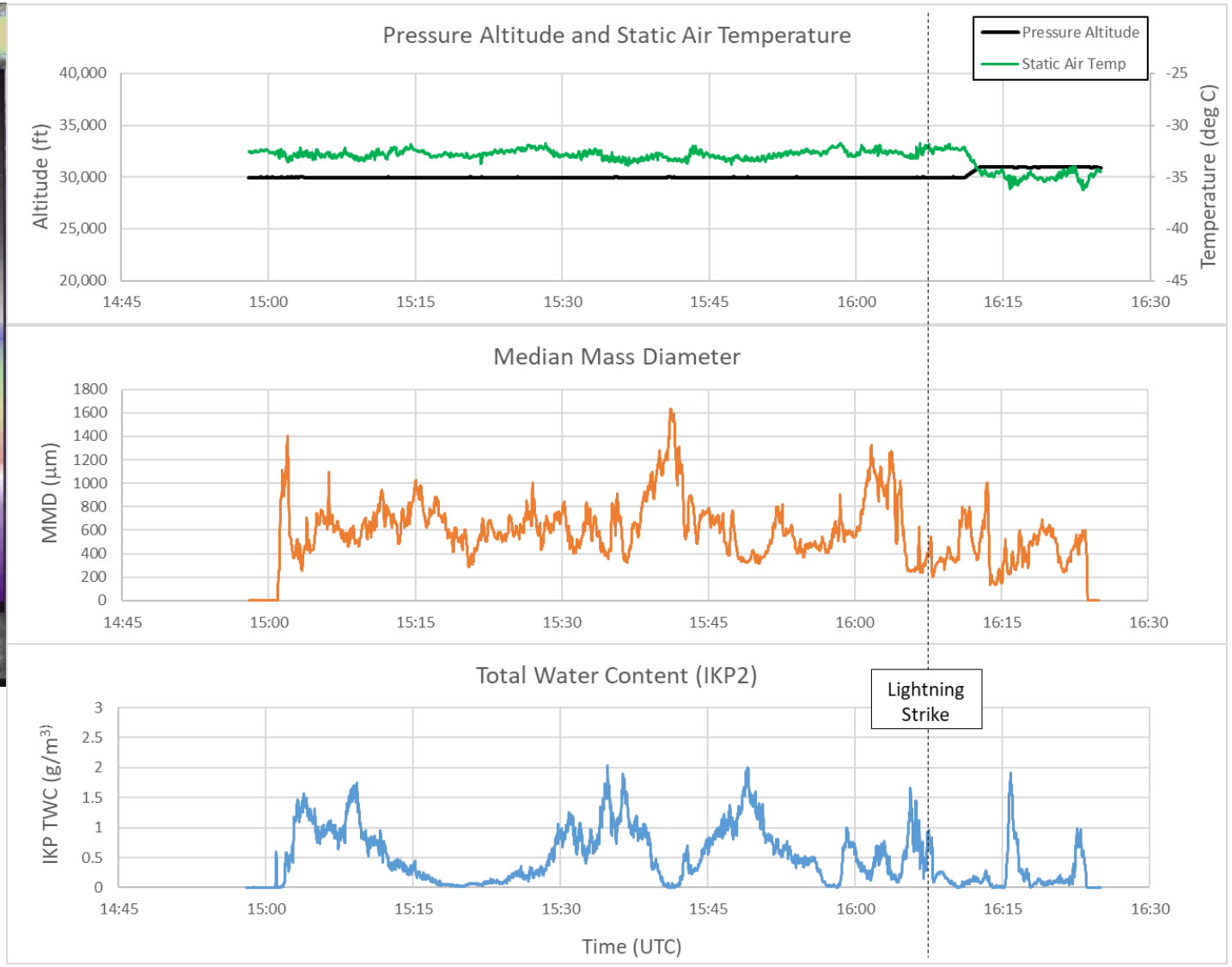




- Lowest IWC peaks;
- Lowest aerosol; PCASP 85 #/SCC

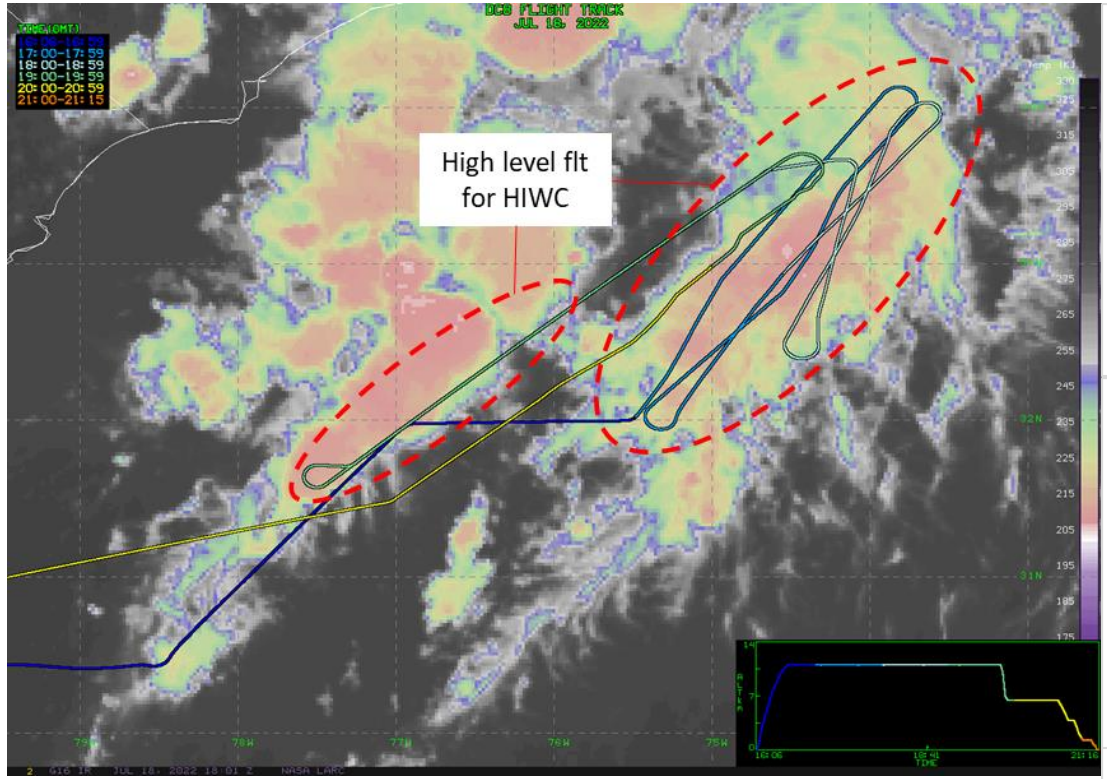
16 July 2022



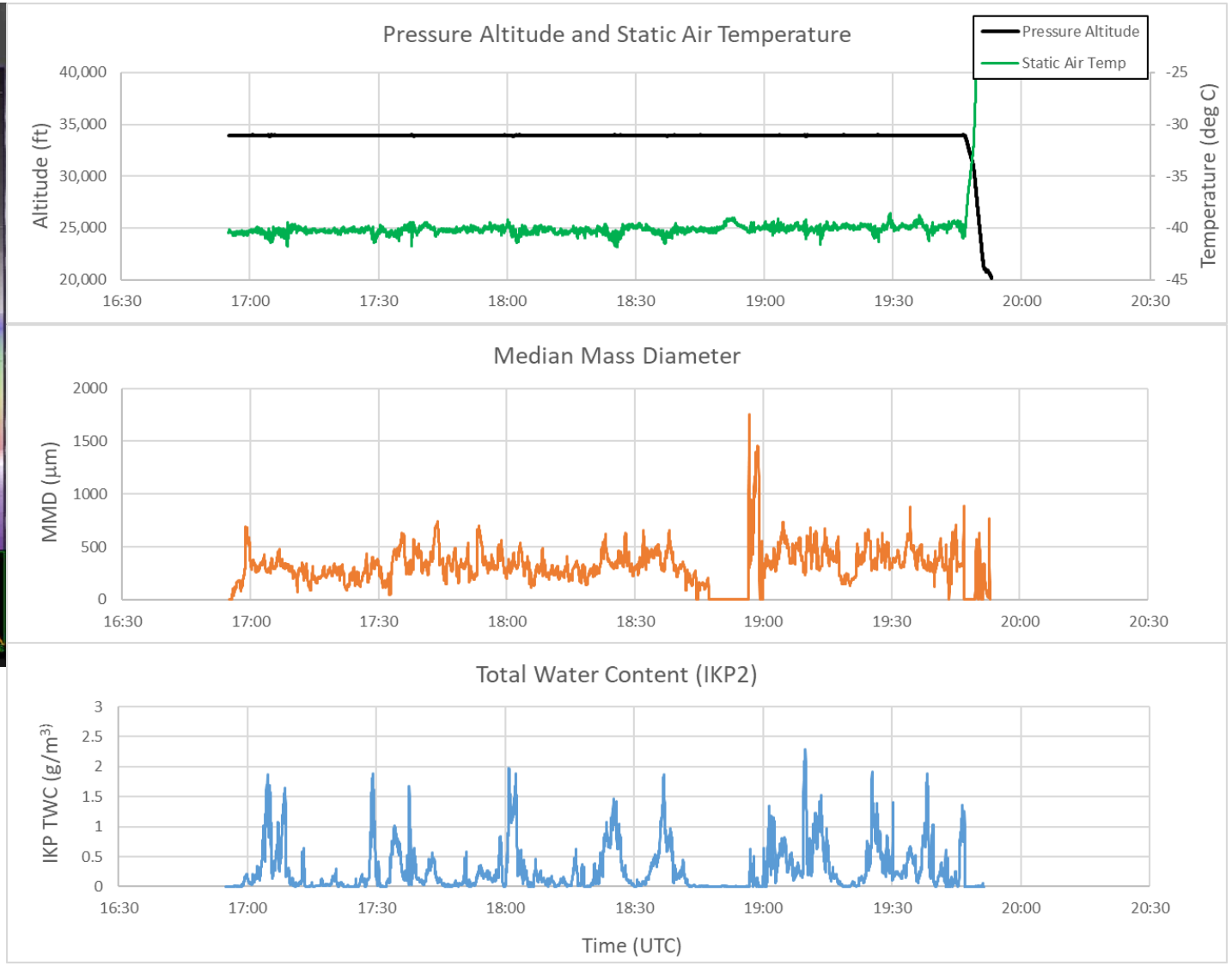


- Lower altitude due to ATC
- Large aggs in northwest region of storm
- Lightning strike; graupel observed

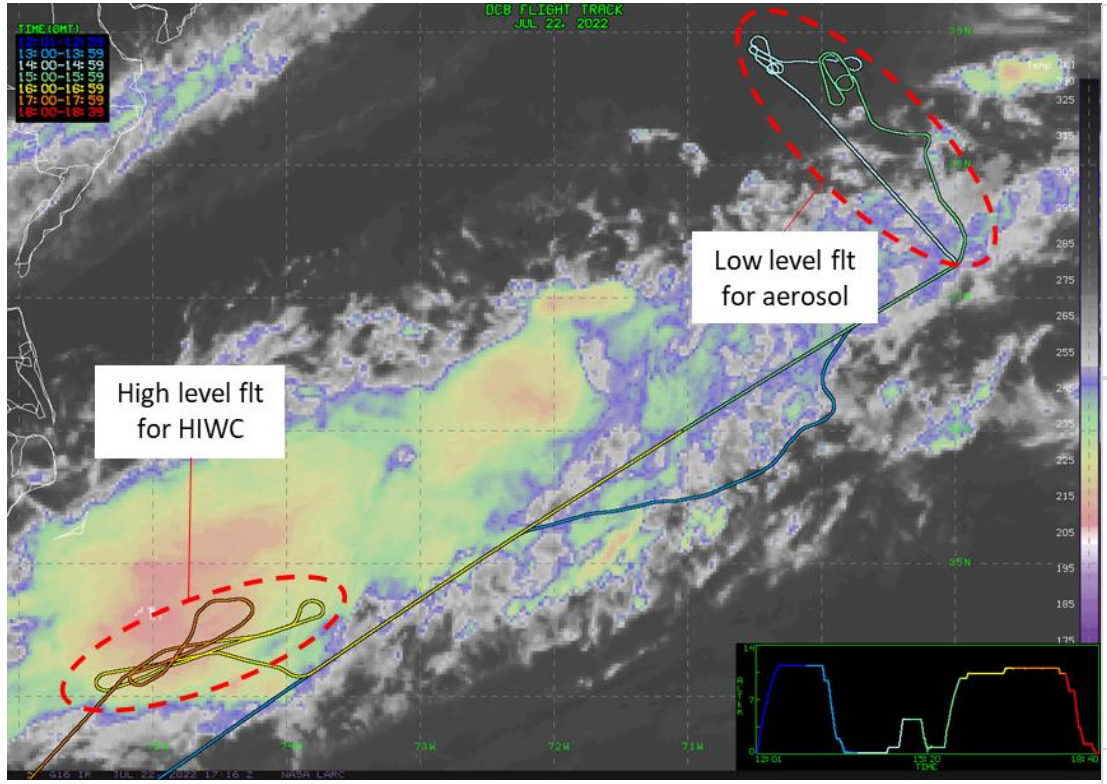
18 July 2022

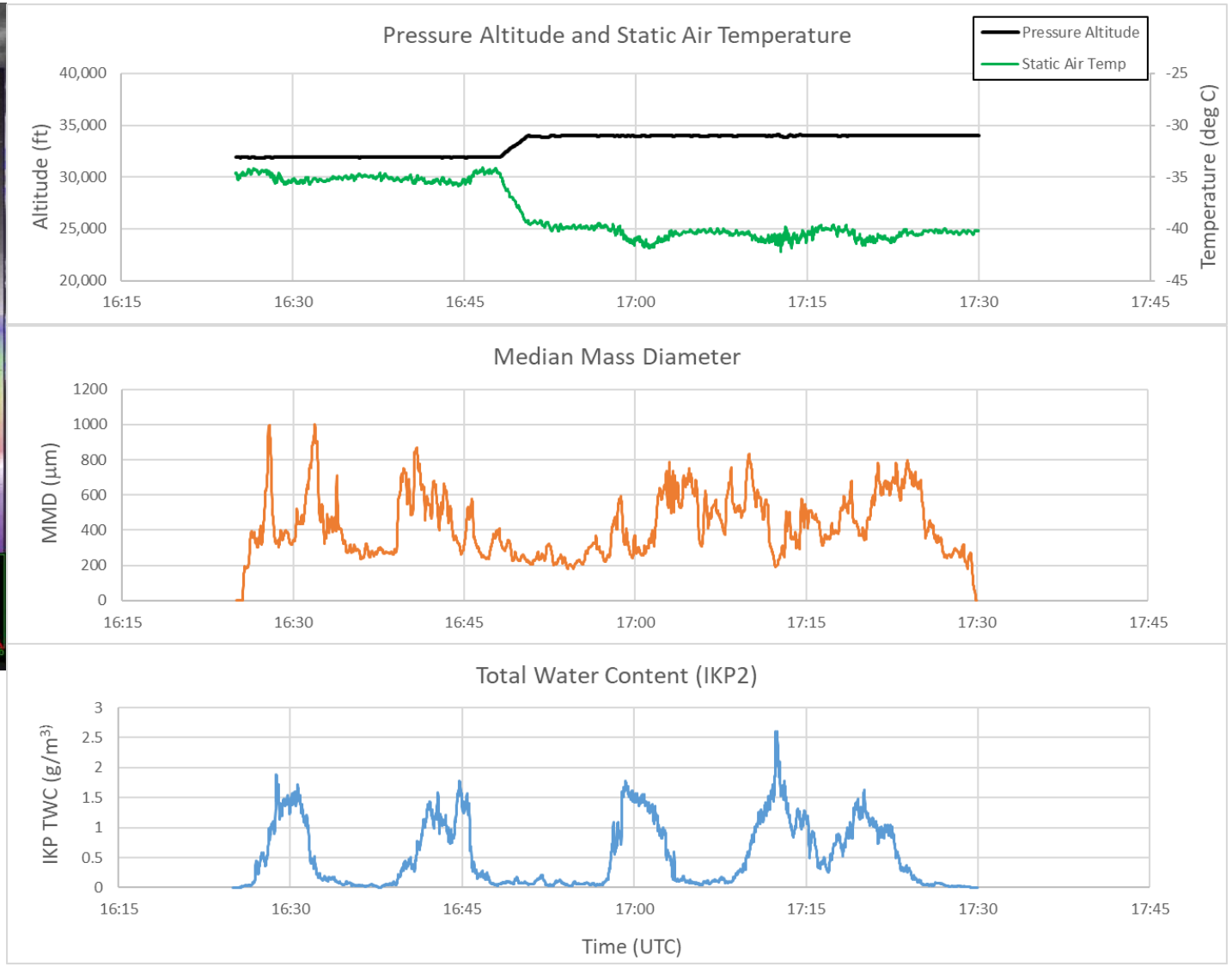


- No large areas of deep convection
- Flight terminated early due to cabin pressure control issue



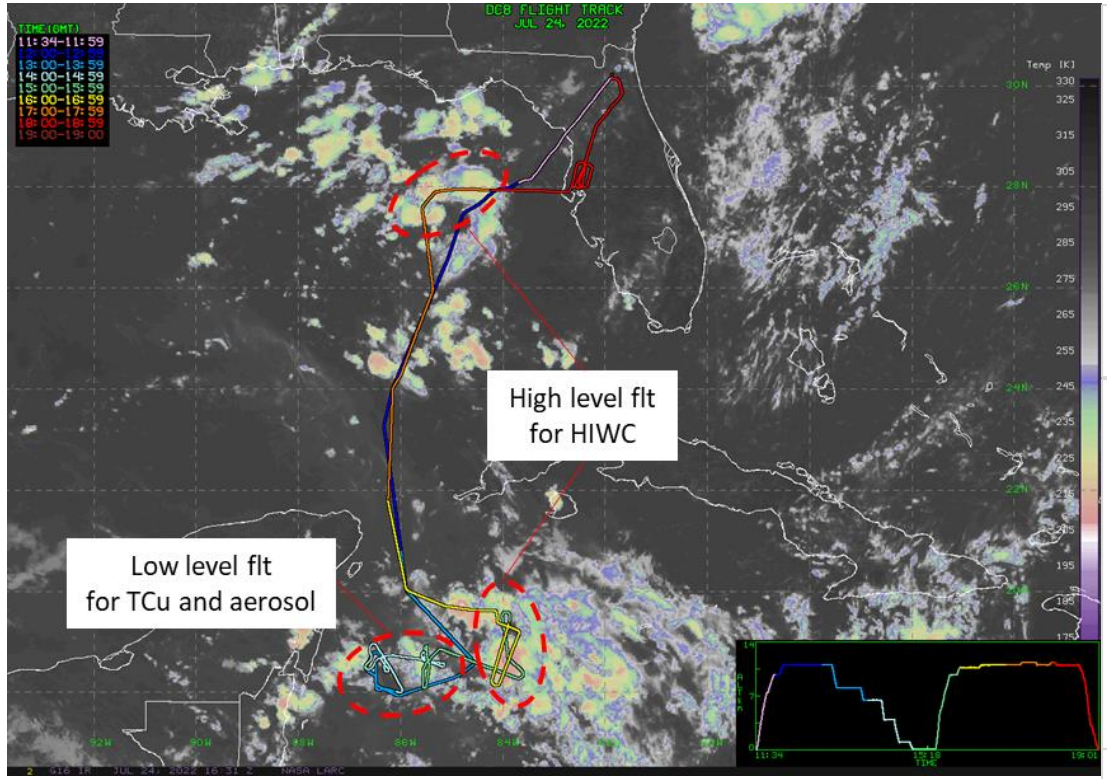
22 July 2022

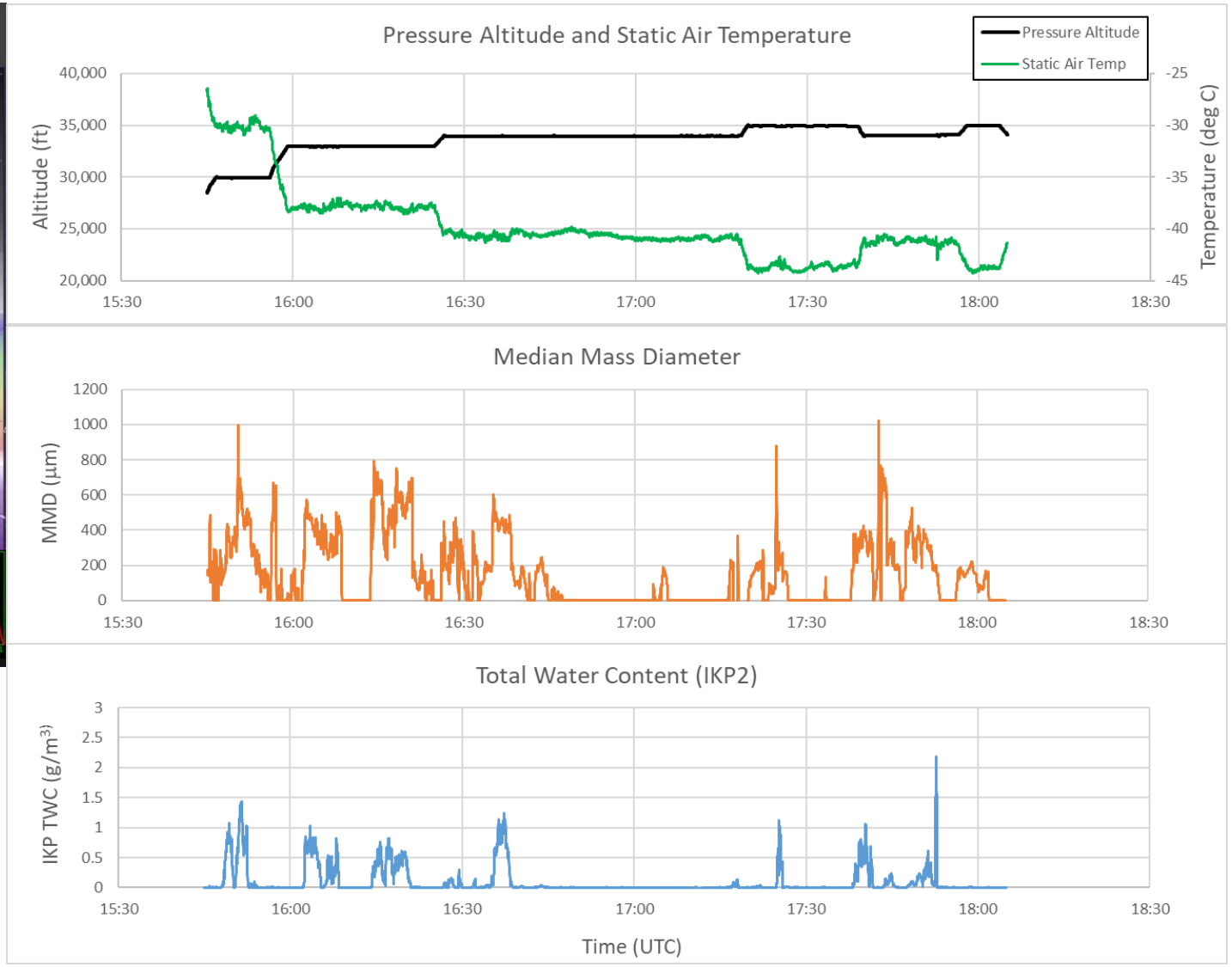




- Low level flight 350 NM to NE of high level flight
- High level flight an unexpected opportunity to work in military special purpose area

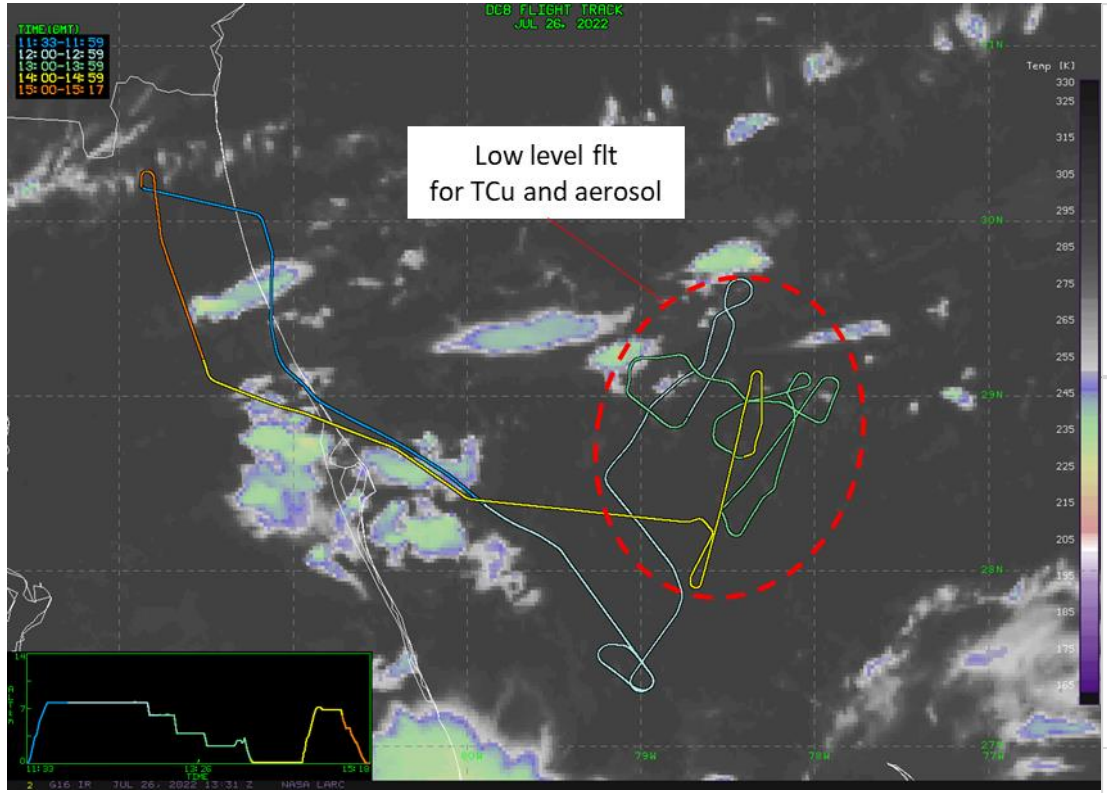
24 July 2022

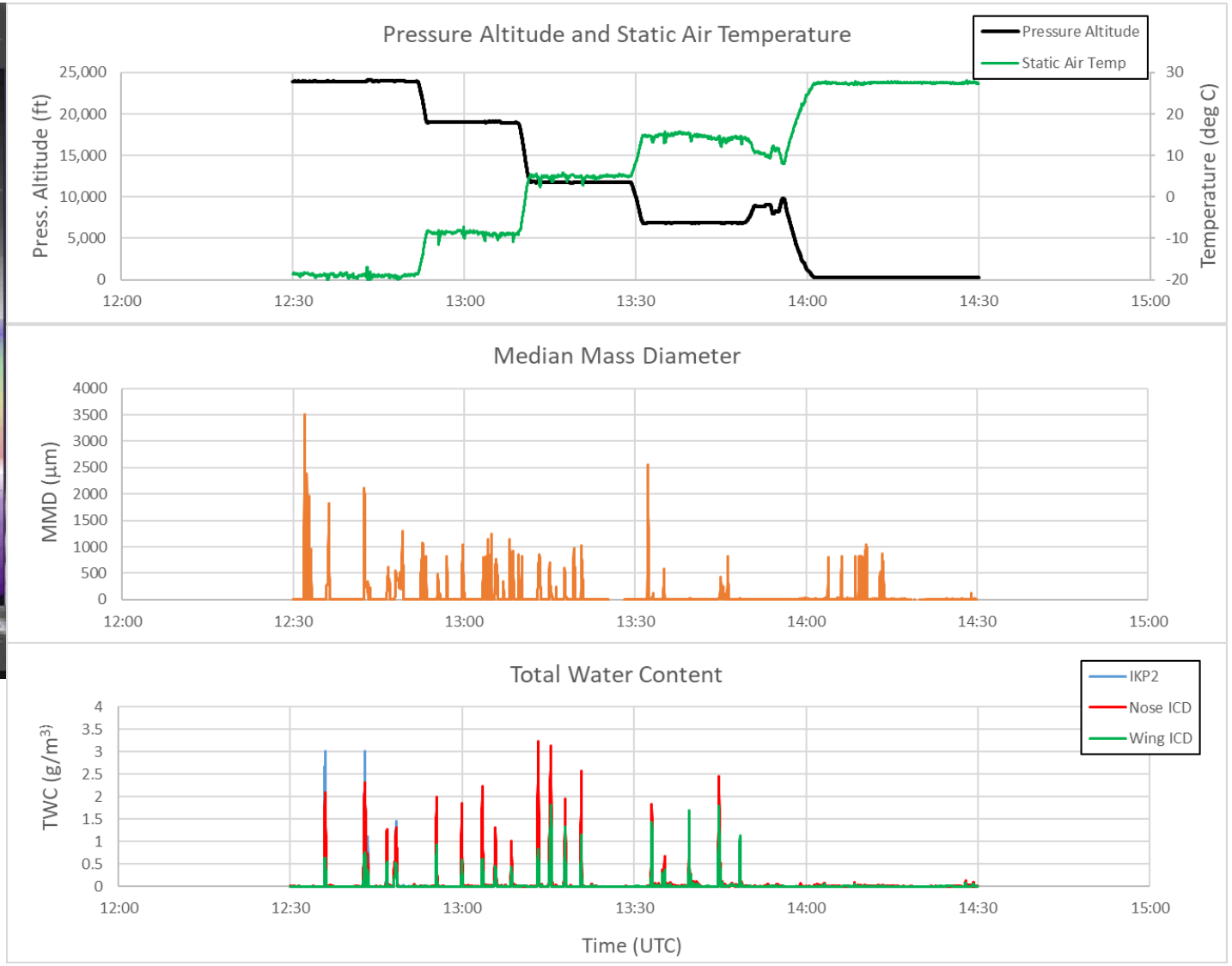




- Low level flight in TCu and below cloud base
- Least amount of time in HIWC

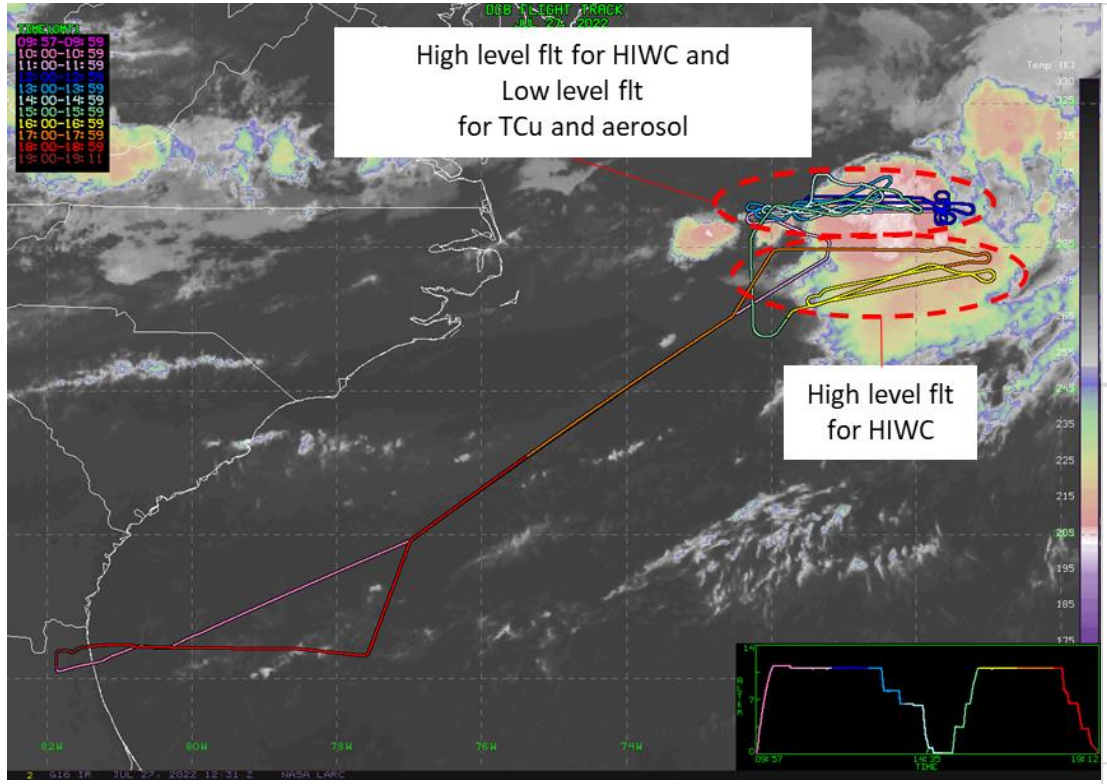
26 July 2022

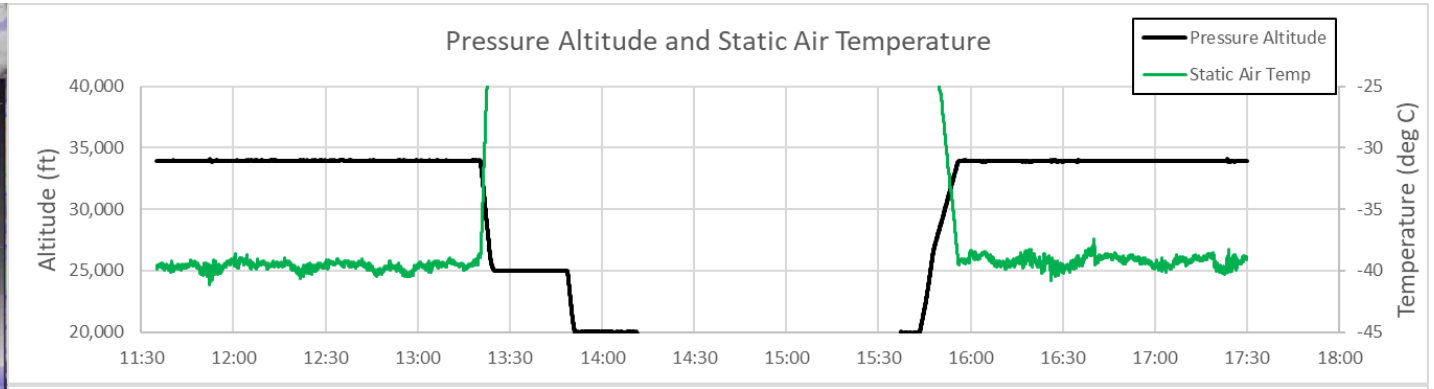


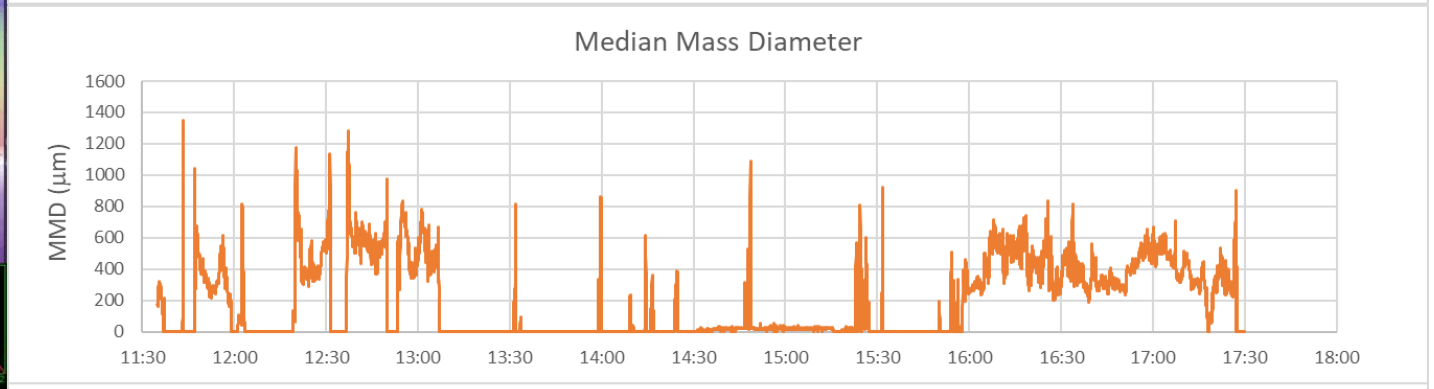


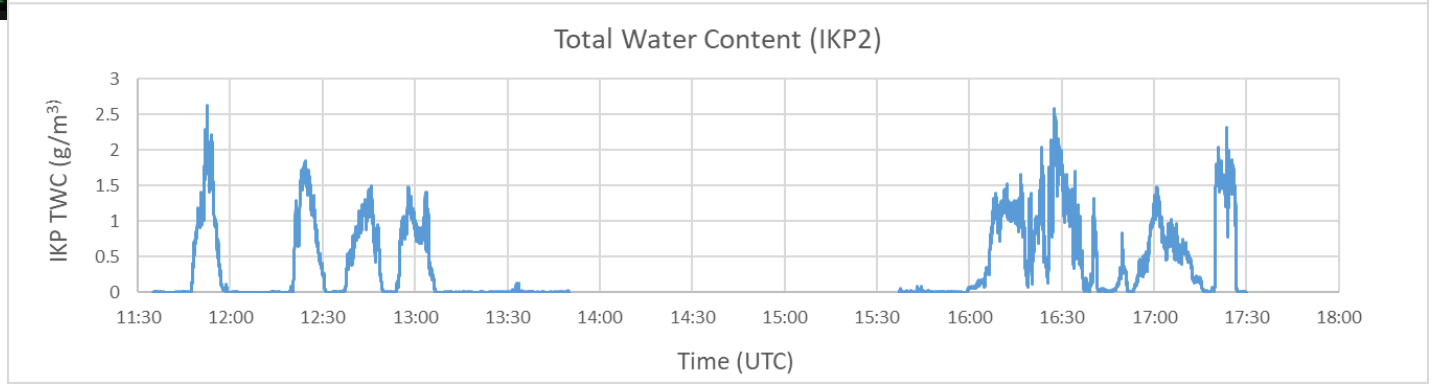
- Dedicated flight to TCu and aerosol
- TWC from ICD when SAT>-10C

27 July 2022



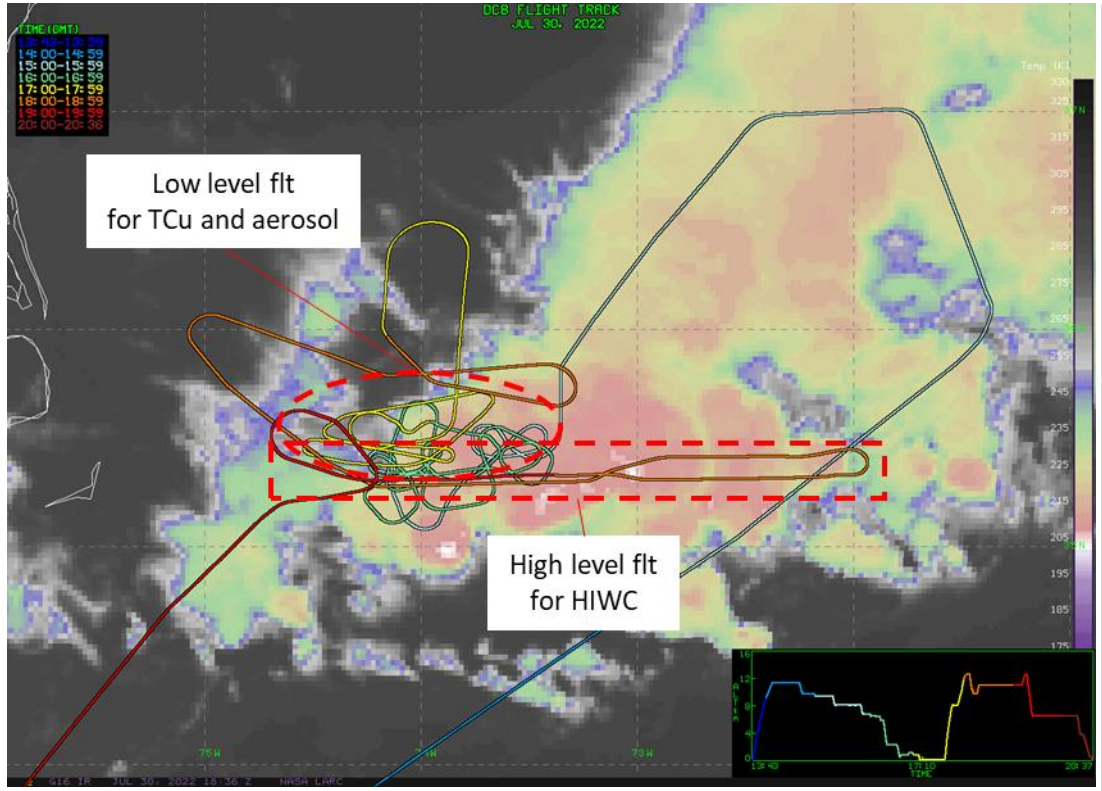




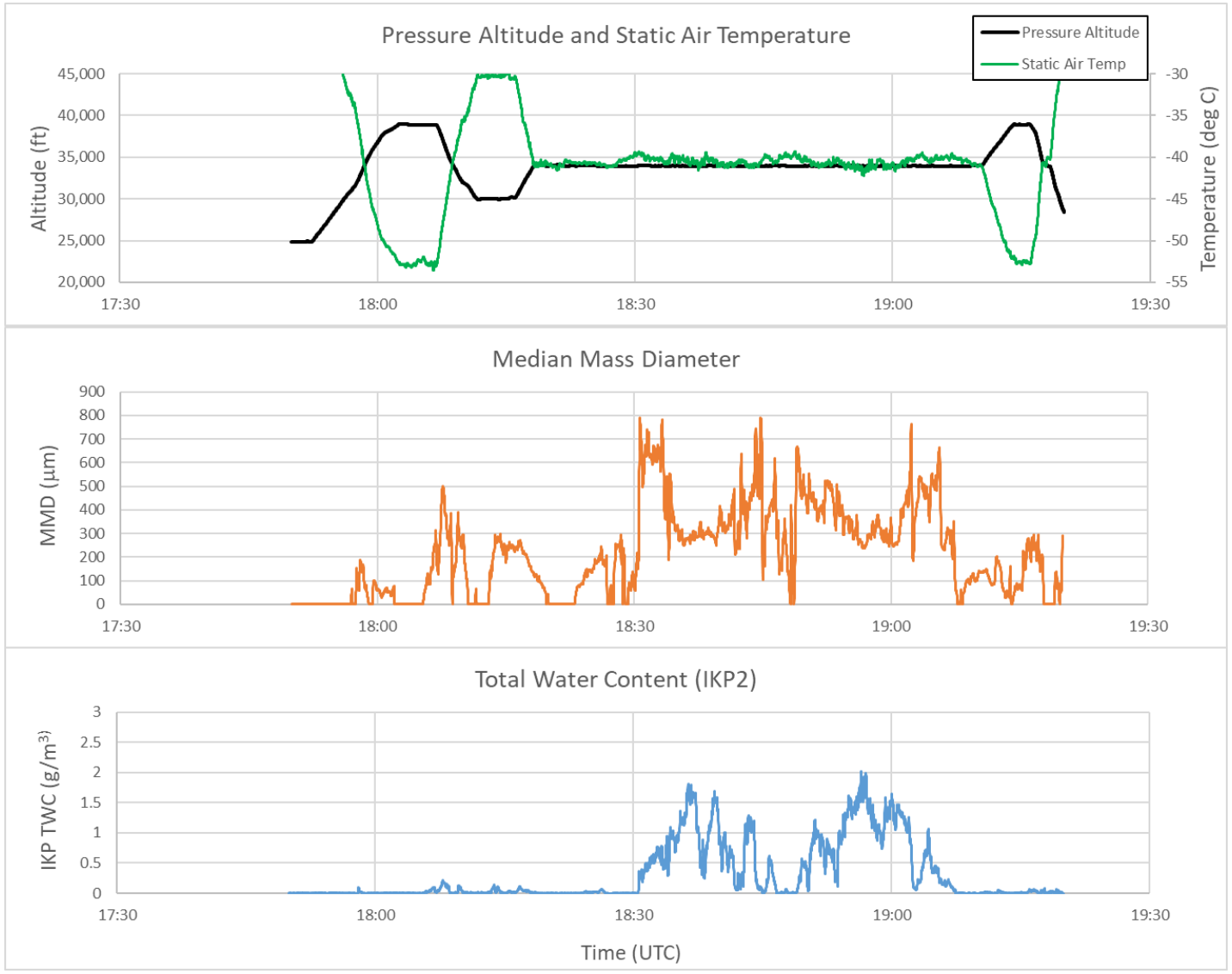


- Most time/ longest runs in HIWC in 2022
- Sampled HIWC on north and south side of storm
- No pitot anoms; TWC>2 at SAT= -40C

30 July 2022

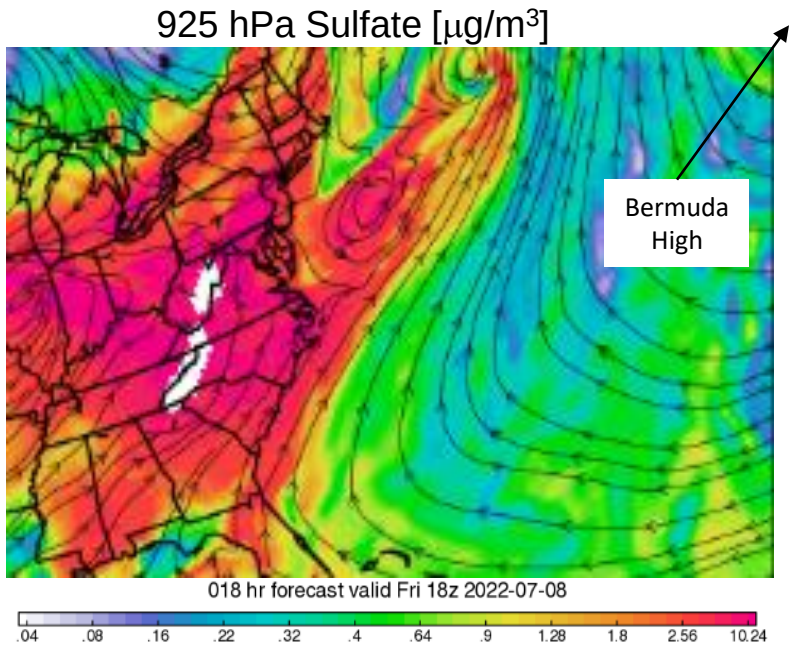


- Highest aerosol; PCASP 840 #/SCC
- Only 2 runs at -40C; attempted runs at -53C for CPEX correlations, but cabin pressure control not maintained



HIWC-2022 Flight Campaign Outcomes:

- Original goal was to conduct 5 flights in MCSs with high-aerosol and 3 flights in MCSs with low-aerosol
- Impediments to achieving goal:
  - Low-aerosol conditions prevailed over much of the operational area during the campaign period (Bermuda High)
  - High-aerosol areas were far to the north of Florida and devoid of deep convective systems
  - High-aerosol areas with MCSs often only occurred in coastal “hot” military special use airspace
    - » usually inaccessible
  - Early termination of two flights due to lightning strikes and cabin pressurization control issue



HIWC-2022: Summary and Preliminary Conclusions

- Completed 10 flights; only one flight with MCS and high aerosols
  - Low-aerosol conditions dominated oceanic operation area due to Bermuda high which pushed higher aerosol conditions near inaccessible coastal military reserved airspace or further north
  - Data from the one MCS in high aerosol did not support the 1st order hypothesis of higher TWCs relative to lower aerosol cases. Inconclusive due to lack of cases.
- The combined requirement of co-located high aerosol and MCSs in a one-month campaign was very challenging due to access to optimum areas, unpredictable weather, research aircraft schedules, etc.
  - Conducting a US government-led future campaign in an optimum location would require overcoming very difficult obstacles, and entail an unrealistic timeline, budget and project risk.
- In spite of the obstacles, the HIWC-2022 data include storms with higher lightning rates, more graupel, and smaller cross sections that were not represented in FAA TC-18/1 dataset.
  - Technical reports on TWC, MMD and aerosol sensitivity studies are planned for 2024

Acknowledgment and POC

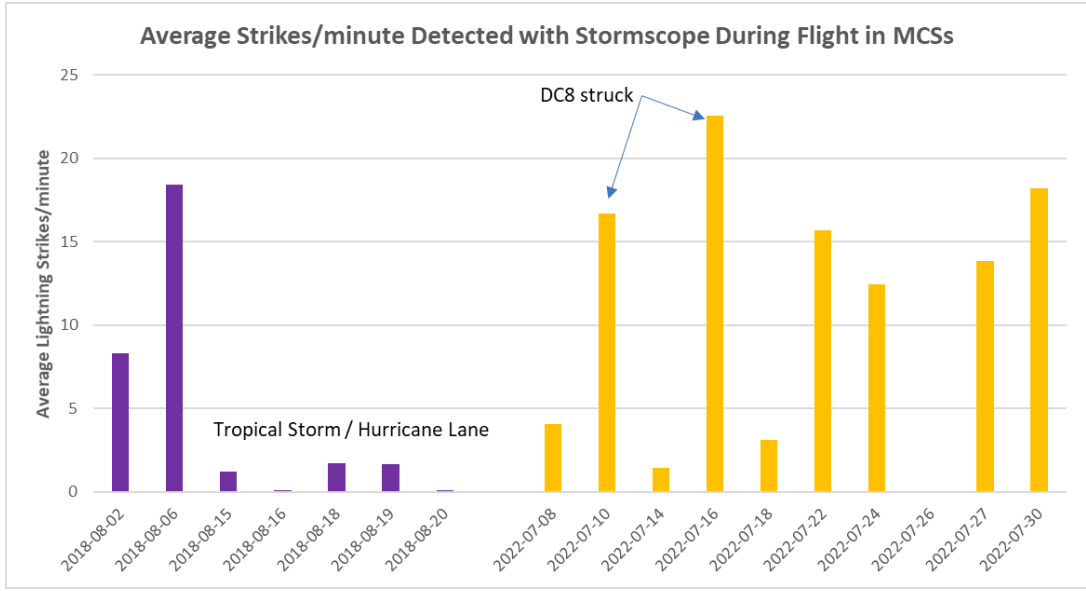
- **HIWC 2022 was sponsored by FAA, NASA AATT project, and Nagoya University**
- **POC Information:**
  - **Tom Ratvasky, NASA Glenn Research Center, Cleveland Ohio**
    - » **Phone: 216-433-3905, email: thomas.p.ratvasky@nasa.gov**

Backup Slides

Preliminary Results: Lightning

- Lightning detection using onboard “WX1000 Stormscope”
  - Identifies lightning (distance and bearing) within 250 Nm radius of airplane
- Computed avg number of strikes/minute for HIWC RADAR II (2018) and HIWC 2022
  - 60% 2022 flights exceeded 10 strike/min vs 14% in 2018
  - DC-8 struck during two flights in 2022. Operational procedures added to mitigate further events
- Increased lightning in 2022 likely related to flights through earlier stages of MCSs with shorter life-cycles (more vigorous) compared to tropical storms/hurricane from previous HIWC flight campaigns.

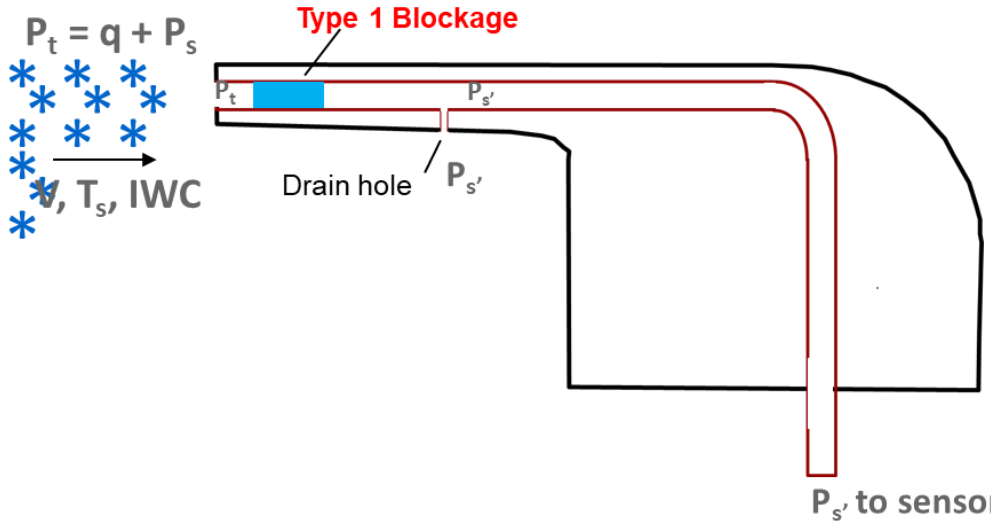
Pilot displays of Stormscope and Multi-Function Display with Radar and Lightning

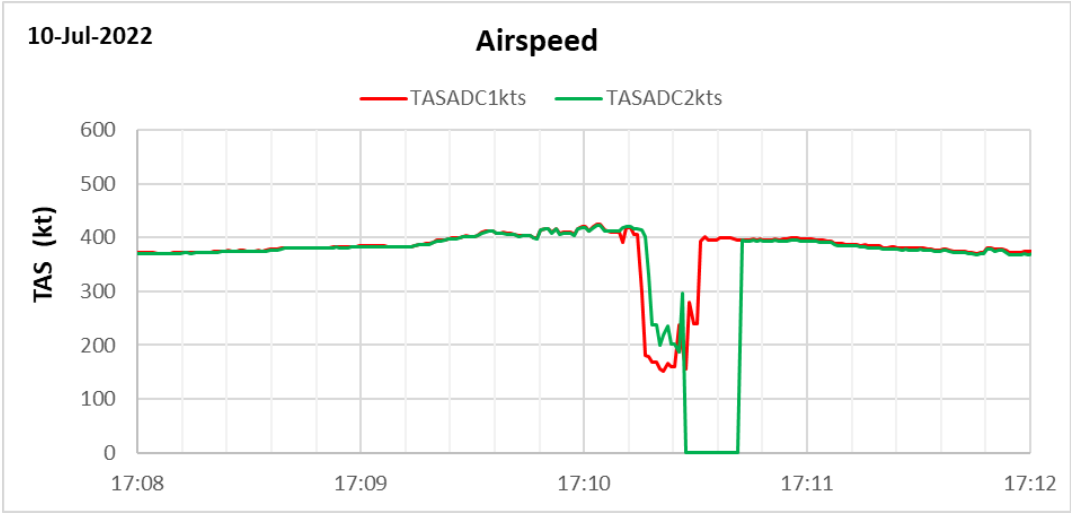


Preliminary Results: Pitot Anomalies

- Pitot anomalies occur when ice water content and air temperature overcome pitot probe heat and water drain capabilities.
  - Airspeed can drop quickly or become invariant with airspeed changes

- DC-8 pitot anomalies occurred during 6 time periods during the HIWC 2022 campaign
  - Anomalies were short and did not result in flight deviations or avoidance of sampling. Research pitot probe remained operational.
  - Analyses ongoing to identify atmospheric conditions that triggered these events





ADC1 for Pilot display. ADC2 for Co-pilot display

Useful Tools for HIWC Flight Campaigns

- NASA LaRC Satellite HIWC Potential*
  - Developed and used in previous HIWC flight campaigns
  - Identifies potential for HIWC conditions exceeding 0.5 gm^{-3}
  - Near-real-time large area diagnostic for more strategic flight decisions. Stay with this MCS or move on…
  - In-situ data to be used for algorithm validation

* Yost, C. R, et al., "A Prototype Method for Diagnosing High Ice Water Content Probability Using Satellite Imager Data," Atmos. Meas. Tech., 11, 1615–1637, https://doi.org/10.5194/amt-11-1615-2018, 2018.

- NASA LaRC RADAR-IWC (R-IWC)**
  - Developed and used in previous HIWC flight campaigns
  - Real-time onboard tactical diagnostic for locating HIWC cells: e.g. provide offset of next transect or optimum heading
  - In-situ data to be used for algorithm validation

** Harrah, S., et al., "Radar Detection of High Concentrations of Ice Particles – Methodology and Preliminary Flight Test Results," SAE Technical Paper 2019-01-2028, 2019, doi:10.4271/2019-01-2028.