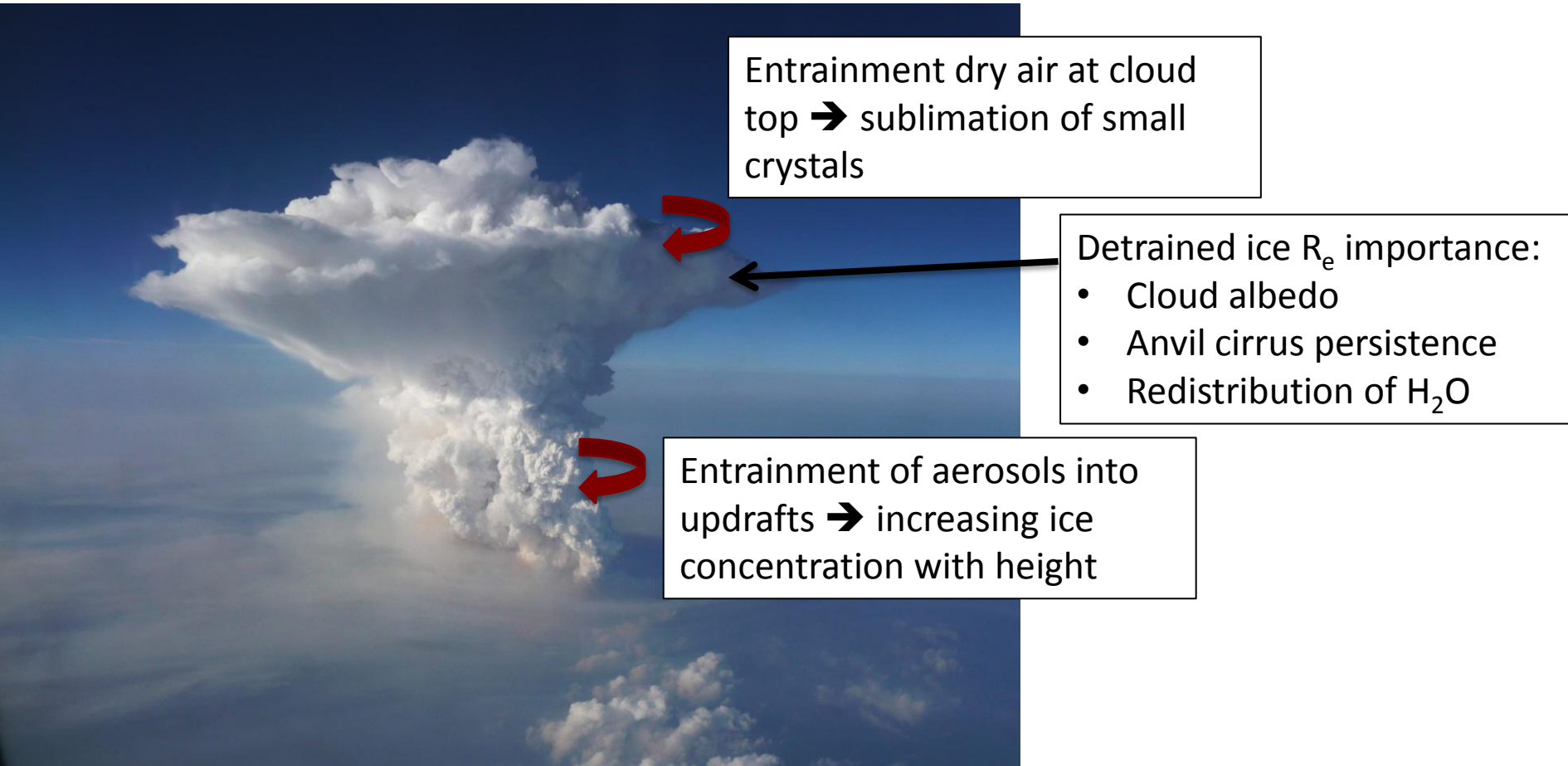


Ice crystal properties in high-altitude tropical anvil cirrus

E. Jensen, P. Lawson, S. Woods, S. Lance, B. Gandrud

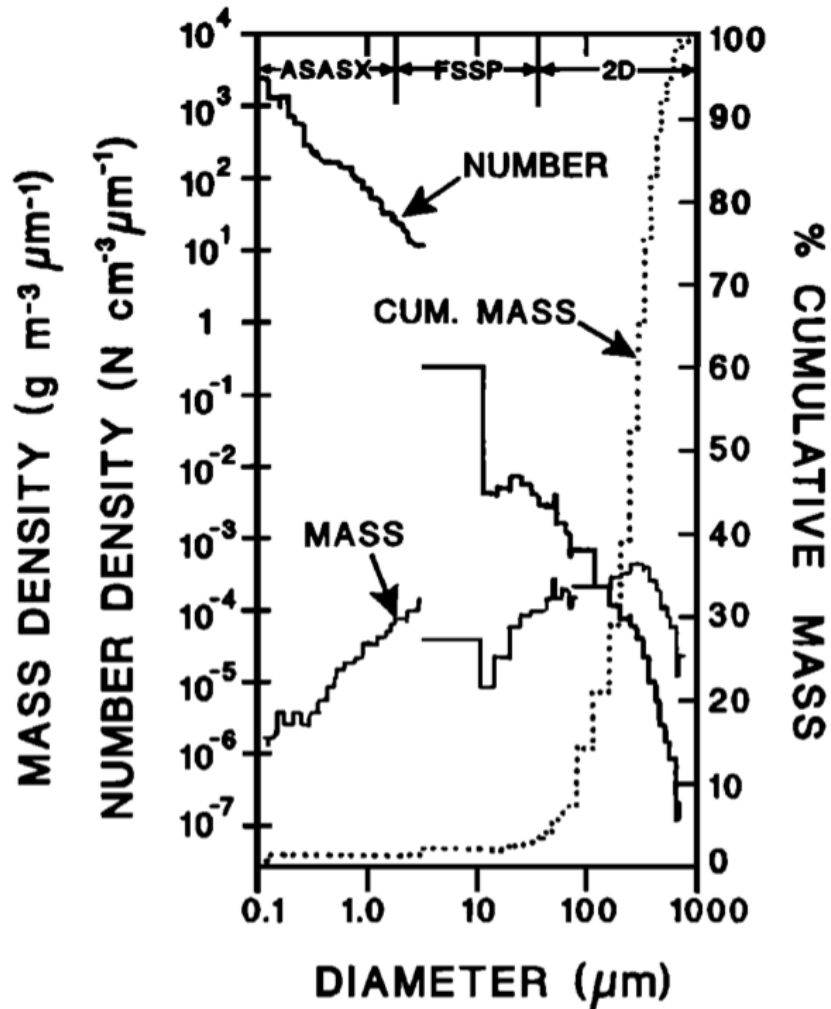


Outline:

- Past measurements of tropical anvil cirrus microphysical properties
- What do Guam ATTREX observations tell us?

STEP ER-2 (Darwin, 1987)

Knollenberg et al. (JGR, 1993):



- Extremely high ice concentrations ($10\text{--}100 \text{ cm}^{-3}$)
- Modified 2D optical-array probe to mimic FSSP (accuracy difficult to assess)

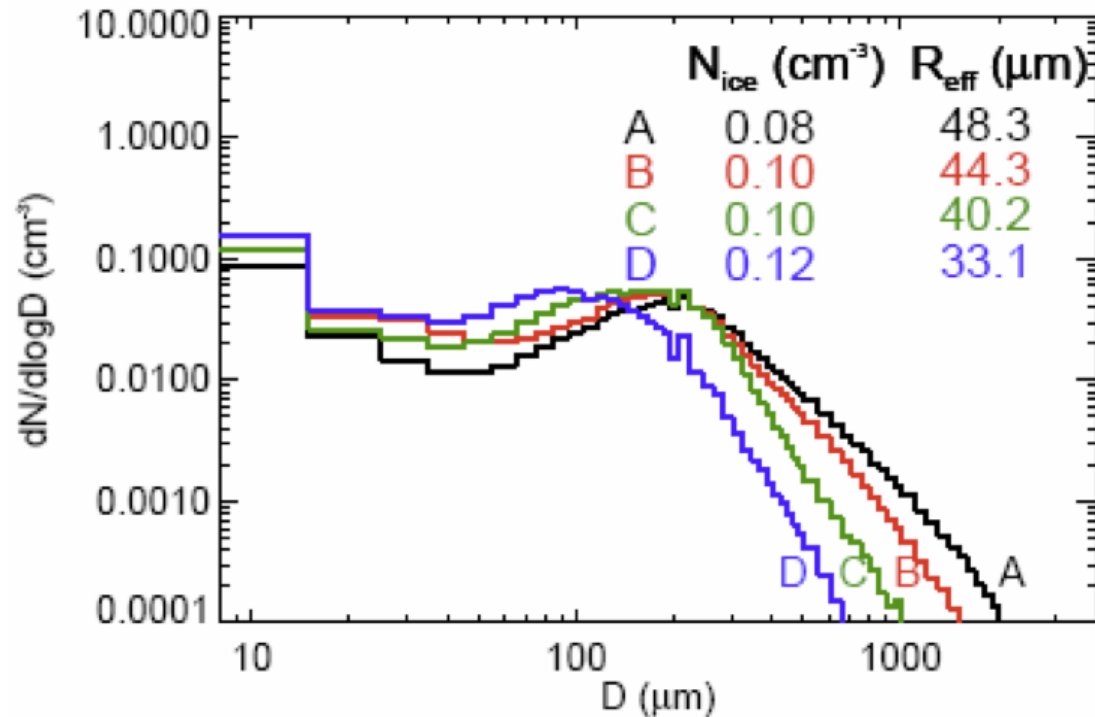
Geophysica campaigns

- APE THESEO (1999), Scout-O₃ (2005), TROCCINOX (2005), SCOUT-AMMA (2006)
- Ice concentrations in cold anvil cirrus up to 1 cm⁻³ (Krämer et al., 2009); higher concentrations in fresh MCS outflow (Frey et al., 2011)
- Mostly FSSP only (+CIP on AMMA): shattering artifacts in anvil cirrus likely, crystals larger than 25–50 μm not measured → Not very useful for anvil cirrus

Hector sampling

- EMERALD-II (2003), TWP-ICE (2006)
- Grob 520T Egrett (up to ~14.5 km), CPI and FSSP (Connolly et al., 2005)
- Proteus (up to ~16 km), FSSP, CDP, CIP (McFarquhar et al., 2007)

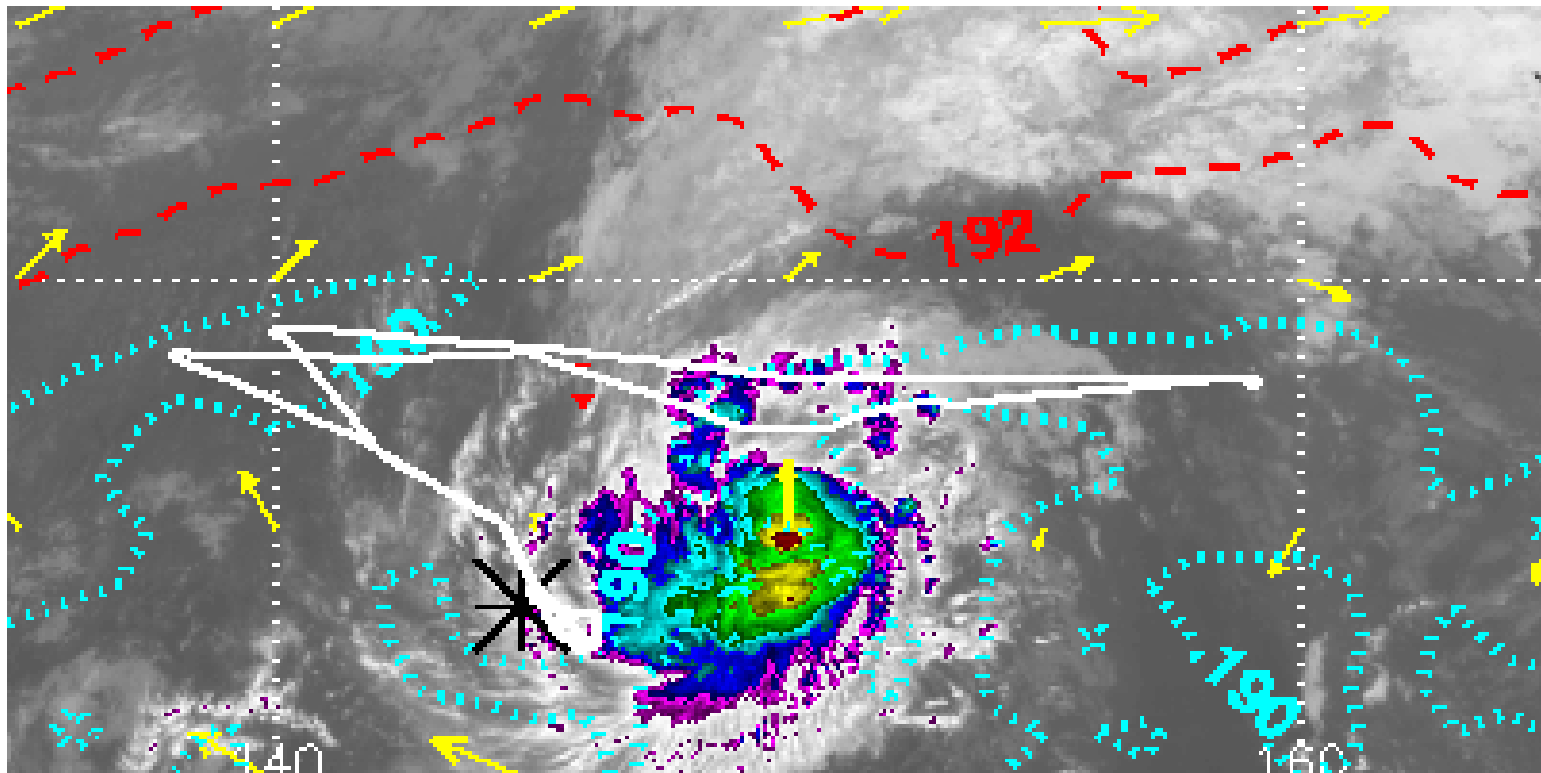
TC4 DC-8 (EastPac, 2007)



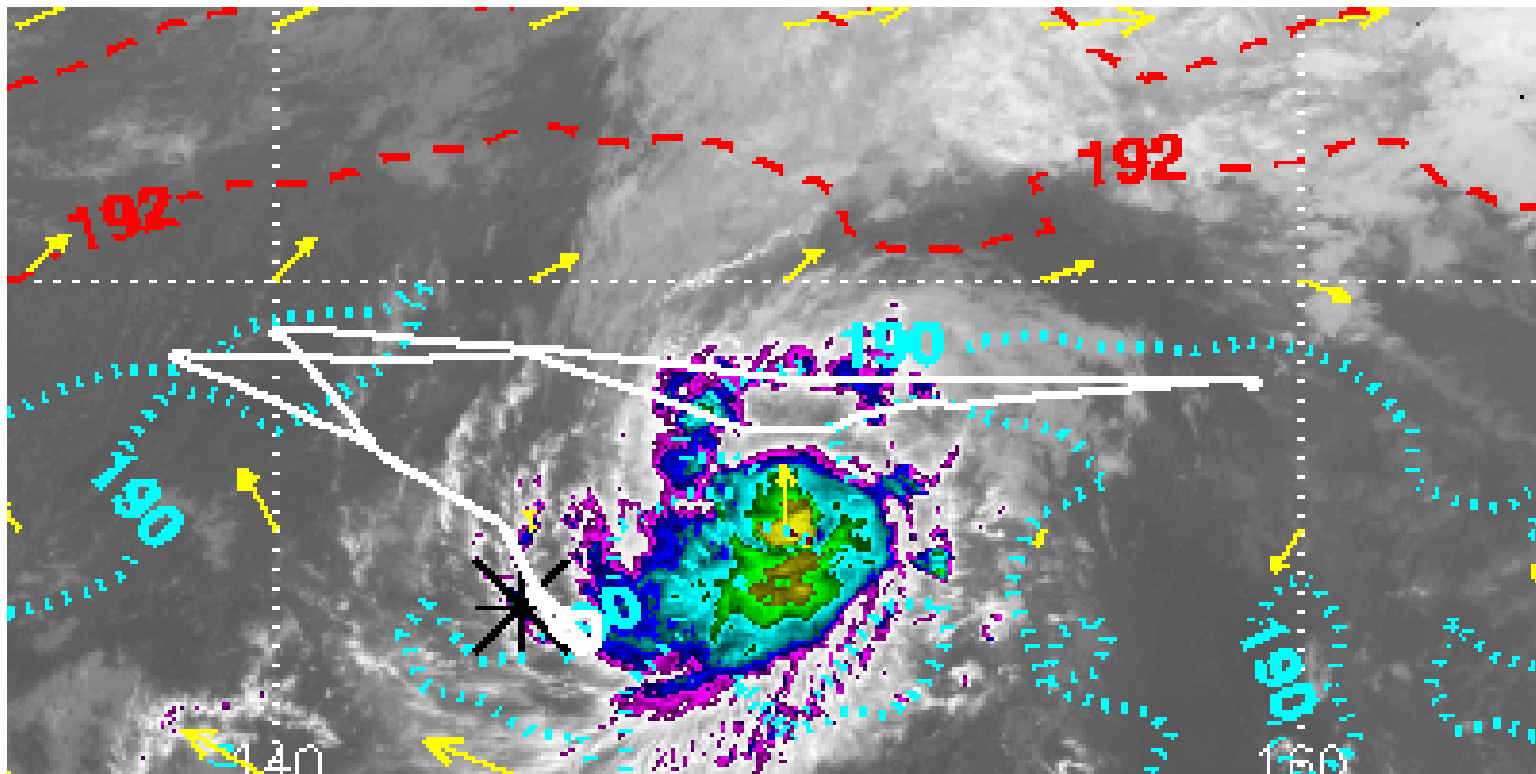
- 2D-S with shattering artifacts removed
- No higher than 12–13 km (sub-TTL)
- Mature anvil ice concentrations $\sim 0.1 \text{ cm}^{-3}$
- Up to 10 cm^{-3} in updraft cores at 12 km \rightarrow depletion by dilution and sublimation

Information lacking for TTL anvil cirrus!

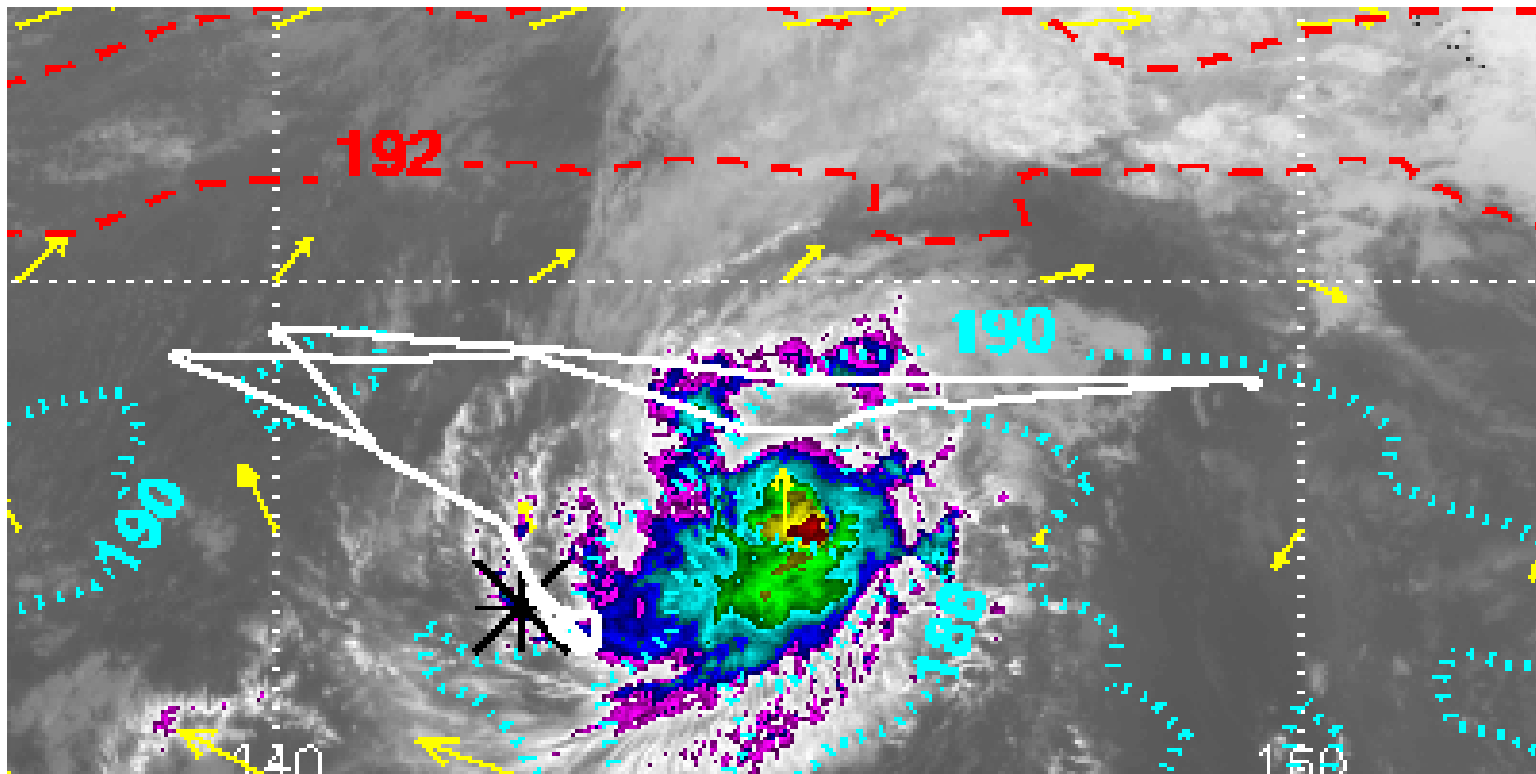
4–5 March Global Hawk flight (RF03)



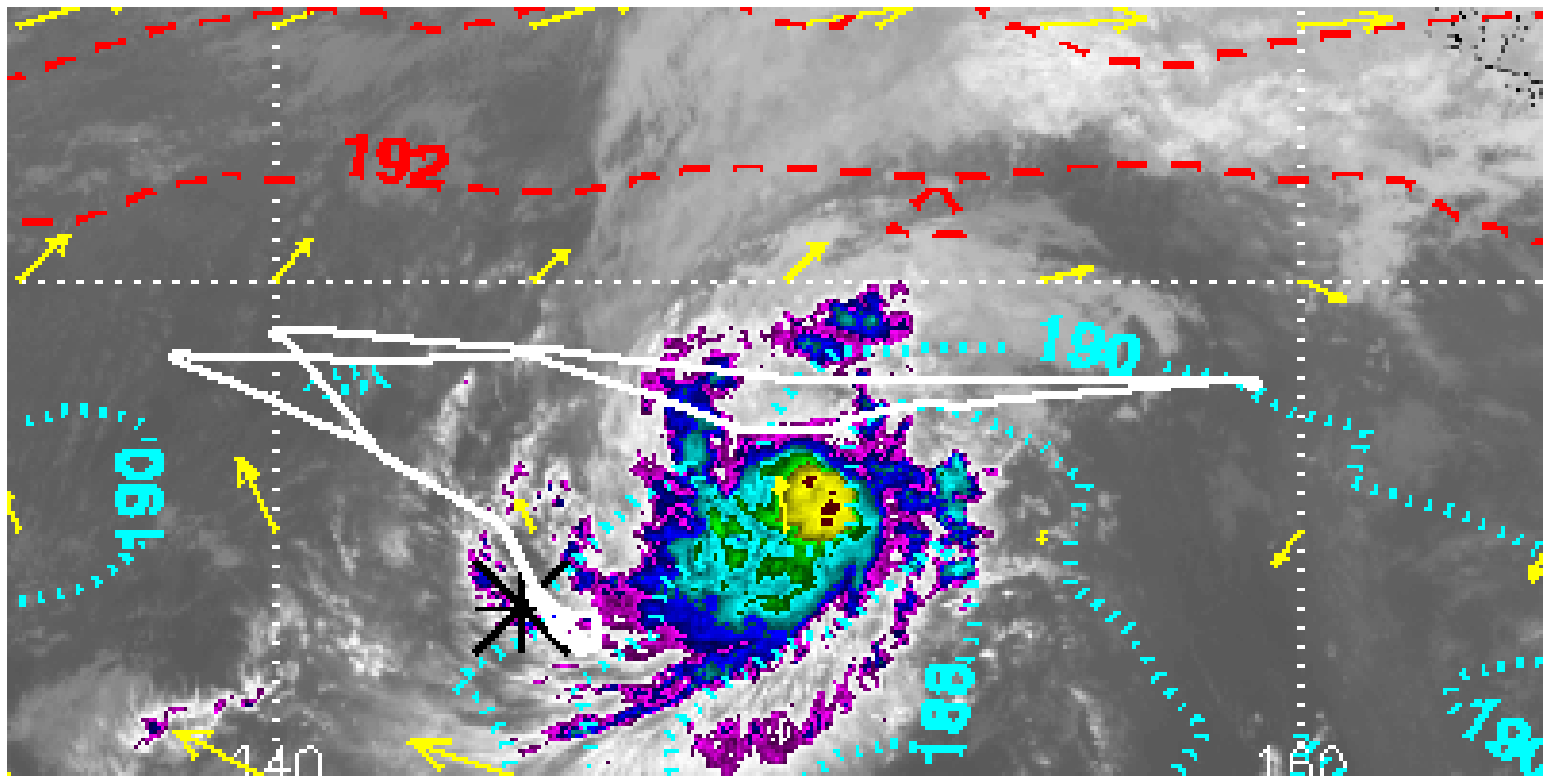
4–5 March Global Hawk flight (RF03)



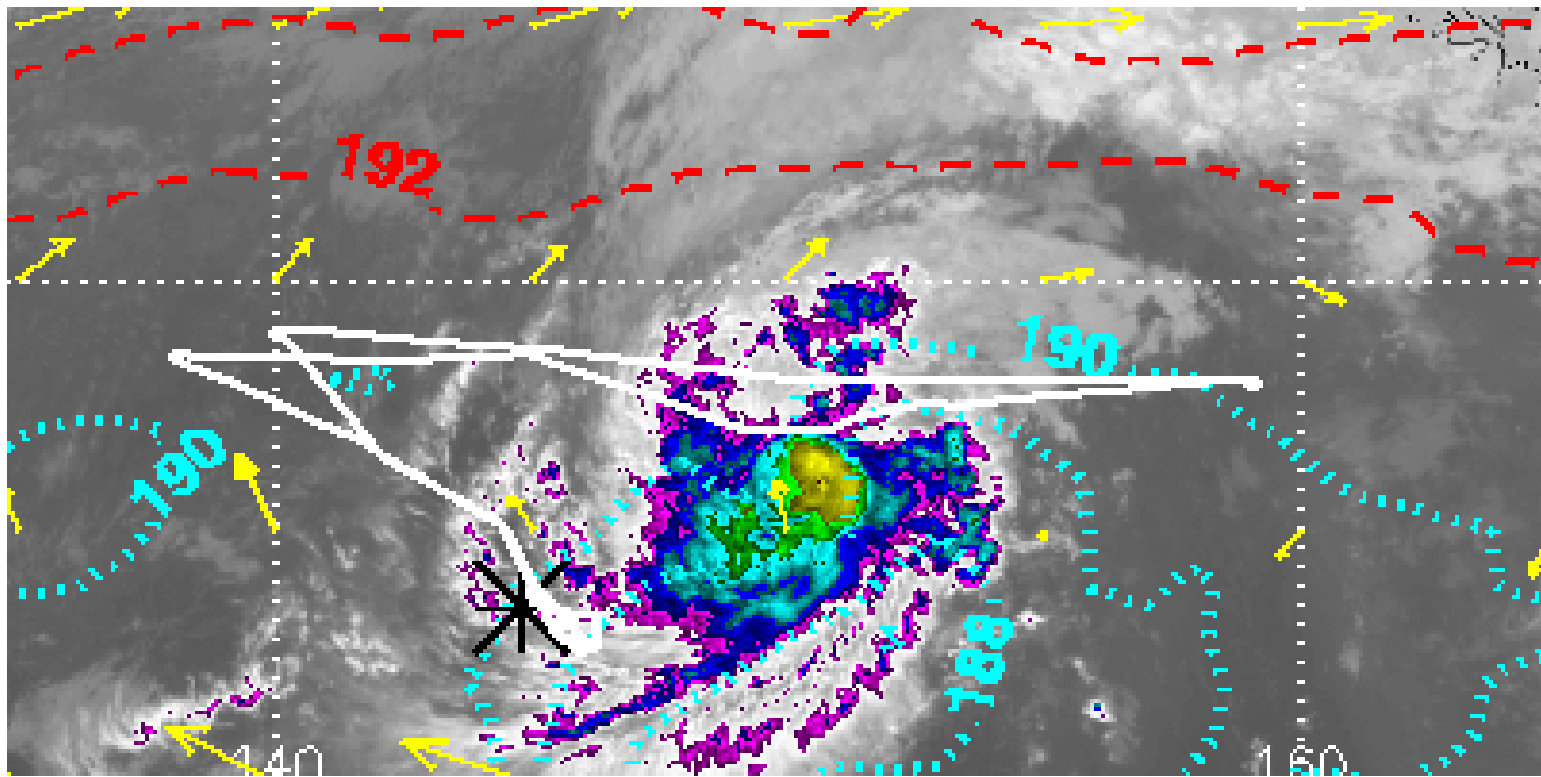
4–5 March Global Hawk flight (RF03)



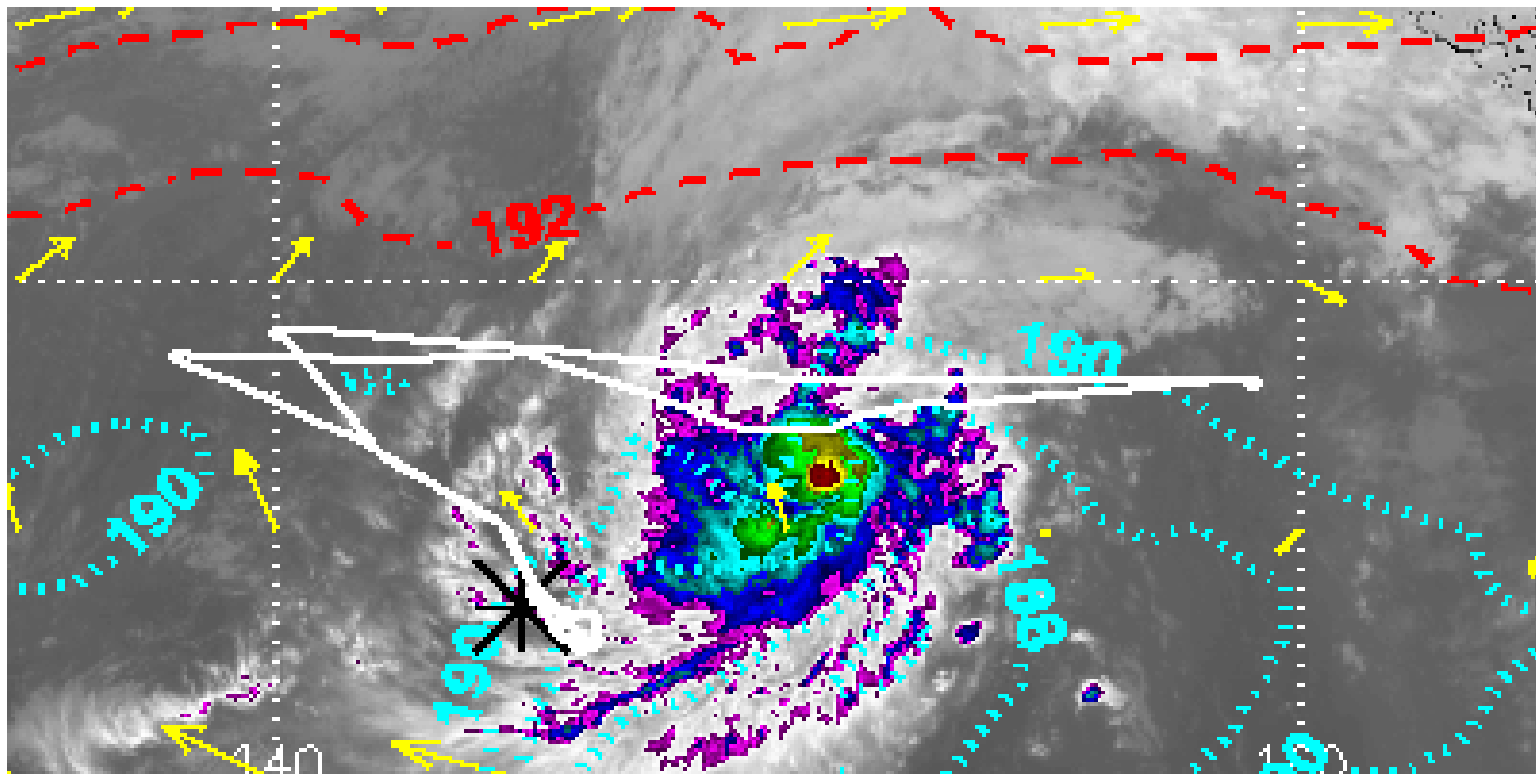
4–5 March Global Hawk flight (RF03)



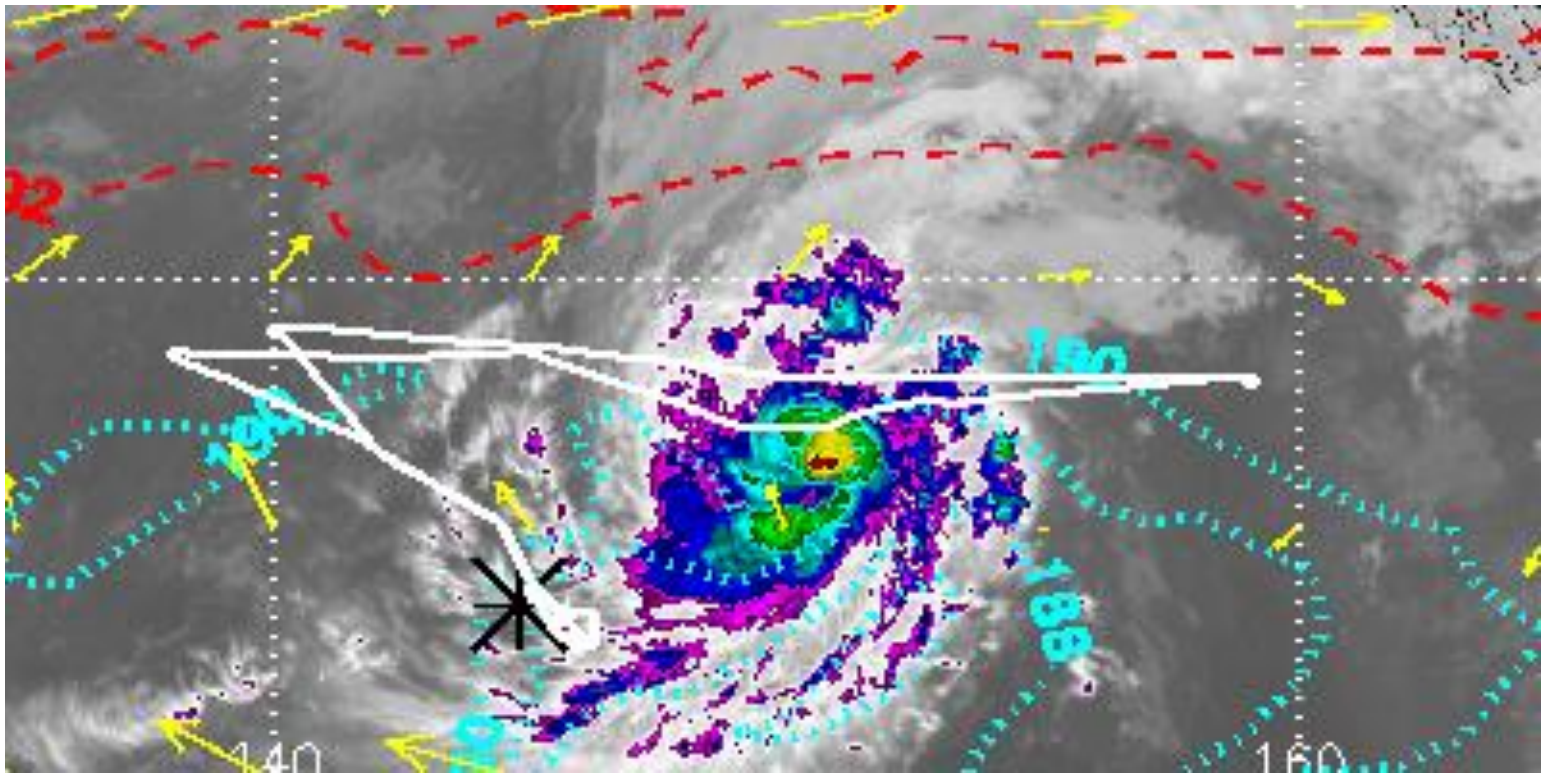
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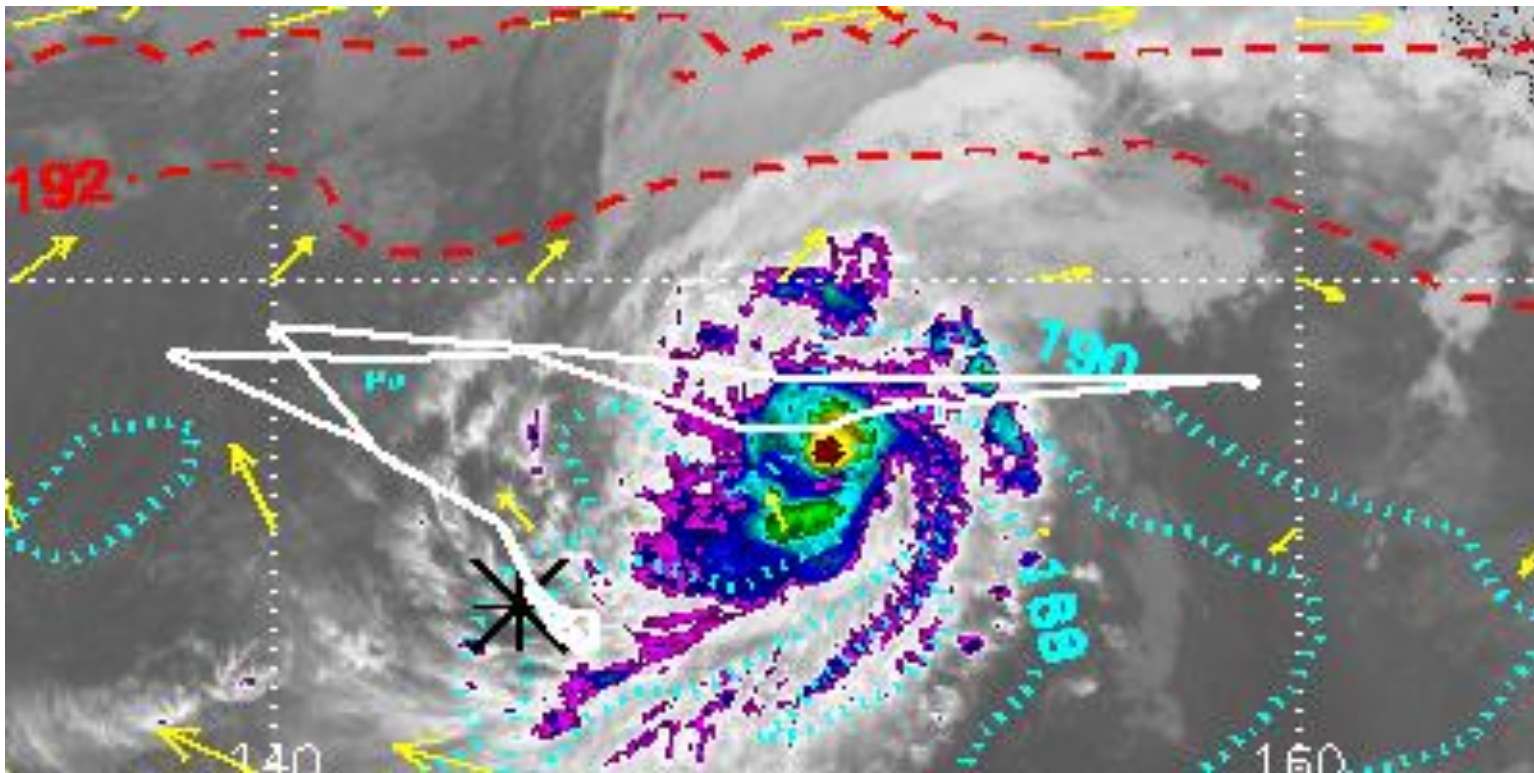
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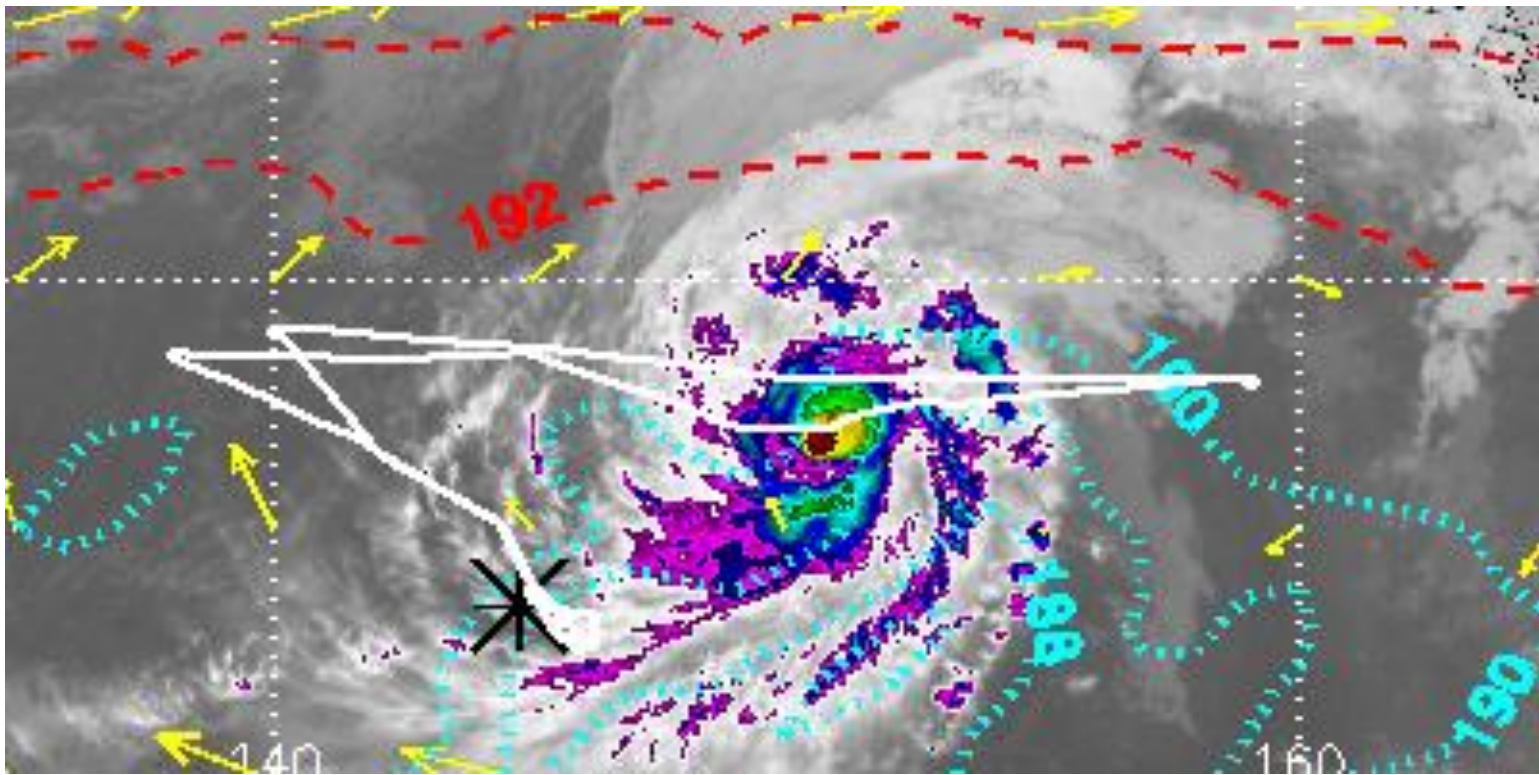
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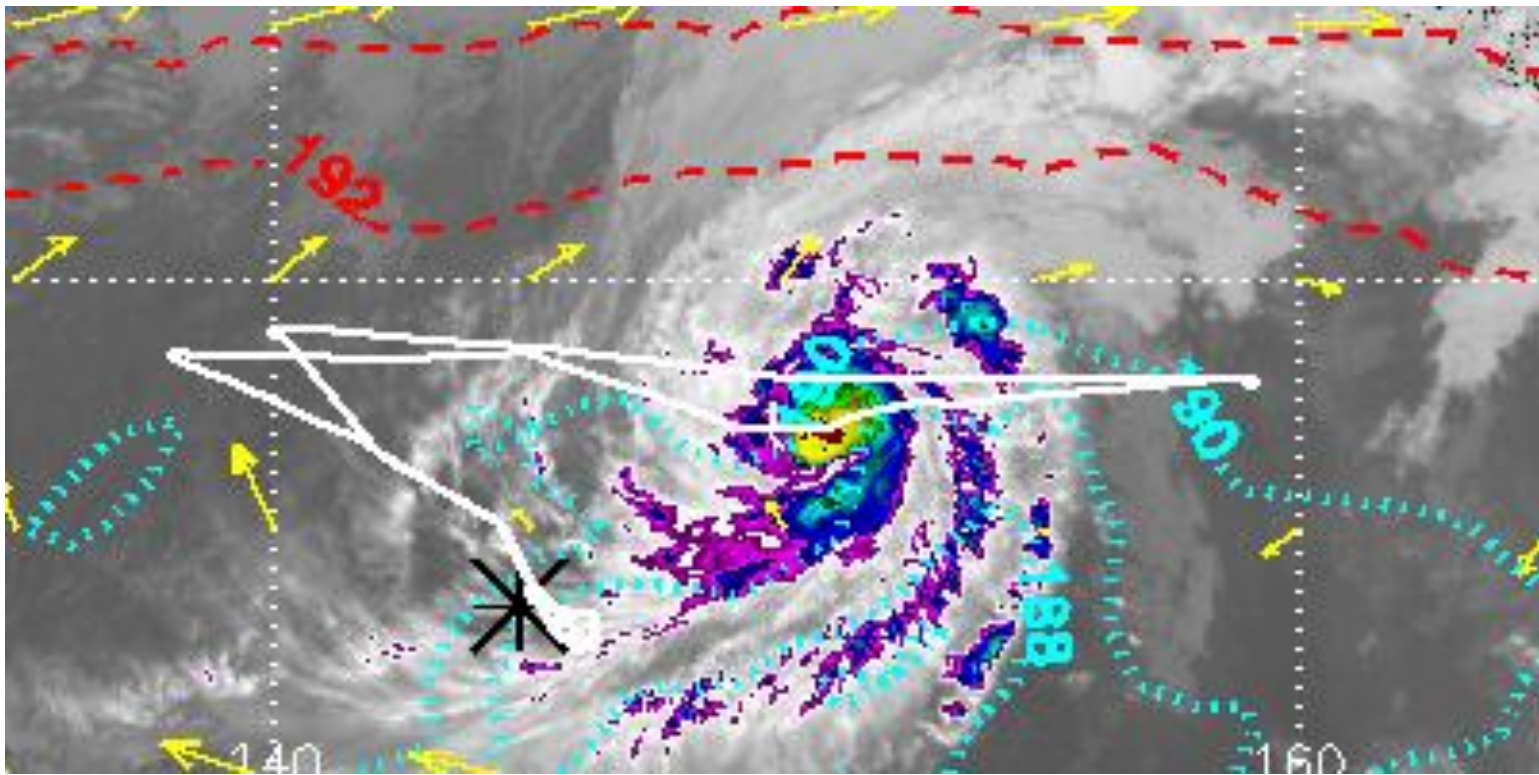
4–5 March Global Hawk flight (RF03)



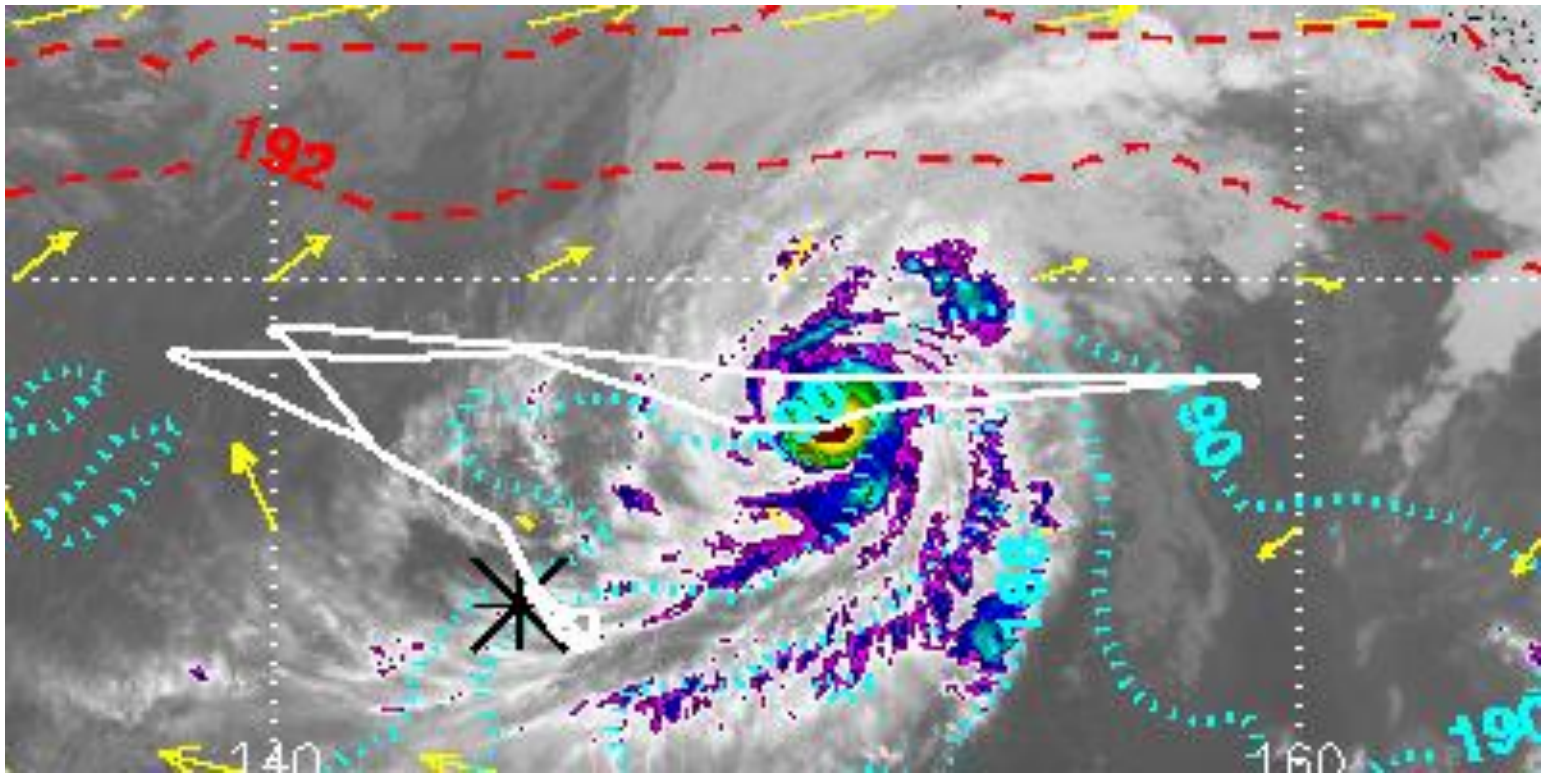
4–5 March Global Hawk flight (RF03)



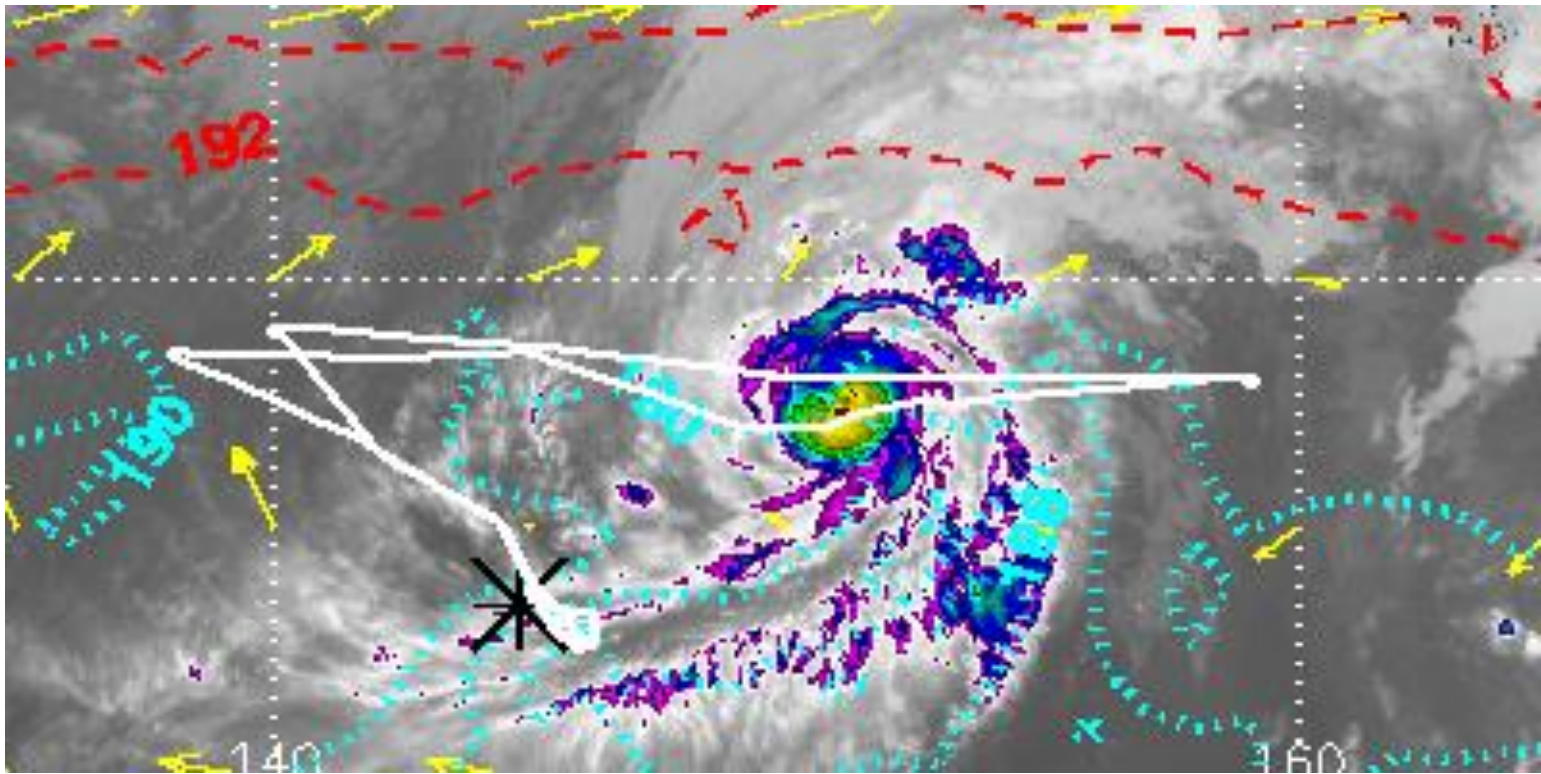
4–5 March Global Hawk flight (RF03)



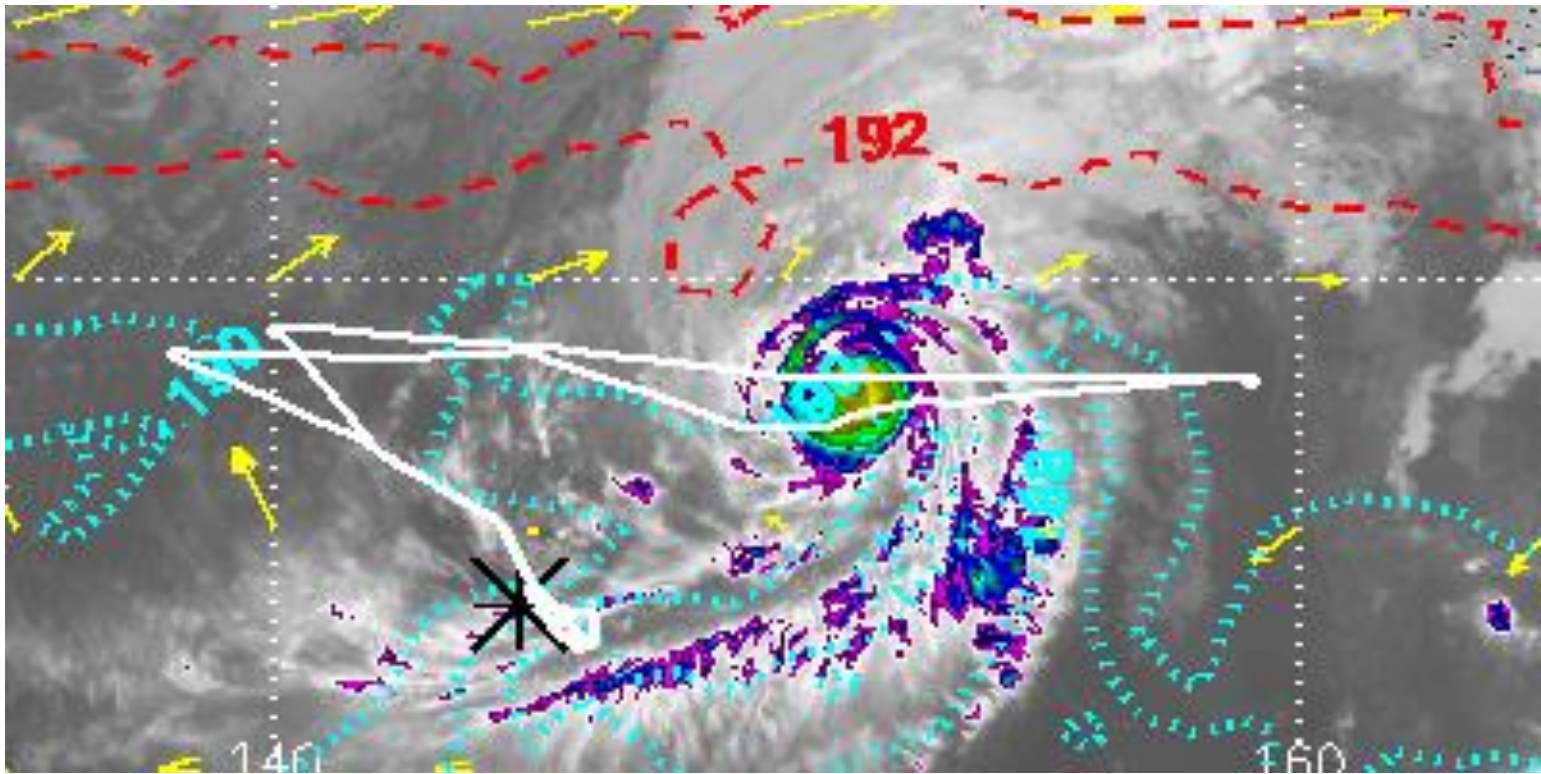
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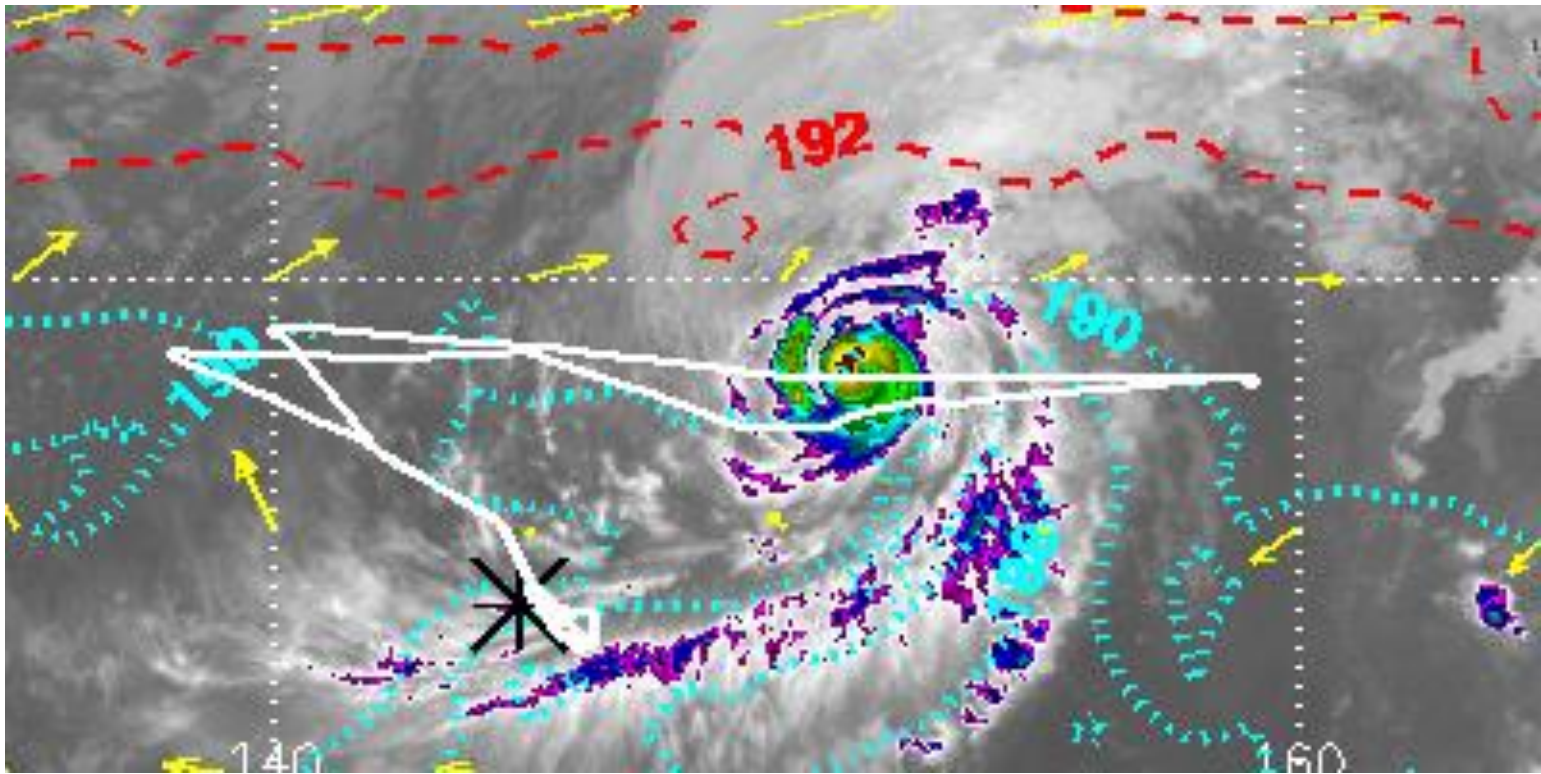
4–5 March Global Hawk flight (RF03)



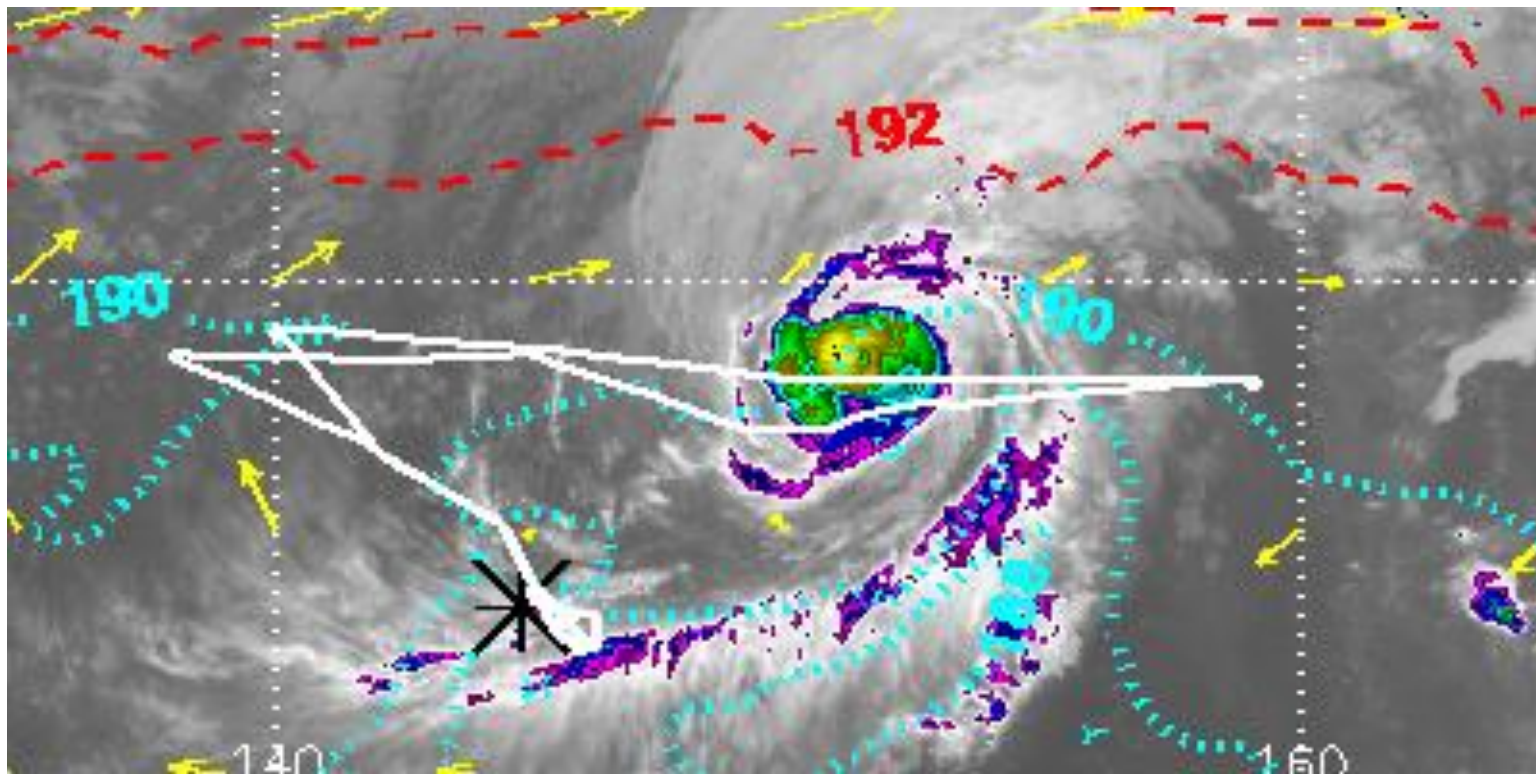
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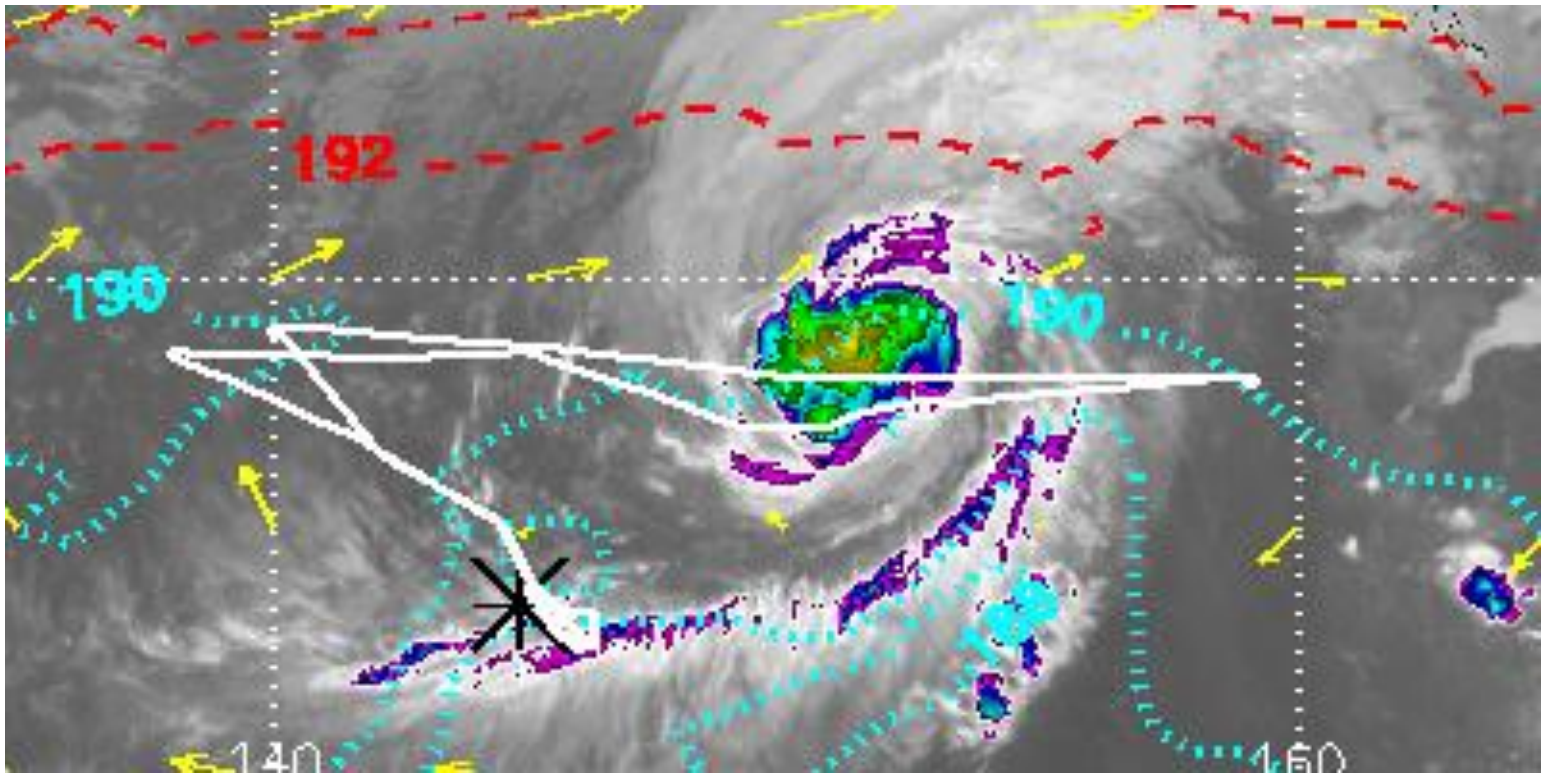
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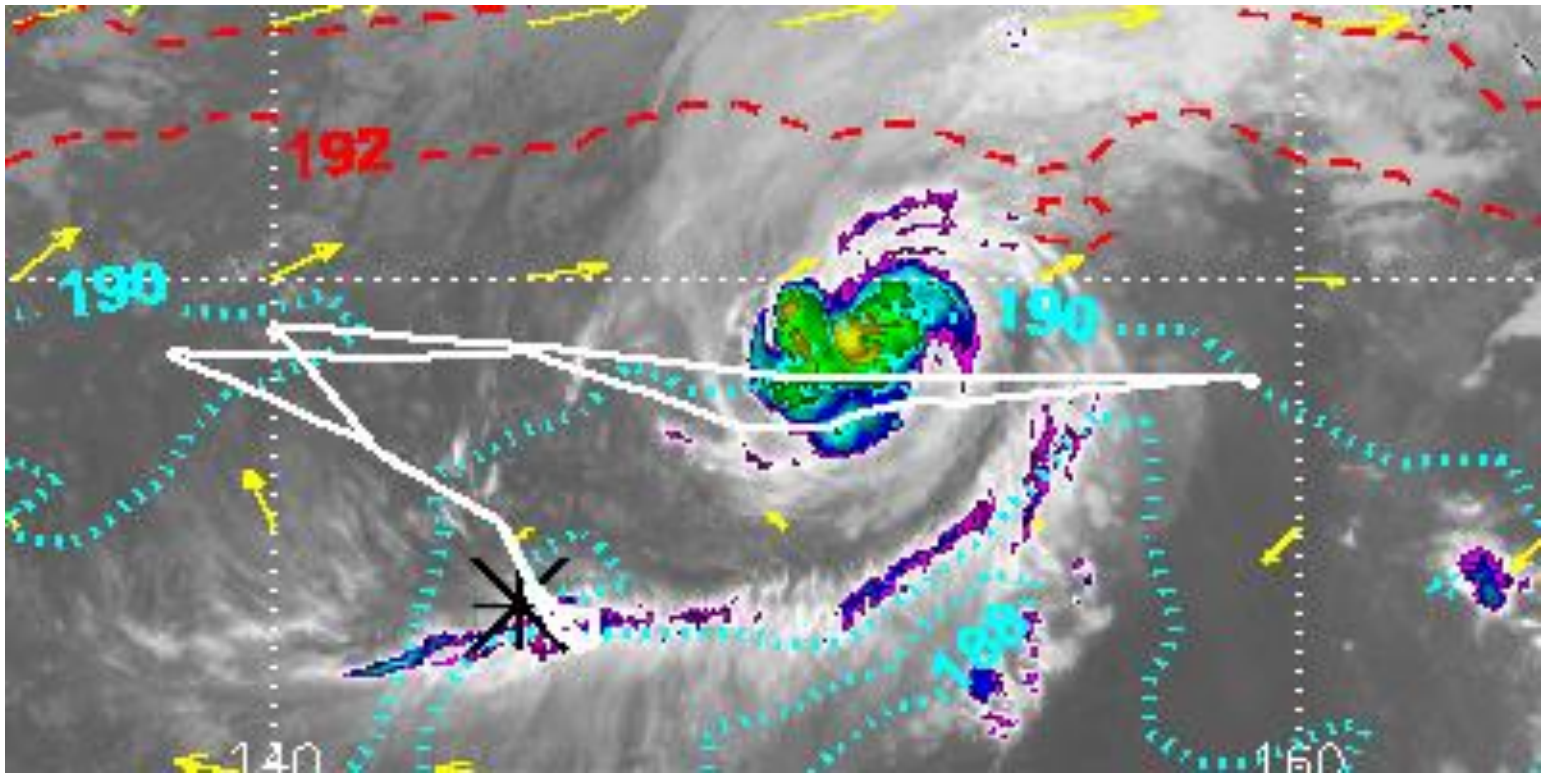
4–5 March Global Hawk flight (RF03)



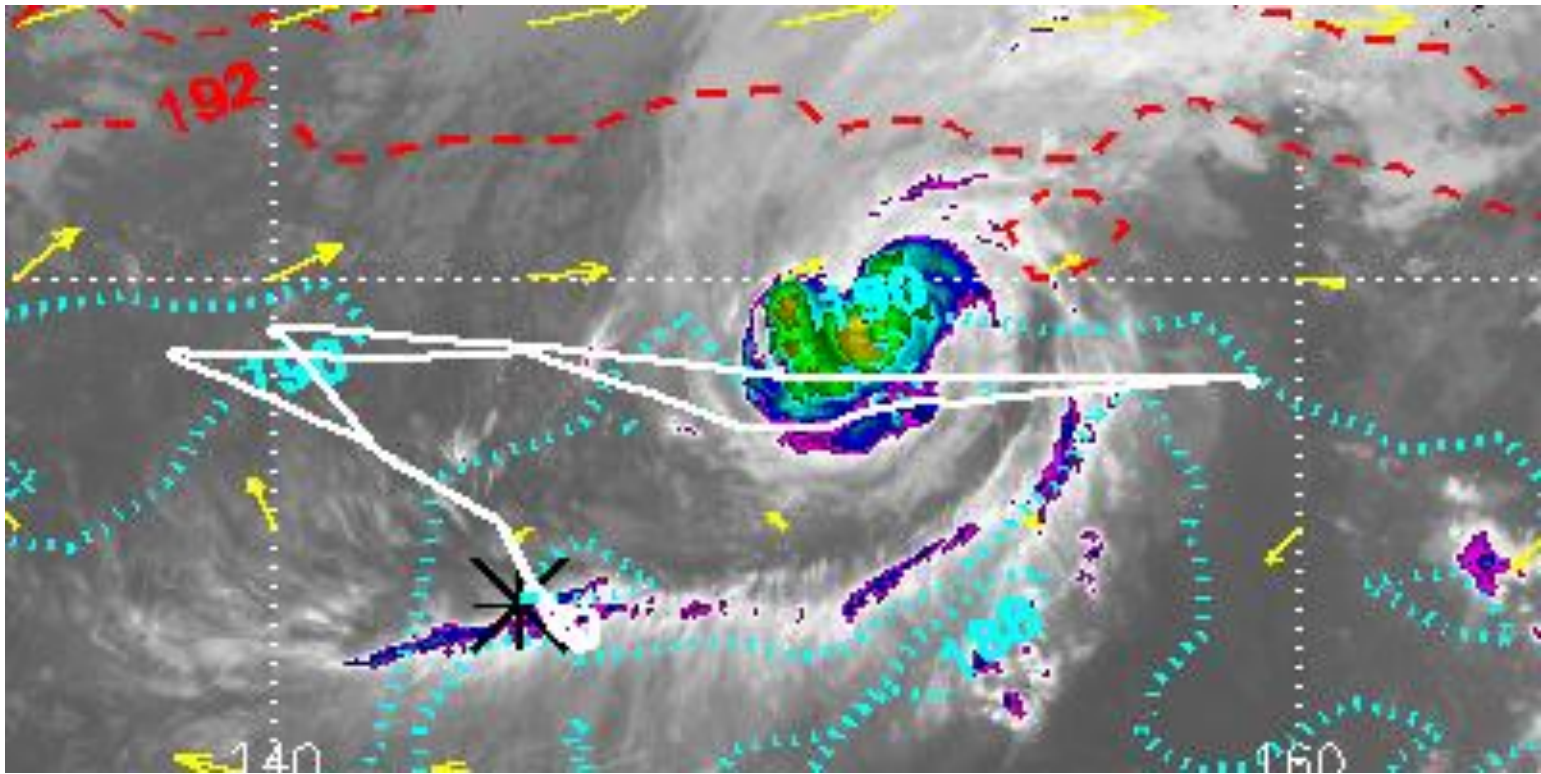
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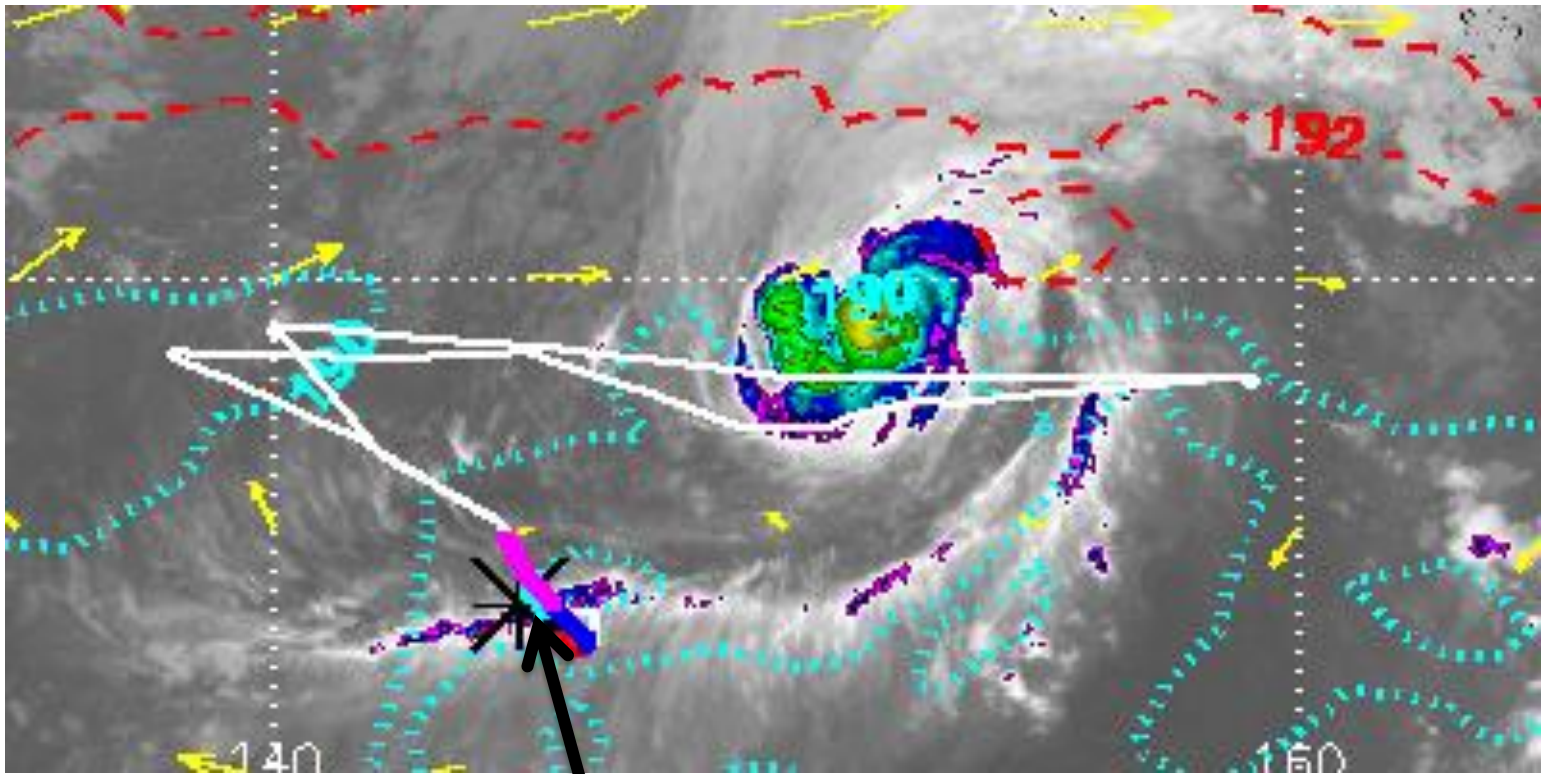
4–5 March Global Hawk flight (RF03)



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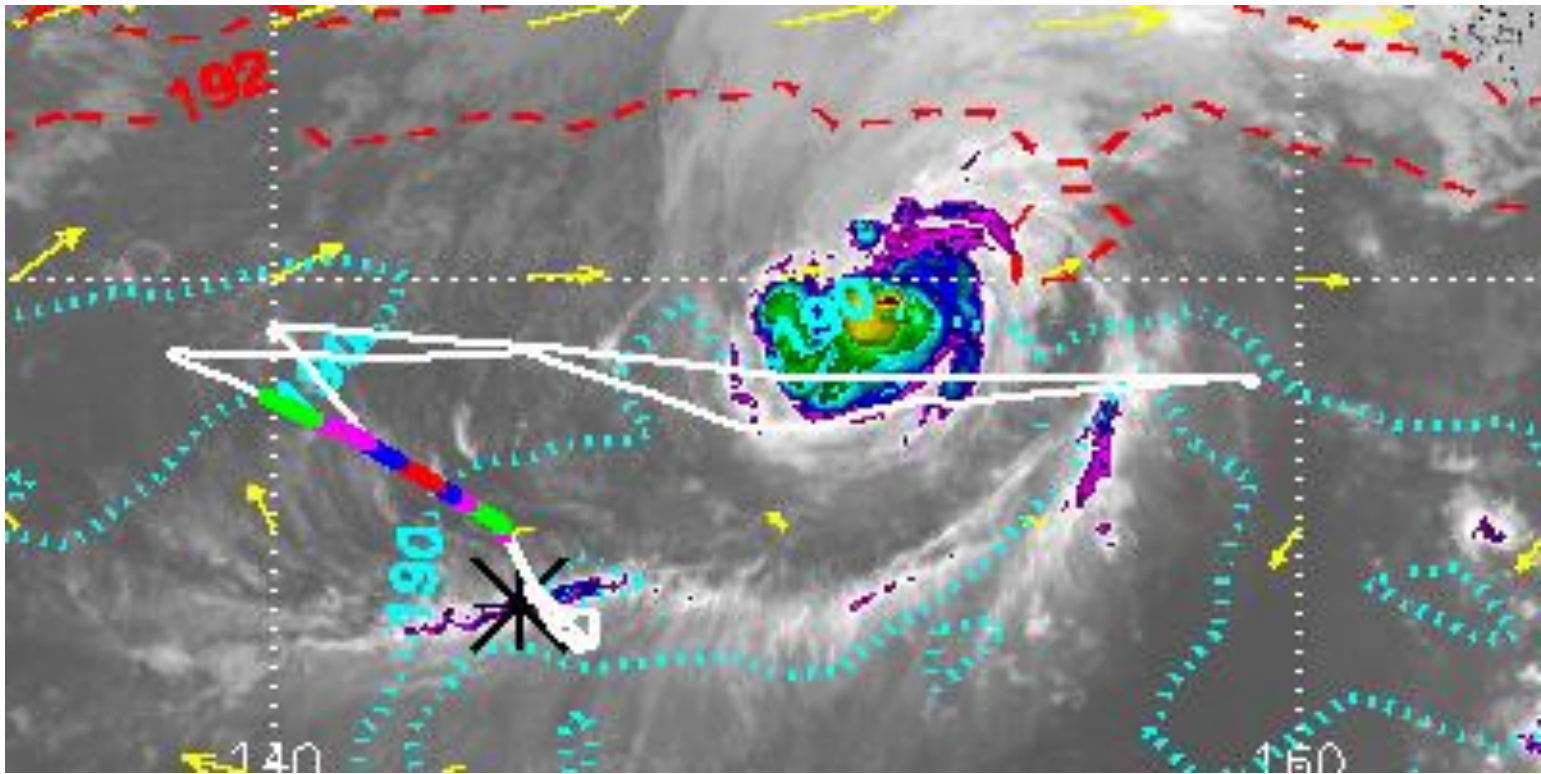


4–5 March Global Hawk flight (RF03)

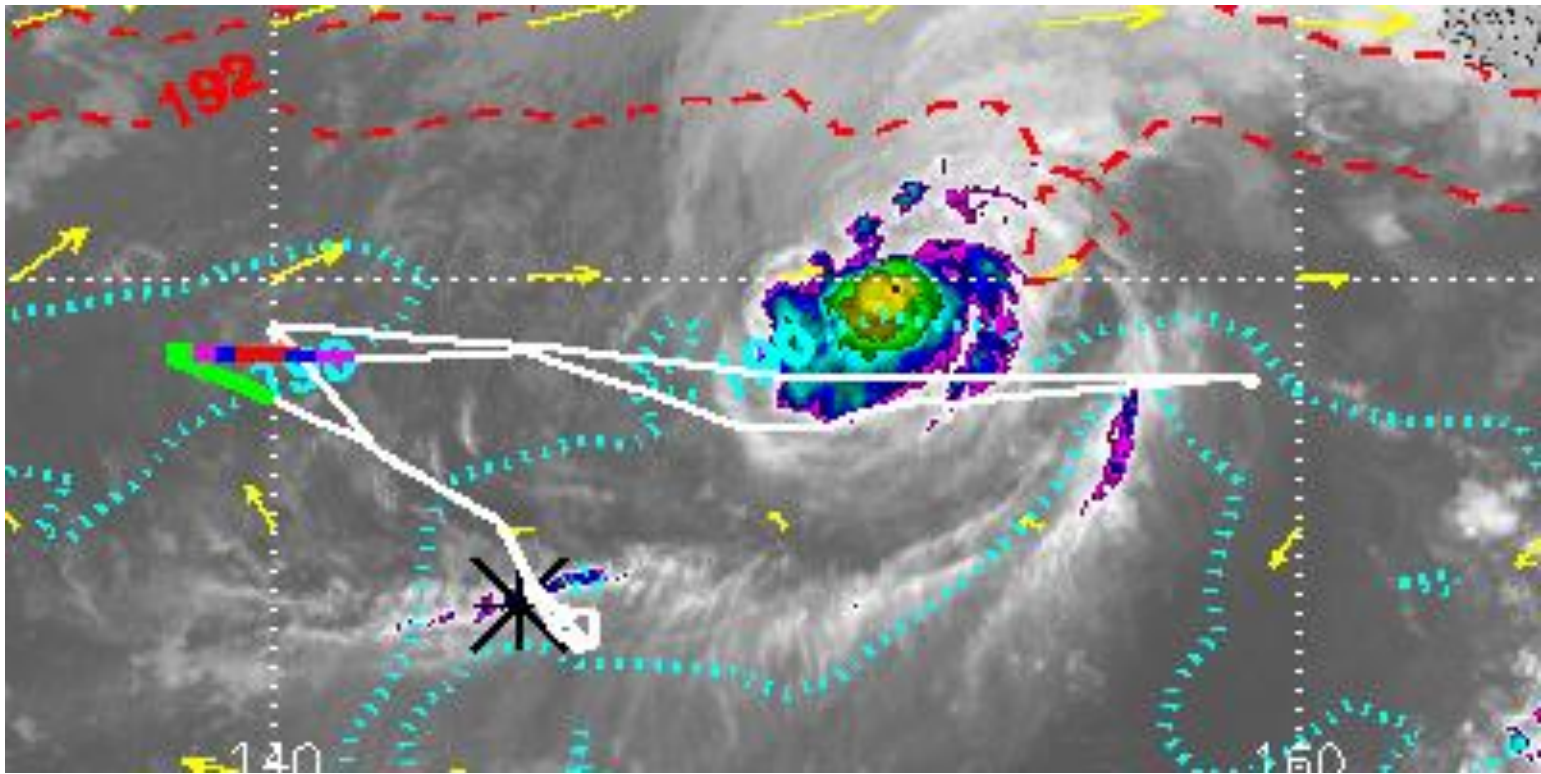


Vertical profile through Faxai cirrus band on GH climbout from Guam

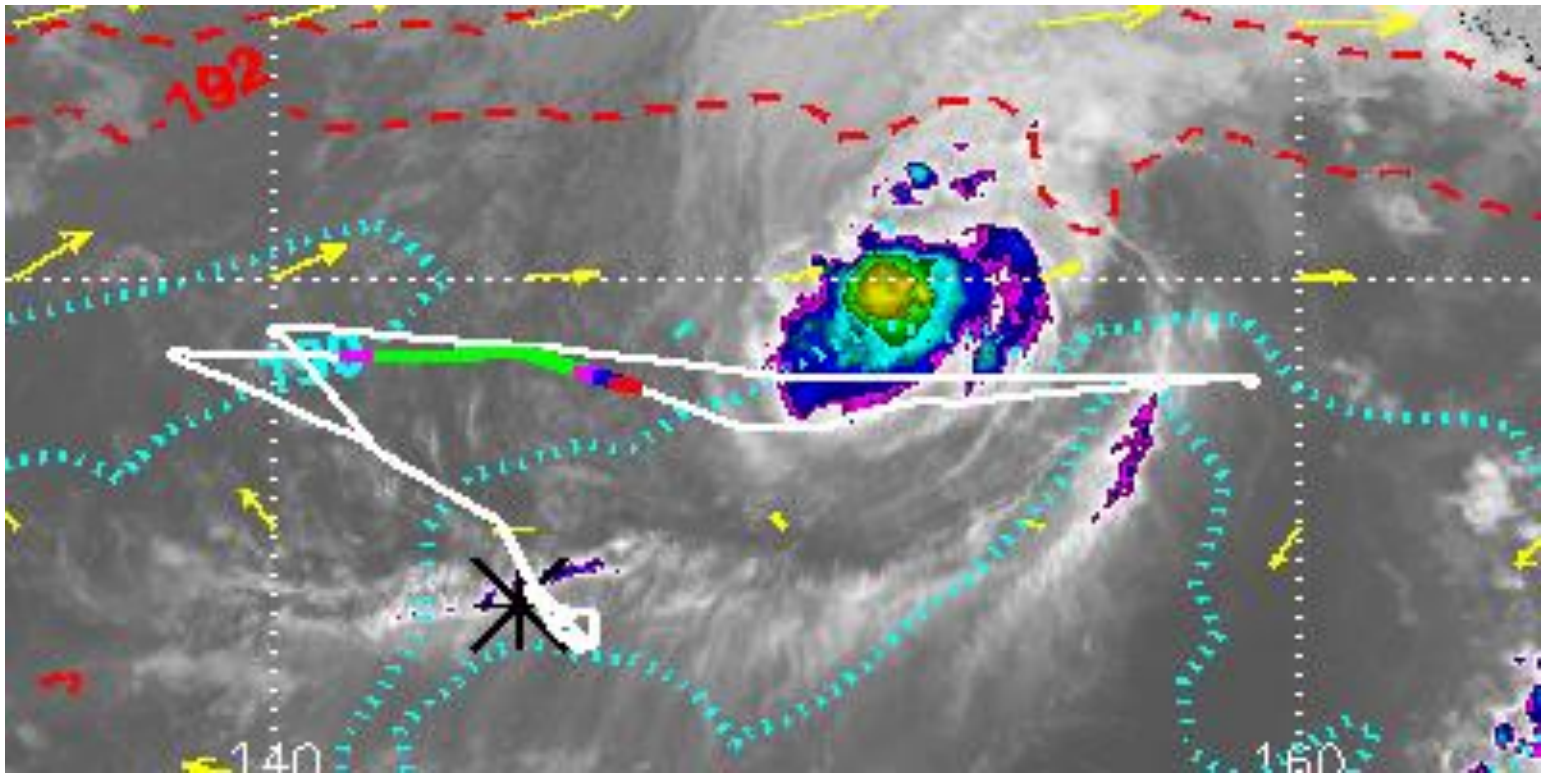
4–5 March Global Hawk flight (RF03)



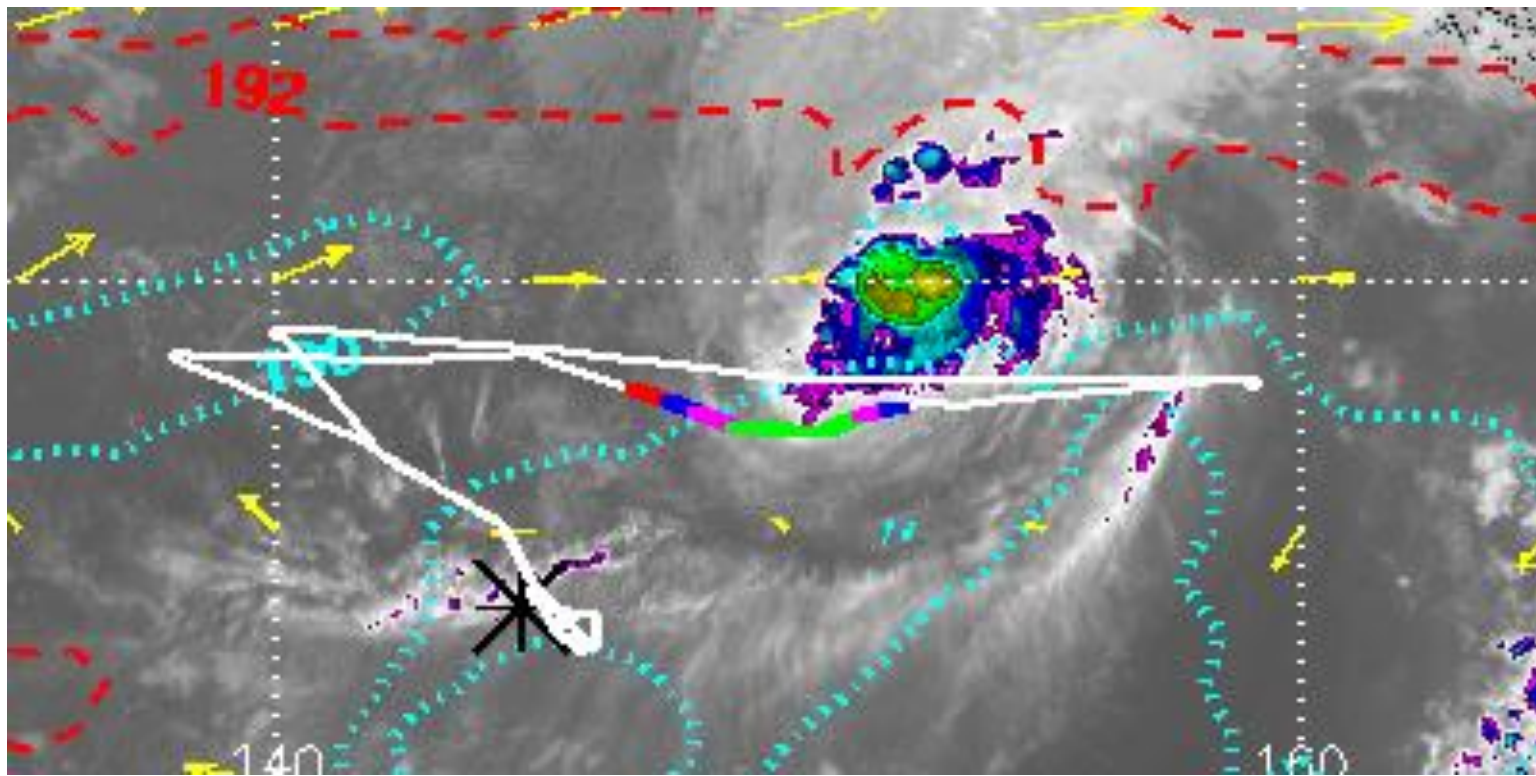
4–5 March Global Hawk flight (RF03)



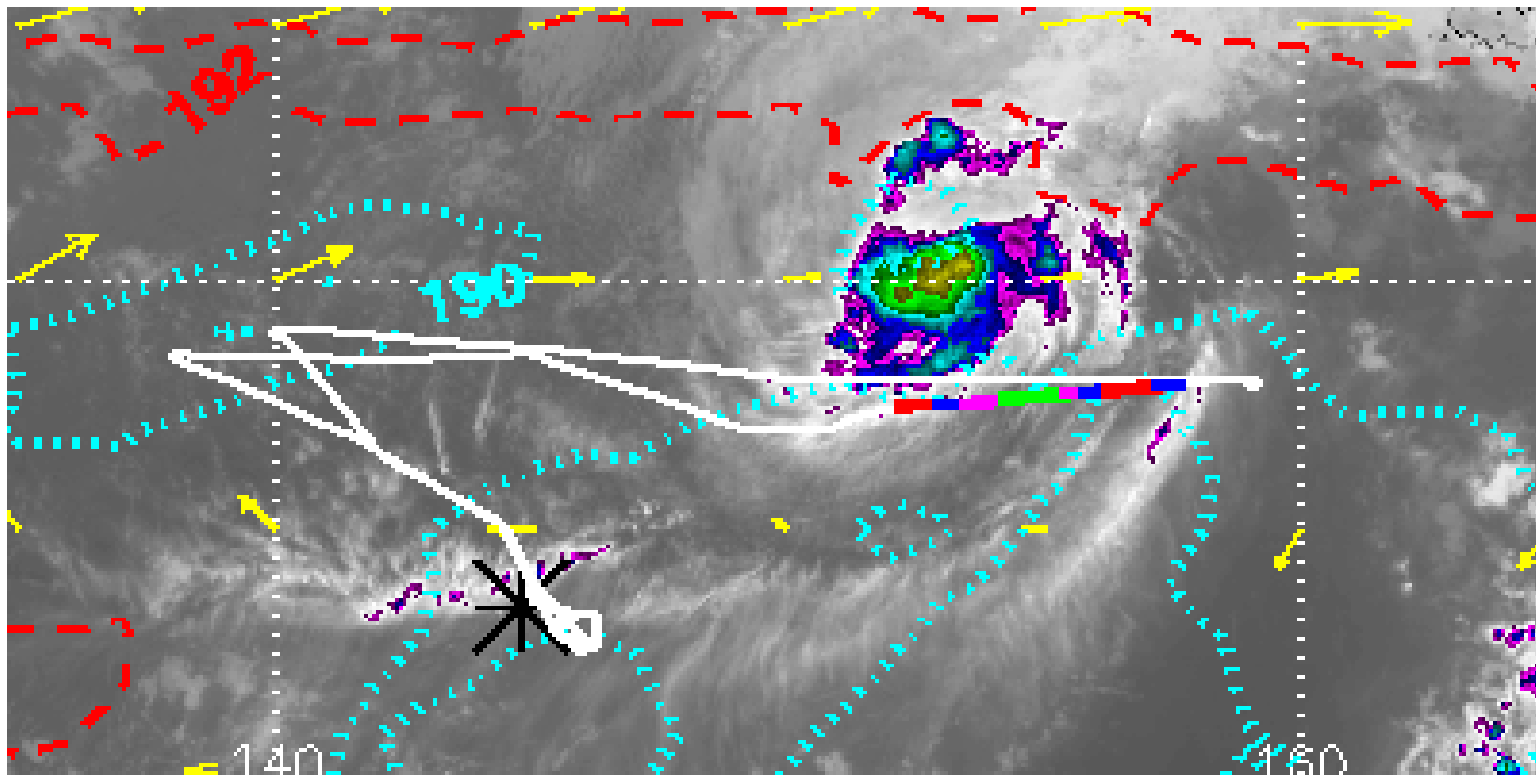
4–5 March Global Hawk flight (RF03)



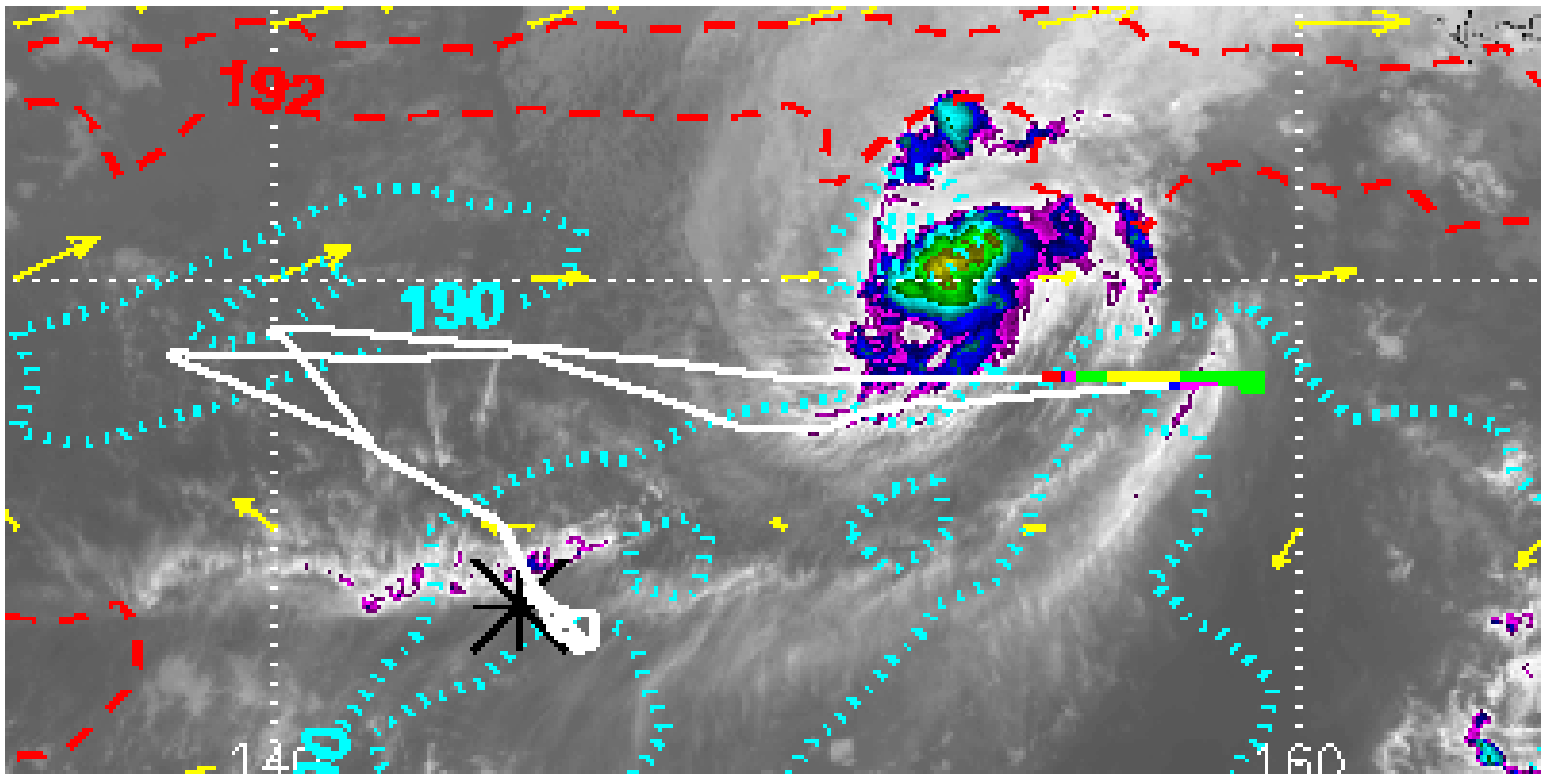
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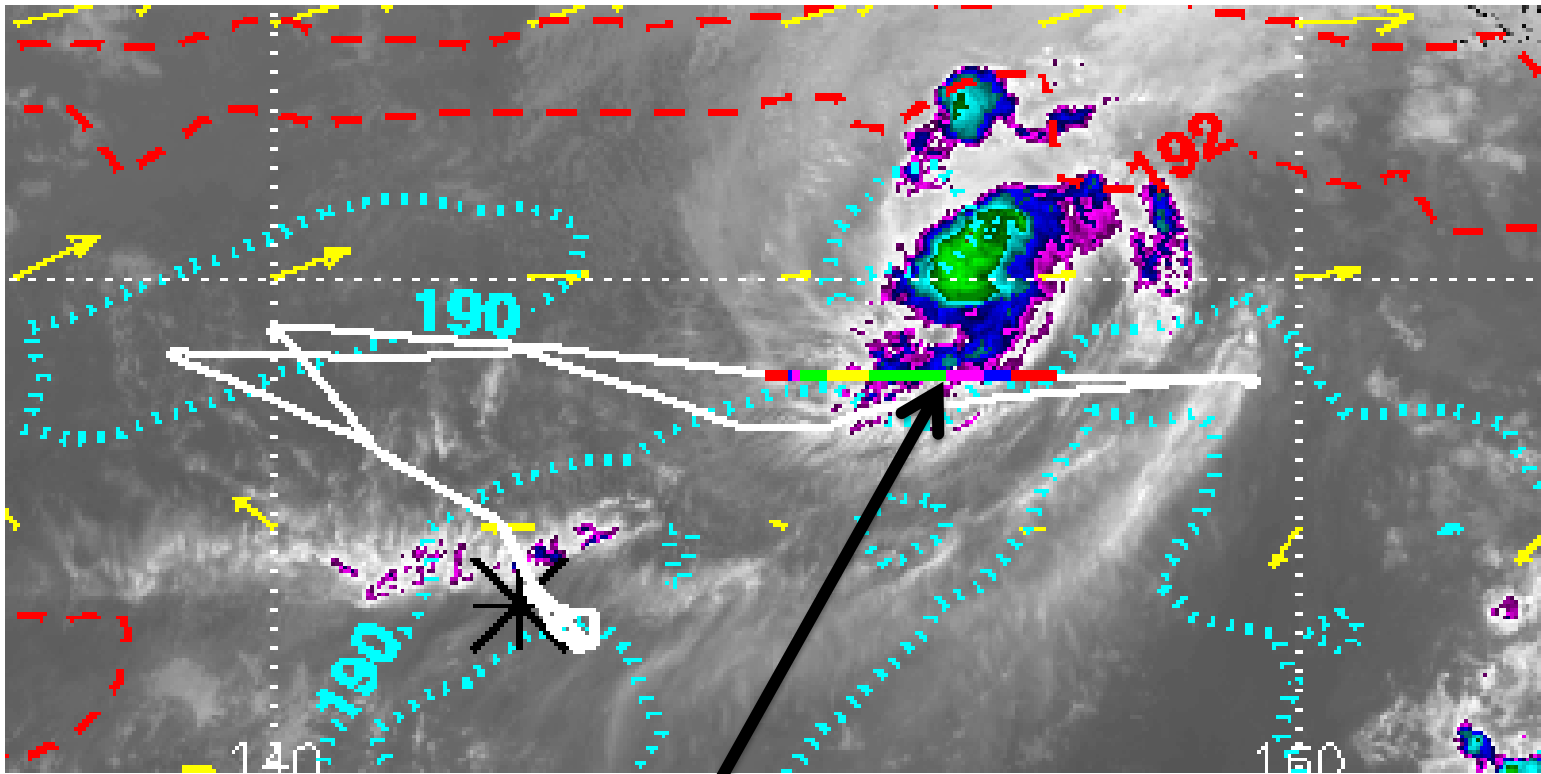
4–5 March Global Hawk flight (RF03)



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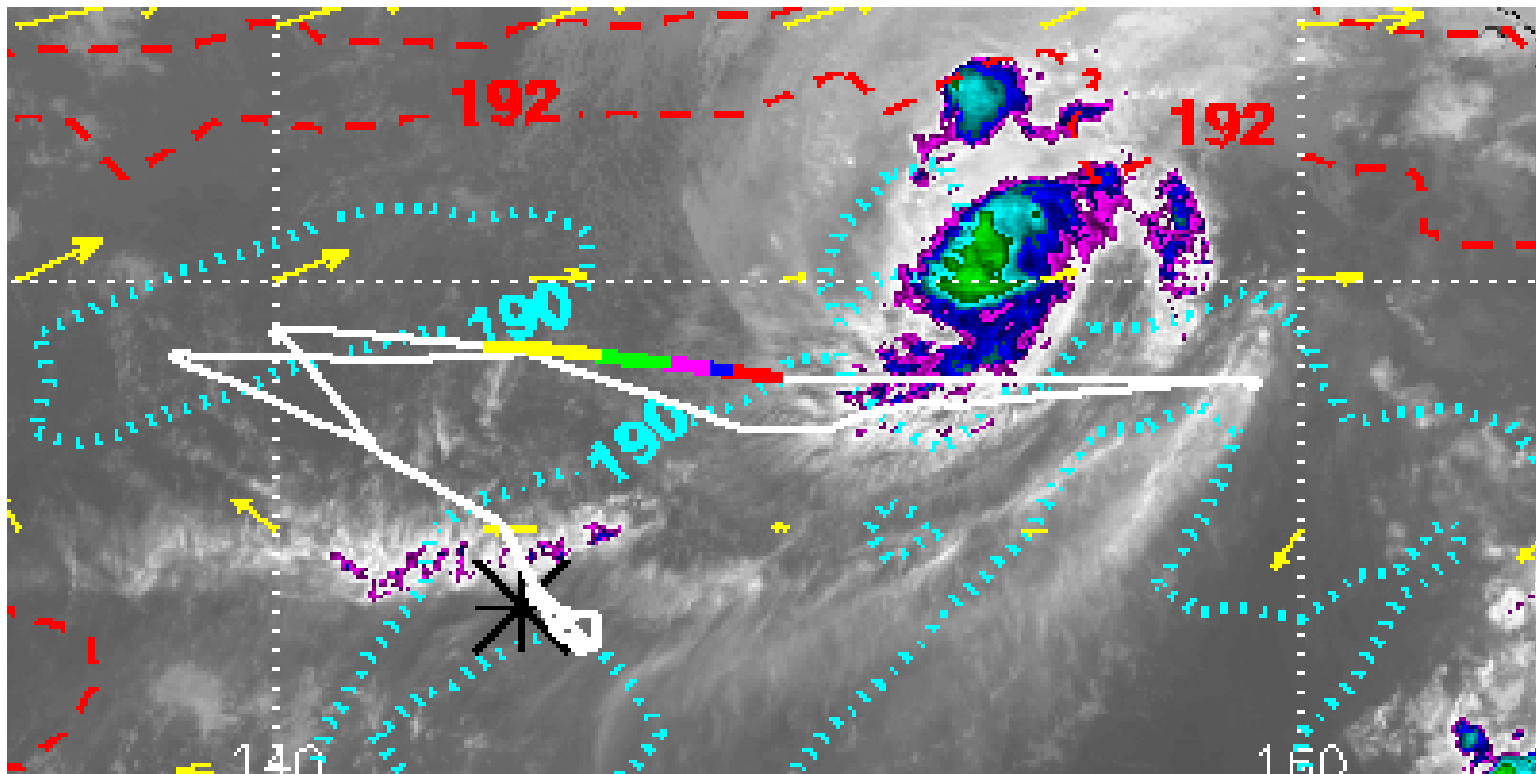


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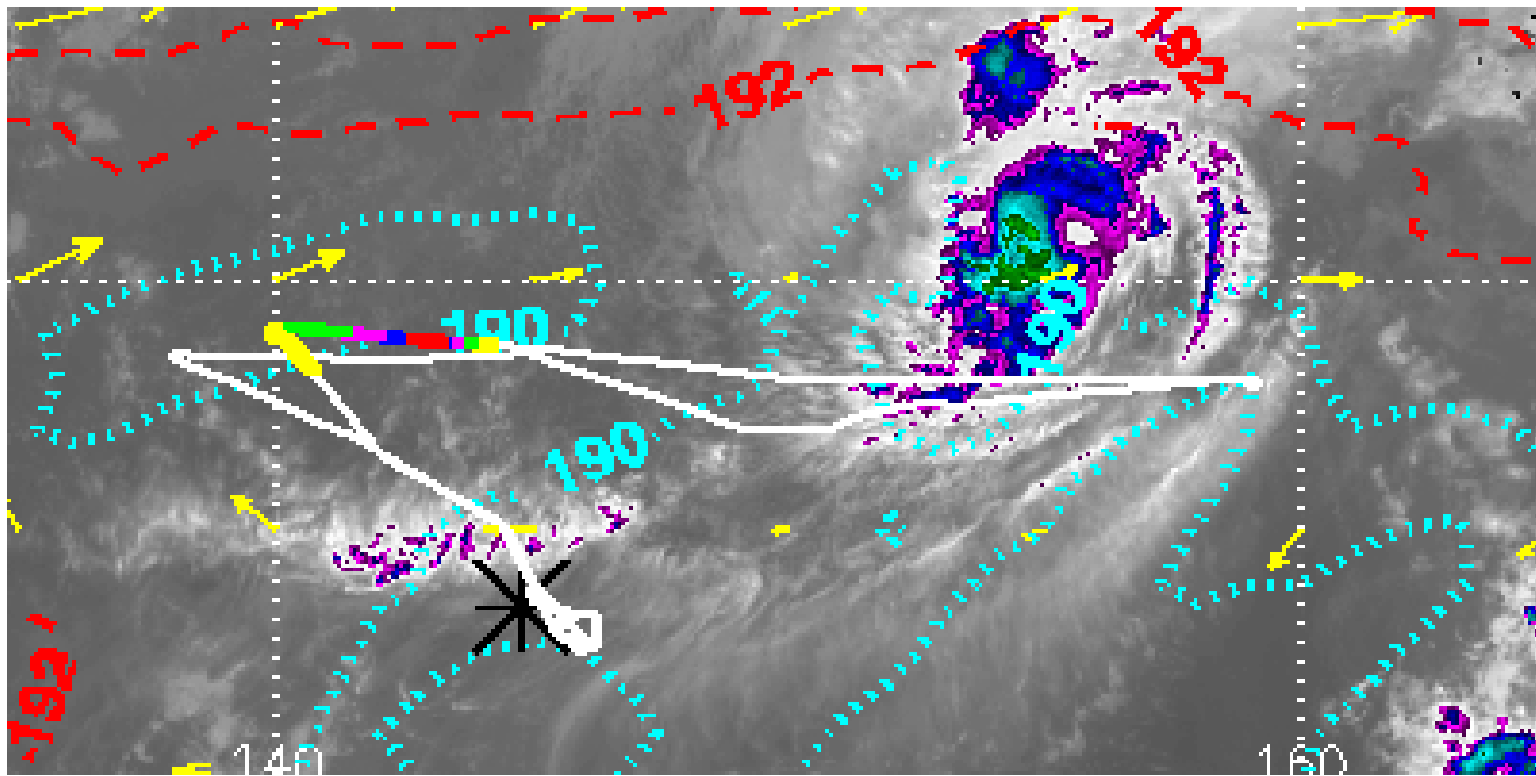


Cirrus band sampled just south of Faxai

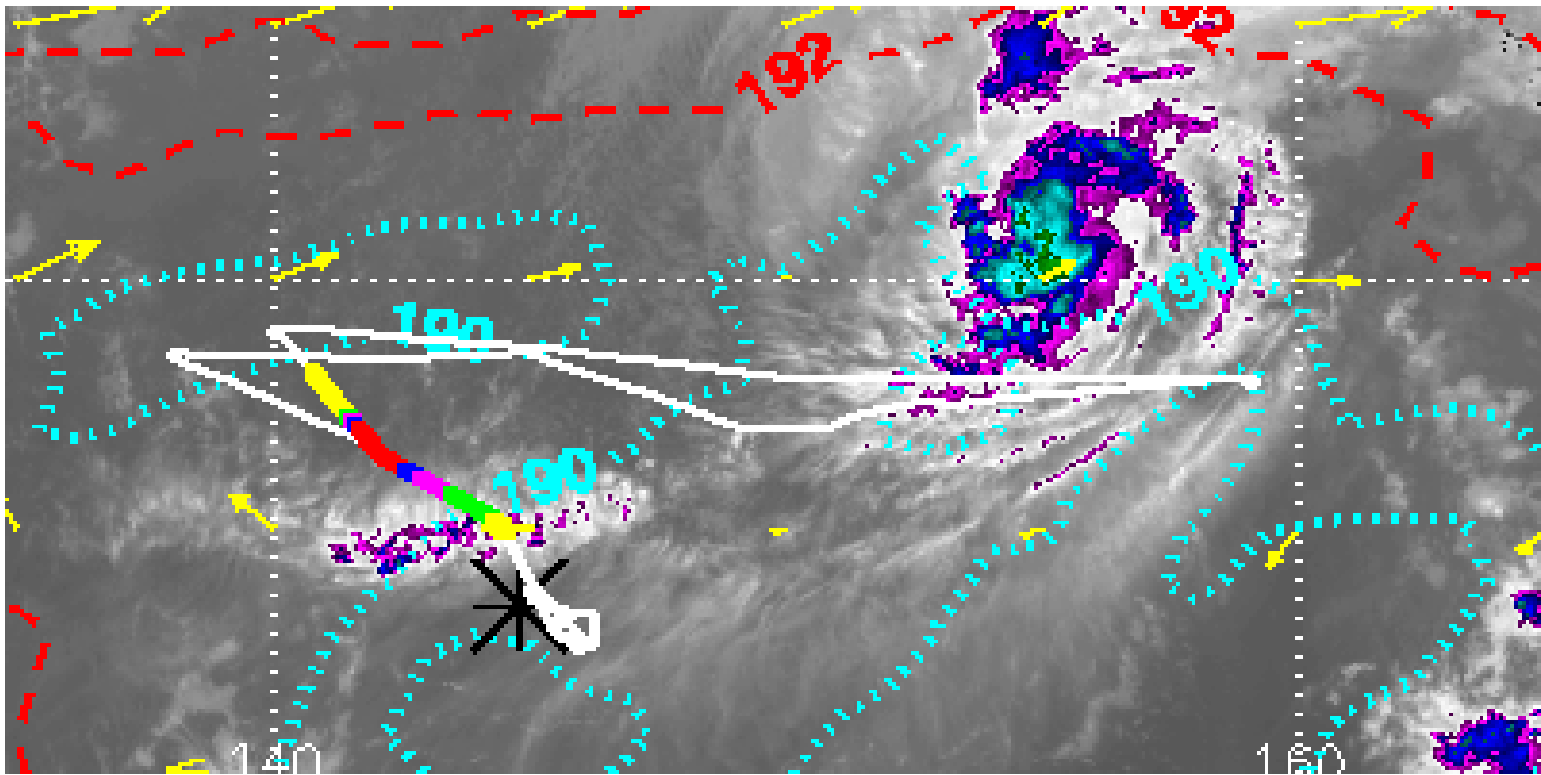
4–5 March Global Hawk flight (RF03)



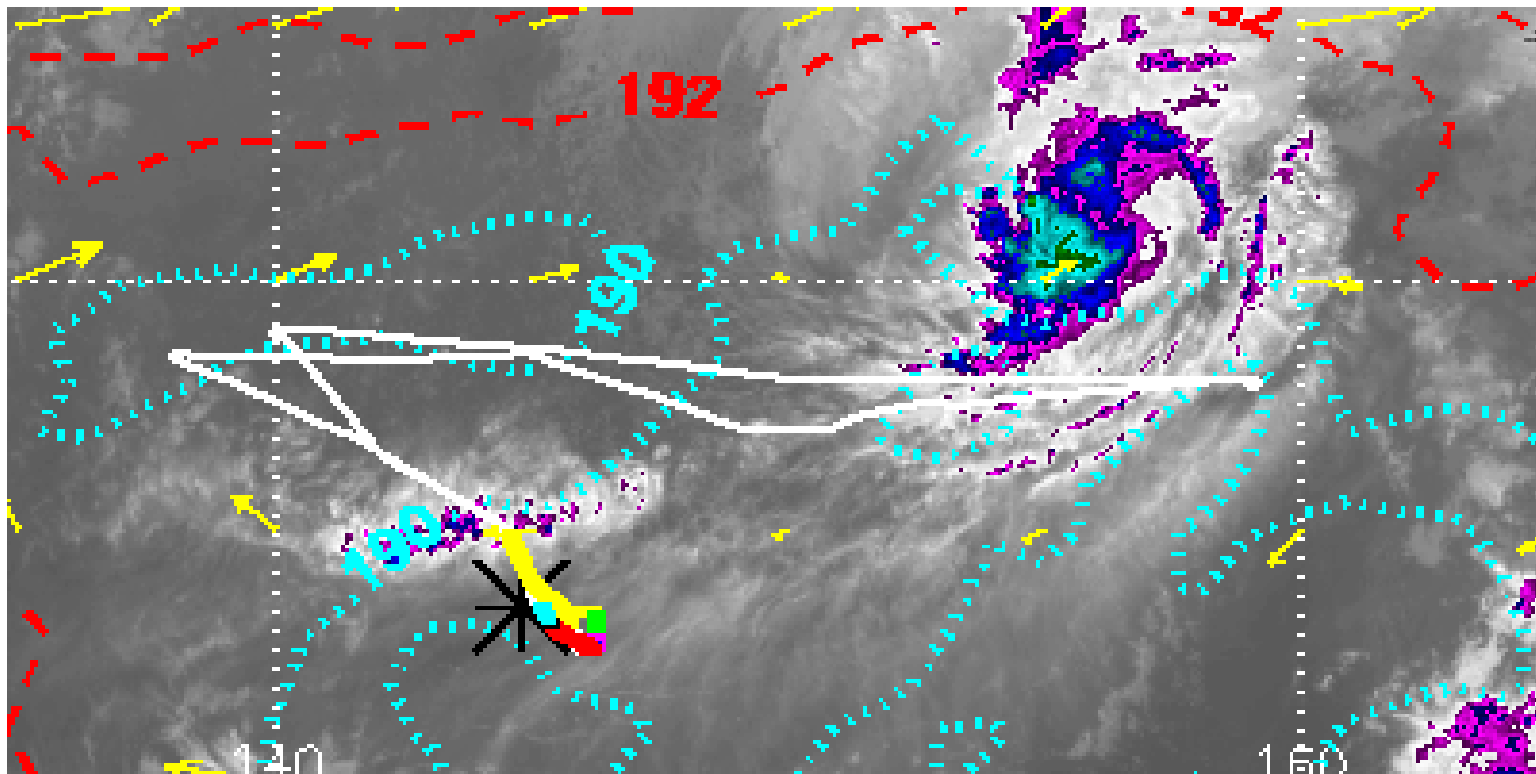
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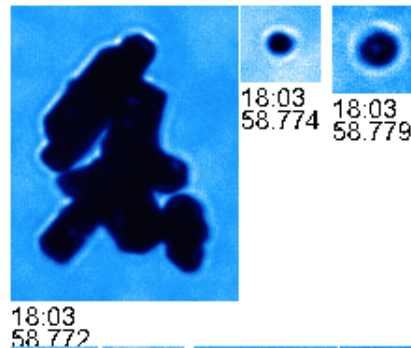
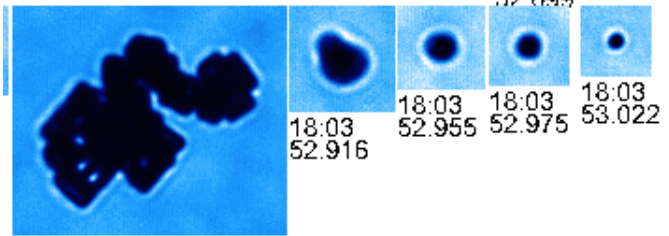
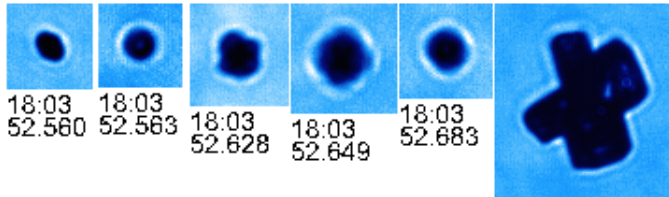
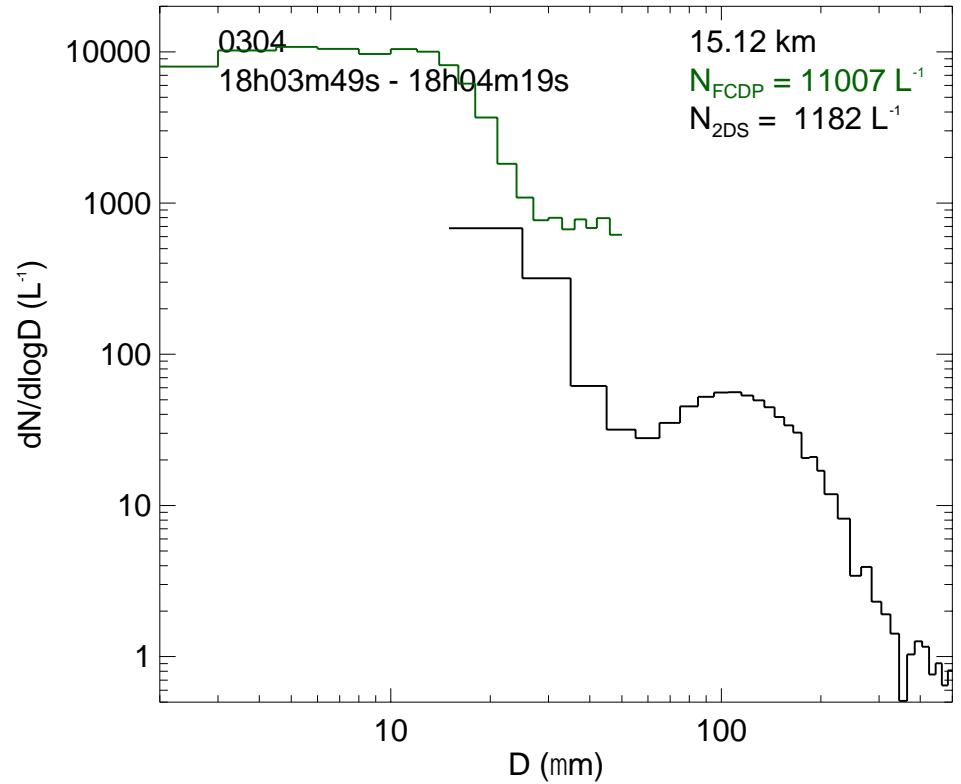
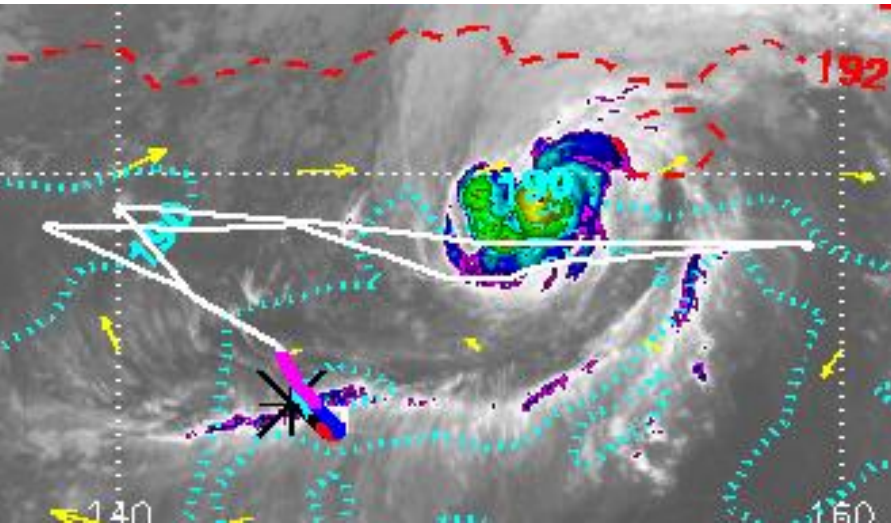
4–5 March Global Hawk flight (RF03)



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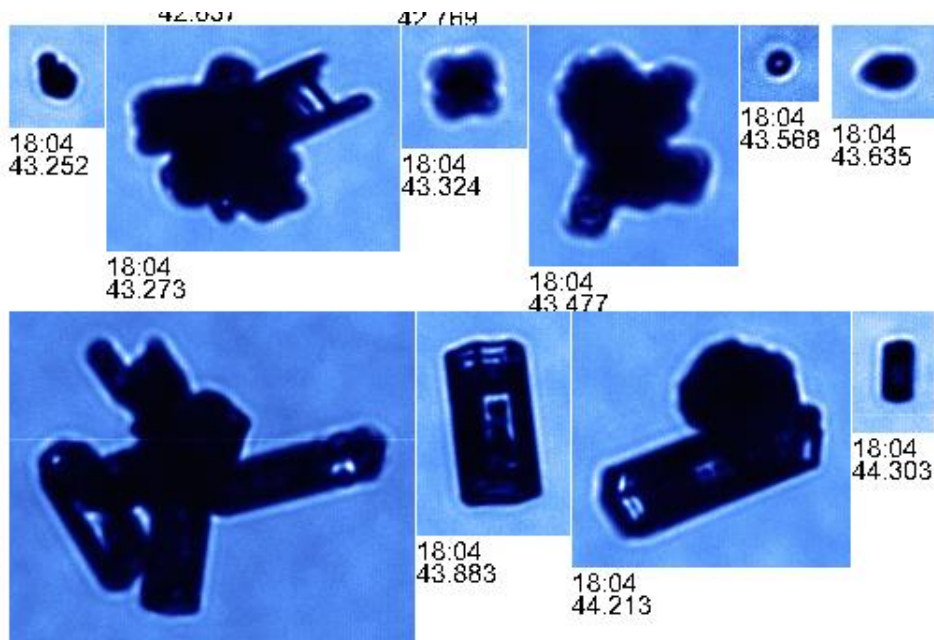
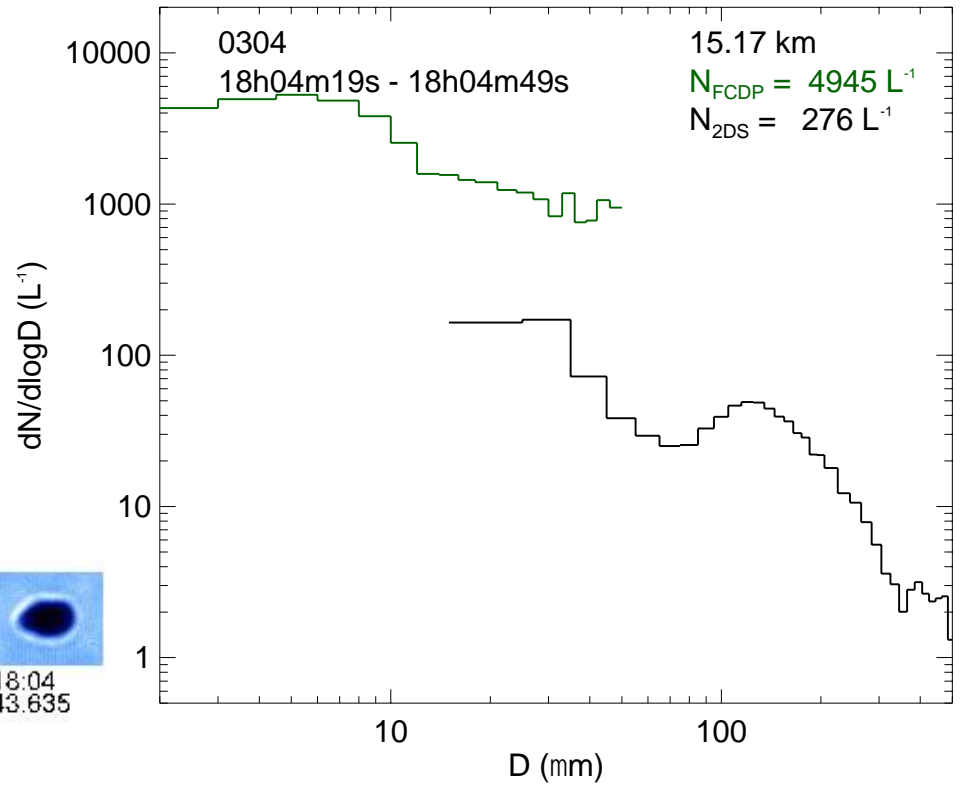
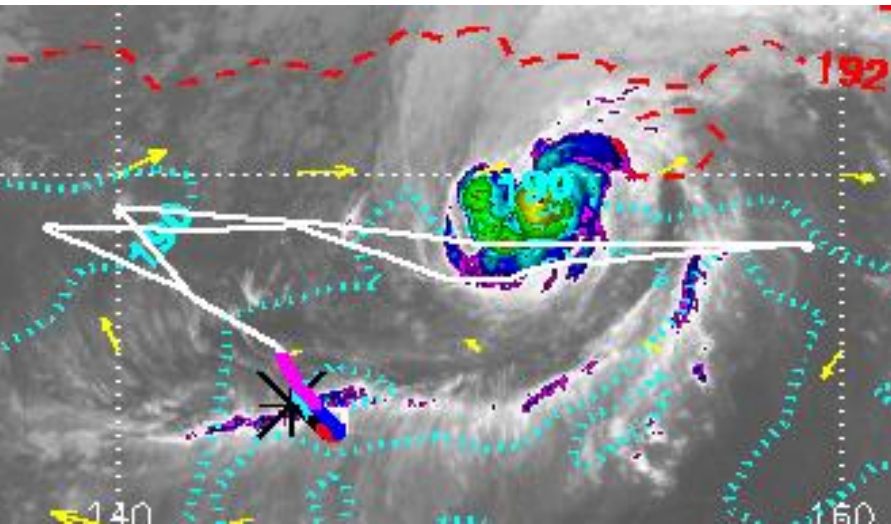


March 4-5 climbout through cirrus



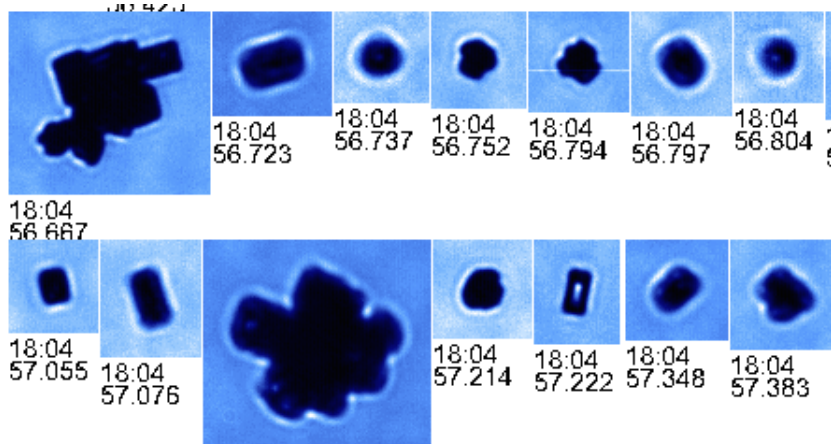
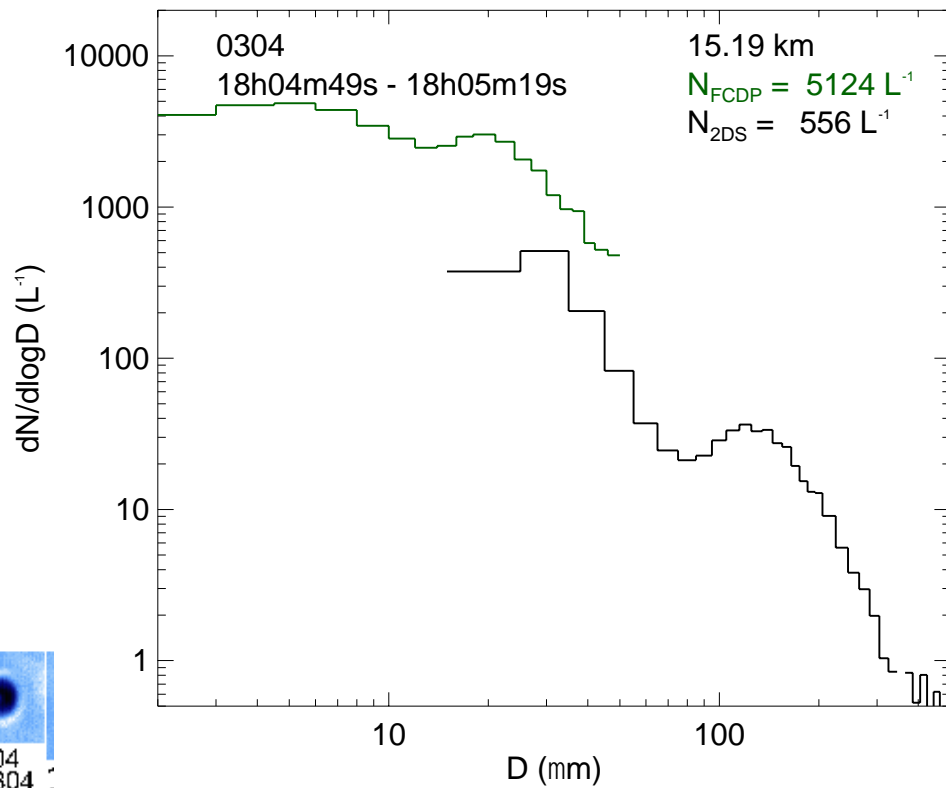
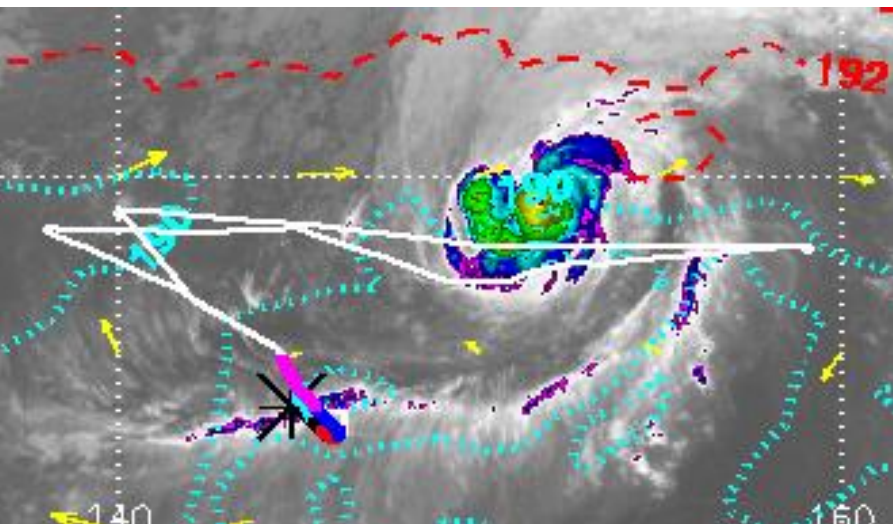
Aggregates and rosettes
near cloud base

March 4-5 climbout through cirrus

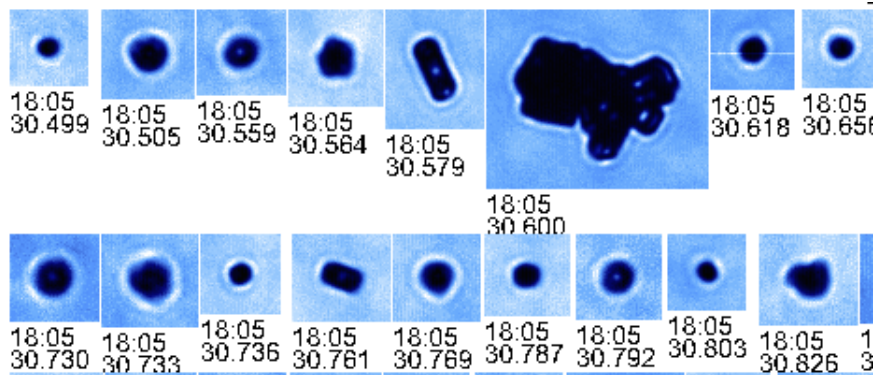
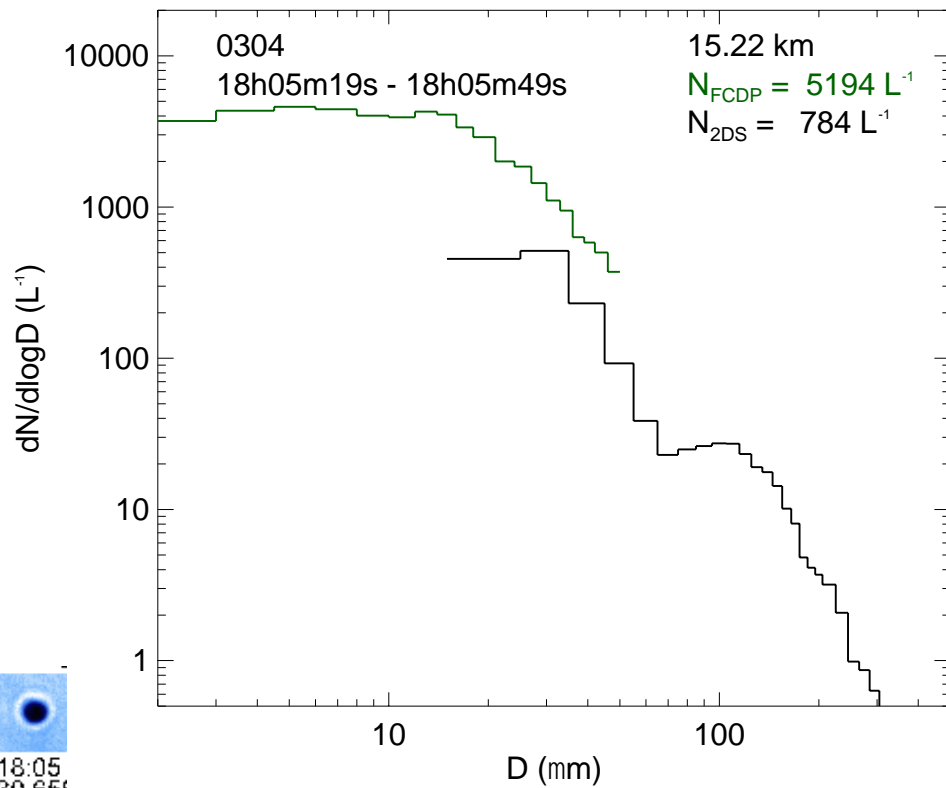
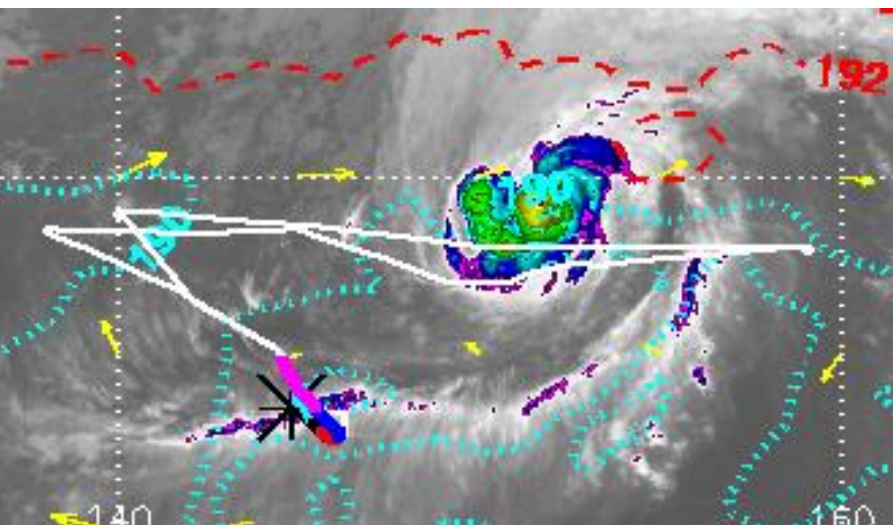


Aggregates and rosettes
near cloud base

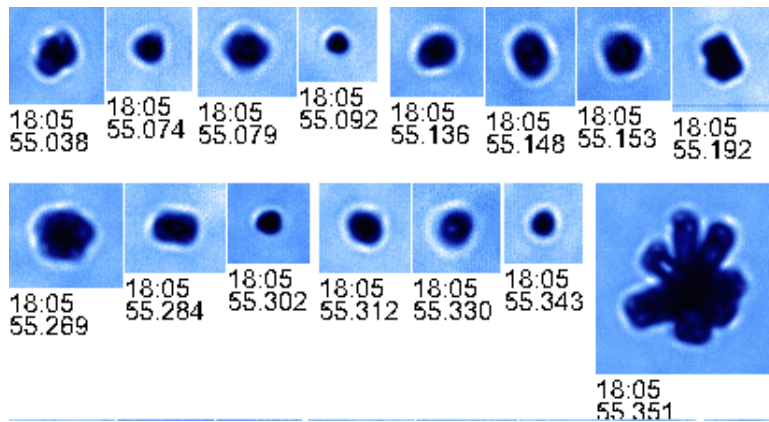
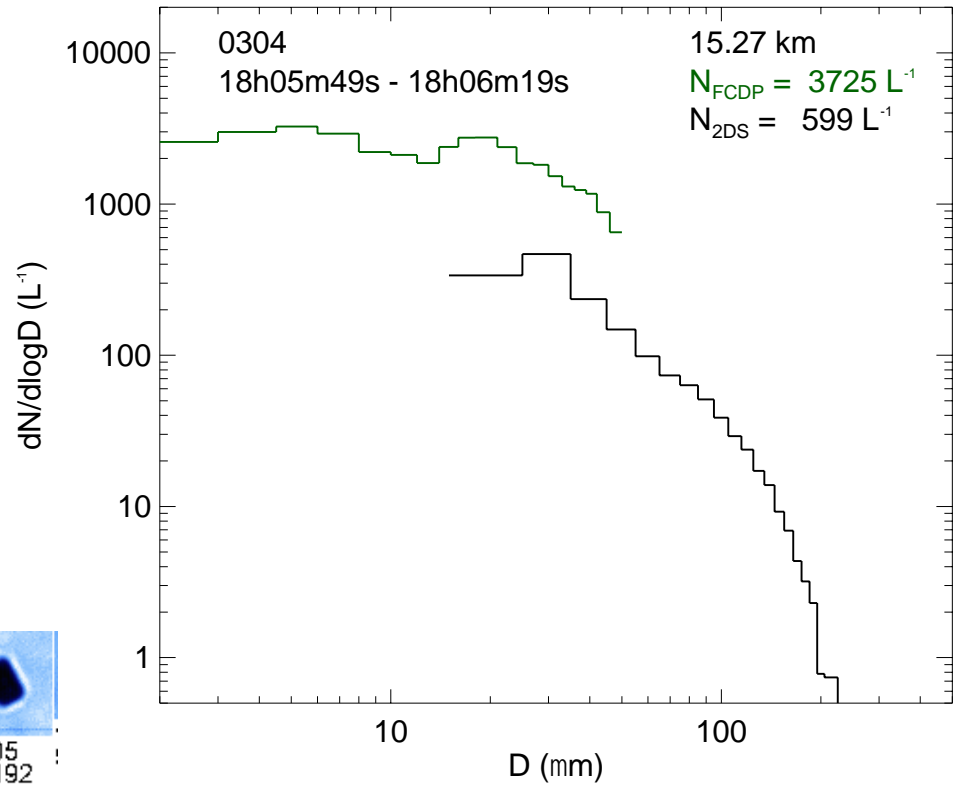
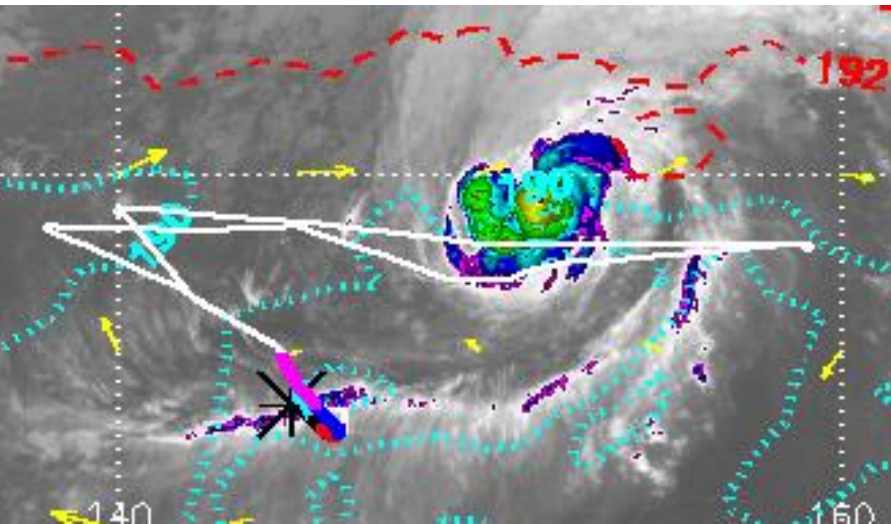
March 4-5 climbout through cirrus



March 4-5 climbout through cirrus

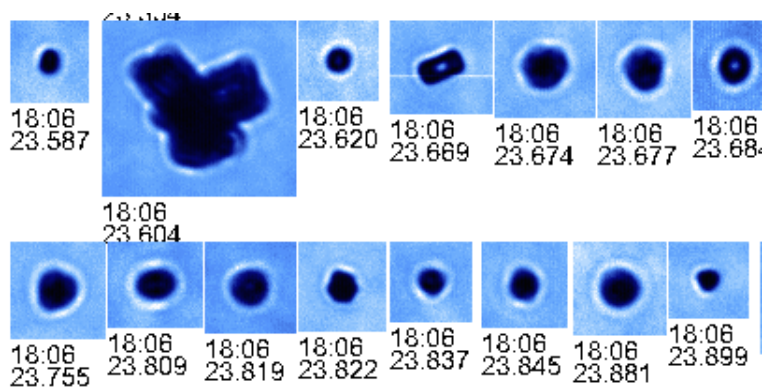
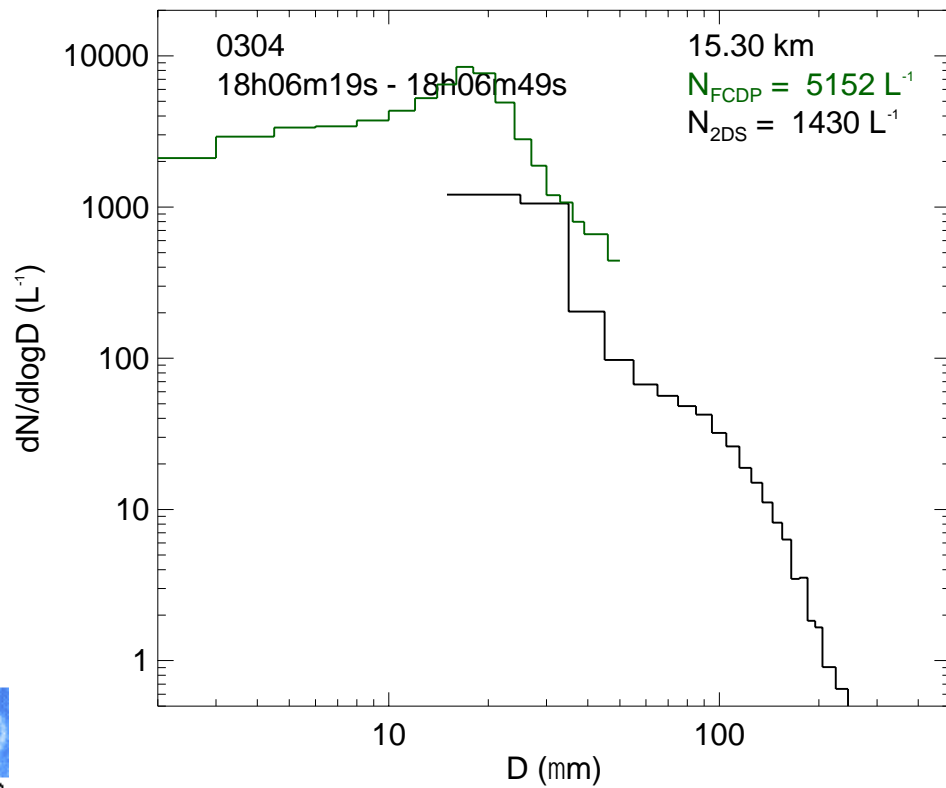
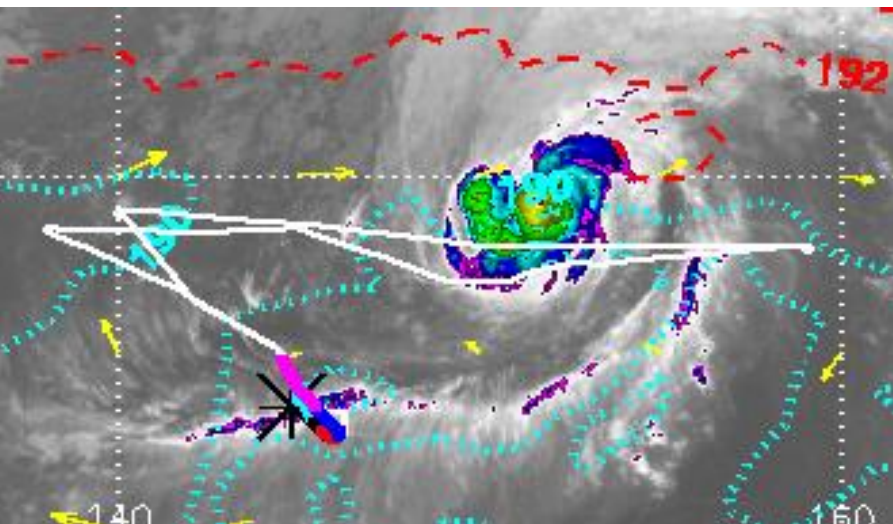


March 4-5 climbout through cirrus

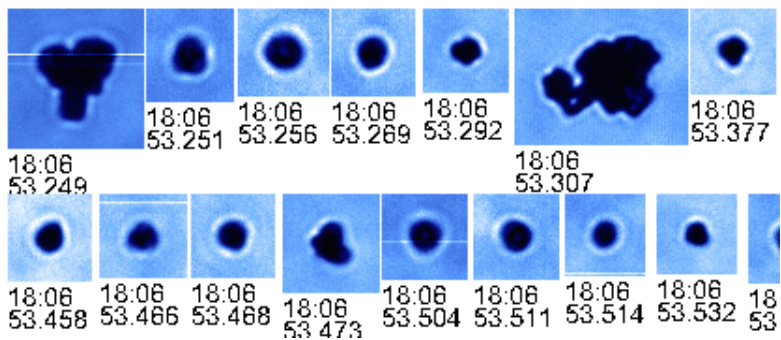
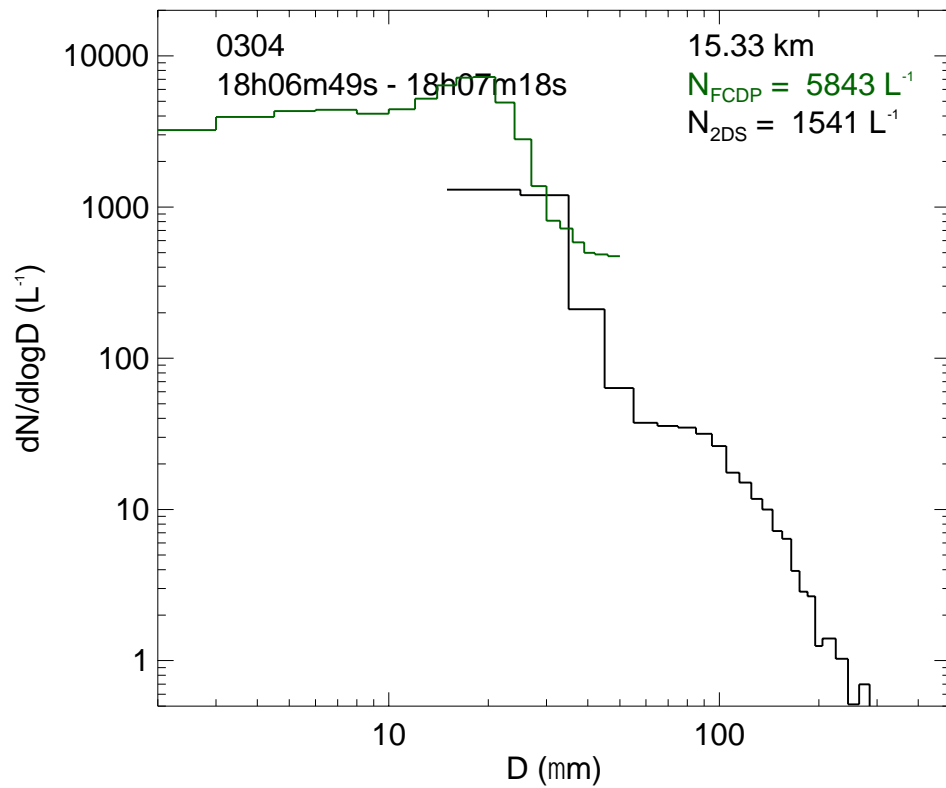
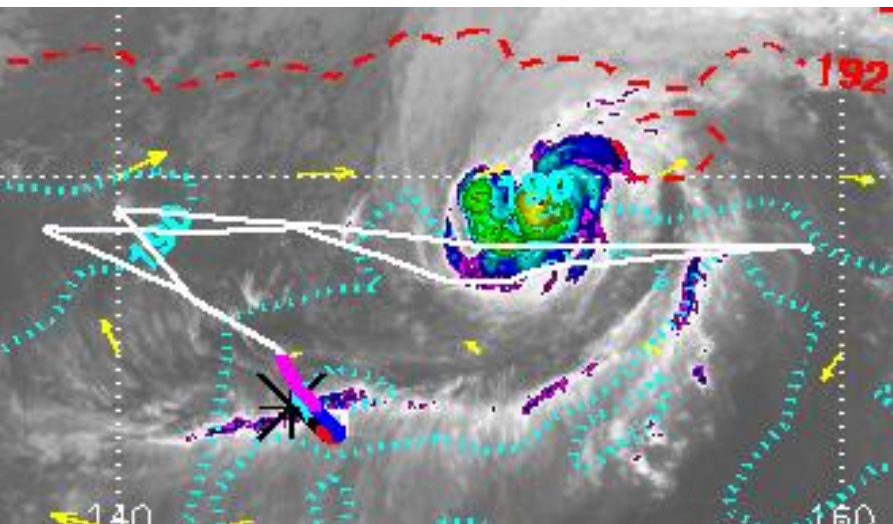


Rosettes and small crystals at intermediate altitudes

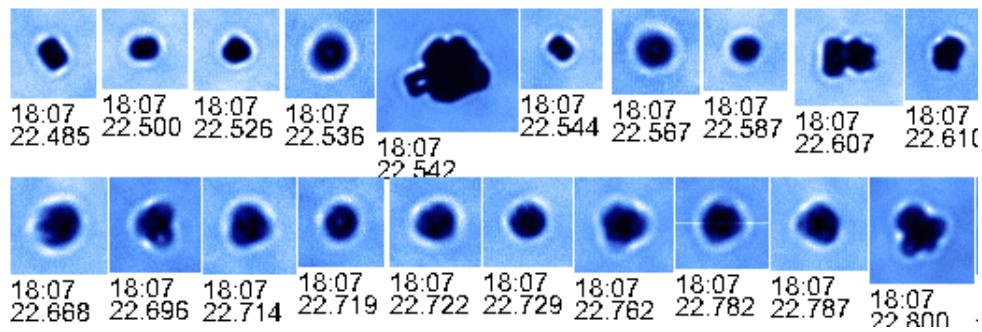
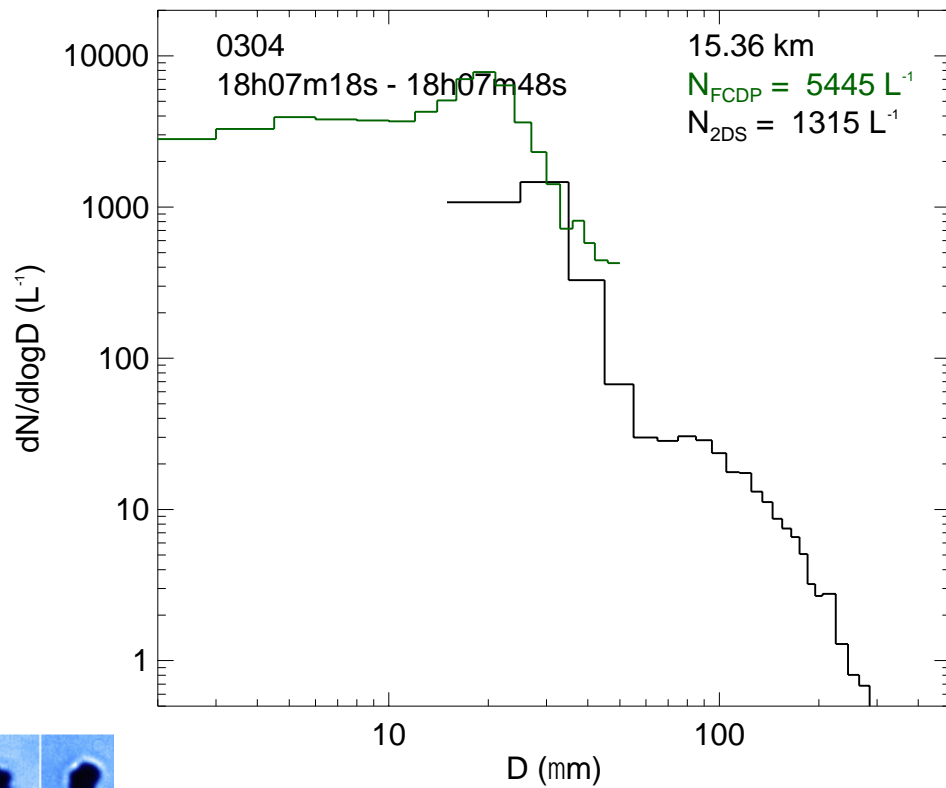
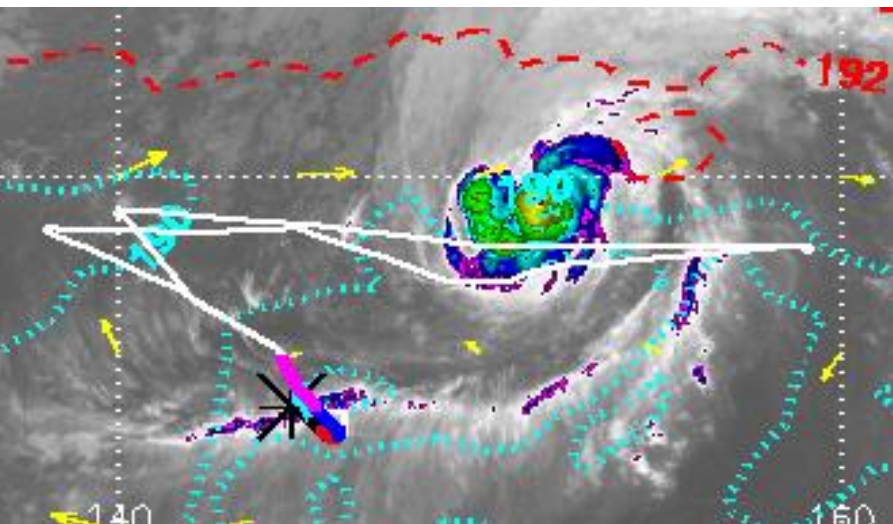
March 4-5 climbout through cirrus



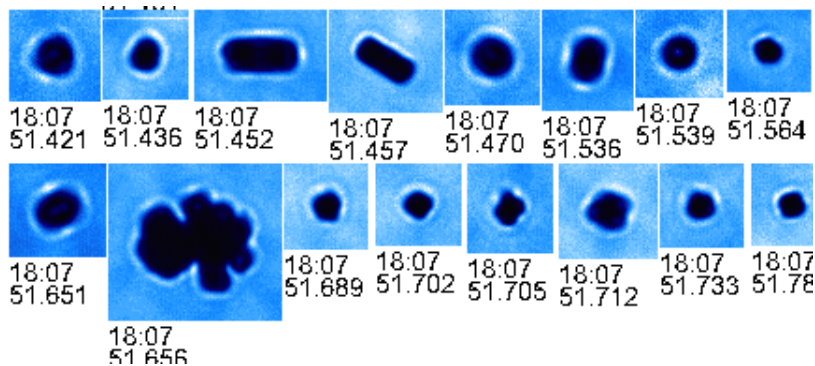
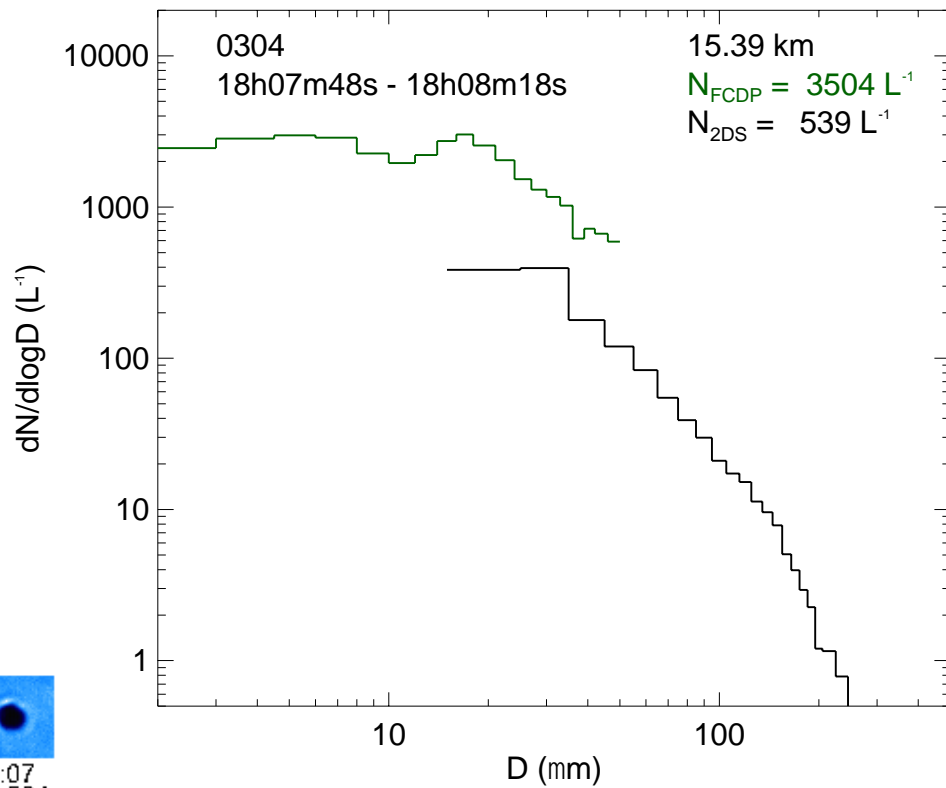
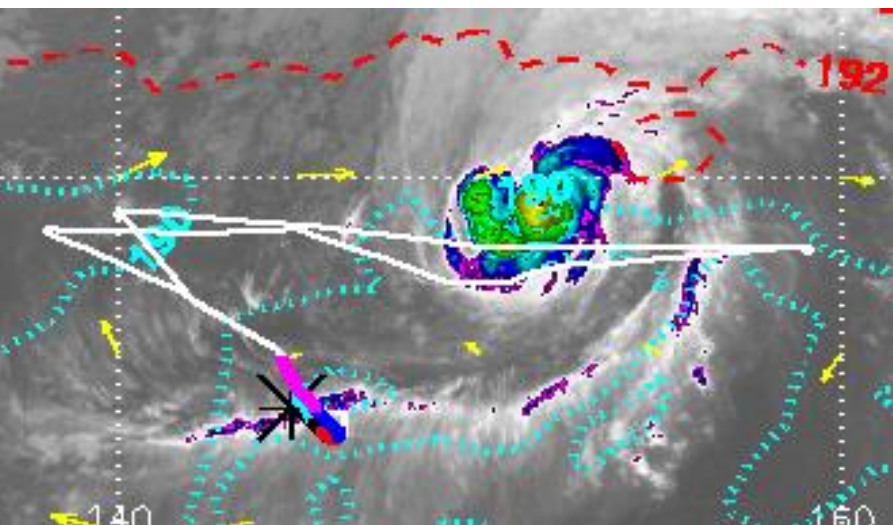
March 4-5 climbout through cirrus



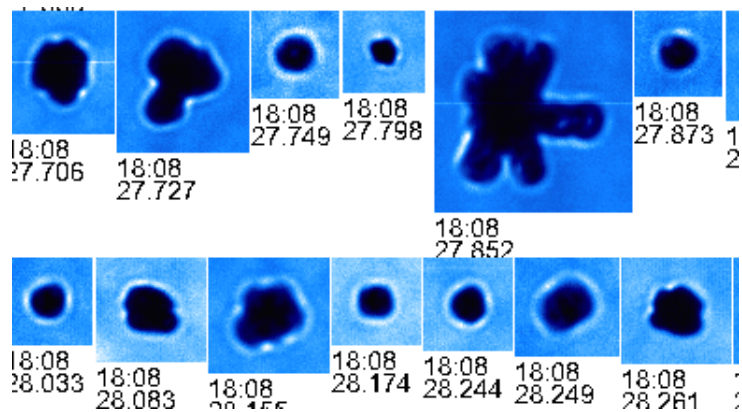
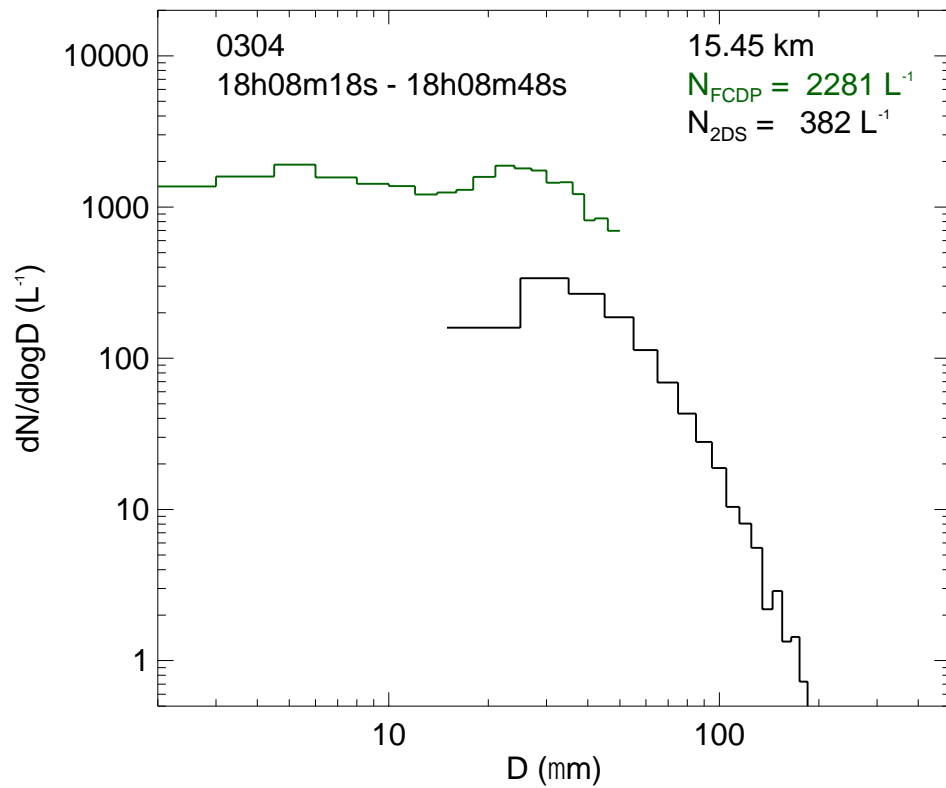
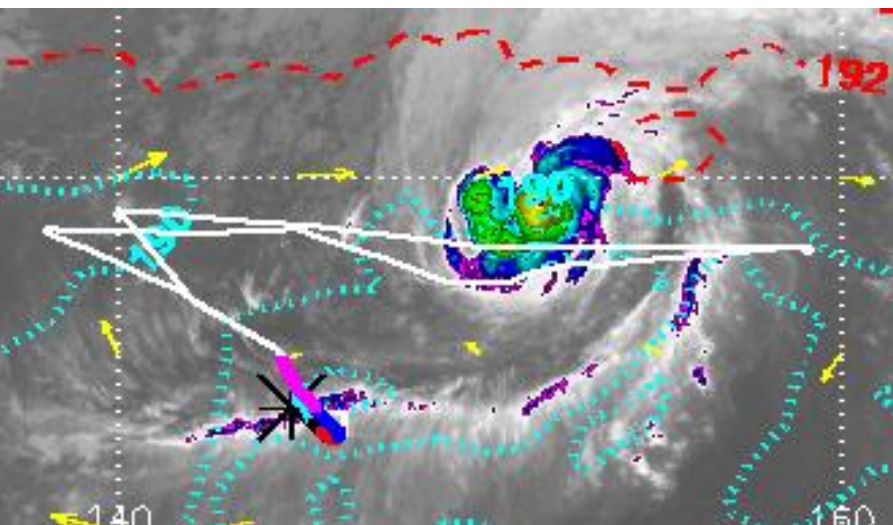
March 4-5 climbout through cirrus



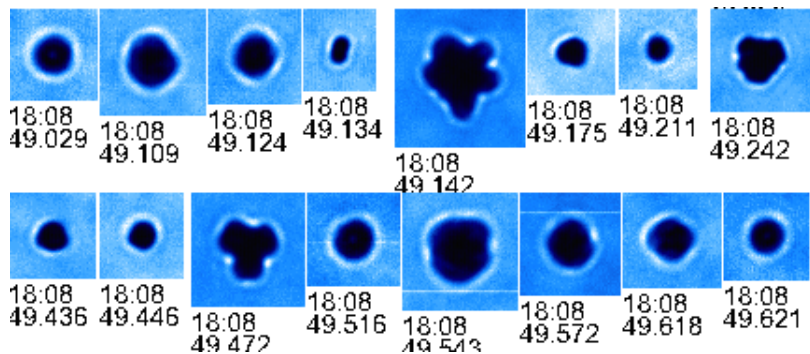
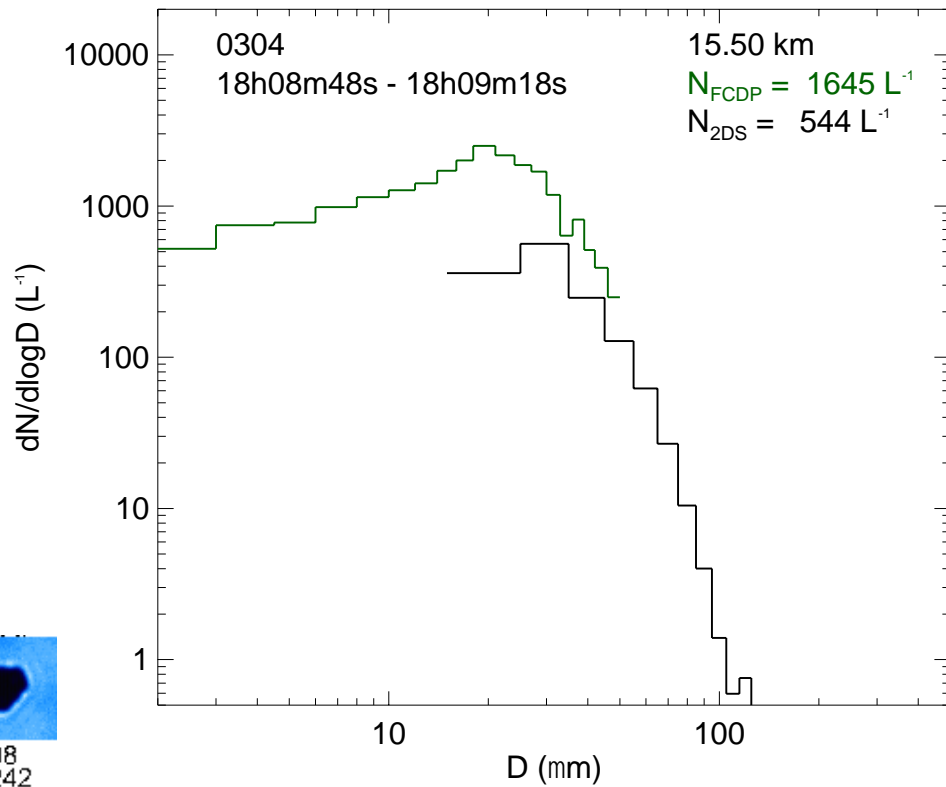
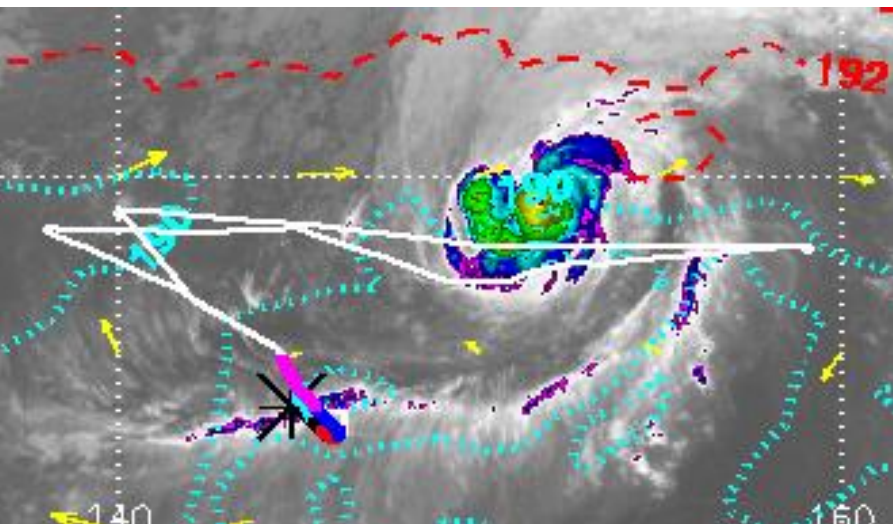
March 4-5 climbout through cirrus



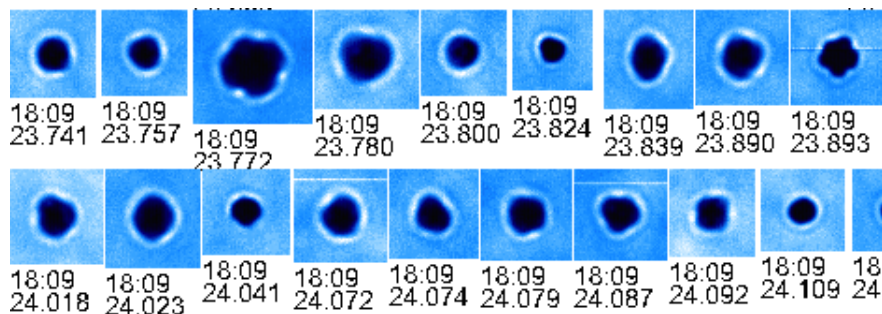
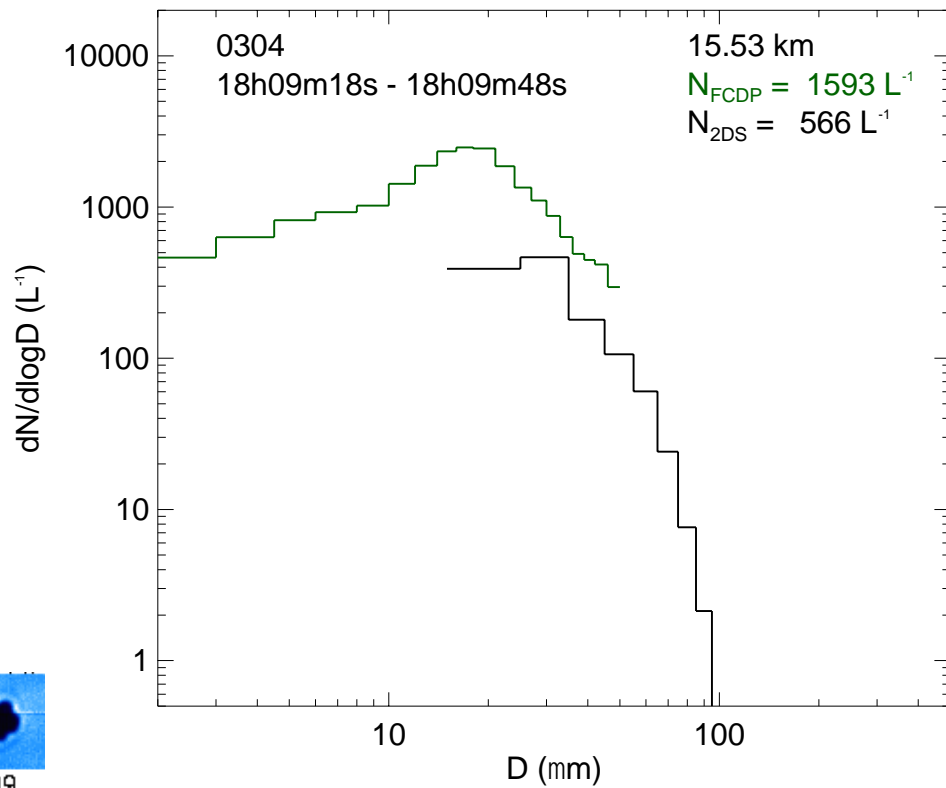
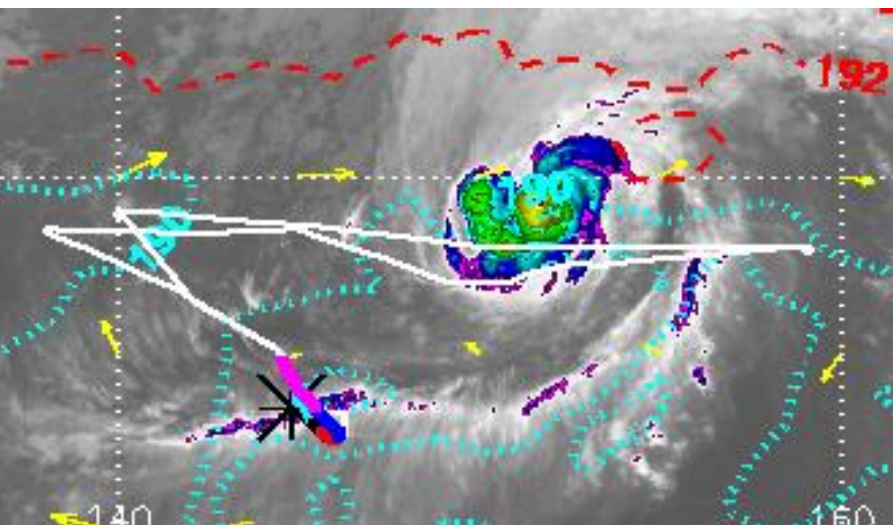
March 4-5 climbout through cirrus



March 4-5 climbout through cirrus

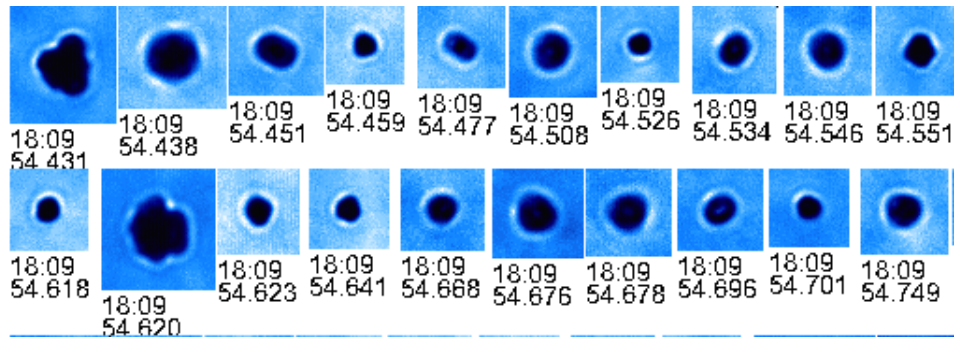
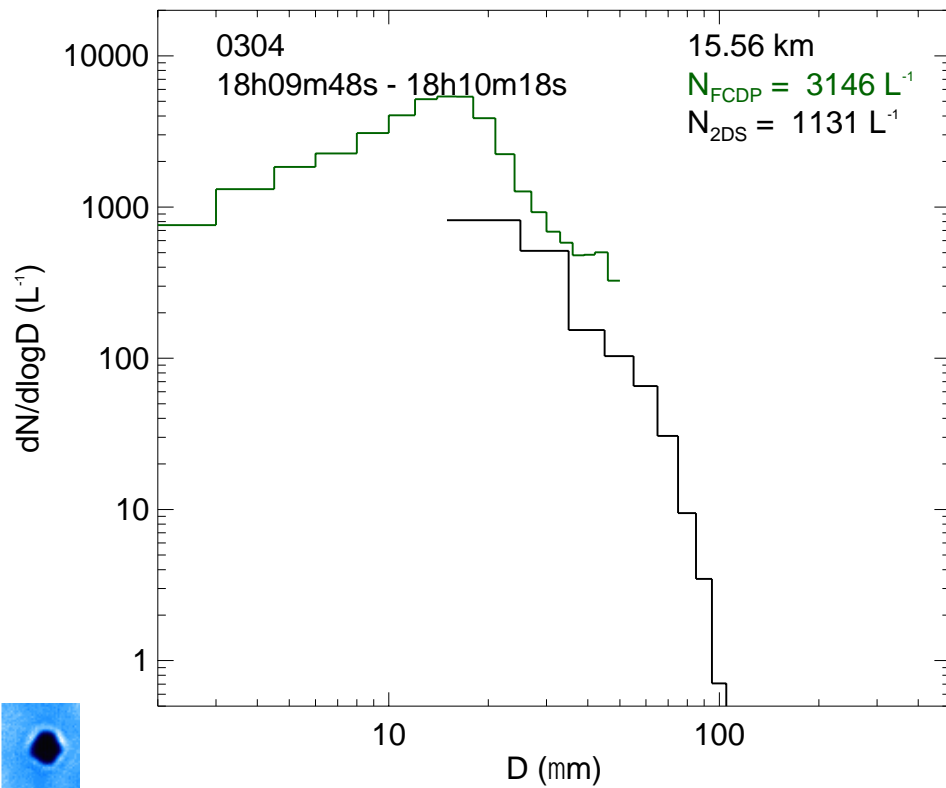
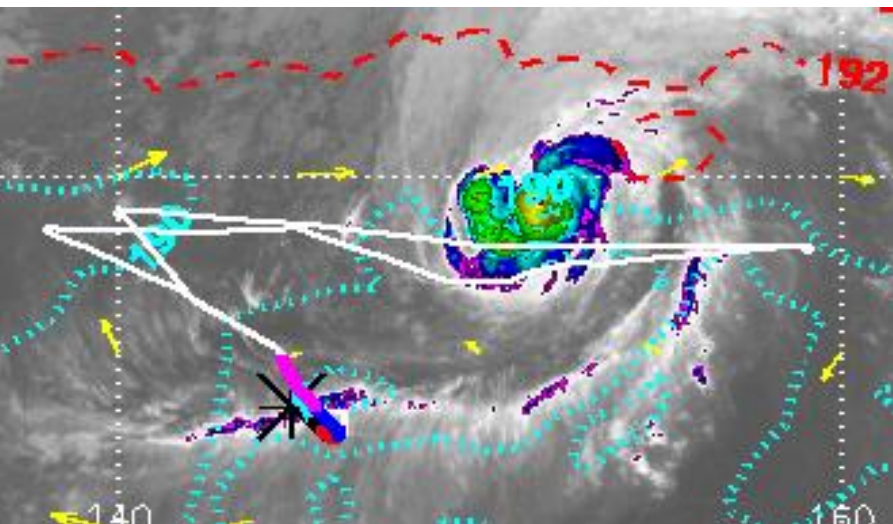


March 4-5 climbout through cirrus

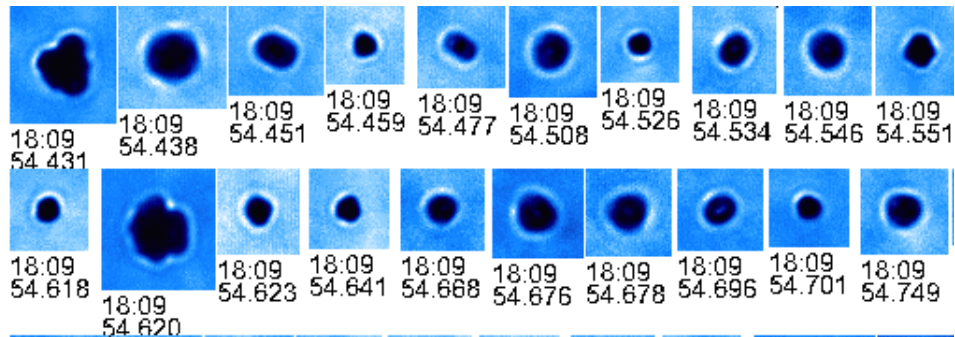
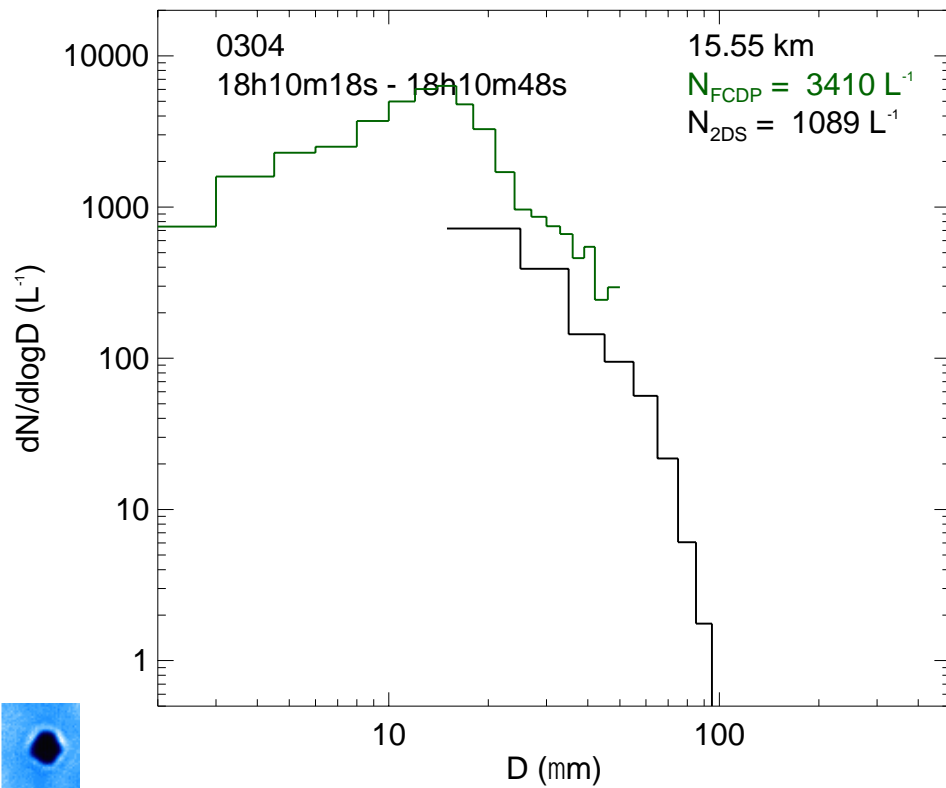
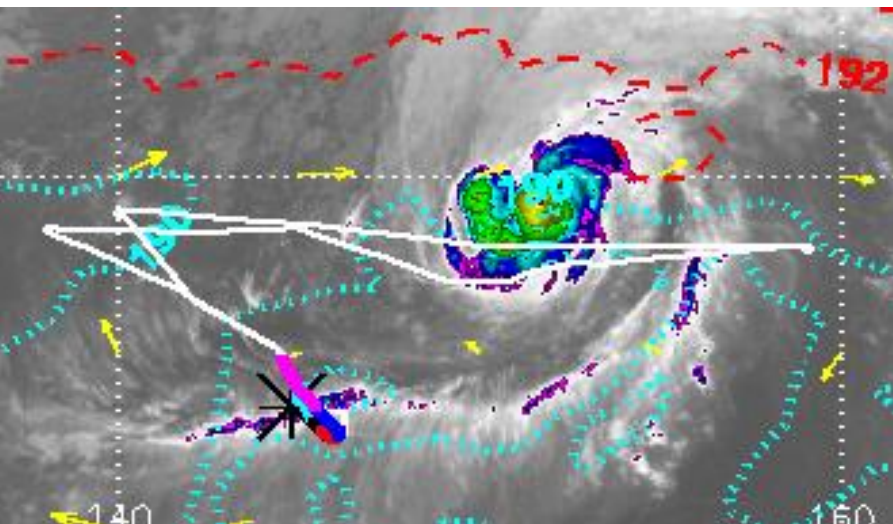


Only small crystals near cloud top

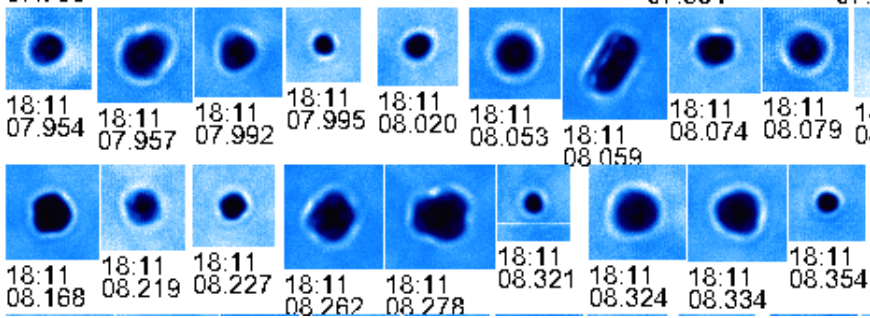
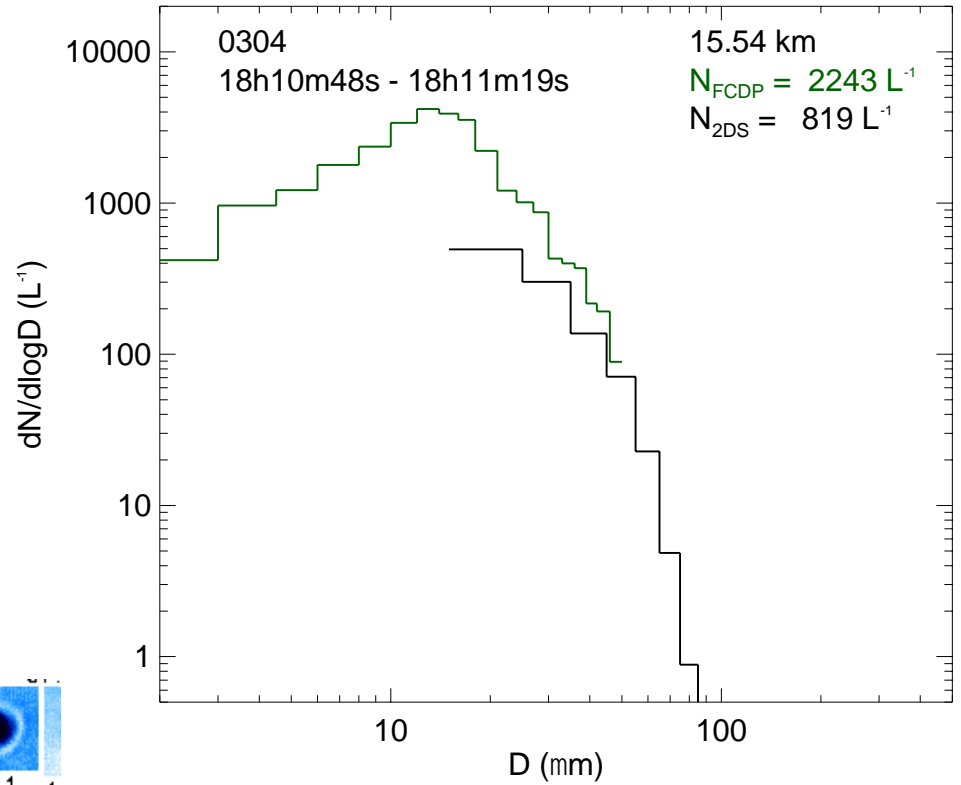
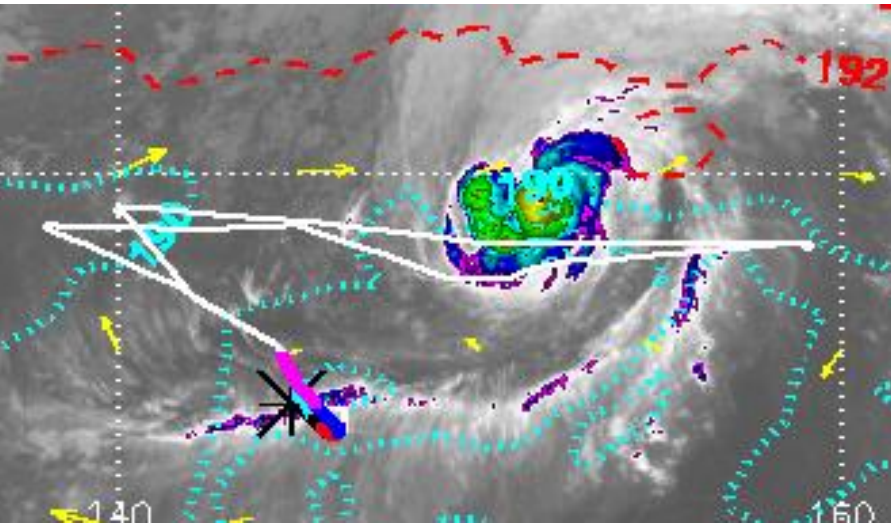
March 4-5 climbout through cirrus



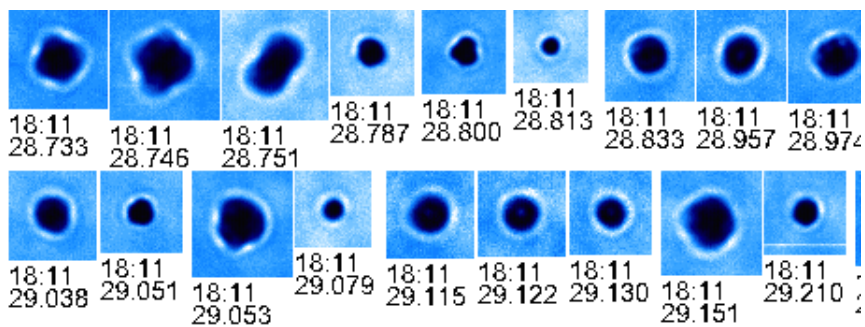
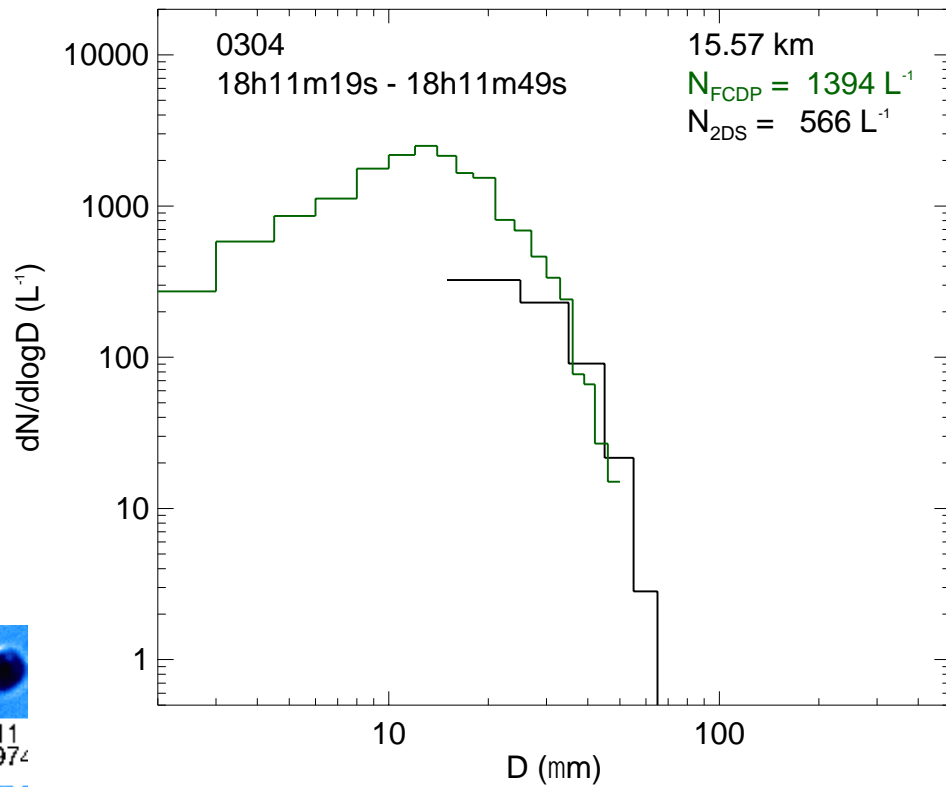
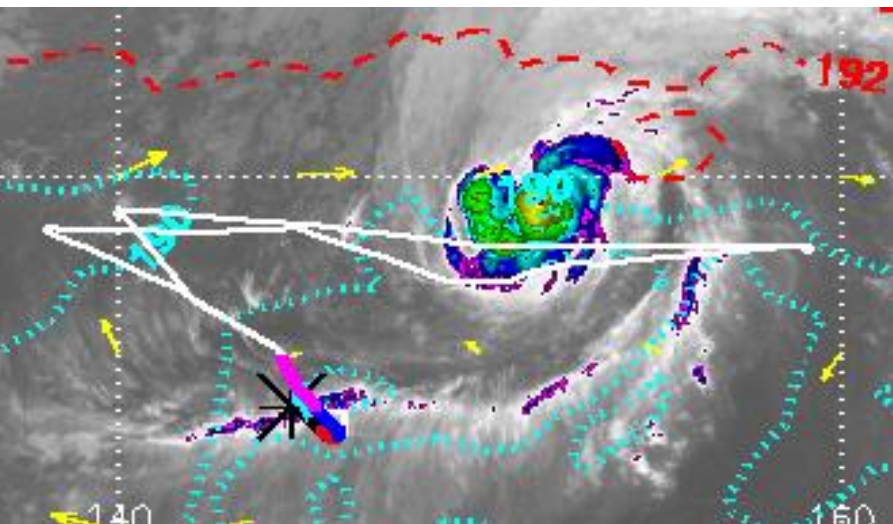
March 4-5 climbout through cirrus



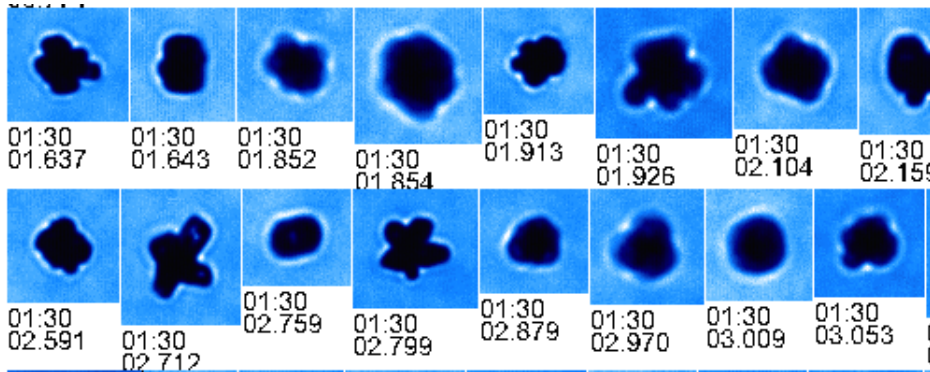
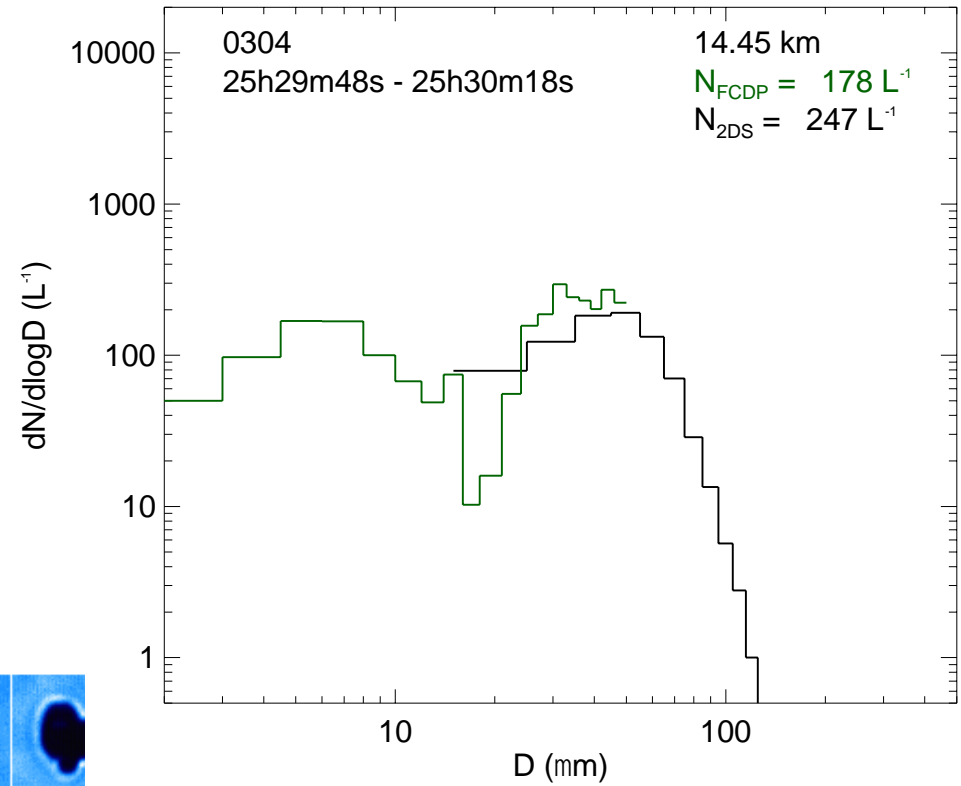
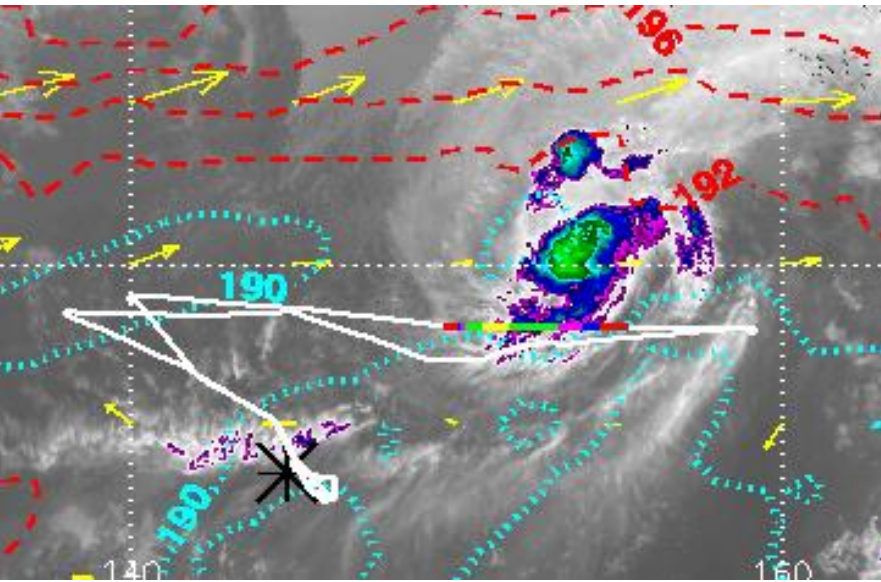
March 4-5 climbout through cirrus



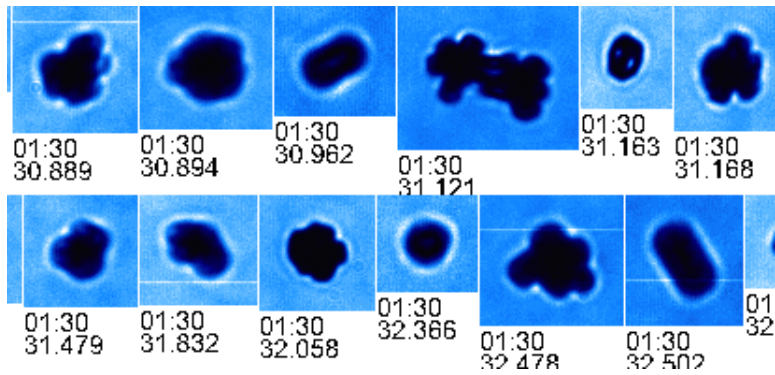
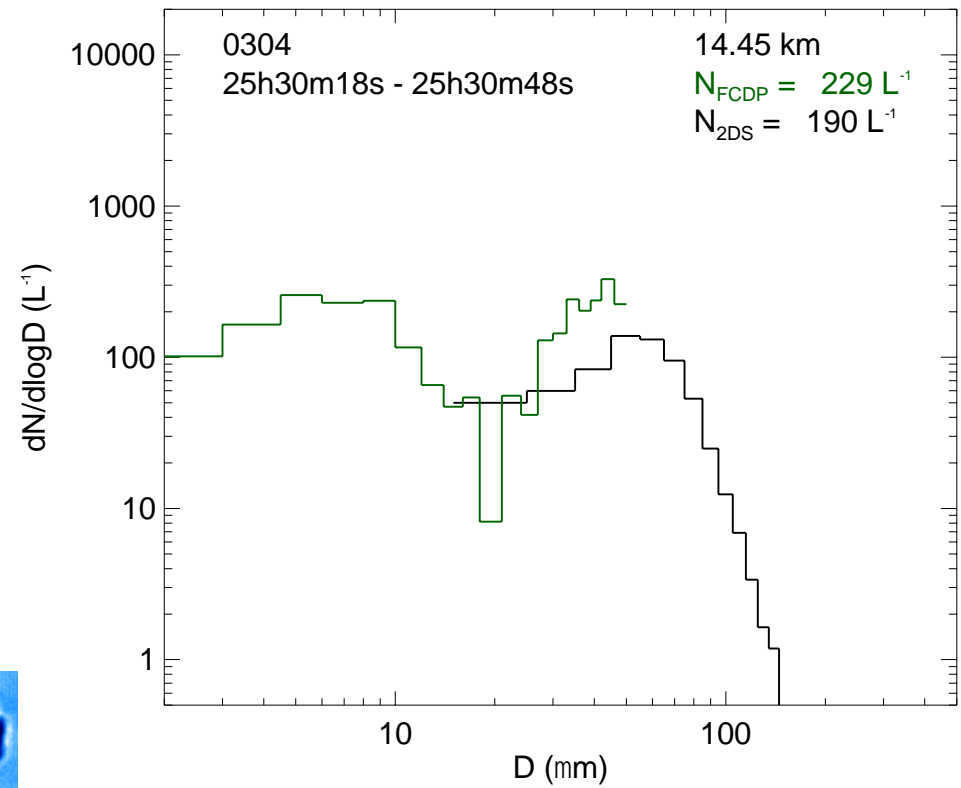
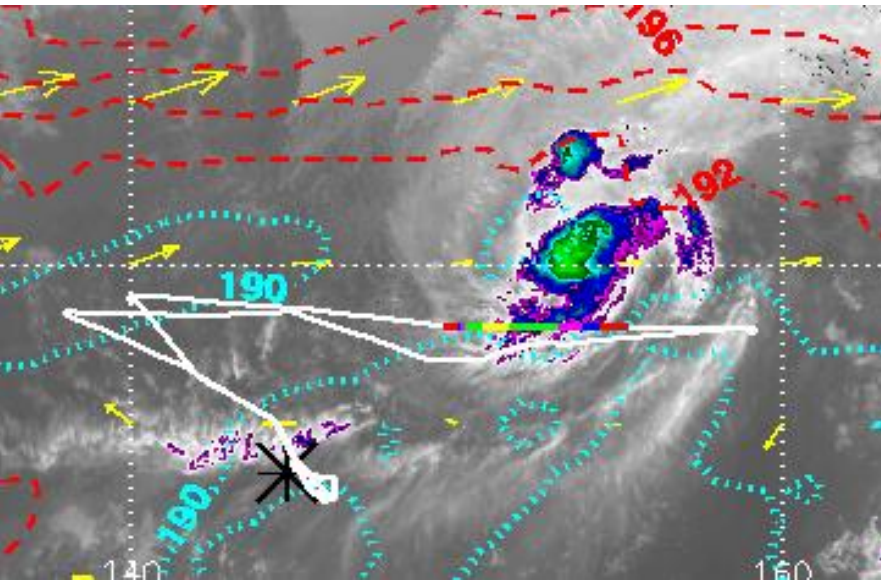
March 4-5 climbout through cirrus



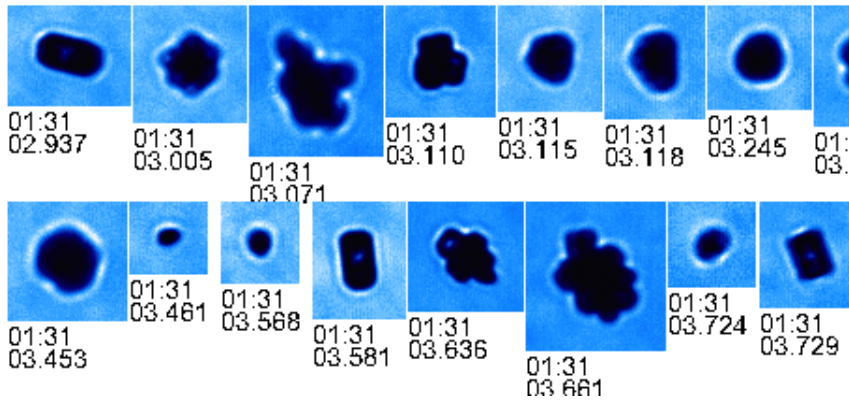
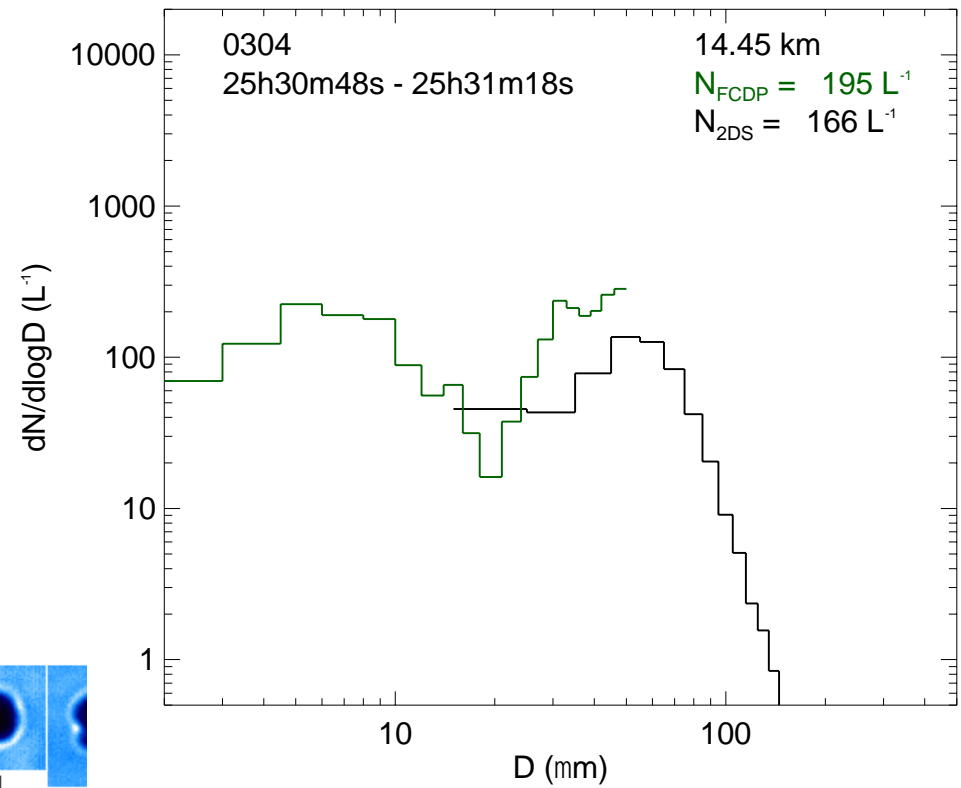
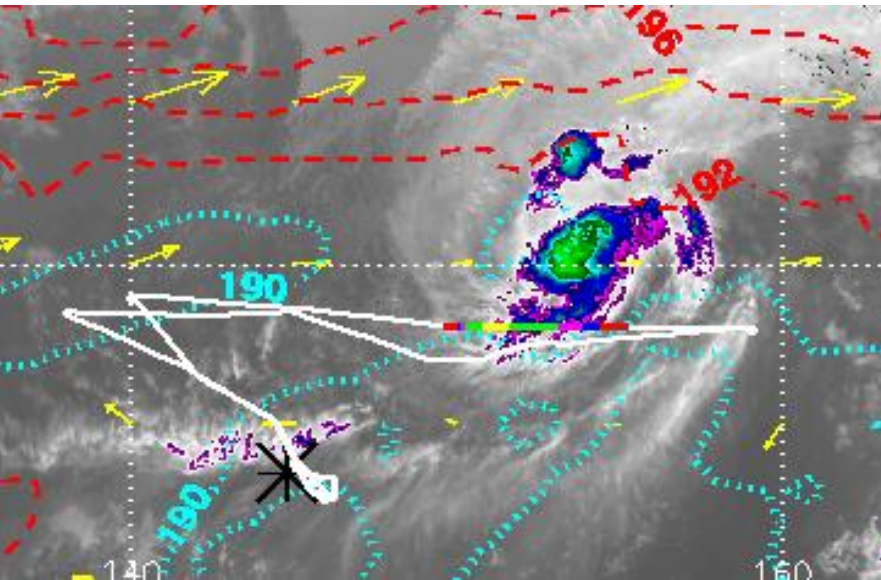
March 4-5 closest approach to Faxai



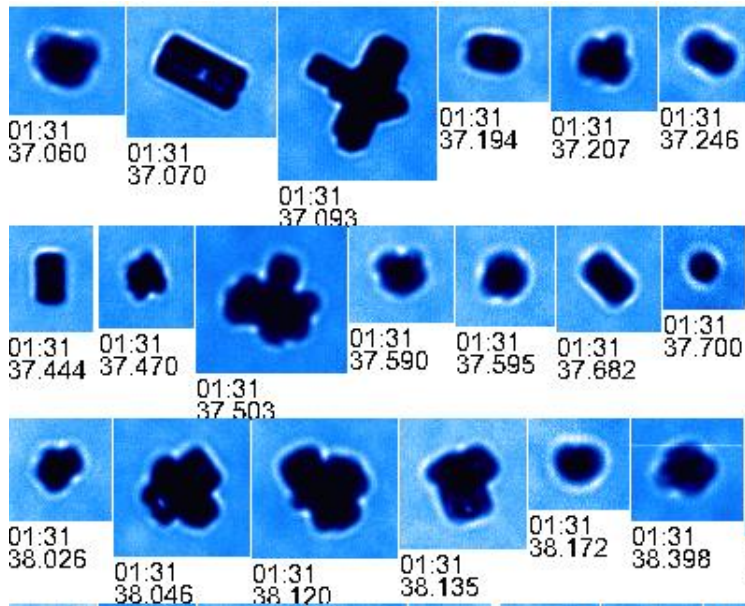
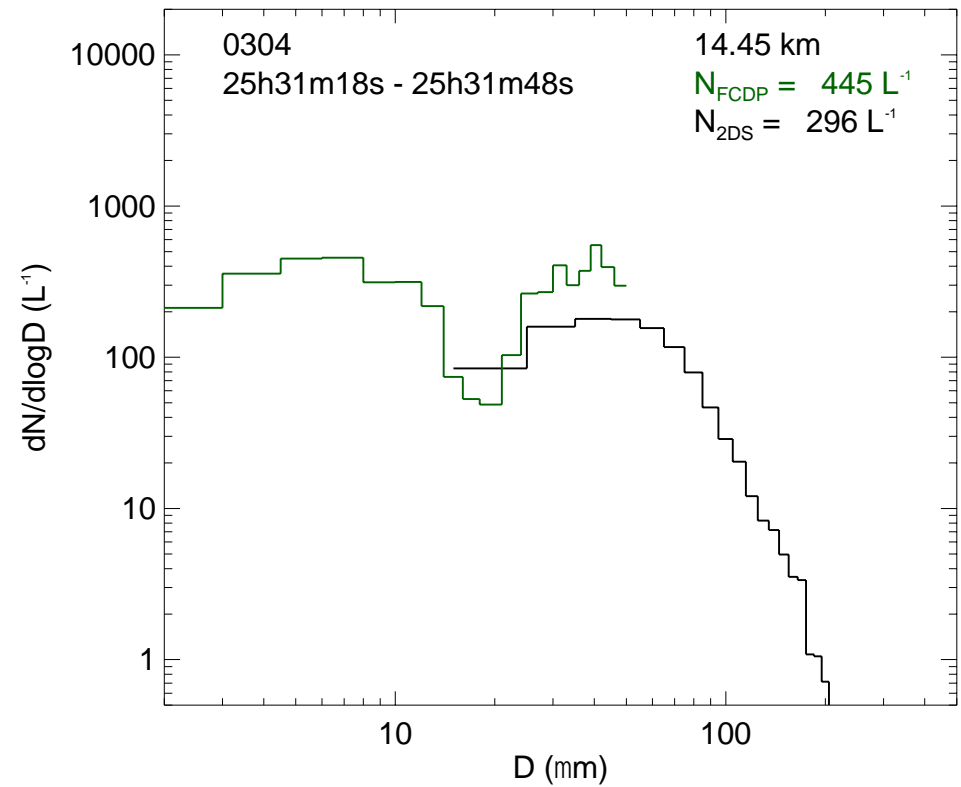
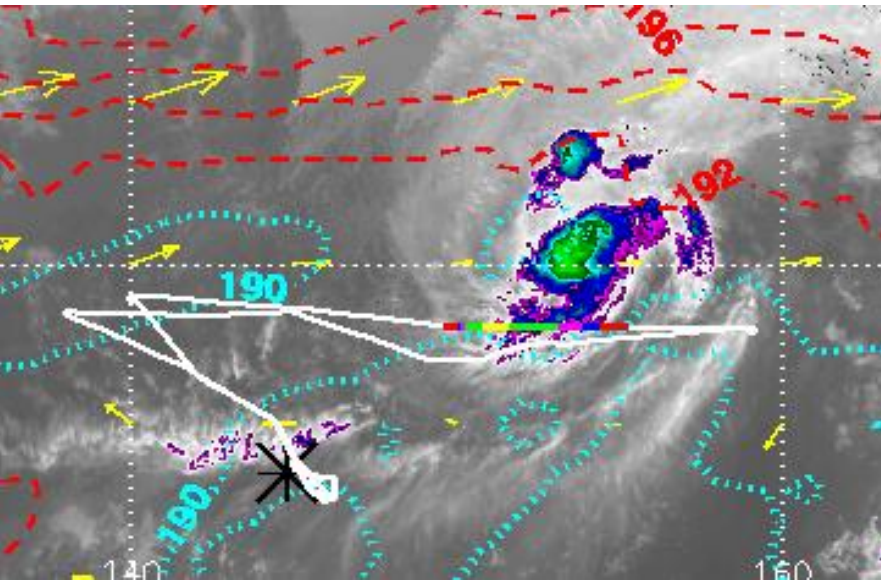
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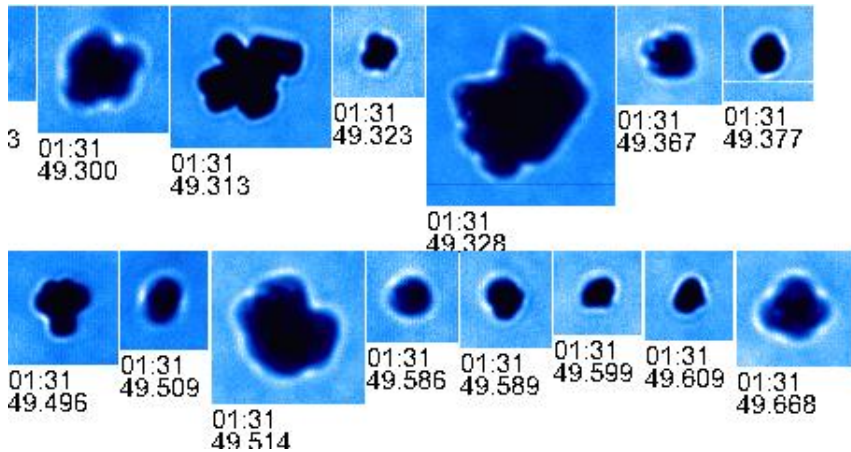
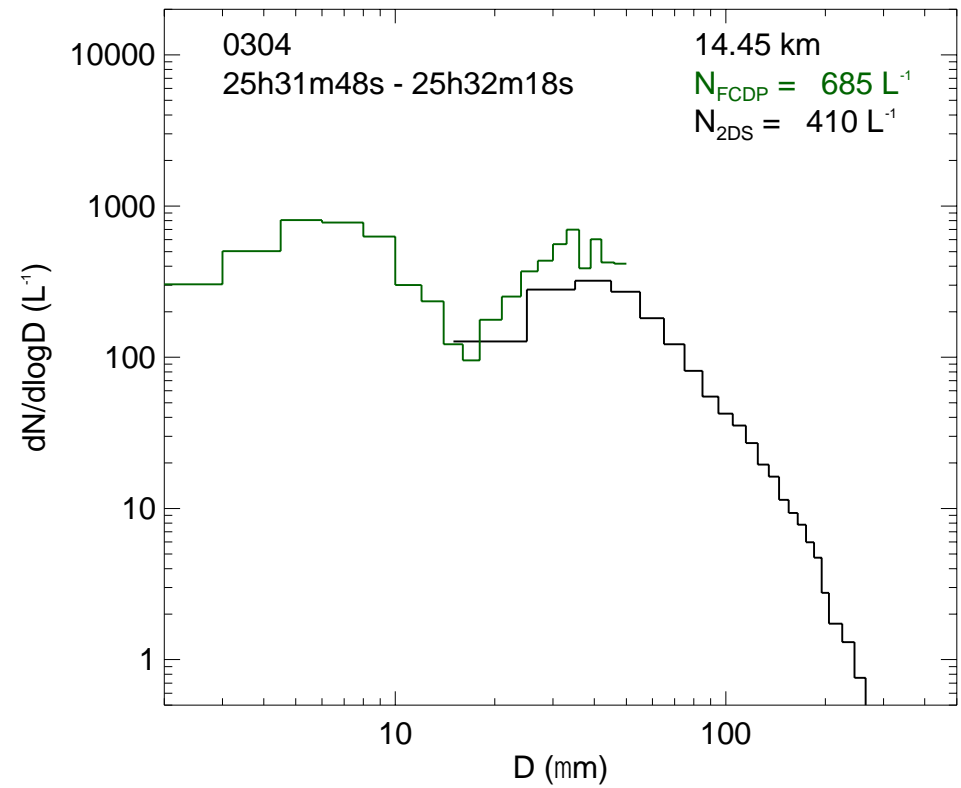
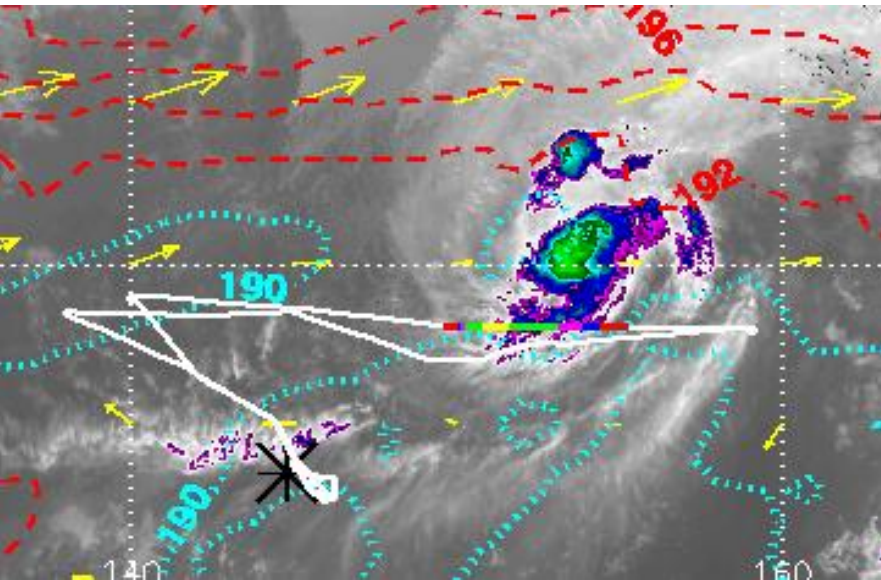
March 4-5 closest approach to Faxai



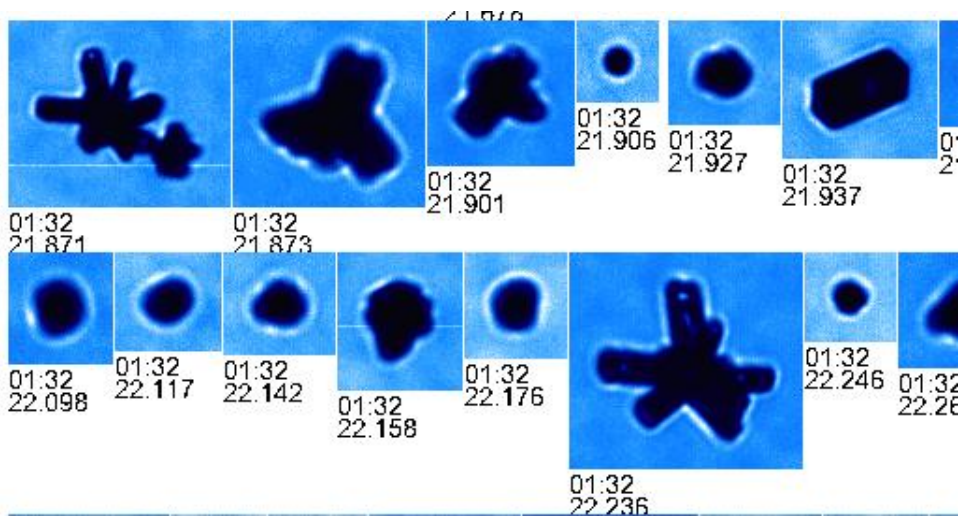
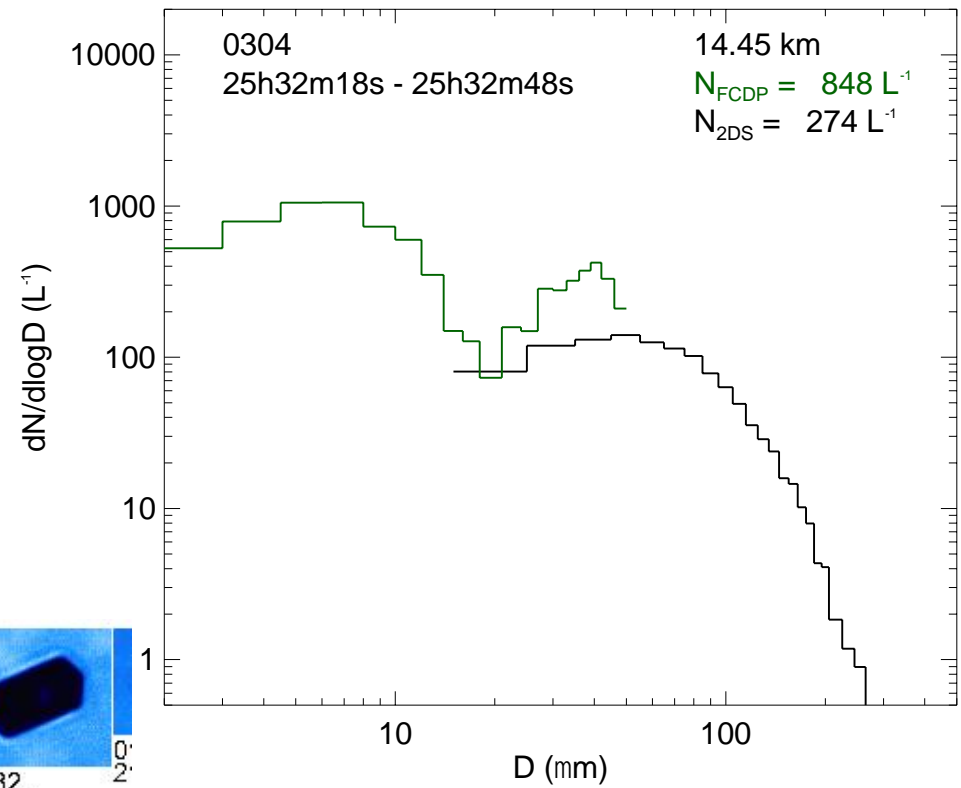
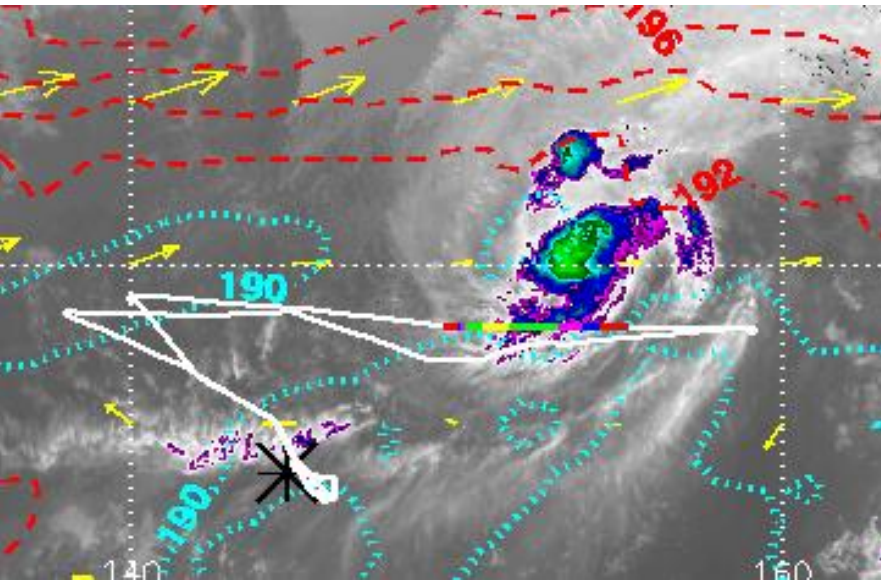
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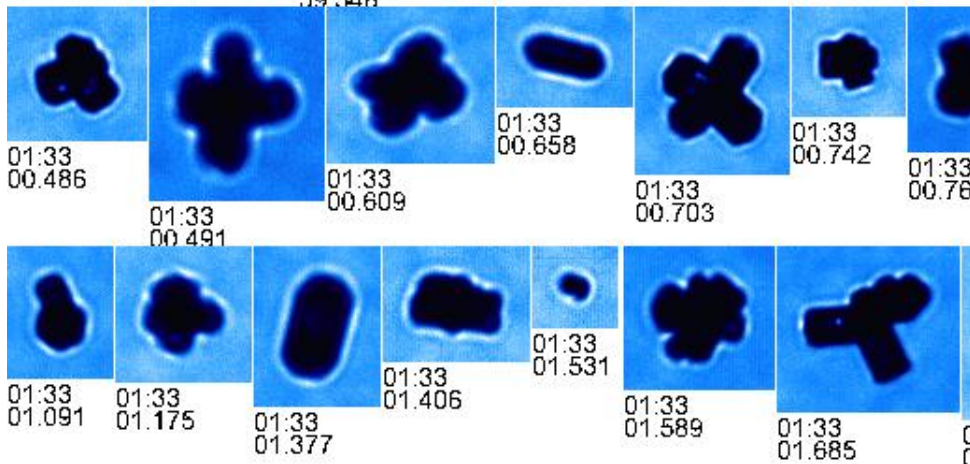
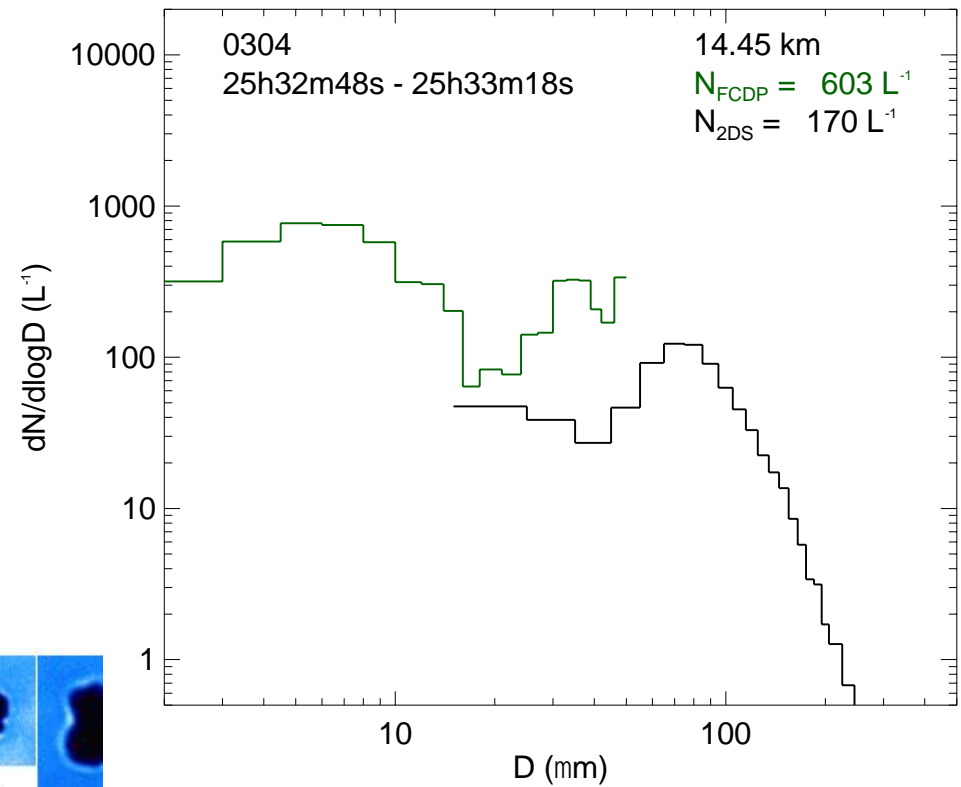
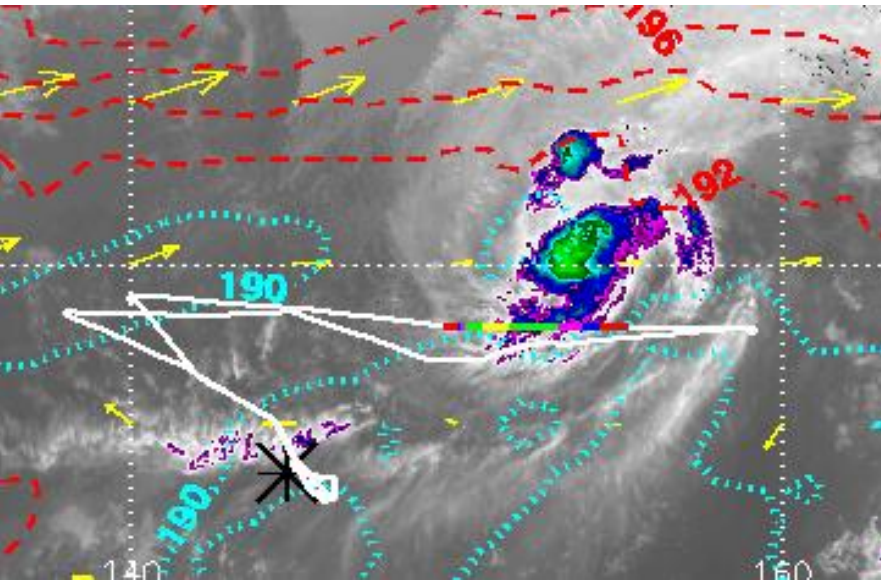
March 4-5 closest approach to Faxai



March 4-5 closest approach to Faxai

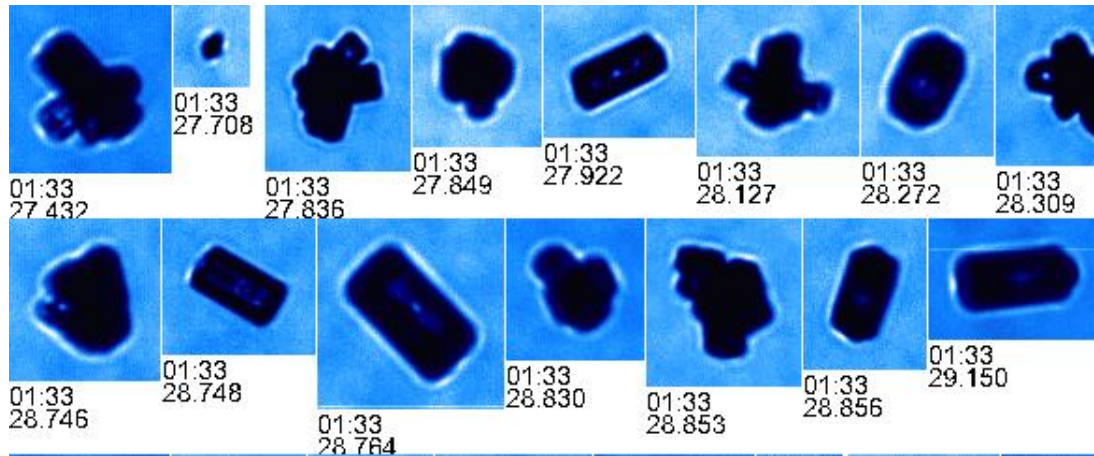
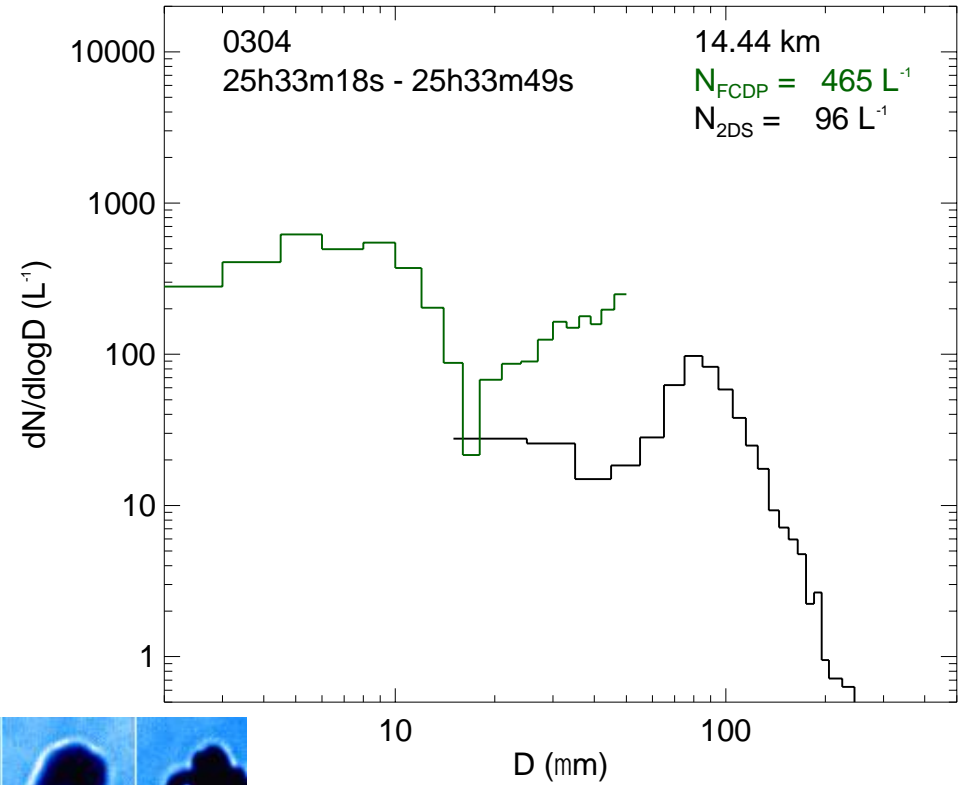
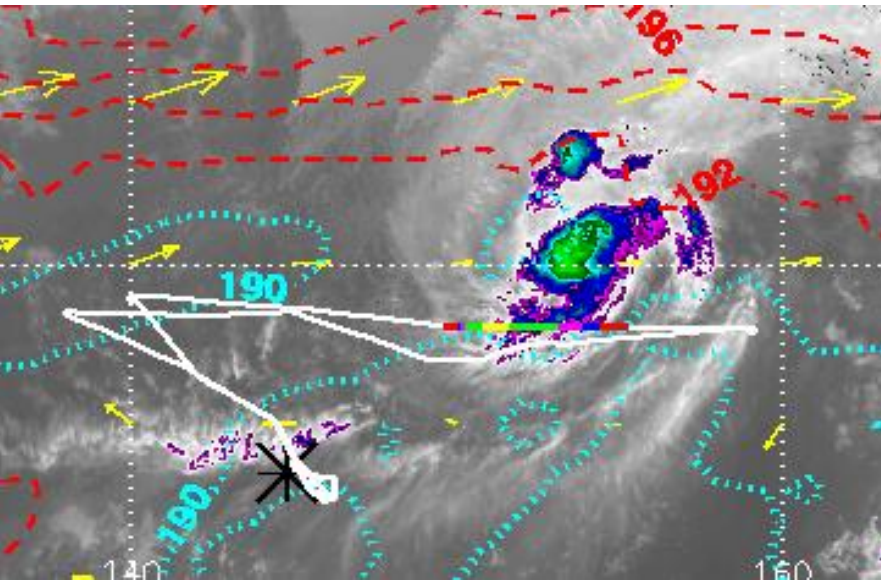


March 4-5 closest approach to Faxai

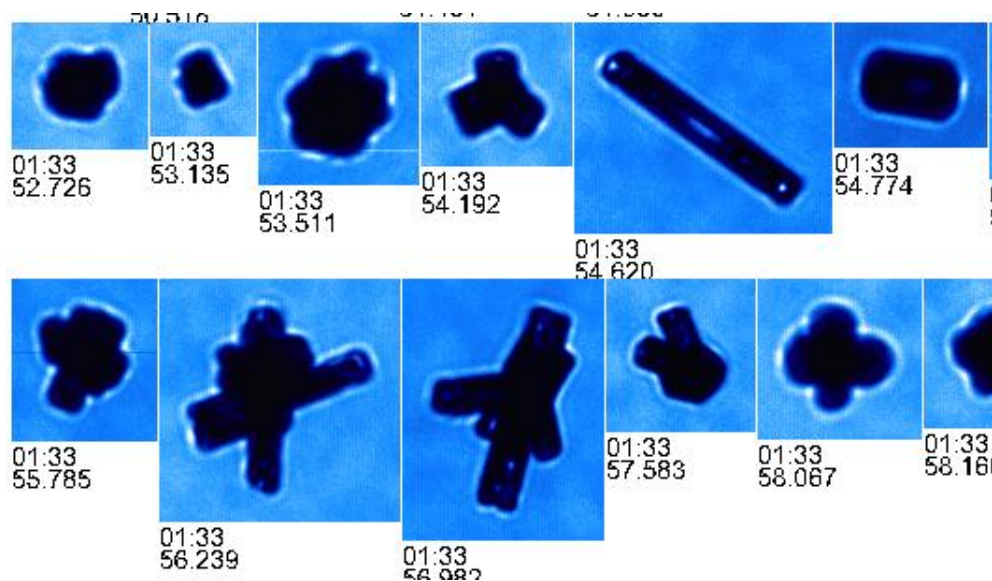
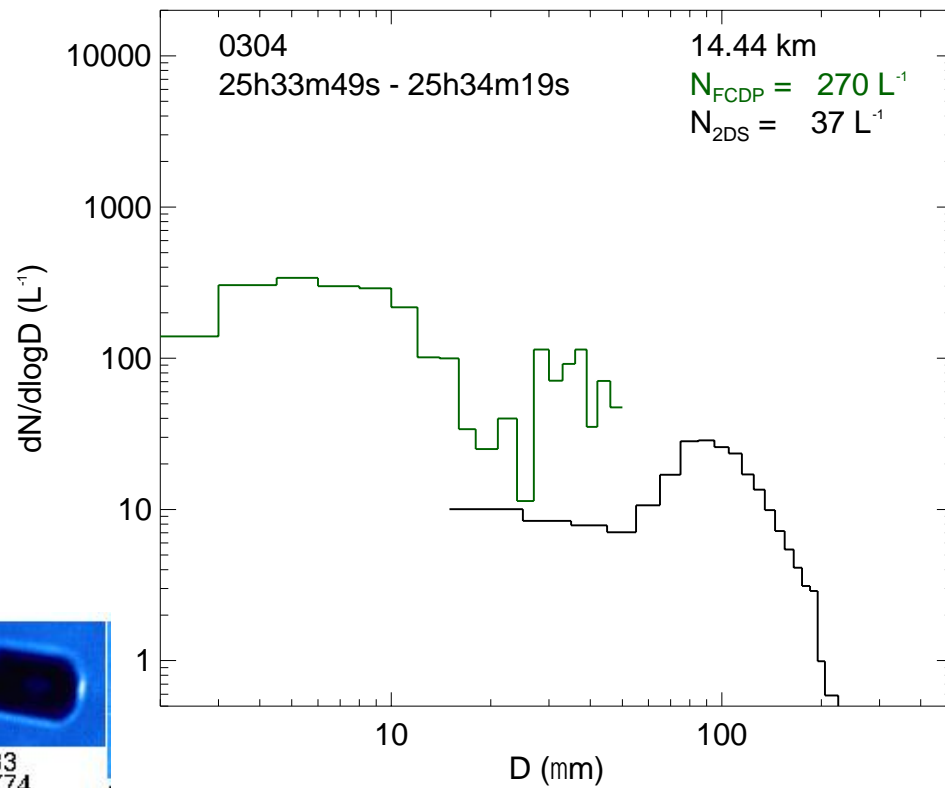
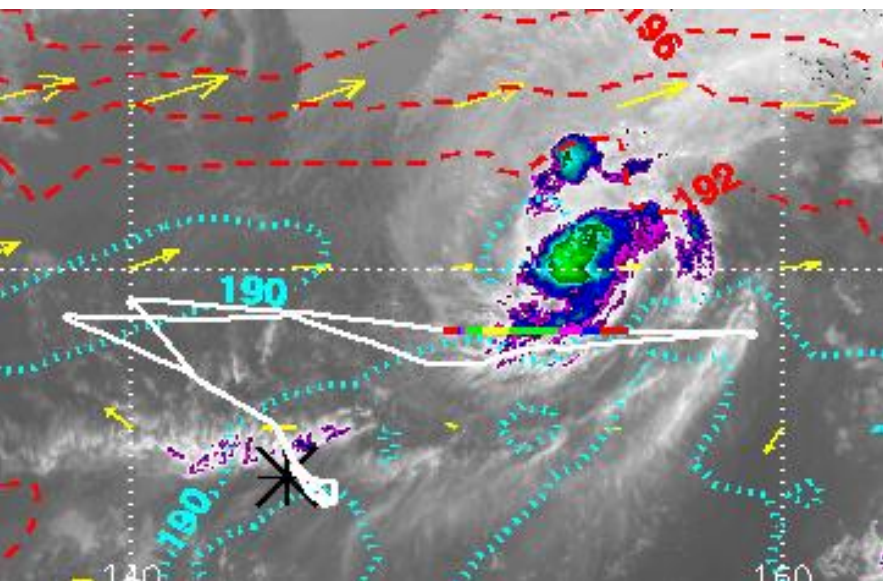


Mostly rosettes and budding rosettes

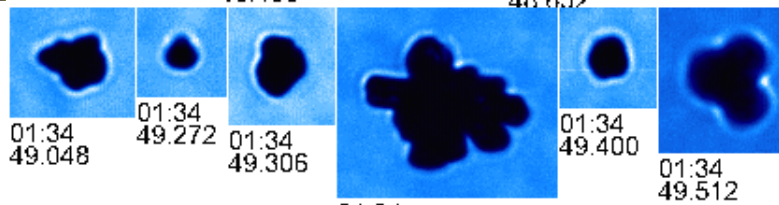
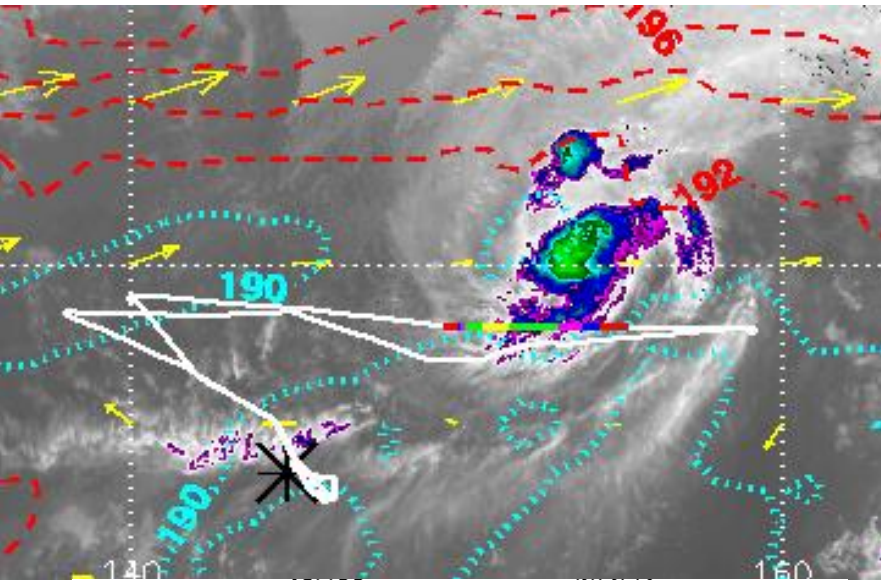
March 4-5 closest approach to Faxai



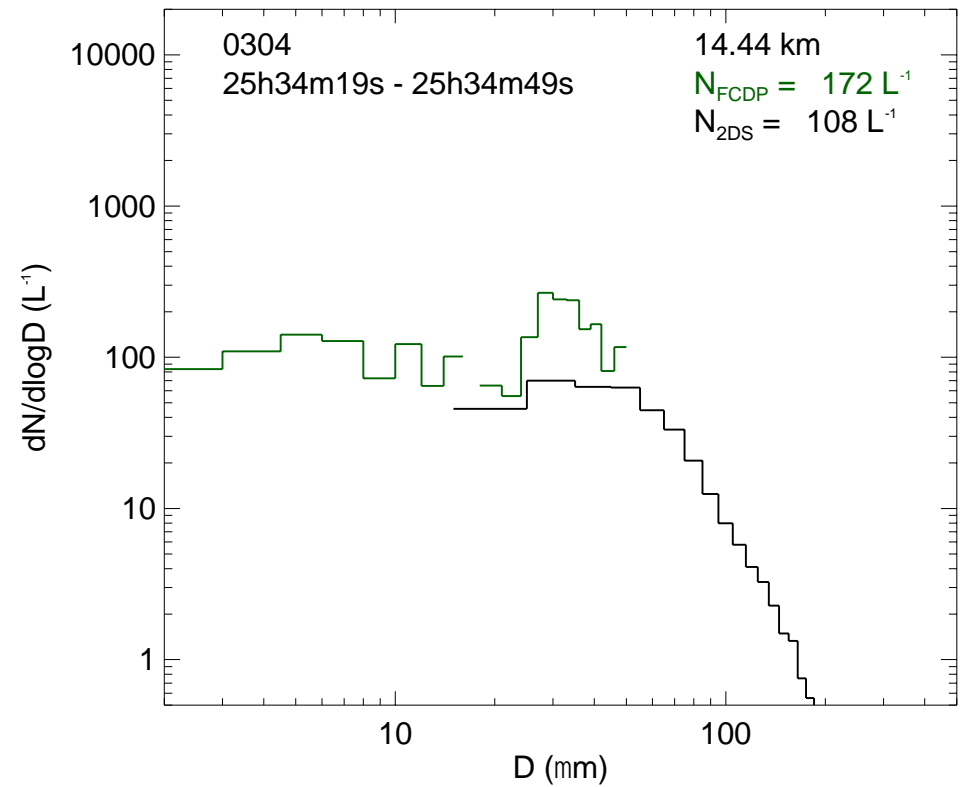
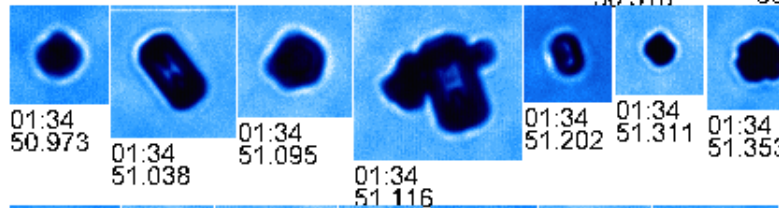
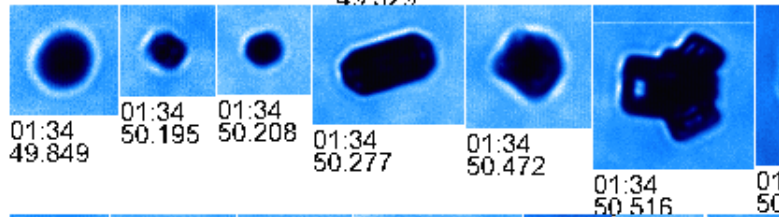
March 4-5 closest approach to Faxai



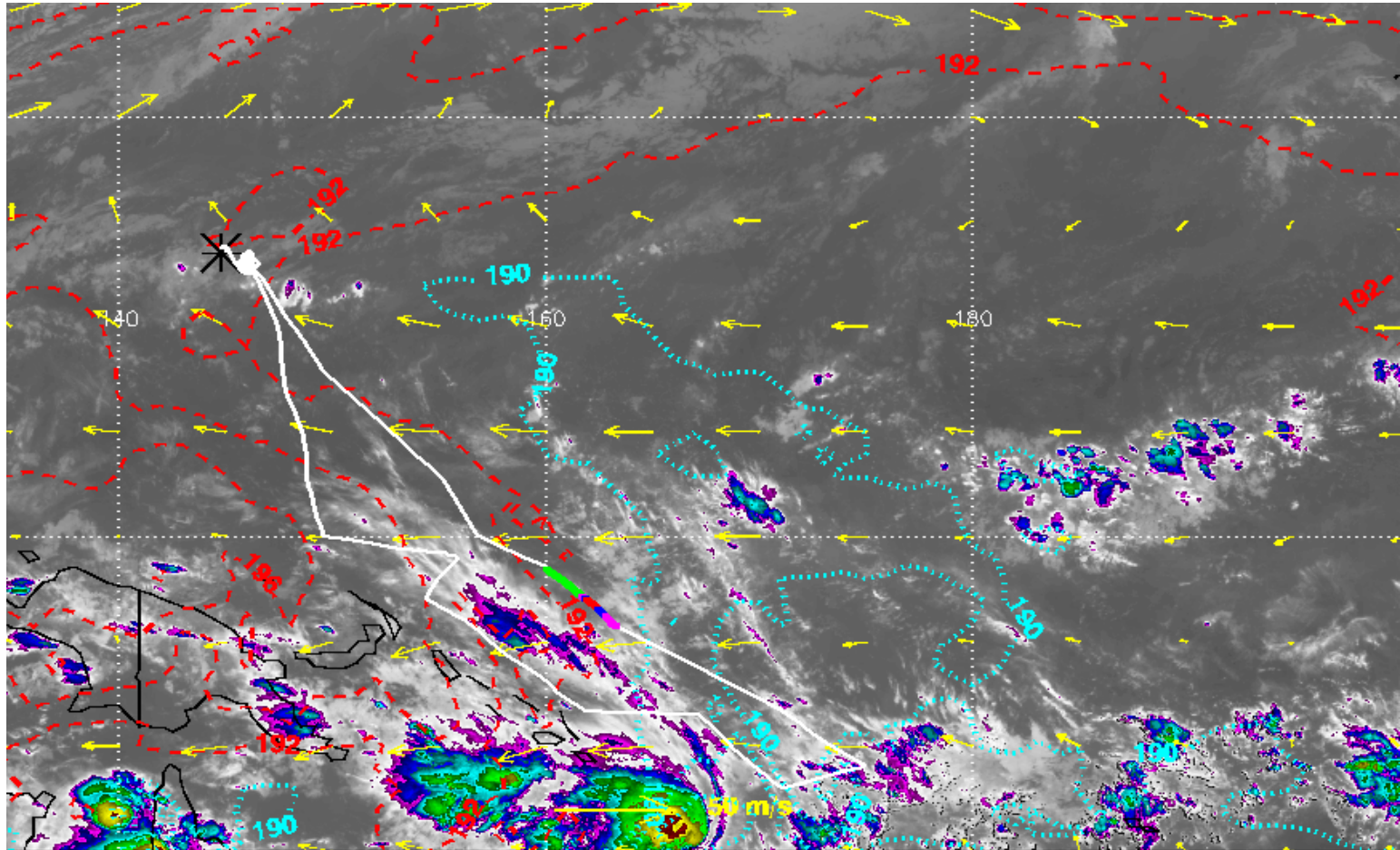
March 4-5 closest approach to Faxai



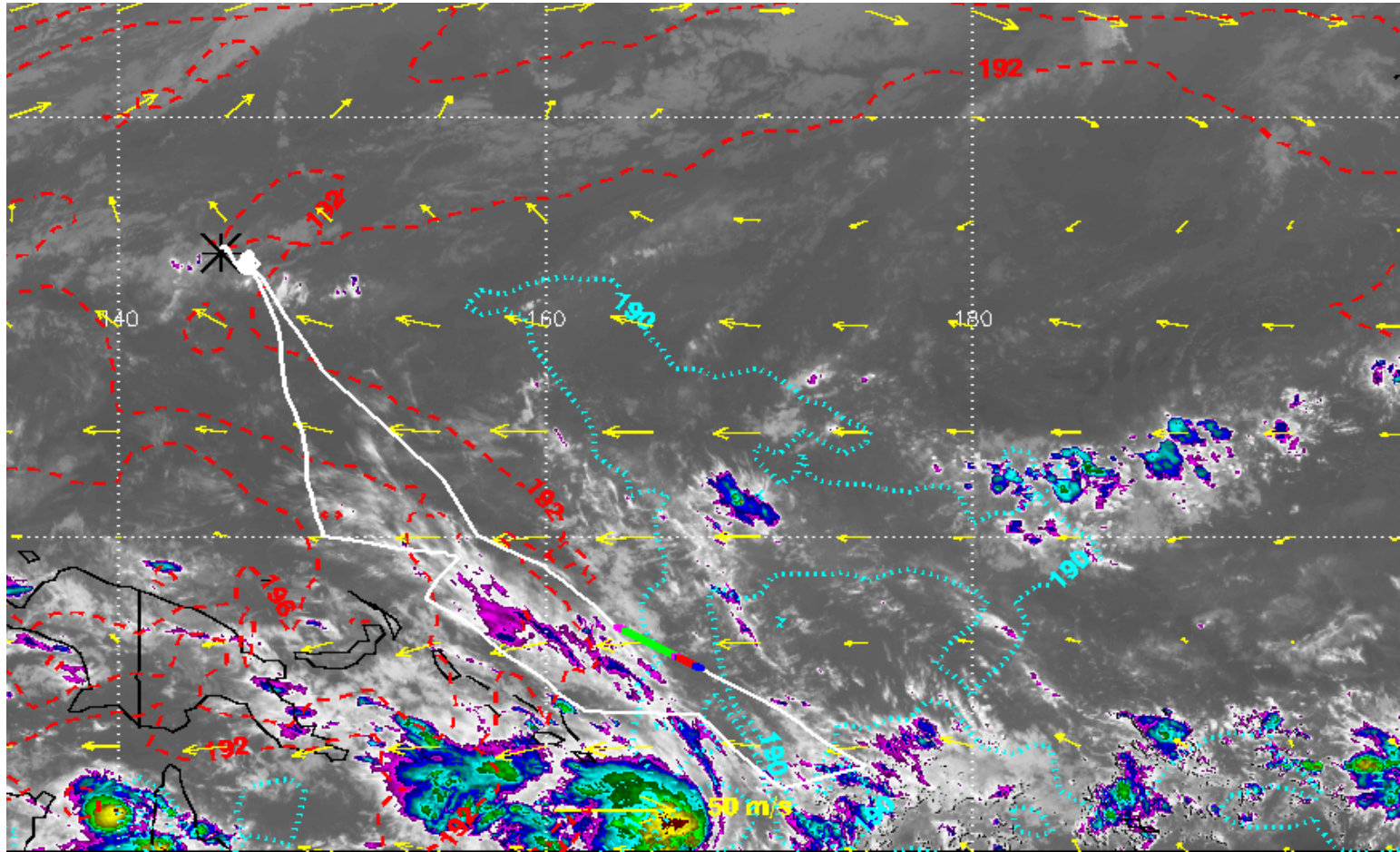
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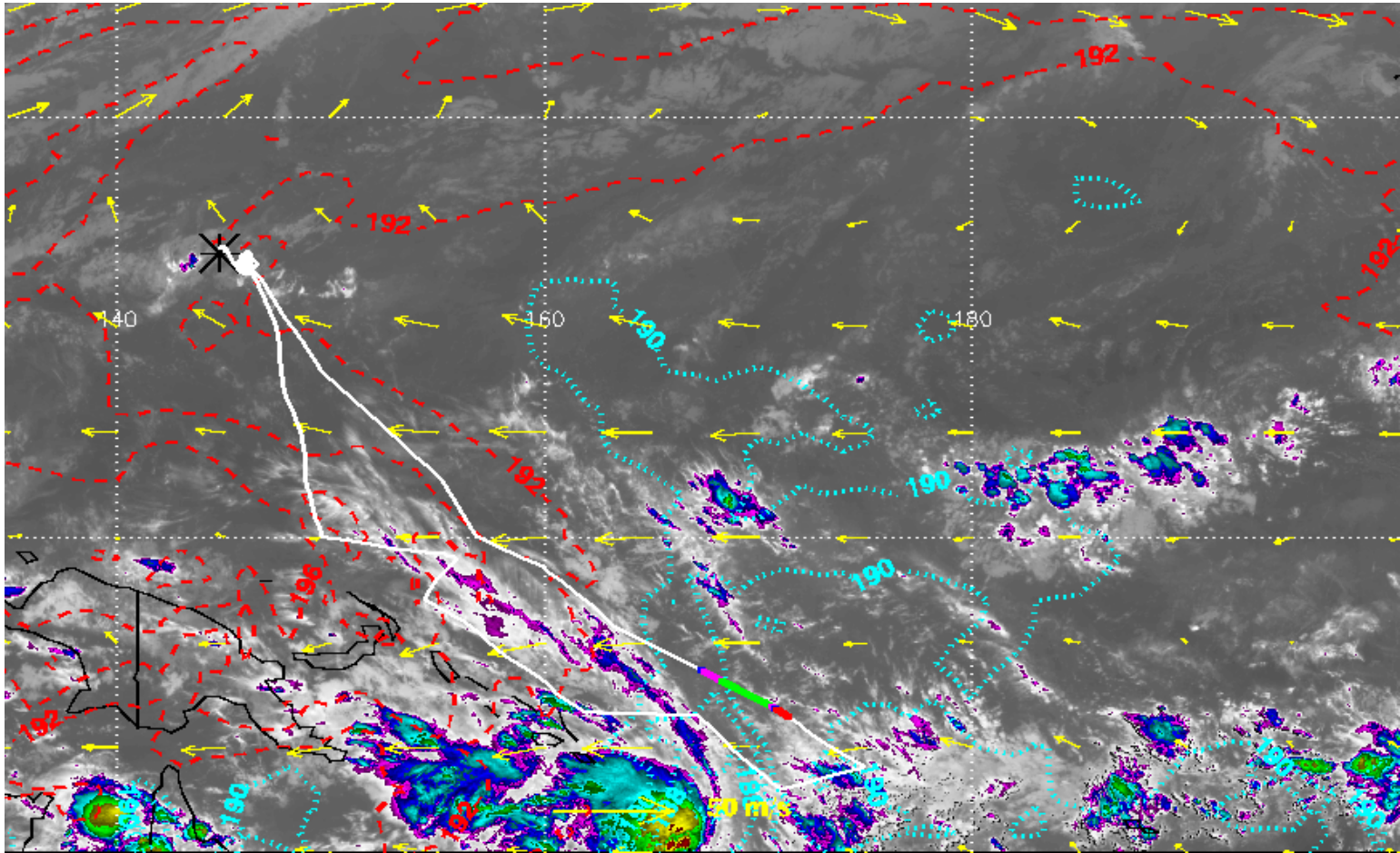
9-10 March Global Hawk flight (RF05)



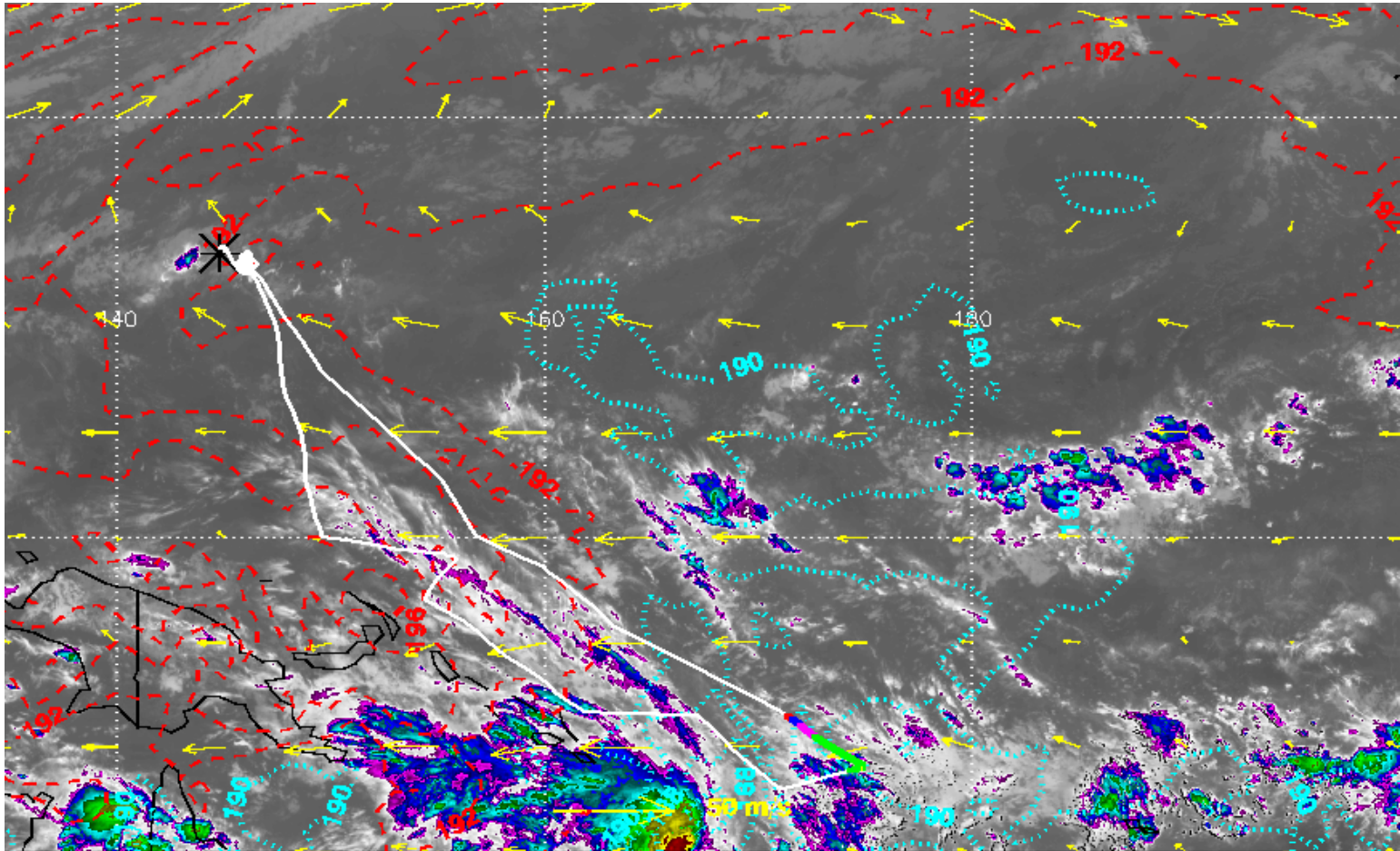
9-10 March Global Hawk flight (RF05)



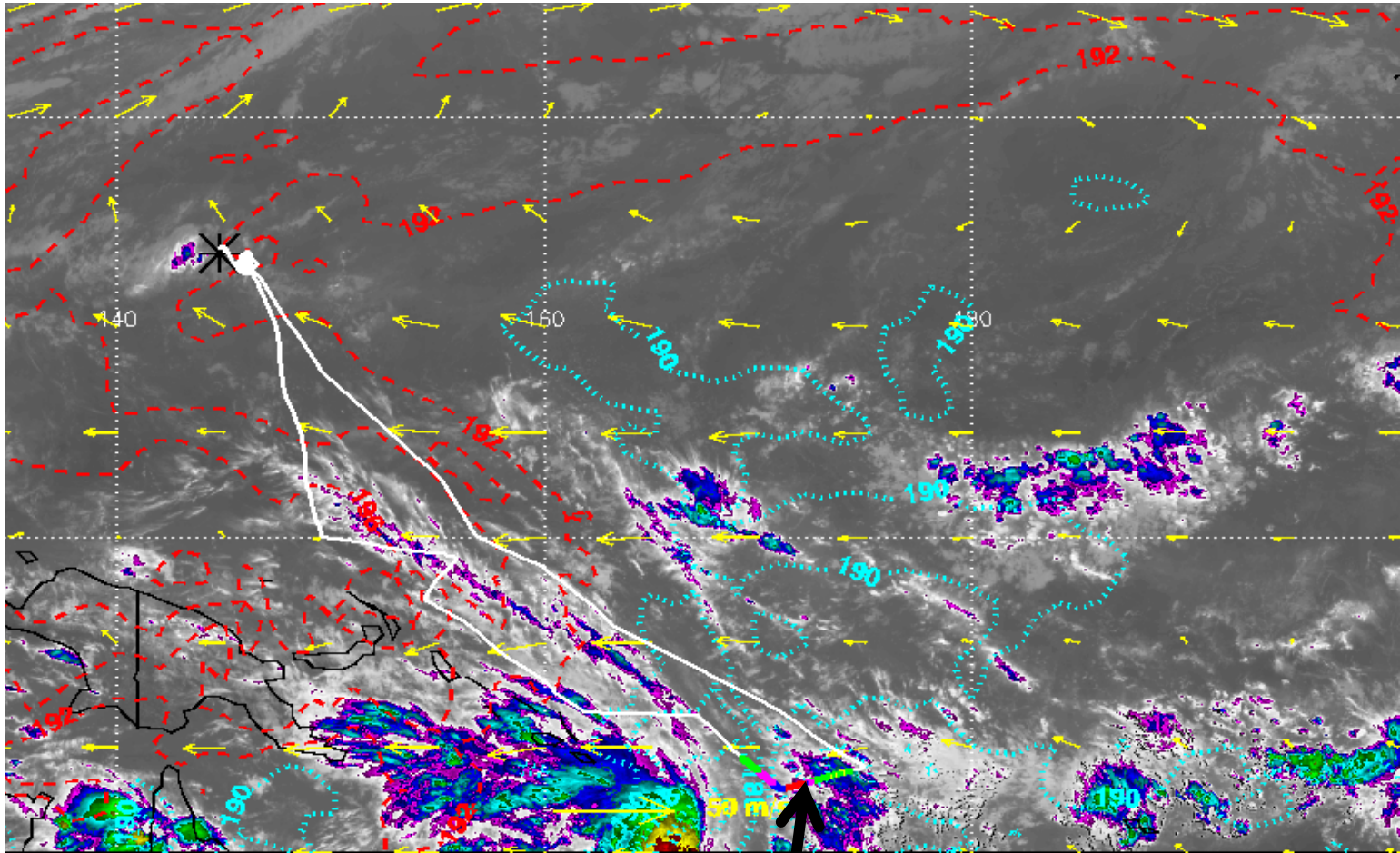
9-10 March Global Hawk flight (RF05)



9-10 March Global Hawk flight (RF05)

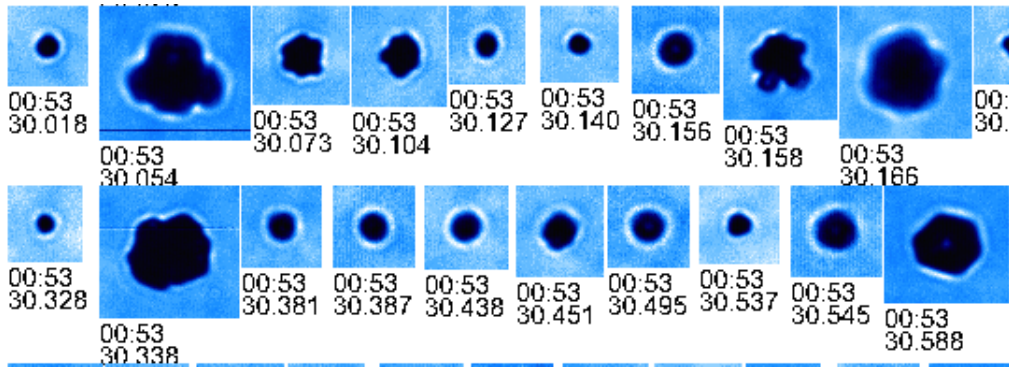
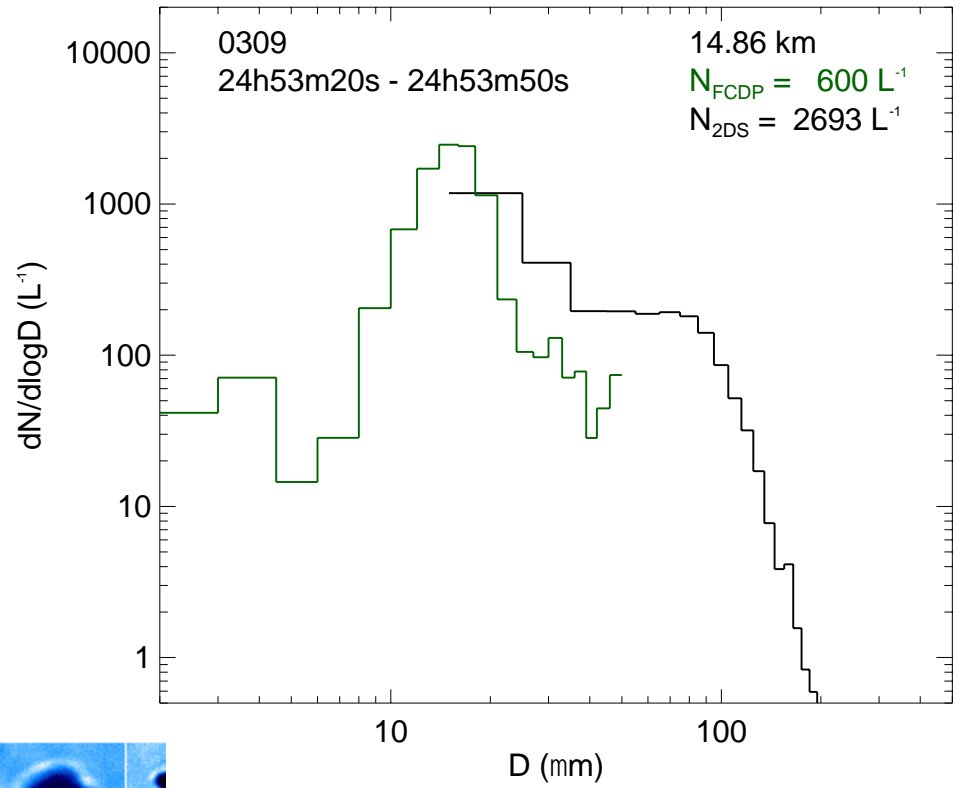
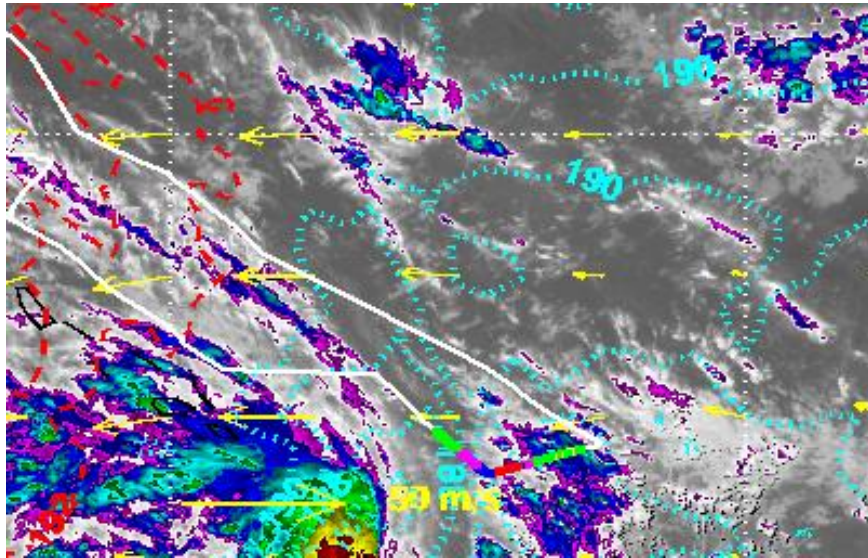


9-10 March Global Hawk flight (RF05)

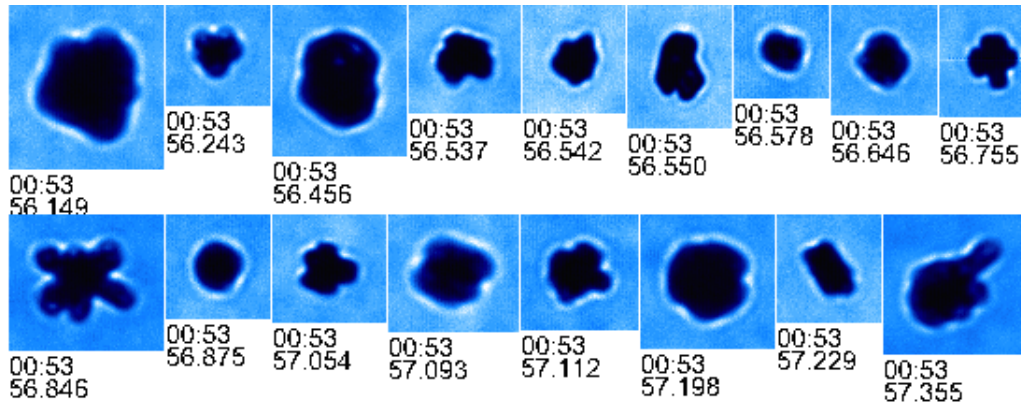
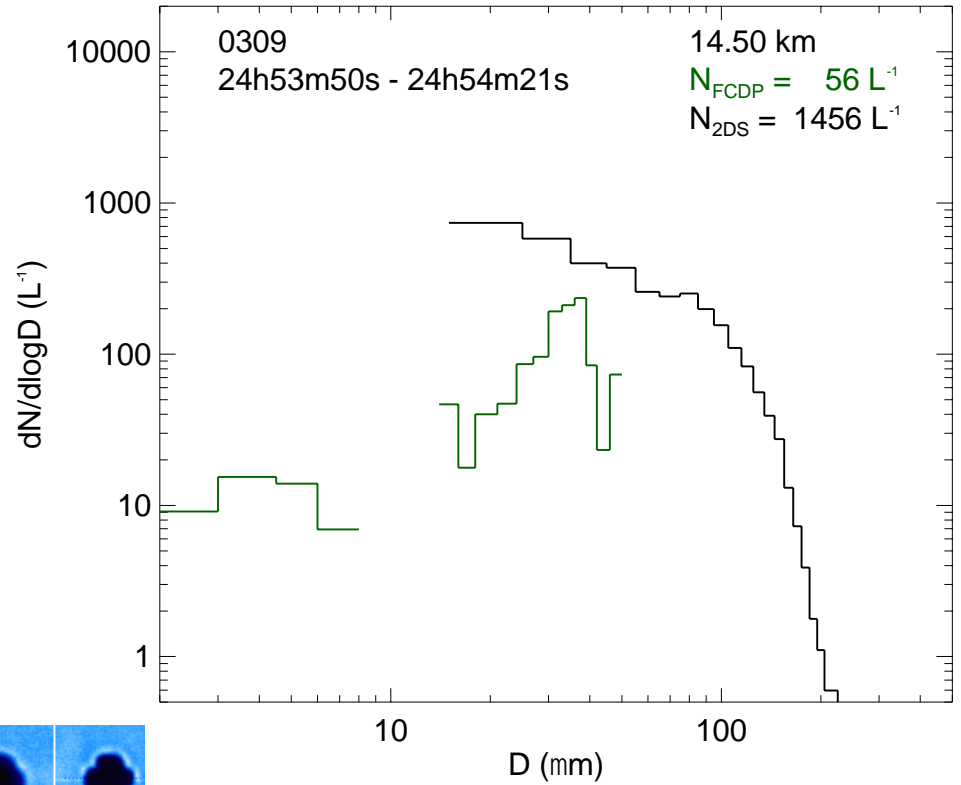
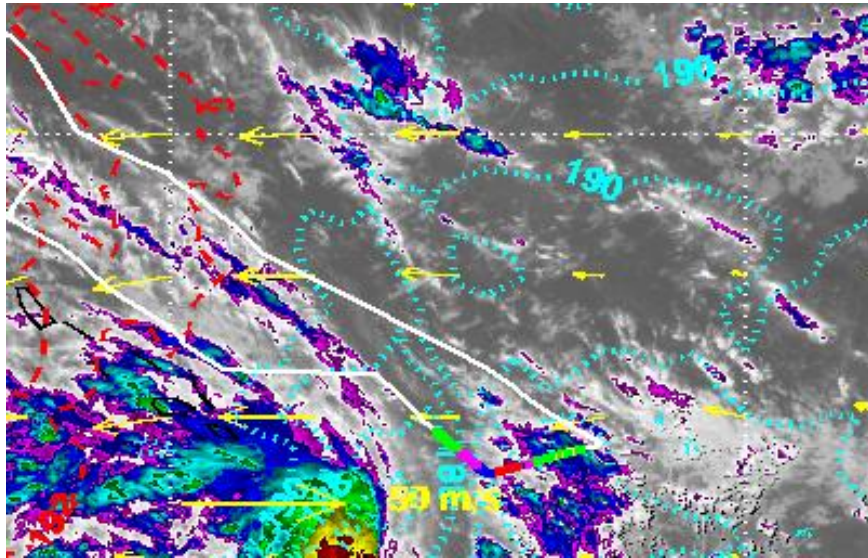


Fresh anvil cirrus sampled

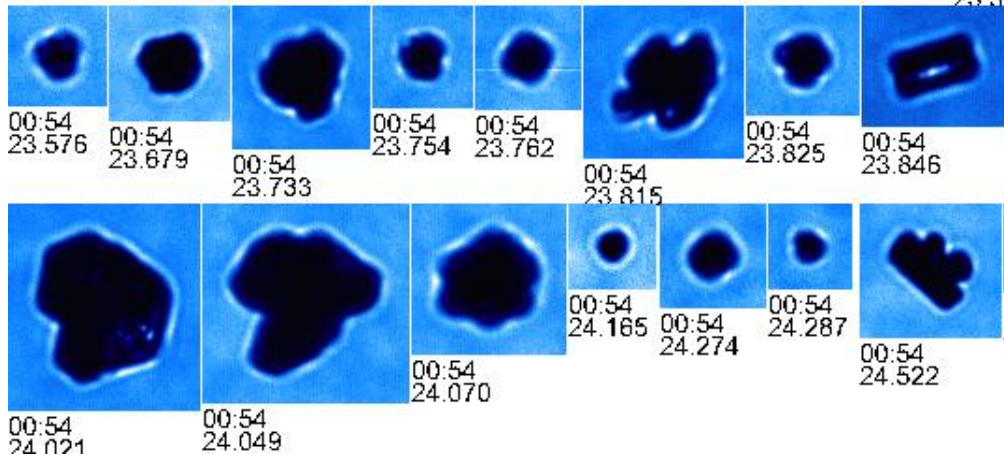
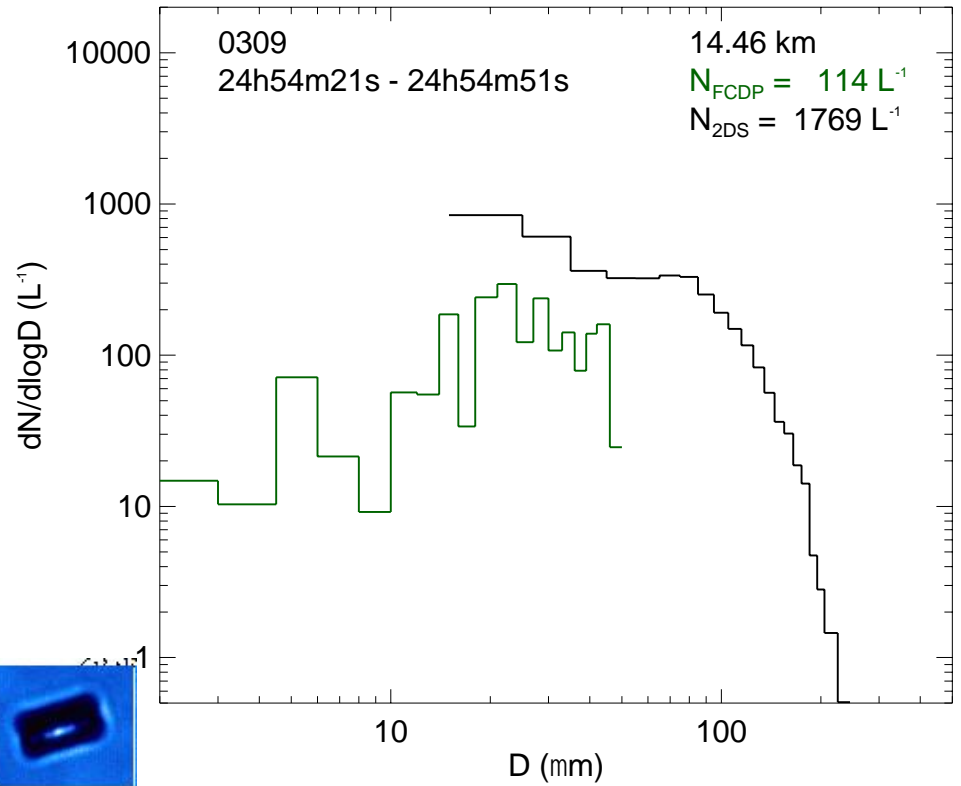
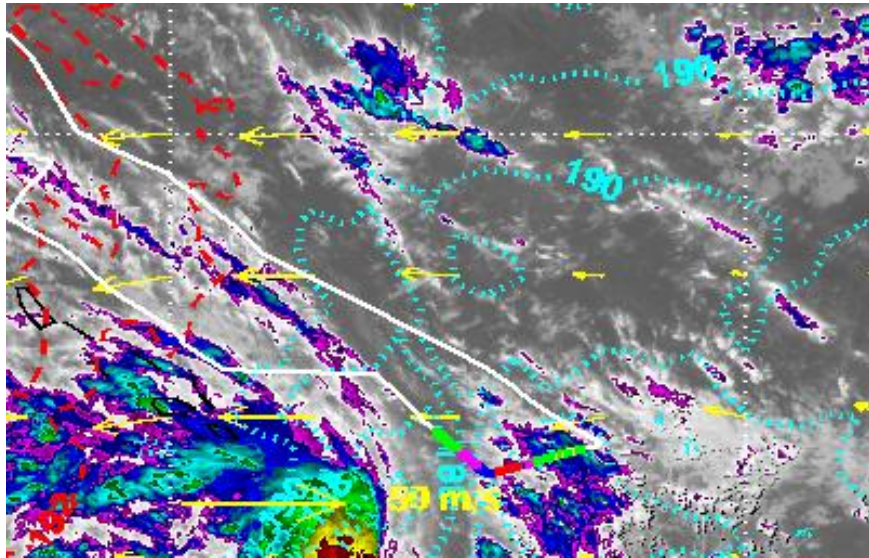
March 9-10 anvil cirrus



March 9-10 anvil cirrus

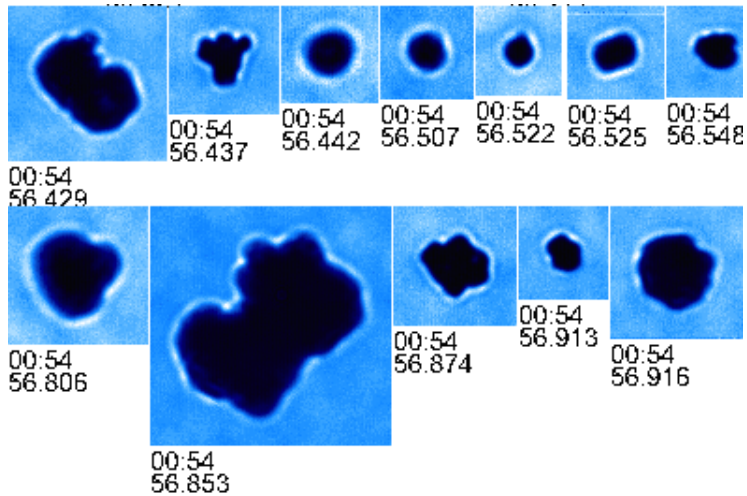
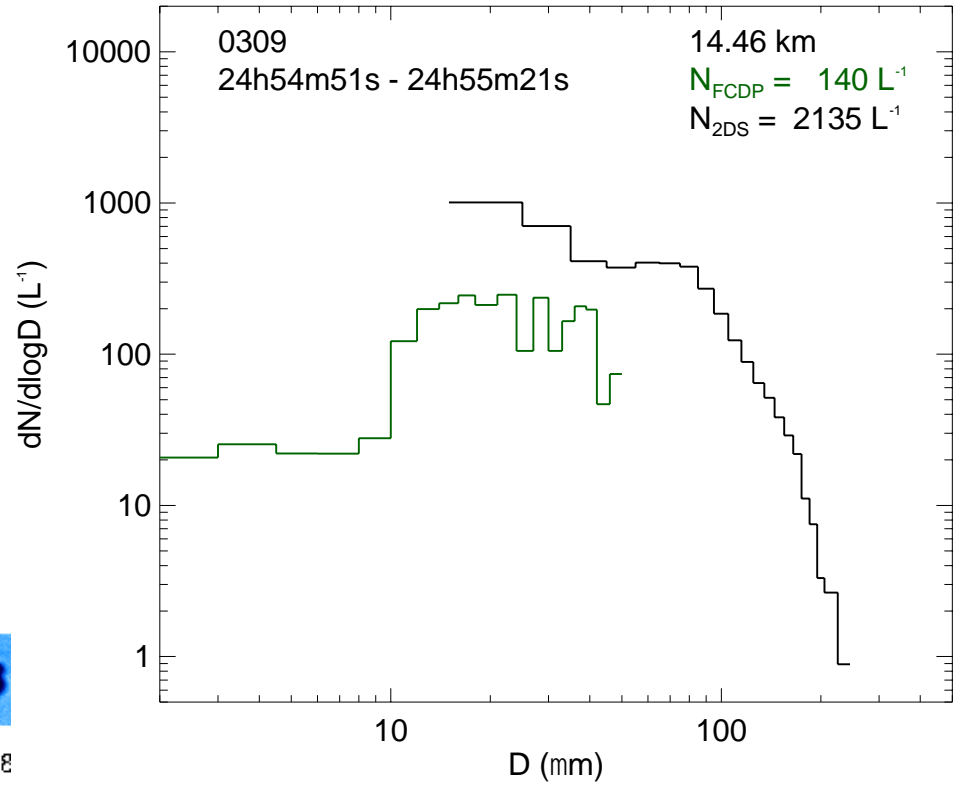
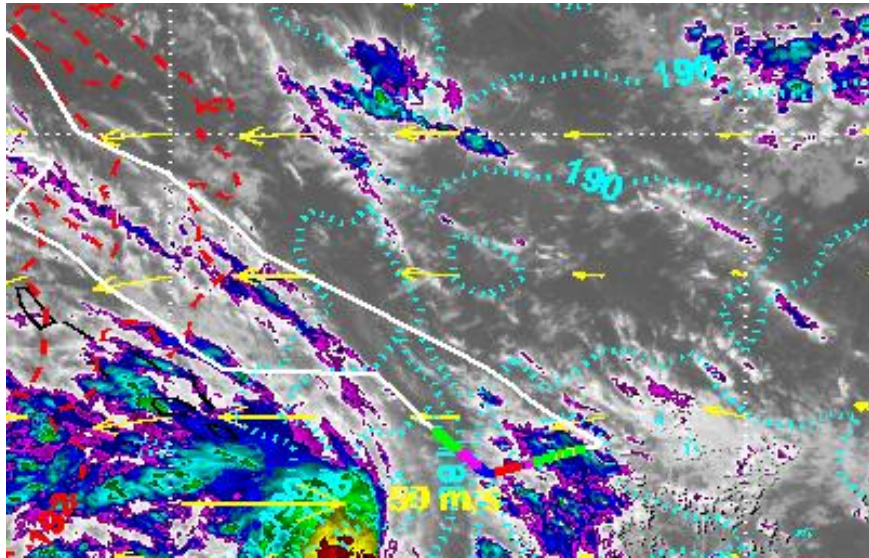


March 9-10 anvil cirrus

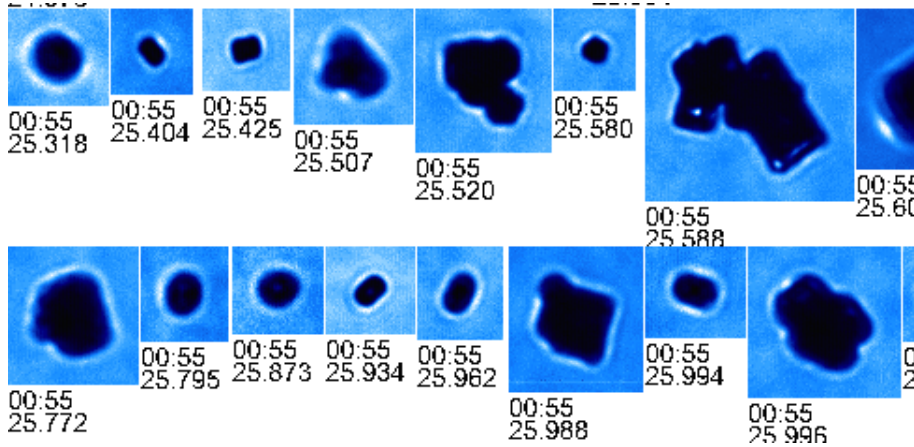
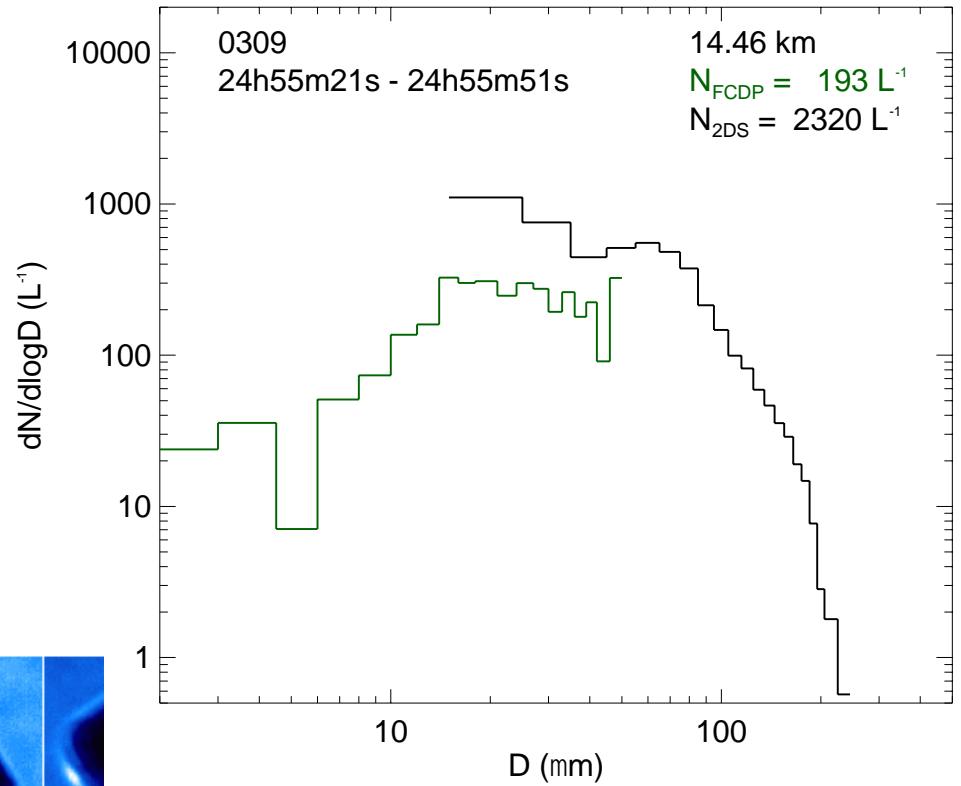
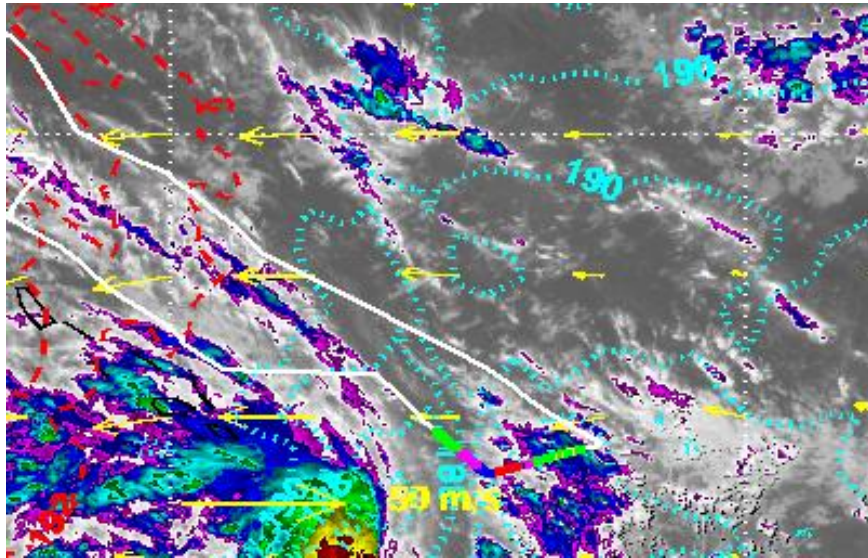


Large compact crystals, budding rosettes, some aggregates

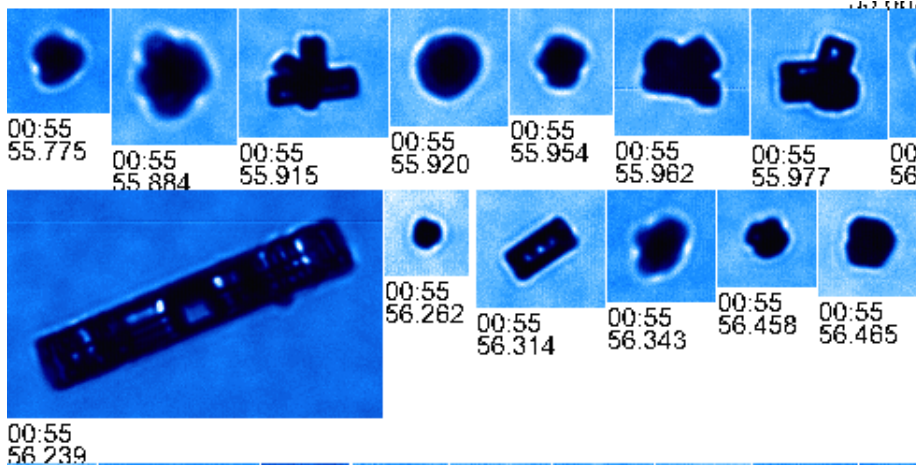
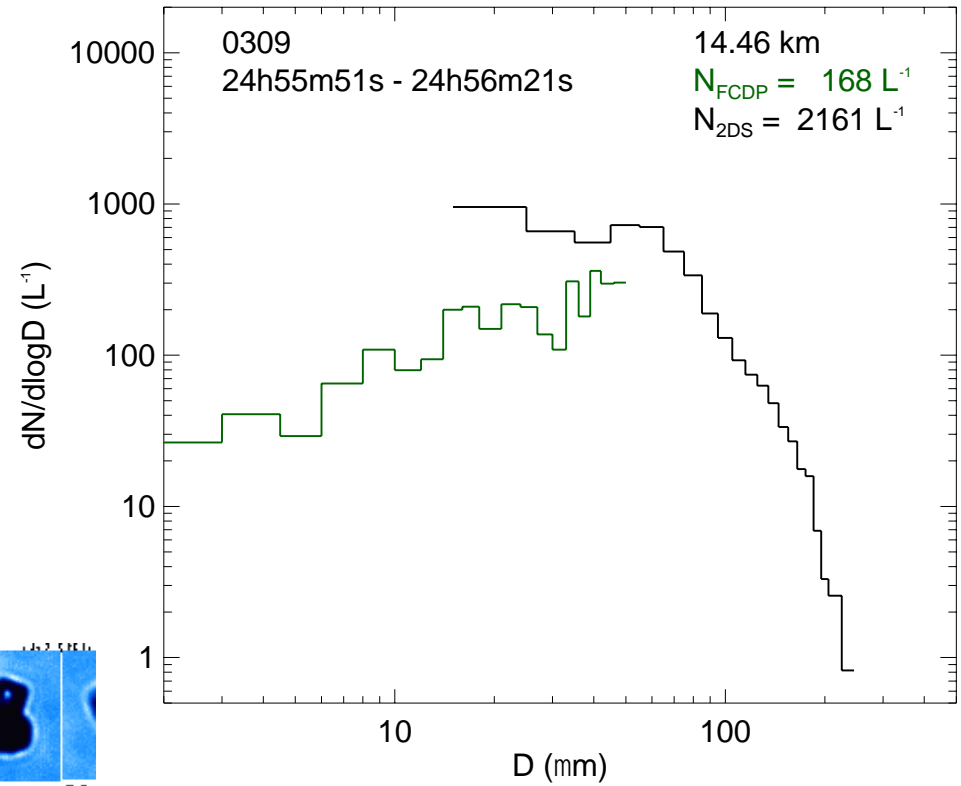
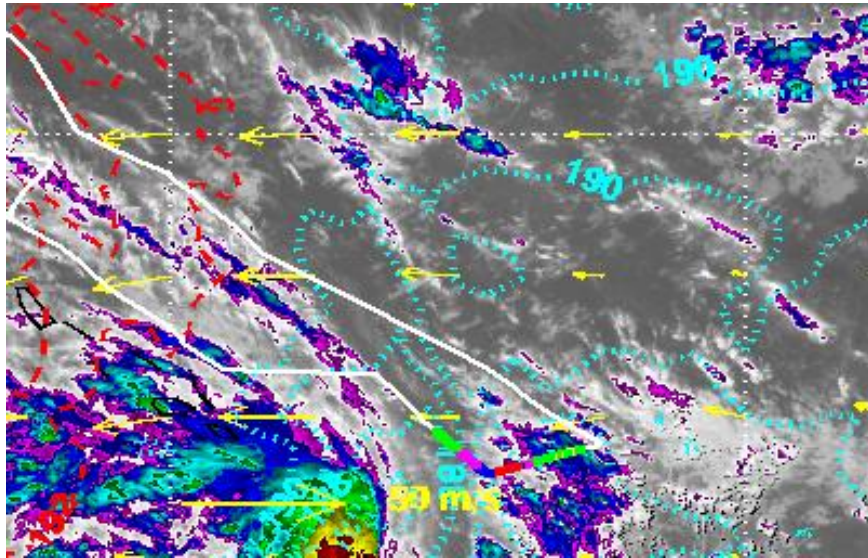
March 9-10 anvil cirrus



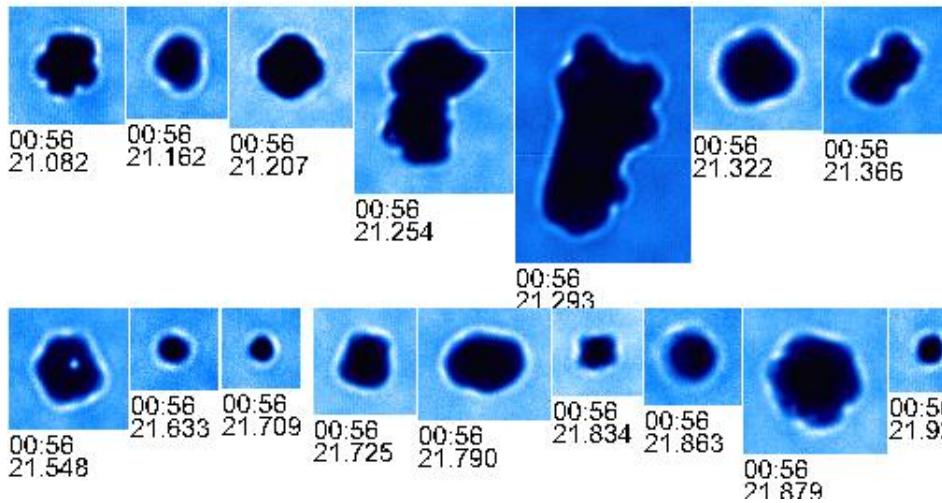
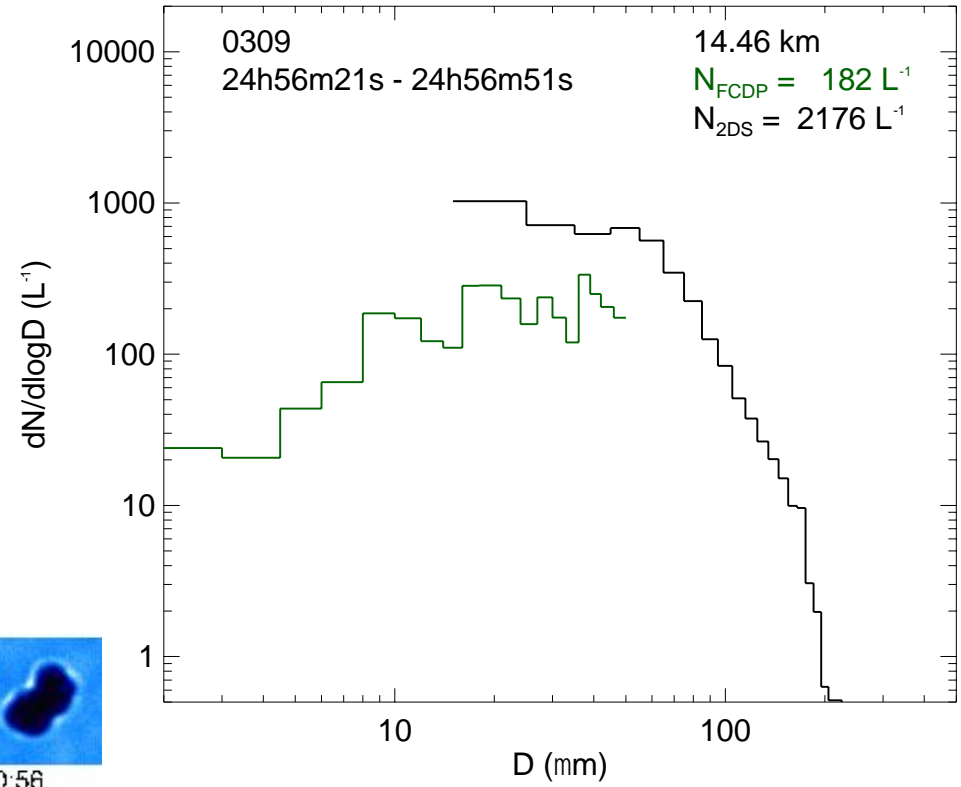
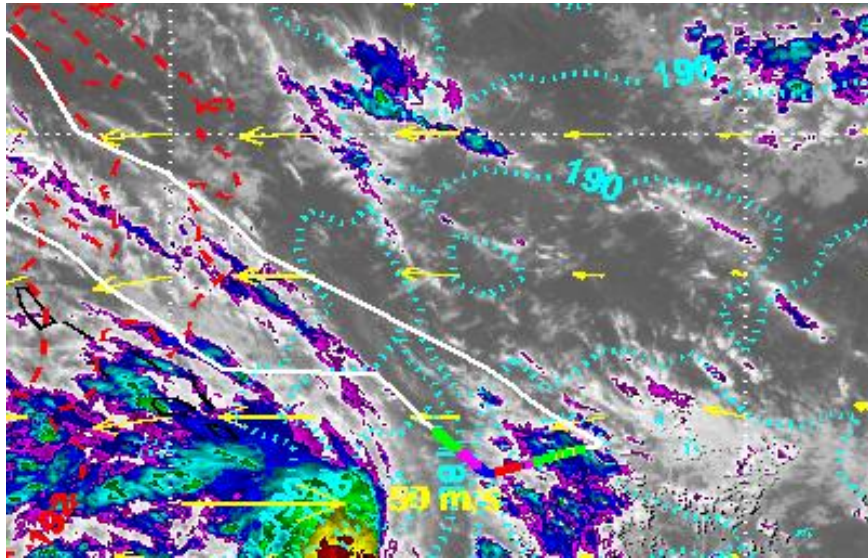
March 9-10 anvil cirrus



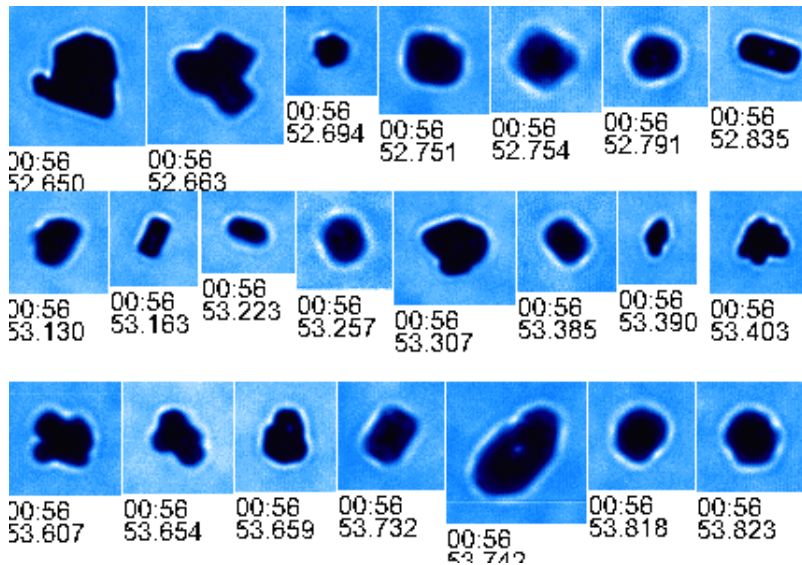
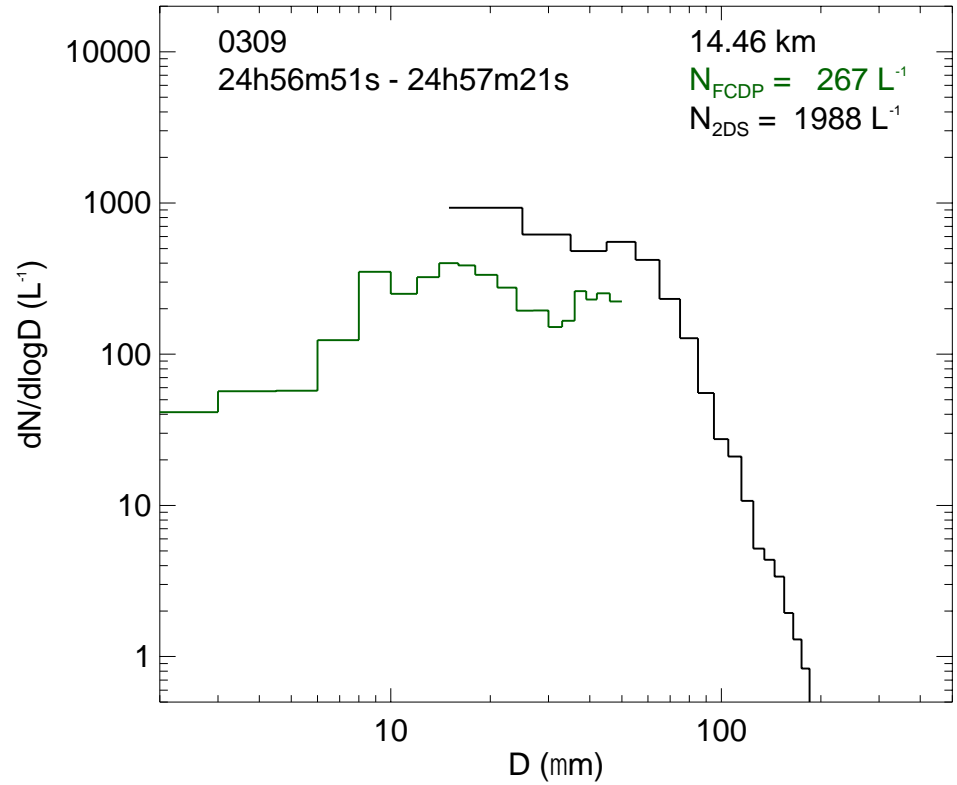
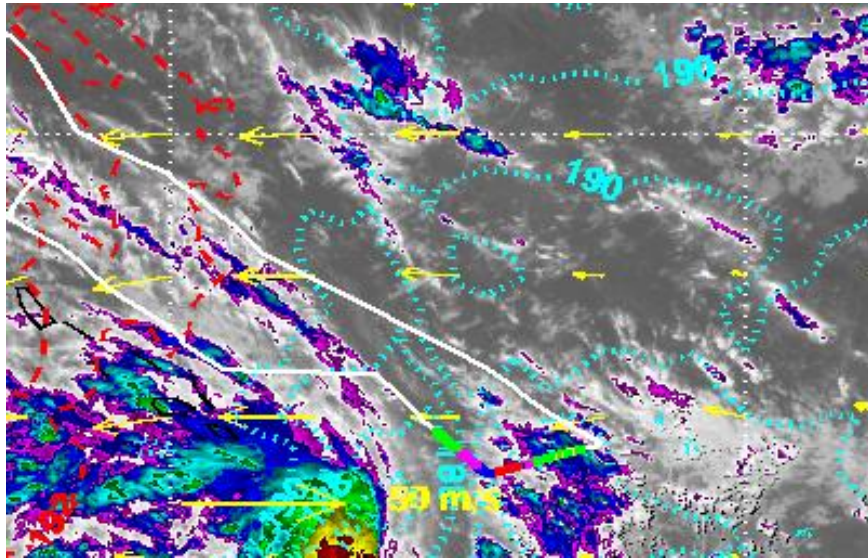
March 9-10 anvil cirrus



March 9-10 anvil cirrus



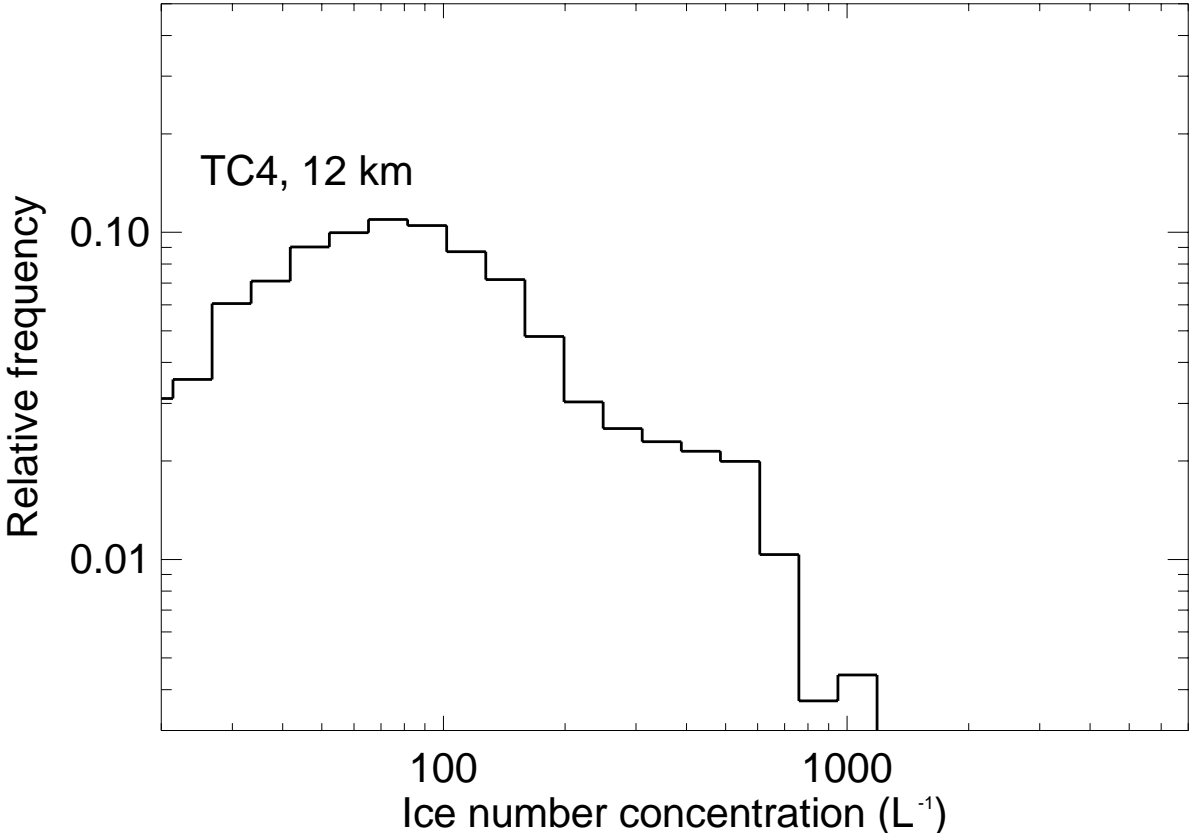
March 9-10 anvil cirrus



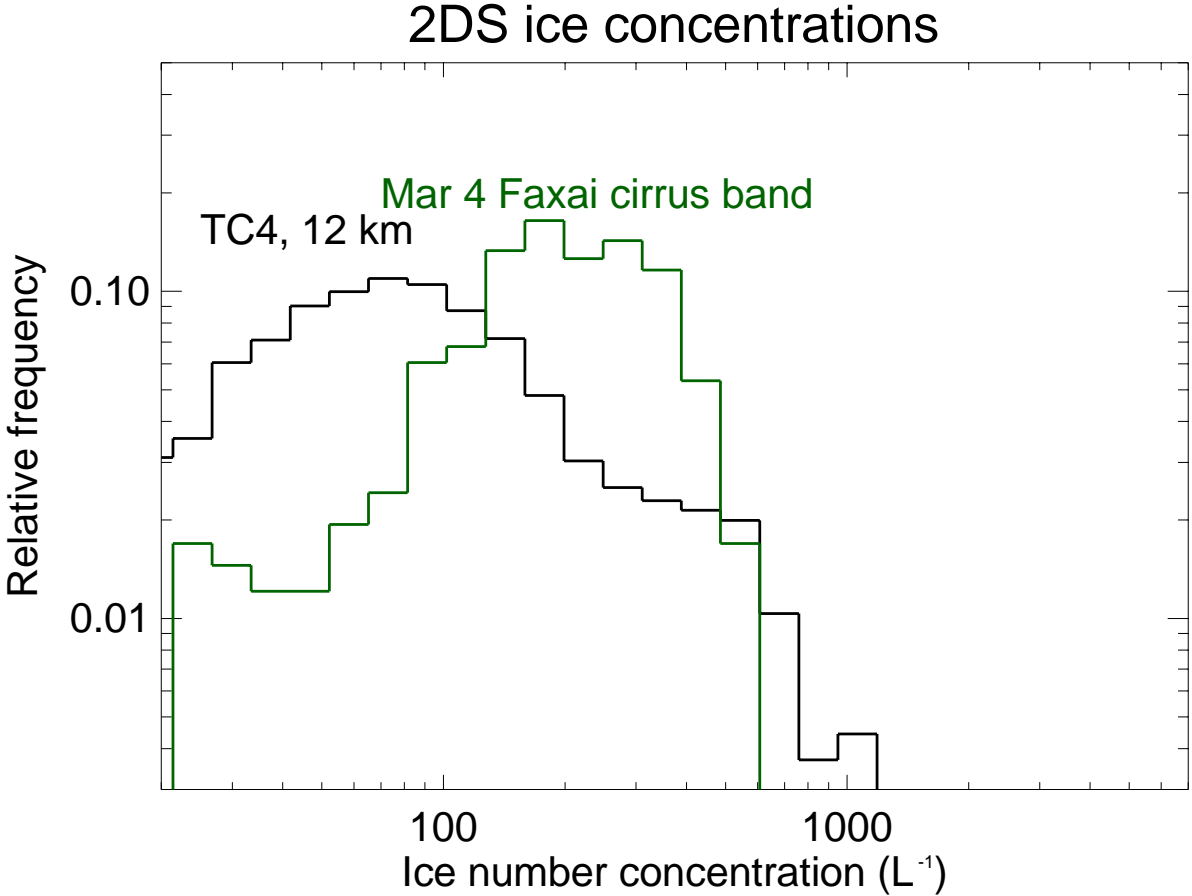
Numerous small crystals ($D < 100 \mu\text{m}$)

2DS ice number concentration comparison

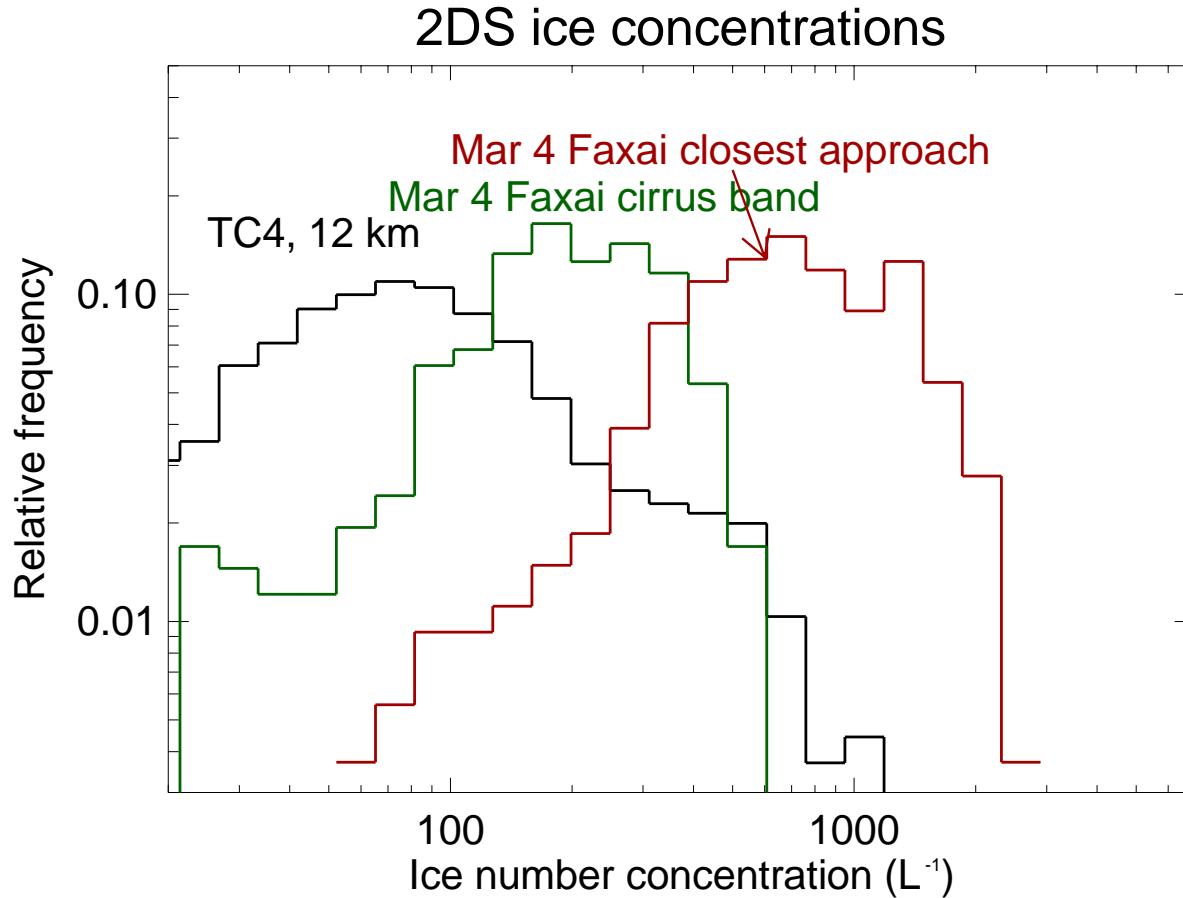
2DS ice concentrations



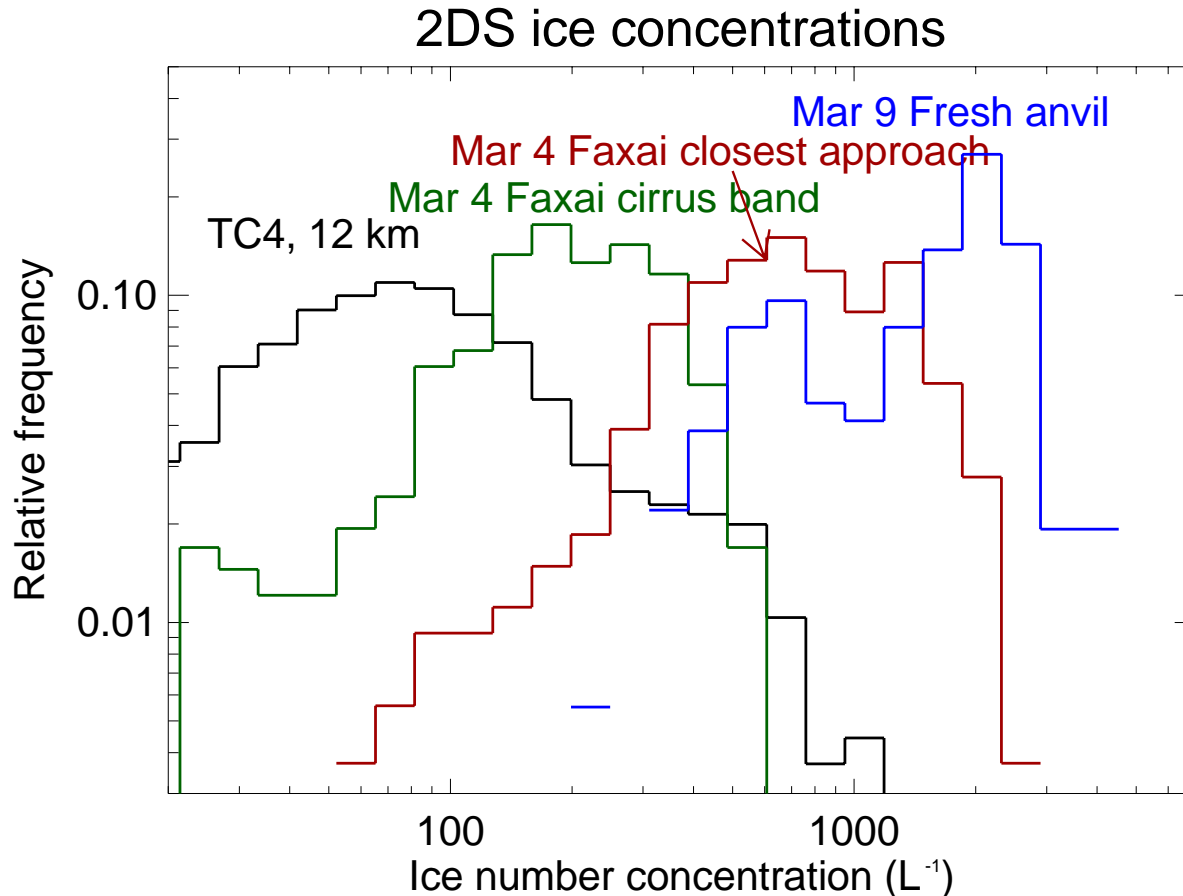
2DS ice number concentration comparison



2DS ice number concentration comparison



2DS ice number concentration comparison



- ATTREX anvils (14–16 km) generally have larger ice concentrations than lower TC4 anvils (<12 km) [1]
- Differences between ATTREX cases likely attributable to location in cloud, cloud age, etc.

[1] Differences between TC4 2DS and ATTREX 2DS (Hawkeye) cannot be ruled out

Summary and outlook

- Relatively high-altitude anvil cirrus sampled during ATTREX appears to have more numerous, smaller crystals than lower TC4 anvils.
 - Convective parameterization R_e assumptions should be adjusted accordingly.
- No evidence for extremely high ice concentrations reported by Knollenberg.
- Information about TTL anvil cirrus ice concentrations and sizes remains limited.
- Predominance of bullet rosettes suggests that much of the TTL “anvil” cirrus nucleates and grows in situ (consistent with Connolly et al. [2005]).