ACTIVATE Summer Process Study Cloud Analysis

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Overview

1. **Summary of summer process study datasets**

   Measurement Report: Cloud and environmental properties associated with aggregated shallow marine cumulus and cumulus congestus, *Crosbie, et al. in prep, ACP* → to be submitted very soon

   → See also poster summarizing process study microphysics

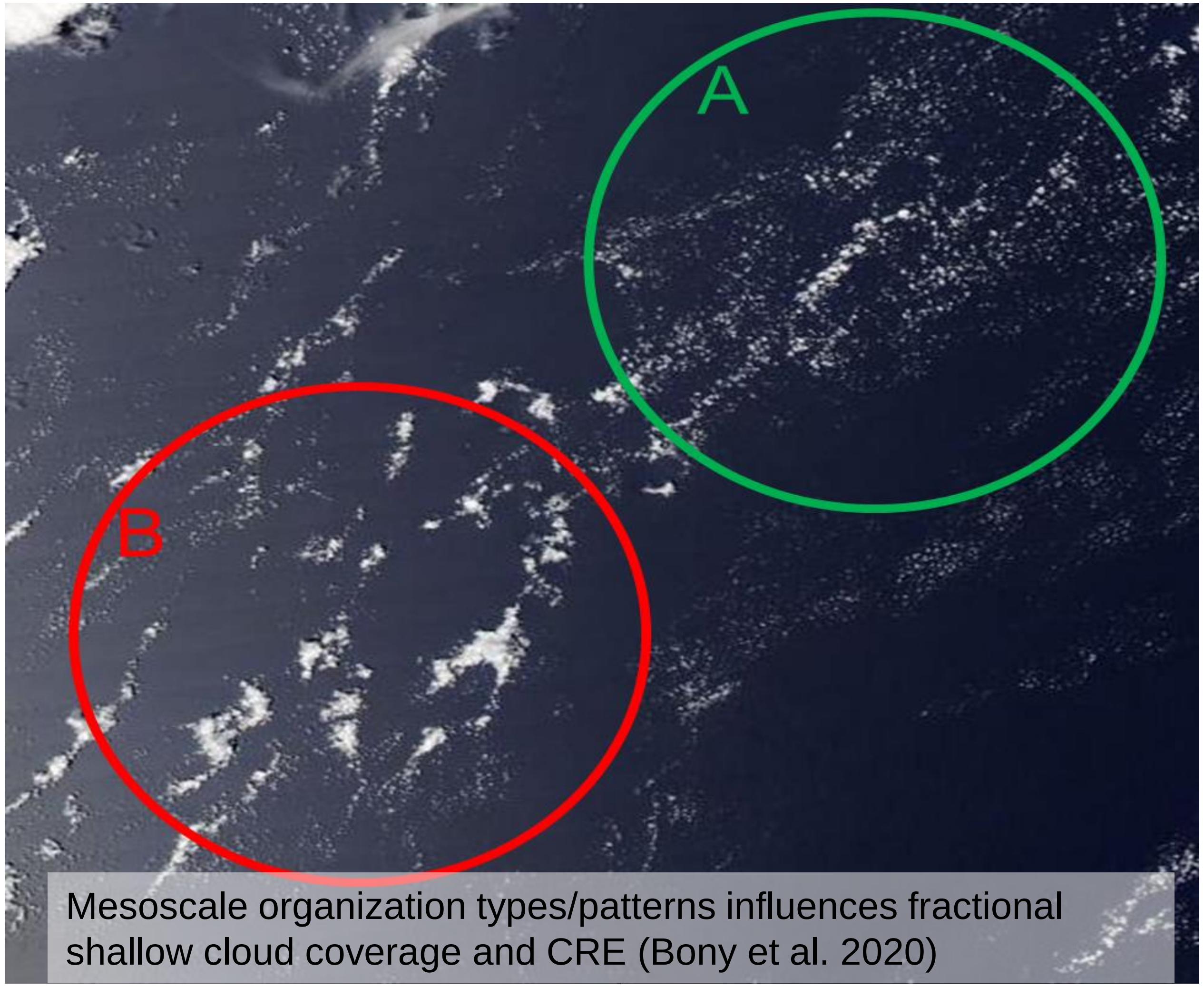
2. **Ongoing work on mechanisms for cloud aggregation**

3. **Ongoing work related to cloud remote sensing**

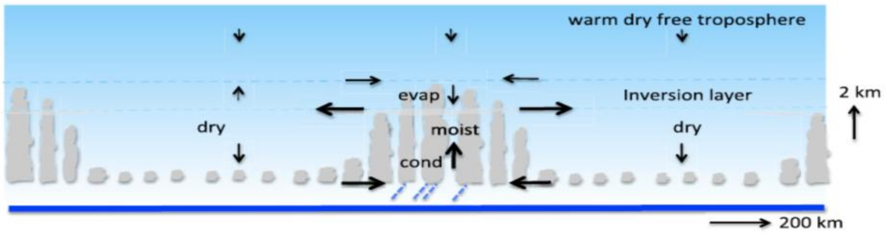
   → See also John Hair's poster

ACTIVATE Summer Process Study - Recap

- **What causes shallow convection to aggregate?**
- **What causes very small Cu (A) and deeper Cu with clearings (B) to regionally coexist?**

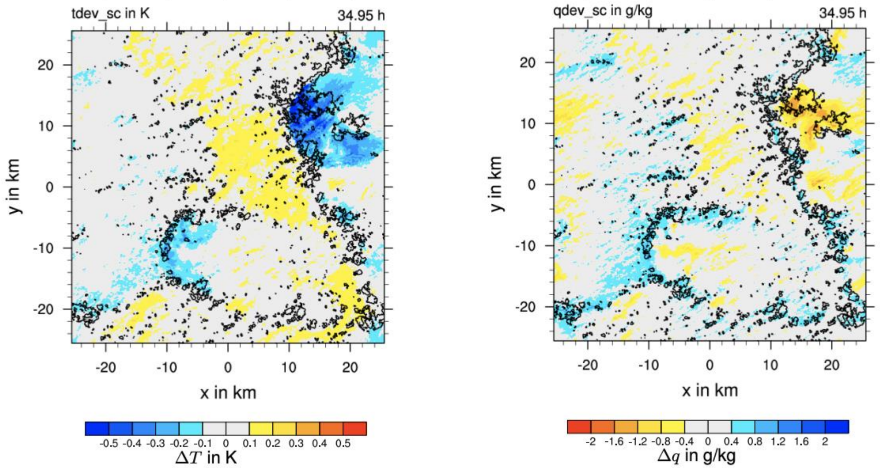


Mesoscale organization types/patterns influences fractional shallow cloud coverage and CRE (Bony et al. 2020)



Bretherton and Blossey, 2017 (BB17)

- anomalies in precipitation, radiation, surface flux not necessary for organization
- Relationship between moisture and stability profile important



Seifert and Heus, 2013

- precipitation necessary, organization caused by evaporation/cold pools

Zuidema et al., 2012, 2017

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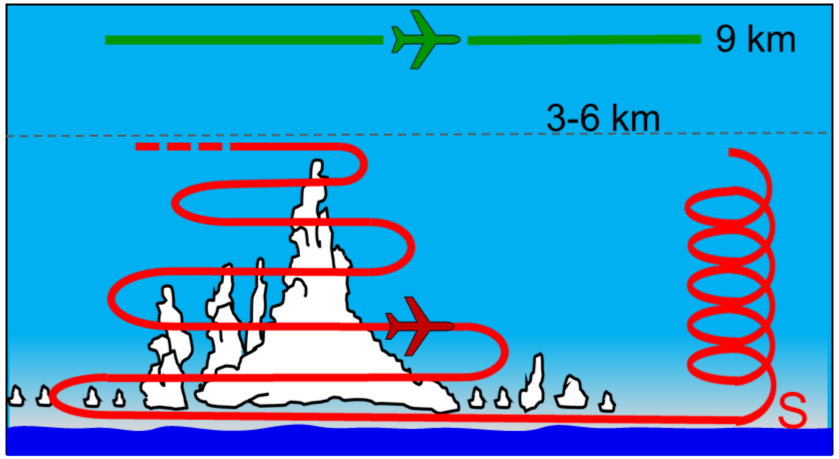

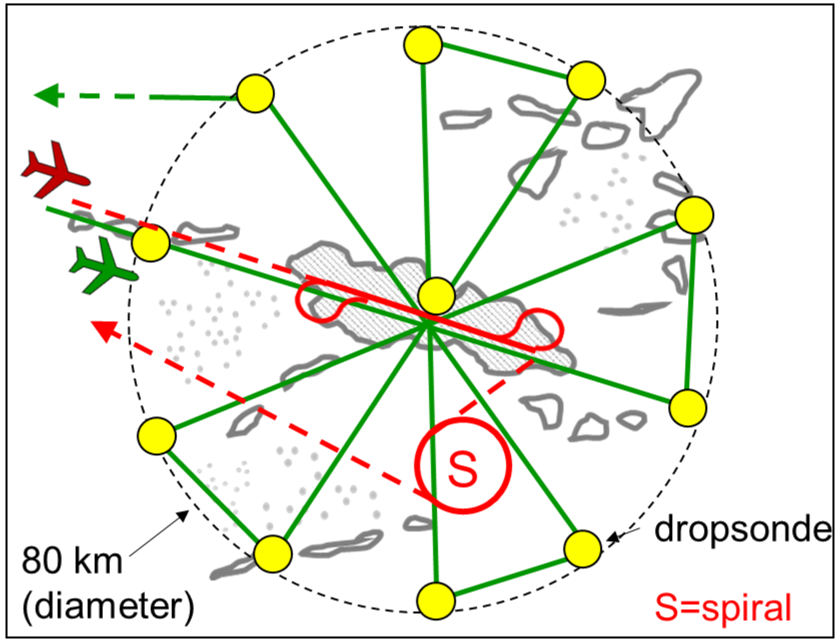

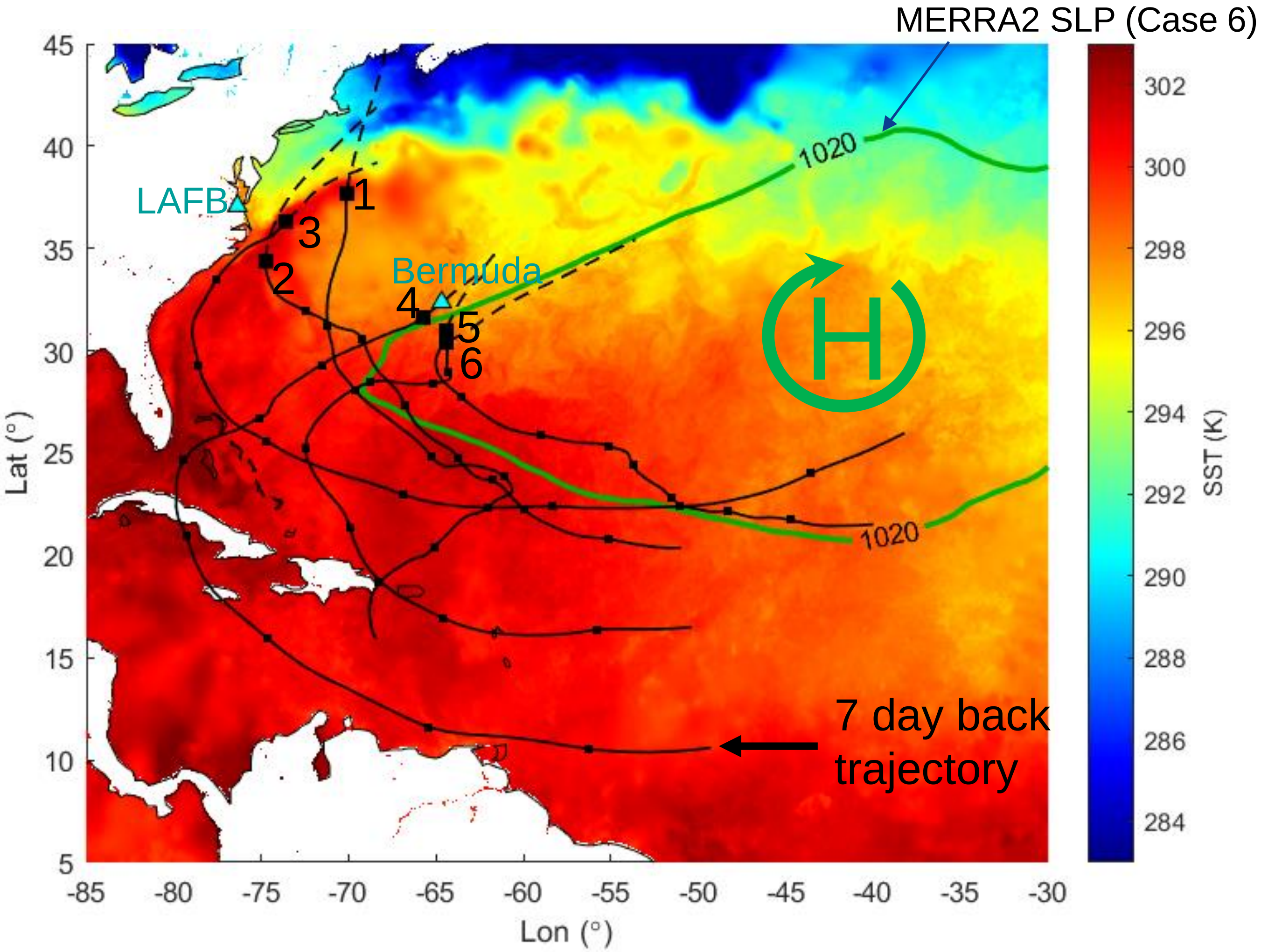

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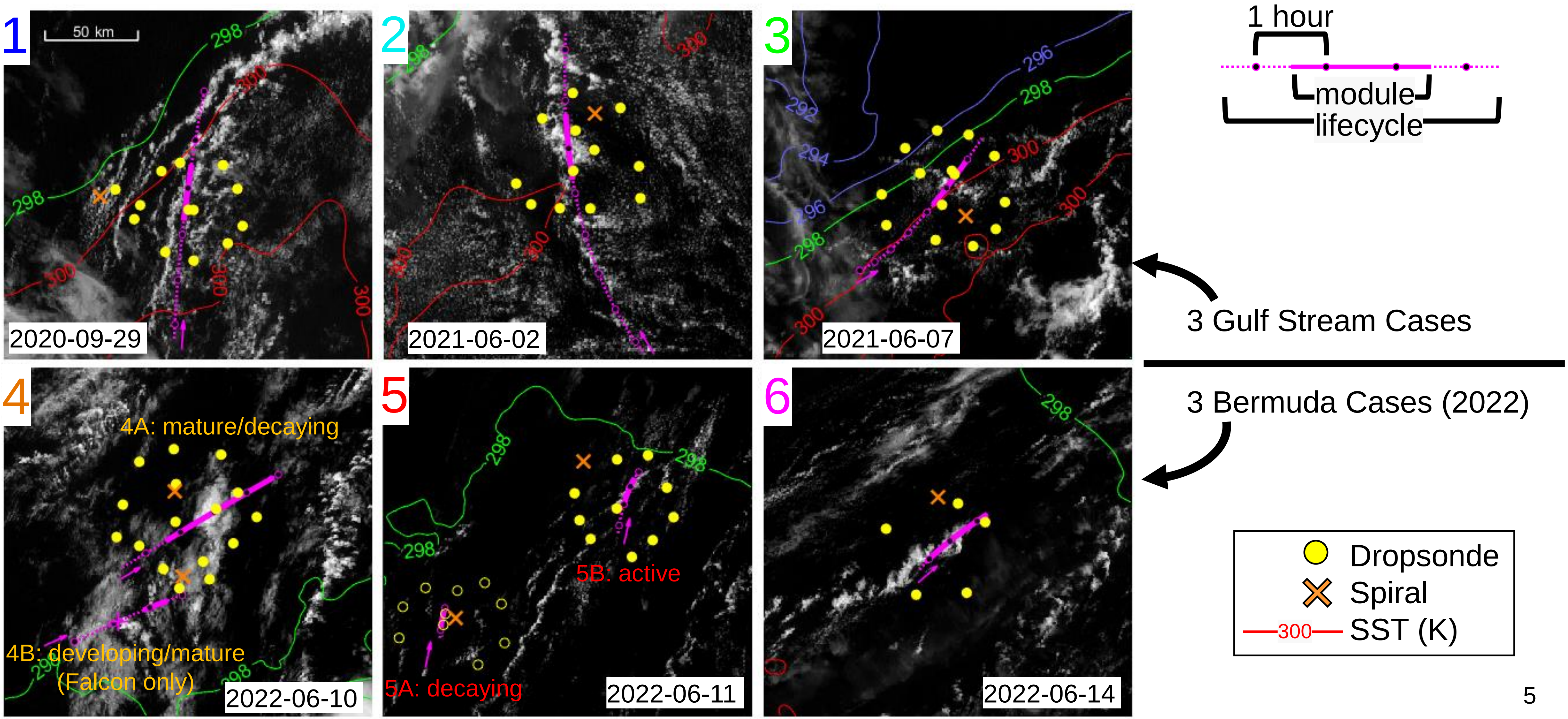
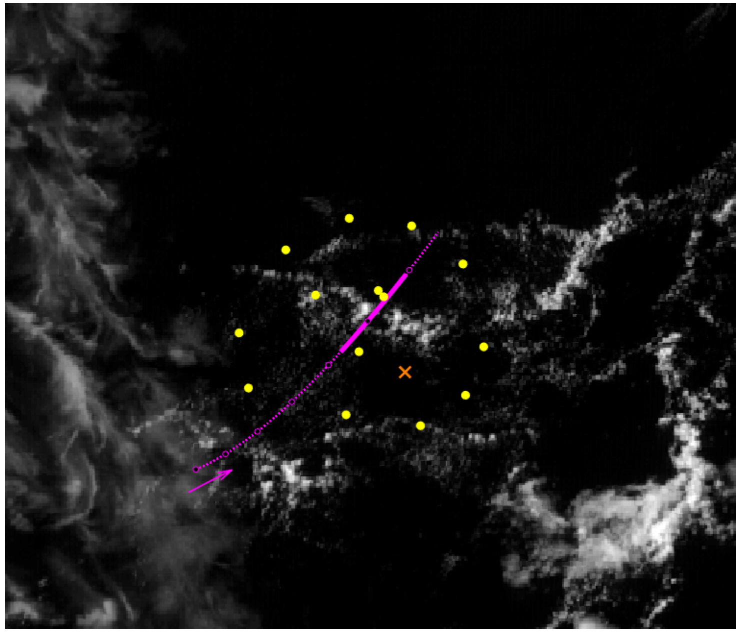
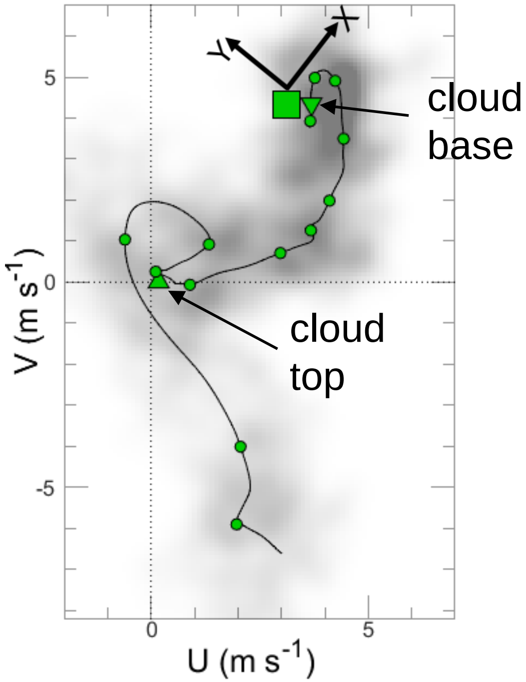
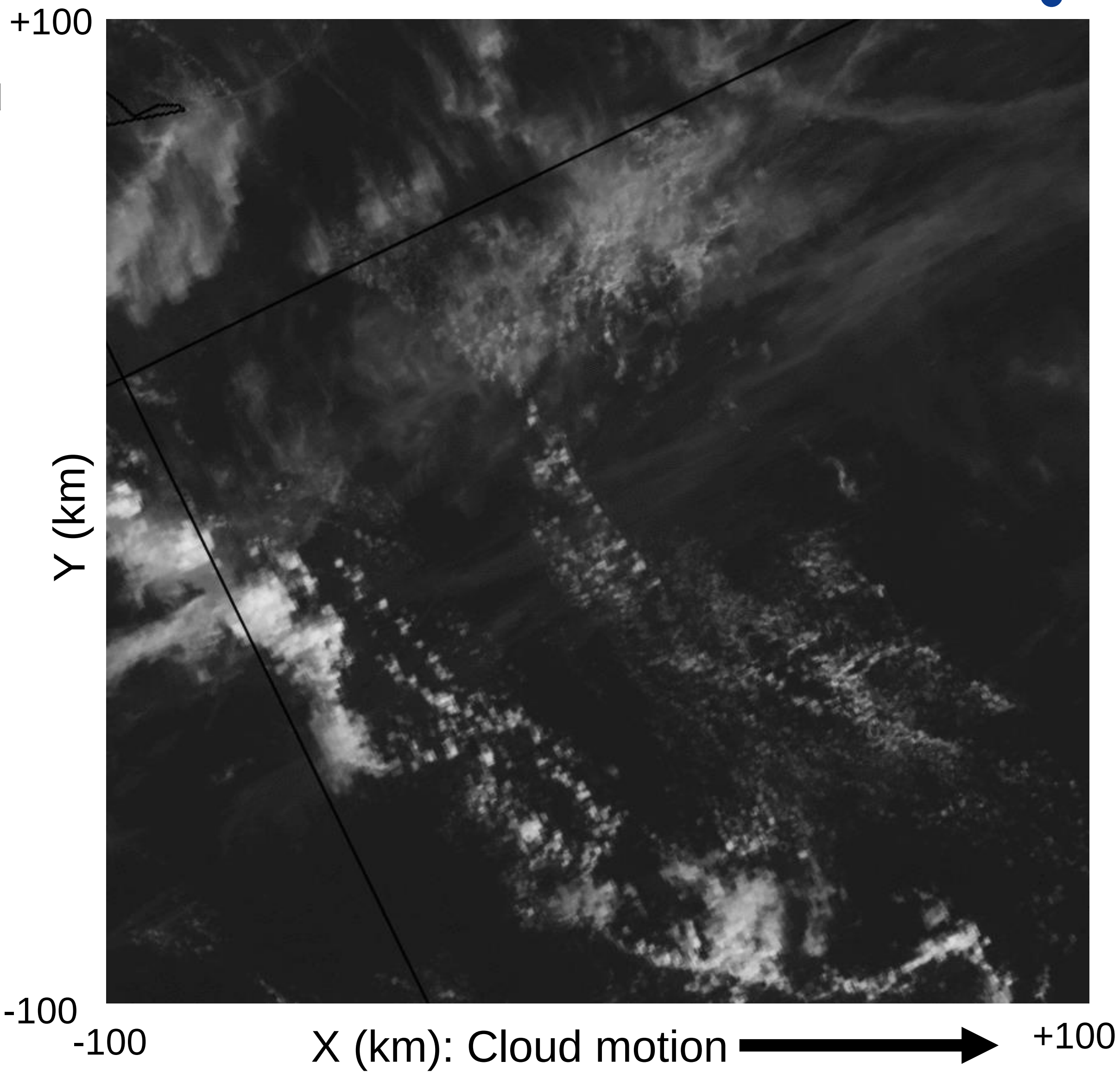


Case 3: 2021-06-07 – Cloud Motion Tracking

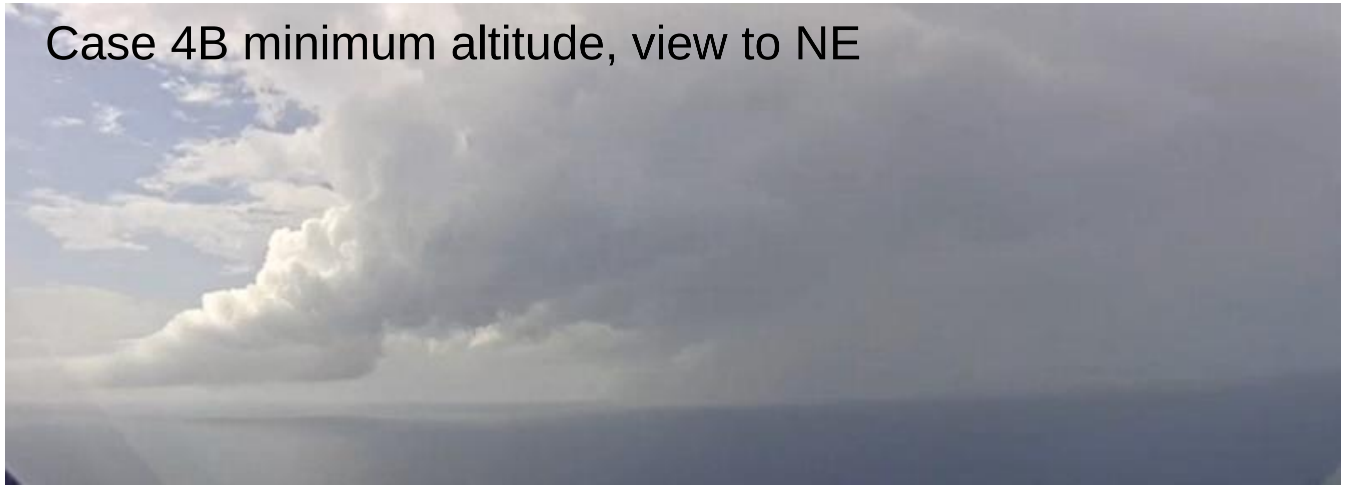






- Image cross correlation used to estimate cloud cluster motion vector
- Lifecycle drift determined using linear regression
- Comparison of cluster motion to wind hodograph shows relationship with the environmental wind profile
- Imagery and aircraft positions projected onto a rotated moving coordinate system
- Aircraft sampling assessed in the context of lifecycle

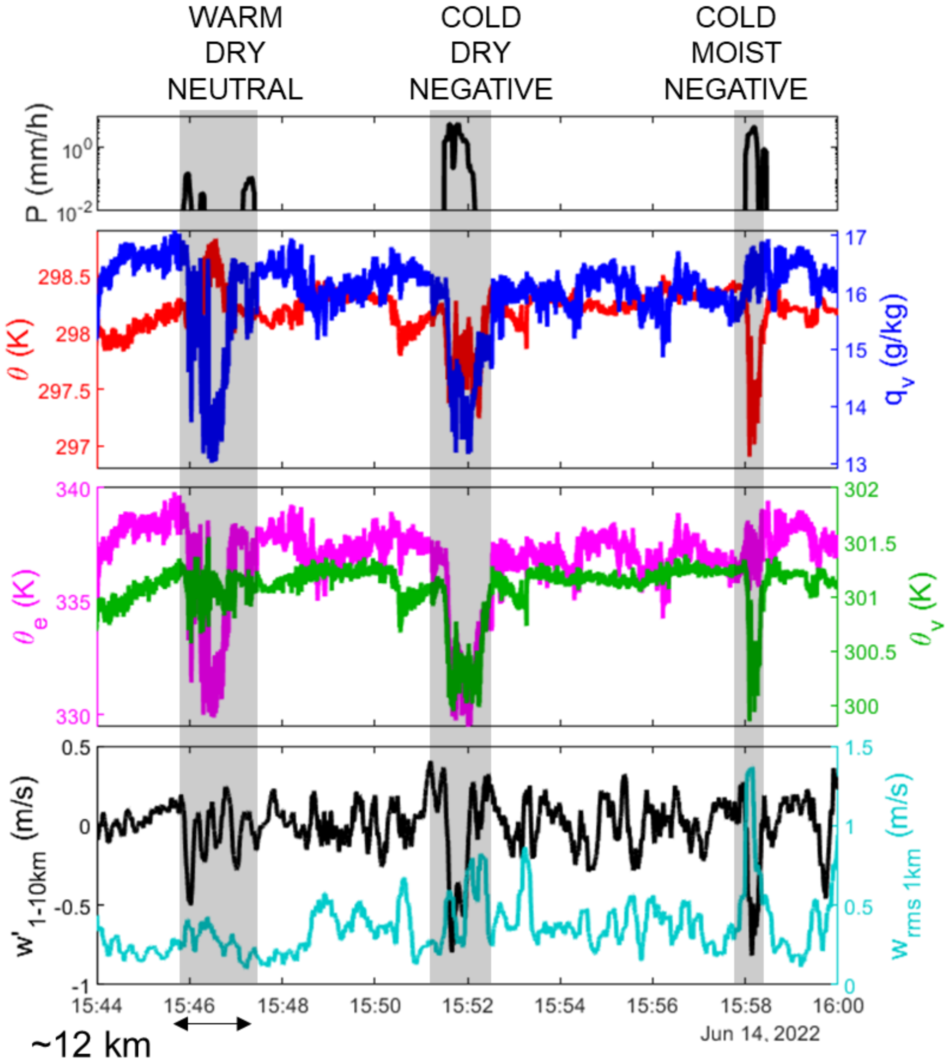
Precipitation



		Case							
		1	2	3	4A	4B	5A	5B	6
90th% Rain Intensity	mm hr⁻¹	No precip. measured	1.55	0.97	2.58	4.29	No precip. measured	3.87	4.41
Mean Intensity	mm hr⁻¹		0.47	0.35	0.97	1.41		1.11	1.53
Rain coverage	km		7.1	0.7	17.1	9.2		0.6	10.4
Fractional coverage	-		0.24	0.02	0.47	0.36		0.02	0.17
Cluster Rain Rate	mm hr⁻¹		0.11	0.007	0.45	0.52		0.02	0.26

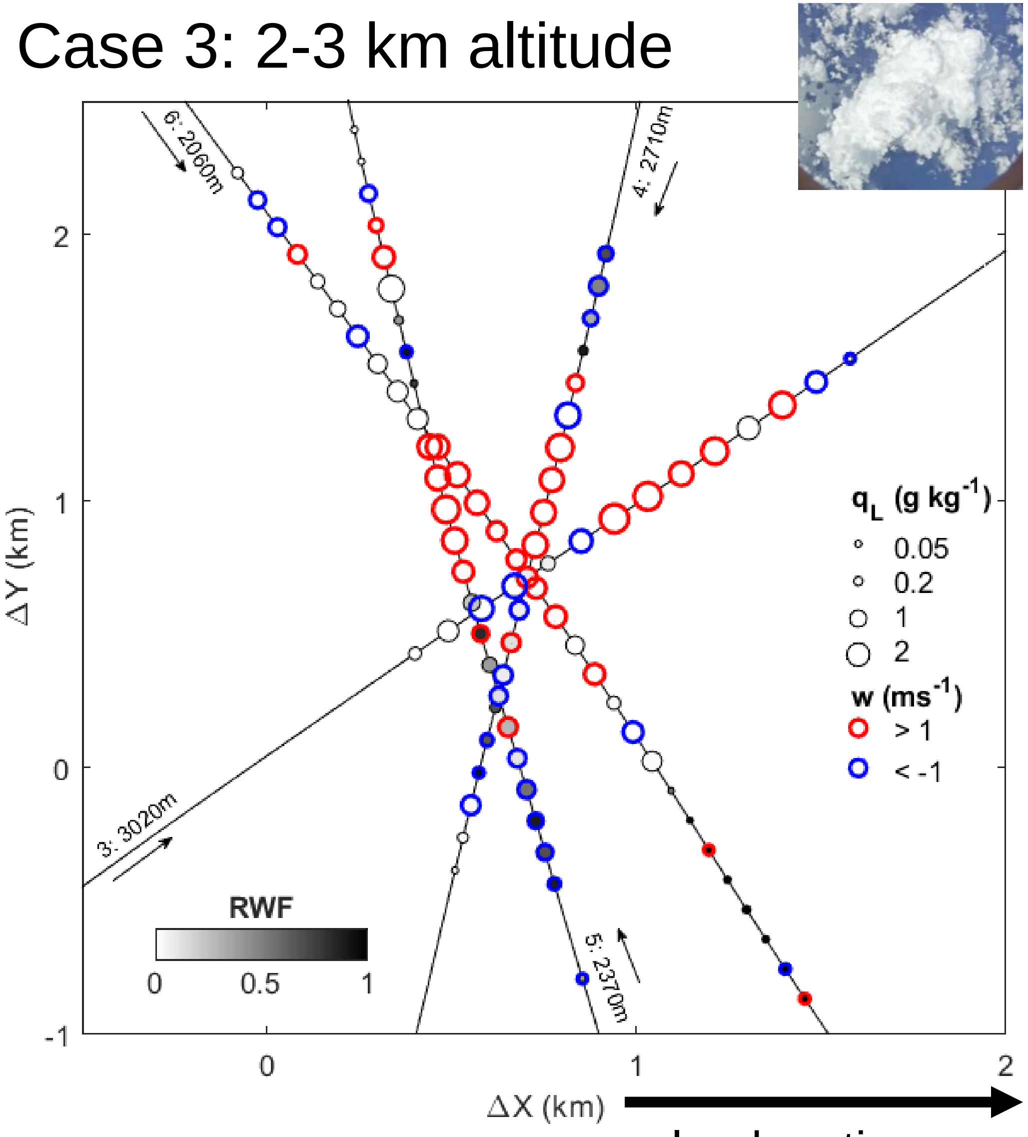
Rain	$\Delta\theta_v$ (K)	-	-0.21	-	-0.14	-0.15	-	-	-0.15
	$\Delta\theta_e$ (K)	-	0.81	-	-1.92	-2.68	-	-	-1.49

Case 6 minimum altitude: 3 rain shafts encountered with distinctly variable downdraft properties



Precipitation

Case 3: 2-3 km altitude



cloud motion

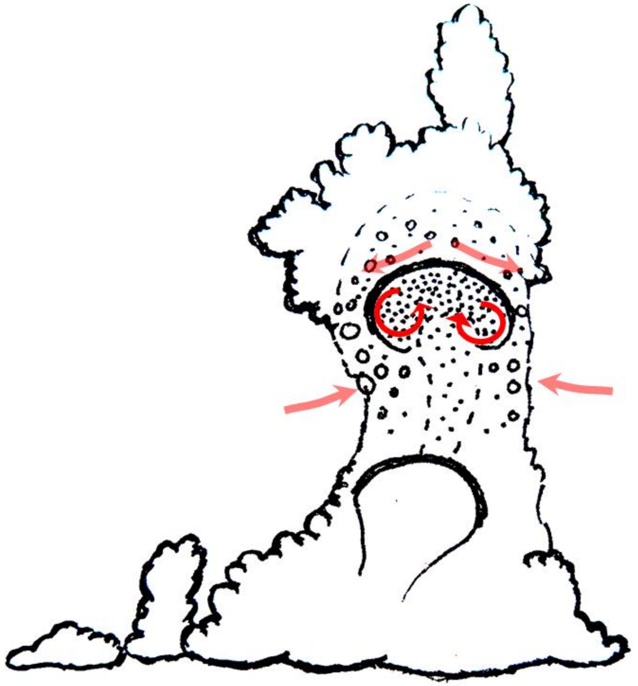
- 4 passes through the main turret of Case 3
- “Core” updraft collocated with peak water content
- Rainwater is found in the downdraft region surrounding the core

Implications:

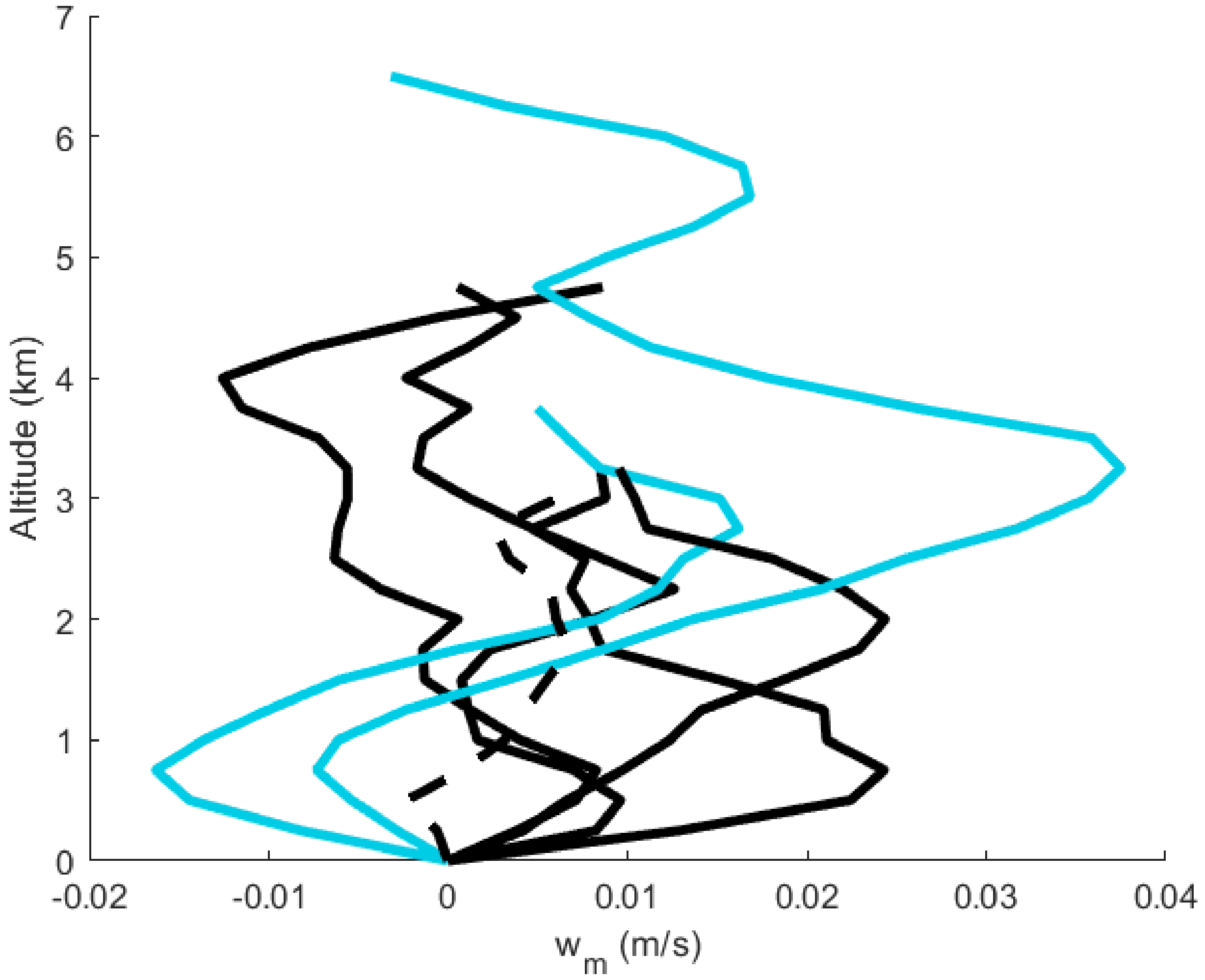
- Evaporation helps drive a subsiding shell
- Accretion is suppressed when nascent raindrops do not fall through the LWC-rich core
- Small raindrops do not survive the cloud periphery because of dry air

Time in cloud $\xrightarrow{\text{collisions}}$ Precipitation initiation

Time in cloud $\xrightarrow{\text{entrainment}}$ Buoyancy depletion



Mesoscale overturning circulation



Control volume analysis of the region enclosed by the dropsondes, moving in the cloud-relative coordinate system

$$w_m(z) \cong \frac{1}{\rho(z)} \int_0^z \rho \left(\left(\frac{\Delta U}{\Delta x} \right)_{fit} + \left(\frac{\Delta V}{\Delta y} \right)_{fit} \right) dz - w_0 \frac{z}{z_{ref}}$$

- x, y, U, V in cloud coordinate, w_0 a large-scale correction at z_{ref}
- Velocity gradients fit using linear regression (e.g., Lenschow et al., 1999). Raymond et al., 2009 also a useful reference.

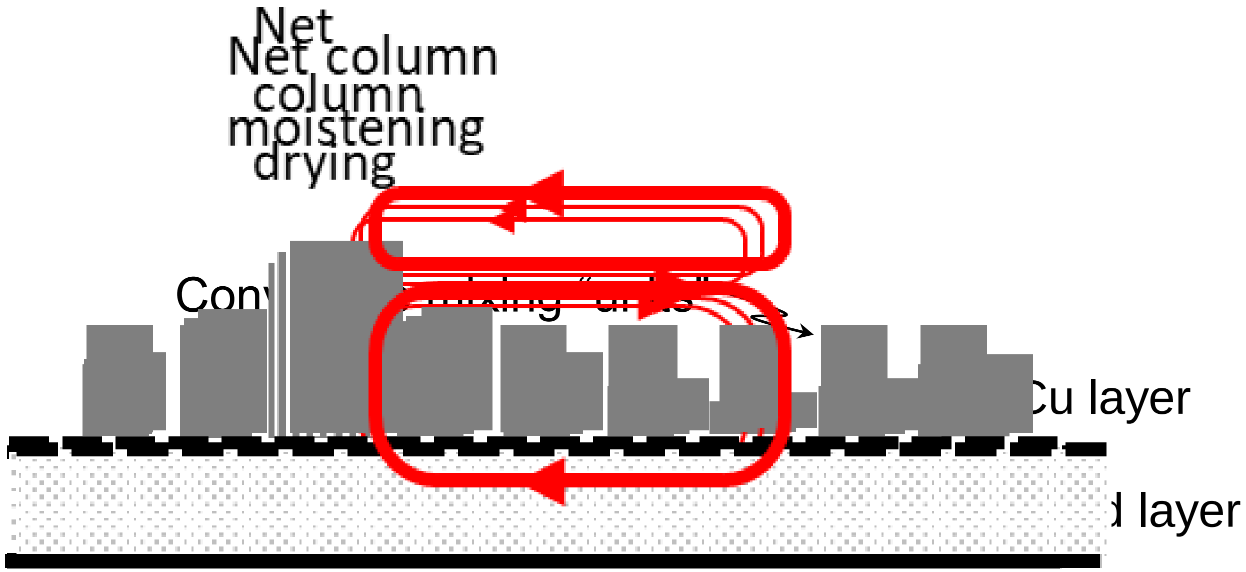
Cases that are less influenced (or not affected) by precipitation thermodynamics and energetics follow a S shape (Cases 2 & 3) or a D shape (Cases 1 & 5B)

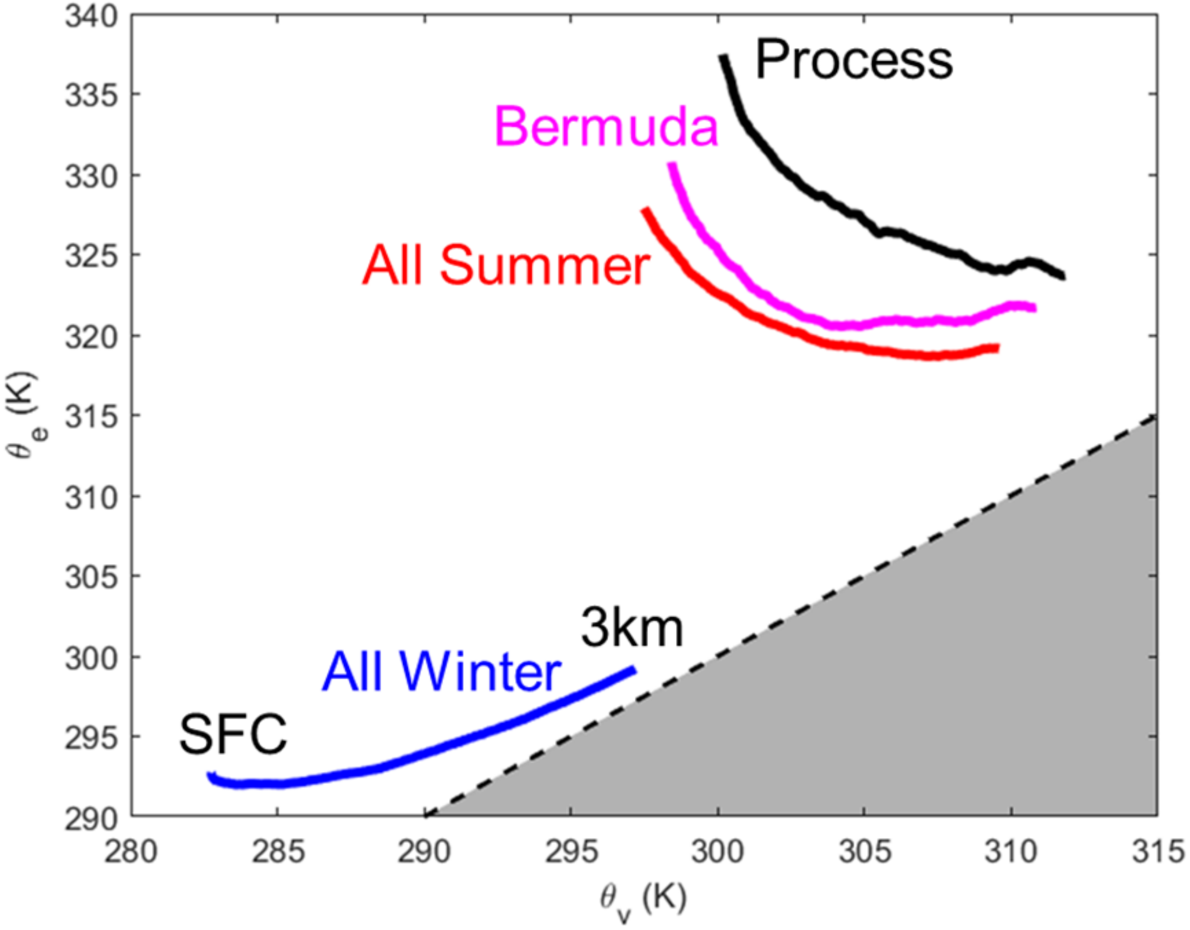
Precipitation dominated cases are reversed and have a Z shape

Mesoscale overturning circulation

BB17 Conceptual Model (linear instability):
Initially uniform cloud field
Perturbation results in anomalous convective activity
→circulation is the adjustment to anomalous apparent heating

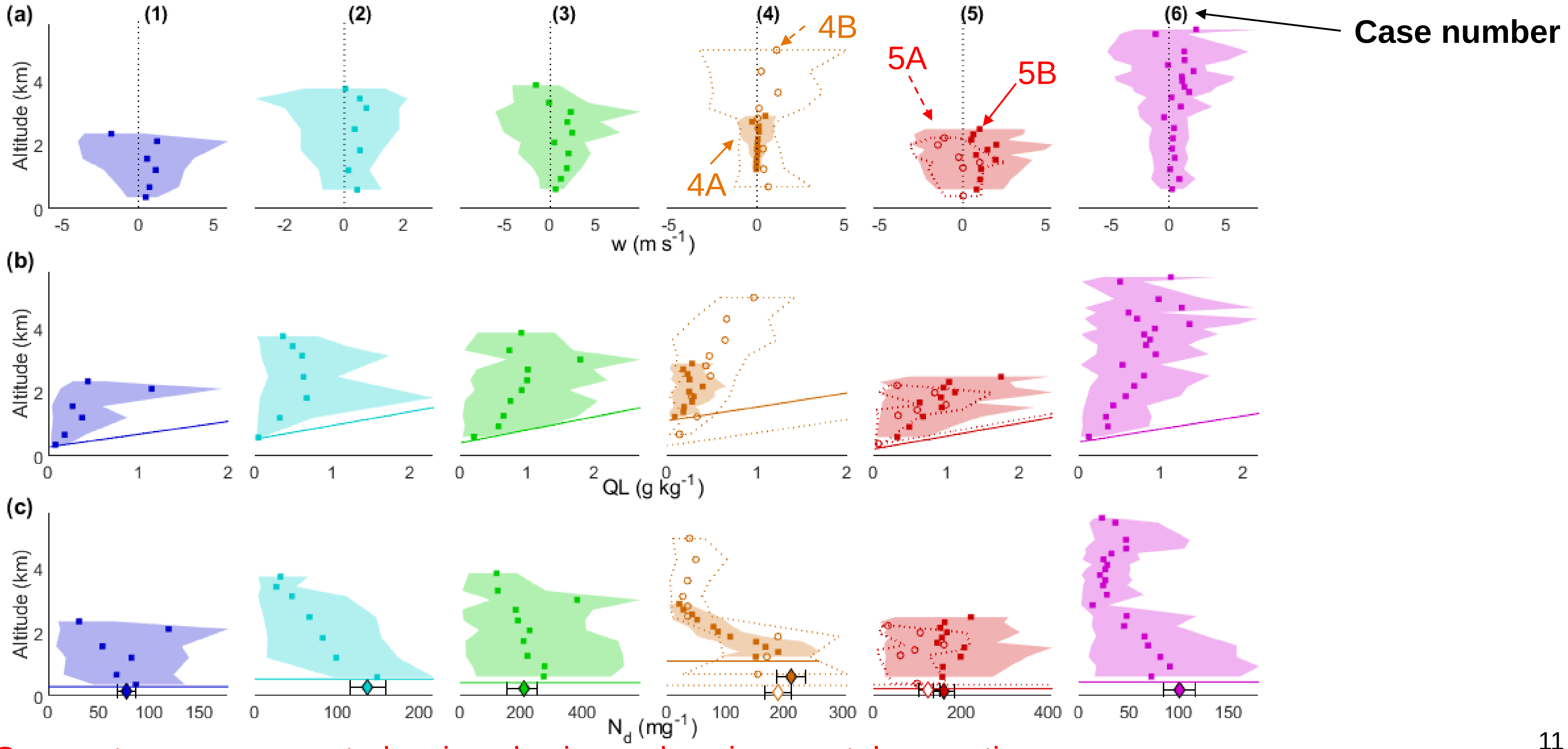
- If this results in net drying, the anomaly is damped
- If this results in net moistening, the anomaly is amplified





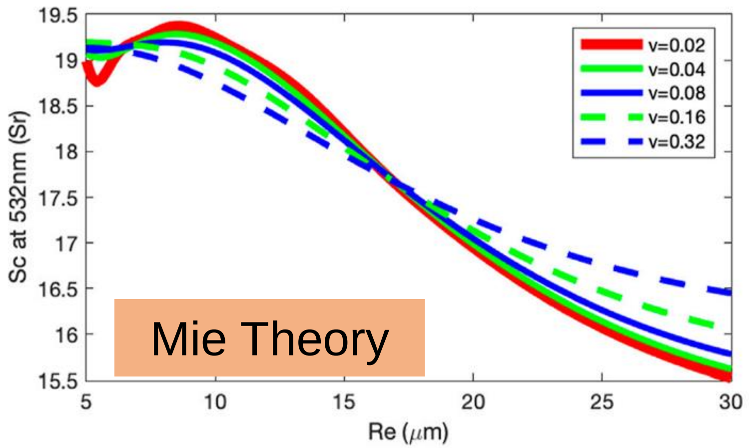
→ **Janssens et al., 2023** – "Nonprecipitating shallow cumulus convection is intrinsically unstable to length scale growth"

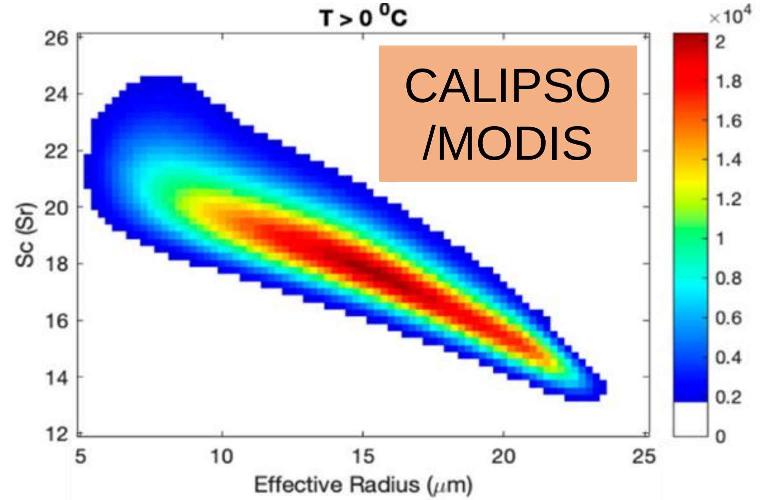
Microphysics



→ See poster on process study microphysics and environmental properties

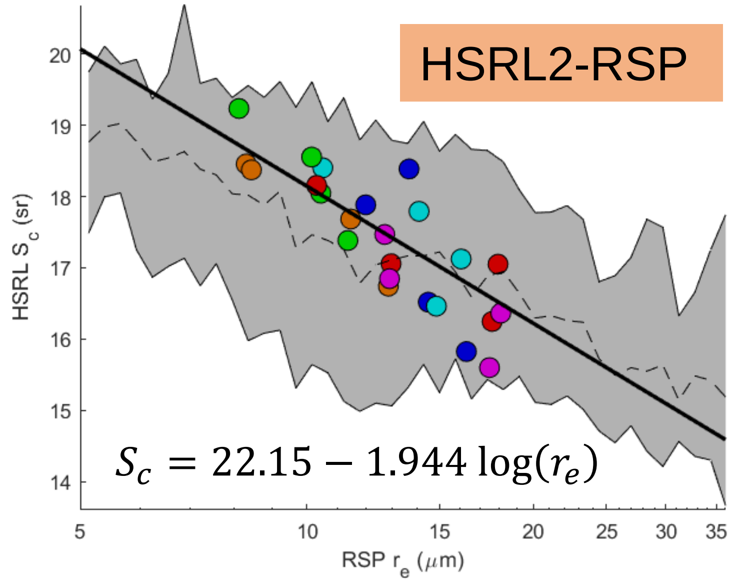
Cloud Remote Sensing – Cloud Lidar Ratio

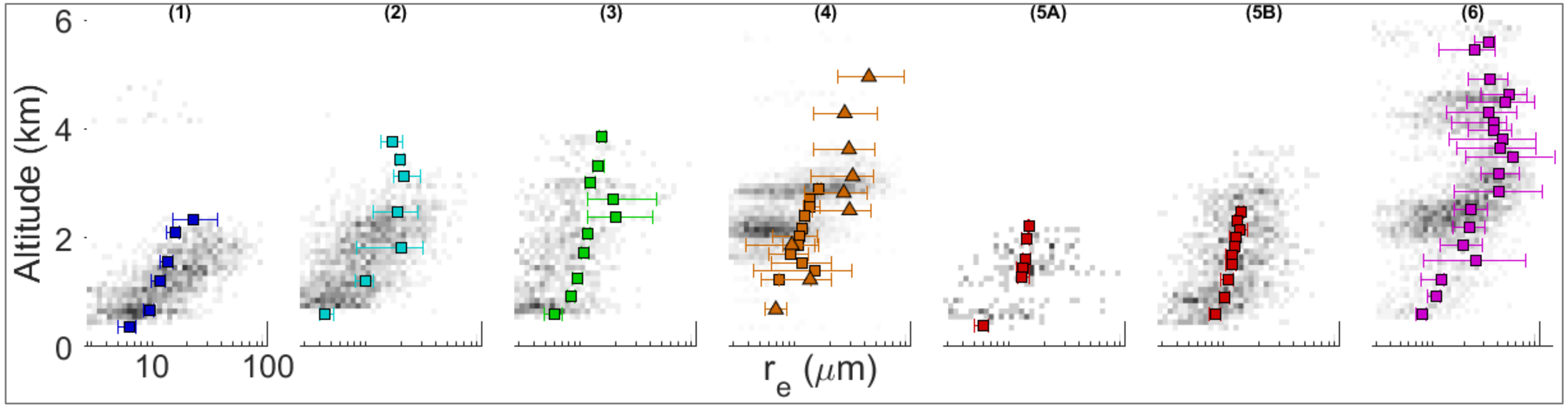




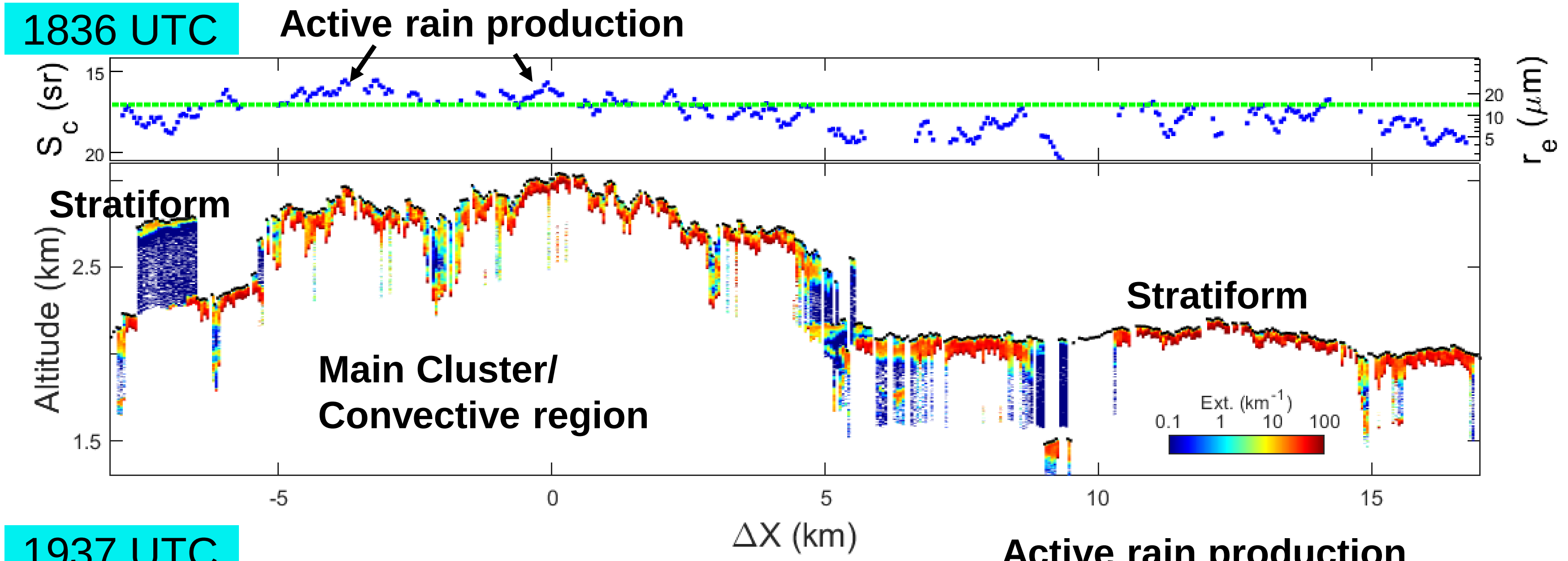
Figures 1A, 2A from Hu et al. 2021

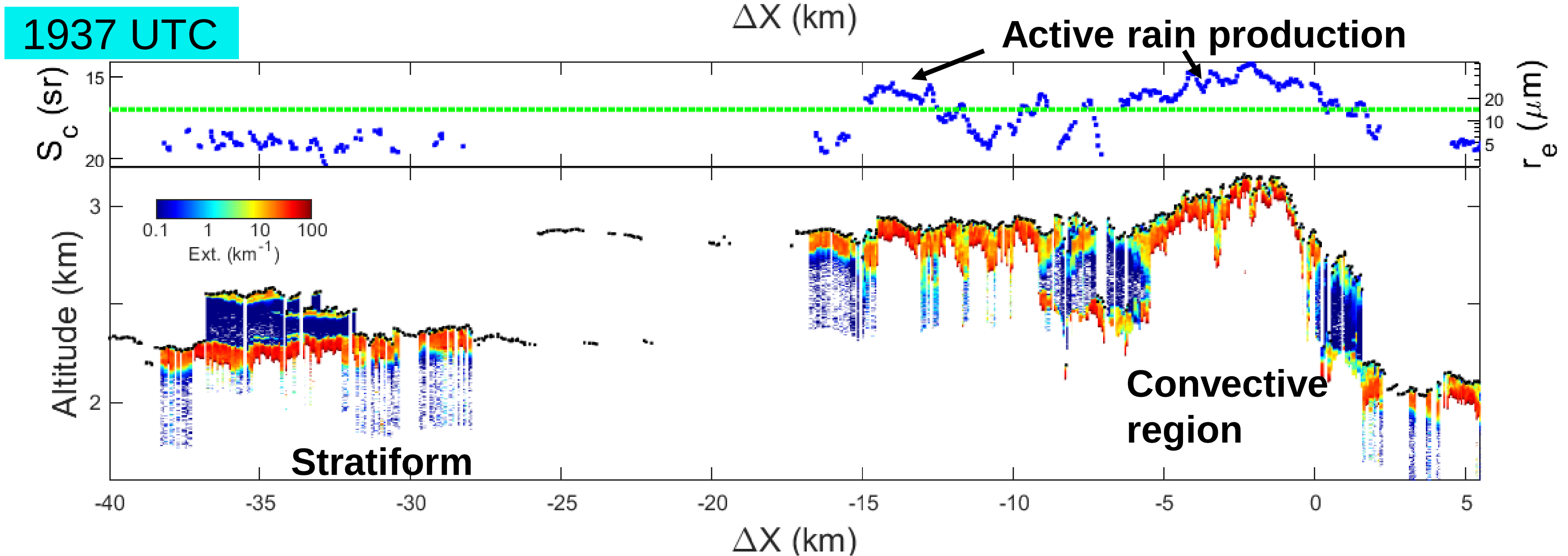
- Inverse relationship between lidar ratio (S_c) and effective radius (r_e)
- S_c sensitivity to size stronger than predicted by theory (based on CALIPSO/MODIS - Hu et al., 2021)
- Similar relationship found for HSRL2-RSP (right)
- S_c extends sizing information to regions where RSP not available
- S_c appears to be more sensitive to precipitation influence on r_e than RSP



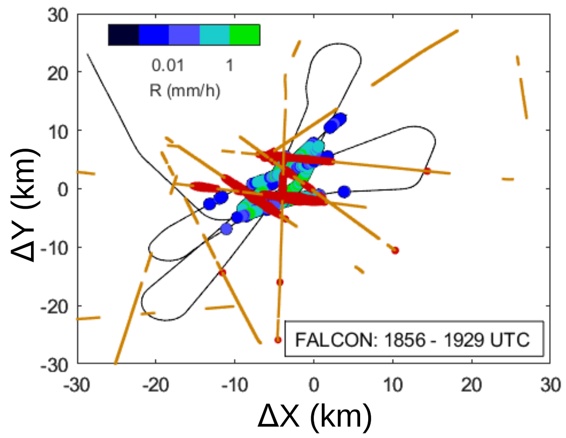


Case 4A: Mature/Decaying Cluster

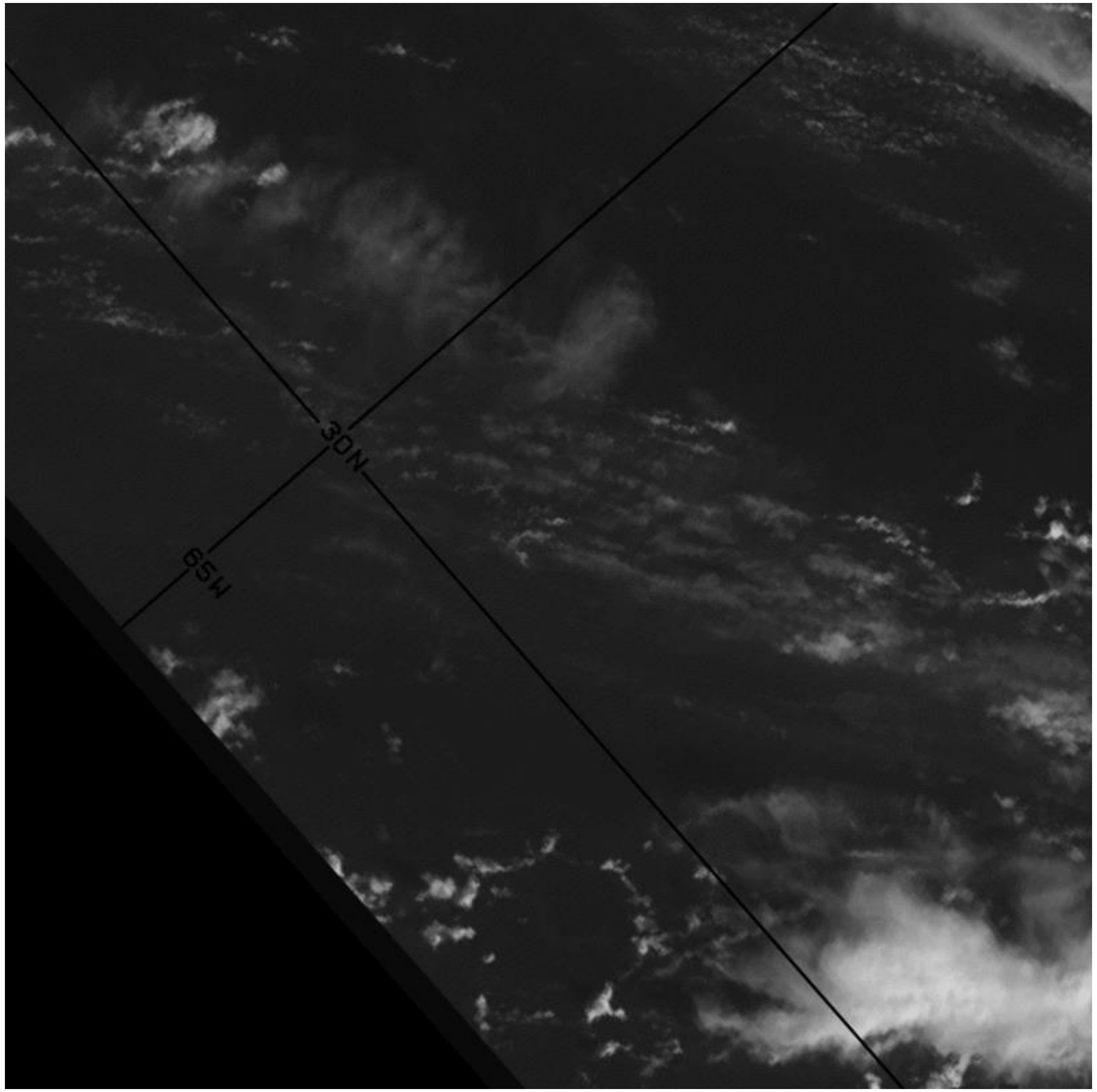


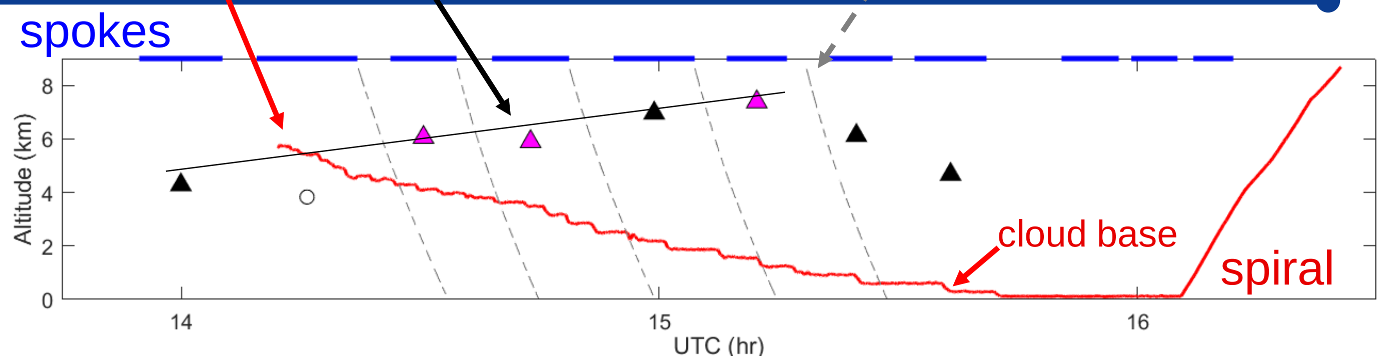


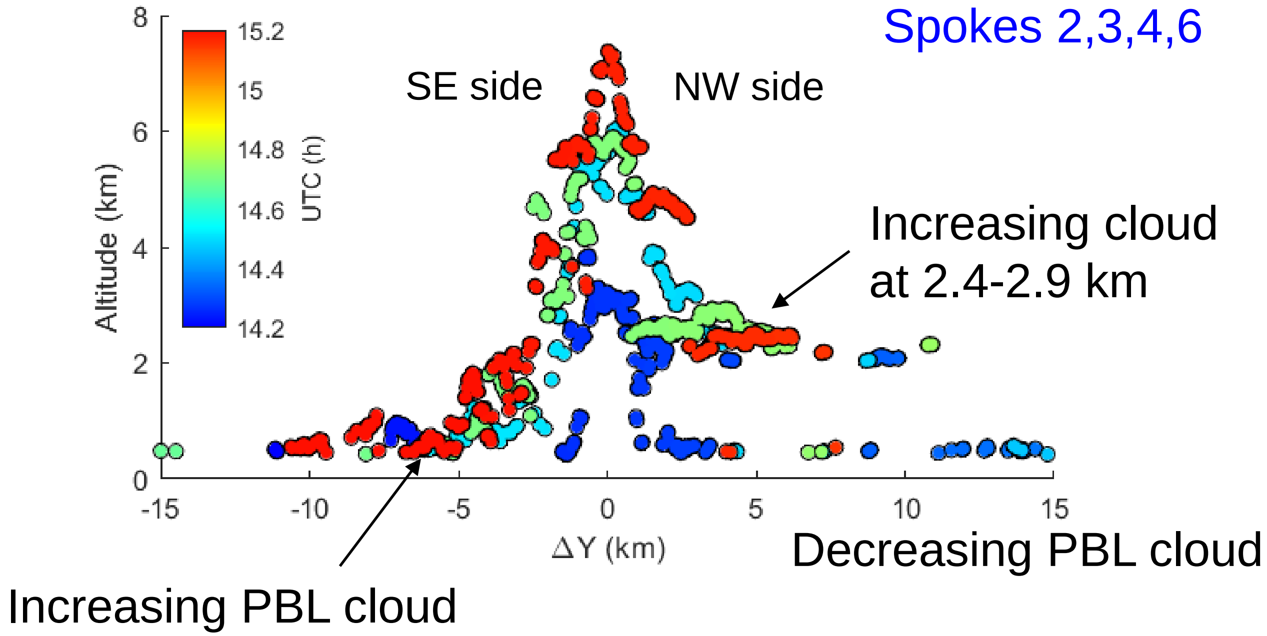
- Case 4A sampled a convective cluster during the latter part of its lifecycle
- Increases in r_e inferred from lidar ratio are spatially correlated with higher cloud tops
- These regions also exhibit higher spatial variance in the cloud top height
- Extinction is more variable in the convective regions
- Peripheral regions are attributed to (sometimes thin) non-precipitating stratiform layers



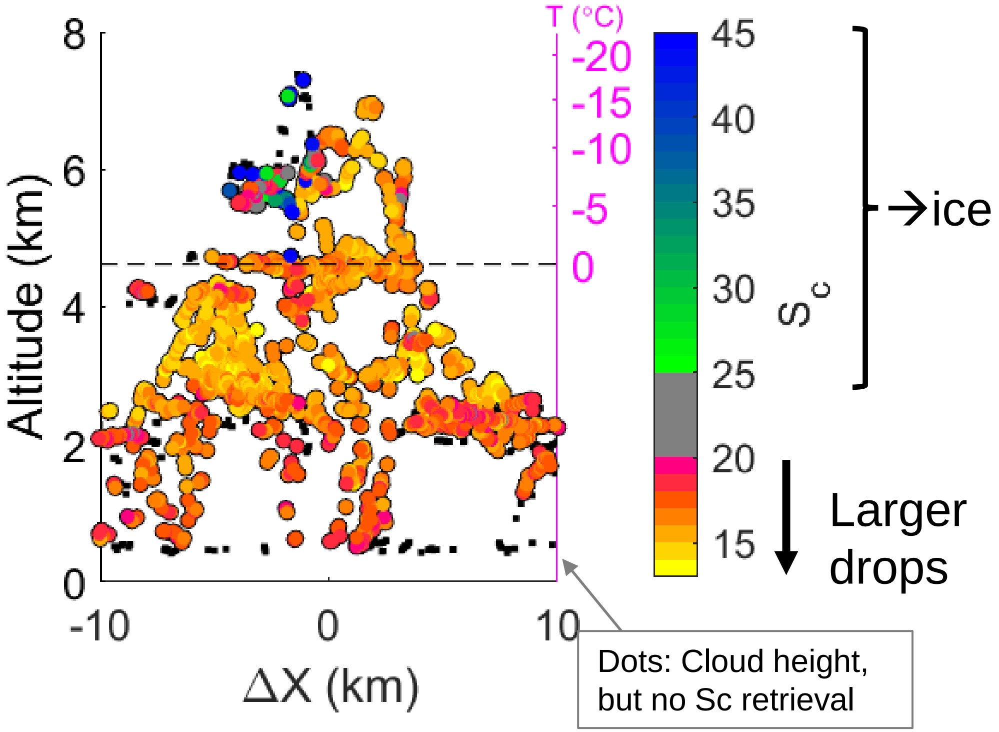
Case 6: Lifecycle

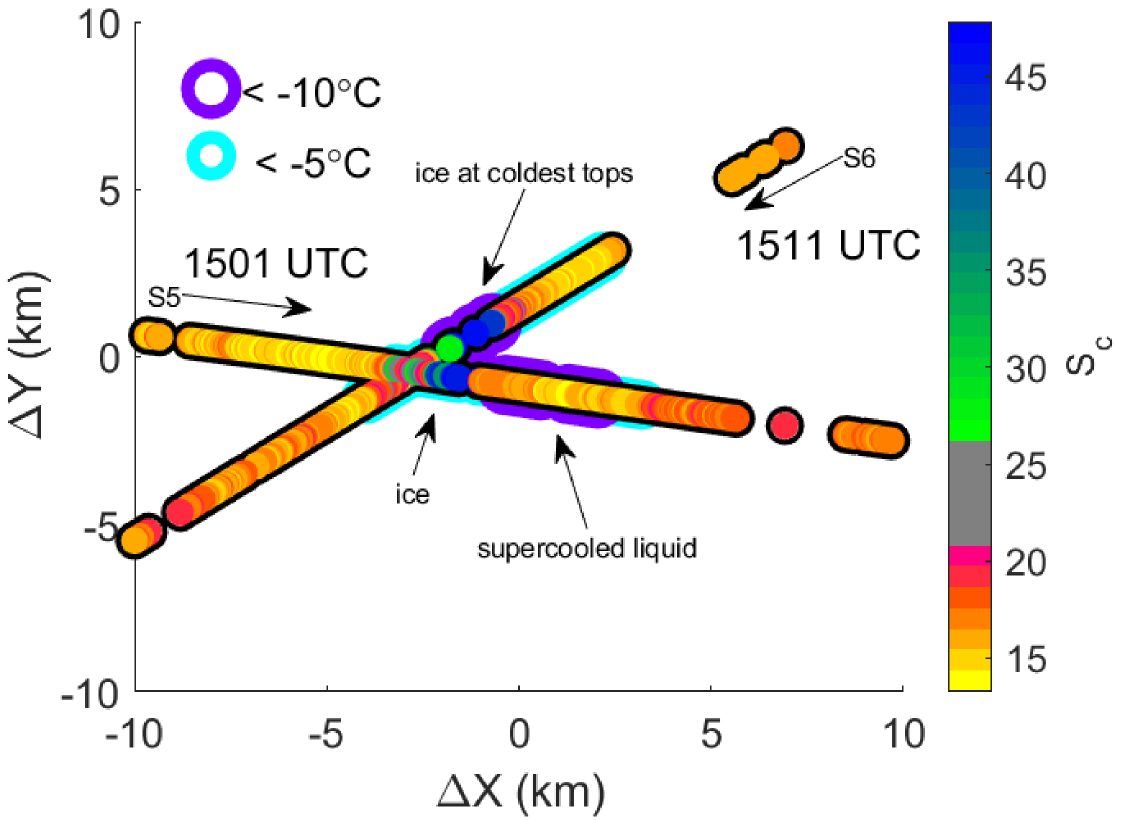






Case 6: HSRL ice detection





- High S_c found in potential freezing locations
- Not sampled in situ (based on cloud growth)
- S_c retrieval assumes depol only from multiple scattering
- Irregular ice particles also produce depol therefore causing a high "effective" S_c

- Spokes 5 and 6 (10 min separation) resulted in a repeated signature of ice in a consistent location
- Spoke 5 indicated that the leading turret was still liquid with ice located on the shoulder
- Spoke 6 showed collocation of ice with the coldest tops

Conclusion: (Working Hypothesis)

- agrees with BB17 conceptual model
- Precipitation an effect not a cause
- Surface buoyancy flux anomalies important (Gulf Stream)
- Nature generates many other modes of variability external to the system (e.g. not an idealized LES)

- Asymmetry an aspect of deeper systems with more significant precipitation
- Cold pools may exist but downward transport of low θ_e air may occur without significant negative buoyancy

- Fully decoupled remnants not able to tap into surface θ_e
- Onset of this phase caused by internally generated shearing of the inflow
- → precipitation may both help and hinder scale growth

Questions?
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