Relationships between Lightning and Thunderstorm Microphysics: Insights from StickNets, LMA, and WSR-88D

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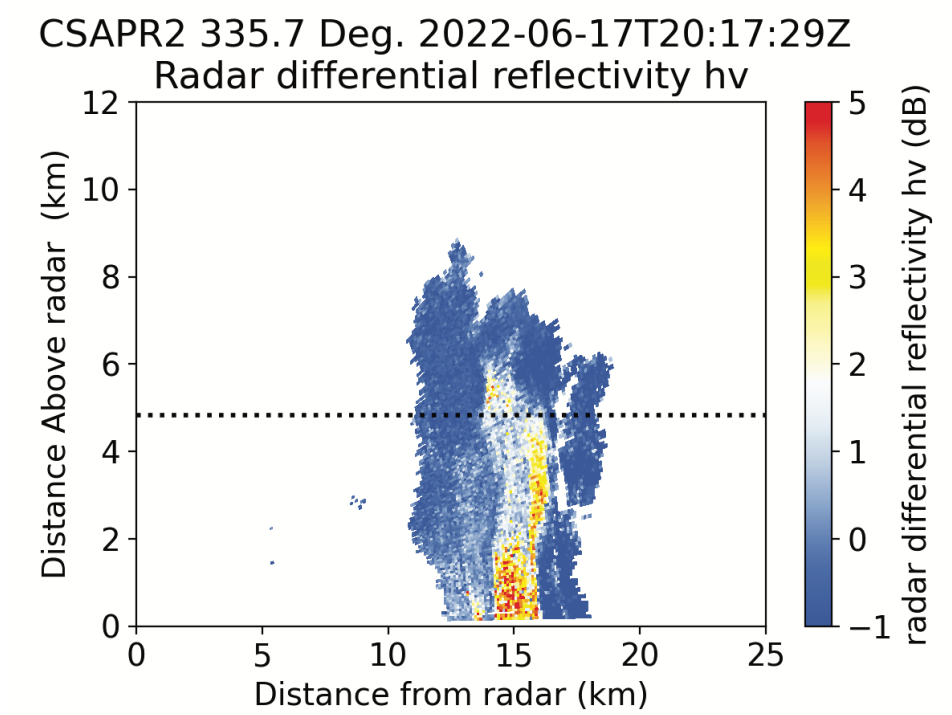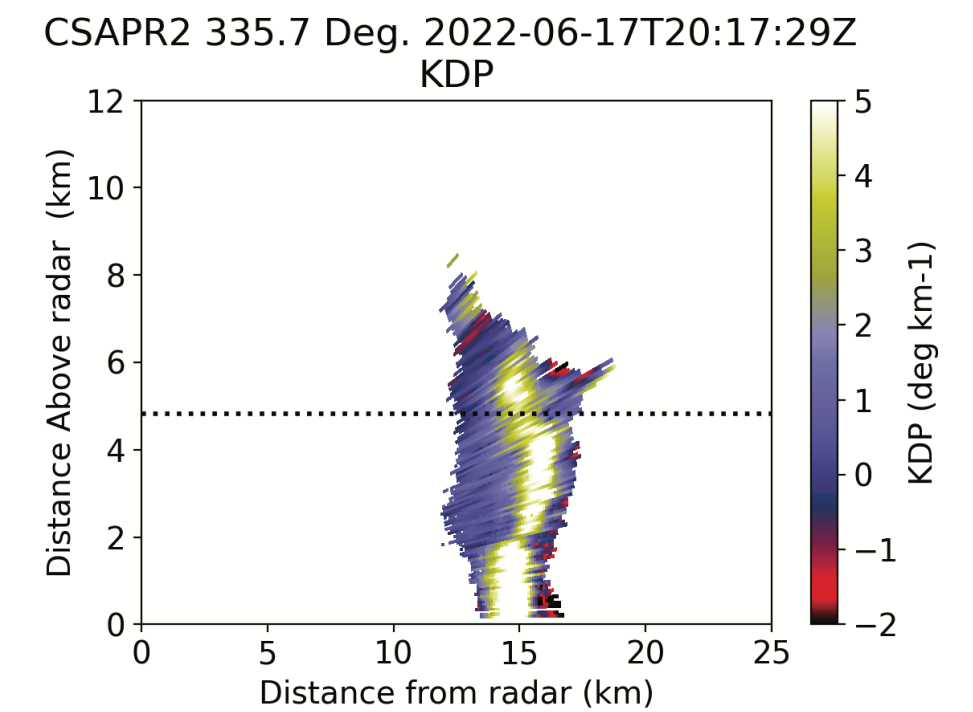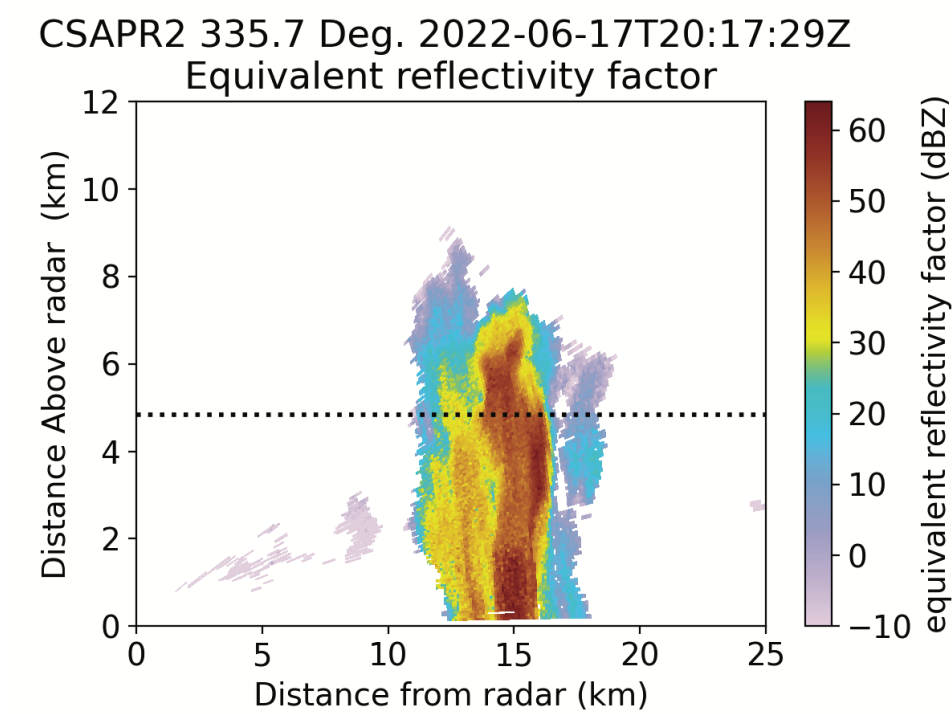
1. Texas Tech University Geosciences Dept.
2. National Severe Storms Lab
3. Cooperative Institute for Severe and High-Impact Weather Research and Operations

Lightning Signals in Thunderstorms
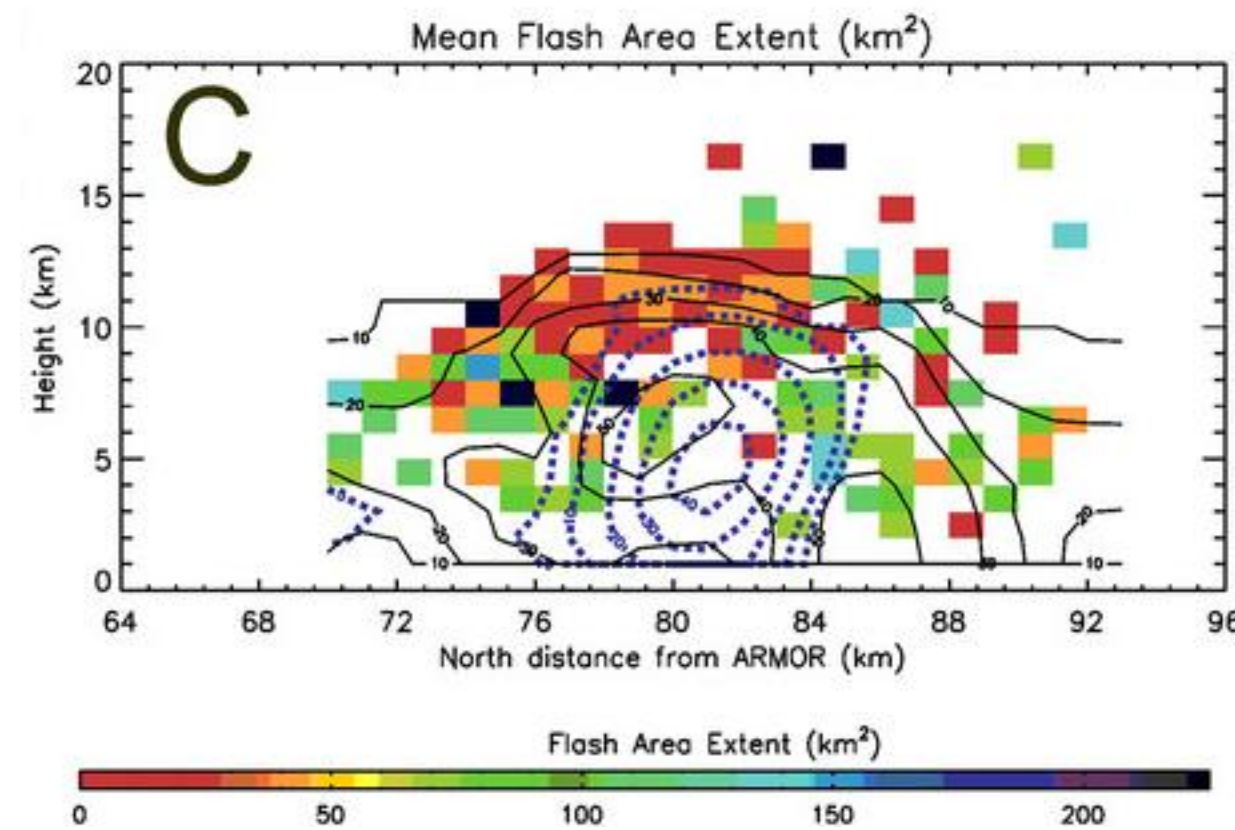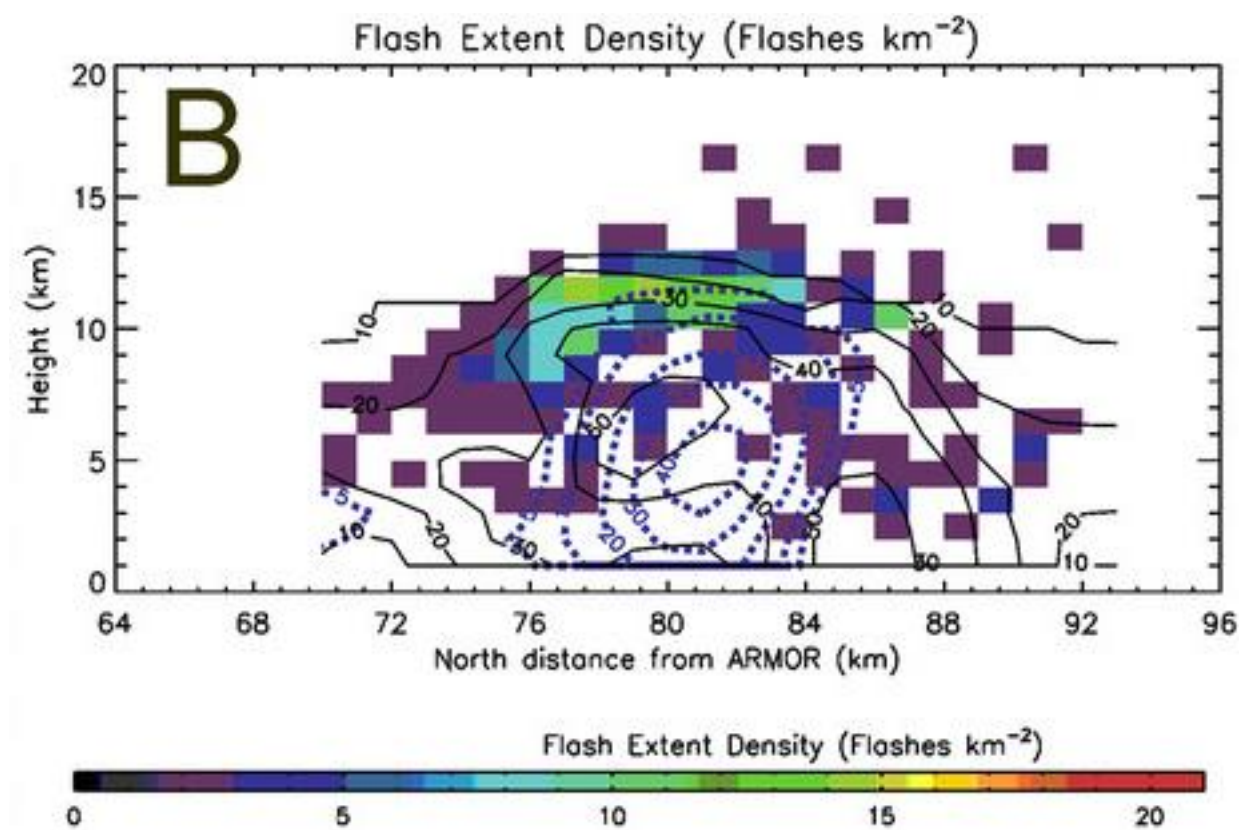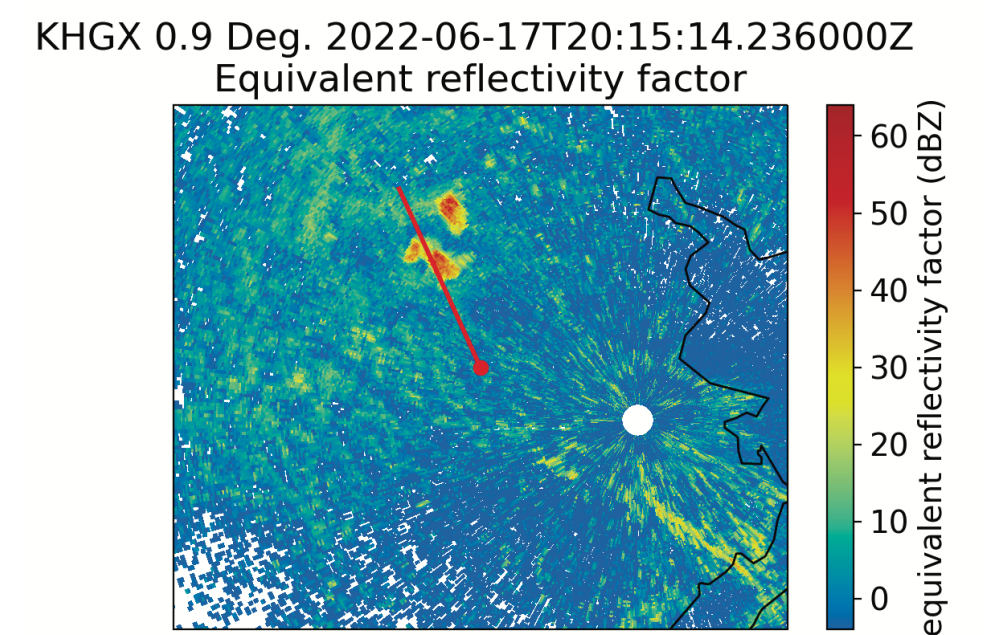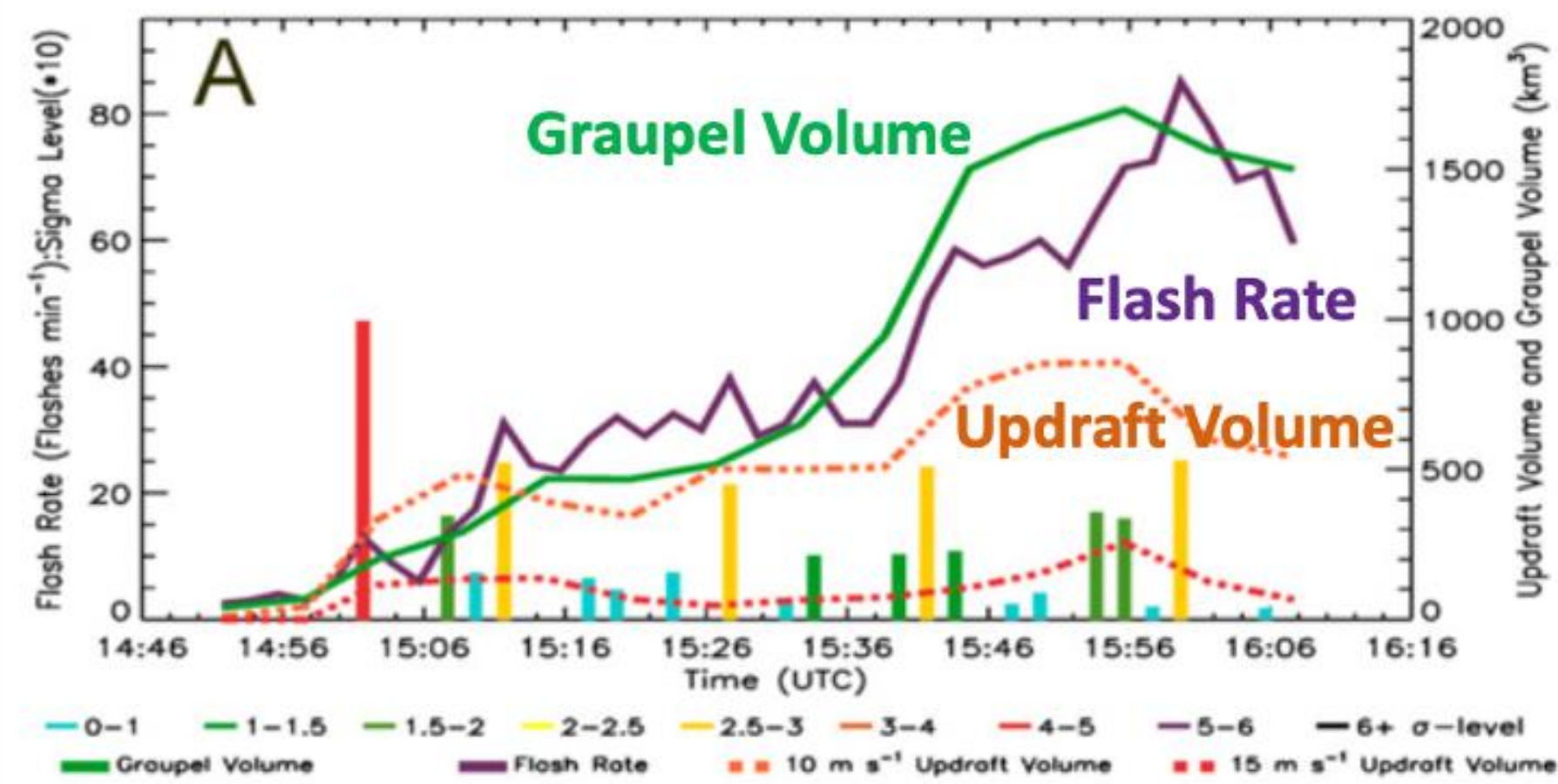
Schultz, et al., 2015 (A), 2017 (B, C)

Bruning, ARM/ASR 2022

Microphysics and Electrification
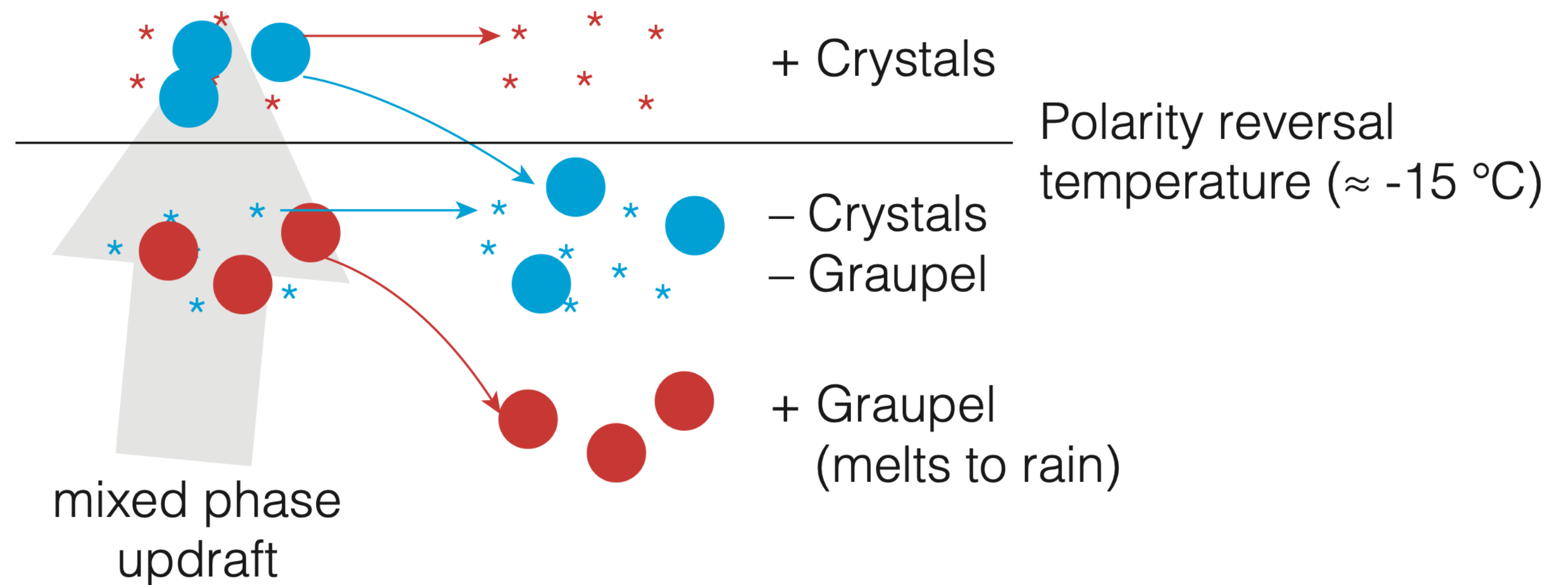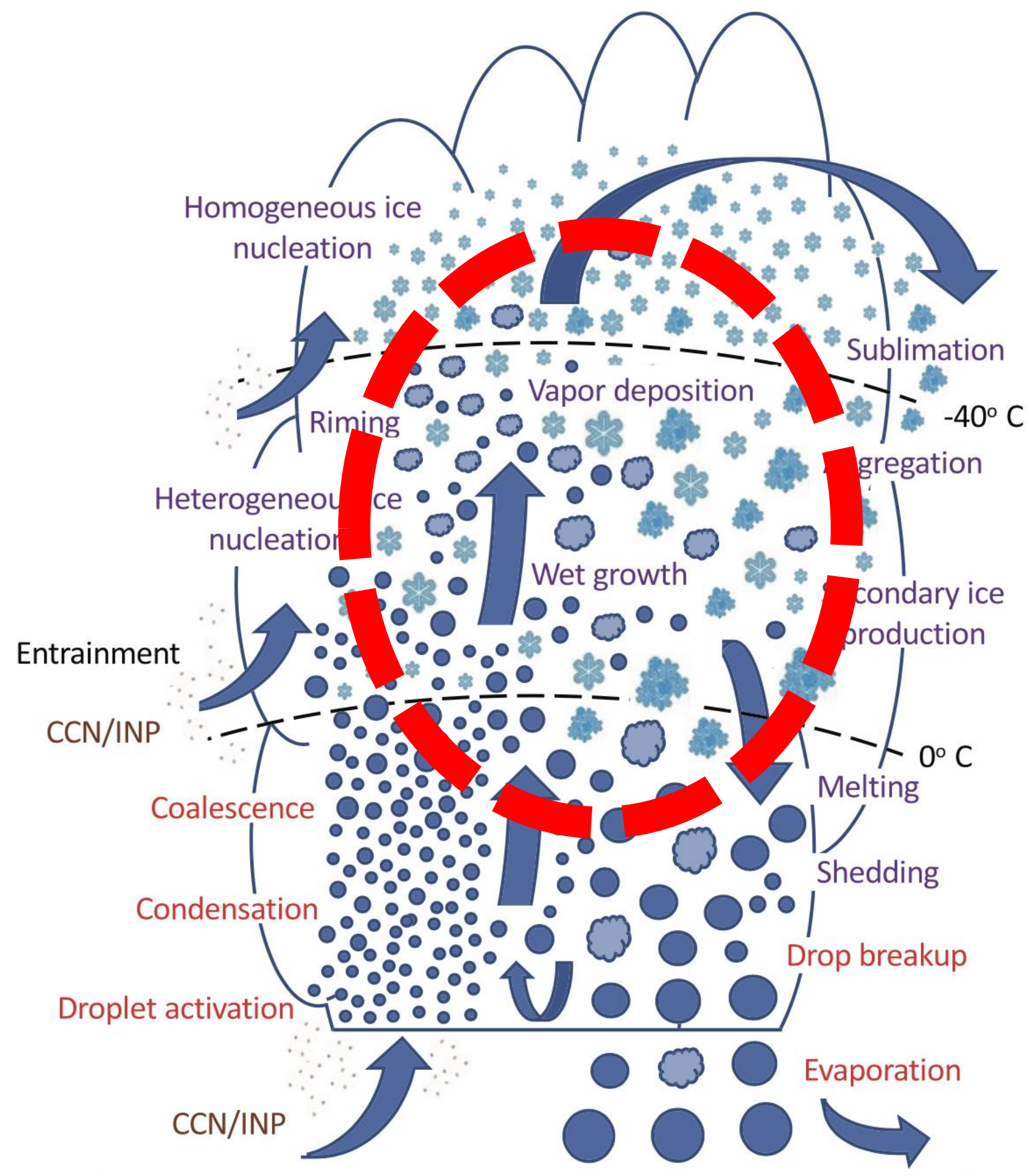
Homogeneous ice nucleation

Sublimation

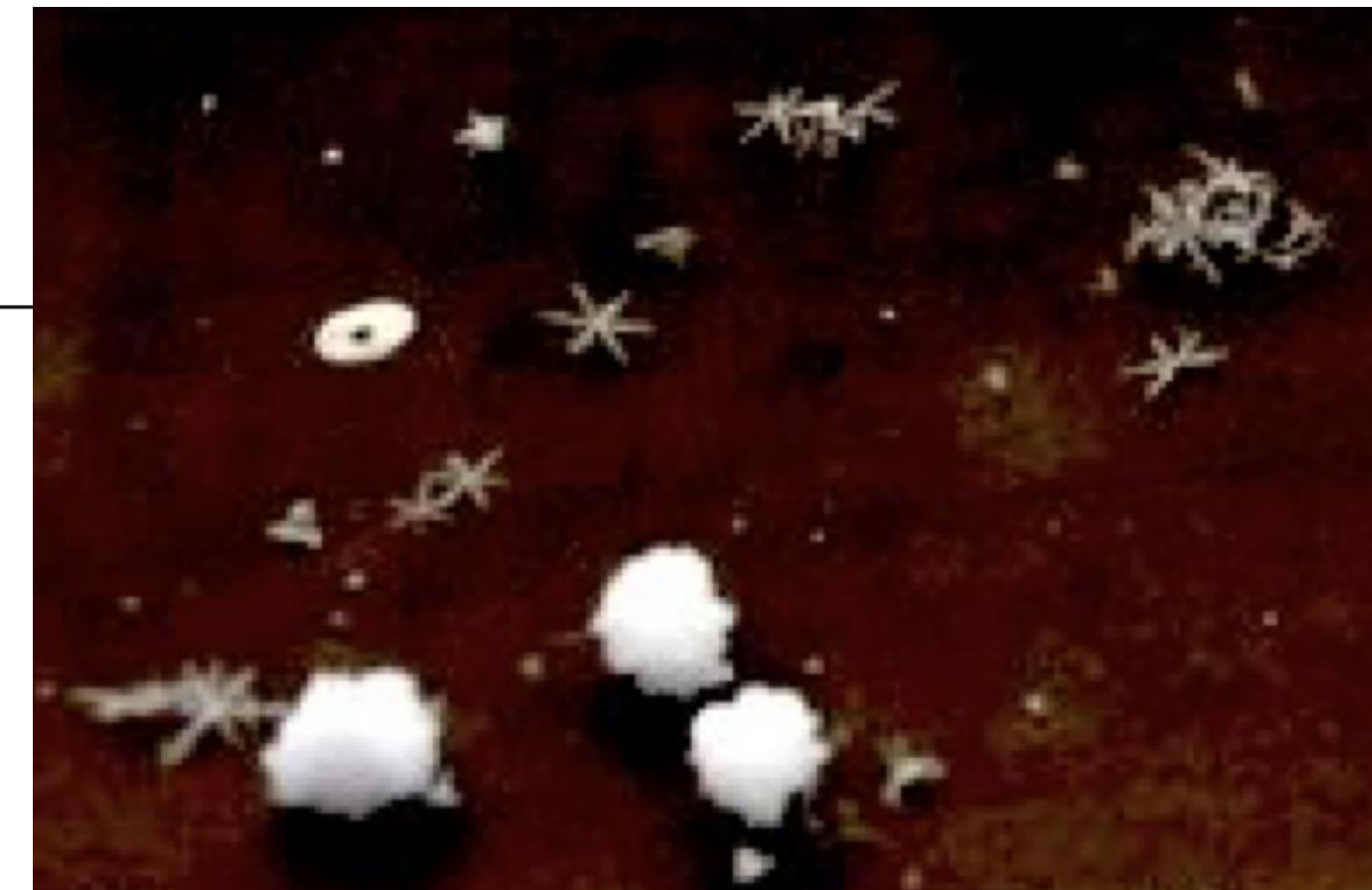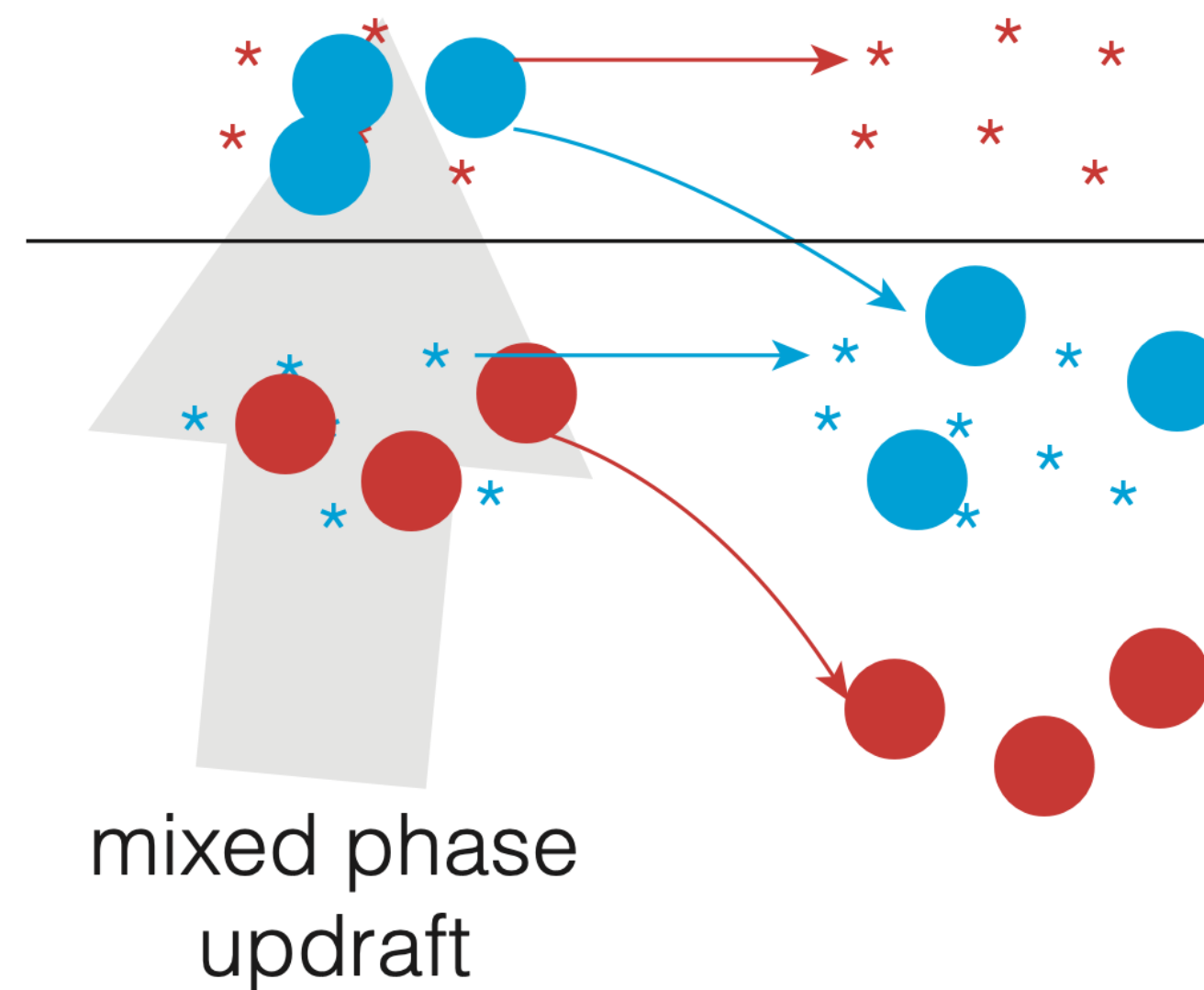Vapor deposition

Riming

-40° C

Heterogeneous ice nucleation

Aggregation

Wet growth

Secondary ice production

Entrainment

CCN/INP

Coalescence

Melting

0° C

Condensation

Shedding

Droplet activation

Drop breakup

CCN/INP

Evaporation

mixed phase updraft

Thunderstorm primary electrification results from collisions of ice crystals of graupel in the presence of supercooled liquid water. Non-inductive: operates independently of background electric field.

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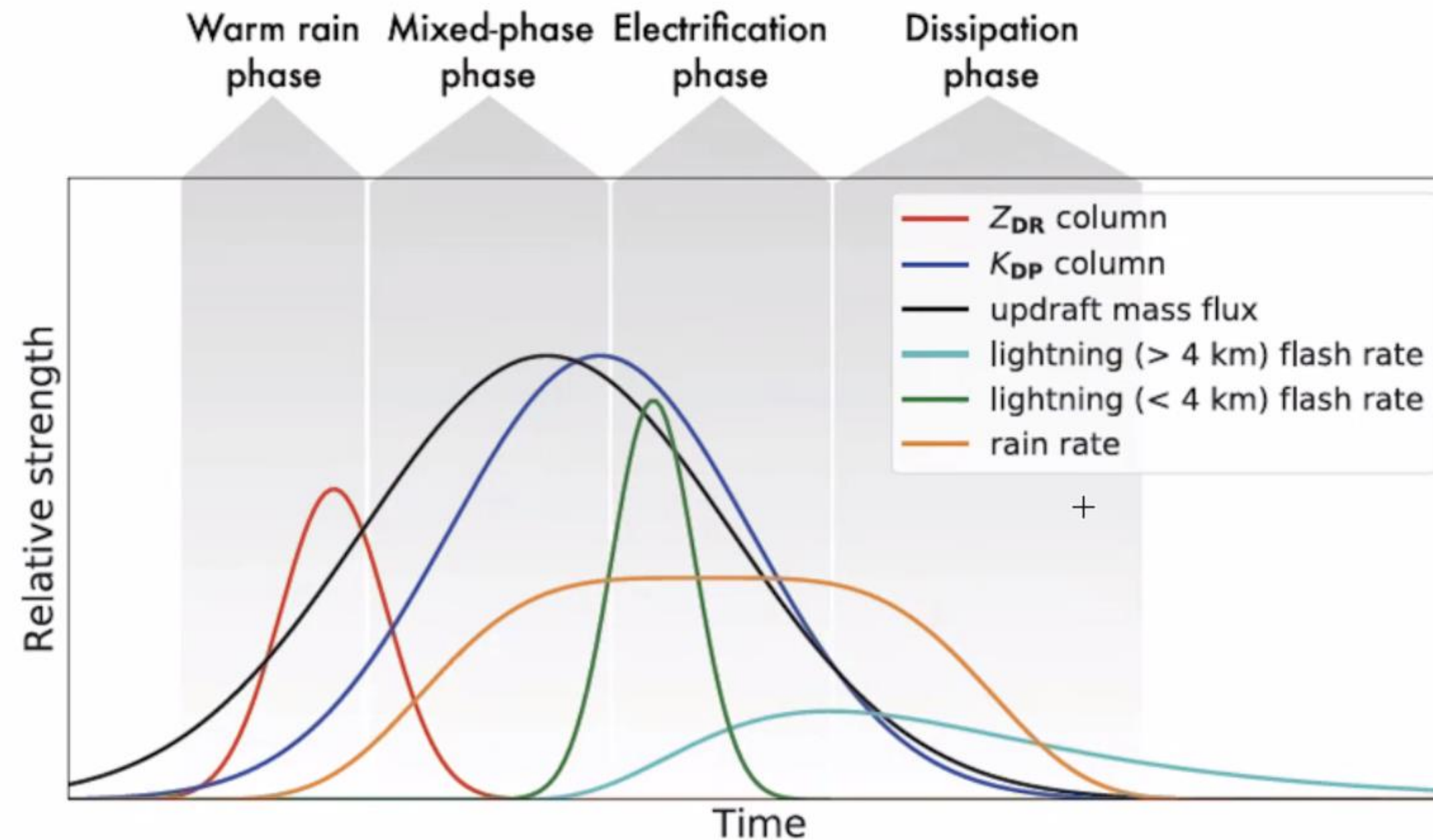
Lightning Signals in Thunderstorms

Single-cell storms

Fridlind et al. (2019, AMT)

- Single cell storms follow a conceptual model:

  - Updraft lofts supercooled water in the mixed phase region, we have glaciation, graupel grows in the mixed phase region, charging occurs as graupel and ice collide, charge regions form and lightning begins

  - Small flashes peak first, larger flashes occur more slowly through dissipation

- How are QLCS, multi cell Thunderstorms different?

  - Lower flash rates

  - High Shear/Low Cape

  - Convolutions of the conceptual processes

Lightning in Southeast Thunderstorms

Multi-cell storms: overlapping phases

Fridlind et al. (2019, AMT)
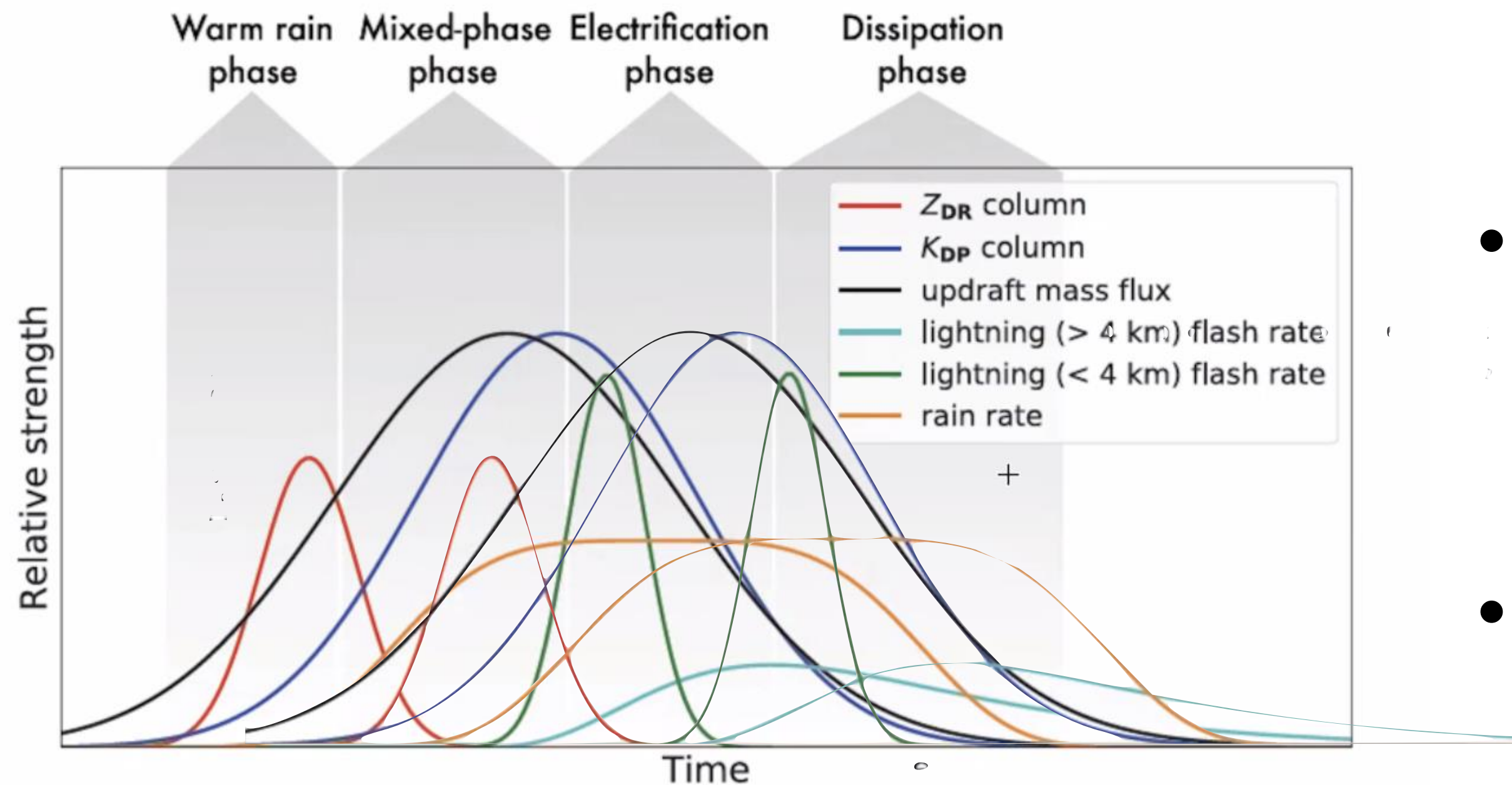
- What do stronger polarimetric columns mean for electrification?

  - What's the time lag between a polarimetric column and lightning?

- What signals are consistent between storm types?

  - Single cell vs. complex/multicell

- What kinematic and microphysical relationships can be observed in the environment?

  - Sticknet observations

TOBAC: Tracking and Object-Based Analysis of Clouds

Tracking methods
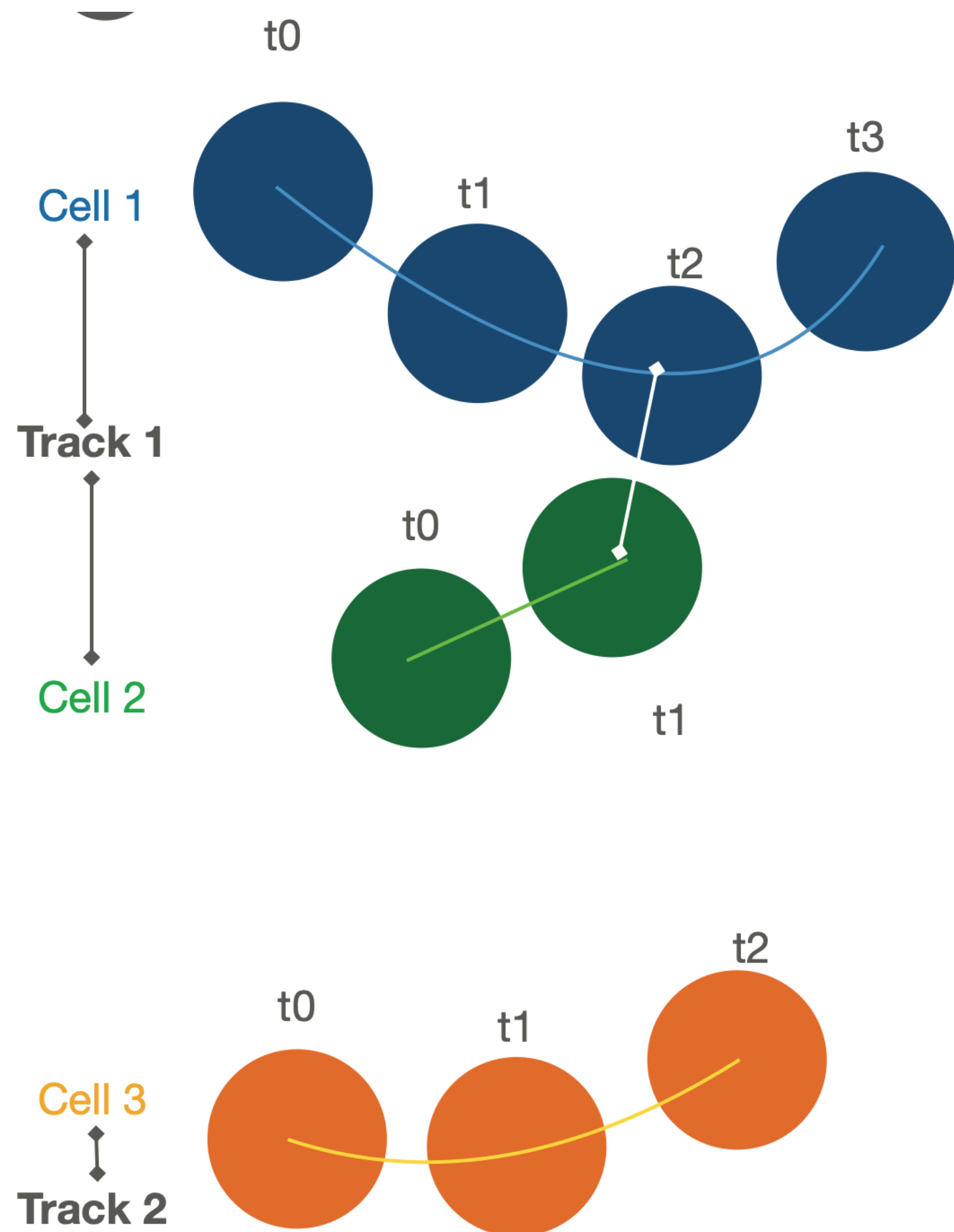
- Tracking using the open source package tobac:

  - https://github.com/tobac-project/tobac

  - Heikenfeld, et al., 2019

  - Based on watershed + TrackPy linking, including merge/split

  - Creates Features, 2d id mask, cells, and Tracks
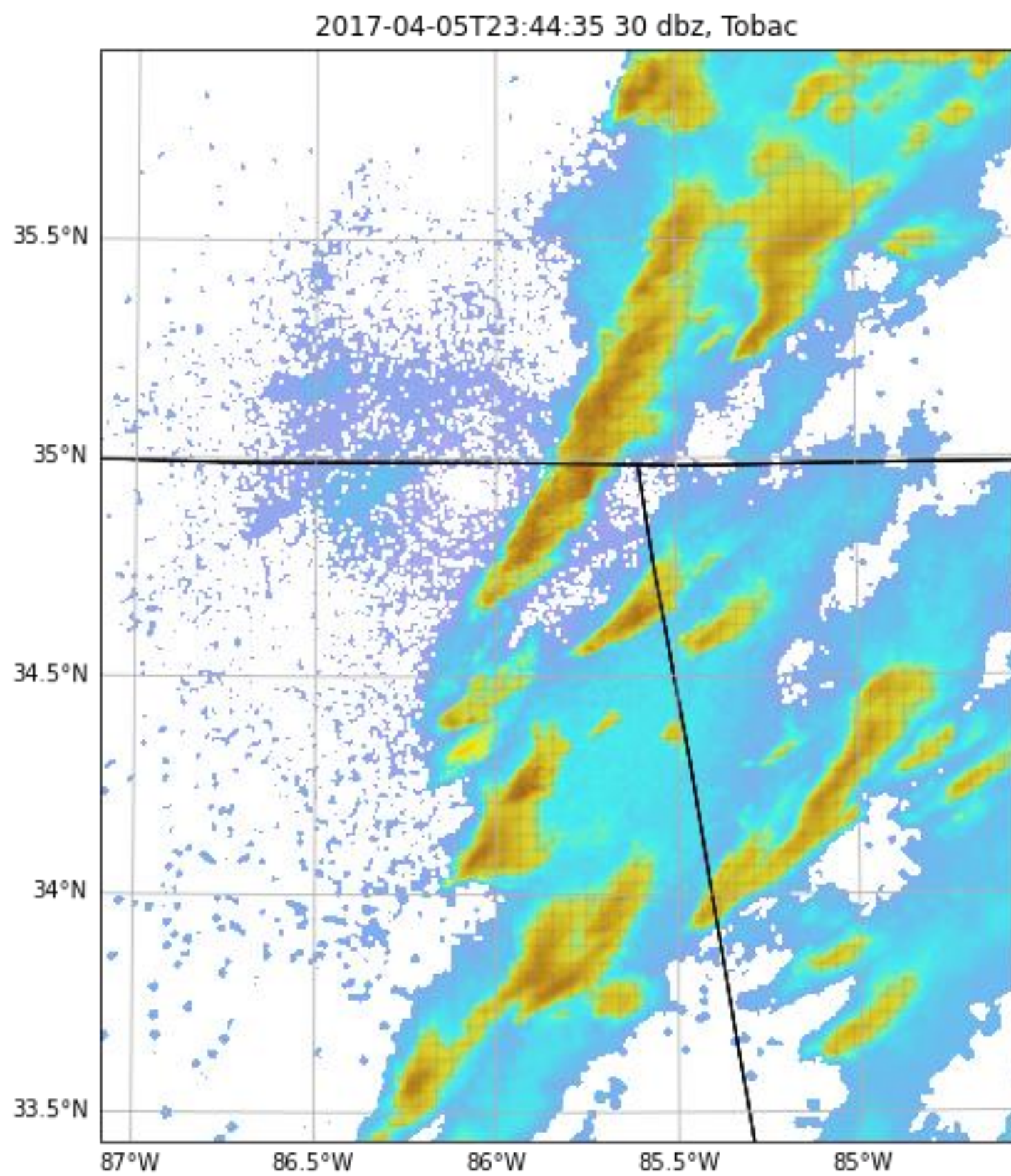
- Radar: composite reflectivity at 30dBz

Date
20160331
20160430
20170405
20170430
20220322
20220330
20220405
20220413

VORTEX-SE

PERiLS

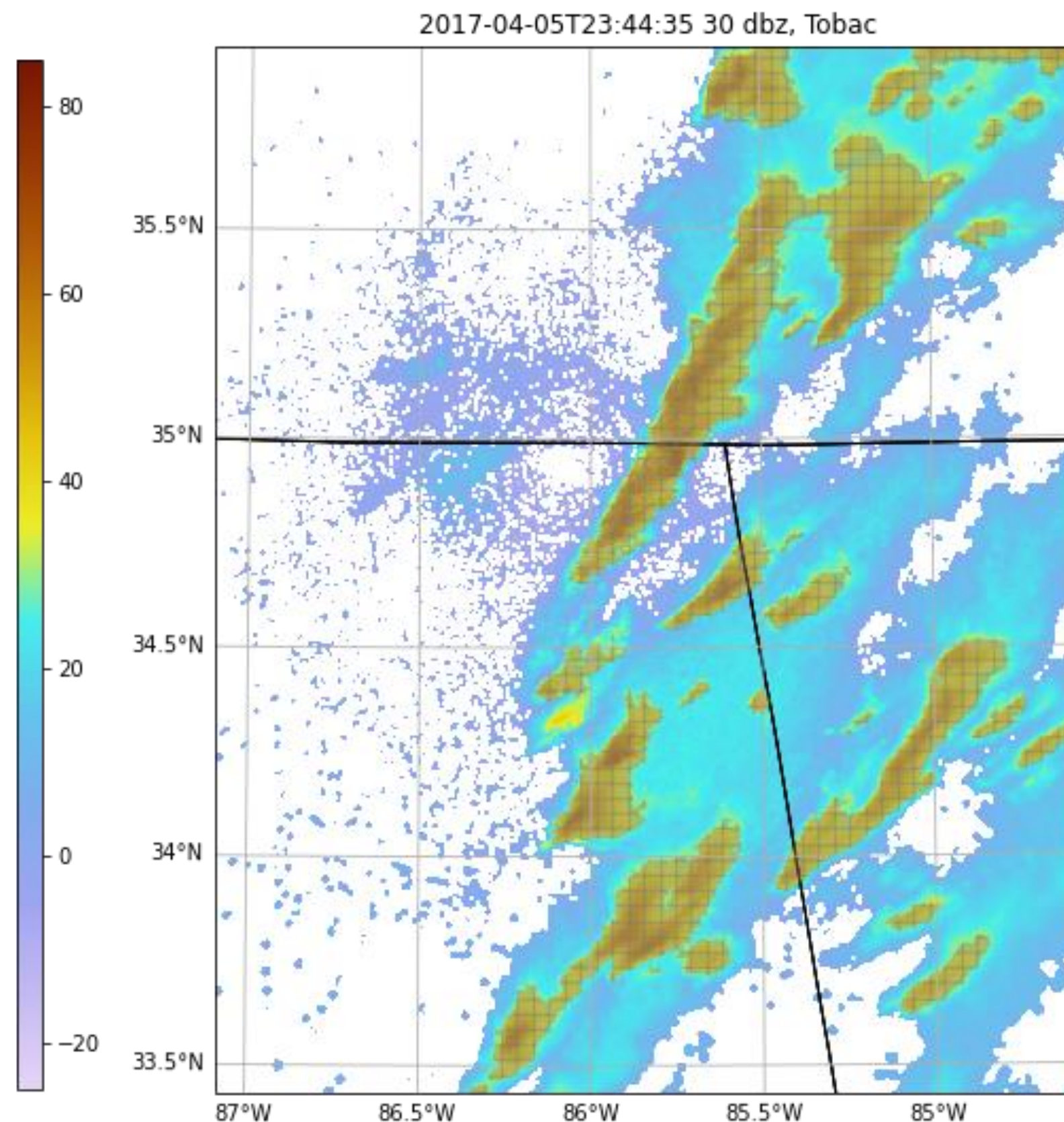# TOBAC: Tracking and Object-Based Analysis of Clouds
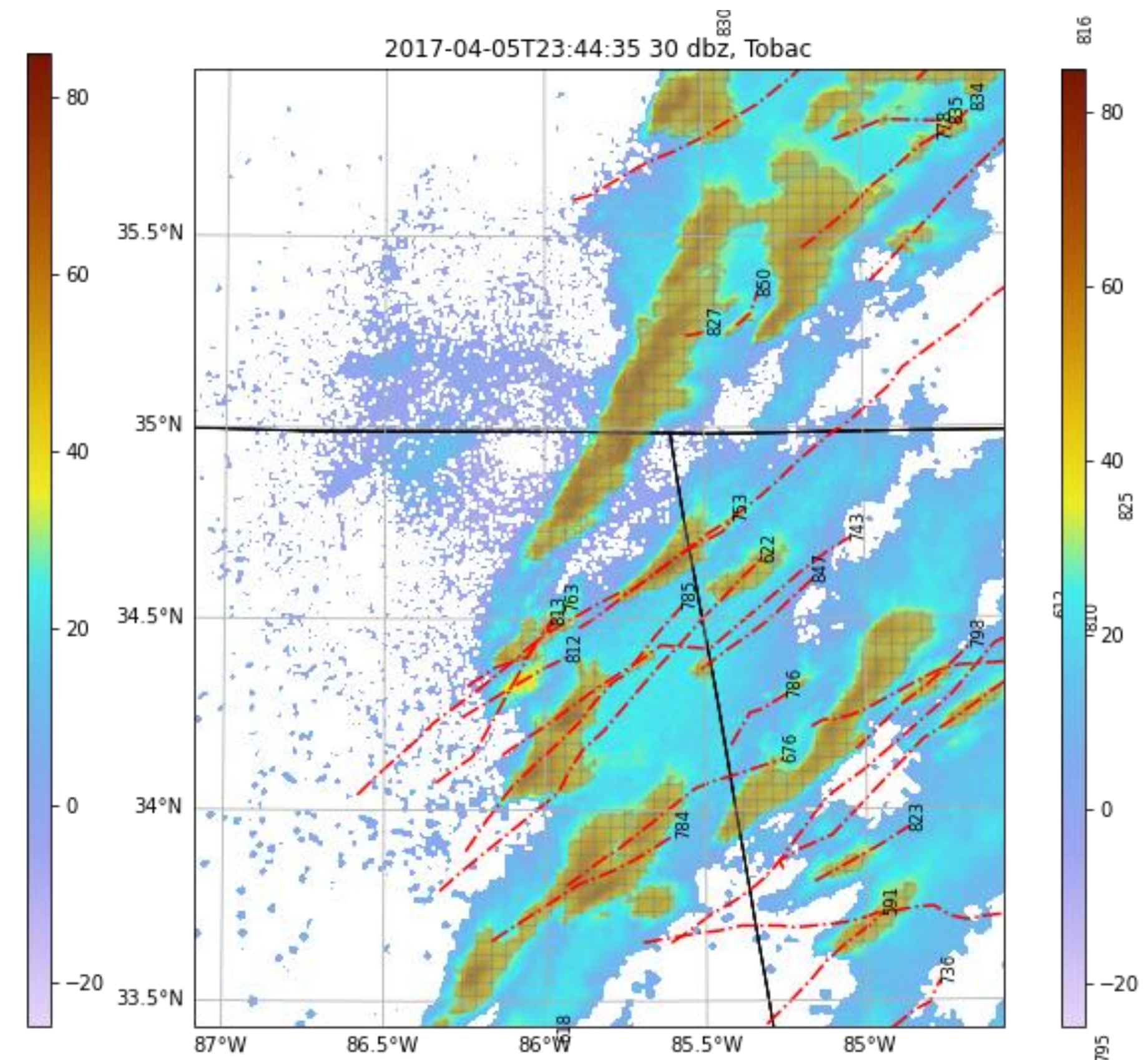
Tracking methods
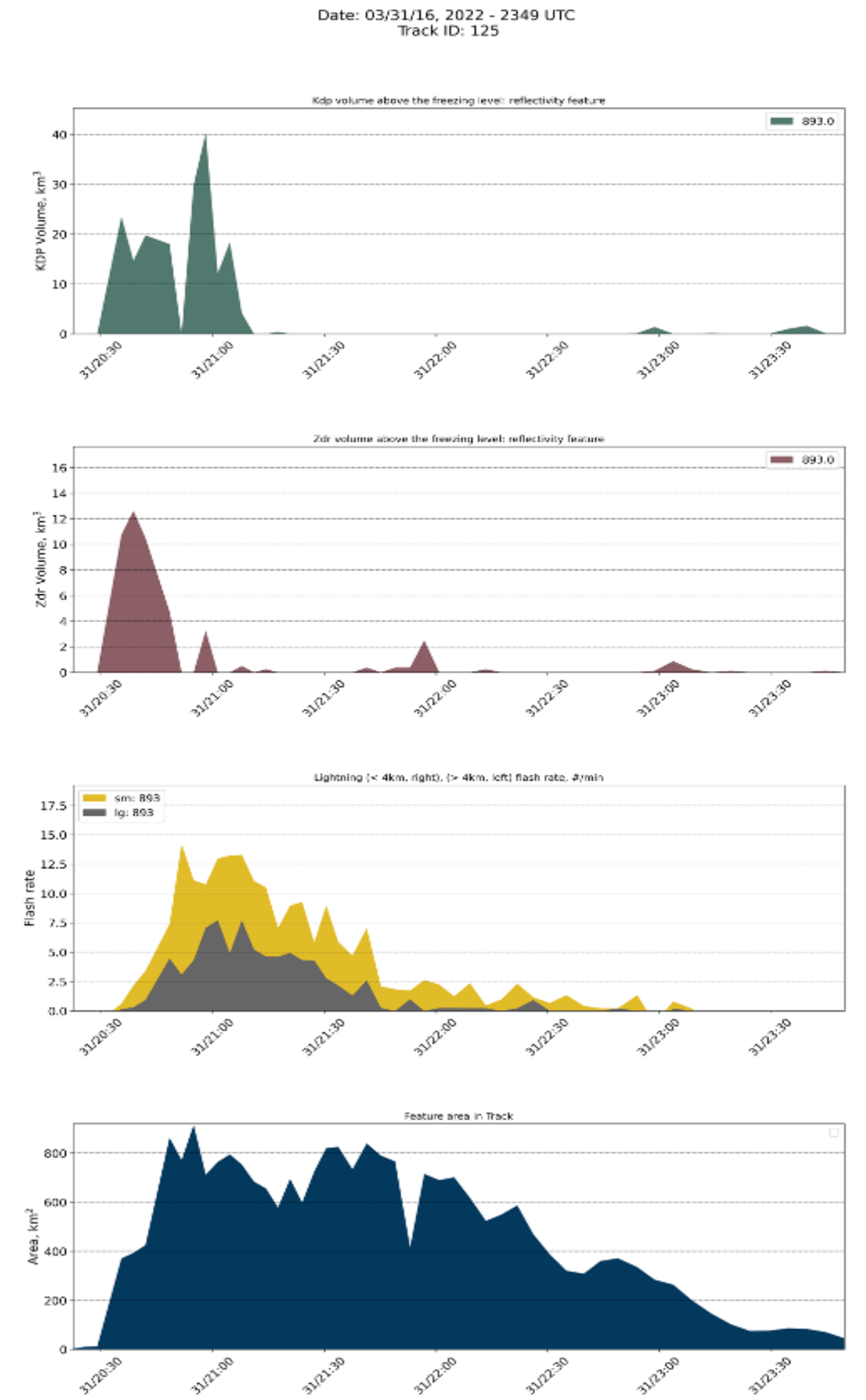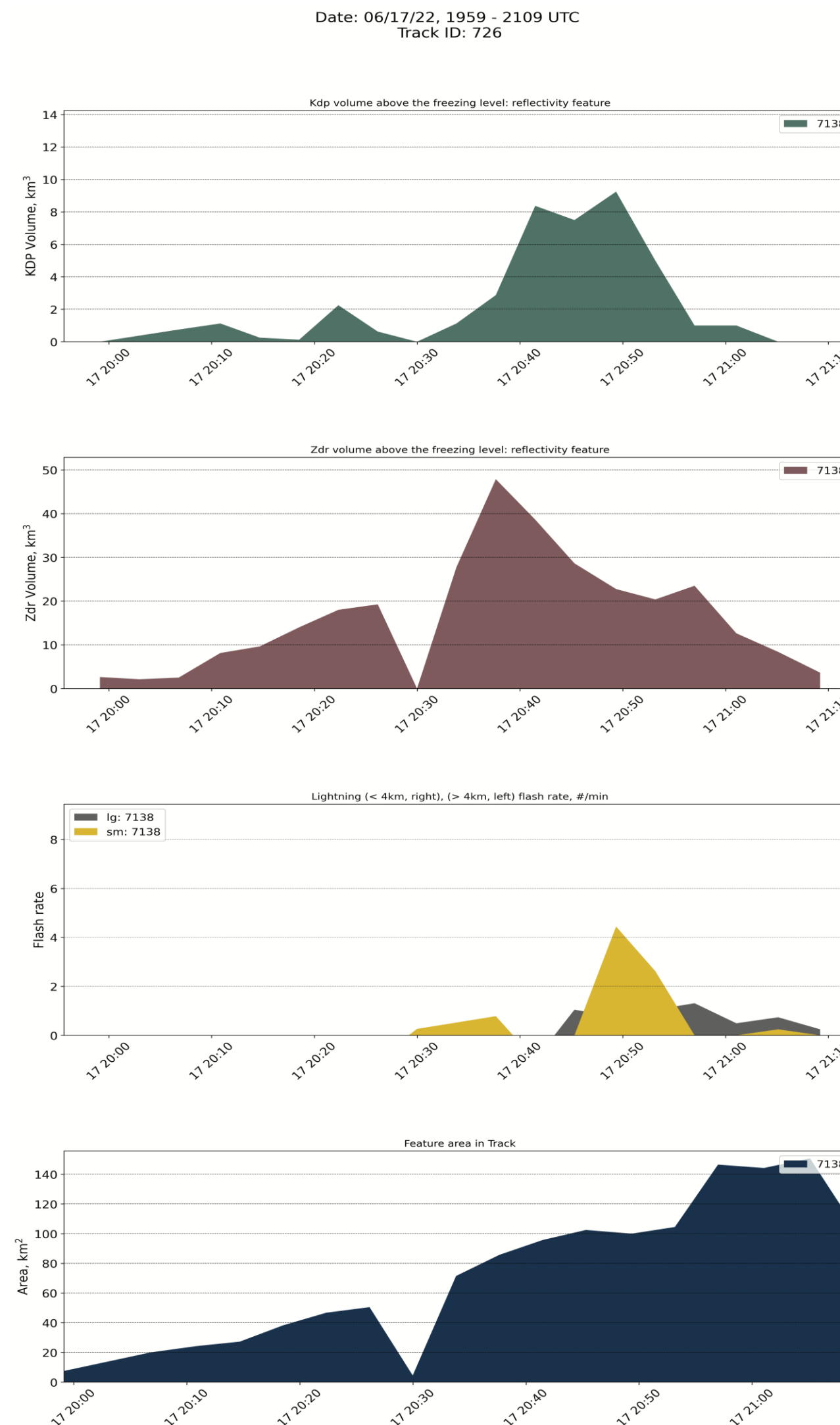

Identify Features

Feature Mask

Link Features

What can we do with Tracks: Microphysical patterns

Radar and dual-polarimetry methods

- Zdr/Kdp column:

  - Volume in 3km above the melting level

  - Column Strength – vertically integrated in same 3km slab

- Cell area/max reflectivity

- Flash rate by size:

  - Small flashes with area < 4km

  - Large flashes with area > 4km

How can we dig in the data?

- **Track type**

- **Environment influences**

- **Column Strength**

- **Temporal offsets between polarimetry and lightning**

What can we do with Tracks: Microphysical patterns
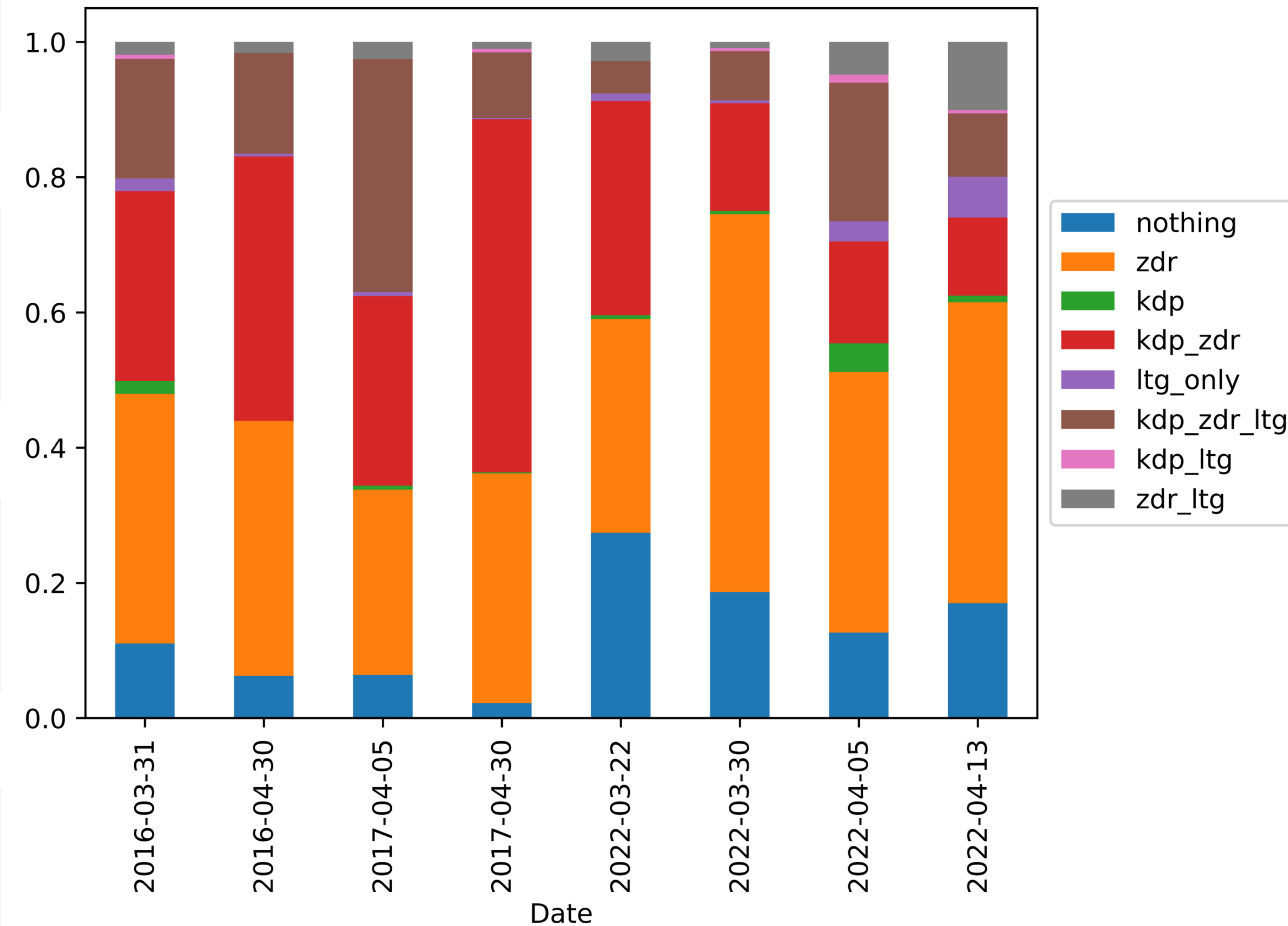
Sorting by timeseries 'flavor'

- Tracks that have 'idealized' cell development

- Tracks that have ZDR and KDP columns, NO lightning

- Tracks with only a ZDR Column

- Tracks without lightning and NO ZDR and NO KDP column

Date: 03/31/16, 2022 - 2349 UTC
Track ID: 125
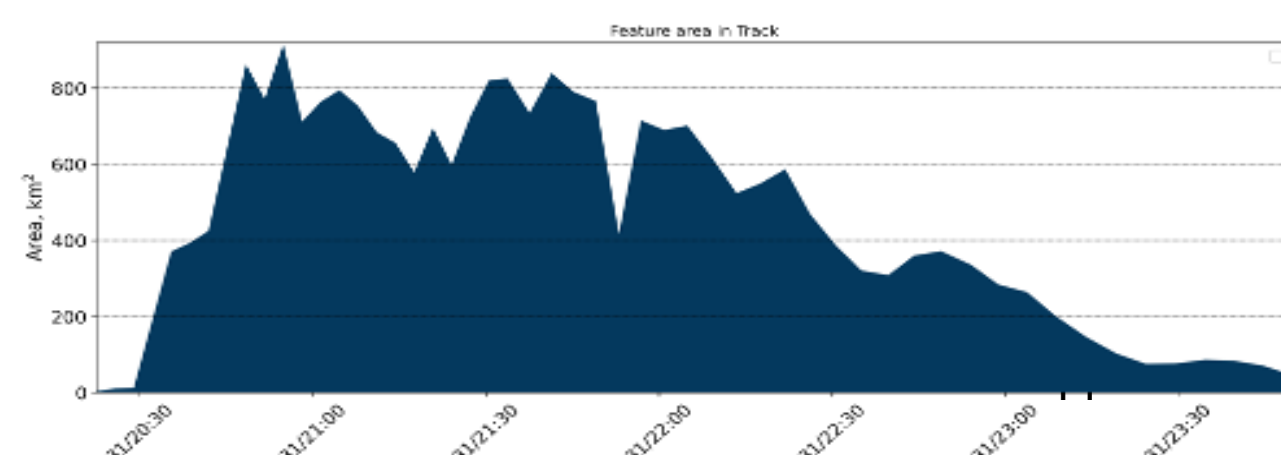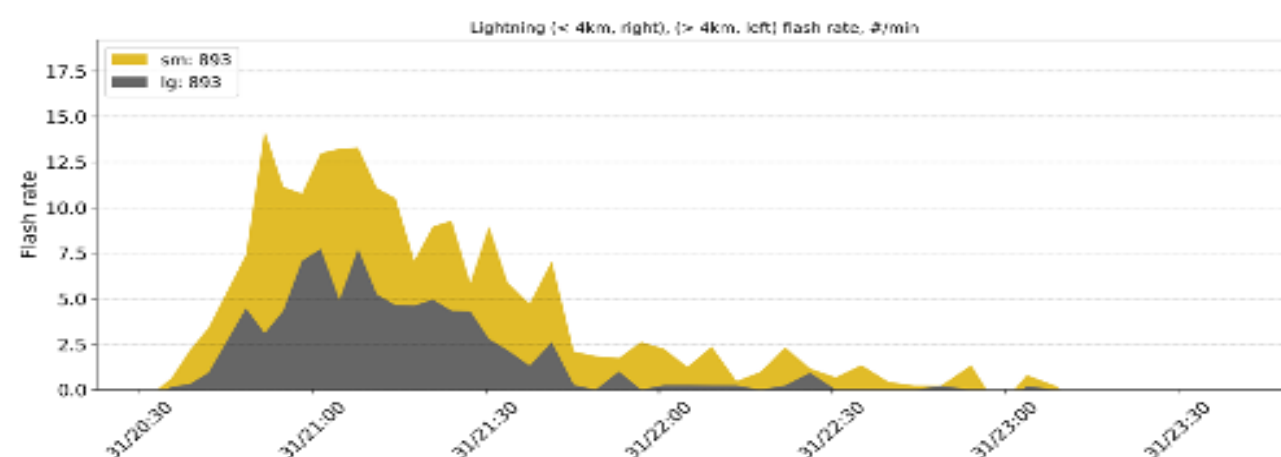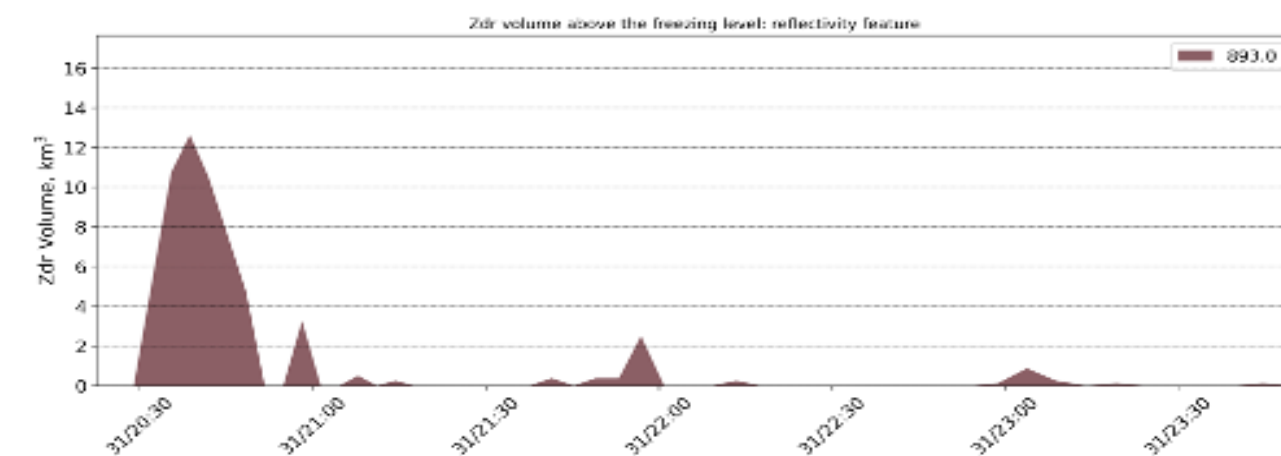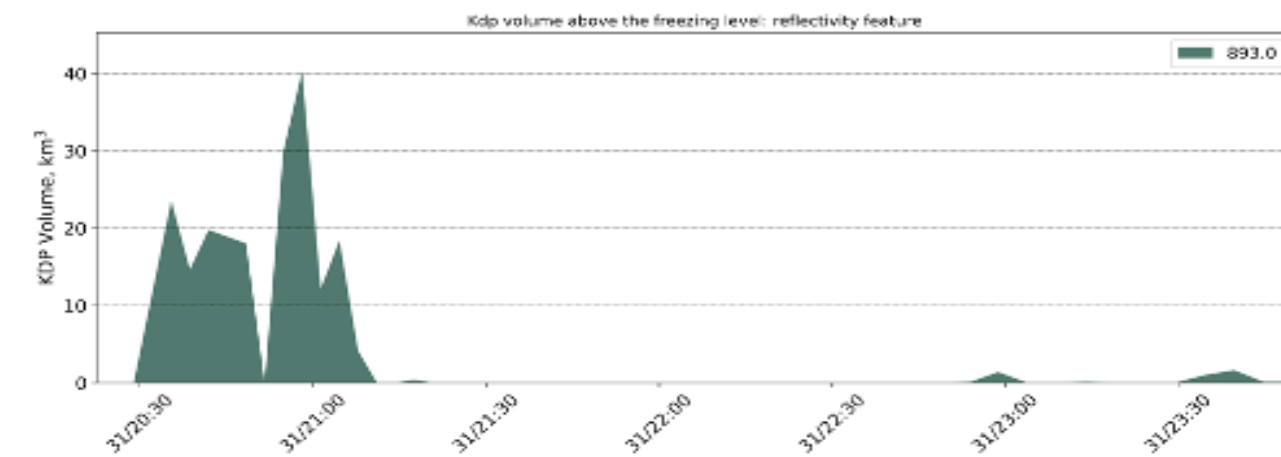
Complex/Multicell Dominant

| 317 | 496 | 157 | 586 | 354 | 220 | 166 | 813 |

Environment: StickNets

- "Rapidly" deployable 2.25 m meteorological observing station

- Temp, Pressure, Relative Humidity, Wind, and the occasional lightning sensor

- 10Hz Sample Rate

- 20% of tracks fall within the StickNet array

- 5% of tracks are targets, even fewer fall within the array

- **Overwhelmingly**, tracked cells with Z_{DR}, K_{DP}, and lightning have a sharp decrease in both θ_v and θ_e – <u>signatures of a cold-pool deficit</u>

12
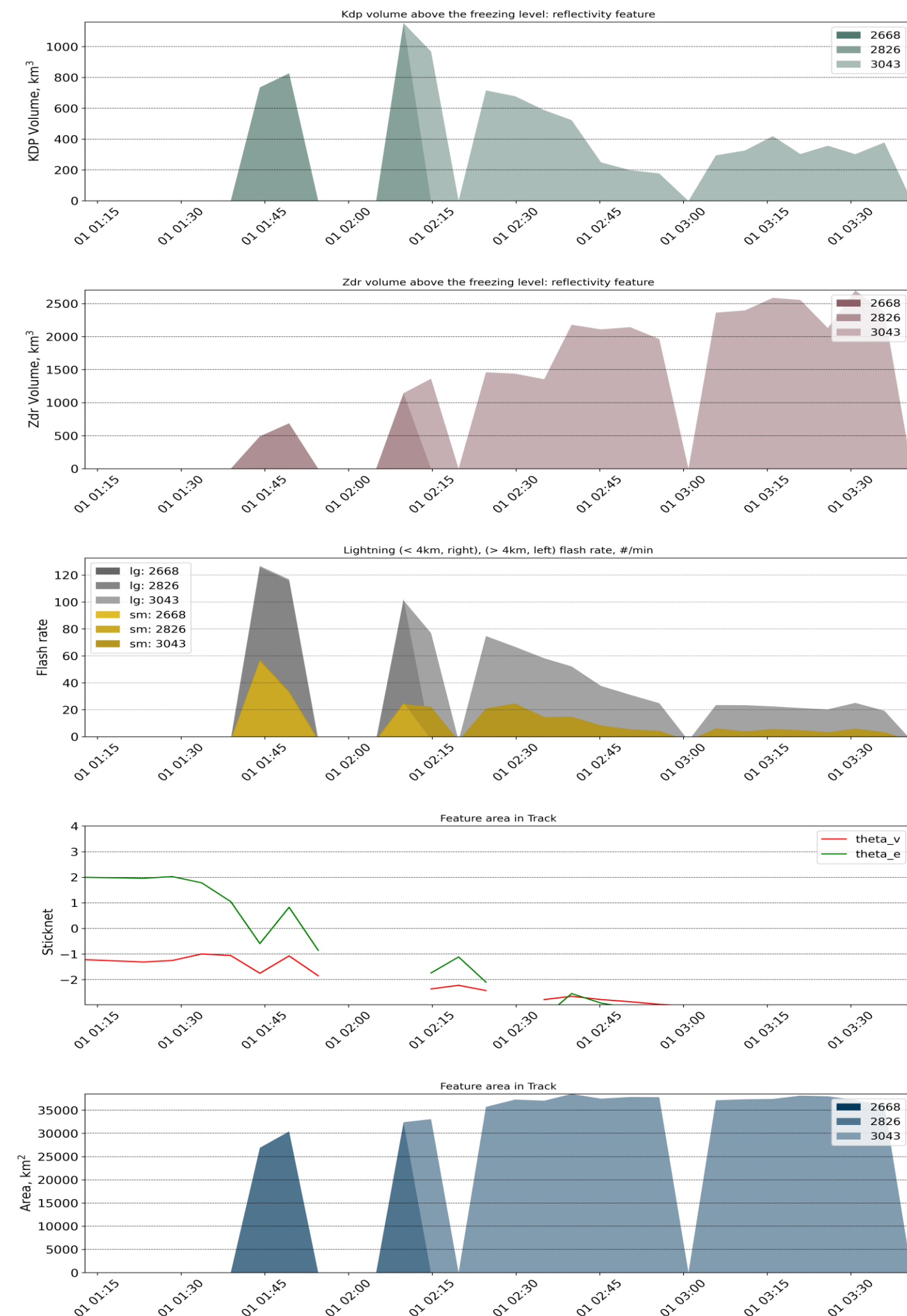
What can we do with Tracks: Forecast Performance
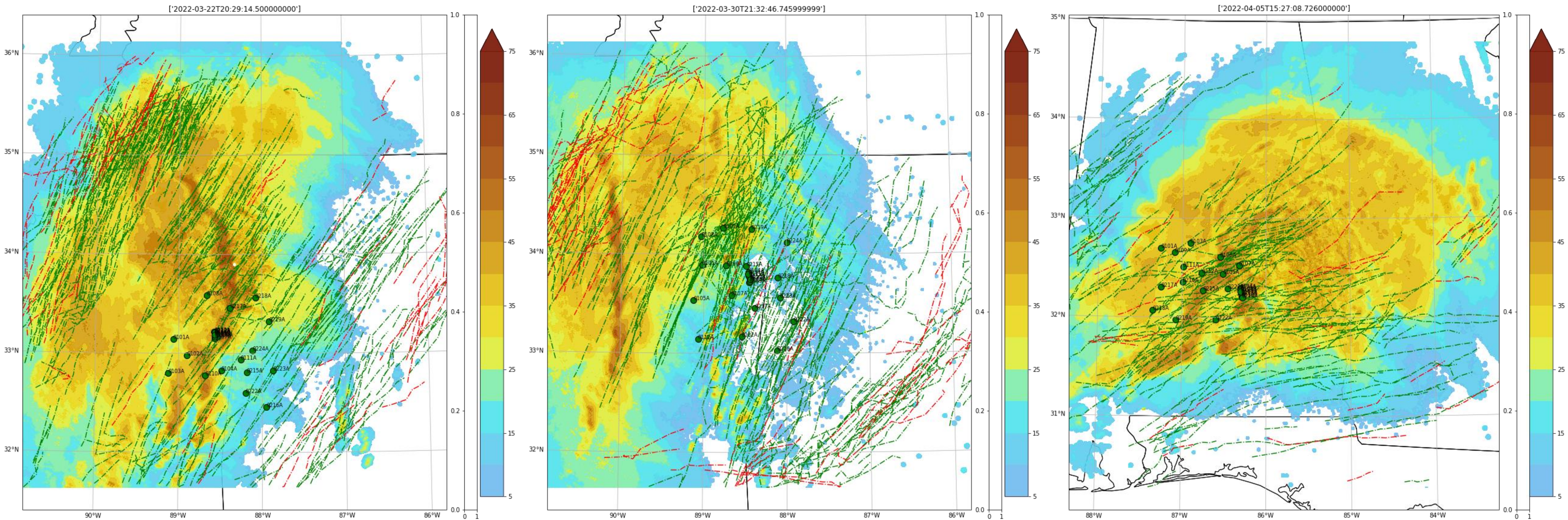
03/22/2022/IOP1 **03/30/2022/IOP2** **04/05/2022/IOP3**

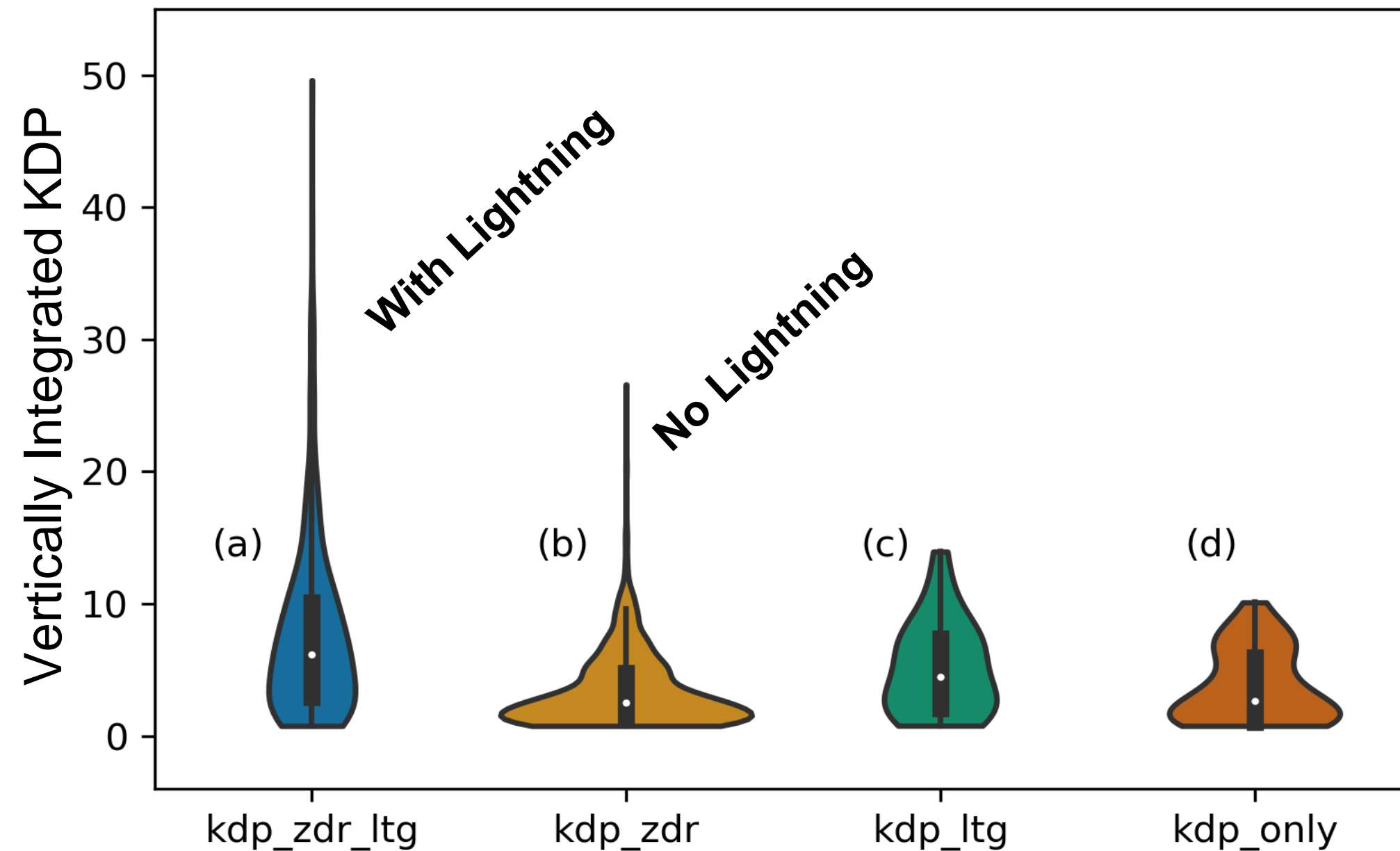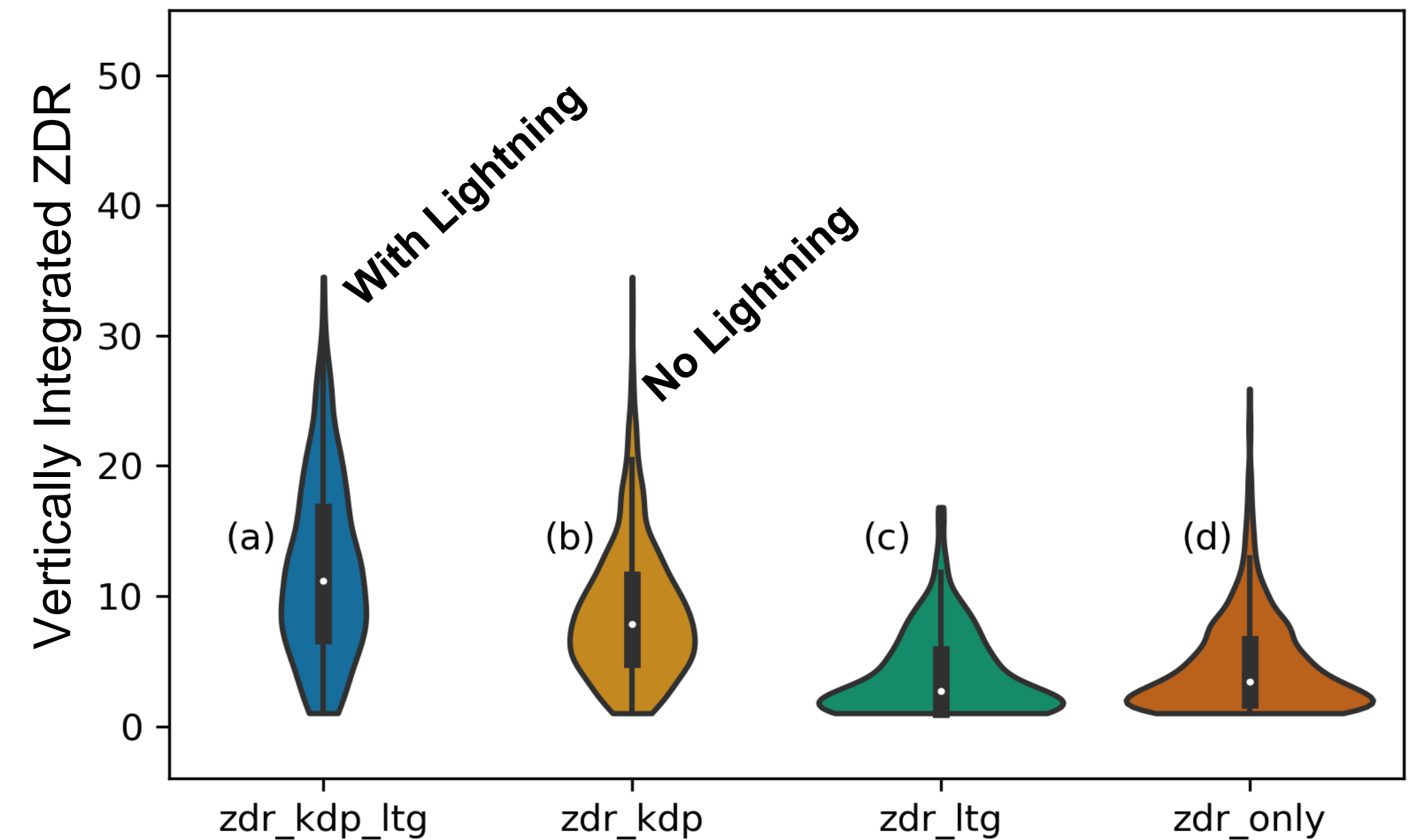Polarimetric columns   Benign Cells

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KDP Column Strength

Specific Differential Phase (KDP) Column Strength

Differential Reflectivity (ZDR) Column Strength

- Vertically integrated KDP describes the column strength
- KDP columns are more intense when they occur with lightning
- <u>Mean KDP column strength is ~2.5x larger when lightning is produced in both single cell and complex storms</u>

- Vertically integrated ZDR describes the column strength
- ZDR column strength can be similar with and without lightning
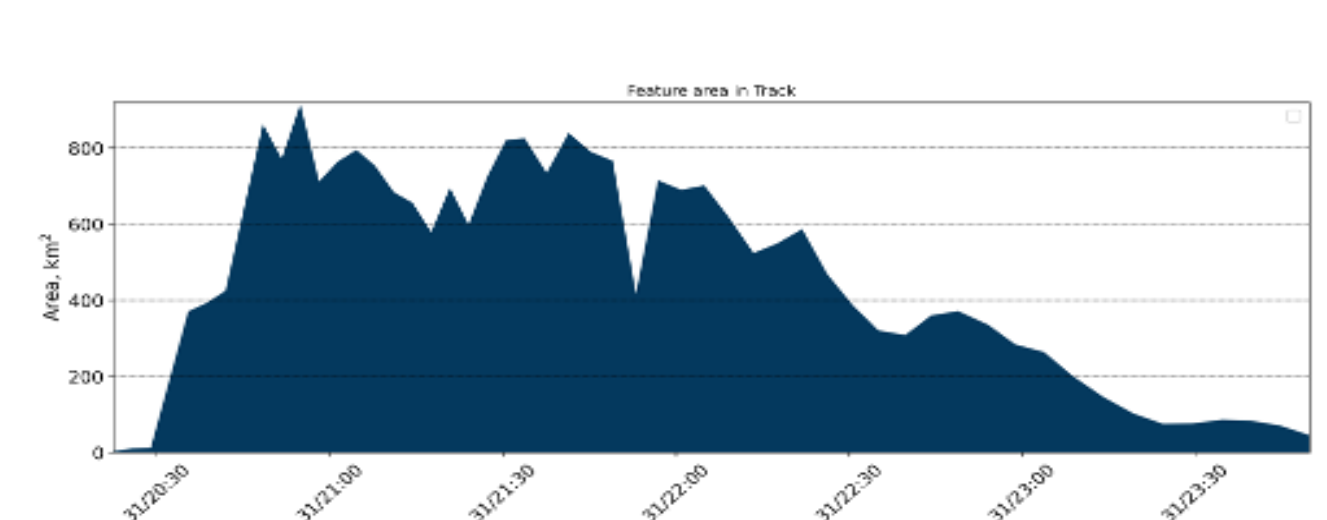
Temporal evolution: columns and lightning

Cells with KDP/ZDR Columns with Lightning

Time Delta (minutes)	Raw (median)	Sum Version (median)	Raw (Houston)	Sum Version (Houston)
First Zdr peak	13	11	12	9
First Zdr – LTG peak	13	10	16	17
First Zdr – Kdp peak	9	8	18	18
First Kdp – LTG peak	0	0	0	0

Cells with KDP/ZDR Columns

Time Delta (minutes)6	Raw	Sum Version	Raw (Houston)	Sum Version (Houston)
First Zdr peak	12	6	11	6
First Zdr – Kdp peak	10	8	16	14

Date: 03/31/16, 2022 - 2349 UTC
Track ID: 125
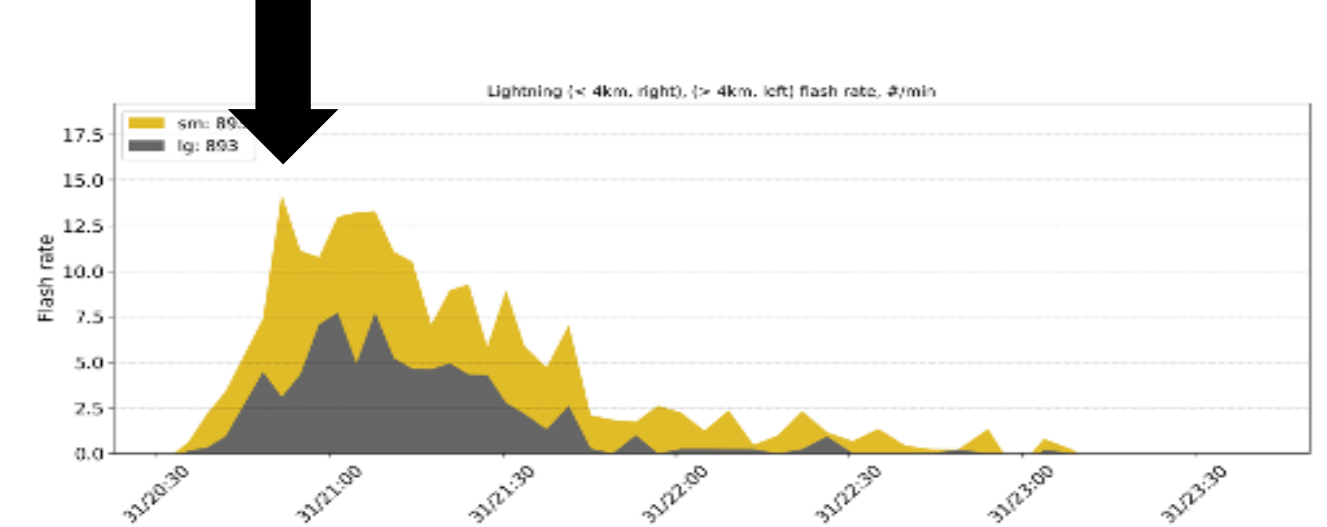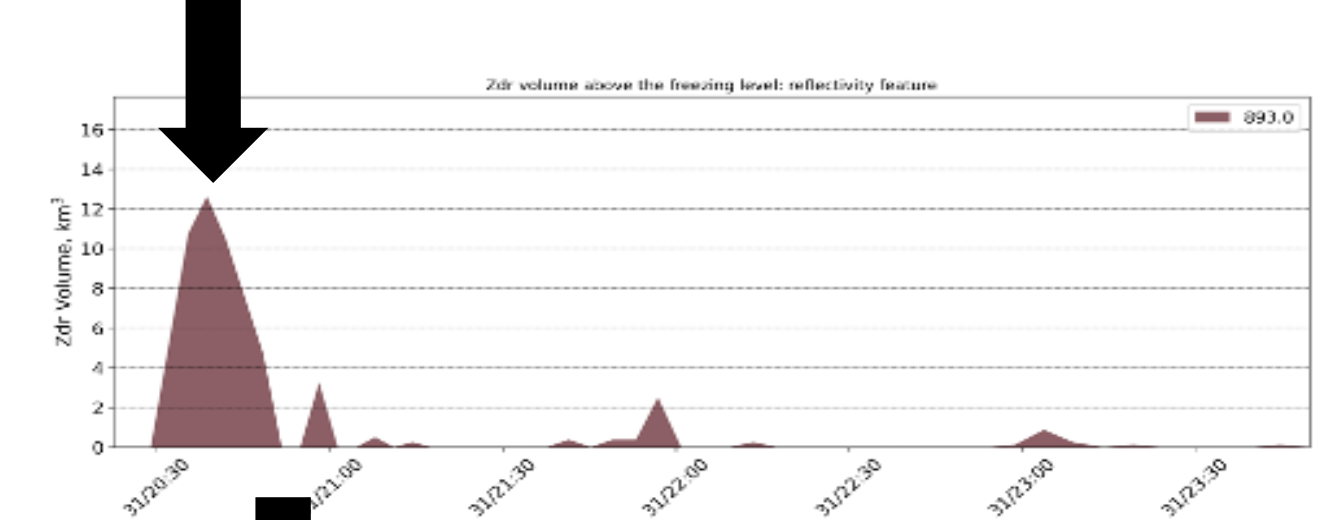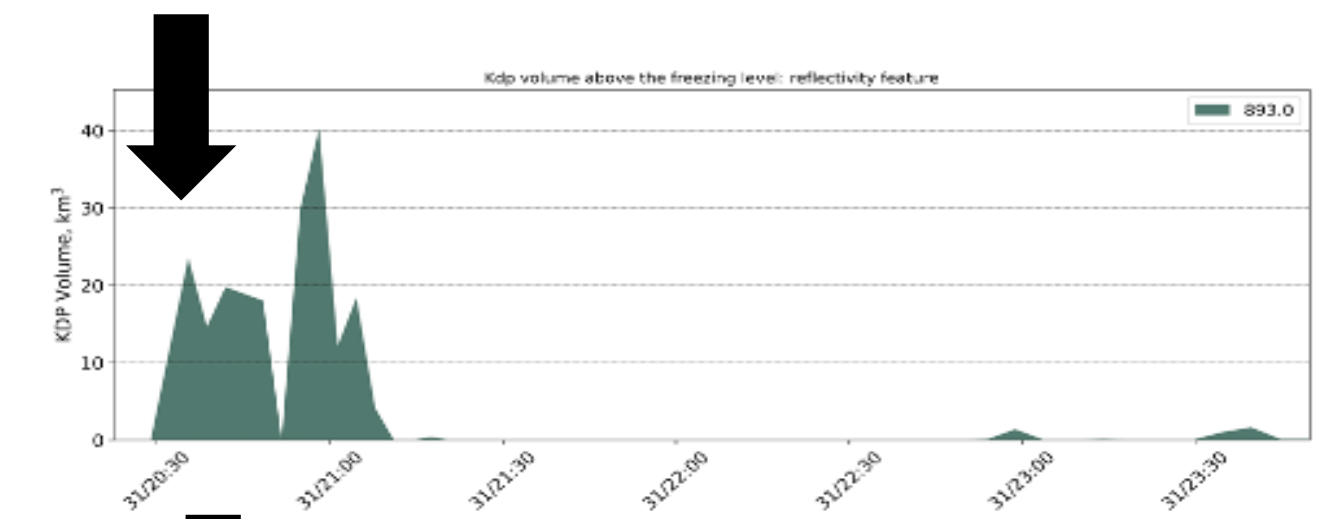
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Time Delta (minutes)6	Raw	Sum Version	Raw (Houston)	Sum Version (Houston)
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- Storm type influences time to between Zdr and Kdp, and Zdr and lightning
- Kdp columns have little/no lag time with lightning, regardless of storm type
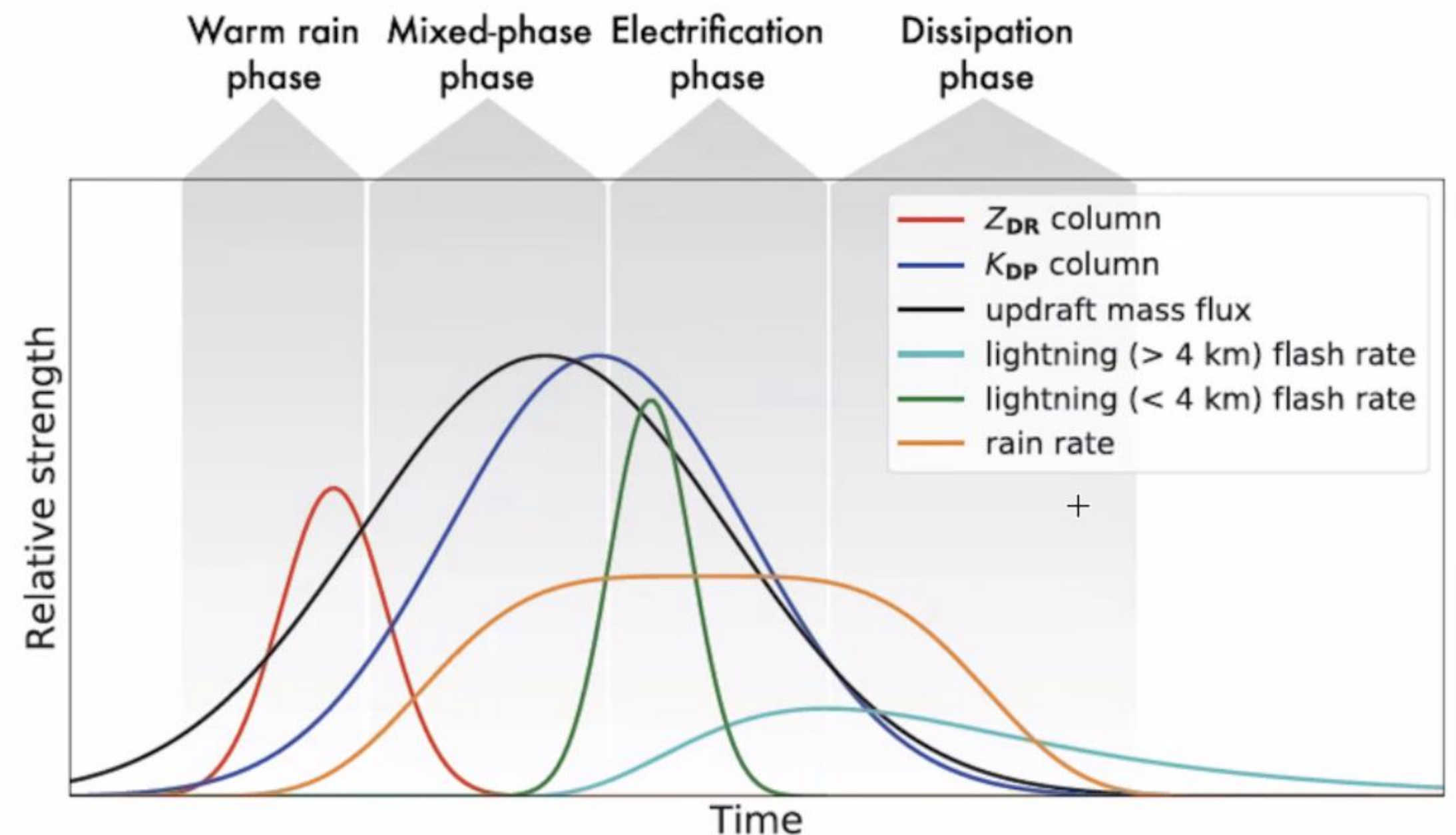- Column strength doesn't impact (generally) how quickly we see a Kdp column

Date: 03/31/16, 2022 - 2349 UTC
Track ID: 125
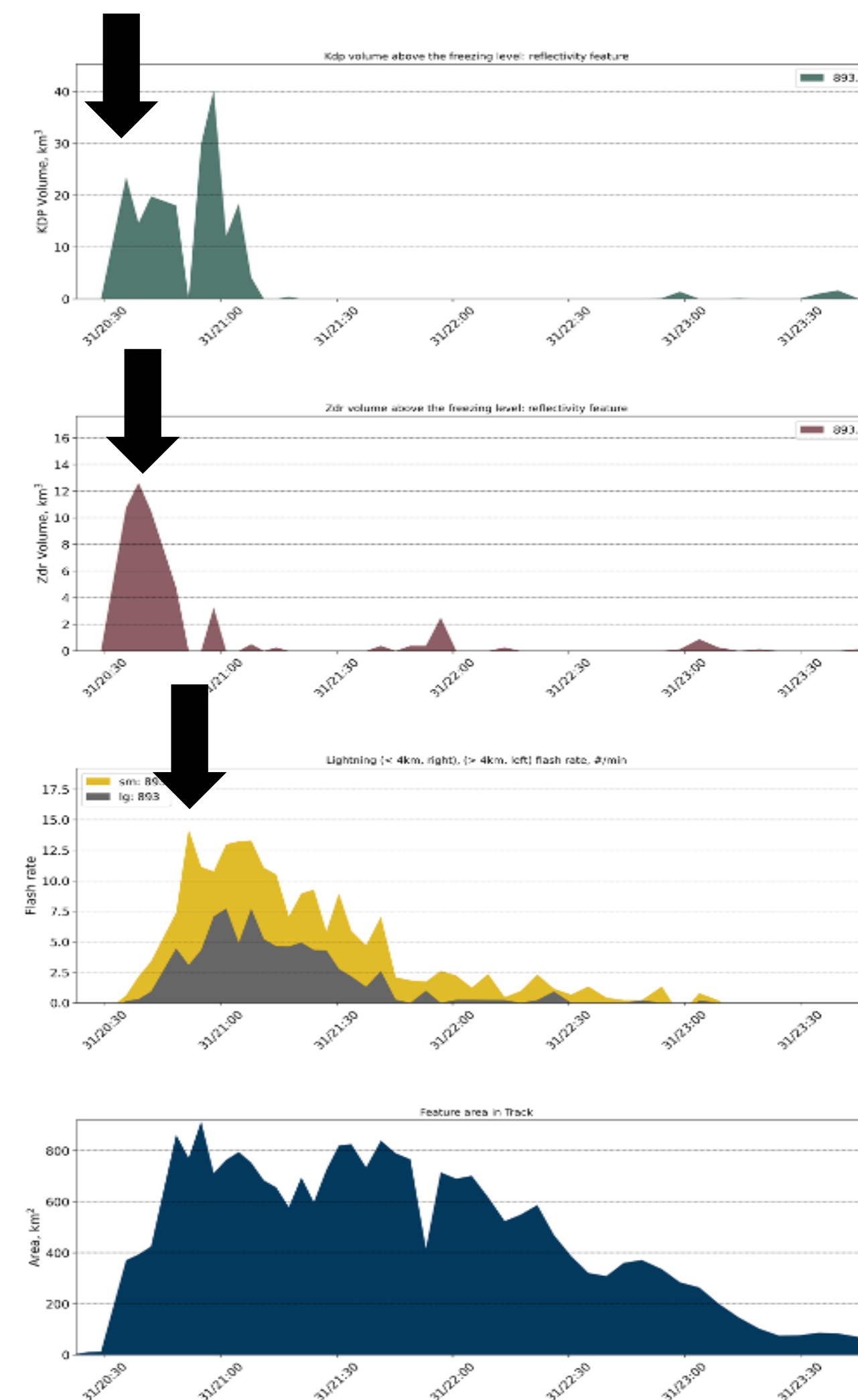
Takeaways and Acknowledgements

- How prevalent is the conceptual model and what is consistent across storm type?

  - **K_{dp} column intensity and onset are consistent signals with lightning**

  - **K_{dp} column intensity is not tied to first flash, but columns associated with lightning are 2-2.5x more intense**

  - **Columns of K_{dp} indicate little to no lag with the onset of lightning**

  - **ZDR Columns occur frequently, at a large range of values, volumes, and intensity with and without lightning.**

- Lightning is the end result of many processes, and regardless of storm type the timing of lightning is consistent

Single-cell storms

Acknowledgements