The synergistic use of polarimetric radar data and spectral bin models for improving weather nowcasting

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PROM All Hands Meeting

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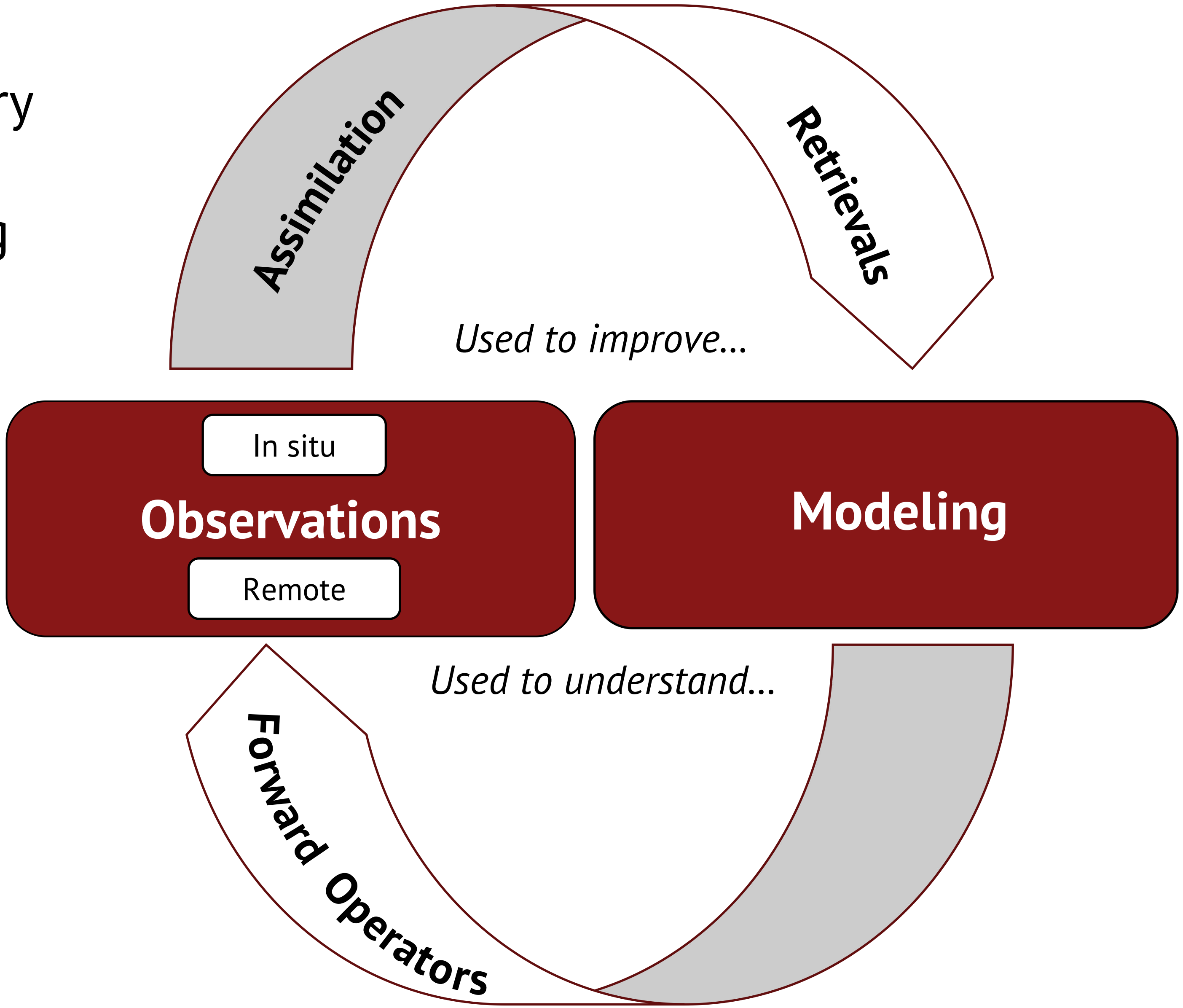
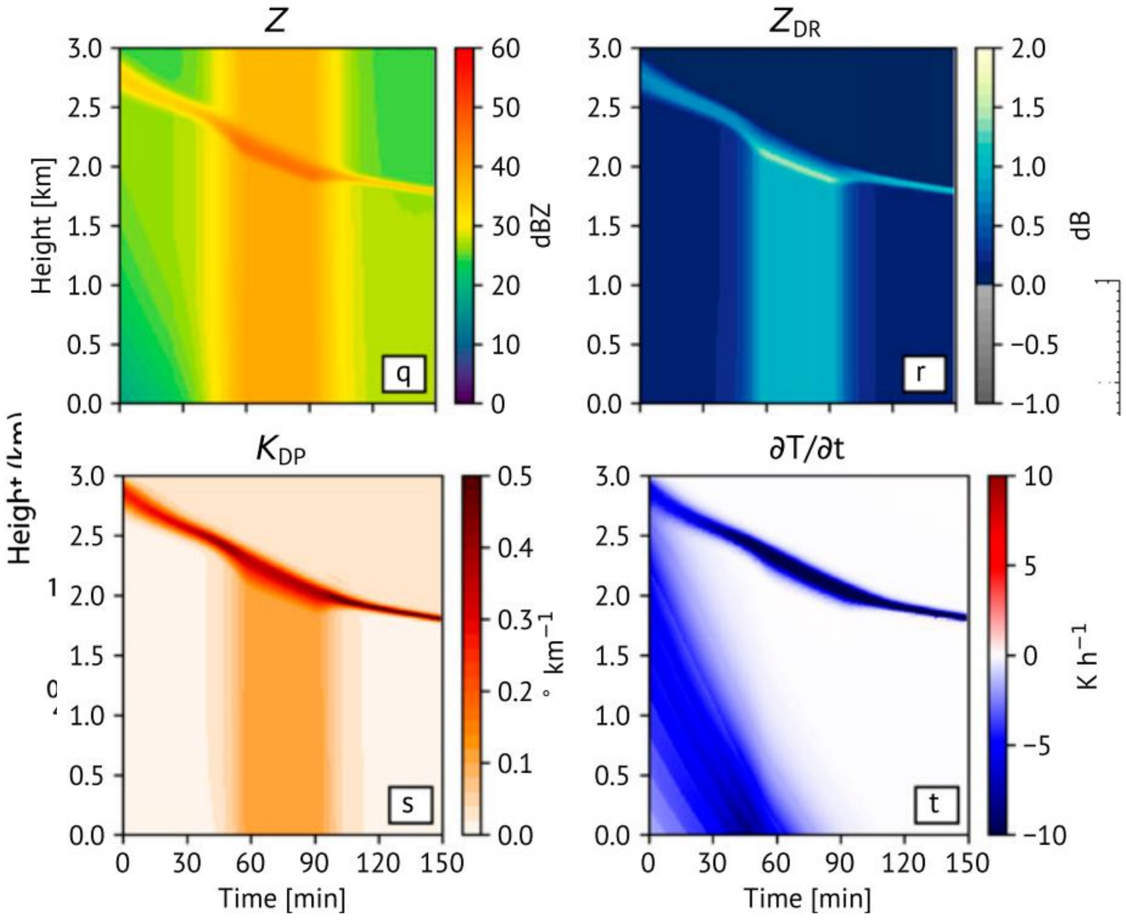
Model of radar polarimetry + modeling synergy



Examples of Past Basic Research

- Raindrop evaporation (e.g., Kumjian and Ryzhkov 2010)
- Size sorting (e.g., Kumjian and Ryzhkov 2012)
- Raindrop freezing (e.g., Kumjian et al. 2012)
- Hail melting (e.g., Ryzhkov et al. 2013)
- Snow melting (e.g., Carlin et al. 2019)

The **goal** of these studies was to understand observed (static) dual-polarization radar signatures and their underlying microphysics.



Adapted from Kumjian and Ryzhkov (2010)

Can this approach be adapted for nowcasting?

- Two principle additions:
  - Evolution of environment in time in response to latent heating/cooling and attendant moistening
    - Sub-hourly information in-between model analyses
  - Expansion from 1D to 3D along Lagrangian trajectories
- Initialization from polarimetric microphysical retrievals that vary in time and space

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1D Spectral Bin Model for Ice Microphysics

- Column model with explicit calculations of hydrometeor melting, refreezing, sublimation, and evaporation
  - Environment evolves in response to these cooling/heating and moistening/drying processes
- Density effects of riming
- Can be initialized at the top from polarimetric radar data and use model background or observed sounding as environment
  - Particles then fall and evolve in their respective bins
- Coupled polarimetric radar forward operator (Ryzhkov et al. 2011) for Z, Z_{DR}, K_{dp}, A_H, and A_{DP} using T-matrix calculations
  - Various mixing formula options, etc.
- Processes still to add to 1D model:
  - Explicit representation of riming
  - Ice nucleation
  - Drop breakup/coalesence
  - Secondary ice production a la Deshmukh et al. (2022)?

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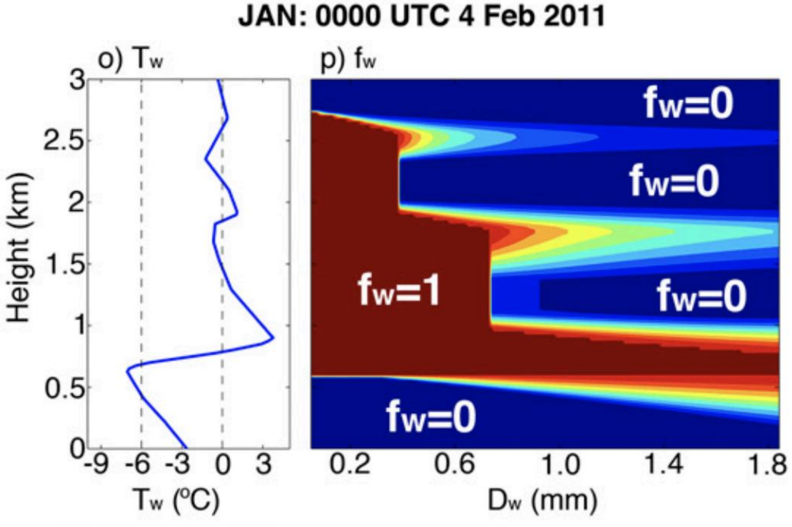
Precipitation-type classification

TABLE 2. PODs (%) for the different algorithms using observed soundings. In BG, NSSL, and Ramer, the second value corresponds to the score if one assumes the IP–FZ mix (or IP–FZ uncertainty in BG) is a hit.

	SN	RA	IP	FZRA	IP/FZRA combined	SFZR
B1	86.7	96.1	89.6	28.4	42.4	48.0
B2	97.1	96.1	56.0	28.4	34.7	48.0
BG	92.6	96.1	50.4/60.0	48.8/55.7	56.7	68.0/76.0
NSSL	94.1	96.4	26.4/70.4	40.3/78.9	77.0	56.0/90.0
Ramer	94.9	99.6	25.6/25.6	65.4/66.1	68.7	90.0/90.0

Adapted from Reeves et al. (2014)

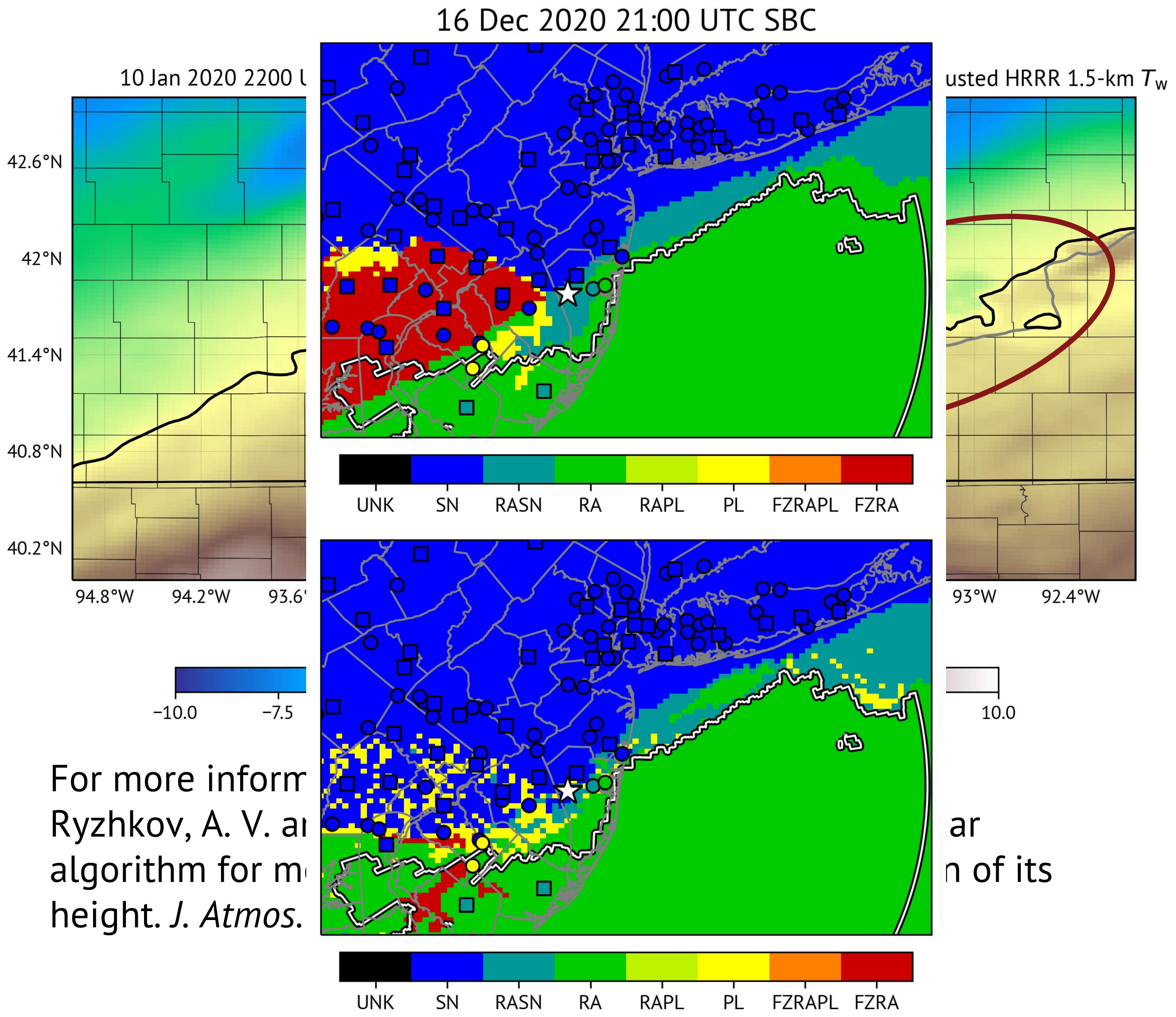


Adapted from Reeves et al. (2016)

- Motivation:
  - Severe winter weather impacts
  - Below-beam effects
  - Sparse observations
  - FZRA v. RA indistinguishable on radar
  - Existing model p-type algorithms often struggle
- Uses liquid water fraction from each particle size bin to determine precipitation type at the surface and aloft at every model grid point
- Expanded upon since original

Precipitation-type classification

- How can polarimetric radar data help?
  - Time- and space-varying PSDs (**ongoing**)
  - Identifying riming
  - Polarimetric melting-layer detection algorithm to correct model background error
    - Garbage in → garbage out problem



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Ryzhkov, A. V. ar...
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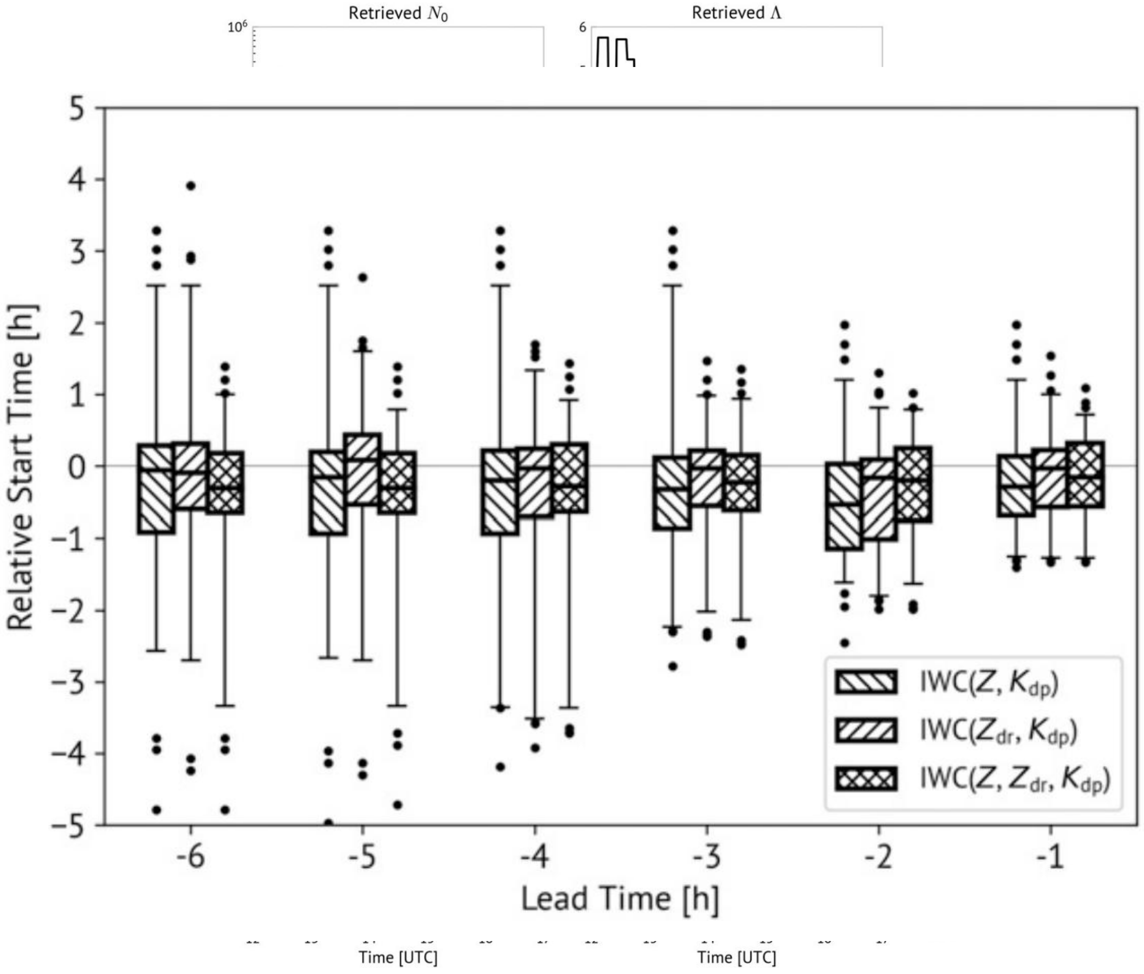
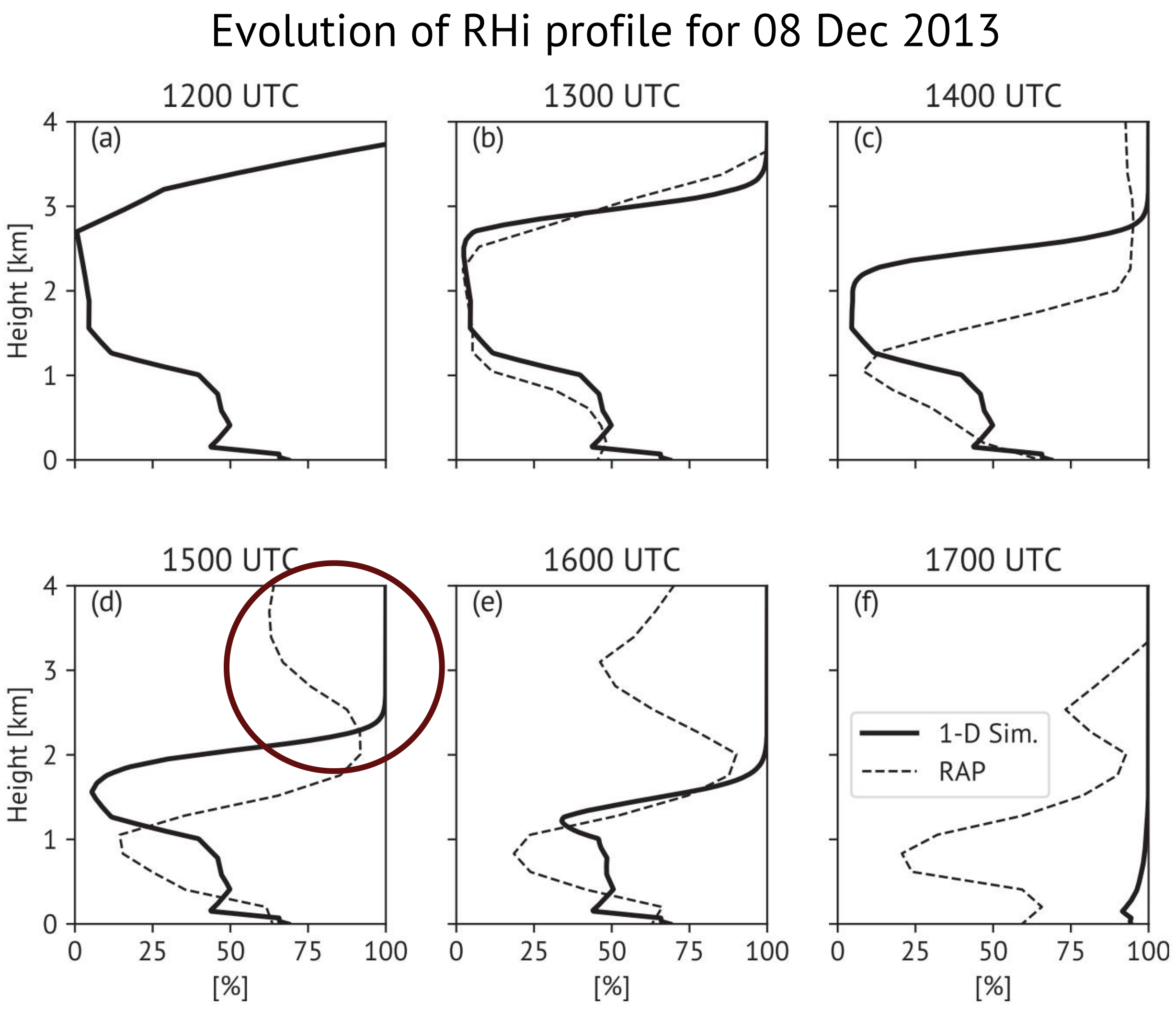
Nowcasting start time of snow at surface

- Model initialized with time-varying polarimetric retrievals from QVPs for 12 cases of sublimating snow
- Compared when snow saturated the dry air and reached the surface in the model compared to observations
- Median bias was -18 minutes out to a lead time of 6 h



Adapted from Carlin et al. (2021)

Nowcasting start time of snow at surface



- Model background had erroneous pocket of dry air advect into area that prevented accurate prediction of snow’s arrival at surface
- 1D model + QVP was able to correctly predict moistening and start time

Adapted from Carlin et al. (2021)

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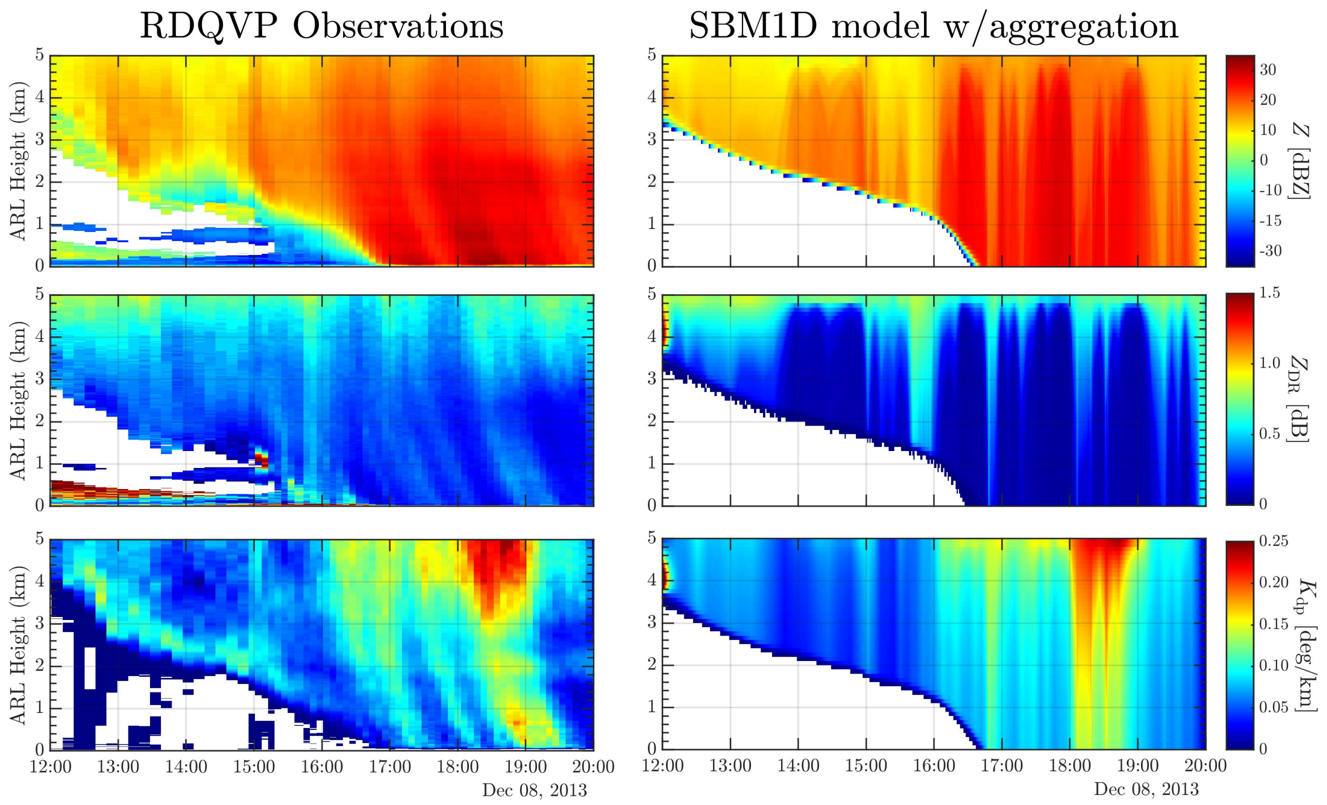
Addition of aggregation to 1D model

- Polarimetric retrievals work best in areas of strong anisotropic signals (e.g., the dendritic growth layer)
  - Aggregation can mask polarimetric signatures
- Option: perform retrievals aloft, then evolve PSDs down to lower levels (e.g., into the melting layer)
- Recently added to 1D model
- Many uncertain parameters → optimization using Lagrangian profiles of aggregating snow as constraint….



Reproduction of RDQVP using time-varying polarimetric retrievals for 08 Dec 2013

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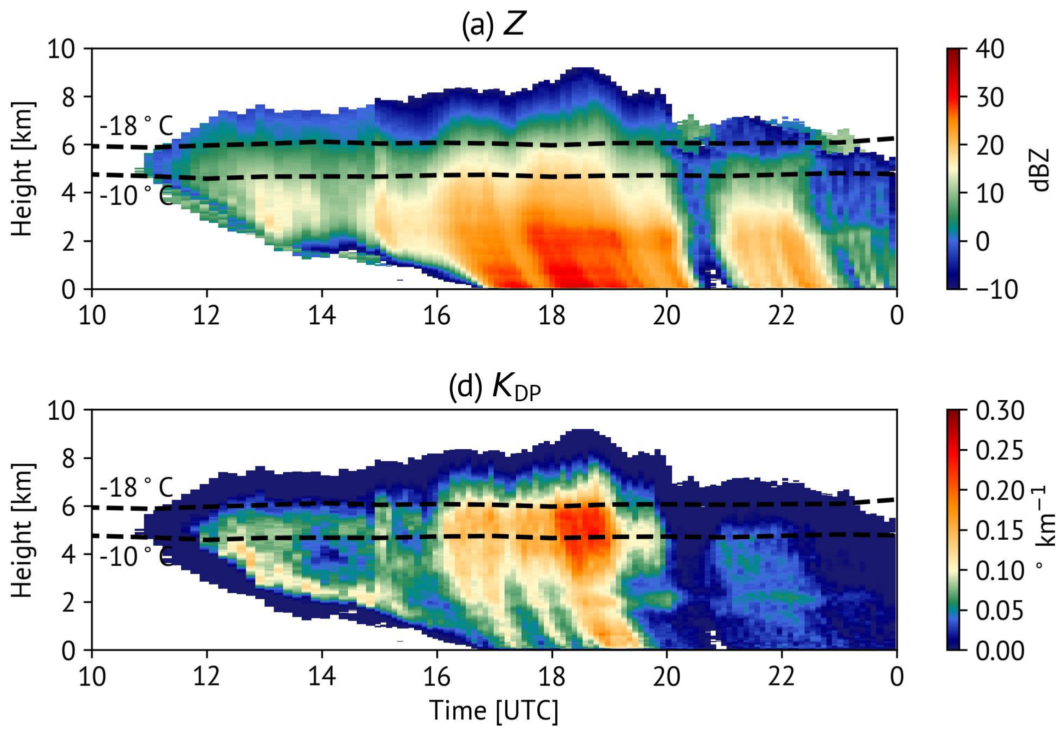
Heavy snow nowcasting motivation

- In order to make short-term predictions about how the surface precipitation rate will change, we **look aloft.**
  - Snow falls relatively slowly → longer lead times!
- K_{dp} often high in regions of enhanced snowflake concentrations and saturation (e.g., Dunnavan et al. 2022) that leads to heavy snowfall



KDIX on 08 December 2013

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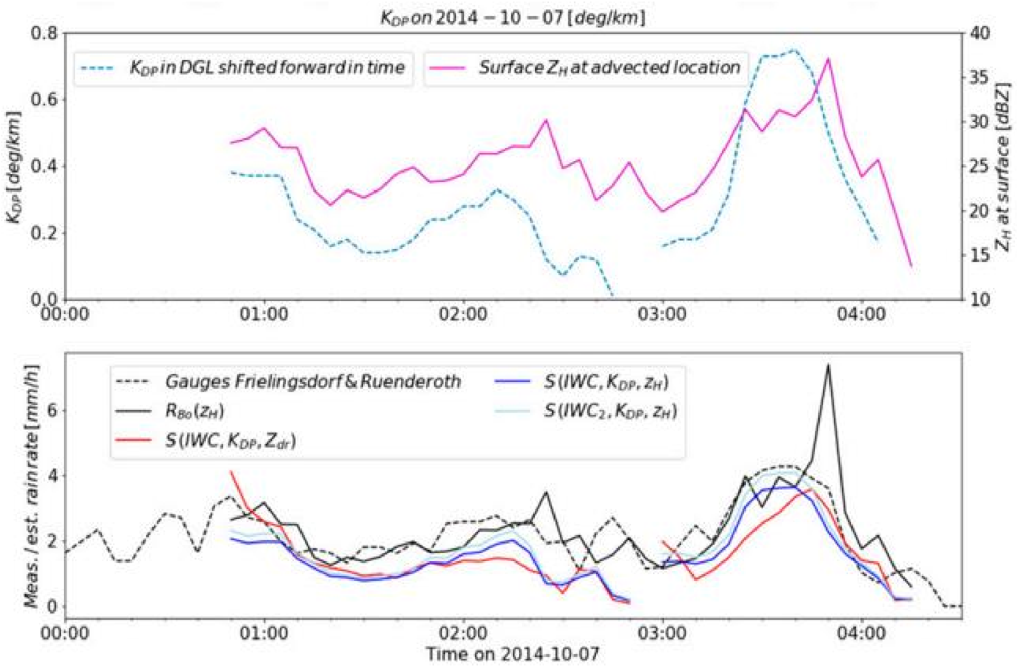
Heavy snow nowcasting motivation



Adapted from Trömel et al. (2019)

- Motivated by results of Trömel et al. (2019) who correlated K_{dp} aloft with Z at the surface using VAD winds
  - Lead times can be ⩾ 1 hour
    - Mean: 44 minutes

Heavy snow nowcasting methodology

- Launch trajectories from -15°C level where K_{dp} exceeds **0.2°/km**
  - Preferentially sampled based on K_{dp} values
  - $N_{traj} \propto$ Area exceeding K_{dp} threshold
- Snowflakes advected using with *model winds* or VAD using fallspeed sampled from [0.7, 1.1] m/s
- Validated against $S(Z, K_{dp})$ from Bukovčić et al. (2020)
- Compute "practically perfect forecast" (Hitchens et al. 2013) that takes discrete points → probabilistic map
- Goal is eventual operational algorithm

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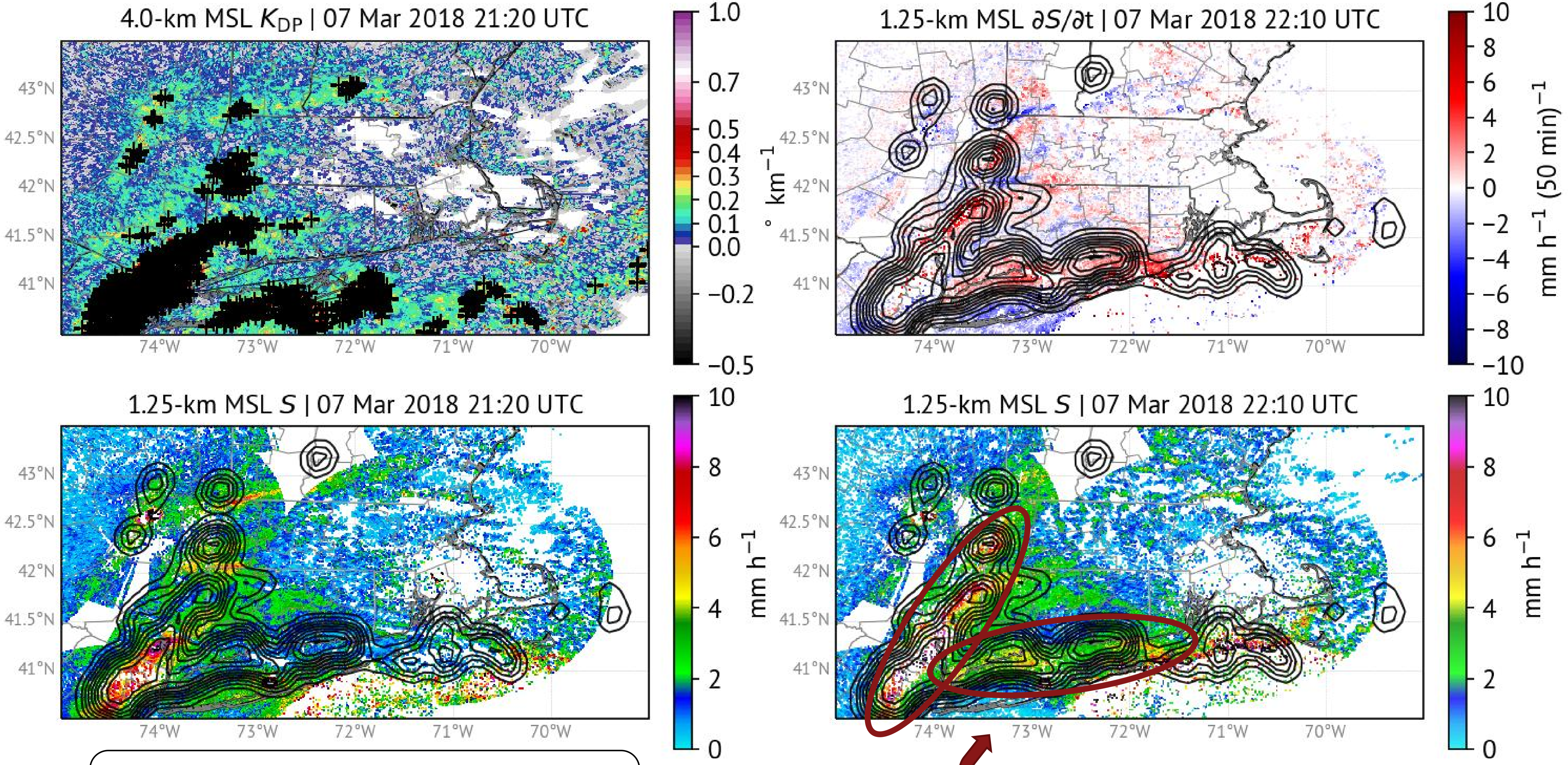

50-minute lead time

Development of heavy snow well-anticipated in multiple regions

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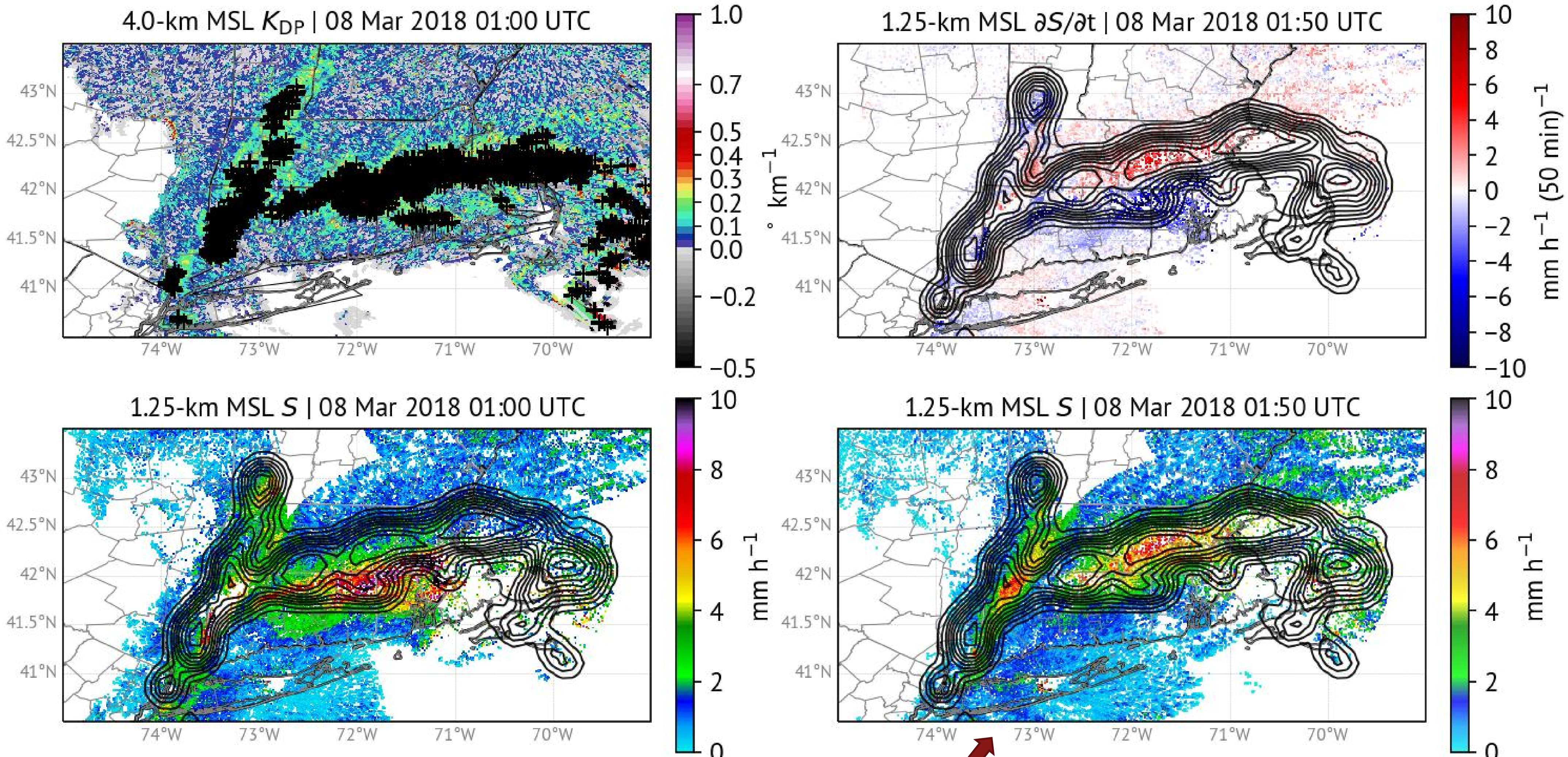

Advection of existing heavy snow band also captured

50-minute lead time

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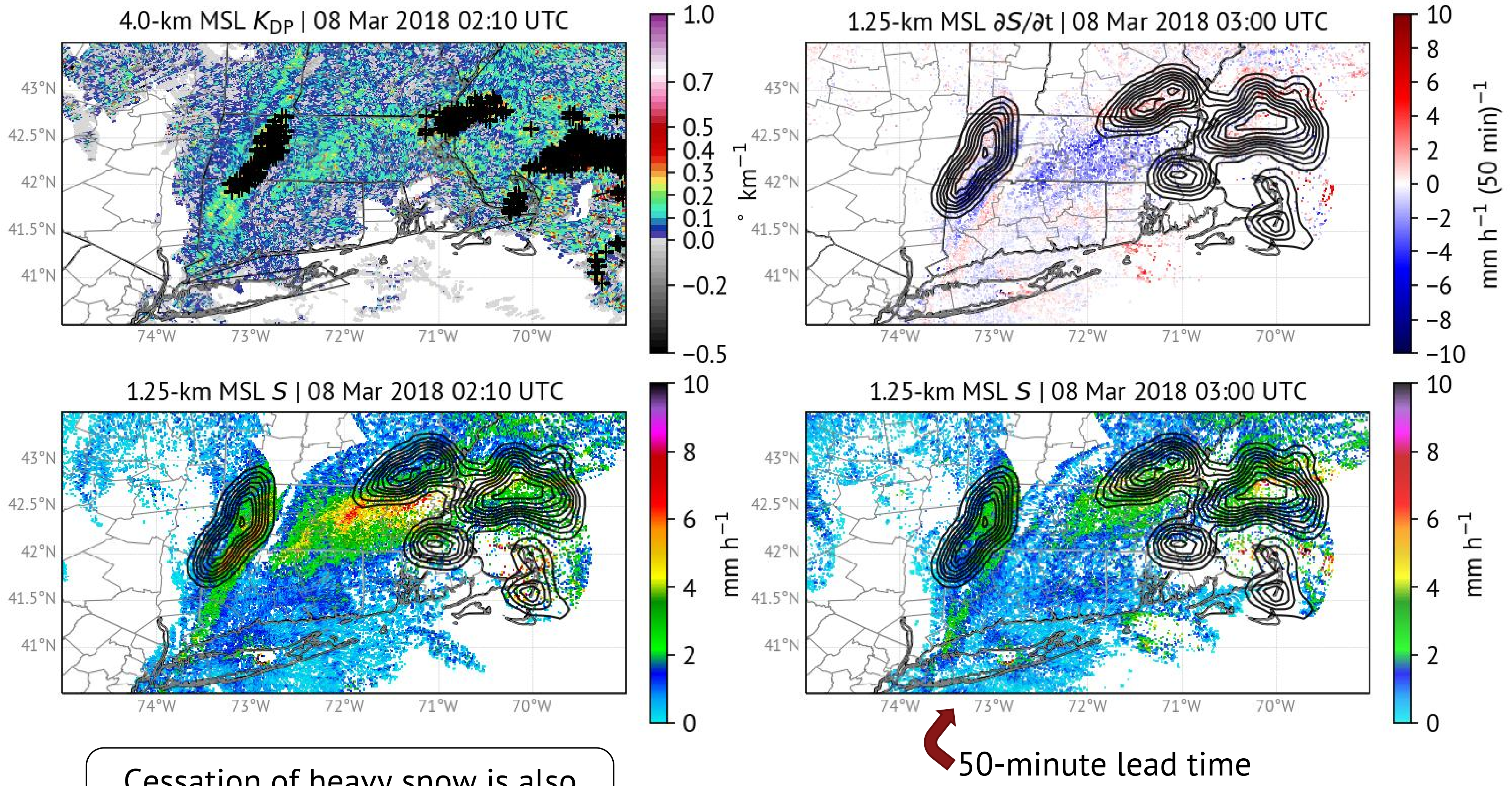
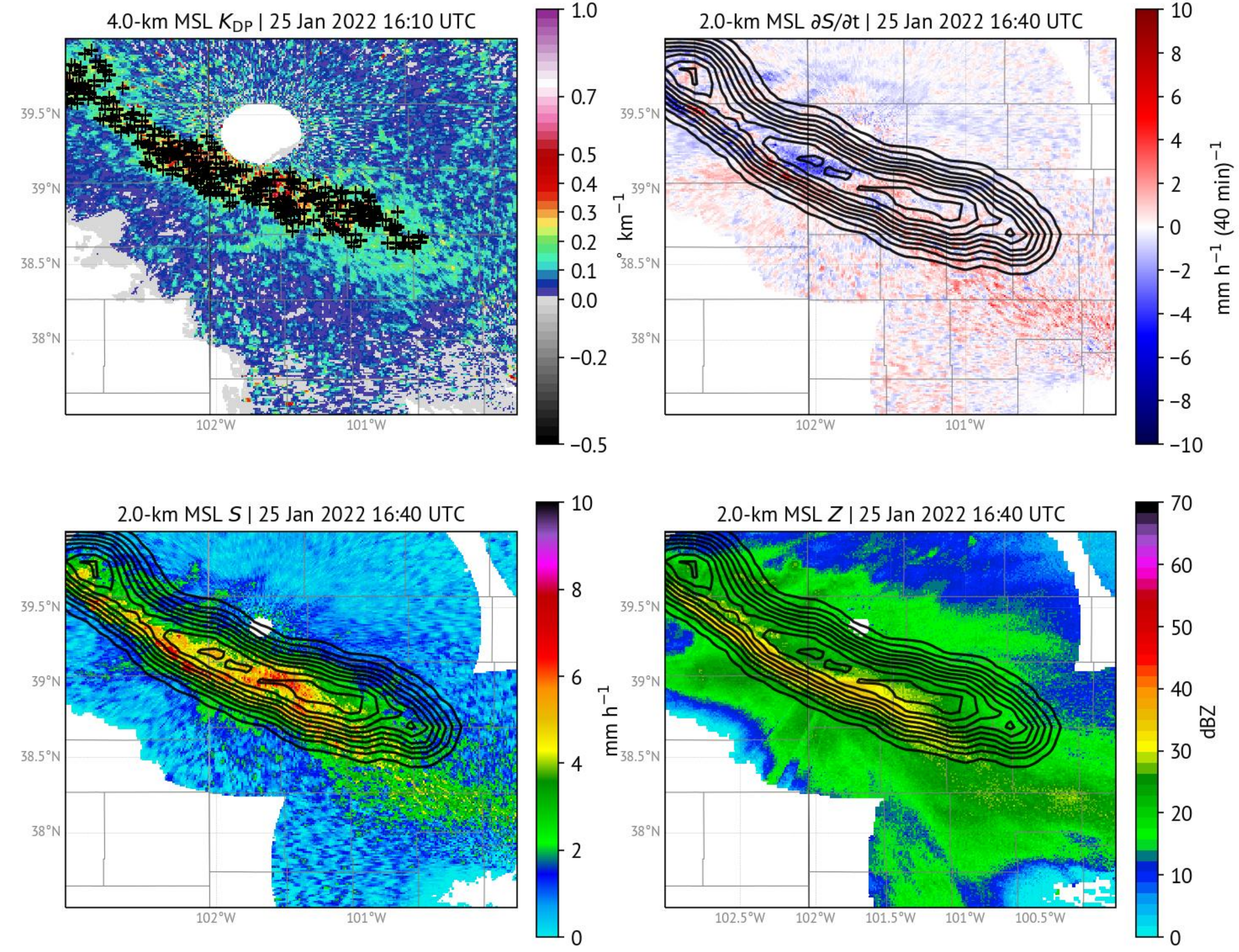


Cessation of heavy snow is also well predicted!



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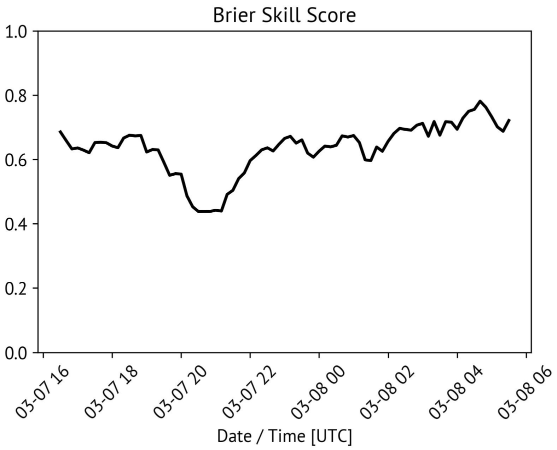
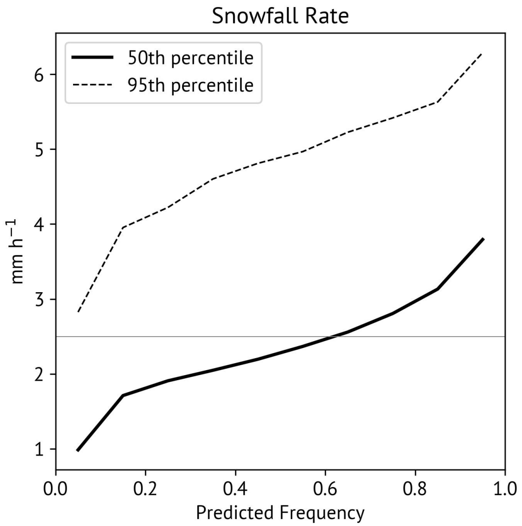
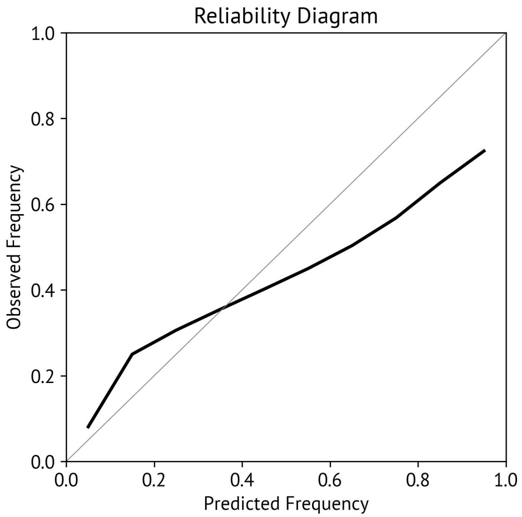
Quantitative verification

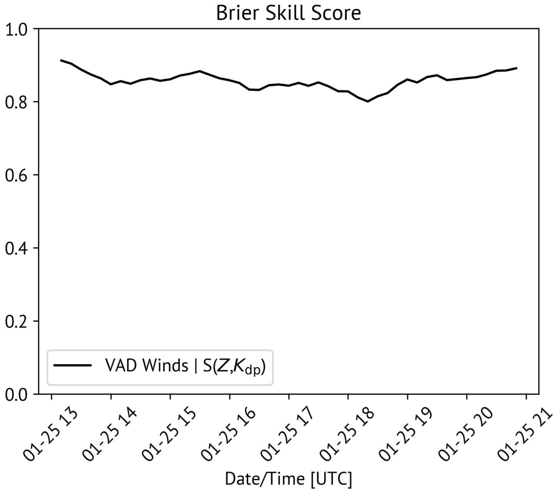
Case 1

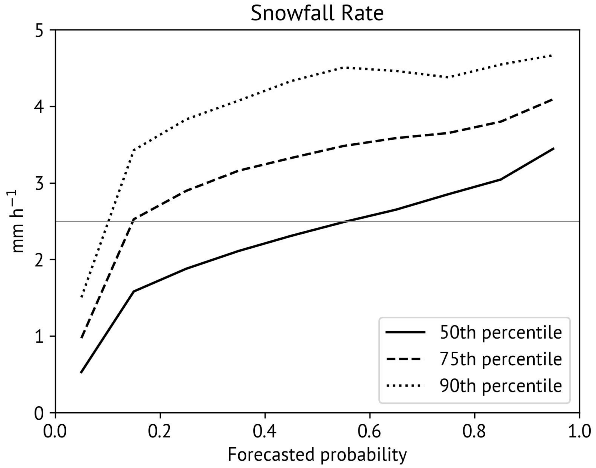


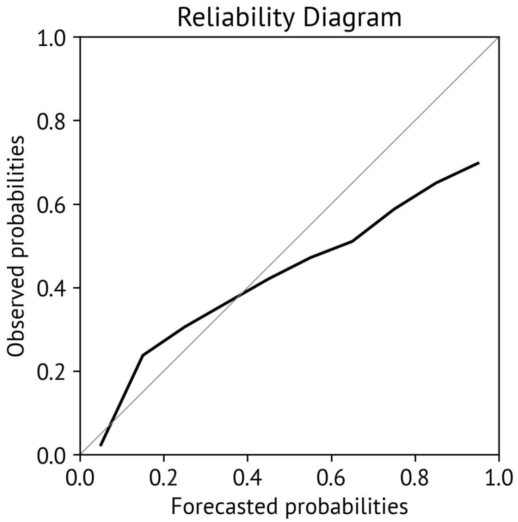




Case 2

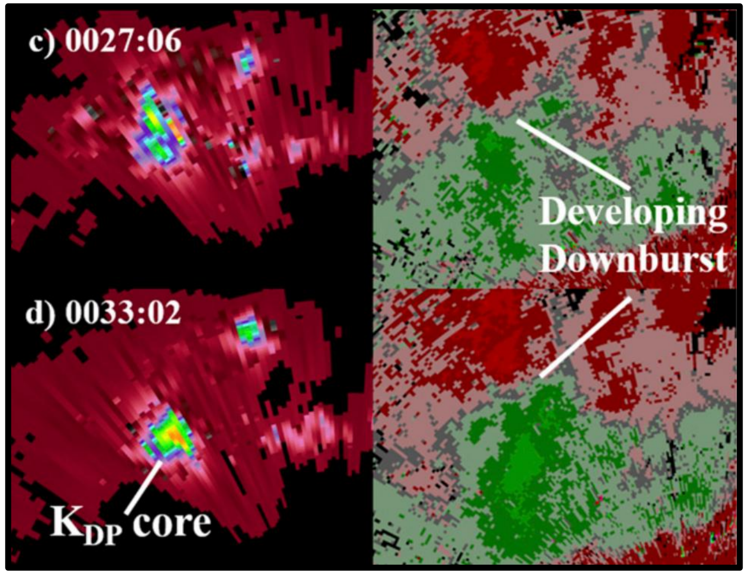


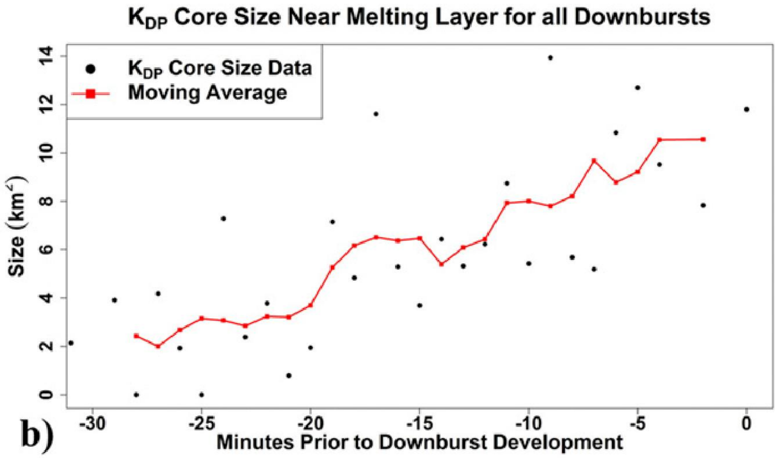




1D modeling of polarimetric signatures of downbursts

- Downbursts present a nowcasting challenge
  - Traditional radar-based metrics (e.g., descending Z cores, storm-top convergence) are not always reliable and can be hard to discern
- Recent evidence (e.g., Kuster et al. 2021) *descending K_{dp} cores* to be a reliable downburst precursor
  - Intensity: *Within a given environment*, larger K_{dp} correlated with more intense downbursts





Adapted from Kuster et al. (2021)

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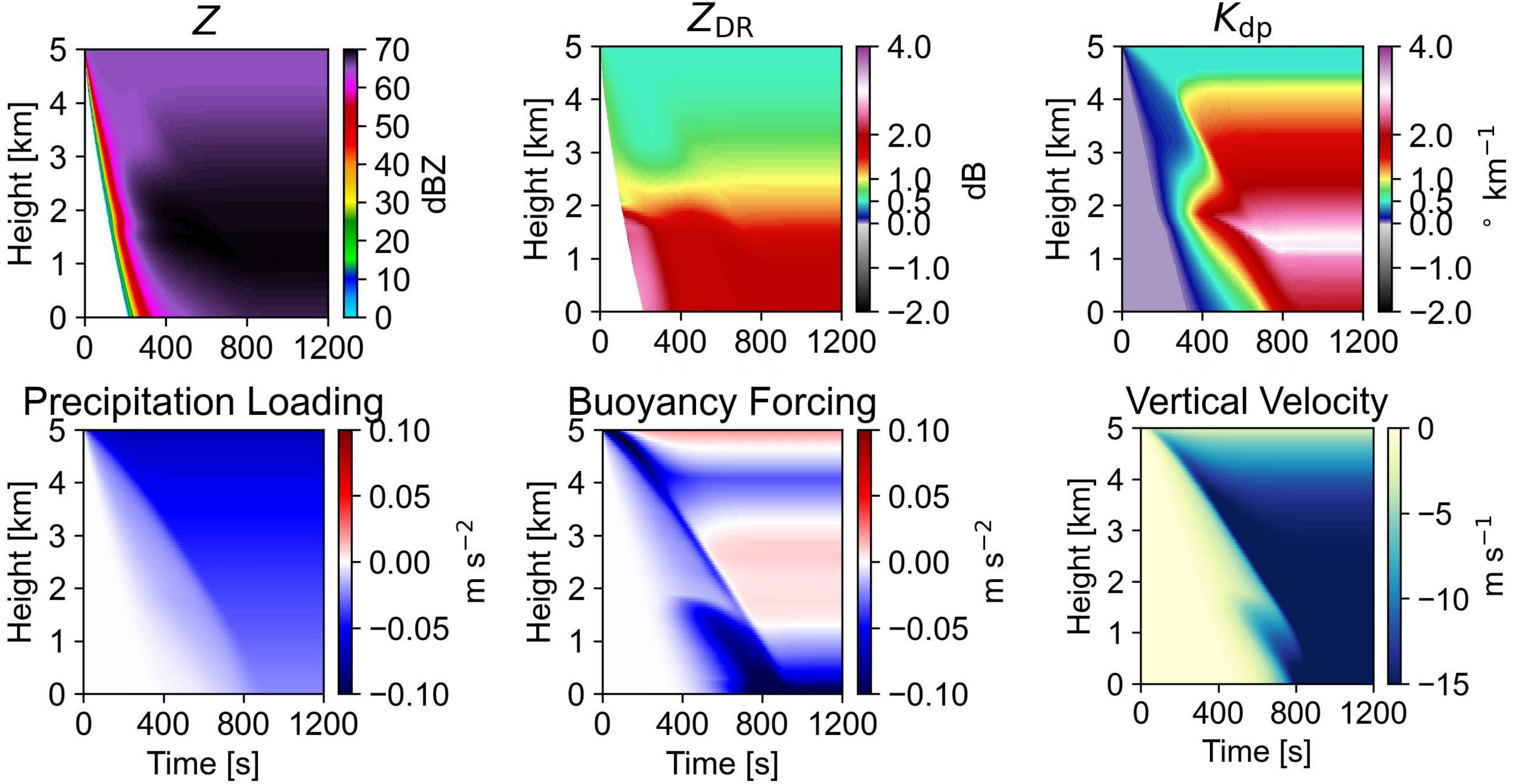
1D modeling of polarimetric signatures of downbursts

- Operational sampling of downburst can be limited…
- Building combined 1D model of polarimetric downburst development
  - Srivastava (1985; 1987) idealized downburst model
  - Melting hail, drop shedding, drop breakup (Ryzhkov et al. 2013)
  - Polarimetric radar forward operator (Ryzhkov et al. 2011, Kumjian et al. 2018)
- Currently implementing latest parameterizations for e.g., melting graupel (Theis et al. 2022)
- **Goal**: Better understand precursor signatures and how they quantitatively relate to downburst forcing terms to improve nowcasting

1D modeling of polarimetric signatures of downbursts



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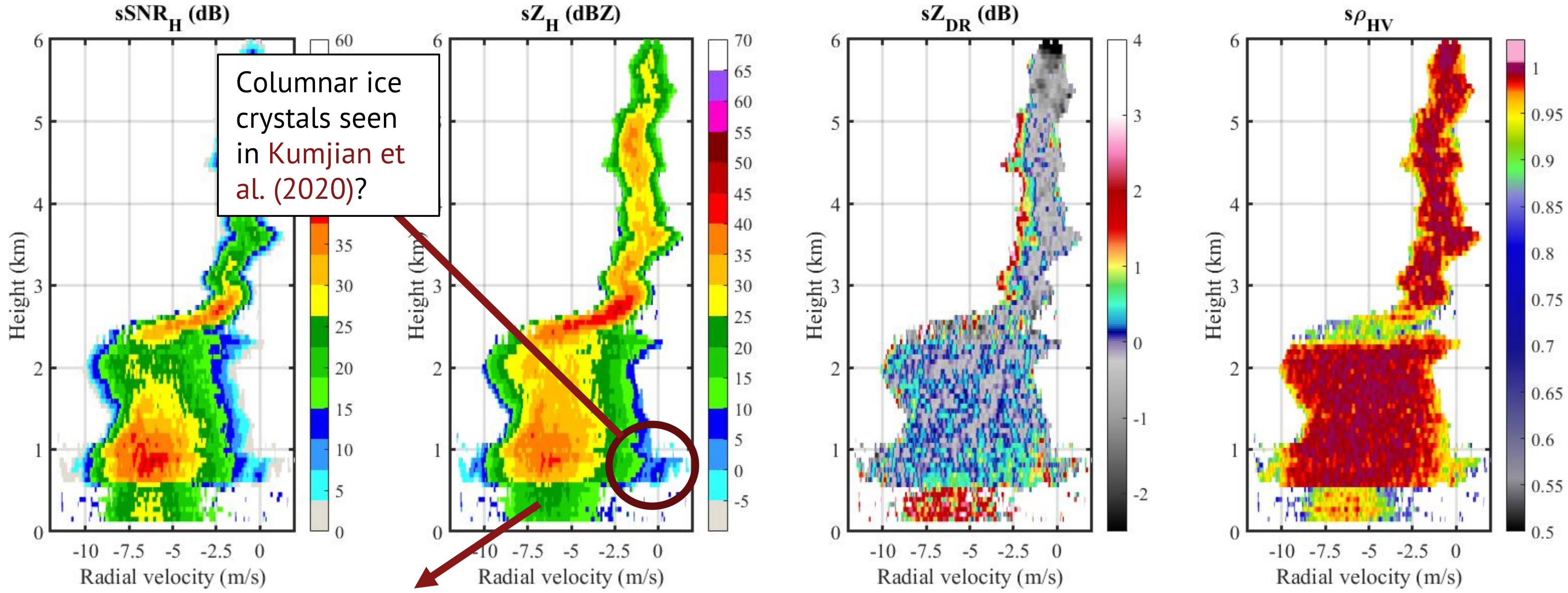
Future work: Refreezing Studies



Refreezing beginning simultaneously for all size bins?

- Preliminary dataset of PPIs, RHIs, and spectral polarimetric radar data from mobile radar during long-lasting ice pellet event in Oklahoma
- Exploring modeling this process (e.g., Tobin and Kumjian 2021) to see if spectral and overall signatures can be reproduced and nowcasting signatures can be identified

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Summary

- The combination of spectral bin models and radar polarimetry can have synergistic benefits for nowcasting
  - Particularly for snow
- More work remains on how to optimally operationalize these approaches
  - Point-by-point microphysical retrievals
  - Single-radar limitations
  - Assumptions in Lagrangian trajectories
  - Uncertainties in forward modeling of polarimetric variables

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Thank you for your attention!

Questions/Comments?

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