Predicting fallout of heavy snow at the surface using polarimetric signatures aloft

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NEXRAD TAC
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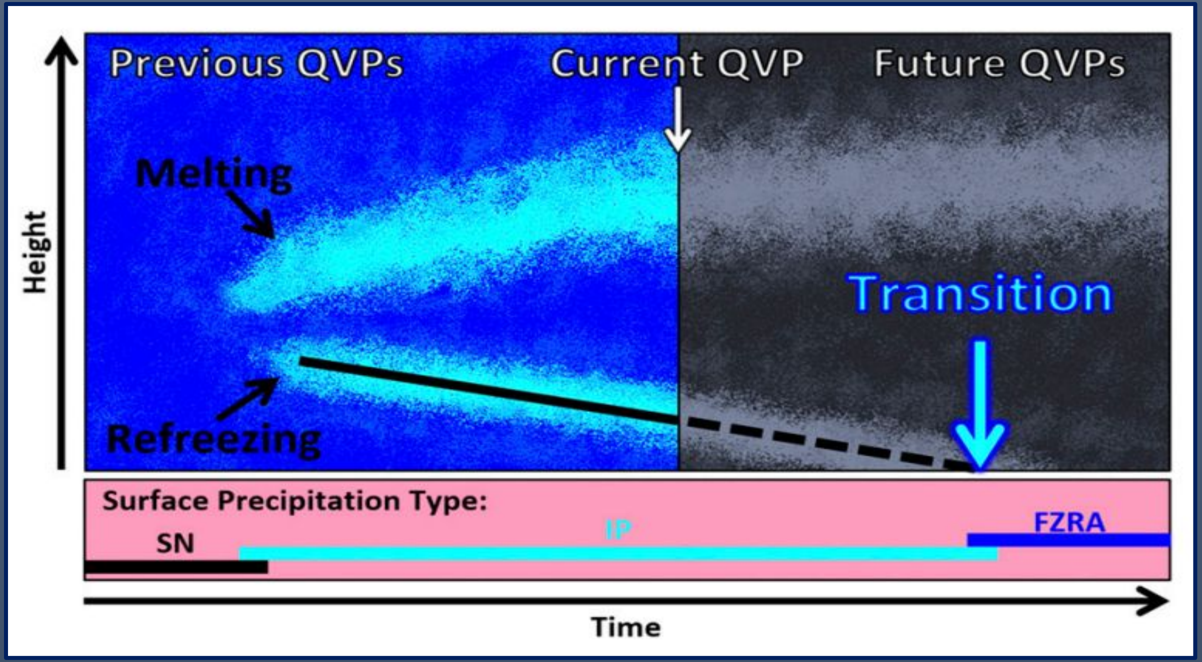
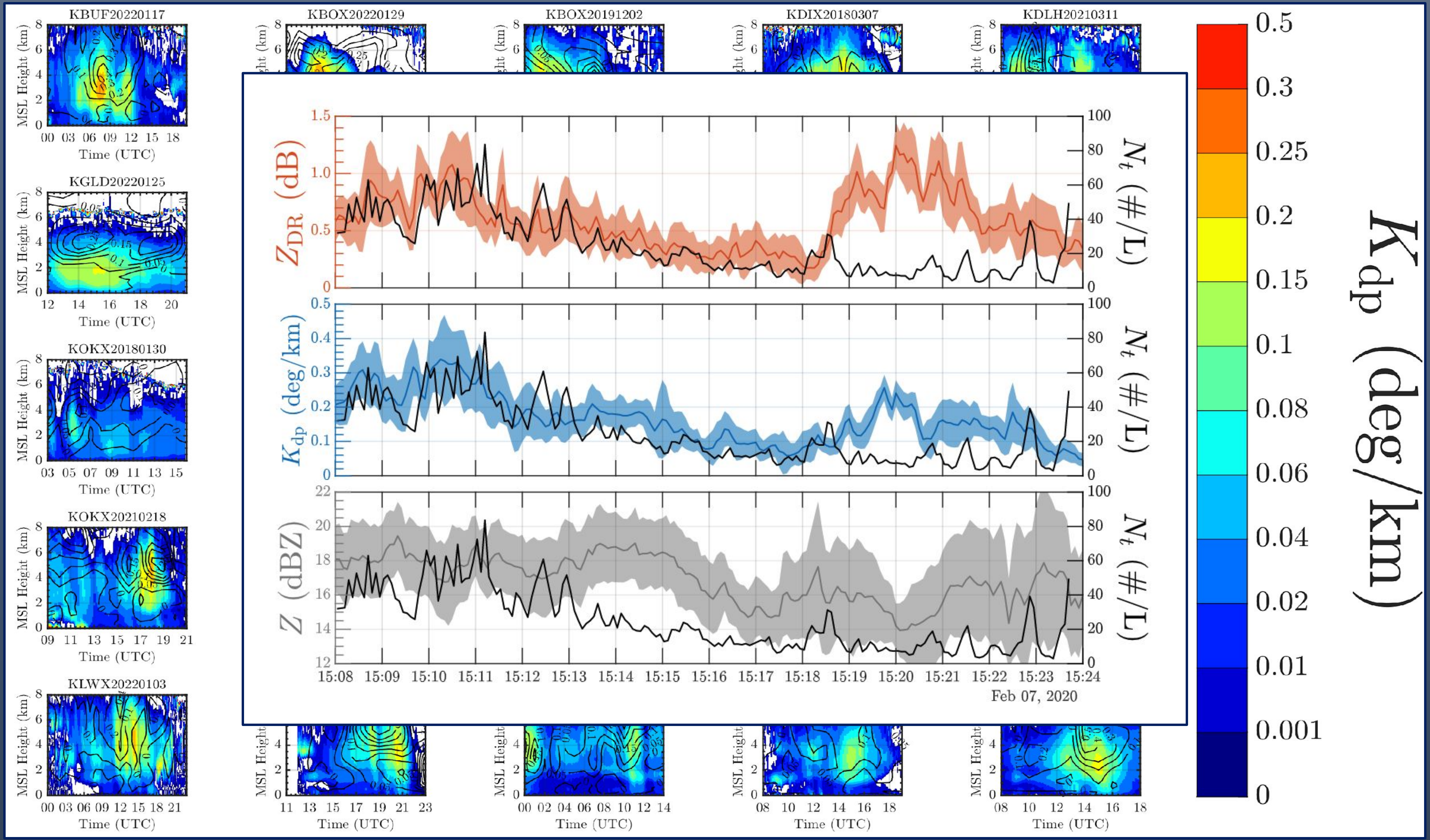
Motivation: Precipitation Nowcasting

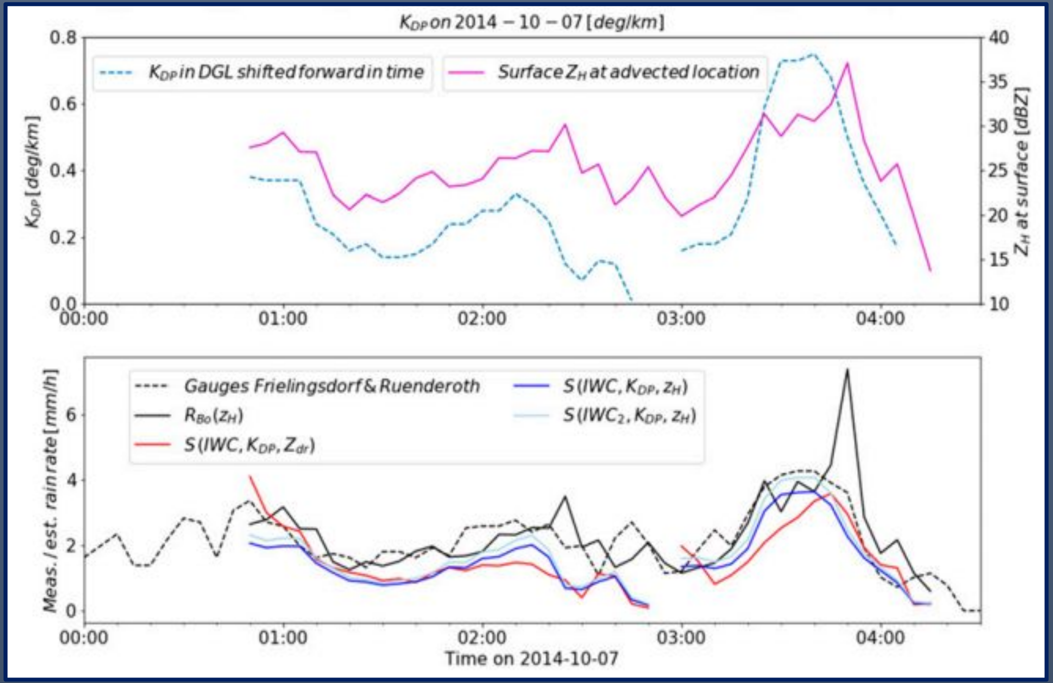
- Nowcasting changes in precipitation type/intensity remains a priority and a challenge.
  - Both operations and short-term NWP
- Strategy: look aloft for precursors
  - The (relatively) slow terminal velocity of snowflakes enables potentially appreciable lead times
- Quasi-vertical profiles (QVPs; Ryzhkov et al. 2016) permit convenient time-height plots of precipitation microphysics but require azimuthal averaging



Adapted from Tobin and Kumjian (2017)


KBUF20220117
KBOX20220129
KBOX20191202
KDIX20180307
KDLH20210311
KGLD20220125
KOKX20180130
KOKX20210218
KLWX20220103
MSL Height (km)
Time (UTC)
Z_{DR} (dB)
K_{dp} (deg/km)
Z (dBZ)
N_t (#/L)
15:08 15:09 15:10 15:11 15:12 15:13 15:14 15:15 15:16 15:17 15:18 15:19 15:20 15:21 15:22 15:23 15:24
Feb 07, 2020
K_{dp} (deg/km)
0.5 0.3 0.25 0.2 0.15 0.1 0.08 0.06 0.04 0.02 0.01 0.001 0

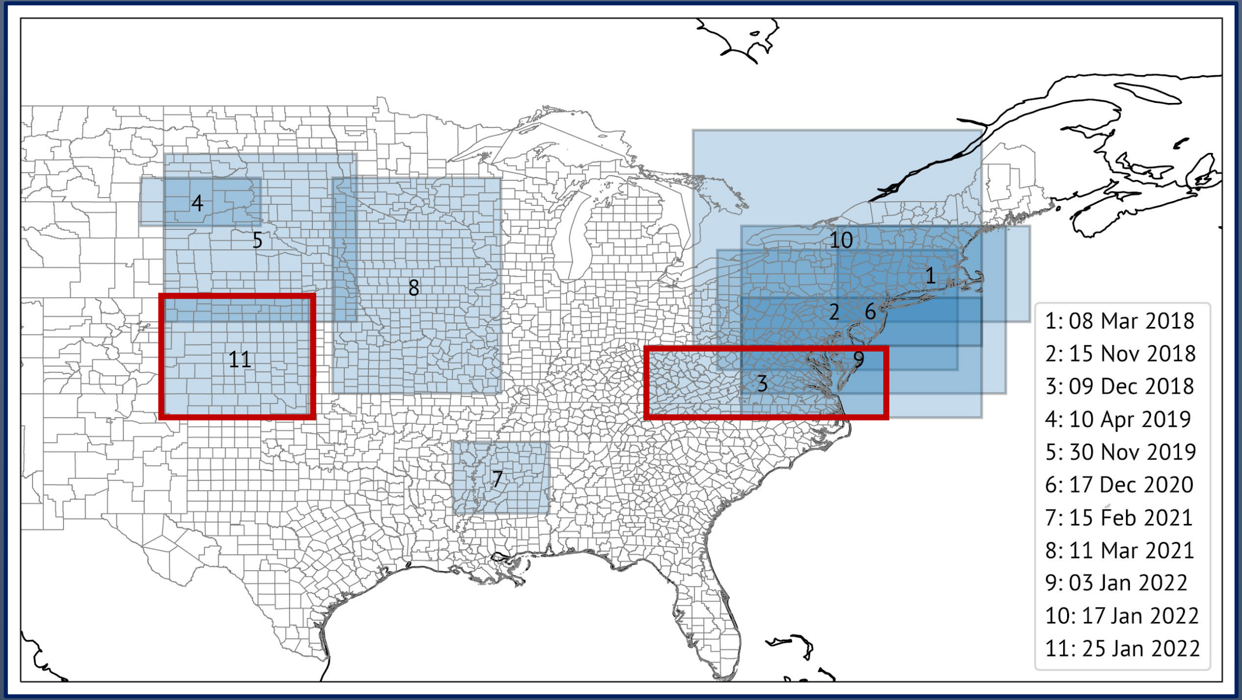
Motivation: Precipitation Nowcasting



Adapted from Trömel et al. (2019)

- Trömel et al. (2019) correlated K_{DP} aloft with Z at the surface using VADs
  - Lead times can be ≥ 1 hour
    - Mean: 44 minutes
  - Correlations varied significantly between cases
  - How does this manifest in space sans azimuthal averaging?

Trajectory Details

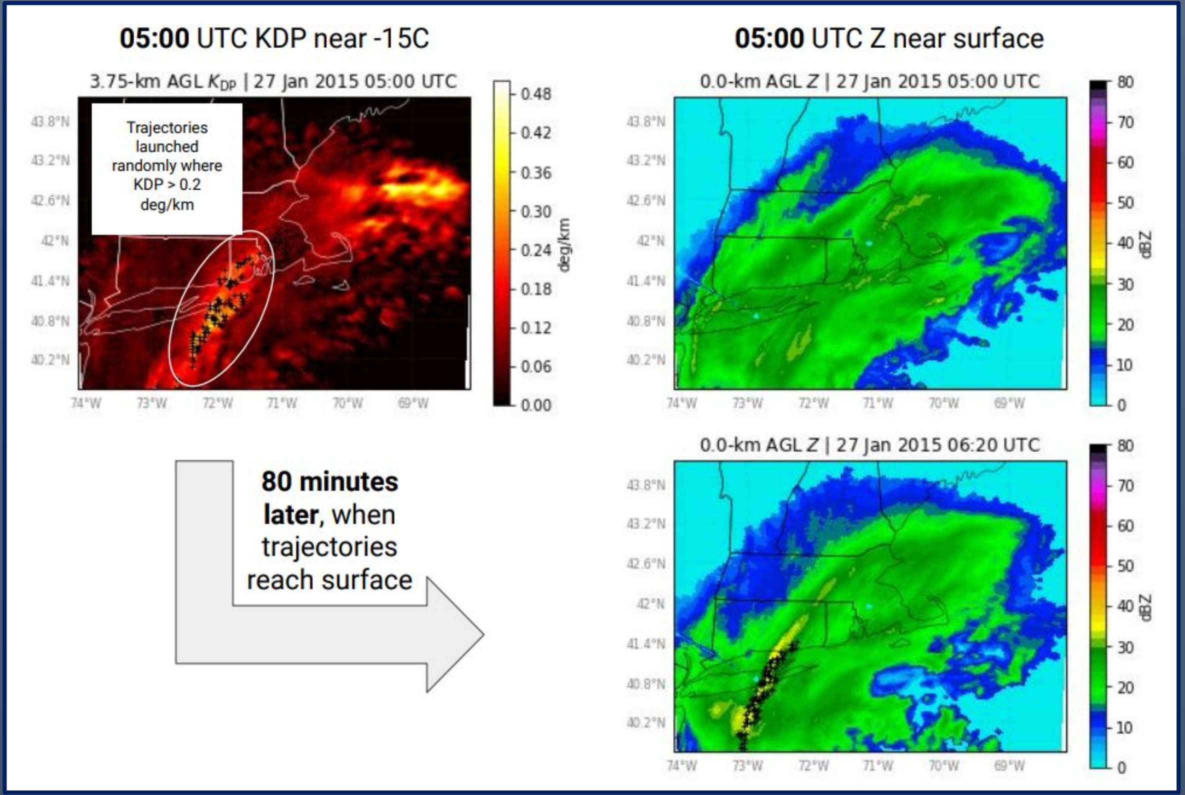


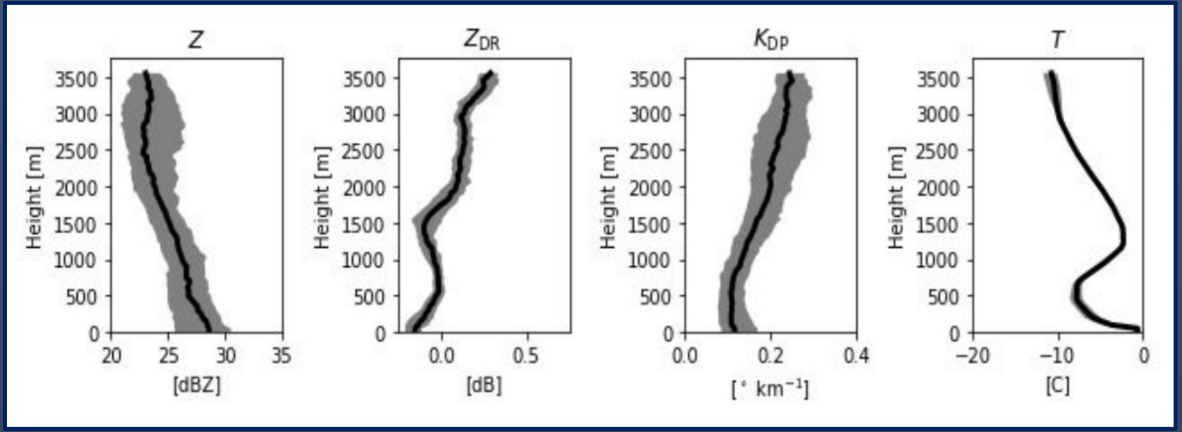
Domains of MRMS polarimetric mosaics

- Selected 11 winter cases with high K_{DP} aloft
  - 2 shown today
- Initialize trajectories in high K_{DP} regions (>0.2 deg/km) around -15°C
  - Polarimetric MRMS CAPPI mosaics
  - Sample preferentially in higher K_{DP} areas
  - Number of trajectories proportional to grids exceeding K_{DP} threshold
- Advect particles using HRRR *u* and *v* winds
  - Fall velocities sampled between 0.8 m/s and 1.2 m/s
- Contour trajectory endpoints at such future time using kernel density estimation
- Gather environmental and radar variables along Lagrangian trajectory

27 January 2015 KOKX

- Trajectories appear to be relatively accurate, predicting onset of heavy snow with lead time of ~75 minutes
  - Alleviates assumptions of azimuthal averaging
  - Lagrangian evolution of polarimetric variables
- Results not always so consistent
  - Sensitive to fallspeed assumptions, ignores PSD evolution, etc.



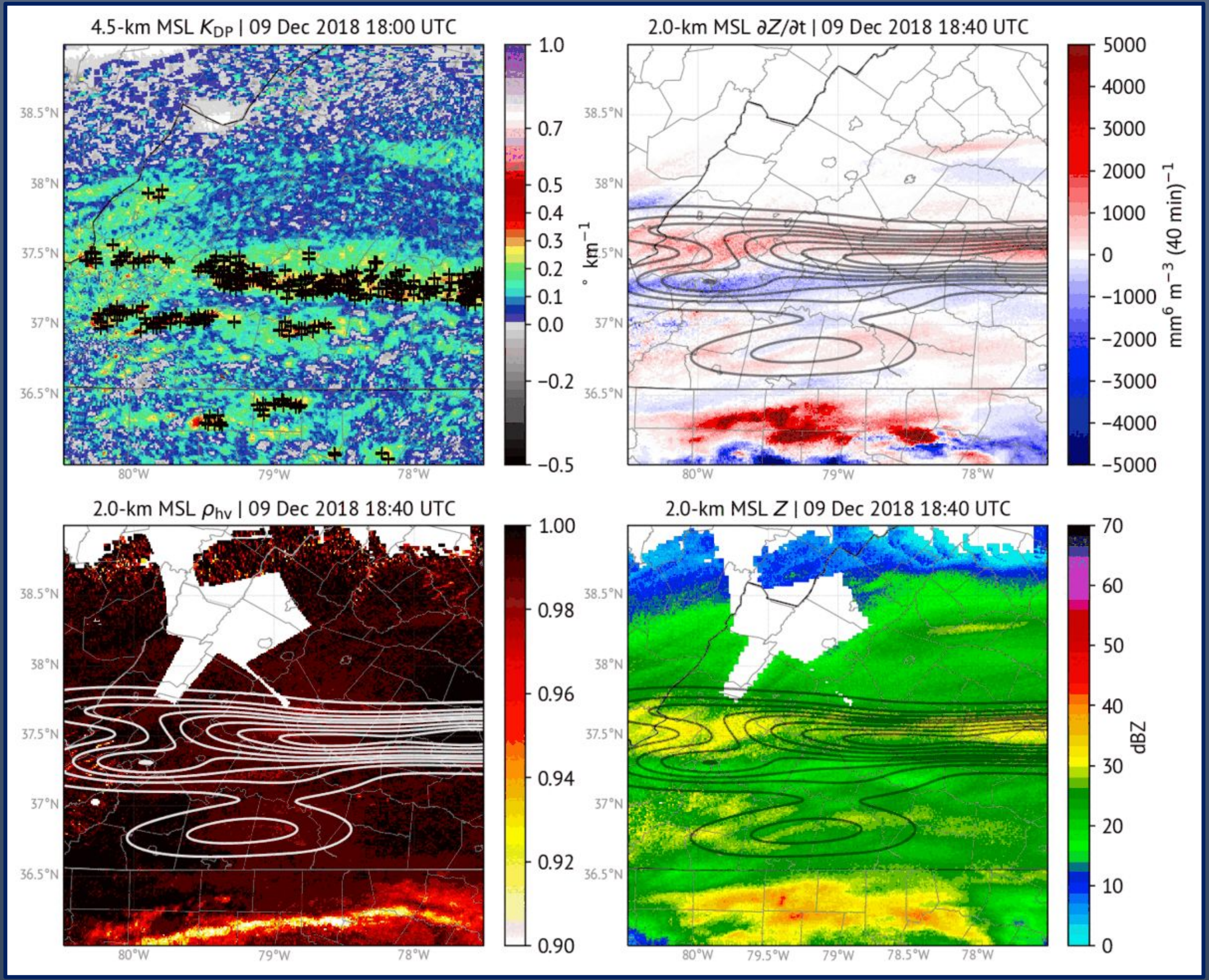


09 December 2018 KAKQ

K_{DP} aloft
$t = t_0$

Z tendency at low-levels

$t = t_0 + 40$ min



ρ_{hv} at low-levels

$t = t_0 + 40$ min

Z at low-levels

$t = t_0 + 40$ min

— = Density of trajectory endpoints

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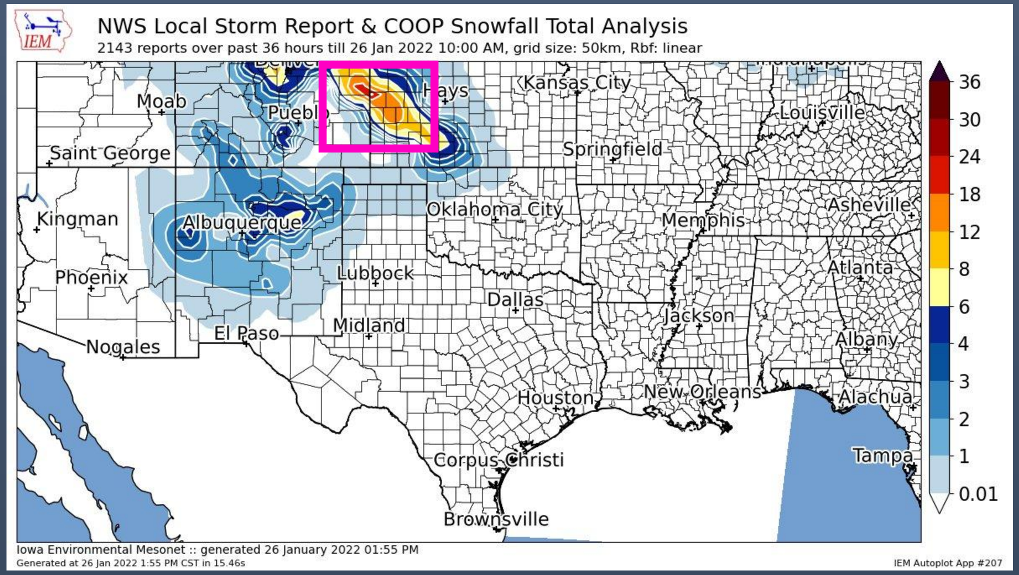
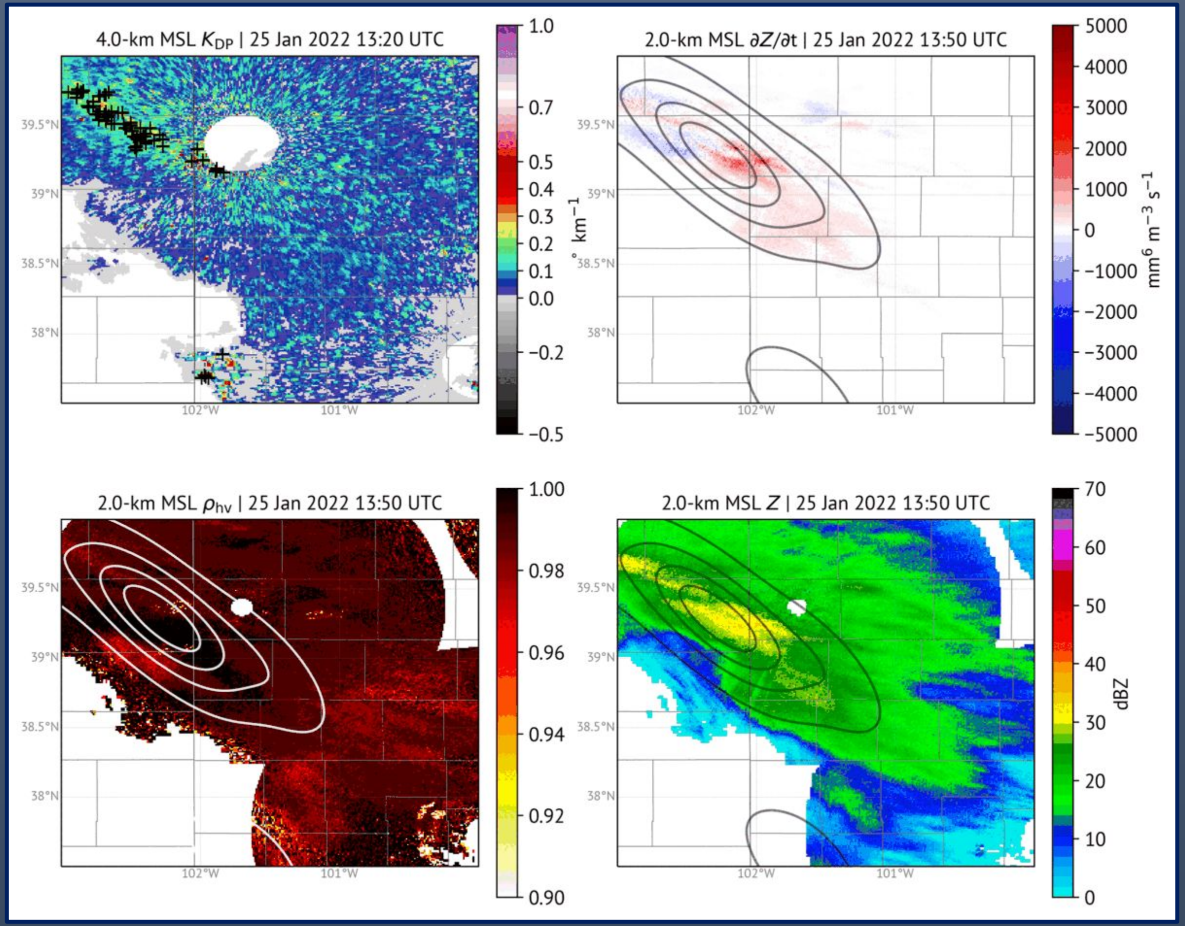
25 January 2022 KGLD

- Extreme case of prolonged narrow band of heavy snow
- Intense K_{DP} associated with band, <u>but</u>: apparent errors in HRRR *v*-component of wind resulted in misplaced trajectories

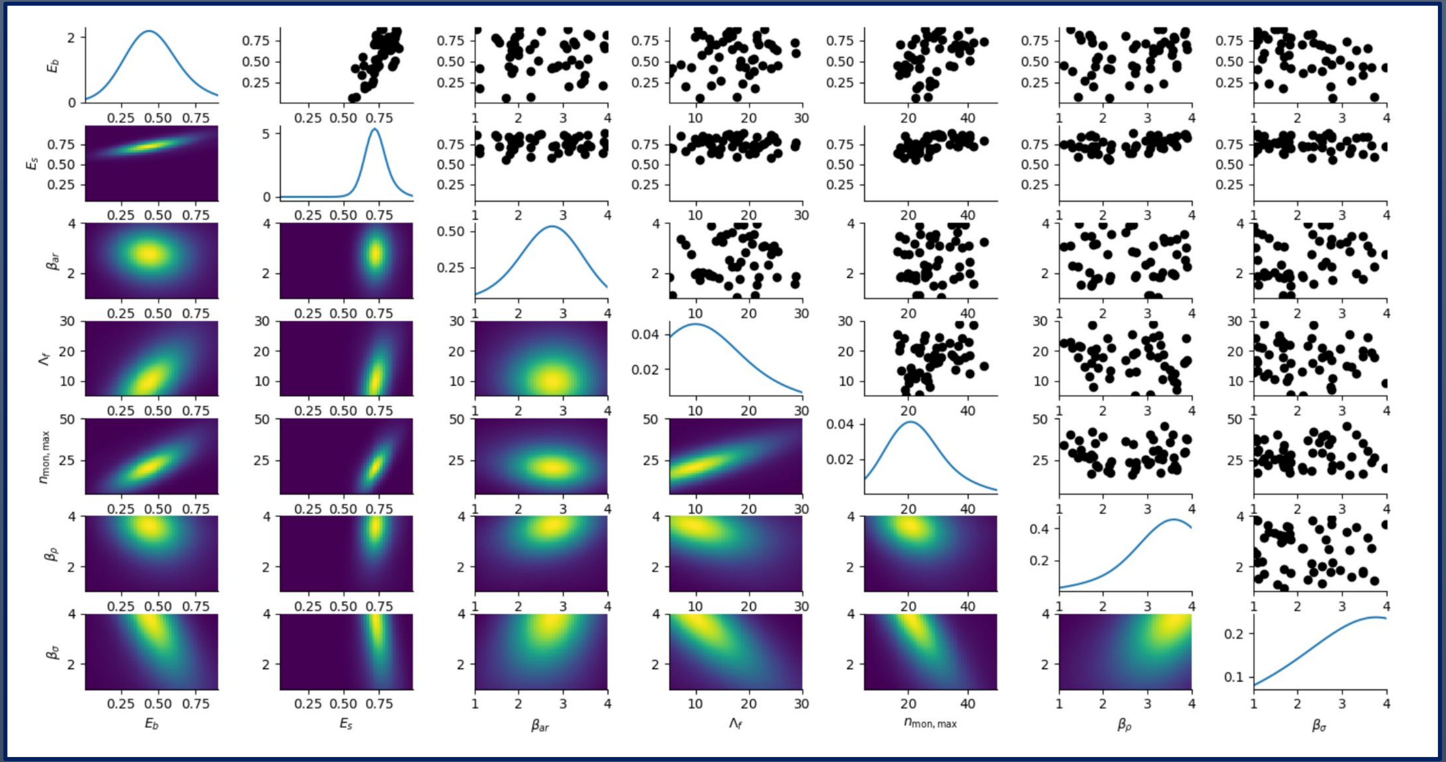


Source: Roger Martin III (@RM3wx)

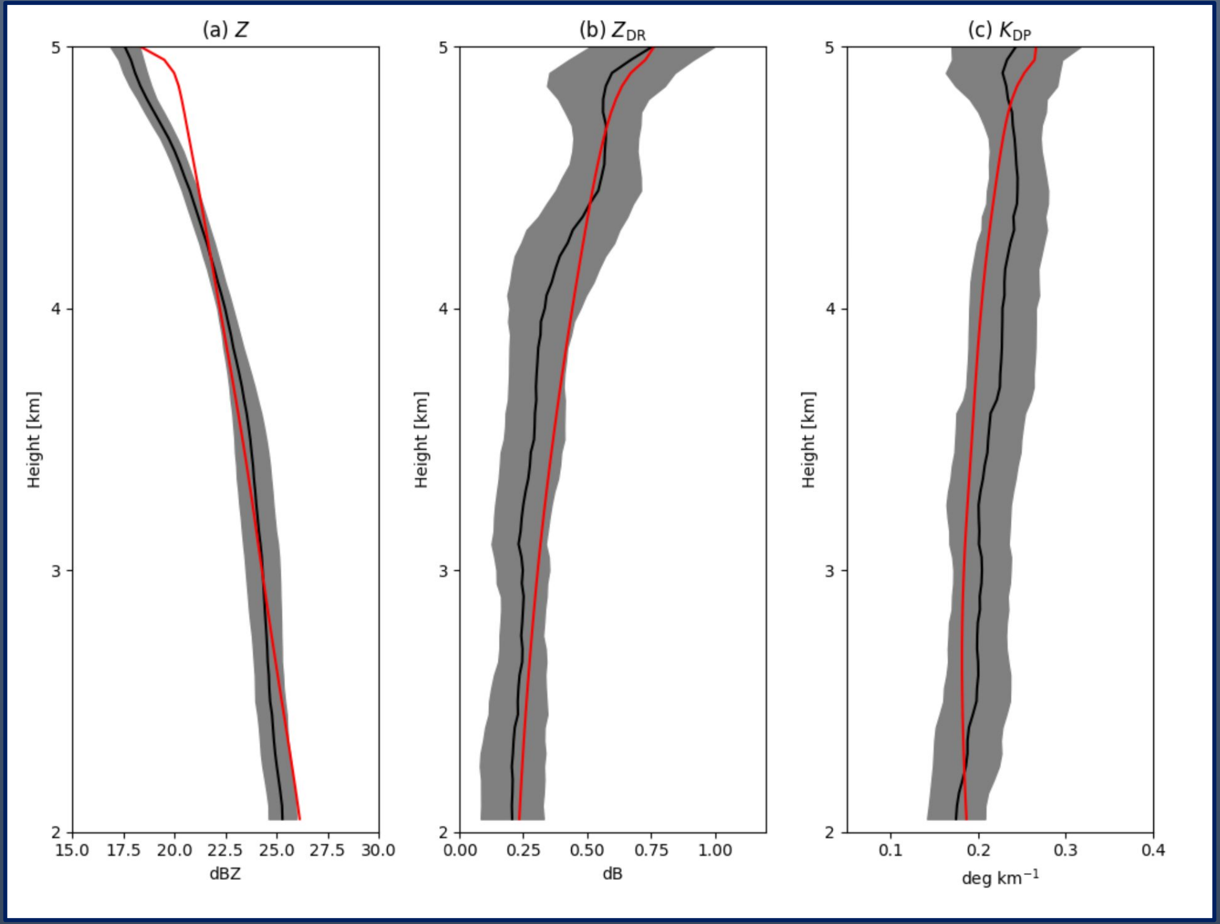


Lagrangian trajectories can help constrain uncertain model parameters

- Approximate Bayesian chain (pyABC) simulations for various aggregation modeling parameters using trajectories from IMPACTS cases
  - Es and Eb well-constrained

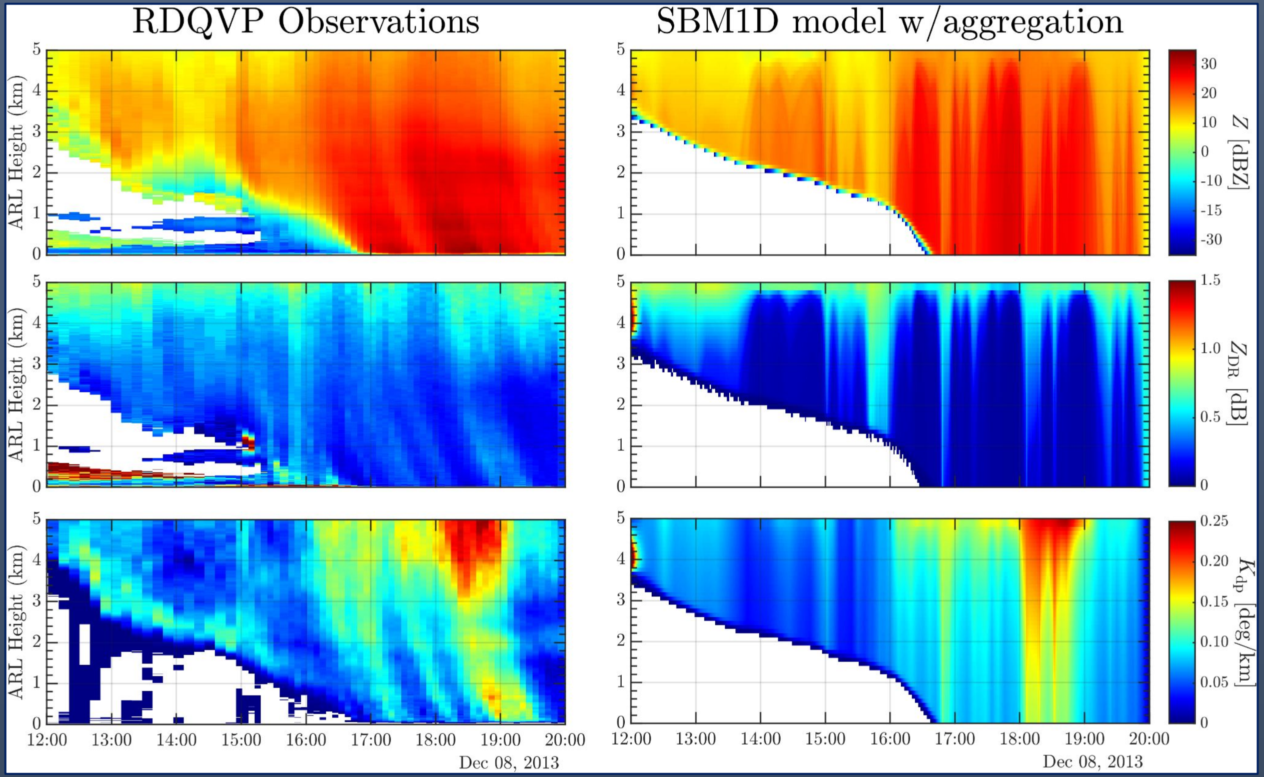


Lagrangian trajectories can help constrain uncertain model parameters



- Able to quantitatively reproduce profiles of aggregating snow
- Important for evolution of PSD down to the surface and resultant changes in visibility, *S*, etc.

Lagrangian trajectories can help constrain uncertain model parameters



08 December 2013 RDQVP

- Able to quantitatively reproduce profiles of aggregating snow
- Important for evolution of PSD down to the surface and resultant changes in visibility, *S*, etc.

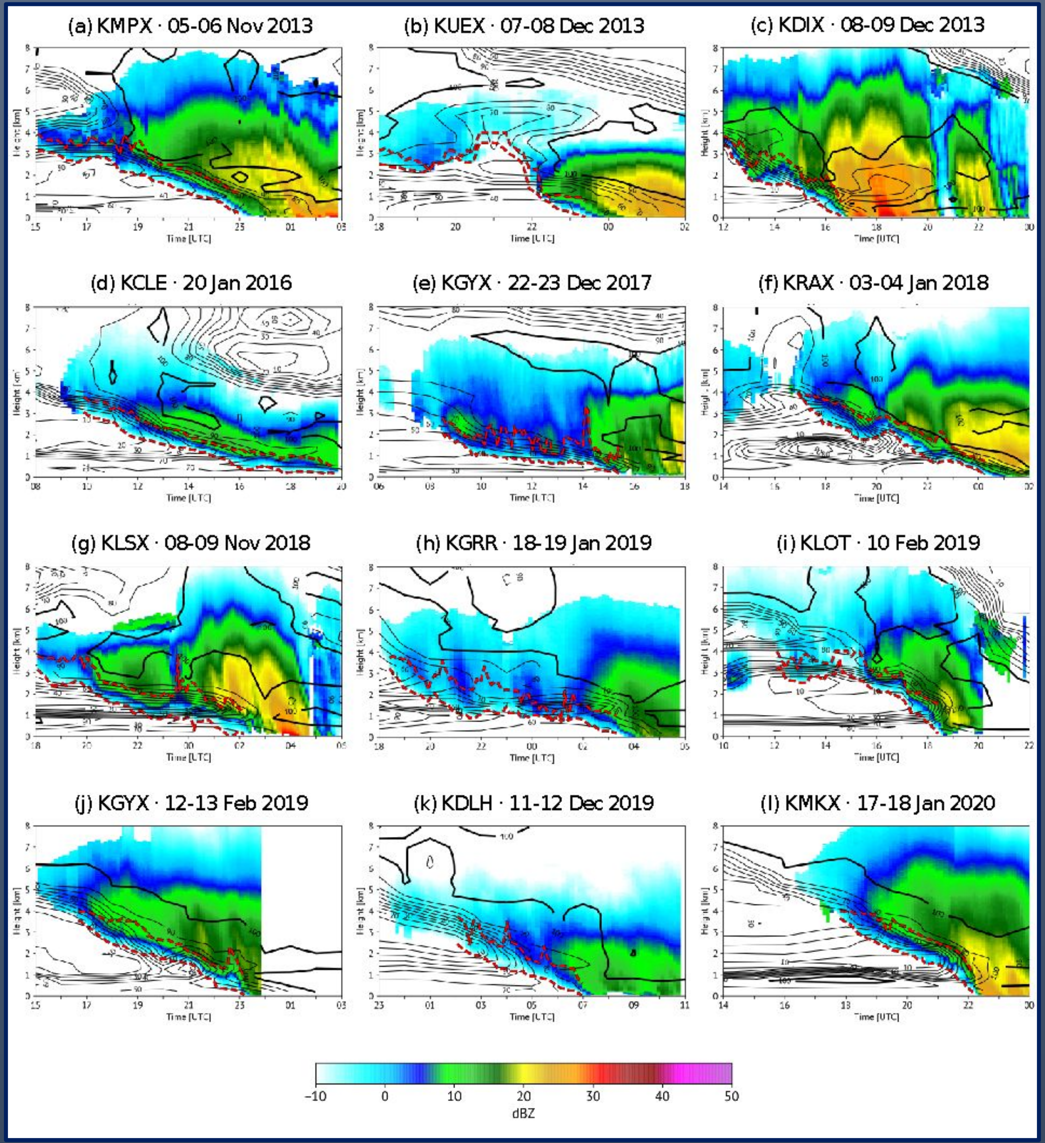
Sublimation nowcasting: Motivation

- Antecedent dry air is often present beneath snow generation layer that must be overcome before snow is observed at the surface
    - Received relatively little attention so far
- Often cited as primarily forecast challenge
    - Affects not only timing but resultant snowfall totals
    - Forbes and Hogan (2006) found large errors in bulk microphysics sublimation rates and layer depths
- "Donut" closing in on radar may not do so linearly depending on variable precipitation intensity and thermodynamic profile
- Can more robust approach be taken?

More information: Carlin, J. T., H. D. Reeves, and A. V. Ryzhkov, 2021: Polarimetric observations and simulations of sublimation snow: Implications for nowcasting. J. Appl. Meteor. Climatol., **60**, 1035 – 1054.

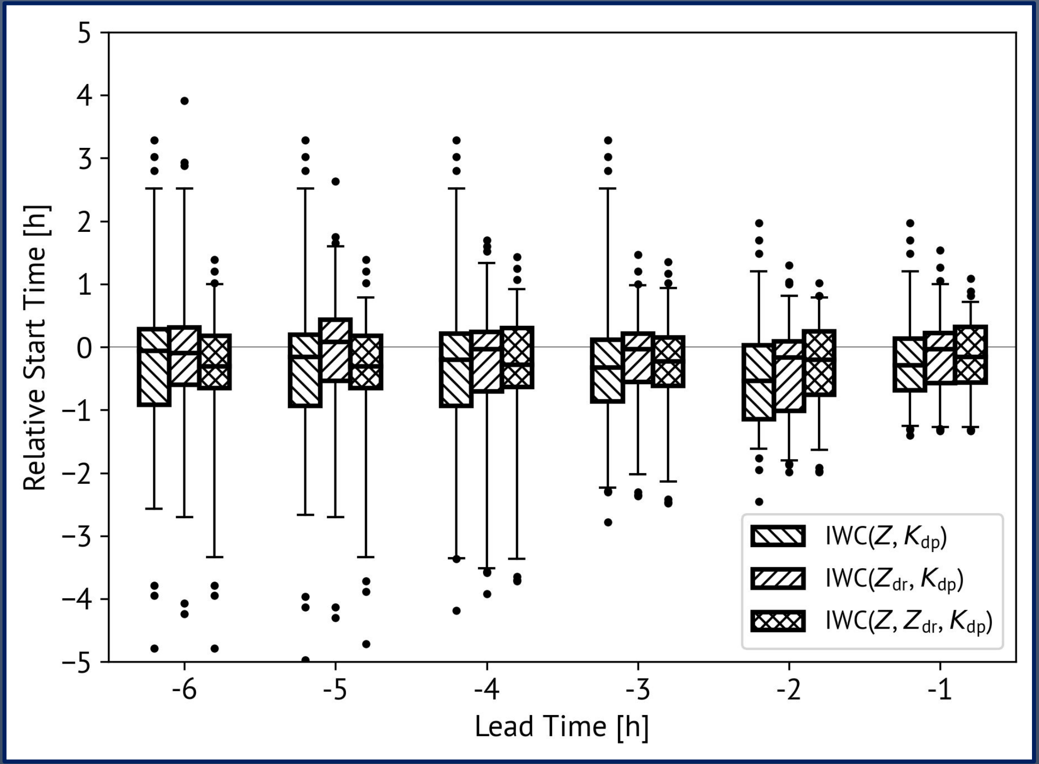
Simulation Methods

- 12 cases examined that featured prolific sublimation
- 1-D sublimation model initialized from RAP
  - Spectral bin microphysics
  - Model environment evolves only in response to microphysical processes (i.e., sublimation)
- Time-varying PSD parameters retrieved from polarimetric QVPs used to drive model
- Tested for a variety of lead times and sets of retrieval equations
- Mean observed start time for each case computed from QVPs, ASOS, and mPING observations



Dashed red = sublimation layer | Contours = RAP RH_i

Simulations Results



Boxplots of model-predicted start time relative to observed start time. Boxes indicate interquartile ranges, horizontal lines indicate medians, and dots indicate outliers outside of the 10th/90th percentiles.

- Median bias:
  - -18.5 minutes at 6-h lead time
  - -9.5 minutes at 1-h lead time
- Interquartile range ~50 minutes
- Distributions generally narrow in time
- Spread inherent to range of observation sources
  - Often span up to 2-h window
- Predicted start times are often remarkably consistent over range of lead times
  - A few cases performed anomalously poorly

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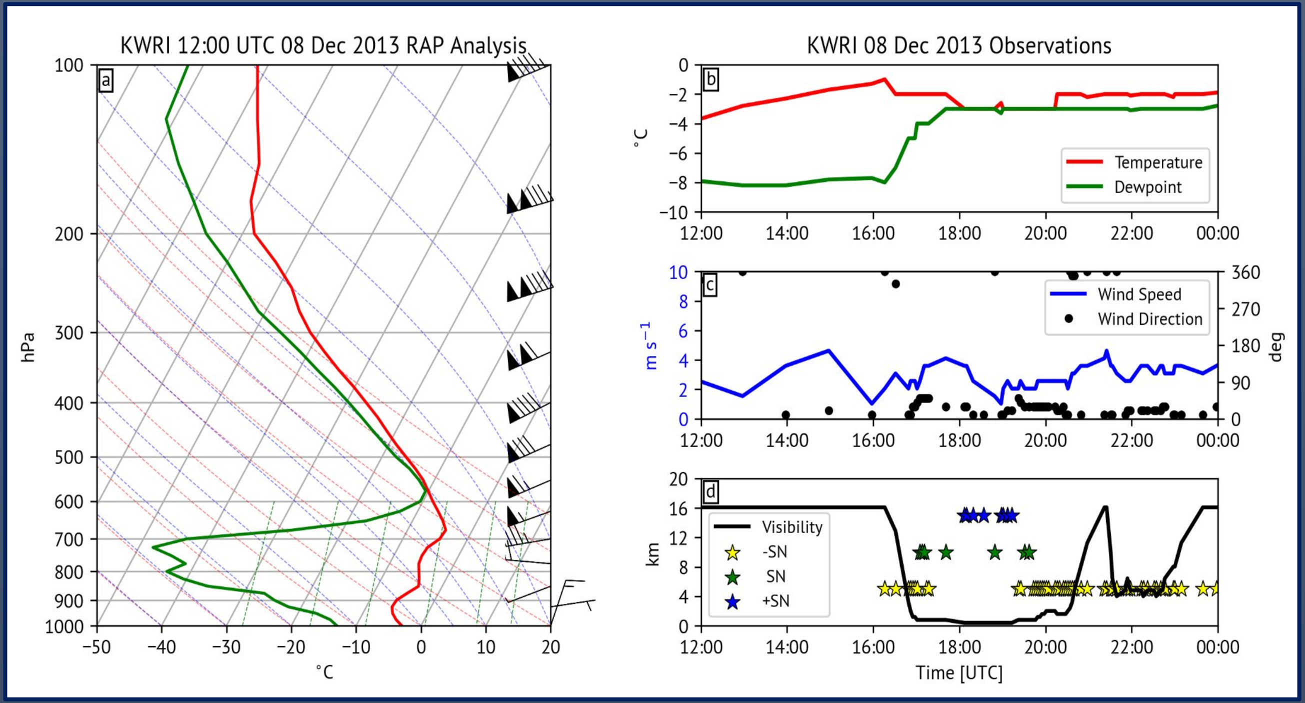
Case Study: 08 December 2013 KDIX

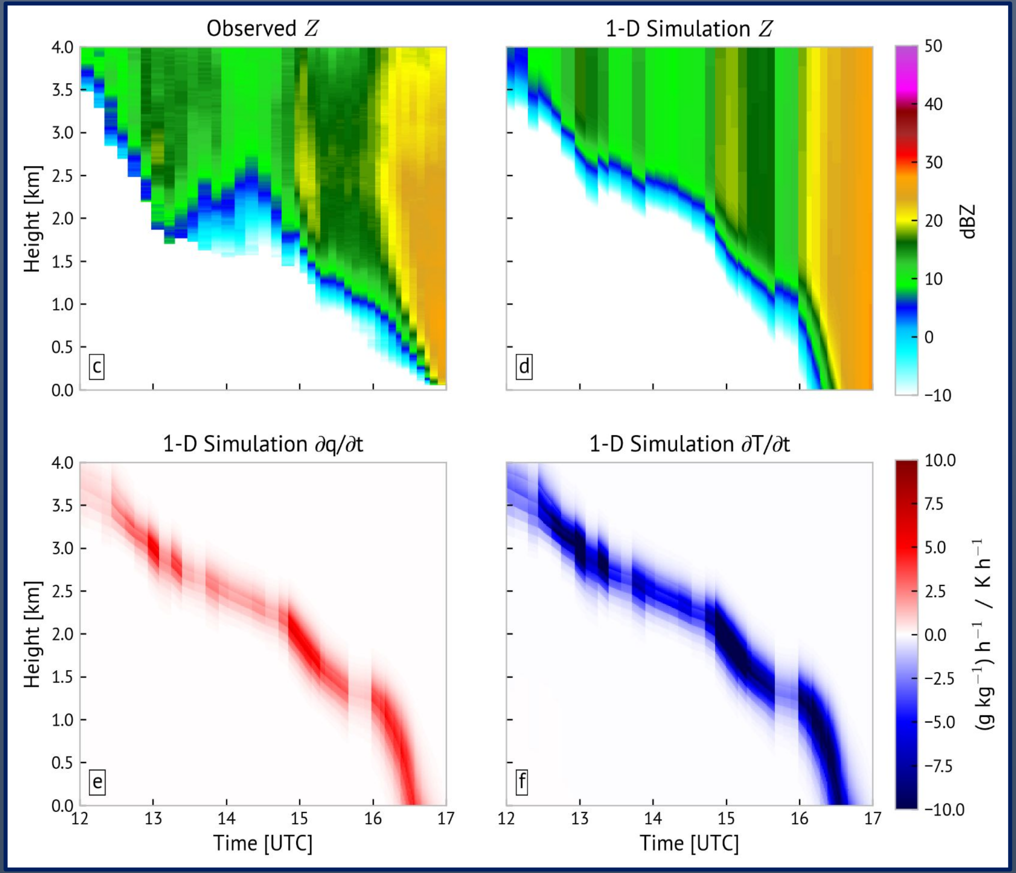
- Unexpectedly heavy snow fell much earlier than forecast during a highly publicized NFL game in Philadelphia.
- Forecasters noted uncertainty regarding extremely dry air in advance of snow.

Source: Associated Press



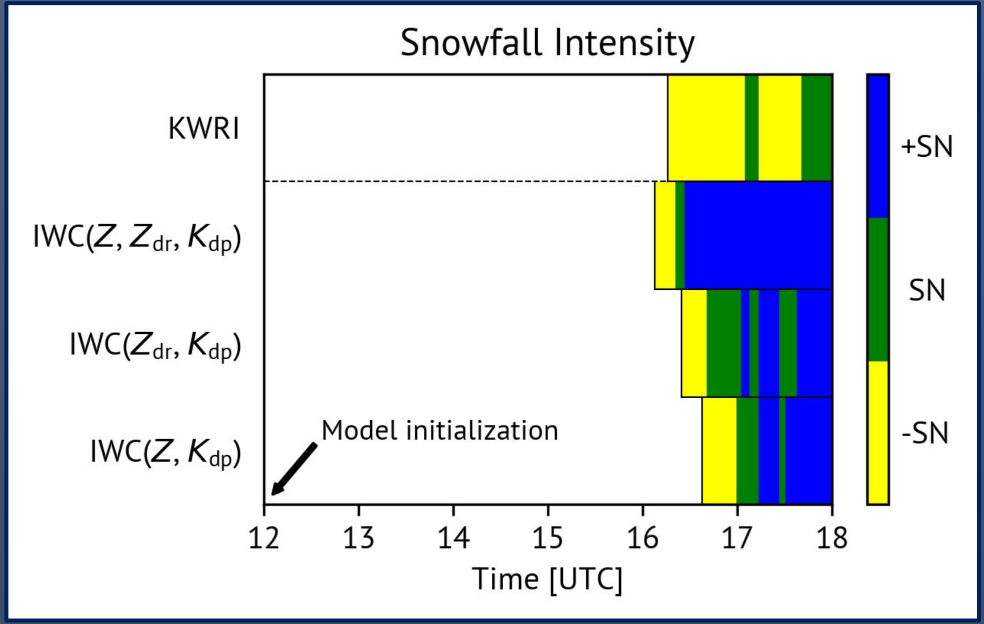
(left) RAP analysis at KWRI location at 1200 08 Dec 2013; (right) KWRI ASOS observations

Case Study: 08 December 2013 KDIX



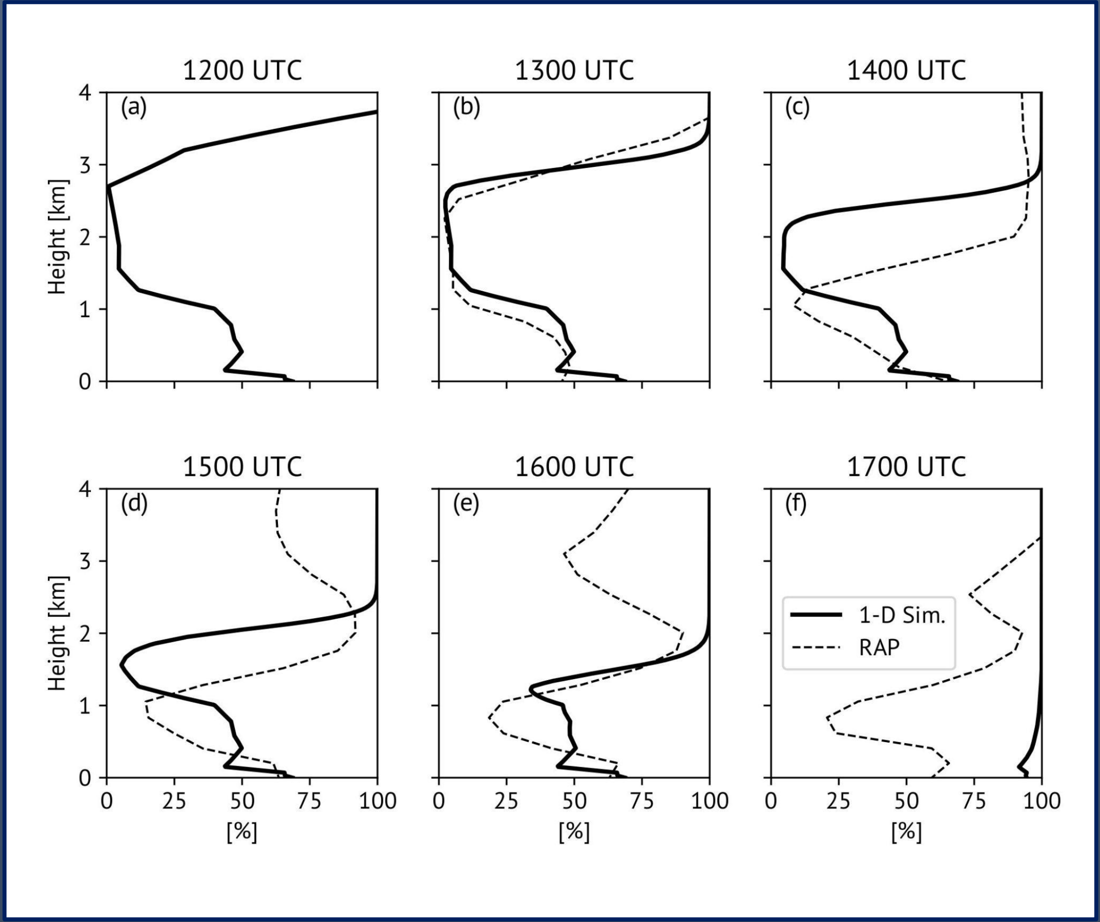
The downward progression of cooling & moistening layer is non-steady.

With 4+ hours lead time, snowfall onset at closest site within 9 minutes of observed.



Case Study: 08 December 2013 KDIX

- Profiles initialized at 1200 UTC with RAP and 1-D forecasts compared
- Moderate agreement through 1400 UTC
- Large divergence from 1500 UTC onward due to erroneous dry air aloft
- Good example of potential benefits of incorporating QVPs (and 1D models) into nowcasting process



Comparison of RH_i evolution between 1-D model (solid) and RAP forecast (dashed) initialized at 12 UTC

Summary

The multifaceted combination of polarimetric QVPs/signatures in the DGL and simplified 1D models can be an effective nowcasting tool that consider both temporal (e.g., PSD evolution) and spatial (e.g., trajectories) factors.

1. Trajectories can predict location of enhanced snowbands at the surface with appreciable lead time (30-60 min)
2. Quantitative ice microphysical retrievals appear to be robust
3. Models initialized from said retrievals were shown to accurately predict when snow would overcome dry air and reach the surface up to six hours out

Additional work is ongoing to

1. Refine microphysical retrieval equations and their sensitivities;
2. Study additional high-K_{DP} cases with coupled trajectory/microphysical model
    - Better constrain parameter and sensitivities