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

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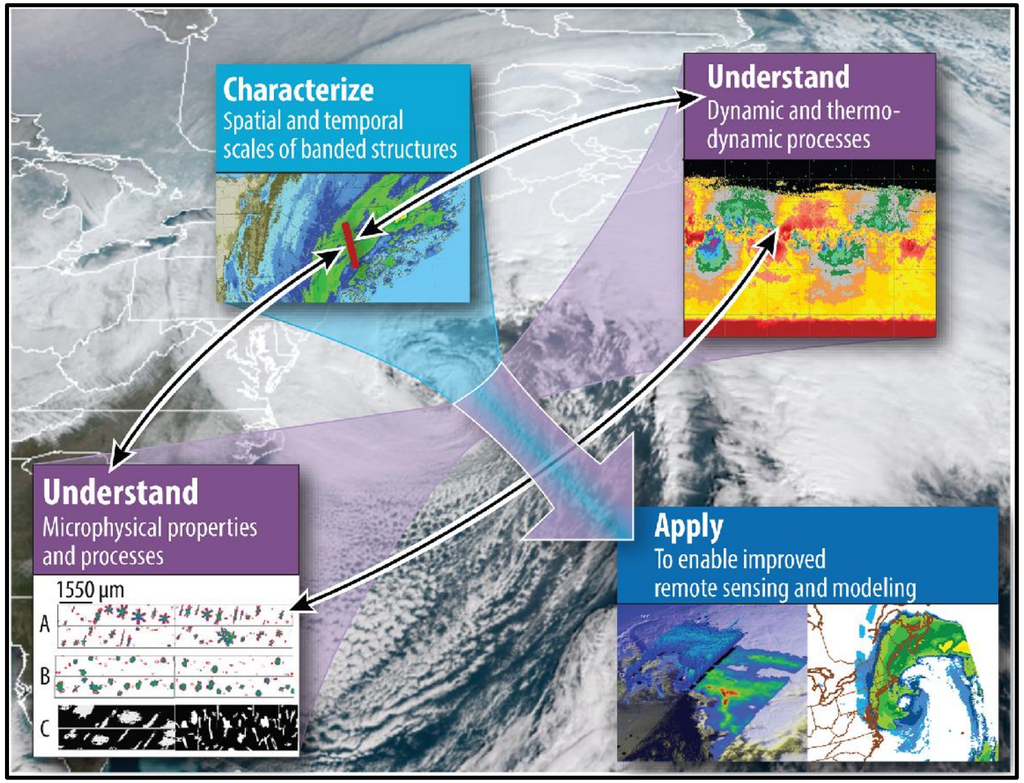
2023 PROM Workshop

NASA Impacts Campaign

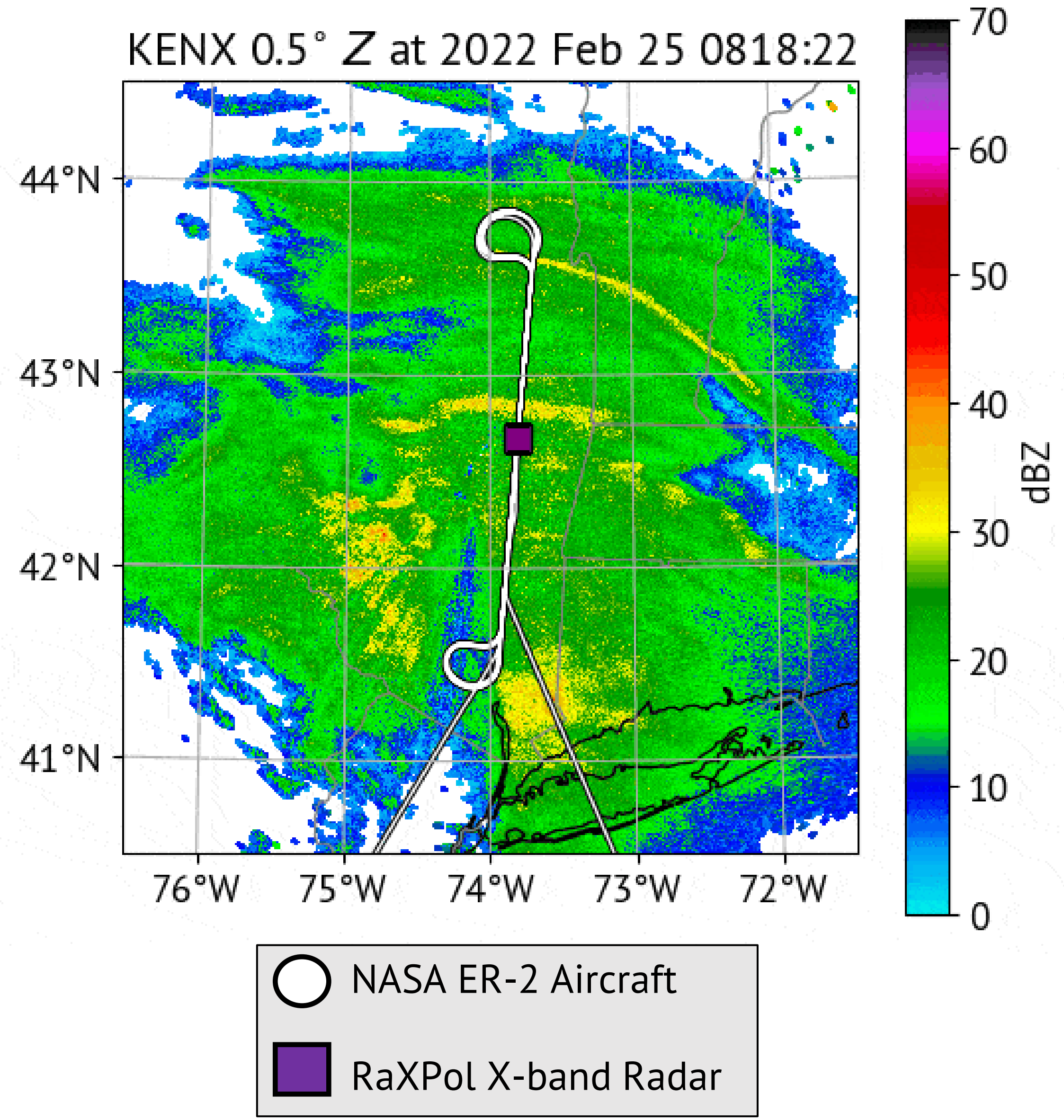
- NASA-led multi-year field campaign in the northeastern U.S.
- Airborne assets include:
  - P3 with suite of in situ microphysical probes
  - ER2 with nadir-pointing EXRAD (X band), HIWRAP (Ku/Ka bands), and CRS (W band) radars
- Ground-based assets include:
  - OU/ARRC RaXPol mobile radar
  - MRR
  - Parsivel disdrometer

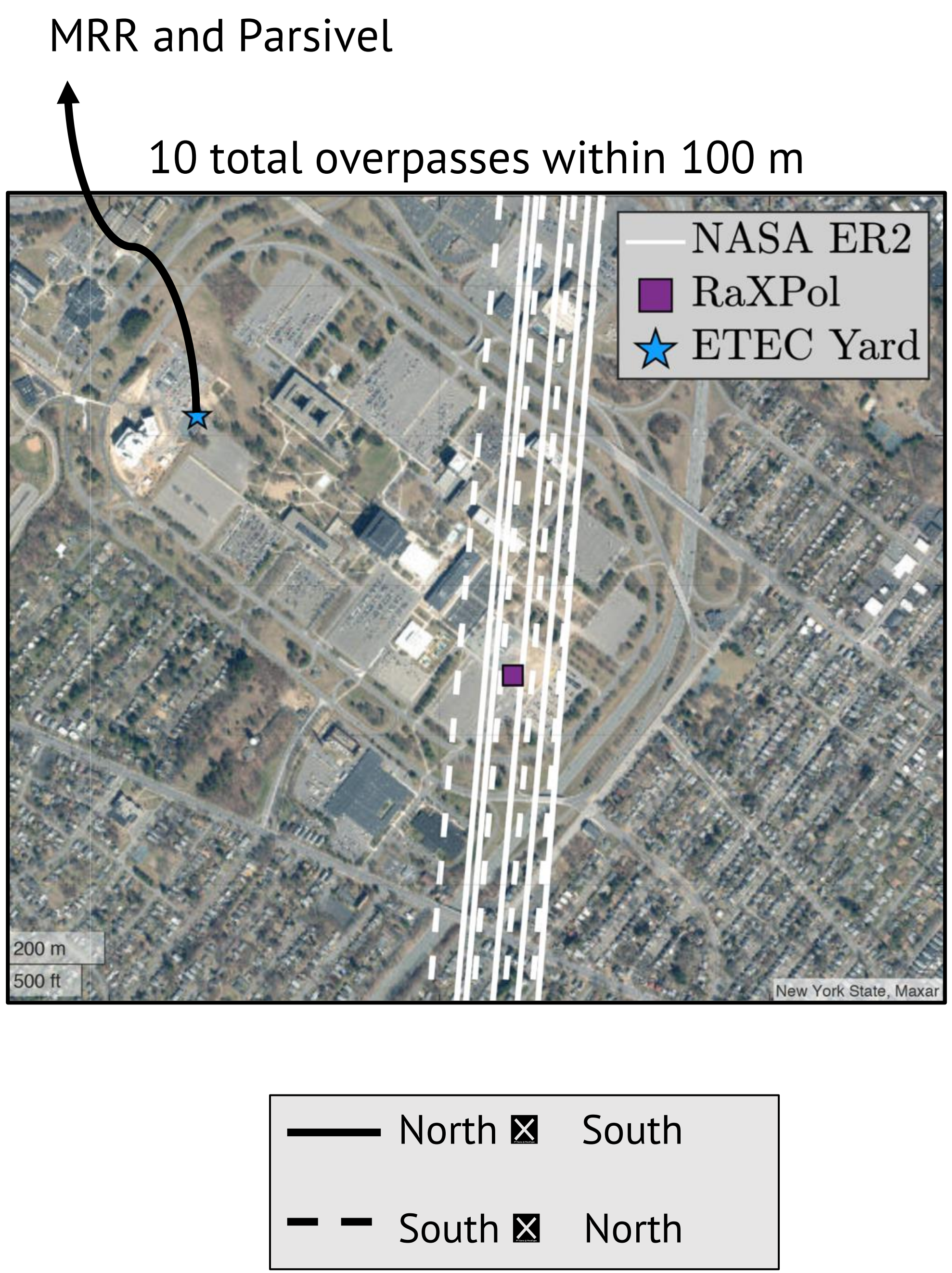


Adapted from McMurdie et al. (2022)

More: Dunnavan, E. L., J. T. Carlin, D. Schvartzman, A. V. Ryzhkov, H. Bluestein, S. Emmerson, G. M. McFarquhar, G. M. Heymsfield, and J. Yorks, 2023: High-resolution snowstorm measurements and retrievals using cross-platform multi-frequency and polarimetric radars. *Geophys. Res. Let.*, **50**, e2023GL103692. doi:10.1029/2023GL103692.

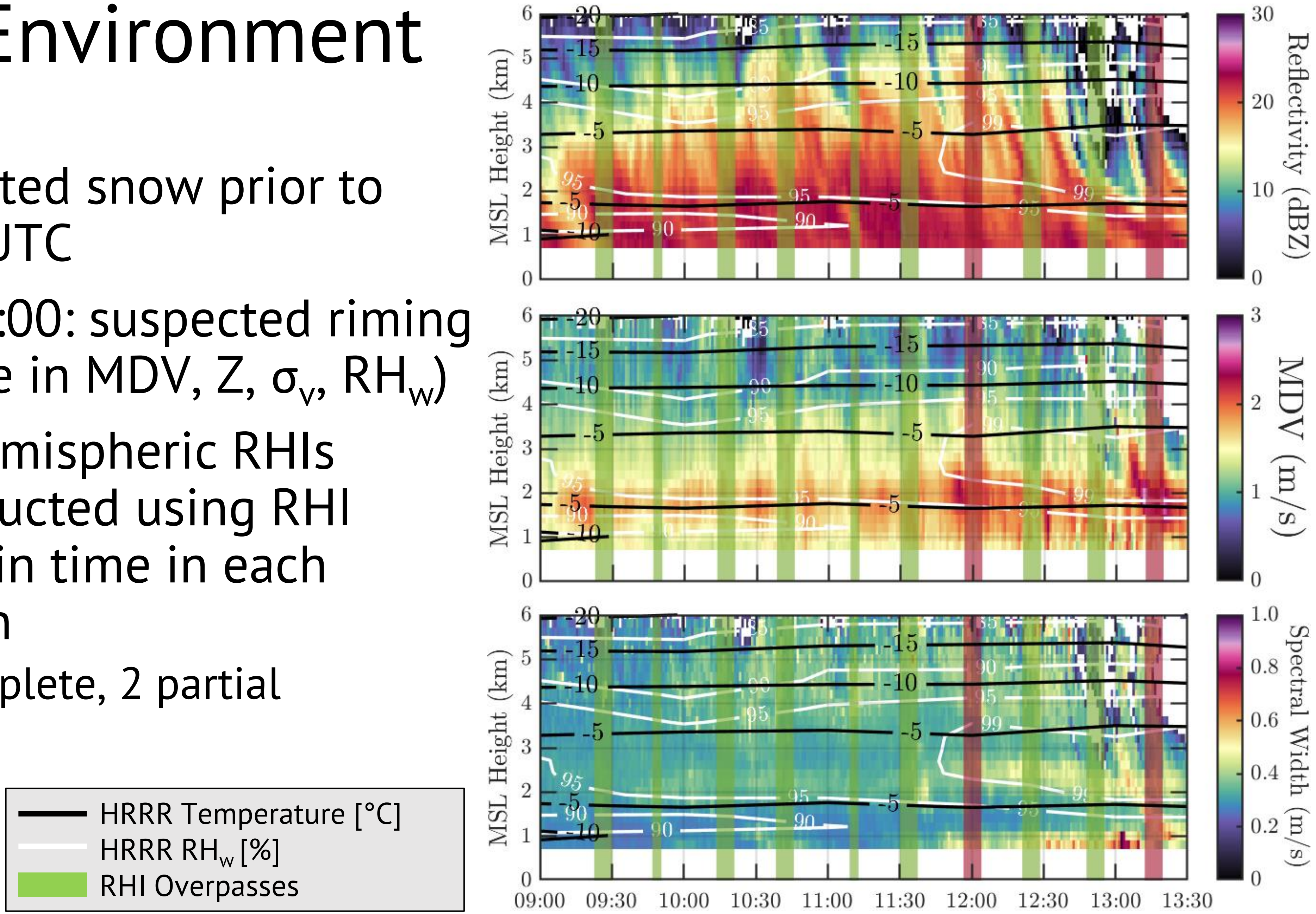
25 February 2022 IOP





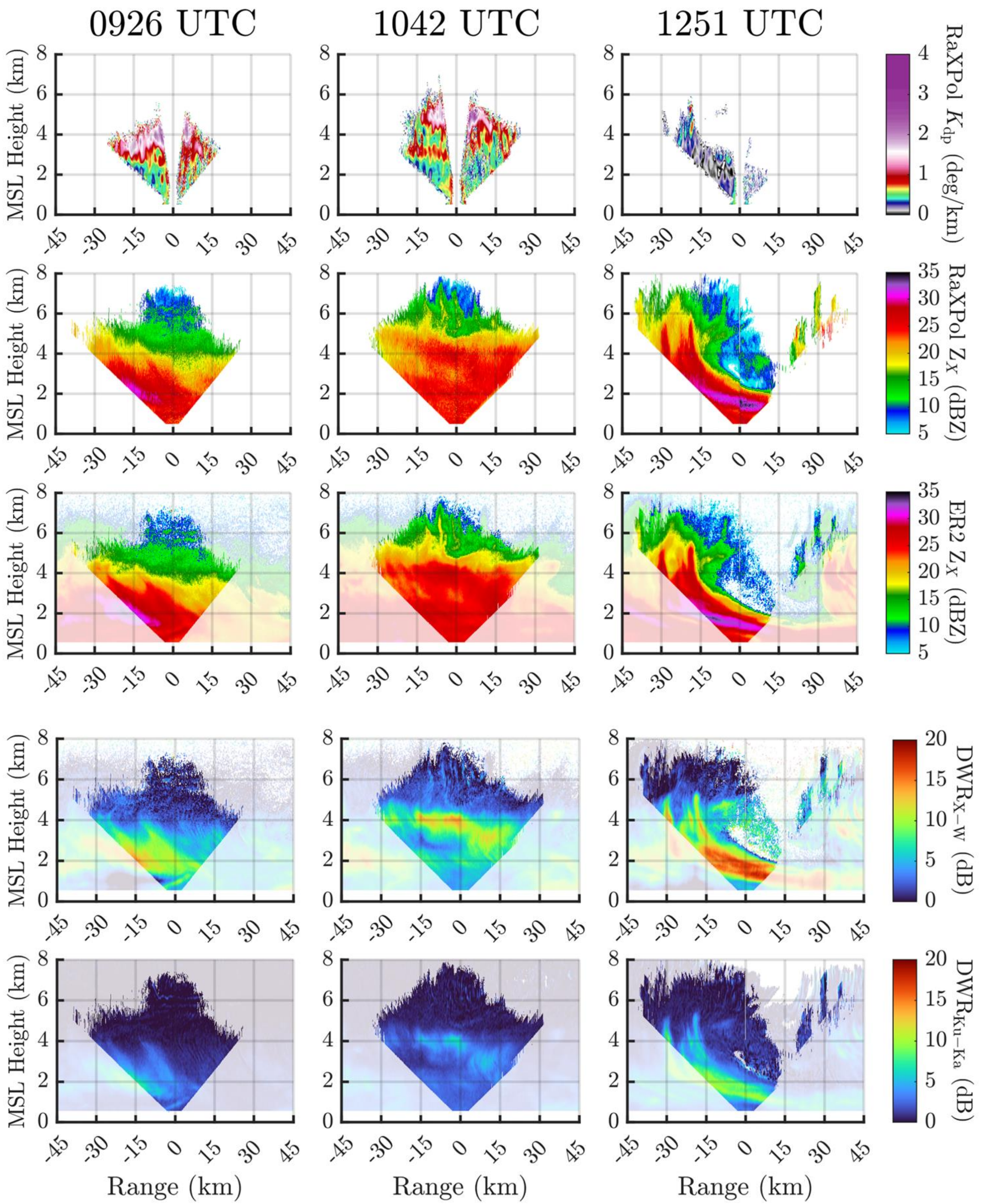
MRR/Environment

- Aggregated snow prior to ~12:00 UTC
- After 12:00: suspected riming (increase in MDV, Z, σ_v, RH_w)
- Semi-hemispheric RHIs reconstructed using RHI nearest in time in each direction
  - 6 complete, 2 partial



Data processing

- Linear interpolation onto common 50 m x 50 m grid
- Attenuation correction for:
  - Water vapor and O_2 (W, Ku, Ka, X)
  - Supercooled liquid water (W, Ku, Ka)
  - Ice scattering (W) following Kulie et al. (2014)
- Absolute calibration with respect to Ku-band data
- K_{dp} calculated according to Vulpiani et al. (2015) and corrected for elevation angles up to 45°



Examined state-of-the-art snow D_m retrievals

1. Matrosov et al. (2022) DWR polynomial method (“DWR Poly”)

$$D_{mv,max} = 1.31 + 0.146 DWR_{X-W} + 0.0209 DWR^2_{X-W} - 0.000427 DWR^3_{X-W} \longrightarrow D_{m,max}$$

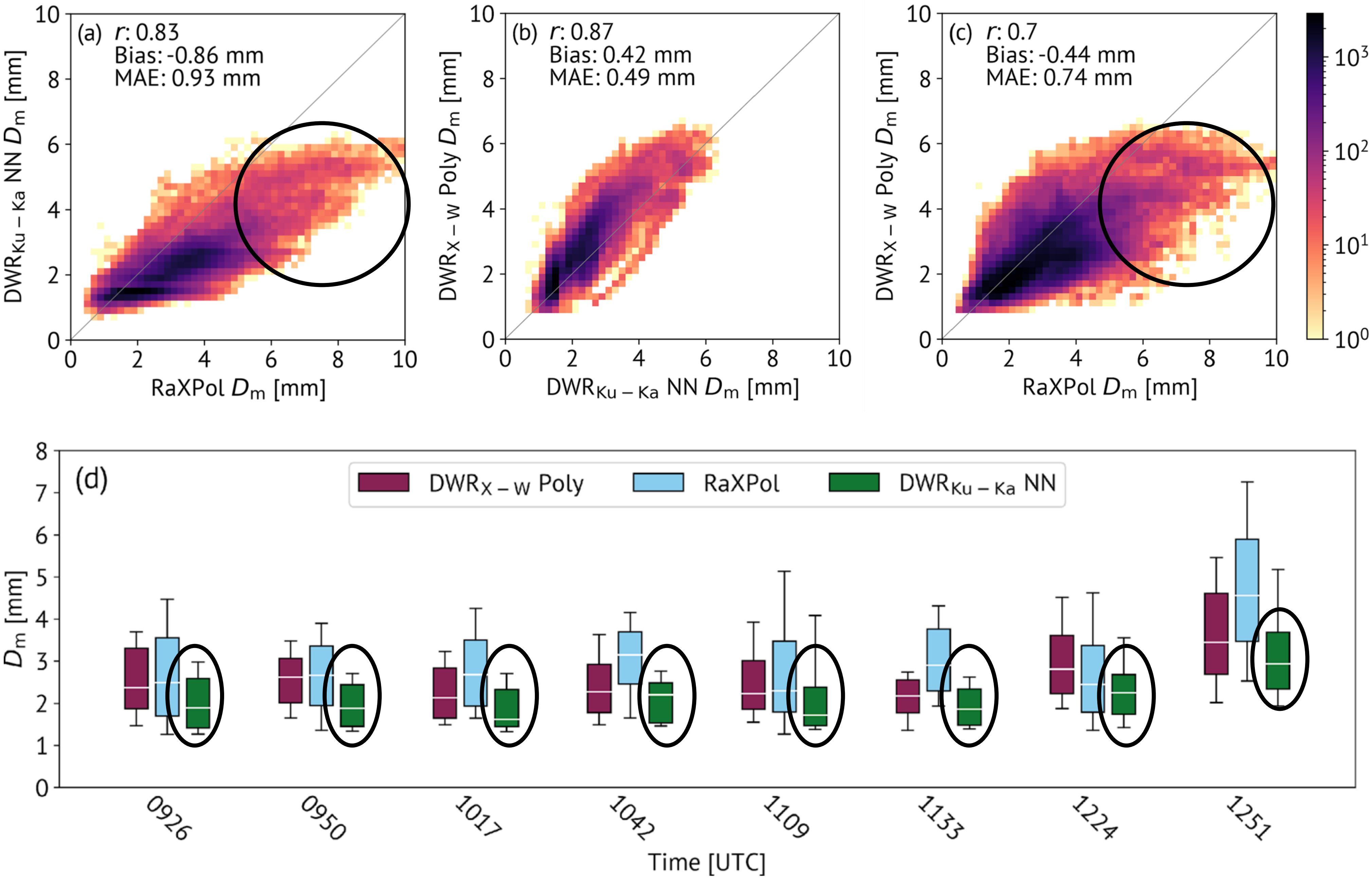
1. Chase et al. (2021) DWR neural network (“DWR NN”)

$D_{m,max}$ via Ku-Ka neural network model

1. Dunnavan et al. (2022) polarimetric retrieval (“RaXPol”)

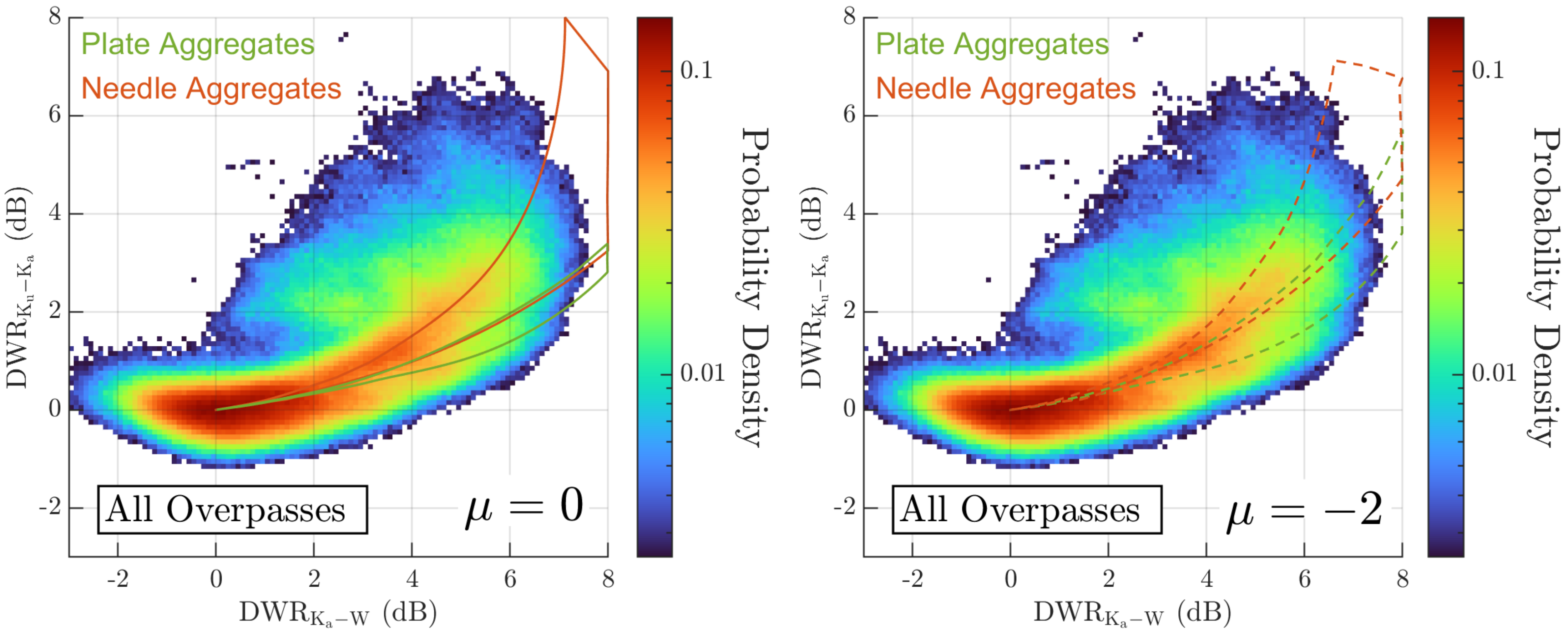
$$D_{mv} = 0.336 Z_h^{1/3} K_{dp}^{-1/3} \longrightarrow D_{mv,max} \longrightarrow D_{m,max}$$

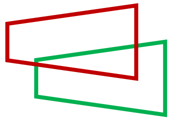
Limited to where 0 dB < DWR < 20 dB for consistency with Matrosov et al. (2022).



(a) r: 0.83
Bias: -0.86 mm
MAE: 0.93 mm
DWR_{Ku-Ka} NN D_m [mm]
RaXPol D_m [mm]
(b) r: 0.87
Bias: 0.42 mm
MAE: 0.49 mm
DWR_{X-W} Poly D_m [mm]
DWR_{Ku-Ka} NN D_m [mm]
(c) r: 0.7
Bias: -0.44 mm
MAE: 0.74 mm
DWR_{X-W} Poly D_m [mm]
RaXPol D_m [mm]
(d)
DWR_{X-W} Poly
RaXPol
DWR_{Ku-Ka} NN
D_m [mm]
0926
0950
1017
1042
1109
1133
1224
1251
Time [UTC]

Triple-frequency diagrams



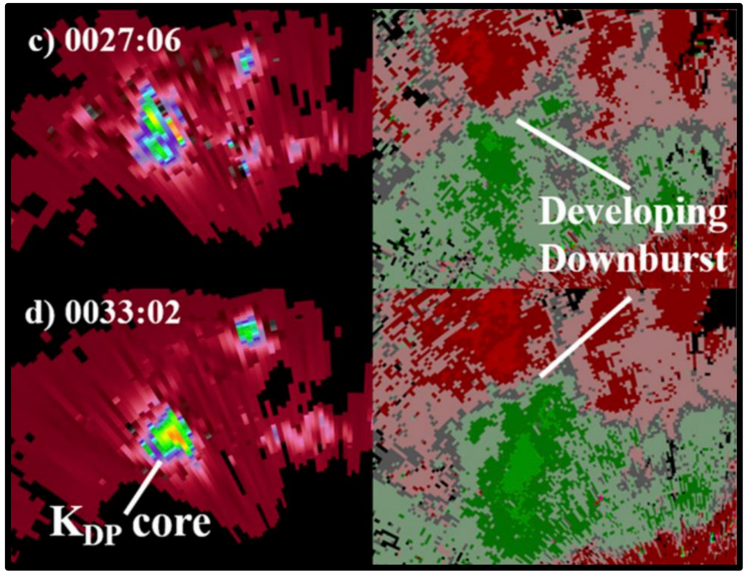


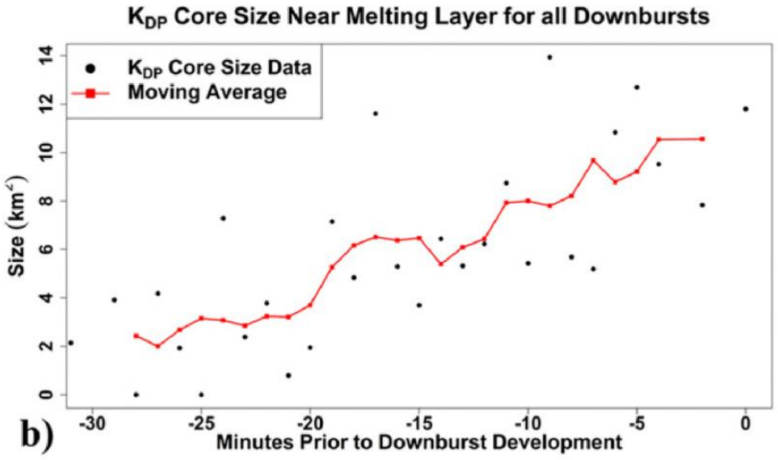
Convex hull of Leinonen and Moisseev (2015) synthetic aggregate DDA simulations for 0.5 mm < D_{mv} < 8 mm and various constituent monomer sizes

1D Idealized Modeling of Downburst Generation

Descending K_{dp} cores are precursors for 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)

How do the dual-pol variables relate to downdraft forcing?

Adapted from Srivastava (1987)

$$\frac{dw}{dt} + w\frac{dw}{dz} = g\left(\frac{T_v - T_{v,env}}{T_{v,env}}\right) - g(q_r + q_g + q_h) - \mu|w|w$$

Thermal buoyancy   "Precipitation loading"

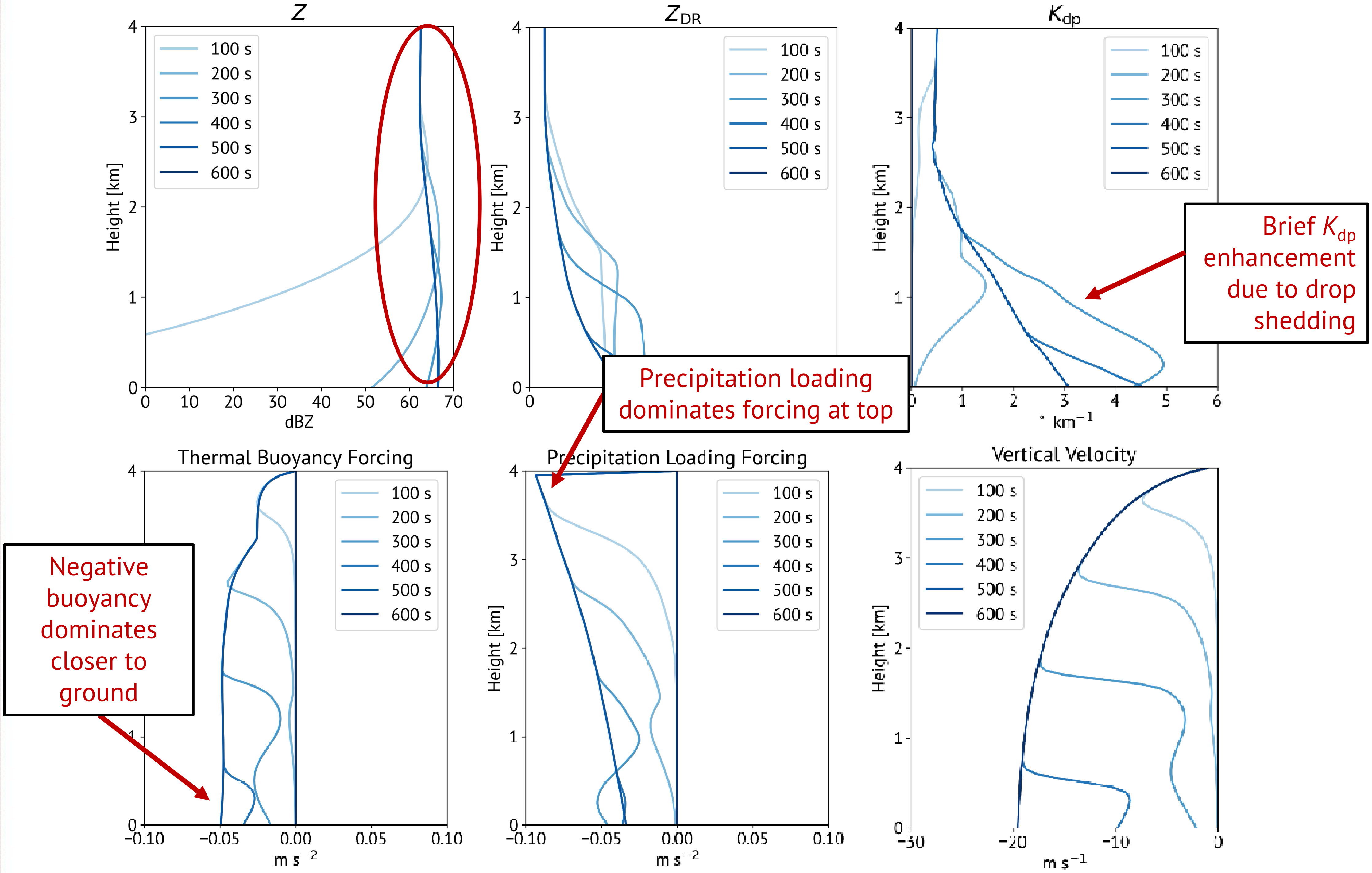
Descending K_{dp} cores associated with impending downbursts.

- More association than e.g., descending Z cores

What can K_{dp} (potentially) tell us about the *intensity* of downbursts?

1D model of downburst development

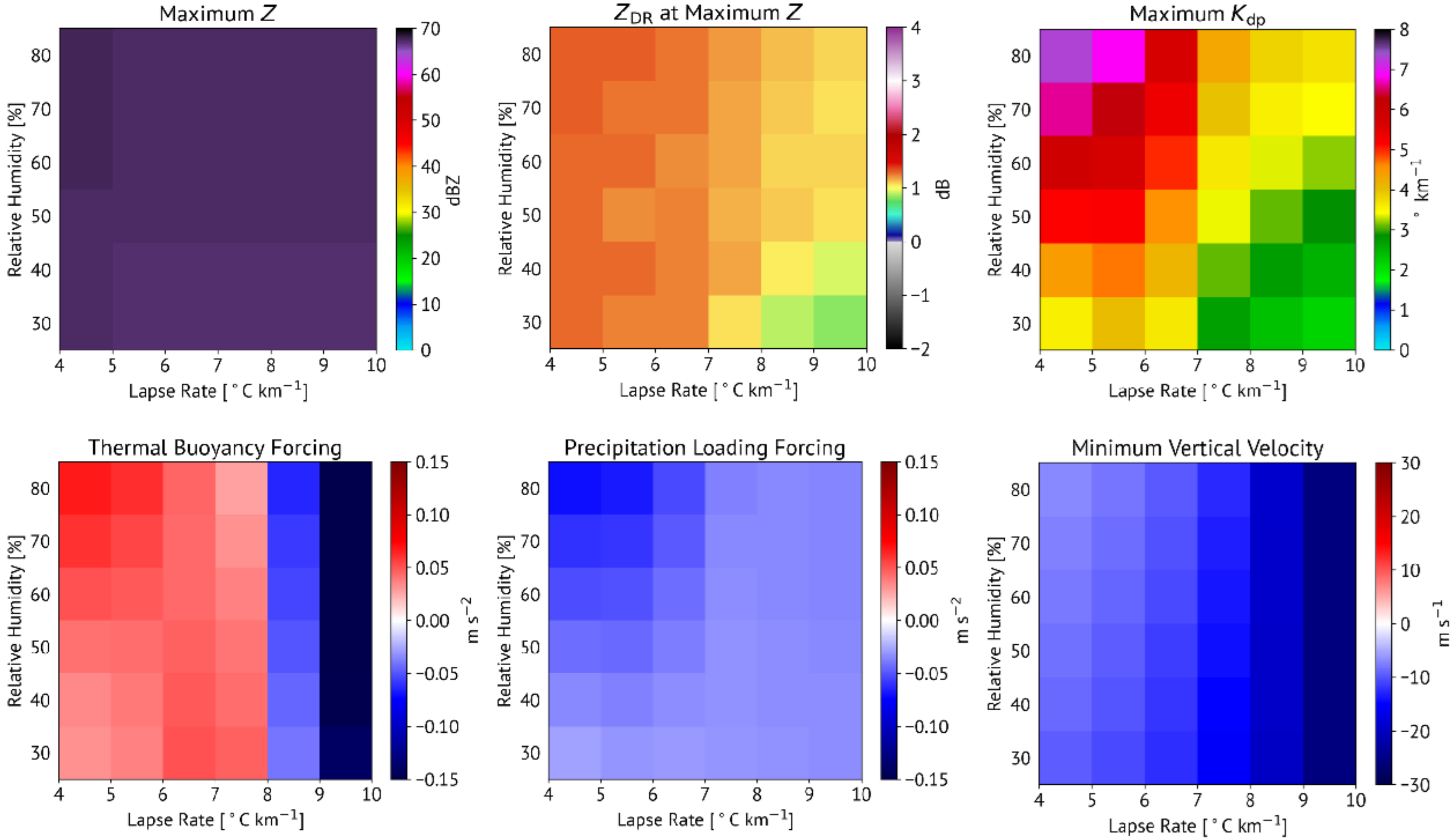
- Based on seminal Srivastava (1987) model of downburst development
- Updated parameterizations include:
  - Hail melting rate (e.g., Ryzhkov et al. 2013, Phillips et al. 2007)
  - Hail canting angle distribution (e.g., Dawson et al. 2014)
  - Graupel melting rate and density (Theis et al. 2022)
  - Melting hail shape (Kumjian et al. 2018)
  - Shed drop size distribution (Theis et al. 2021)
  - Hail mass and fallspeed (e.g., Heymsfield et al. 2018)
- Linked to polarimetric radar forward operator (Ryzhkov et al. 2011)
  - 2-layer T-matrix scattering LUT
- **Goal** is to simulate polarimetric downburst signature and associations between radar and forcing mechanisms



Z
Height [km]
dBZ
100 s
200 s
300 s
400 s
500 s
600 s
Z_{DR}
Height [km]
K_{dp}
Height [km]
° km^{-1}
Brief K_{dp} enhancement due to drop shedding
Precipitation loading dominates forcing at top
Thermal Buoyancy Forcing
m s^{-2}
Negative buoyancy dominates closer to ground
Precipitation Loading Forcing
Height [km]
m s^{-2}
Vertical Velocity
Height [km]
m s^{-1}

How does the environment impact downburst radar characteristics?

For a given initial PSD…



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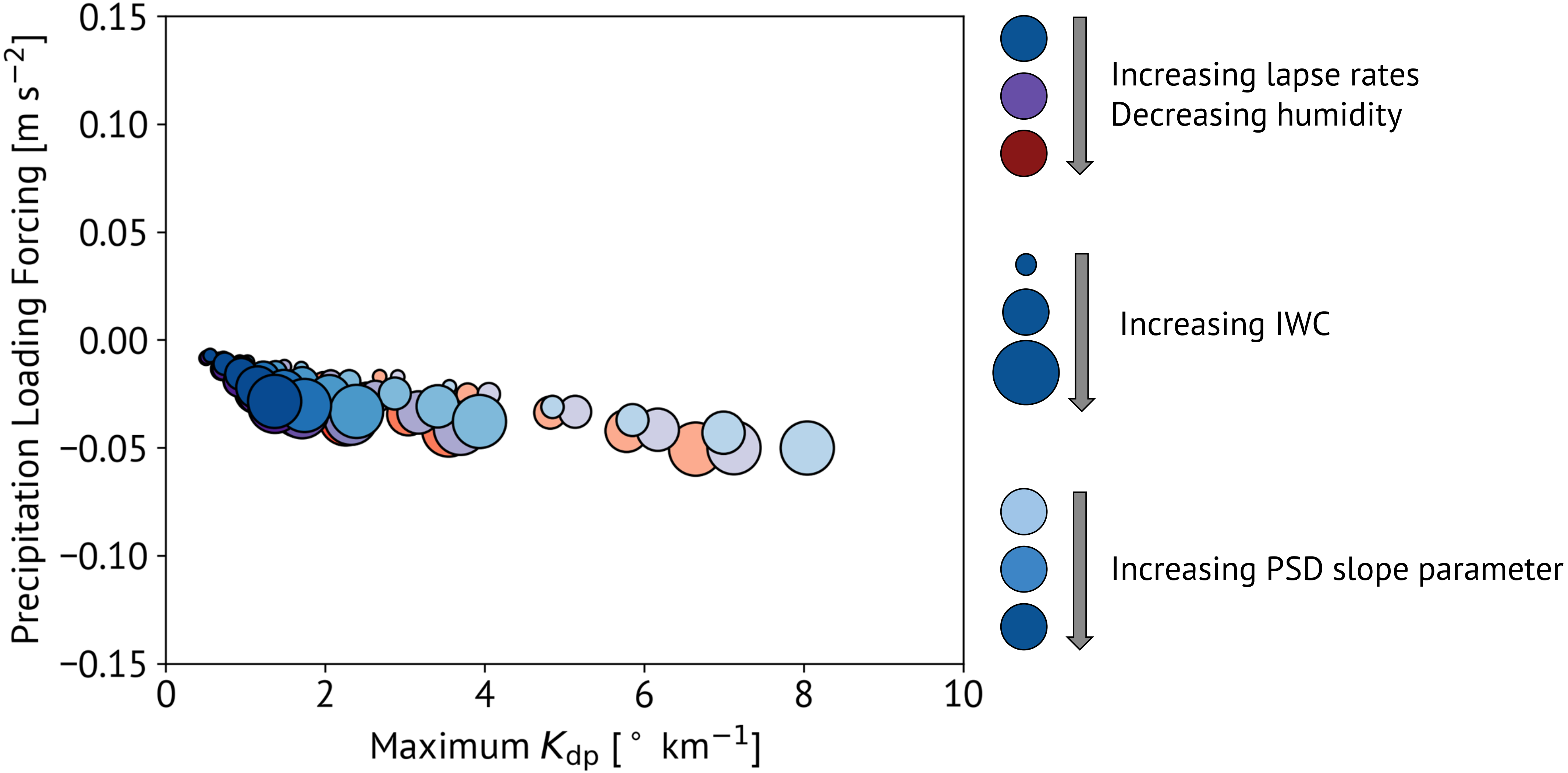

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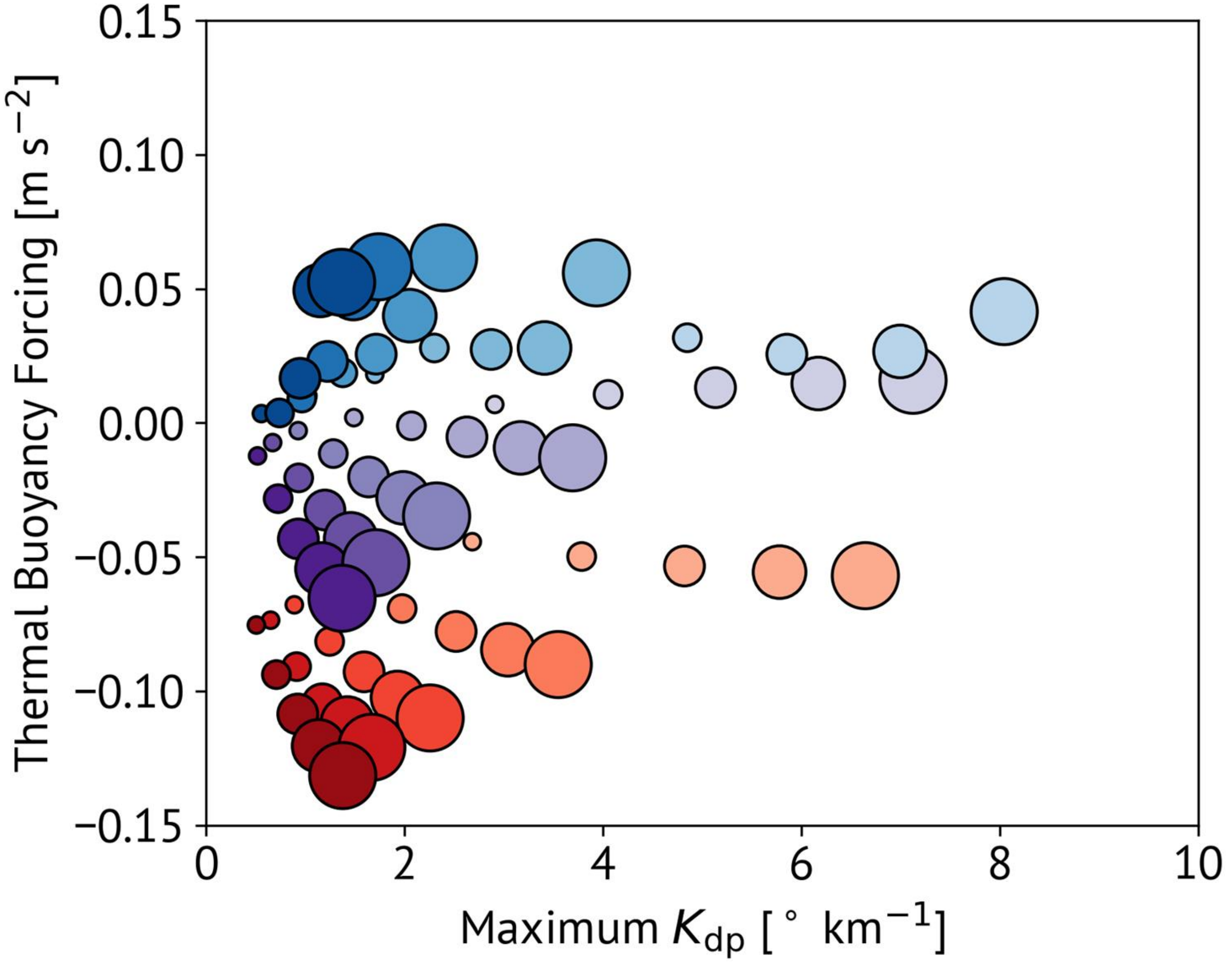

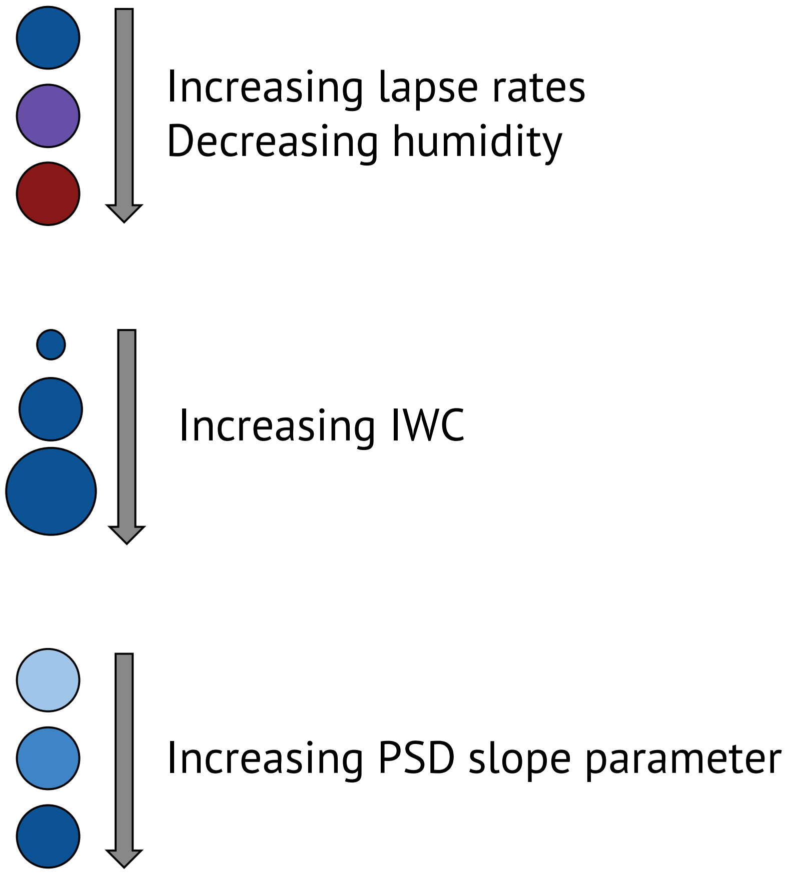

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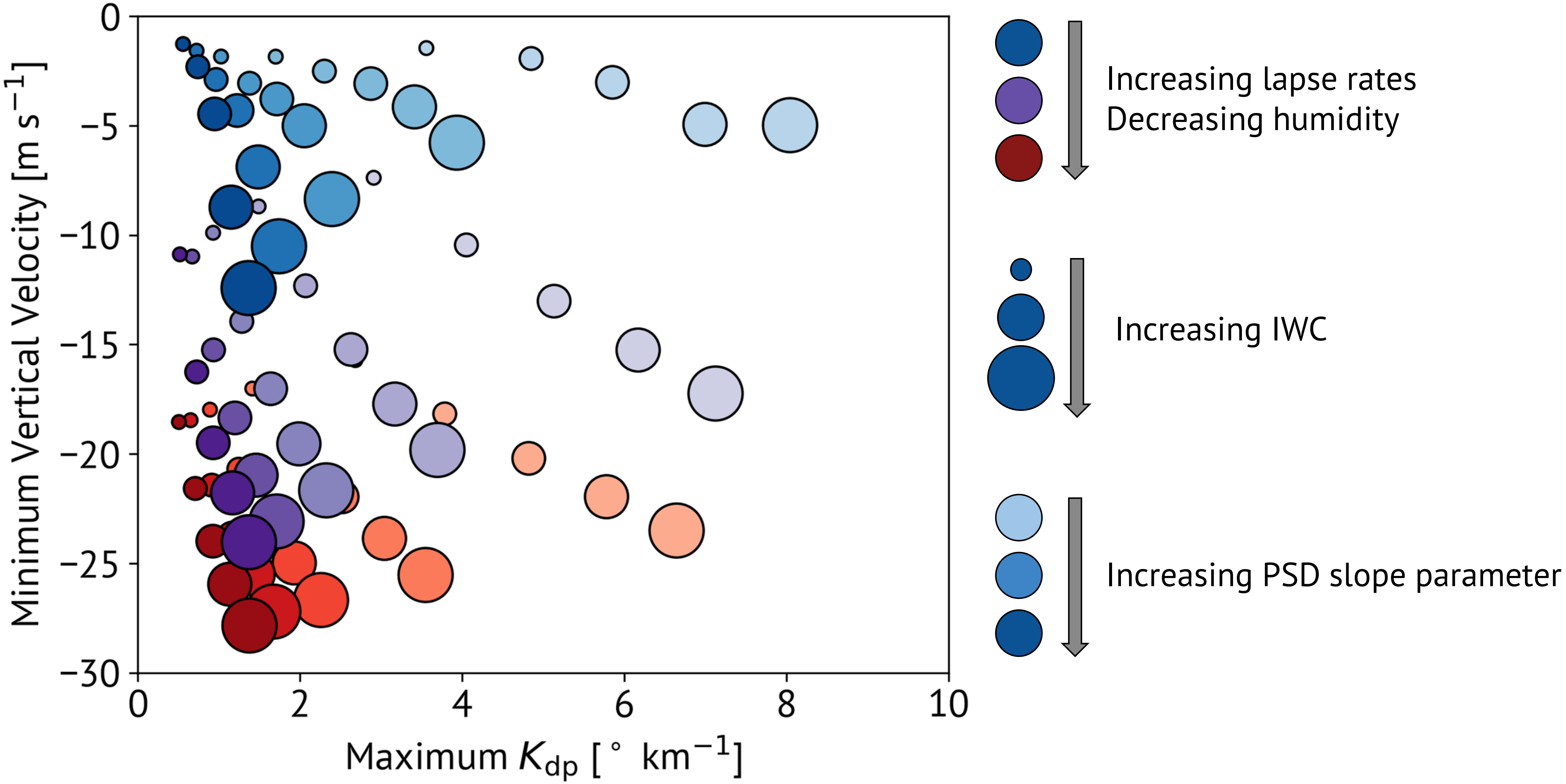

Acknowledgments

- Gerry Heymsfield and John Yorks (NASA Goddard Space Flight Center)
- Lynn McMurdie (IMPACTS PI)
- Howie Bluestein and Sam Emmerson (University of Oklahoma)
- NSF Grant #AGS2110709

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Summary

- Significant disagreement still exists between state-of-the-art microphysical retrievals for D_m in snow
  - More case studies with in situ data needed
- Revisiting seminal spectral bin modeling studies with modern PRFO can reveal new insights into link between radar observations and mechanisms
  - K_{dp} useful for identifying developing downdrafts, but relationship is tenuous with forcing mechanisms for inferring intensity

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