Development of New Icing Products for Supercooled Large Drop Conditions

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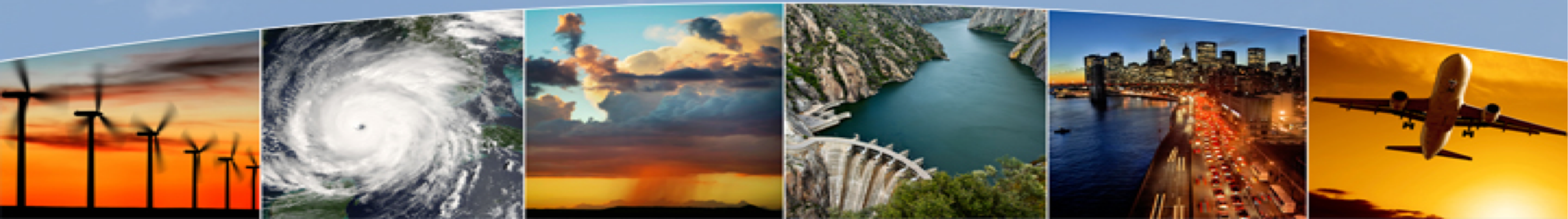

Photo by M. Fizer (AOPA Article, Feb. 2015)

The Large Drop Aviation Hazard

Supercooled Large Drops (SLD) can be more hazardous than small drop icing:

- Drops “roll back” before freezing
- Can freeze behind deicing boots
- Texture can increase drag more than small drops

Government regulations (Appendix O) use Maximum Supercooled Liquid Diameter (DMax) to define:

- Freezing Drizzle (FZDZ): DMax 100-500μm
- Freezing Rain (FZRA): DMax > 500μm
- Smaller drops in Appendix C regulations

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Objective to Forecast DMax, especially with respect to 100um and 500um thresholds!

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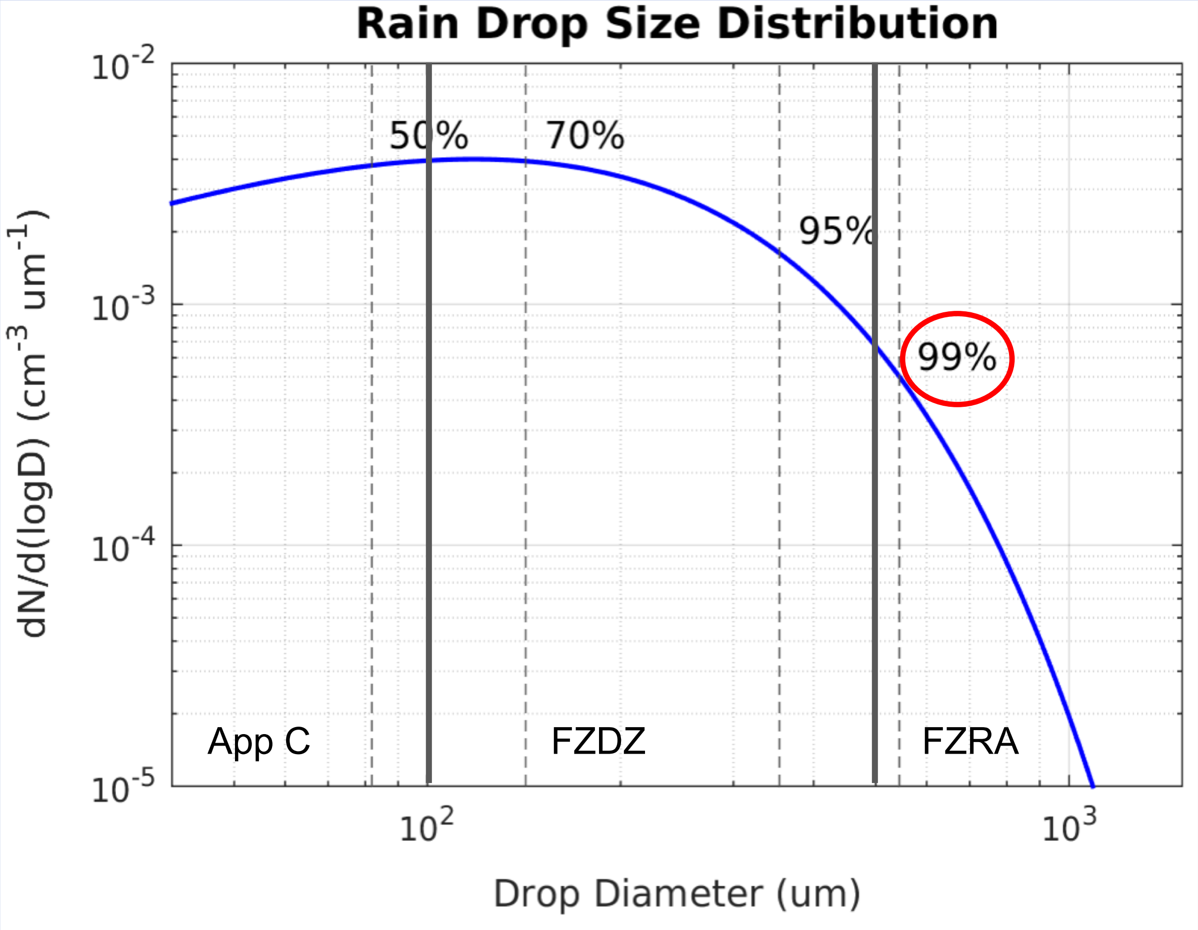
DMax Derivation from the HRRR

Thompson-Eidhammer microphysics in the High Resolution Rapid Refresh (HRRR) forecast model provides particle sizes as an exponential distribution for the rain drop size distribution (DSD)

- **Modeled rain water includes both drizzle and rain sized drops**
- No bins, no “max size” (distribution is infinite)
- Different methods for estimating DMax being evaluated
- For now, define DMax as the 99th percentile
    - 1% of drops are larger



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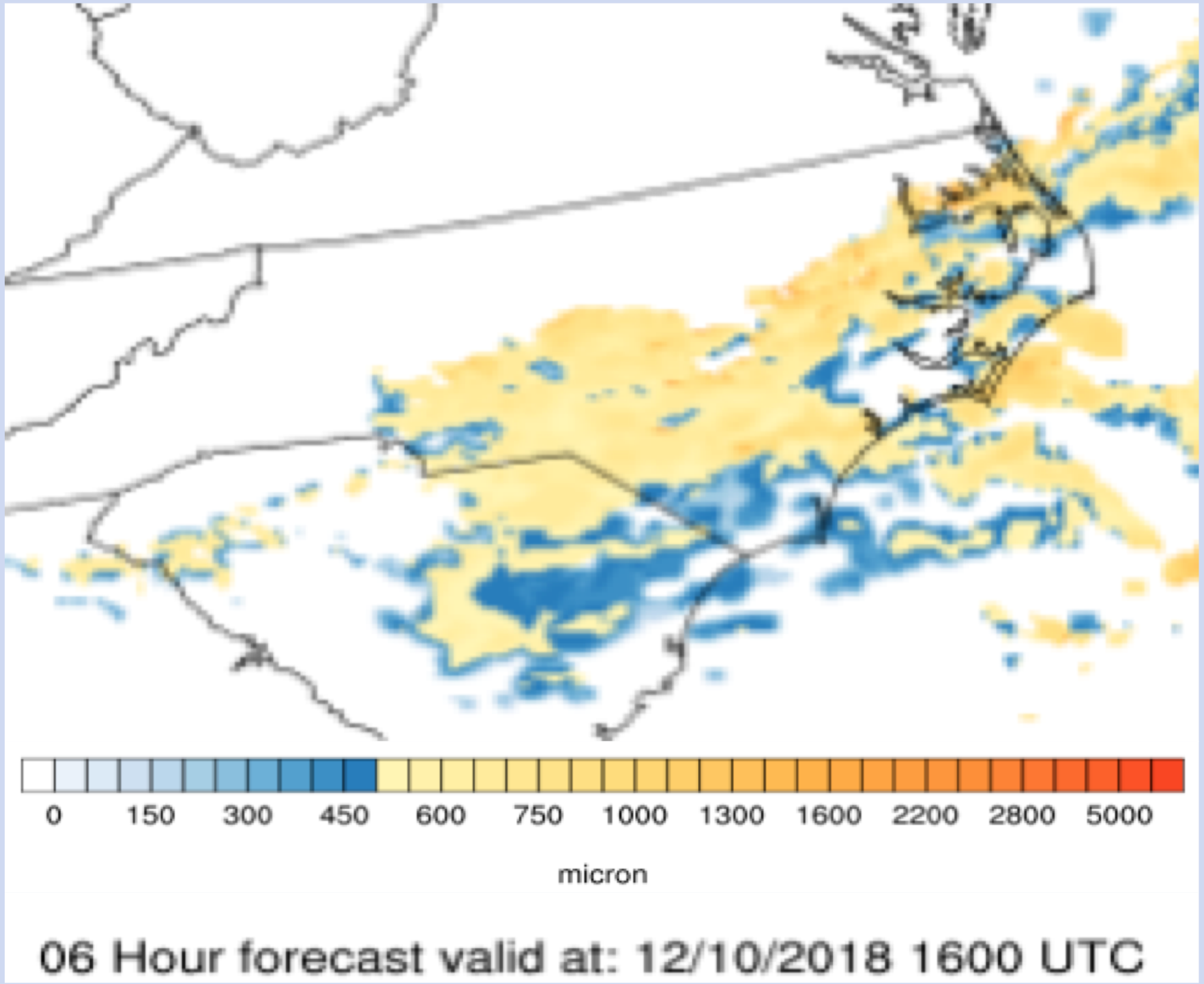
Example of DMax from the HRRR Model

Composite (column max) DMax over the Carolinas

- Colorbar highlights critical 500µm threshold for transition from FZDZ to FZRA conditions
- Realtime experimental product

How Well Does This Work?



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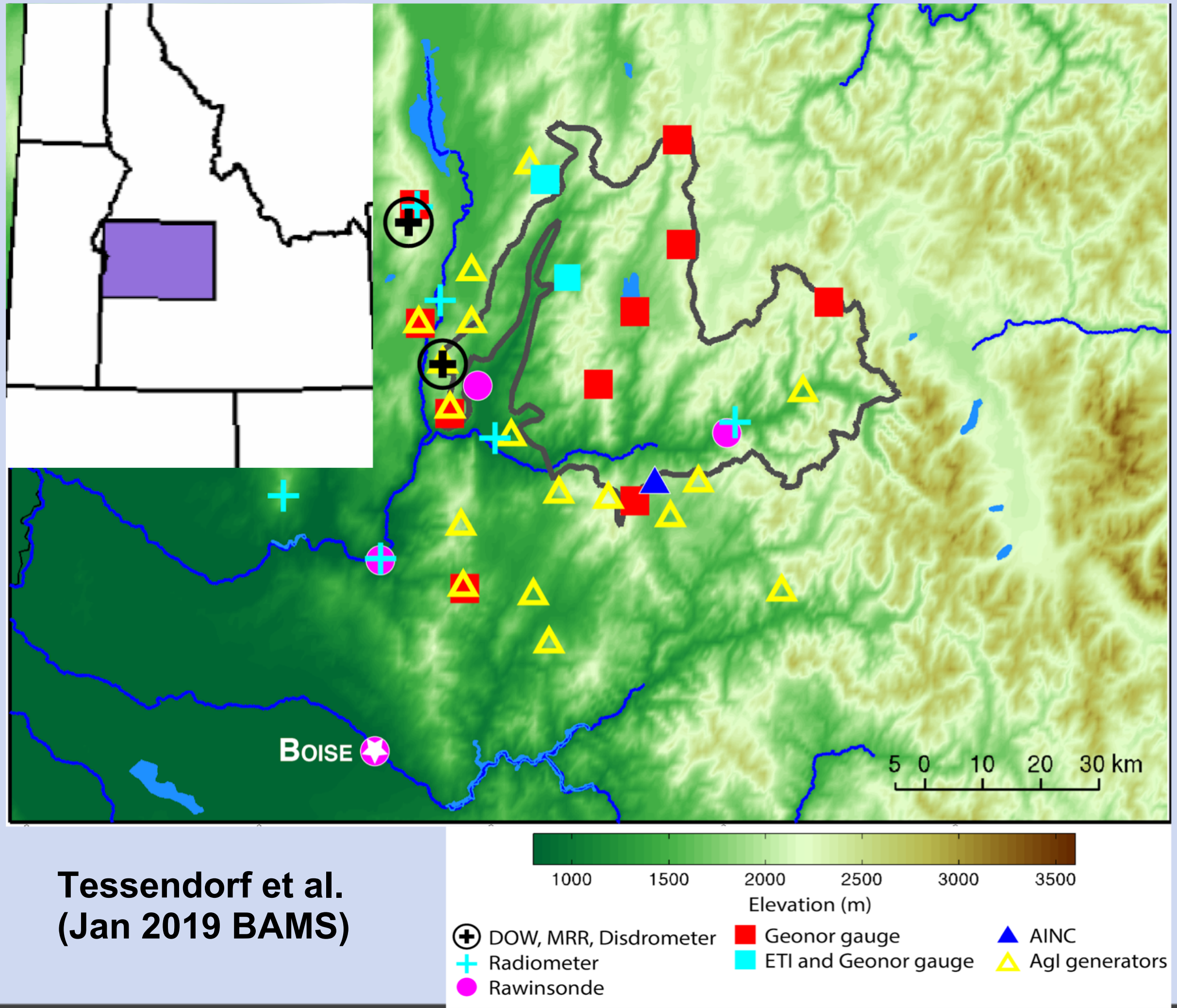
Seeded and Natural Orographic Wintertime clouds: the Idaho Experiment (SNOWIE)

- Jan 7–Mar 17, 2017
  - Near Boise, Idaho
- Flew in regions of supercooled liquid water
  - In situ observations in icing conditions, especially SLD

Focus on 2D-S optical array probe in clouds with icing conditions. Particles 50μm to 1260μm diameter.



Tessendorf et al. (Jan 2019 BAMS)

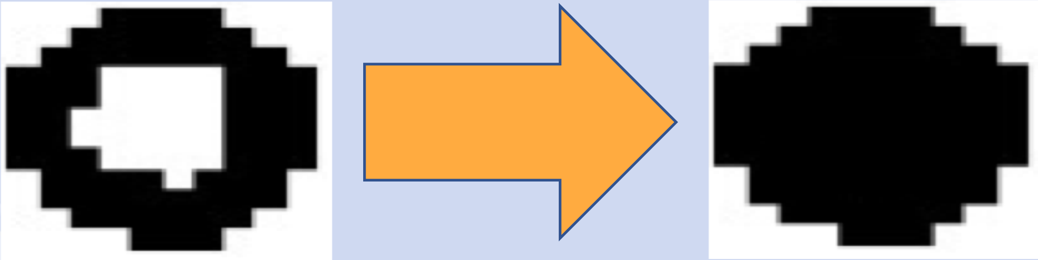
Extracting DMax from 2D-S Particle Images

For each particle:

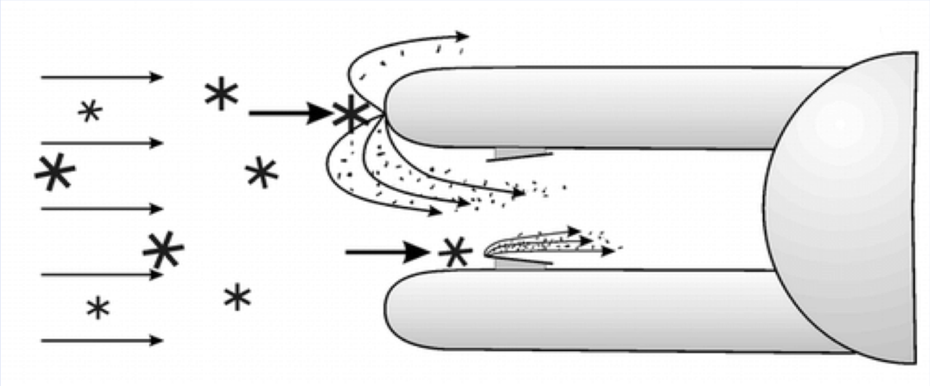
1. Reject particles like shatter, splatter, other artifacts
2. Fill holes in out-of-focus particles
3. Compute diameter (D), perimeter (P), area (A)
4. Compute shape parameter

$$SP = (D*P)/A$$

- ➔ Perfect circle: SP=4
- ➔ Considered liquid if SP<5.65



University of Wyoming – University of Illinois OAP Processing Software
Hollow particle correction by Darcy Jacobson

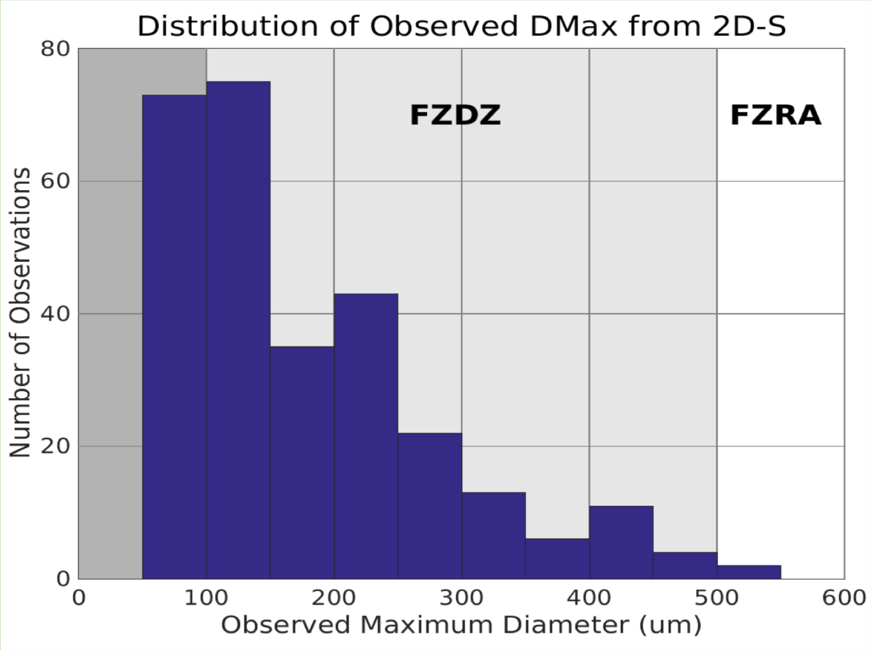


To match HRRR 3km grid spacing:

1. Separate particles into 30-second long windows
2. Compute 99th percentile of the liquid diameters distribution
   a. Other methods considered (e.g. those in Cober & Isaac 2012)
   b. Matched methodology for DMax extraction from the HRRR model

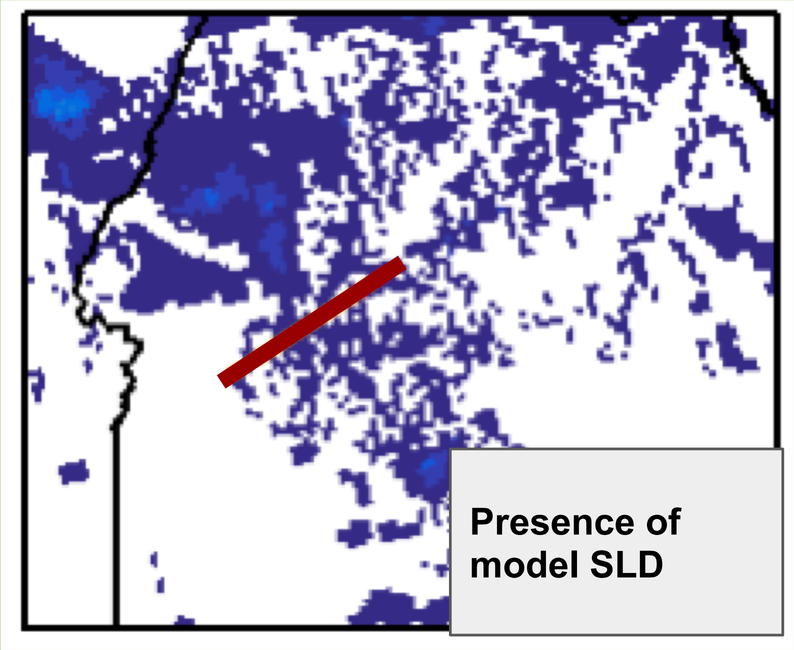
Observations

- 8 Different flights
- Require at least 100 liquid particles in 30-seconds
  - **73** Appendix C
  - **209** FZDZ
  - **2** FZRA
- "Non-classical" SLD
  - no warm nose
  - collision-coalescence driven



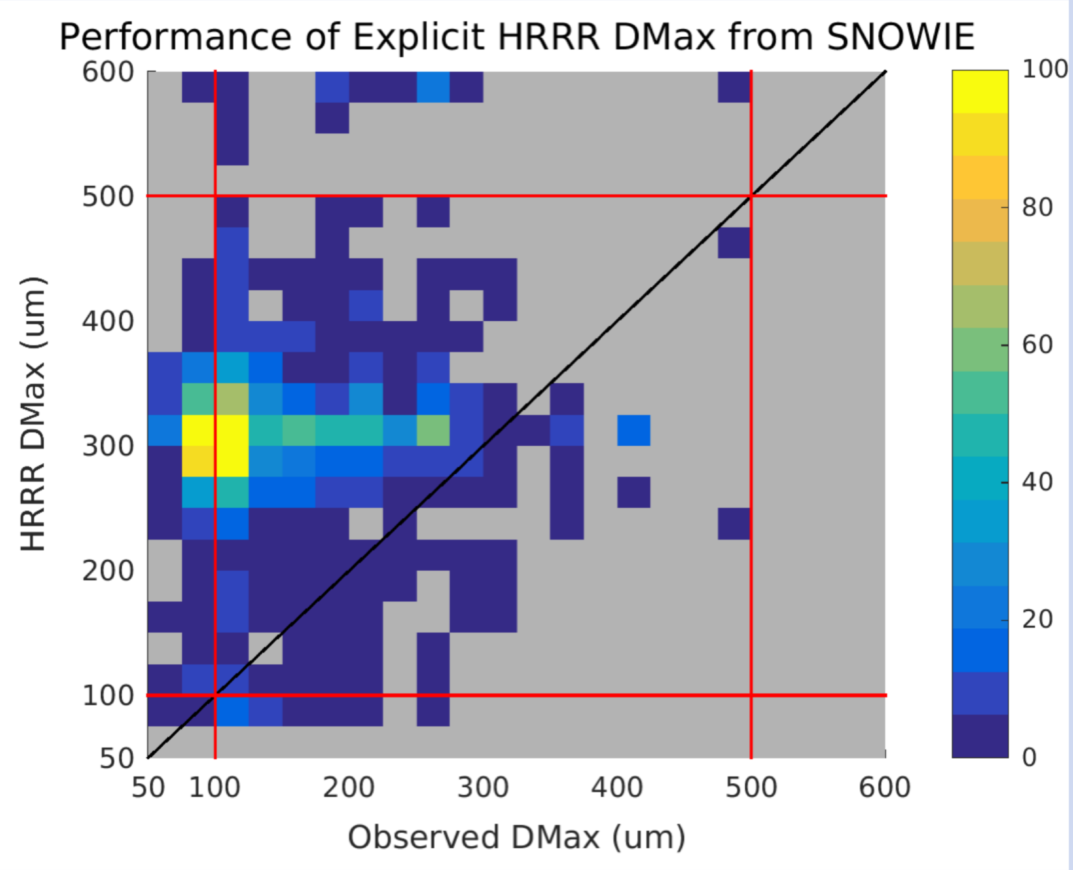
Model

- 3, 6, and 12-hour forecasts
- High spatial variability
  - 5 by 5 by 3 (x,y,z) model grid points used
  - 225 Model points for each observation
  - **POD of any SLD in neighborhood 18.2%**



Accuracy of Existing Model DMax

- Model DMax identified full range of icing categories (Appendix C to FZRA)
  - Capable of producing of a DMax in FZDZ sizes
- DMax generally too large
- Narrow DMax distribution around 300µm
- Root mean squared error (RMSE) of 235µm



What needs improvement?

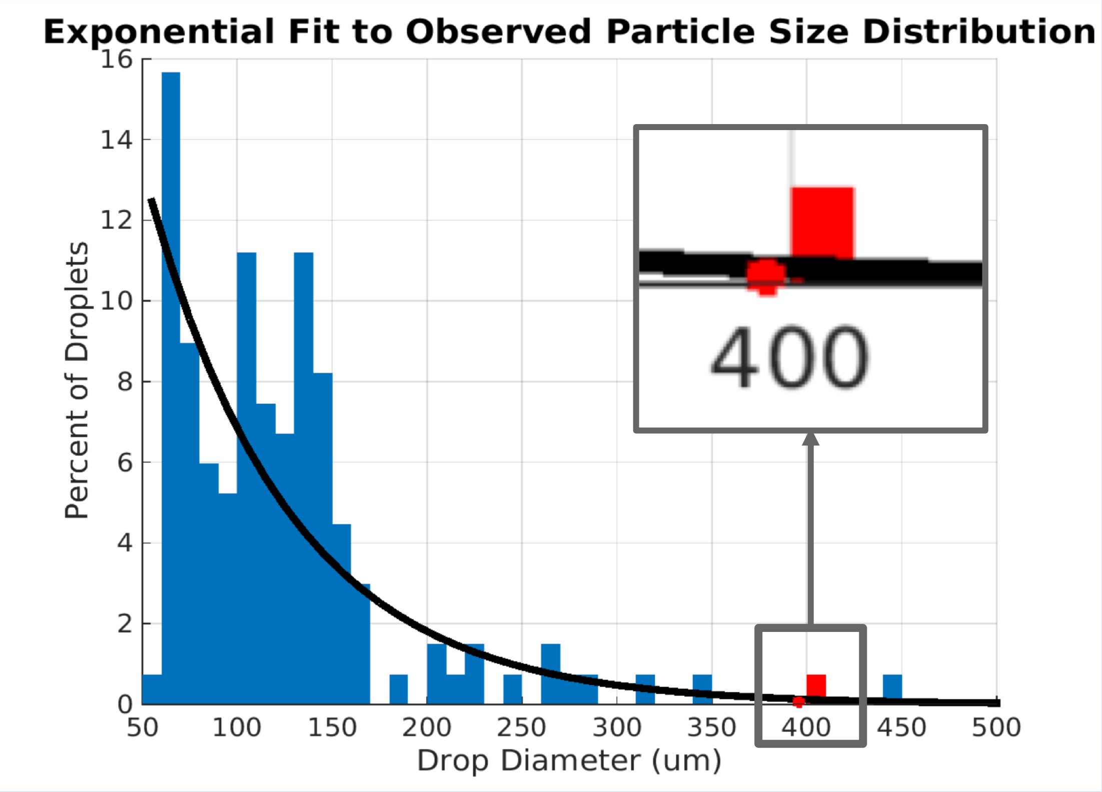
Microphysics Parameterization?

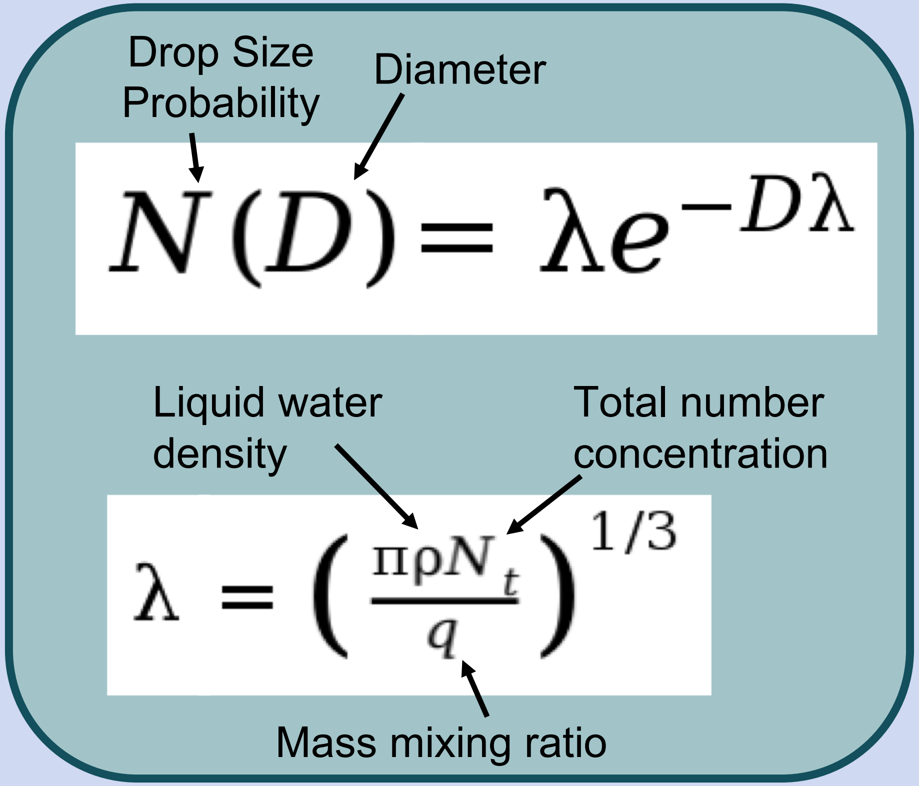
Background Aerosols?

Something Else?

Evaluation of HRRR Drop Size Distribution Functional Form

- HRRR assumes exponential (Marshal Palmer) size distribution
- Fit such probability distribution to observations
  - How well does the resulting DMax match observations?
  - Is the 99th percentile too sensitive to small errors?





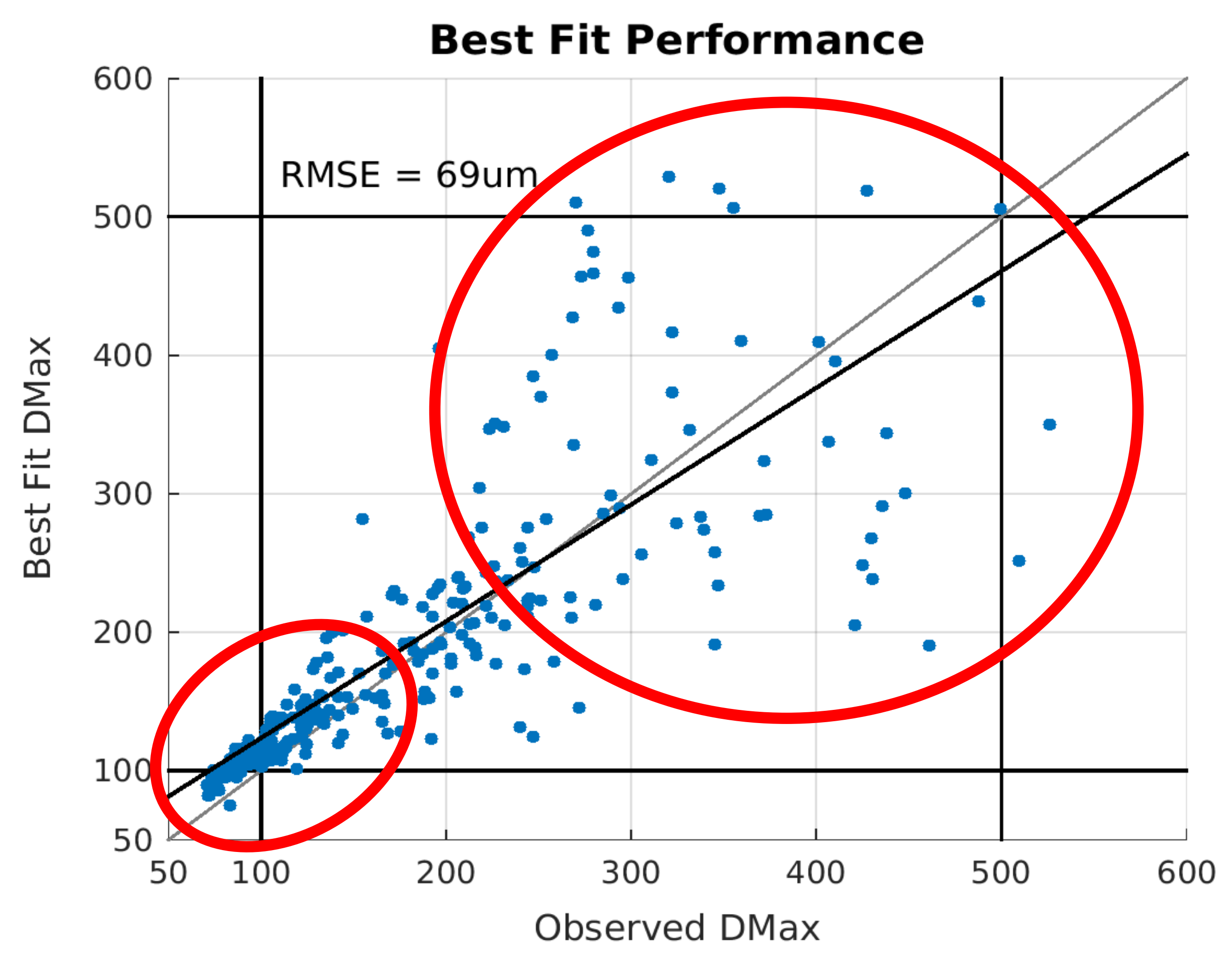
$$N(D) = \lambda e^{-D\lambda}$$

$$\lambda = \left(\frac{\pi \rho N_t}{q}\right)^{1/3}$$

Best Fit Exponential DMax Performance

- RMSE of 69μm
  - 30% of actual model error
- Error greater for larger DMax
- Slight overestimation of DMax for small droplets

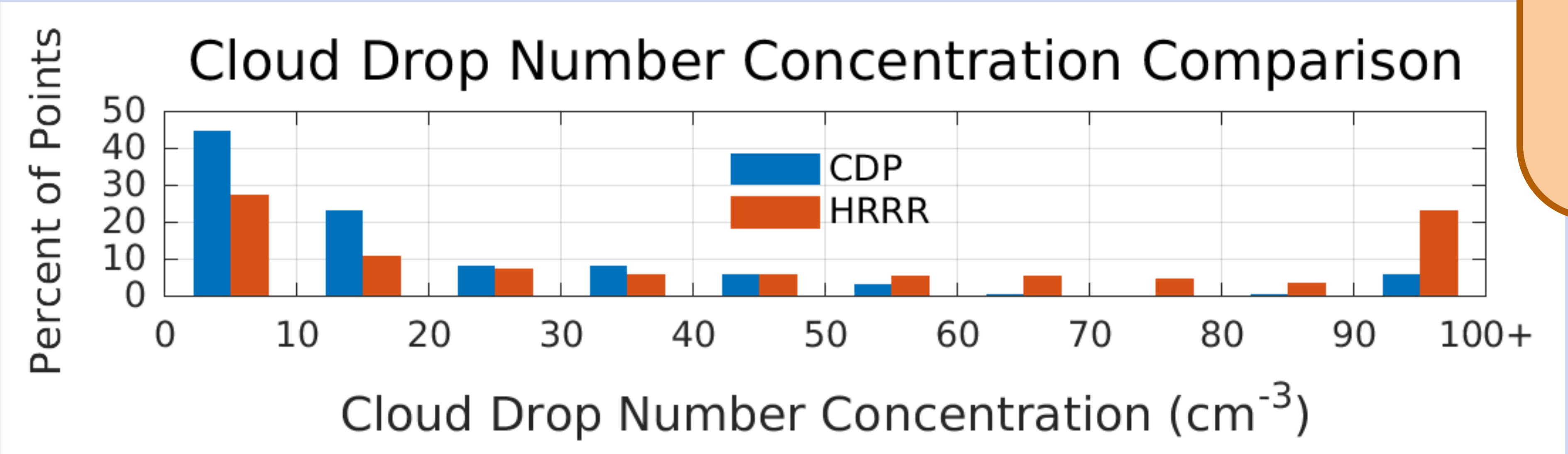
NOT just the drop size distribution functional form



Aerosol Content and Cloud Drop Concentration

- No aerosol measurements from SNOWIE
  - Cloud drop number concentration from cloud droplet probe (CDP) as proxy
  - More cloud droplets, more aerosols
- HRRR had more numerous cloud droplets
- Currently uses monthly climatology for aerosols

Higher aerosol content may have reduced SLD in model



Summary

- Analyzed 8 flights from SNOWIE
    - Mostly freezing drizzle (100-500μm maximum diameter)
- Compared 99th percentiles of 2D-S and HRRR drop sizes
- HRRR produced full range of Appendix C, FZDZ, and FZRA sized drops
    - DMax with prescribed exponential DSD is appropriate

- Low probability of capturing SLD
- Limited accuracy of DMax
    - Generally too large
    - Possibly due to too many cloud droplets which may indicate aerosol background could be improved

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Summary

- Analyzed 8 flights from SNOWIE
  - Mostly freezing drizzle (100-500µm maximum diameter)
- Compared 99th percentiles of 2D-S and HRRR drop sizes
- HRRR produced full range o ... d FZRA sized drops
  - DMax with prescribe

Wait!
What about
snow/ice?
Dynamics?

- Low probability of cap
- Limited accuracy of DM
  - Generally too large
  - Possibly due to too many ... aerosol background could be improved

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Looking Ahead

Future Analysis

- Other possible errors
  - Overproduction of ice and snow
  - Driving (thermo)dynamics
- Algorithm development
  - Account for model weaknesses
  - Fuzzy logic
- Diagnostic product with
  - Satellite, radar, METARs

Additional Data

- Further evaluation especially in
  - Classical (warm nose) SLD conditions
  - More locations
- **B**uffalo **A**rea **I**cing and **R**adar **S**tudy **II** (BAIRS-II; Buffalo, NY area; January-March 2017)
- **I**n-**C**loud **IC**ing and **L**arge-drop **E**xperiment (ICICLE; Rockford, IL; January-March 2019)

Questions?

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