Establishing Simulated Hydrometeor Size Biases Using HAIC-HIWC Retrievals

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Walter Strapp (IKP data)
Alfons Schwarzenboeck and Delphine Leroy (OAP retrievals)
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Rod Potts (CPOL data, model forcing)
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HAIC-HIWC Science Team Meeting
December 2016

Publications Update

Completed

Varble, A., M. Stanford, E. Zipser, J. W. Strapp, J. Delanoe, A. Korolev, D. Leroy, R. Potts, A. Protat, and A. Schwarzenboeck, 2015: Observed and simulated relationships between tropical deep convective updraft dynamics and microphysics, AGU Fall Meeting poster.

Varble, A., M. Stanford, E. Zipser, J. W. Strapp, D. Leroy, A. Schwarzenboeck, A. Korolev, M. Wolde, J. Delanoe, A. Protat, and R. Potts, 2016: Disentangling dynamical and microphysical causes of tropical convective precipitation biases in high-resolution simulations, AMS Conference on Hurricanes and Tropical Meteorology, talk.

Stanford, M. and A. Varble, 2016: Evaluation of simulated tropical convective updraft properties using HAIC-HIWC aircraft observations, AMS Conference on Hurricanes and Tropical Meteorology, poster.

Planned

Stanford, M., A. Varble, E. Zipser, J. W. Strapp, D. Leroy, A. Schwarzenboeck, A. Korolev, and R. Potts: Evaluating simulated tropical convective cores using HAIC-HIWC microphysics and dynamics observations. Poster at AGU Fall Meeting in December 2016.

=> Stanford, M., A. Varble, E. Zipser, J. W. Strapp, D. Leroy, A. Schwarzenboeck, and R. Potts: Evaluation of simulated tropical convective updraft hydrometeor properties using aircraft observations (manuscript based off of McKenna's recently completed Master's thesis to be sent to coauthors December 2016).

Varble, A., M. Stanford, E. Zipser, J. W. Strapp, D. Leroy, A. Schwarzenboeck, A. Korolev, M. Wolde, and possibly others: A comparison of simulated and observed ice microphysical properties in tropical mesoscale convective systems (manuscript to be written in 2017).

The above two planned manuscripts replace Article #32 (first is based on Darwin data and second incorporates Cayenne data).

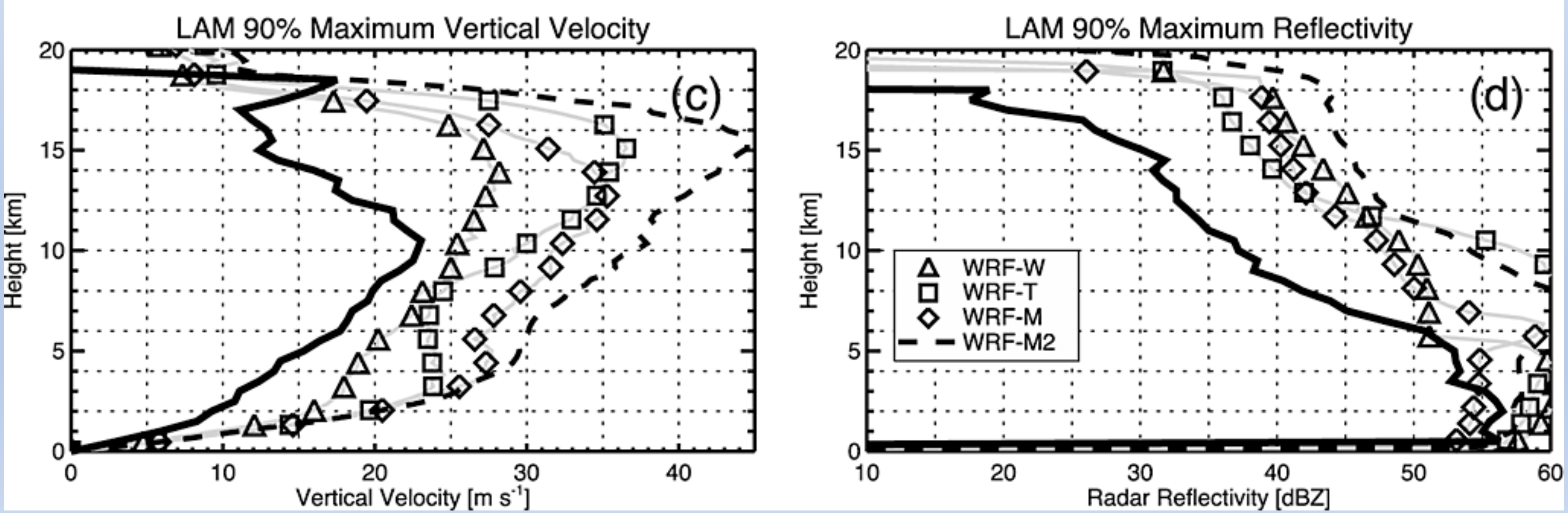
Varble, A., M. Stanford, E. Zipser, J. W. Strapp, D. Leroy, A. Schwarzenboeck, A. Korolev, M. Wolde, and possibly others: Reducing bulk microphysics parameterization biases using HAIC-HIWC field campaign measurements (Article #70 manuscript to be written in 2017)

Varble, A., M. Stanford, E. Zipser, J. W. Strapp, D. Leroy, A. Schwarzenboeck, A. Korolev, M. Wolde, A. Protat, J. Delanoe, and possibly others?: Factors influencing the evolution of high ice water content regions in tropical mesoscale convective systems (Article #30 manuscript to be written in 2017-18?).

High Biases in Radar Reflectivity

Cloud models can help to explain the ways that high IWC regions form and how they evolve in different situations. However, radar reflectivity biases are common in deep convective simulations and result from:

1) Overly large and intense convective updrafts that loft excessive condensate above the freezing level (Varble et al. 2014 – TWP-ICE results shown below)
2) Biases in the parameterization of microphysics

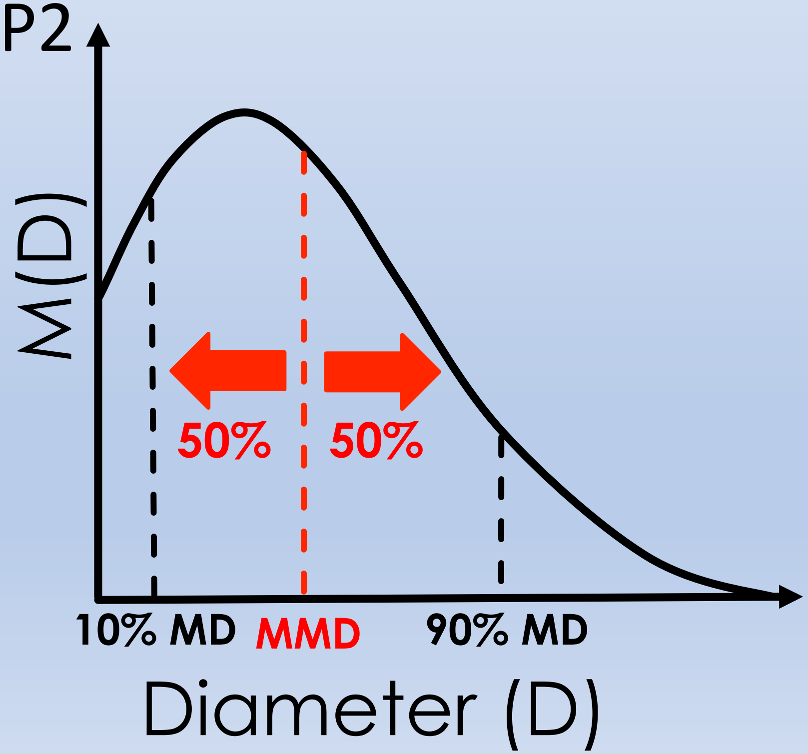


Varble et al., 2014

Hydrometeor Size Contribution to Bias

Controlling for TWC and w, are simulated sizes larger than observed?

- TWC – IKP2 (Strapp et al., 2016)
- PSD (MSD) – 2D-S & PIP (Leroy et al., 2016a)
  - Linearly weighted composite PSD using both OAPs
  - Constrained mass-size distributions using IKP2
- *w* – calculated by SAFIRE



Hydrometeor size comparisons are performed by way of percentiles of the MSD for observations and can be calculated for microphysics schemes

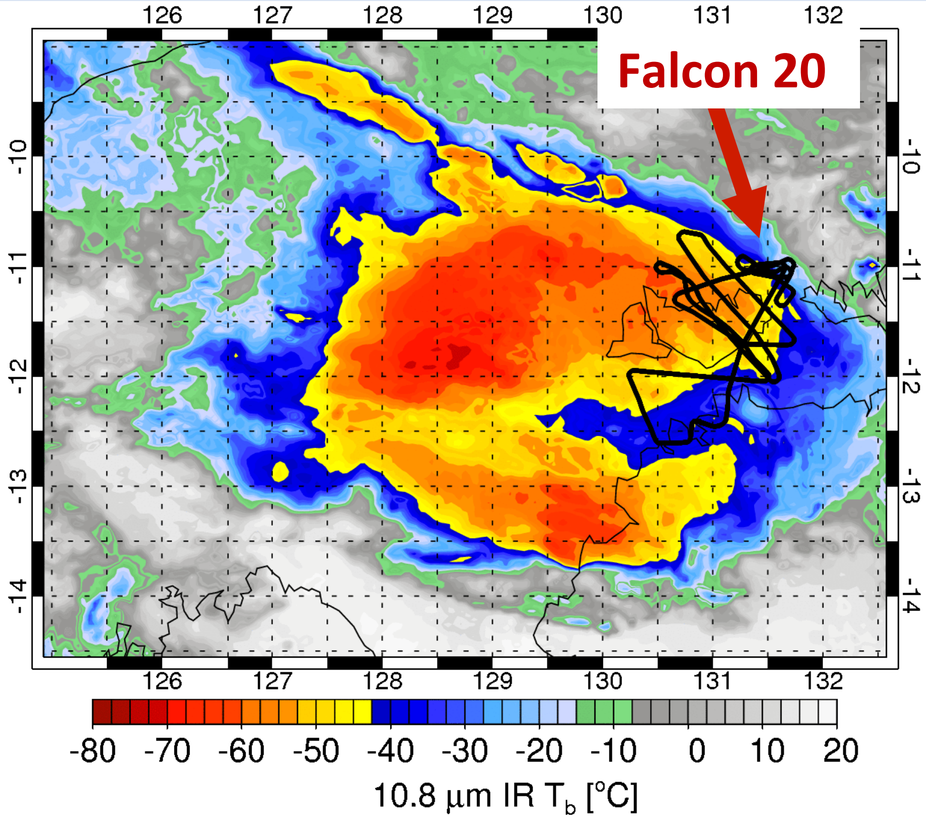
- MMD
- 90% MD
- 10% MD

See Leroy et al., 2016a,b for further detail on MD computations from HAIC-HIWC

Models

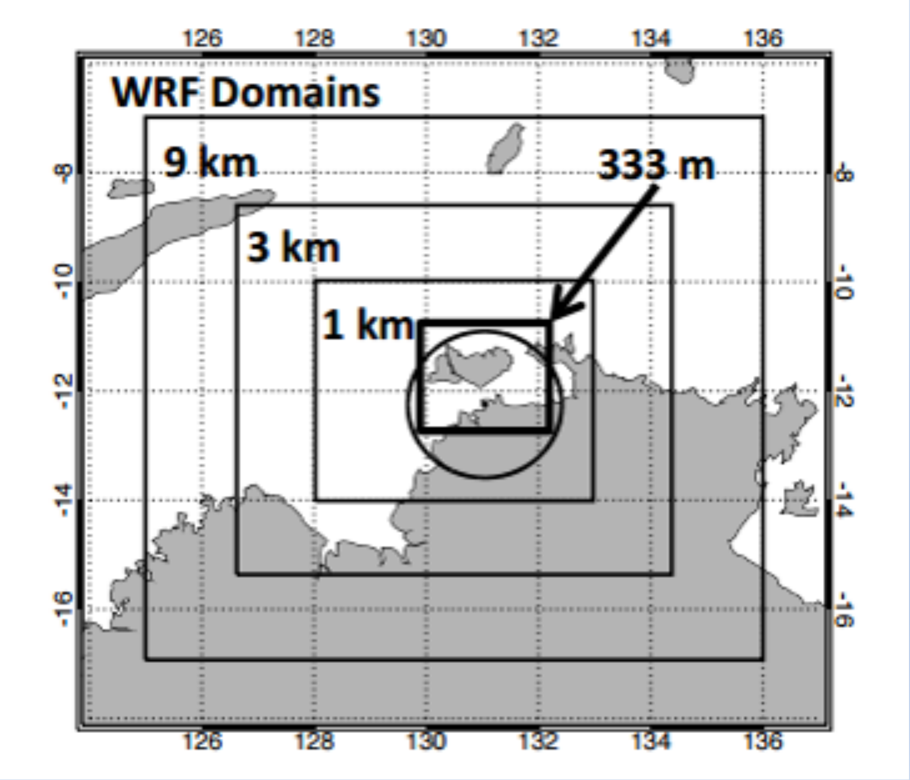
Focus is on 18 Feb. 2014 (Flight 23) simulation. Similar results in TWC-*w*-T-MD space from simulations of 23. Jan (Flight 6), 2-3 Feb. (Flights 12 &13), and 7 Feb. (Flight 16).

MTSAT 18 Feb. IR Imagery



- **WRF-ARW V3.6.1**
- **9:3:1-km two way nesting (1-km control)**
- **Forced with ACCESS-R (BoM) 12 km analyses**
- **Simulated from 00Z on 18th to 06Z on 19th**
- **Embedded 333-m grid spacing domain using one scheme**

Flight 23 Domain Setup



Microphysics Schemes

Bulk Schemes

Assume PSD functional form (typically Gamma) and predict integral moments of PSD

1M: prognostic mass mixing ratio (*q*)

2M: prognostic *q* & number concentration (*N*)

Bin Schemes

Predicts *N* for discrete size bins—assumes no functional form (advantage)

Much more computationally expensive than bulk schemes (disadvantage)

Thompson: 1M - snow, graupel, cloud water; 2M - rain & cloud ice

Morrison: 1M - cloud water; 2M - snow, graupel, cloud ice, & rain

FSBM: 33 mass (size) doubling bins for vapor-grown ice/aggregates, graupel, liquid, and aerosols

Intercomparison Methodology

- *Controlling for temperature, condensate mass, and vertical velocity,* are simulated hydrometeor sizes larger than observed?

Simulation Dataset

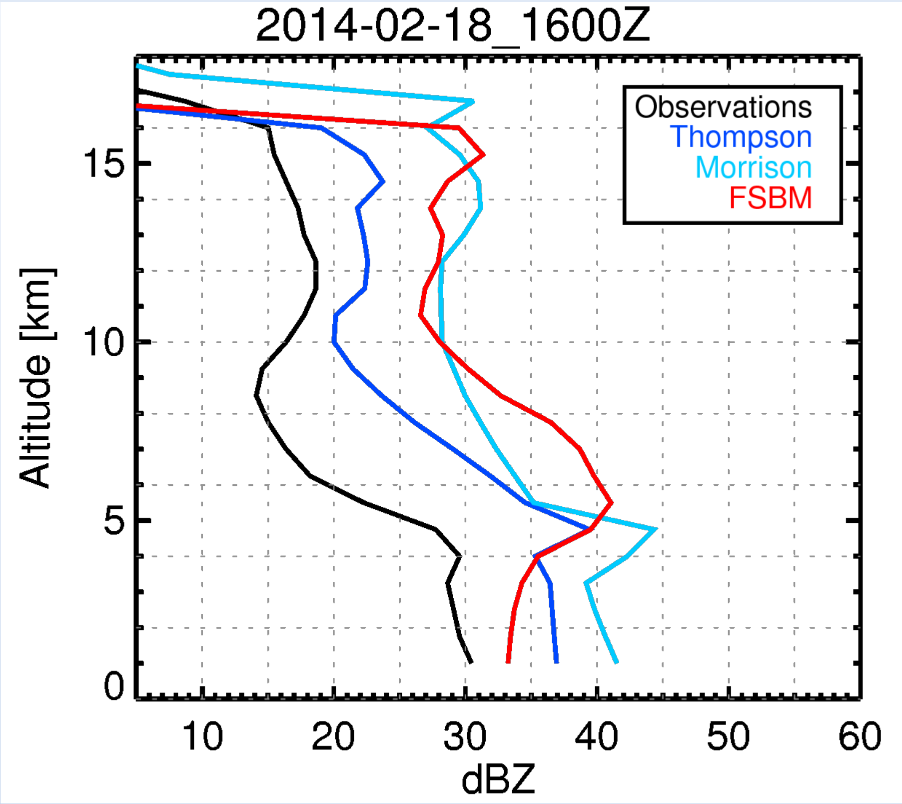
1. 6-hour active time period
2. 1000-m grid spacing (also have 333-m domain for 18 February event w/ Thompson scheme)

Observational Dataset

1. All Darwin flights
2. ~750-m grid spacing

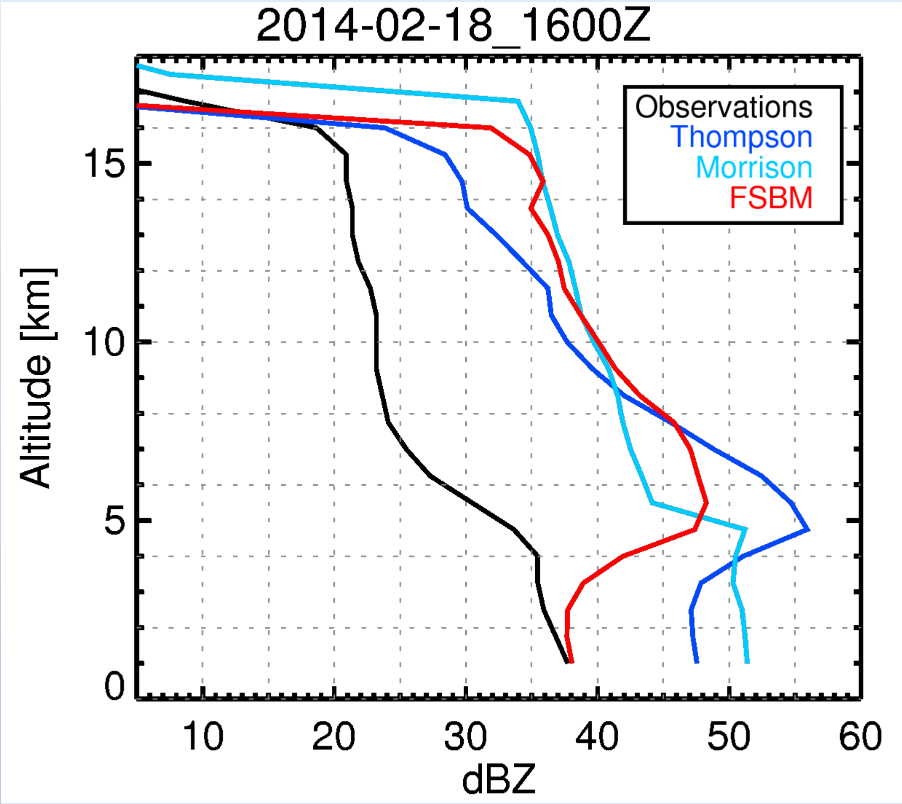
Establishing the reflectivity bias for this case

90th Percentile Reflectivity



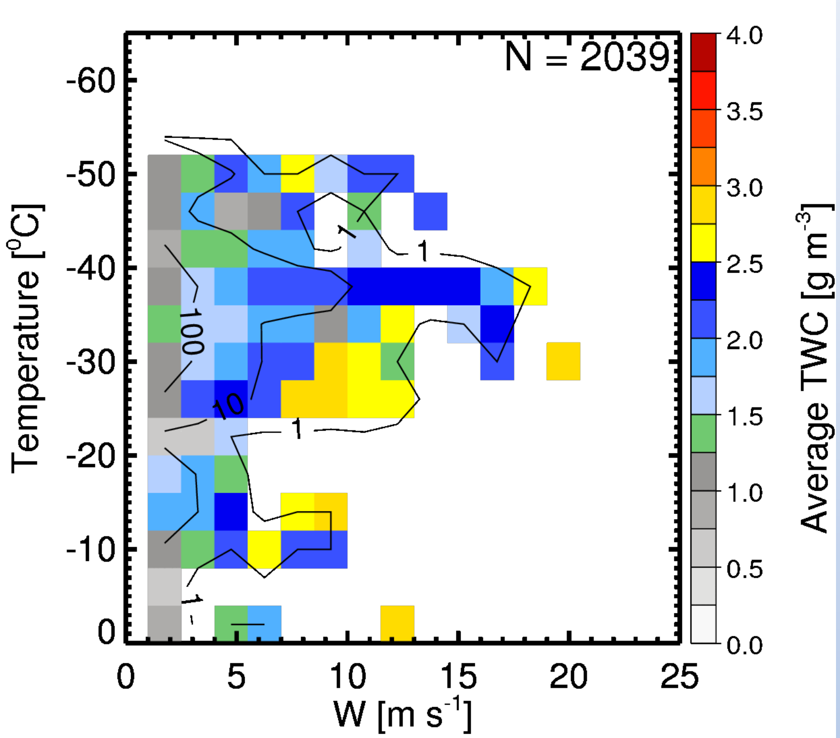
- Observed reflectivity from C-POL
- Simulated reflectivity interpolated to C-POL levels and evaluated for 12 hours when MCS passed through Darwin
- **Simulated reflectivity exceeds observed reflectivity across most of the free troposphere for all times from 12Z on 18th to 00Z on 19th**

99th Percentile Reflectivity

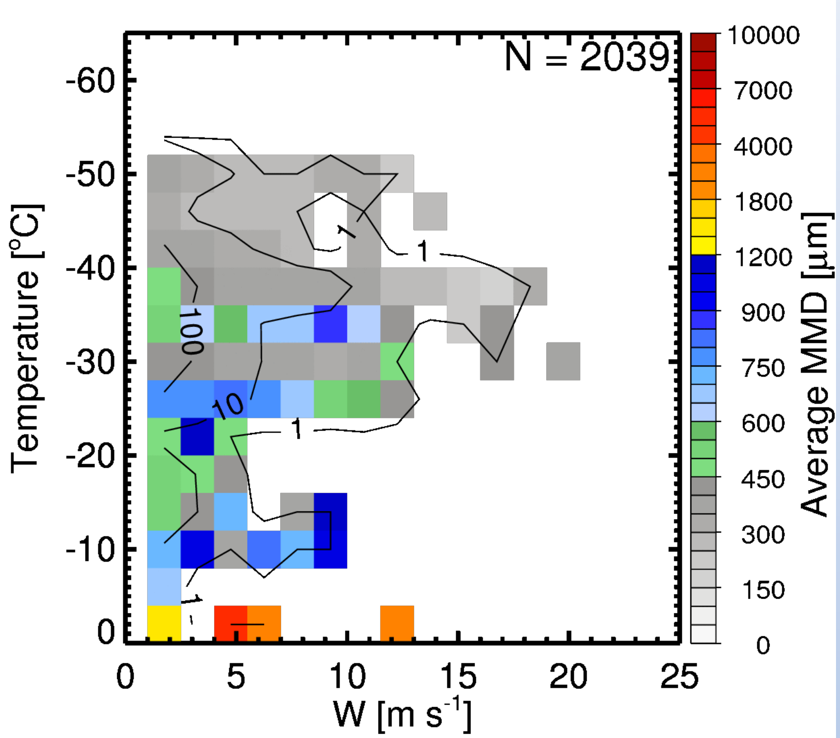


Observed MMD-T-*w*-TWC Relationships

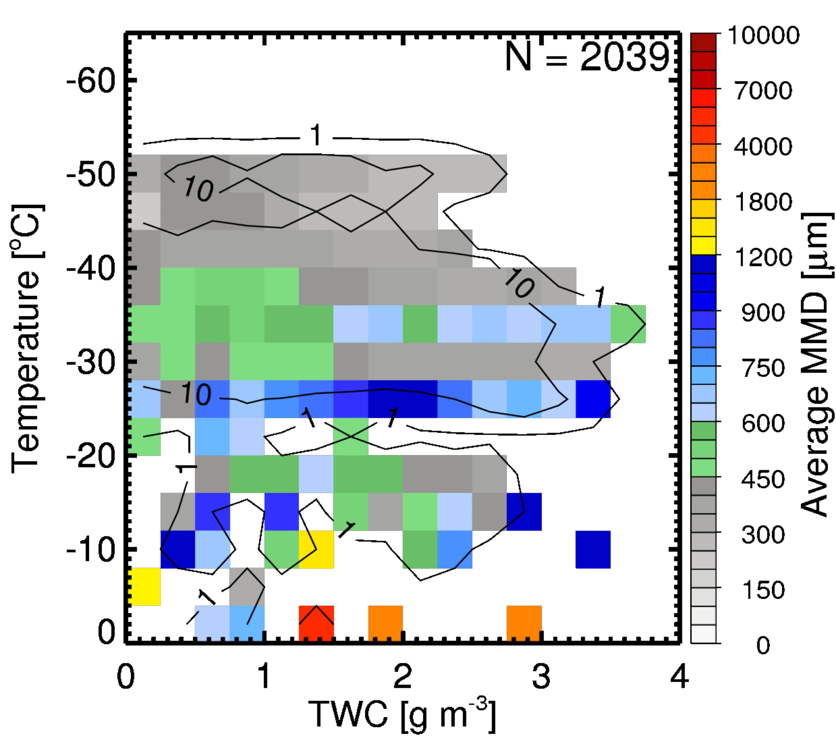
Avg. TWC-*w*-T



Avg. MMD-*w*-T



Avg. MMD-TWC-T

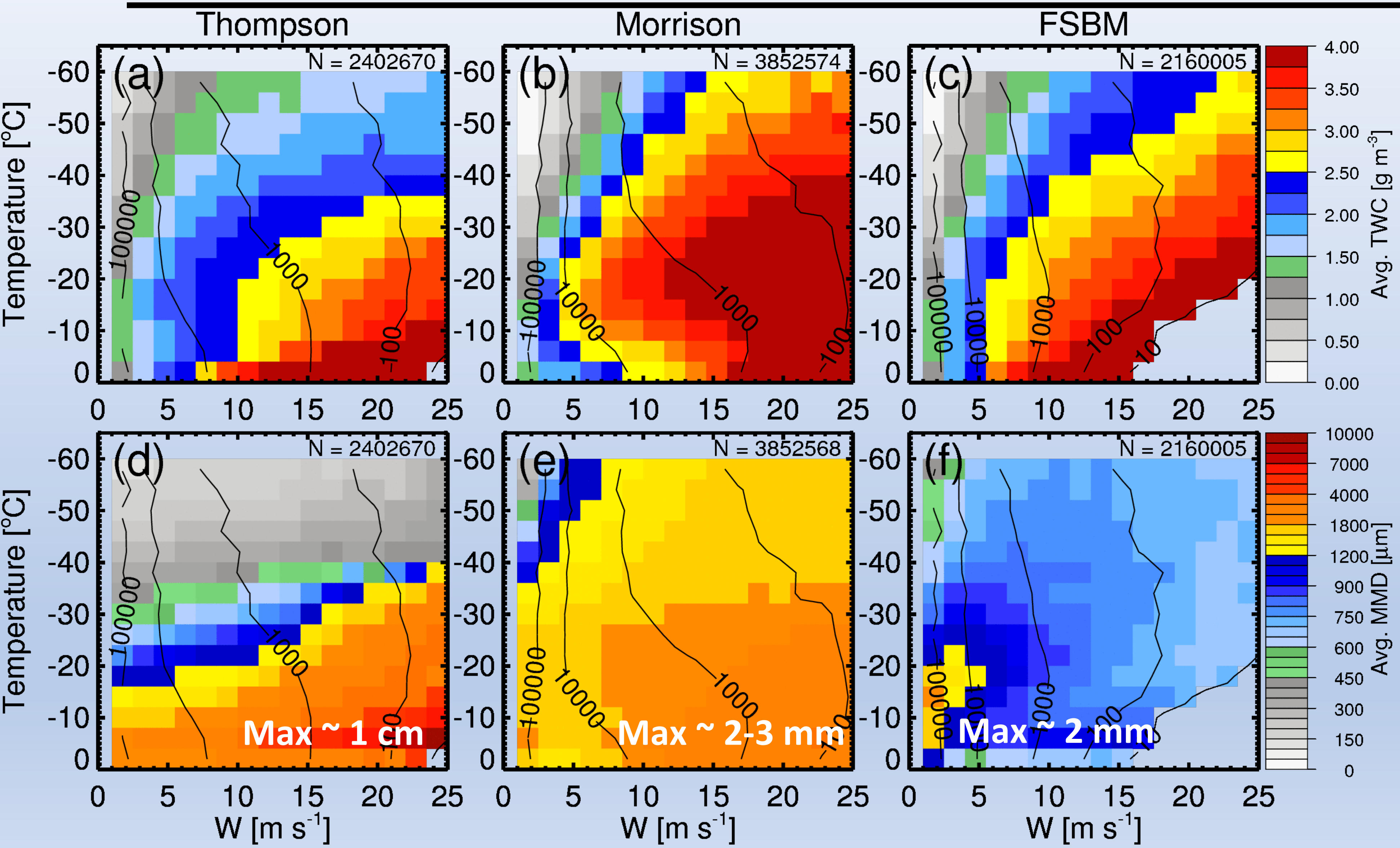


- **TWC generally between 1 and 3 g m^{-3}**
- **TWC increases with increasing *w***

- **MMDs decrease with increasing *w* for T < -25 °C**
- **MMDs decrease with decreasing T**

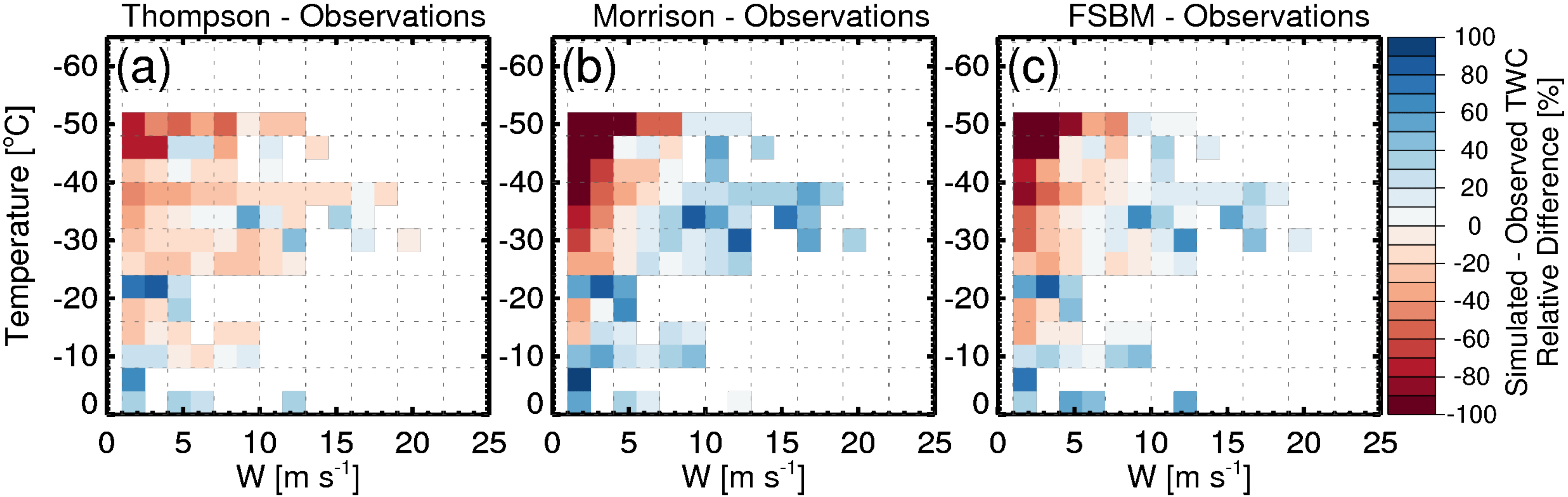
- **MMDs decrease with increasing T and TWC**
  - **Also reported by Leroy et al. (2016b)**

Simulated MMD-T-*w*-TWC Relationships



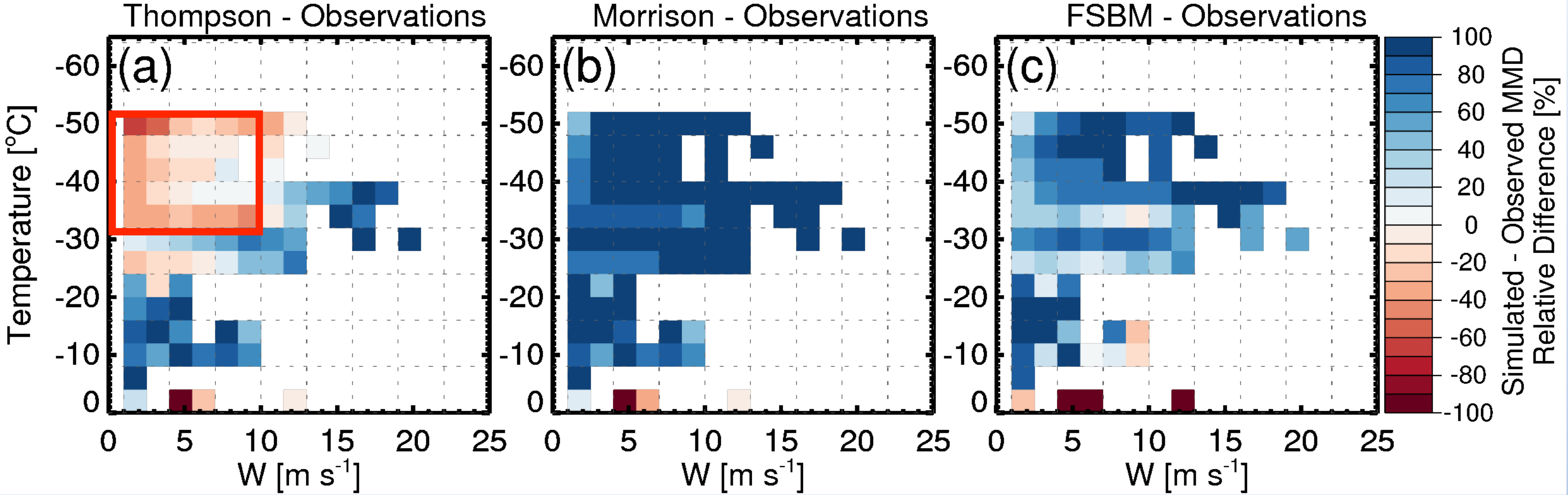
- All schemes produce increasing TWC with increasing *w* and T, similar to observations
- Thompson & Morrison produce increasing MMD with increasing *w* and T.
- FSBM is only scheme able to produce decreasing MMD with increasing *w*, similar to the observed relationship
- **Very large differences in average MMDs as a function of *w* and T exist between schemes**

Simulated vs. Observed T-*w*-TWC



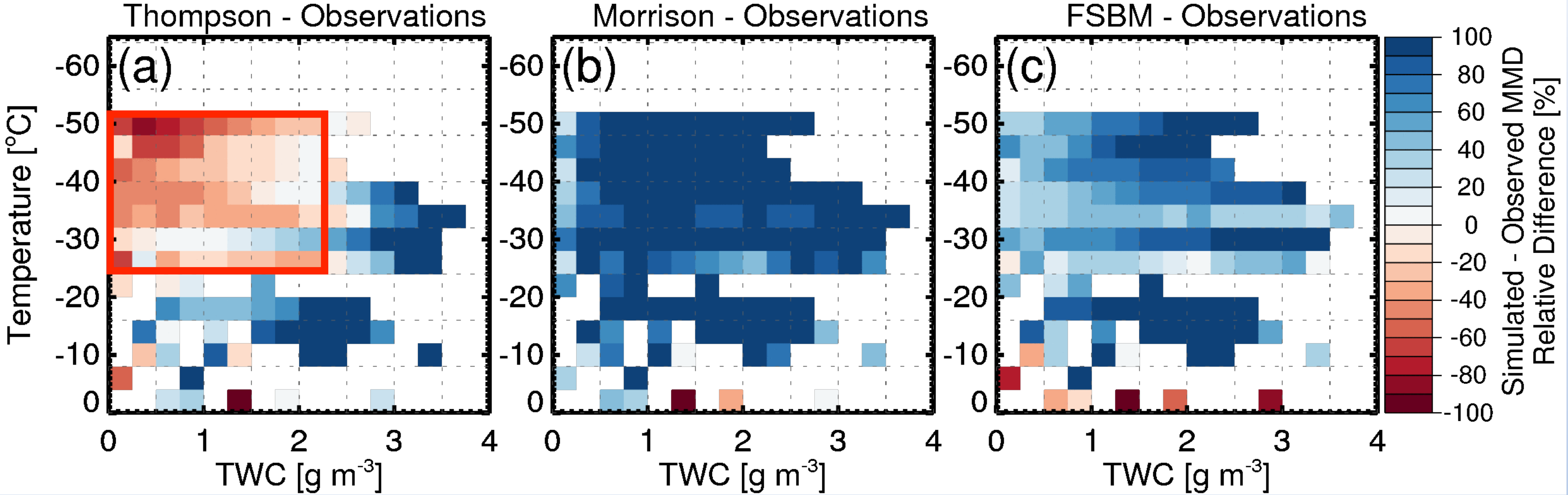
- All schemes produce lesser TWC than observed for -30 °C < T < -50 °C and *w* < 8 m s^{-1} with greater than observed TWC for larger *w* and warmer T.
- Some of this difference could be caused by biased observational sampling, but some of it is also likely related to overproduction of fast-falling, large rimed ice in simulations.

Simulated vs. Observed MMD-T-*w*



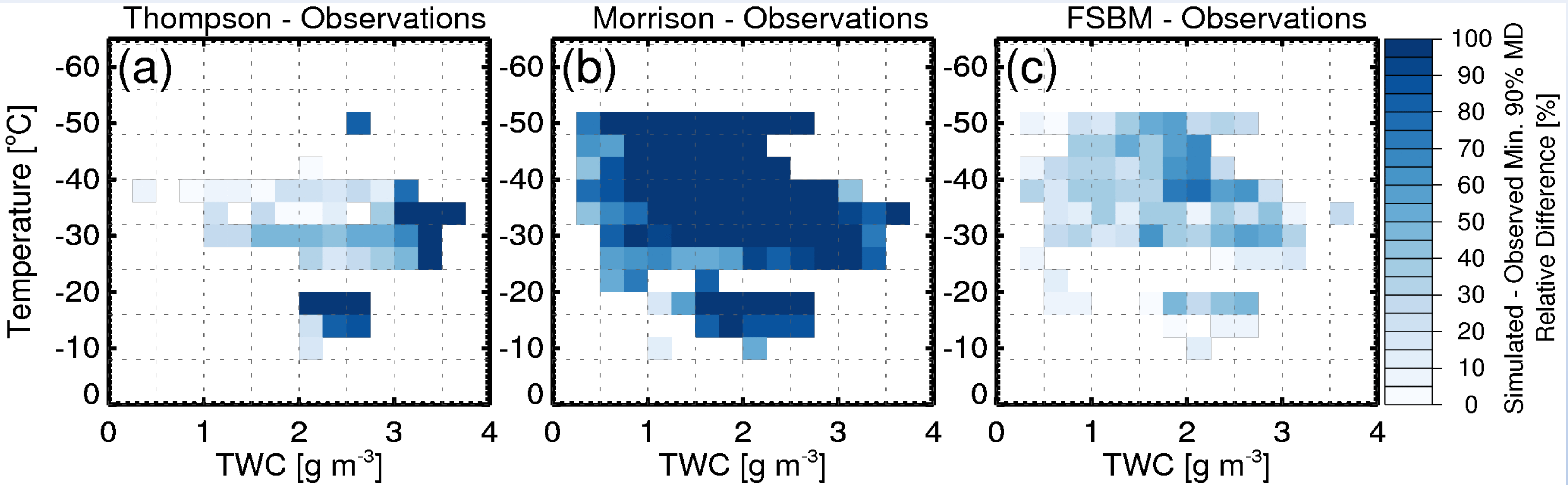
- Morrison & FSBM produce much larger than observed MMDs for most *w*-T bins.
- Thompson produces smaller MMDs for -30°C < T < -50°C and *w* < 10 m s^{-1}, but larger MMDs at warmer T and higher *w.*

Simulated vs. Observed MMD-T-TWC



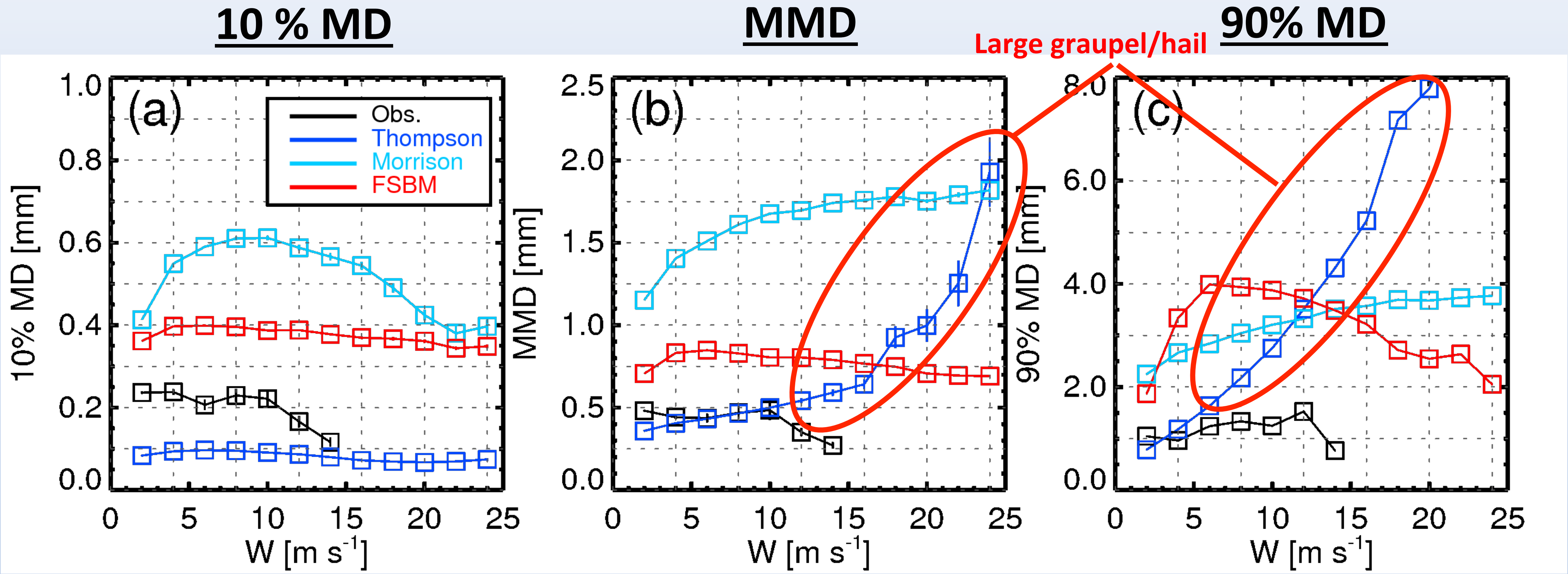
- For a given *w*-T or TWC-T bin, both Morrison & FSBM schemes produce larger than observed MMDs.
- Thompson produces a smaller size mode for colder T, smaller *w*, and smaller TWC, but still exaggerates ice sizes for larger TWC and *w* conditions.

Definitive Model Bias – Minimum 90% MDs



- Simulated sample sizes are ~ 10^3 larger than observed and the most intense cells were avoided during flights; thus, we expect simulation phase space to be greater than observations phase space.
- Instead, TWC-T bins exist where no single scheme produces 90% MDs as small as those observed (everywhere there are blue bins).

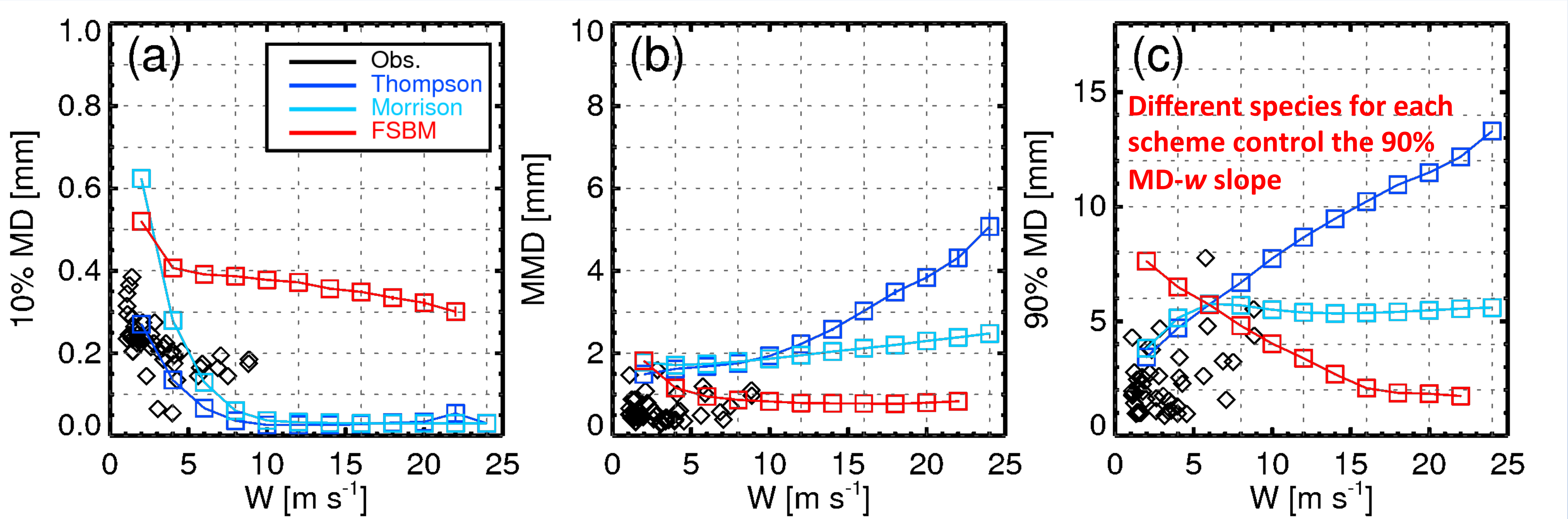
Composite MD(*w*) for -32 °C < T < -40 °C



- Morrison & FSBM exceed observations across all MSD percentiles
- Thompson 10% MDs are smaller than observed and MMDs are remarkably similar for *w* < 10 m s^{-1}, but very large size mode exists at larger *w* for MMD and for all *w* for 90% MD.

Composite MD(*w*) for -8 °C < T < -16 °C

10 % MD | **MMD** | **90% MD**

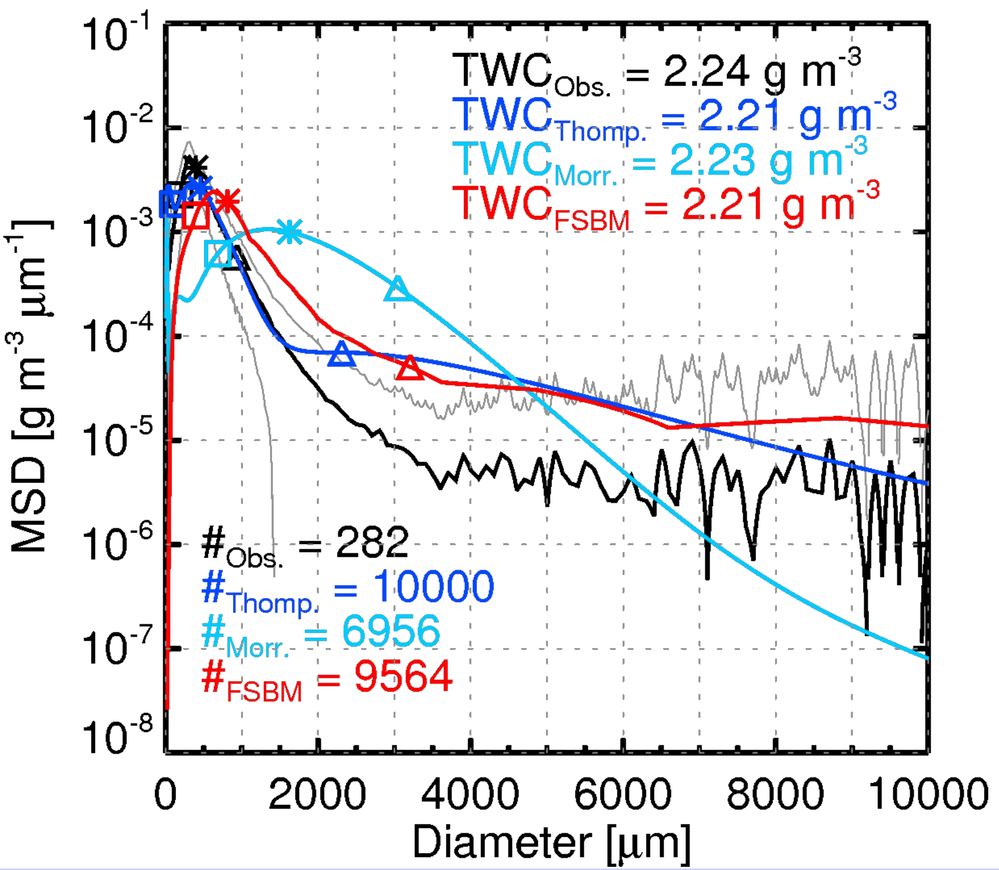


- Few samples for these temperatures, so conclusions are difficult (Cayenne data will help)
- Differing slopes in 90% MD-*w* profiles suggest far different proportioning of ice size and/or mass between graupel and snow particles in different schemes

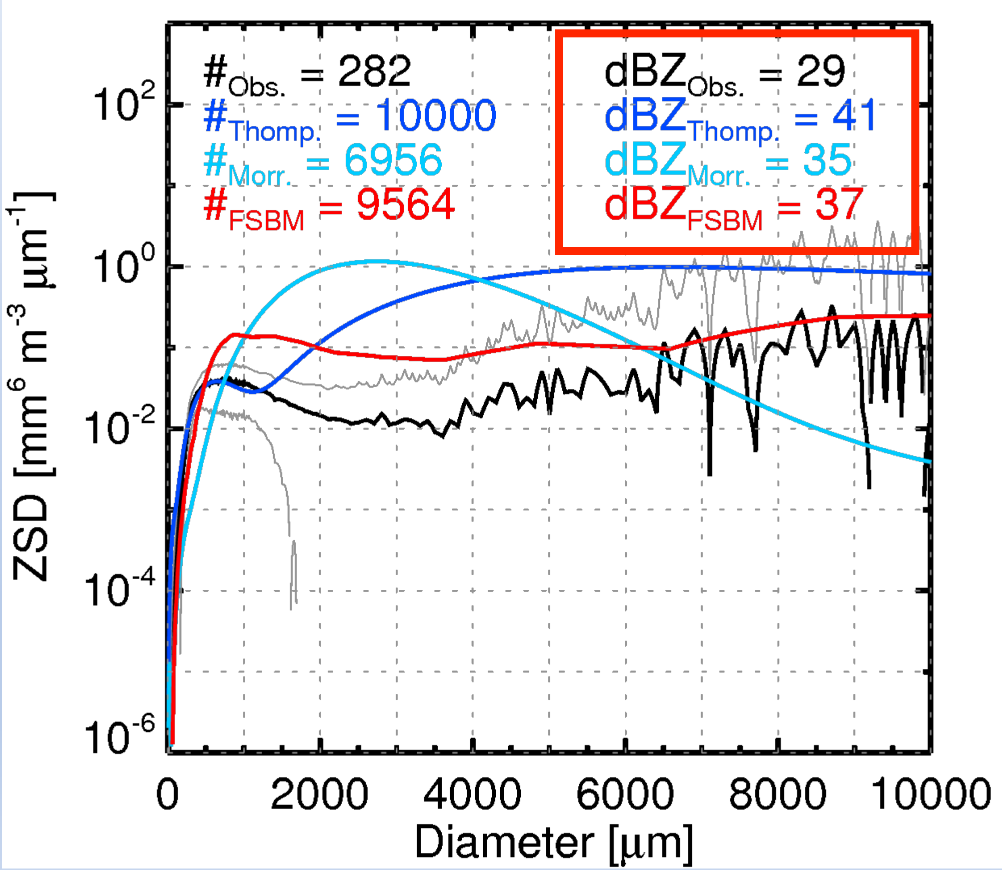
Reflectivity Implications

-32 °C to -40 °C

MSD $2\ g\ m^{-3} \leq TWC \leq 2.5\ g\ m^{-3}$ **ZSD**



- Observational size mode at ~300 μm
- Only Thompson is able to reproduce this; other schemes shift mode to larger sizes
- All schemes distribute too much mass at diameters between 1.5 and 6 mm
- Despite 90% of mass at sub-3mm sizes, larger sizes strongly influence the reflectivity and result in large model-obs. discrepancies



Reflectivity Implications

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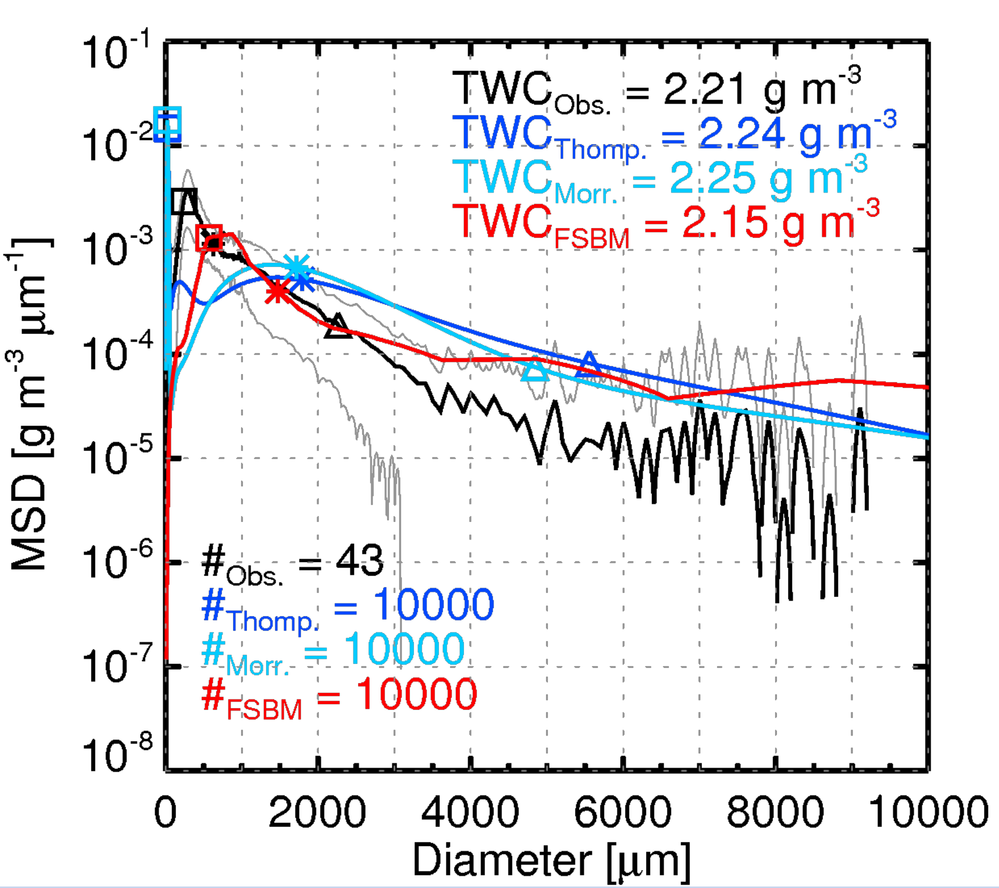
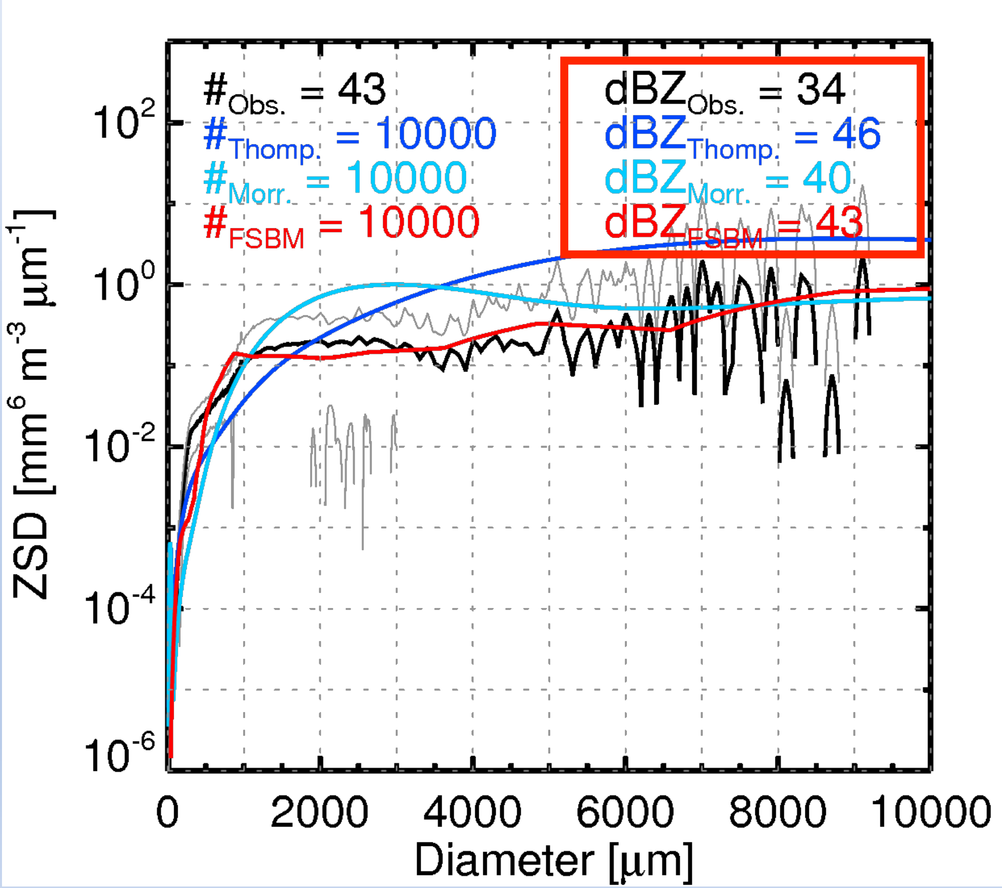


- Observational size mode still at ~300 μm
- All schemes fail to produce observed size mode at this temperature range and place too much mass in larger diameters; only FSBM has the peak mode below 1 mm
- Reflectivity is controlled most by large particles, whereas mass is controlled by smaller particles



Context from Cayenne Falcon 20 Measurements

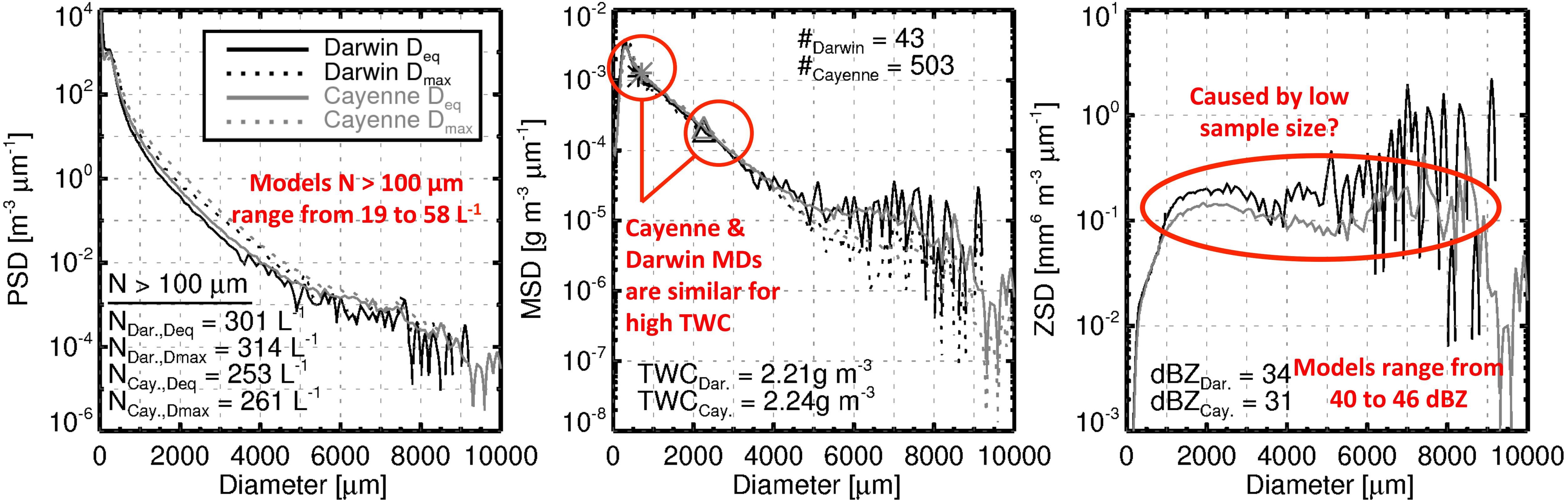
For high TWC at warm T, Cayenne & Darwin PSDs & MSDs are similar.

-8 °C to -16 °C

$2 \text{ g m}^{-3} \leq \text{TWC} \leq 2.5 \text{ g m}^{-3}$

Although not shown, updrafts have significantly more particles than all regions for this TWC and T range.

PSD **MSD** **ZSD**



Context from Cayenne Falcon 20 Measurements

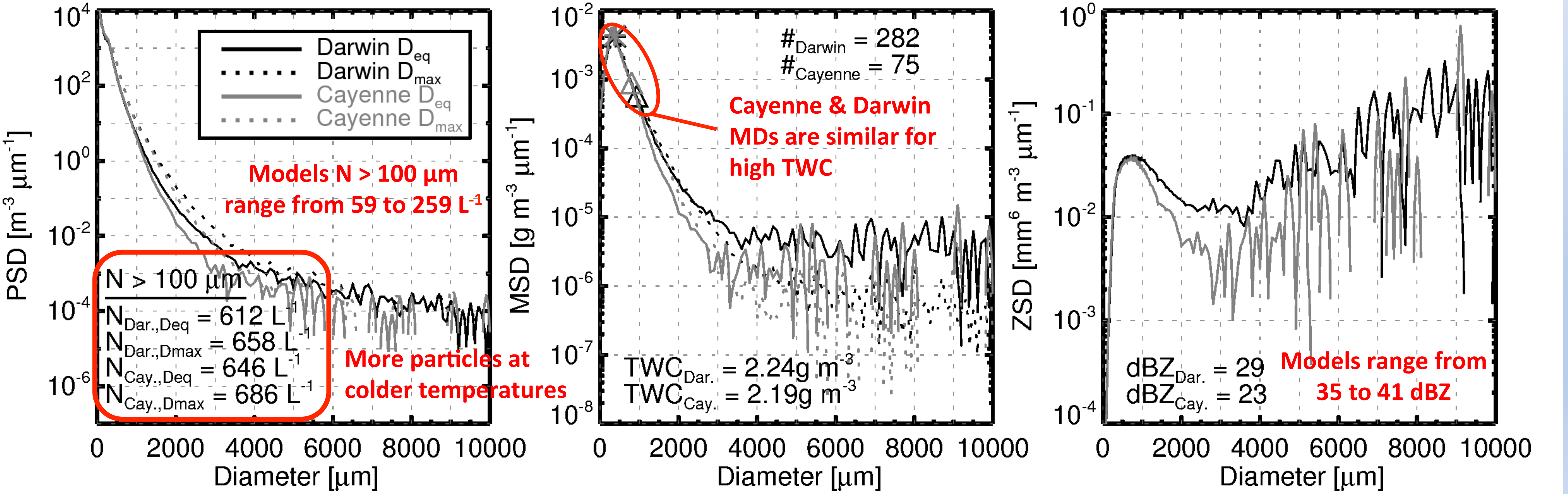
Cayenne observations have fewer large particles and mass at larger diameters, perhaps because of smaller, weaker updrafts. Sample size differences could also play a role.

-32 °C to -40°C

$2\ g\ m^{-3} \leq TWC \leq 2.5\ g\ m^{-3}$

Although not shown, updrafts don't have significantly more particles than all regions for this TWC and T range.

PSD **MSD** **ZSD**



Conclusions

- Simulated hydrometeor sizes are larger than observed, and the contribution of different ice species to the high bias varies by scheme and temperature range
  - This results from assumed hydrometeor properties (m-D relationships, Gamma PSD parameters) as shown by the large differences between schemes, but also likely results from key errors in mixed-phase microphysical process parameterizations that favor large rimed ice over small vapor-grown ice as shown by similar biases in all schemes
  - 2M schemes do not appear to perform better than diagnostic 1M schemes, even though they more realistically represent physical processes; the bin scheme should be able to perform the best, but only performs better in select metrics
- All schemes place too much mass in larger particle sizes than observed, which high biases radar reflectivity for a given T-*w*-TWC condition
- Although not shown, increasing grid spacing to 333 m only slightly improves results and does not significantly reduce model bias
- Also not shown, simulated hydrometeor sizes in a T-*w*-TWC phase space are largely the same for bulk simulations of several other HAIC-HIWC Darwin events varying in thermodynamic and kinematic structure

Future Work

- Utilize additional TWC and MSD data from NRC Convair 580 (w/Alexei)
  - Falcon 20 & Convair during Cayenne phase provide much more information around -10 to -15 °C than was collected during the Darwin campaign
- Utilize X-band airborne radar data for select Cayenne cases (w/Mengistu)
- Simulate select Cayenne cases
  - Possibly test novel new microphysics schemes in WRF
- Explore microphysical pathways to increase ice number concentrations in microphysics schemes
- Explore the life cycle of high ice water content regions and their relationship with convective and mesoscale circulations (w/anyone interested)

Publications Update

Completed

Varble, A., M. Stanford, E. Zipser, J. W. Strapp, J. Delanoe, A. Korolev, D. Leroy, R. Potts, A. Protat, and A. Schwarzenboeck, 2015: Observed and simulated relationships between tropical deep convective updraft dynamics and microphysics, AGU Fall Meeting poster.

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Stanford, M. and A. Varble, 2016: Evaluation of simulated tropical convective updraft properties using HAIC-HIWC aircraft observations, AMS Conference on Hurricanes and Tropical Meteorology, poster.

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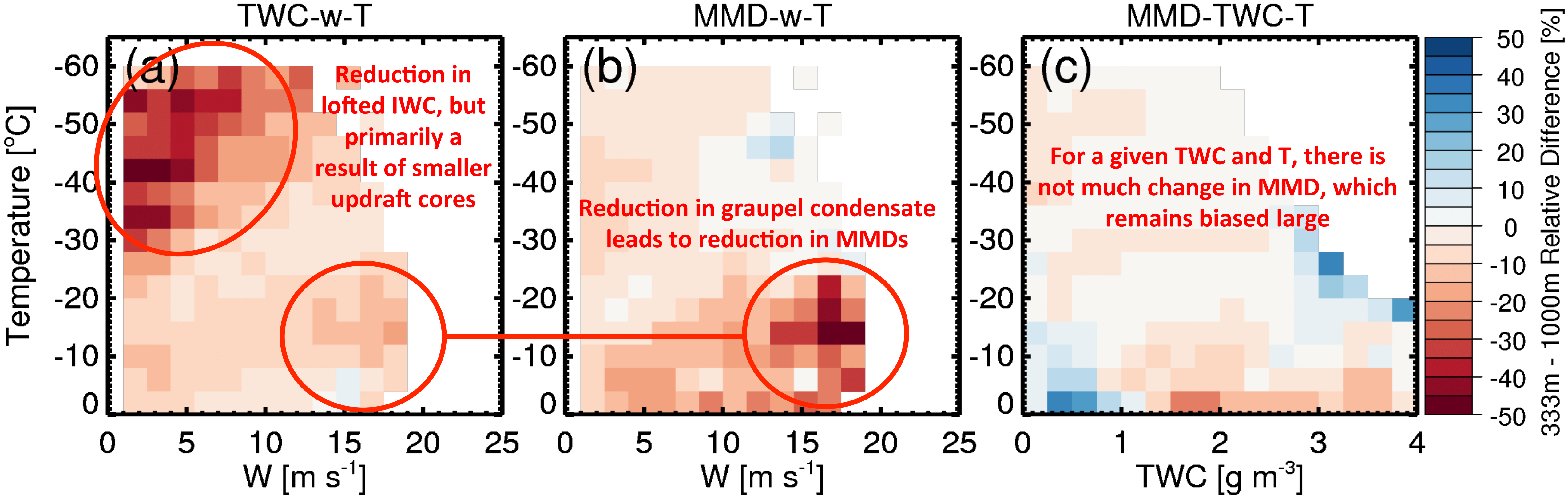
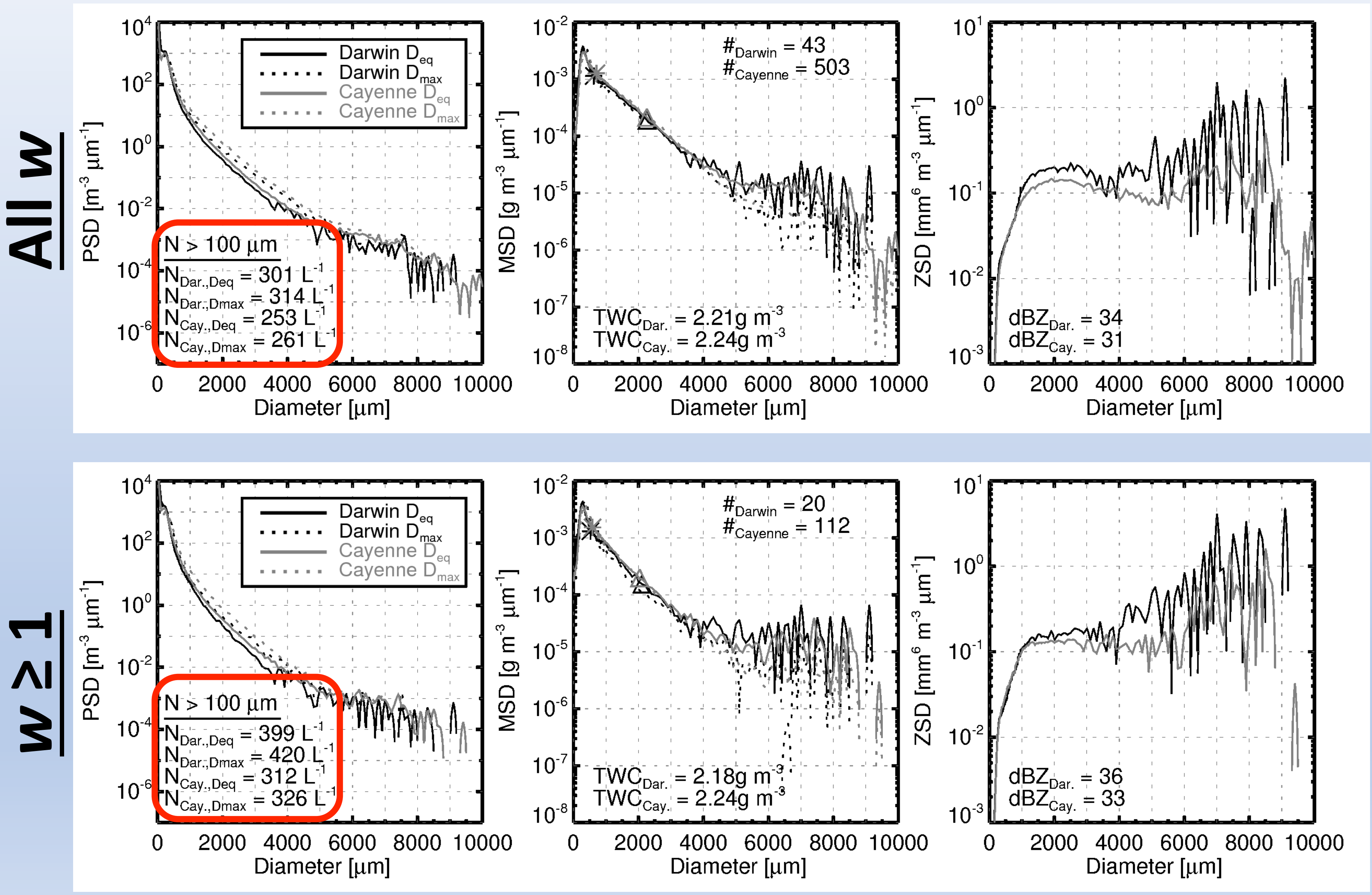
Thompson 333-m simulation, 18 Feb. 2014



- Largest reduction in MMD results from a reduction in GWC (and consequently graupel MMDs) since GWC largely controls TWC in this temperature region
- Increasing resolution decreases updraft size, allowing easier sedimentation of large ice, but MMDs for a given TWC-T changes little (TWC decreases rather than MMD for a given TWC)

Composite Distributions in Updrafts



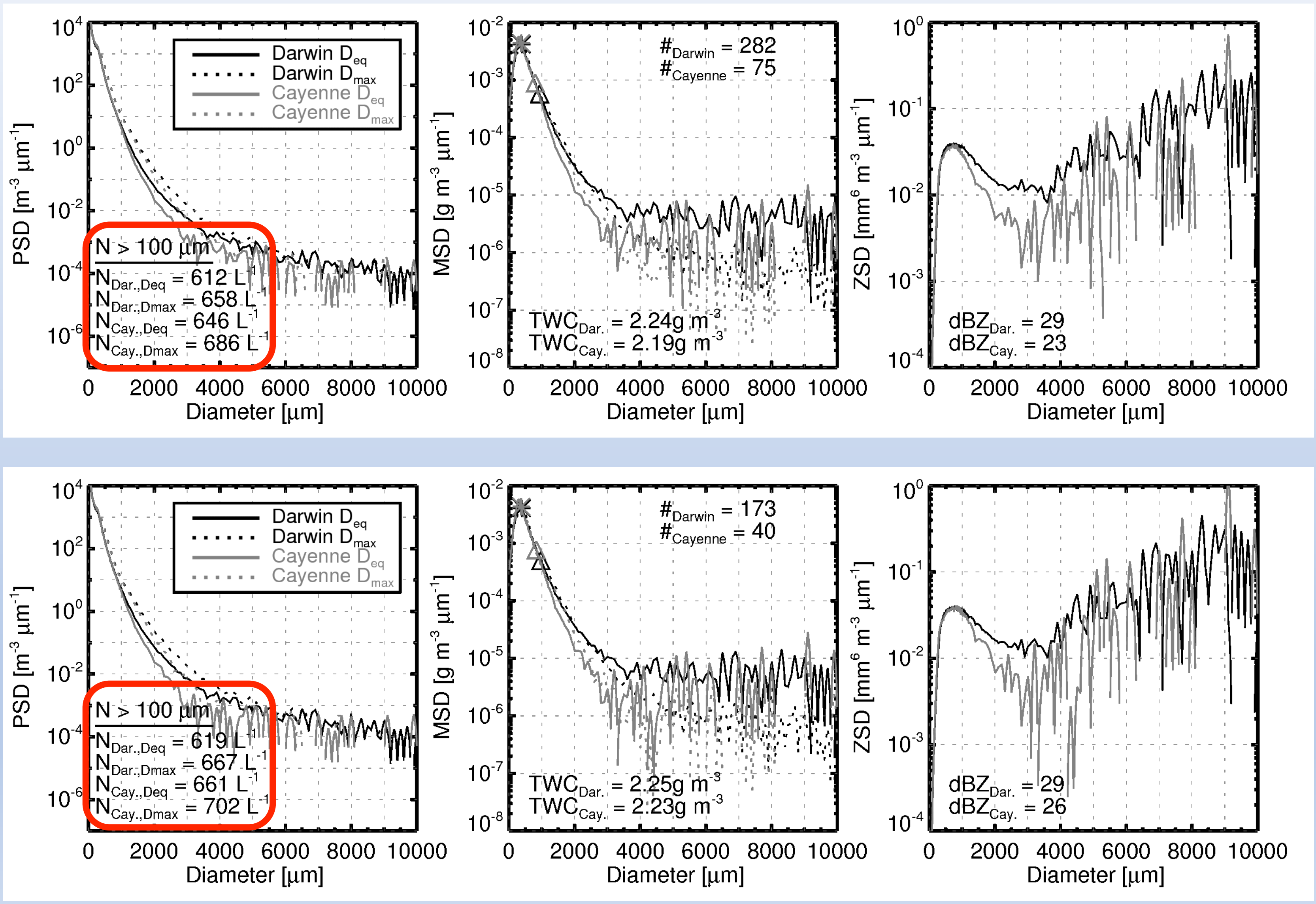
-8 °C to -16 °C

- Number of particles increases in updrafts only – decreased aggregation efficiency/secondary ice production?
- More mass is distributed at larger diameters in updrafts
- Reflectivities increase in updrafts

Composite Distributions in Updrafts

All *w*

w ≥ 1



-32 °C to -40 °C

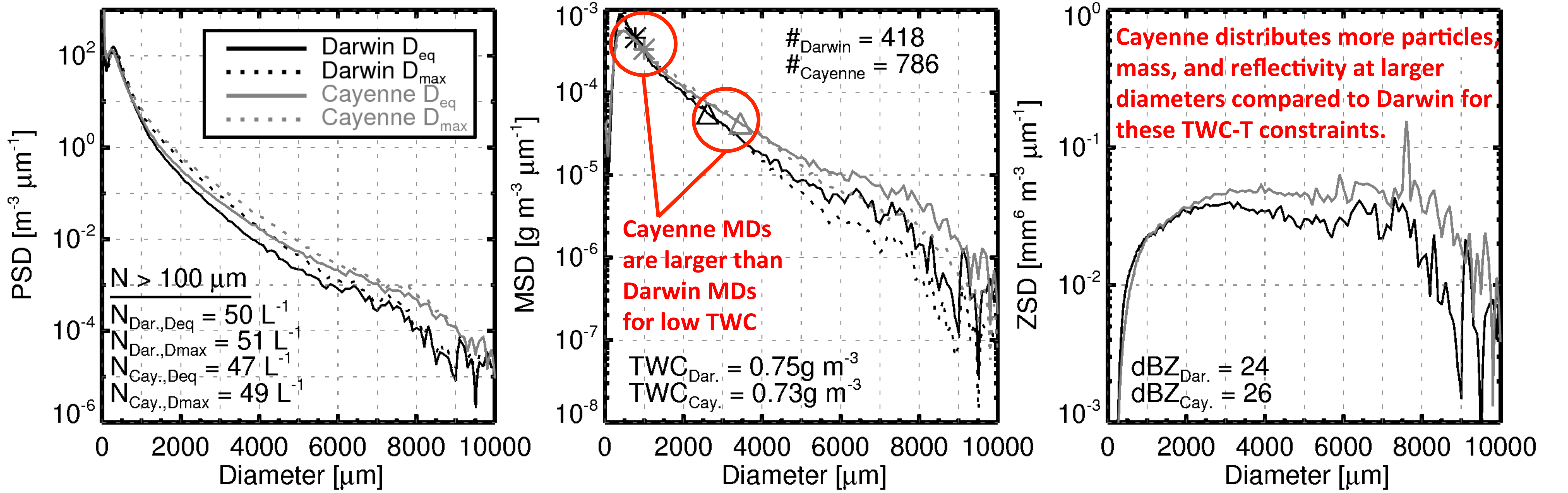
- At colder temperatures, total number of particles in updrafts are only slightly higher than for no *w* constraint
  - Slight increase in number concentration is mostly from large particles
- More mass is distributed at larger particles in updrafts
- Reflectivities slightly increase in updrafts

Context from Cayenne Falcon 20 Measurements

-8 °C to -16 °C

$0.5\ g\ m^{-3} \leq TWC \leq 1.0\ g\ m^{-3}$

PSD **MSD** **ZSD**



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-32 °C to -40°C

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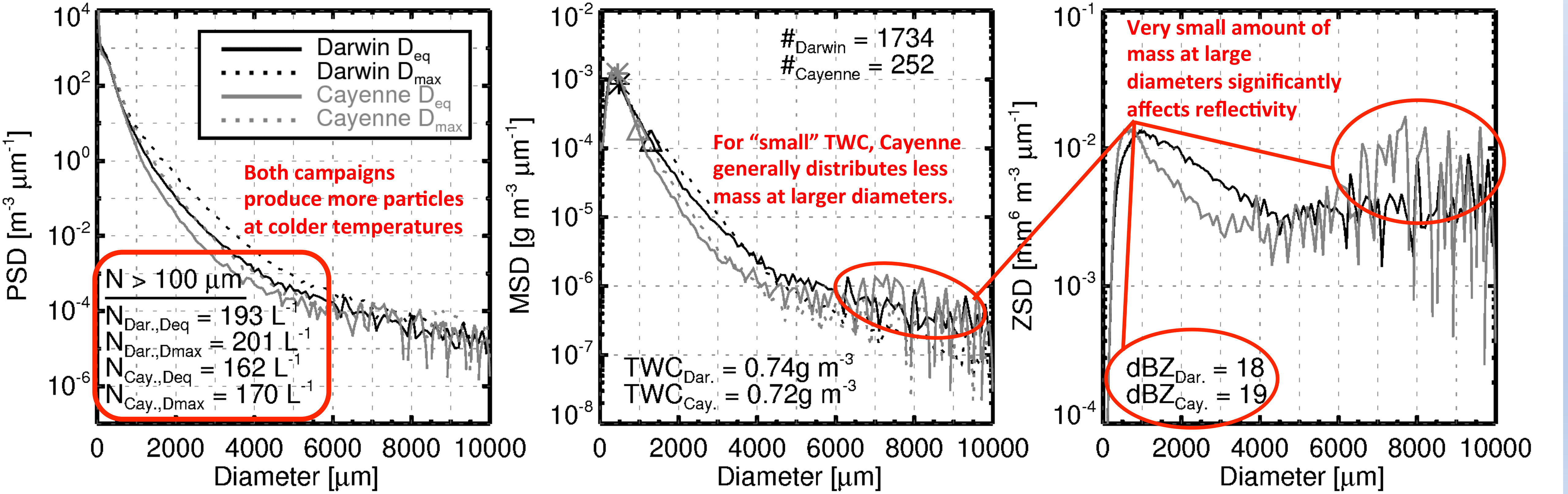
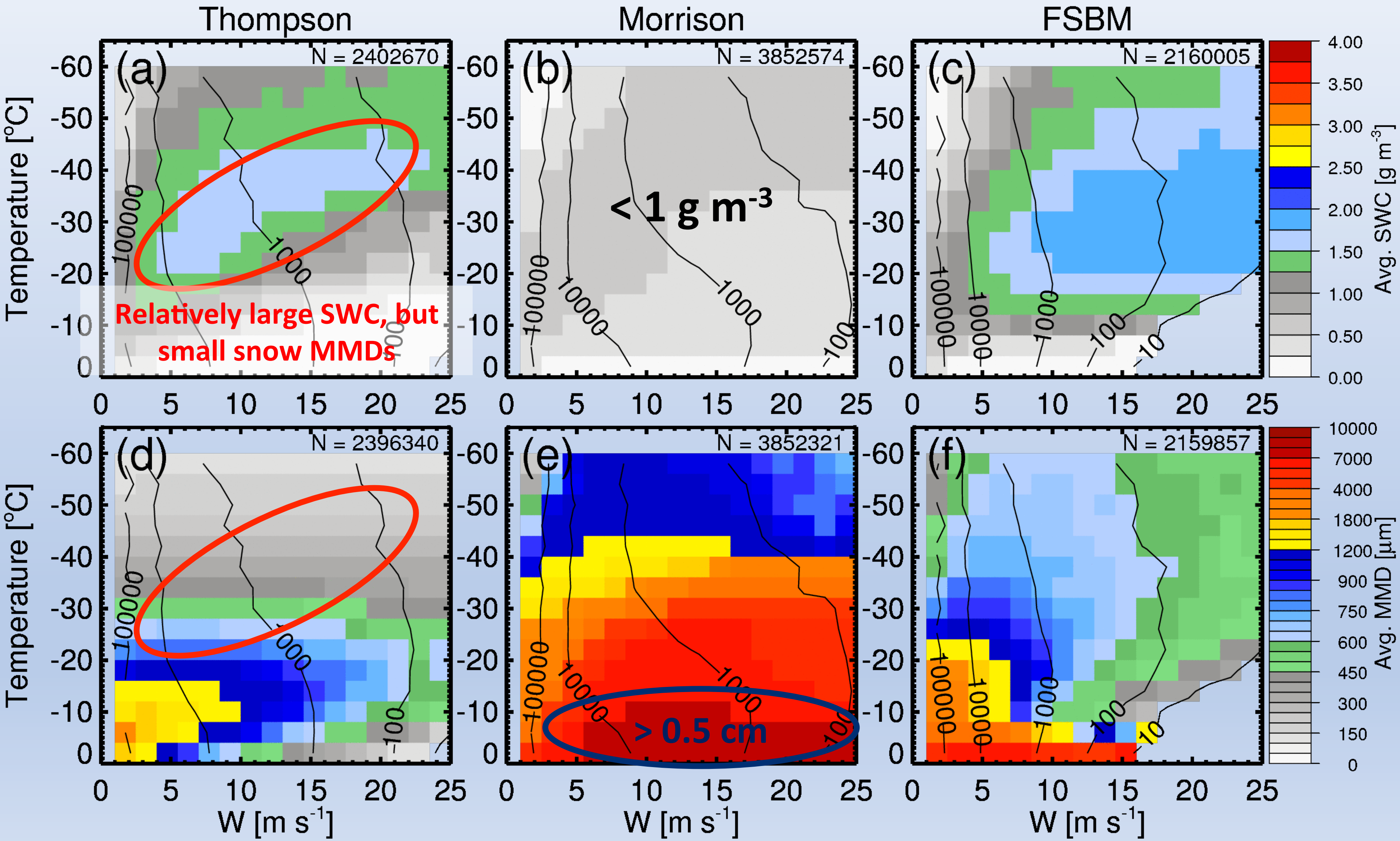
PSD **MSD** **ZSD**

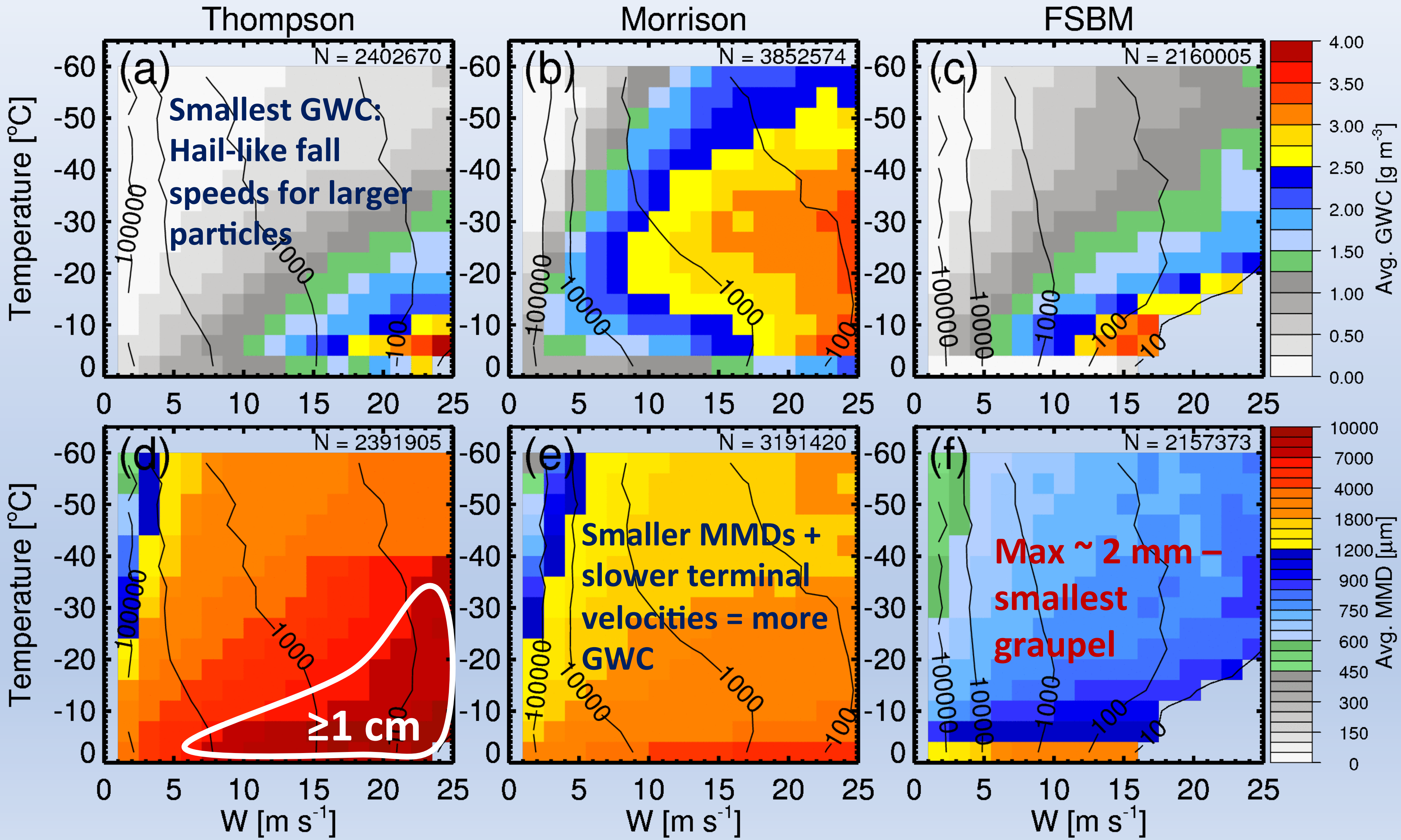


Species Partitioning - Snow



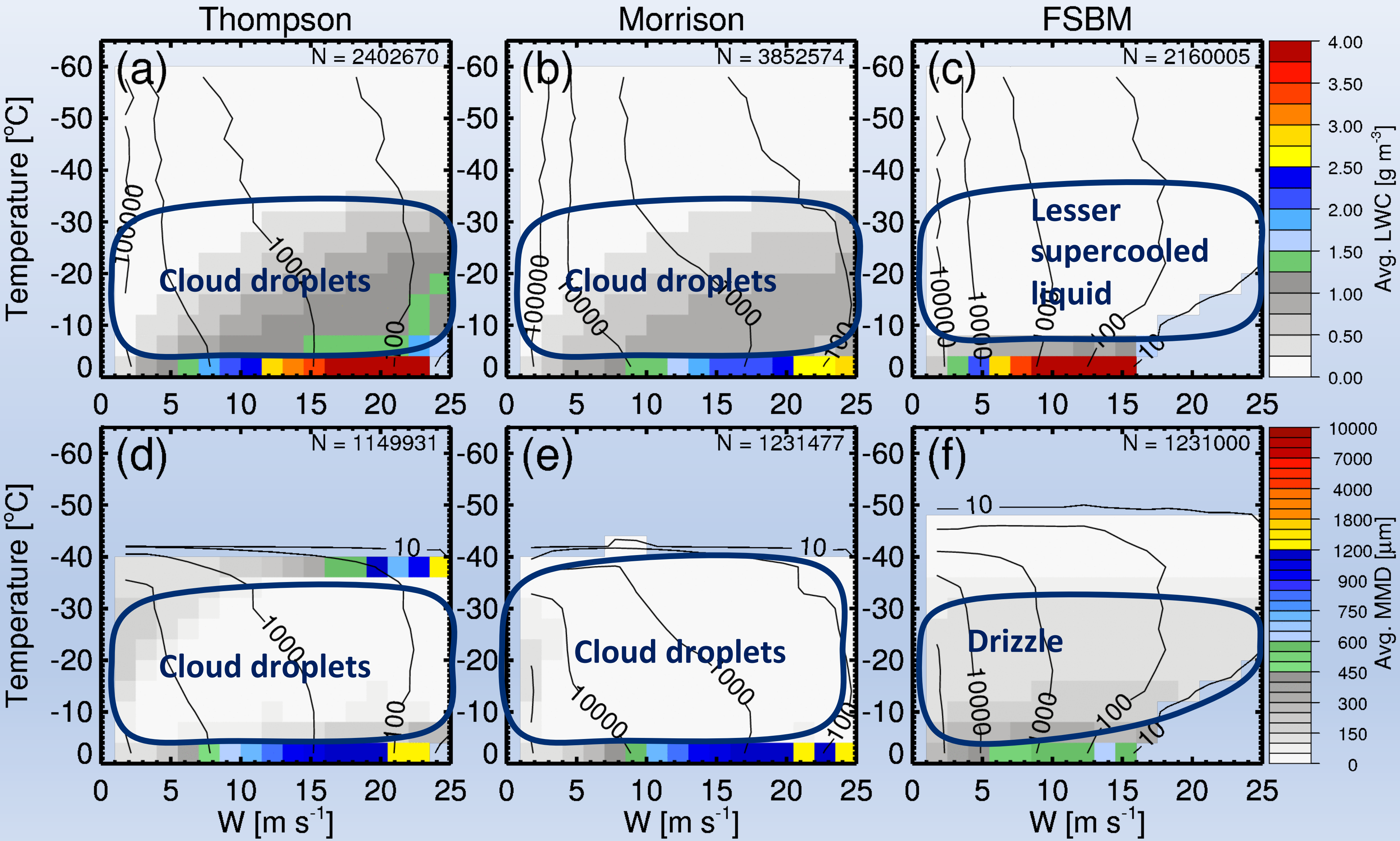
- FSBM & Thompson produce much more snow than Morrison—smaller MMDs → slower fall speeds
- Morrison snow aggregates get very large near melting level—contribute to reflectivity bias
- Unique Thompson snow parameterization (temperature dependent double gamma) & non-spherical m-D relationship is more agreeable with obs

Species Partitioning - Graupel



- Thompson graupel-hail hybrid species forces particles to larger sizes with increasing mass
- Morrison graupel MMDs are smaller than snow—2M graupel may reduce size biases compared to 1M diagnostic relationships
- FSBM graupel is smallest of all schemes and smaller than FSBM snow – small graupel may be linked to size of lofted raindrops & amount of available supercooled liquid

Species Partitioning - Liquid



- Thompson & Morrison schemes produce much more supercooled liquid than FSBM
- Less supercooled liquid and smaller raindrops in FSBM may be a cause for smaller graupel sizes
  - Potentially caused by explicit CCN nucleation and maintenance of supersaturation over liquid