Upper Great Lakes Snowfall Observations: A Five-Year Retrospective

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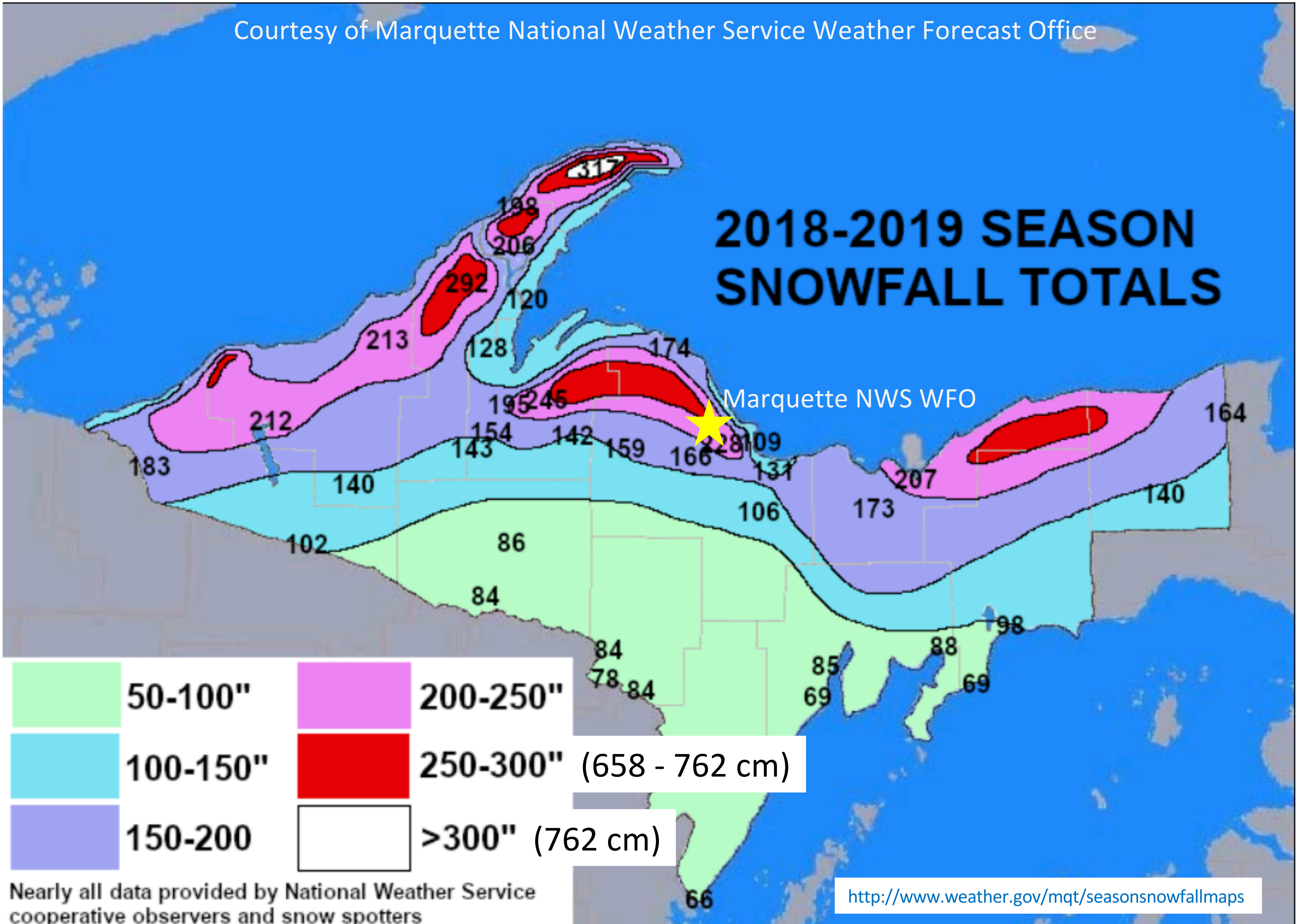
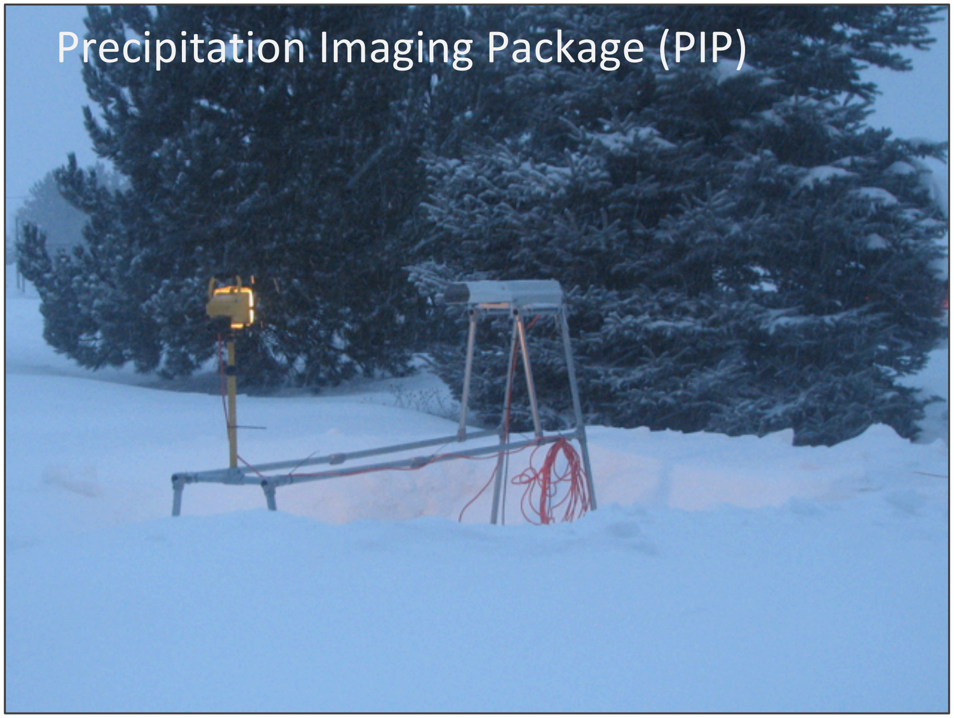

Courtesy of Marquette National Weather Service Weather Forecast Office
2018-2019 SEASON
SNOWFALL TOTALS
Marquette NWS WFO
198
206
292
120
213
128
174
195
245
212
154
143
142
159
166
109
131
183
140
164
207
173
106
102
86
84
84
78
84
85
69
88
69
98
66
50-100"
100-150"
150-200
200-250"
250-300" (658 - 762 cm)
>300" (762 cm)
Nearly all data provided by National Weather Service cooperative observers and snow spotters
http://www.weather.gov/mqt/seasonsnowfallmaps

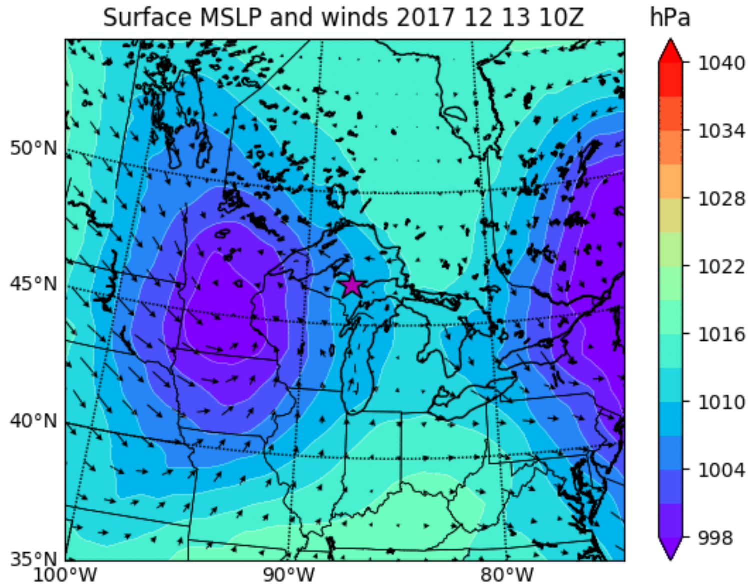


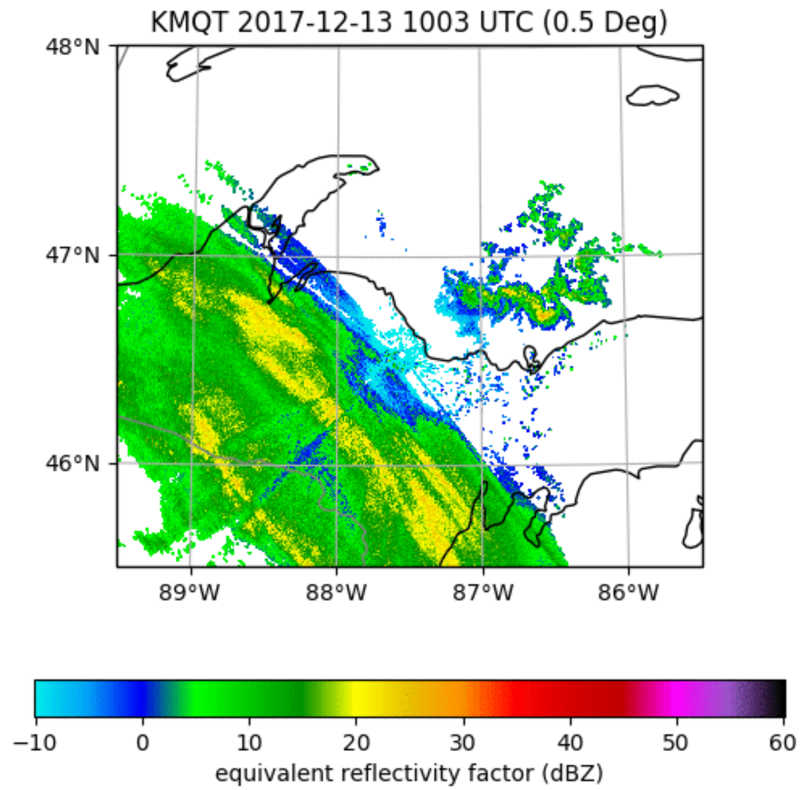
Dataset Duration:
January 2014 – Present

Project Objectives

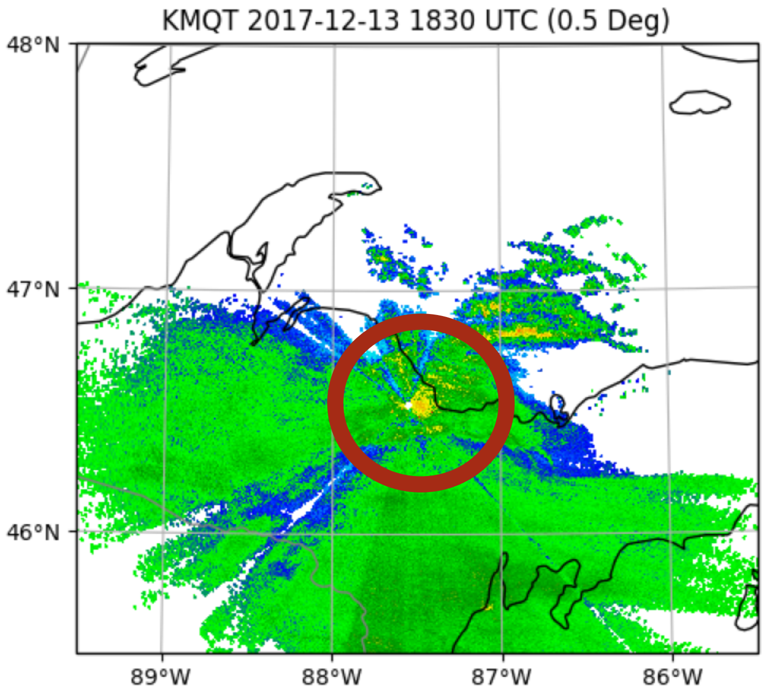
- Snowfall regimes/partitioning statistics
- Microphysical variability
- Quantitative Precipitation Estimation (QPE):
  - Radar reflectivity (Z) – Snowfall Rate (S)
  - Spaceborne radar/radiometer
  - Numerical Weather Prediction
- Algorithm development and evaluation

Lesson 1:
Snowfall regime transitions = microphysical transitions





KMQT 0.5^o



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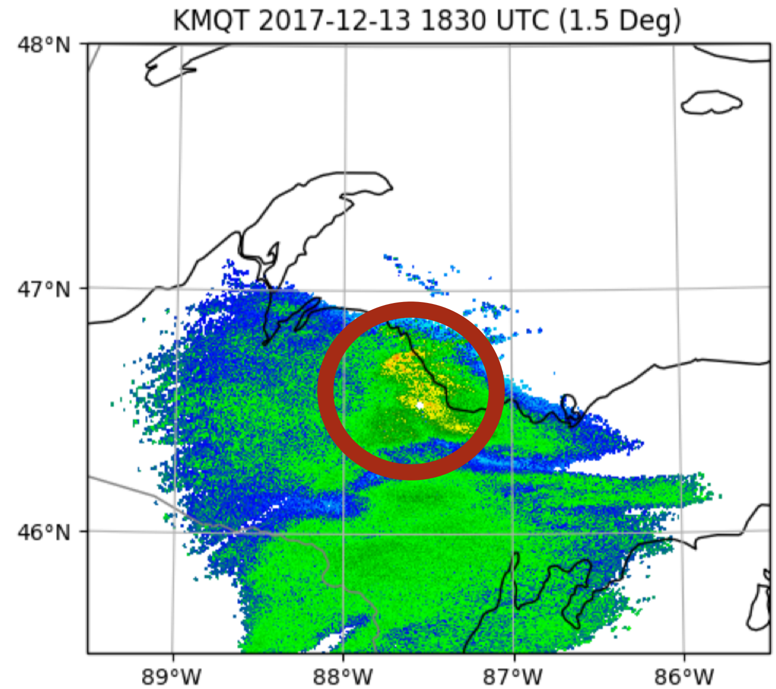
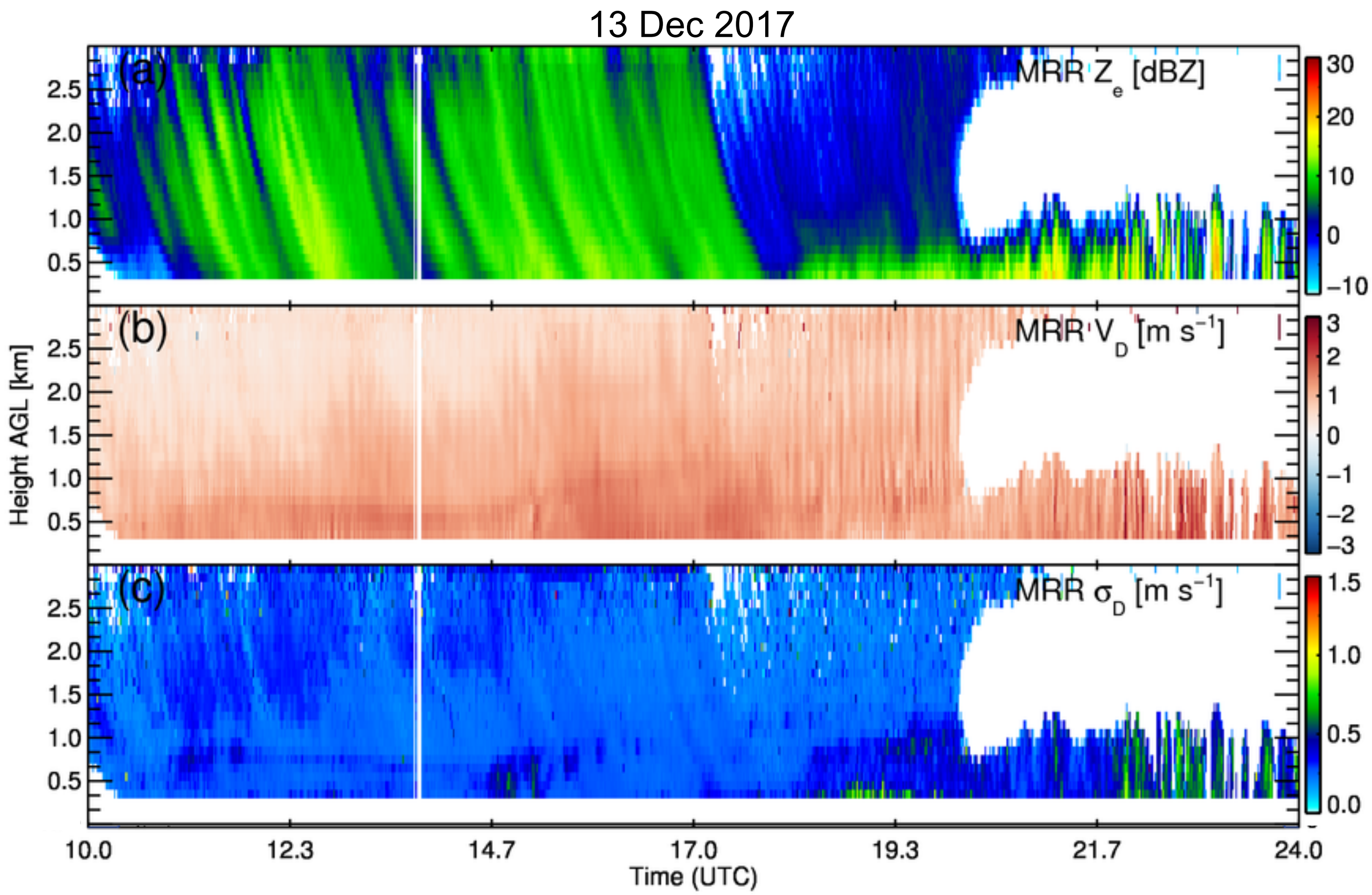
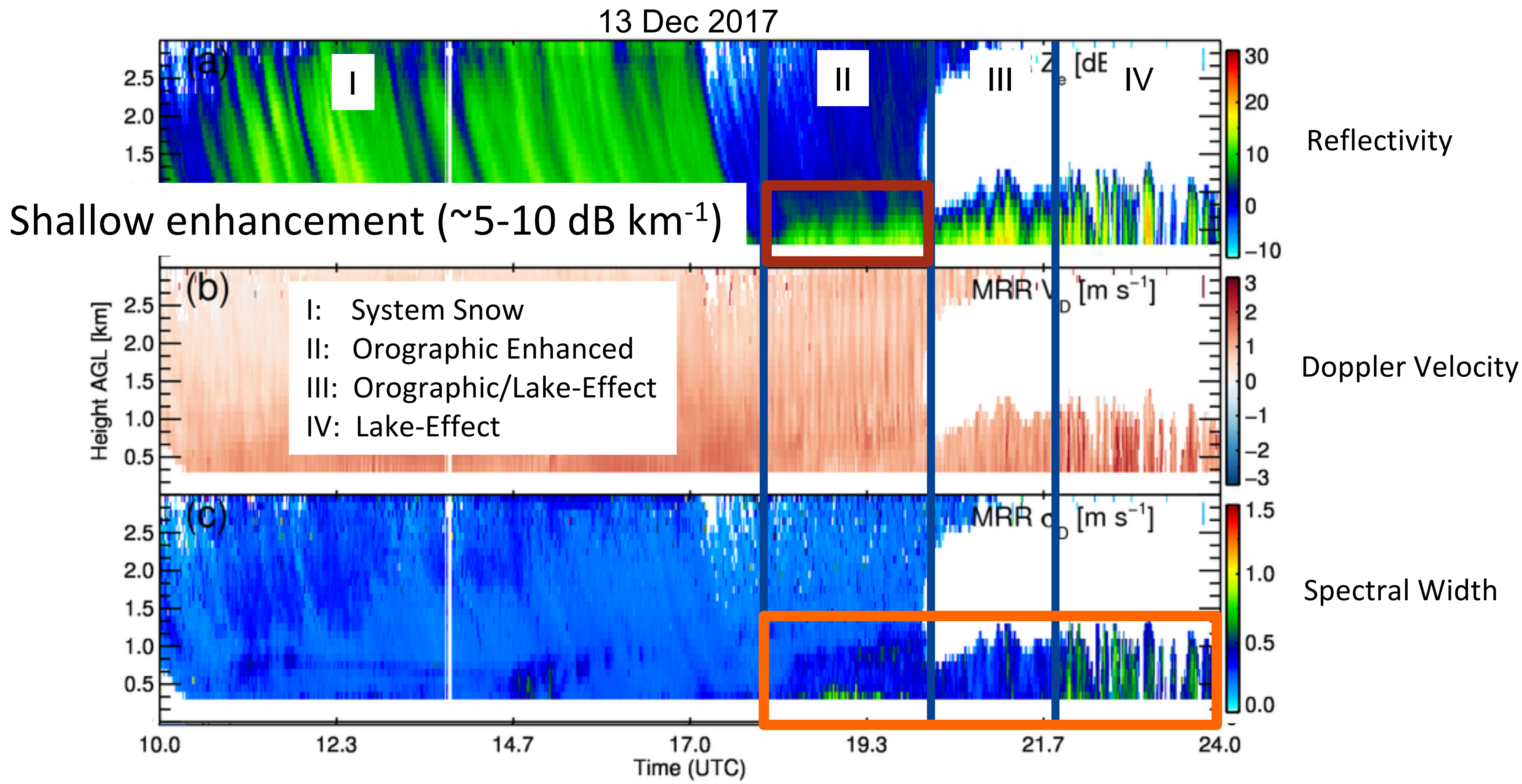
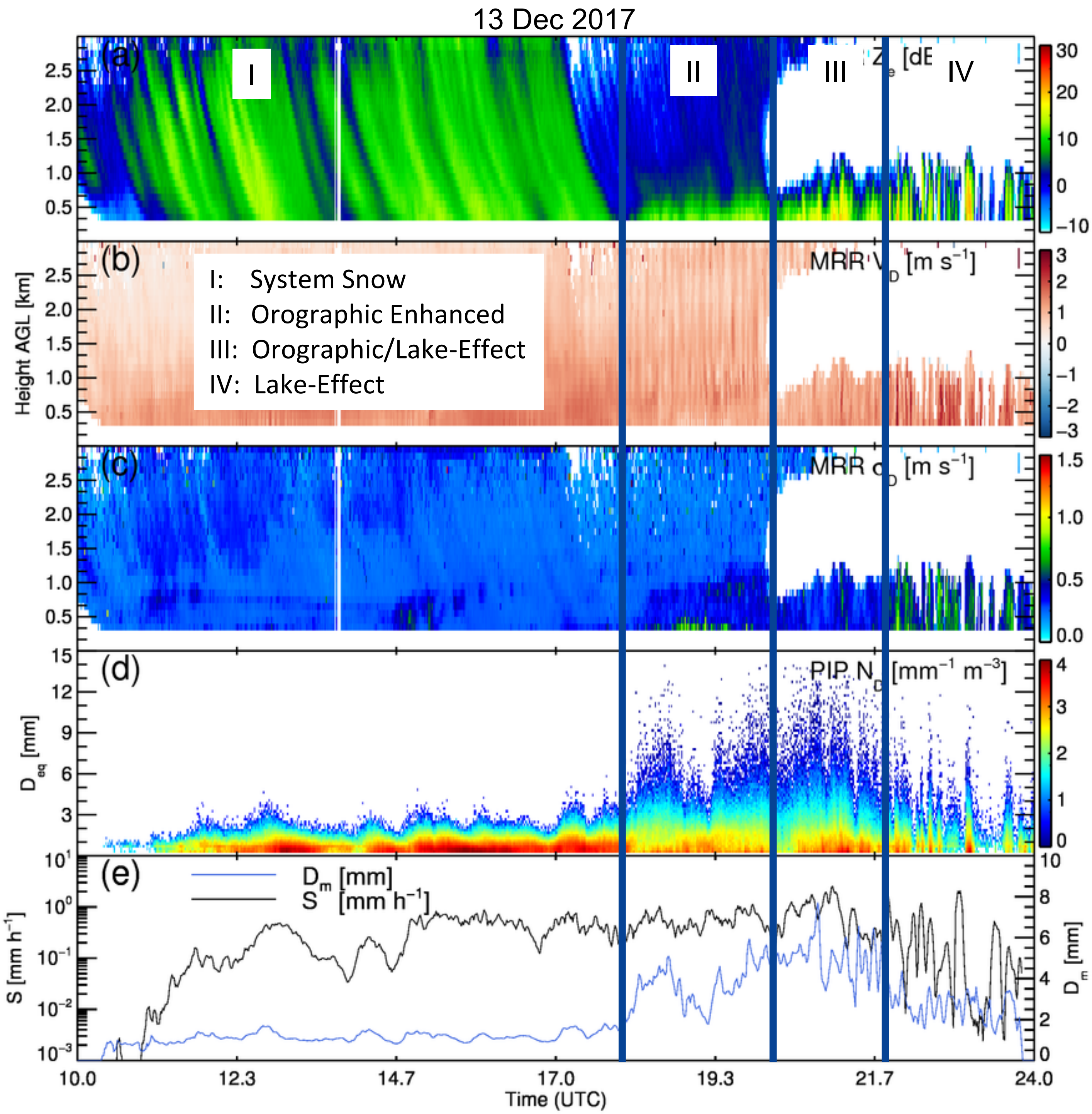


Orographic enhancement

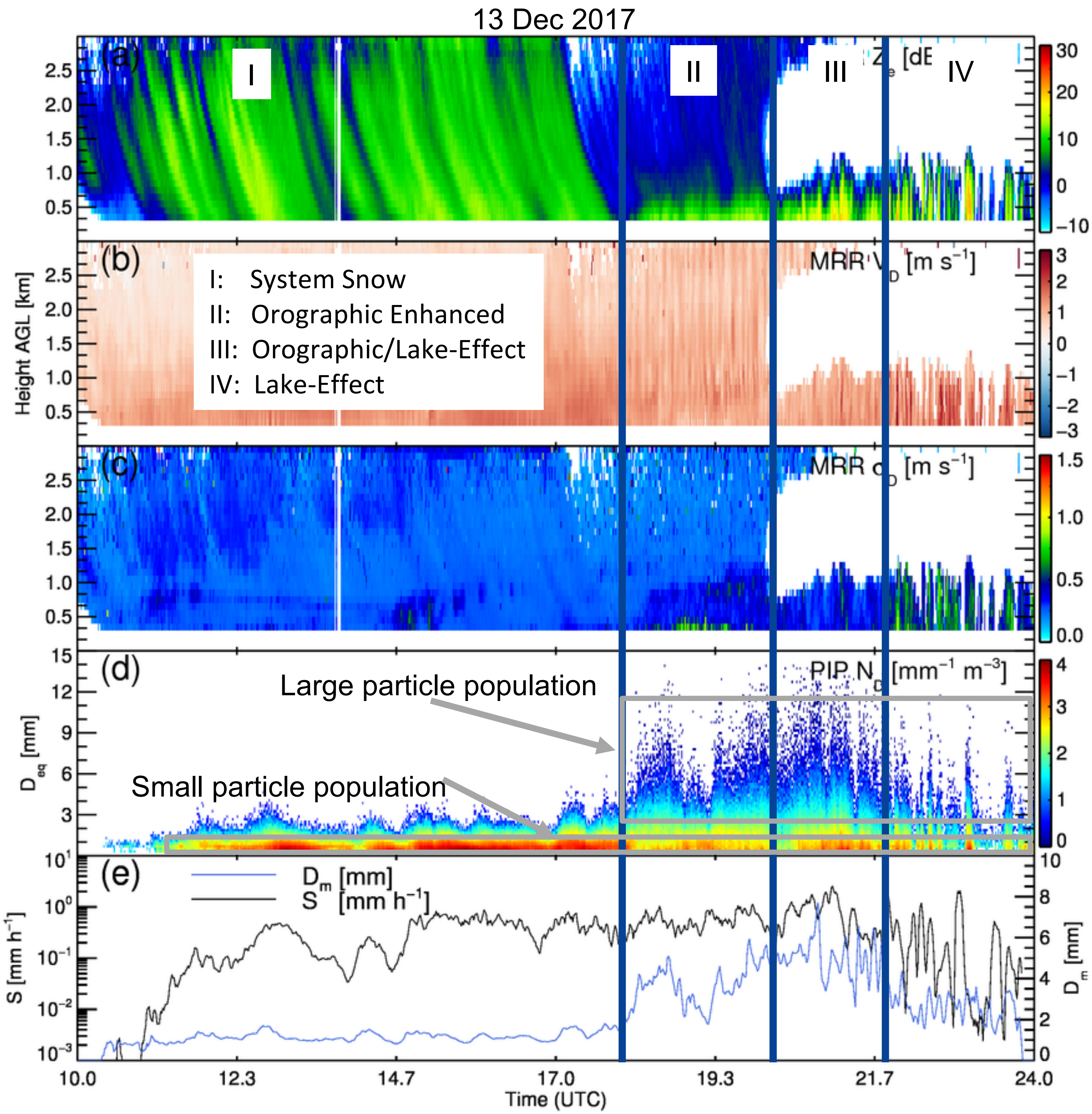


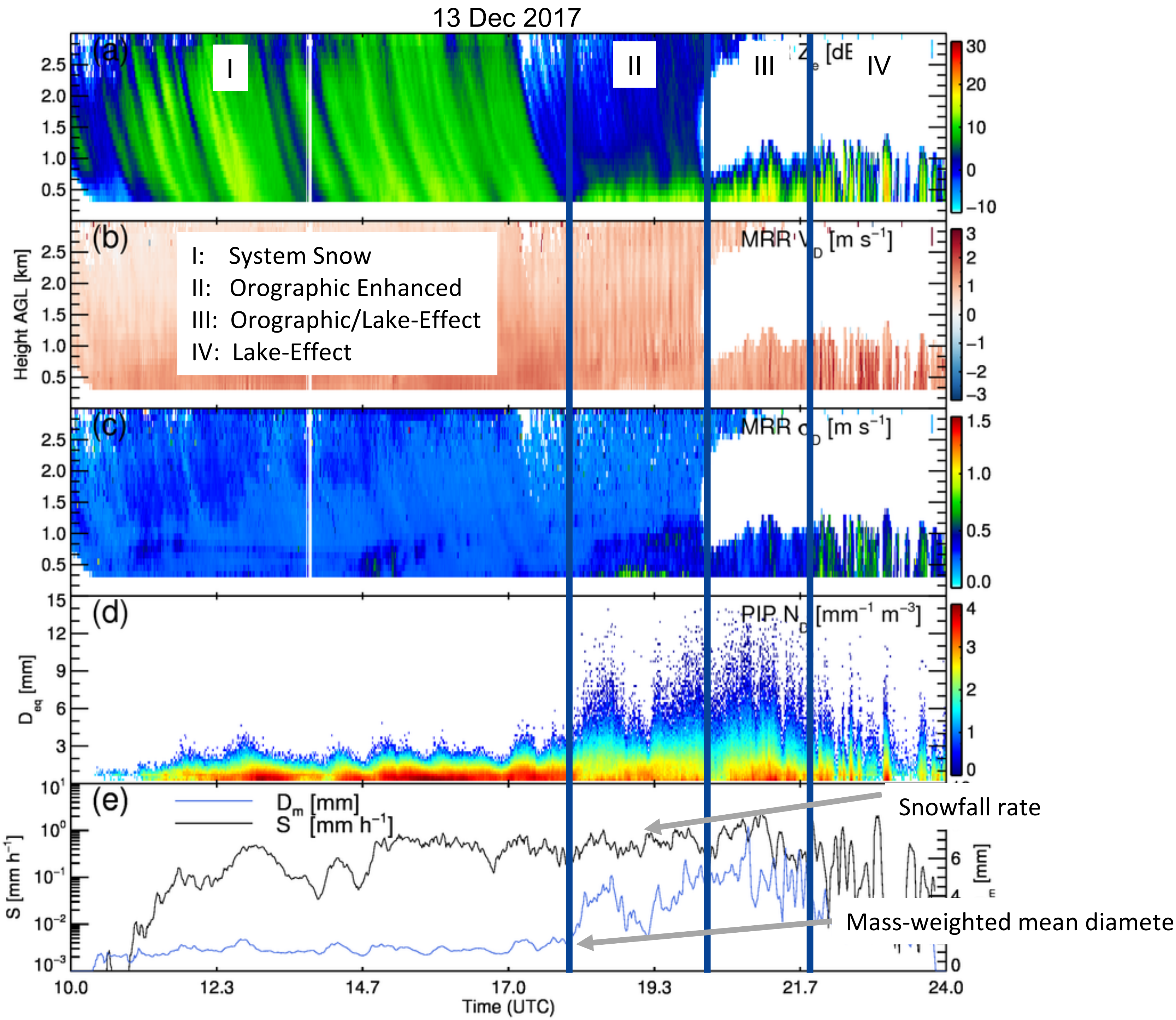
Kulie et al. (2020) *BAMS*


13 Dec 2017
(a)
I
II
III
IV
Z_e [dB
Reflectivity
Shallow enhancement (~5-10 dB km^-1)
(b)
I: System Snow
II: Orographic Enhanced
III: Orographic/Lake-Effect
IV: Lake-Effect
MRR V_D [m s^-1]
Doppler Velocity
(c)
MRR σ_D [m s^-1]
Spectral Width
Height AGL [km]
Time (UTC)
10.0
12.3
14.7
17.0
19.3
21.7
24.0



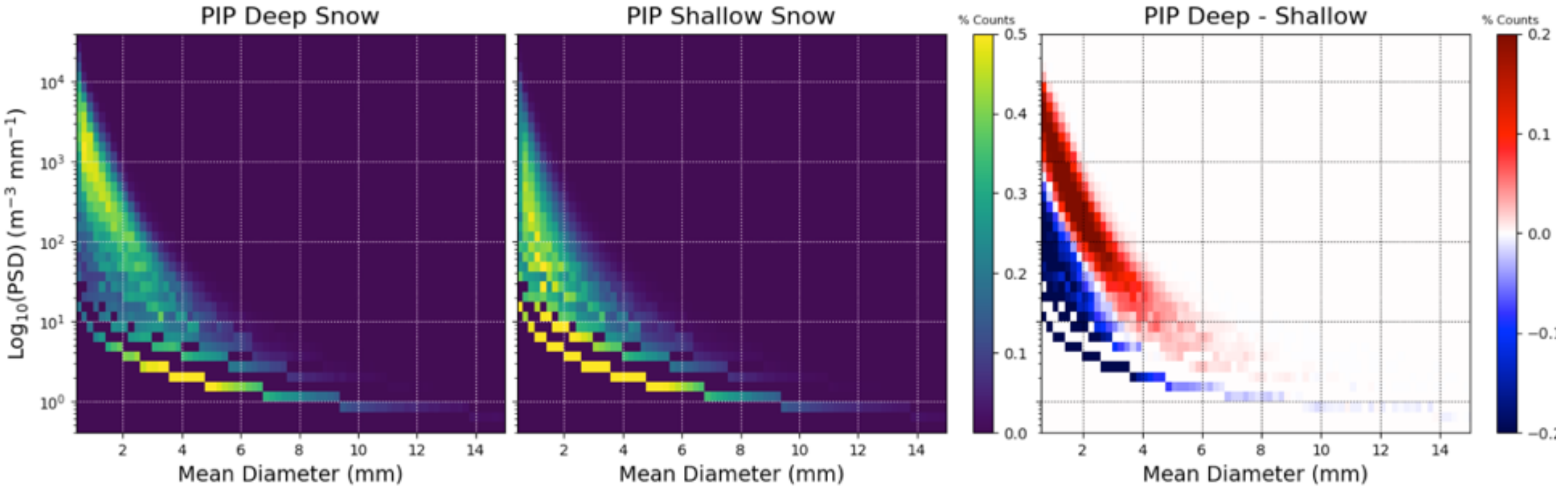
13 Dec 2017
(a)
I
II
III
IV
Z_e [dB
(b)
MRR V_D [m s^-1]
I: System Snow
II: Orographic Enhanced
III: Orographic/Lake-Effect
IV: Lake-Effect
(c)
MRR σ_D [m s^-1]
(d)
PIP N_D [mm^-1 m^-3]
(e)
D_m [mm]
S [mm h^-1]
Height AGL [km]
D_eq [mm]
S [mm h^-1]
D_m [mm]
Time (UTC)
10.0
12.3
14.7
17.0
19.3
21.7
24.0


13 Dec 2017
(a)
I
II
III
IV
Z_e [dB
(b)
I: System Snow
II: Orographic Enhanced
III: Orographic/Lake-Effect
IV: Lake-Effect
MRR V_D [m s^-1]
(c)
MRR σ_D [m s^-1]
(d)
PIP N_D [mm^-1 m^-3]
Large particle population
Small particle population
(e)
D_m [mm]
S [mm h^-1]
Height AGL [km]
D_eq [mm]
S [mm h^-1]
D_m [mm]
Time (UTC)
10.0
12.3
14.7
17.0
19.3
21.7
24.0



13 Dec 2017
(a)
I
II
III
IV
Z
[dB
(b)
I: System Snow
II: Orographic Enhanced
III: Orographic/Lake-Effect
IV: Lake-Effect
MRR V
[m s⁻¹]
(c)
MRR σ
[m s⁻¹]
(d)
PIP N
[mm⁻¹ m⁻³]
(e)
D
[mm]
S [mm h⁻¹]
Snowfall rate
Mass-weighted mean diameter
Height AGL [km]
S [mm h⁻¹]
Time (UTC)
10.0
12.3
14.7
17.0
19.3
21.7
24.0

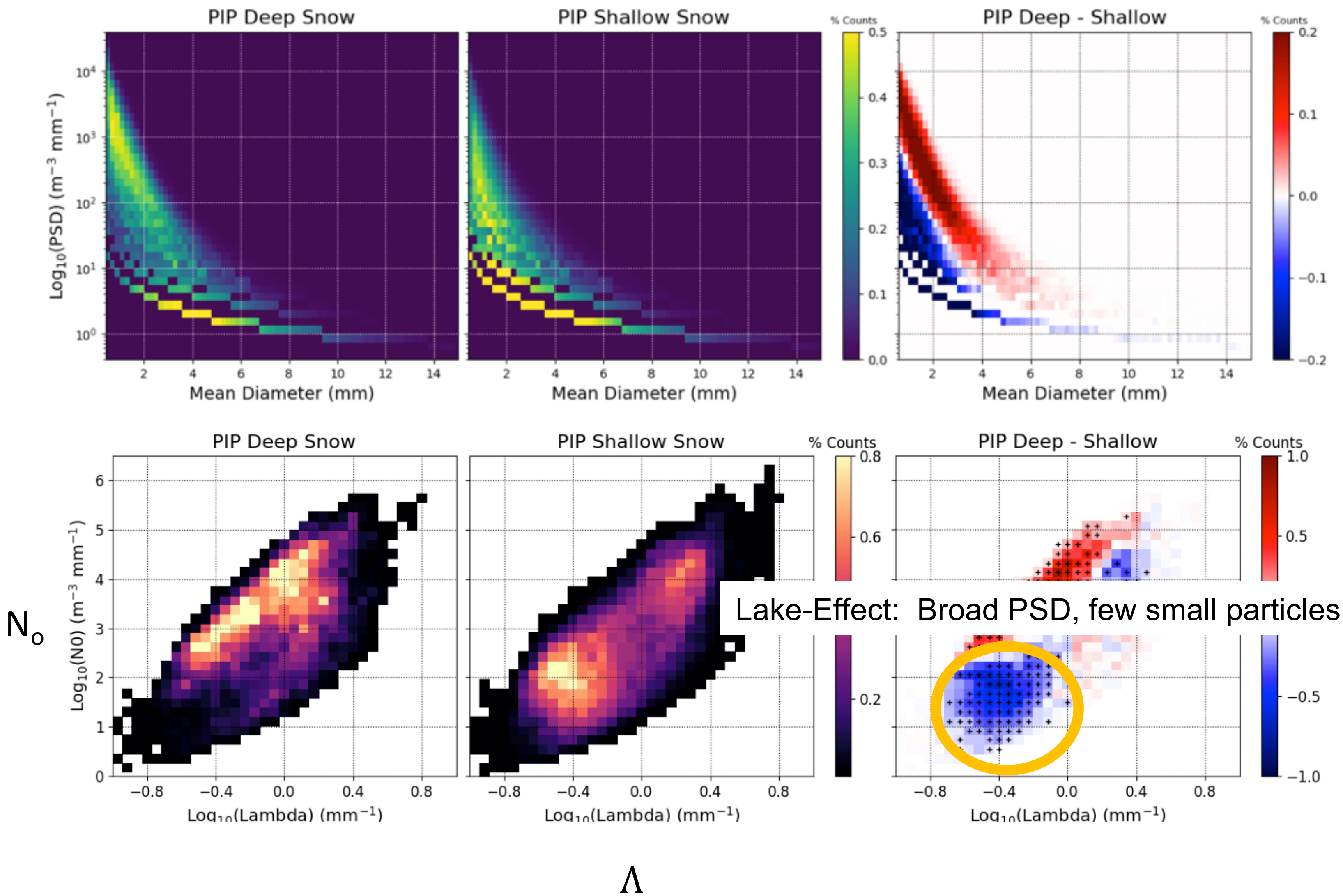
PIP Microphysics: Regime-Dependent Variability



Deep vs. Shallow: MRR-defined
5 Year Analysis

Pettersen et al. (2019), *JAMC:* 10.1175/JAMC-D-19-0099.1

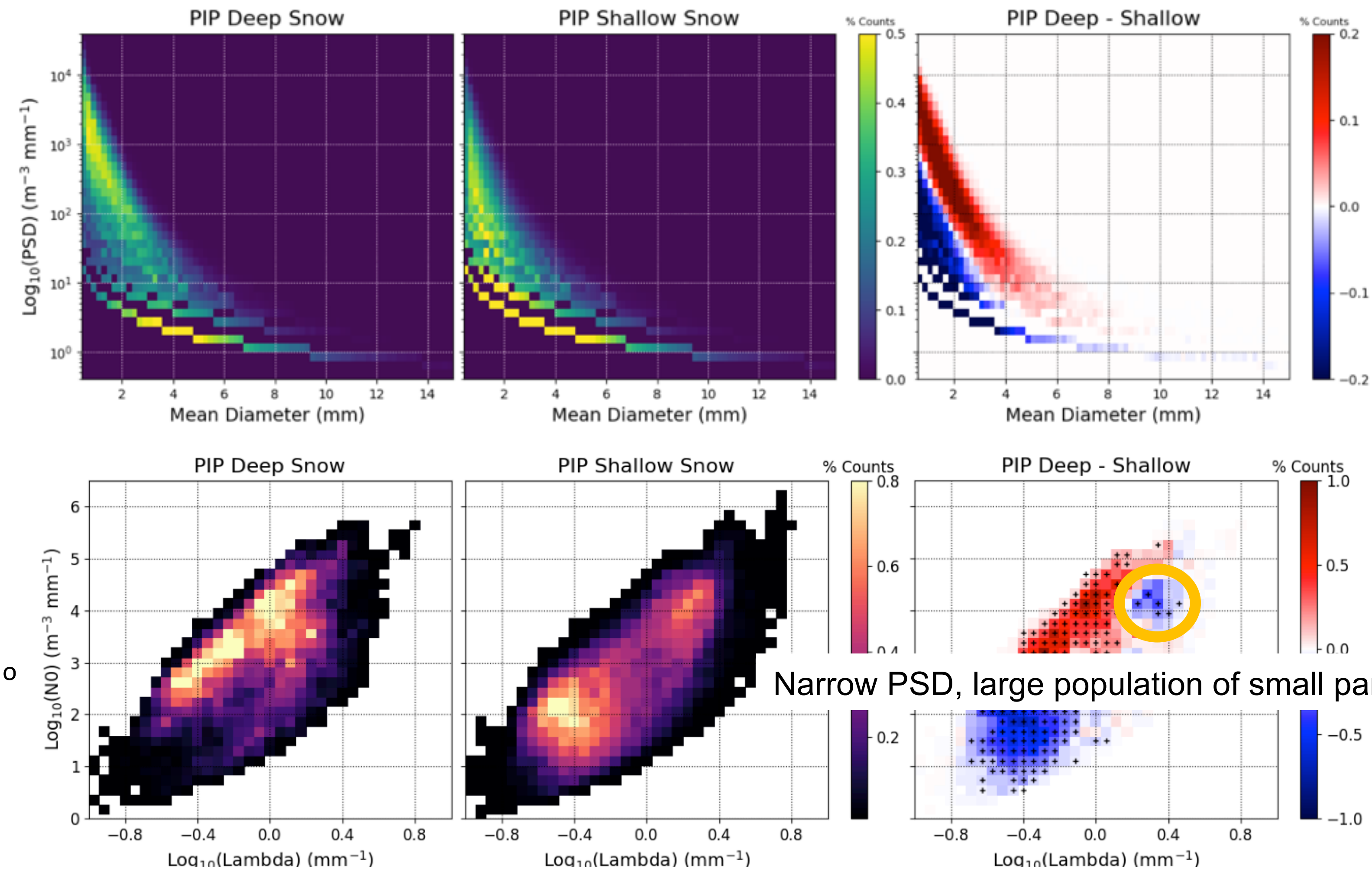
5-Year Dataset Analysis: PIP Microphysics



Particle Size Distribution: $N(D)=N_o\exp(-\Lambda D)$

Pettersen et al. (2019) *JAMC*

5-Year Dataset Analysis: PIP Microphysics



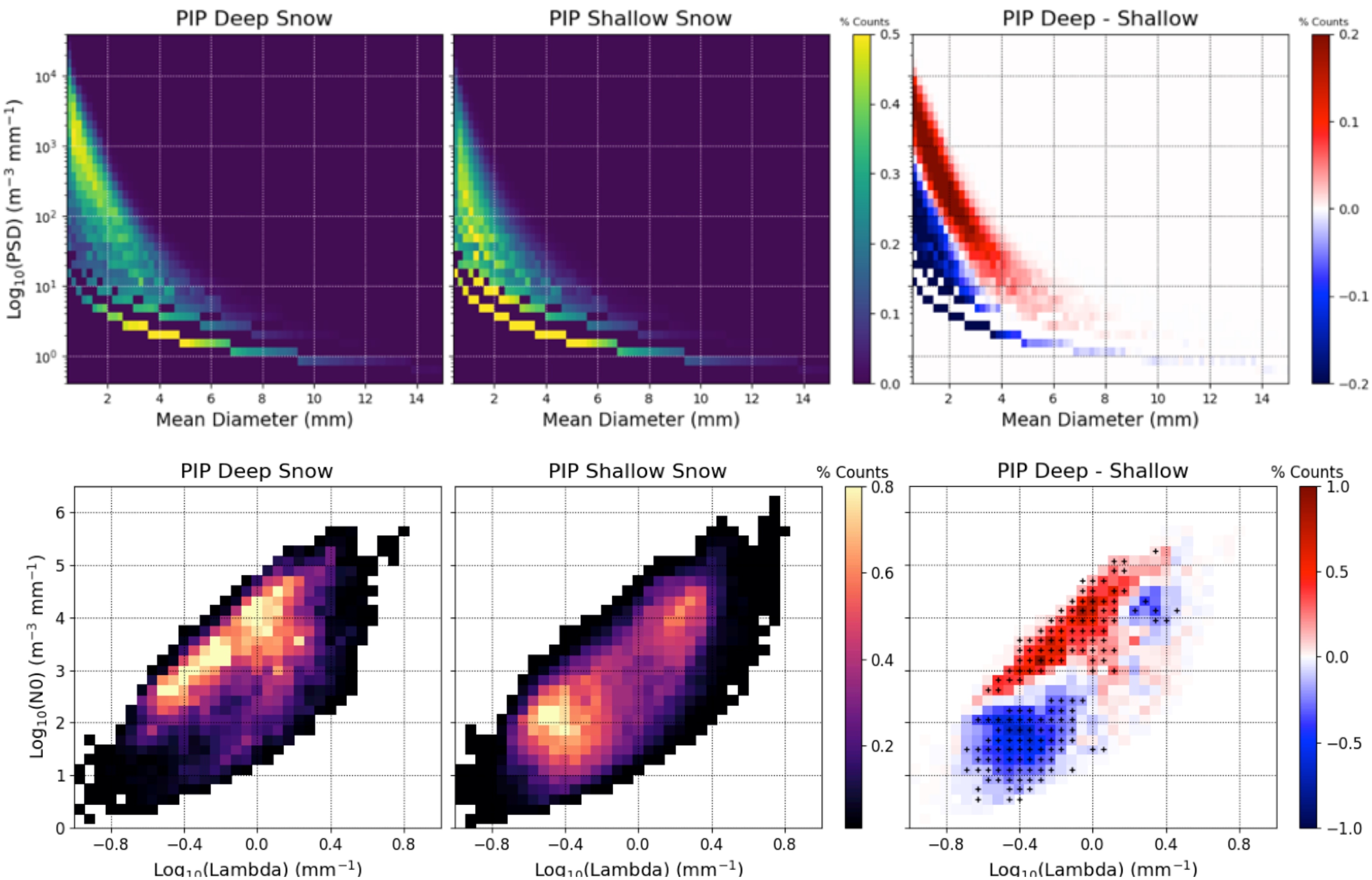
N_o

Λ

Particle Size Distribution: $N(D)=N_o \exp(-\Lambda D)$

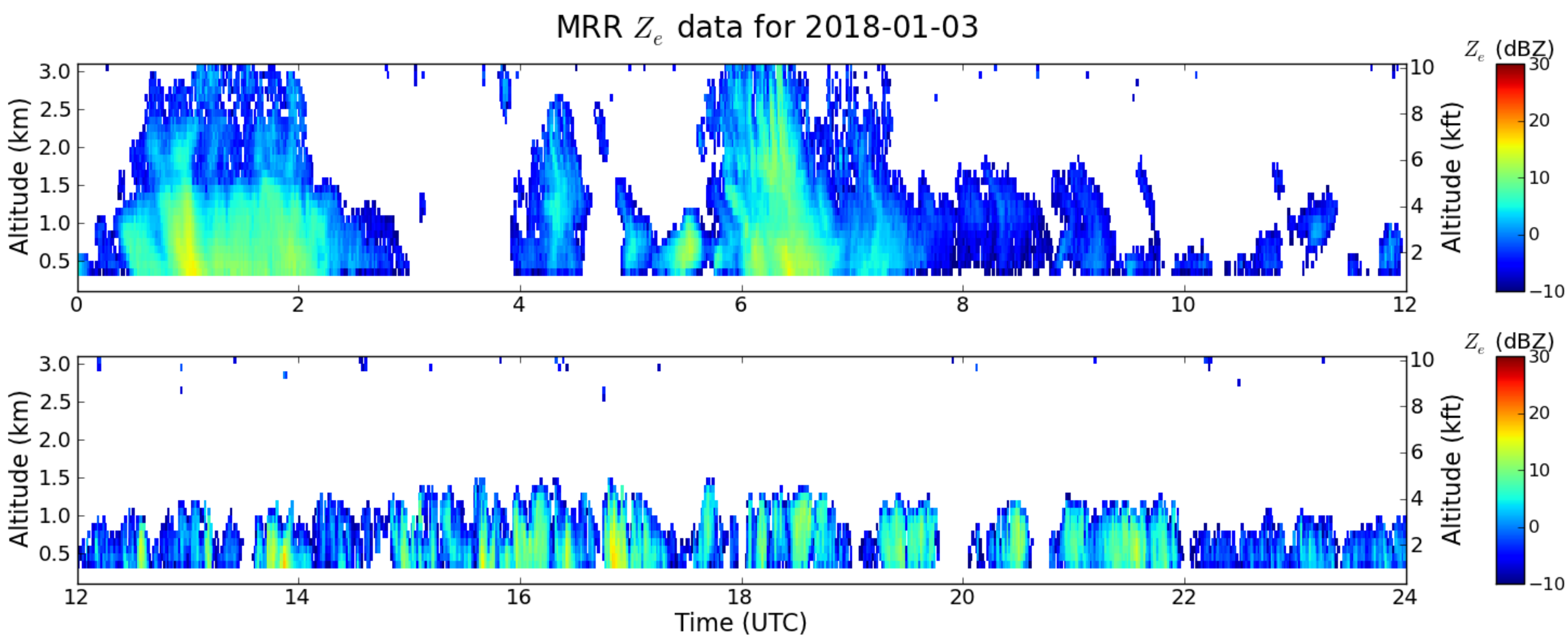
Pettersen et al. (2019) *JAMC*

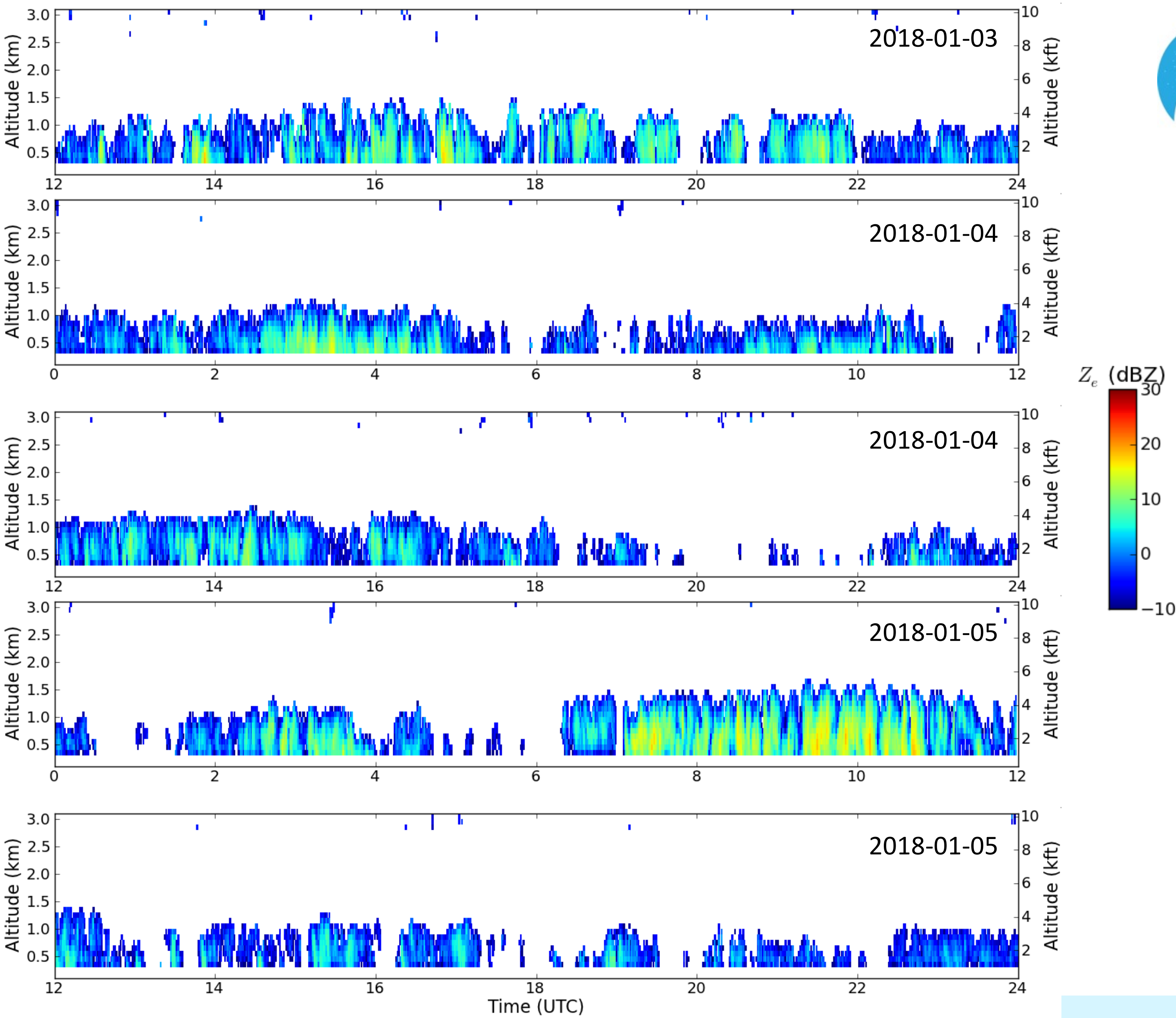
5-Year Dataset Analysis: PIP Microphysics



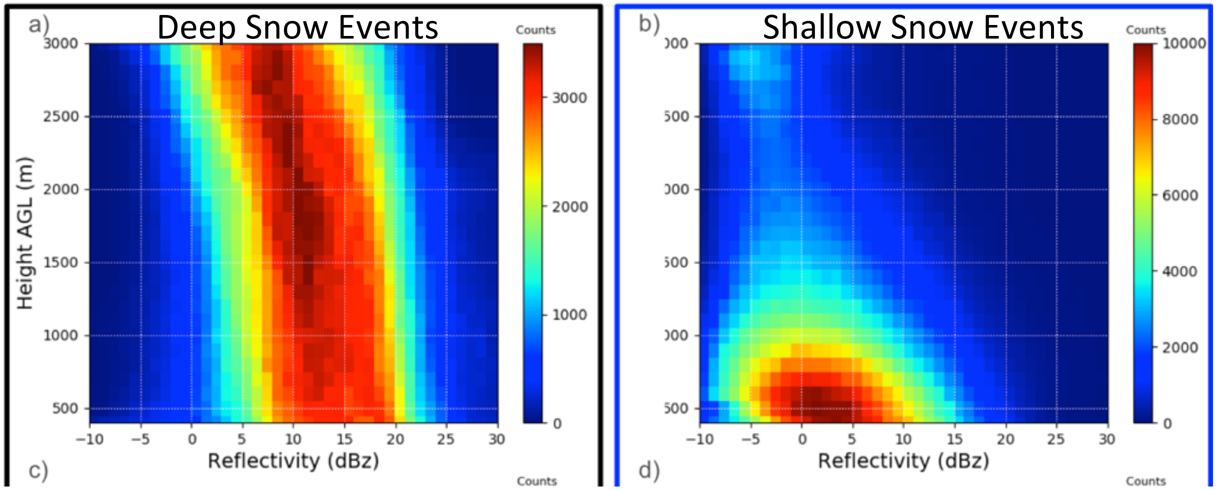
GPM algorithm microphysics assumptions?

Lesson 2: Ignore shallow snow at your own scientific peril!



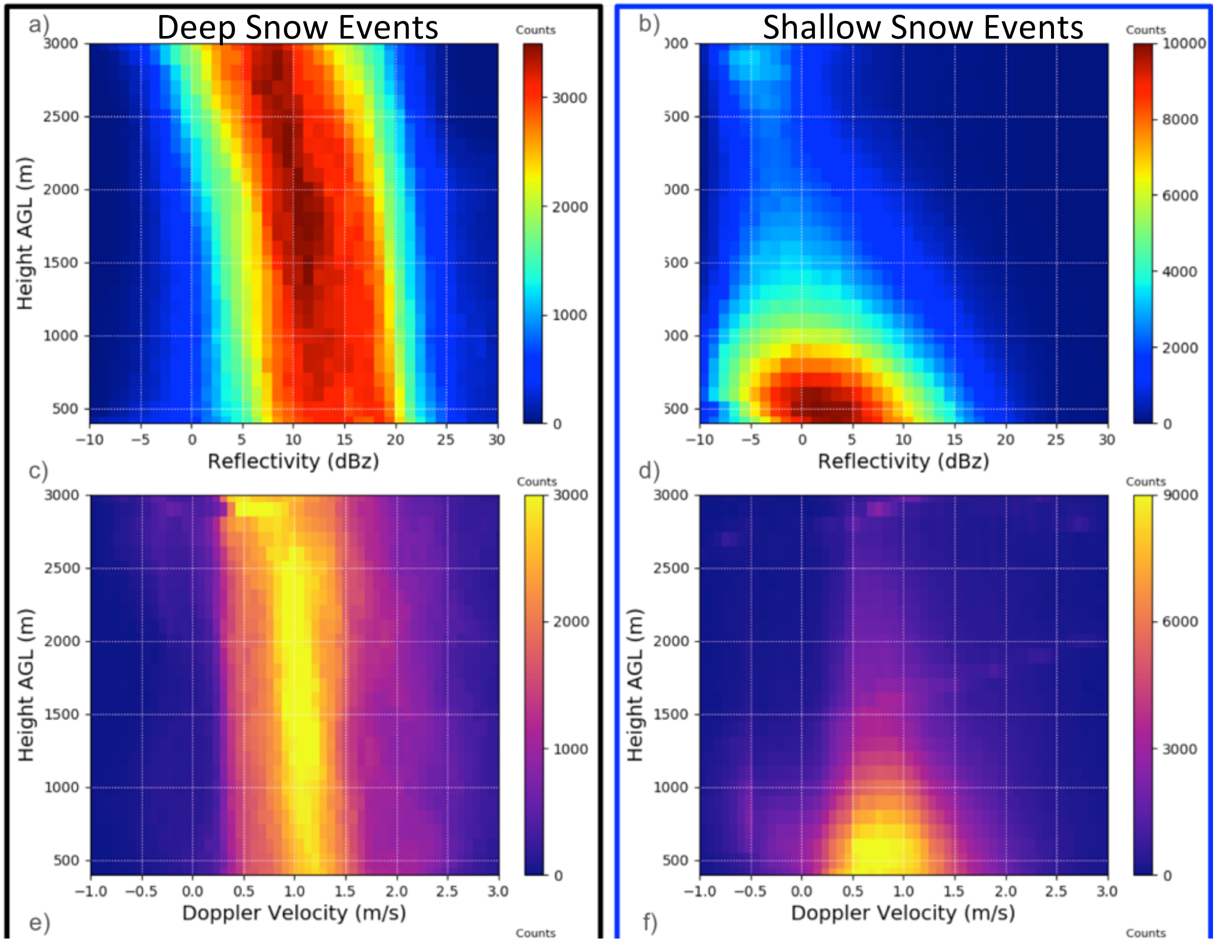

2018-01-03
2018-01-04
2018-01-04
2018-01-05
2018-01-05
Altitude (km)
Altitude (kft)
Time (UTC)
Z_e (dBZ)

MRR-defined



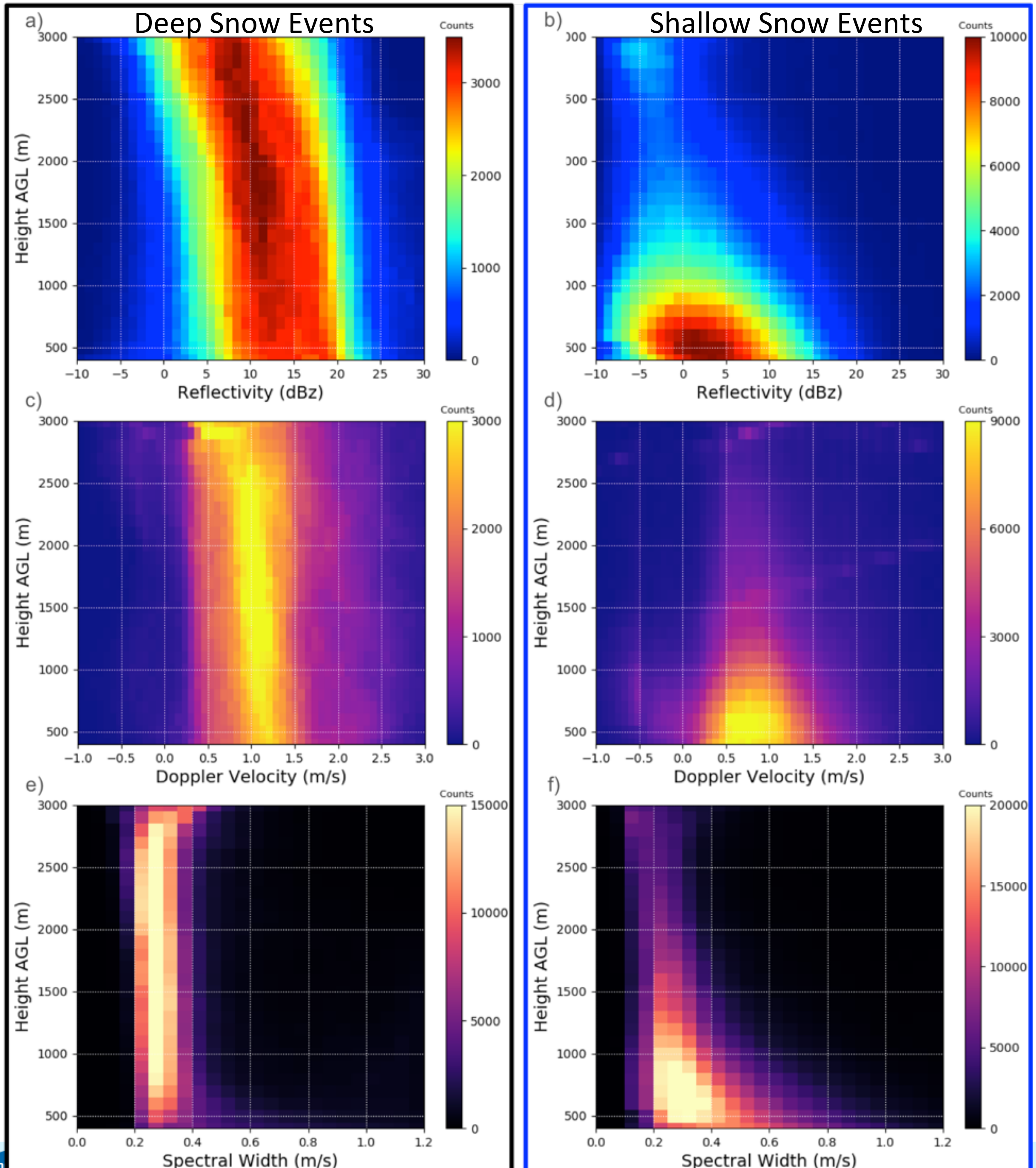
5-Year Dataset Analysis

Pettersen et al. (2019) *JAMC*



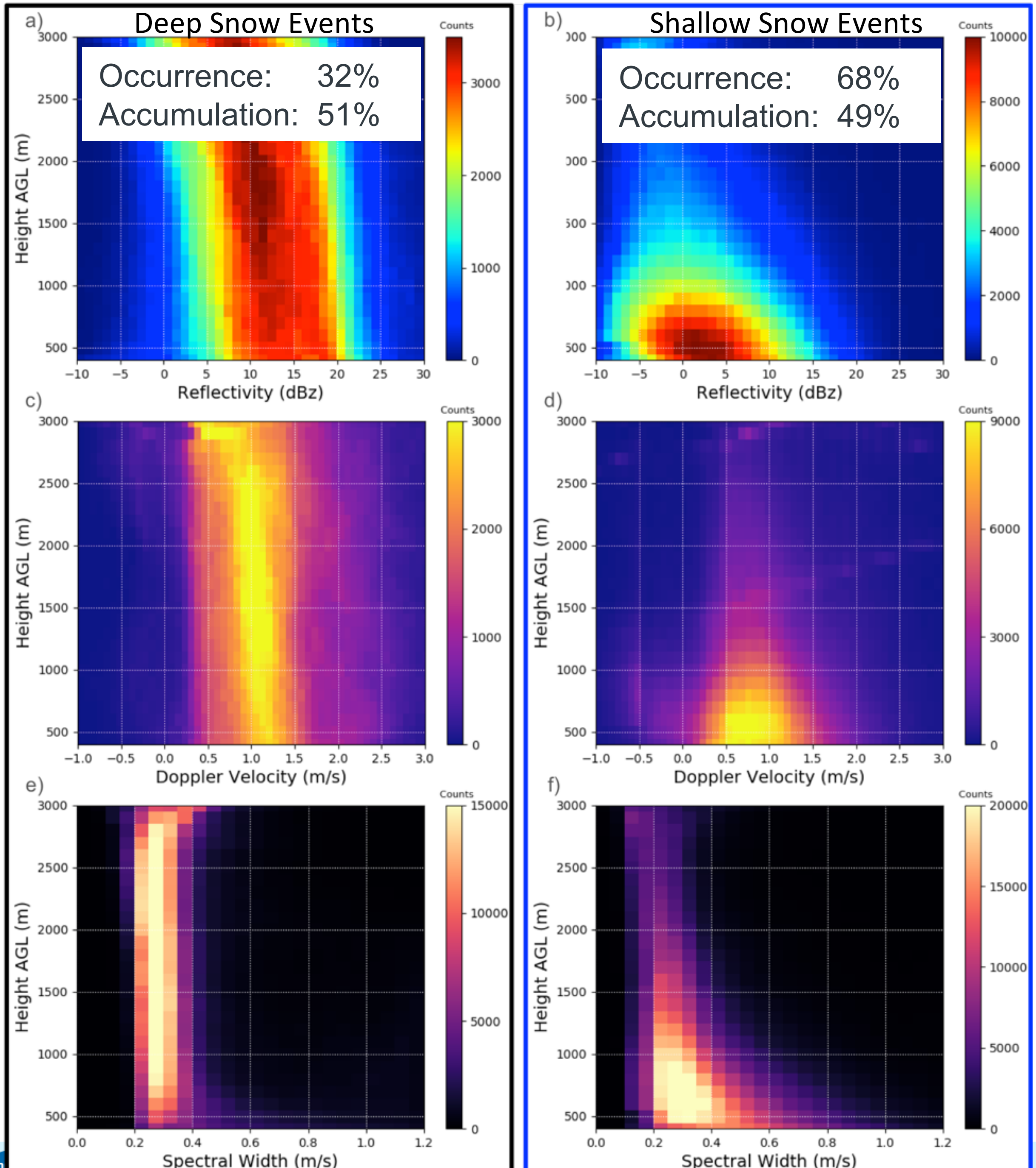
5-Year Dataset Analysis

Pettersen et al. (2019) *JAMC*



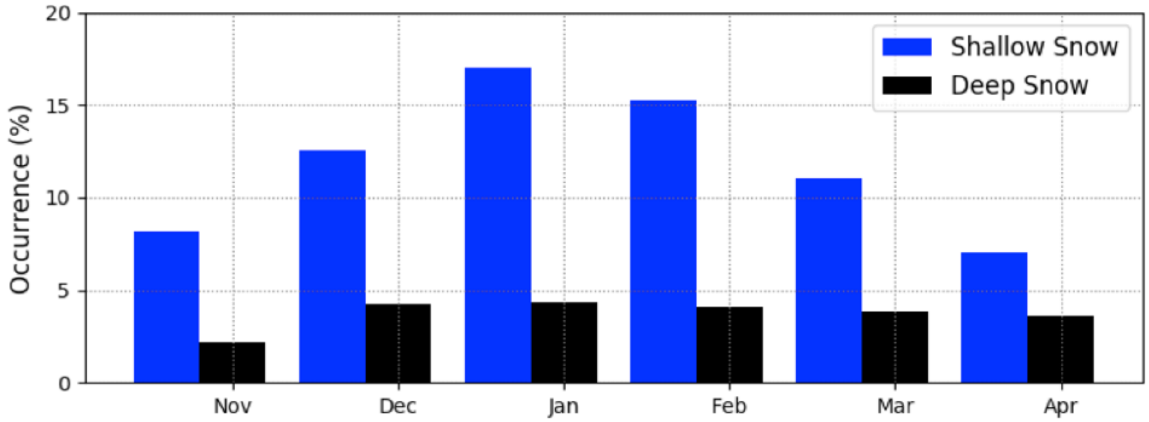
5-Year Dataset Analysis

Pettersen et al. (2019) *JAMC*



5-Year Dataset Analysis

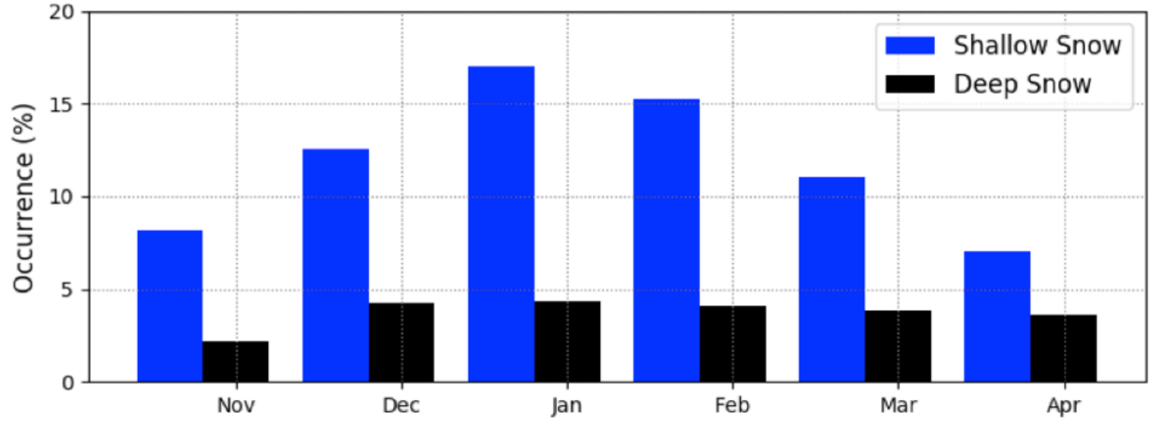
Pettersen et al. (2019) *JAMC*



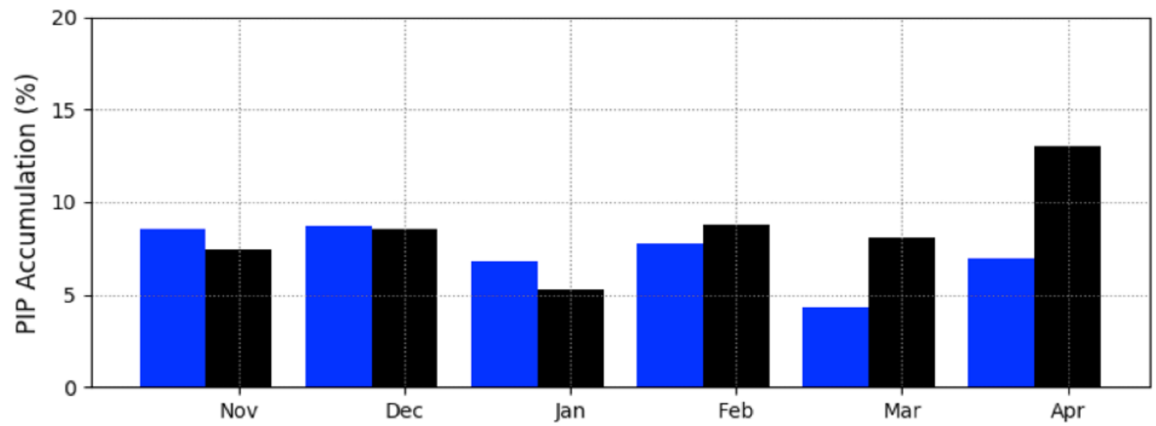
Snowfall Occurrence %

GPM evaluation statistics

Pettersen et al. (2019) *JAMC*



Snowfall Occurrence %



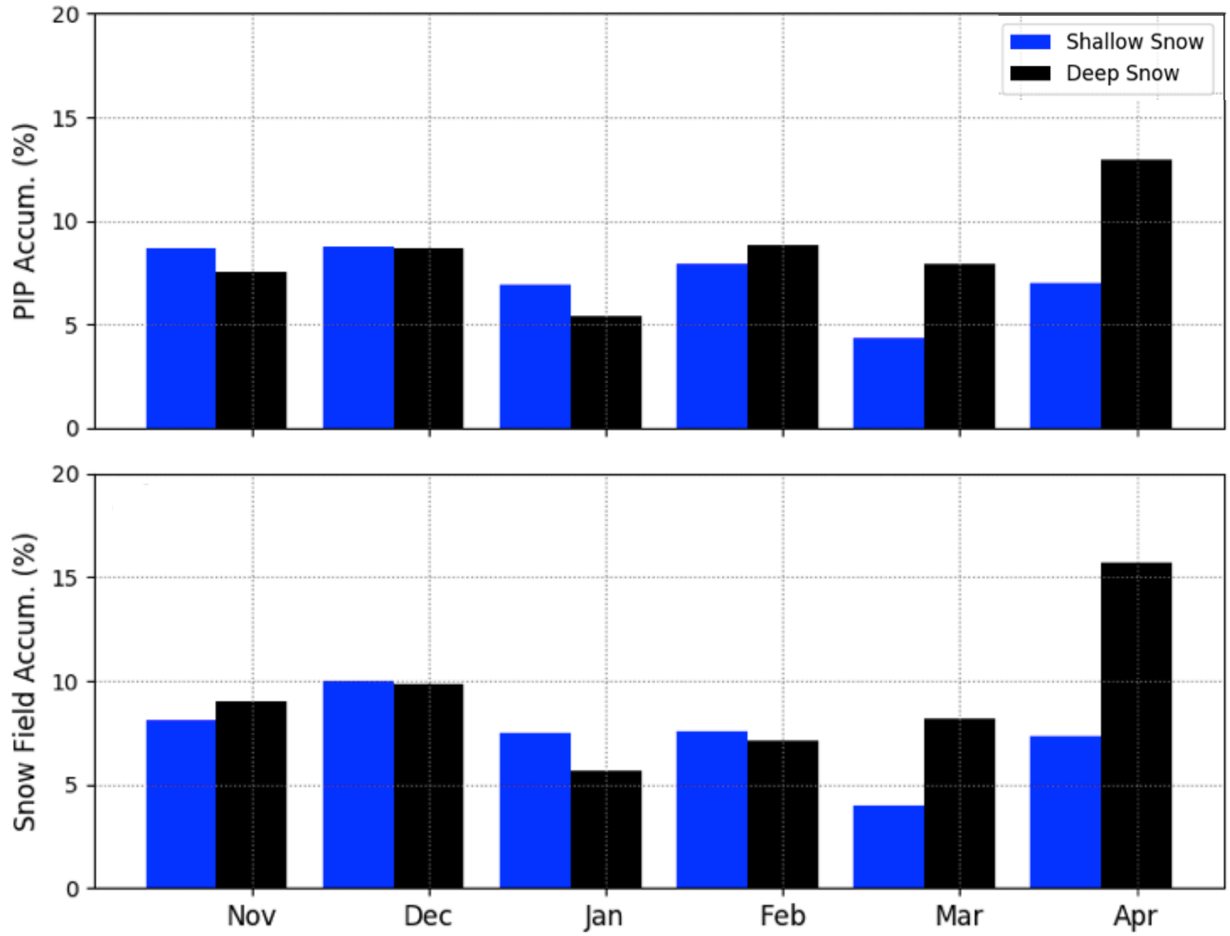
Accumulation Partitioning

Pettersen et al. (2019) *JAMC*

PIP vs. "Manual" NWS Accumulation Statistics

PIP

NWS



Pettersen et al. (2019) *JAMC*

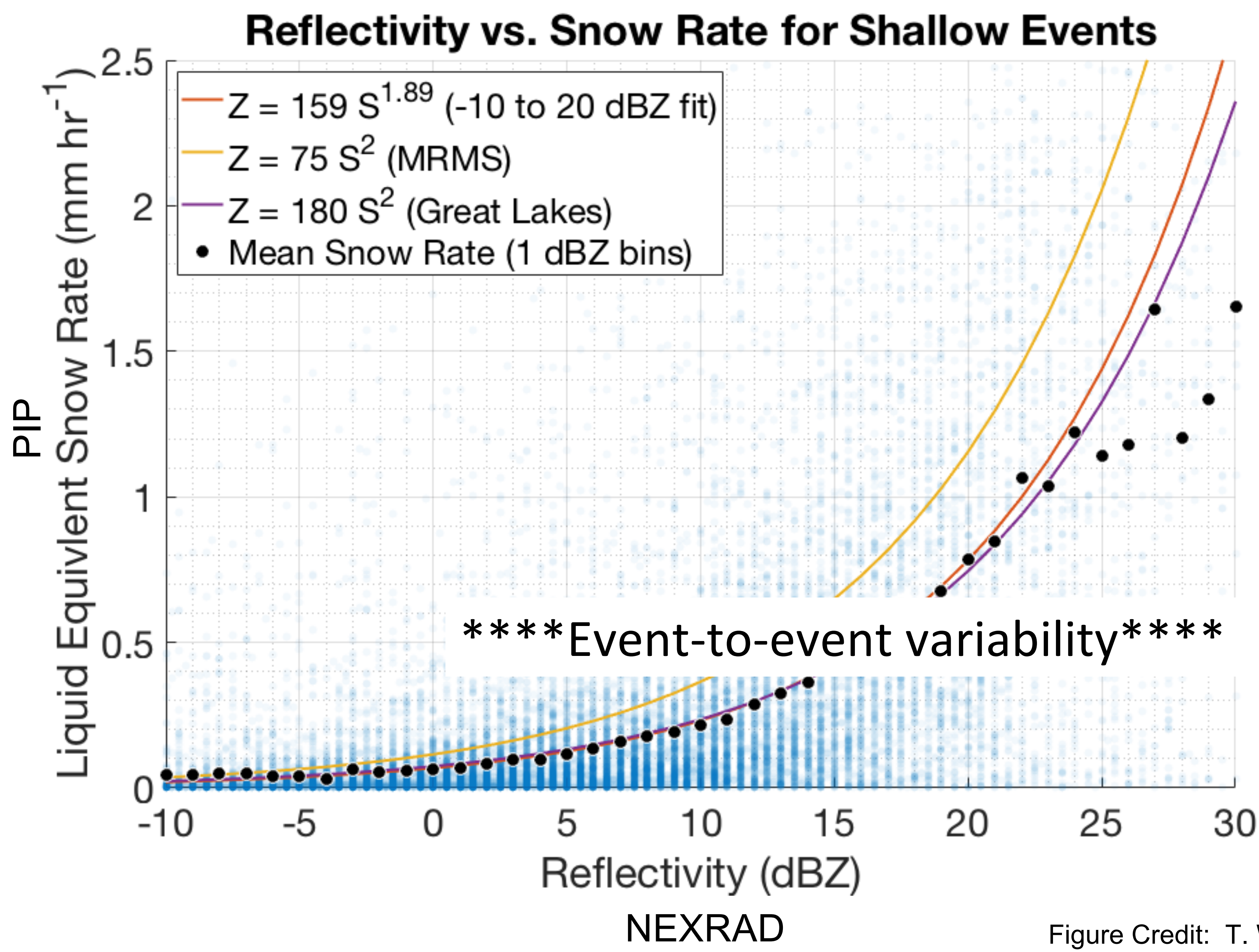


Figure Credit: T. Wagner

Reflectivity vs. Snow Rate for Deep Events

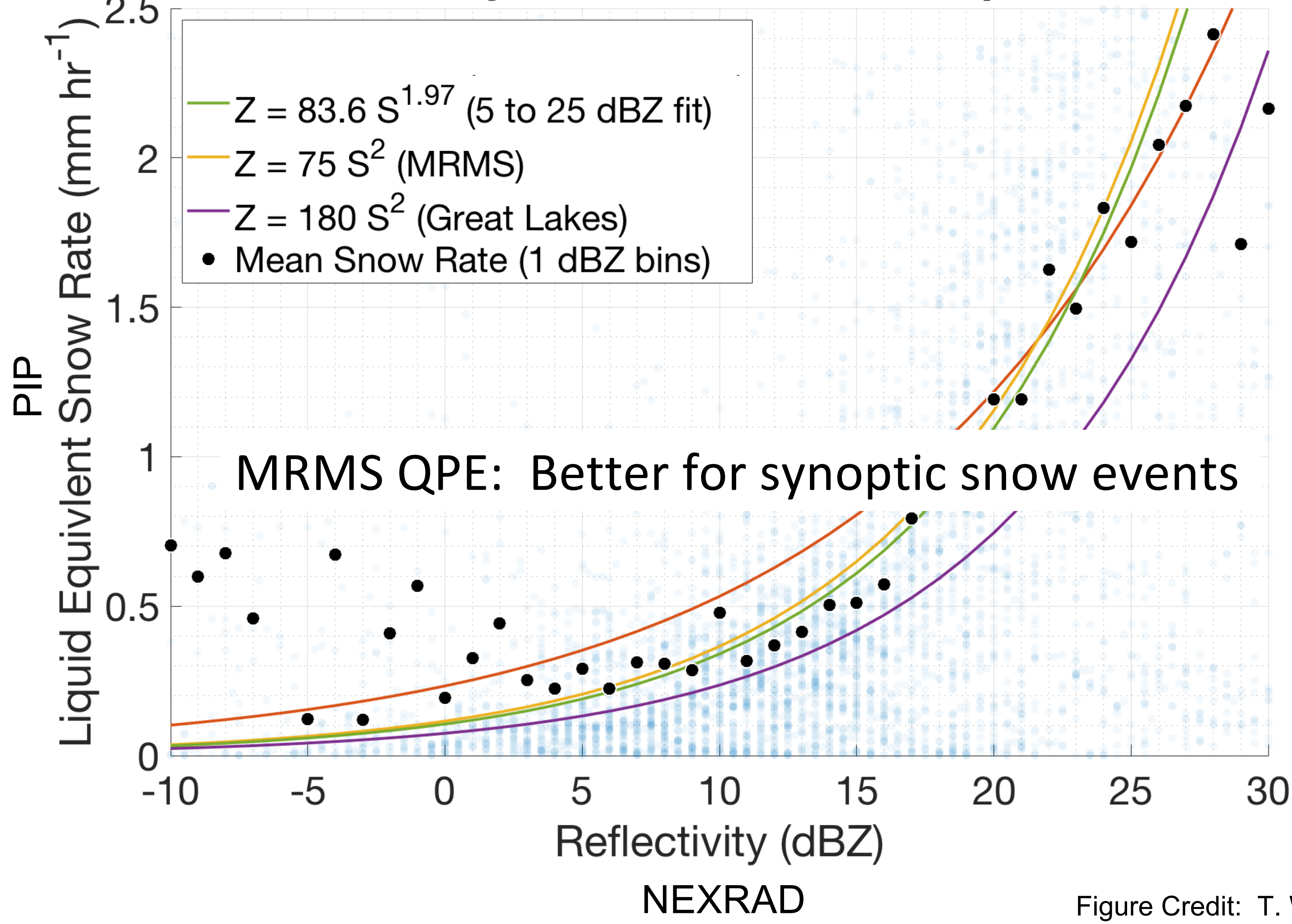
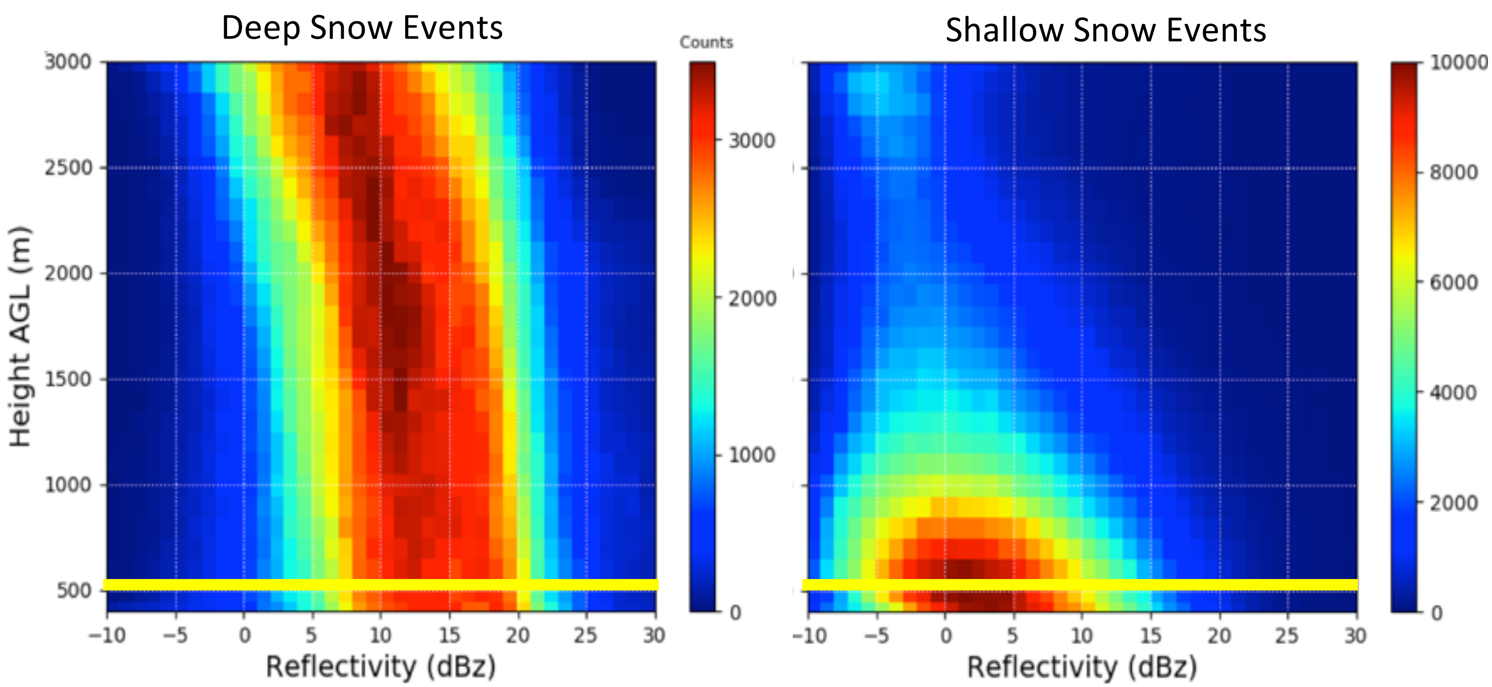


Figure Credit: T. Wagner

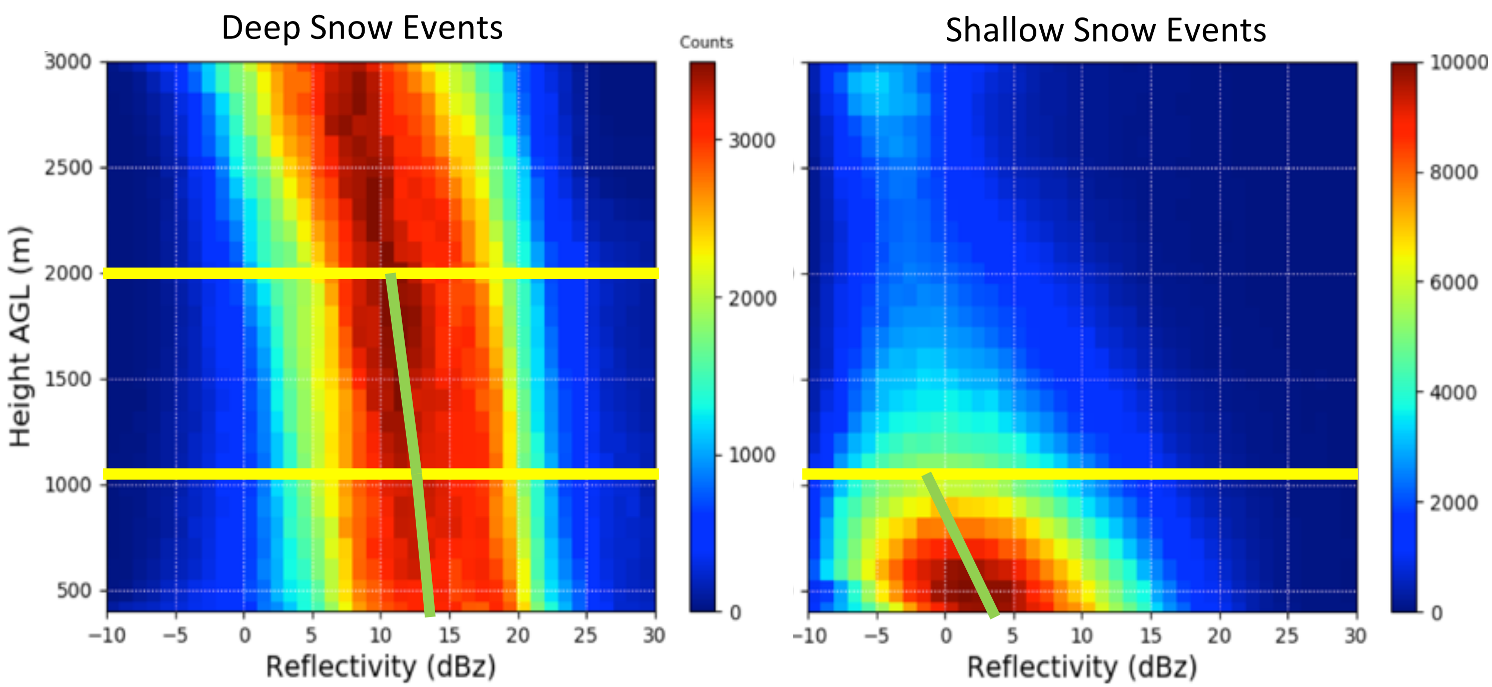
Spaceborne Radar Applications



GPM DPR Nadir Lowest Clutter-Free Bin: ~500 m AGL

Pettersen et al. (2019) *JAMC*

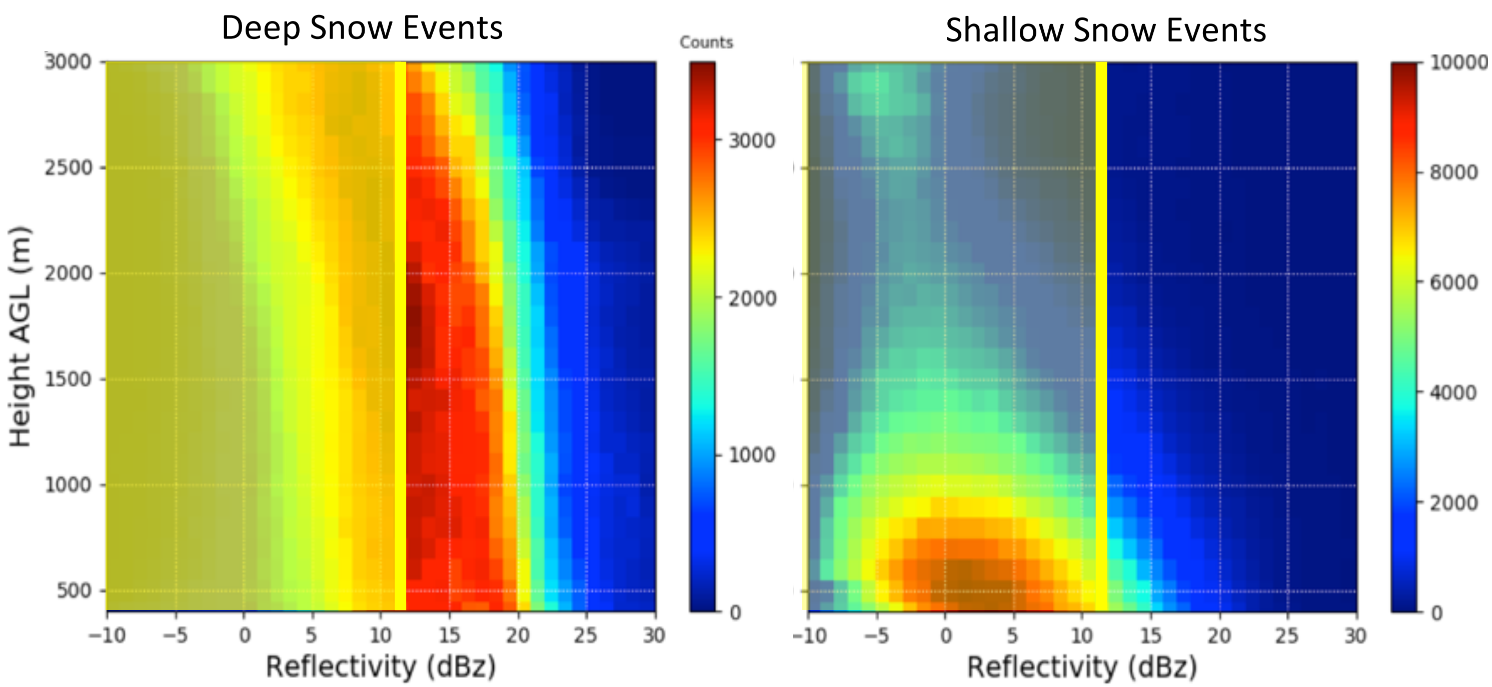
Spaceborne Radar Applications



GPM DPR Off-Nadir Lowest Clutter-Free Bin: > 1-2 km AGL

Pettersen et al. (2019) *JAMC*

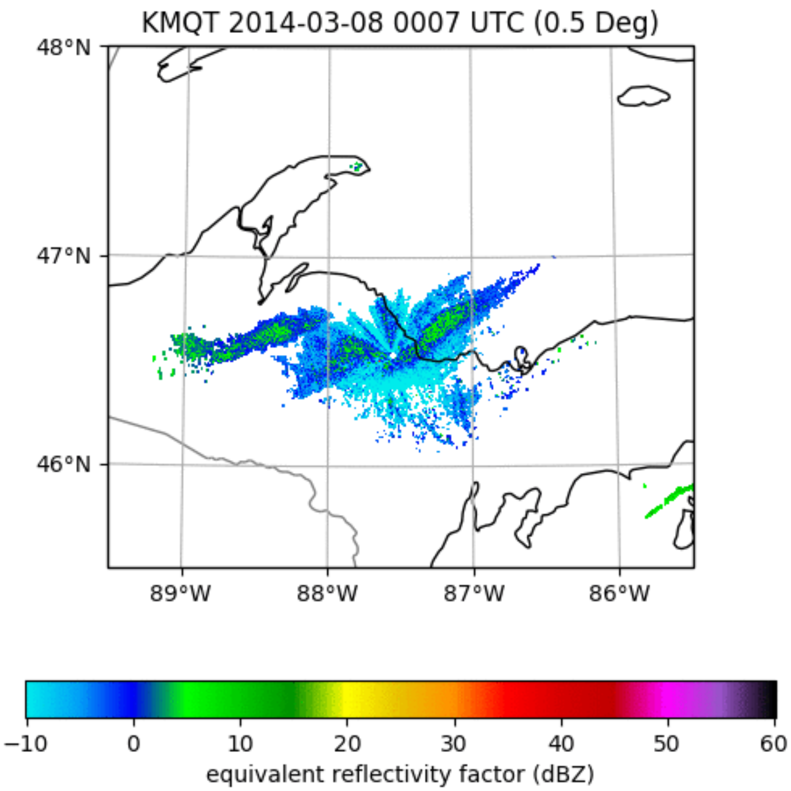
Spaceborne Radar Applications



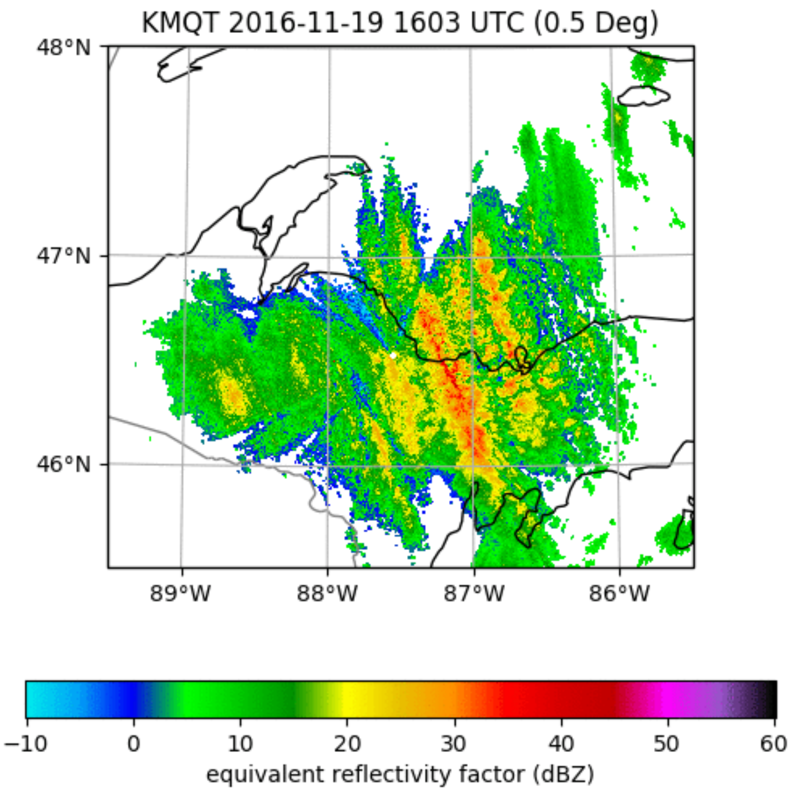
Pettersen et al. (2019) *JAMC*

Lesson 3: Shallow snow – distinct flavors

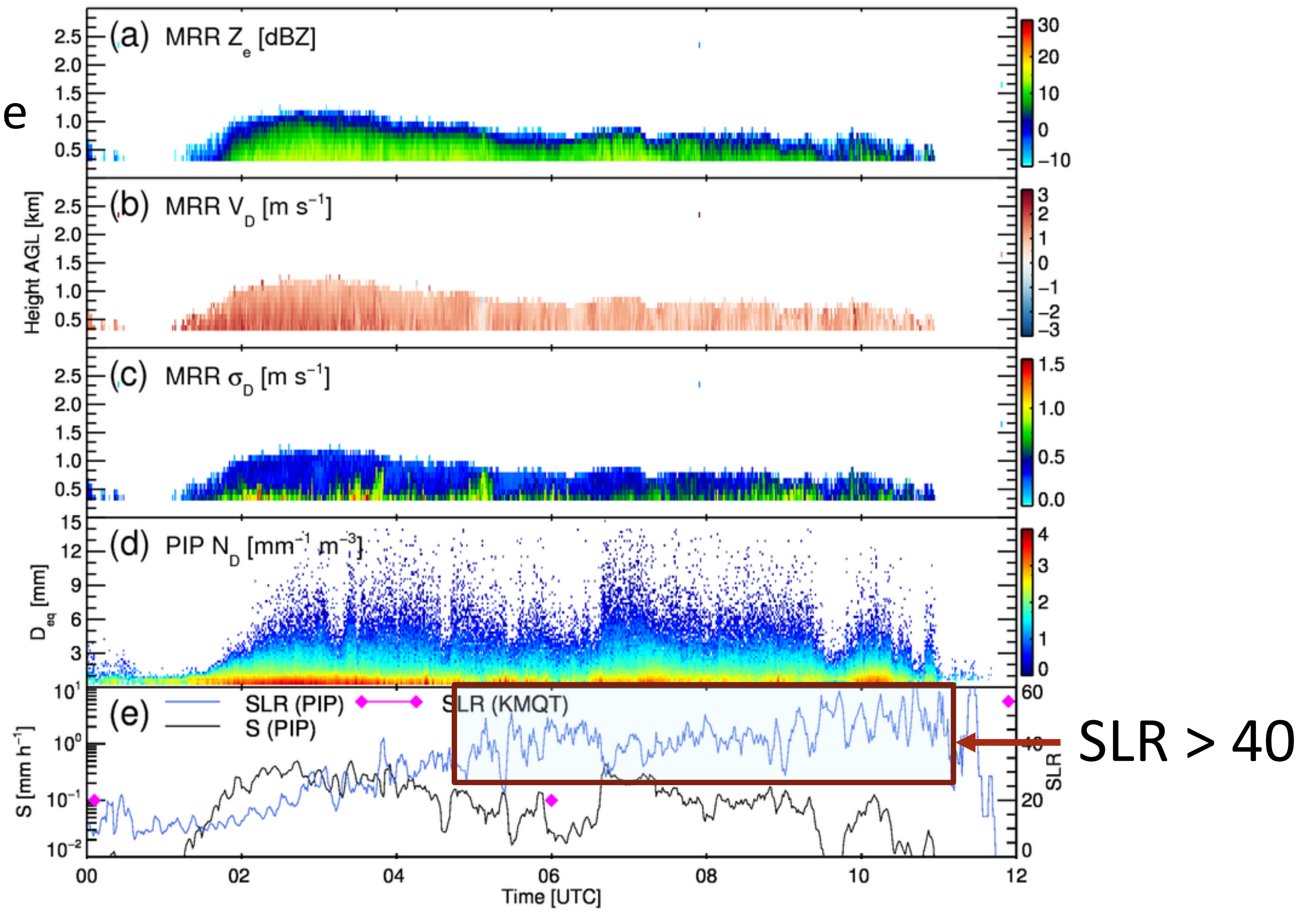
Orographic/Upslope Snow



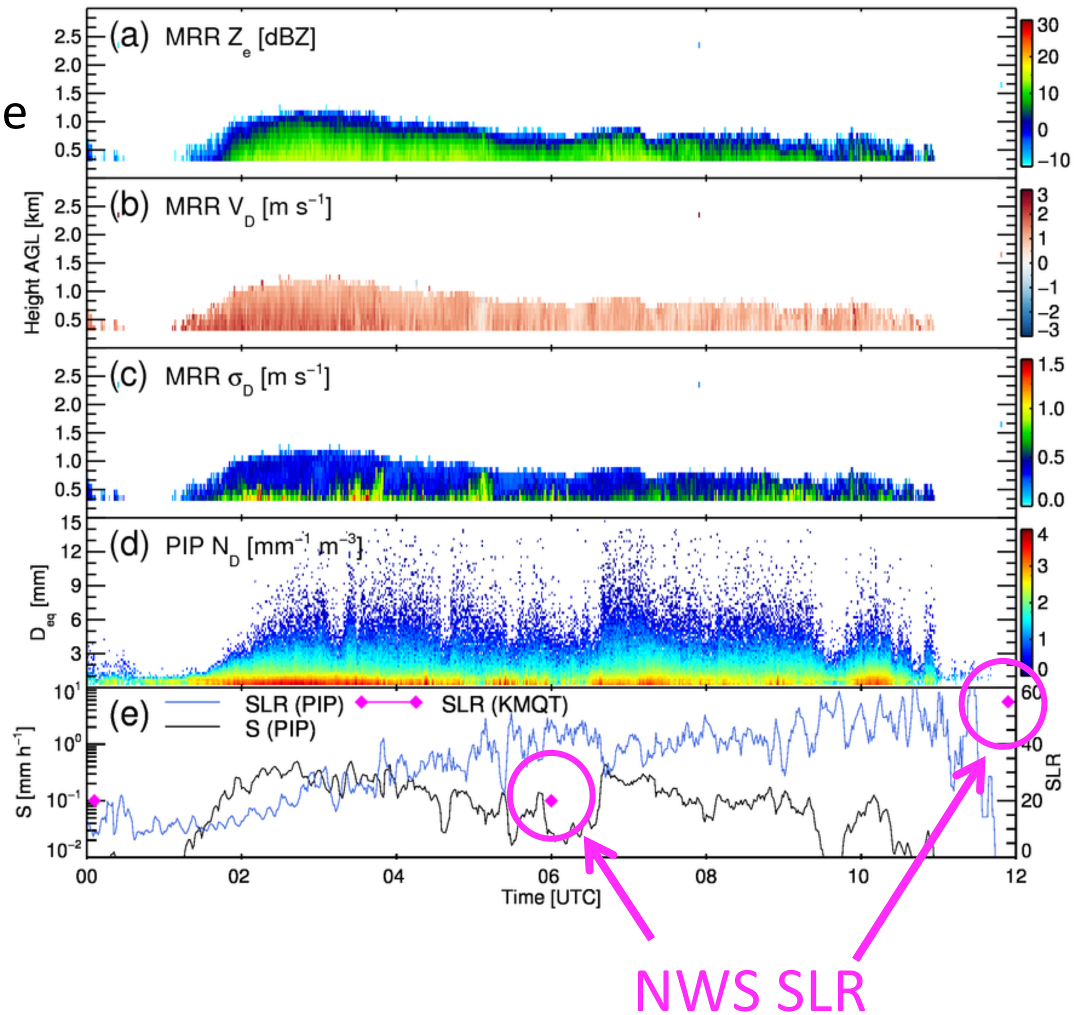
Lake-Effect Snow

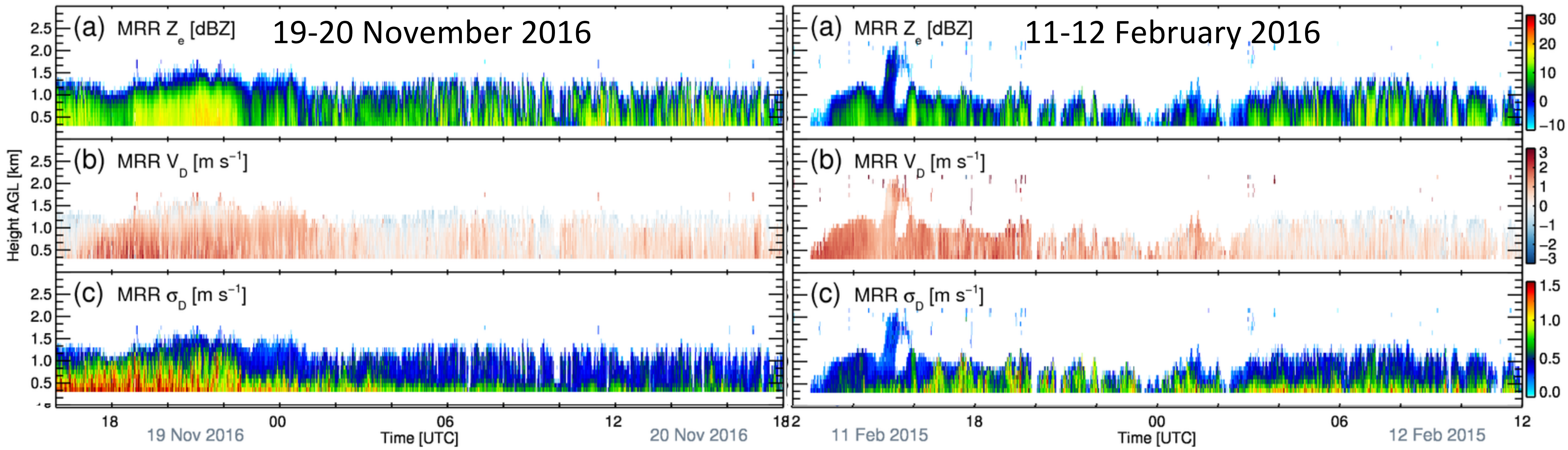


8 March 2014: Orographic/Upslope

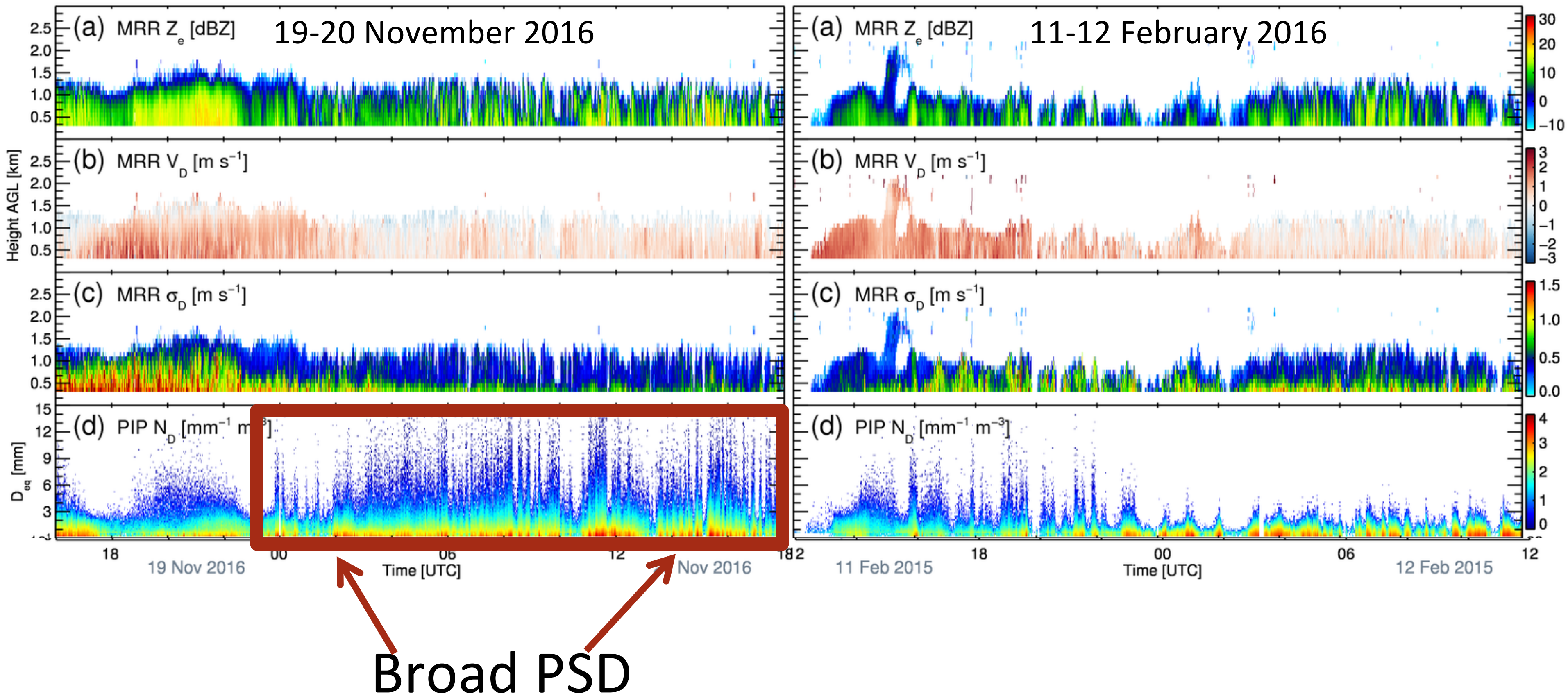


8 March 2014:
Orographic/Upslope

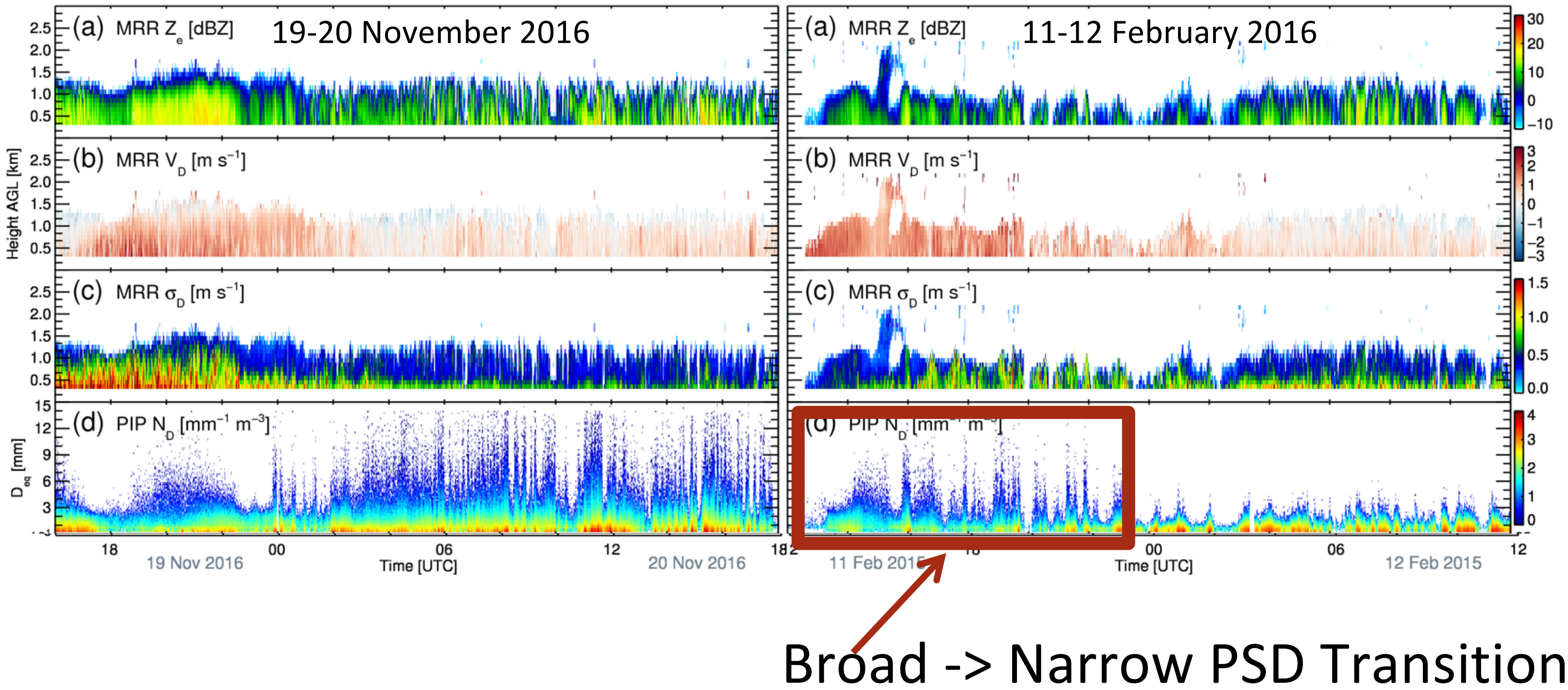




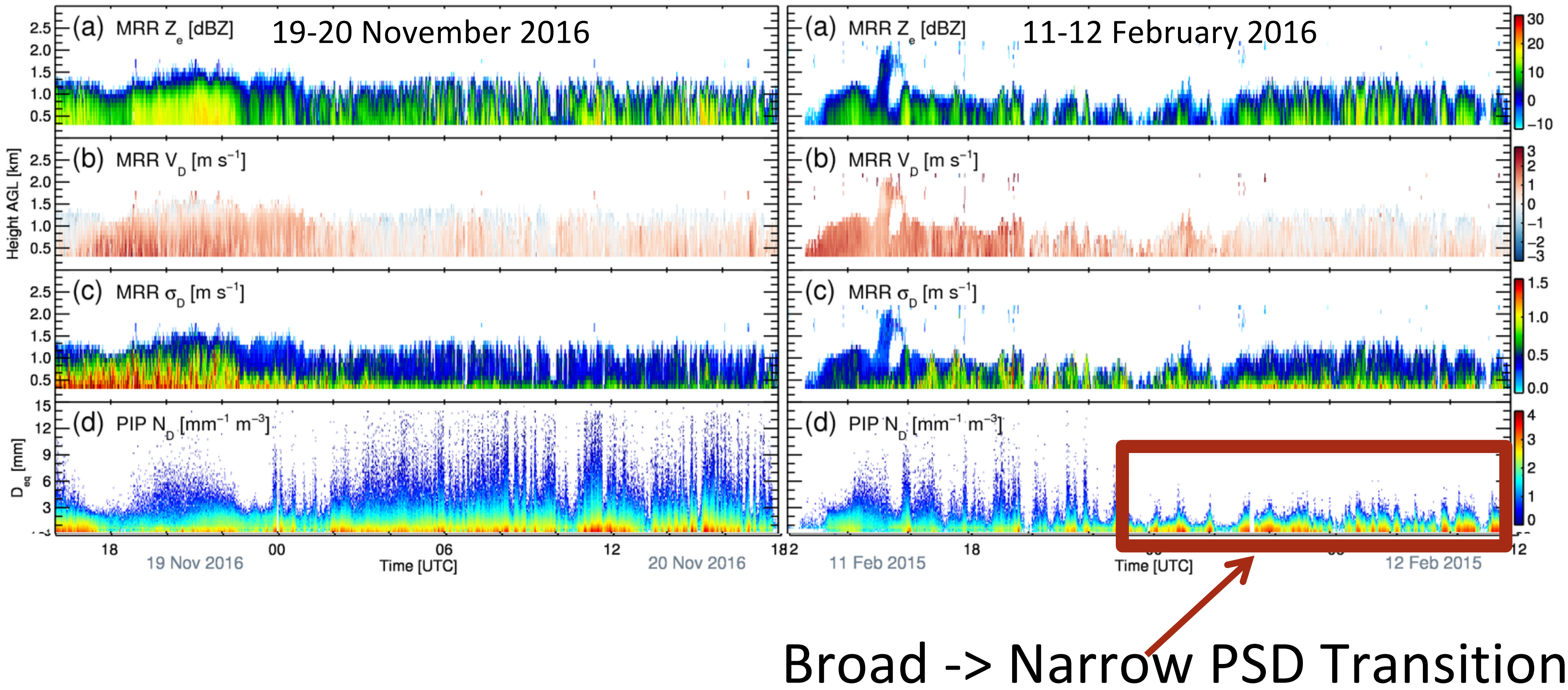
Lake-Effect Snow Variability



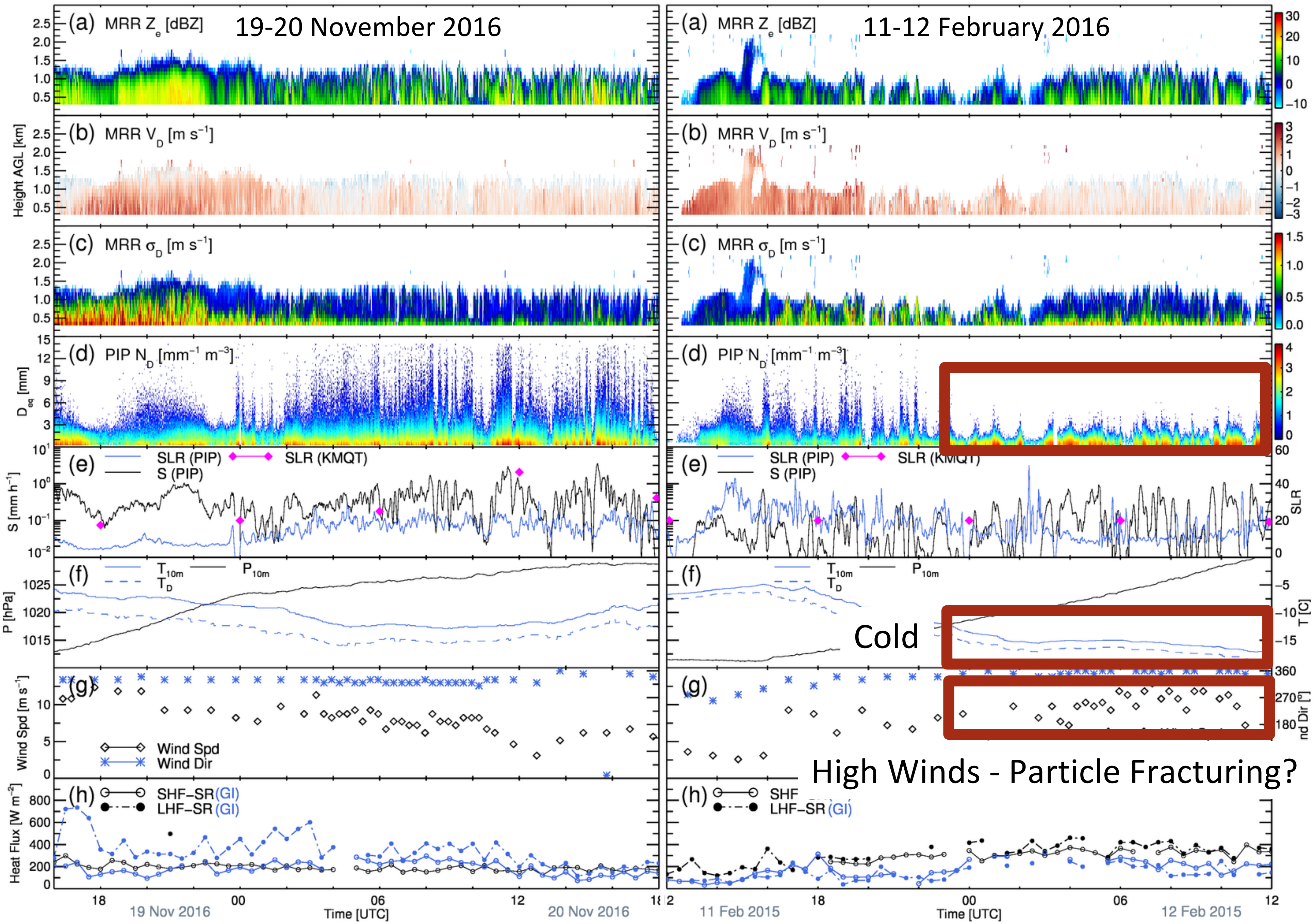
Kulie et al. (2020) *BAMS*



Kulie et al. (2020) *BAMS*

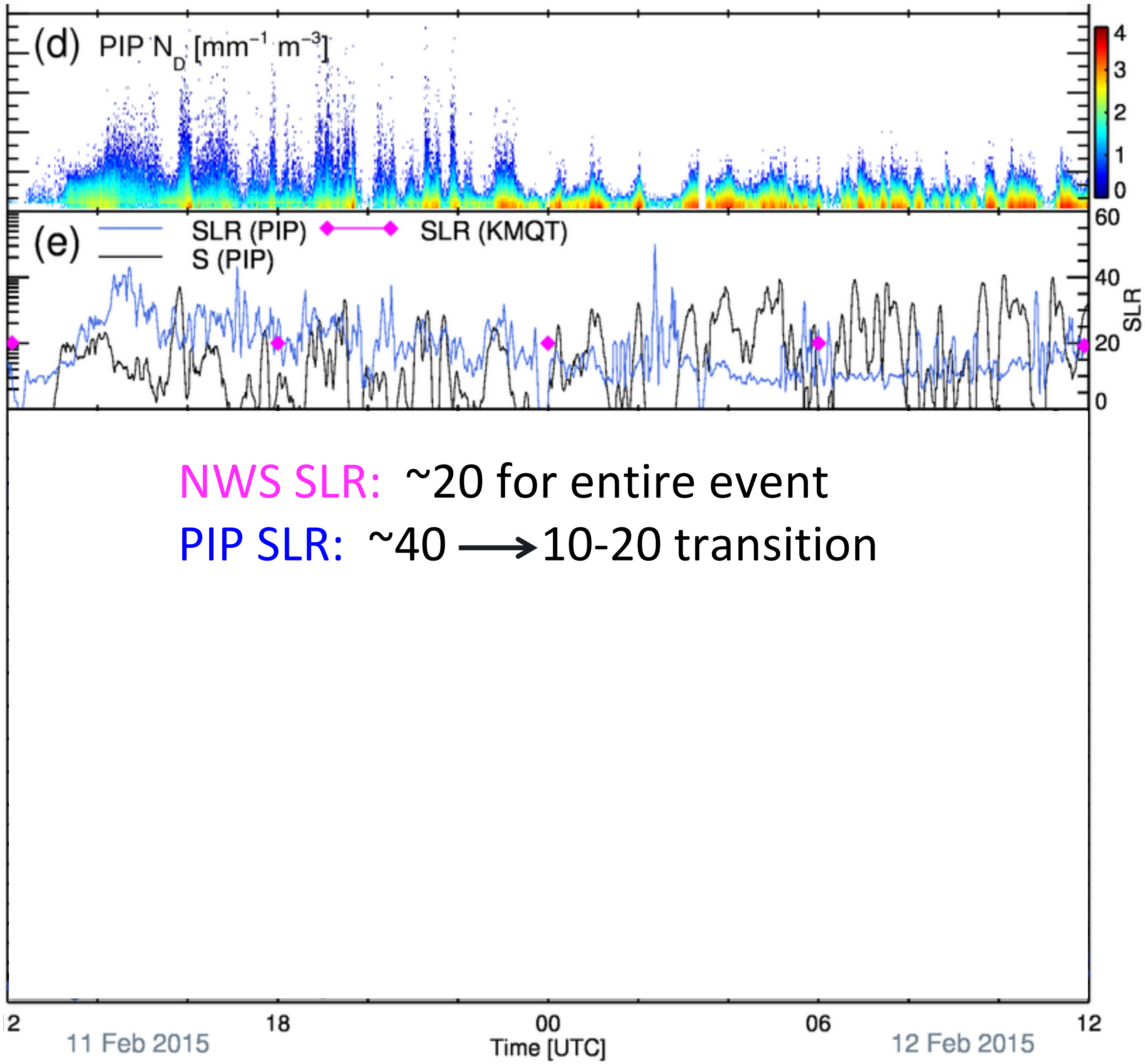


Kulie et al. (2020) *BAMS*



Kulie et al. (2020) *BAMS*

11-12 February 2016



Kulie et al. (2020) *BAMS*

GMI/GPROF Applications

Shallow Convective Snow from a GPM Microwave Imager Perspective: Snowfall Quantitative Precipitation Estimation Strengths and Weaknesses

Lisa Milani[1,2], Mark S. Kulie[3], Daniele Casella[4], Pierre E. Kirstetter[5], Giulia Panegrossi[4], Veljko Petkovic[1,6,7], Sarah E. Ringerud[1,2], Jean-François Rysman[8], Paolo Sanò[4], Gail Skofronick-Jackson[9], Nai-Yu Wang[1], Yalei You[1]

[1]Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD
[2]NASA Goddard Space Flight Center, Greenbelt, MD
[3]NOAA/NESDIS/STAR/Advanced Satellite Products Branch, United States
[4]Institute of Atmospheric Sciences and Climate, National Research Council, Rome, Italy
[5]University of Oklahoma, Norman, OK / NOAA
[6]Department of Atmospheric Science, Colorado State University, Fort Collins, CO
[7]Cooperative Institute for Climate and Satellites-Maryland, University of Maryland
[8]Laboratoire de Météorologie Dynamique, CNRS, Palaiseau, France
[9]NASA Headquarters, Washington DC

Introduction

Shallow convective snow related to cold air outbreaks interacting with large bodies of unfrozen water influences regional hydrology and is often associated with extreme snowfall accumulation events. This work focuses on the ability of the Global Precipitation Measurement (GPM) passive microwave sensors to detect and provide quantitative precipitation estimates for intense convective lake-effect snowfall events over the United States Lower Great Lakes region.

The two main scientific questions we want to address with this work are:

- Is GPM's Microwave Imager (GMI) able to detect intense shallow convective snowfall events?
- If yes, is the GMI Goddard PROfiling (GPROF) algorithm able to translate the TB's signal into physically meaningful snowfall rate estimates?

Case Studies

We present here two intense, multi-day lake-effect snow events, on November 19-21 2014 and January 8-10 2015 over the Lower Great Lakes Region. GPM overpasses the region of interest on November 20 2014 at 18.20 UTC (orbit #4140) and on January 09 2015 at 12.26 UTC (orbit #4914).

TB's signatures:

- In both cases high frequencies (89 to 183 GHz) Brightness Temperature (TB) signatures show a clear signals (e.g., TB depressions due to ice scattering in intense snow bands and/or TB increases due to cloud liquid water emission at 89 GHz) for the snow bands over Lakes Erie and Ontario (figs.1 and 2).

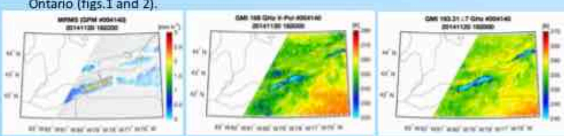


Figure 1: a) MRMS precipitation product and GMI b) 166 GHz V-pol and c) 183 ± 7 GHz TBs over Lakes Erie and Ontario on 20 November 2014 at 1820 UTC (orbit #4140).

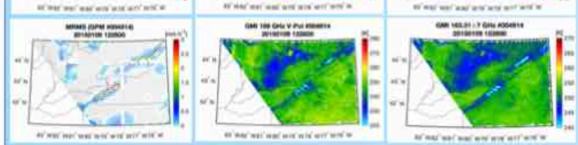


Figure 2: a) MRMS precipitation product and GMI b) 166 GHz V-pol and c) 183 ± 7 GHz TBs over Lakes Erie and Ontario on 09 January 2015 at 12.26 UTC (orbit #4914).

'Original' GPROF (V05)

- Comparing original GPROF (precipitation threshold 0 mmh^{-1}) to MRMS precipitation product (precipitation threshold 0.1 mmh^{-1}):
  - Many false alarm pixels over land (Table 1 'FAR orig.')
  - The 'non random hit' rate is low in both cases (Table 1 'HSS orig.')
  - Correlation is higher for #4140 (R=0.65) and lower for #4914 (R=0.43)

'Precipitation Rate Threshold' (PRT) GPROF (V05)

- Since GPROF indicates light precipitation over non precipitating areas according to MRMS, we filtered out false precipitating pixels applying a Precipitation Rate Threshold (PRT). PRT has been chosen case-by-case with an HSS systematic analysis (PRT=0.08 mmh^{-1} #4140, PRT=0.11 mmh^{-1} #4914)
  - FAR and HSS are both improved (Table 1 'FAR PRT' and 'HSS PRT')
  - Correlation is improved for #4914 and slightly decreased for #4140 (Table 1 'R PRT')

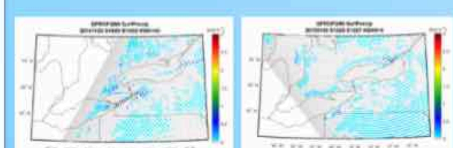


Figure 3: 'Original' GPROF precipitation rate (using SurfPrecip parameter) with 0 mmh^{-1} precipitation threshold for a) orbit #4140 and b) orbit #4914.

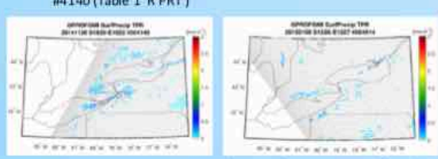


Figure 4: PRT GPROF precipitation rate (using SurfPrecip parameter) for a) orbit #4140 with 0.08 mmh^{-1} precipitation threshold and b) orbit #4914 with 0.11 mmh^{-1} precipitation threshold.

Results

- *A-priori database representativeness*

Considering 'coastline' and 'snow covered' surfaces, the number of profiles within the TPW<5 mm and T2m<273 K sub-sets (bins in the bottom left corner of the plots, red lines plotted as reference – Fig.5), is low, with just 1.3% of all precipitating elements for 'coastline' (fig.5a) and 7,2% of 'Maximum snow cover' sub-set (Fig.5b).

The Probability Density Functions (PDFs) of each *a-priori* database sub-set illustrate the low probability of higher precipitation rate events within the database. Only 120 (126) elements with rates over 1 mmh^{-1} are found in the 'coastline' ('maximum snow cover') for T2m<273K and TPW<5mm (black and light blue solid lines in Fig.6) corresponding to the only 0.03% (0.3%) of all precipitating elements in the *a-priori* low T2m and low TPW subsets.

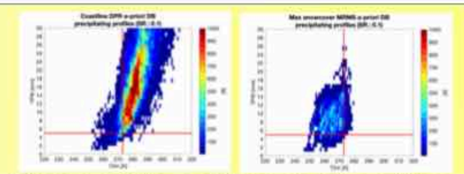


Figure 5: 2D distributions of GPROF a-priori database elements (surface precipitation elements with PR ≥ 0.1 mm h^{-1}) (red lines for T2m=273K and TPW=5mm are plotted as reference). GPM (GMI and DPR) data from September 2014 to August 2015 are used to construct the coastal GPROF a-priori database and GMI and MRMS data from April 2014 to August 2016 are used to construct the snow cover GPROF a-priori database. a) DPR a-priori database is used for 'coastline' b) MRMS-GV a-priori database is used for 'maximum snow cover'.

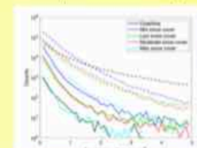


Figure 6: PDFs of precipitation rates associated with precipitating elements in the a-priori databases. Dashed lines represent the distribution of all precipitating events (PR≥0.1 mm h^{-1}), solid lines precipitating events with T2m<273K and TPW<5mm. Colors represent the different surface types.

- *Surface classification*

Since snow covered surfaces are classified by a monthly surface emissivity 'climatology' or the daily Autosnow NOAA product, the surface classification, mainly for 'coastline' could sometimes be misclassified. We forced GPROF to consider all surfaces as snow covered and therefore the only MRMS a-priori database has been used for test purposes. In fig.7, the resulting maps show that there is an improvement from both a detection and a quantification viewpoint (Table 1 'forced surf.' columns).

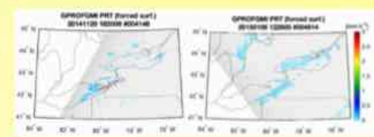


Figure 7: GPROF retrieval forcing the use of only MRMS a-priori database for a) orbit #4140 and b) orbit #4914

- *High frequency channels sensitivity*

The sensitivity of the retrieval to high frequency channels is based on pre launch calculations and some tests demonstrated that changing the sensitivity, there is an actual improvement in the snowfall retrieval and detection performances (maps are shown in fig.8 and statistical scores in Table 1 'ch sens.' columns).

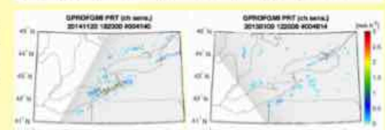


Figure 8: GPROF retrieval with a different combination of channel sensitivity for a) orbit #4140 and b) orbit #4914

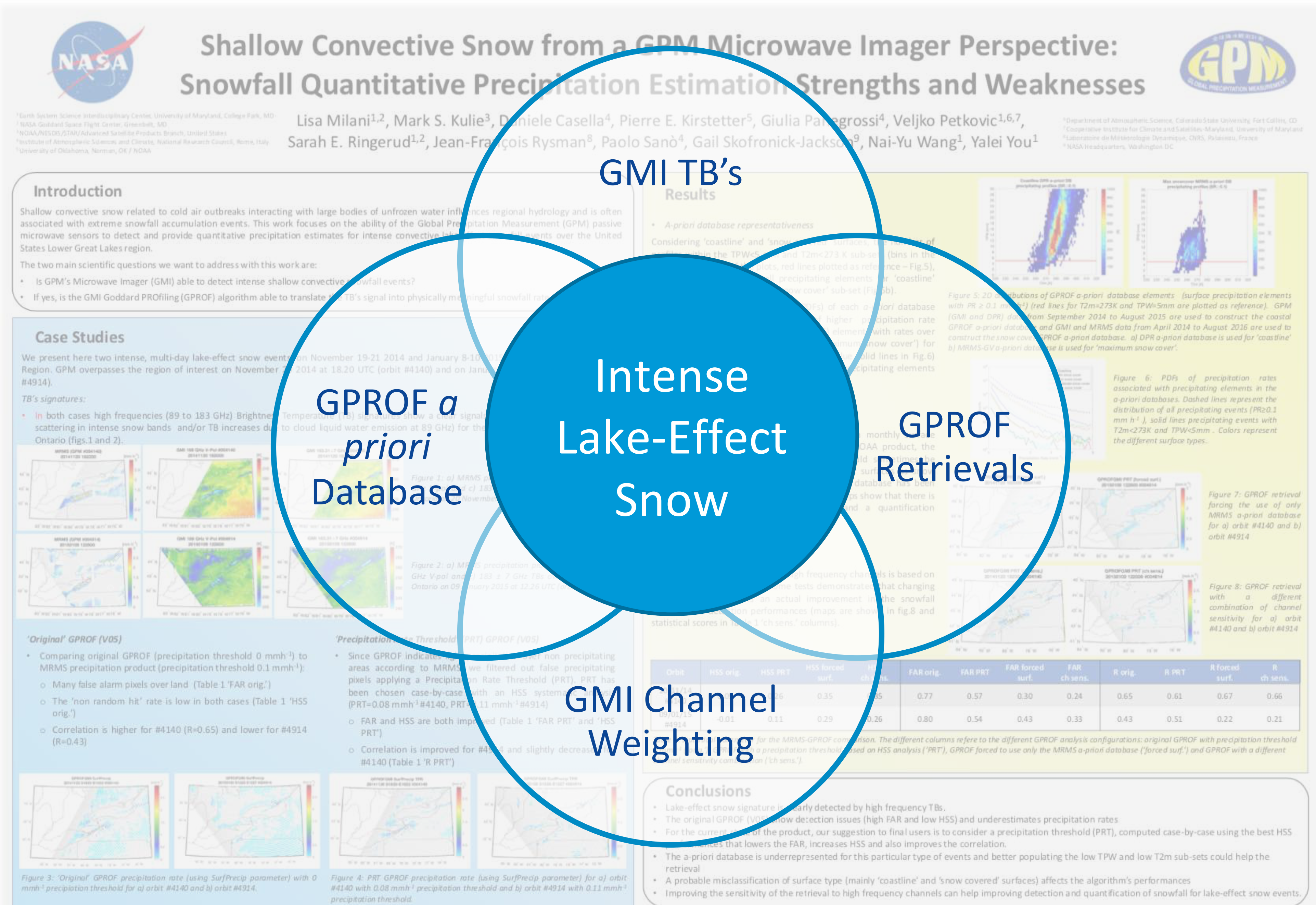
Orbit	HSS orig.	HSS PRT	HSS forced surf.	HSS ch sens.	FAR orig.	FAR PRT	FAR forced surf.	FAR ch sens.	R orig.	R PRT	R forced surf.	R ch sens.
20/11/14 #4140	0.09	0.26	0.35	0.35	0.77	0.57	0.30	0.24	0.65	0.61	0.67	0.66
09/01/15 #4914	-0.01	0.11	0.29	0.26	0.80	0.54	0.43	0.33	0.43	0.51	0.22	0.21

Table 1: statistical parameter for the MRMS-GPROF comparison. The different columns refere to the different GPROF analysis configurations: original GPROF with precipitation threshold 0 mmh^{-1} ('orig.'), GPROF with a precipitation threshold based on HSS analysis ('PRT'), GPROF forced to use only the MRMS a-priori database ('forced surf.') and GPROF with a different channel sensitivity combination ('ch sens.').

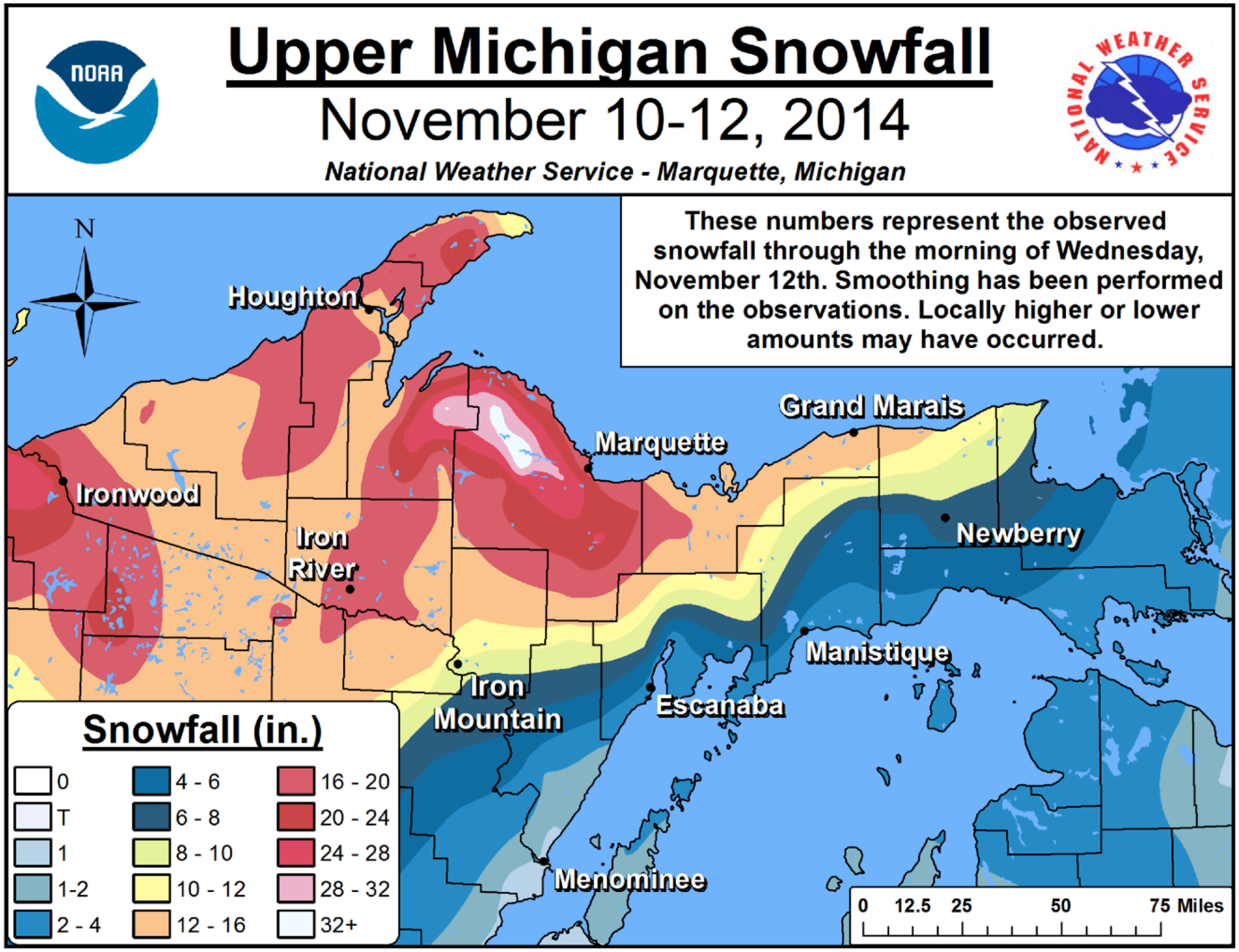
Conclusions

- Lake-effect snow signature is clearly detected by high frequency TBs.
- The original GPROF (V05) show detection issues (high FAR and low HSS) and underestimates precipitation rates
- For the current state of the product, our suggestion to final users is to consider a precipitation threshold (PRT), computed case-by-case using the best HSS performances that lowers the FAR, increases HSS and also improves the correlation.
- The a-priori database is underrepresented for this particular type of events and better populating the low TPW and low T2m sub-sets could help the retrieval
- A probable misclassification of surface type (mainly 'coastline' and 'snow covered' surfaces) affects the algorithm's performances
- Improving the sensitivity of the retrieval to high frequency channels can help improving detection and quantification of snowfall for lake-effect snow events.

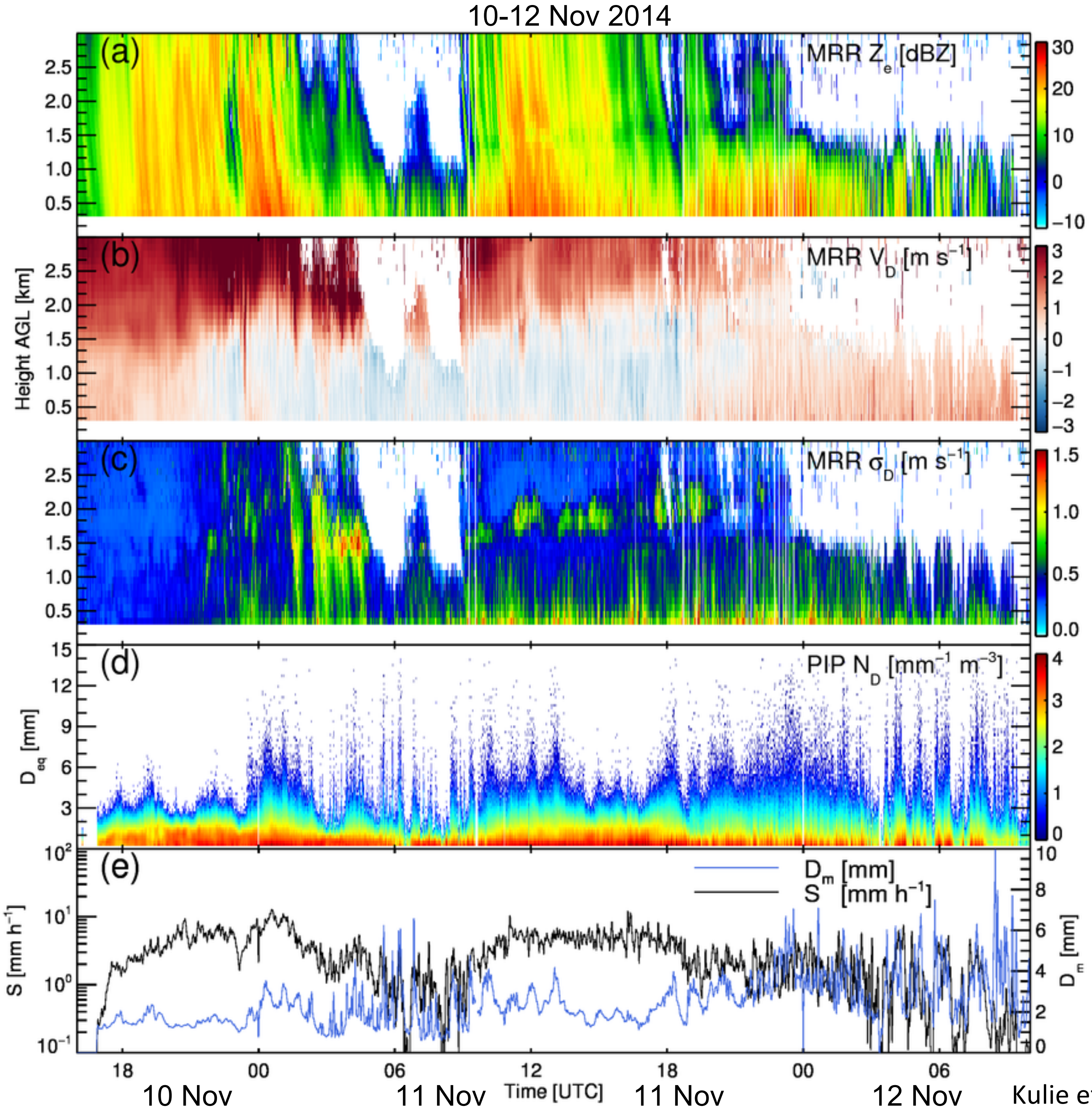
GMI/GPROF Applications



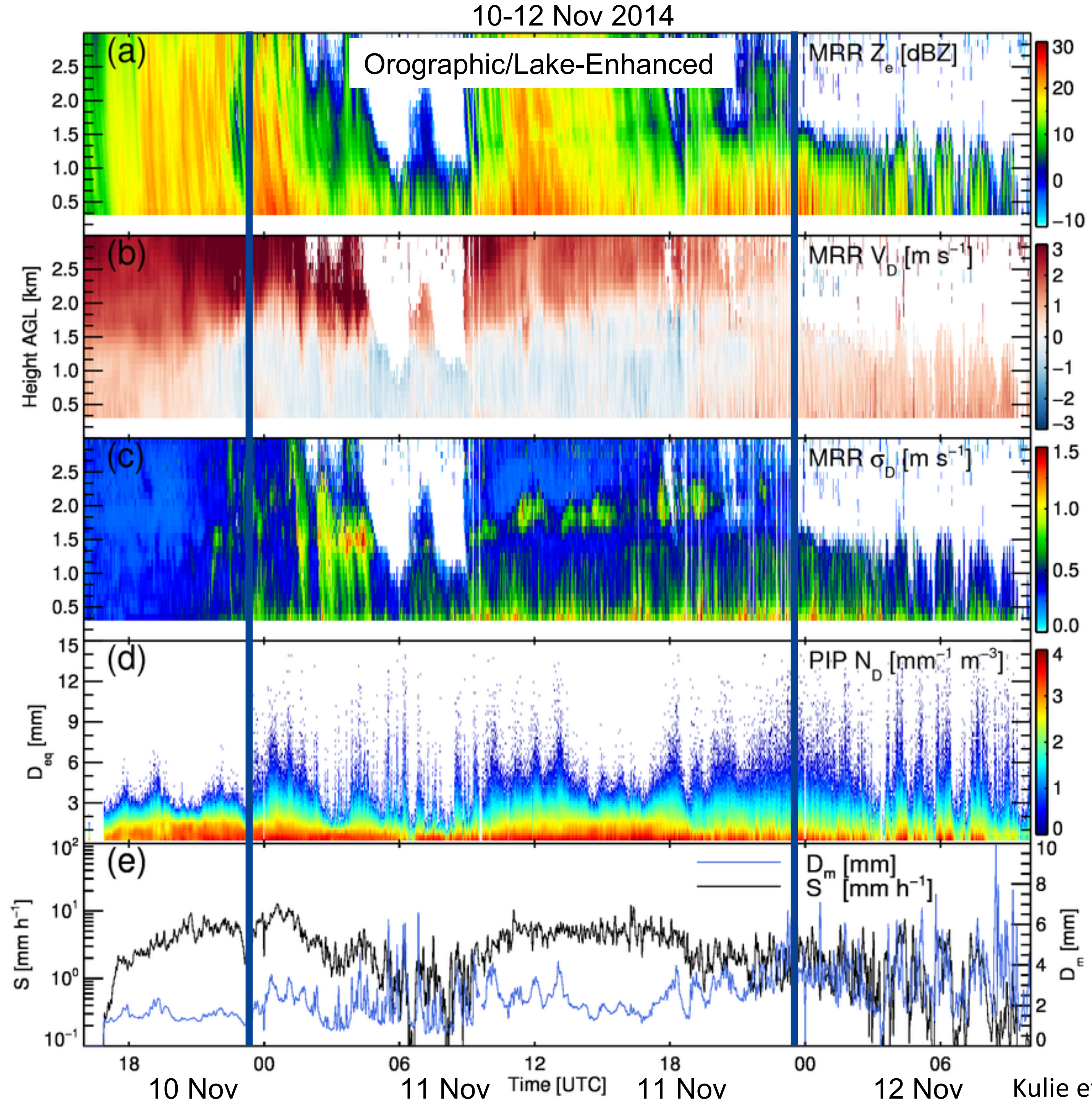
Lesson 4: Enhancement processes in extreme events



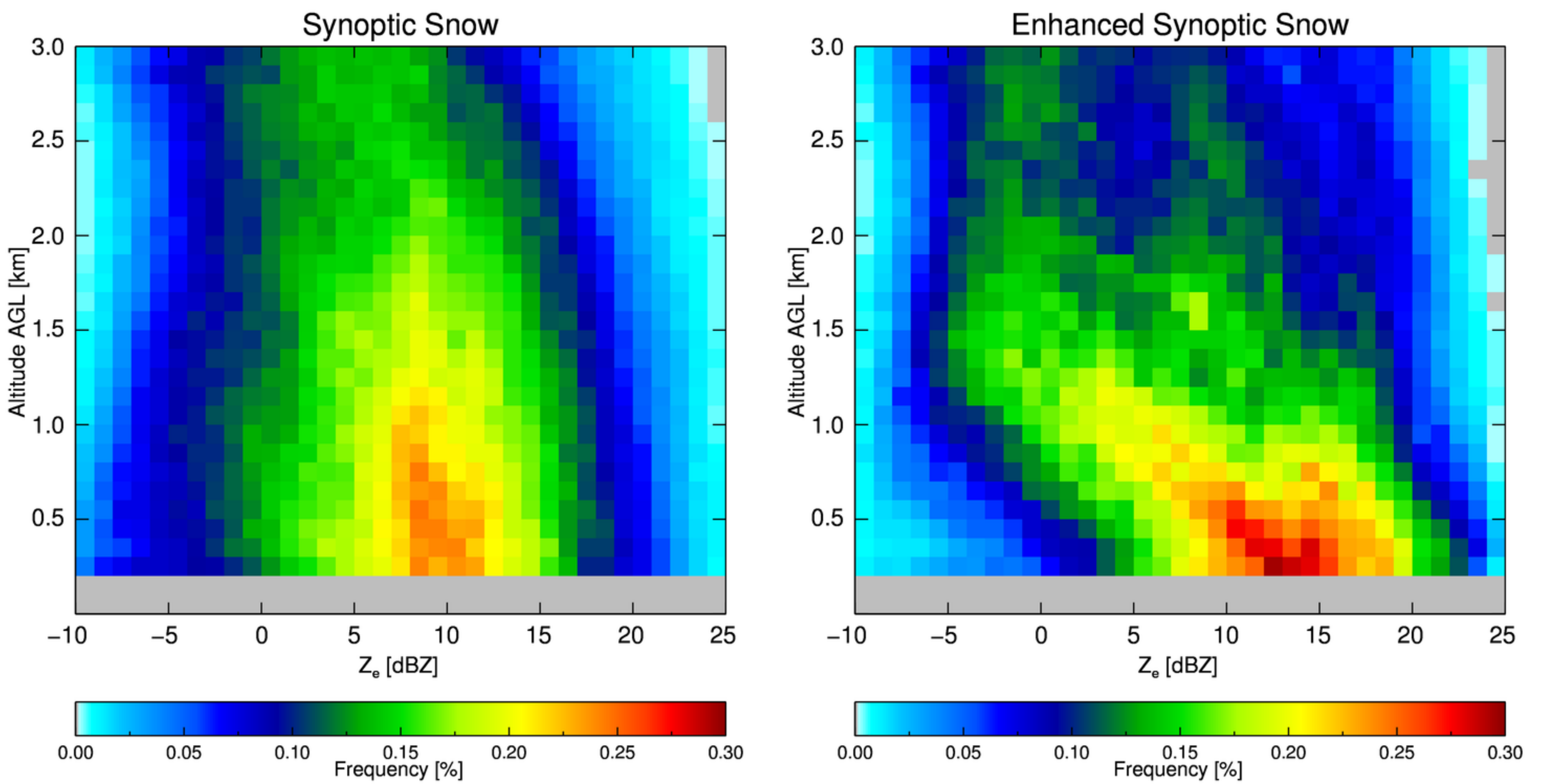
Courtesy Marquette NWS



Kulie et al. (2019) *BAMS*



Kulie et al. (2019) *BAMS*



"Manual" 4 Year Dataset Analysis (MRR, NEXRAD, Met Obs)

MQT Observations: Lessons Learned

- Snowfall regime microphysical transitions
- Shallow snow – do not ignore!
- Shallow snow – different flavors
- Enhancement processes – extreme events
- **Long term datasets are invaluable**

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Future Work

- Further partitioning studies
- GMI/DPR product evaluation/algorithm assumptions
- Regime-dependent PSD parameterization

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