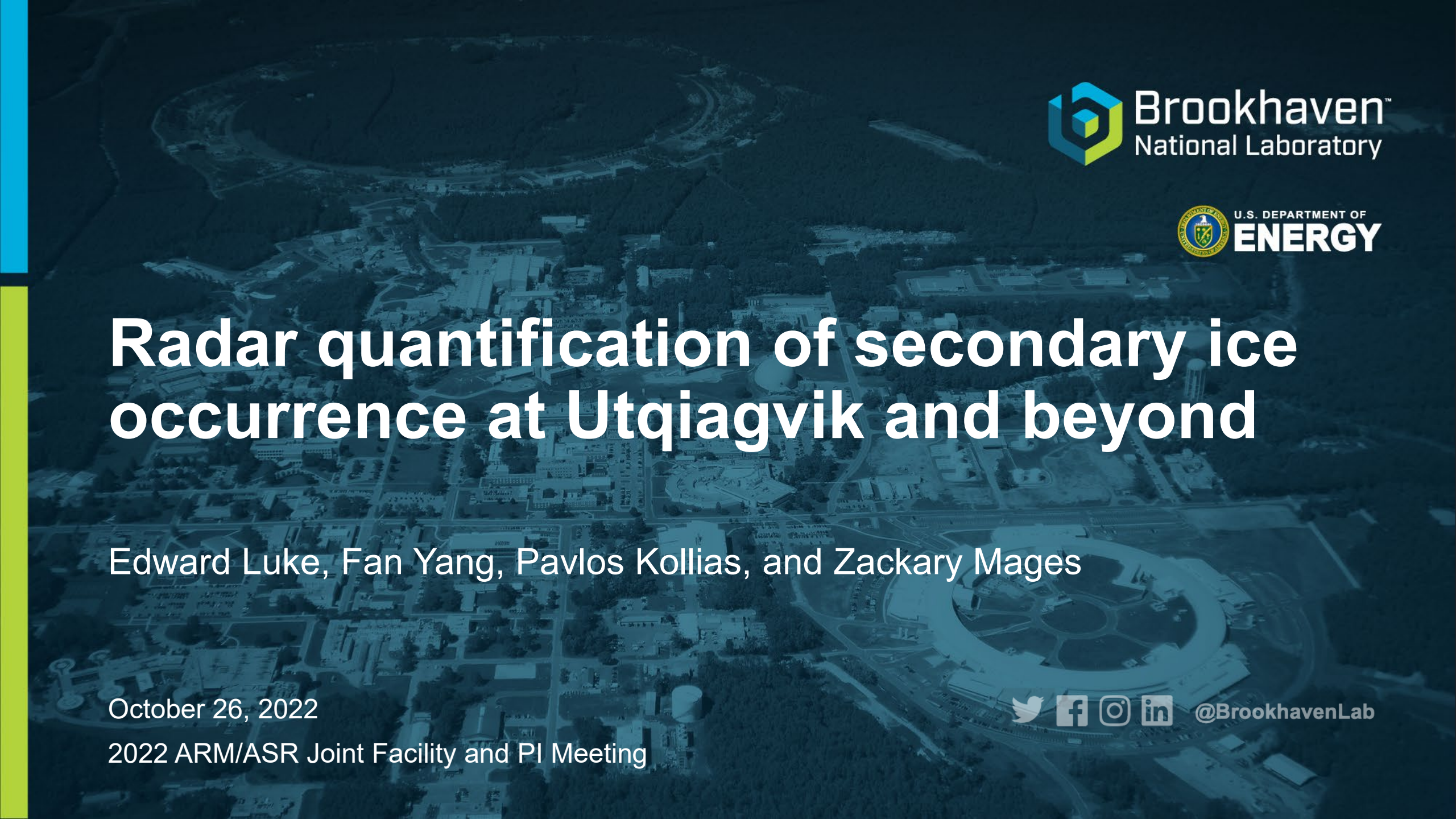


Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Radar quantification of secondary ice occurrence at Utqiagvik and beyond

Edward Luke, Fan Yang, Pavlos Kollias, and Zackary Mages

October 26, 2022

2022 ARM/ASR Joint Facility and PI Meeting

@BrookhavenLab

First-ever long-term statistics of secondary ice processes

Secondary ice (SI) process studies are historically based on

- Laboratory experiments
- Aircraft data
- Episodic remote sensing case studies

Paradigm shift using long-term ARM data

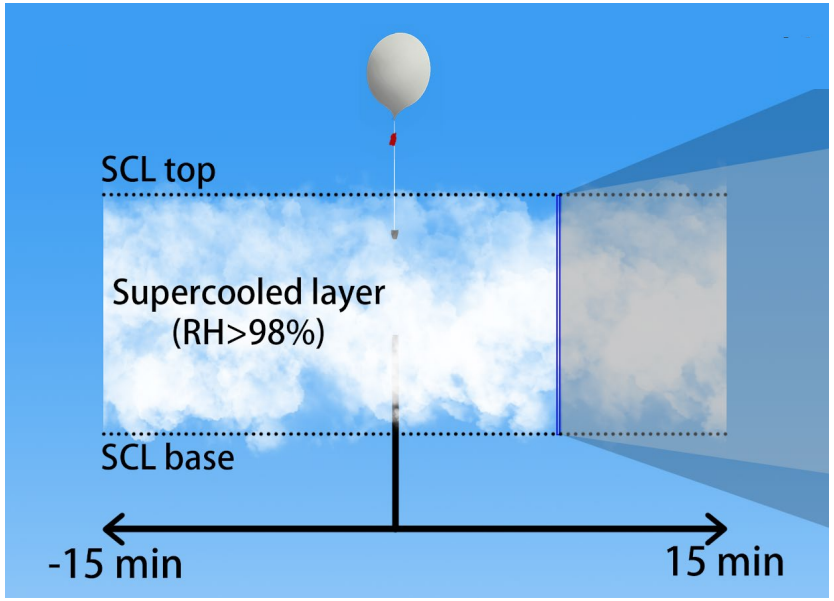
- Continuous SI process observations
- New remote sensing retrieval technique
- Statistical quantification of SI processes and uncertainties

Luke et al., 2021 PNAS

Processes targeted

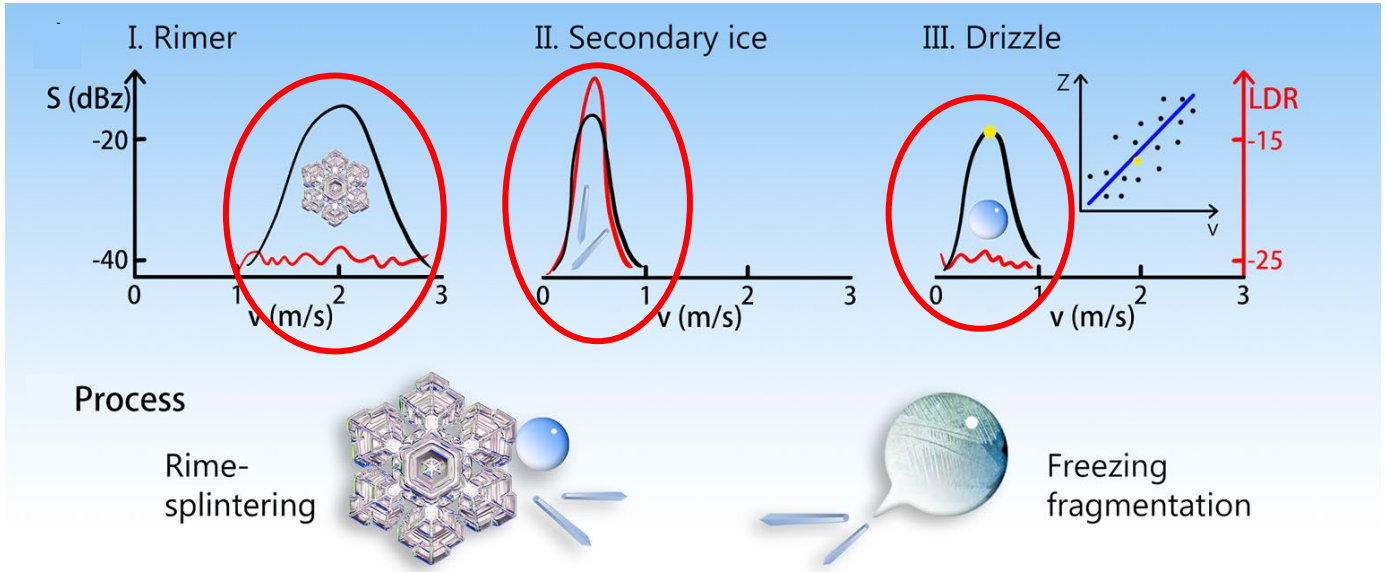
Secondary ice production in slightly supercooled conditions (-10 to 0 C)

Secondary ice retrieval approach



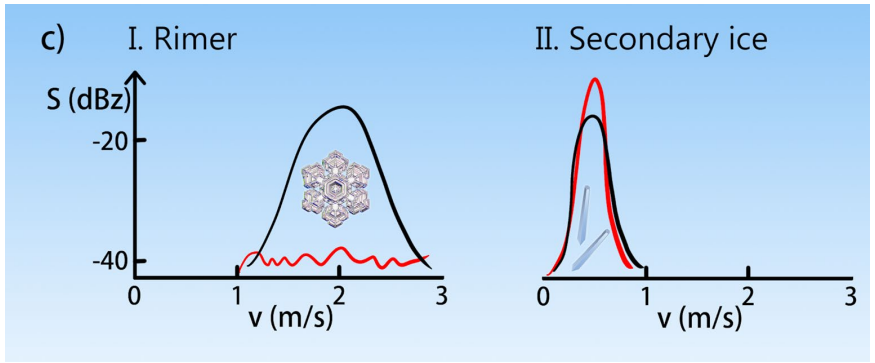
Radiosonde locates supercooled liquid layers (over 4500 launches)

Analyze polarimetric radar Doppler spectra within the liquid layers (spanning 6 years)

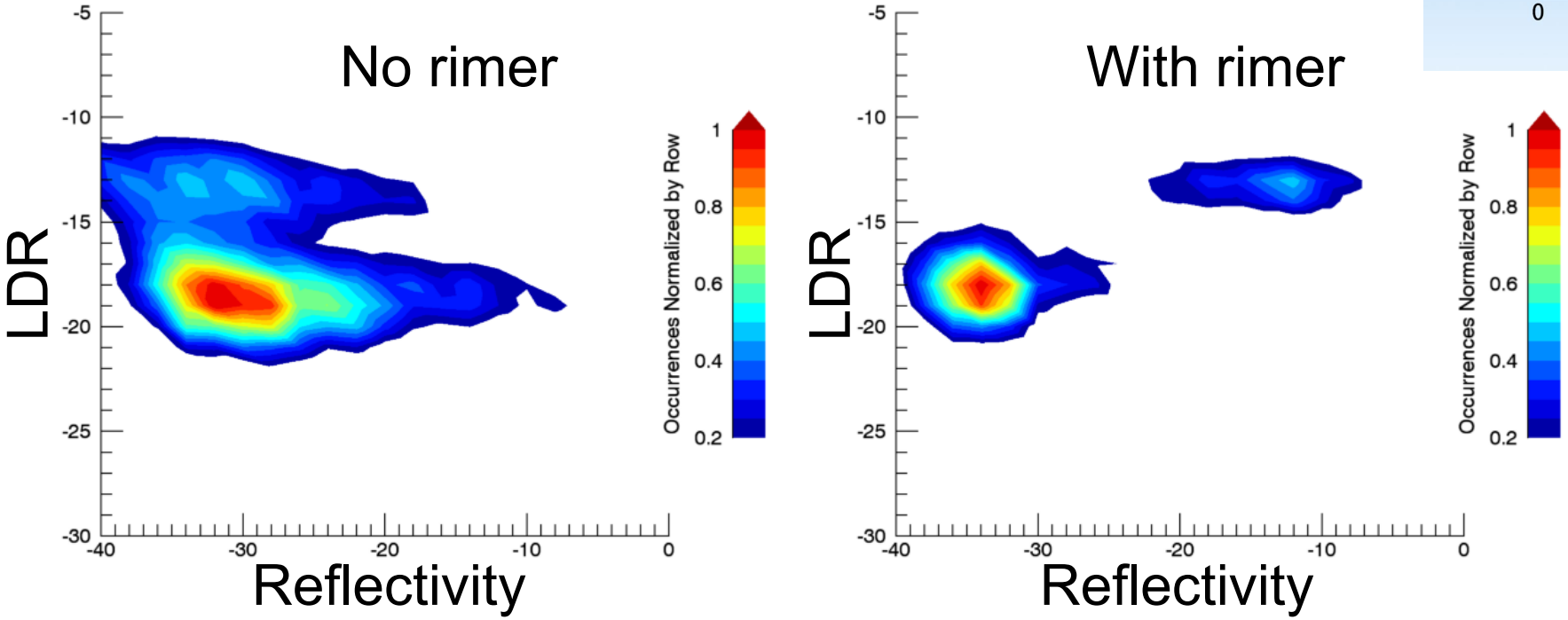


Brookhaven National Laboratory

Determining SI radar threshold

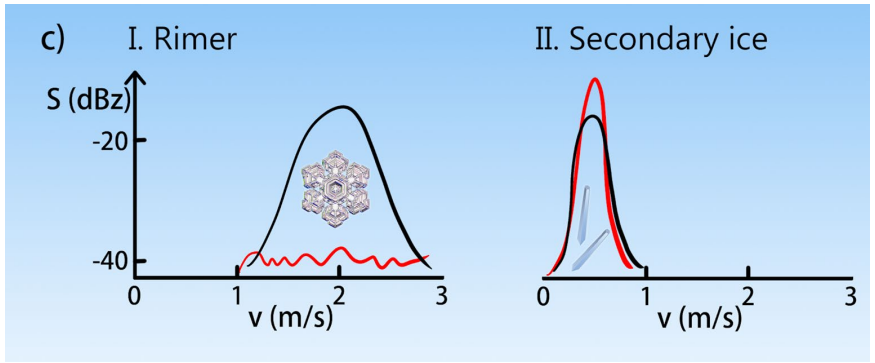


LDR vs Reflectivity @ -5 +/- 1 ^{O}C

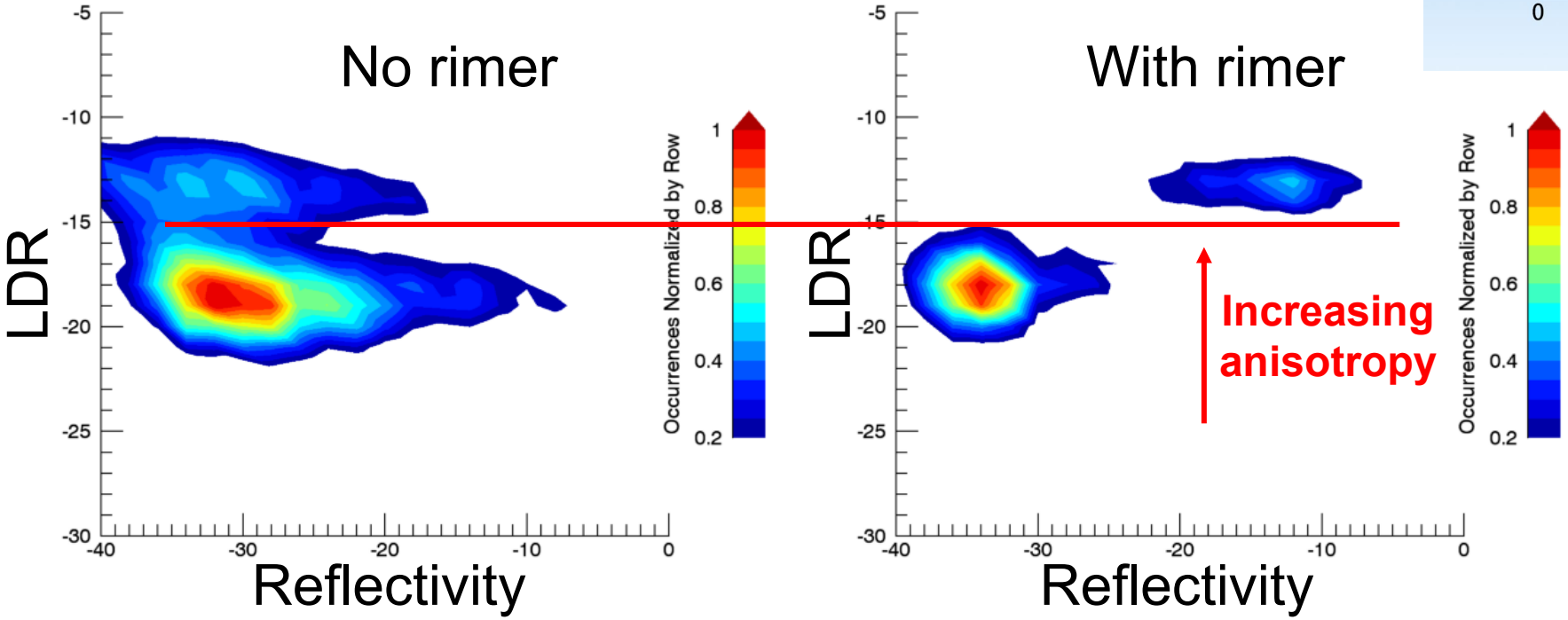


Brookhaven National Laboratory

Determining SI radar threshold

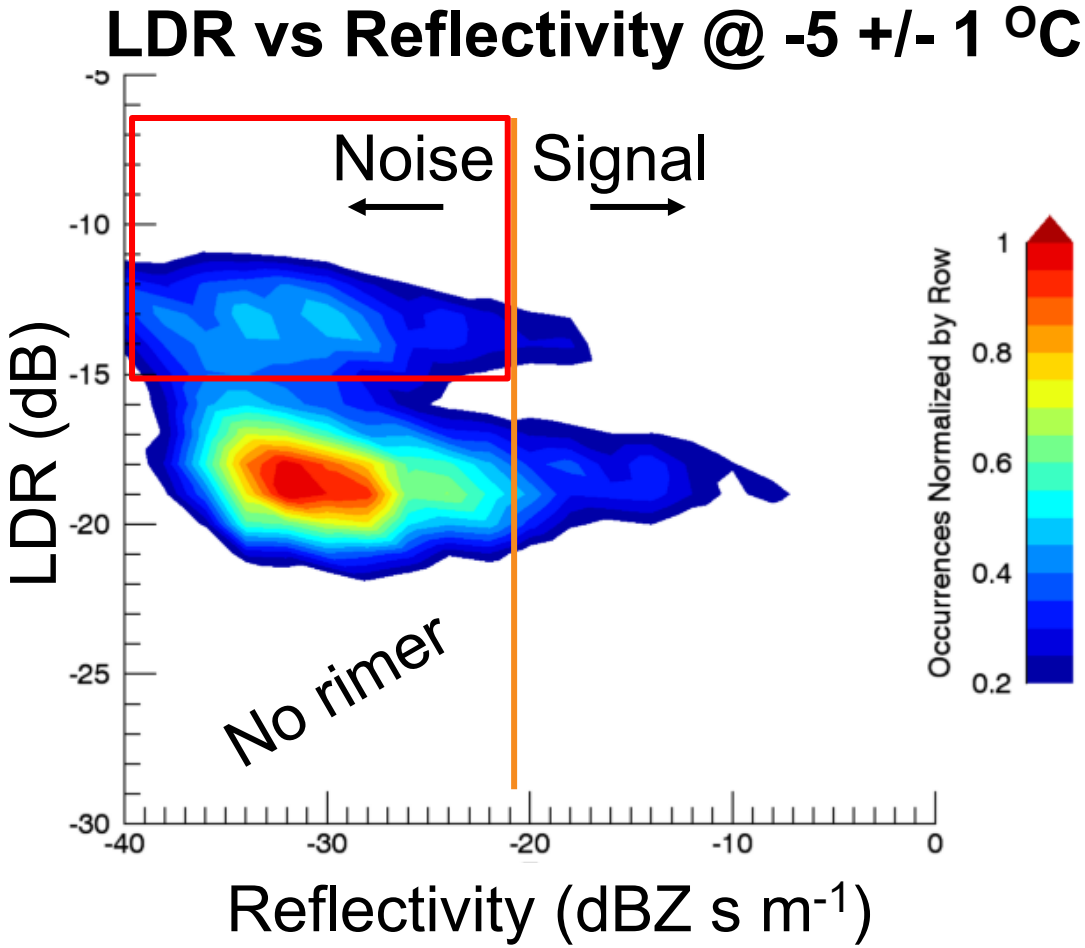


LDR vs Reflectivity @ -5 +/- 1 °C

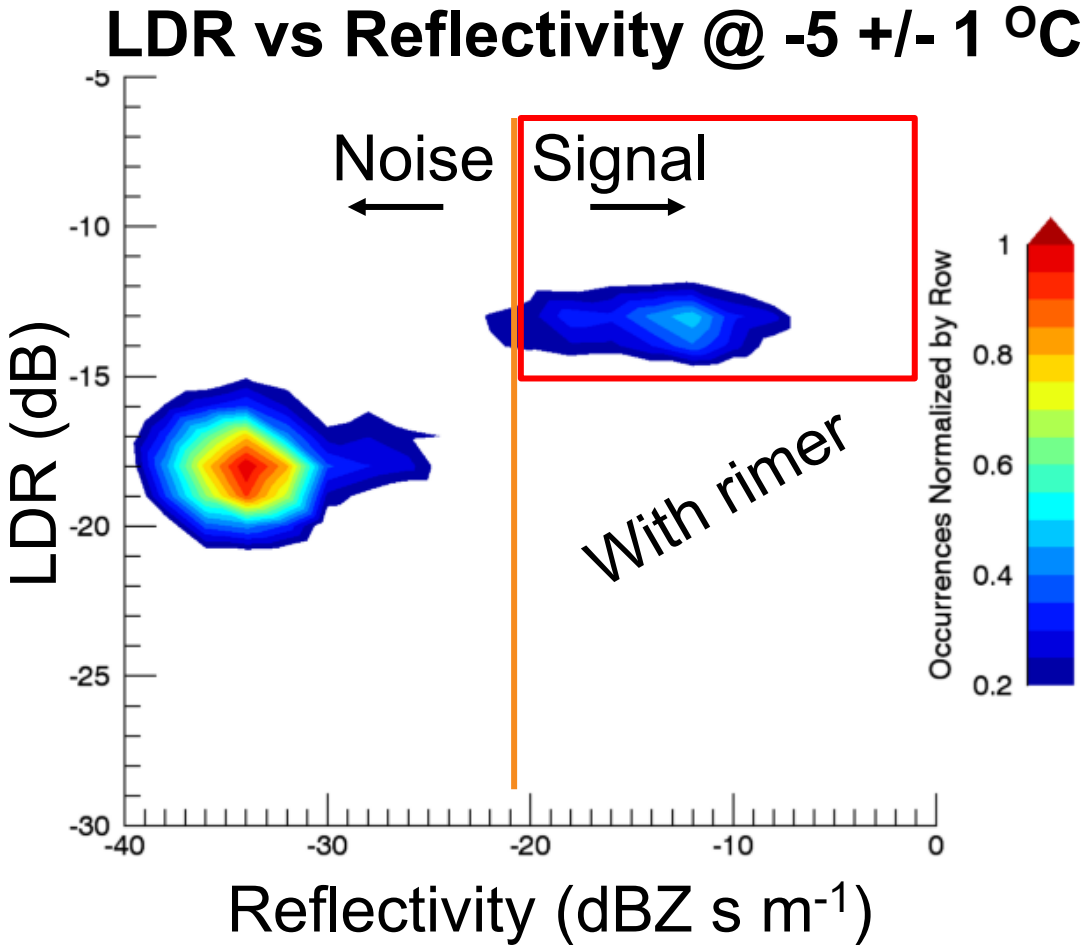


Brookhaven National Laboratory

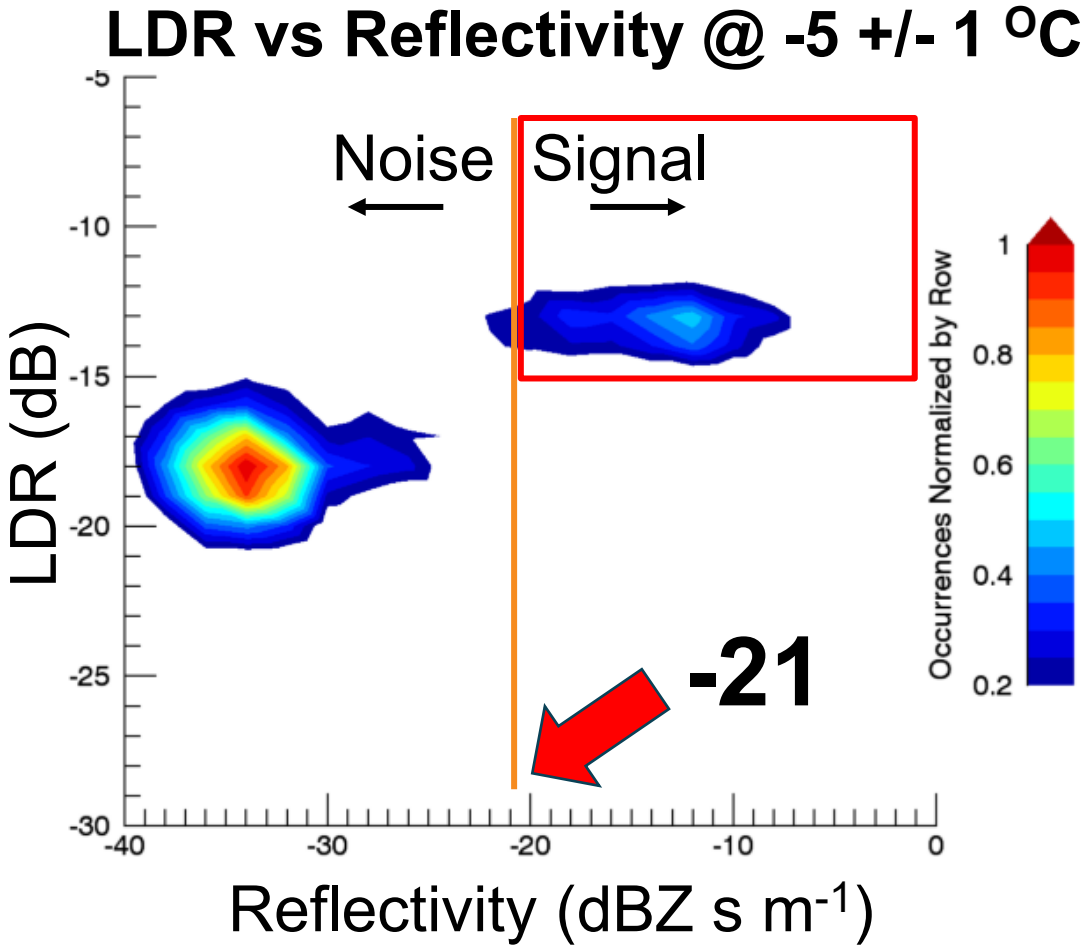
Determining SI radar threshold



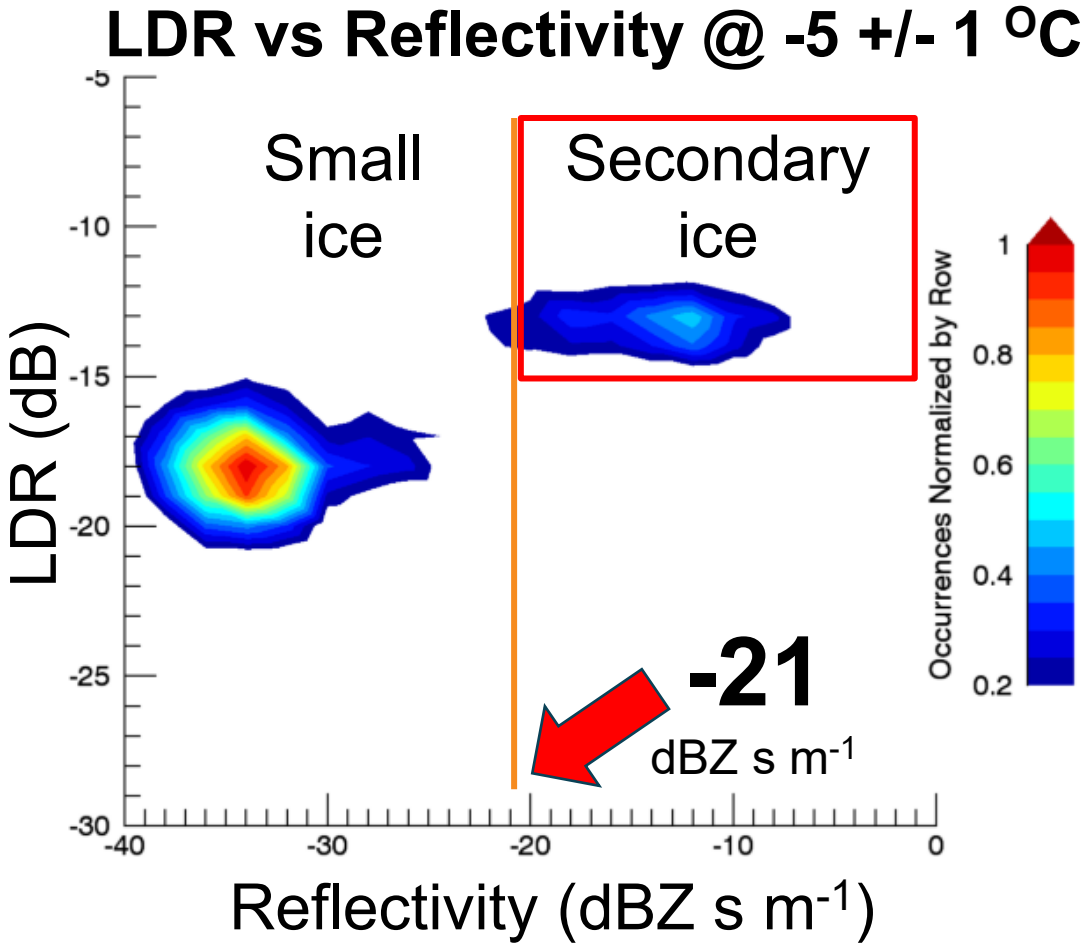
Determining SI radar threshold



Secondary ice threshold is -21 dBZ s m^{-1}

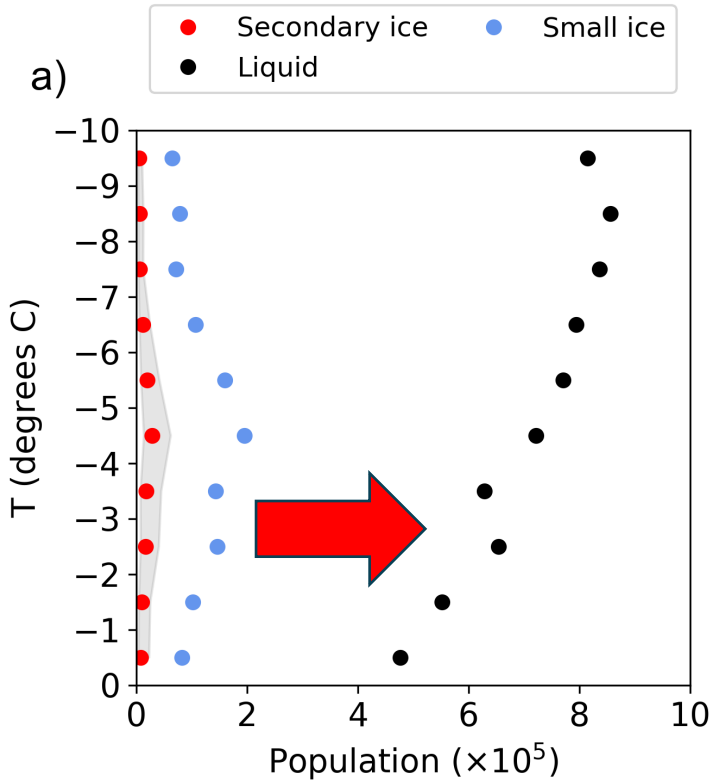


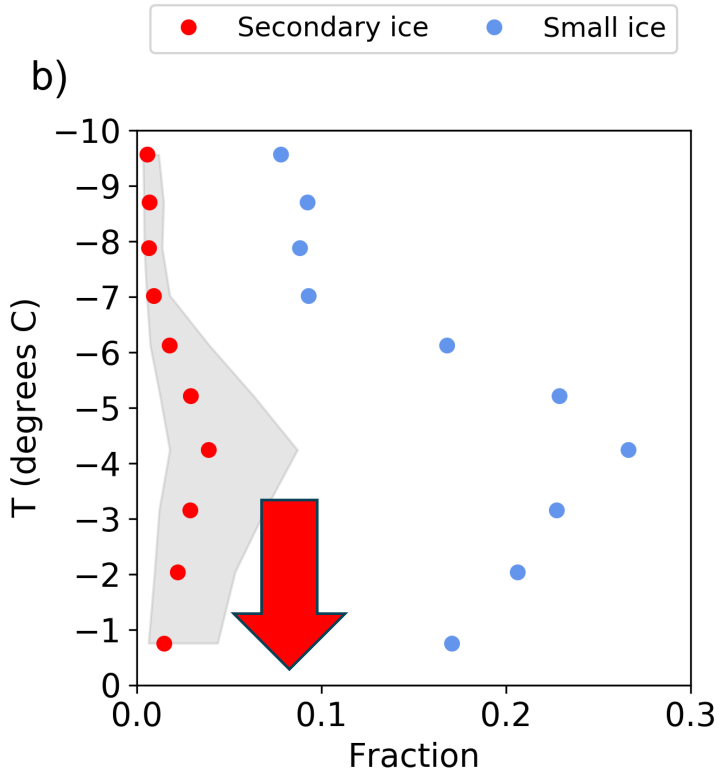
Secondary ice threshold is -21 dBZ s m^{-1}



Secondary ice frequency of occurrence

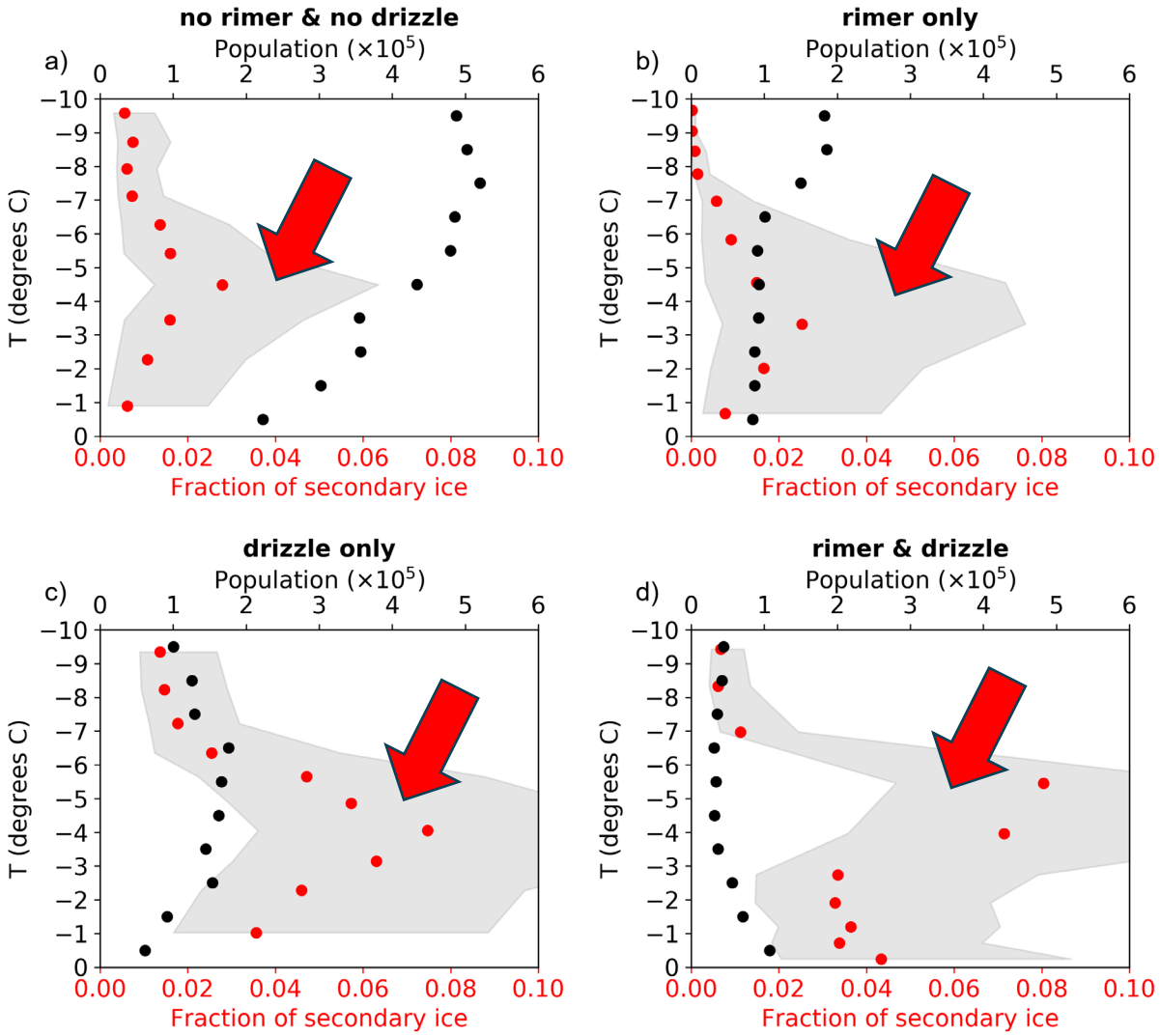
- Supercooled liquid most frequent at colder temperatures
- Small ice most frequent at -5°C
- Secondary ice occurs less than 10% of the time





Brookhaven National Laboratory

SI from splintering vs fragmentation

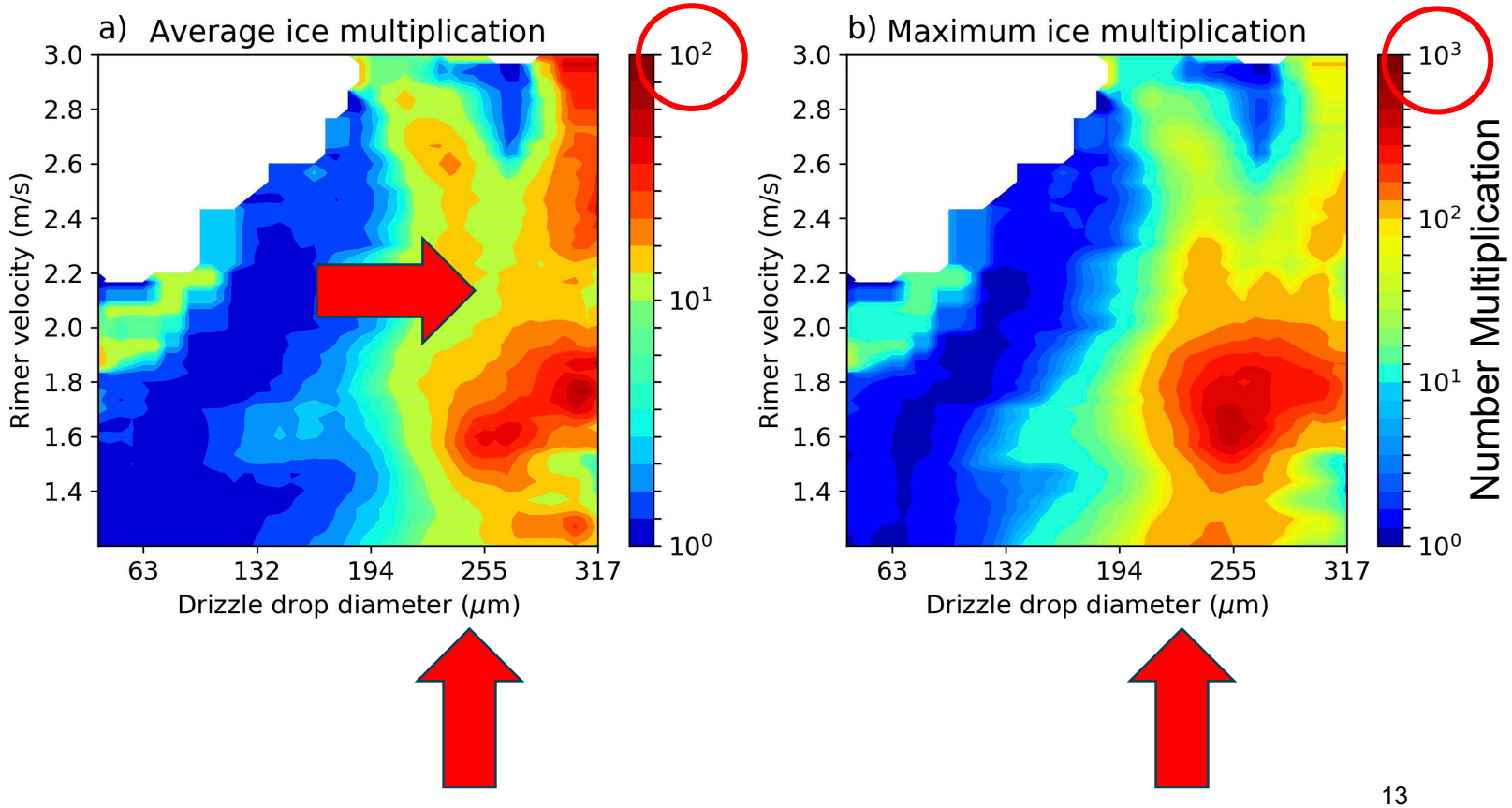


- Rimer alone has weakest association with secondary ice
- Drizzle alone has a significantly higher SI fraction
- Rimer and drizzle together have the highest SI fraction
- **Freezing fragmentation** more important than **rime splintering**

Rime-splintering, freezing fragmentation joint distribution

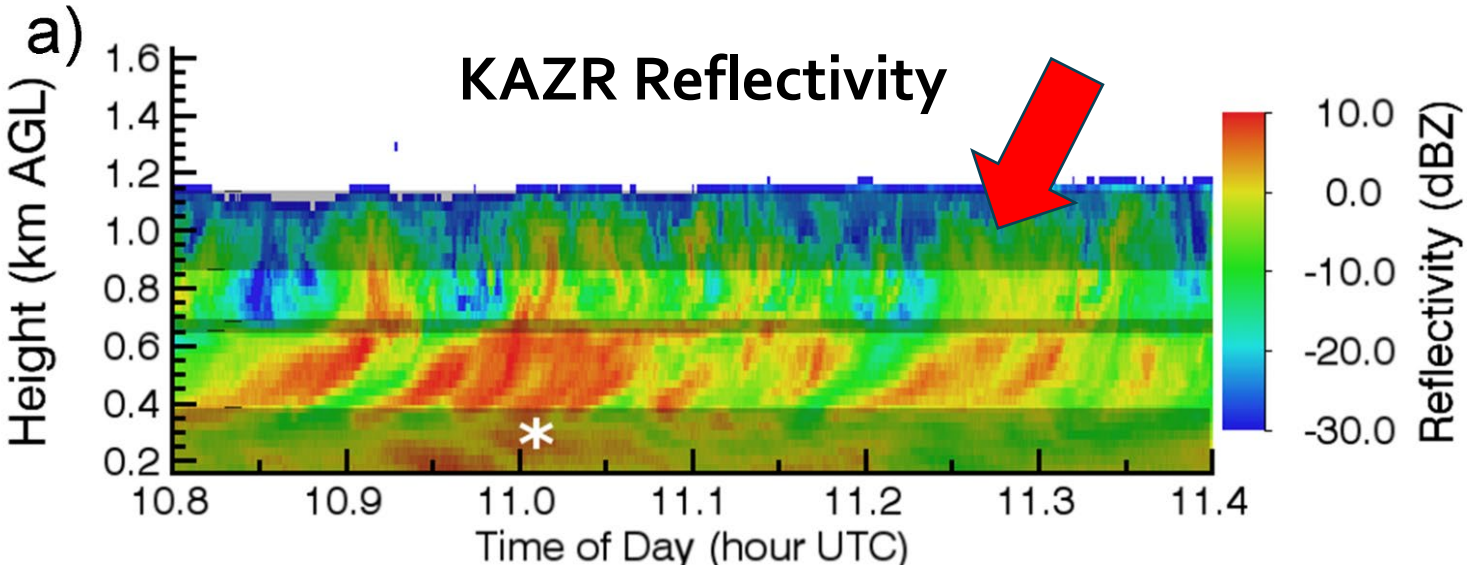
- Ice multiplication peaks for **drizzle** drops larger than **250 μm**.
- Ice multiplication is **bimodal** with **rimer speed**
- Average ice multiplication can reach **100x**, while peak occurrences can reach **1000x**.

Ice multiplication as a function of rimer velocity and drizzle drop diameter



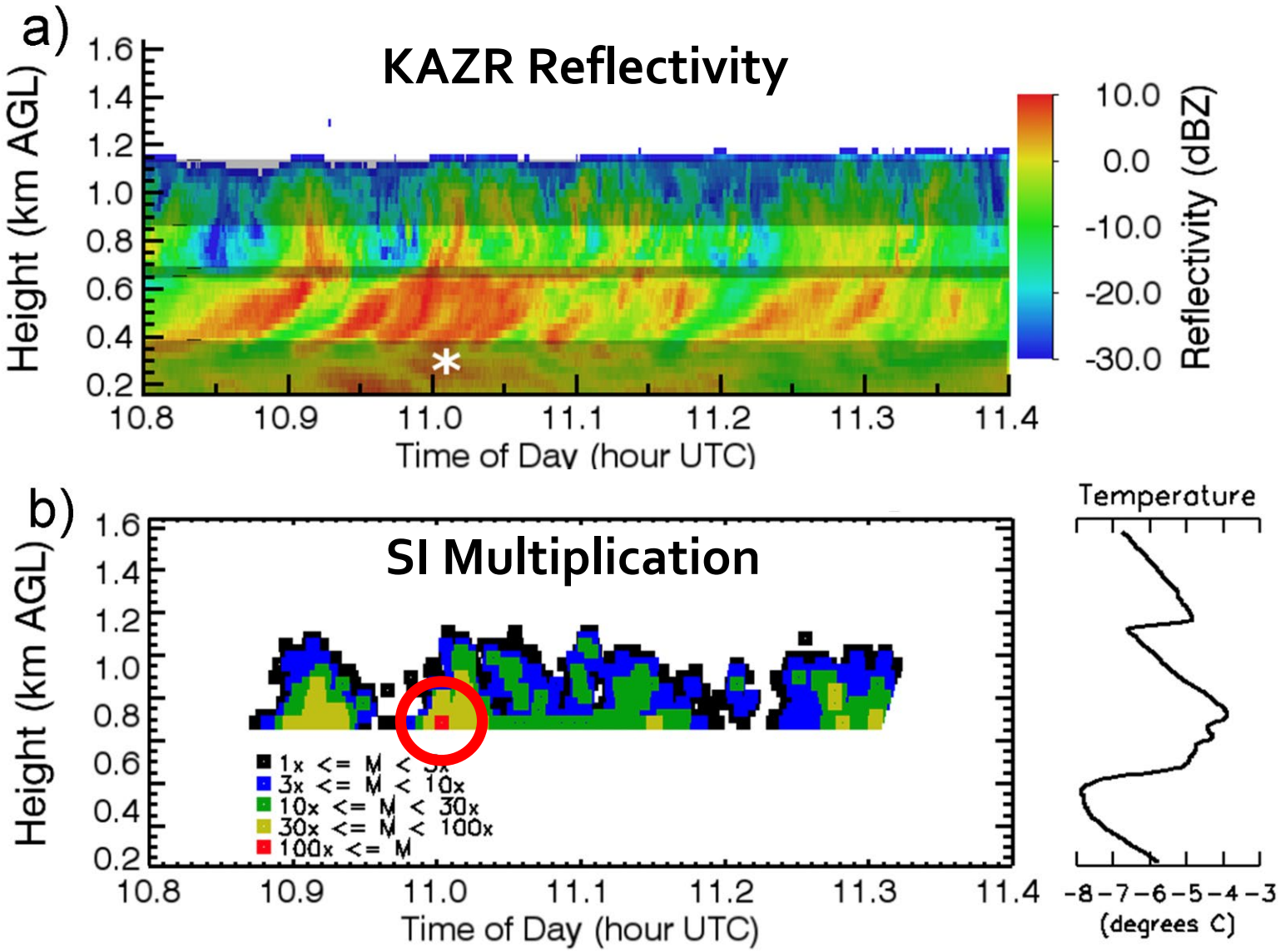
Brookhaven National Laboratory

An example case



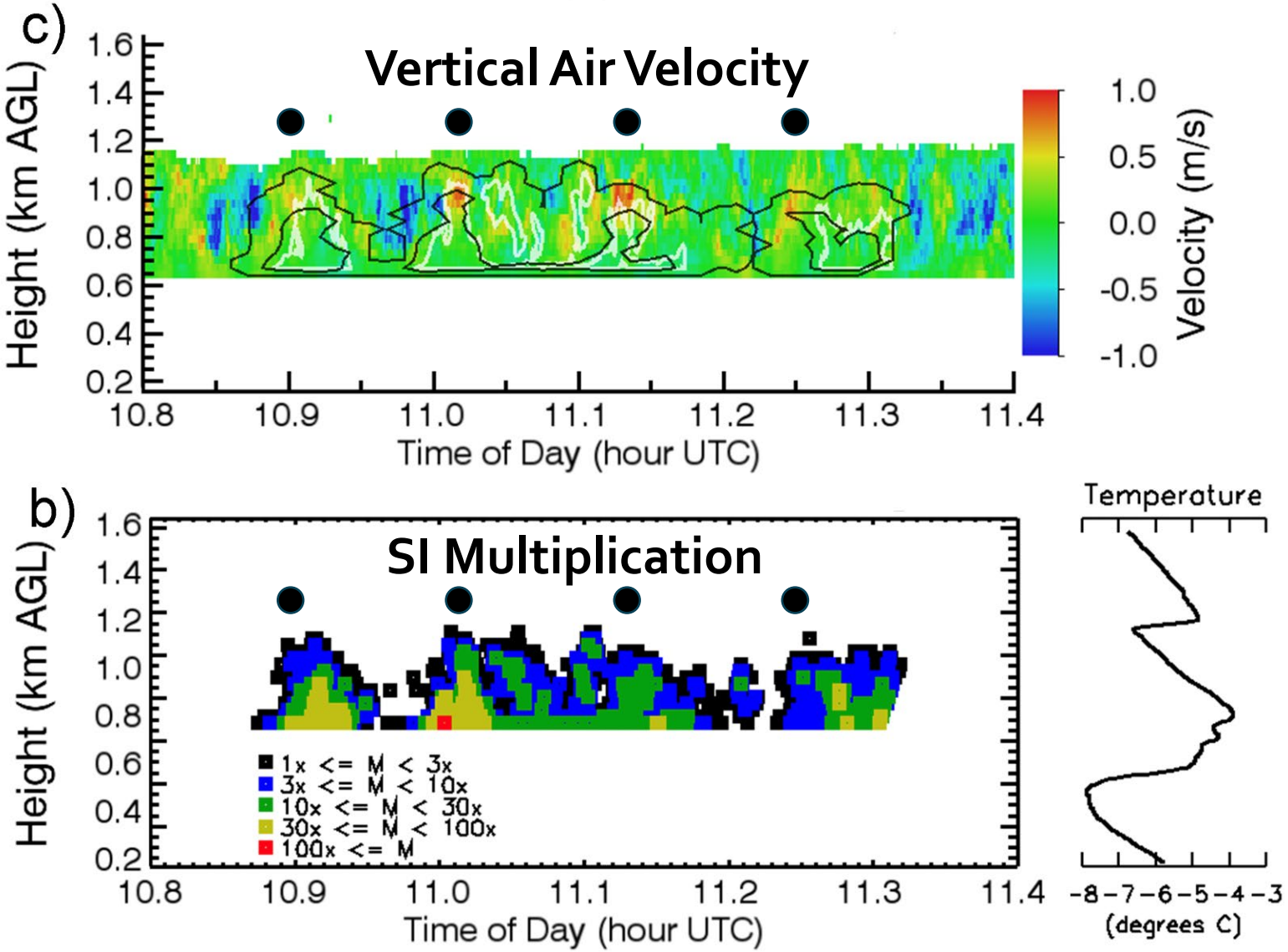
- SI production in shallow stratiform cloud

Ice multiplication up to 100x observed



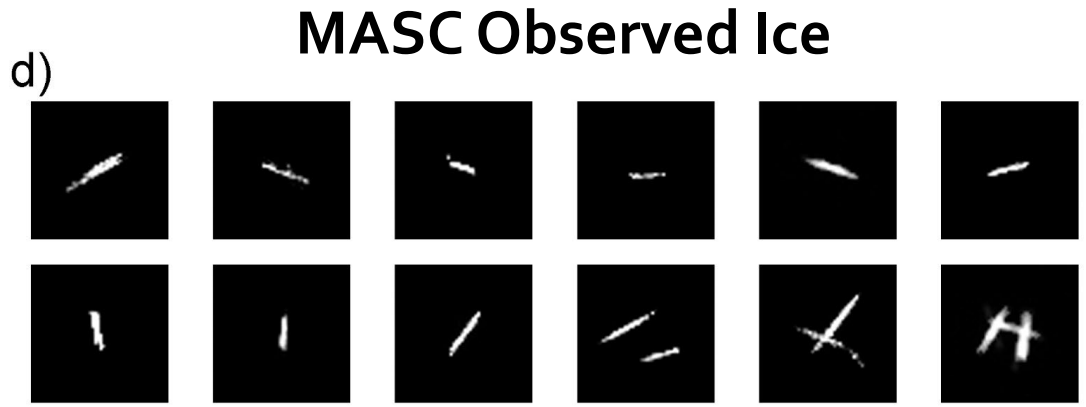
- SI production in shallow stratiform cloud
- Multiplication reaches 100x

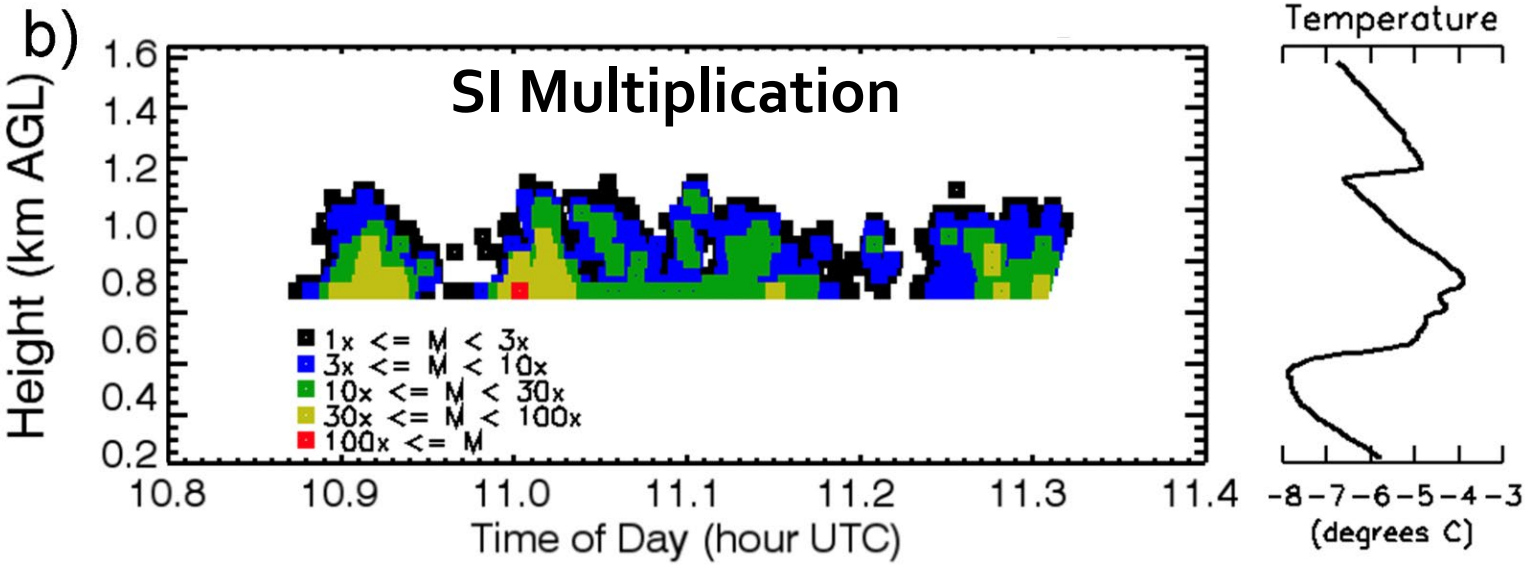
SI correlates with updrafts



- SI production in shallow stratiform cloud
- Multiplication reaches 100x
- Updrafts are favorable to SI production

In-situ needle observations at surface





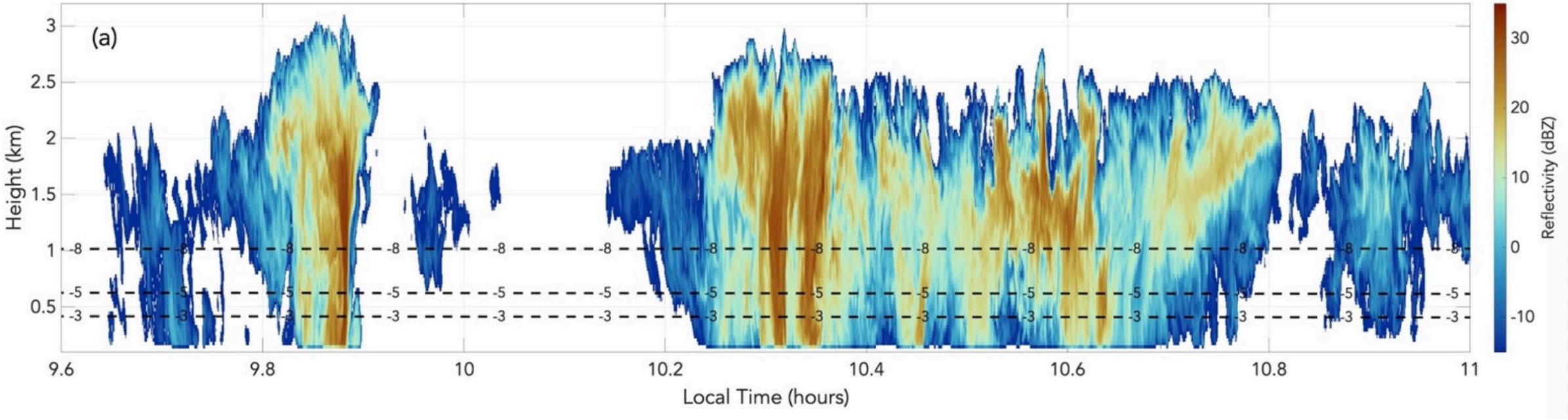
- SI production in shallow stratiform cloud
- Multiplication reaches 100x
- Updrafts are favorable to SI production
- MASC confirms needle precipitation

MASC needle observations video

MASC Observations during
Detected Secondary Ice Event

Brookhaven National Laboratory

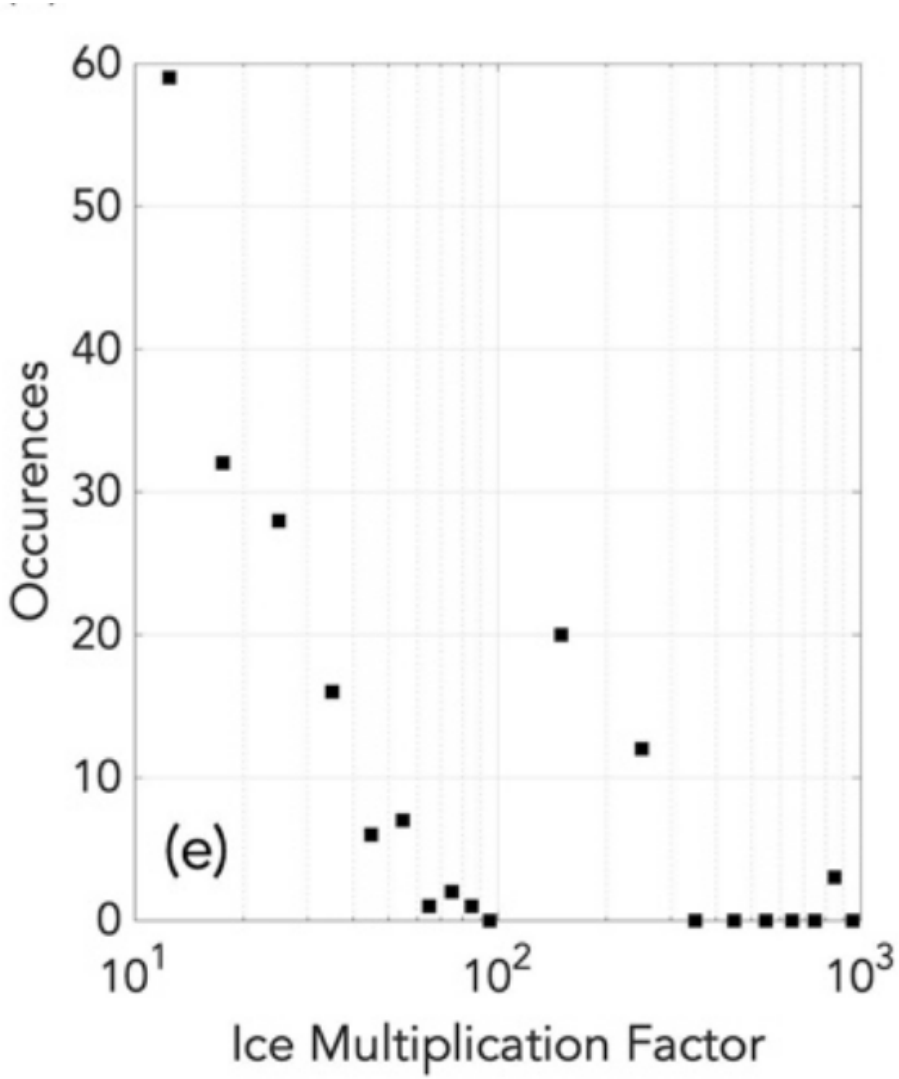
Apply retrieval at COMBLE



Mages et al., in review, ACP

Brookhaven National Laboratory

COMBLE: Ice multiplication up to 1000x



Mages et al., in review, ACP

Conclusions & Recommendations

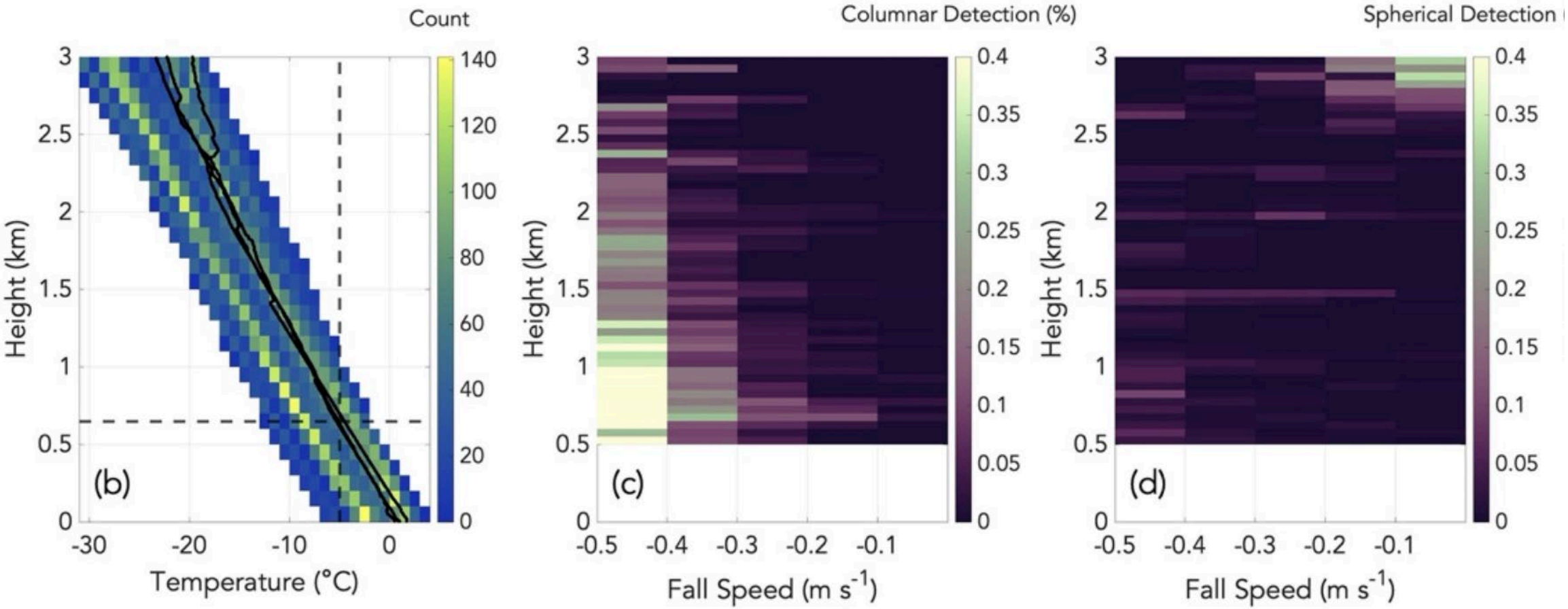
- Up to **10x** ice multiplication from **rimer** alone
- Drizzle **enhances** ice multiplication by up to an additional **100x**
- Ice multiplication peaks at rimer speeds of 1.6 to 1.8 m/s and largest drizzle drop size
- Although **overall** frequency of SI is < 10%, it can have dramatic **local** impacts
- Operate cloud radars in **dual-polarization** for high latitude deployments
- Consider **extra sonde launches** during conditions favoring secondary ice

References

Luke, E. P., Yang, F., Kollias, P., Vogelmann, A. M., and Maahn, M. New insights into ice multiplication using remote-sensing observations of slightly supercooled mixed-phase clouds in the Arctic. *Proceedings of the National Academy of Sciences* **118**, e2021387118, doi:10.1073/pnas.2021387118 (2021)

Mages, Z., Kollias, P., Zhu, Z., and Luke, E. P.: Surface-based observations of cold-air outbreak clouds during the COMBLE field campaign, *Atmos. Chem. Phys. Discuss.* [preprint], https://doi.org/10.5194/acp-2022-546, in review, 2022

Maximum needles at -5 C



Mages et al., in review, ACP