Antarctic Cloud Property Retrievals from Infrared Radiances

Penny M. Rowe, Von P. Walden, Jonathon Gero, Connor Krill, Matthew Fergoda, and Steven Neshyba

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Motivation

- Improved understanding of Antarctic clouds needed
- Particularly for supercooled liquid
- Cloud radiative effect depends on the complex refractive index (CRI)
- Lab measurements show that the liquid water CRI is temperature dependent, but this is typically ignored.

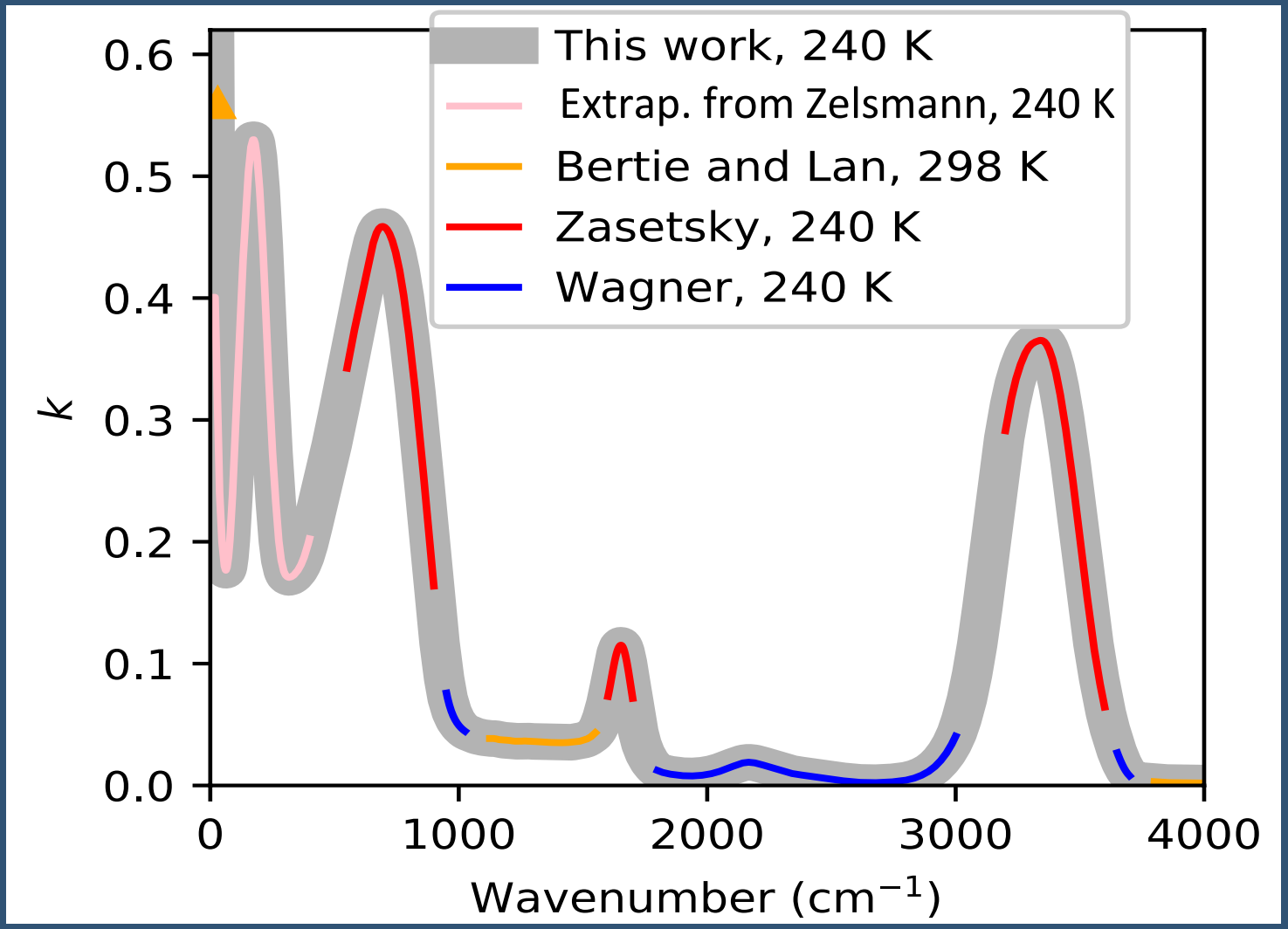
Goals

- Compile a temperature-dependent liquid water CRI for the infrared.
- Retrieve Antarctic cloud properties (South Pole 2001; McMurdo, 2016)
- Determine biases if temperature dependence of CRI is ignored.

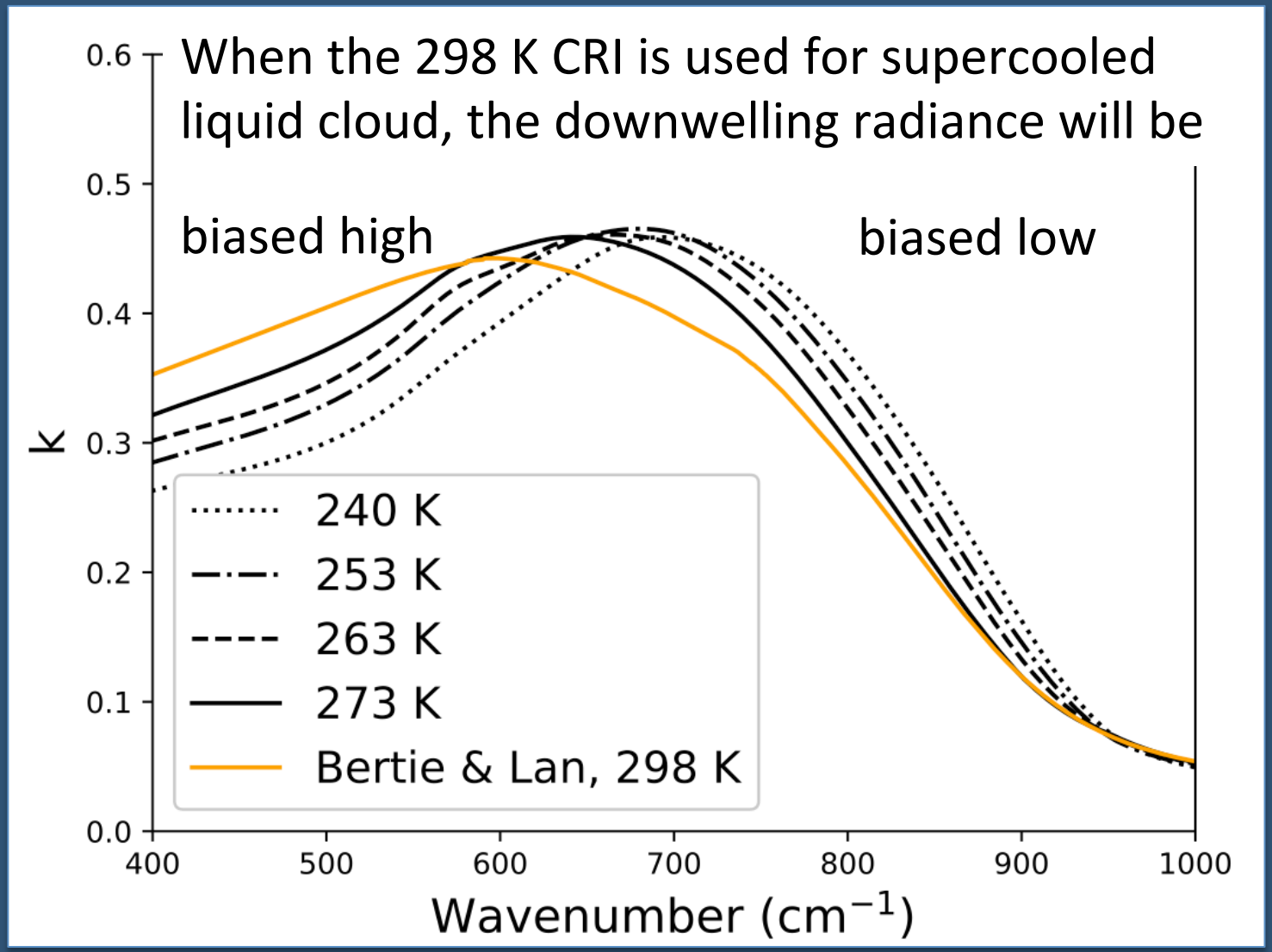
Field Experiments

Image courtesy of NASA ‘s Landsat Image Mosaic of Antarctica Project

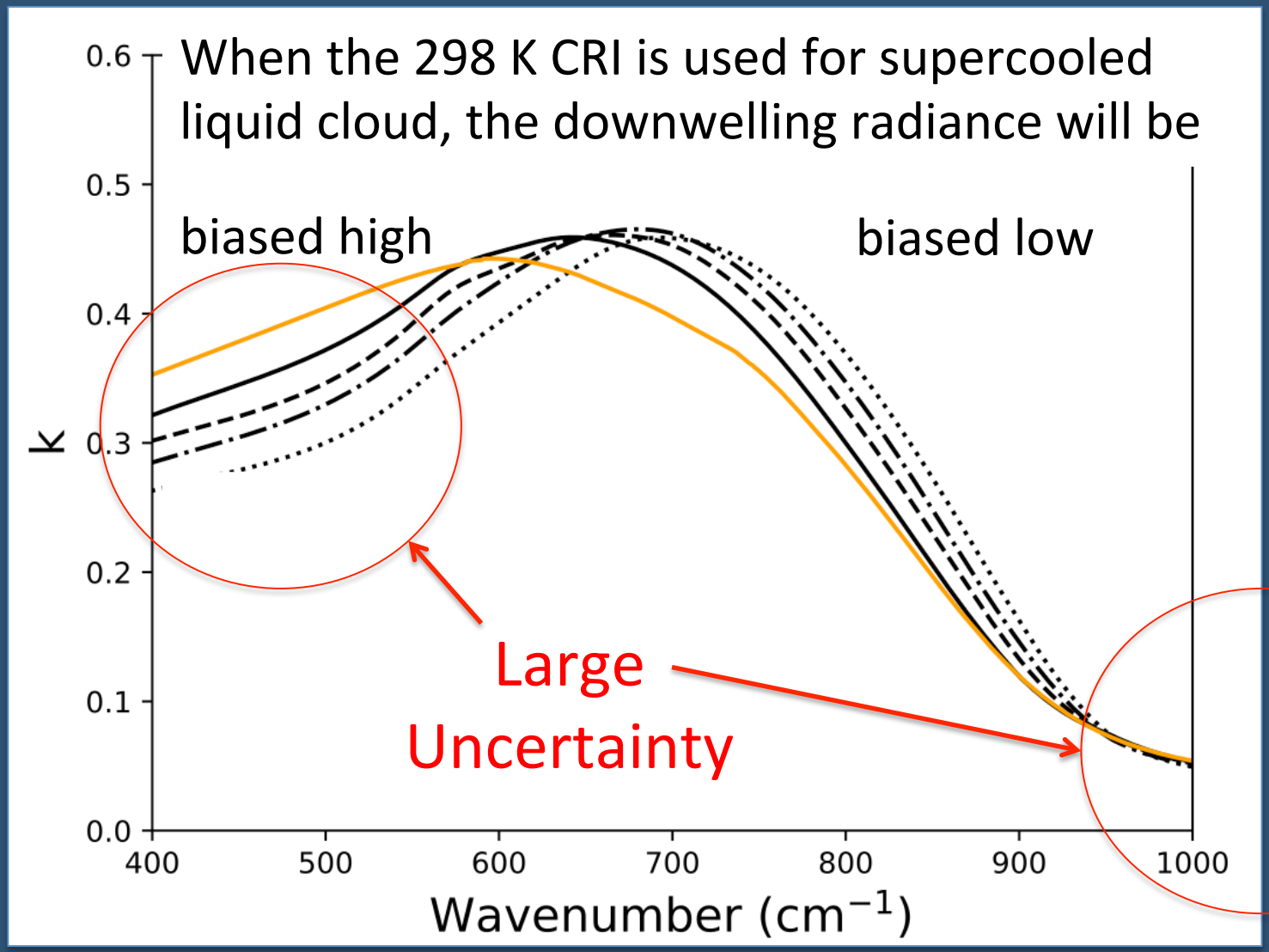
Imaginary Part of liquid water CRI: 240 K



Imaginary Part of liquid water CRI



Imaginary Part of liquid water CRI

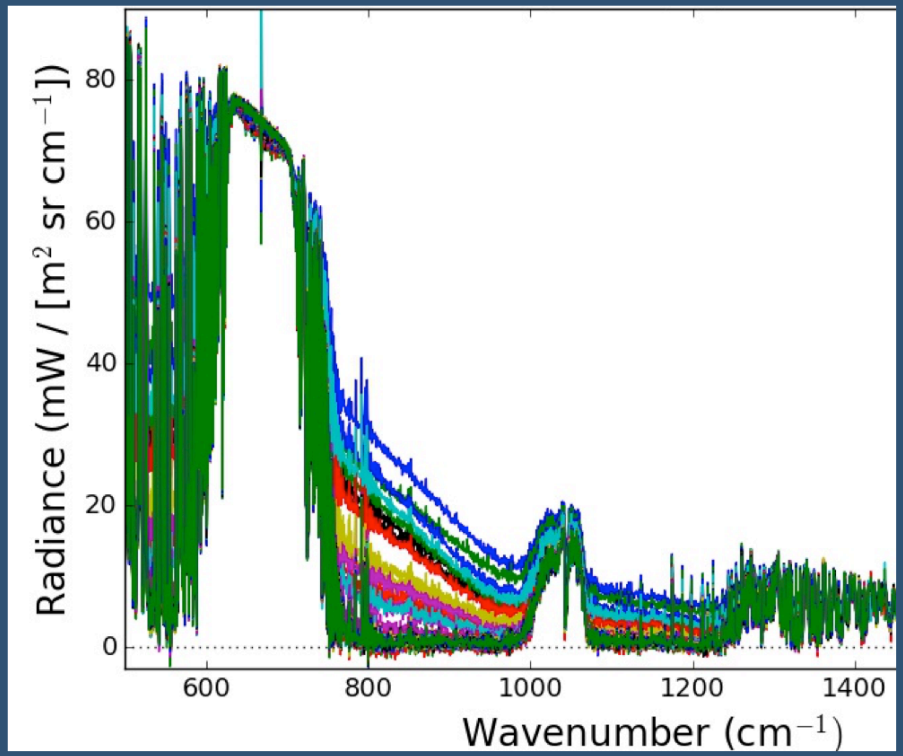


Retrieval algorithm: CLARRA

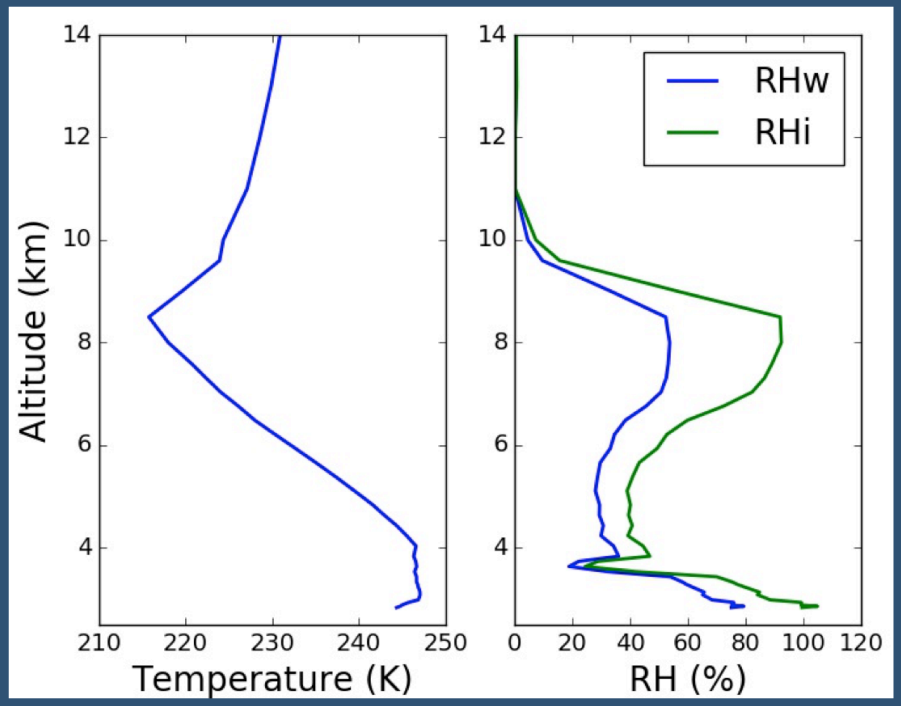
- CLARRA: Cloud and Atmospheric Radiation Retrieval Algorithm
- Cloud properties retrieved from downwelling infrared radiance measurements
- CLARRA: Rowe et al 2019; 2020
  https://doi.org/10.5194/amt-9-3641-2016
  http://doi.org/10.5194/amt-12-5071-2019
- Optimal estimation, Bayesian framework
- Iterative, Gauss-Newton / Levenberg-Marquardt (Rodgers 2000) :

$$x_{i+1} = x_i + \left[(1+\gamma) S_a^{-1} + K_i^T S_e^{-1} K_i \right]^{-1} \left\{ K_i^T S_e^{-1} \left[y - F(x_i) \right] - S_a^{-1} \left[x_i - x_a \right] \right\}$$

Inputs to CLARRA

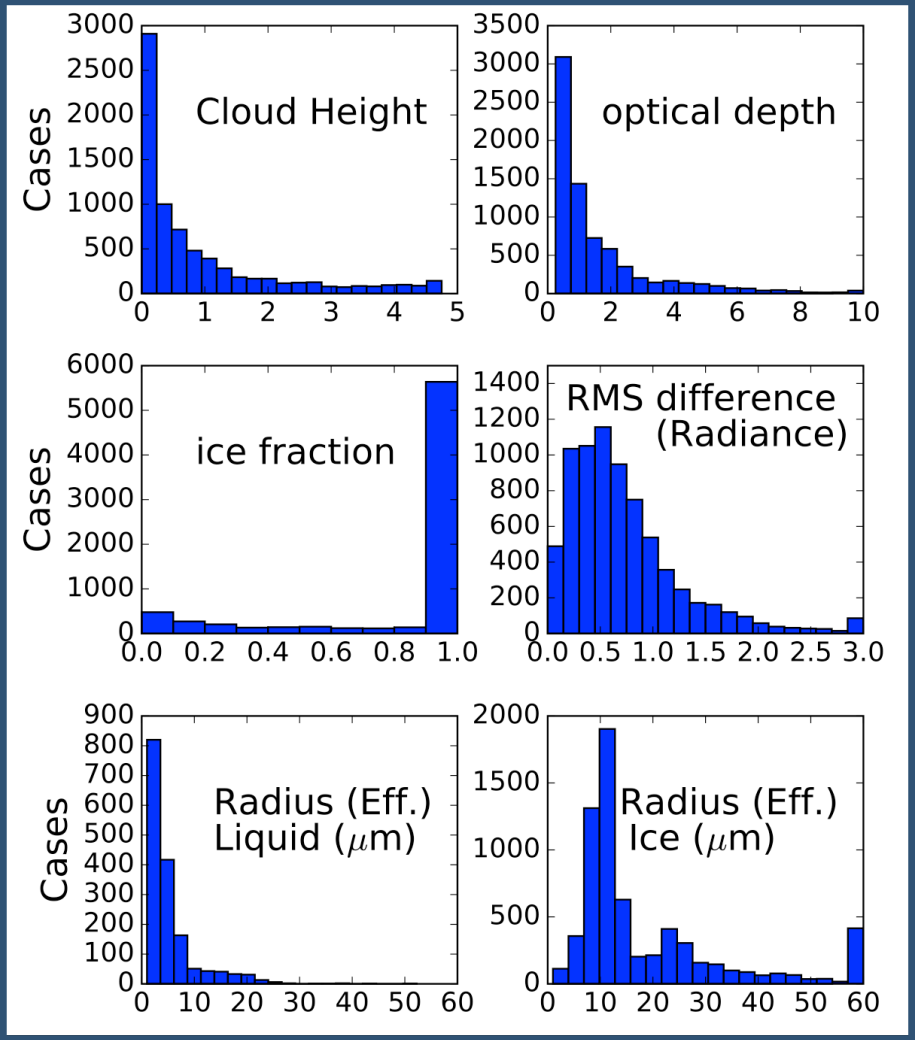


Downwelling
Infrared Radiances

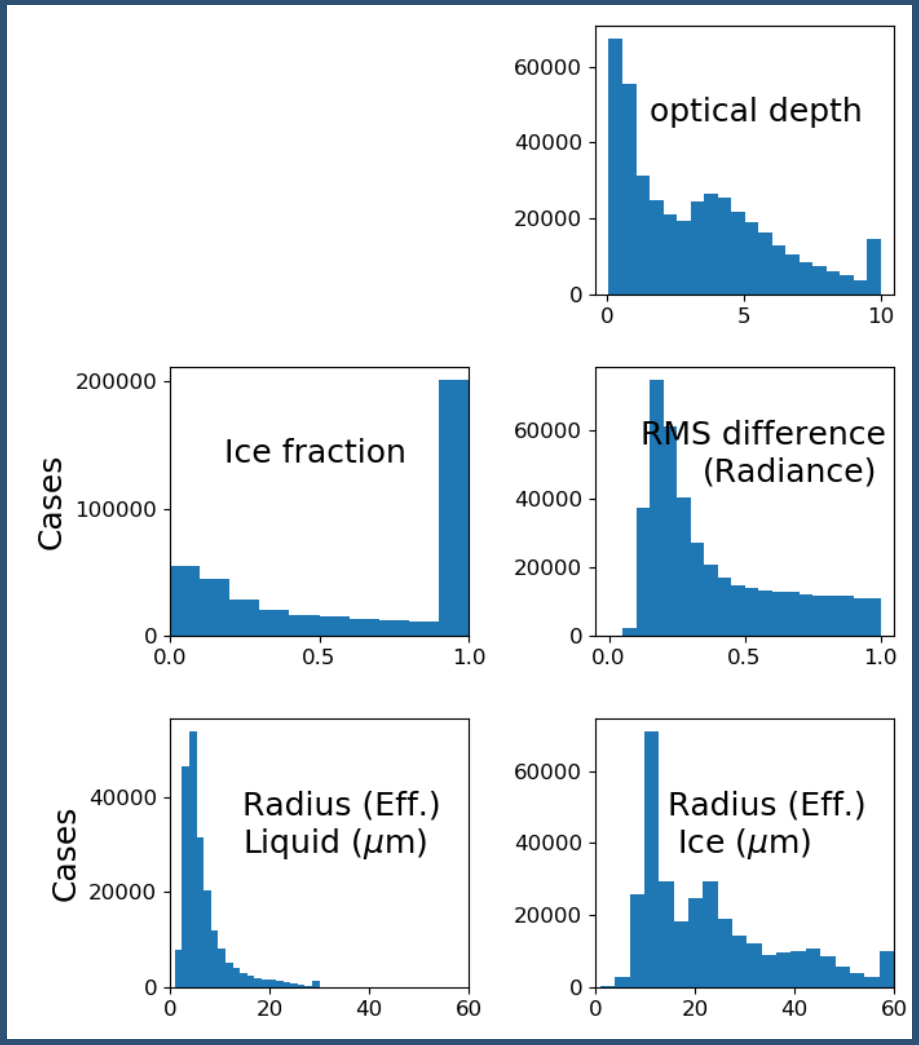


Atmospheric
profiles

Retrieved Cloud Properties: In the Antarctic

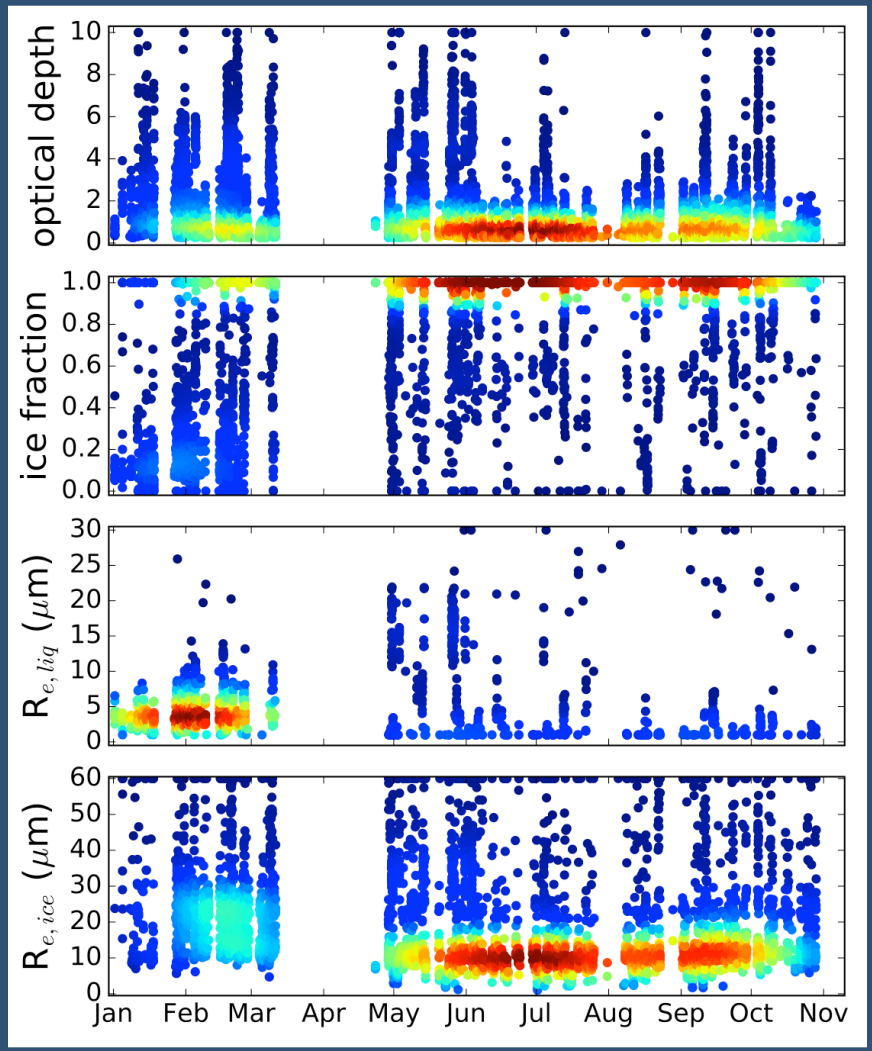


South Pole

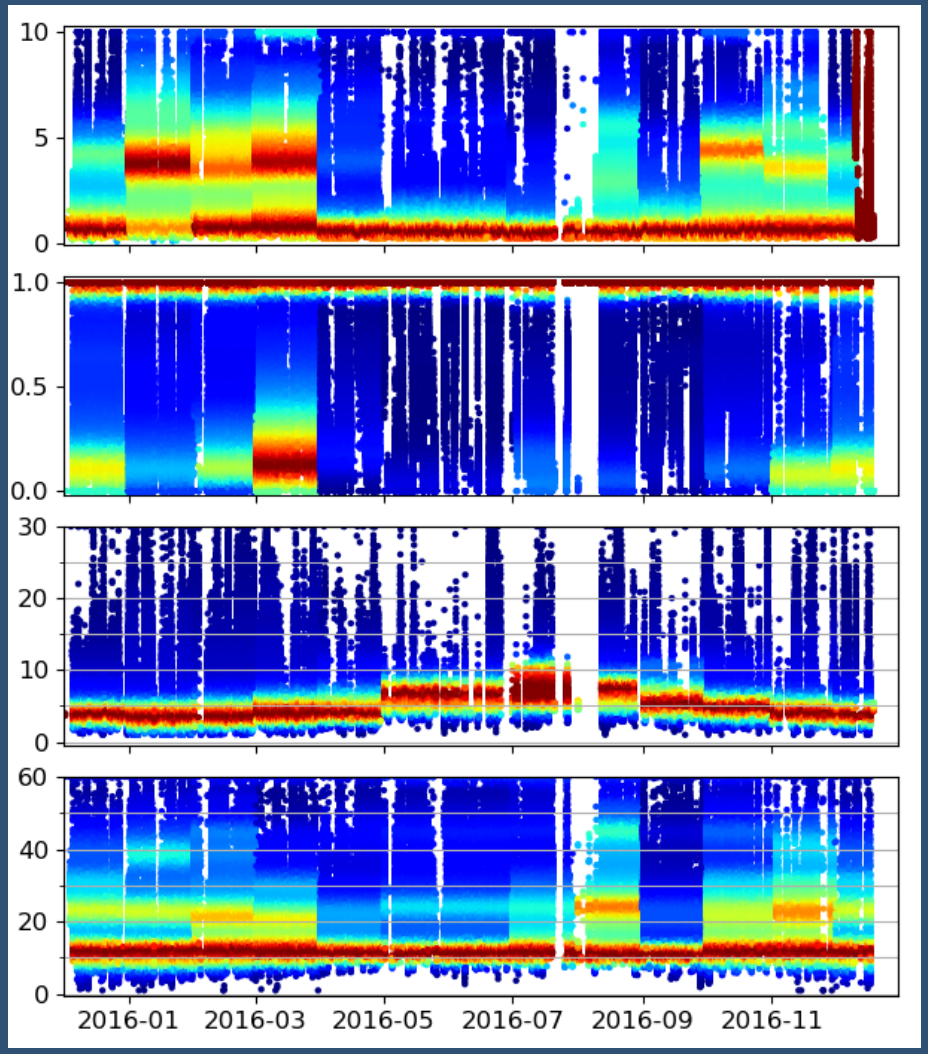


McMurdo

Retrieved Cloud Properties: In the Antarctic

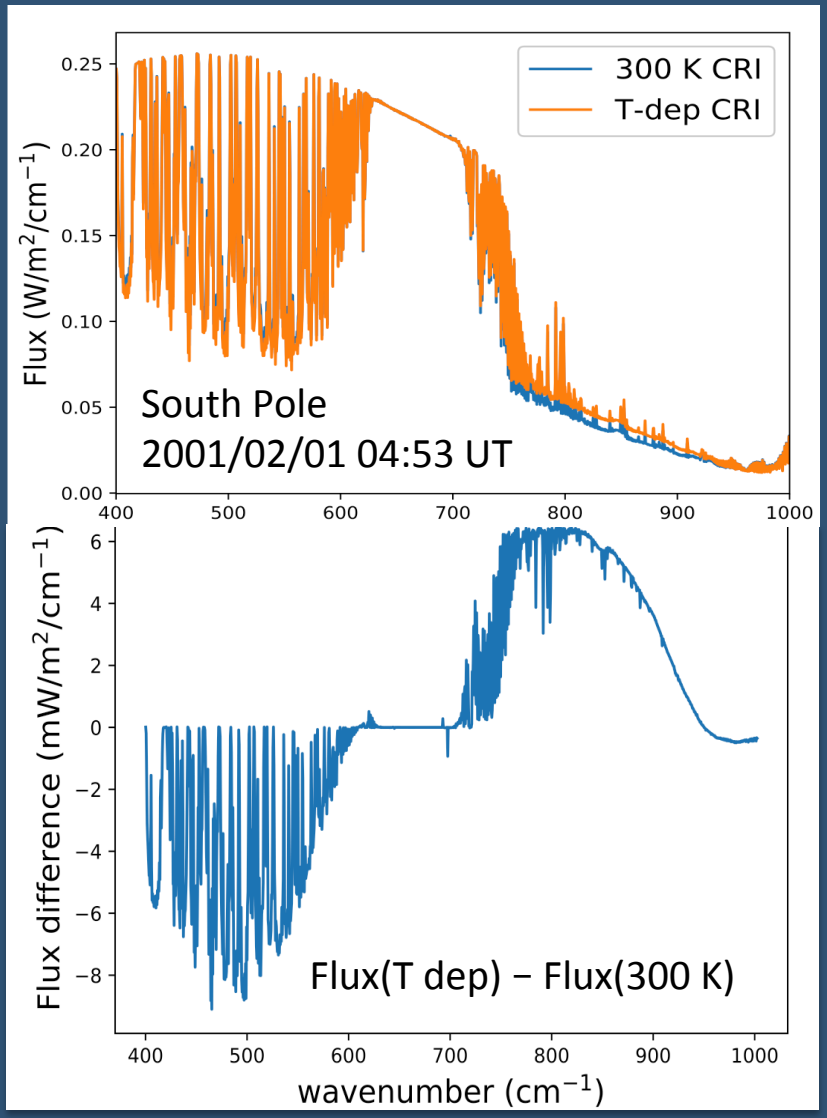


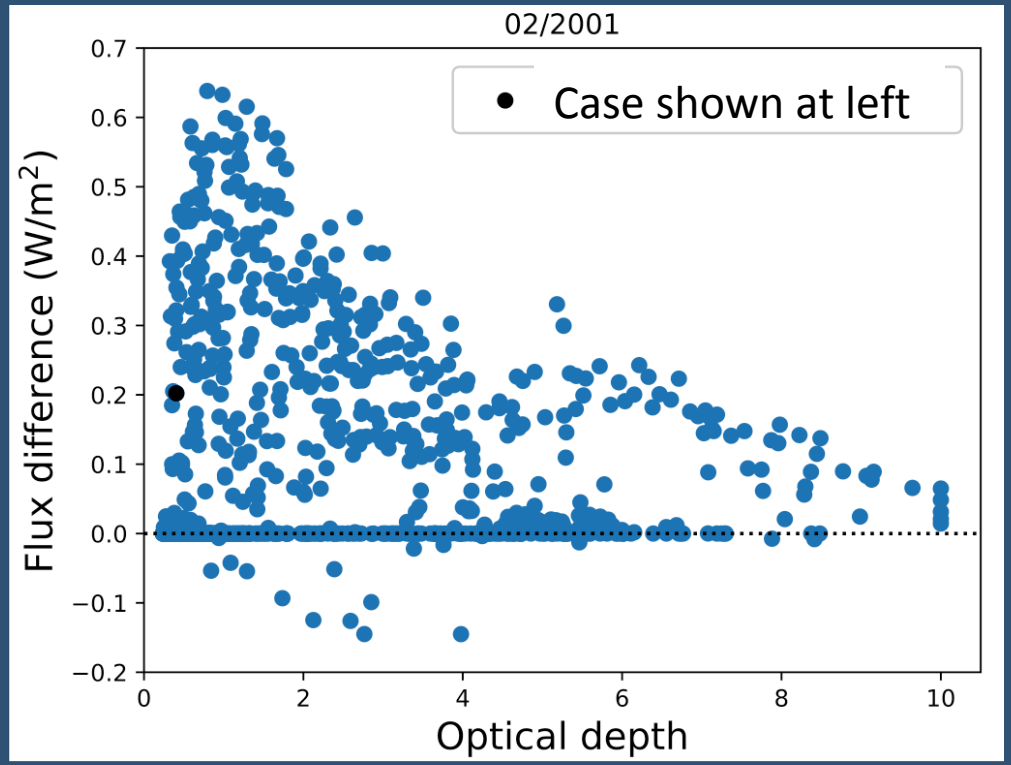
South Pole



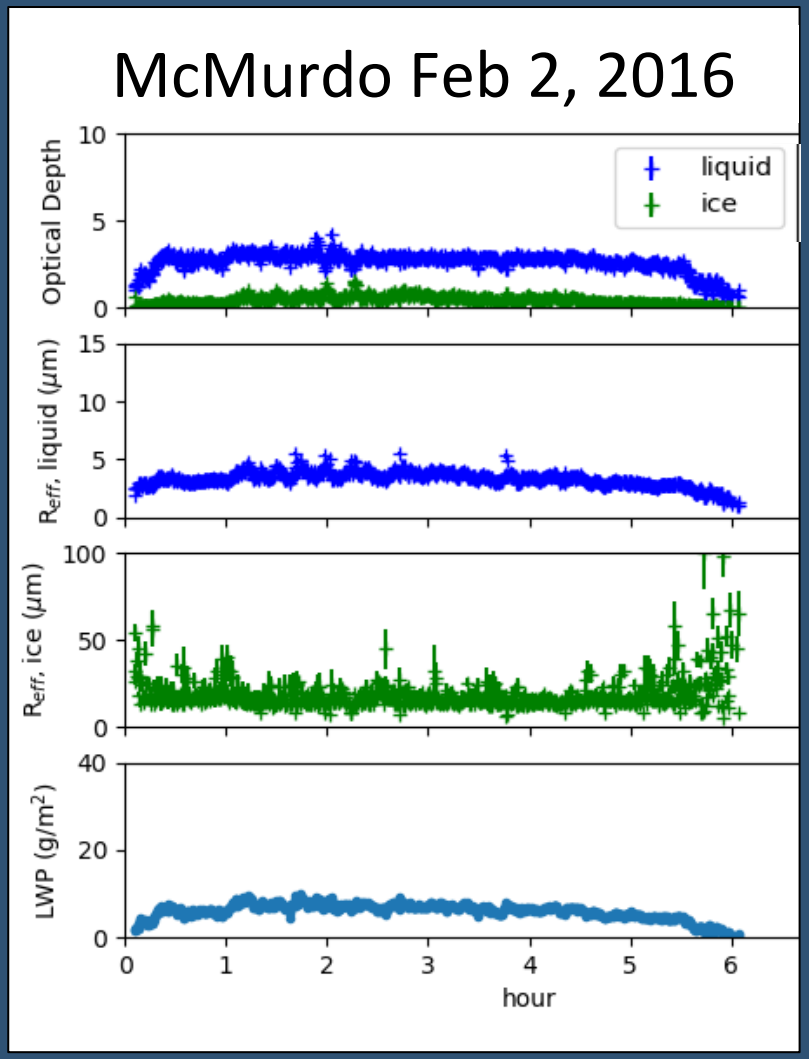
McMurdo

Effect of Ignoring Temperature Dependence of CRI

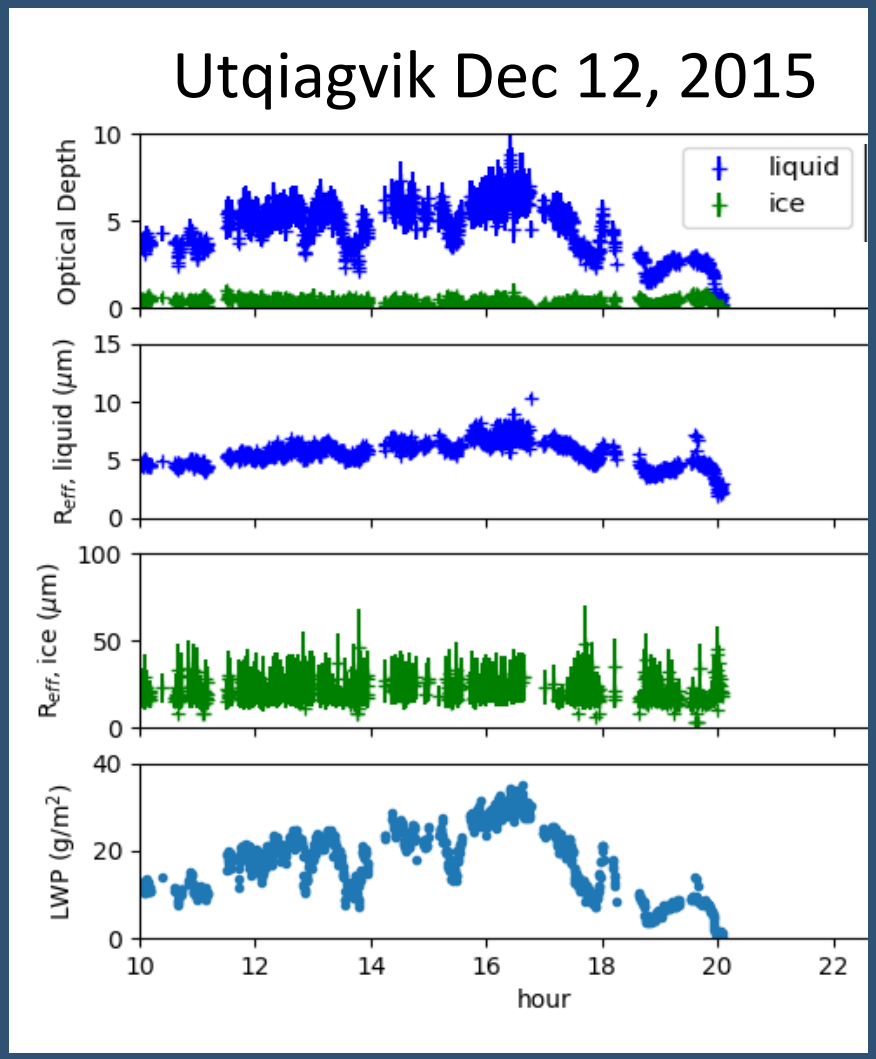




Comparing Antarctic and Arctic Clouds



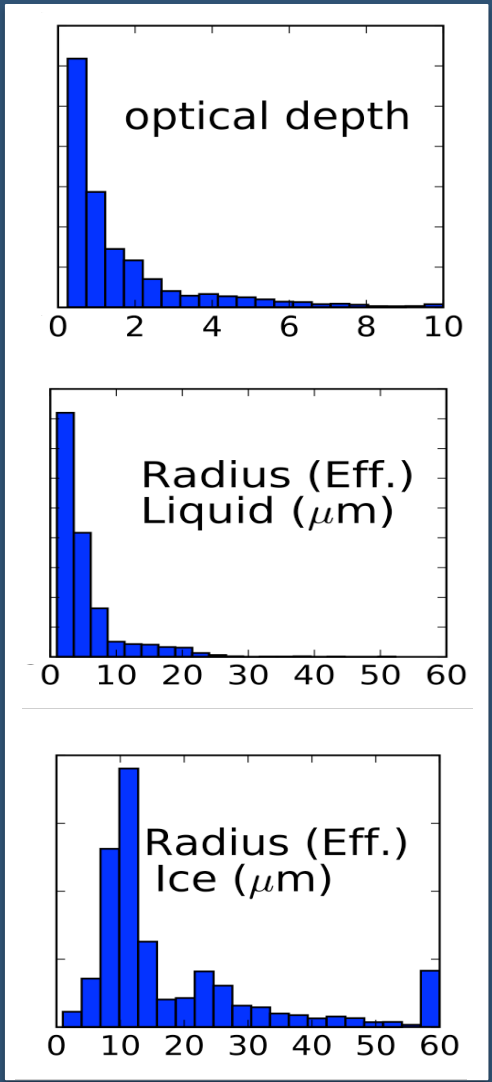
Antarctic



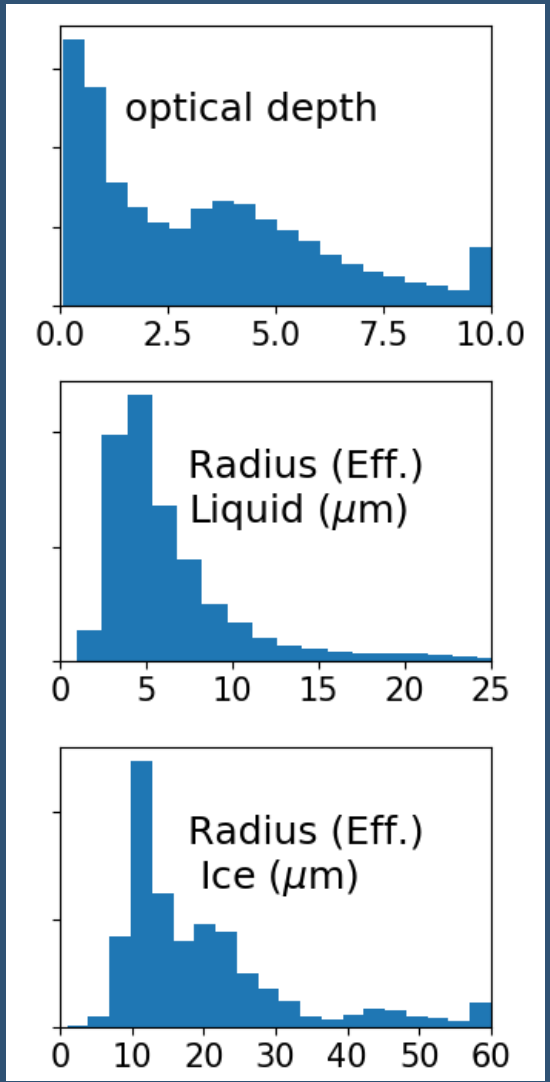
Arctic

Lubin et al 2020: https://doi.org/10.1175/BAMS_D_18_0278.1

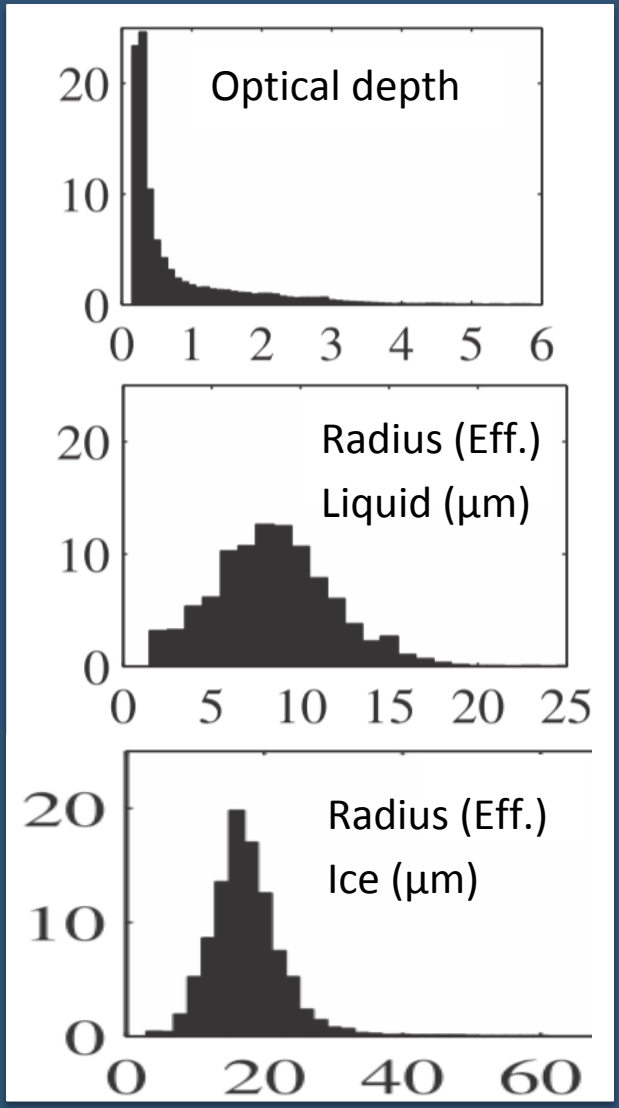
Comparing Antarctic and Arctic Clouds



South Pole



McMurdo



Eureka (Cox et al 2014)

Conclusions

- Antarctic cloud properties were retrieved from infrared radiances, using CLARRA.
- South Pole:
  - Clouds optically thin, near the surface
  - Ice effective radii larger in summer than winter
- McMurdo:
  - More liquid cloud than at South Pole
  - Bimodal distribution of optically thin and thick clouds.
  - Liquid effective radii larger in winter than summer.

Conclusions

- Ignoring the temperature dependence of the CRI of supercooled liquid cloud resulted in flux bias estimates as large as 0.6 W/m^2.
- However, there is a lot of uncertainty in the temperature dependence of the CRI in spectral regions that are important for the infrared, so more measurements of the CRI are needed.

Conclusions

- Compared to the Arctic, Antarctic clouds are
  - Optically thinner (except at Eureka)
  - Composed of smaller ice crystals (e.g. 5 vs 8 µm)
  - Have a bimodal ice crystal size distribution with a peak at a lower value (e.g. 12 vs 18 µm)

Future Work

- Various improvements: quality control of radiances, temperature dependent CRI refined
- Improve retrievals for multi-layer clouds (not handled well).
- Estimate biases for Antarctica as a whole (down- and upwelling)

Acknowledgements

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