The Infrared Radiative Impact of Antarctic Clouds

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Motivation

- Antarctic clouds have a strong influence on the radiation budget
- However, measurements in Antarctica are limited.
- Archived and recent infrared data exist that can be used to retrieve cloud properties over Antarctica and examine their infrared radiative impact.
  - South Pole: January – November 2001
  - Dome C: Austral Summer 2003
  - McMurdo: December 2015 – January 2017

SOUTHERN OCEAN
KONG HÅKON VII HAV
South Orkney Is
Signy (UK)
Antarctic Circle 66°34'S
South Shetland Is
ANTARCTIC PENINSULA
WEDDELL SEA
Halley (UK)
Palmer (USA)
Rothera (UK)
PALMER LAND
RONNE ICE SHELF
BELLINGSHAUSEN SEA
DRONNING MAUD LAND
ENDERBY LAND
COATS LAND
KEMP LAND
MACROBERTSON LAND
EAST ANTARCTICA
QUEEN ELIZABETH
PRINCESS ELIZABETH LAND
South Pole
Amundsen-Scott (USA)
90°W
90°E
ELLSWORTH LAND
WILHELM II LAND
WEST ANTARCTICA
Transantarctic Mountains
QUEEN MARY LAND
AMUNDSEN SEA
MARIE BYRD LAND
ROSS ICE SHELF
80°S
WILKES LAND
McMurdo (USA)
Dome C
McMurdo
ROSS SEA
VICTORIA LAND
TERRE ADÉLIE
GEORGE V LAND
OATES LAND
180°
0
1000
2000
Km
0
200
400
600
800
1000
Miles

Outline

- Background: Infrared remote sensing
- CLoud Atmospheric Radiation Retrieval Algorithm (CLARRA)
- Preliminary Results from South Pole: January – November 2001

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Infrared Remote Sensing

- Passive, from surface (downwelling) or satellite (upwelling)
- Retrievals of trace gases, cloud height, cloud microphysics.
- Variety of methods, including:
  - Minimum Local Emissivity Variance (MLEV; cloud height)
  - Cloud Slicing/Sorting (cloud height)
  - Optimal estimation (trace gases, cloud microphysics)

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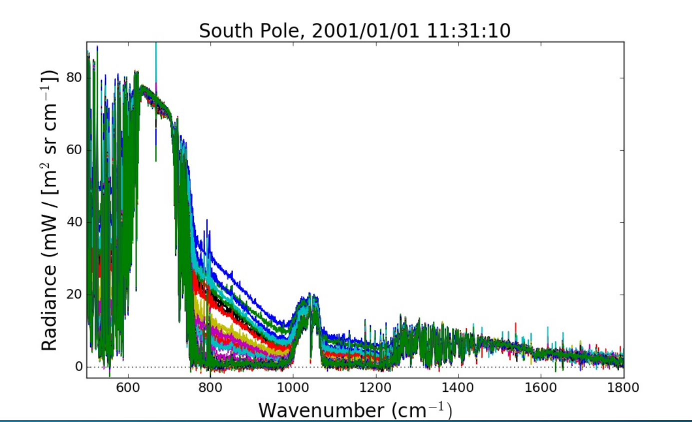
Retrievals from IR Remote Sensing (example: Downwelling Radiance)

Atmospheric gases, clouds, aerosols

Downwelling Infrared radiance

Ground-based spectrometer



Outline

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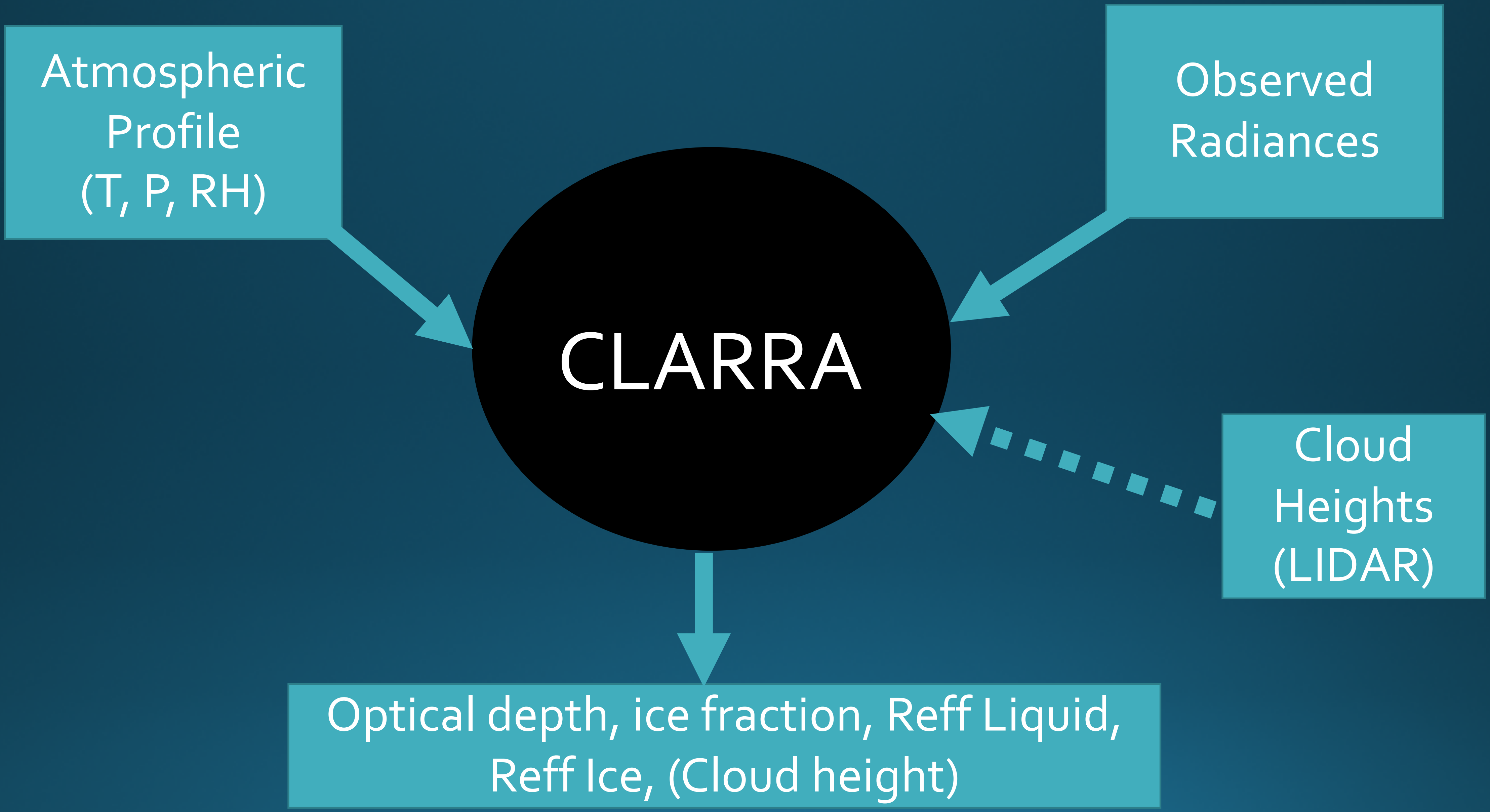
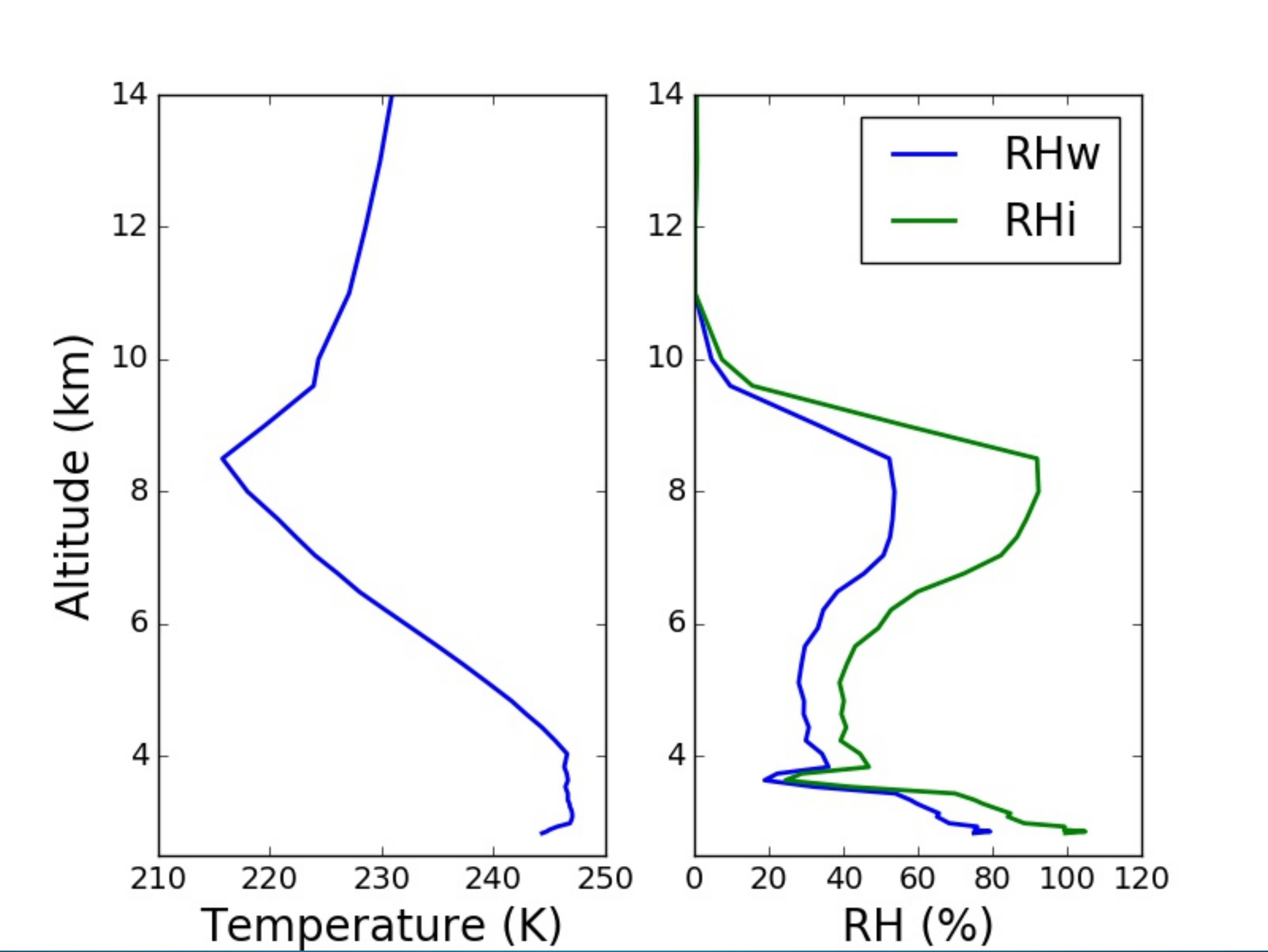
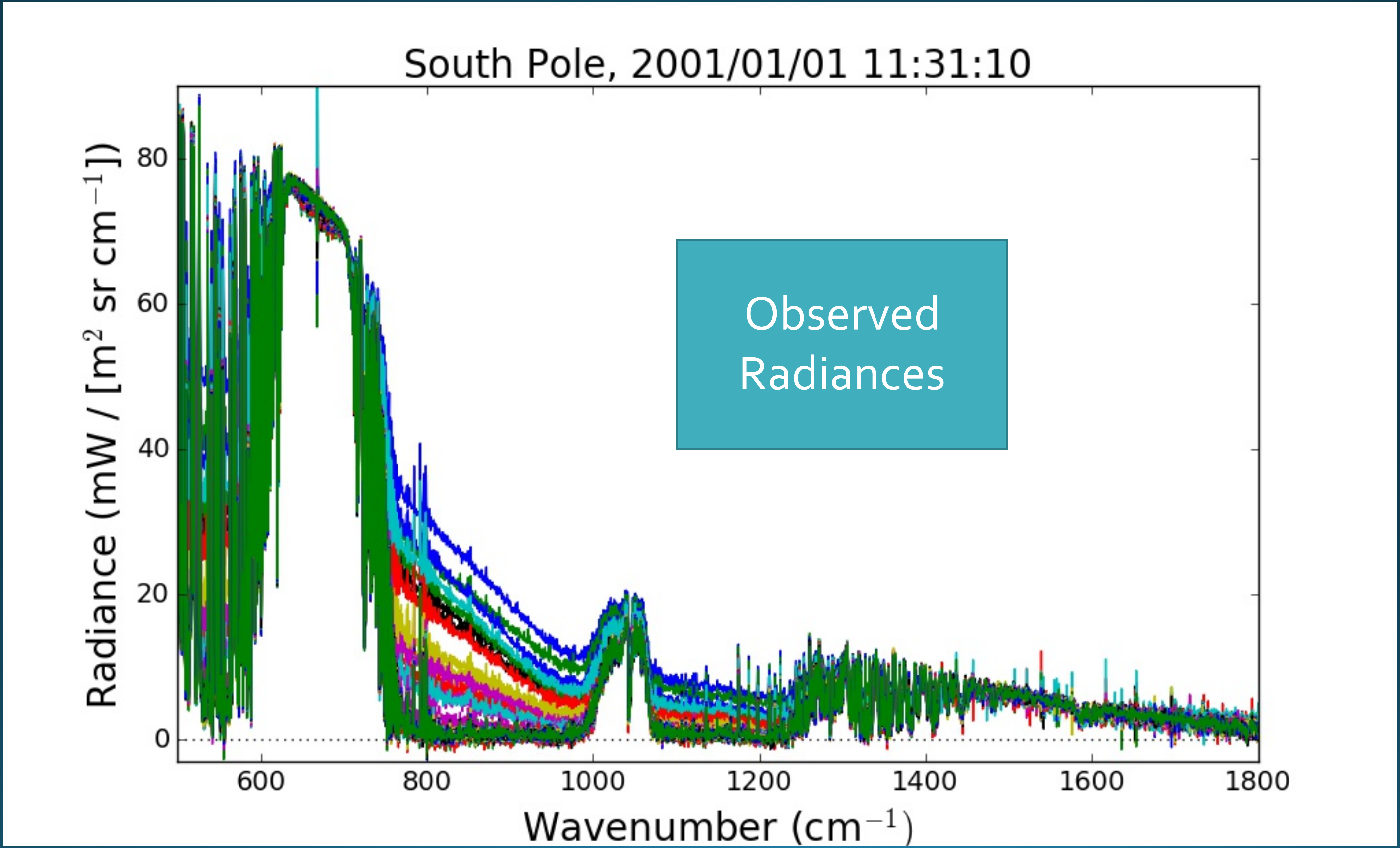

Atmospheric Profile (T, P, RH)
Observed Radiances
CLARRA
Cloud Heights (LIDAR)
Optical depth, ice fraction, Reff Liquid, Reff Ice, (Cloud height)

Atmospheric Profile
(T, P, RH)

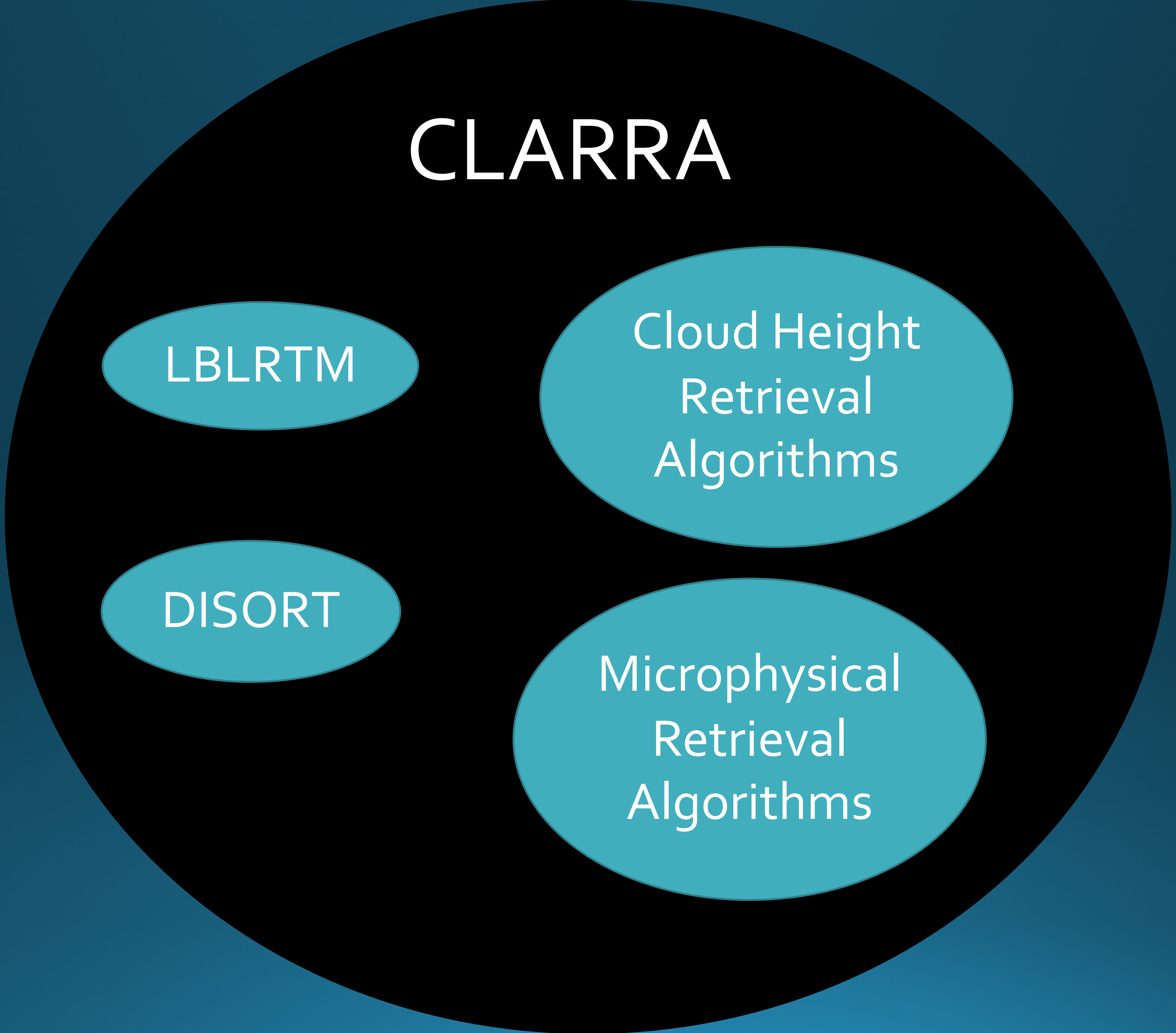




South Pole, 2001/01/01 11:31:10
Radiance (mW / [m^2 sr cm^{-1}])
80
60
40
20
0
600
800
1000
1200
1400
1600
1800
Wavenumber (cm^{-1})
Observed Radiances

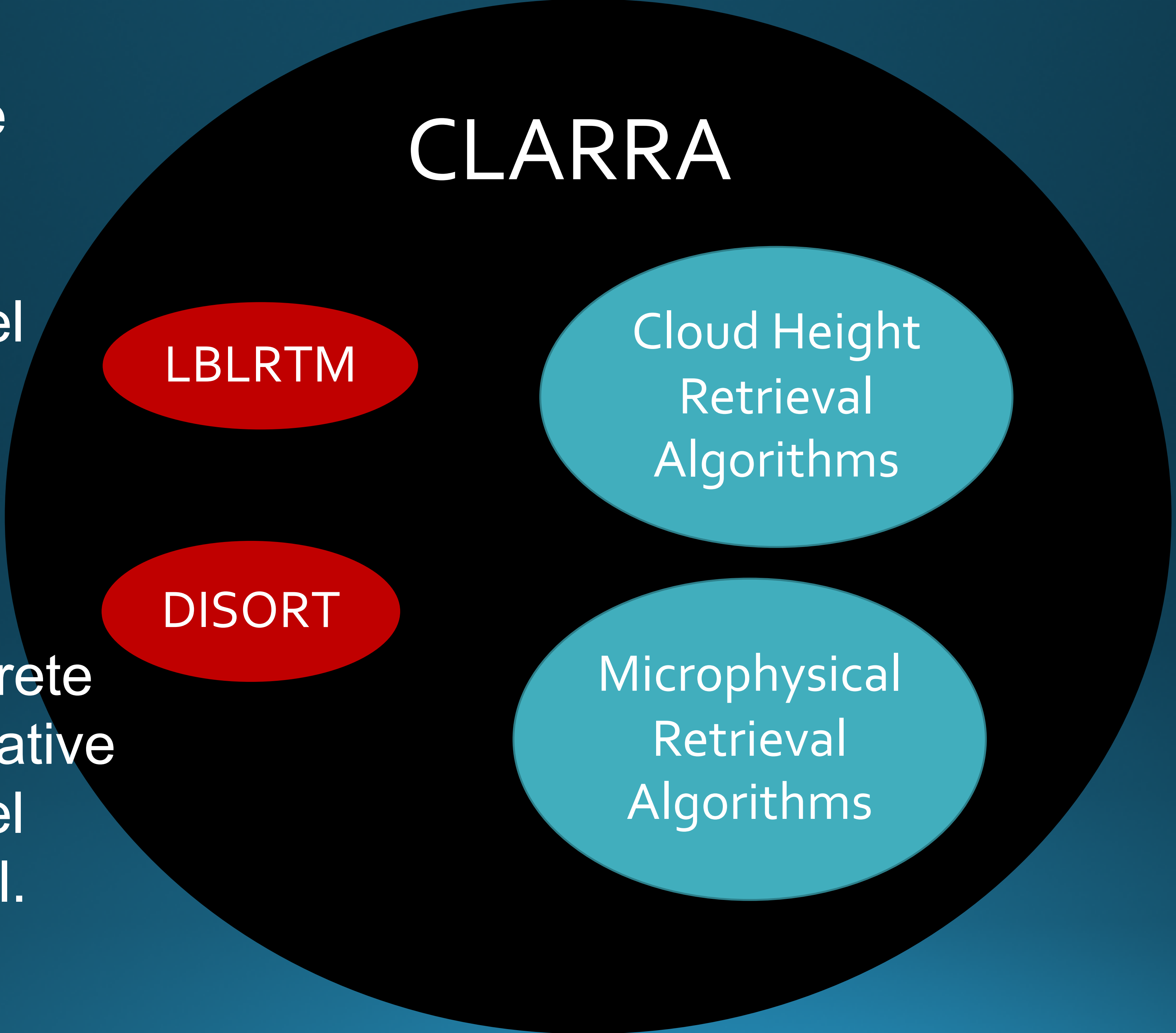
CLARRA

- Cloud property retrievals from IR radiances
- Downwelling or Upwelling
- Can perform cloud height retrieval or use input heights (e.g. from Lidar)
- Variety of zenith viewing angles
- Flexible cloud representation (e.g. mixed phase)
- Instrument-resolution matching, enabling thin cloud retrievals


CLARRA
LBLRTM
Cloud Height Retrieval Algorithms
DISORT
Microphysical Retrieval Algorithms

LBLRTM: Line by Line Radiative Transfer Model (Clough et al. 1992).

DISORT: Discrete Ordinate Radiative Transfer Model (Stamnes et al. 1988).

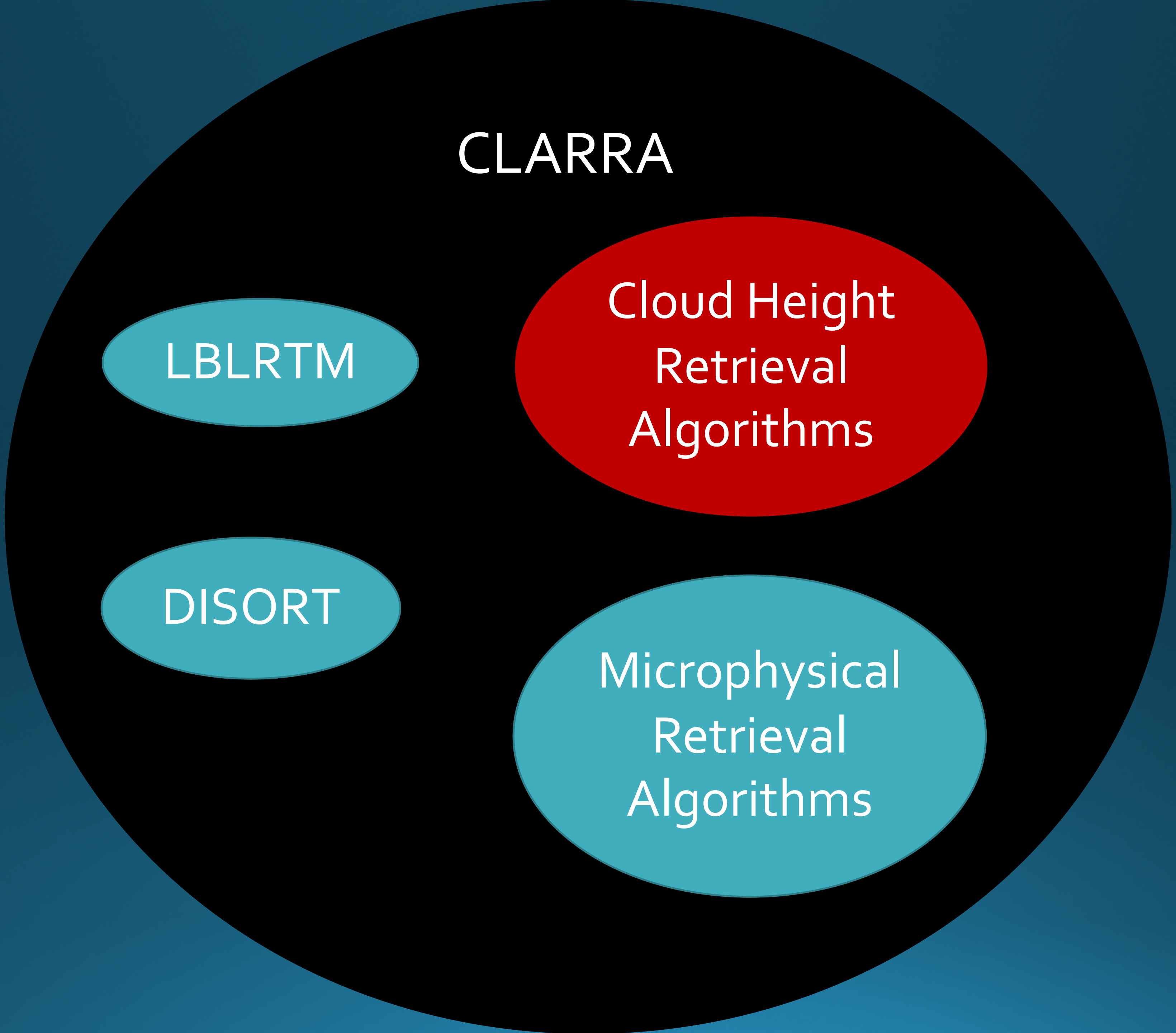


LBLRTM

- Line by Line Radiative Transfer Model (Clough et al. 1992).
- Used to compute optical depths of trace gases (cloud-free)
- These optical depths are “perfect” resolution; CLARRA includes an algorithm to account for finite instrument resolution.

DISORT

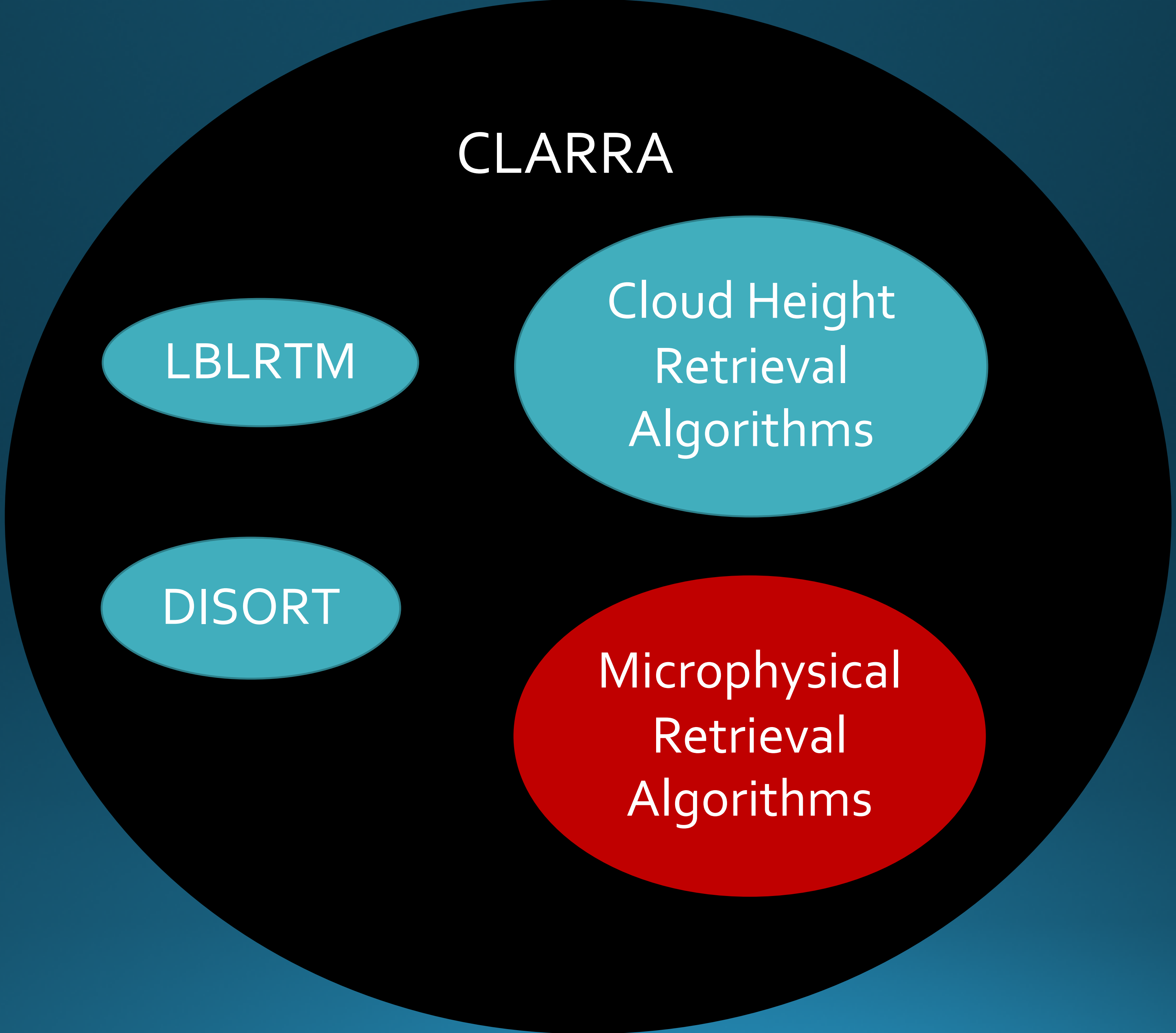
- Discrete Ordinate Radiative Transfer Model (DISORT; Stamnes et al. 1988).
- Performs radiative transfer, including scattering.


CLARRA
LBLRTM
DISORT
Cloud Height Retrieval Algorithms
Microphysical Retrieval Algorithms

Cloud Height Retrievals

- ➢ Minimum Local Emissivity Variance (MLEV; Huang et al., 2004)
- ➢ CO2 slicing/sorting

- Cox, C.J., Rowe, P.M., Neshyba, S. P., and Walden, V.P., “A synthetic data set of high-spectral-resolution infrared spectra for the Arctic Atmosphere,” Earth Syst. Sci. Data, 8, 199-211, 2016.
- Rowe, P. M., Cox, C.J, and Walden, V.P., “Toward autonomous surface-based remote sensing of polar clouds: cloud-height retrievals,” 2016, Atmos. Meas. Tech., 9, 3641-3659, 2016.


CLARRA
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Microphysical Retrievals

- Optimal estimation within a Bayesian framework
- Iterative inverse retrieval
- Gauss-Newton and Levenberg-Marquardt
- Rodgers, 2000

$$\begin{aligned} \mathbf{x}_{i+1} &= \mathbf{x}_i + [(1+\gamma)\mathbf{S}_a^{-1} + \mathbf{K}_i^T \mathbf{S}_\epsilon^{-1} \mathbf{K}_i]^{-1} \\ &\quad \{\mathbf{K}_i^T \mathbf{S}_\epsilon^{-1} [\mathbf{y} - \mathbf{F}(\mathbf{x}_i)] - \mathbf{S}_a^{-1} [\mathbf{x}_i - \mathbf{x}_a]\} \end{aligned}$$

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Outline

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Preliminary Results from South Pole

- Downwelling infrared radiance
- Measured from the surface
- Polar Atmospheric Emitted Radiance Interferometer (PAERI)
- January – November 2001
- Lidar cloud heights available from Jan-June, but have not yet been incorporated.
- Improvements expected after further QC!

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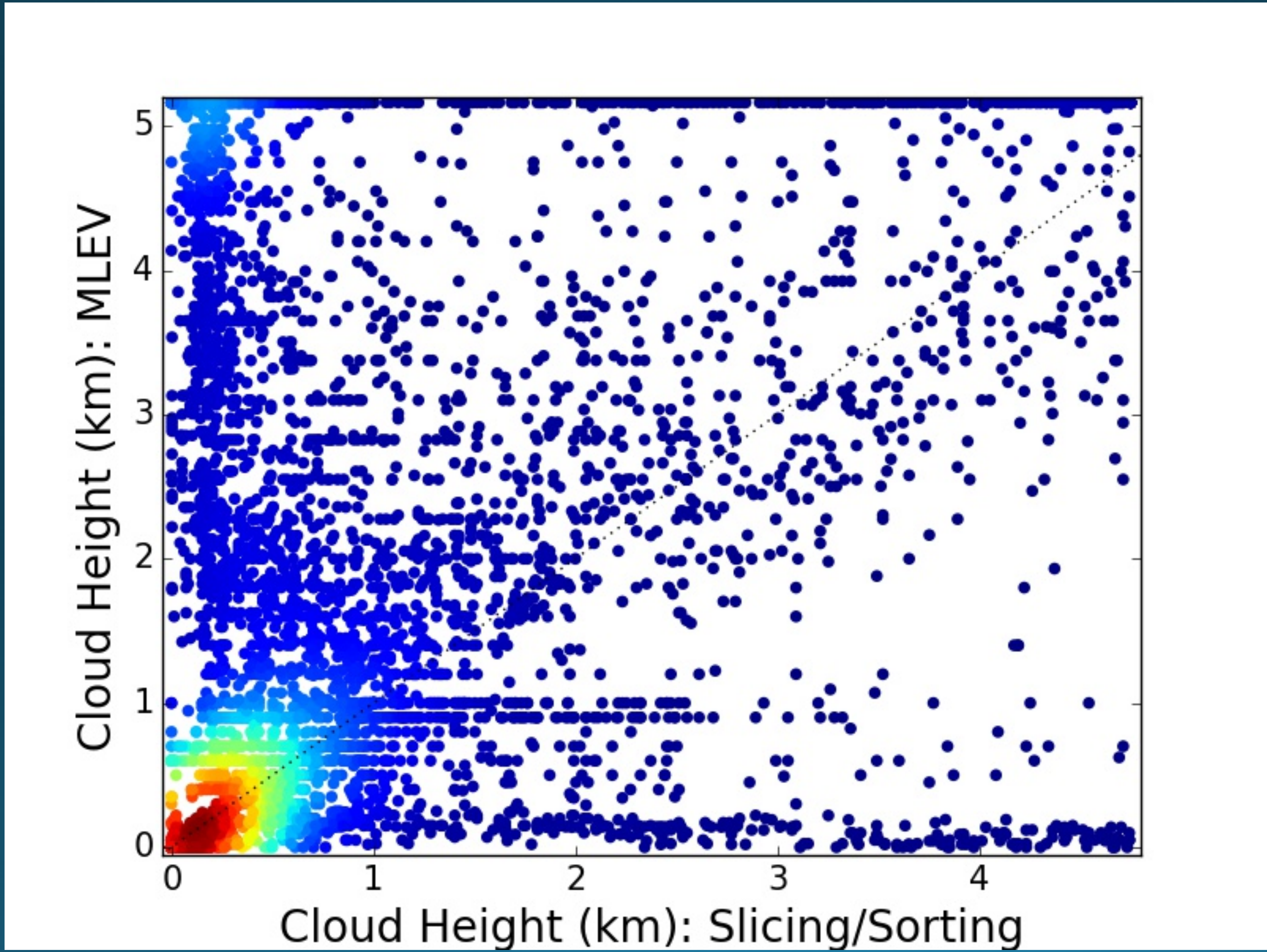
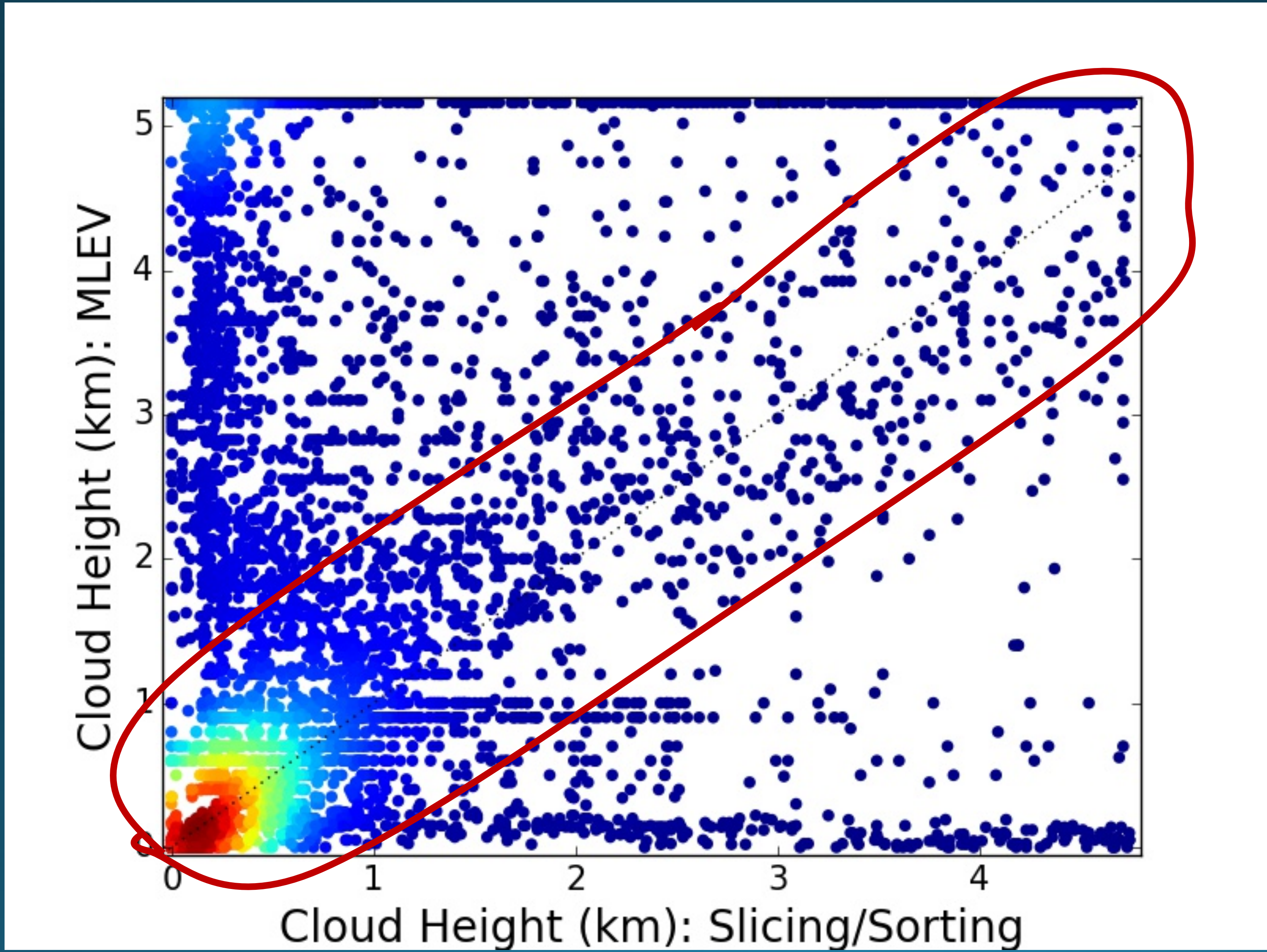
Cloud Height



Optical depth > 0.25

Cloud Height

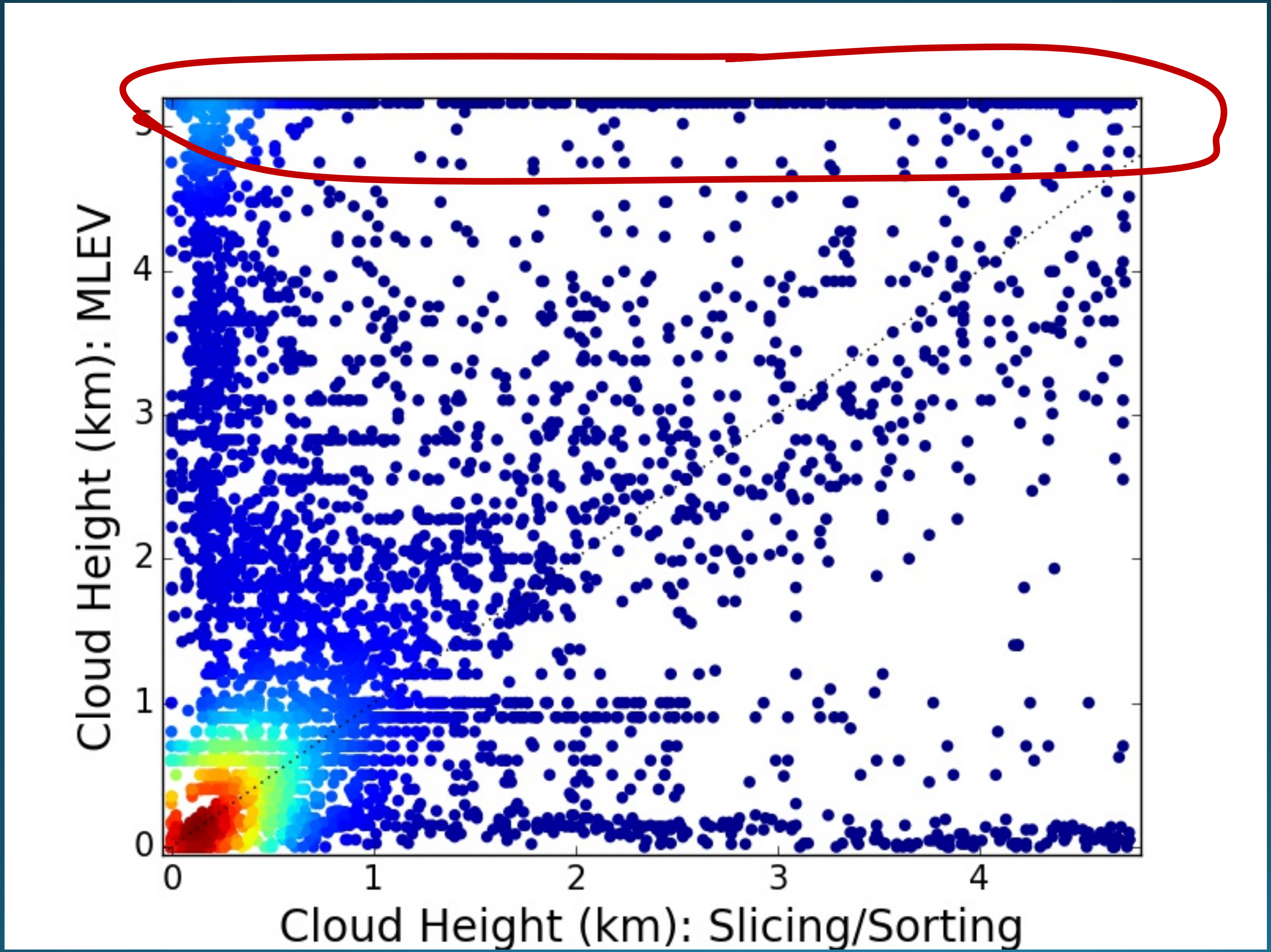
Methods agree



Optical depth > 0.25

Cloud Height

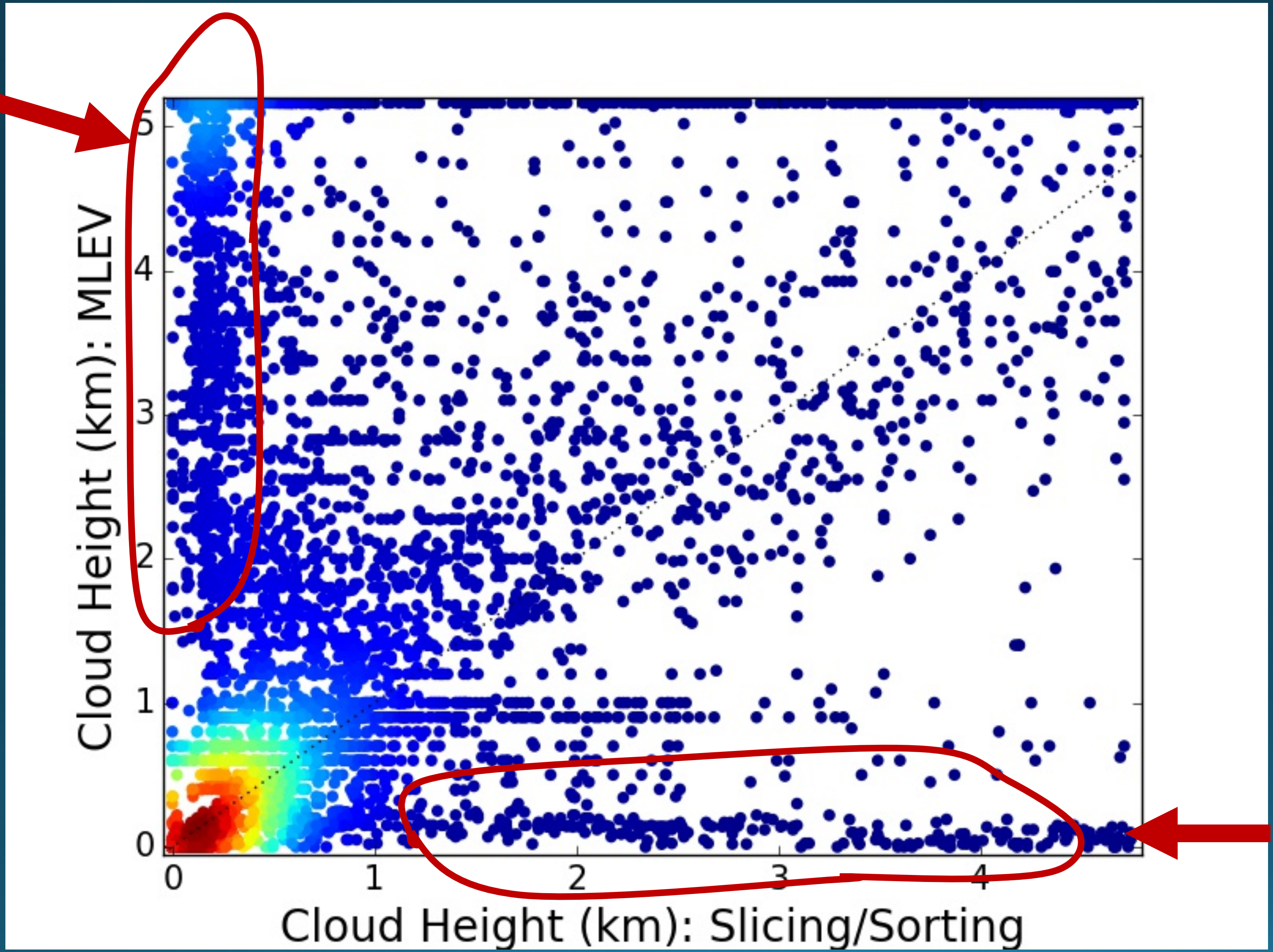
MLEV wrong: Use Slicing/ sorting



Optical depth > 0.25

Cloud Height

Trust MLEV?



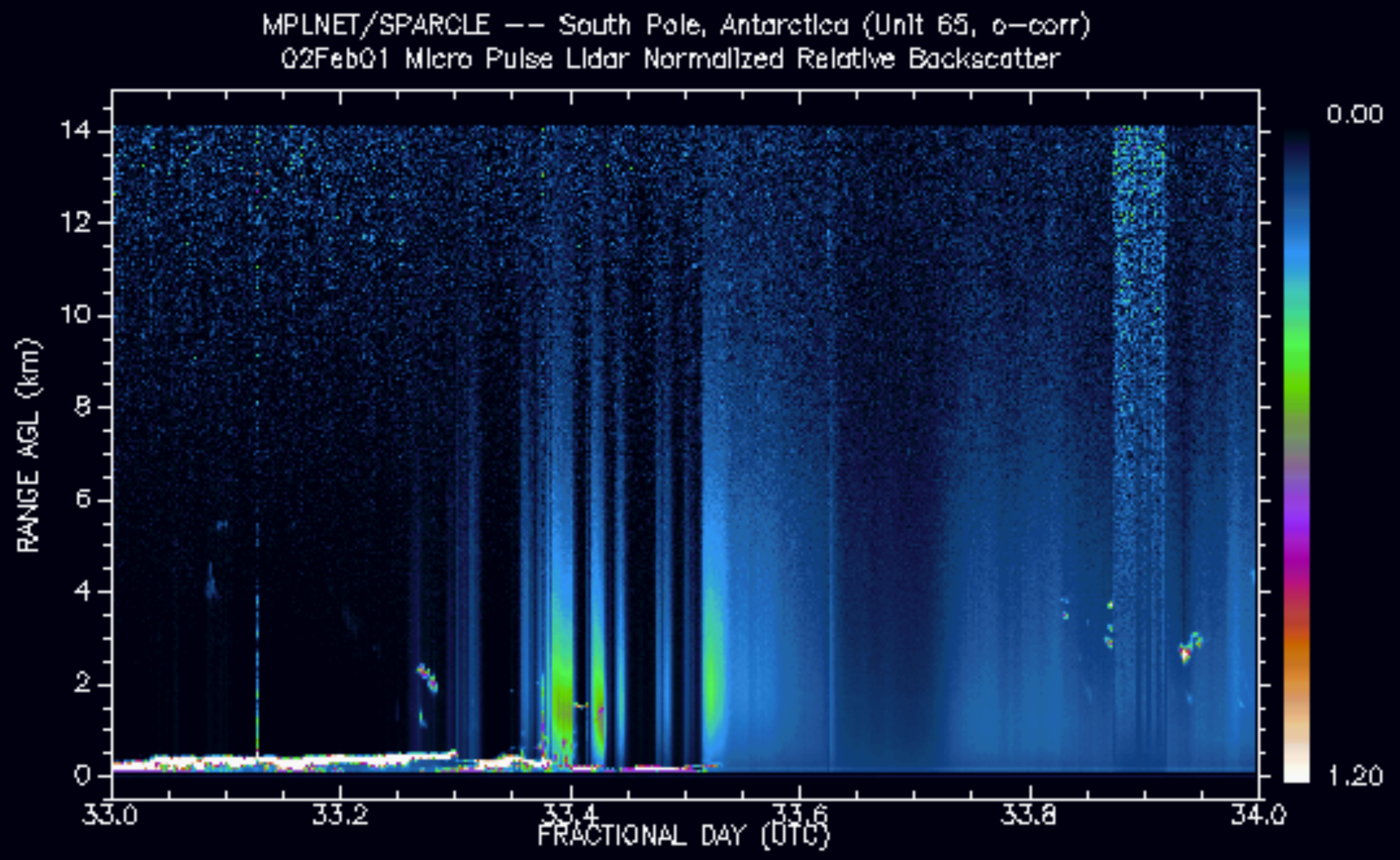
Optical depth > 0.25

Trust Slicing/ sorting?

Lidar (Jan – June)

Cloud Heights from LIDAR

Coming Soon…



Cloud Height

- Use lidar cloud heights when possible.
- Also use lidar cloud heights to verify which technique is better for which types of cases.
- Simulated results indicate, e.g.: CO_2 slicing/sorting will be better when humidity is less certain, MLEV when temperature is less certain.
- Choose best technique for cases when lidar unavailable (July – November; Dome C)

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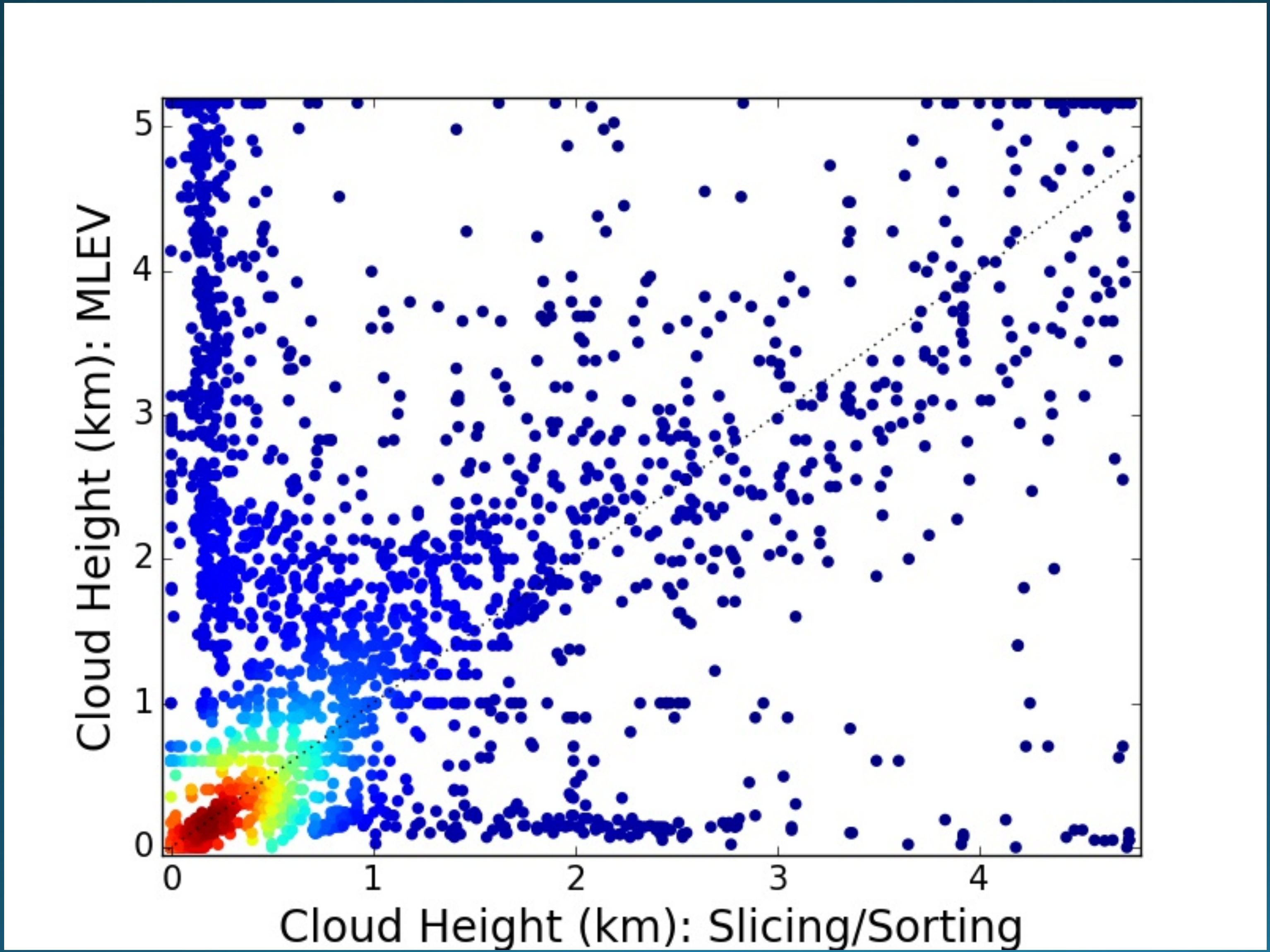
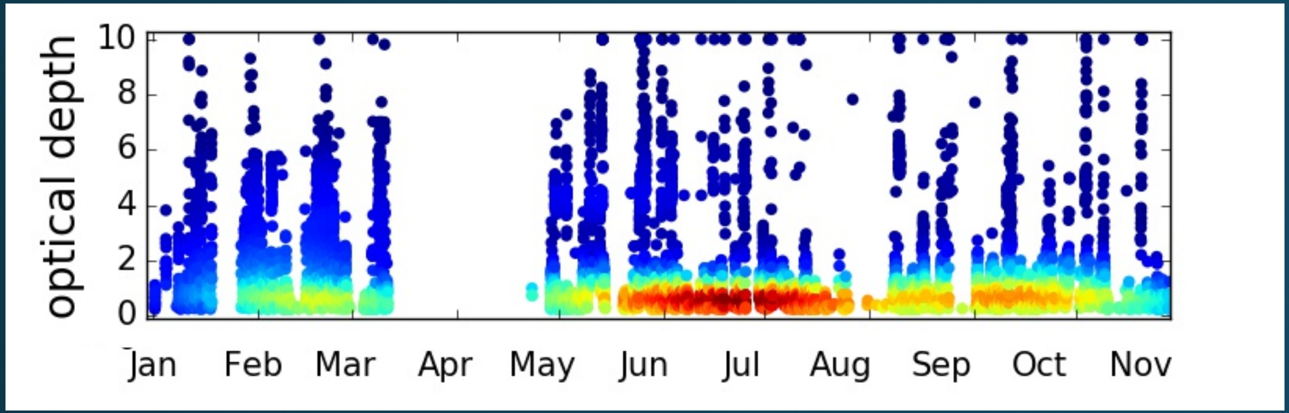
Cloud Height

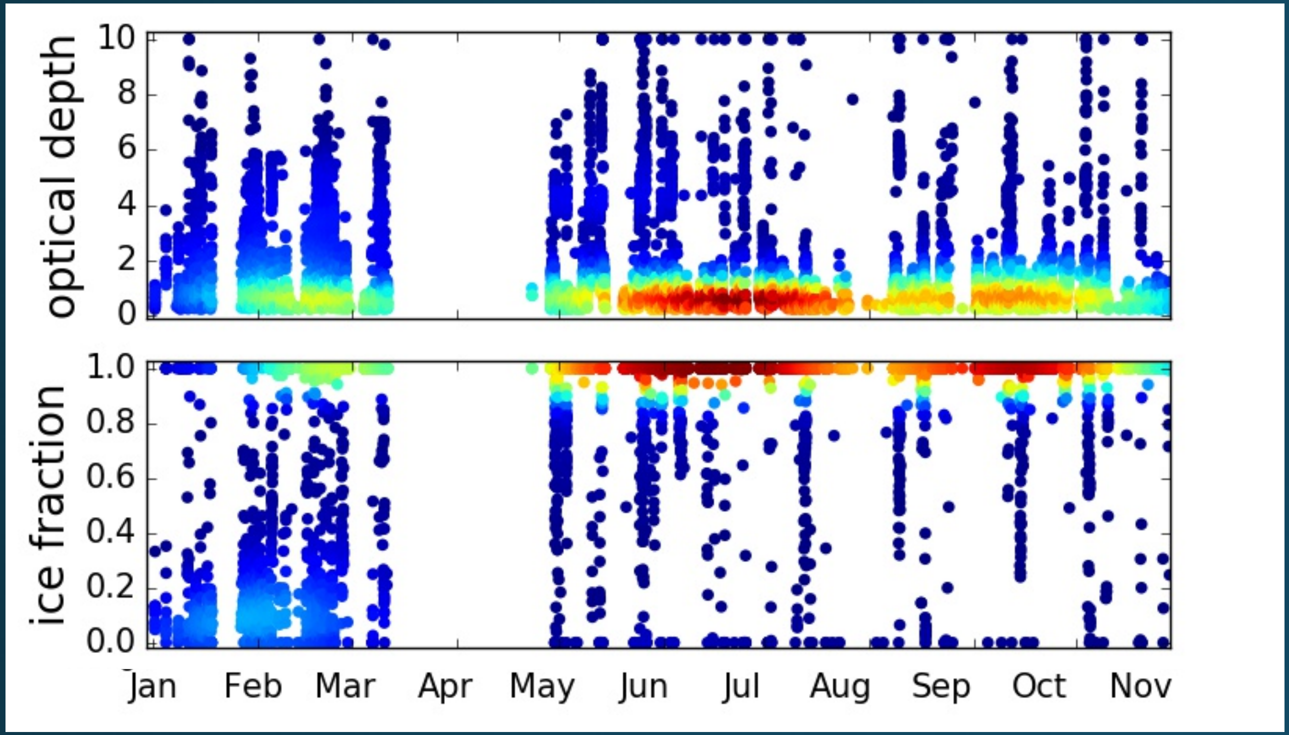
If all else fails, we can screen out thinnest clouds.



Optical depth > 1

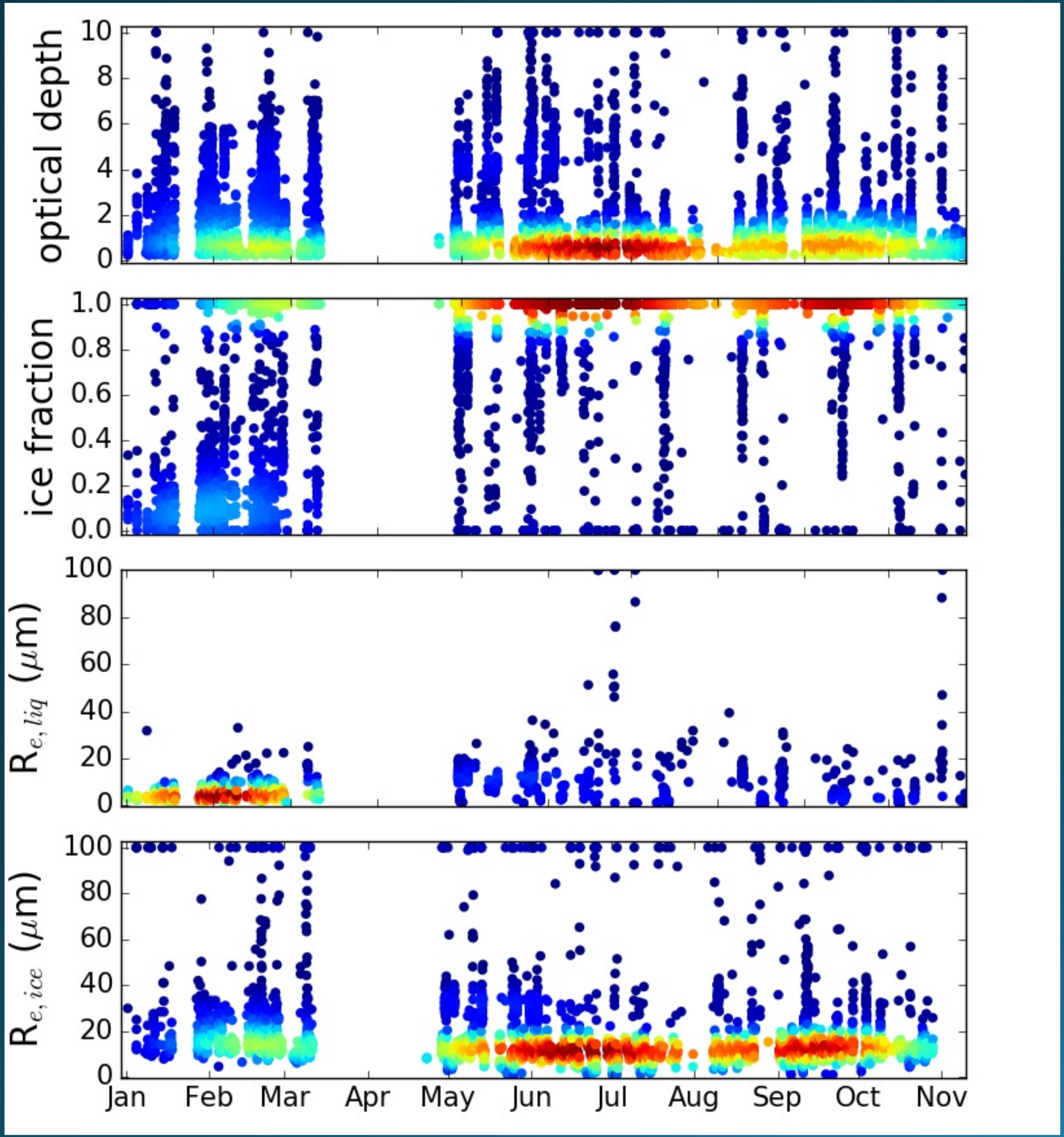


Microphysical Retrievals

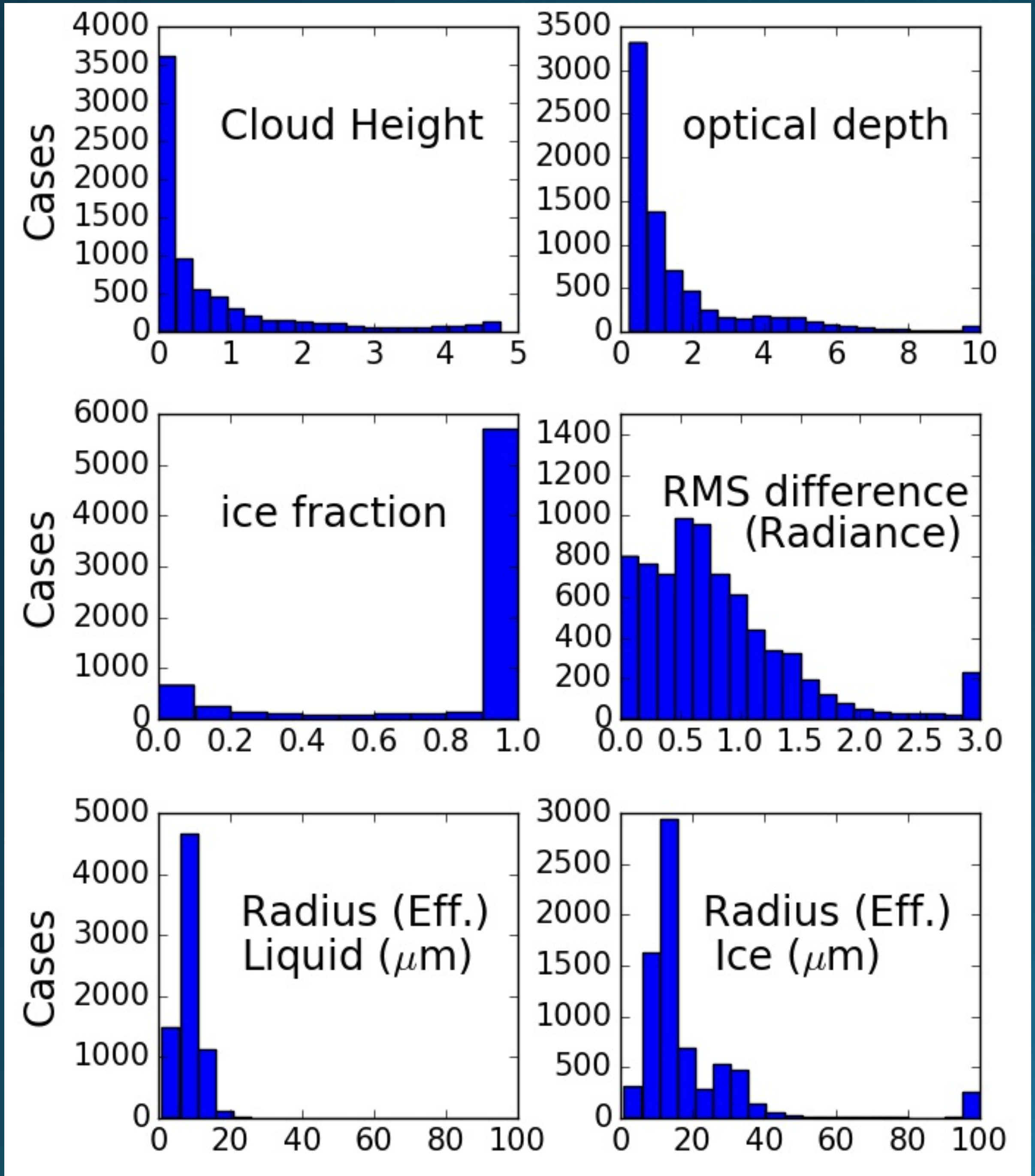


Microphysical Retrievals

Microphysical Retrievals



Microphysical Retrievals



Conclusions

- CLARRA was developed for retrieving cloud height and microphysical properties (optical depth, ice fraction, effective radius) from up or downwelling infrared radiances, and verified using simulations.
- Preliminary results with measured downwelling radiances from South Pole, 2001, overall look reasonable
- Much more quality control is needed, and is underway (spectra, atmospheric profiles, use of lidar cloud heights)
- Future work will include Dome C and AWARE retrievals, as well as characterization of IR radiance over Antarctica.

Acknowledgements

Michael Town & Stephen Hudson (collecting PAERI data), ESRL/NOAA (ancillary data), James Campbell and Ellsworth J. Dutton (lidar), South Pole Meteorology Office (radiosondes), Boyan Petkov (correction of radiosondes), NSF Grants OPP-9726676 and OPP-0230466 (collection of PAERI data), and NSF grants ARC-1108451 and PLR 1543236 .

Thank you

Retrievals from IR Remote Sensing

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Retrievals from IR Remote Sensing

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Retrievals from IR Remote Sensing

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- Pan, L-J and Lu, Da-Ren, 2012: Cloud base height and effective cloud emissivity retrieval with Ground-based Infrared Interferometer

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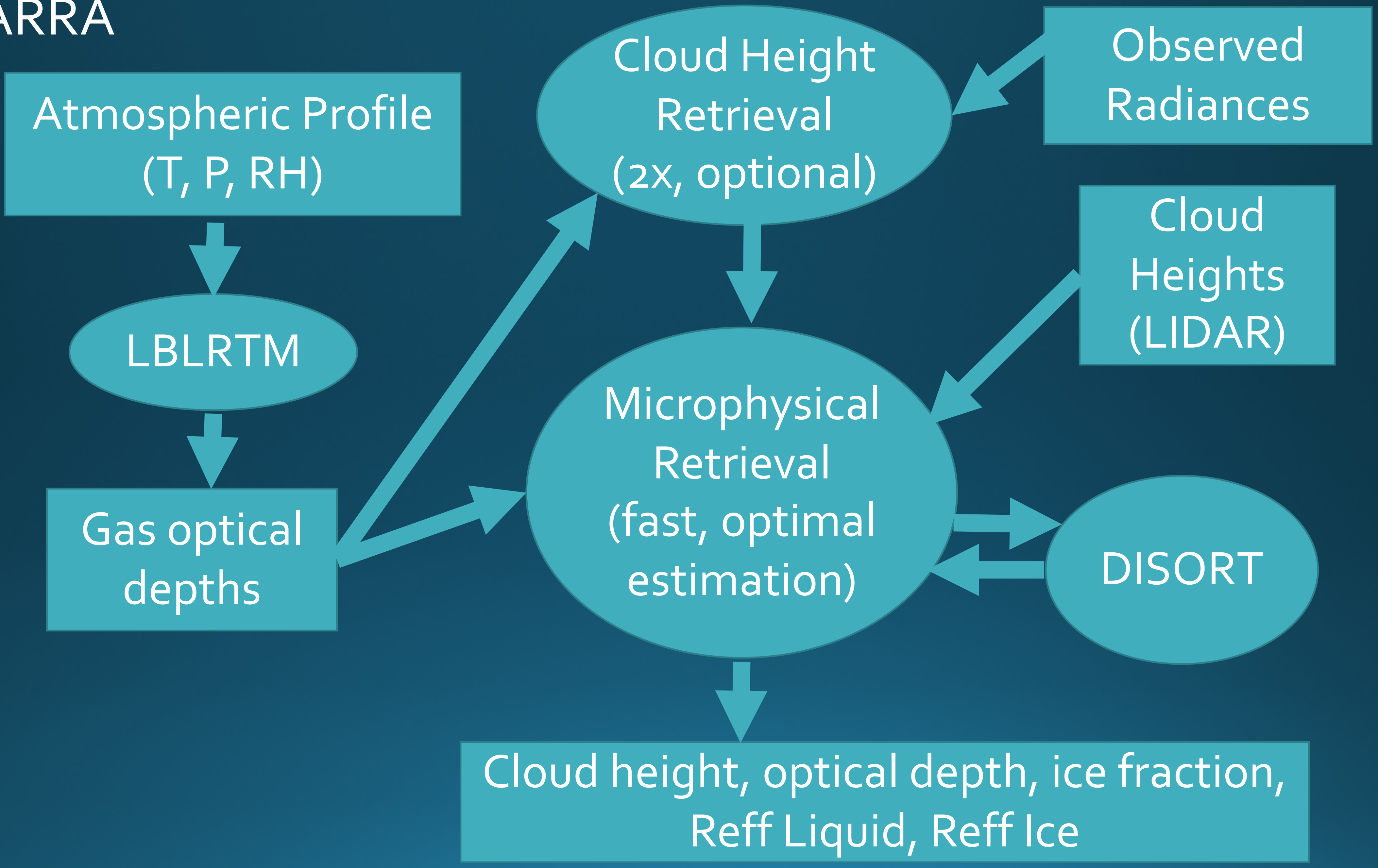
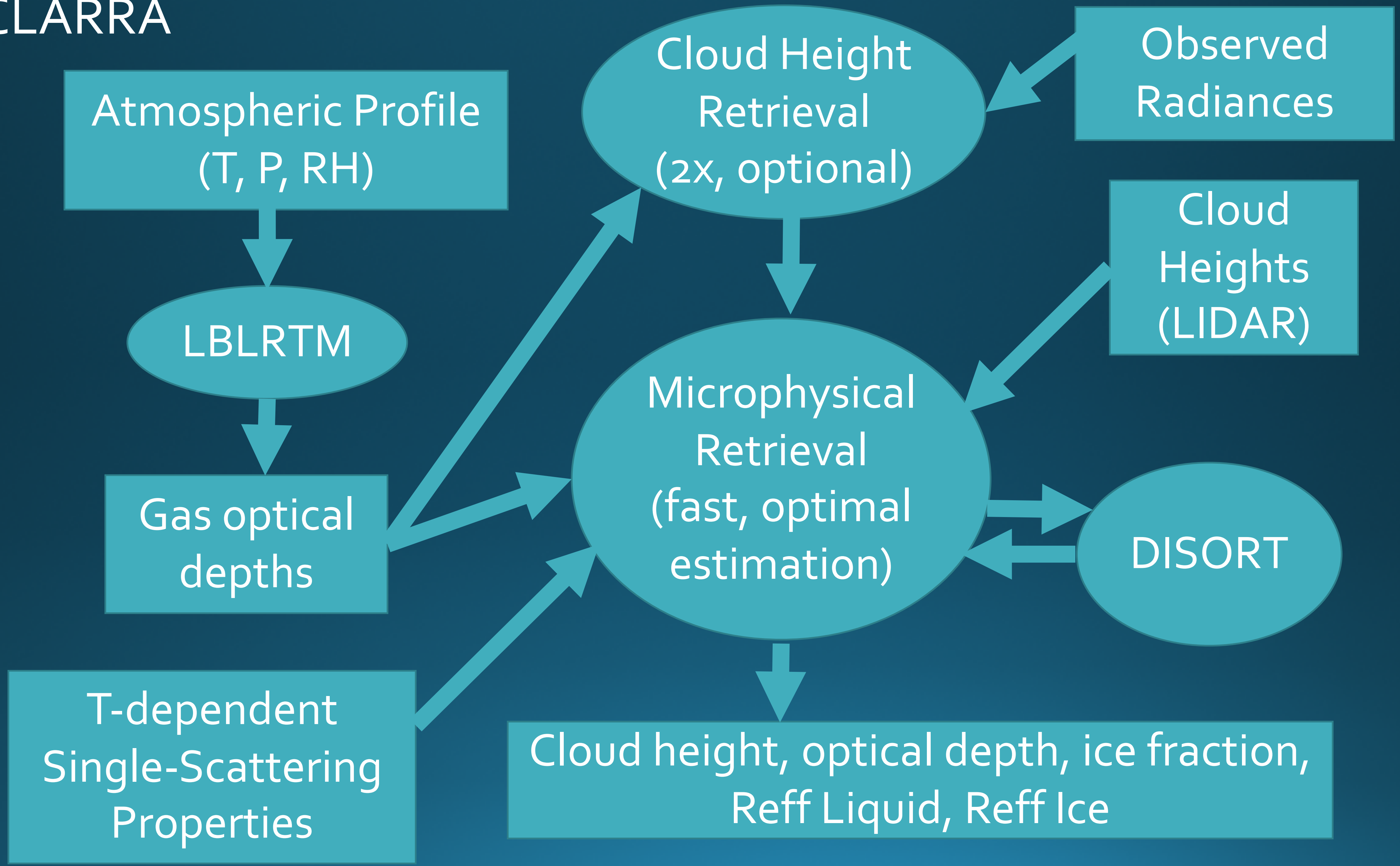
CLARRA


Atmospheric Profile (T, P, RH)
LBLRTM
Gas optical depths
Cloud Height Retrieval (2x, optional)
Observed Radiances
Cloud Heights (LIDAR)
Microphysical Retrieval (fast, optimal estimation)
DISORT
Cloud height, optical depth, ice fraction, Reff Liquid, Reff Ice

CLARRA


Atmospheric Profile (T, P, RH)
LBLRTM
Gas optical depths
T-dependent Single-Scattering Properties
Cloud Height Retrieval (2x, optional)
Observed Radiances
Cloud Heights (LIDAR)
Microphysical Retrieval (fast, optimal estimation)
DISORT
Cloud height, optical depth, ice fraction, Reff Liquid, Reff Ice