Short-Range Structure of Cloud Optical Depth in North Central Oklahoma Determined by High Resolution Photography From the Surface

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OBJECTIVE

Characterize cloud radiative properties at high resolution from the surface.

APPROACH

Digital photography with ***long-focal-length lens***.

Camera facing upwards takes photos at regular intervals.

Use radiative transfer model to relate counts in camera to radiance and then to ***cloud optical depth***, ***cloud albedo***, ***radiative cloud fraction***.

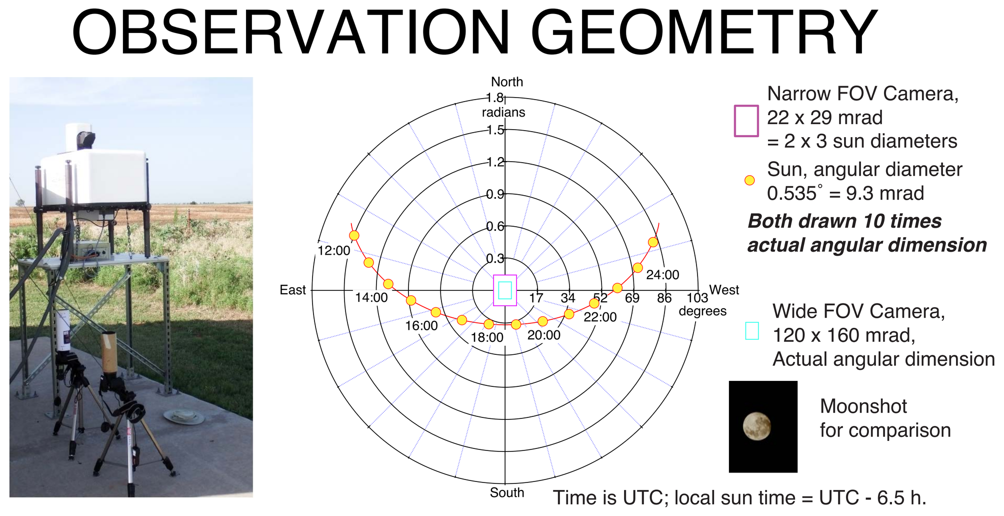
COMMERCIALLY AVAILABLE HIGH-RESOLUTION CAMERA

1200 mm equivalent 35 mm focal length; f/5.6

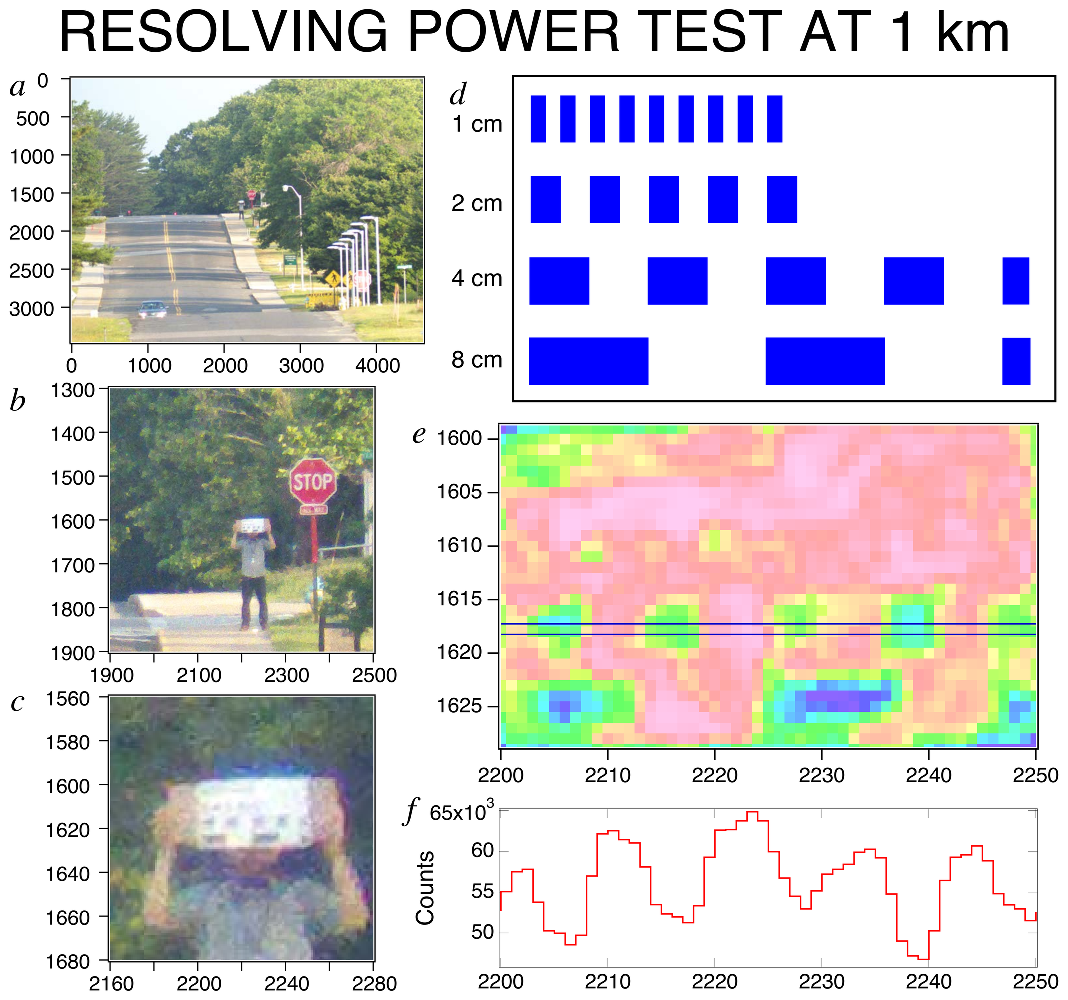
$180,000 — $350

Nominal resolution 6 µrad (6 mm at 1 km)

OBSERVATION GEOMETRY



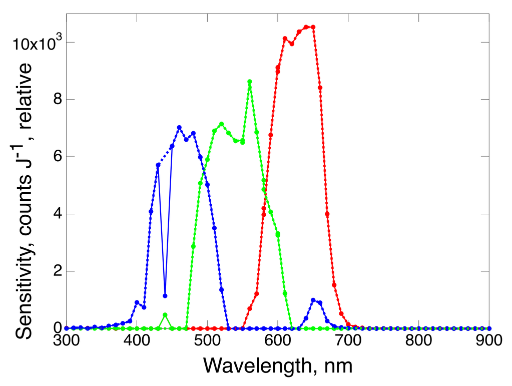
RESOLVING POWER TEST AT 1 km



Actual resolution 20 µrad (20 mm at 1 km)

WAVELENGTH CALIBRATION

Integrating sphere,
Hg-Xe lamp,
Calibrated photodiode
Peaks: 460, 640 nm

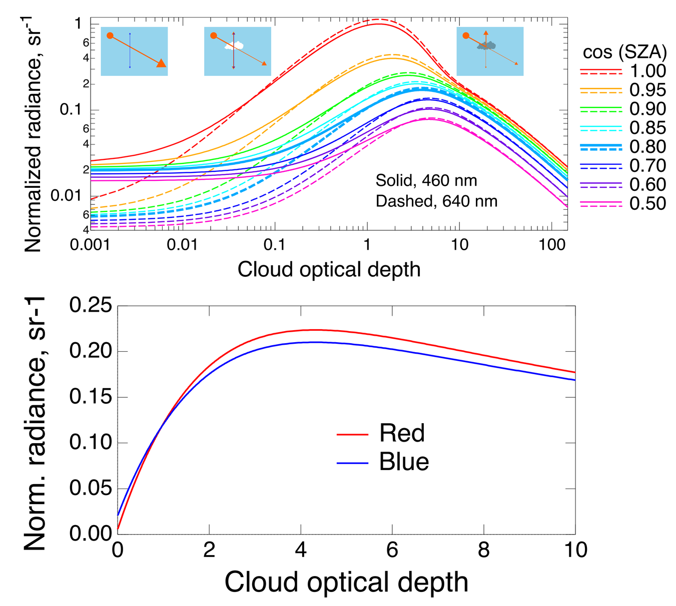


THEORY

RADIATION TRANSFER CALCULATIONS WITH DISORT

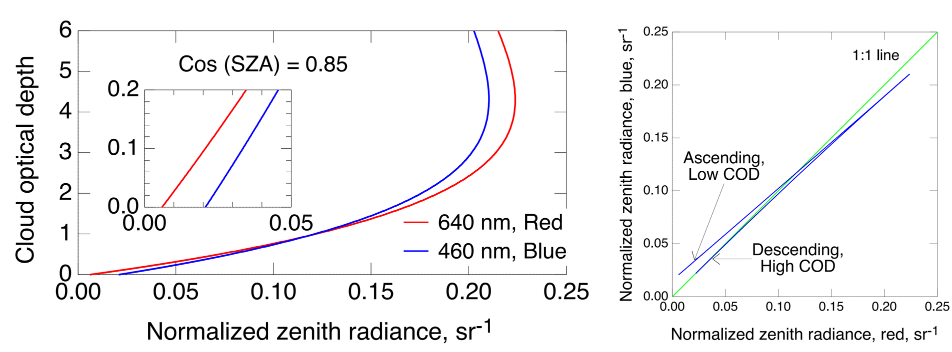
NORMALIZED ZENITH RADIANCE: Zenith radiance per incoming direct normal solar irradiance, function of cloud optical depth (COD) and solar zenith angle (SZA)

W m^{-2} nm^{-1} sr^{-1} per W m^{-2} nm^{-1}, or sr^{-1}



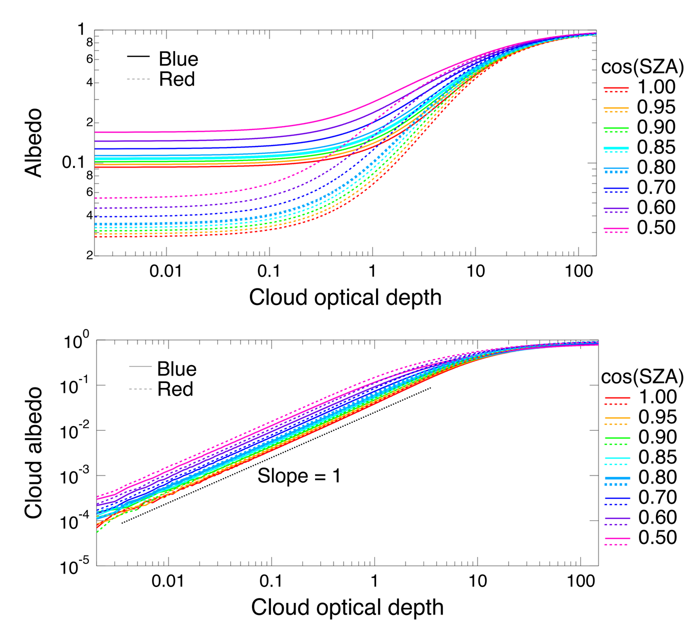
Rayleigh sky is dark. ***Clouds initially increase zenith radiance***

CLOUD OPTICAL DEPTH by inverting radiance



COD is not monotonic; inversion is limited to thin clouds, COD ≤ 3.

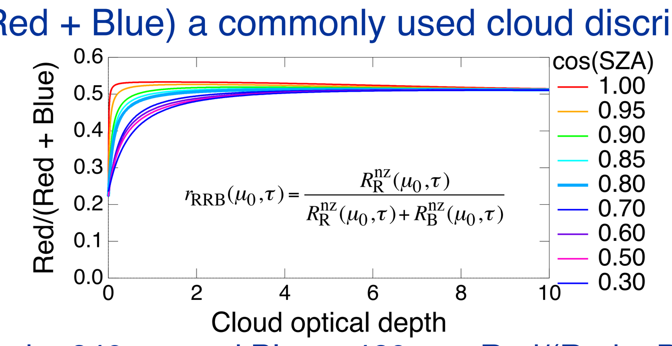
CLOUD ALBEDO calculated from COD



Cloud albedo is nearly independent of color.
Cloud albedo varies linearly with COD for COD ≤ 3.

COLOR: Sky is blue, clouds are white

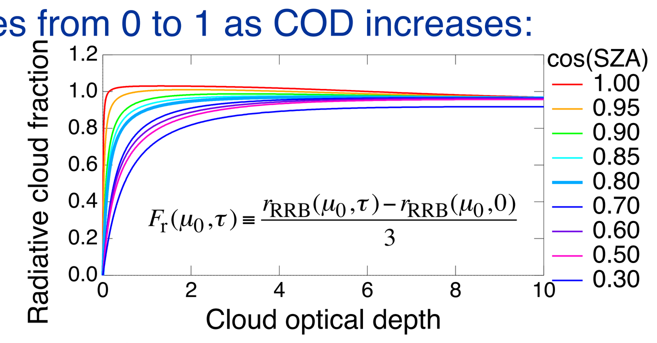
Red/(Red + Blue) a commonly used cloud discriminant:



$$r_{RRB}(\mu_0,\tau) = \frac{R_R^{nz}(\mu_0,\tau)}{R_R^{nz}(\mu_0,\tau)+R_B^{nz}(\mu_0,\tau)}$$

For Red = 640 nm and Blue = 460 nm, Red/(Red + Blue) ranges from about 0.22 to 0.52 with increasing COD.

Define **RADIATIVE CLOUD FRACTION**, a variable that ranges from 0 to 1 as COD increases:

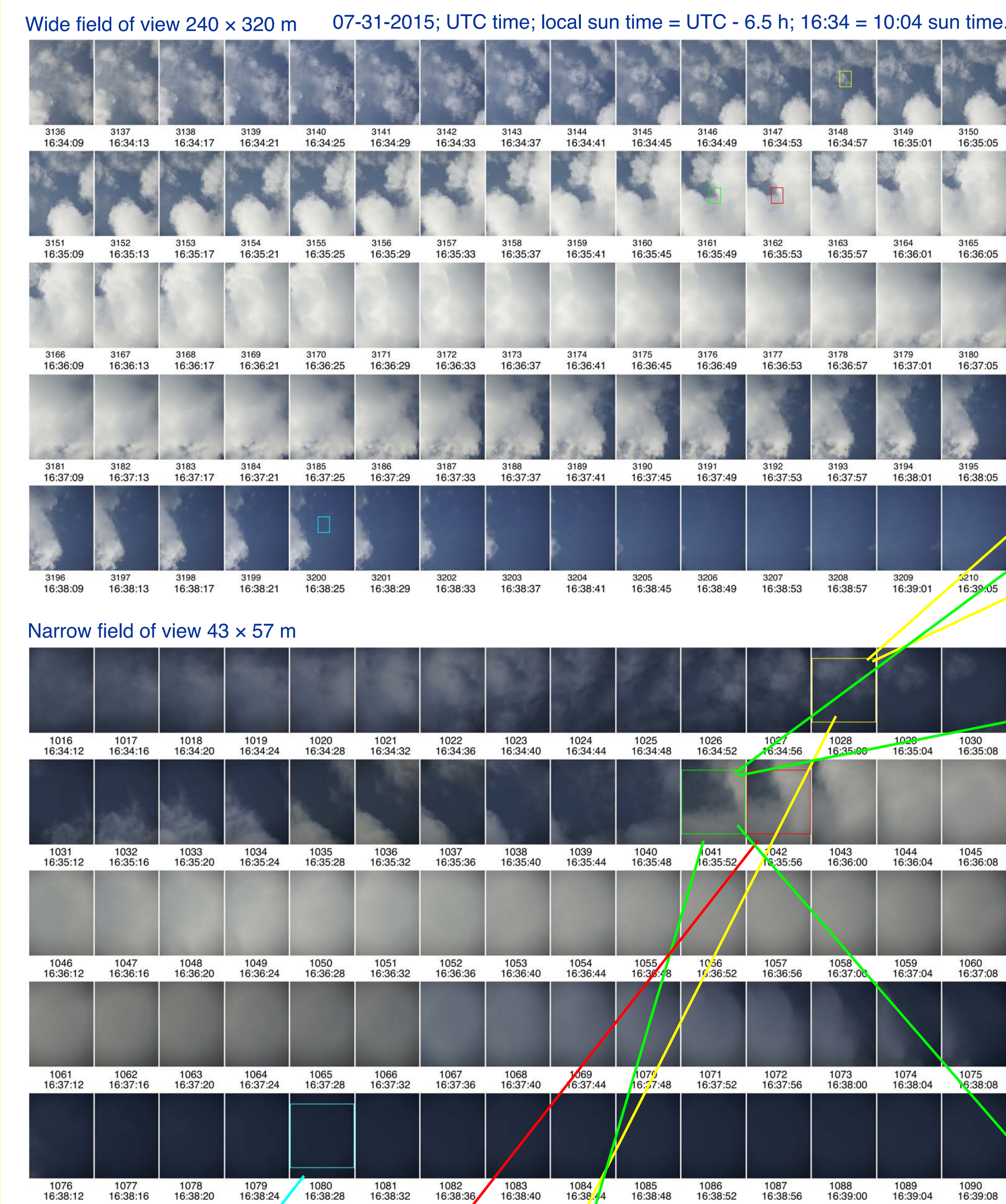


$$F_r(\mu_0,\tau) = \frac{r_{RRB}(\mu_0,\tau) - r_{RRB}(\mu_0,0)}{3}$$

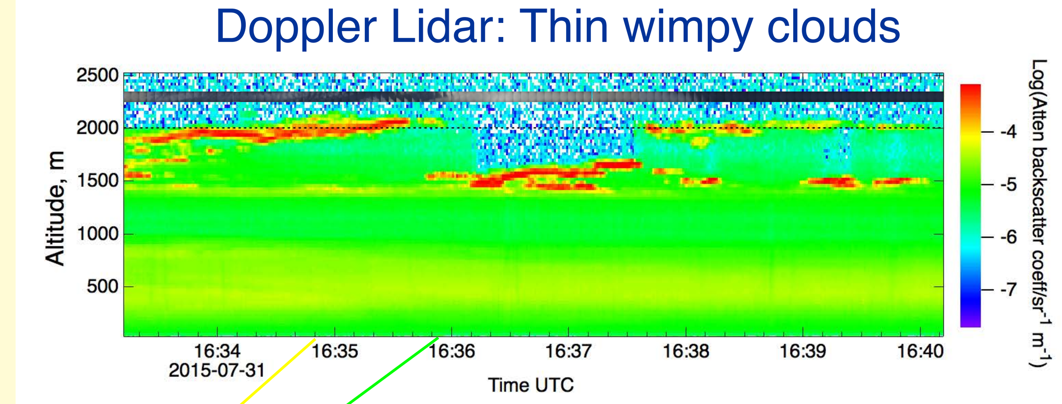
Radiative cloud fraction can be determined on ***pixel-by-pixel basis***.

SOME INITIAL RESULTS

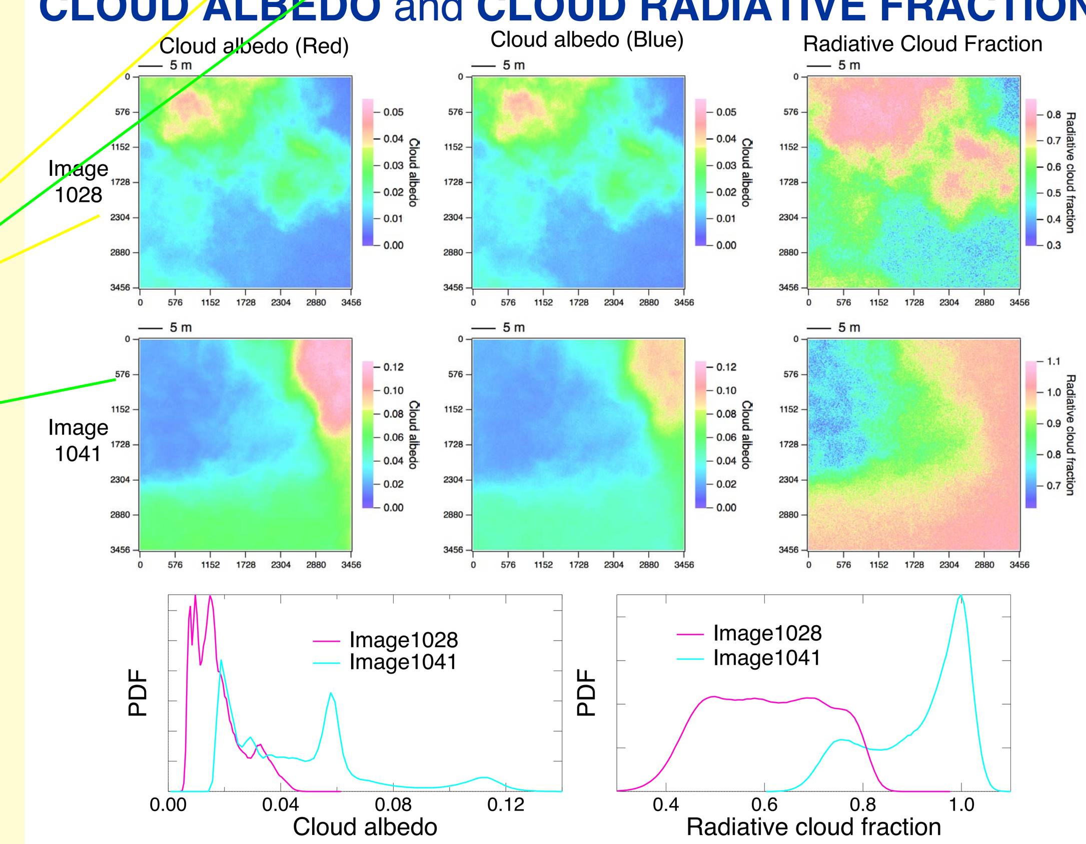
ZOOMING IN, IN SPACE AND TIME FIVE MINUTES IN OKLAHOMA



Doppler Lidar: Thin wimpy clouds



CLOUD ALBEDO and CLOUD RADIATIVE FRACTION

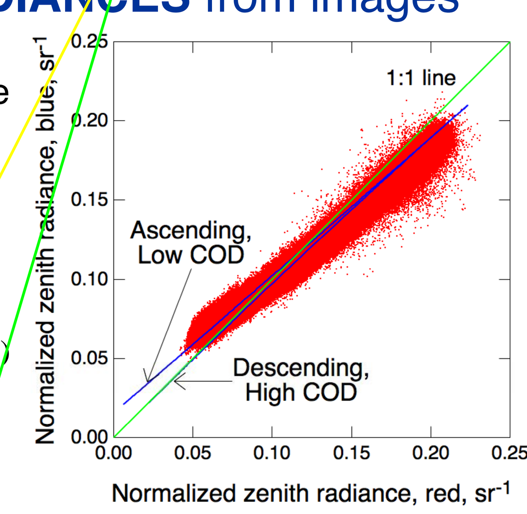


SCALING OF RADIANCES from images

Identify darkest and brightest regions of images to determine C_{min} and C_{max}. Scaled normalized radiance R_s is evaluated from measured counts C as

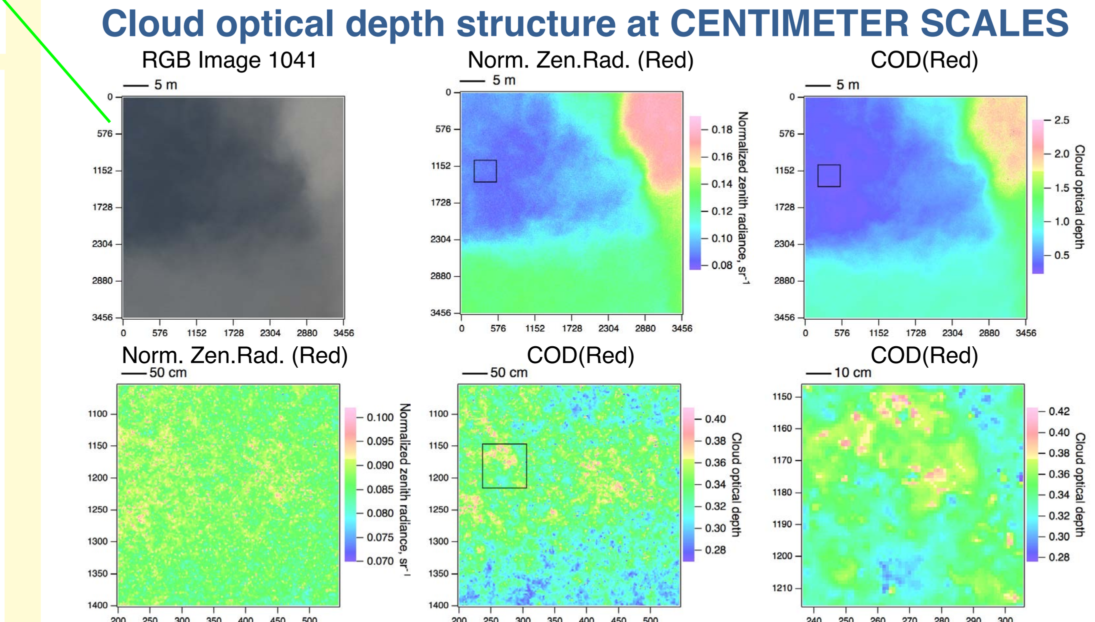
$$R_s = R_{min} + \frac{C - C_{min}}{C_{max} - C_{min}}(R_{max} - R_{min})$$

R_{min} and R_{max} are from radiation transfer calculations.

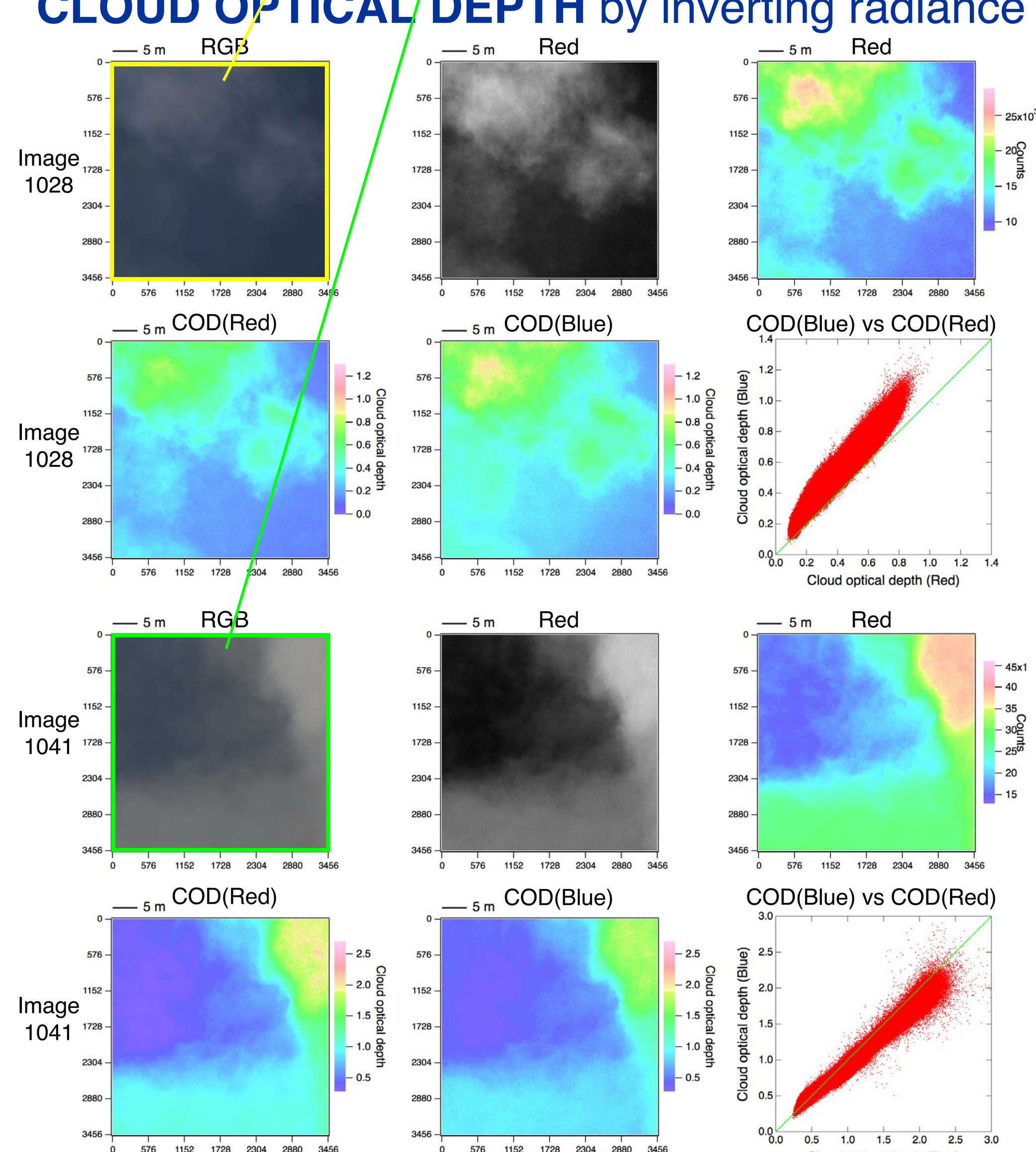


Agreement of scaled radiances with theory lends confidence to the approach.

Cloud optical depth structure at CENTIMETER SCALES



CLOUD OPTICAL DEPTH by inverting radiance



CONCLUSIONS

- ***Photography of clouds from the surface provides*** a novel way of looking at clouds and their radiative effects at ***much higher resolution than other cloud imaging techniques***.
- Readily available commercial cameras provide a ***resolution of about 20 µrad*** (corresponding to 4 cm for cloud base at 2 km), ***3 orders of magnitude higher than typical satellite products***.
- ***Cloud properties are highly variable in space (a few meters or less) and time (a few seconds or less)***.
- ***Cloud optical depth can be accurately retrieved*** at native resolution of the camera ***for optically thin clouds, optical depth ≲ 3***.
- ***10 Million determinations*** of COD, cloud albedo, radiative cloud fraction, etc.,for each image.
- Images and analyses of these should be of ***value to cloud modelers***.
- ***Manuscript about to be submitted!***

Acknowledgments

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