Optical Depth and Structure of Thin Clouds at Centimeter Scales

U.S. DEPARTMENT OF ENERGY Office of Science ASR Atmospheric System Research ARM

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OBJECTIVE

Characterize radiative properties of thin clouds at high resolution from the surface

MOTIVATION

Thin clouds are radiatively important.

Thin clouds are not well represented in climate models; cloud amount is under-represented, compensated by too-high albedo – the "too few, too bright" problem.

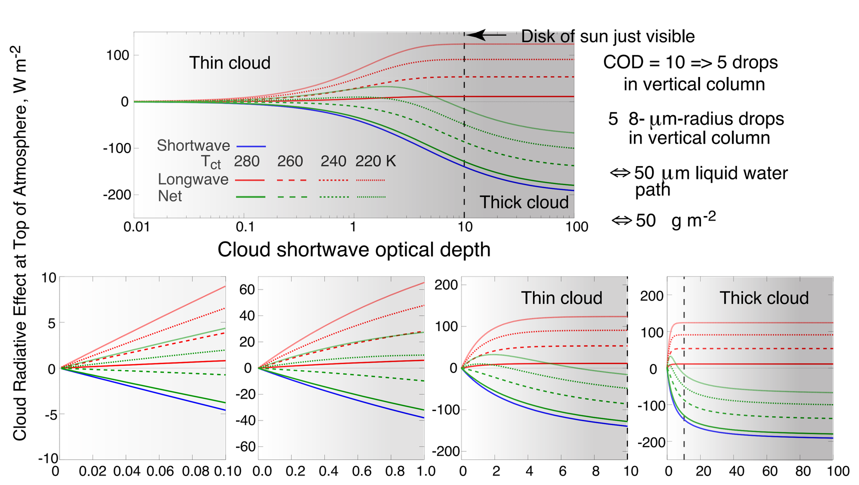
Thin clouds are difficult to detect and characterize.

Imaging provides much information not available from non-imaging techniques

IMPORTANCE

Of thin clouds

24-Hour average cloud radiative effect at equinox at SGP



Optically thin clouds exert strong radiative effects.

Radiative effects scale nonlinearly with COD or LWP.

ADVANTAGES

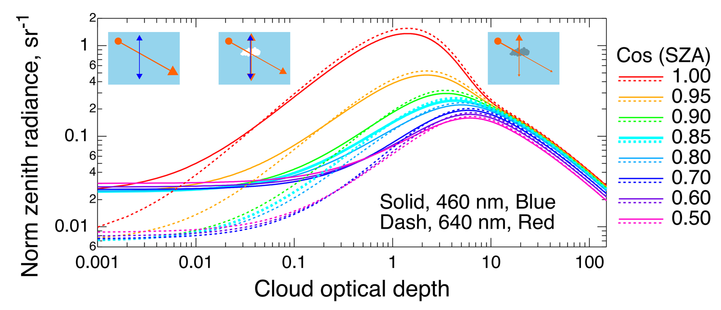
Of this approach

May lead to ability to study cloud dynamics controlling mixing and droplet growth by remote sensing.

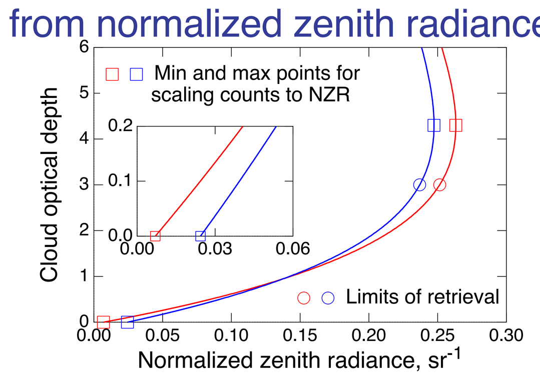
Quantify cloud amount and variability on unprecedentedly short time and distance scales.

THEORY

Radiation transfer calculations with DISORT to obtain normalzed zenith radiance (Zenith radiance per hemispheric downwelling irradiance)



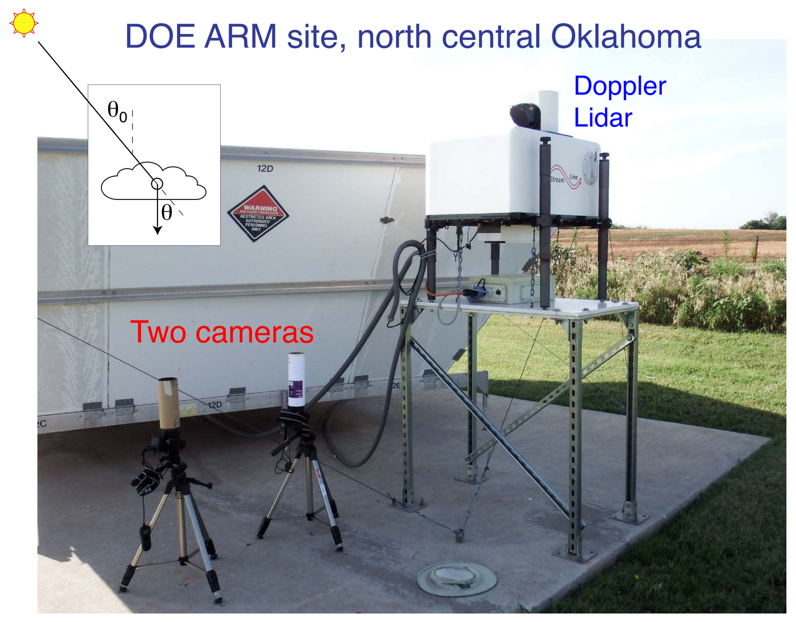
Invert to obtain Cloud Optical Depth from normalized zenith radiance



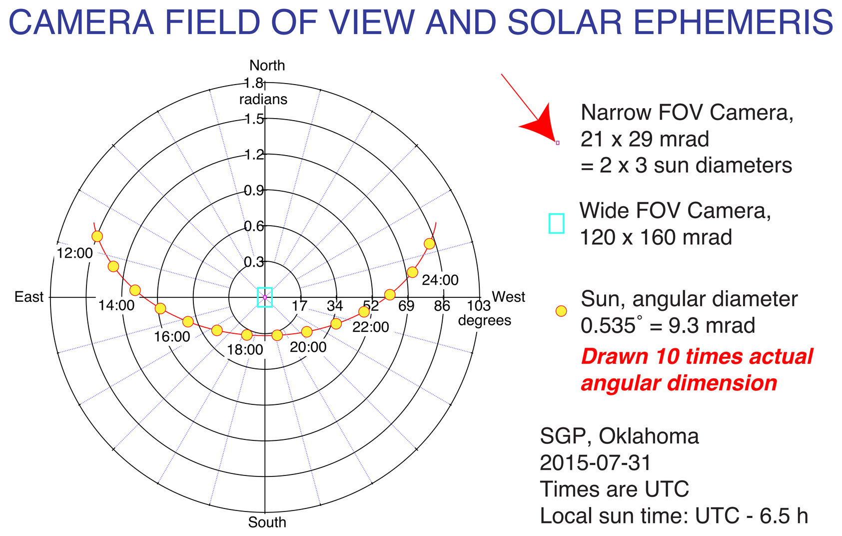
MEASUREMENTS

DEPLOYMENT OF CAMERAS AT SGP

DOE ARM site, north central Oklahoma



CAMERA FIELD OF VIEW AND SOLAR EPHEMERIS



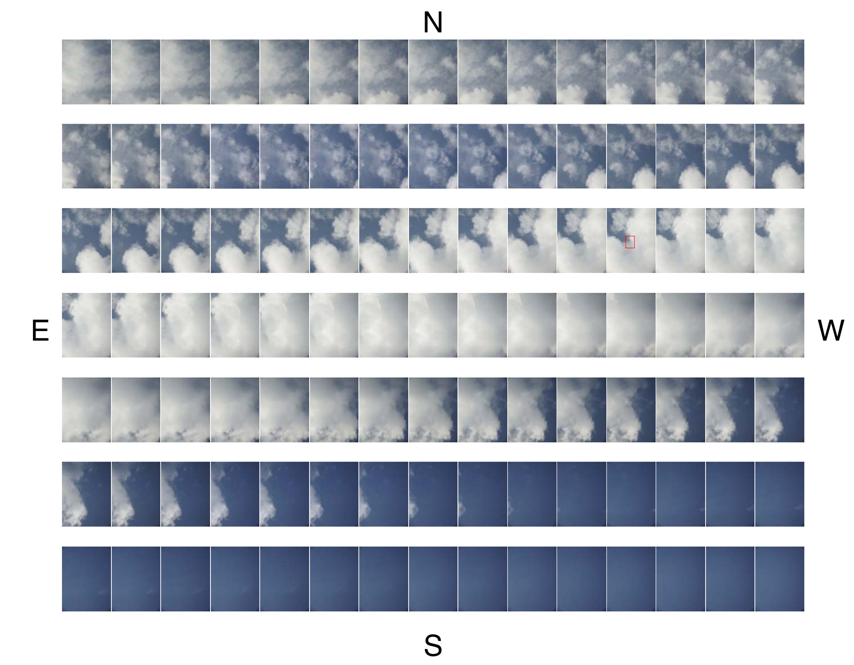
Measurements are hyper local!

SOME RESULTS

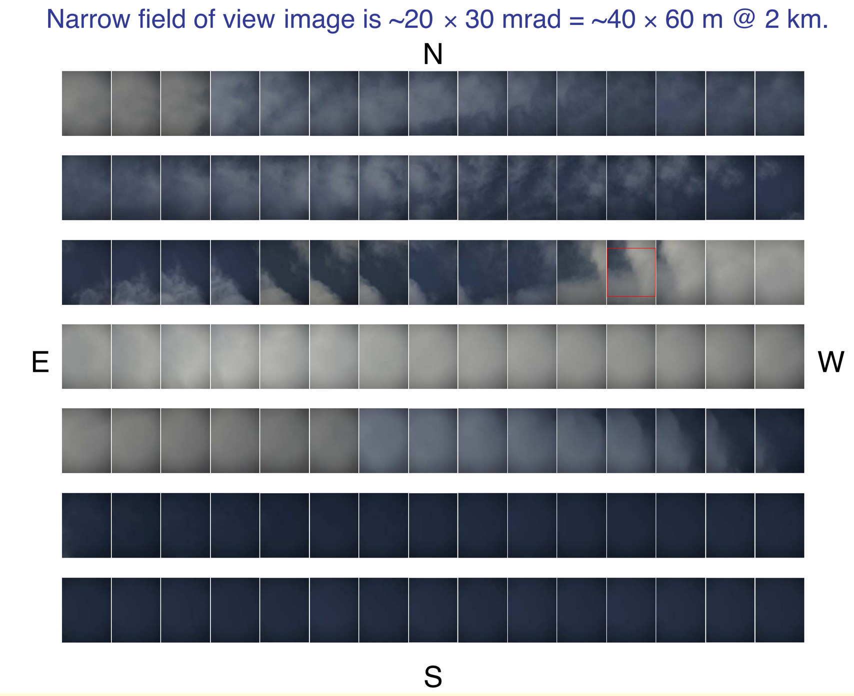
7 MINUTES IN OKLAHOMA

1 Photo every 4 s

Wide Field of view.120 × 160 mrad = ~240 × 320 m @ 2 km.

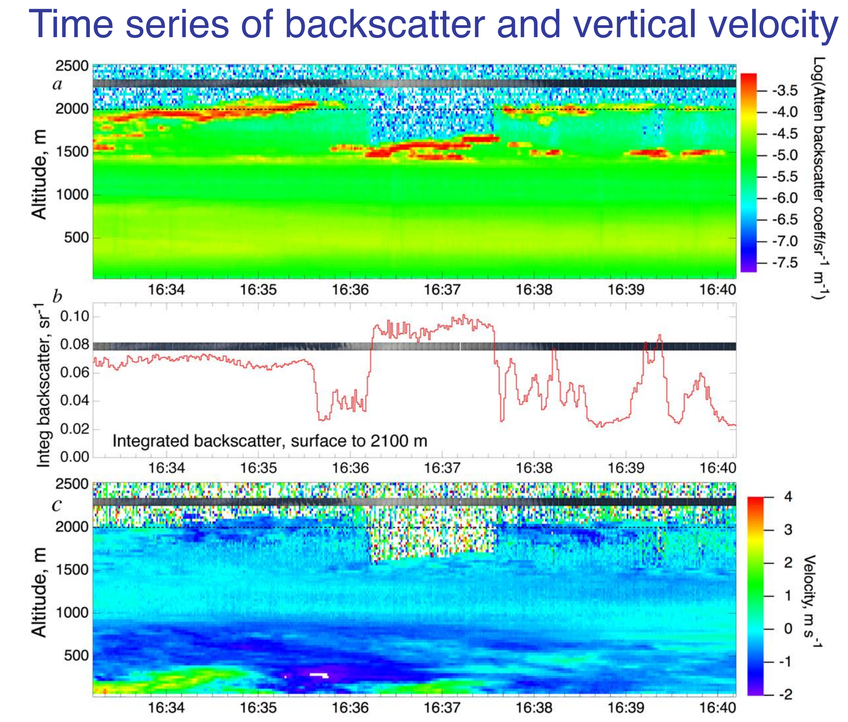


Narrow field of view image is ~20 × 30 mrad = ~40 × 60 m @ 2 km.



DOPPLER LIDAR

Time series of backscatter and vertical velocity



Cloud height: 1.5, 2 km

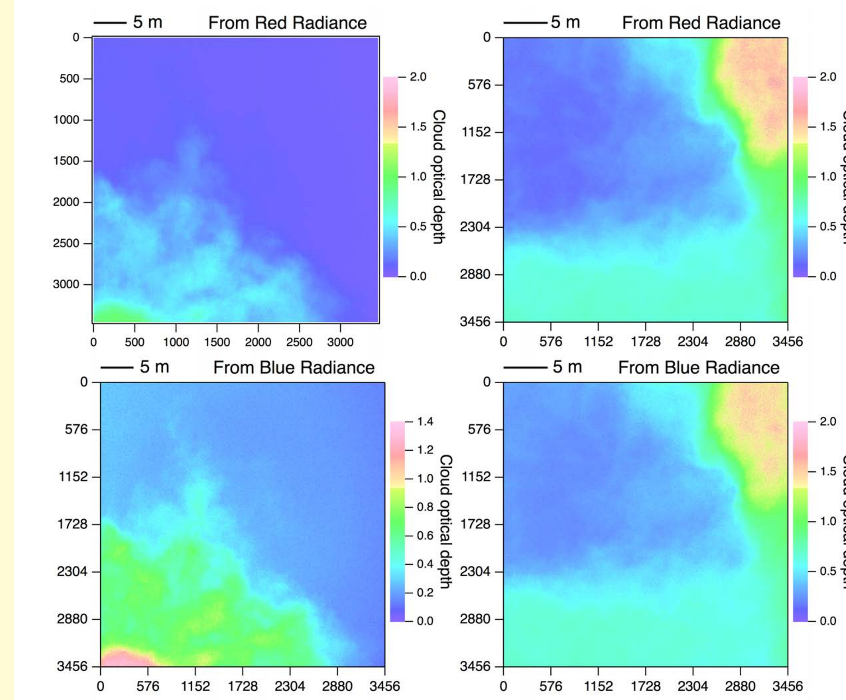
Low, optically thin aerosol layer.

Little vertical motion.

These are thin wimpy clouds.

OPTICAL DEPTH

3 Million indepenent determinations in each of 2 colors



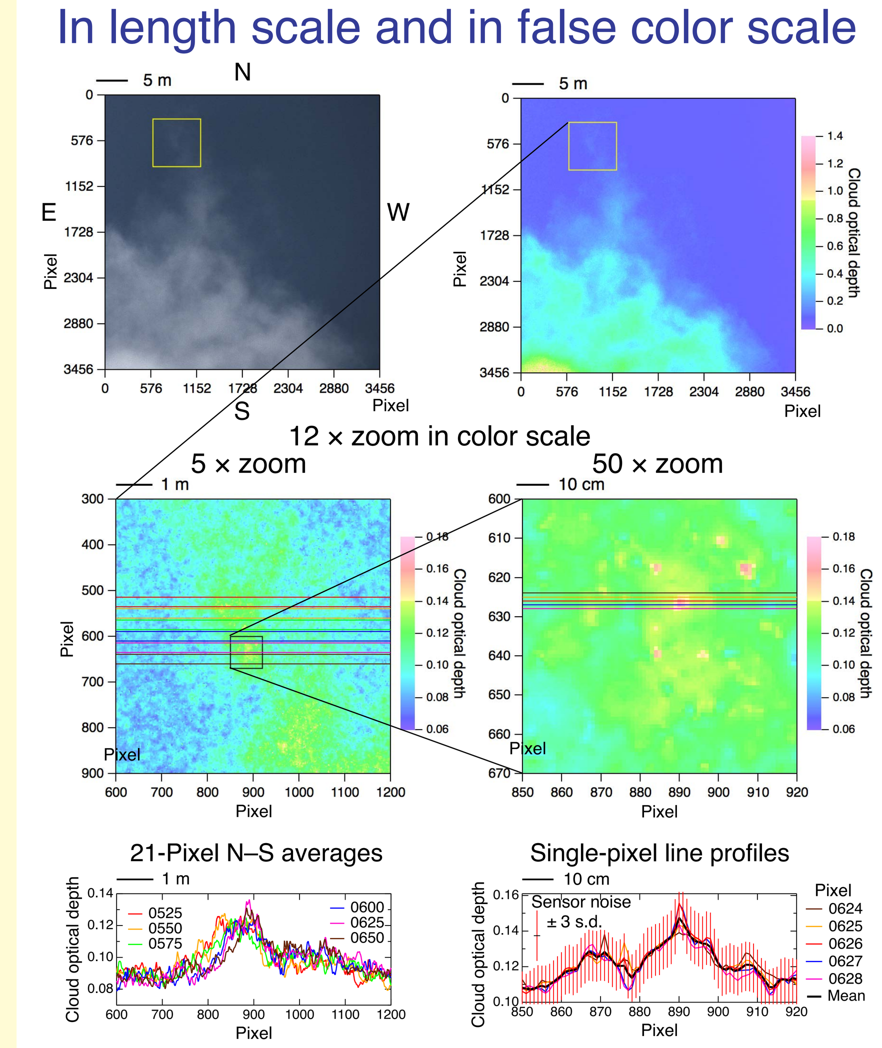
Close agreement between two determinations.

Able to determine very low COD.

Much variation and structure over small distances.

ZOOMING IN

In length scale and in false color scale

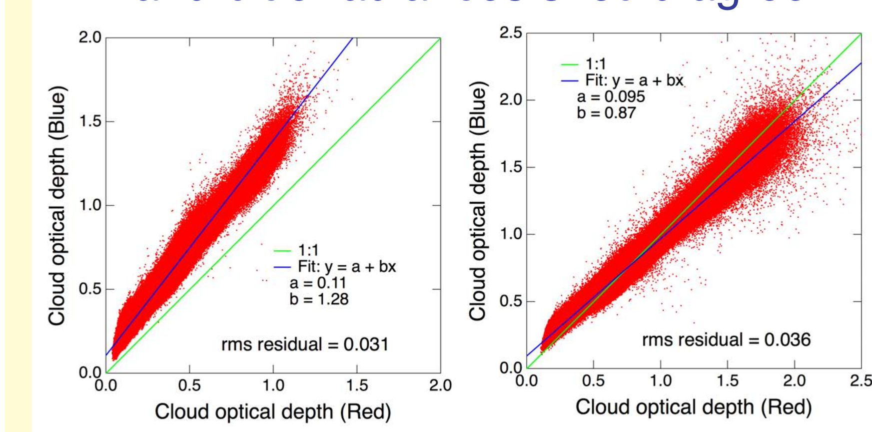


Coherent features ~ 10 cm are evident.

1-σ noise in optical depth = 0.005 (increases with increasing radiance)

COMPARE COD

Cloud optical depth from red and blue radiances should agree

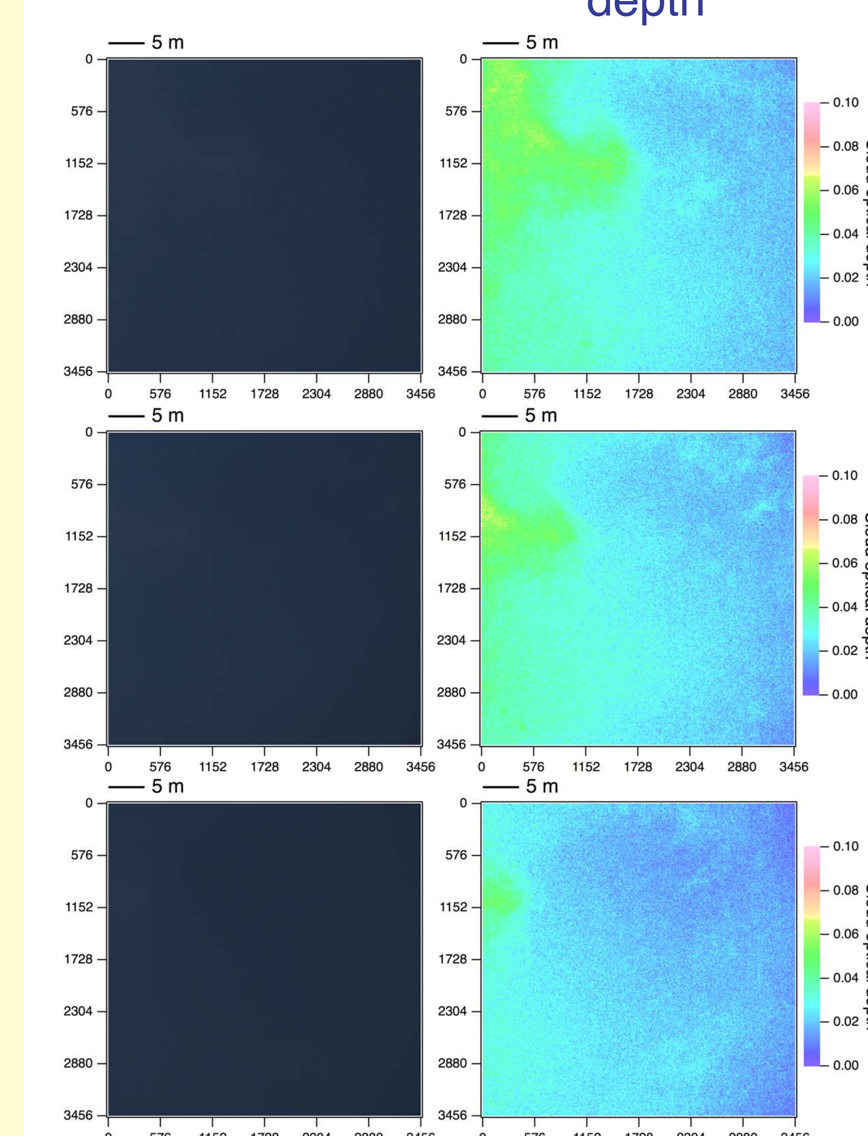


Disagreement is a measure of error in retrieval.

VERY THIN CLOUD

Found in translation

RGB Images / Cloud optical depth



Cloud optical depth in successive images at 4-second intervals reveals thin cloud (maximum COD ~ 0.07) advected by wind.

Inferred wind speed is 1.4 m s^{-1} eastward and 0.12 m s^{-1} northward.

KEY POINTS

Radiance and optical depth of thin clouds are retrieved pixel-by-pixel from digital camera images at resolution of ~4 cm for cloud at 2 km.

Cloud radiance and optical depth exhibit rich spatial structure for example order of magnitude variation over 30 m × 30 m domain.

Variation in radiance on scales down to ~10 cm is attributed to variation in cloud optical depth.

FUTURE DIRECTIONS

Extend to higher optical depth.

Examine spatial variation.

Infer turbulent motion from radiance variation.

Proposed deployment at ENA (Azores) during ACEENA, June - July, 2017.

REFERENCE

Our first paper is ***just published in JGR***: High-Resolution Photography of Clouds from the Surface: Retrieval of Optical Depth of Thin Clouds down to Centimeter Scales, Schwartz, S. E., Huang, D., and Vladutescu D. V., *J. Geophys. Res. - Atmos.*, Paper #2016JD025384

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