WHAT CAN WE LEARN FROM HIGH RESOLUTION PHOTOGRAPHY OF CLOUDS FROM THE SURFACE?

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Gordon Research Conference, Radiation and Climate, Bates College, Lewiston ME, July 26-31, 2015; cite as personal communication

MOTIVATION

Clouds have a strong impact on Earth's radiation budget: -45 W m^{-2} shortwave; +30 W m^{-2} longwave.

Slight change in cloud amount or properties could augment or offset greenhouse gas induced warming – cloud feedbacks.

Accurate representation of cloud radiative effects in climate models is essential.

Clouds exhibit structure on small scales not resolved by satellite imagery.

APPROACH

COMMERCIALLY AVAILABLE
HIGH-RESOLUTION CAMERA/LENS
1200 mm equivalent 35 mm focal length; $f/5.6$

vs.

$350 $180,000

Nominal resolution 6 μrad (6 mm at 1 km)

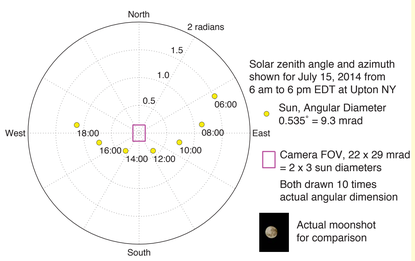
STRENGTHS AND ADVANTAGES

High resolution: 6 μrad nominal (6 mm at 1 km); 20 μrad actual.
Many independent measurements: 14 M pixel nominal.
High dynamic range: 16 bit.
Multispectral: Three wavelengths nominal, Red, Green, Blue.
Black background of outer space: Minimal surface effects.
No sidewall issues; no correction sky cover to ground cover.
Readily available data acquisition hardware and software.
Available, easy-to-use image processing software.
Simplicity: Get going right away.
Low cost.
Lots of data!

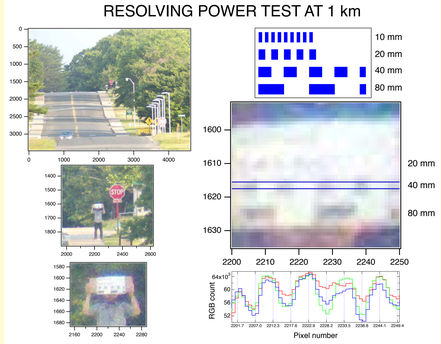
WEAKNESSES AND LIMITATIONS

Two-dimensional only.
Daytime only.
Limited wavelength range.
Small fraction of sky; extremely local.
Aerosol masquerades as cloud.
Lots of data!

OBSERVATION GEOMETRY



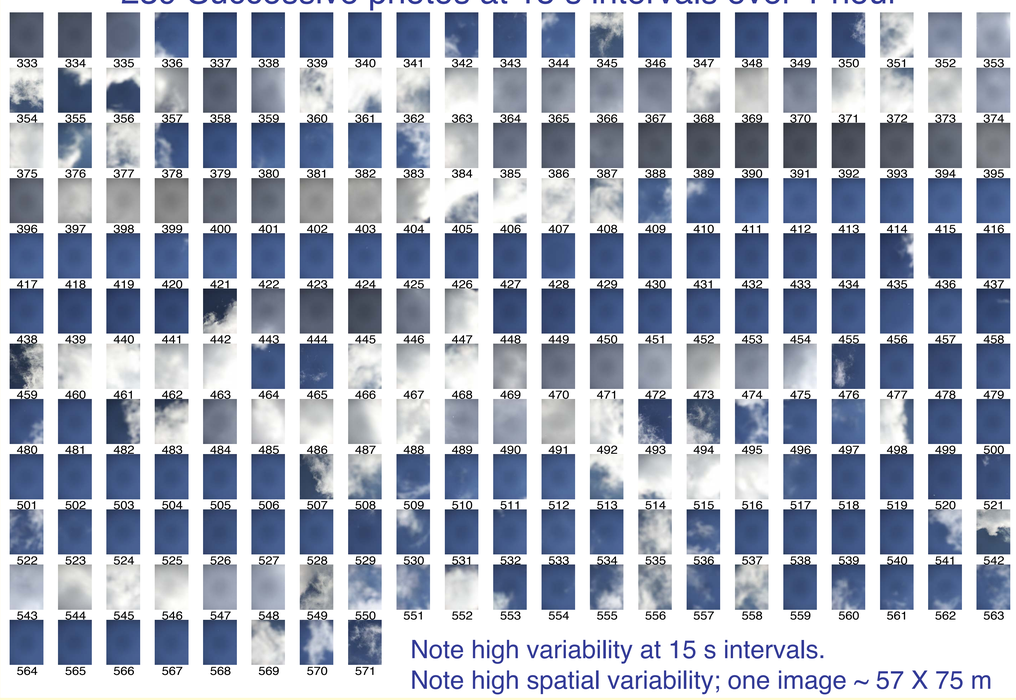
RESOLVING POWER TEST AT 1 km



Actual resolution 20 μrad (20 mm at 1 km)

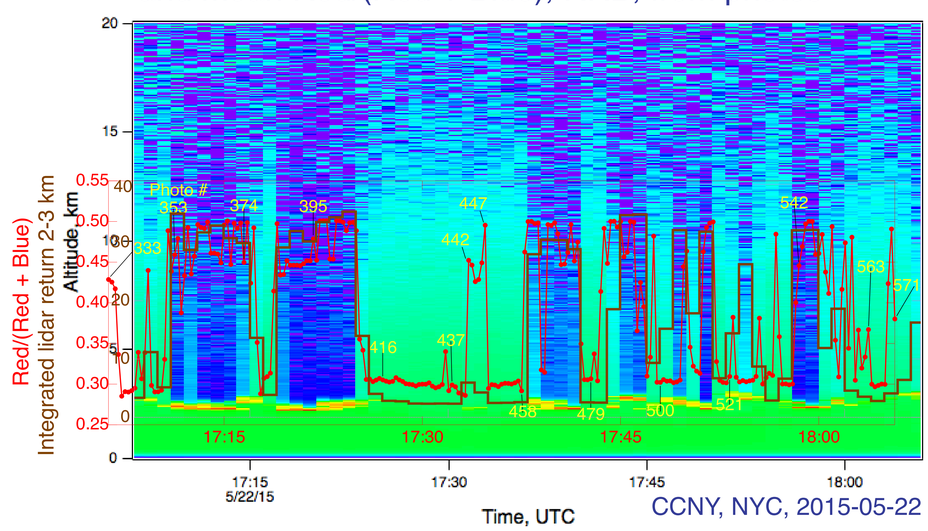
SOME INITIAL RESULTS

239 Successive photos at 15 s intervals over 1 hour



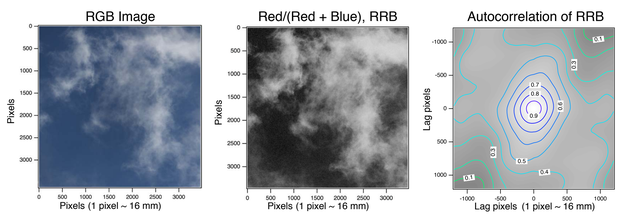
Note high variability at 15 s intervals.
Note high spatial variability; one image ~ 57 X 75 m

Lidar over same 1 hr period; superimposed integrated lidar signal and mean Red/(Red + Blue), RRB, from photos



Thin, single cloud layer, base ~ 2.6 km.
Note high RRB for cloud; low for clear.
Note high RRB even for very thin cloud, e.g. 442-447.
Could be broken cloud (442) or thin uniform cloud (443-447) more likely.
Note strong effect on radiance despite low optical depth inferred from transmittance.

Autocorrelation analysis of Image 571



Autocorrelation distance ~1000 pixels in this example corresponds to ~16 m.

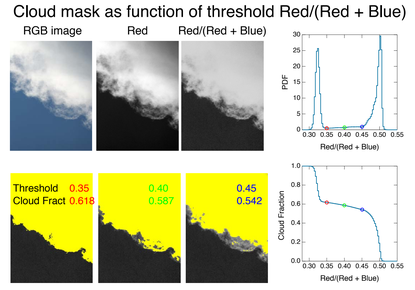
Such short autocorrelation distances are commonly found in these analyses.

CLOUD FRACTION

Cloud area fraction a is widely used measure of cloudiness, the fraction of surface area covered by cloud.
Here two methods of determining cloud fraction are applied to photos to assess the effects of unresolved subpixel clouds on retrievals.
Average method, based on average value of Red/(Red + Blue) in pixel.
Perfect detector method counts a pixel as cloudy if there is any cloud (above threshold) within pixel.

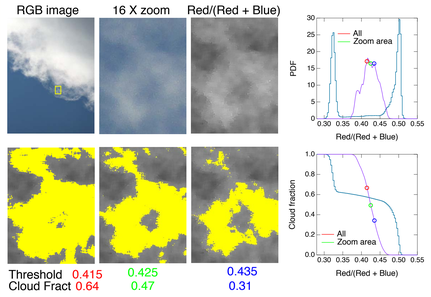
AVERAGE METHOD

Cloud mask as function of threshold Red/(Red + Blue)



Cloud fraction is constrained between ~0.54 and ~0.62.

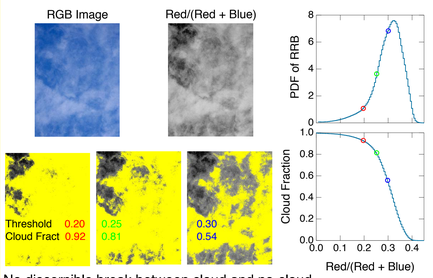
ZOOM IN ON BOUNDARY



Cloud fraction in zoom area is ***indeterminate***. This is very often the case

EFFECT OF THRESHOLD

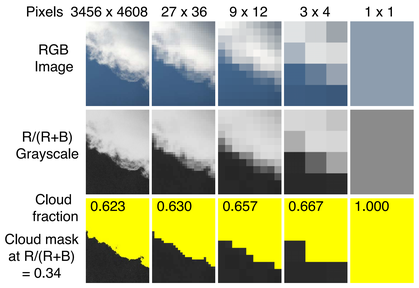
Cloud mask as function of threshold Red/(Red + Blue)
Pixels exceeding threshold are counted as cloud



No discernible break between cloud and no-cloud.
Cloud fraction cannot be uniquely determined; depends on threshold.

EFFECT OF RESOLUTION

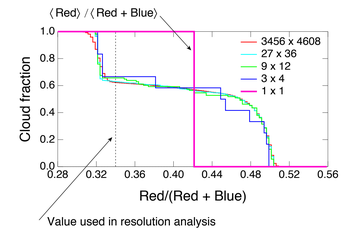
Resolution artificially degraded from 6 μrad to 20 X 30 mrad at constant threshold



As resolution is degraded, cloud fraction increases.

EFFECT OF THRESHOLD AND RESOLUTION

Cloud fraction as resolution is artificially degraded from 6 μrad to 20 X 30 mrad, as function of threshold

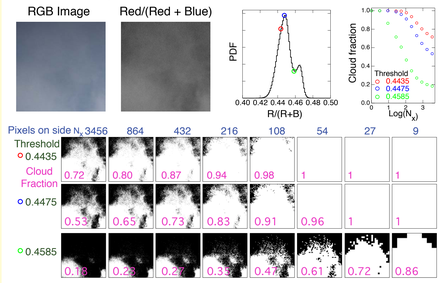


As resolution is degraded, cloud fraction tends to increase if threshold is below mean, and vice versa.

PERFECT DETECTOR METHOD

DEPENDENCE ON THRESHOLD AND RESOLUTION

All pixels with ***any*** cloud are counted as cloud



Cloud fraction depends strongly on on threshold and resolution.
Cloud fraction approaches unity with increasing pixel size.

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 20 mm for cloud base at 1 km), much higher than usual cloud imaging techniques, such as from satellite.
- Autocorrelation distances are commonly of order a few meters.
- Cloud area fraction, a widely used product of surface-based and satellite observations, is inherently dependent on choice of threshold and resolution.

Acknowledgments
Viviana Vladutescu, Antonio Aguirre
CityTech, CUNY;
Clement Li, CCNY