WHAT CAN WE LEARN FROM HIGH RESOLUTION DIGITAL PHOTOGRAPHY OF CLOUDS?

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GLOBAL AND ANNUAL MEAN RADIATIVE FLUXES AND CLOUD RADIATIVE EFFECT FROM ERBE

JOURNAL OF GEOPHYSICAL RESEARCH, 1990

Seasonal Variation of Cloud Radiative Forcing Derived From the Earth Radiation Budget Experiment

E. F. HARRISON, P. MINNIS, B. R. BARKSTROM, V. RAMANATHAN, R. D. CESS, AND G. G. GIBSON

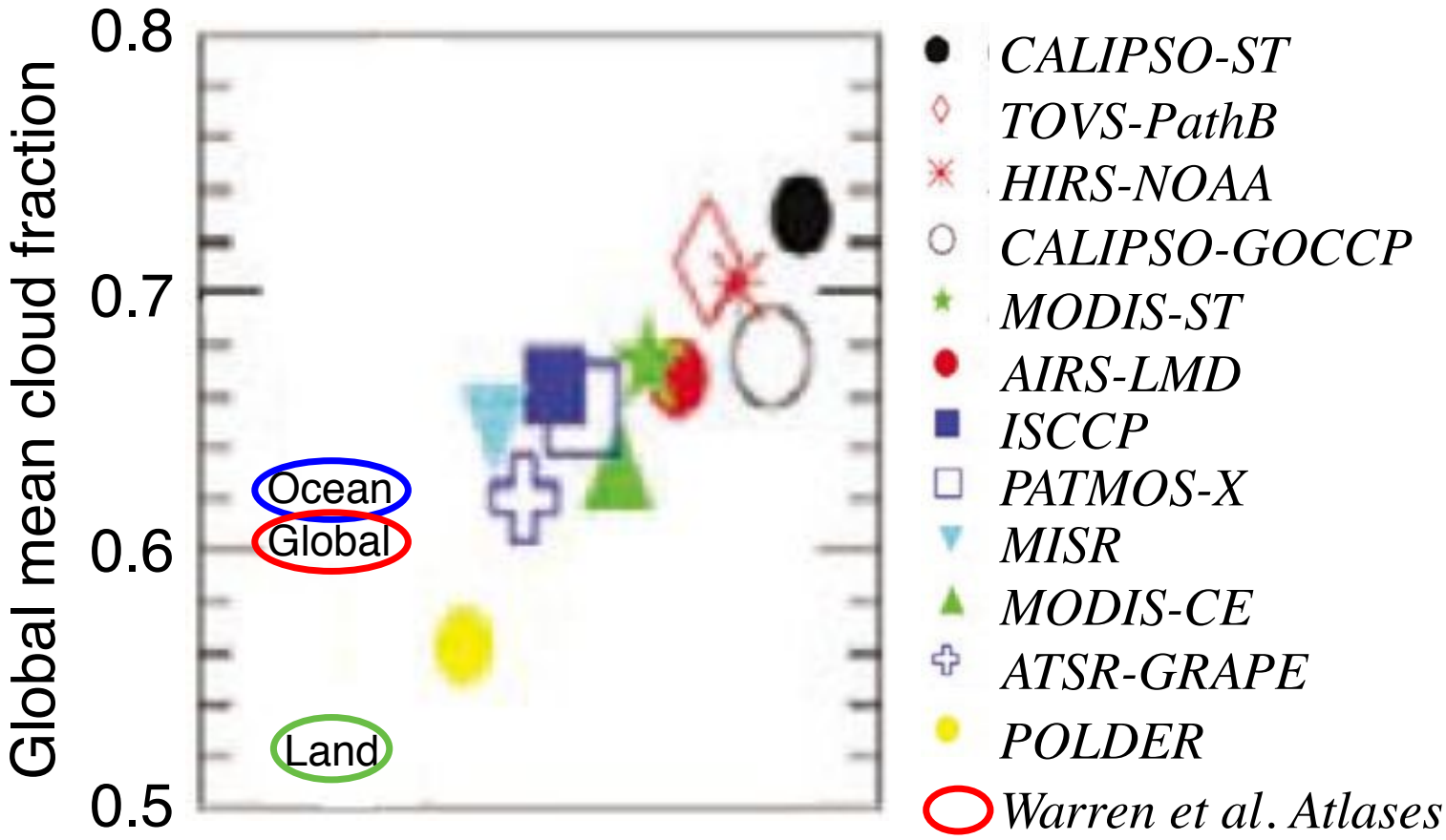
The effects of clouds on Earth's radiation balance are examined as the difference between the ***cloud-free*** and the ***all-sky*** radiative fluxes. This difference is defined as ***cloud-radiative forcing*** (cloud radiative effect).

	All-Sky	Cloud-Free	CRE
	W m^{-2}	W m^{-2}	W m^{-2}
Shortwave absorbed	239.3	287.7	-48.4
Longwave emitted	234.5	265.6	31.1
Net	4.8	22.1	-17.3

Uncertainties ~ 5 W m^{-2}.

Two planets for the price of one – Cess

MEASUREMENTS OF GLOBAL CLOUD FRACTION



- Global total cloud amount (fractional cloud cover) is about 0.68 (±0.03), when considering clouds with optical depth > 0.1.
- The value increases to 0.73 when including subvisible cirrus with optical depth down to 0.01 (e.g. CALIPSO) and decreases to about 0.56 for clouds with optical depth > 2 (e.g. POLDER).

Modified from Stubenrauch, Rossow, ... Ackerman, ... Chepfer, DiGirolamo, ... Winker et al., BAMS, 2013

HIGH RESOLUTION IMAGER

Fujifilm FinePix S1

14 Megapixels 3456 × 4608

3 Color, RGB, 16bit

1200 mm focal length
(35 mm equiv)

1 Pixel = 6 μrad (20 μrad)

FOV 22 × 29 mrad
(2 × 3 sun diameters)

Programmable

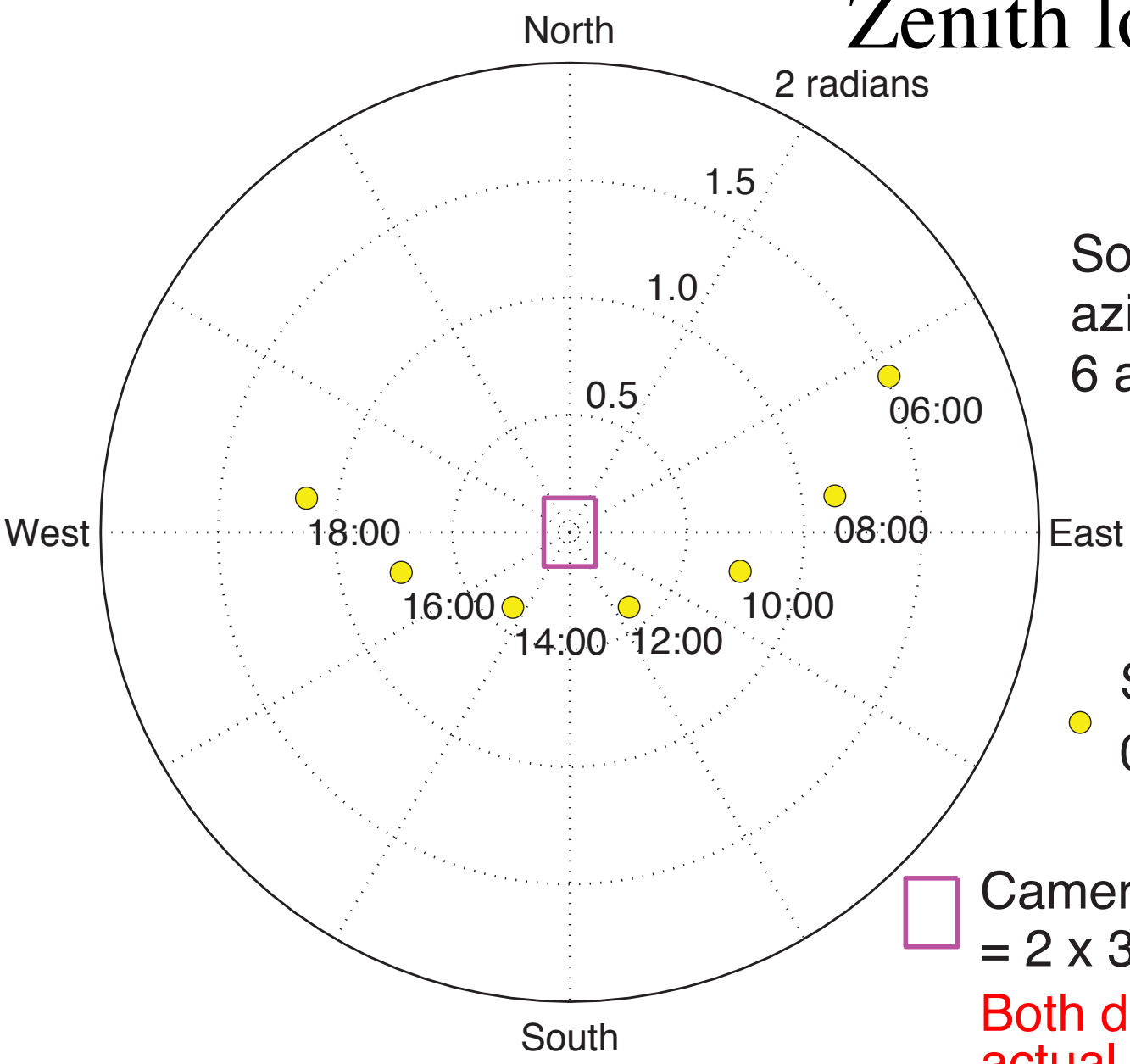
Wi-Fi communication

Weather resistant

$400

OBSERVATION GEOMETRY

Zenith looking



Solar zenith angle and azimuth, July 15, 2014, 6 am to 6 pm EDT

Sun, angular diameter 0.535° = 9.3 mrad

Camera FOV, 22 x 29 mrad = 2 x 3 sun diameters

Both drawn 10 times actual angular dimension

STRENGTHS AND ADVANTAGES

Black background of outer space: No surface effects (to first order).

No side-wall issues; no correction sky cover to ground cover.

Readily available ***data acquisition hardware and software***.

Available, easy-to-use ***image-processing software***.

Lots of data!

WEAKNESSES AND LIMITATIONS

Two-dimensional only.

Daytime only.

Limited wavelength range.

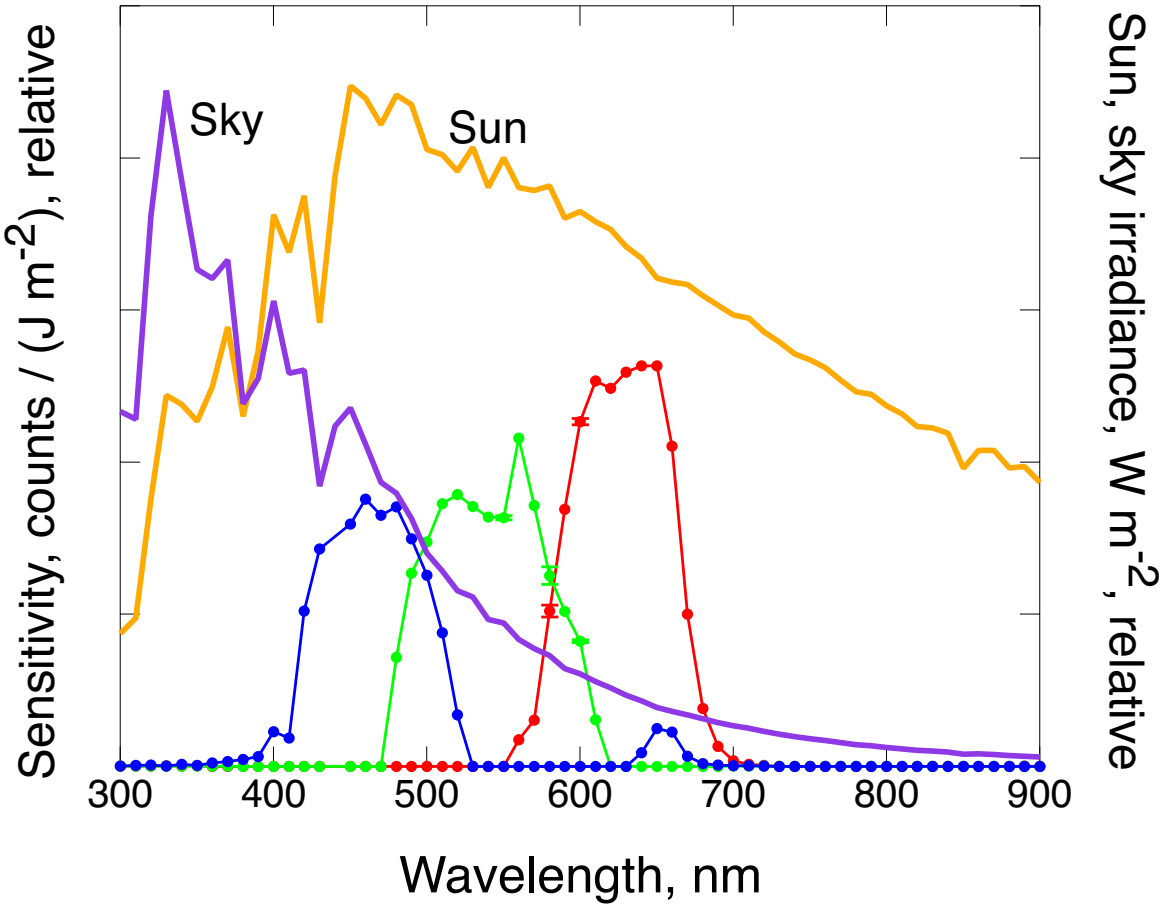
Small fraction of sky; ***extremely local***.

Aerosol masquerades as thin cloud.

Lots of data!

CAMERA WAVELENGTH RESPONSE

Comparison with Sun and Sky spectral irradiance



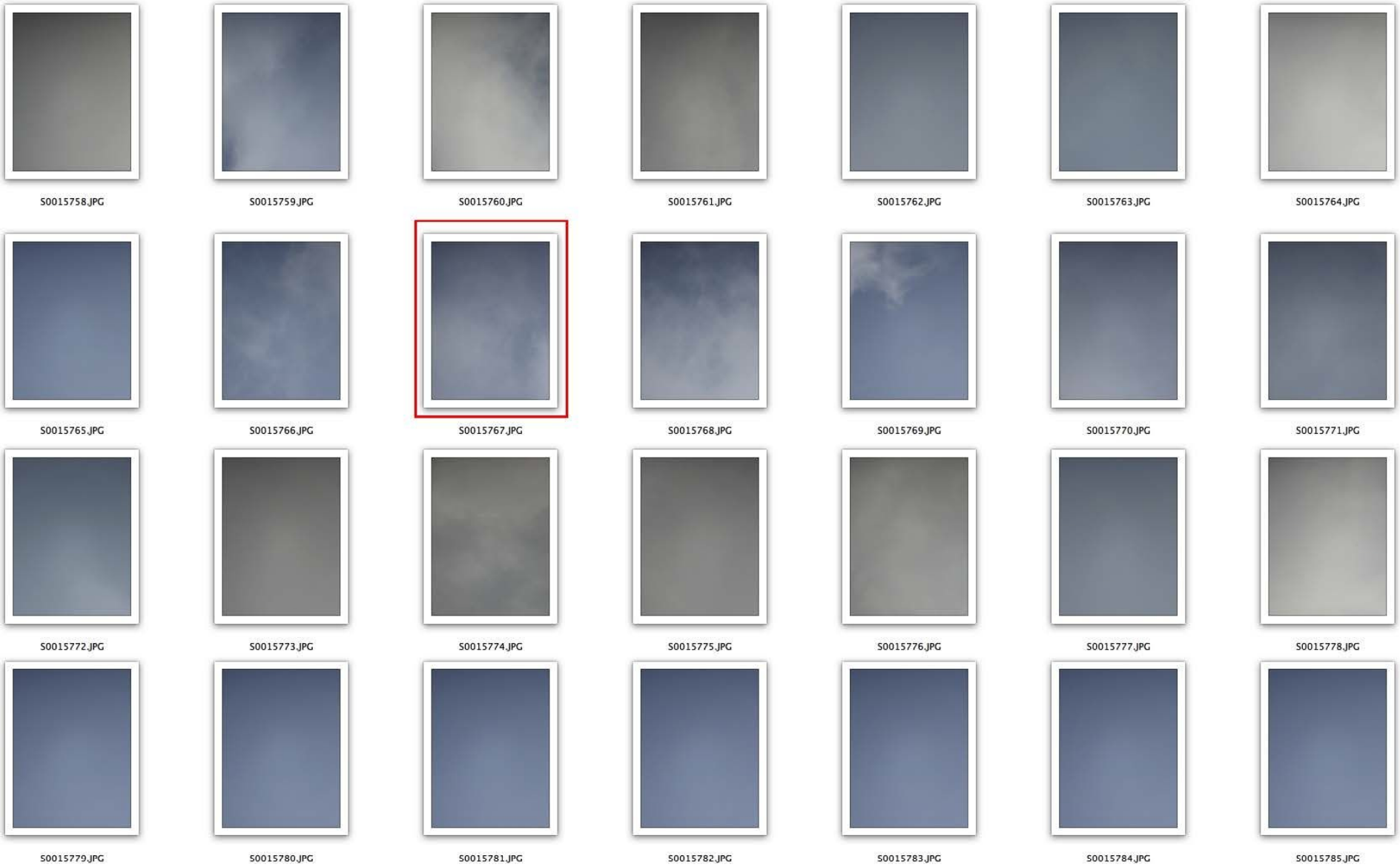
Red and Blue are fairly well separated.

Sun and Sky spectra overlap both Red and Blue, but with different weights.

This can be exploited in distinguishing cloudy and cloud-free sky.

SUCCESSIVE IMAGES AT 1 MINUTE INTERVALS

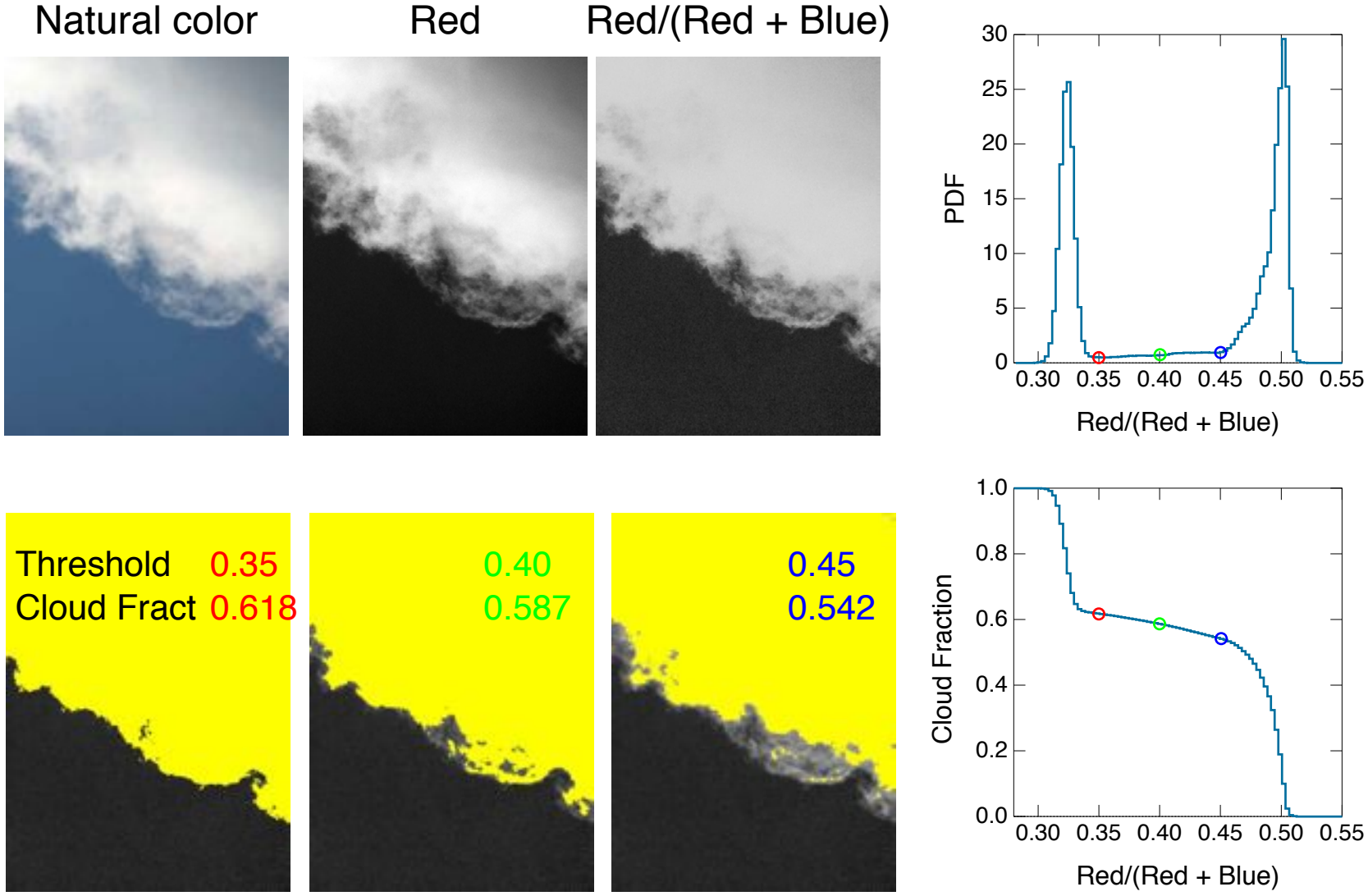
Based on sounding, thin single cloud layer at ~2300 m (images 50 × 70 m)



Rapid changes in cloudiness and cloud properties.

DETERMINING CLOUD FRACTION

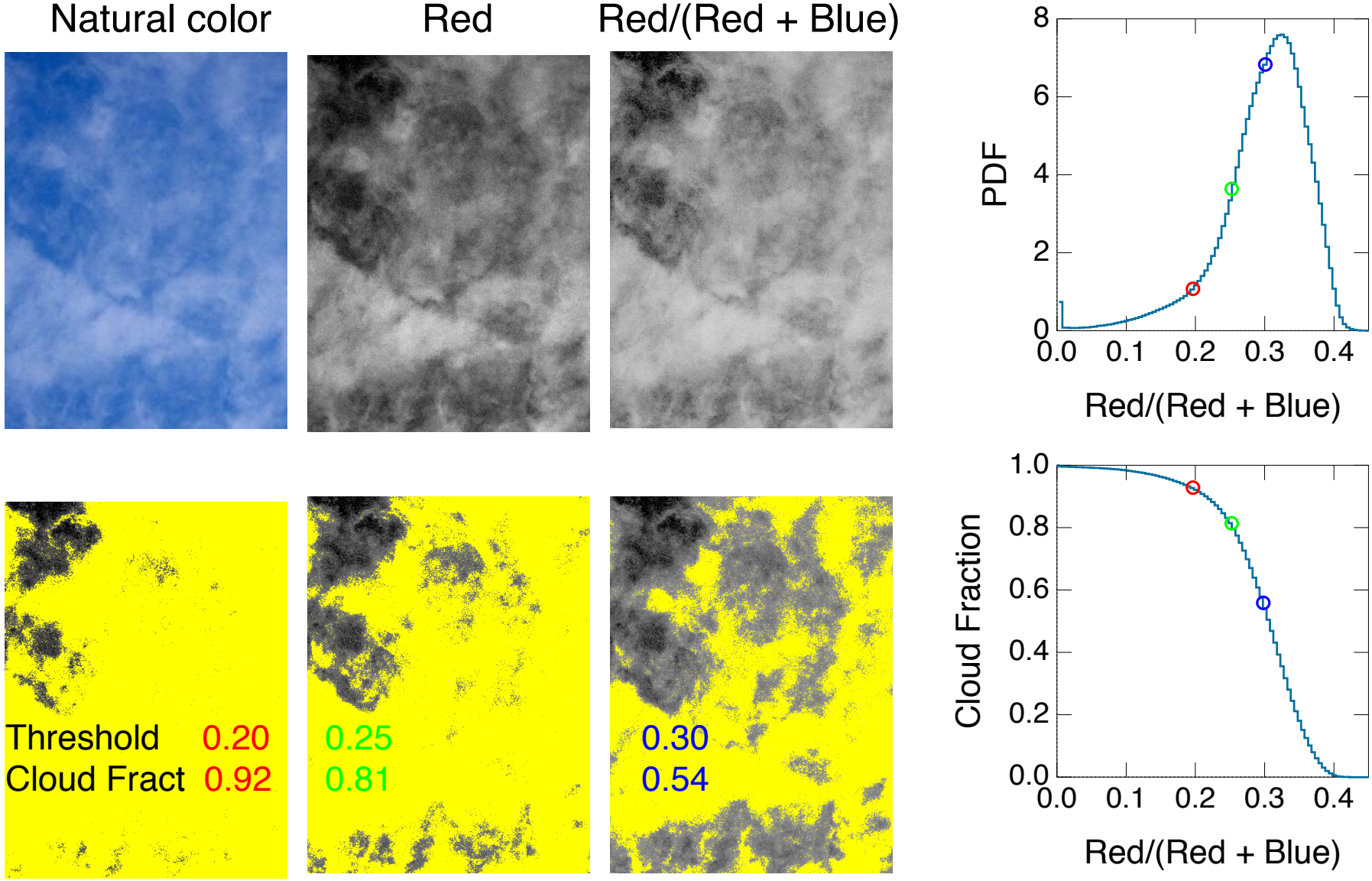
Cloud mask as function of threshold Red/(Red + Blue)



Cloud fraction is constrained between ~0.54 and ~0.62.

DETERMINING CLOUD FRACTION

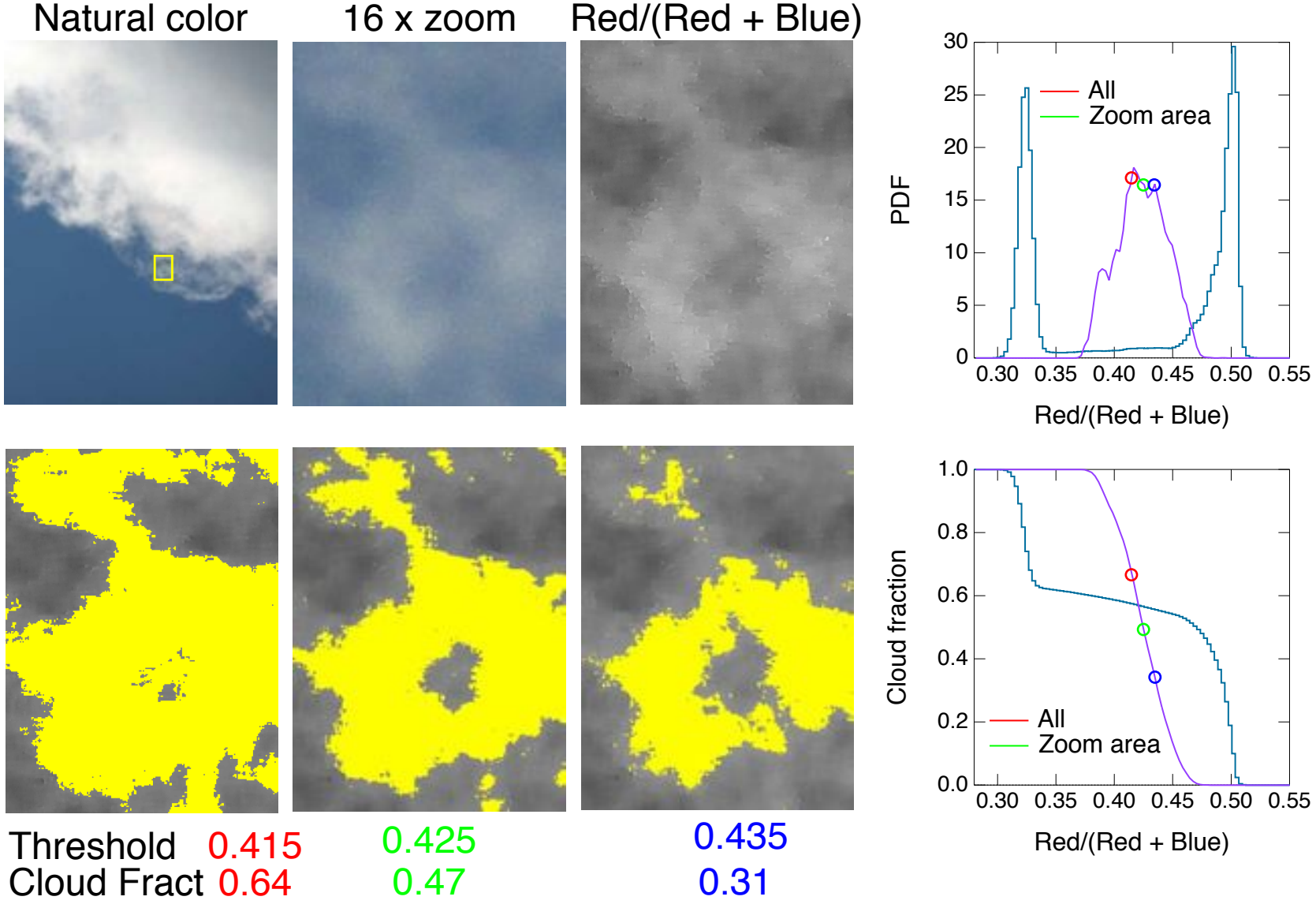
Cloud mask as function of threshold Red/(Red + Blue)



Cloud fraction is indeterminate.

DETERMINING CLOUD FRACTION

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



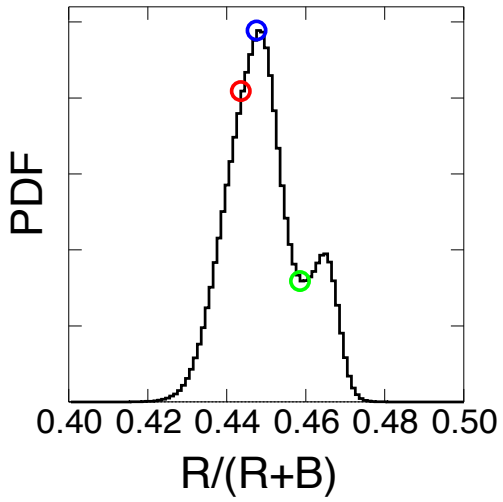
Cloud fraction in zoom area is indeterminate.

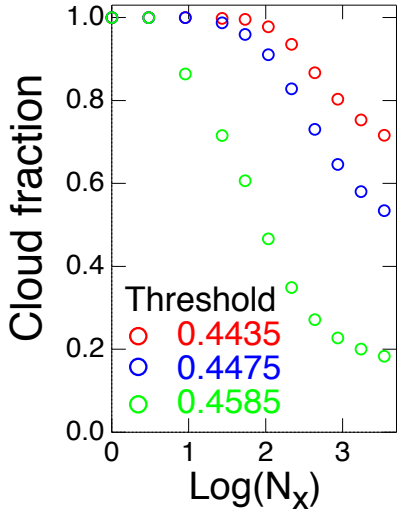
CLOUD FRACTION: THRESHOLD & RESOLUTION

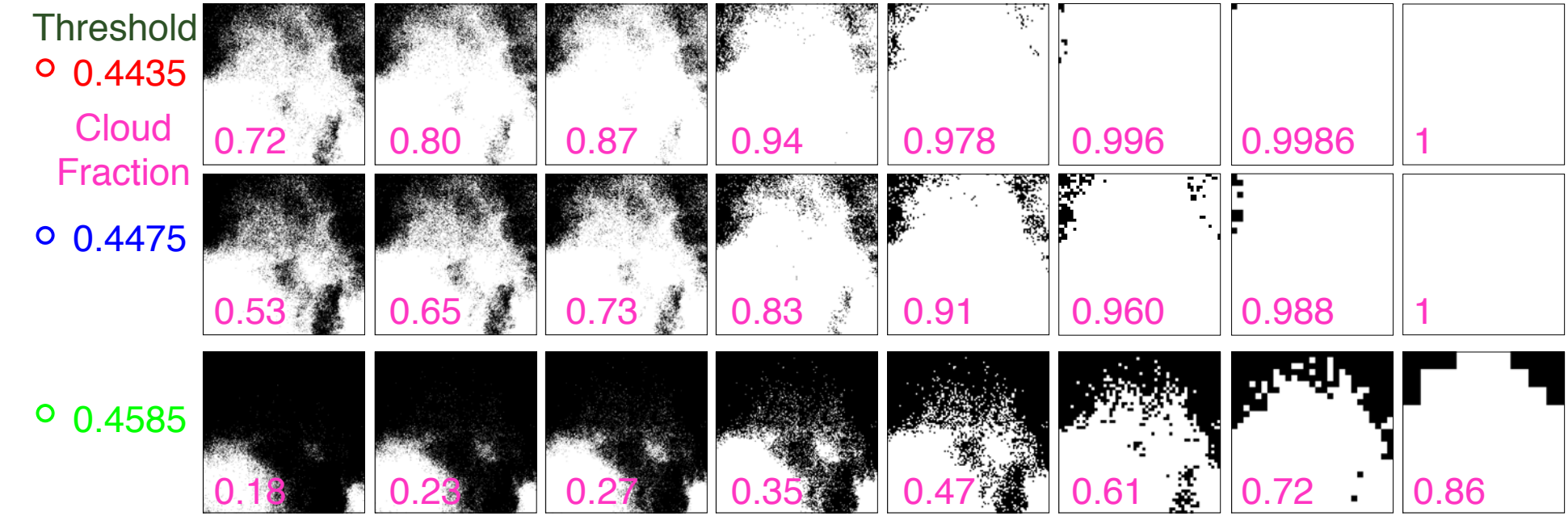
All pixels with ***any*** cloud are counted as cloud

Original Image

Red/(Red + Blue)



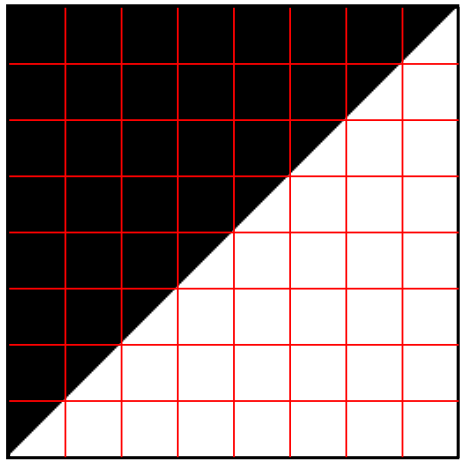




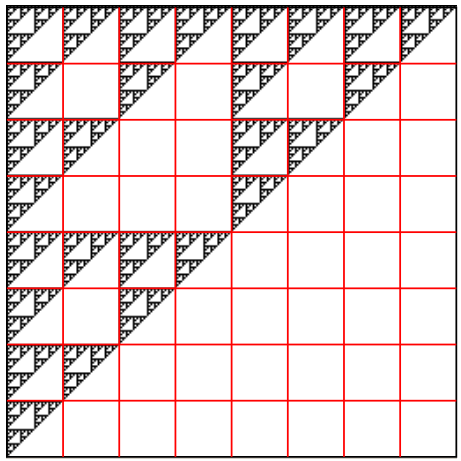
Cloud fraction depends strongly on on threshold and resolution.

FRACTAL DIMENSION

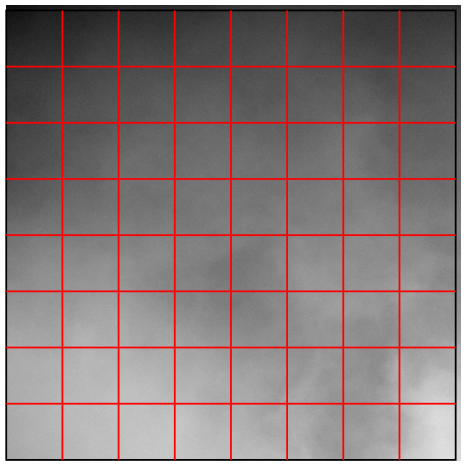
d log (number of elements)/*d* log (# of boxes on side)



2



log3/log2 = 1.58



?

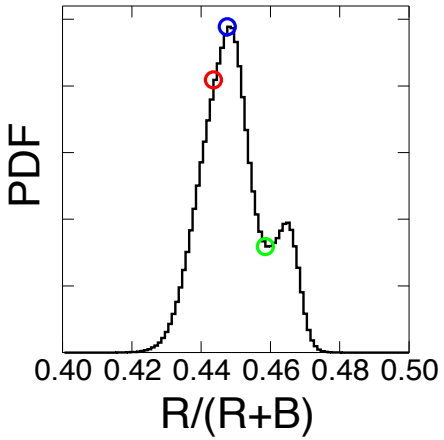
What is the fractal dimension of a 2-D image of a cloud?

CLOUD FRACTAL DIMENSION: DEPENDENCE ON THRESHOLD

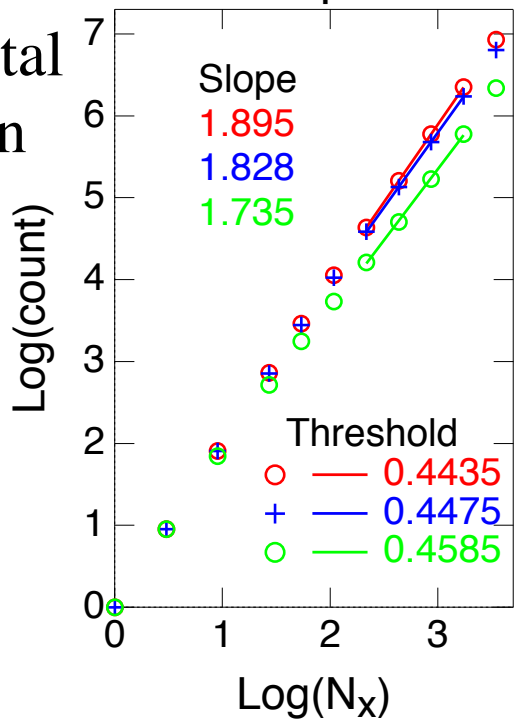
Box counting method: All pixels with ***any*** cloud are counted as cloud.

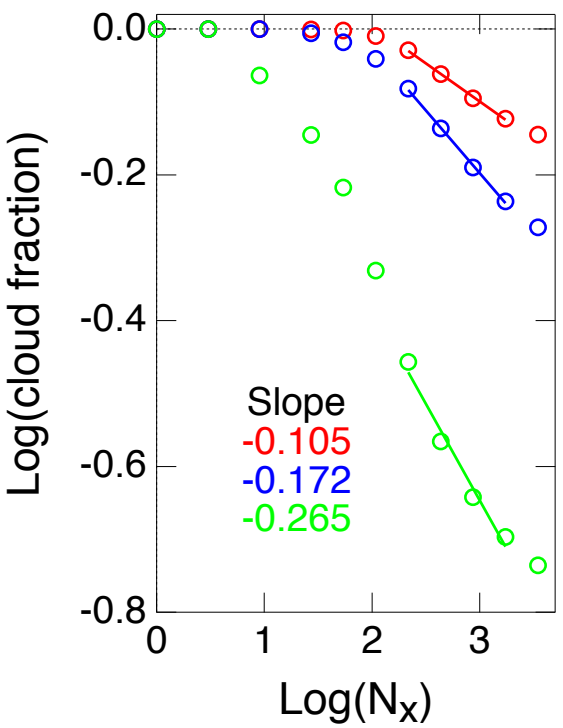
Original Image

Red/(Red + Blue)



Cloud fractal dimension = slope.





Difference in slopes = 2. Hence fits are equivalent.

Fitting as cloud fraction displays the differences.

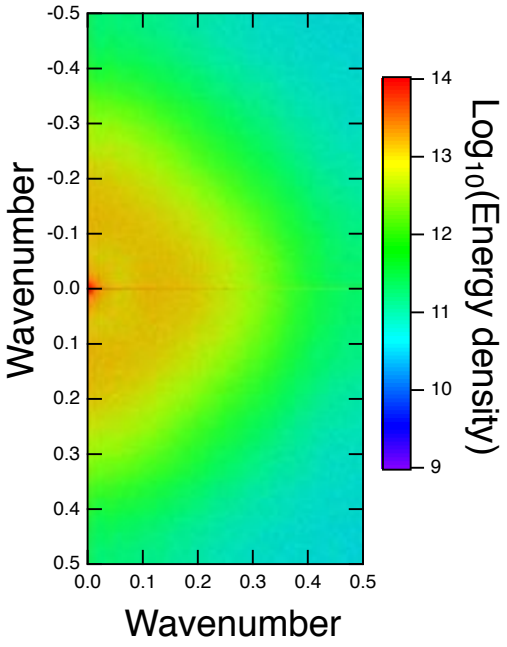
Cloud ***fractal dimension*** depends on on threshold.

POWER SPECTRUM AND FRACTAL DIMENSION

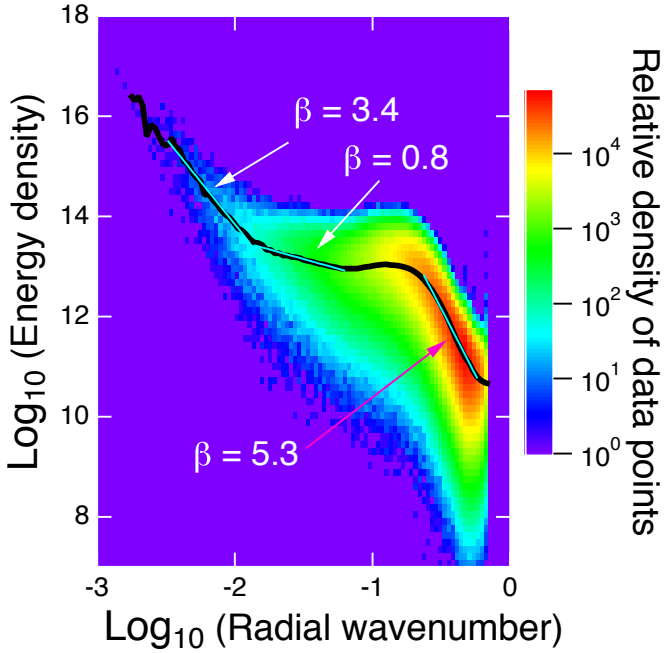
Natural color

Grayscale

2-D FFT



Cartesian to polar;
Bin and average;
Determine slopes



Energy spectrum: $S \sim k^{-\beta}$; $\beta = -\dfrac{d\log S}{d\log k}$

Fractal dimension (Turcotte; Goff): $D = 4 - \dfrac{\beta}{2}$

β	D
3.4	2.3
0.8	3.6
5.3	1.4

No indication of scale invariance or constant fractal dimension.

CONCLUSIONS AND QUESTIONS

- Surface-based high resolution photography of clouds provides a new and interesting view of clouds.
- Cloud amount and downwelling radiance exhibit ***high variability at scales down to ~ 1 meter***.
- Cloud fraction ***cannot be uniquely defined or measured***: Inherently depends on threshold and resolution.
- Can clouds be characterized by a ***fractal dimension***? Do different approaches to determining fractal dimension yield the same results?
- How can fractal properties of clouds be used to improve representation of cloud radiative effects?