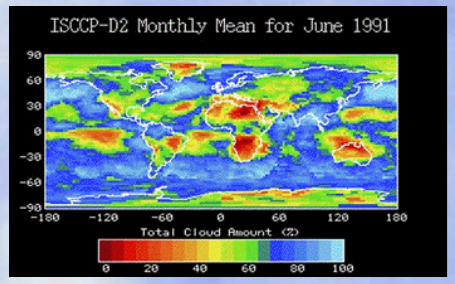
RADIATIVE CLOUD FRACTION

Determination by high resolution photography from the surface looking upward

Stephen E. Schwartz

BROOKHAVEN NATIONAL LABORATORY

Upton NY USA



ISCCP

Clouds, Their Properties, and Their Climate Feedbacks
What have we learned in the satellite era?

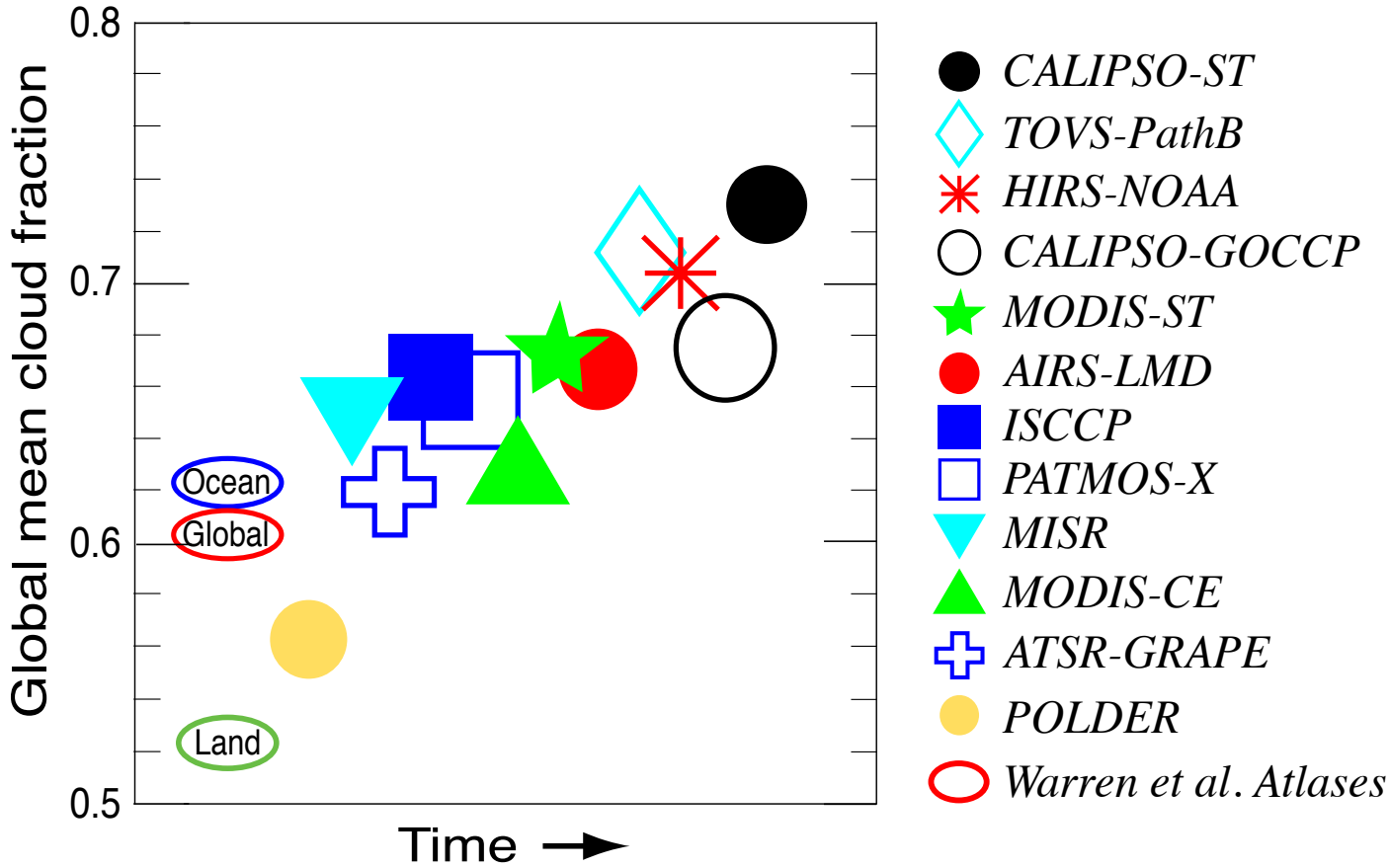
A symposium to celebrate William B. Rossow's science contributions and retirement

Columbia University, New York, N.Y.June 6-8, 2017

Schwartz, Huang & Vladutescu, JGR, 2017

www.ecd.bnl.gov/steve

MEASUREMENTS OF GLOBAL CLOUD FRACTION



*Modified from **Stubenrauch**, **Rossow**, Kinne, S. Ackerman, Cesana, Chepfer, Di Girolamo, Getzewich, Guignard, Heidinger, Maddux, Menzel, Minnis, Pearl, Platnick, Poulsen, Riedi, Sun-Mack, Walther, Winker, Zeng, and Zhao, BAMS, 2013*

- For clouds with optical depth > 0.1 global cloud fraction is about 68%.
- Cloud fraction increases to 73% when including subvisible cirrus with optical depth down to 0.01 (e.g. CALIPSO) and decreases to about 56% for clouds with optical depth > 2 (e.g. POLDER).
- Key reasons for differences: ***threshold*** and ***resolution***.

The cloud fraction is unity.

It's a question of threshold.

– Attributed to Bill Rossow

CLOUD FRACTION: CAN IT BE DEFINED, CAN IT BE MEASURED, AND IF WE KNEW IT WOULD IT BE OF ANY USE TO US ANYWAY?

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CLOUD FRACTION: CAN IT BE DEFINED, CAN IT BE MEASURED, AND IF WE KNEW IT WOULD IT BE OF ANY USE TO US ANYWAY?

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Short Abstract

No

No

No

www.ecd.bnl.gov/steve

RADIATIVE CLOUD FRACTION: CAN IT BE DEFINED, CAN IT BE MEASURED, AND IF WE KNEW IT WOULD IT BE OF ANY USE TO US ANYWAY?

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Short Abstract

~~No~~ Yes

~~No~~ Yes

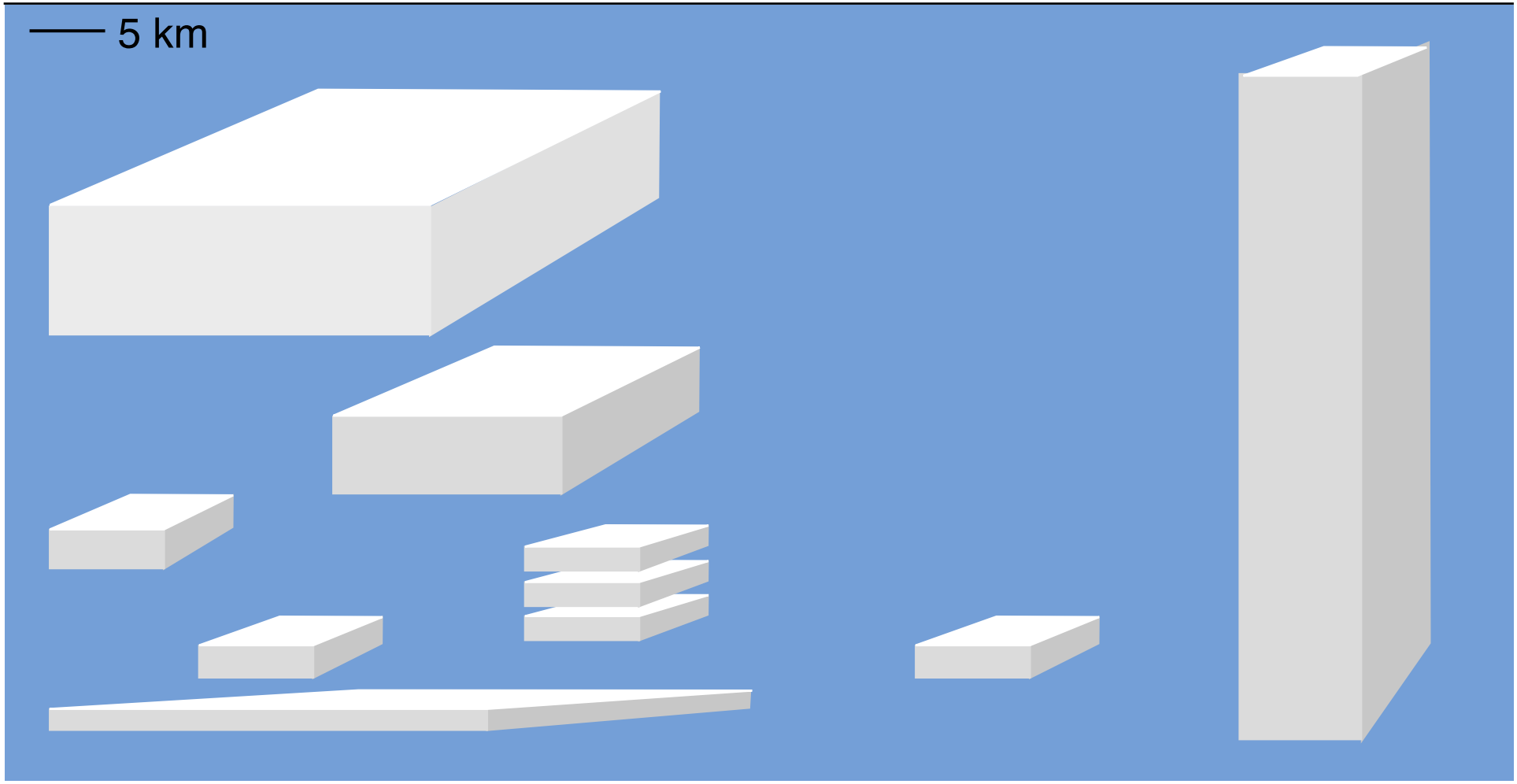
~~No~~ Yes

www.ecd.bnl.gov/steve

OBJECTIVES OF THIS TALK

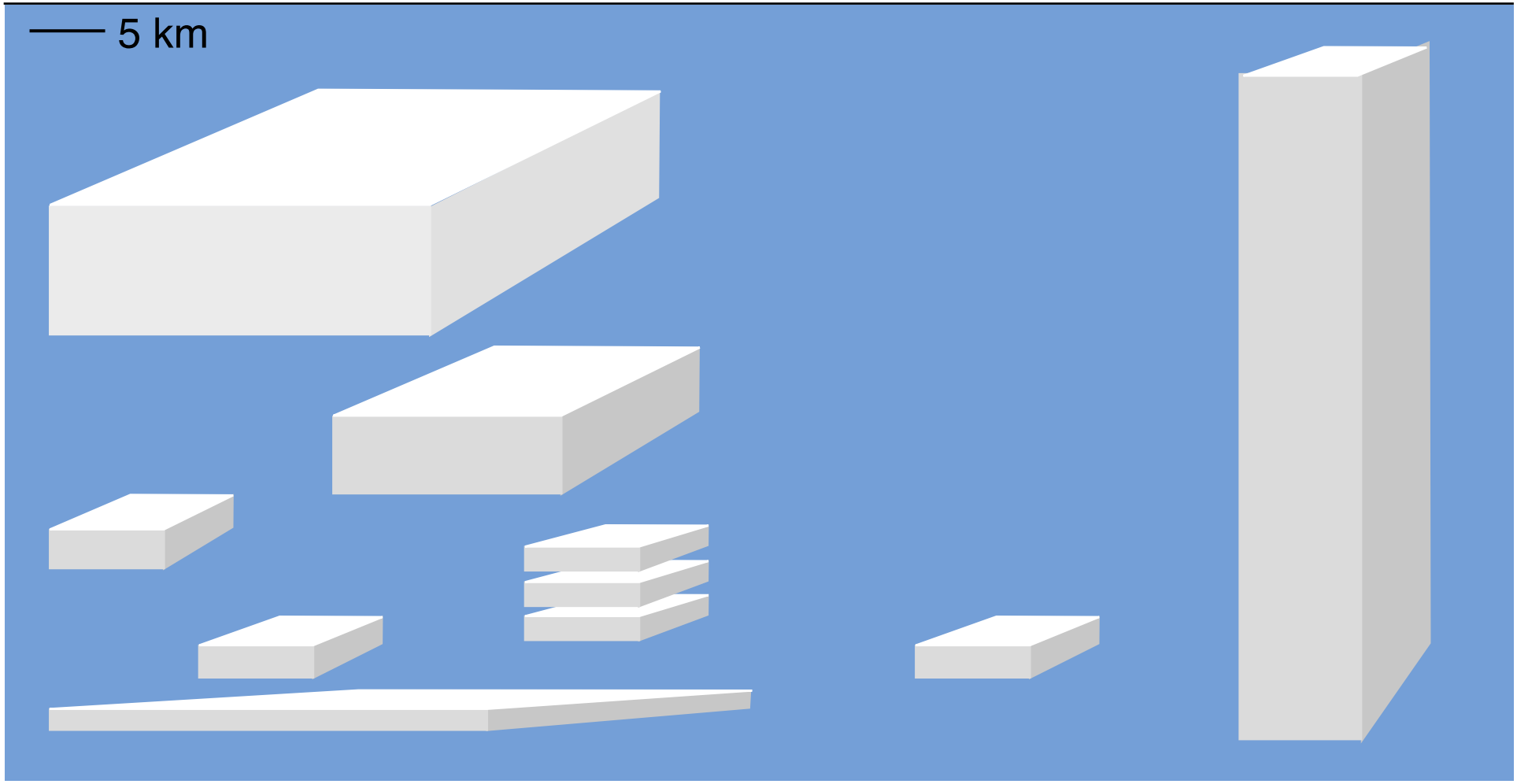
- Describe high characterization of clouds by high resolution photography from the surface
- Define and evaluate Radiative Cloud Fraction, RCF.
- Show that RCF is a useful measure of cloud amount.
- Convince the audience to ***abandon conventional areal cloud fraction as a measure of cloud amount***.

CLIMATE MODELER'S VIEW OF CLOUDS



Clouds are represented as homogeneous rectangular parallelepipeds.
A fraction of a grid cell is filled with clouds.

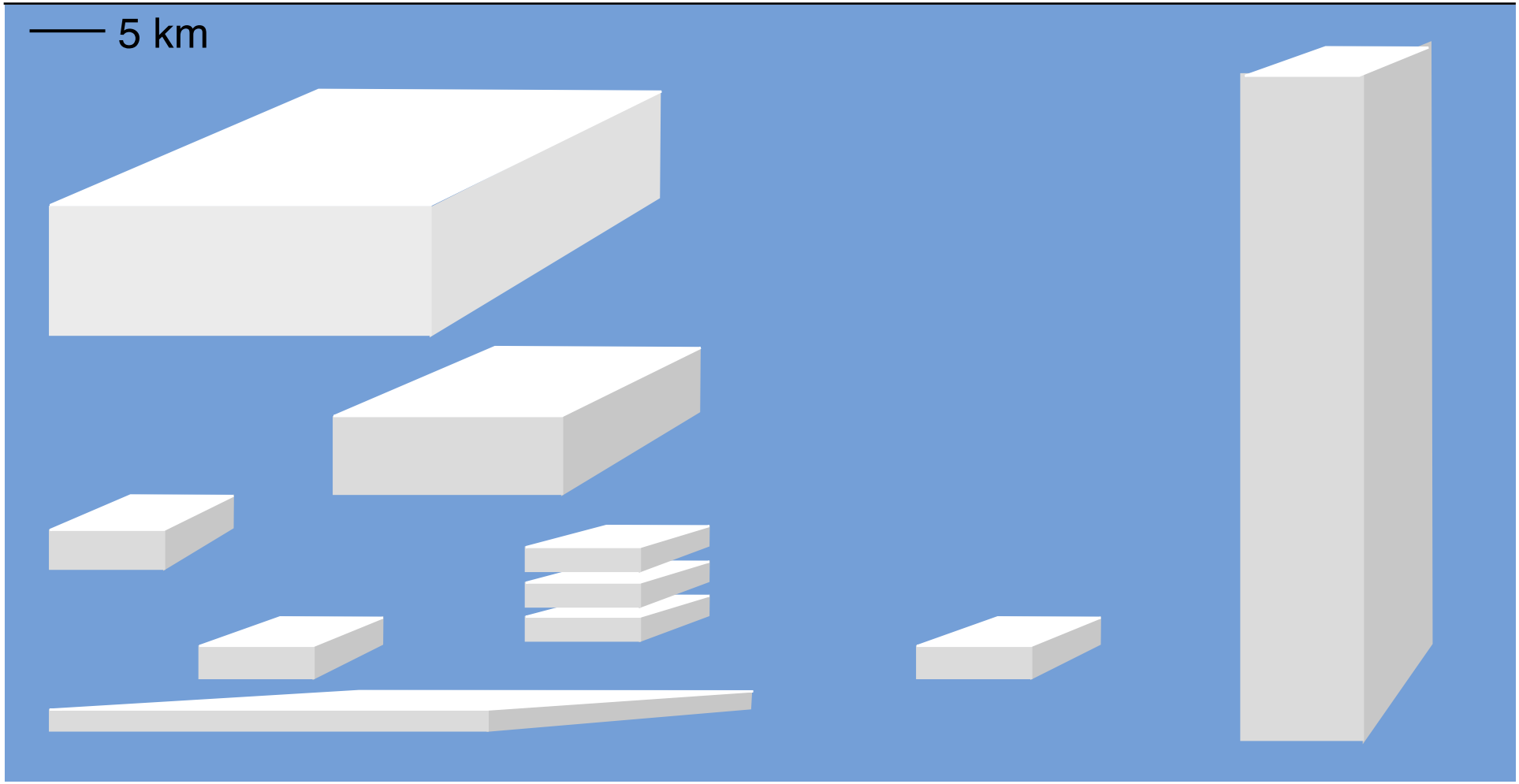
CLIMATE MODELER'S VIEW OF CLOUDS



Clouds are represented as homogeneous rectangular parallelepipeds.
A fraction of a grid cell is filled with clouds.

Too few, too bright.

CLIMATE MODELER'S VIEW OF CLOUDS



Clouds are represented as homogeneous rectangular parallelepipeds.
A fraction of a grid cell is filled with clouds.

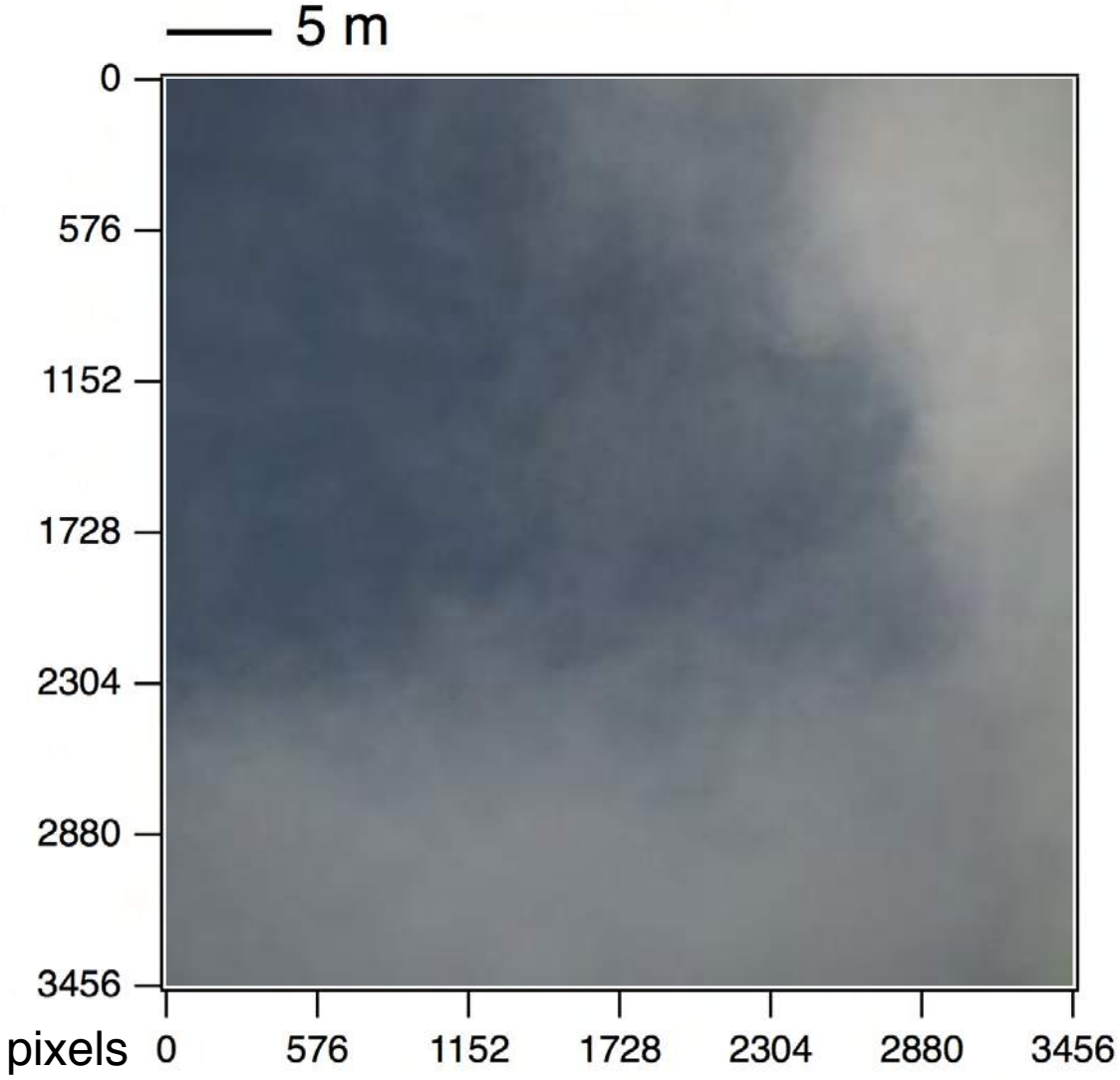
Too few, too bright.

These are not clouds.

THIS IS NOT A CLOUD

THIS IS NOT A CLOUD

It is an ***image*** of a cloud

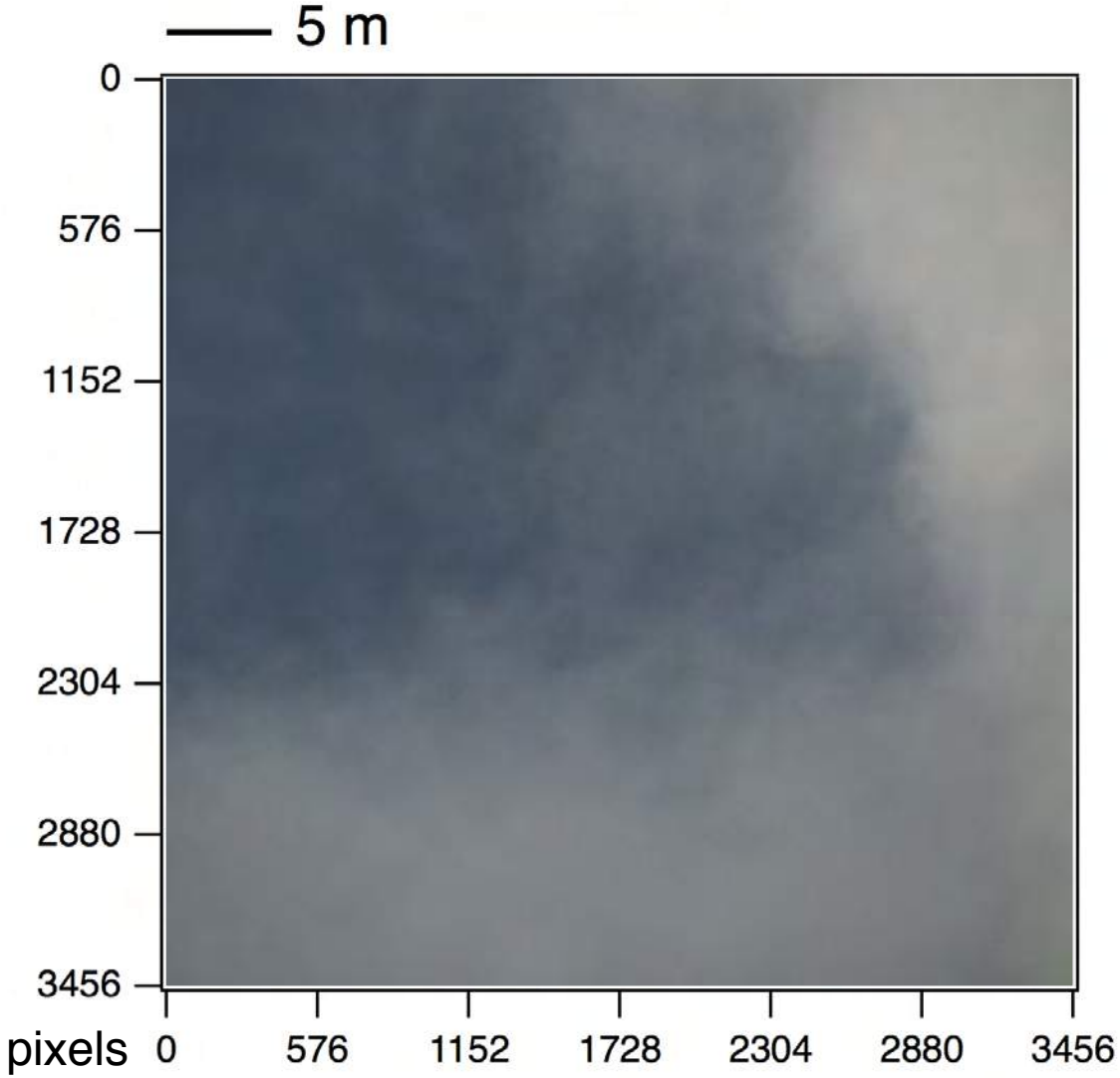


ARM SGP site, 2016-0731, 16:35:52 UTC (10:05:52 local sun time)

RGB image obtained with zenith-pointing digital camera at surface.

THIS IS NOT A CLOUD

It is an *image* of a cloud

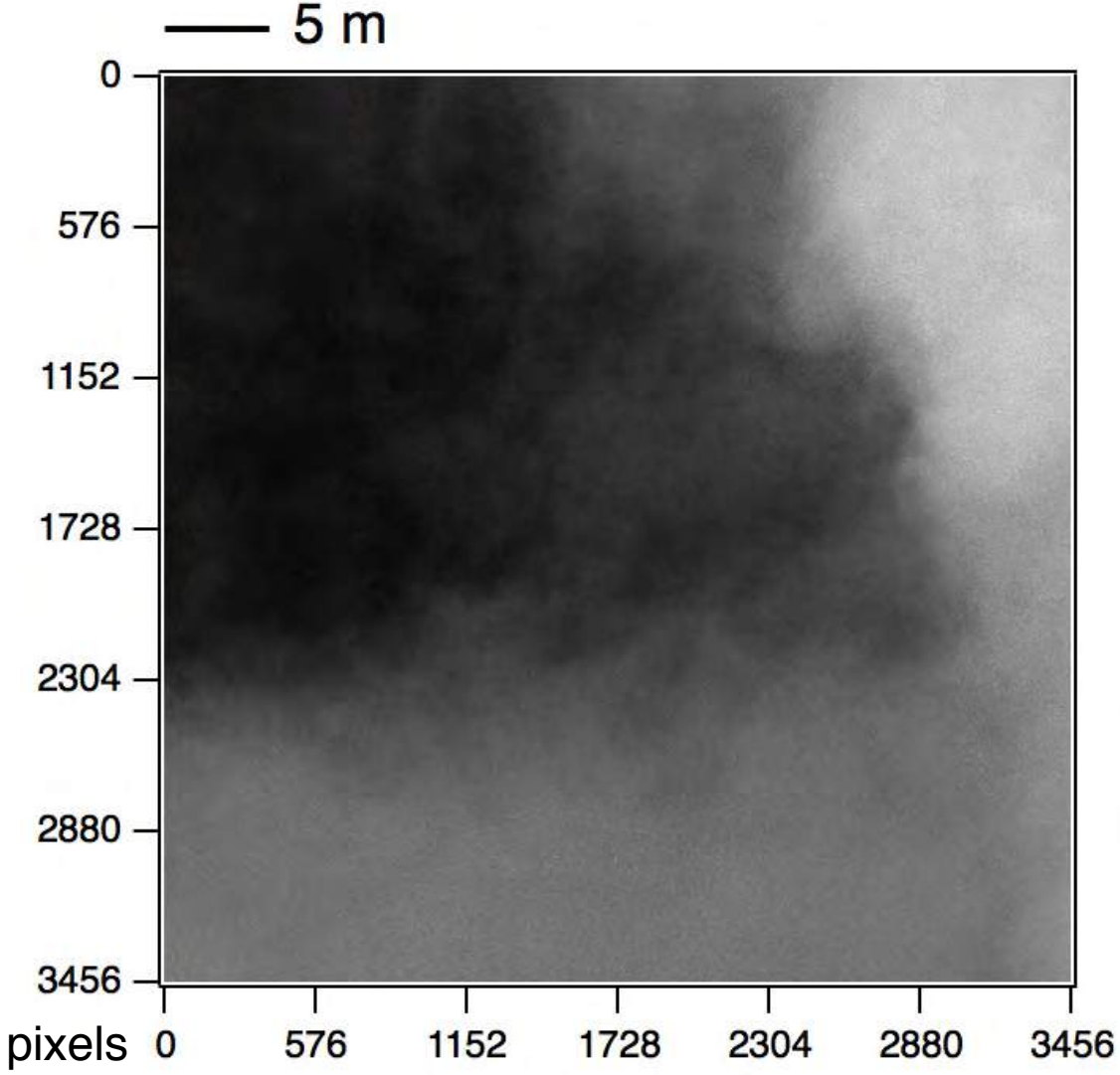


ARM SGP site, 2016-0731, 16:35:52 UTC (10:05:52 local sun time)

RGB image obtained with zenith-pointing digital camera at surface.
12 M pixel, 16-bit. One pixel = 6 μrad = 12 mm at cloud height 2 km

THIS IS NOT A CLOUD

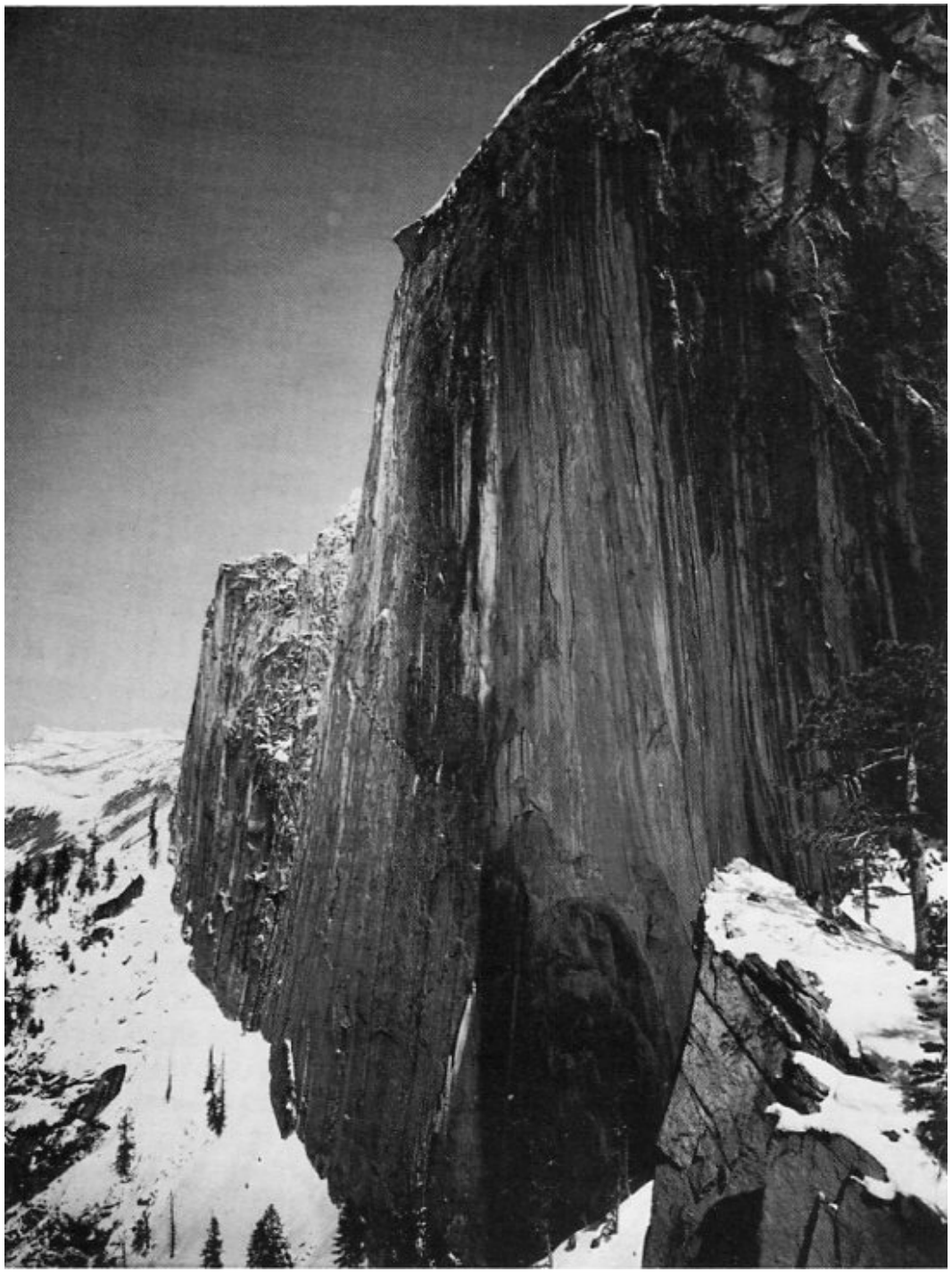
It is the **red channel** of the cloud image



ARM SGP site, 2016-0731, 16:35:52 UTC (10:05:52 local sun time)

The red channel of the camera is sensitive to the red component of the white cloud but is insensitive to the blue of the sky.

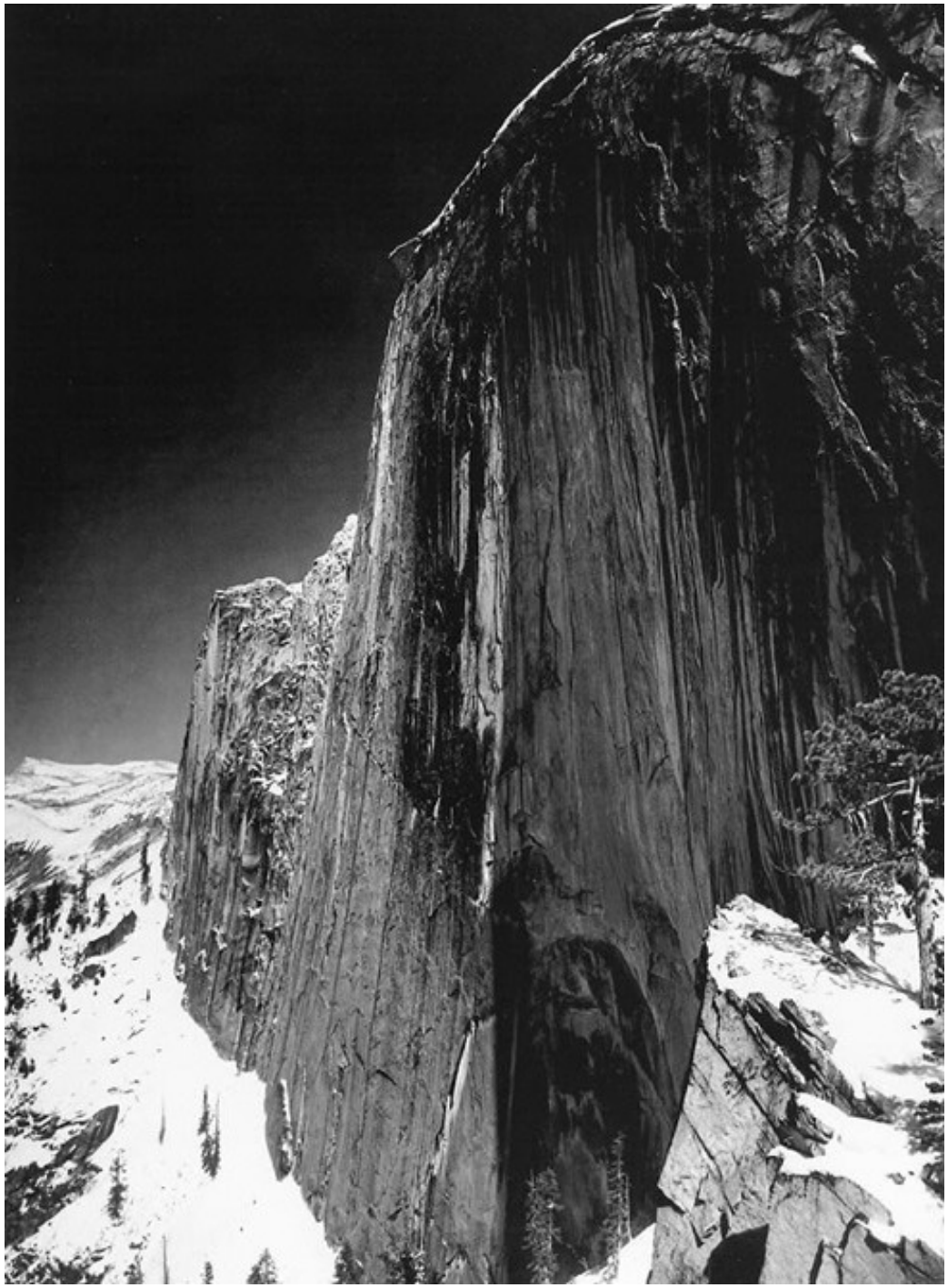
Black and White Photography



Monolith, The Face of Half Dome, Yosemite National Park, 1927. I consider this my first visualization – seeing in my mind the image I wanted before making the exposure. Using a conventional yellow filter, I realized after exposing that the image would not express the particular mood of overwhelming grandeur the scene evoked. I visualized a ***dark sky***, deeper shadows, and a crisp horizon in the distance.

– ***Ansel Adams***

Black and White Photography with a Red Filter



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– ***Ansel Adams***

MEASUREMENTS

HIGH RESOLUTION IMAGER

Fujifilm FinePix S1

16 Megapixels, 3456 × 4608

3 Color, RGB, 16 bit

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1200 mm focal length
(35 mm equiv)

1 Pixel = 6 μrad

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

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Fujifilm FinePix S1

16 Megapixels, 3456 × 4608

3 Color, RGB, 16 bit

1200 mm focal length
(35 mm equiv)

1 Pixel = 6 μrad

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

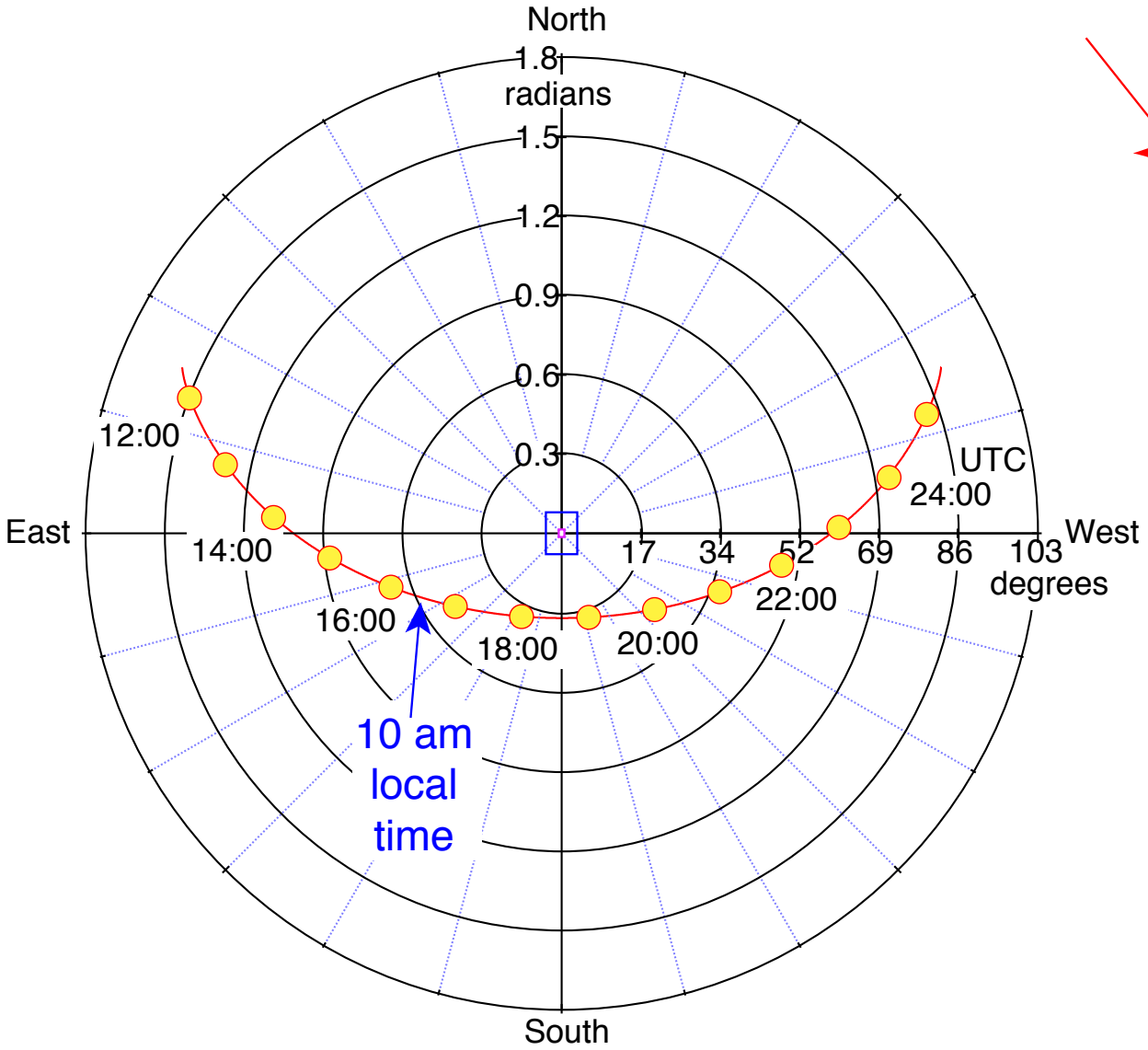
$350

SHORT RANGE CLOUD VARIABILITY

Moon diameter = 9 mrad.

DEPLOYMENT OF CAMERAS AT SGP

CAMERA FIELD OF VIEW AND SOLAR EPHEMERIS



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

Wide FOV Camera,
120 x 160 mrad

Sun, angular diameter
0.535° = 9.3 mrad

Drawn 10 times actual angular dimension

SGP, Oklahoma
2015-07-31
Times are UTC
Local sun time: UTC - 6.5 h

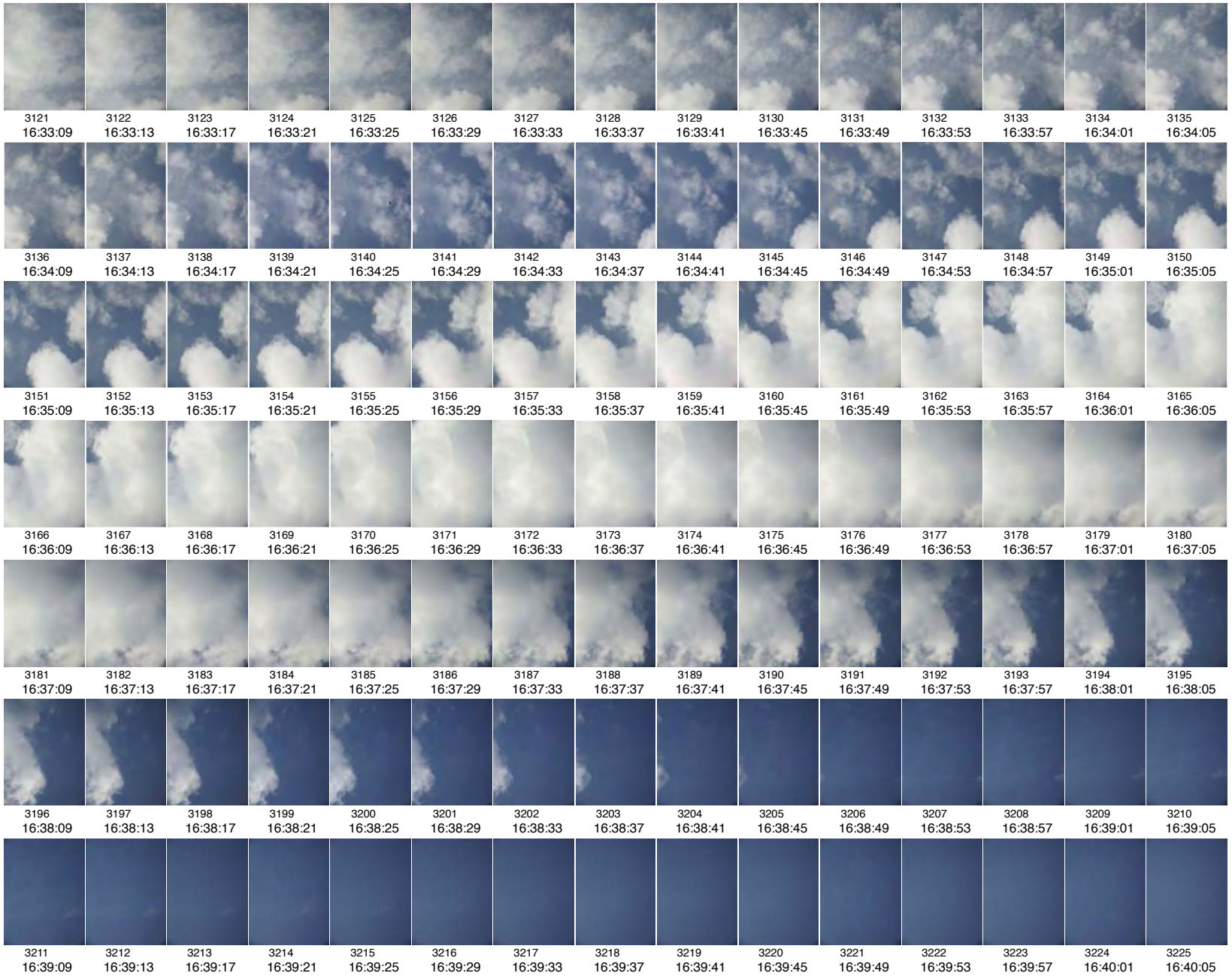
Measurements are hyper local!

7 MINUTES IN OKLAHOMA, WIDE FIELD OF VIEW CAMERA

N

E

W



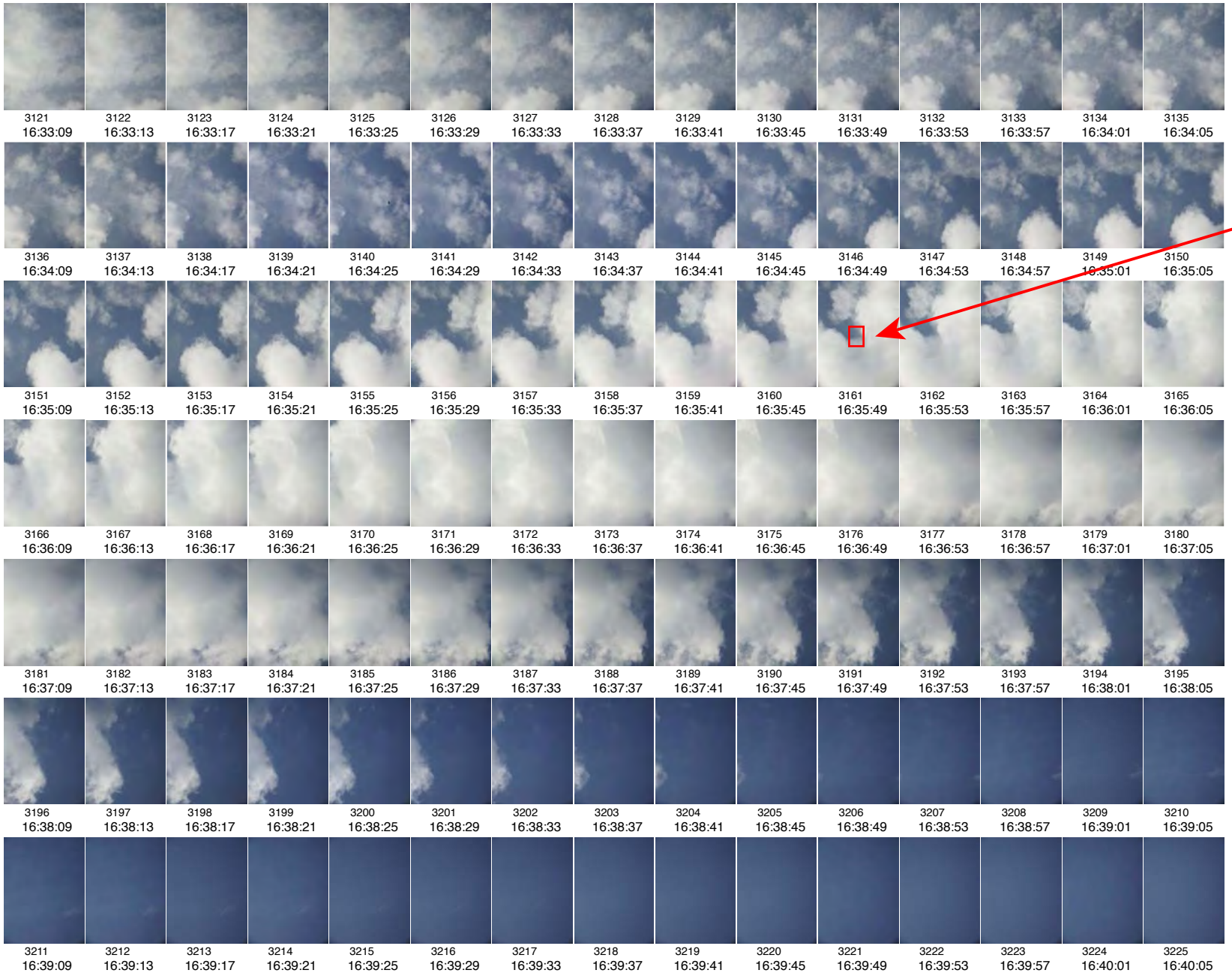
S

Schwartz, Huang & Vladutescu, JGR, 2017

Image is ~120 × 160 mrad = ~240 × 320 m @ 2 km. 1 Photo every 4 s.

7 MINUTES IN OKLAHOMA, WIDE FIELD OF VIEW CAMERA

N



Narrow Field of View Camera

E W

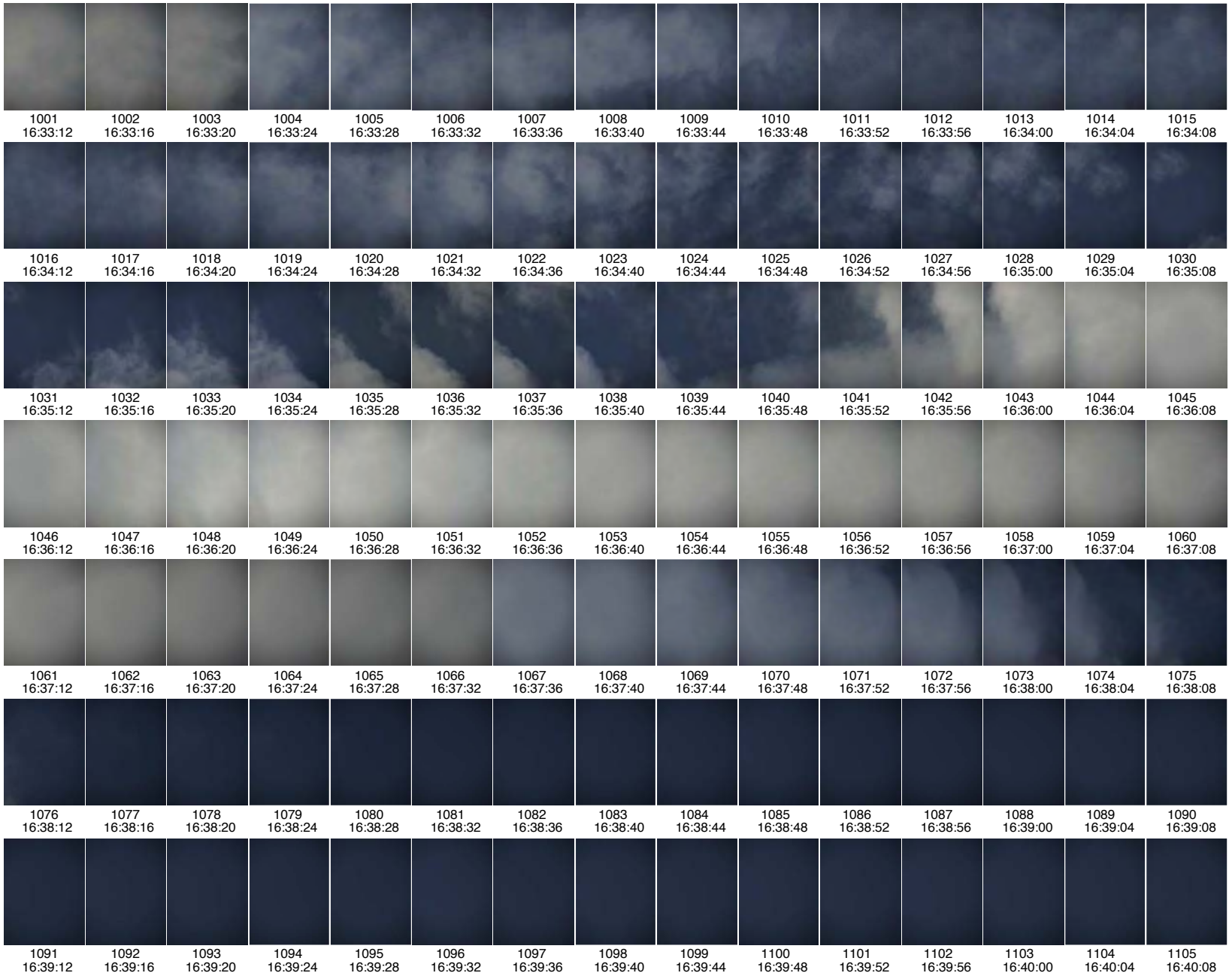
S

Image is ~120 × 160 mrad = ~240 × 320 m @ 2 km. 1 Photo every 4 s.

7 MINUTES IN OKLAHOMA, NARROW FIELD OF VIEW CAMERA

N

E



W

S

Image is ~20 × 30 mrad = ~40 × 60 m @ 2 km. 1 Photo every 4 s.

7 MINUTES IN OKLAHOMA, NARROW FIELD OF VIEW CAMERA

N

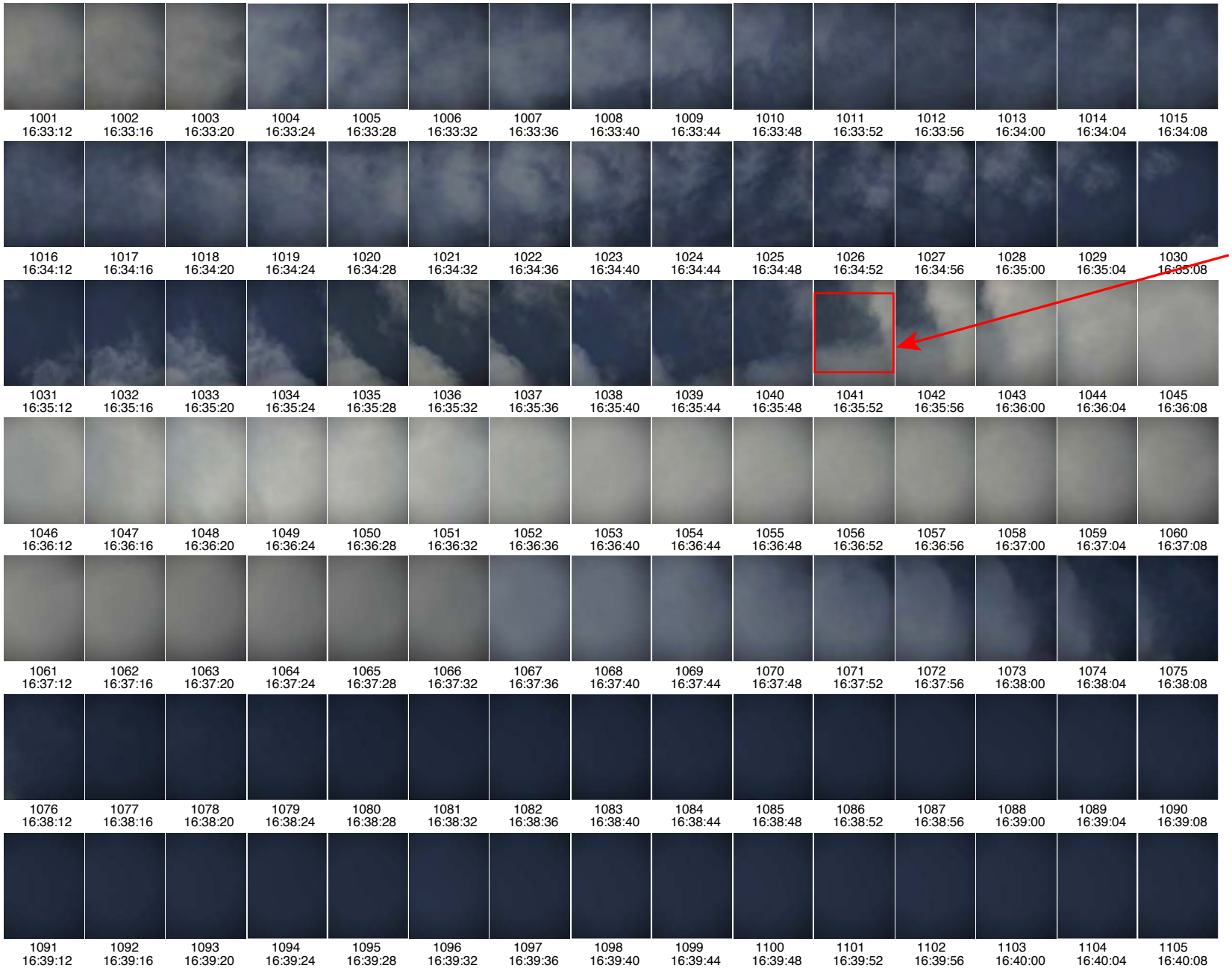


Image analyzed here

E

W

S

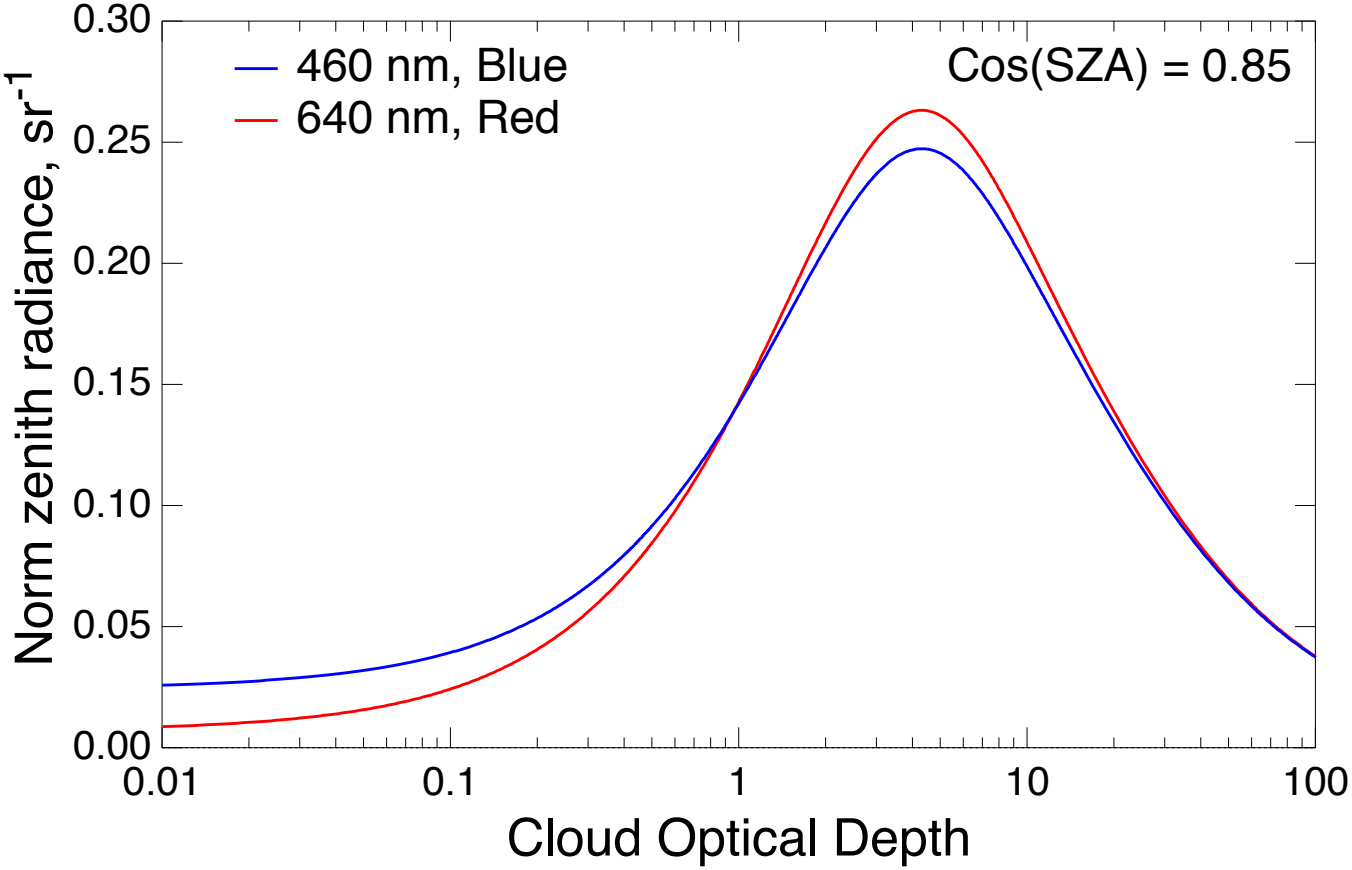
Image is ~20 × 30 mrad = ~40 × 60 m @ 2 km. 1 Photo every 4 s.

RADIATION TRANSFER CALCULATIONS AND DEFINITION OF RADIATIVE CLOUD FRACTION

ZENITH RADIANCE DEPENDENCE ON COD

Normalized zenith radiance: Zenith radiance per hemispheric TOA solar irradiance

Unit: W m^{-2} nm^{-1} sr^{-1} / W m^{-2} nm^{-1} = sr^{-1}



Downwelling radiance is low in absence of clouds; increases with increasing cloud optical depth, reaches a peak, and then decreases.

Schwartz, Huang & Vladutescu, JGR, 2017

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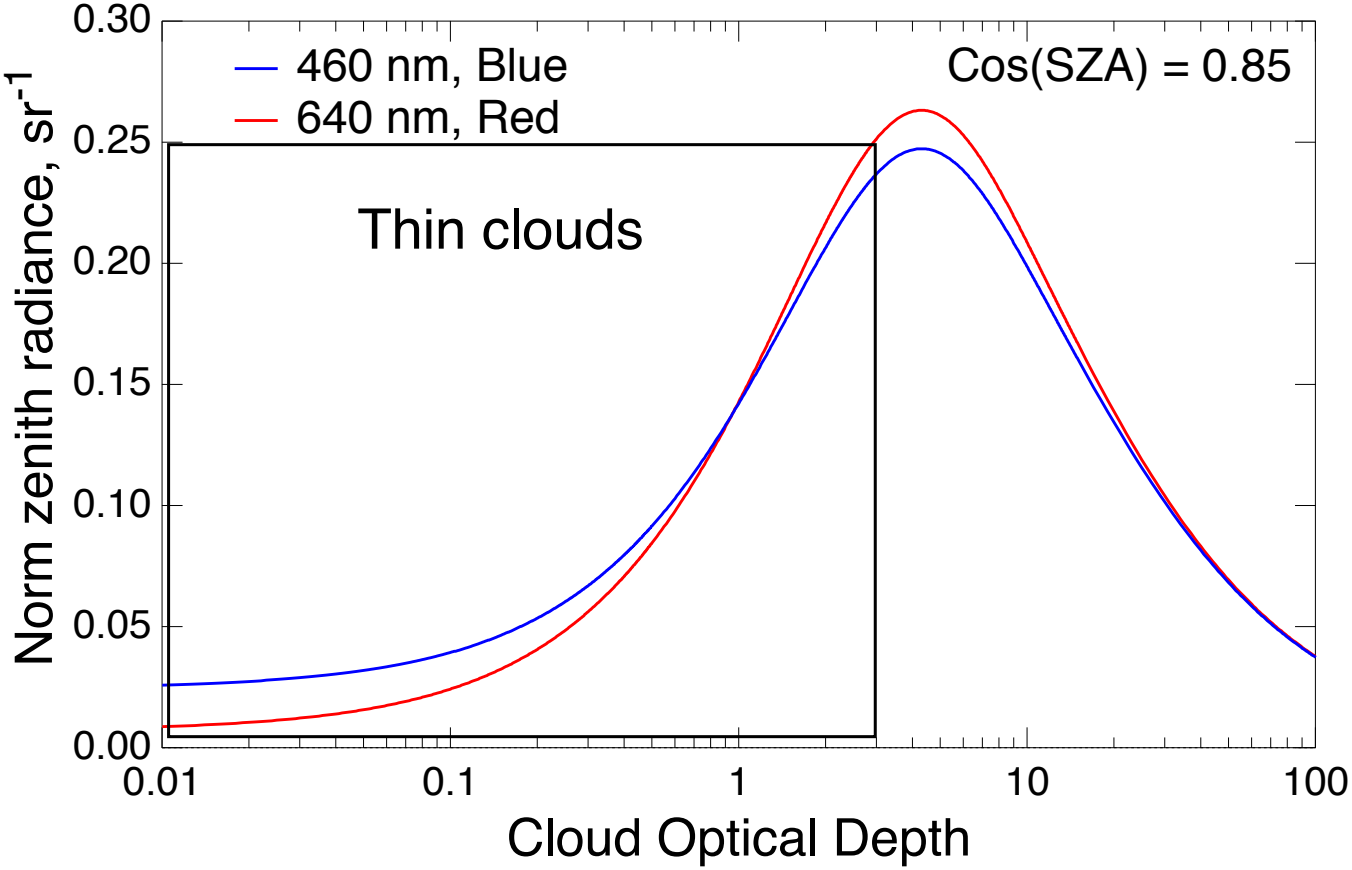
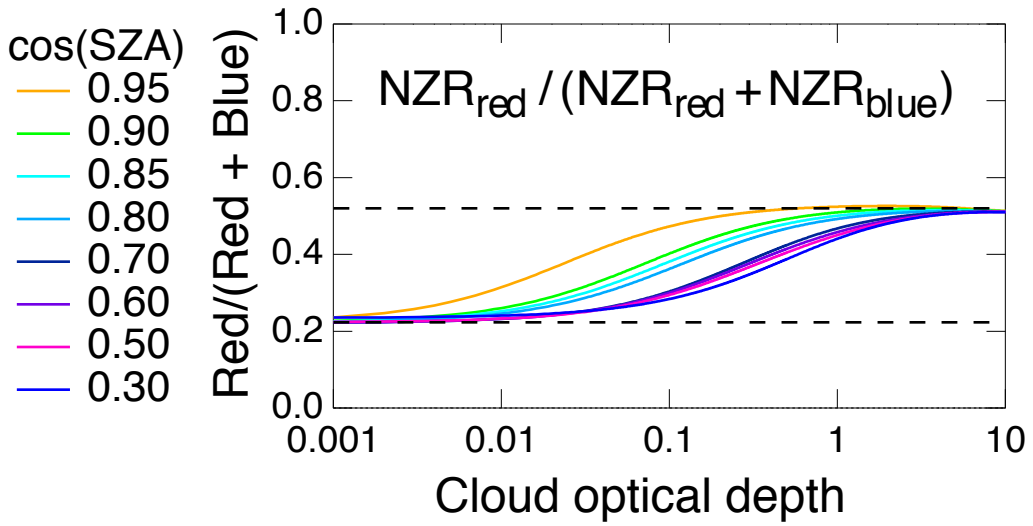


For thin clouds $R^{nz}(\theta_0, \tau_{cld}) \approx [\tau_{Ray} p_{Ray}(\theta_0)(1-\tau_{cld}) + p_{cld}(\theta_0)\tau_{cld}] / \cos(\theta_0)$

Downwelling radiance is low in absence of clouds; increases with increasing cloud optical depth, reaches a peak, and then decreases.

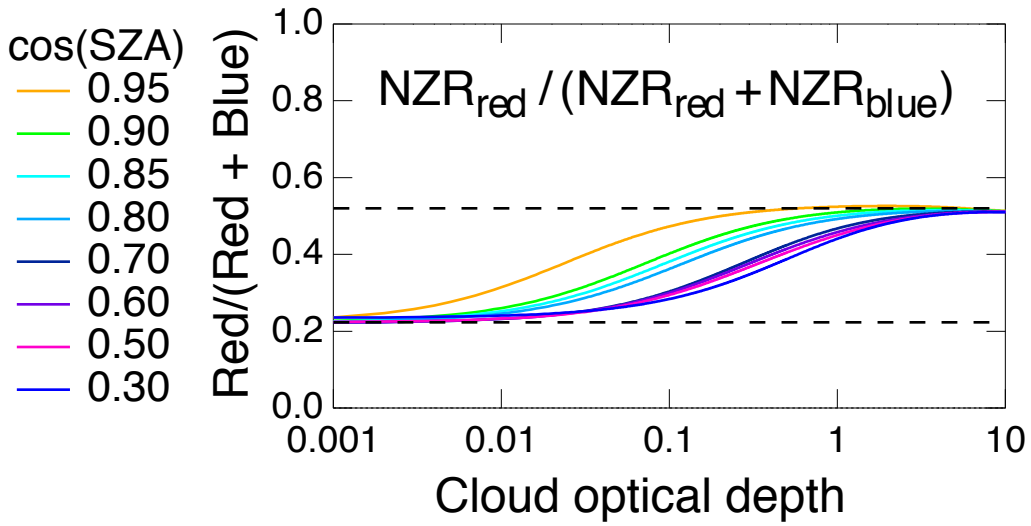
Schwartz, Huang & Vladutescu, JGR, 2017

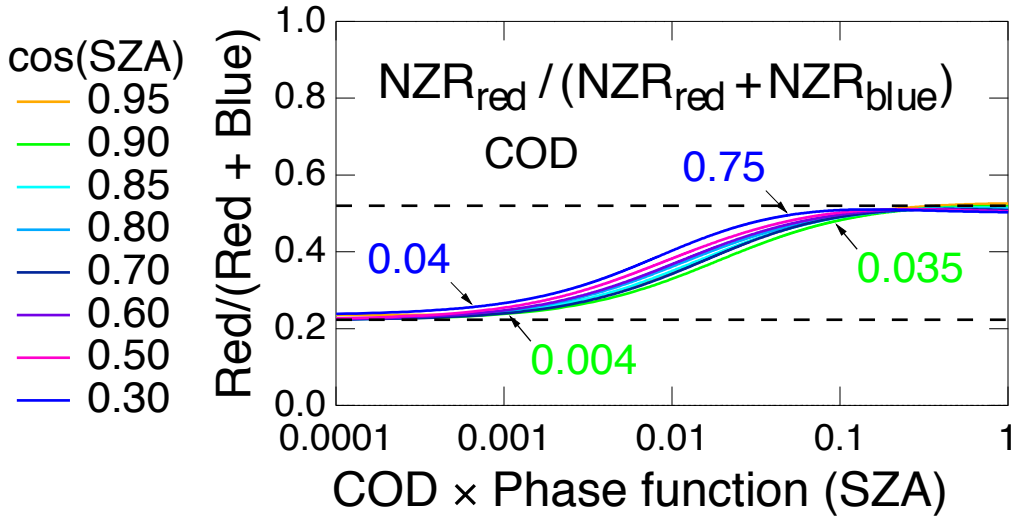
RED/(RED + BLUE)



- Obtained from radiation transfer calculations of NZR.
- A commonly used discriminant for clouds.
- Increases with increasing COD.

RED/(RED + BLUE)





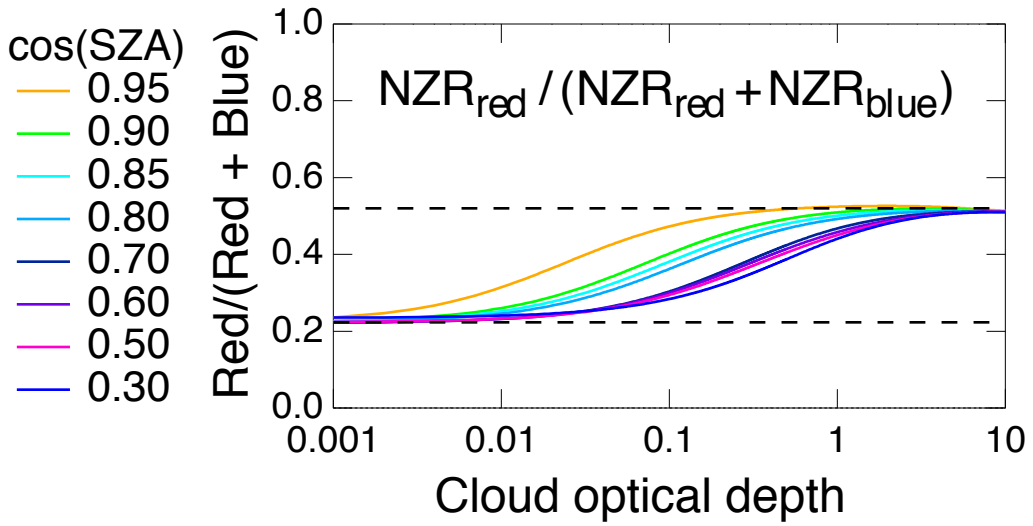
Obtained from radiation transfer calculations of NZR.

A commonly used discriminant for clouds.

Increases with increasing COD.

Using COD × phase function as independent variable greatly narrows width of envelope.

RADIATIVE CLOUD FRACTION

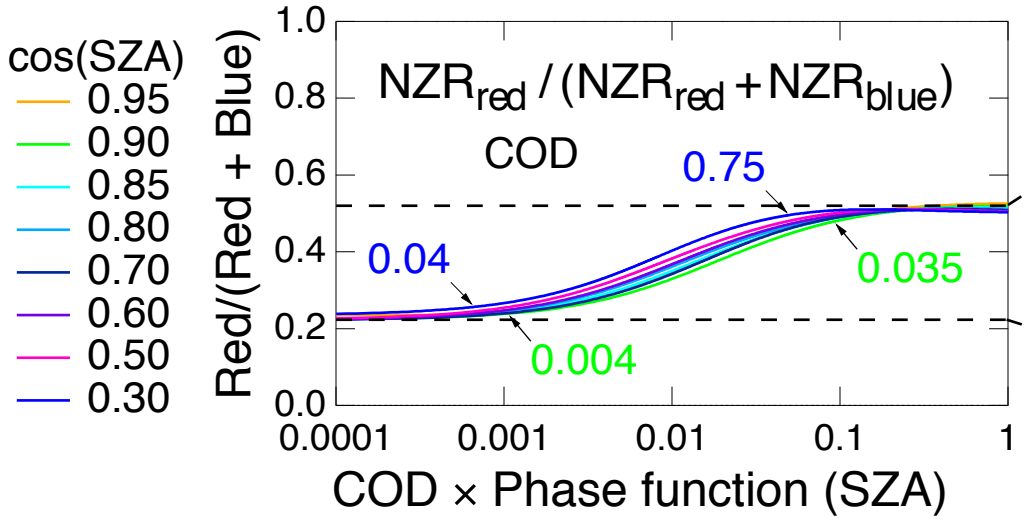


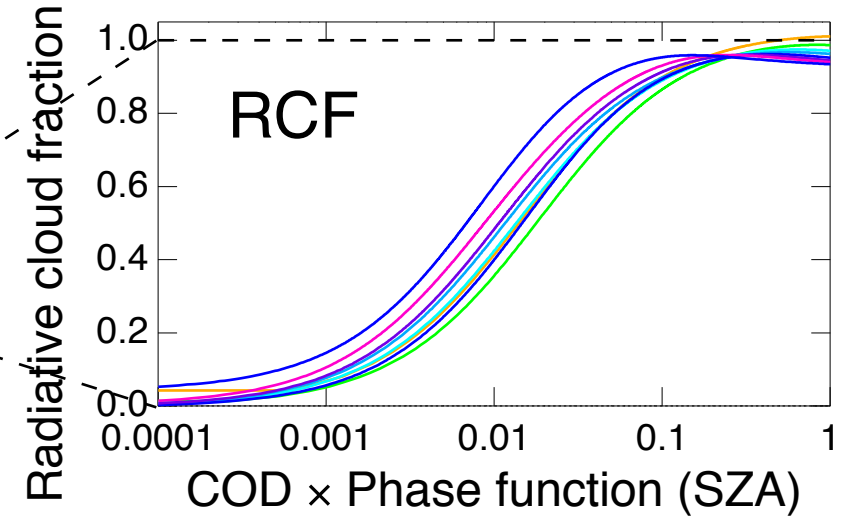
Obtained from radiation transfer calculations of NZR.

A commonly used discriminant for clouds.

Increases with increasing COD.

Linear transformation to RCF.



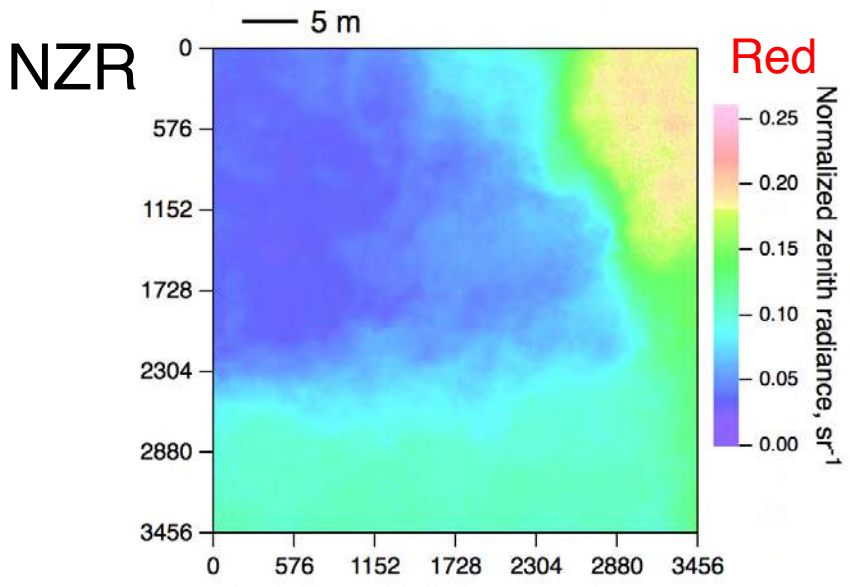


Using COD × phase function as independent variable greatly narrows width of envelope.

Radiative cloud fraction, ranging from 0 to 1, can be determined for each pixel of an image.

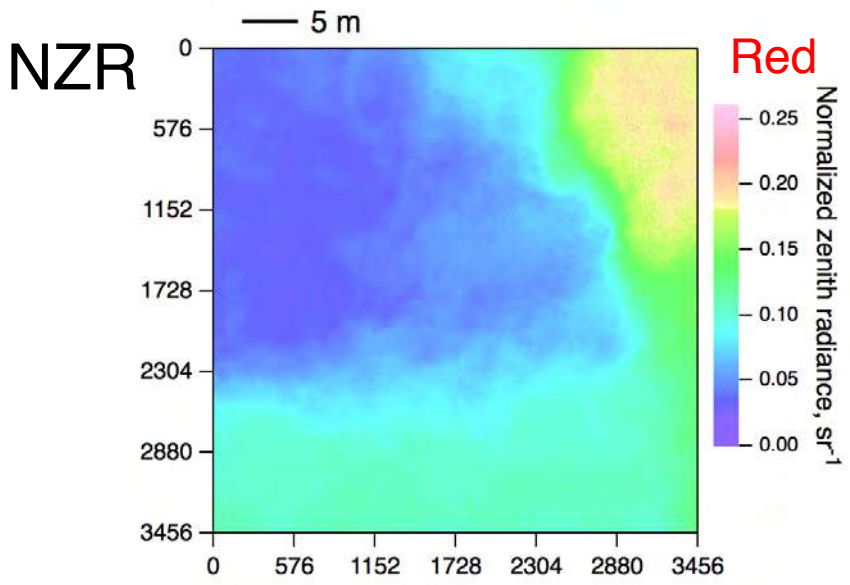
DETERMINATION OF RADIATIVE CLOUD FRACTION FROM OBSERVATIONS

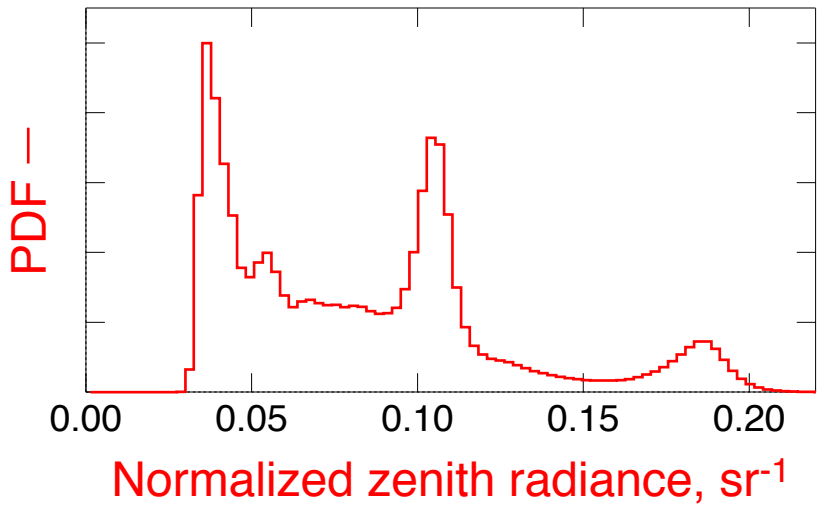
NORMALIZED ZENITH RADIANCE



Normalized zenith radiance varies substantially over the 40 m × 40 m image, on scales of less than 1 m.

NORMALIZED ZENITH RADIANCE

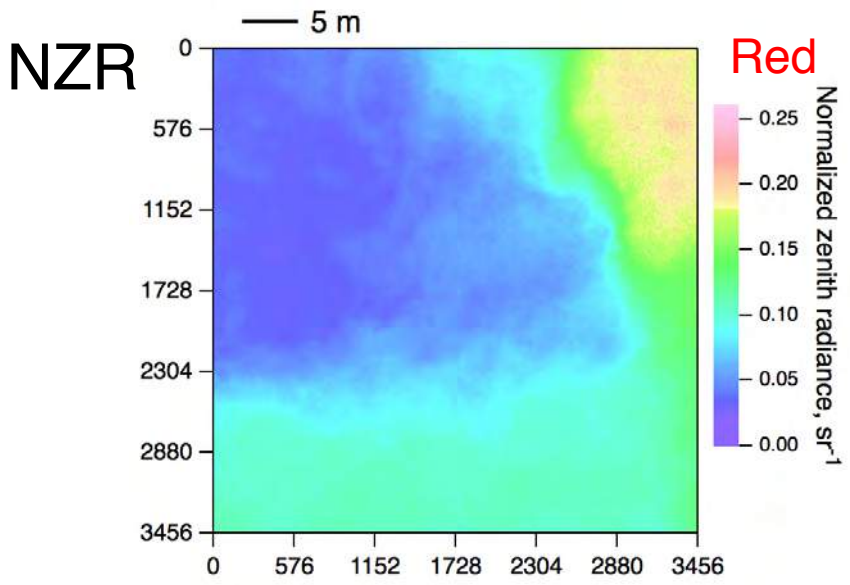


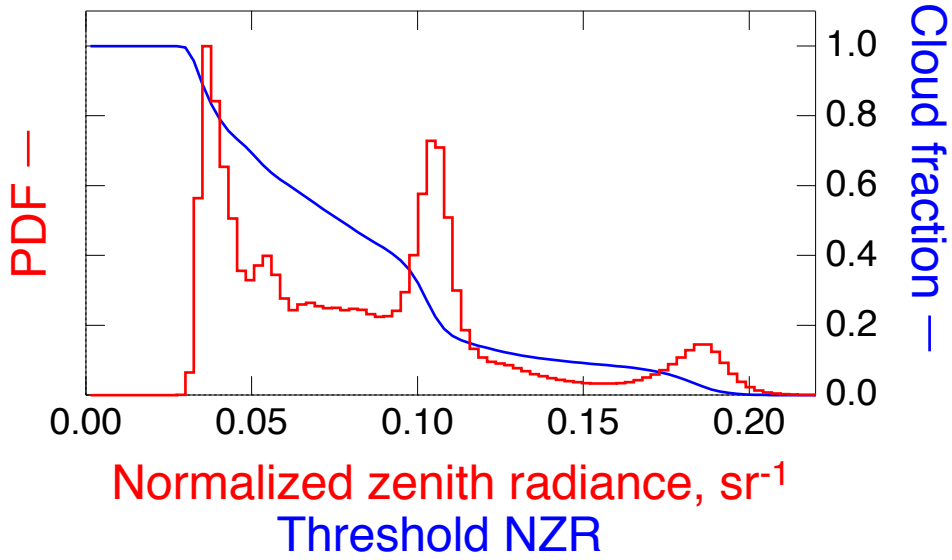


Large variation in NZR is displayed in probability distribution function.

CLOUD FRACTION

Dependence on threshold

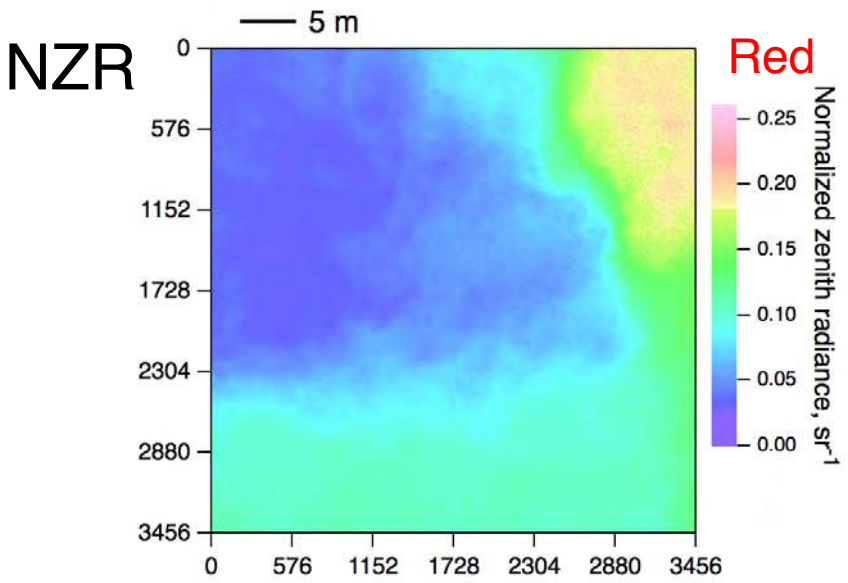


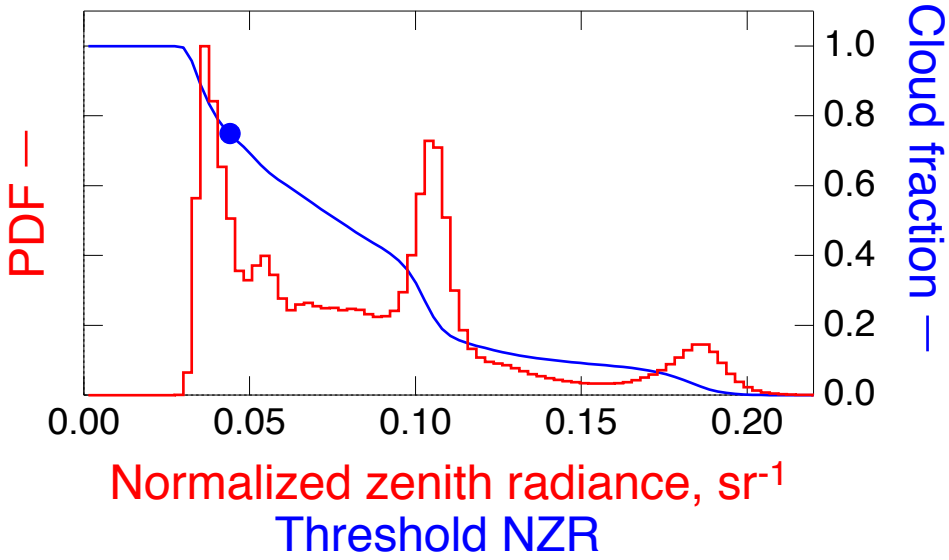


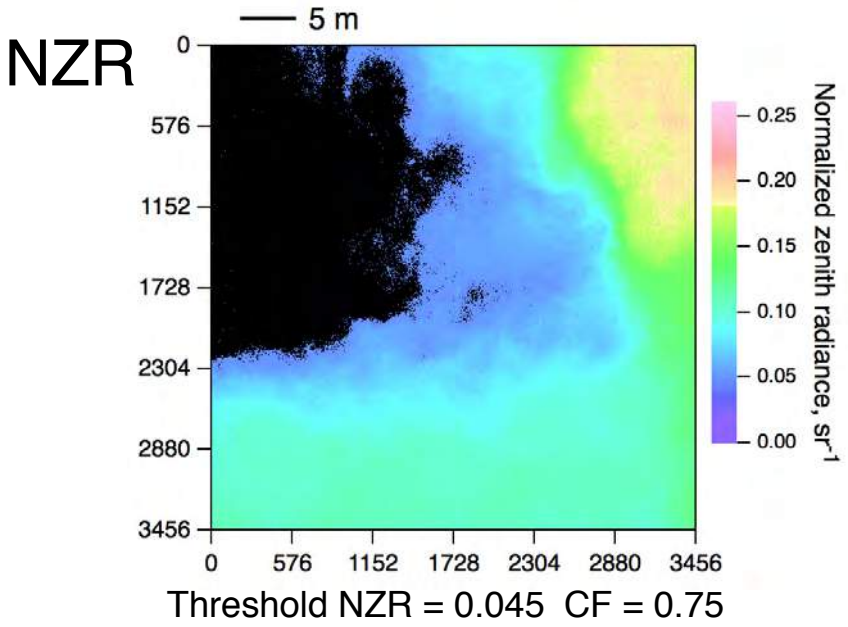
Cloud fraction as function of NZR is the complement of the cumulative integral of PDF, decreasing with increasing threshold NZR.

CLOUD FRACTION

Dependence on threshold



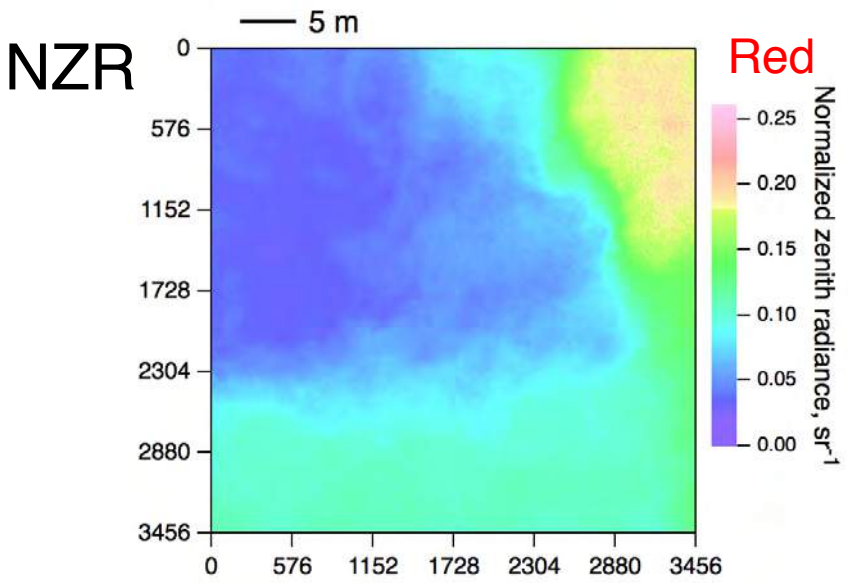


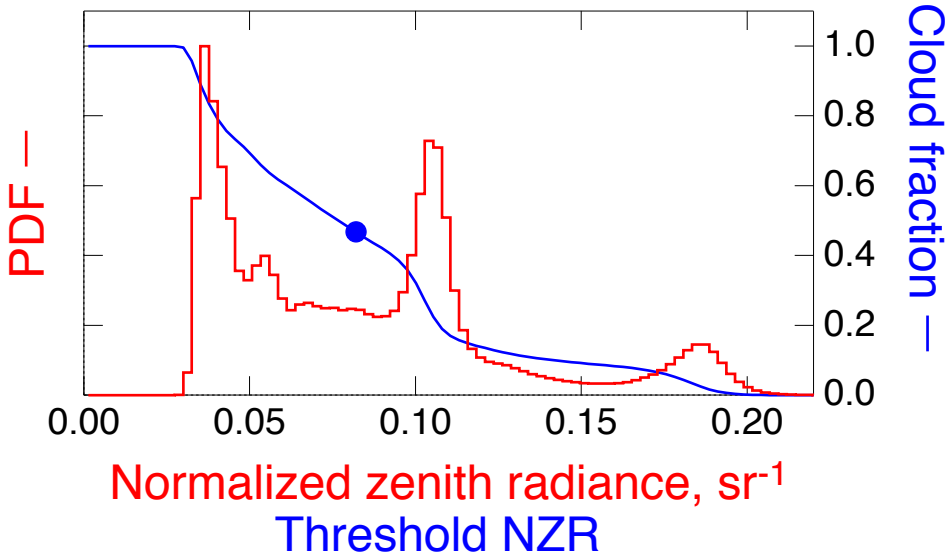


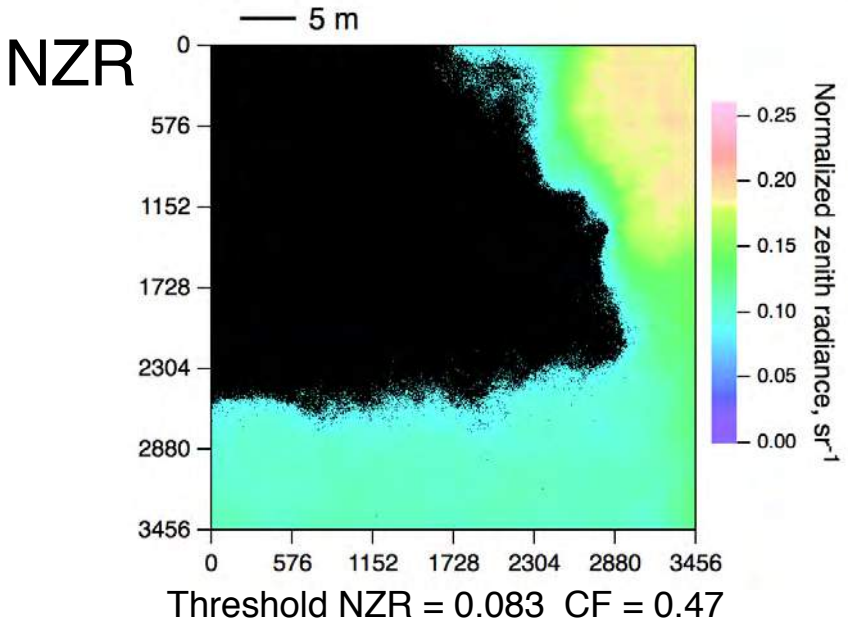
Conventional cloud mask is ***binary*** on a pixel-by-pixel basis:
1 if threshold < NZR, and 0 if threshold > NZR.

CLOUD FRACTION

Dependence on threshold





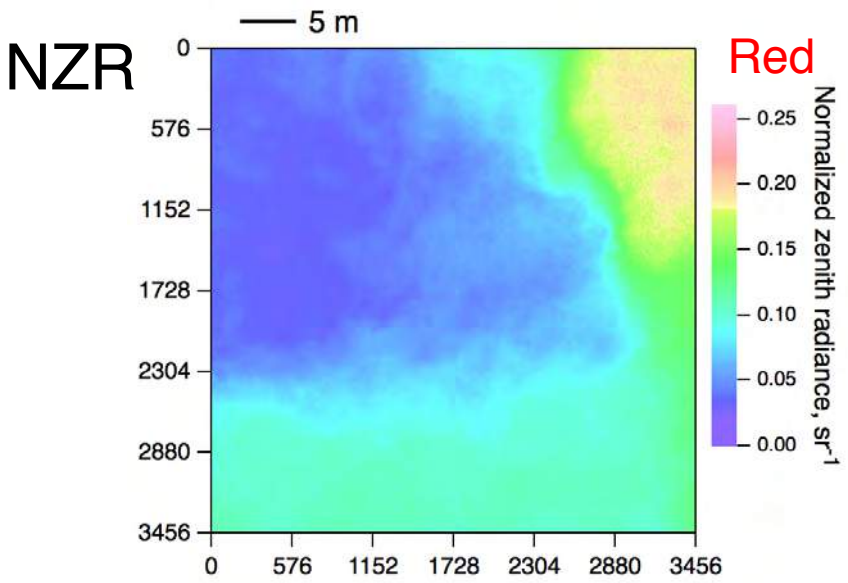


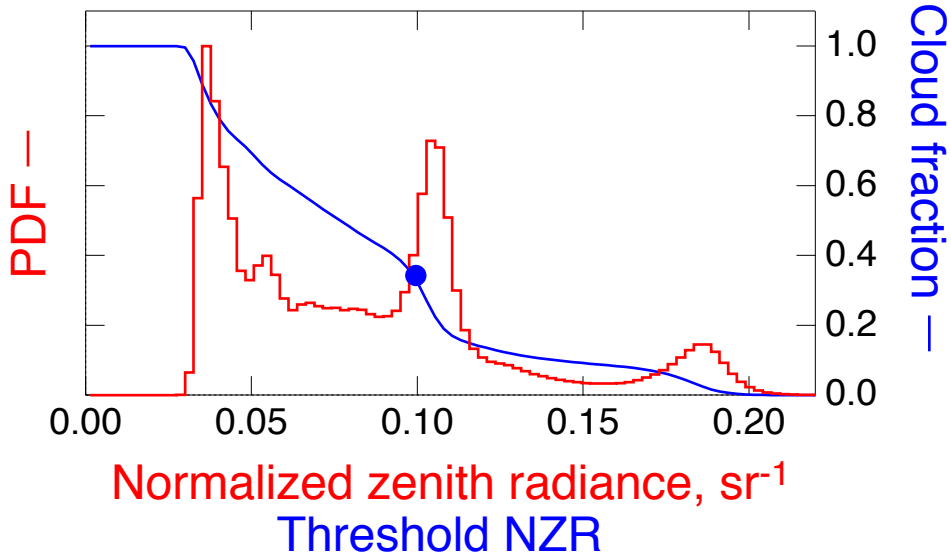
Threshold NZR = 0.083 CF = 0.47

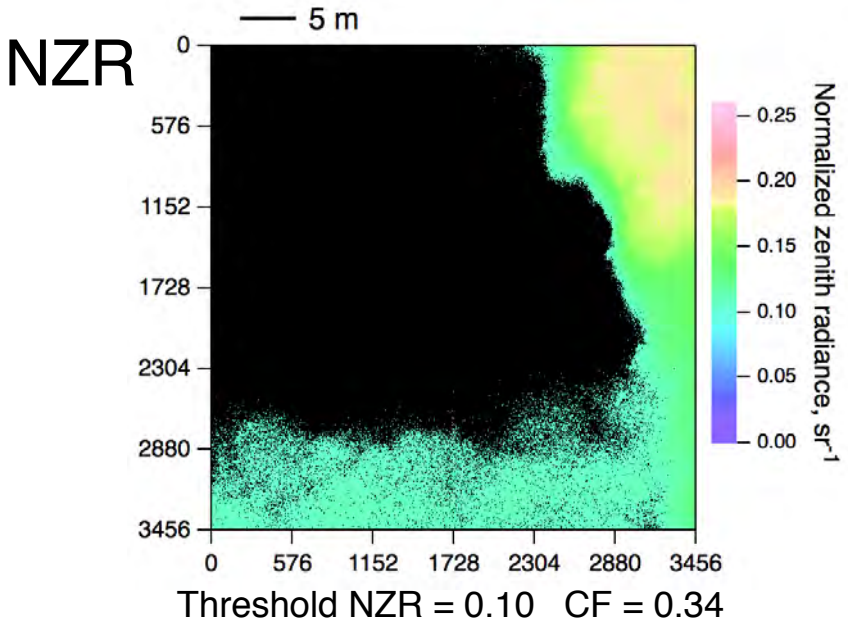
Cloud fraction decreases with increasing threshold NZR.

CLOUD FRACTION

Dependence on threshold





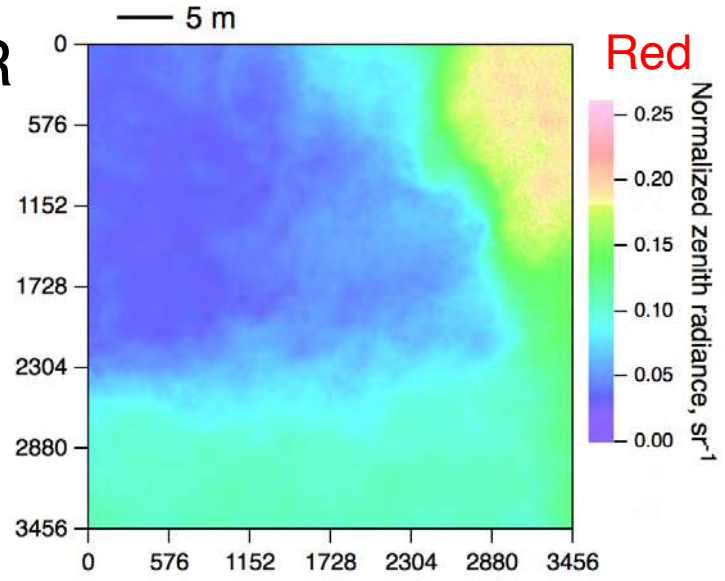


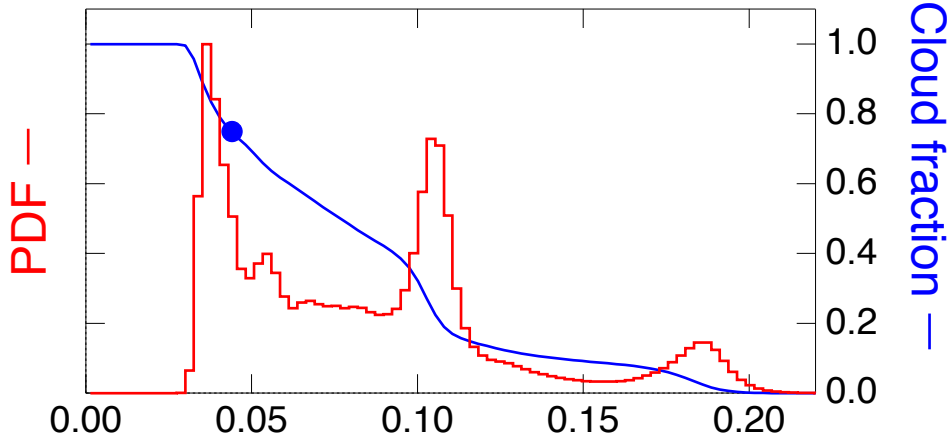
Conventional cloud fraction ***depends strongly on threshold***.

CLOUD FRACTION AND *RADIATIVE CLOUD FRACTION*

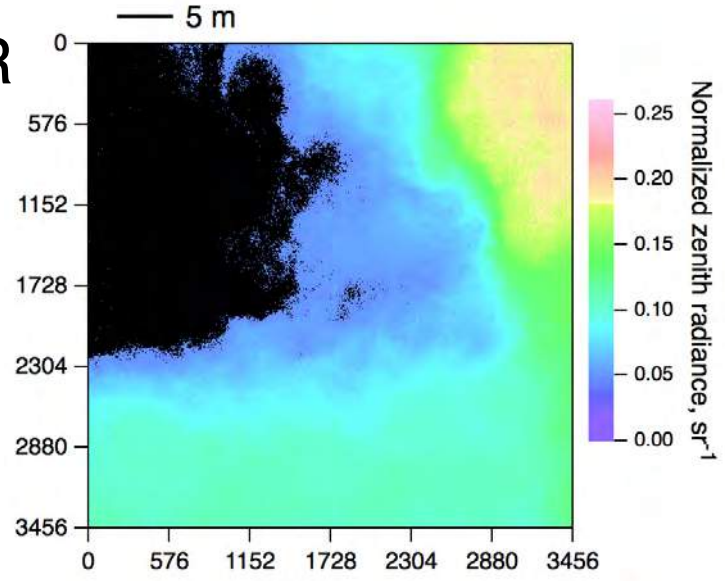
Dependence on threshold

NZR



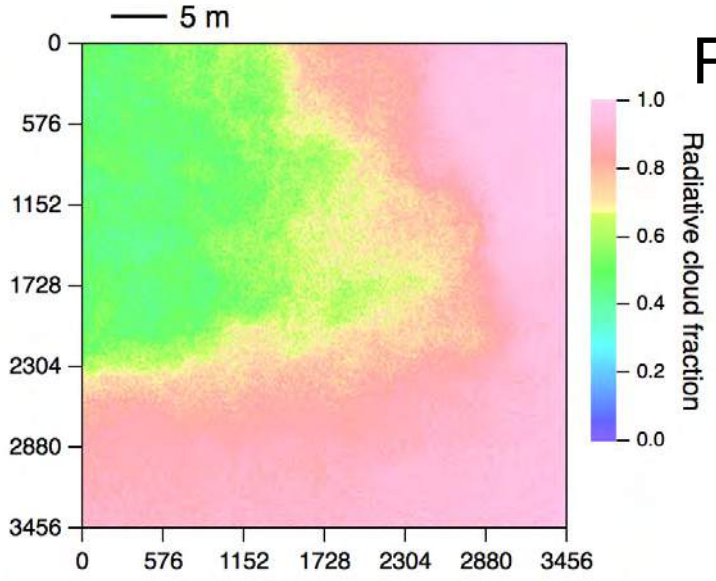


NZR



Threshold NZR = 0.045 CF = 0.75

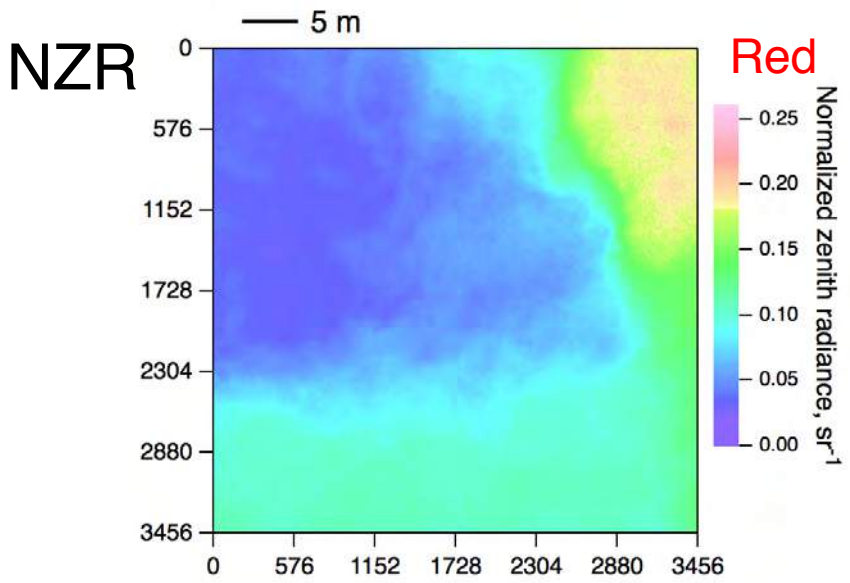
RCF

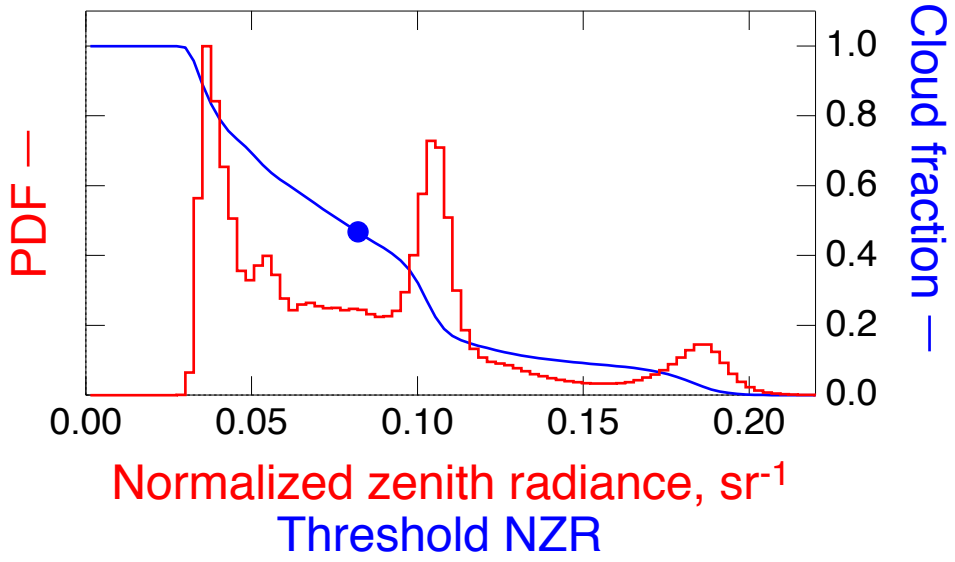


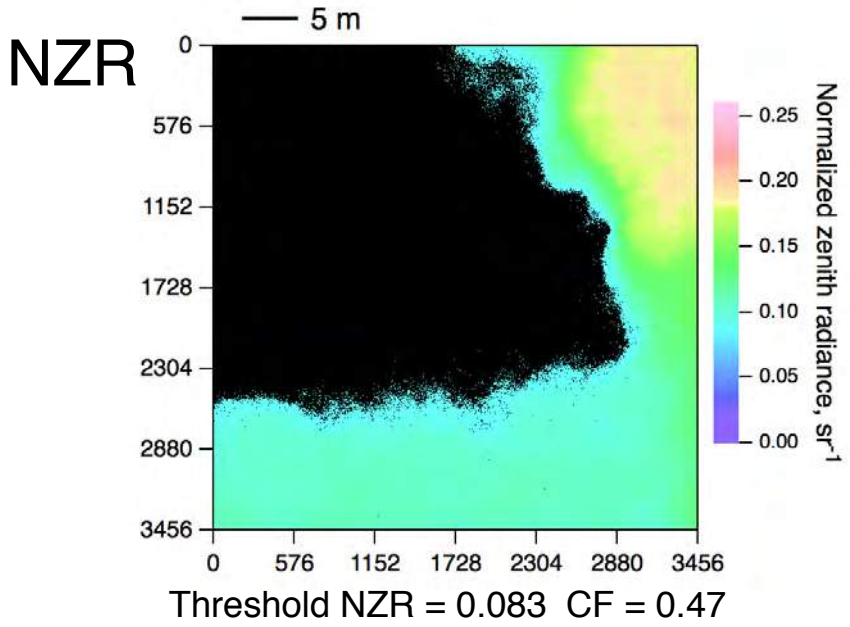
Radiative cloud fraction RCF is continuously variable quantity, not binary mask.

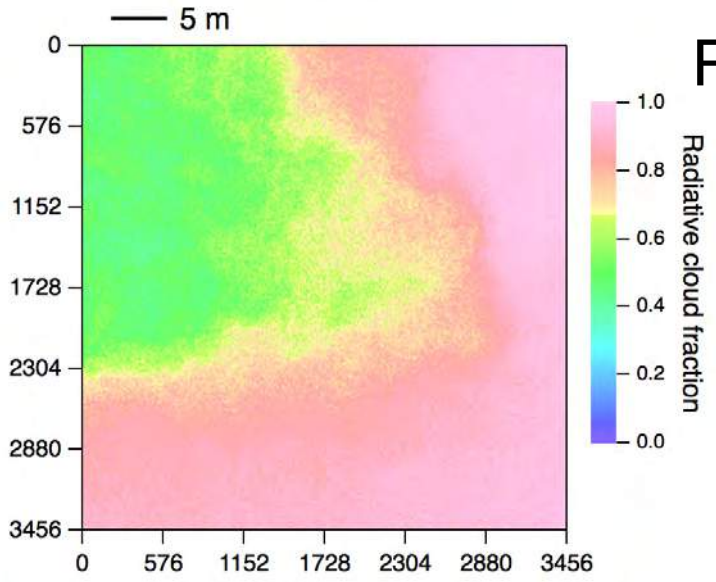
CLOUD FRACTION AND *RADIATIVE CLOUD FRACTION*

Dependence on threshold







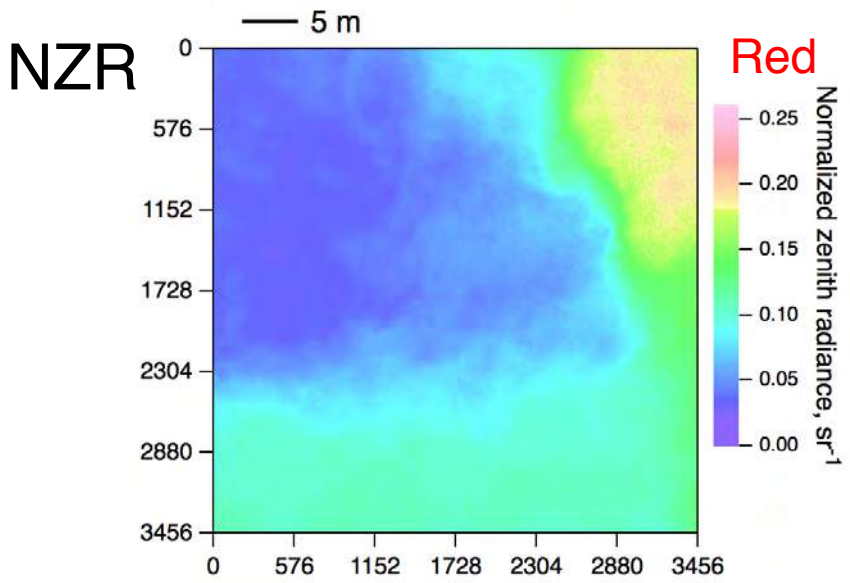


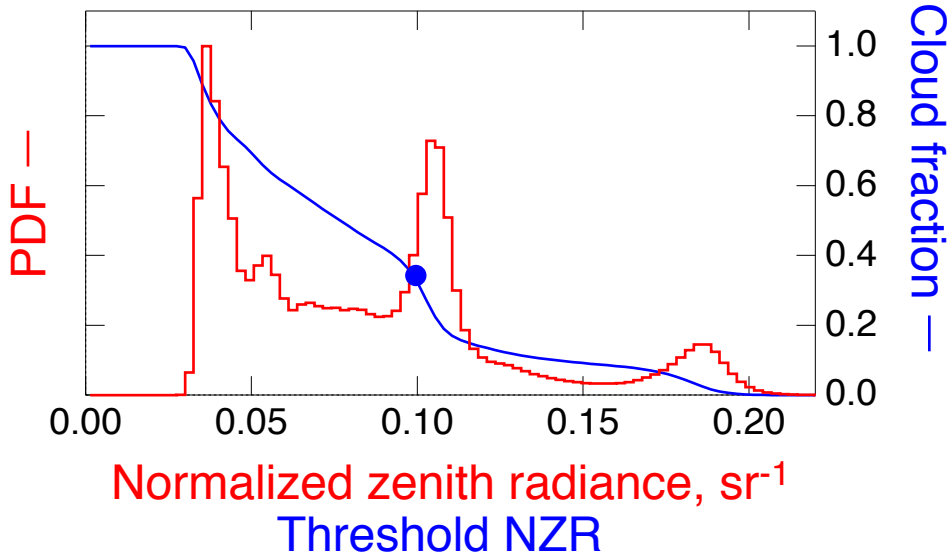
Radiative cloud fraction RCF is continuously variable quantity, not binary mask.

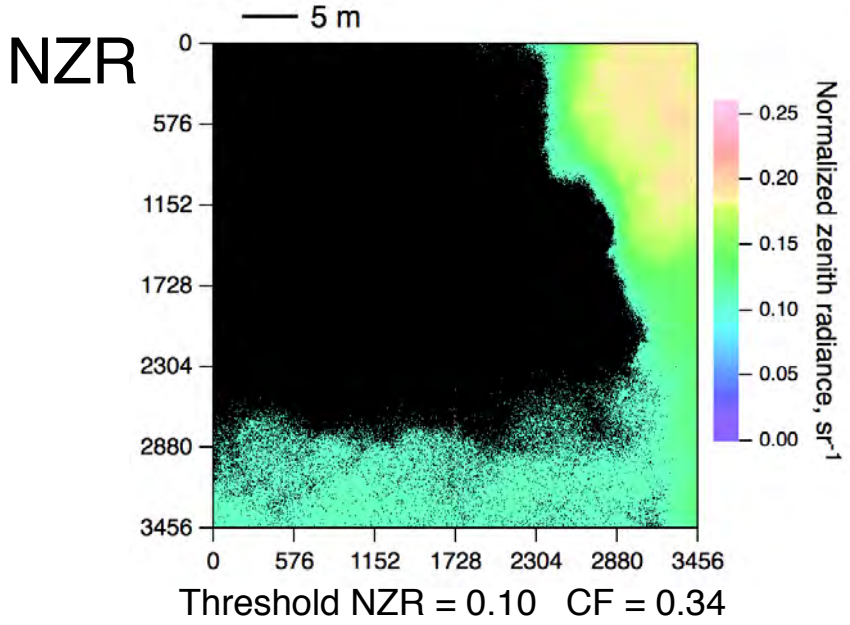
Radiative cloud fraction ***has no threshold***.

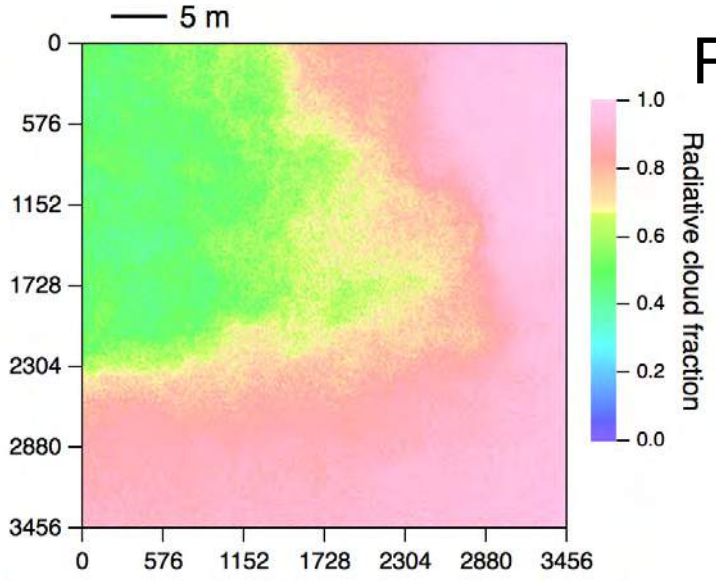
CLOUD FRACTION AND *RADIATIVE CLOUD FRACTION*

Dependence on threshold







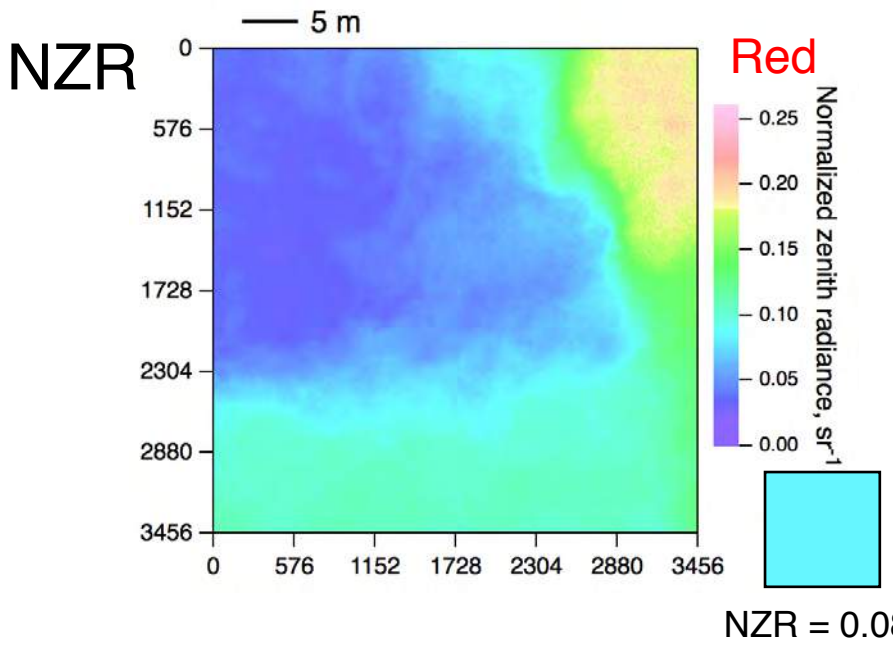


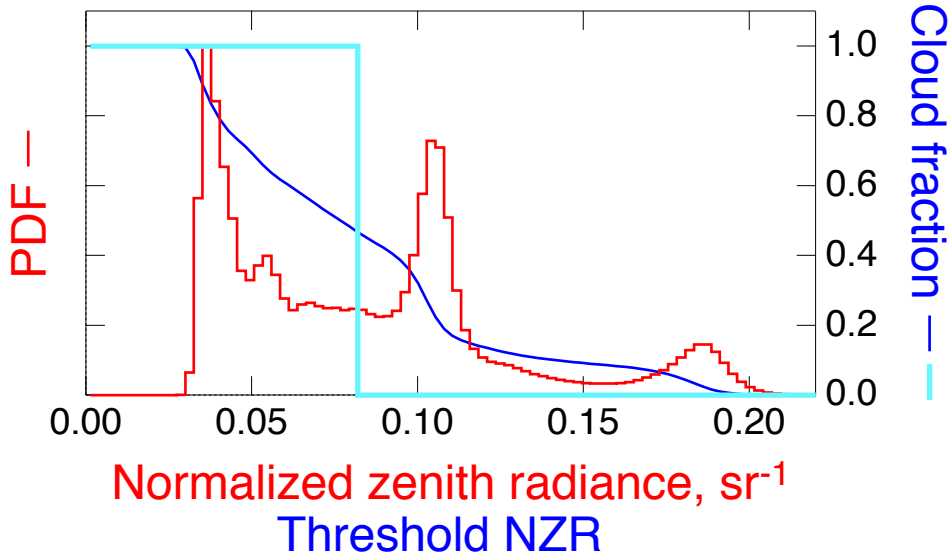
Radiative cloud fraction RCF is continuously variable quantity, not binary mask.

Radiative cloud fraction ***has no threshold***.

CLOUD FRACTION

Dependence on threshold *and resolution*

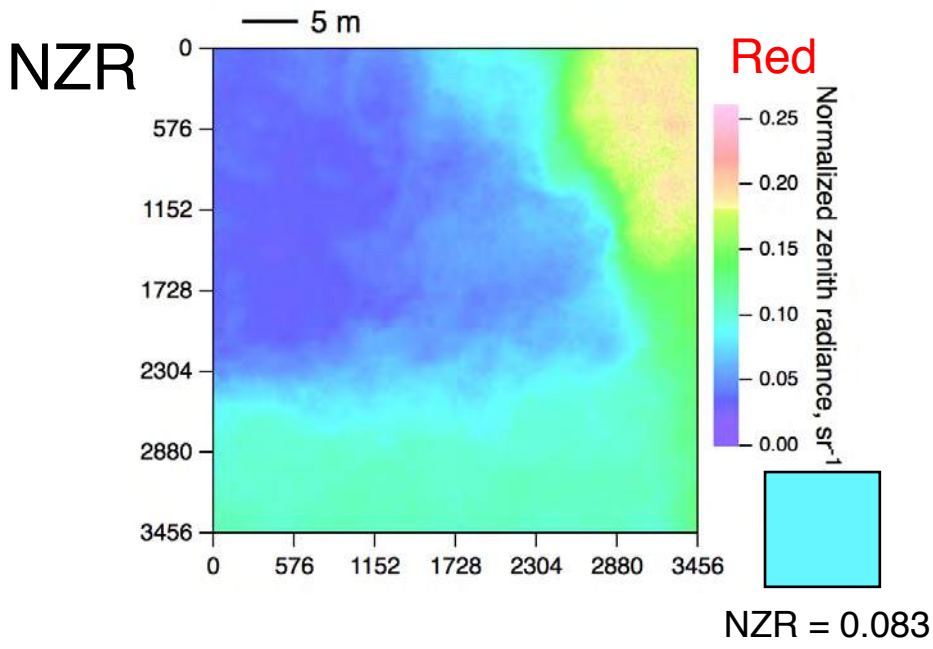


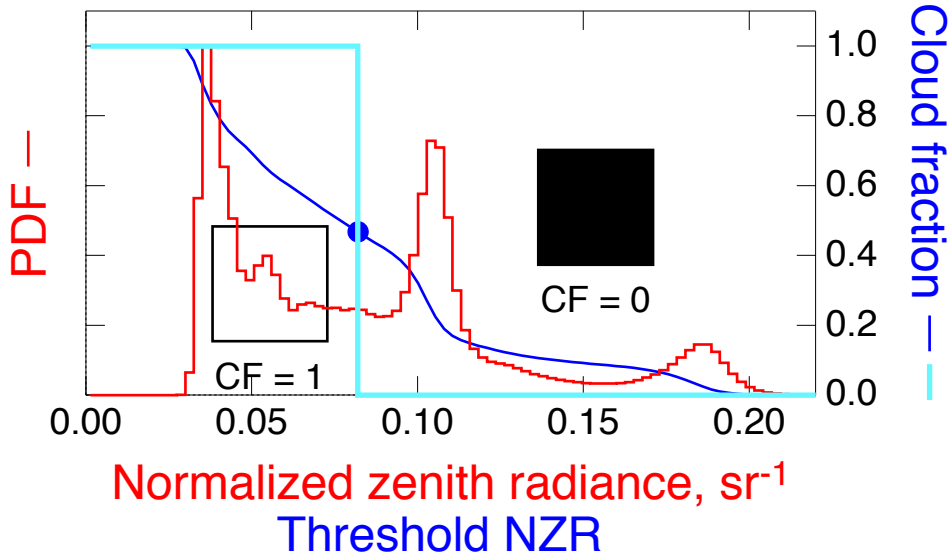


NZR of the 40 m × 40 m image with resolution degraded to a single pixel.

CLOUD FRACTION

Dependence on threshold *and resolution*

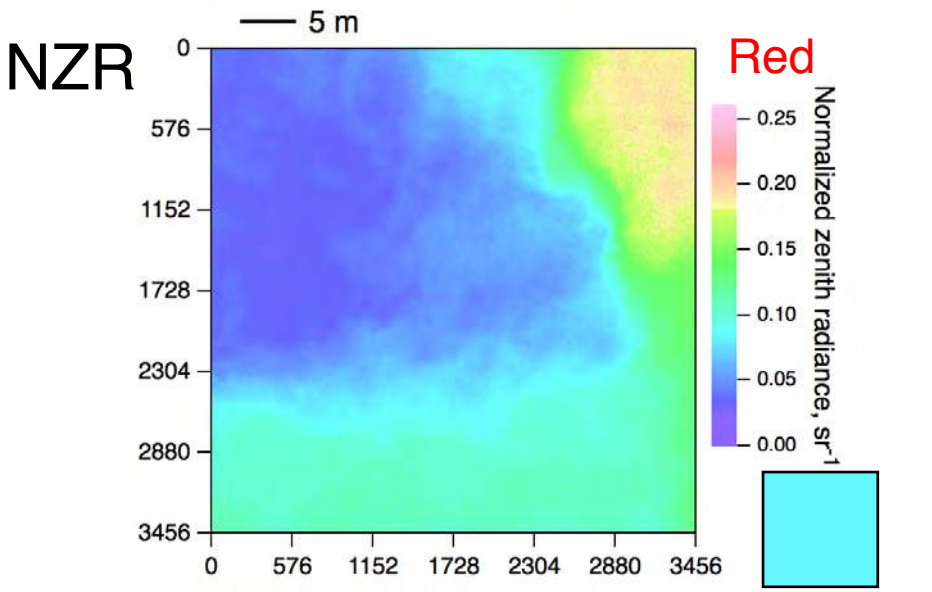


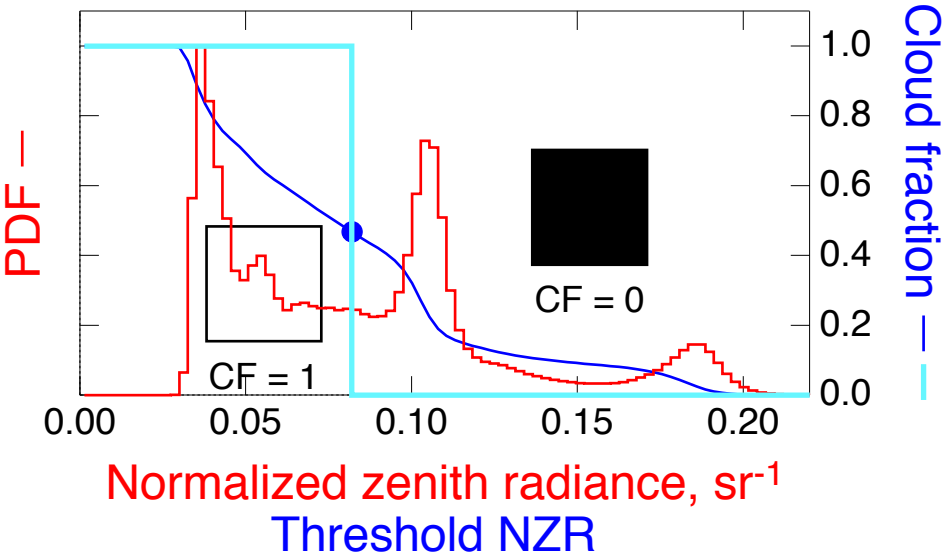


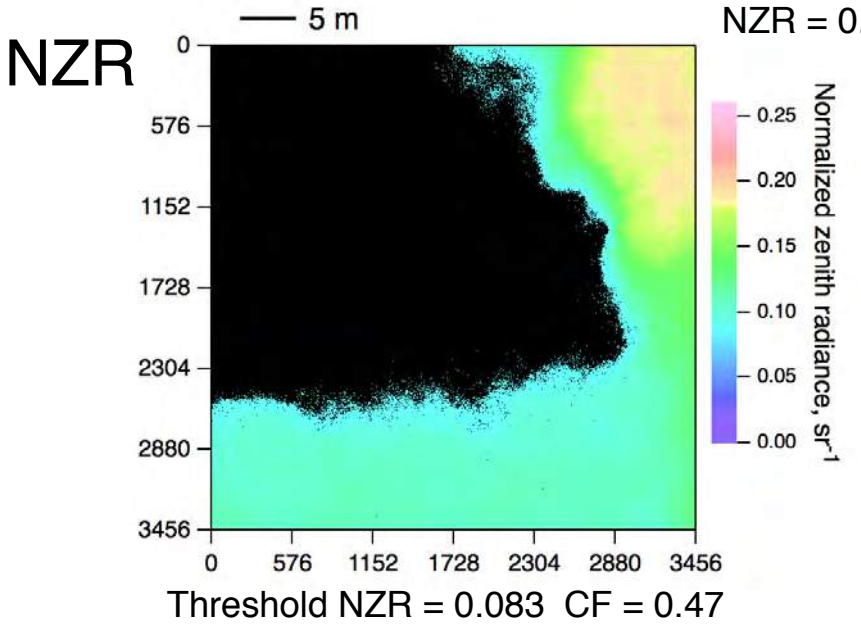
Cloud fraction of image degraded to single pixel is 1 or 0, depending on whether threshold < NZR or > NZR.

CLOUD FRACTION

Dependence on threshold *and resolution*

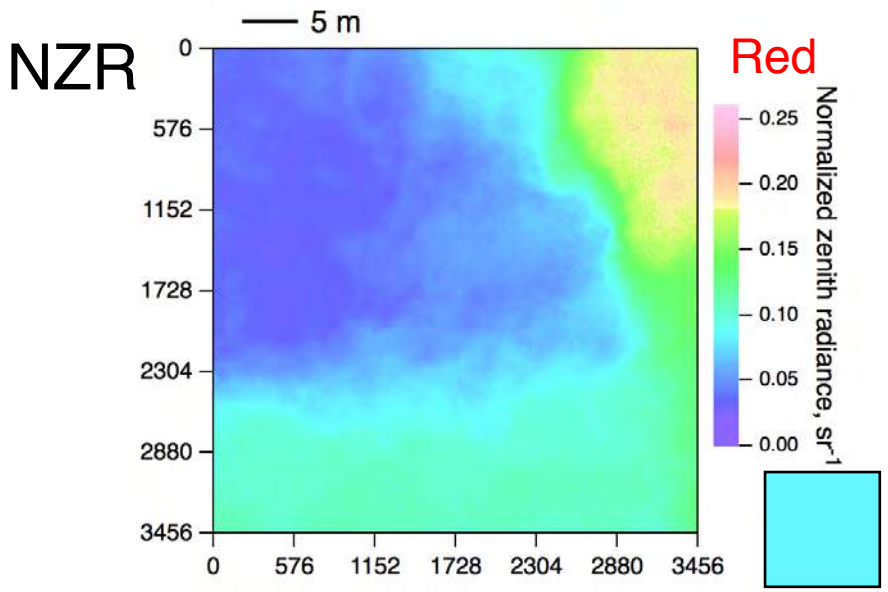


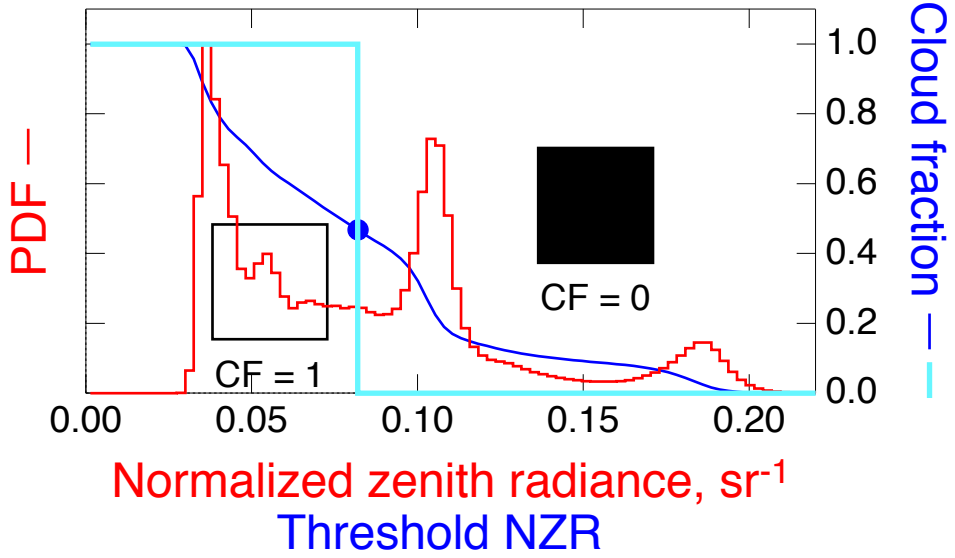


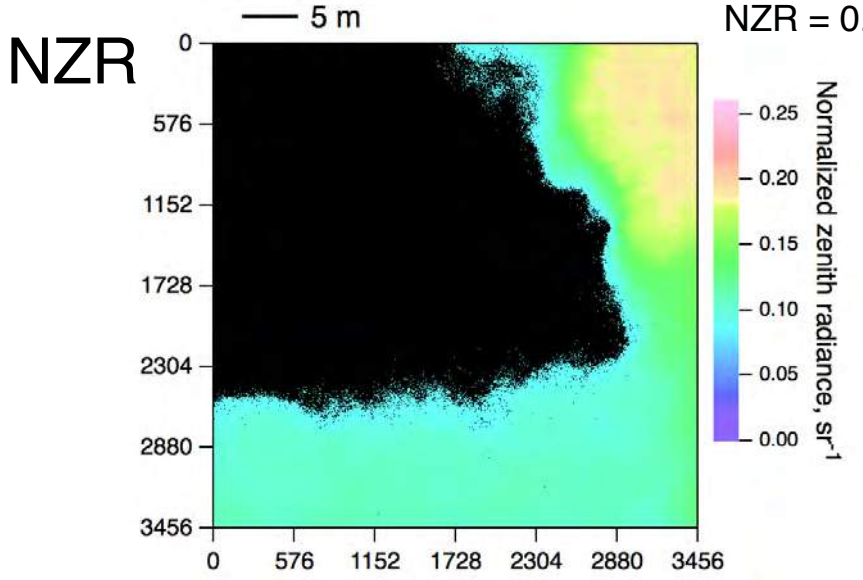


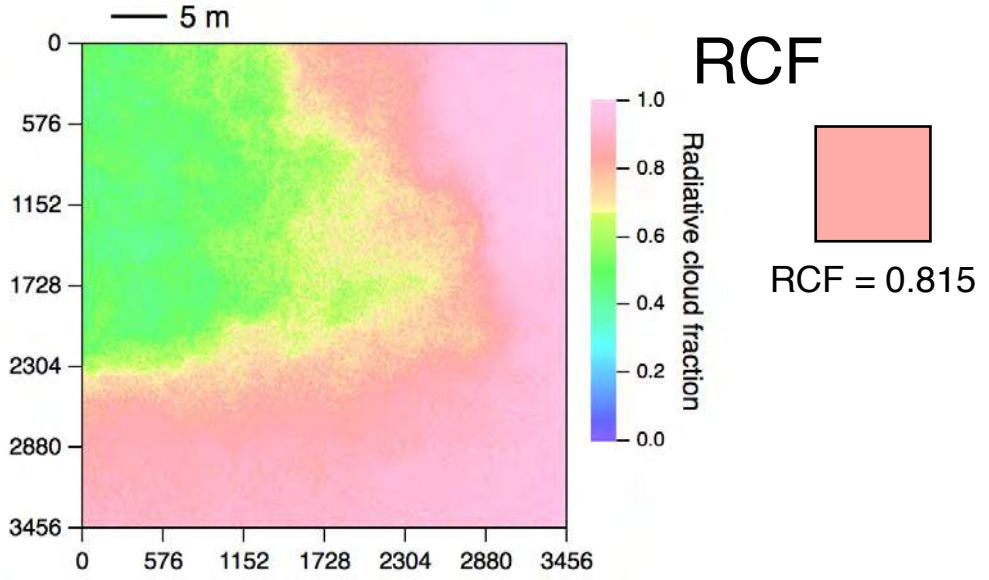
Cloud mask for individual pixels for threshold NZR = 0.083 sr^{-1} yields conventional cloud fraction 0.47.

CLOUD FRACTION AND *RADIATIVE CLOUD FRACTION*
Dependence on threshold *and resolution*



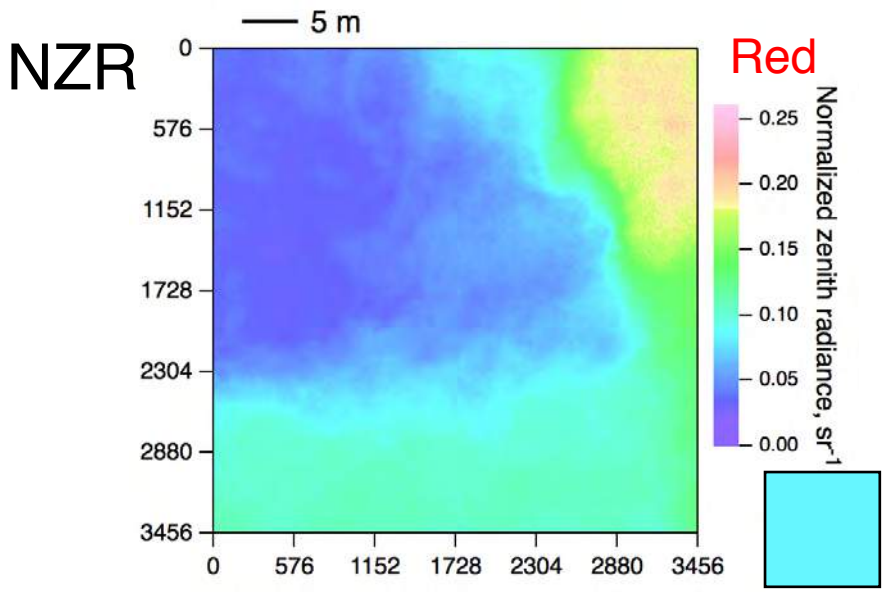




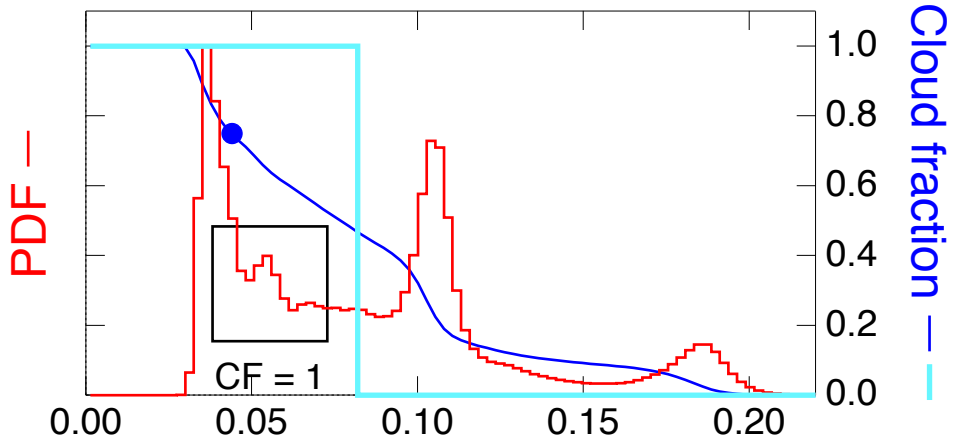


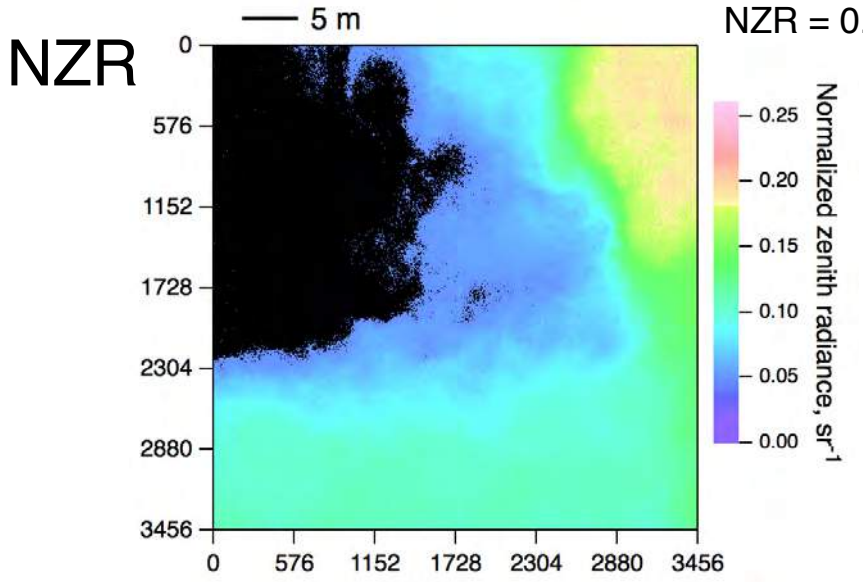
Radiative cloud fraction for resolution degraded to a single pixel is ***same as mean for high-resolution image***.

CLOUD FRACTION AND *RADIATIVE CLOUD FRACTION*
Dependence on threshold *and resolution*

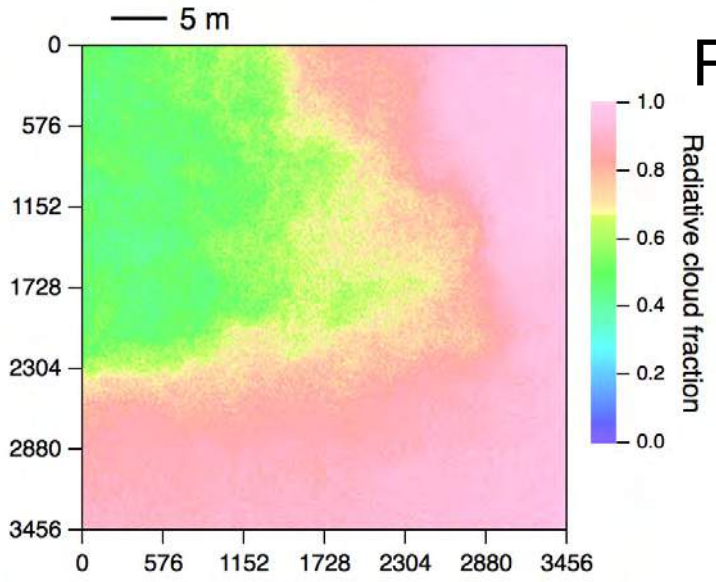


NZR = 0.083





Threshold NZR = 0.045 CF = 0.75



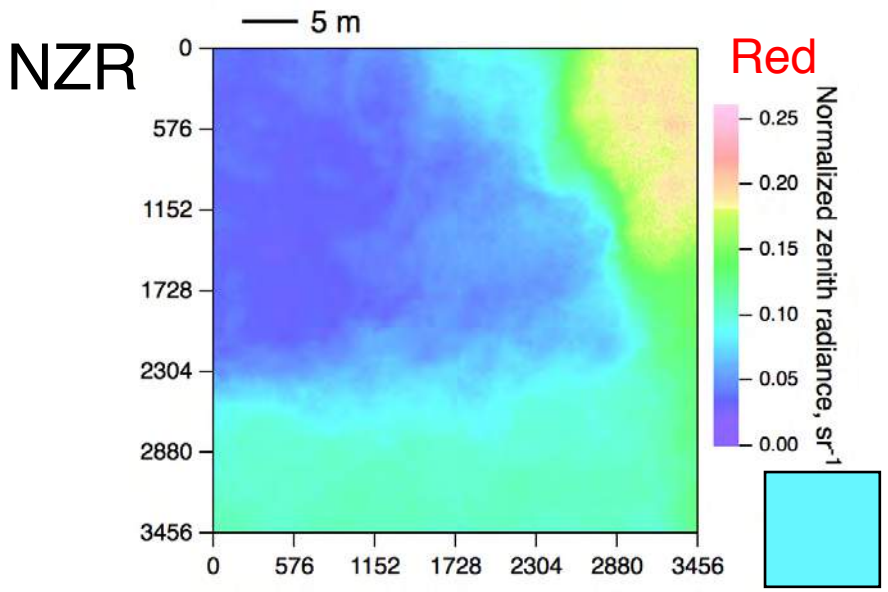
RCF

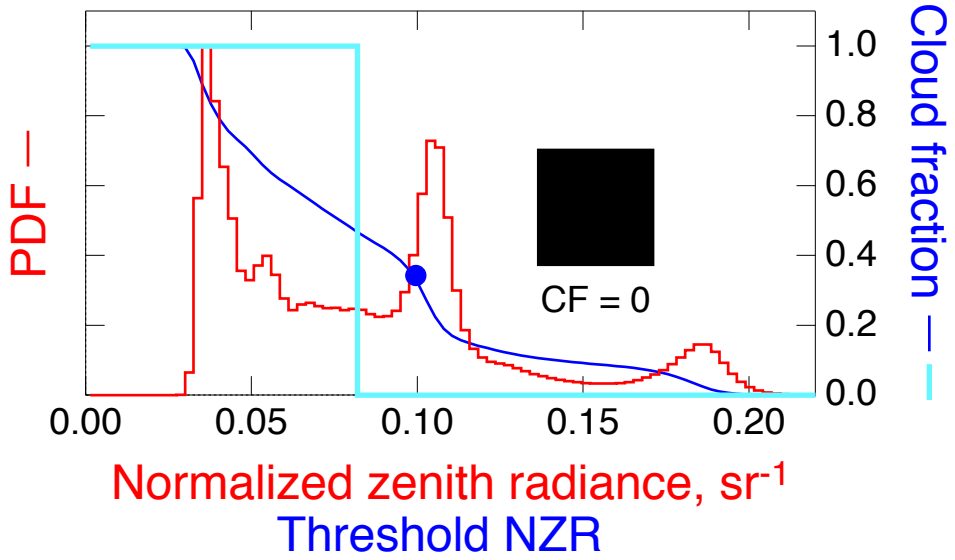
RCF = 0.815

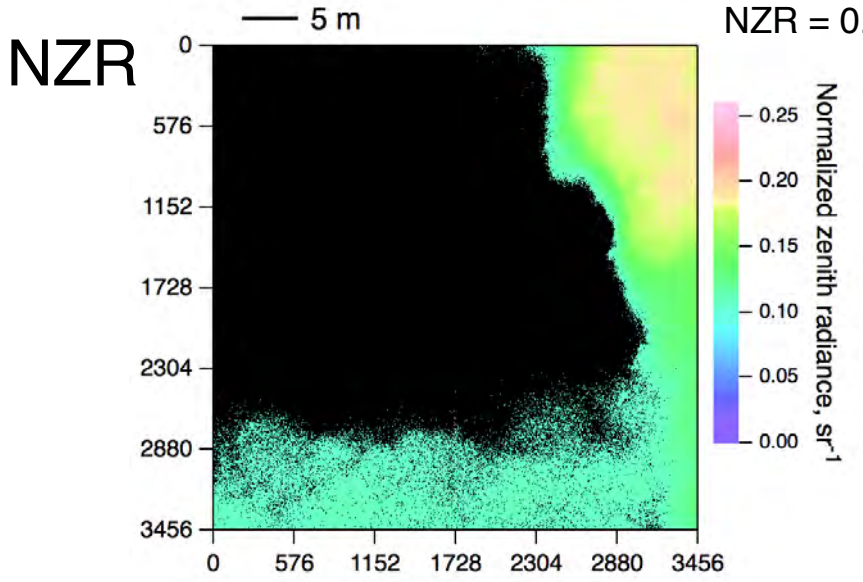
⟨RCF⟩ = 0.815 ⟨RCF⟩ from ΣRed/Σ(Red + Blue)

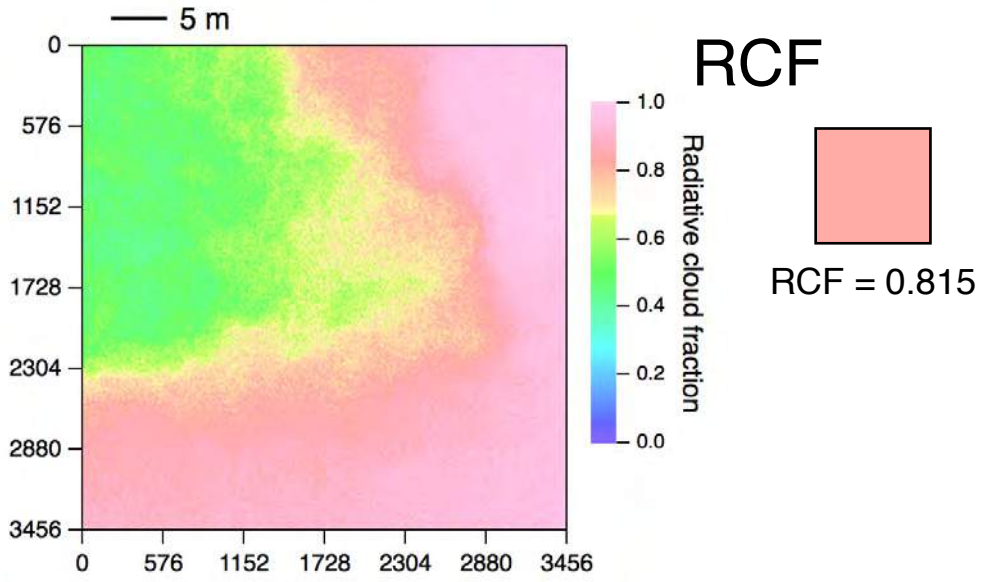
Conventional cloud fraction depends strongly on threshold and resolution.
Radiative cloud fraction has ***no threshold*** and is ***independent of resolution***.

CLOUD FRACTION AND *RADIATIVE CLOUD FRACTION*
Dependence on threshold *and resolution*









Conventional cloud fraction depends strongly on threshold and resolution.
Radiative cloud fraction has ***no threshold*** and is ***independent of resolution***.

CONCLUDING OBSERVATIONS

- Radiative Cloud Fraction (RCF) is a ***useful measure of cloud amount and radiative influence***.
- Unlike conventional cloud fraction RCF is ***insensitive to resolution and threshold***.
- Conventional cloud fraction ***should be abandoned*** as a measure of cloud amount.
- RCF may be useful for ***comparison with model calculations*** from local scales to GCMs.
- Up-looking measurements are minimally subject to interference because the background is the black of outer space.
- RCF might be applicable to cloud quantification by satellite over oceans because of the uniform blue background.
- ***Variation of NZR and RCF down to sub meter scales may be means of examining cloud dynamics on these scales.***