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

Stephen E. Schwartz

BROOKHAVEN NATIONAL LABORATORY

Upton NY USA

AGU FALL MEETING

San Francisco | 9–13 December 2013

Cloud Properties, Observations, and their Uncertainties

www.bnl.gov/envsci/schwartz

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

CONCLUSIONS

No.

No.

No.

I come to bury cloud fraction, not to praise it.

- Shakespeare, 1599

WHAT IS A CLOUD?

AMS Glossary of Meteorology (2000)

A ***visible aggregate*** of minute water droplets and/or ice particles in the atmosphere above the earth's surface.

Total cloud cover: Fraction of the sky hidden by all ***visible clouds***.

Clothiaux, Barker, & Korolev (2005)

Surprisingly, and in spite of the fact that we deal with clouds on a daily basis, to date there is ***no universal definition of a cloud***. . . . Ultimately, the definition of a cloud ***depends on the threshold sensitivity*** of the instruments used.

Ramanathan, JGR (ERBE, 1988)

Cloud cover is a ***loosely defined term***.

Potter Stewart (U.S. Supreme Court, 1964)

I shall not today attempt further to define it, but ***I know it when I see it***.

WHY DO WE WANT TO KNOW CLOUD FRACTION, ANYWAY?

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

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

Getting cloud fraction "right" is an evaluation criterion for global climate models.

DOE/ER/60085-H1
NCAR/TN-273 + STR
NCAR Technical Notes

Prepared for:
United States Department of Energy
Office of Energy Research
Office of Basic Energy Sciences
Carbon Dioxide Research Division

and

National Center for Atmospheric Research
Boulder, Colorado 80307

October 1986

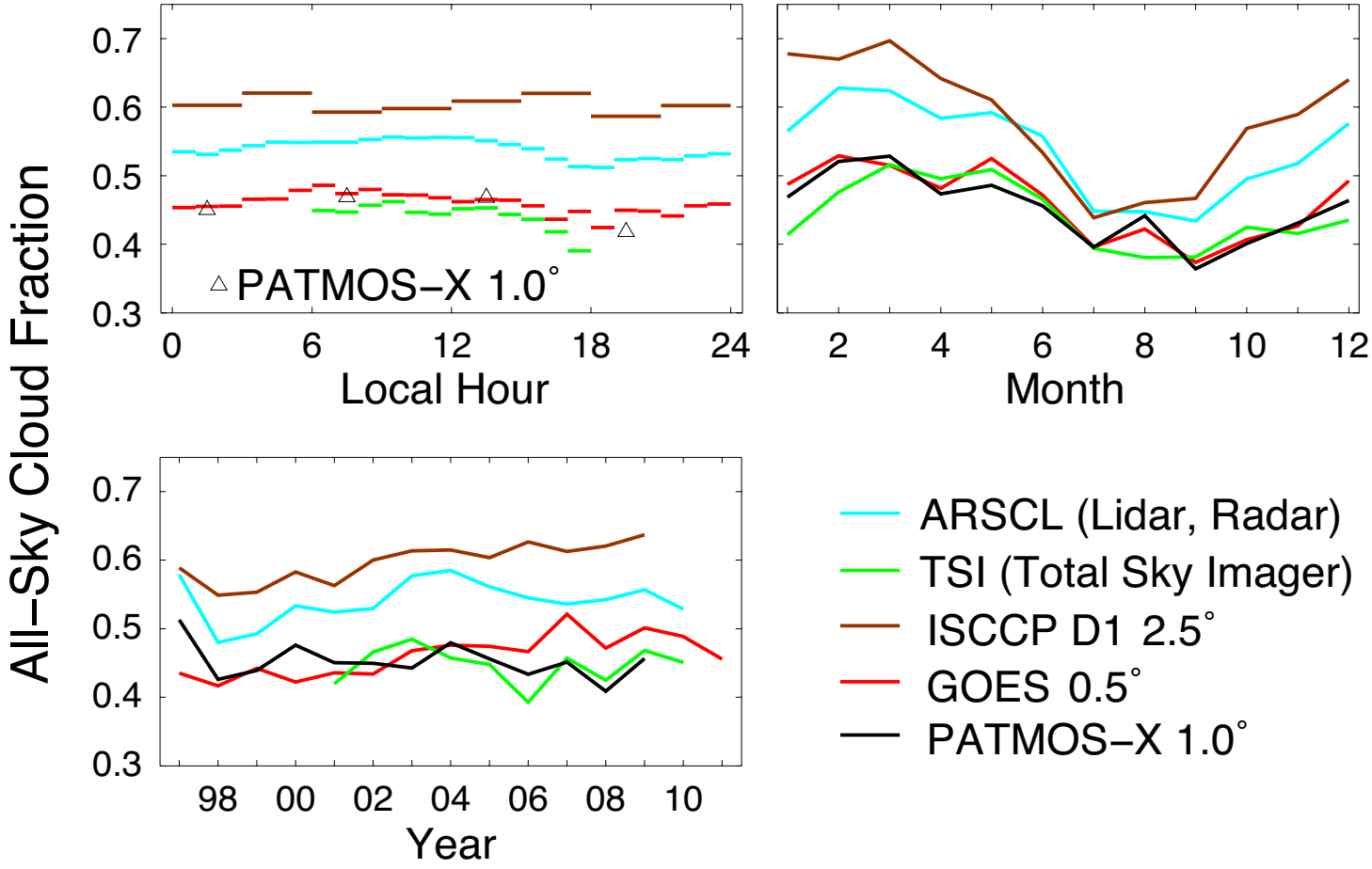
Global Distribution of Total Cloud Cover and Cloud Type Amounts Over Land

Domain	Observations Millions	Cloud cover %
Land	116	52.4
Ocean	43.3	64.8
Global	159	61.2

Warren, Hahn, London, Chervin, Jenne

CLOUD FRACTION BY MULTIPLE METHODS

2 Surface, 3 satellite methods at U.S. Southern Great Plains; 10 years data

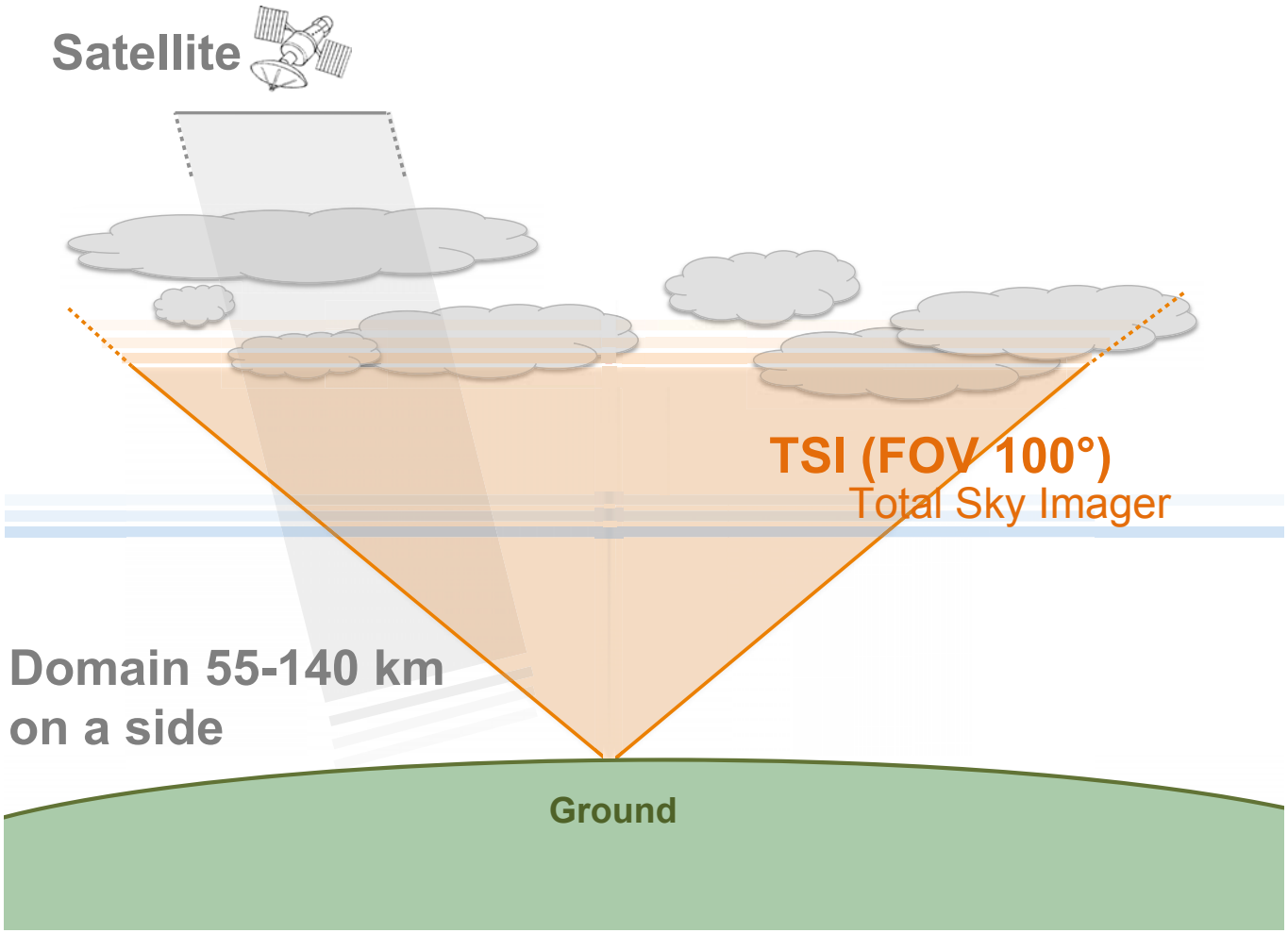


Wu, Liu, Jensen, Toto, Foster & Long, JGR, in review

Different methods yield ***substantial systematic differences in the mean***.

Error of 0.1 in cloud fraction is ~ 9 W m^{-2} in shortwave, 6 W m^{-2} in longwave.

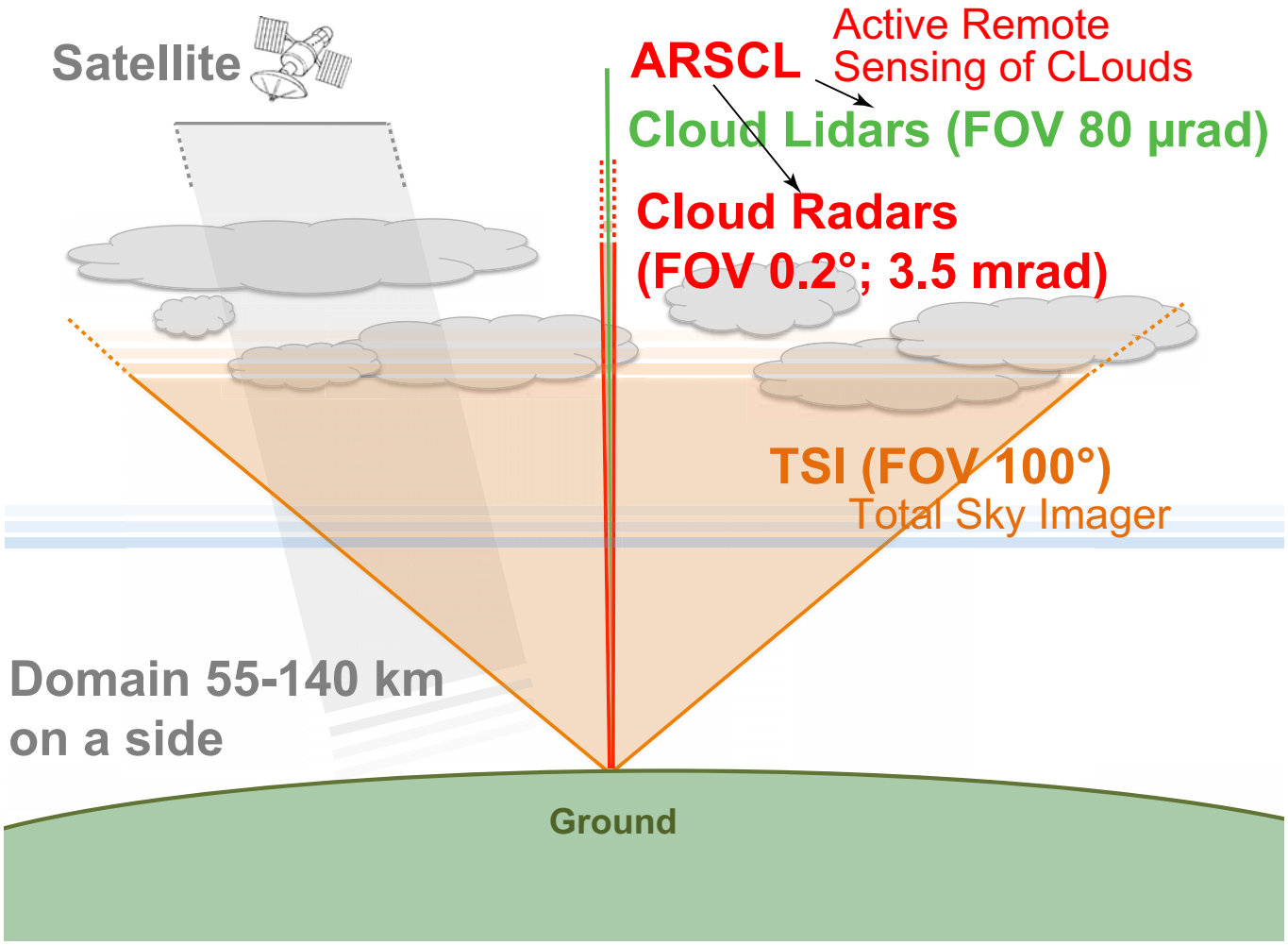
MULTIPLE APPROACHES TO DETERMINING CLOUD FRACTION



Modified from Wu, Liu, Jensen, Toto, Foster & Long, JGR, in review

Although different approaches yield different instantaneous, local CF, they would be expected to yield the same ***average*** CF.

MULTIPLE APPROACHES TO DETERMINING CLOUD FRACTION



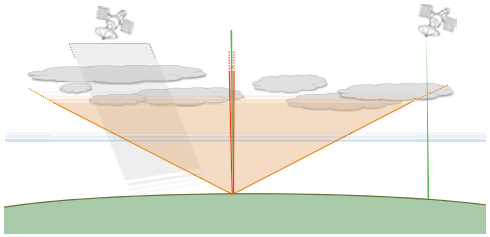
Modified from Wu, Liu, Jensen, Toto, Foster & Long, JGR, in review

Although different approaches yield different instantaneous, local CF, they would be expected to yield the same ***average*** CF.

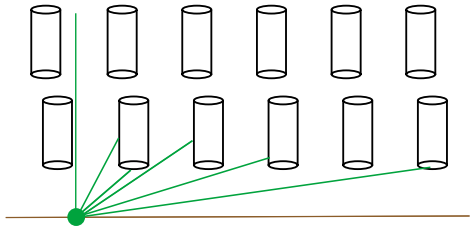
REASONS FOR DIFFERENCES IN MEASURED CLOUD FRACTION

Trivial

Mismatch of spatial and/or temporal domain.

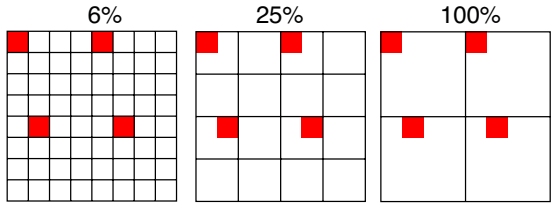


View angle – sidewall effect – cloud aspect ratio.

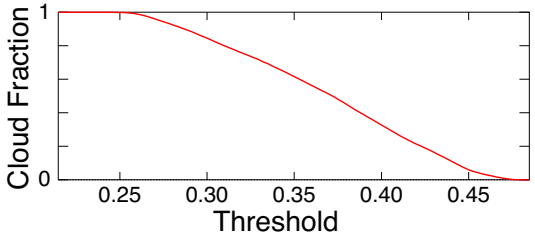


Intrinsic

Spatial resolution.



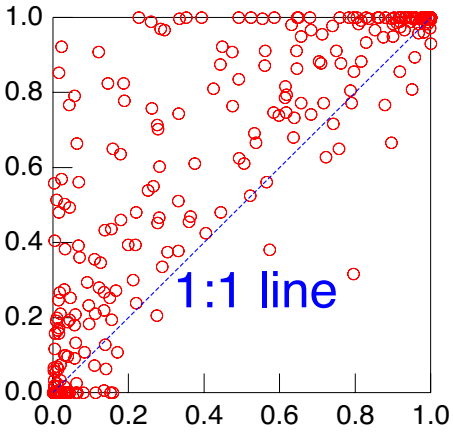
Threshold.

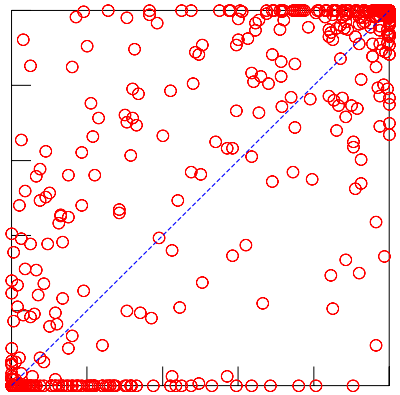


COMPARISON OF CLOUD FRACTION BY DIFFERENT METHODS

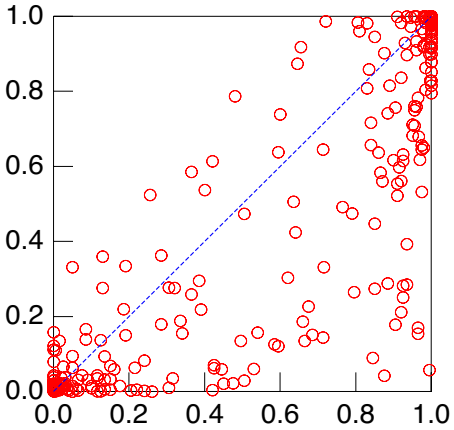
Hourly cloud fraction at SGP by multiple methods, May, 2009

ARSCL
Active Remote Sensing by Radar, Lidar





TSI
Total Sky Imager



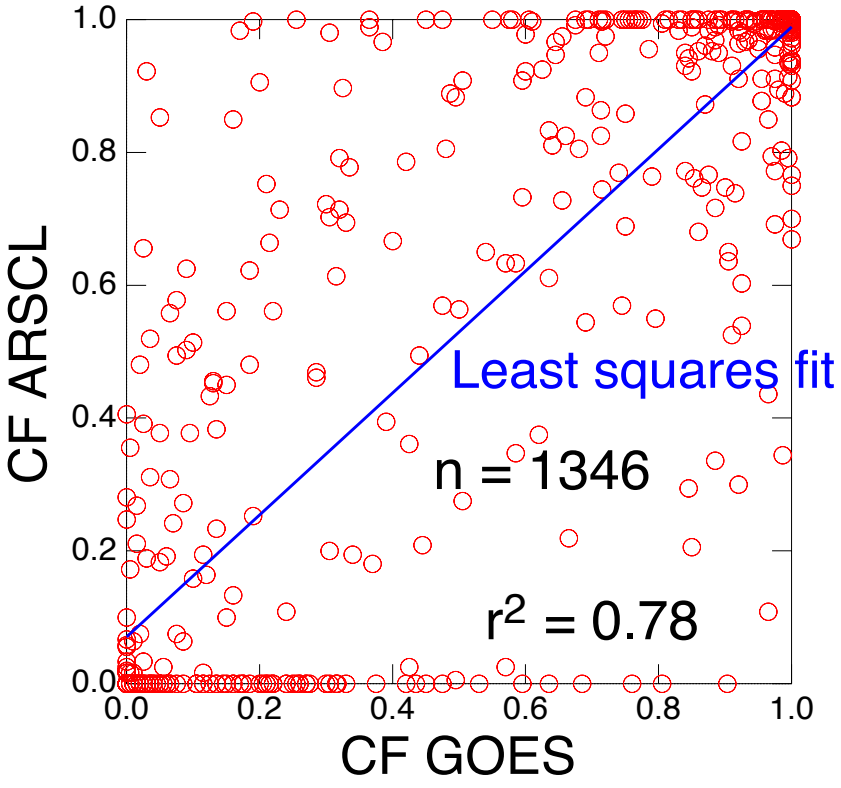
GOES
Satellite, 0.5˚

Comparison plots show some skill but substantial differences.

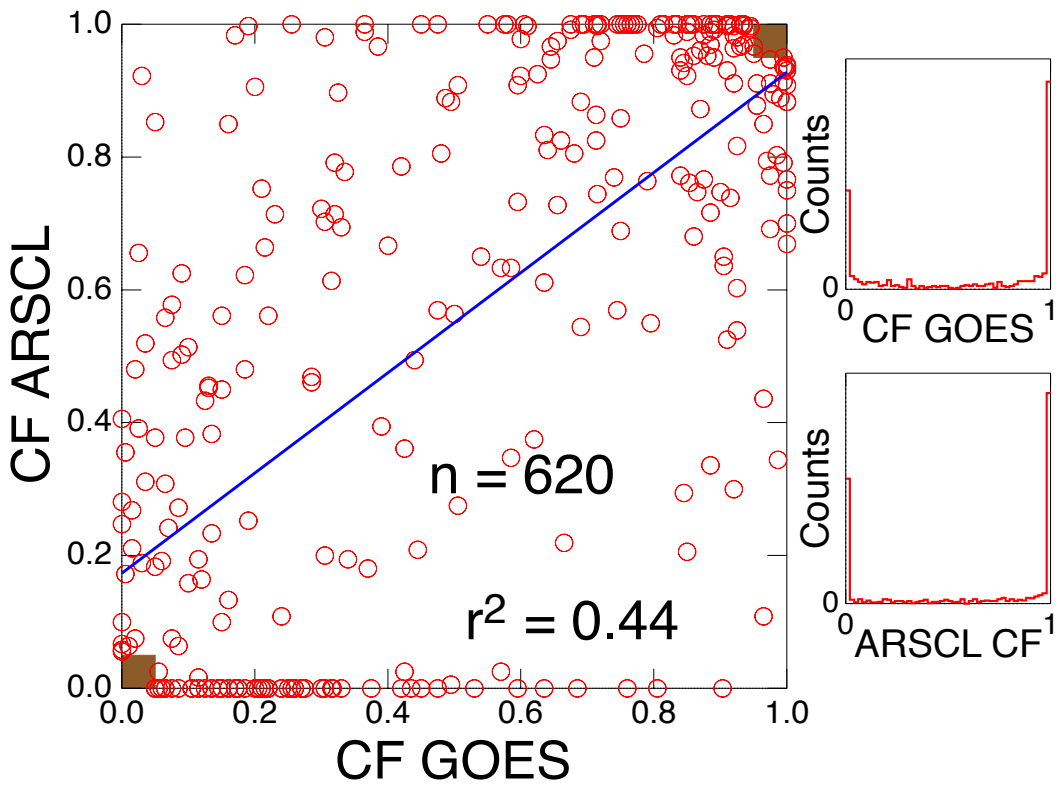
CORRELATION IS DOMINATED BY ONES AND ZEROES

Hourly cloud fraction at SGP by ARSCL AND GOES, May, 2009

All points, May, 2009



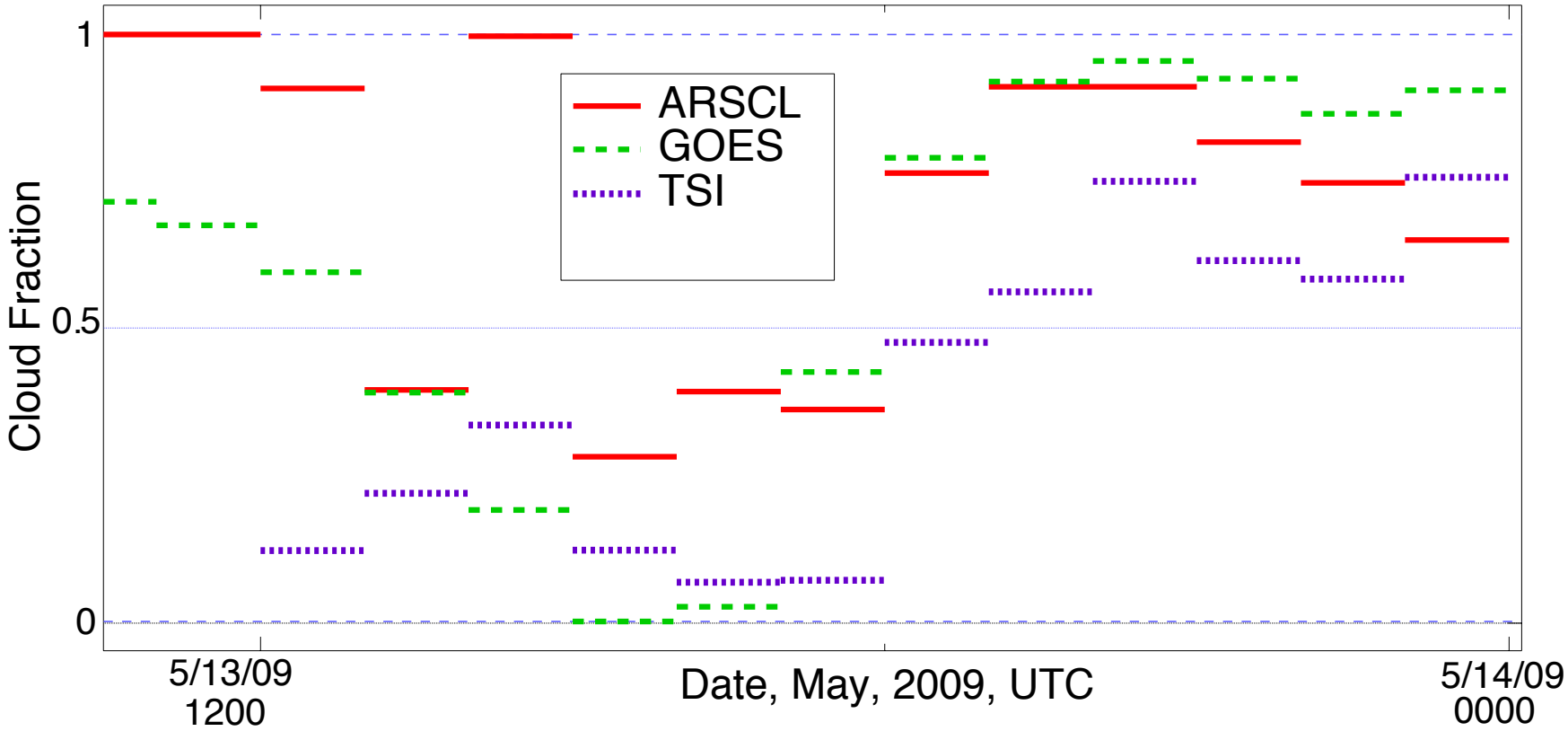
Points within 5% of 0 or 1
in both data sets excluded



Excluding all-cloud and no-cloud scenes reduces variance accounted for by the regression from 78% to 44%.

TIME SERIES OF CLOUD FRACTION BY MULTIPLE METHODS

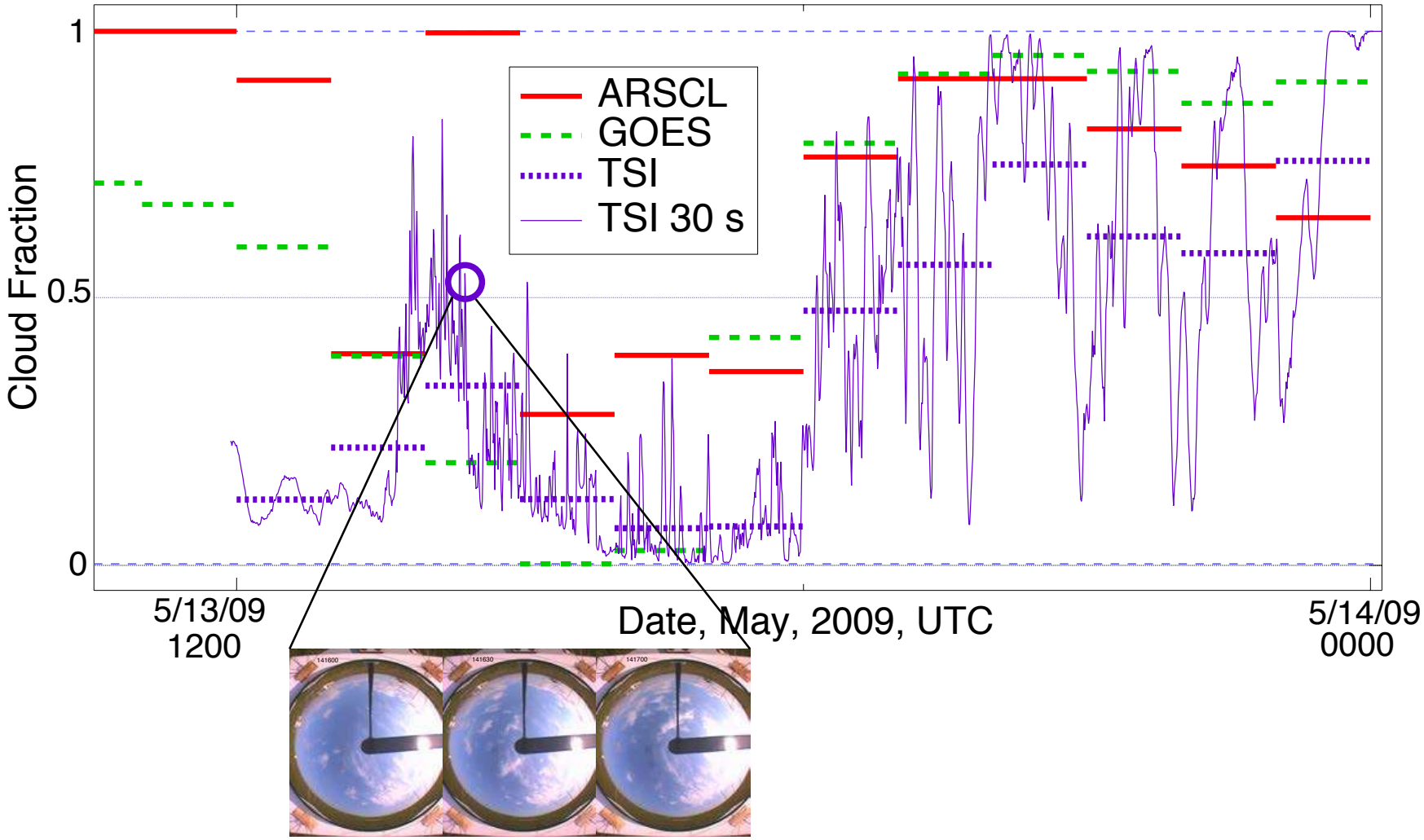
ARM SGP site (north central OK) May 13, 2009



Substantial variation among methods.

TIME SERIES OF CLOUD FRACTION BY MULTIPLE METHODS

ARM SGP site (north central OK) May 13, 2009

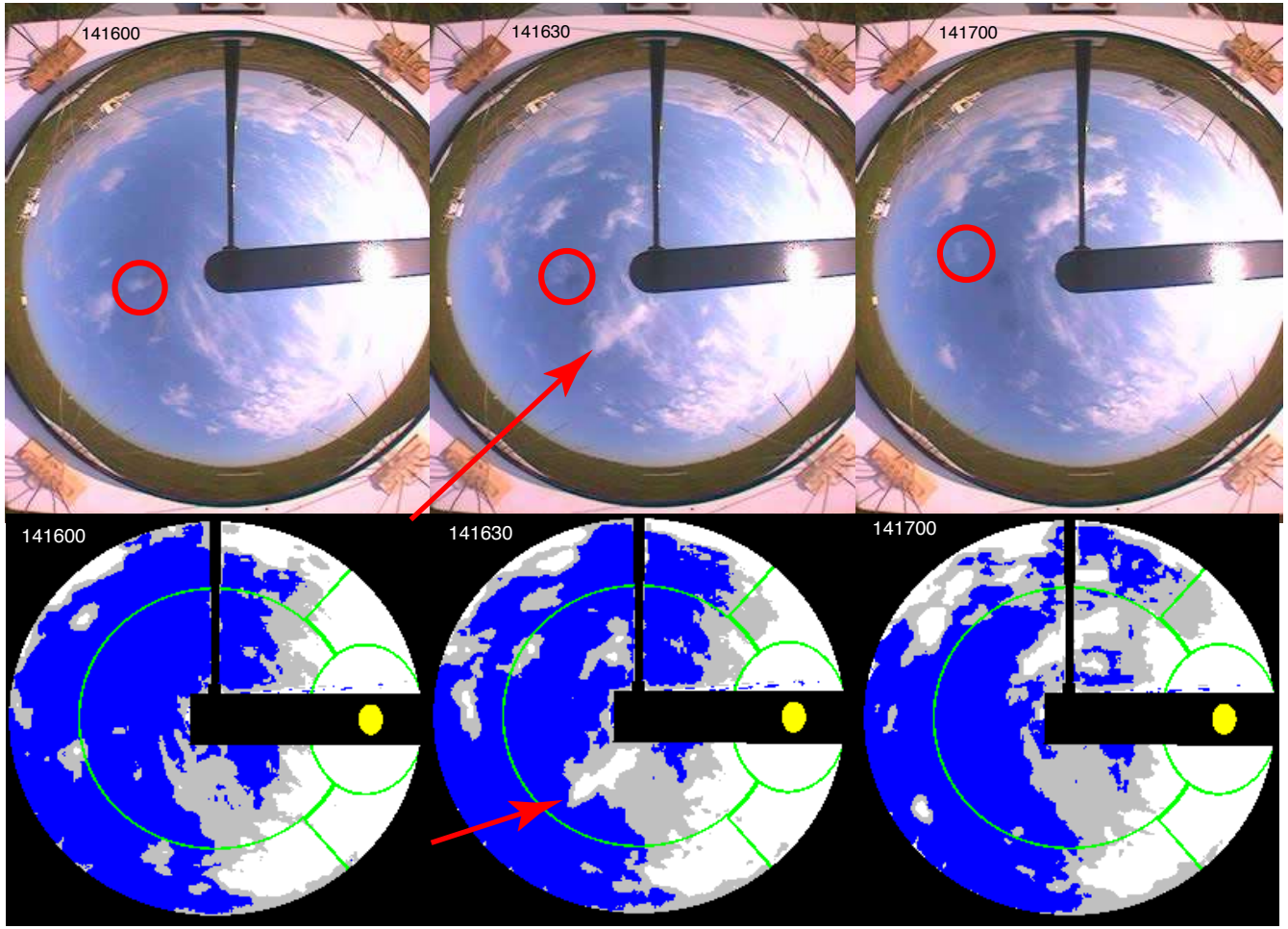


Substantial variation among methods.

Substantial fluctuation in TSI images taken at 30-second intervals.

TOTAL SKY IMAGES AND CLOUD MASKS FROM TSI ALGORITHM

ARM SGP site (north central OK) May 13, 2009, 1416-1417



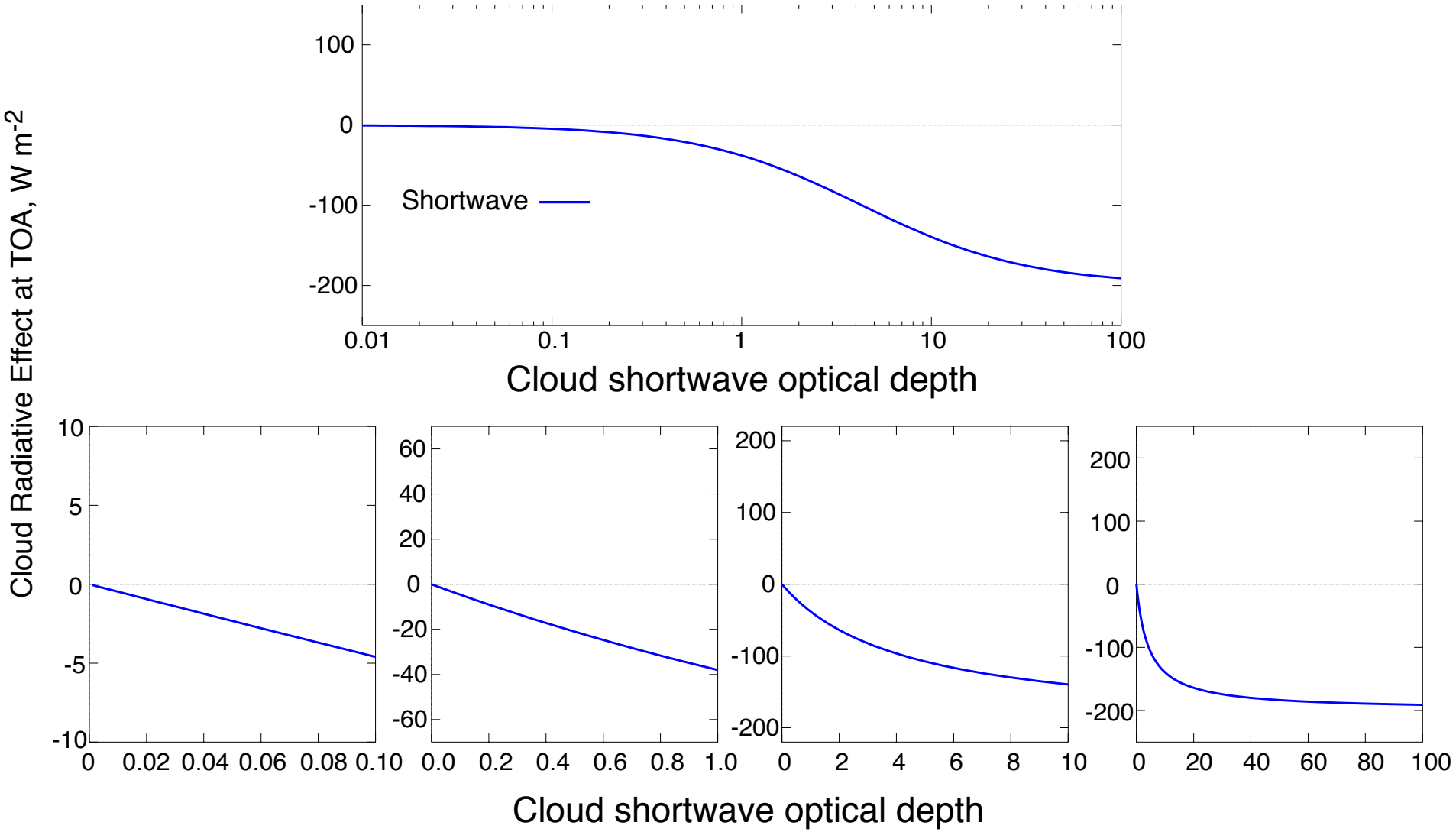
TSI threshold misses thin visible clouds

Substantial changes at 30-s intervals as clouds are blown by wind.

CLOUD RADIATIVE EFFECT

Dependence on shortwave optical depth and cloud-top temperature

24-Hour average CRE, north central Oklahoma, at equinox

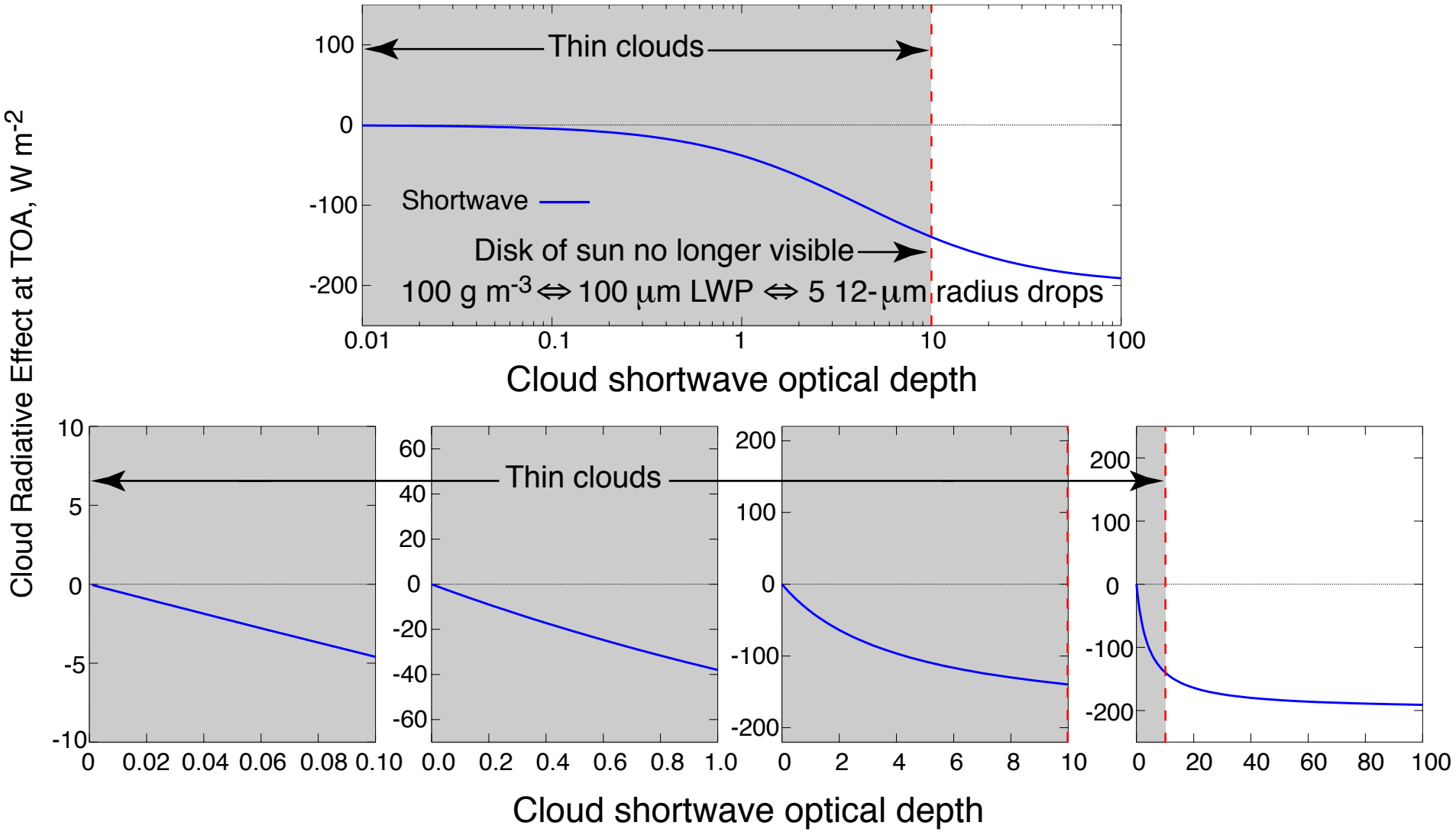


CRE is initially linear in optical depth, saturating at high optical depth.

CLOUD RADIATIVE EFFECT

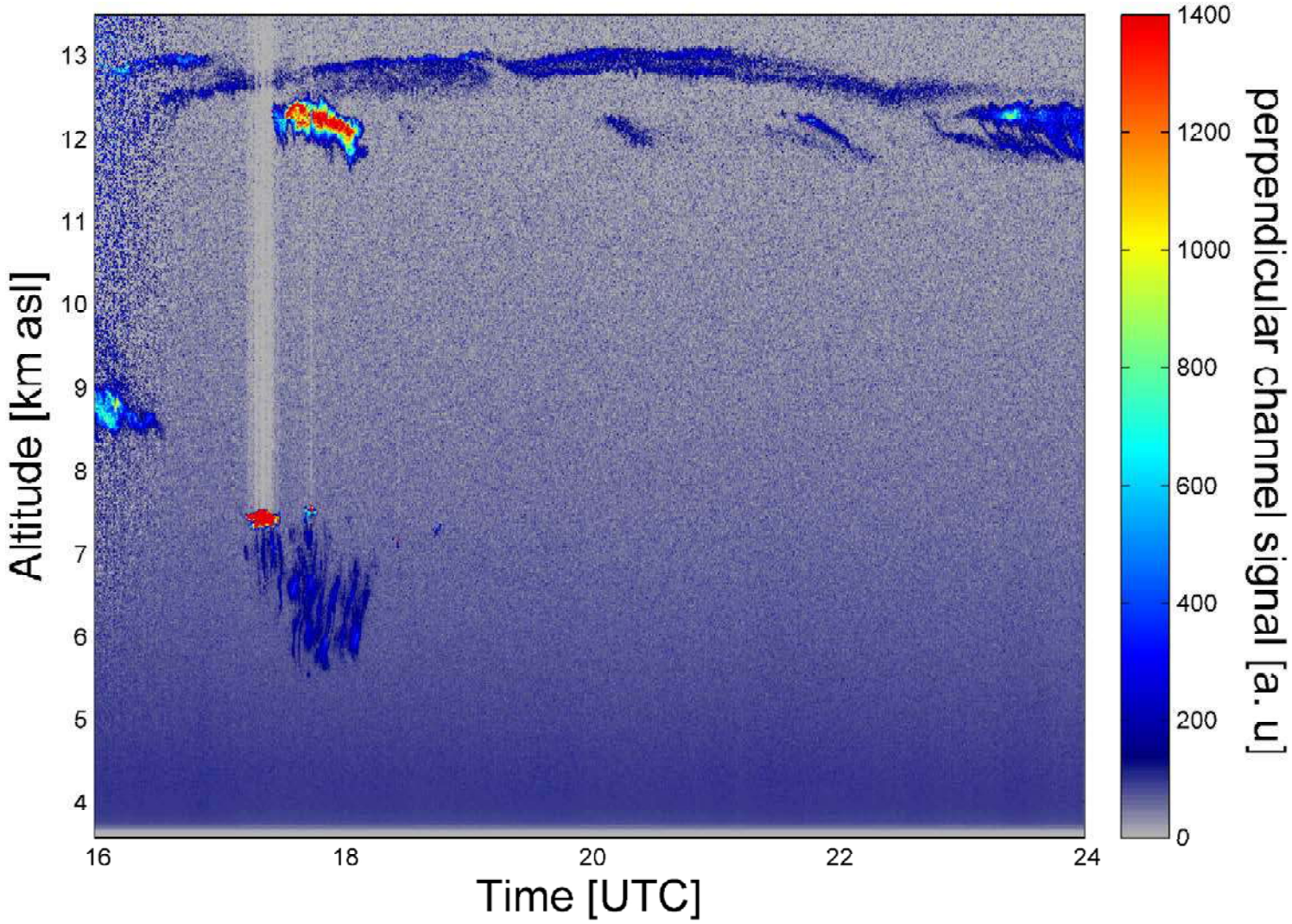
Dependence on shortwave optical depth and cloud-top temperature

24-Hour average CRE, north central Oklahoma, at equinox



Even clouds of very low optical depth exert substantial radiative effect.

PERSISTENT VERY THIN CIRRUS AT MIDLATITUDE SITE



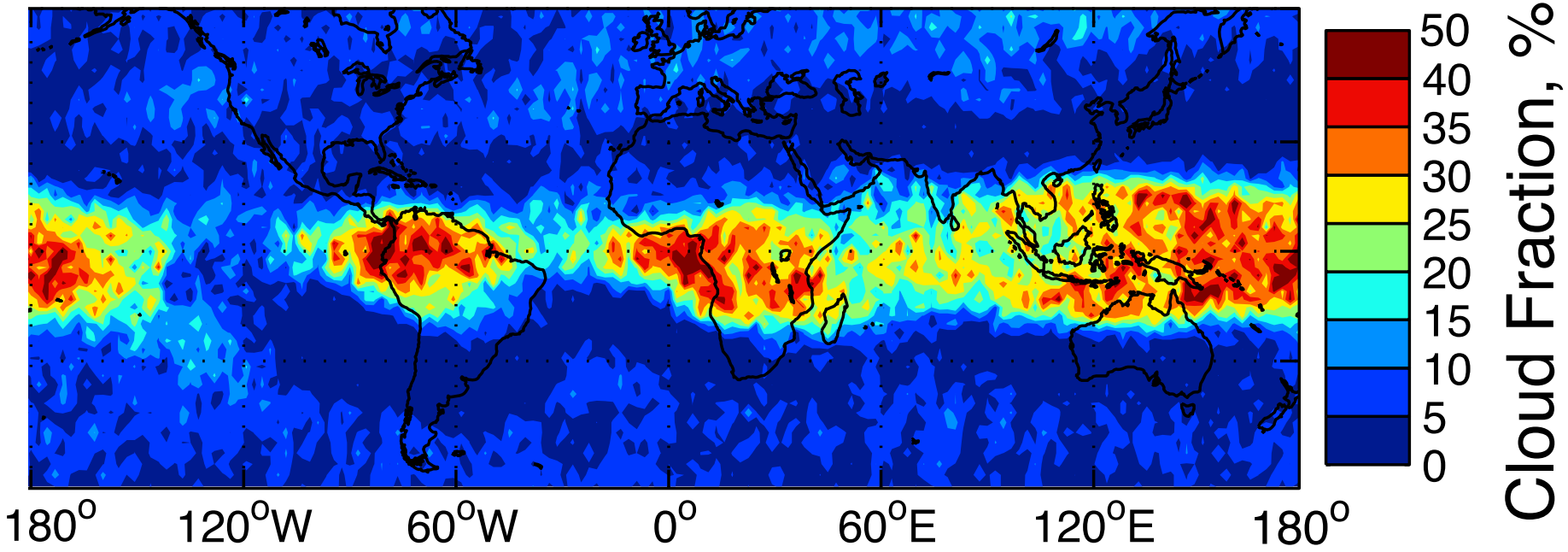
Kienast-Sjögren et al., 9th Int. Symp. on Tropospheric Profiling, 2012

Optical depth of cirrus layer estimated from lidar return as ***0.003 to 0.004***.

OPTICALLY THIN CLOUDS CAN BE PREVALENT IN TROPICS

Subvisible cirrus detected by lidar from space, DJF

$0.01 \leq \tau \leq 0.03$

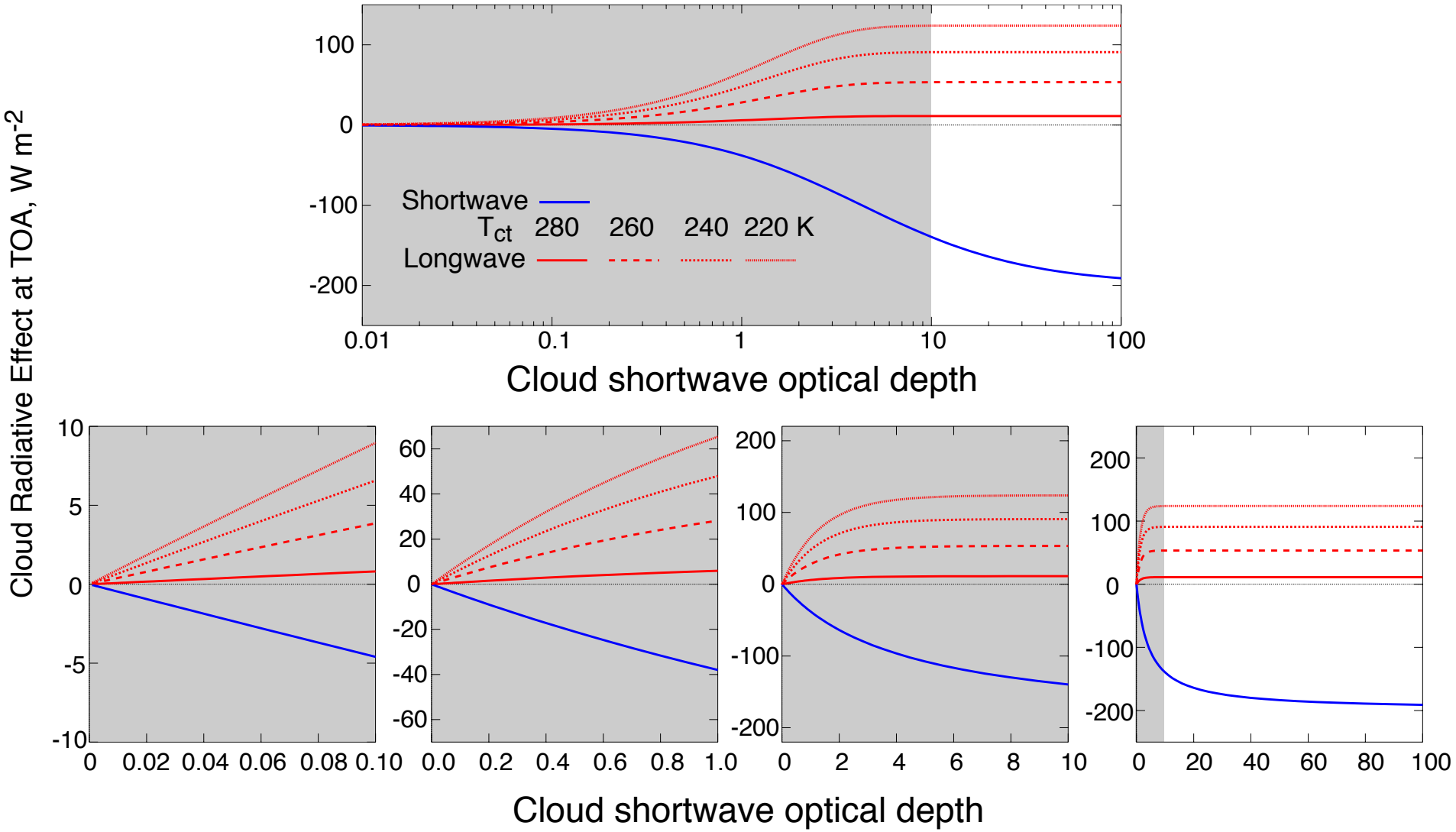


Martins Noel & Chepfer, JGR, 2011

CLOUD RADIATIVE EFFECT

Dependence on shortwave optical depth and cloud-top temperature

24-Hour average CRE, north central Oklahoma, at equinox

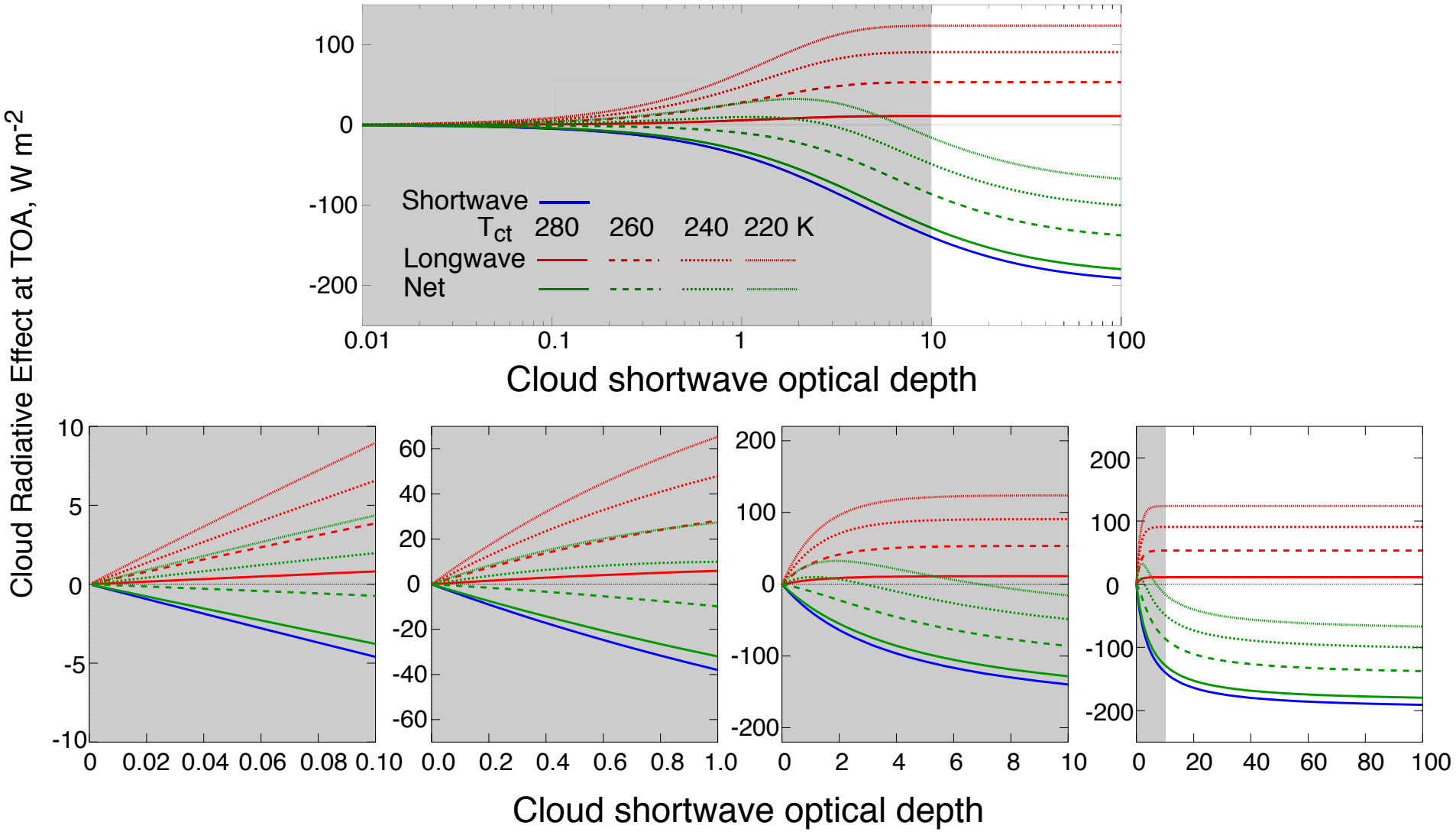


Longwave CRE also initially linear; saturates; depends on cloud-top temp.

CLOUD RADIATIVE EFFECT

Dependence on shortwave optical depth and cloud-top temperature

24-Hour average CRE, north central Oklahoma, at equinox



Net CRE depends on optical depth and cloud-top temperature ***even in sign***.

Knowledge of cloud fraction ***tells you nothing*** about the cloud radiative effect.

A FOOL'S ERRAND

Threshold photometric determination of cloud fraction

Natural color photo

What is the cloud fraction?

A FOOL'S ERRAND

Threshold photometric determination of cloud fraction

Natural color photo

Red/(Red + Blue)

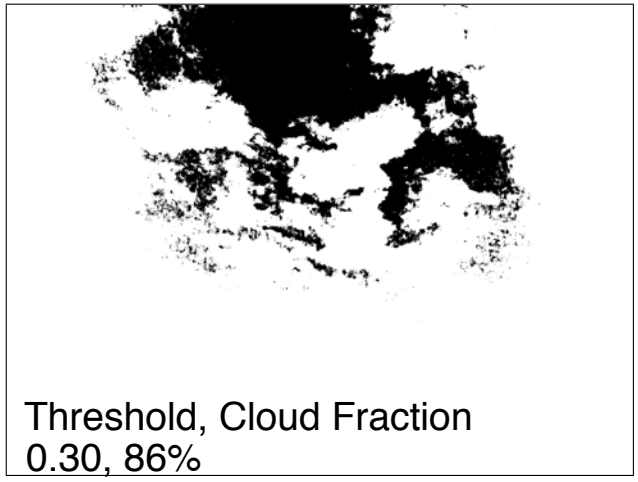
Examine ratio Red/(Red + Blue), common cloud discrimination technique.

A FOOL'S ERRAND

Threshold photometric determination of cloud fraction

Natural color photo

Red/(Red + Blue)



Threshold, Cloud Fraction
0.30, 86%

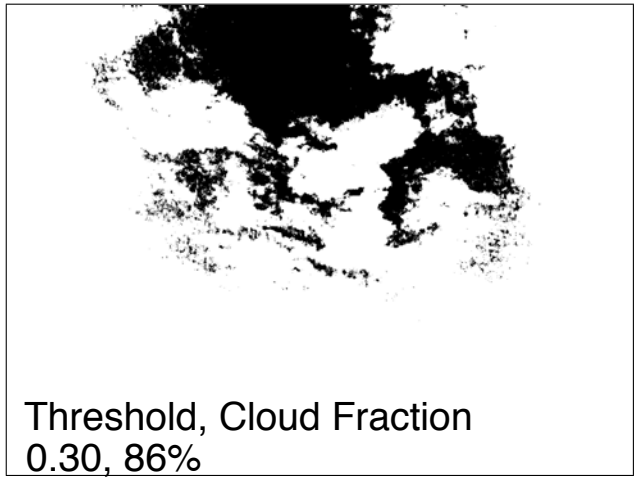
Apply cloud mask with threshold $R/(R+B) \geq 0.30$. Cloud fraction 86%. Threshold is too low.

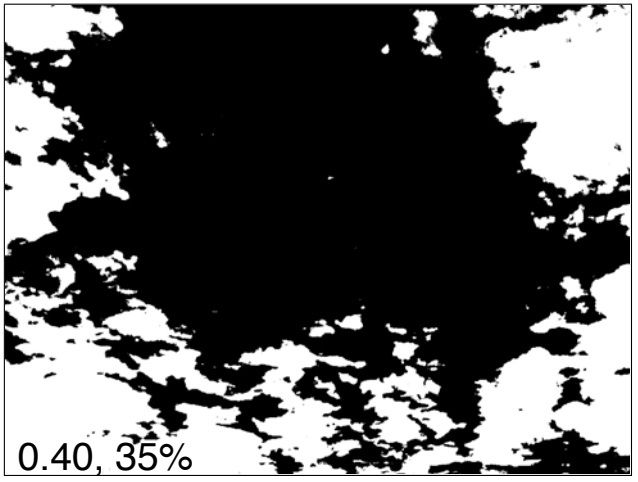
A FOOL'S ERRAND

Threshold photometric determination of cloud fraction

Natural color photo

Red/(Red + Blue)





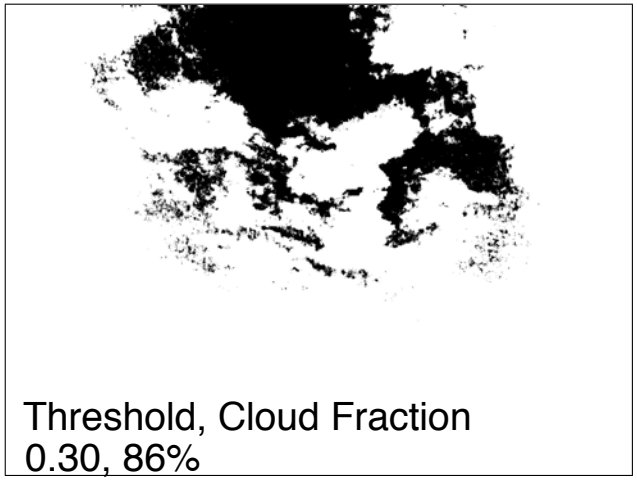
Try threshold 0.40. Cloud fraction is 35%.
That threshold is too high.

A FOOL'S ERRAND

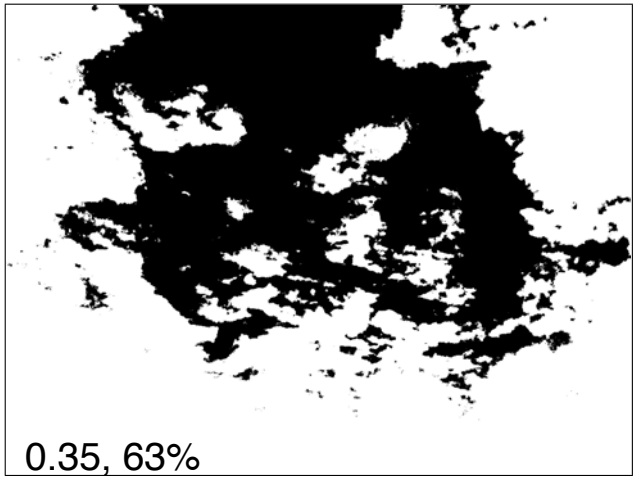
Threshold photometric determination of cloud fraction

Natural color photo

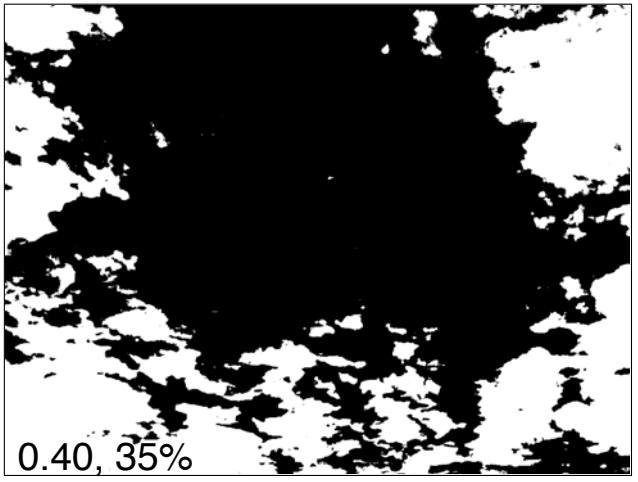
Red/(Red + Blue)



Threshold, Cloud Fraction
0.30, 86%



0.35, 63%



0.40, 35%

Try threshold 0.35. Cloud fraction is 63%.

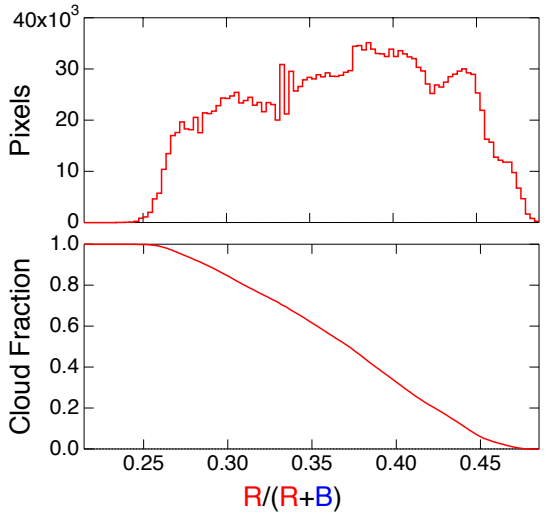
There is no "just right". False positives and false negatives.

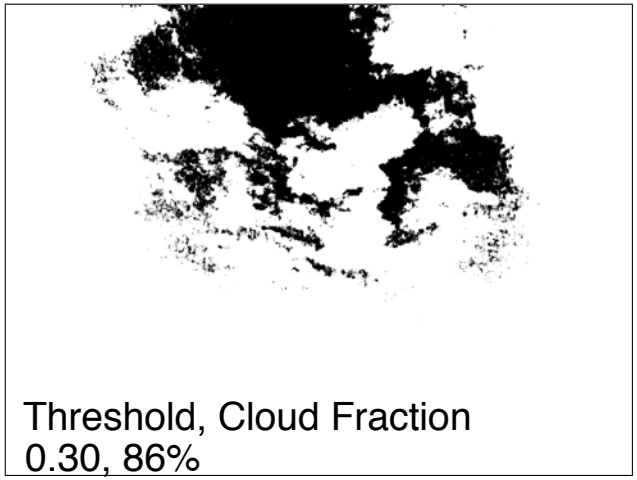
A FOOL'S ERRAND

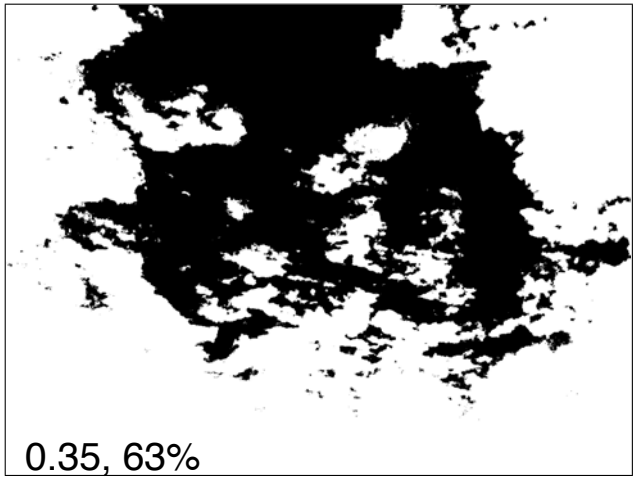
Threshold photometric determination of cloud fraction

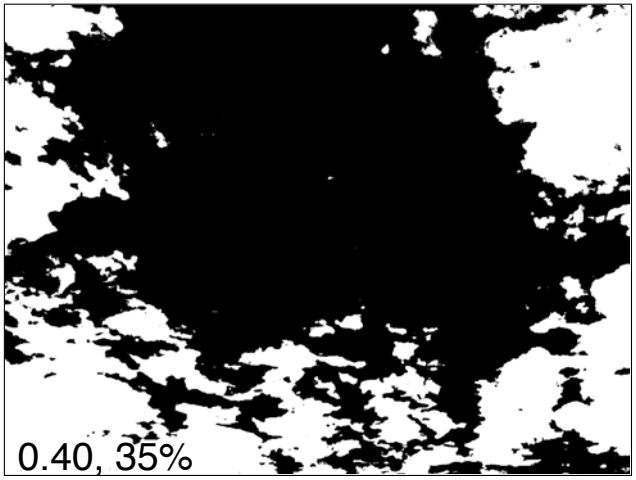
Natural color photo

Red/(Red + Blue)









Examination of cloud fraction as function of Red/(Red + Blue) threshold. There is no unique threshold.

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

CONCLUSIONS

No!

No!

No!

Cloud fraction is dead! Do not resuscitate.