SOME ISSUES REGARDING CLOUD FRACTION

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BROOKHAVEN NATIONAL LABORATORY

ASR Science Team Meeting

FASTER Breakout Session

Potomac MD

March 18-21, 2013

CLOUD FRACTION

Can it be unambiguously defined?
Can it be uniquely measured?
And if we knew it would it be of any use to us?

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Photo: Ernie Lewis

MOTIVATION

- Clouds are the most uncertain component of GCMs.
- Climate sensitivity in GCMs depends strongly on the representation of clouds.
- GCMs must be evaluated on the basis of their representation of clouds.
- Cloud fraction is the *de facto* zeroth order measure of clouds in models and observations.

WHAT IS A CLOUD?

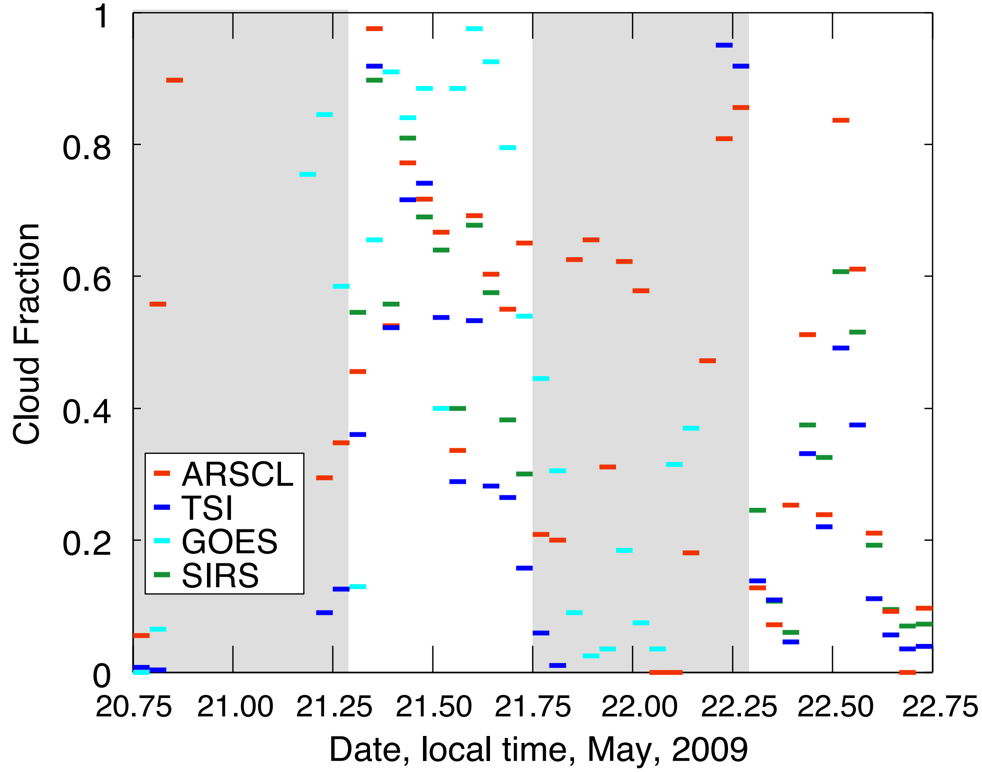
"Surprisingly, and in spite of the fact that we deal with clouds on a daily basis, to date there is no universal definition of a cloud....

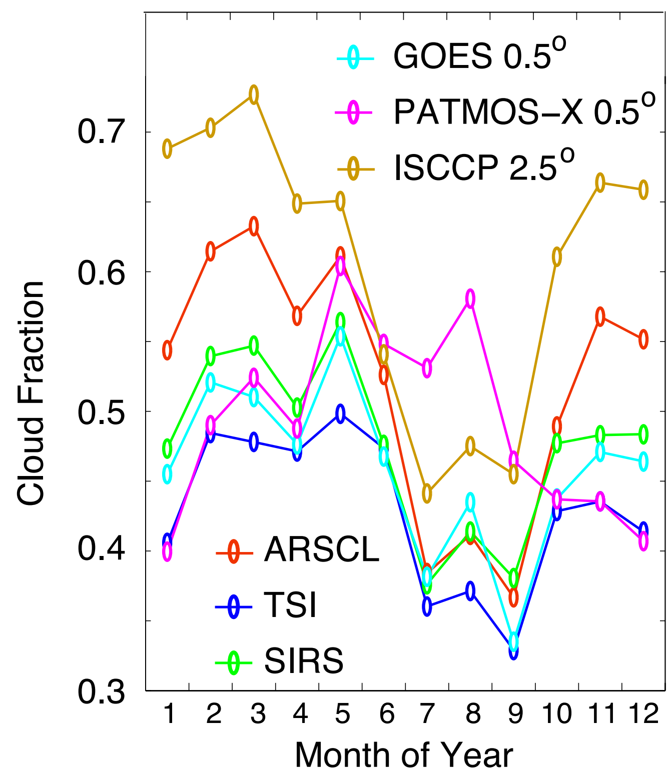
Ultimately, the definition of a cloud depends on the threshold sensitivity of the instruments used in cloud studies."

Clothiaux, Barker & Korolev (2005)

DIFFERENT MEASURES YIELD DIFFERENT CLOUD FRACTION

Cloud fraction at SGP by multiple methods





Cloud fraction by different methods differs substantially on hourly averages to multi-year monthly averages.

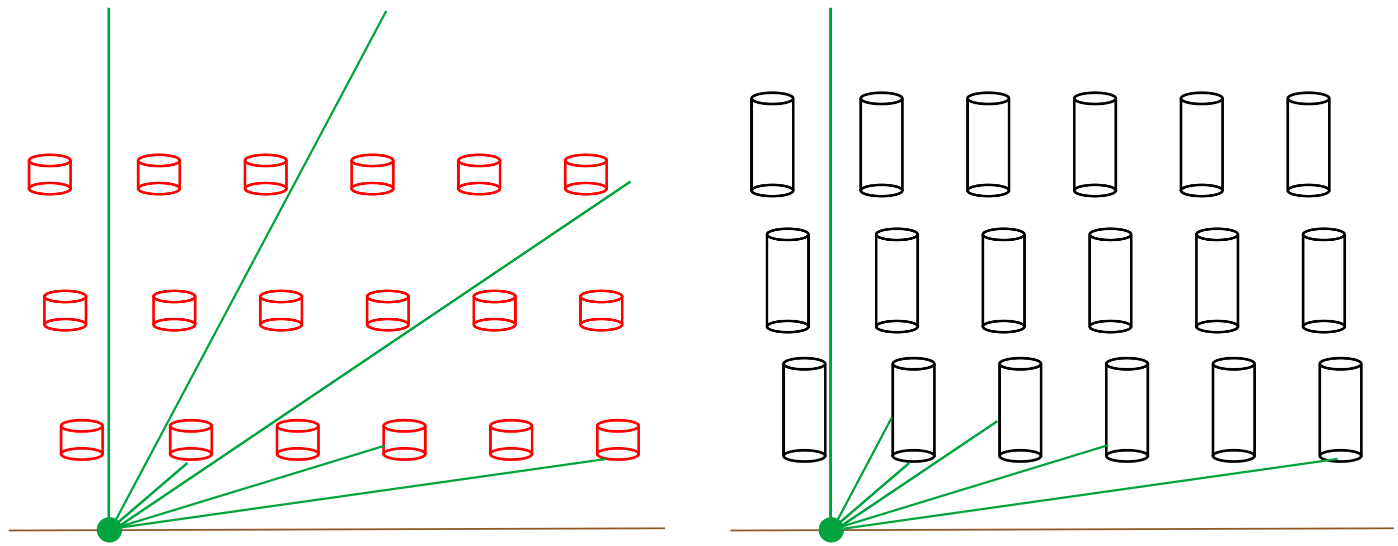
Such differences would have major implications on atmospheric radiative fluxes.

REASONS FOR DIFFERENCES IN MEASURED CLOUD FRACTION

- Angular (geometric) effects.
- Resolution: cloud-free sky in a pixel containing clouds can be miscounted as cloudy sky.
- Threshold: what is the minimum reflectance that constitutes a cloud?
- Mismatch between measurements in time and/or space – point *vs* area; hourly *vs* instantaneous, etc.

CLOUD SIDEWALL EFFECT

Both cloud fields have same cloud area fraction



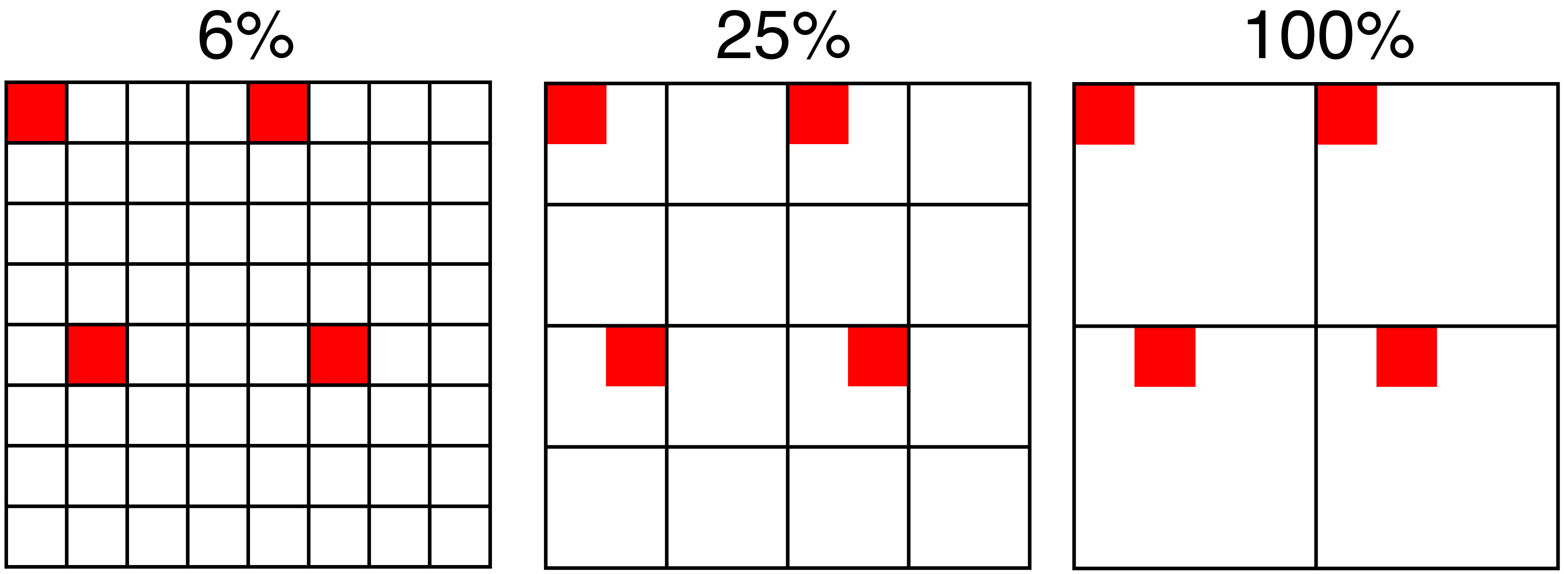
Vertical view angle yields same cloud fraction.

Slant view angle yields artifact high cloud fraction because of cloud sidewalls, more so for tall clouds.

Pertains to cloud fraction from satellite and from surface.

The effect can be minimized by restricting viewing zenith angle.

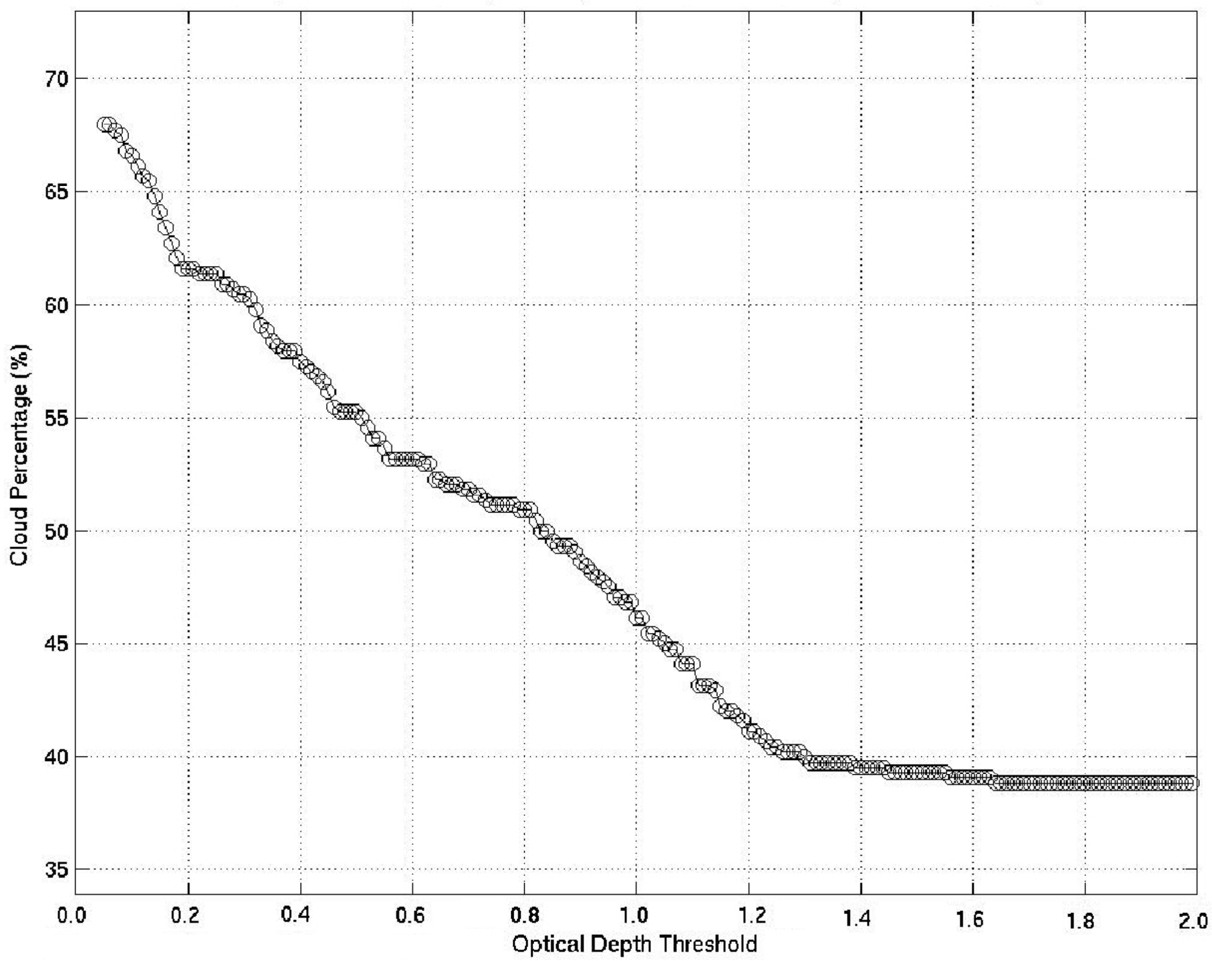
RETRIEVED CLOUD FRACTION DEPENDS ON RESOLUTION



Cloud-free sky in a pixel containing clouds can be miscounted as cloudy sky, and vice versa.

But the high spatial variability of many cloud types implies that clear-sky elements can be present in "cloudy" pixels no matter how high the resolution, and vice versa.

CLOUD FRACTION – DEPENDENCE ON OPTICAL DEPTH THRESHOLD



Mores (MS Thesis, Univ. Wisc., 2004, Eloranta)

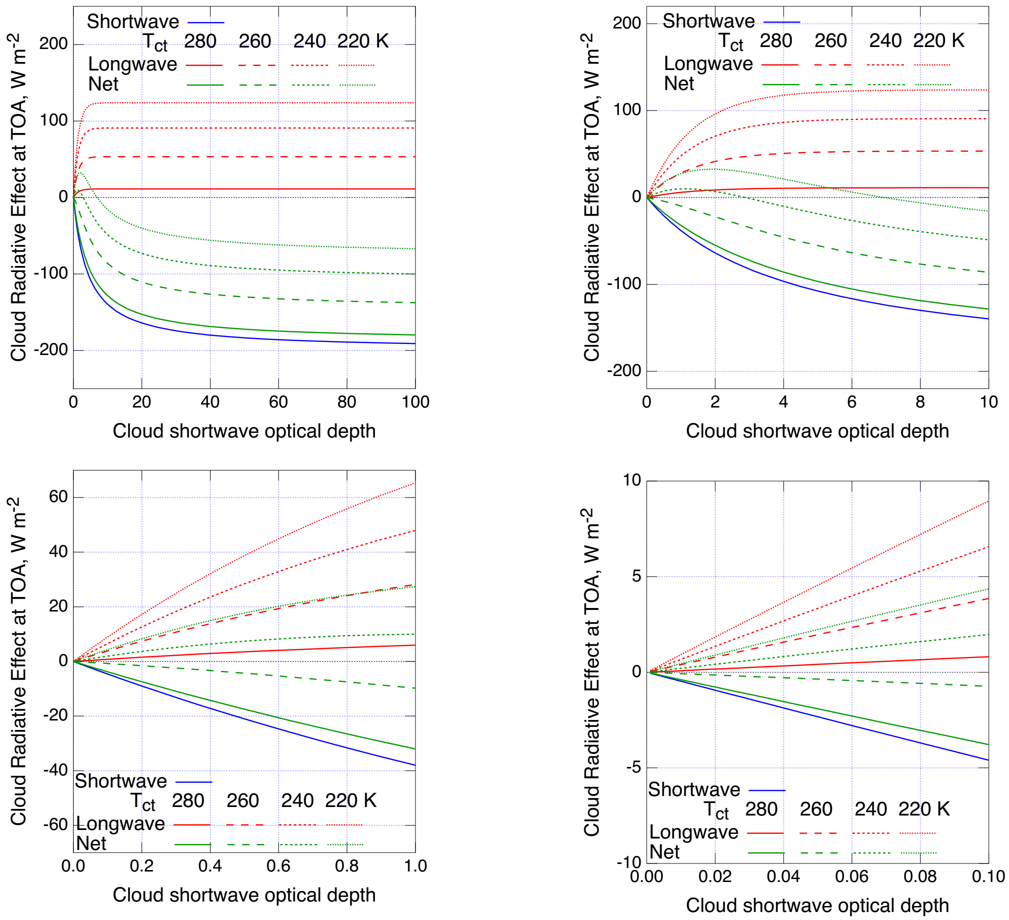
Fraction of time cloud detected by lidar as function of optical depth threshold during a single night of observations.

Cloud fraction increases strongly with decreasing threshold.

ALL CLOUDS ARE NOT THE SAME

Radiative effects of clouds depend on their microphysical and optical properties and on their location in the atmosphere, even for the same cloud amount.

CLOUD RADIATIVE EFFECT – DEPENDENCE ON OPTICAL DEPTH AND CLOUD-TOP HEIGHT



Shortwave TOA CRE is 24-hour average at equinox for latitude of ARM SGP site. Surface temperature, 285K; surface albedo, 0.15.

Even for thin cirrus clouds, τ_{sw} ~0.01, the radiative effects are substantial, -0.5 W m^{-2} in the shortwave and as great as 1.8 W m^{-2} in the longwave.

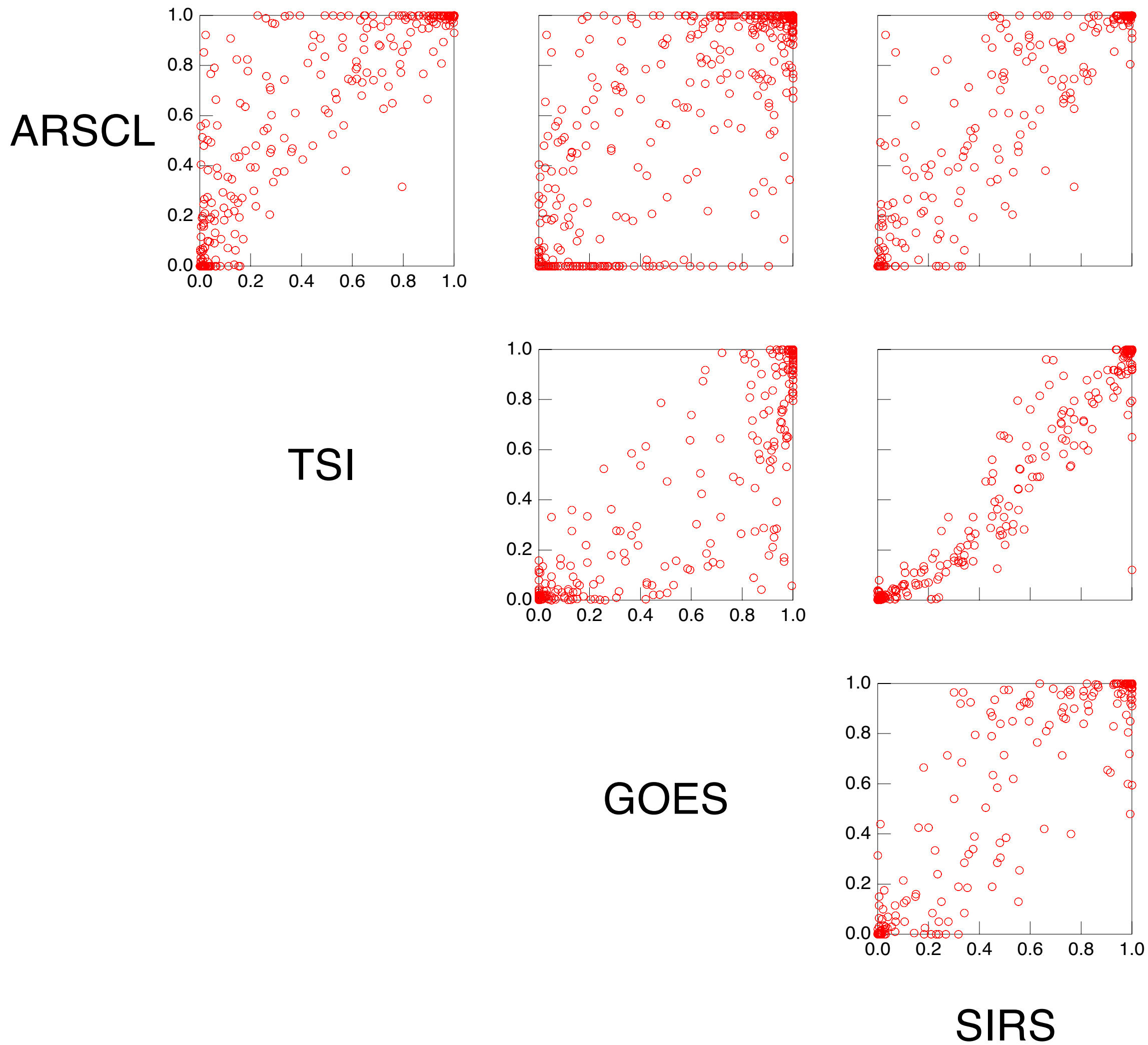
Reference: Corti & Peter, ACP, 2009

CONCLUDING OBSERVATIONS

- Measured cloud fraction inherently depends on ***threshold and scale***.
- If done at all, comparisons of cloud fraction by different methods, or between models and observations, must take this into account.
- Cloud radiative effects inherently depend on cloud properties, importantly shortwave optical depth and cloud top height, not just on the amount of cloud.
- Even if cloud fraction were accurately known, for some agreed-on threshold and resolution, this knowledge would be of little value in reducing uncertainties of representations of clouds in climate models.
- Evaluation of model representation of clouds would more profitably focus on continuously variable cloud properties such as liquid water path, rather than the binary quantity "cloud fraction".

COMPARISON OF CLOUD FRACTION BY DIFFERENT METHODS

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

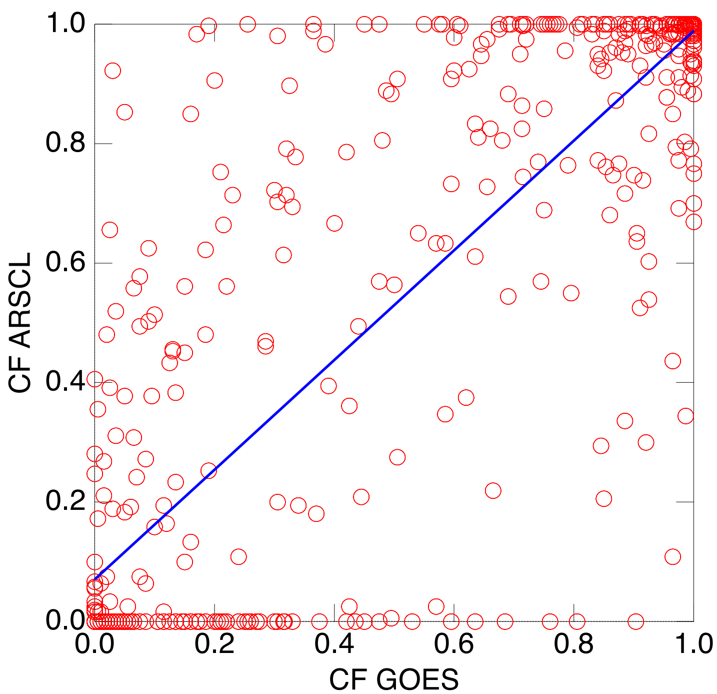


Comparison plots show some skill but substantial differences.

CORRELATION IS DOMINATED BY ONES AND ZEROES

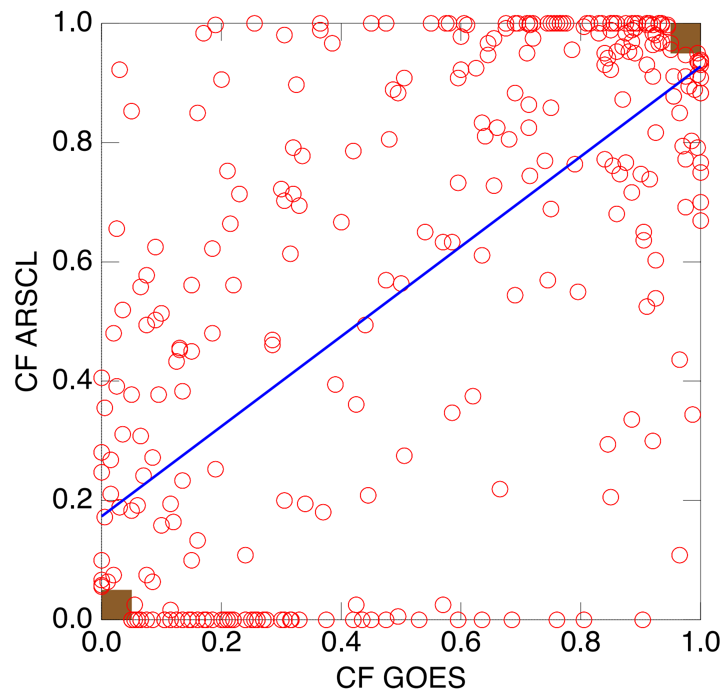
Hourly cloud fraction at SGP by ARSCL AND GOES, May, 2009

All points, May, 2009



Coefficient values ± one standard error	
a	0.071 ± 0.010
b	0.918 ± 0.013
r^2	0.78
N	1346

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

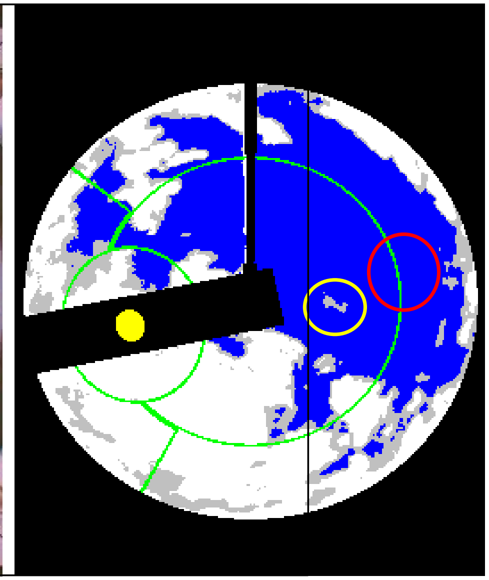


Coefficient values ± one standard error	
a	0.174 ± 0.022
b	0.754 ± 0.035
r^2	0.44
N	620

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

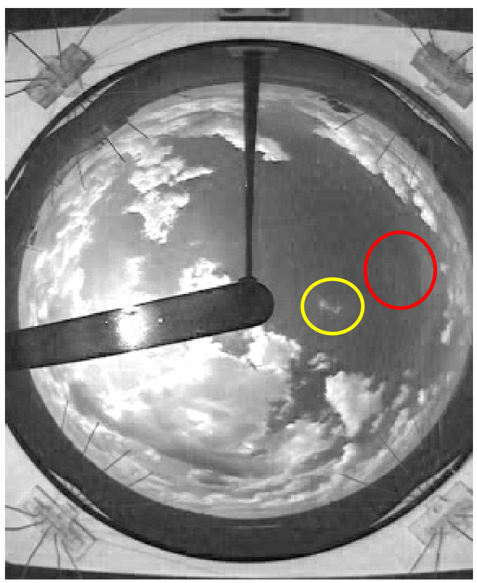
CLOUD DISCRIMINATION ALGORITHMS CAN MISS THIN CLOUDS

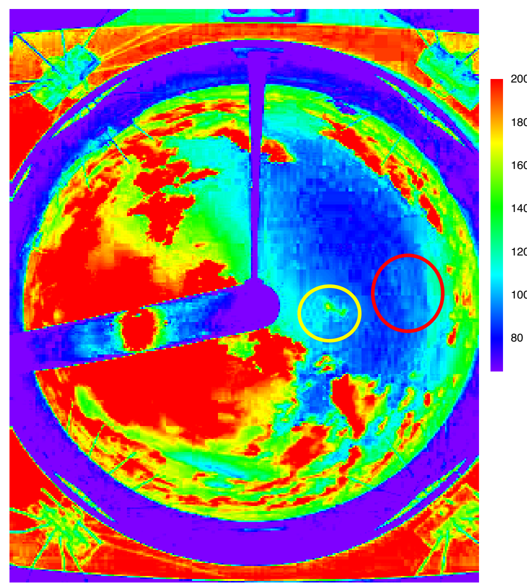
TSI image,
Natural
Color



ARM
Cloud Mask Product
Blue: no cloud
Gray: thin cloud
White: opaque cloud

Red Channel
From TSI





Red Channel
In False Color

ARM Total Sky Imager photo and cloud mask product

APPLICATION OF IMAGE PROCESSING

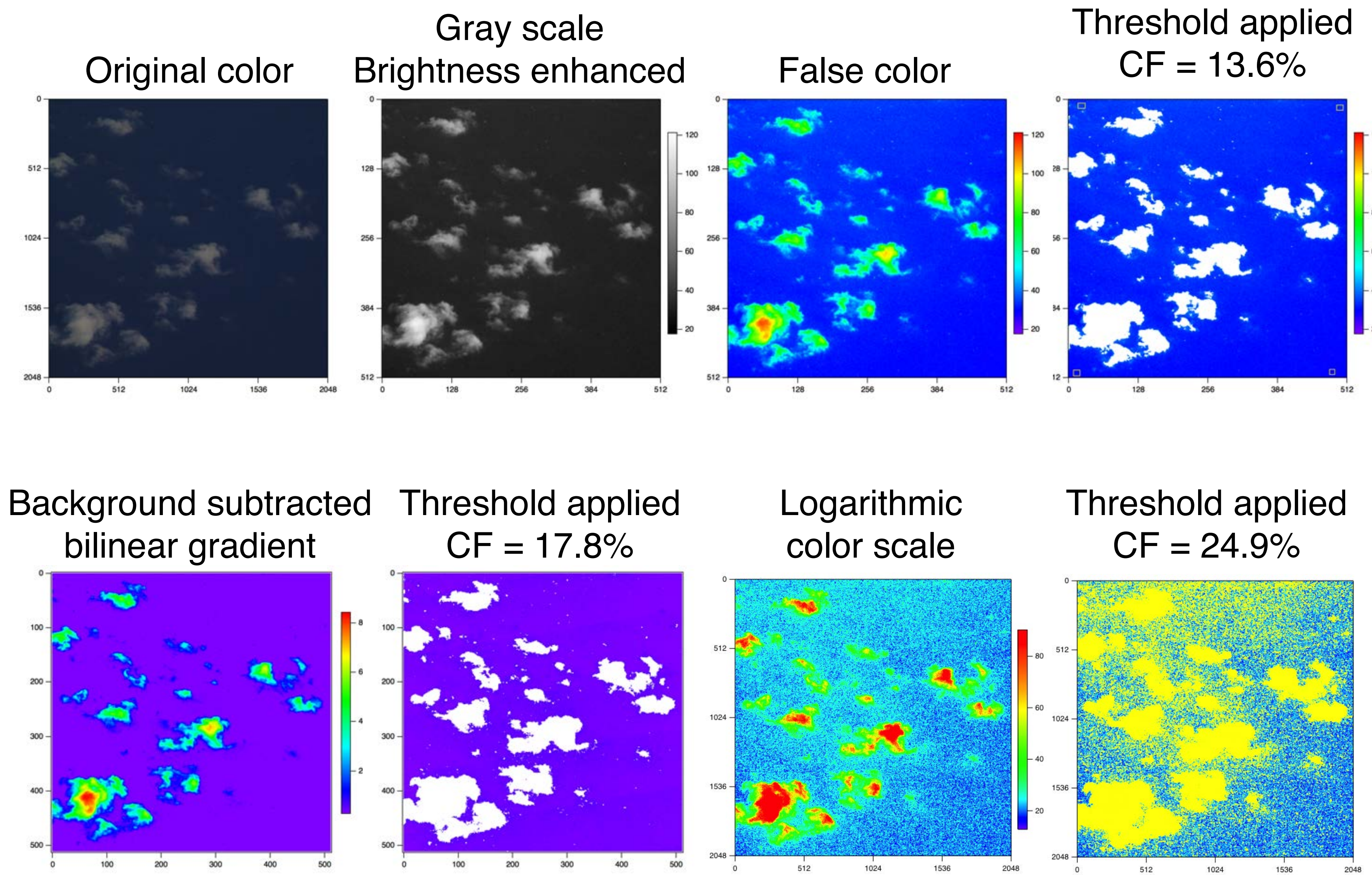
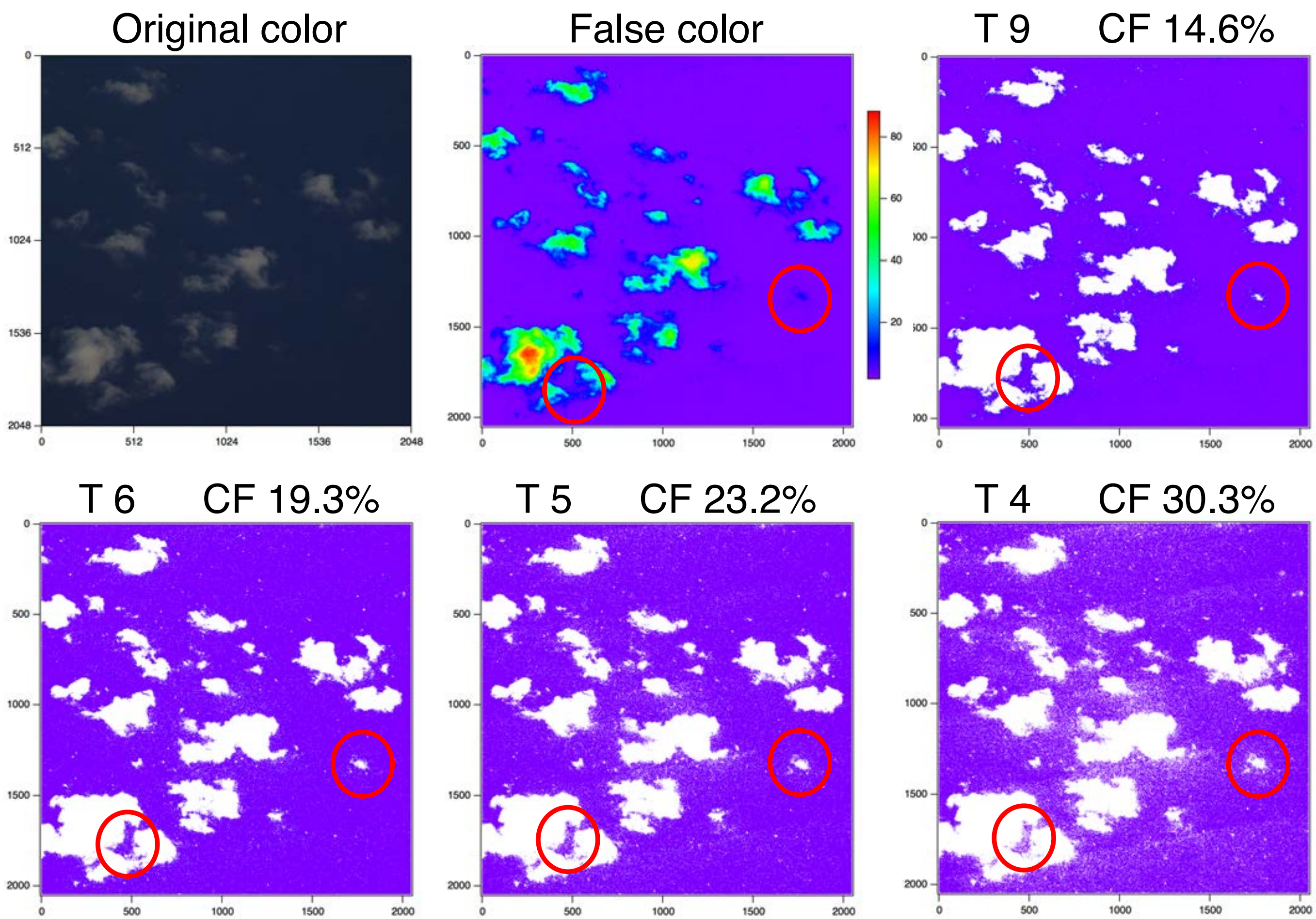
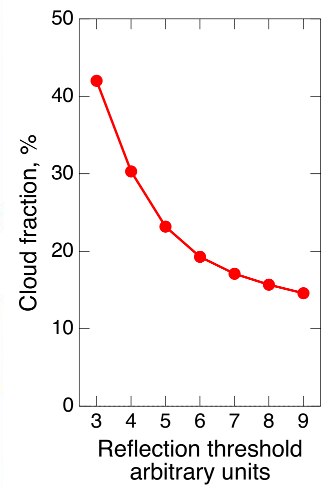


Image processing improves cloud boundary detection and increases retrieved cloud fraction, ***perhaps artificially***.

CLOUD FRACTION DEPENDENCE ON THRESHOLD



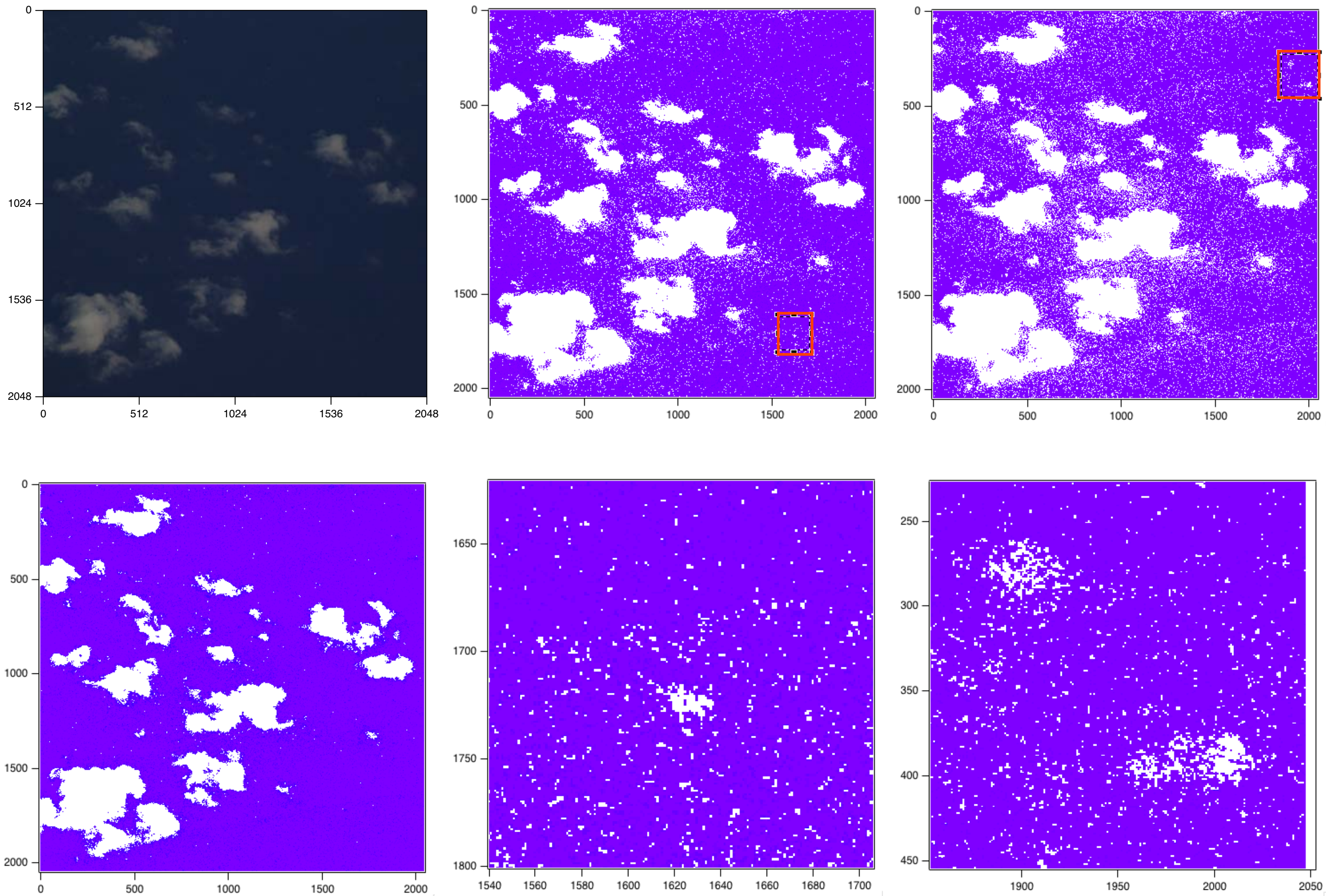


Low-reflectance cloud boundaries add substantially to cloud fraction.

Reducing threshold increases cloud fraction along cloud boundaries but may introduce false positives.

Difficult to find threshold that avoids false positives and false negatives.

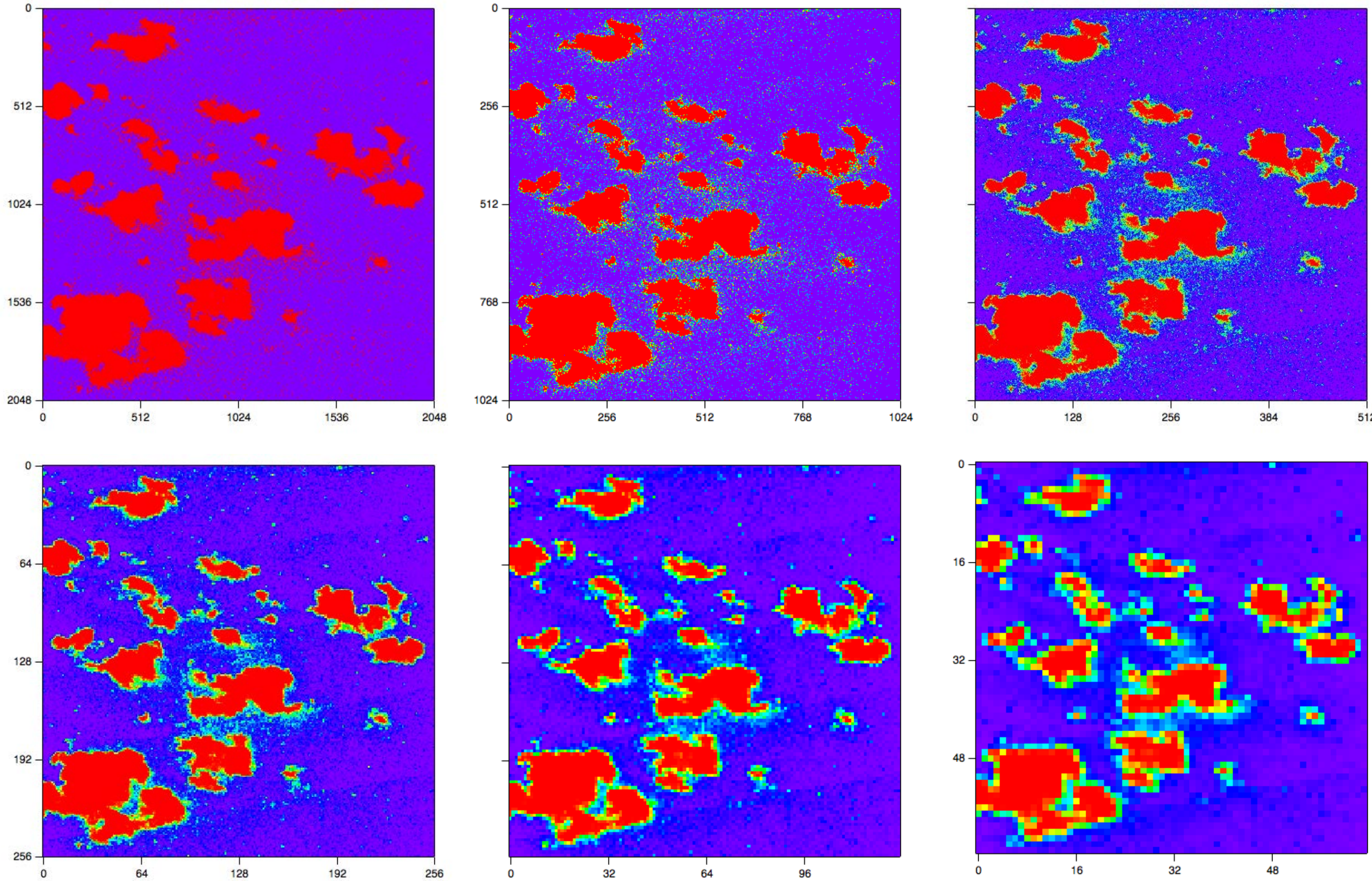
SOME OF THOSE REJECTED SPECKS MIGHT ACTUALLY BE CLOUDS



Reducing threshold reveals clusters of relatively high reflectance that would appear to be clouds.

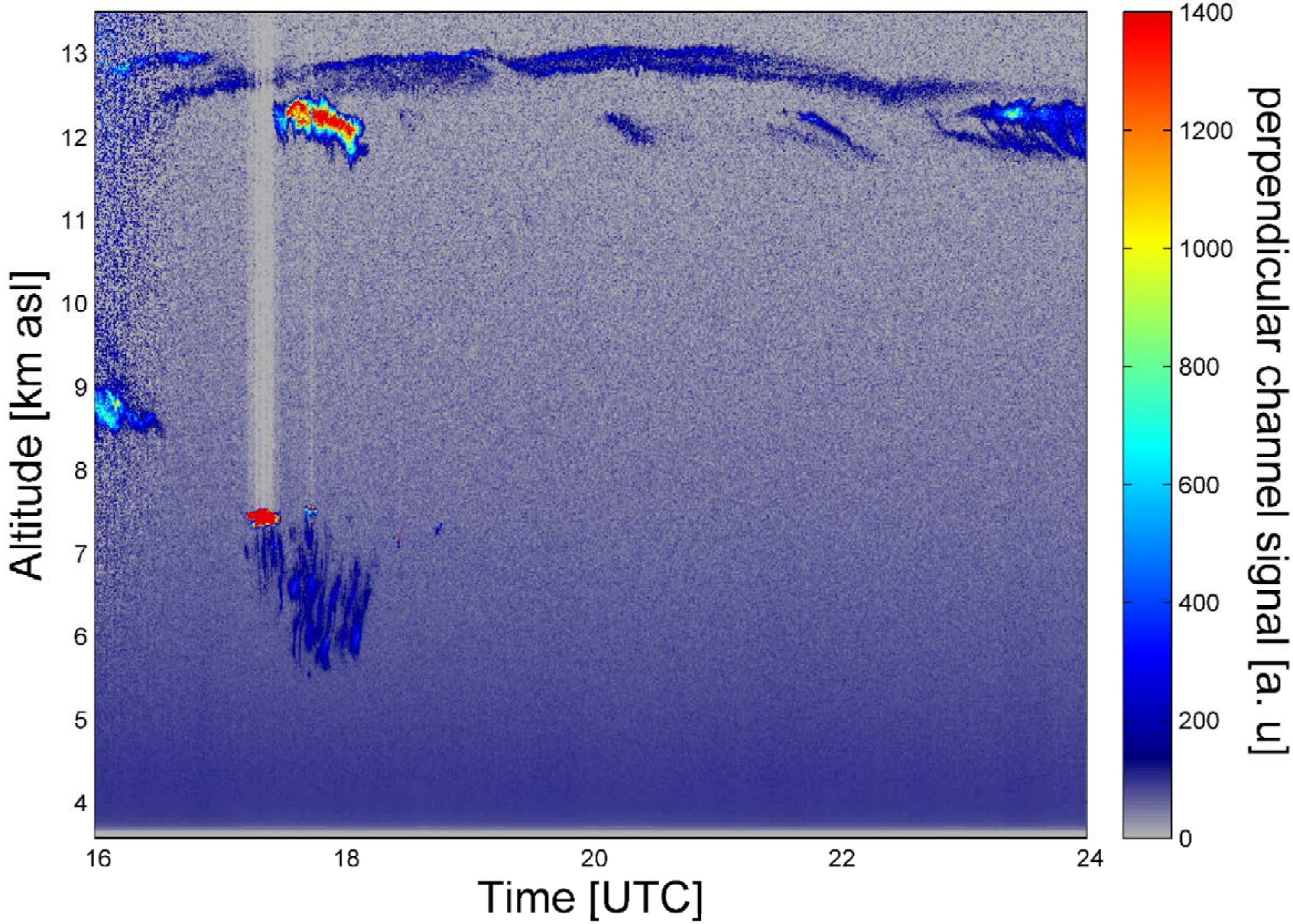
DECREASING RESOLUTION ARTIFICIALLY ENHANCES CLOUD FRACTION

Start with binary cloud; decrease resolution by factors of 2



Reducing resolution results in realistic looking spreading of cloud boundaries and artificial increase in cloud fraction.

PERSISTENT VERY THIN CIRRUS AT MIDLATITUDE SITE



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

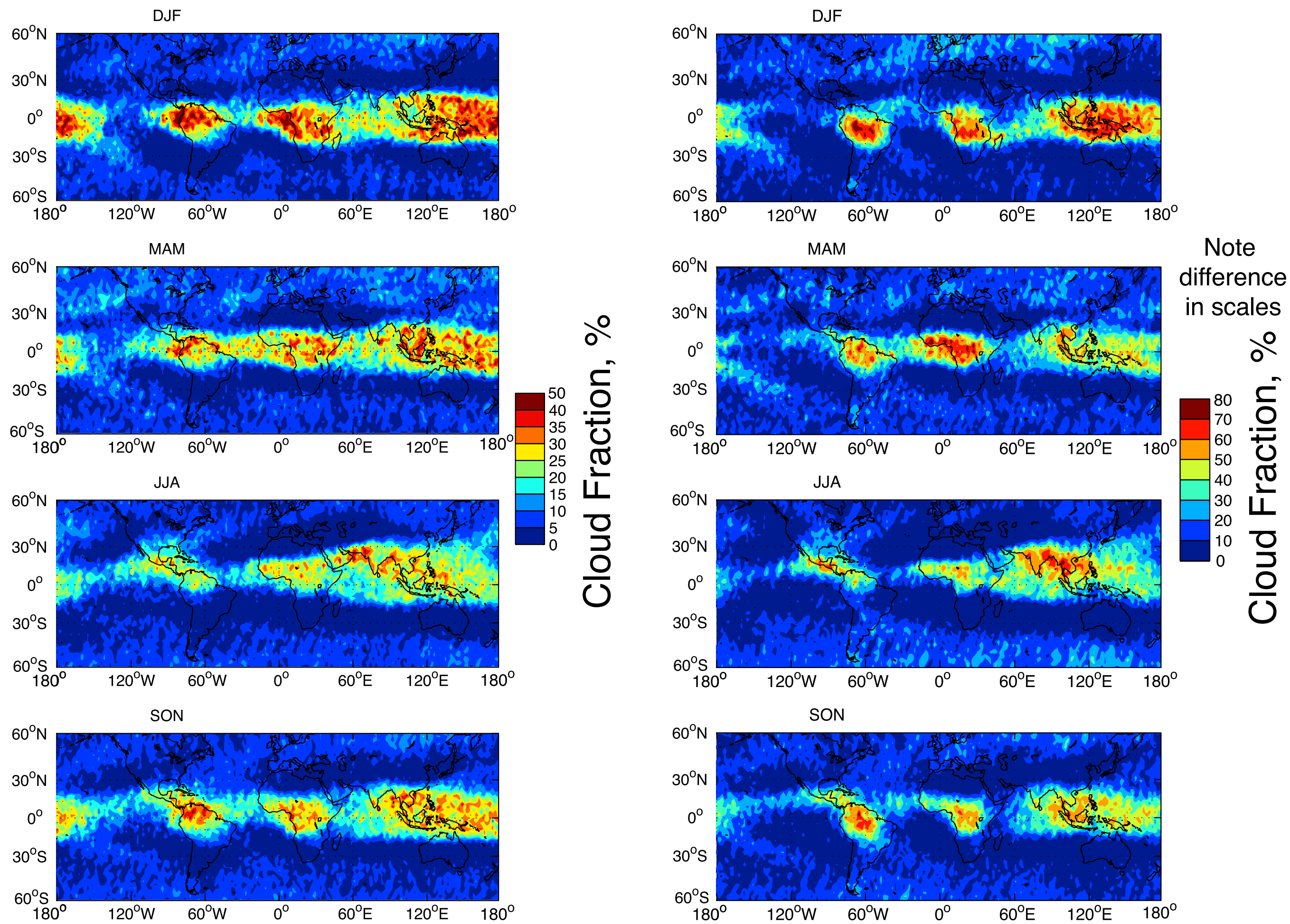
Optical depth of cirrus layer estimated as 0.003 to 0.004.

OPTICALLY THIN CLOUDS CAN BE PREVALENT, ESPECIALLY IN TROPICS

Subvisible cirrus and cirrus detected by lidar from space

Subvisible cirrus,
$0.01 \leq \tau \leq 0.03$

Cirrus,
$\tau \geq 0.03$



Martins et al., JGR, 2011