Cloud and shadow detection

(with a primer on cloud retrievals)

Lazaros Oreopoulos (NASA-GSFC)

with contributions by Mike Wilson, Kerry Meyer, and John Gasch

- ✓Thin cirrus detection thresholds
- ✓Simple cloud and shadow masking
- ✓L7 ACCA and MODIS CF comparisons
- ✓Cloud property retrievals

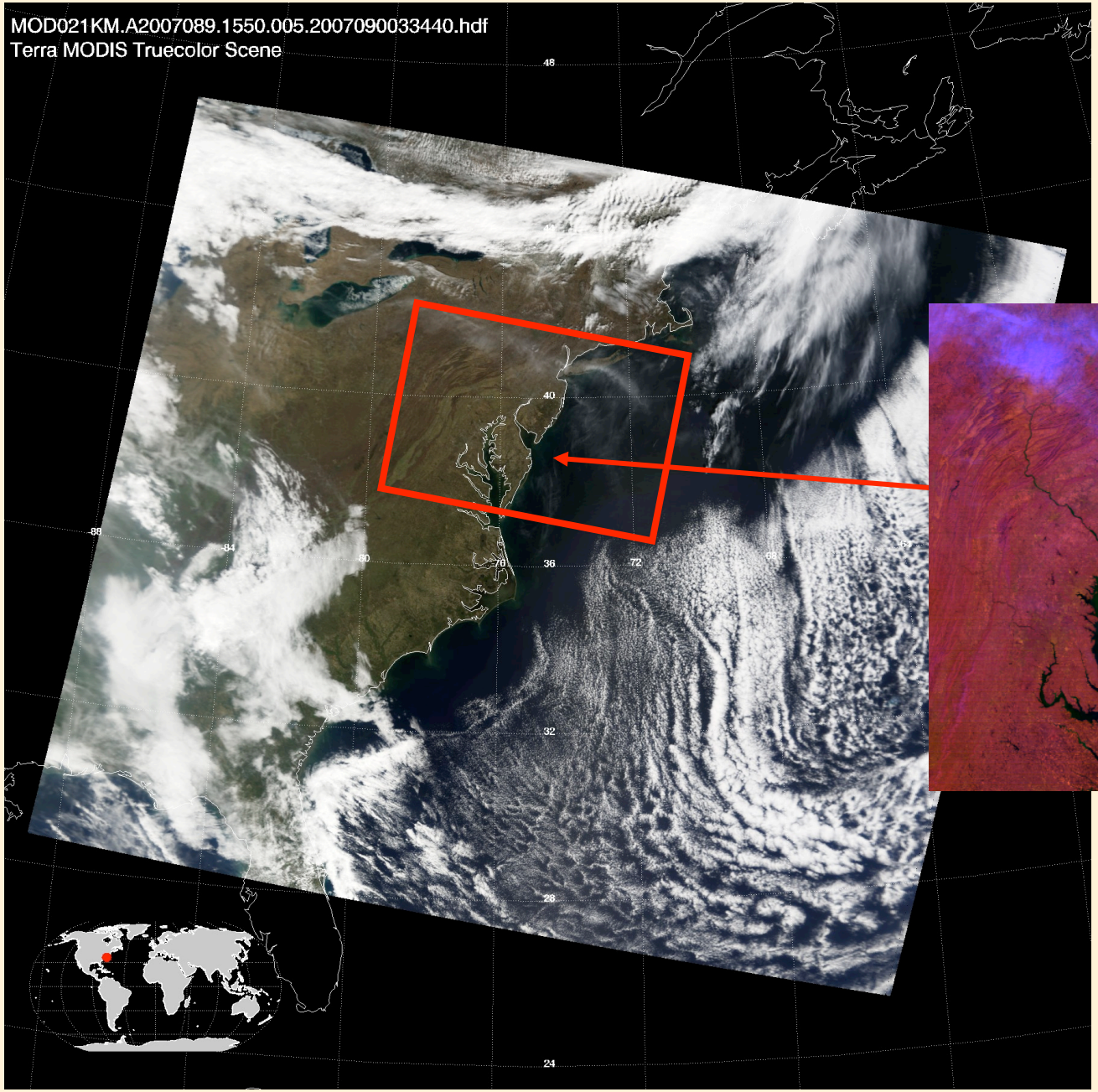
L A N D S A T

LDCM

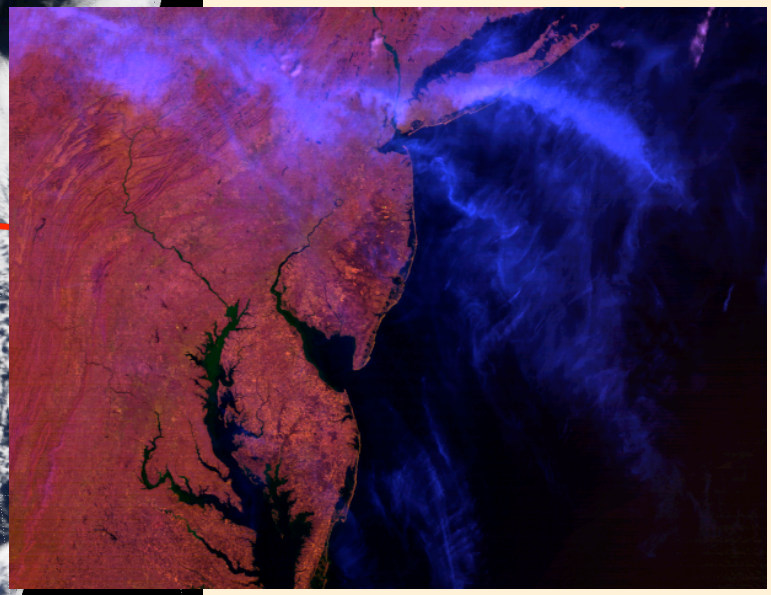
Data Continuity Mission

Setting Cirrus detection thresholds

Jersey Cirrus Case (courtesy of Kerry Meyer)

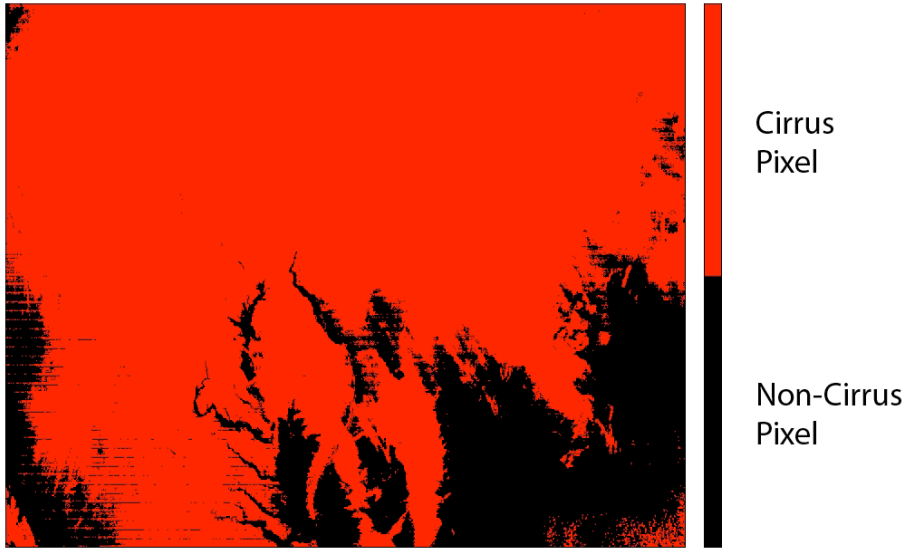


False-color image
(R:2.1um, G:0.65um,B: 1.38um)

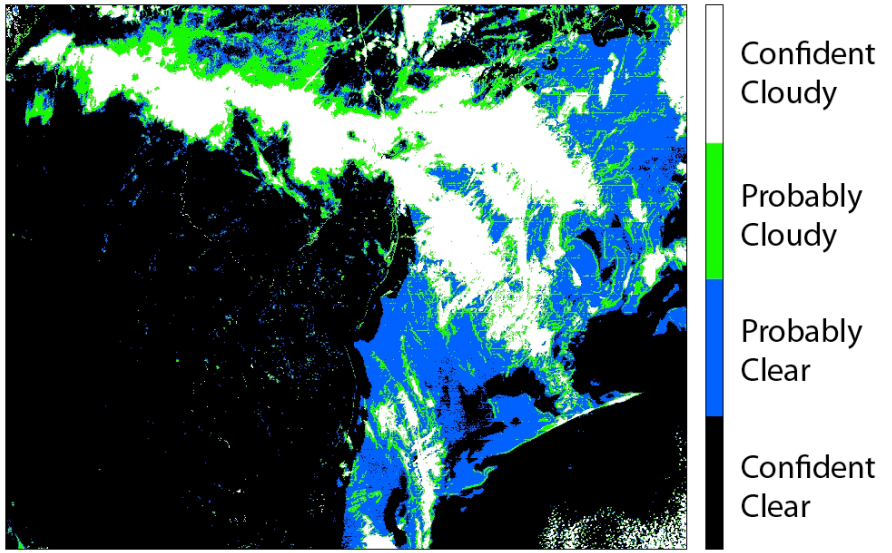


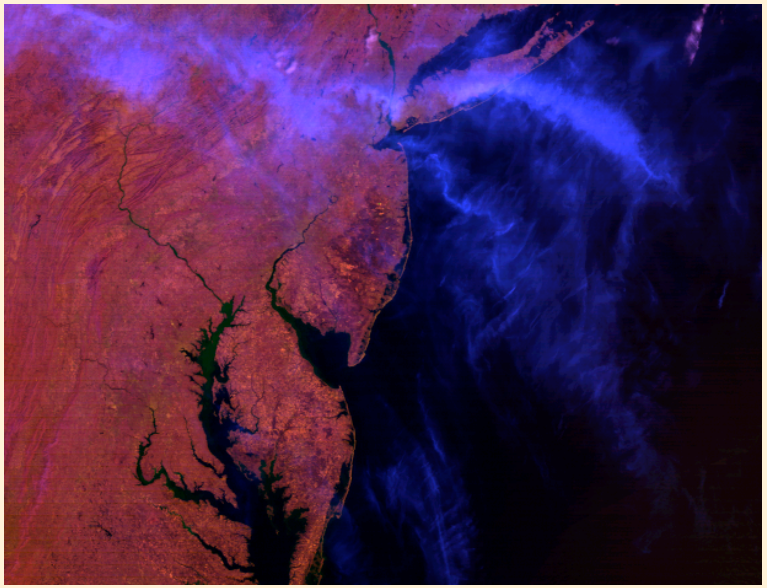
Region examined in following slides

Cirrus Reflectance Flag



MOD06 Cloud Mask



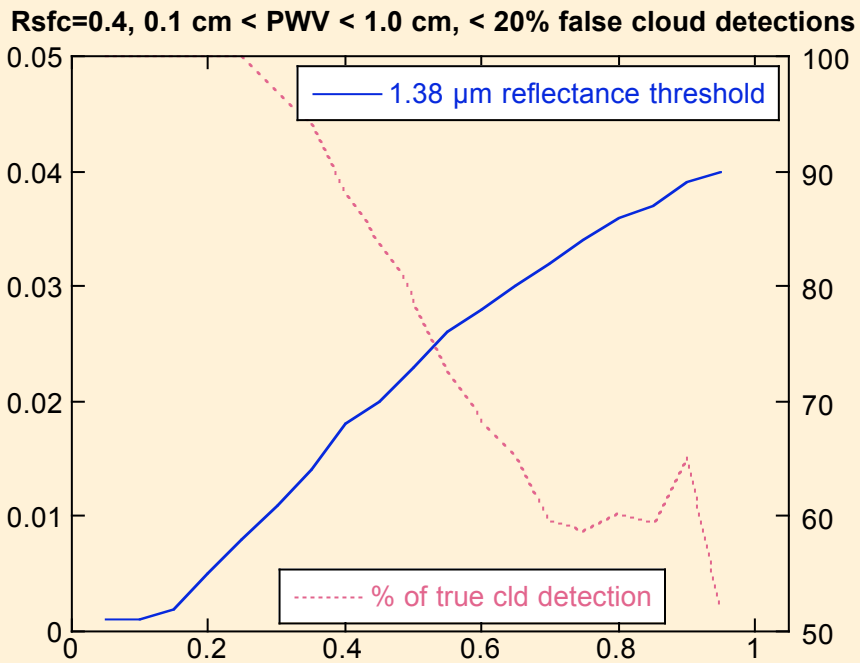


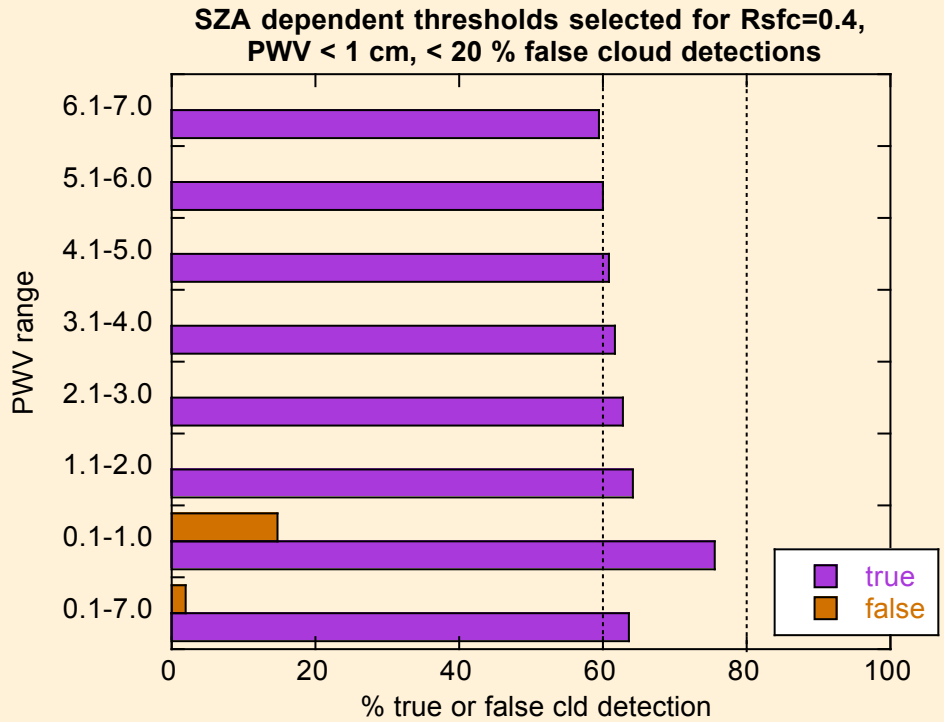
Setting thresholds for cirrus detection
(1.38 μm simulations with DISORT tool)

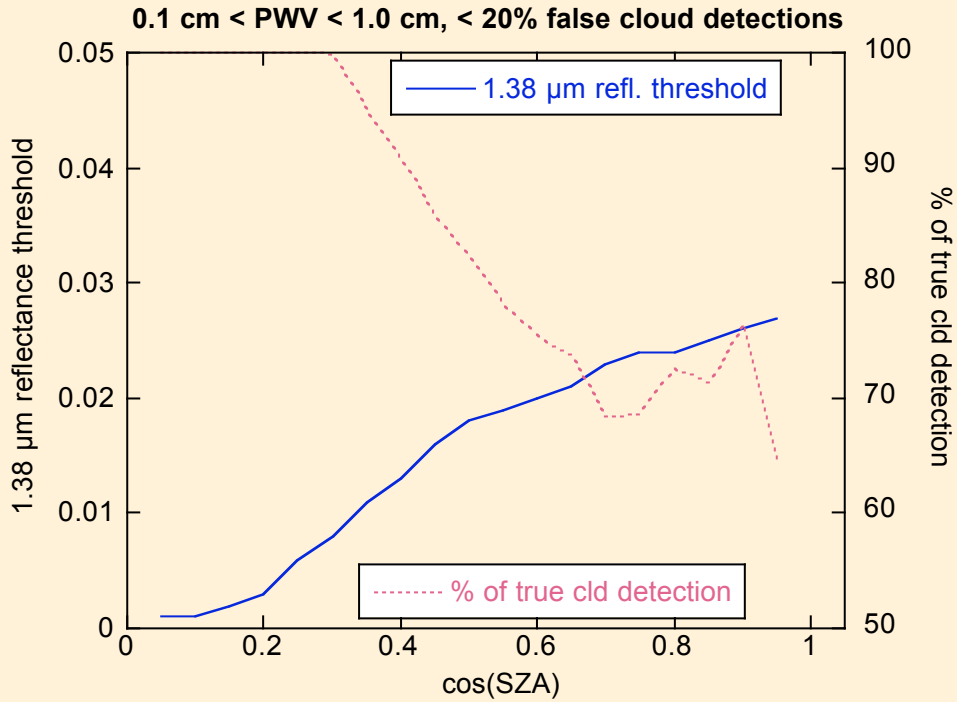
- **Summary of simulations performed:**
- Cirrus clouds with ice crystal effective diameter d=50, 60, 70 μm, optical depth OD=0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0,1.5, 2.0, 2.5….
- …placed at 8-9, 9-10, 10-11, 11-12 km layers…
- …within 15 different atmospheres whose PWV was forced to range from 0.1 to 7.0 cm, in steps of 0.1 (the WV vertical distribution is different among the atmospheres).
- Surface albedo used was 0.1, 0.2, 0.3, 0.4.
- SZA varied from 0.05 to 0.95 in steps of 0.05.
- Obviously, the above numbers give a large number of permutations: DISORT was run > 12,000,000 times!

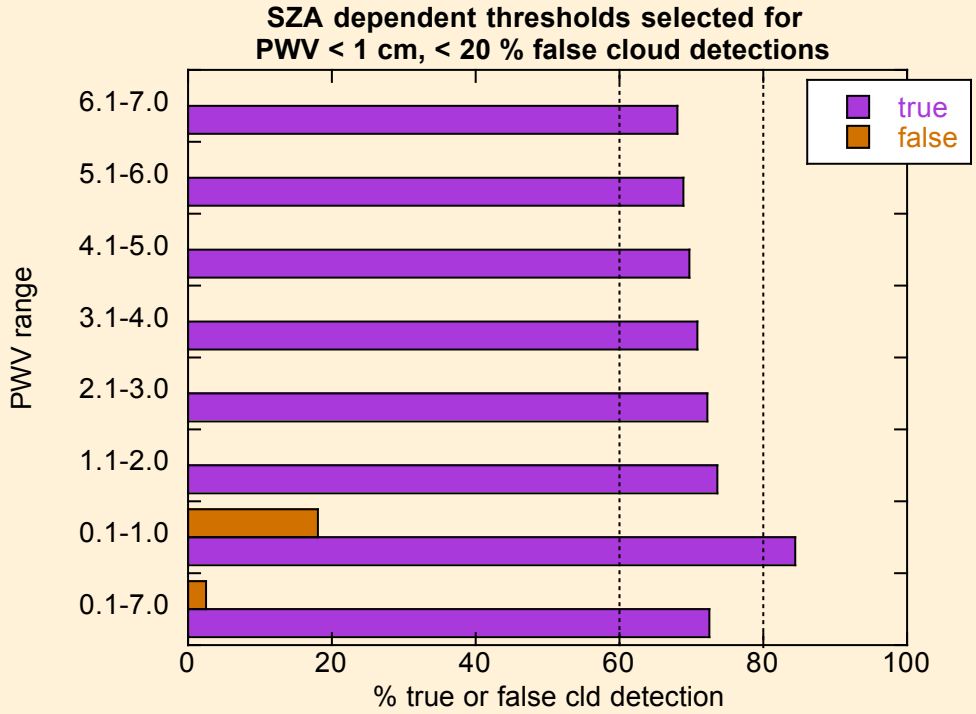
- Runs with the above atmospheres, sfc albedos, and SZAs were also performed for clear skies (~80 K runs)

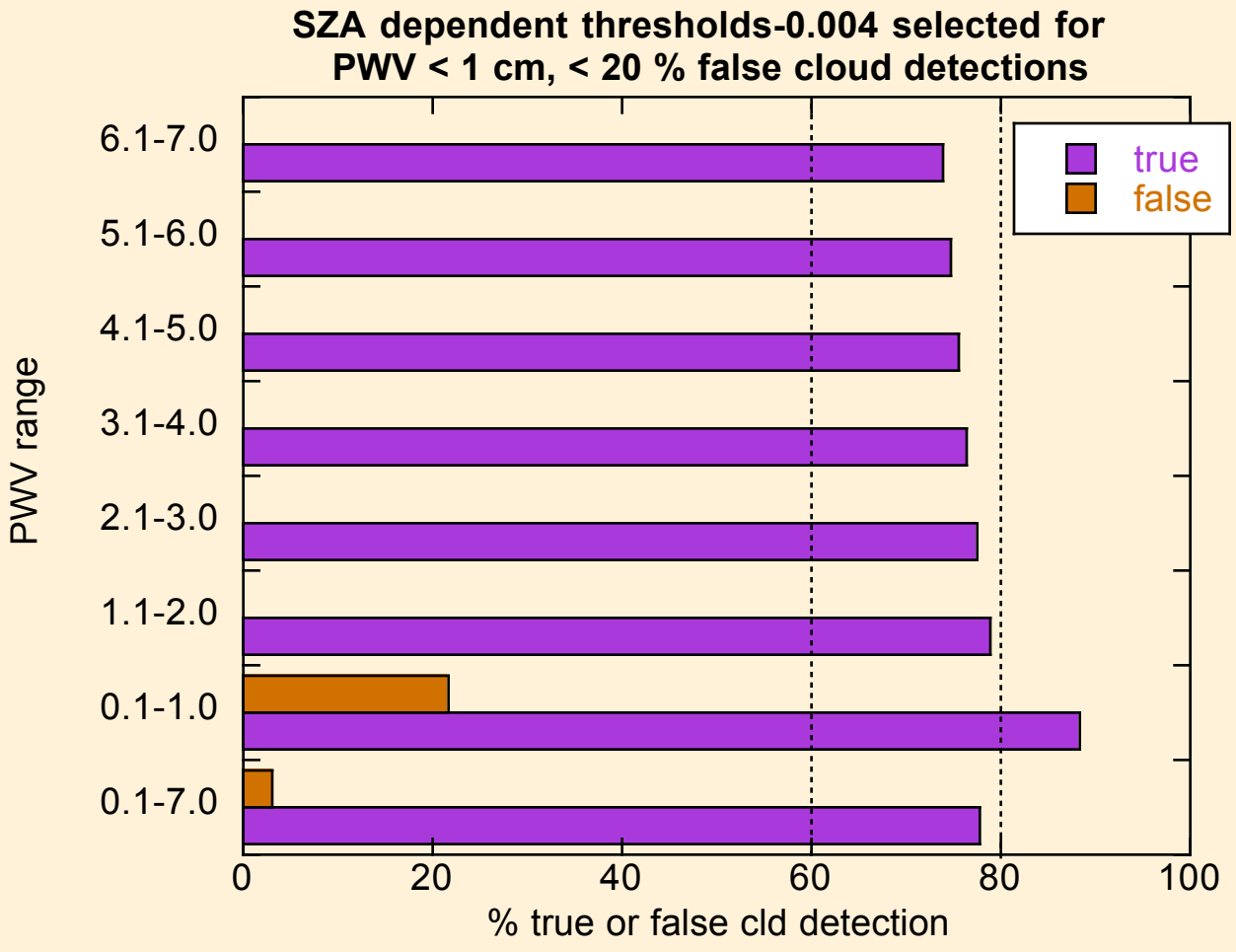
Tool courtesy of Kerry Meyer

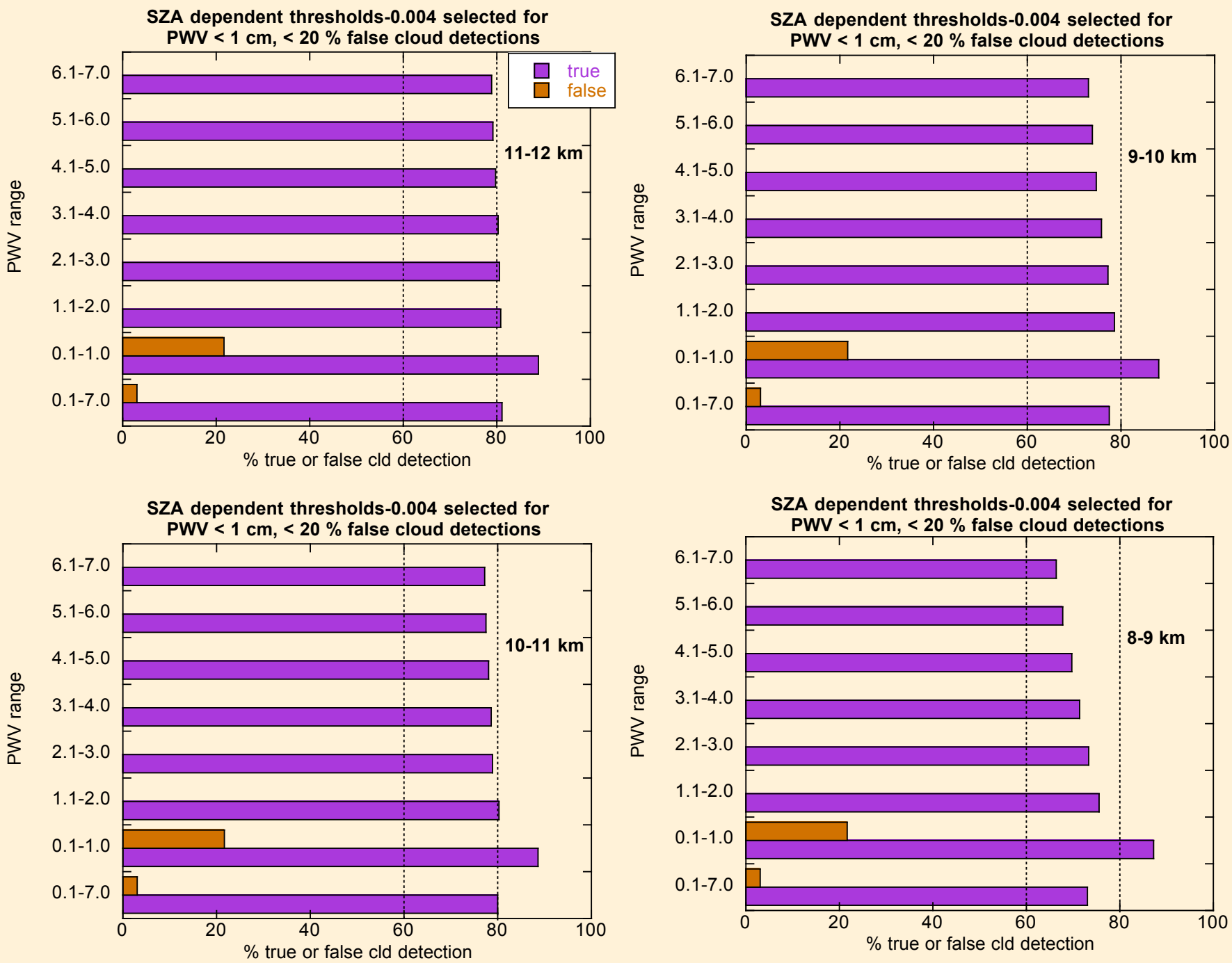

Rsfc=0.4, 0.1 cm < PWV < 1.0 cm, < 20% false cloud detections
1.38 µm reflectance threshold
% of true cld detection
0.05
0.04
0.03
0.02
0.01
0
100
90
80
70
60
50
0
0.2
0.4
0.6
0.8
1

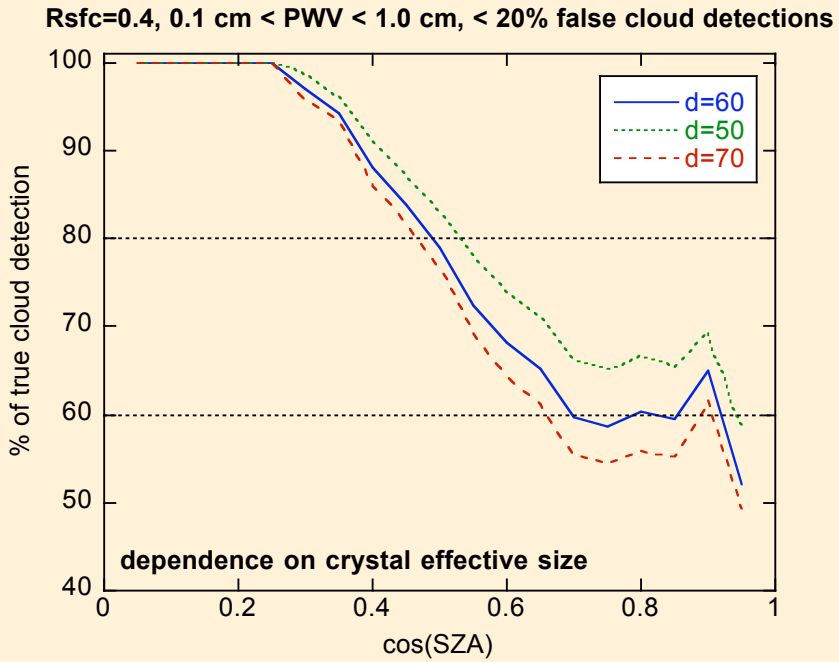

SZA dependent thresholds selected for Rsfc=0.4,
PWV < 1 cm, < 20 % false cloud detections
PWV range
6.1-7.0
5.1-6.0
4.1-5.0
3.1-4.0
2.1-3.0
1.1-2.0
0.1-1.0
0.1-7.0
true
false
0
20
40
60
80
100
% true or false cld detection

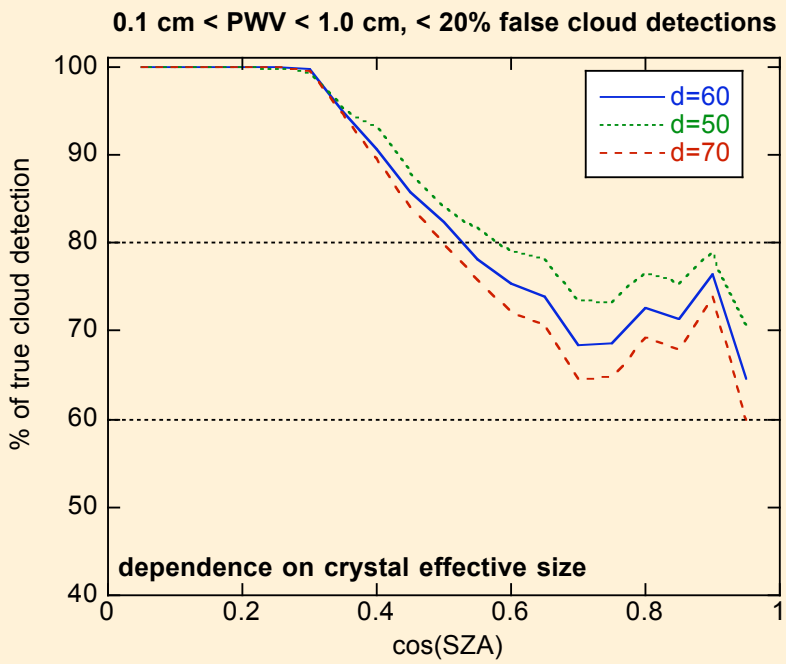

0.1 cm < PWV < 1.0 cm, < 20% false cloud detections
1.38 µm refl. threshold
% of true cld detection
1.38 µm reflectance threshold
% of true cld detection
cos(SZA)
0.05
0.04
0.03
0.02
0.01
0
100
90
80
70
60
50
0
0.2
0.4
0.6
0.8
1


SZA dependent thresholds selected for
PWV < 1 cm, < 20 % false cloud detections
true
false
PWV range
6.1-7.0
5.1-6.0
4.1-5.0
3.1-4.0
2.1-3.0
1.1-2.0
0.1-1.0
0.1-7.0
0
20
40
60
80
100
% true or false cld detection


SZA dependent thresholds-0.004 selected for
PWV < 1 cm, < 20 % false cloud detections
PWV range
6.1-7.0
5.1-6.0
4.1-5.0
3.1-4.0
2.1-3.0
1.1-2.0
0.1-1.0
0.1-7.0
0
20
40
60
80
100
% true or false cld detection
true
false

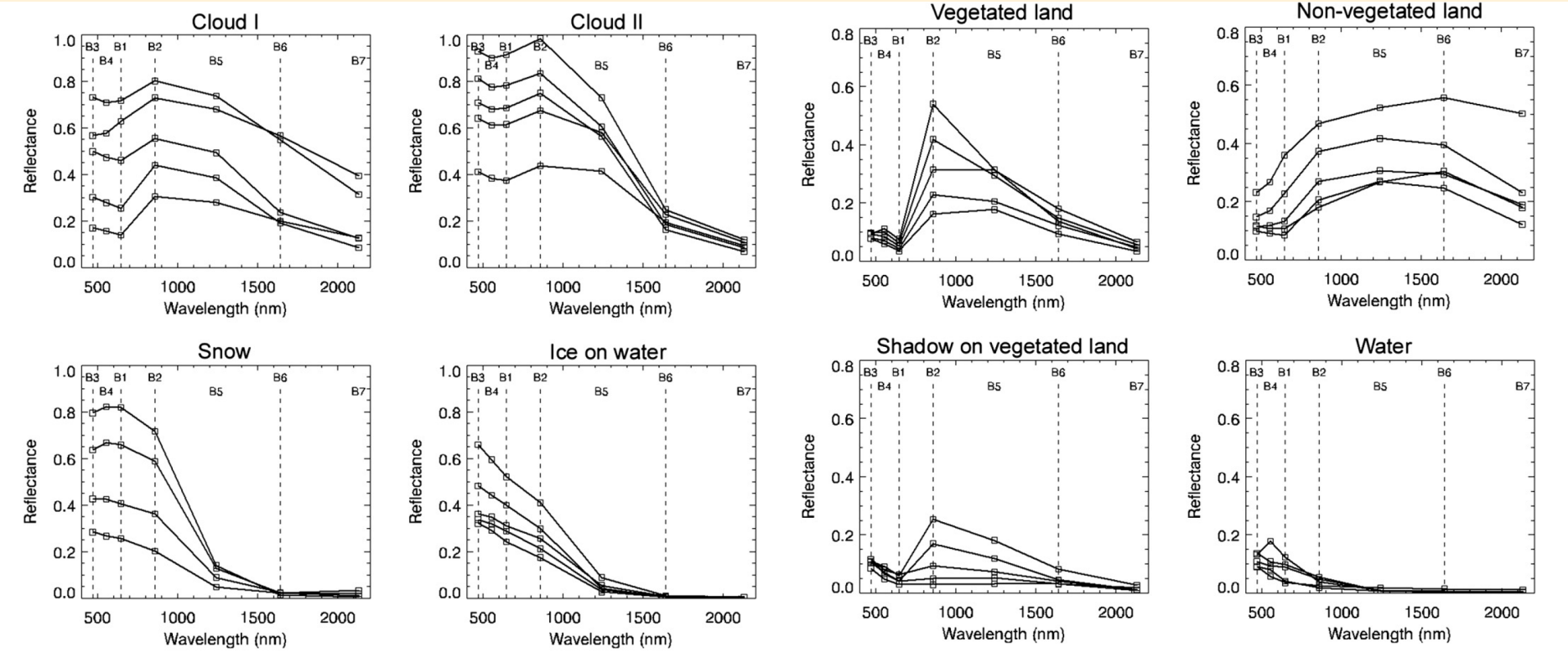

SZA dependent thresholds-0.004 selected for
PWV < 1 cm, < 20 % false cloud detections
true
false
11-12 km
9-10 km
10-11 km
8-9 km
PWV range
6.1-7.0
5.1-6.0
4.1-5.0
3.1-4.0
2.1-3.0
1.1-2.0
0.1-1.0
0.1-7.0
0
20
40
60
80
100
% true or false cld detection


Rsfc=0.4, 0.1 cm < PWV < 1.0 cm, < 20% false cloud detections
% of true cloud detection
cos(SZA)
d=60
d=50
d=70
dependence on crystal effective size
100
90
80
70
60
50
40
0
0.2
0.4
0.6
0.8
1

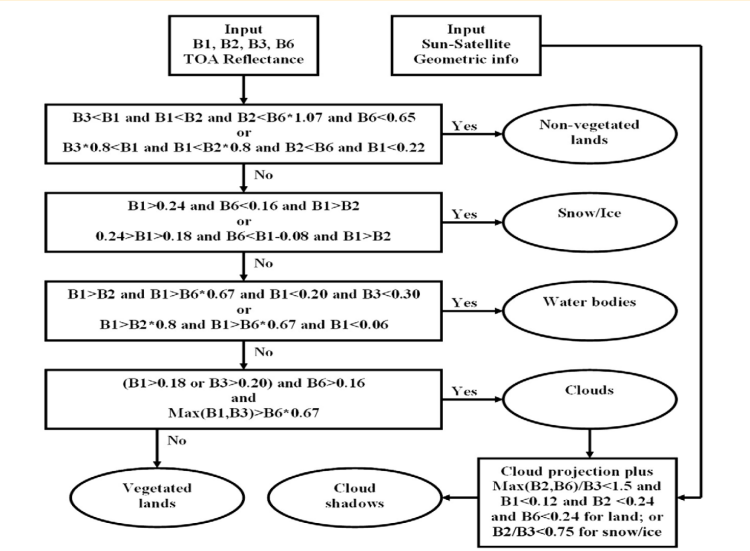

0.1 cm < PWV < 1.0 cm, < 20% false cloud detections
% of true cloud detection
cos(SZA)
d=60
d=50
d=70
dependence on crystal effective size
100
90
80
70
60
50
40
0
0.2
0.4
0.6
0.8
1

Simple cloud mask tests

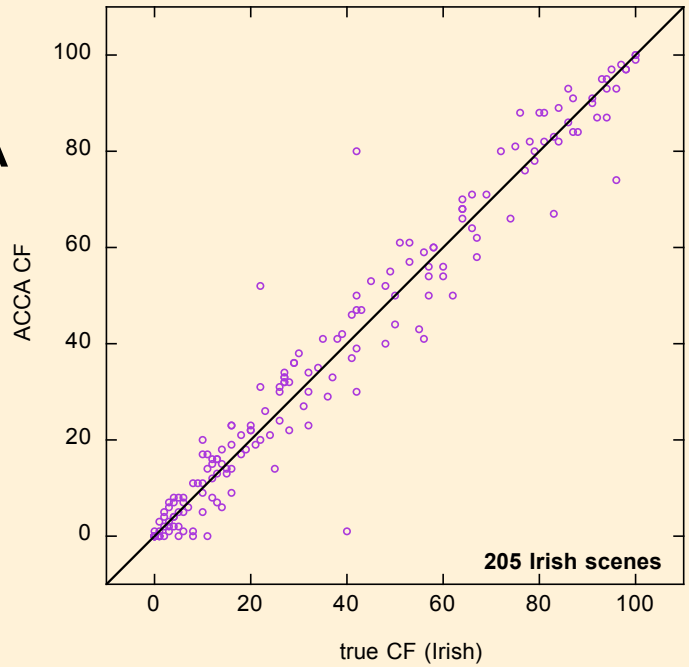
A simple algorithm with no thermal



Luo et al., RSE (2008)

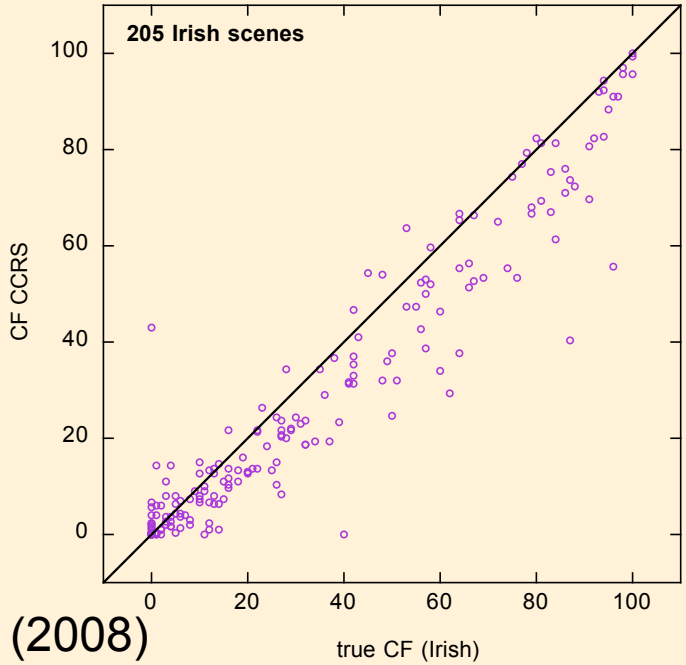


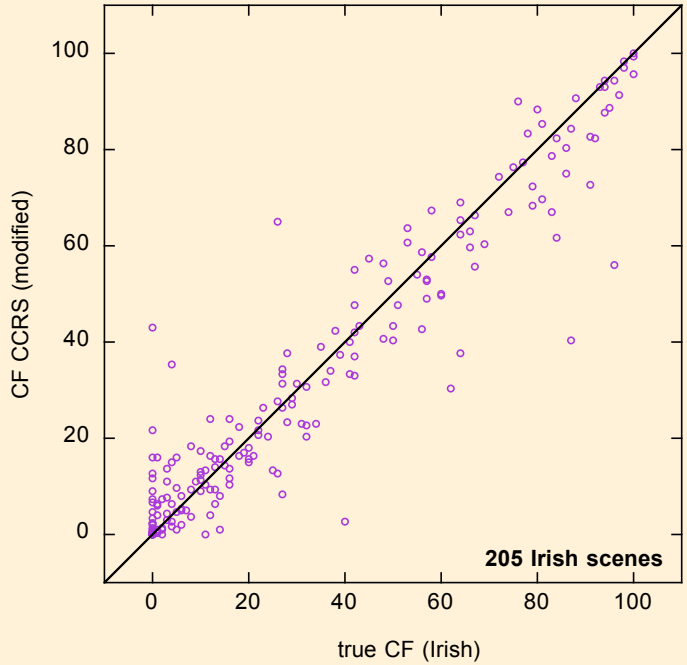
ACCA



Scara

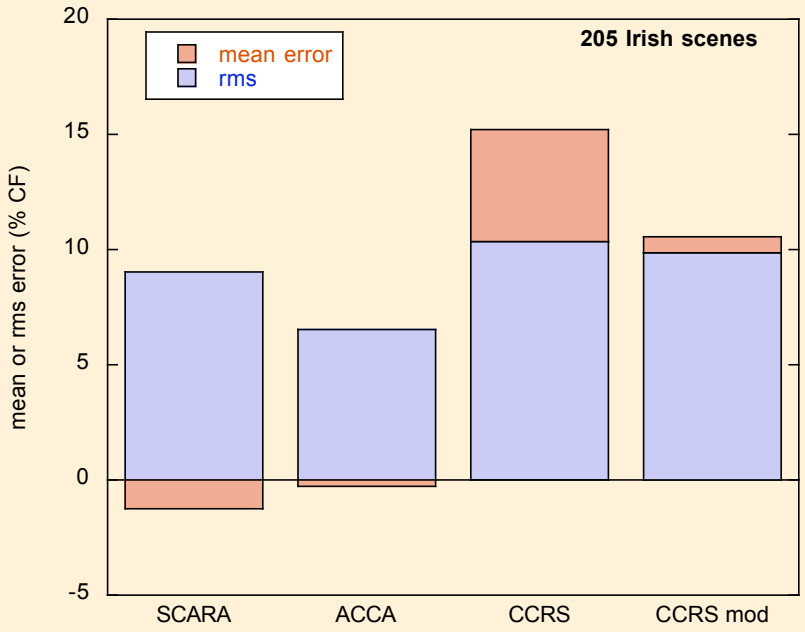
CCRS



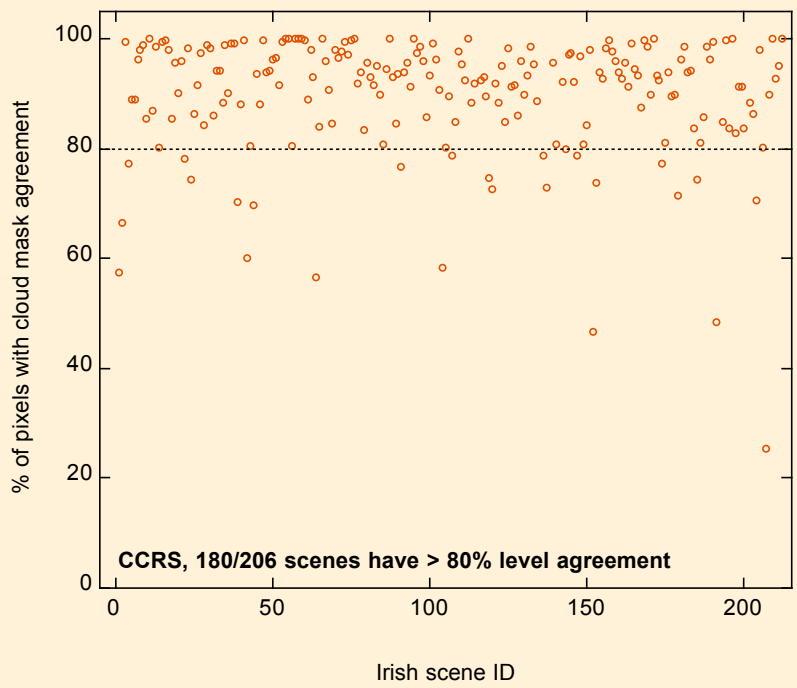


CCRS mod

Luo et al. (2008)



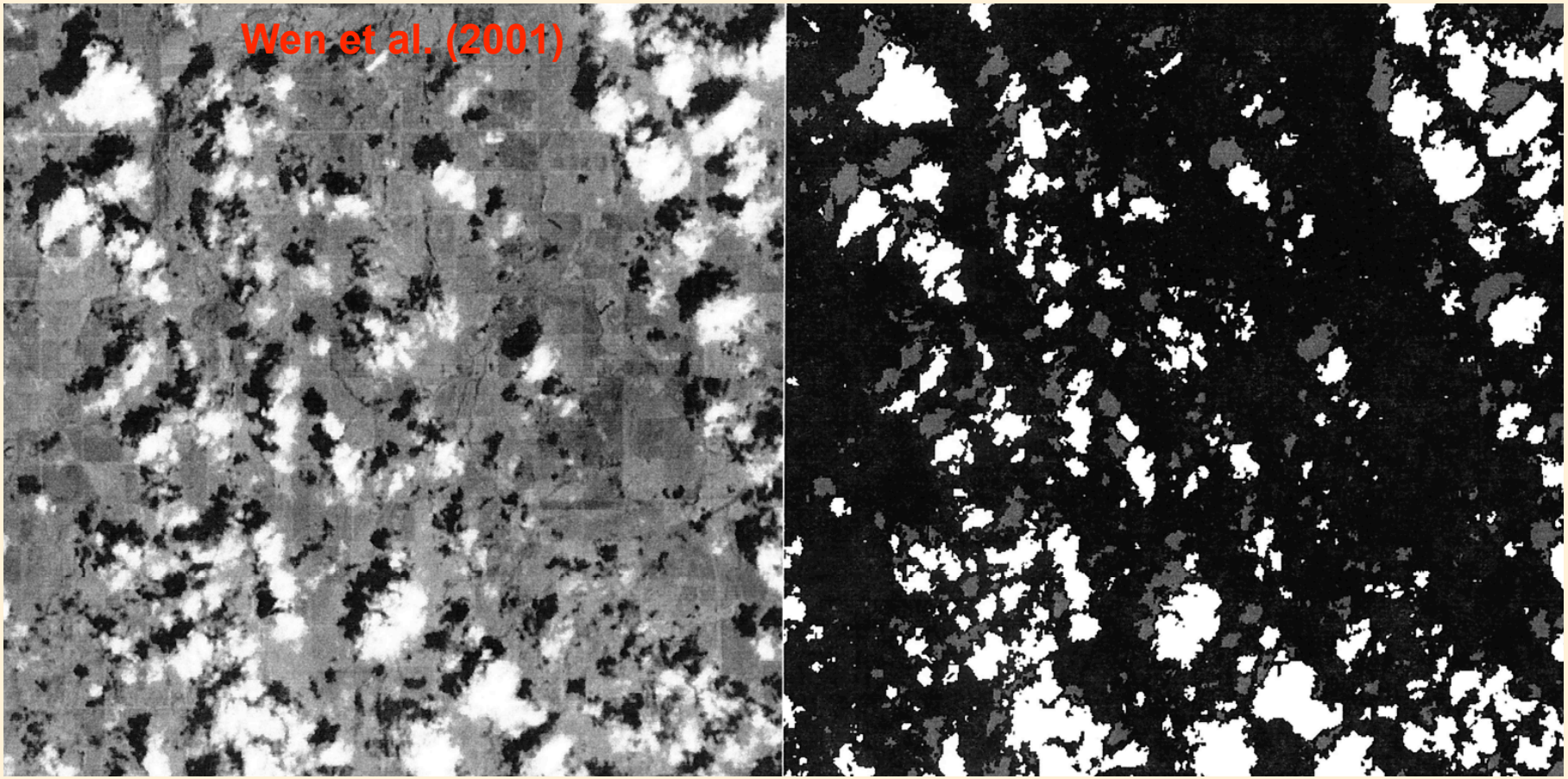
Score comparison



Mask comparison

Cloud shadows

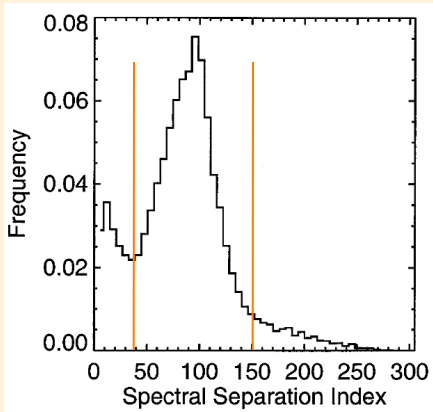
Spectral Separation Index (SSI)



$$SSI = \frac{\mathbf{P} \cdot \mathbf{I}}{r_2^2}$$

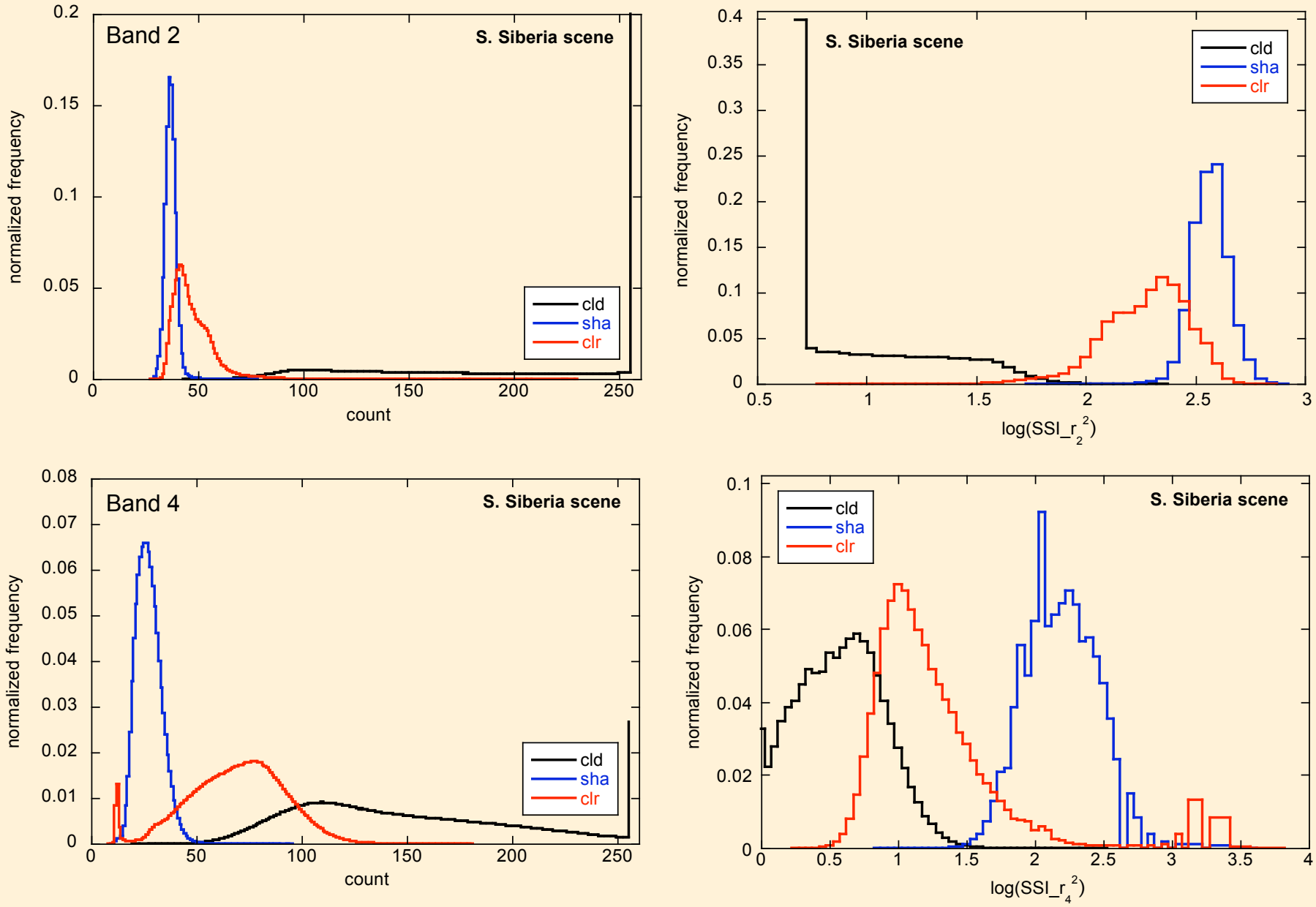
$$\mathbf{P} = \frac{(r_2, r_4)}{\sqrt{r_2^2 + r_4^2}}$$

$$\mathbf{I} = \left(\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}} \right)^{\mathrm{T}}$$

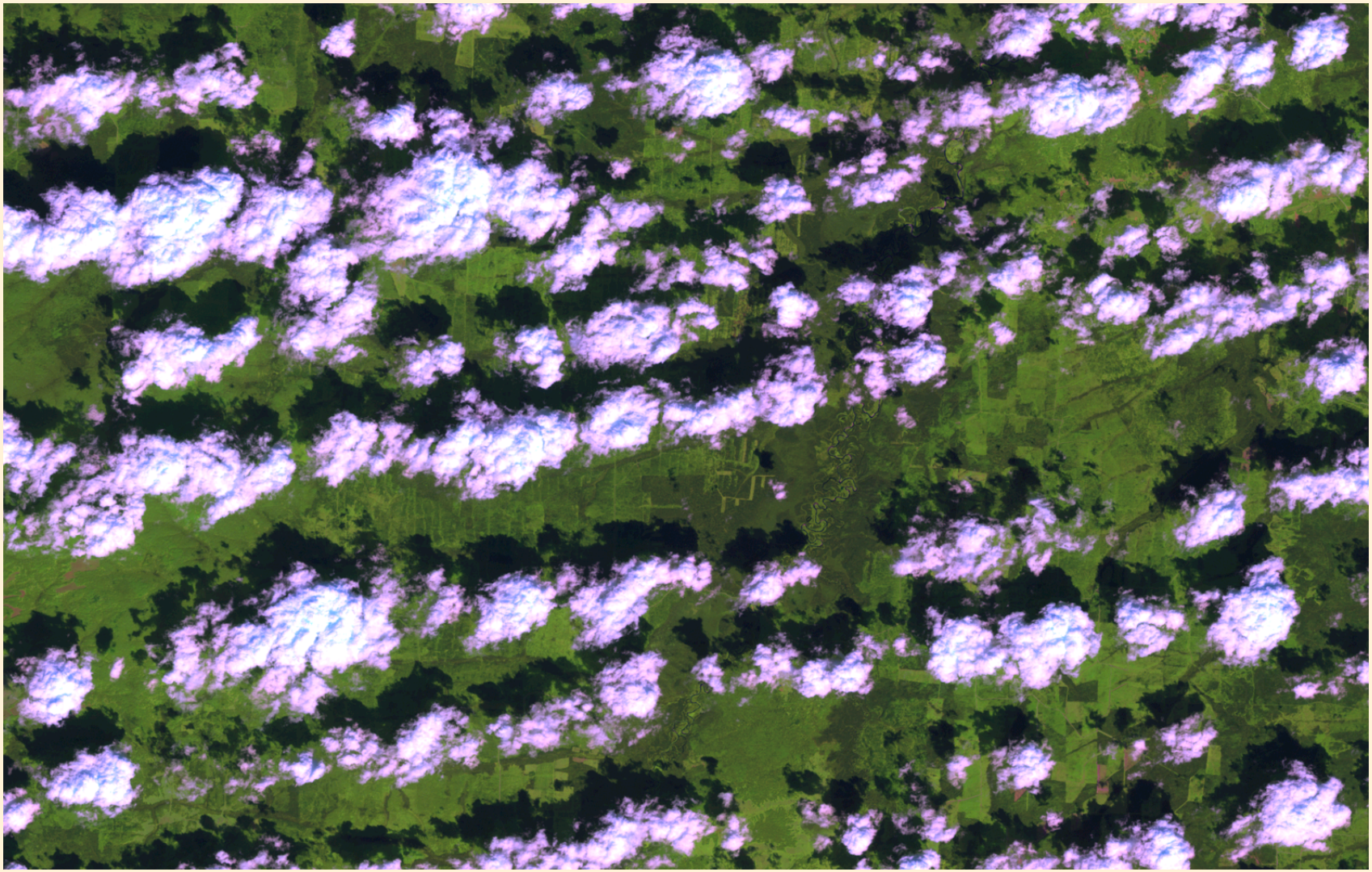


$$SSI = \frac{\dfrac{r_2 + r_4}{\sqrt{2(r_2^2 + r_4^2)}}}{r_2^2}$$

Histogram analysis with a truth dataset

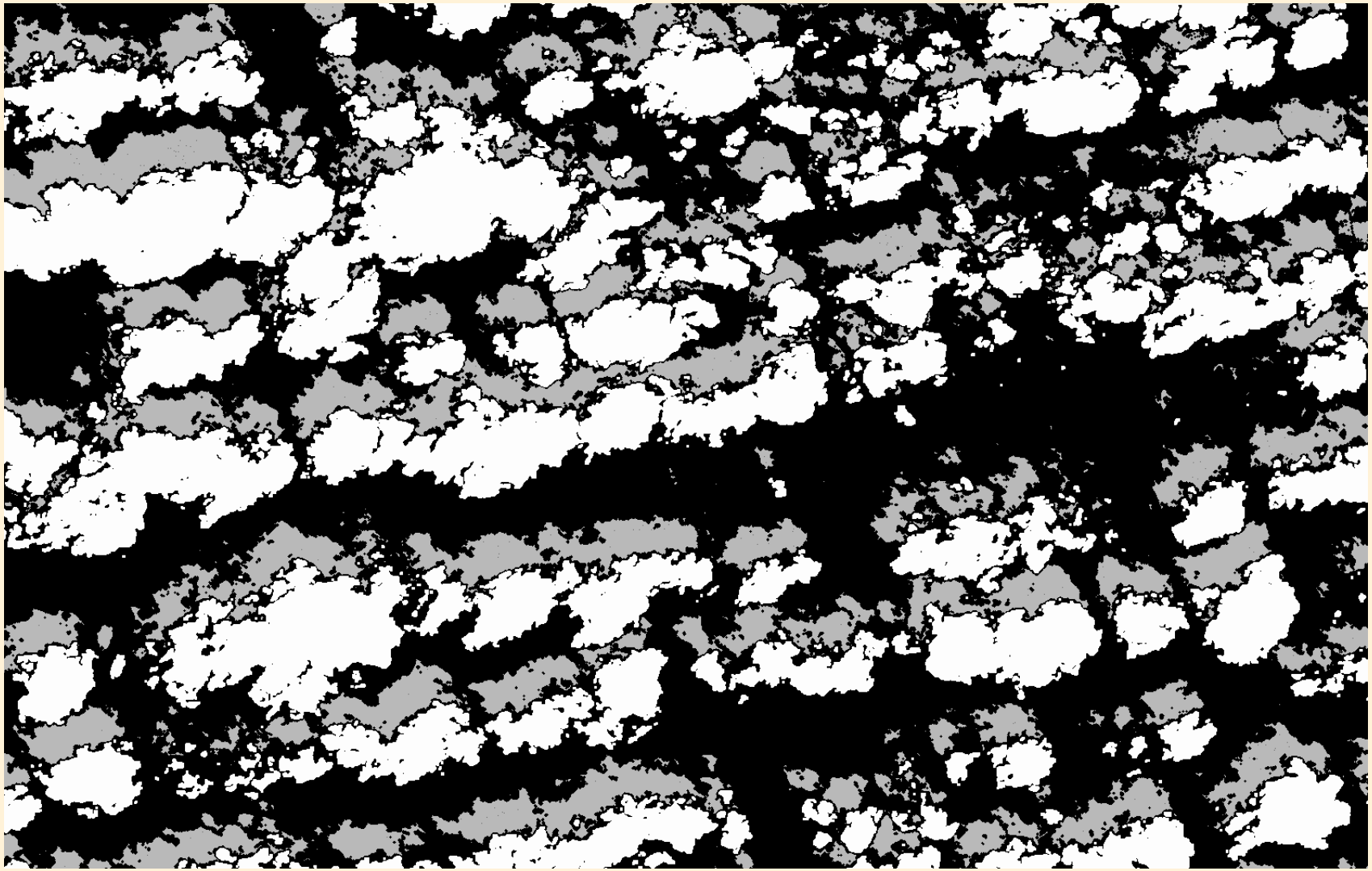


SSI revival



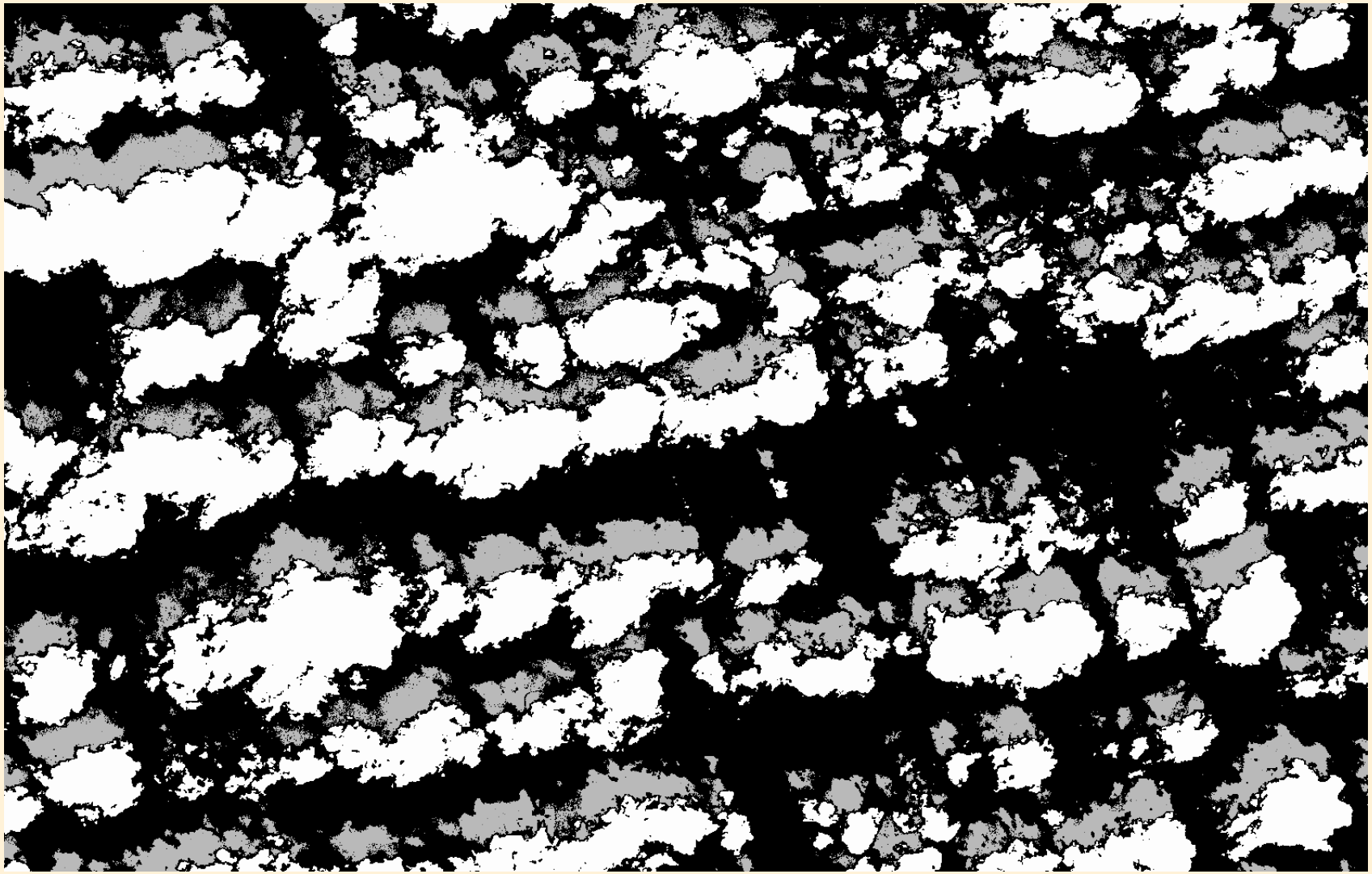
Portion of P143/R21 (southern Siberia), Aug. 3, 2001

SSI revival

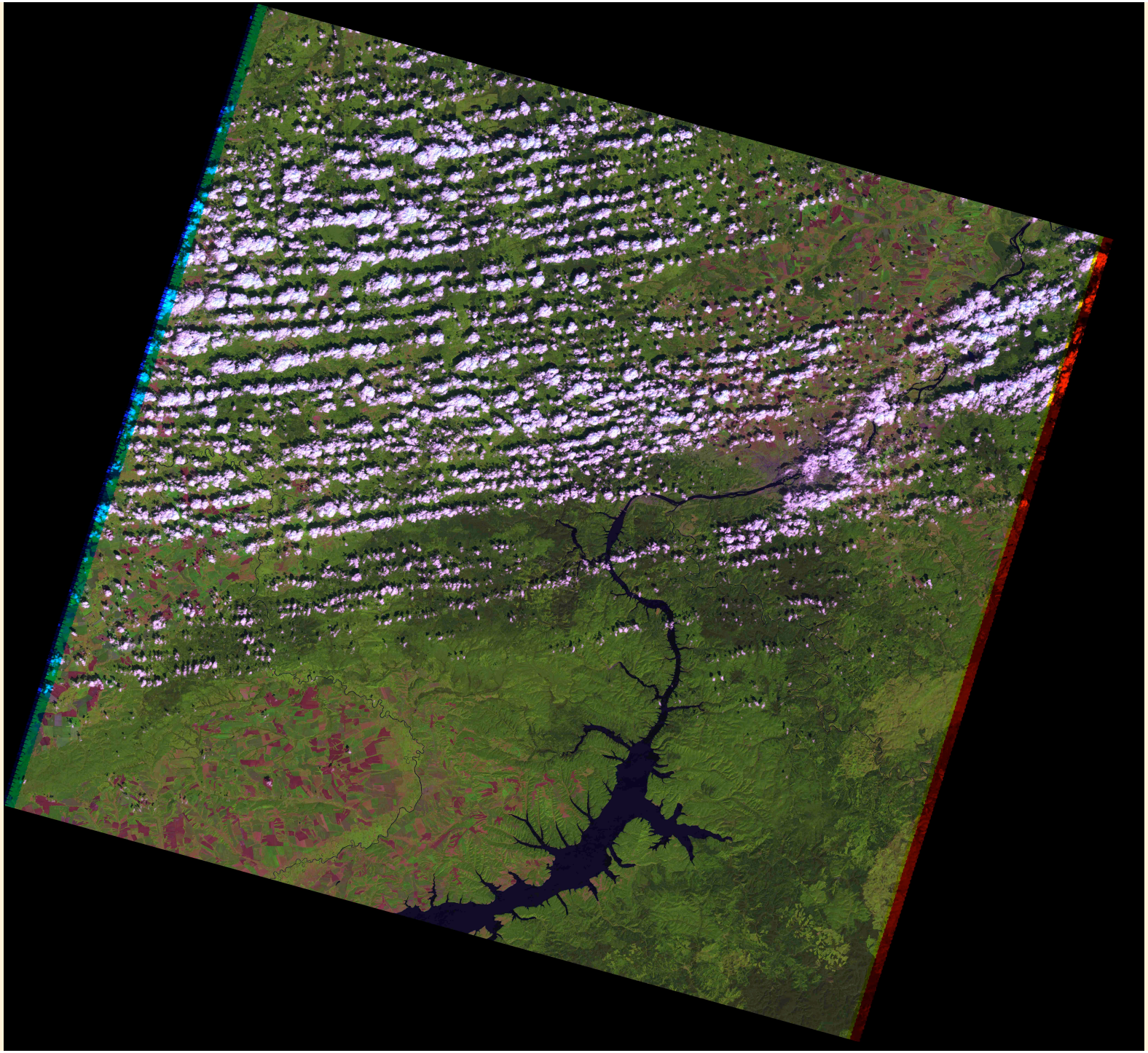


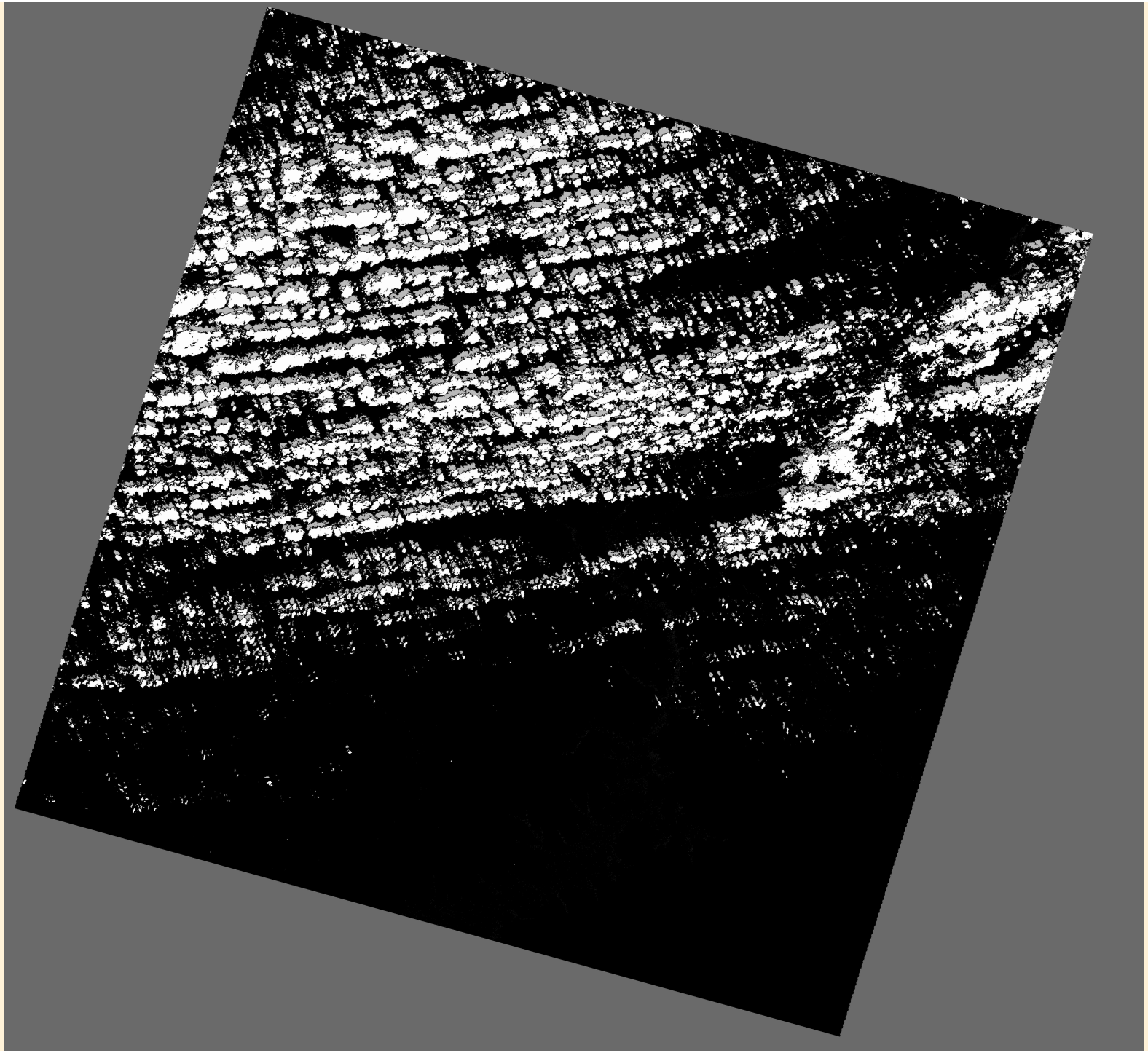
Cloud/shadow mask “truth”

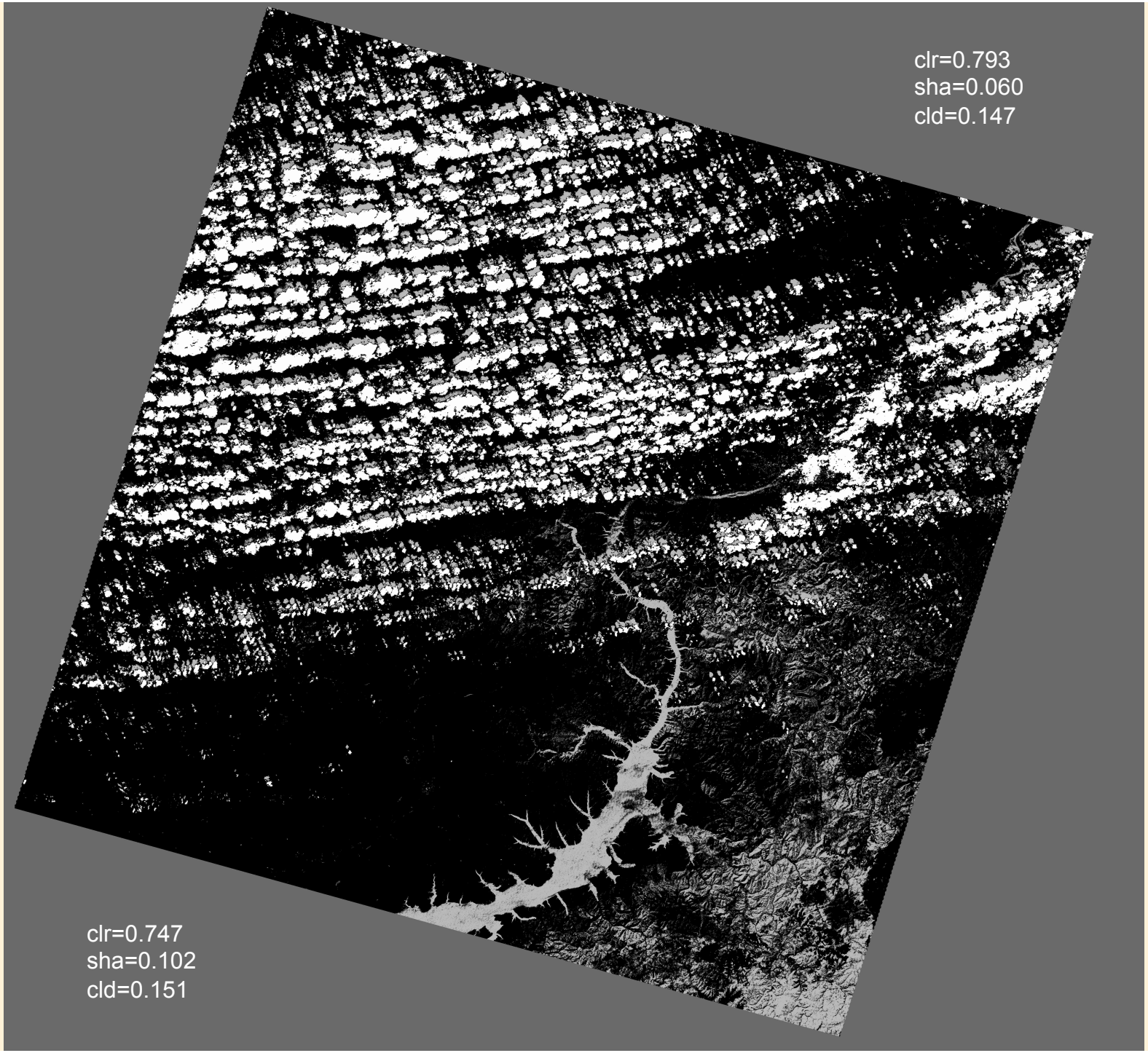
SSI revival



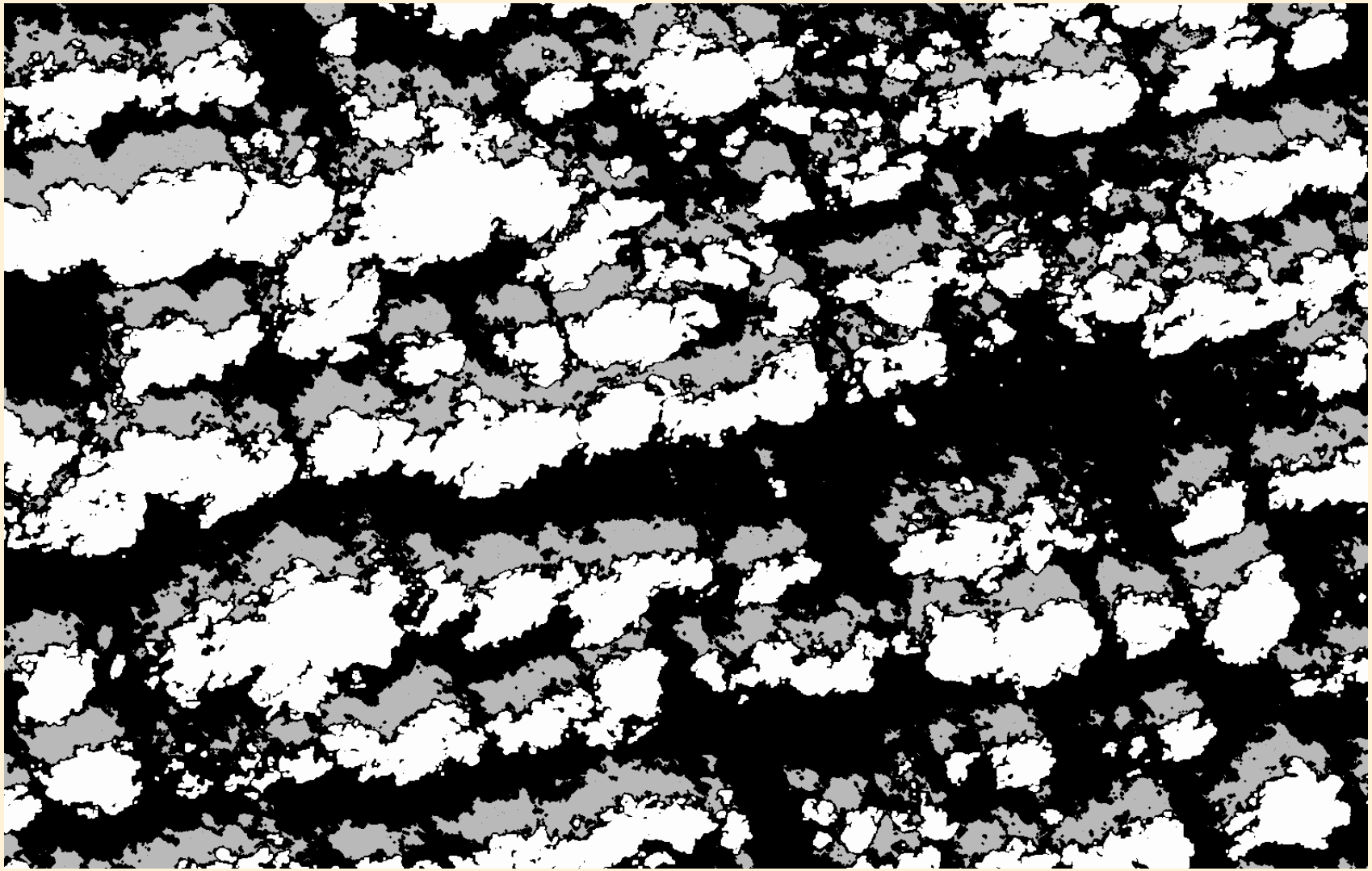
SSI-based cloud/shadow mask; SSI_{cld}=50, SSI_{sha}=316





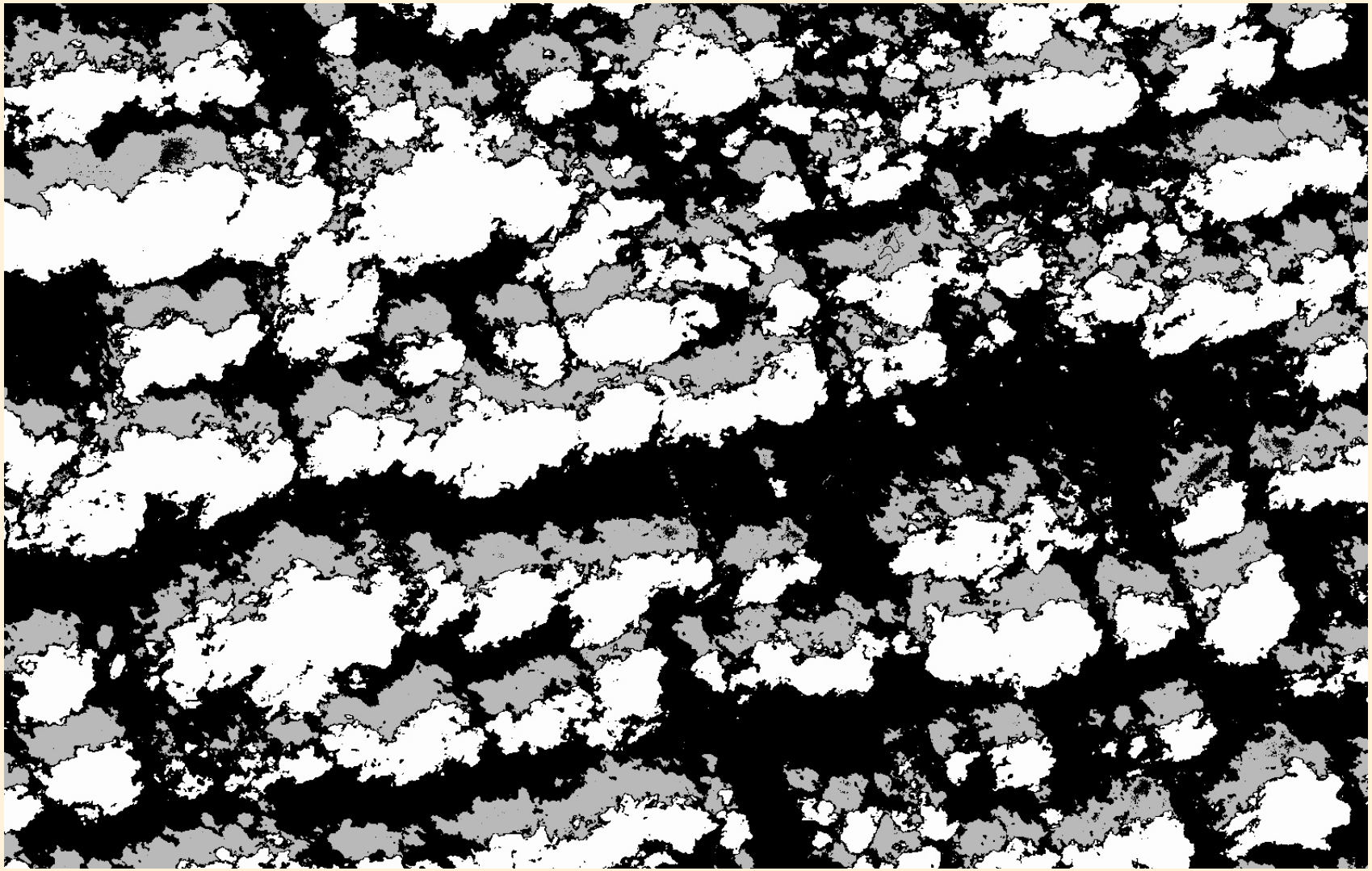

clr=0.793
sha=0.060
cld=0.147
clr=0.747
sha=0.102
cld=0.151

SSI revival

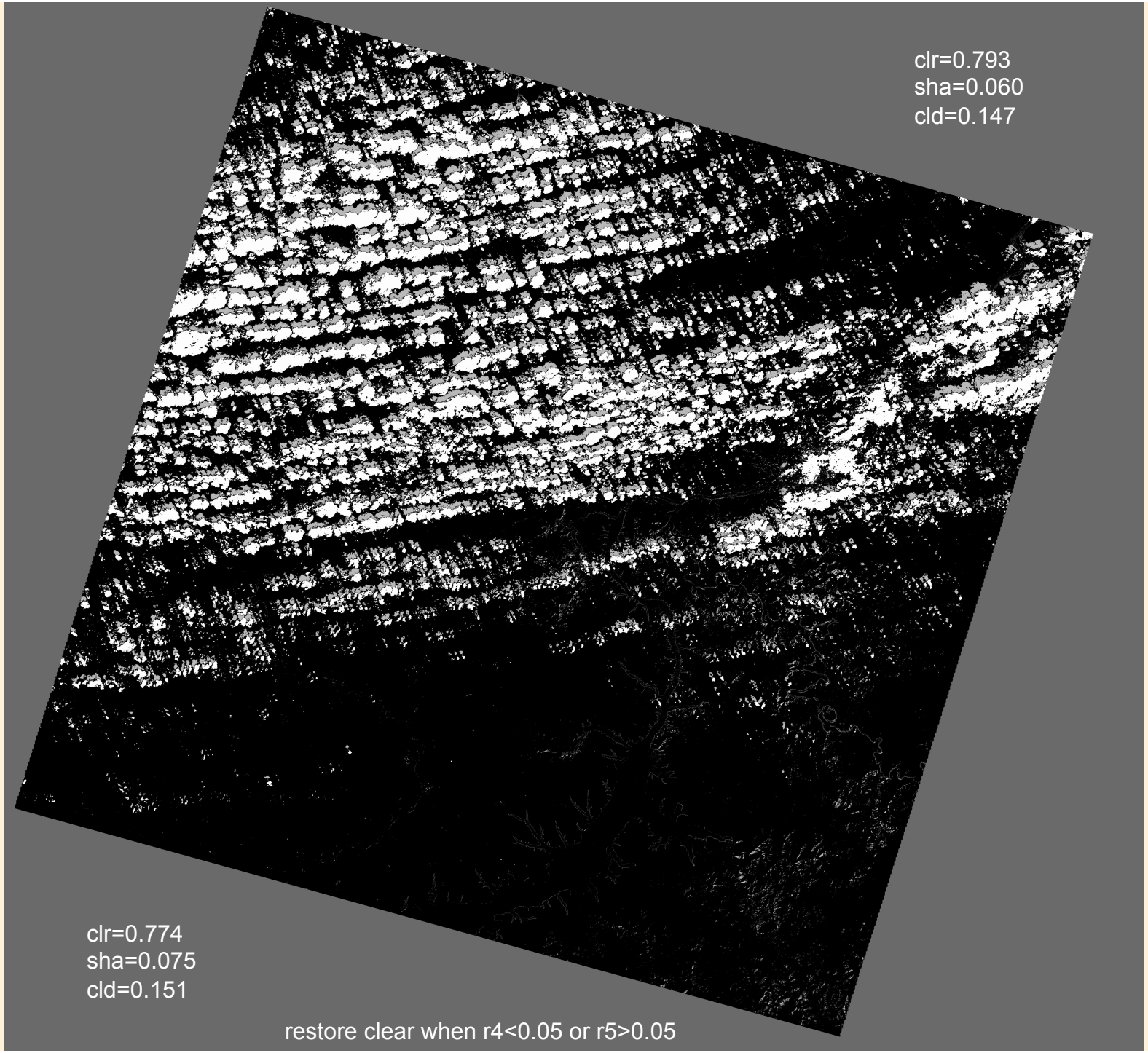


Cloud/shadow mask “truth”

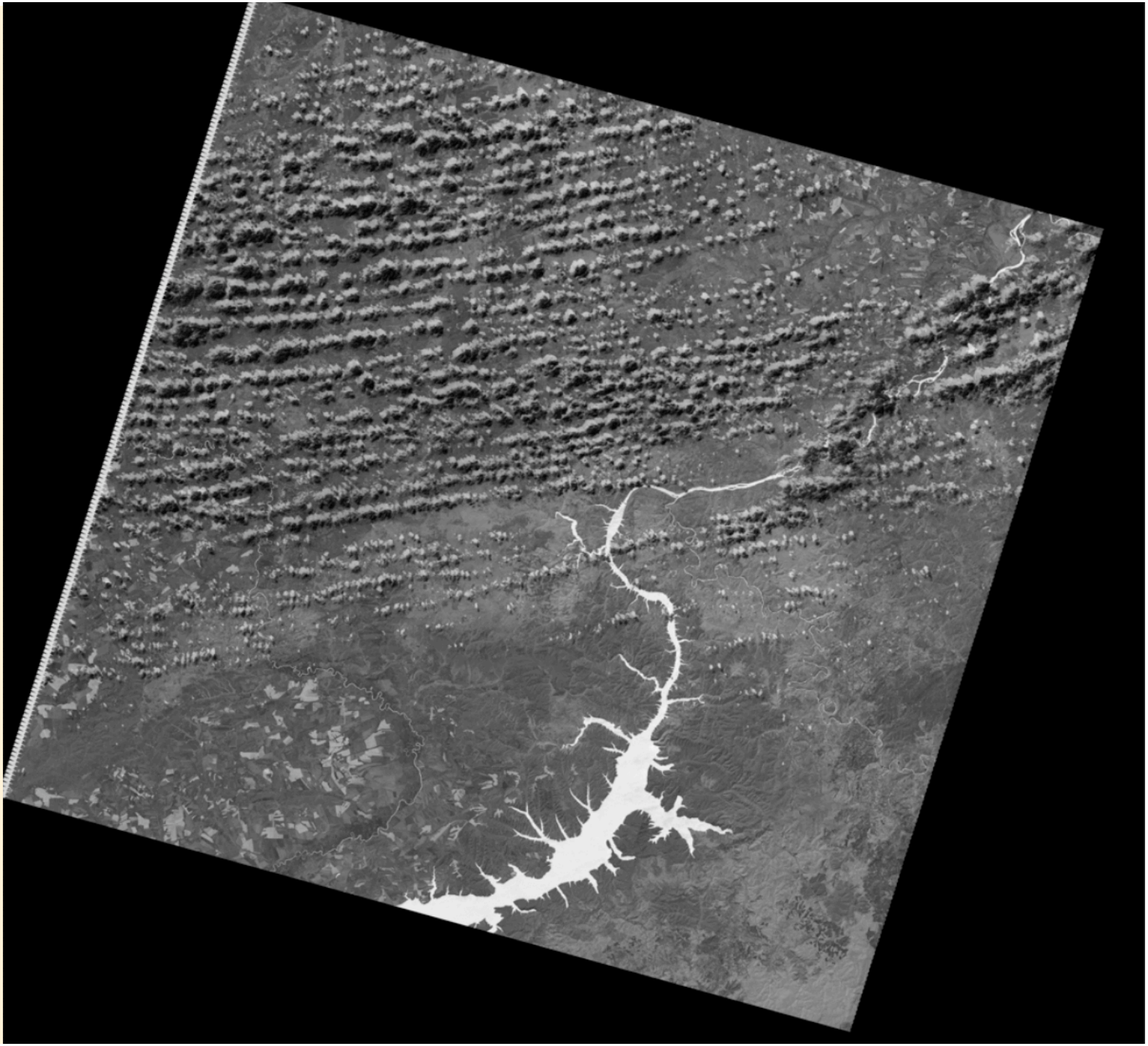
SSI revival



SSI-based cloud/shadow mask; SSI_{cld}=50, SSI_{sha}=251


clr=0.793
sha=0.060
cld=0.147
clr=0.774
sha=0.075
cld=0.151
restore clear when r4<0.05 or r5>0.05

$$SSI = \frac{\dfrac{r_2 + r_4}{\sqrt{2(r_2^2 + r_4^2)}}}{r_4^2}$$

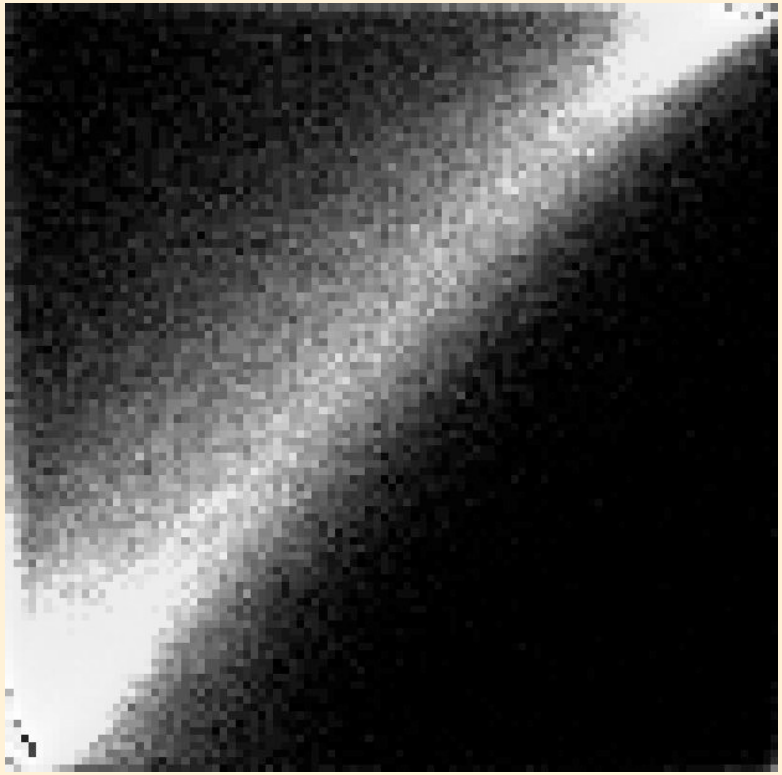


MODIS-L7/ACCA CF comparisons

MODIS-L7 comparisons (for LTAP modeling)

courtesy of John Gasch

MODIS CF



L7 ACCA CF

4 yrs of data (Sep05-Sep09), ~354 K scenes

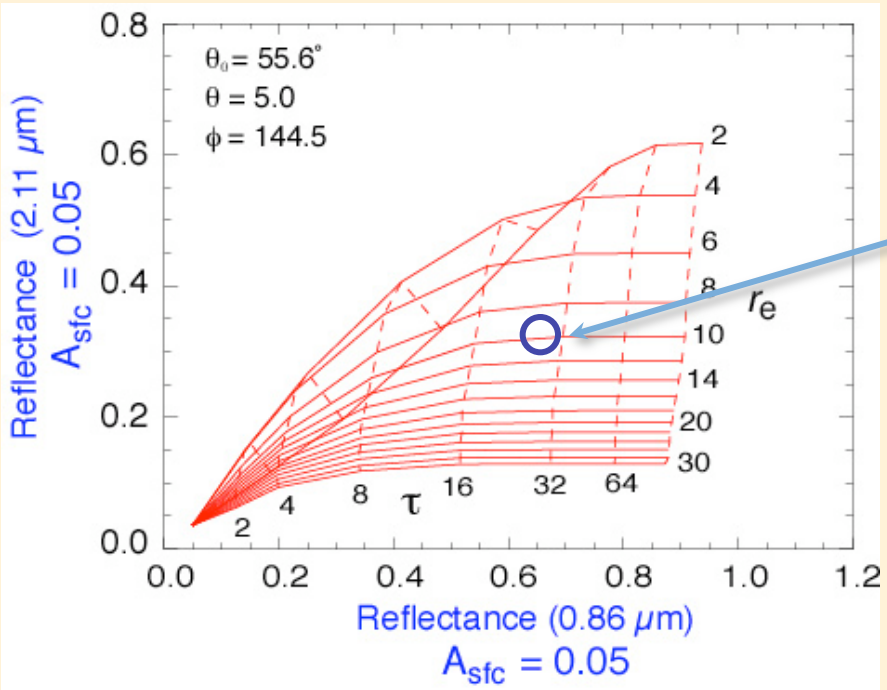
For a *Cloud Forecast Confidence* lookup table to be integrated into the LTAP.

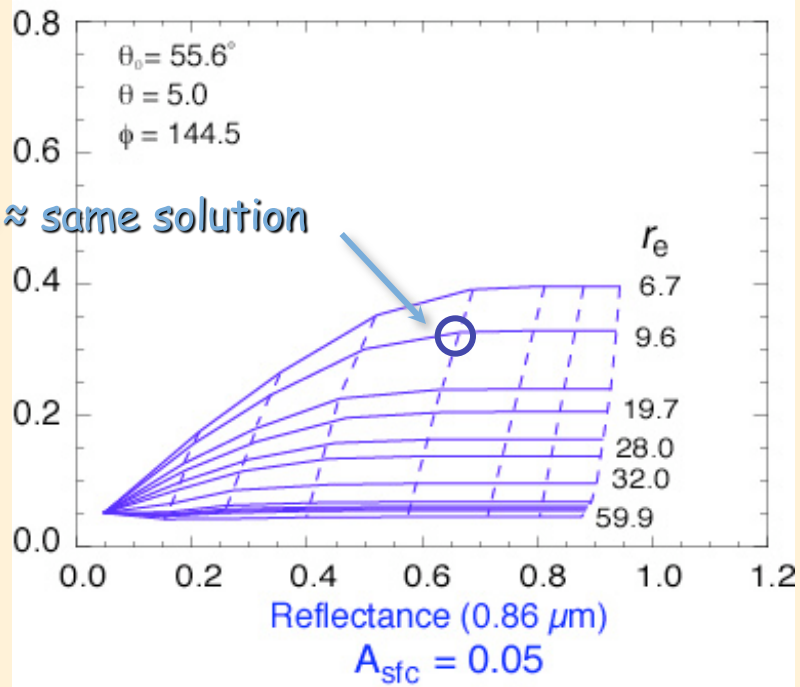
Appropriately normalized MODIS CFs will be used in LTAP simulations for candidate L7 scenes that were eventually not acquired

Cloud property retrievals

Cloud Optical & Microphysical Retrievals

Retrieval space examples



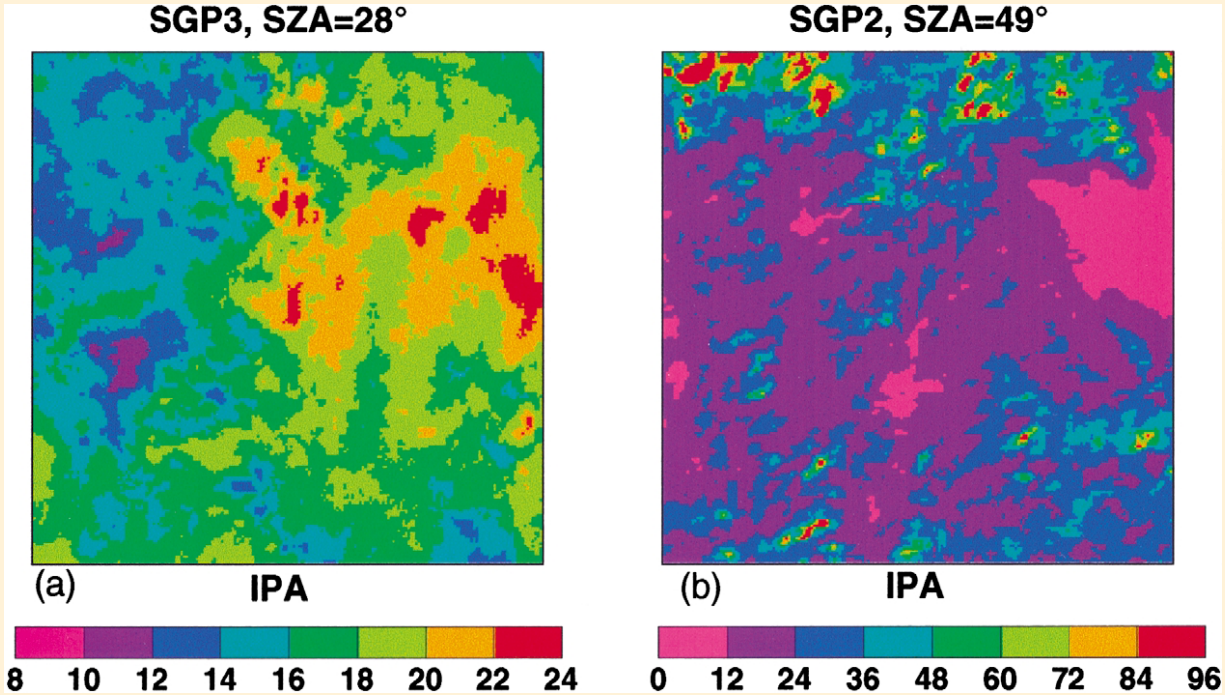


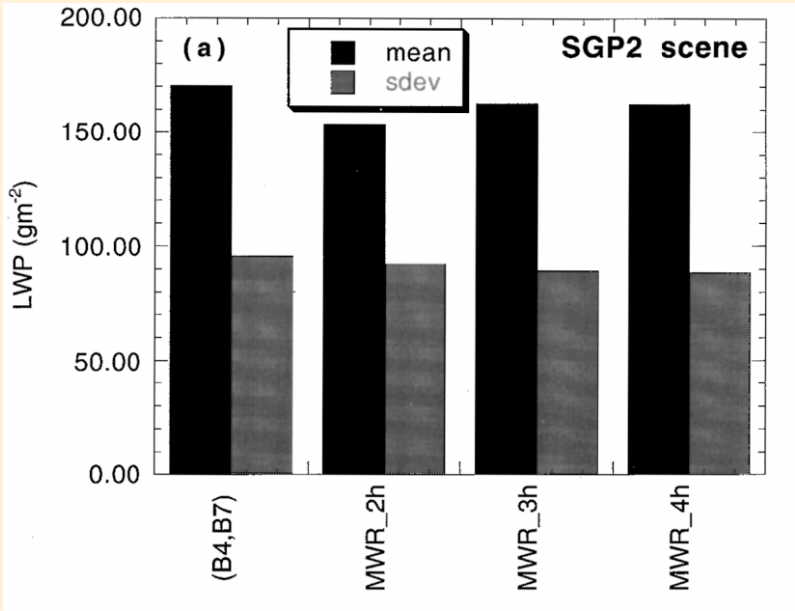
Liquid water cloud
ocean surface

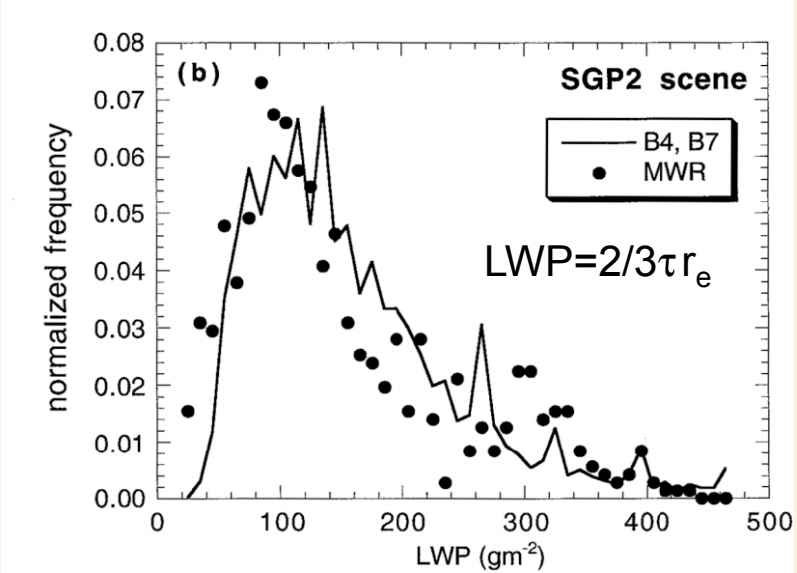
Ice cloud
ocean surface

Based on Nakajima and King (1990) algorithm

Landsat-7 examples (Cahalan, Oreopoulos et al., 2001)

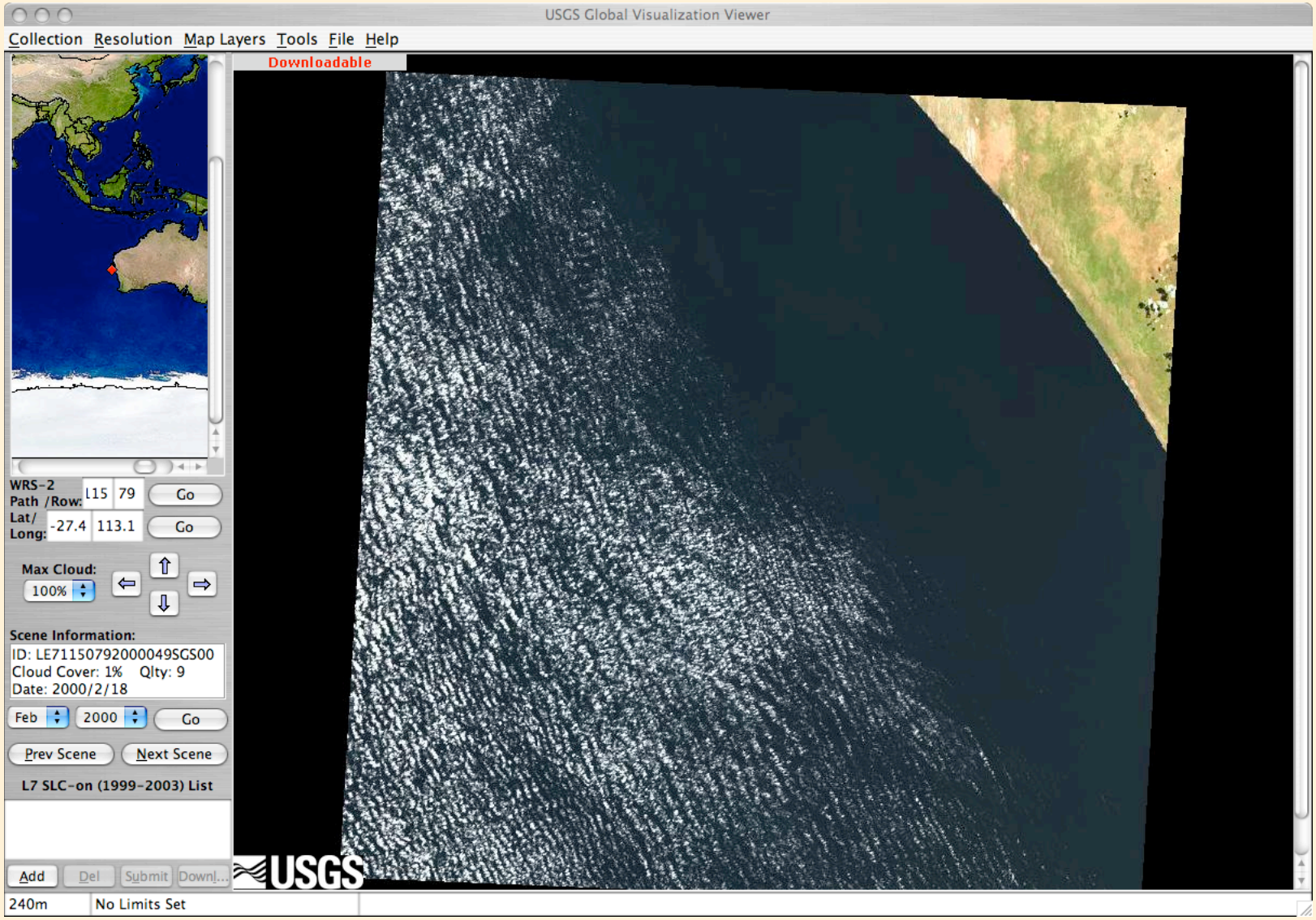






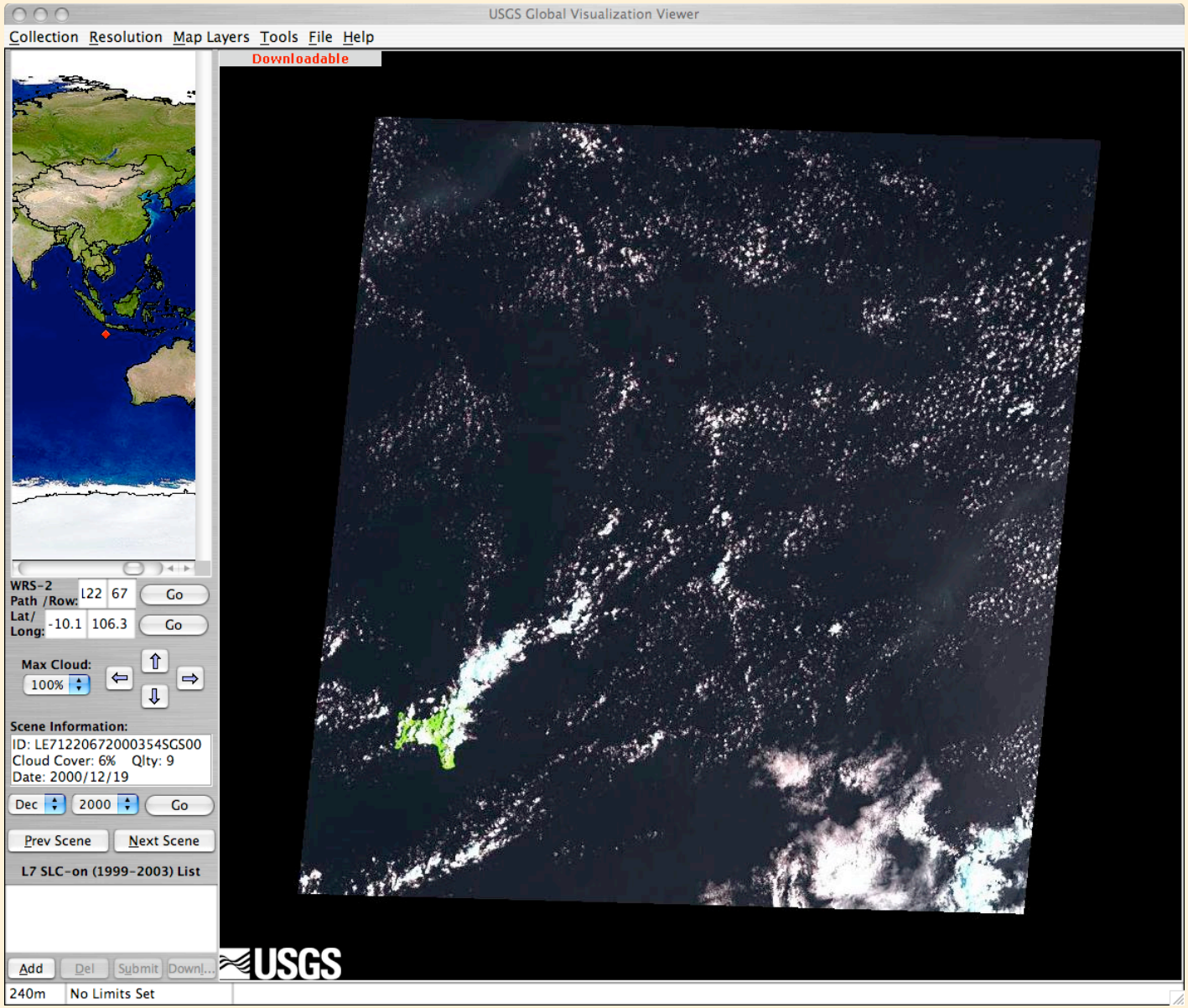
Additional slides

Marine cloud detection



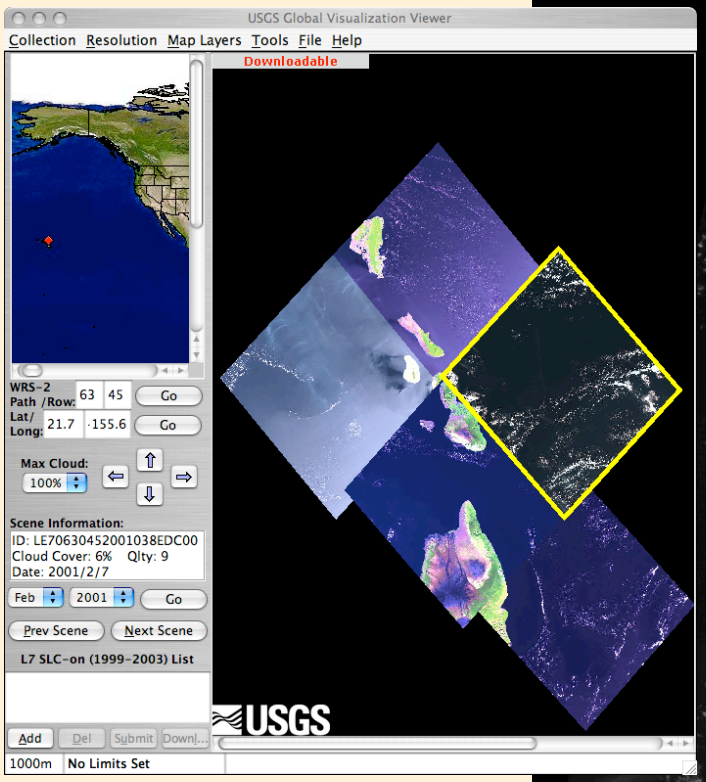
ACCA CF=1%

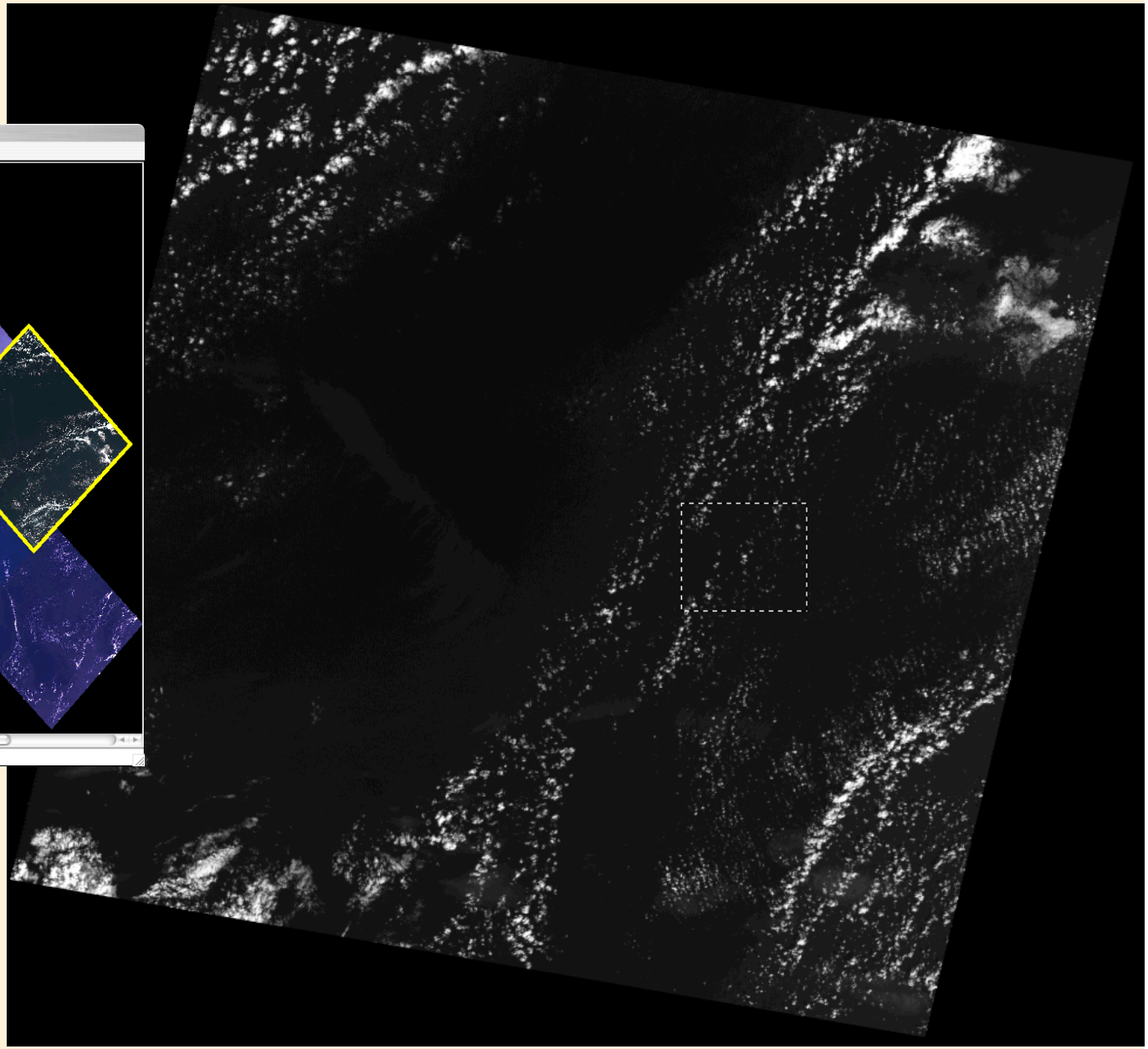
ACCA underestimates Cloud Cover!



ACCA CF=6%

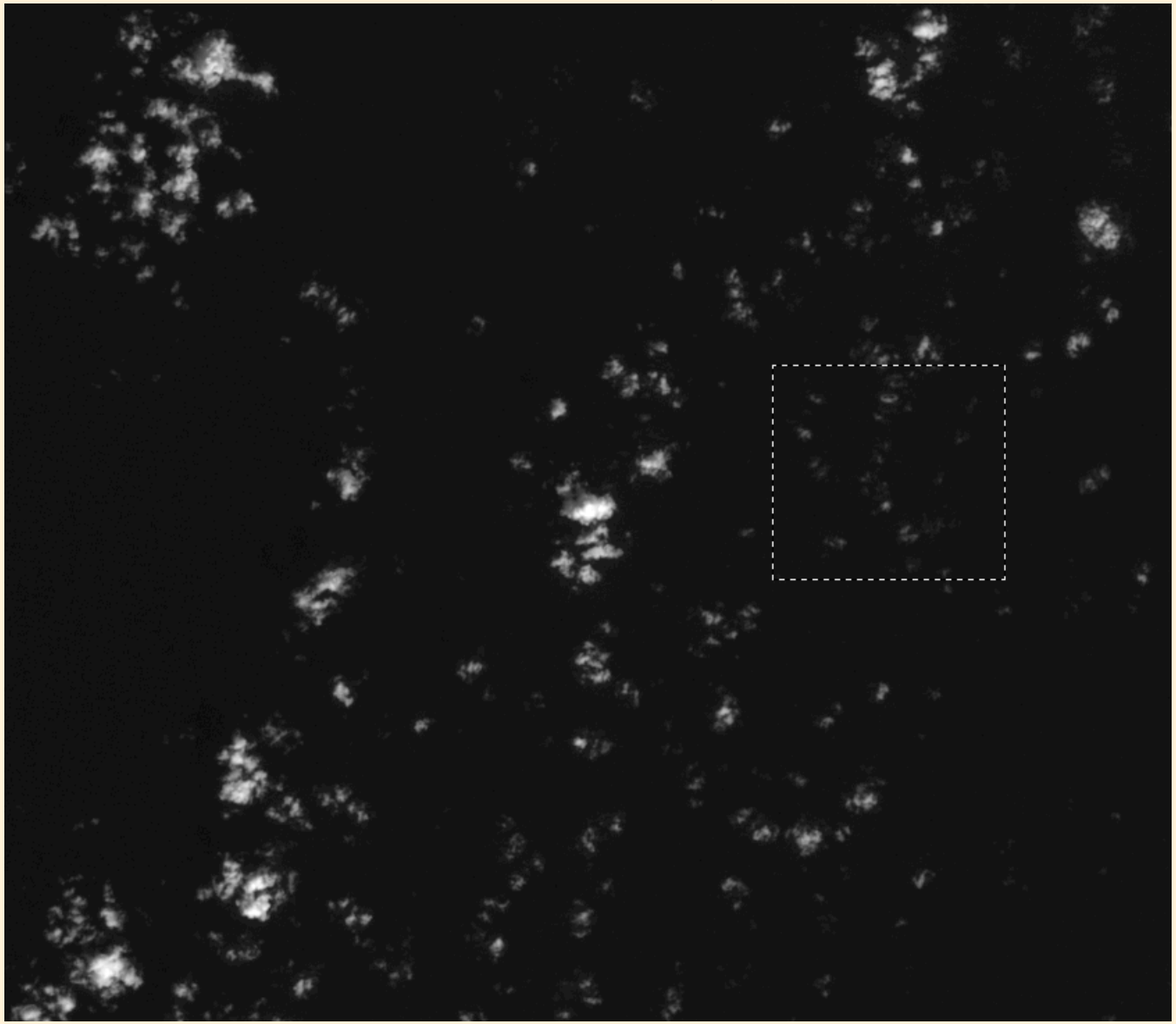
A more detailed look



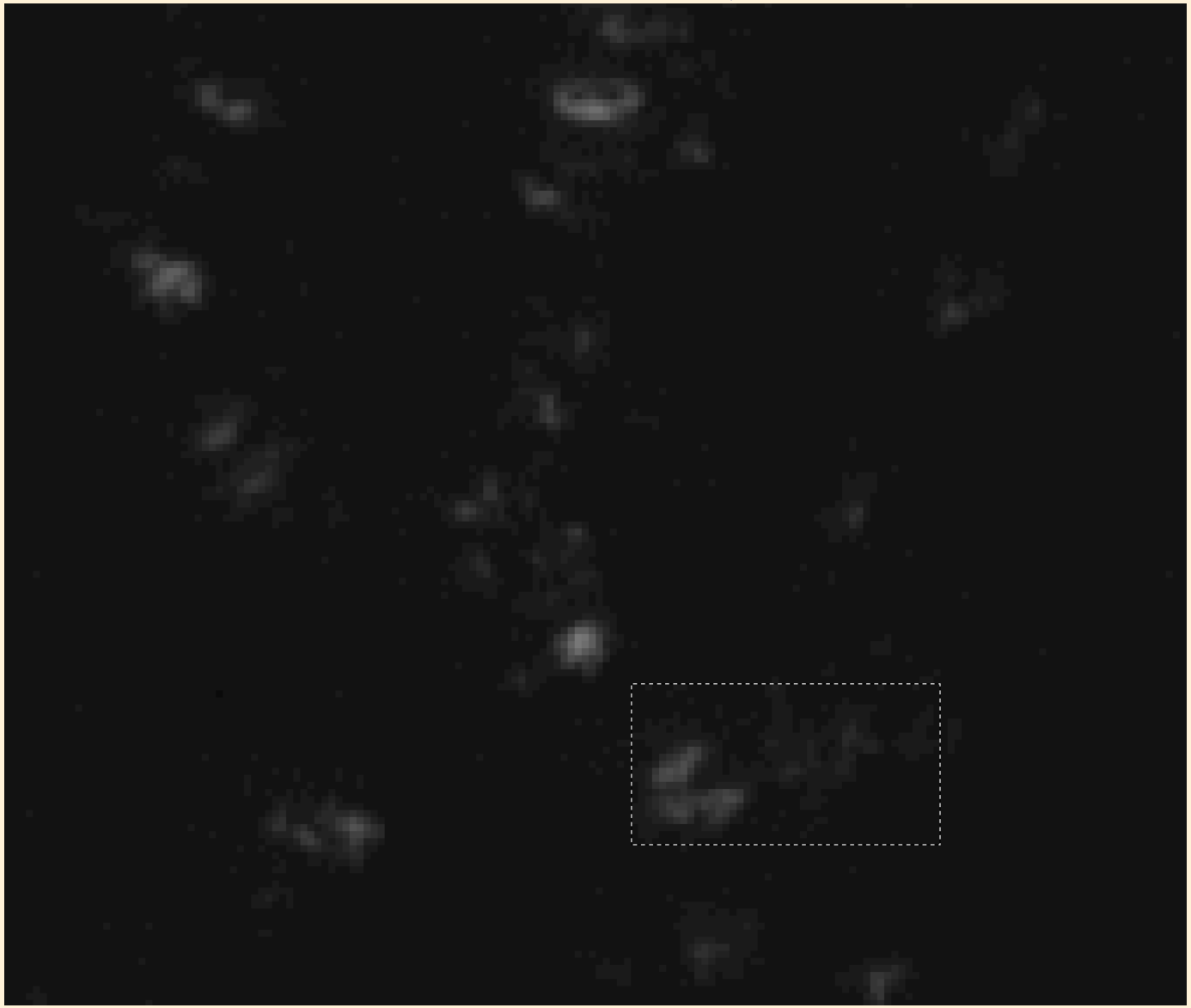


ACCA CF=6%

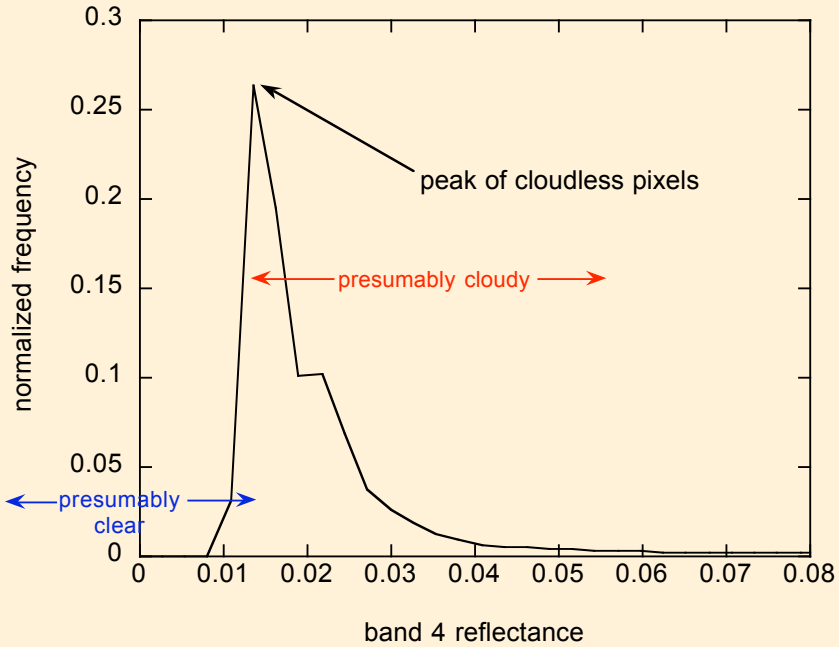
Detail of P63/R45, 2001/2/7

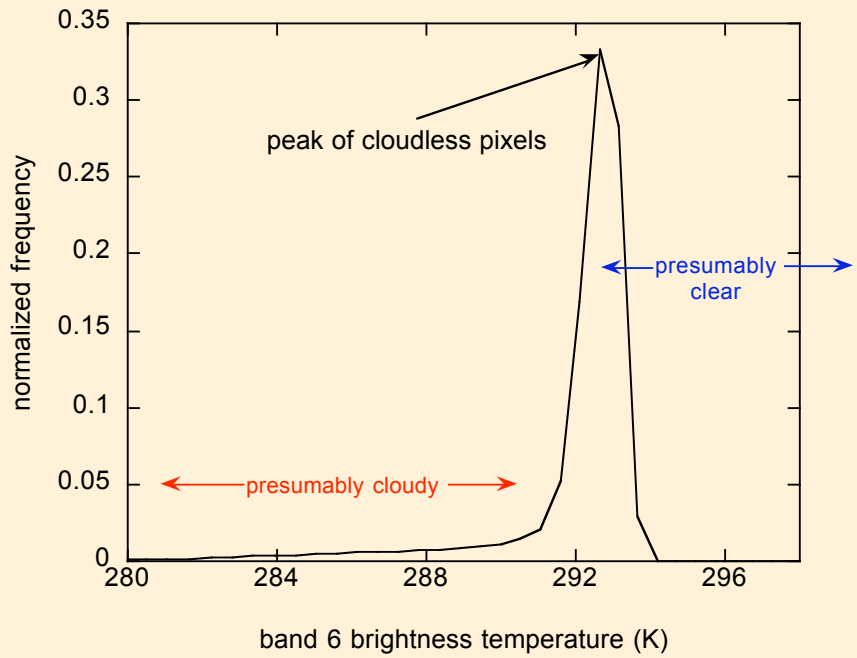


Detail of P63/R45, 2001/2/7

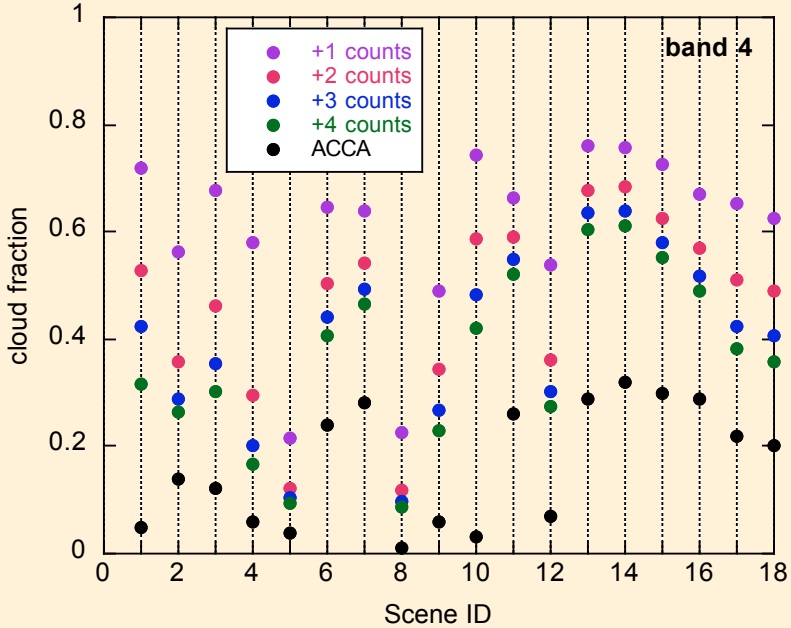


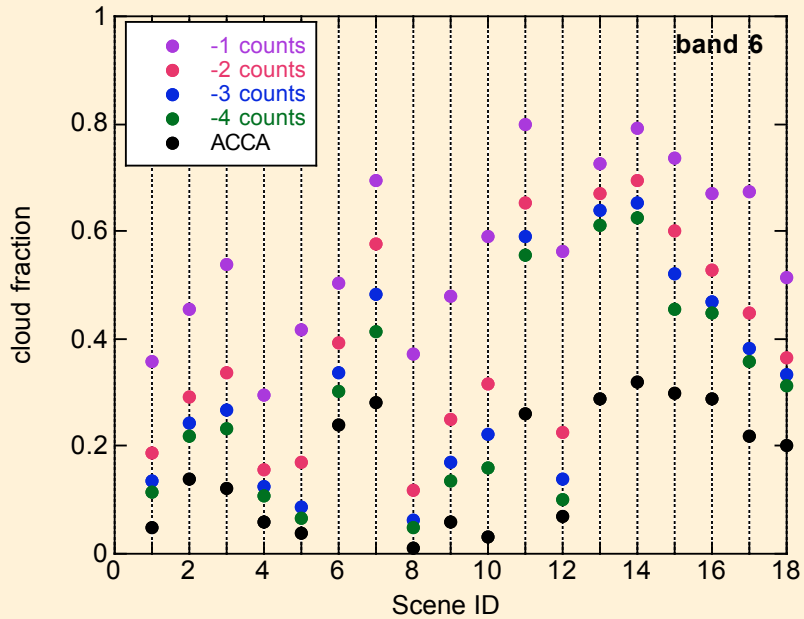
Threshold selection

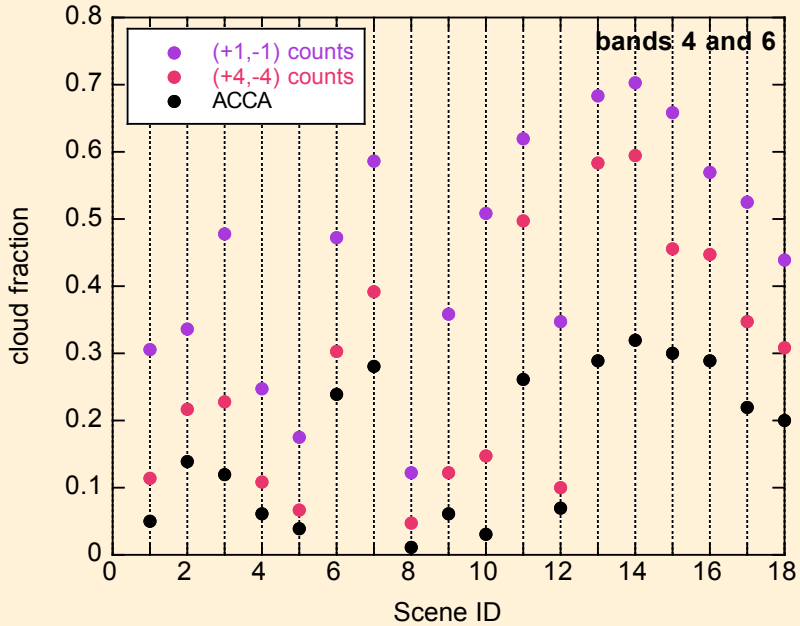




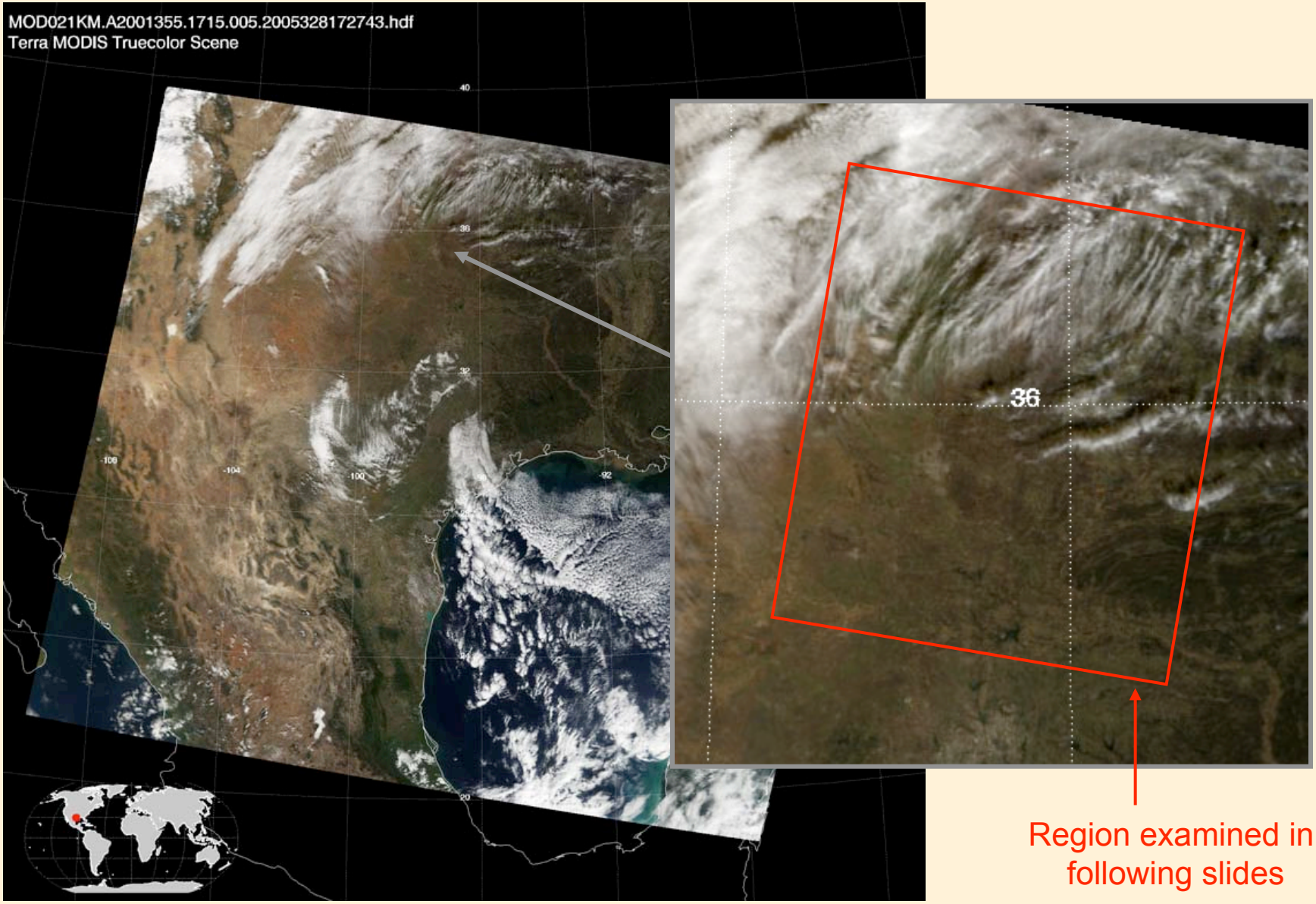
Sensitivity to threshold



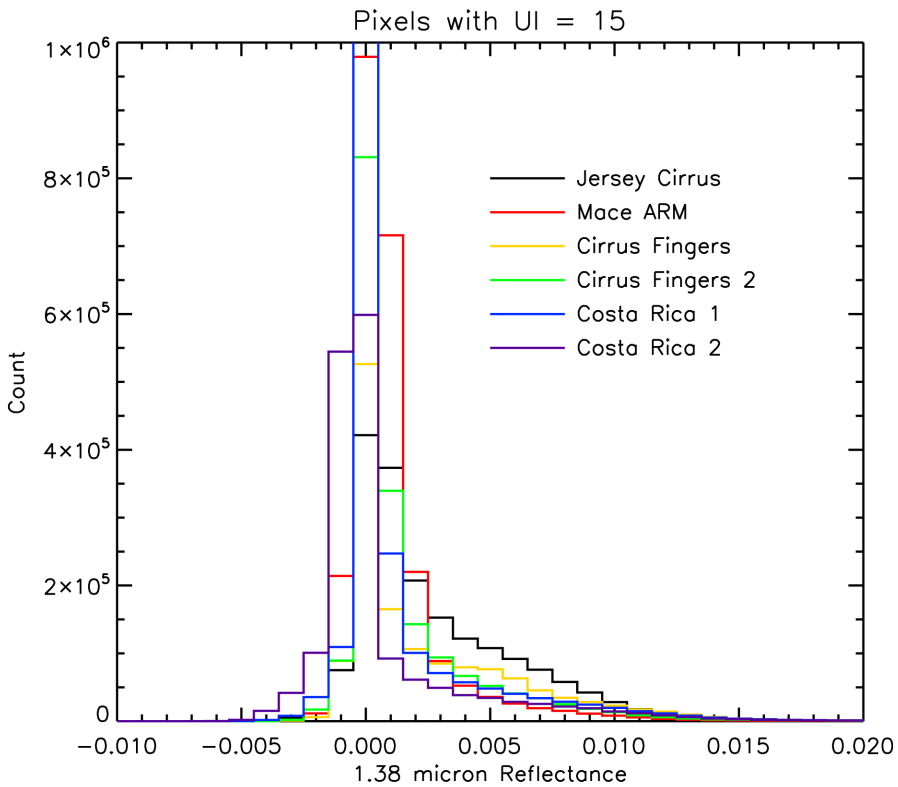


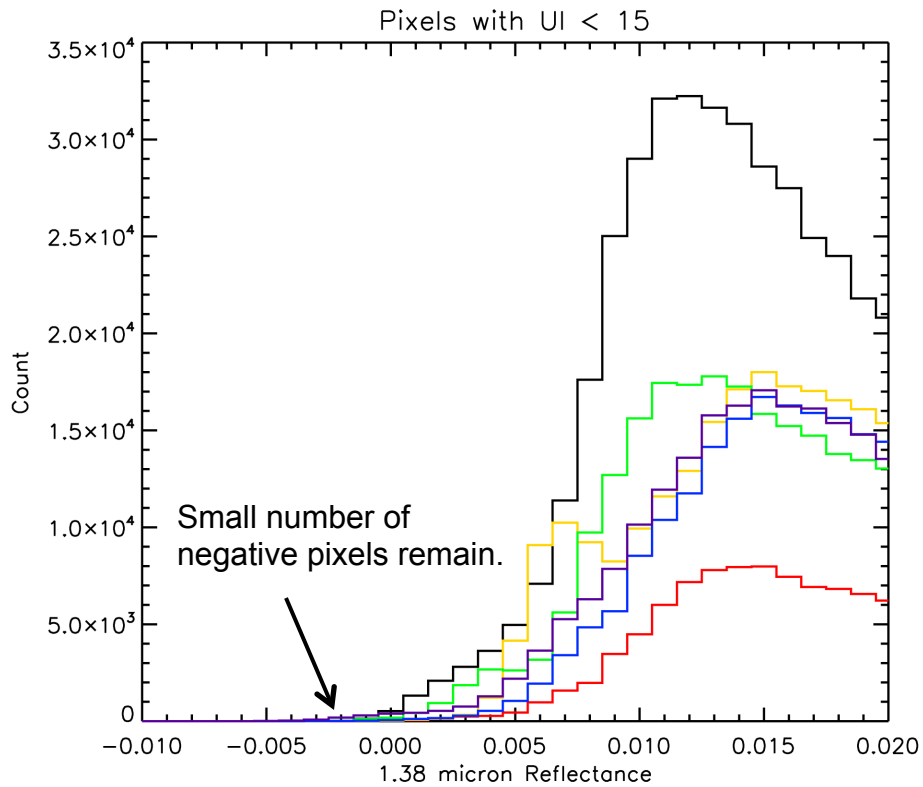


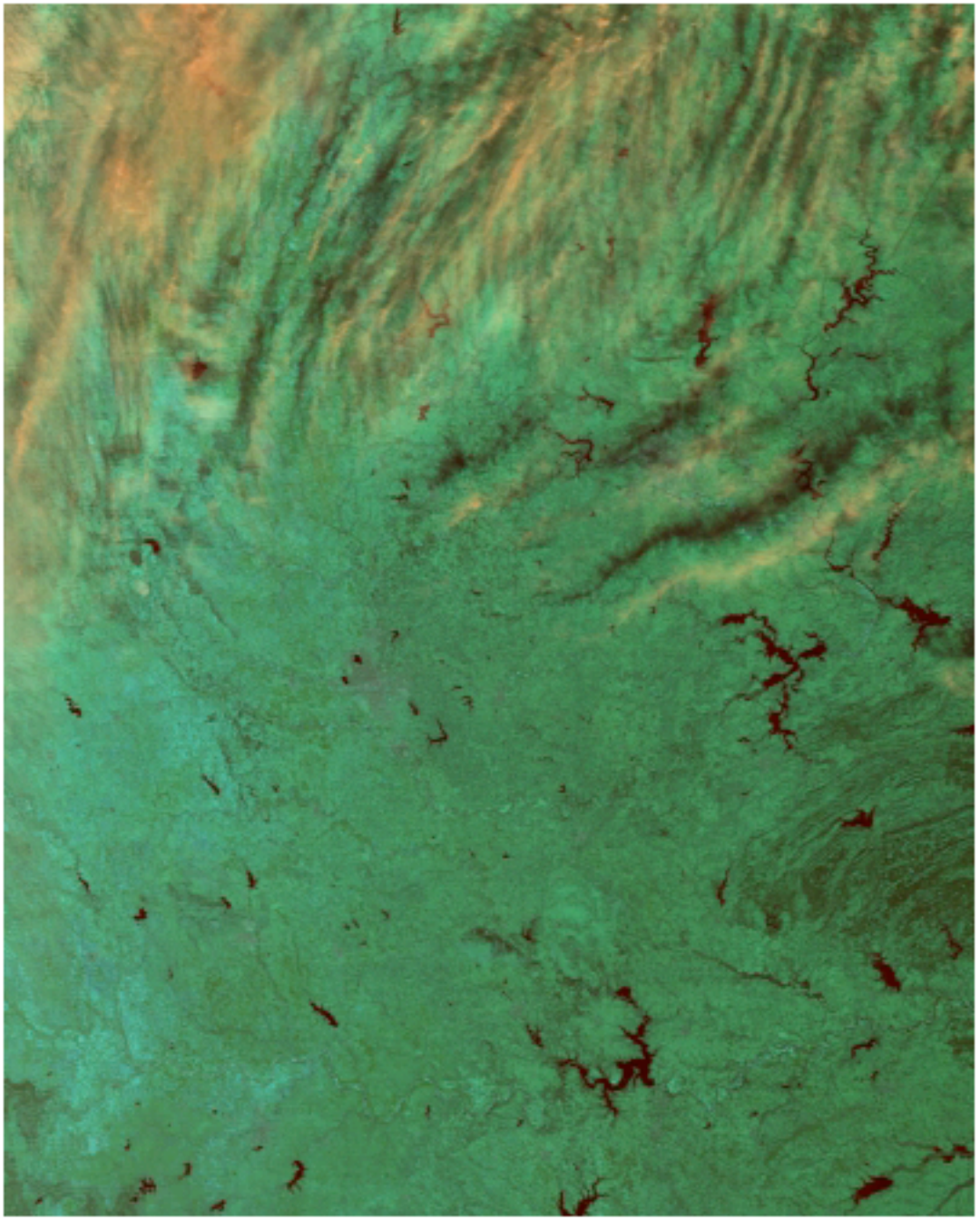
Jay Mace ARM Case



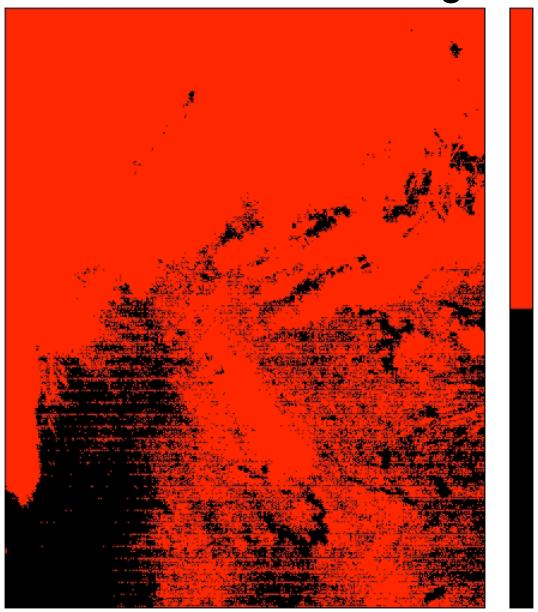
Region examined in following slides


Pixels with UI = 15
Count
1.38 micron Reflectance
Jersey Cirrus
Mace ARM
Cirrus Fingers
Cirrus Fingers 2
Costa Rica 1
Costa Rica 2


Pixels with UI < 15
Count
1.38 micron Reflectance
Small number of
negative pixels remain.



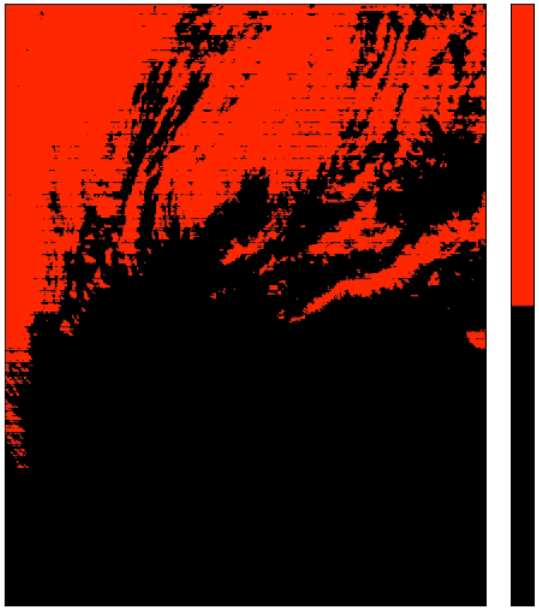
Cirrus Reflectance Flag



Cirrus Pixel

Non-Cirrus Pixel

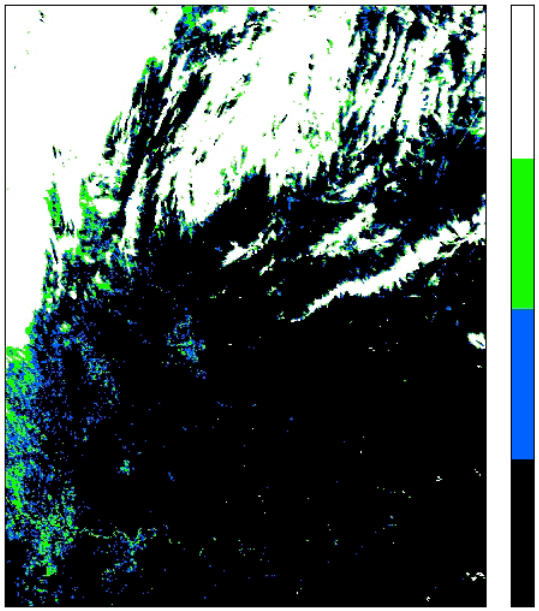
Cirrus Reflectance Flag (without UI=15)



Cirrus Pixel

Non-Cirrus Pixel

MOD06 Cloud Mask



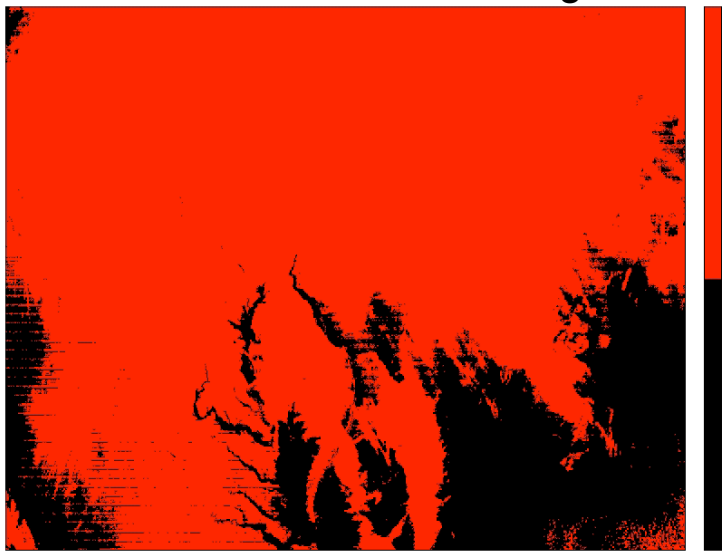
Confident Cloudy

Probably Cloudy

Probably Clear

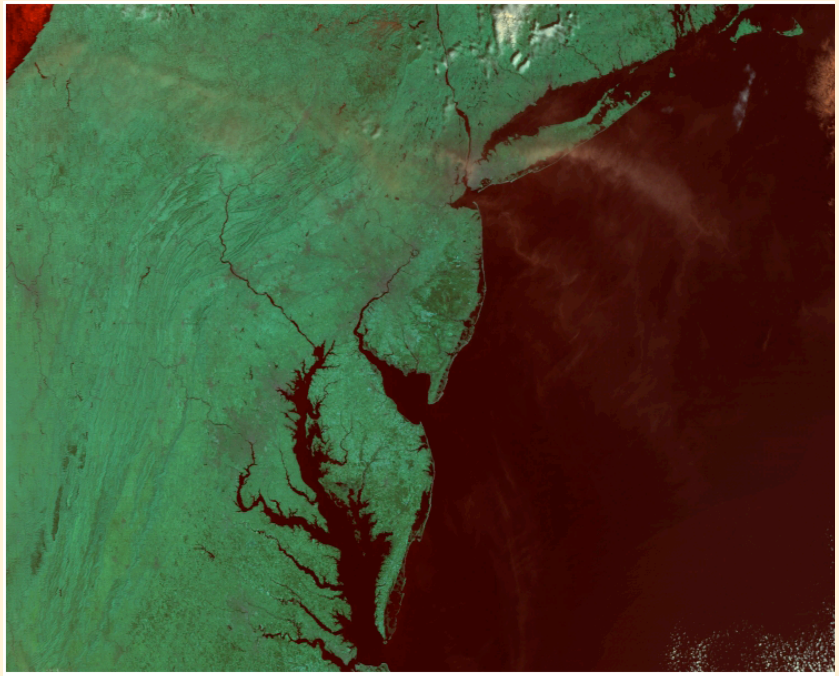
Confident Clear

Cirrus Reflectance Flag

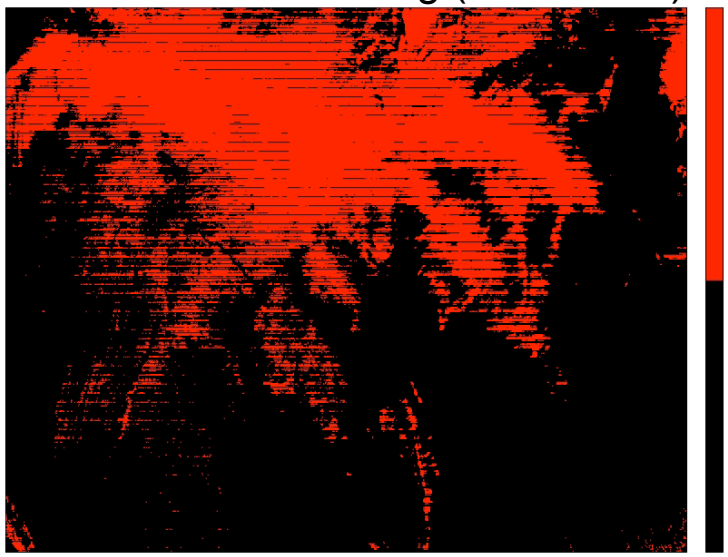


Cirrus Pixel

Non-Cirrus Pixel



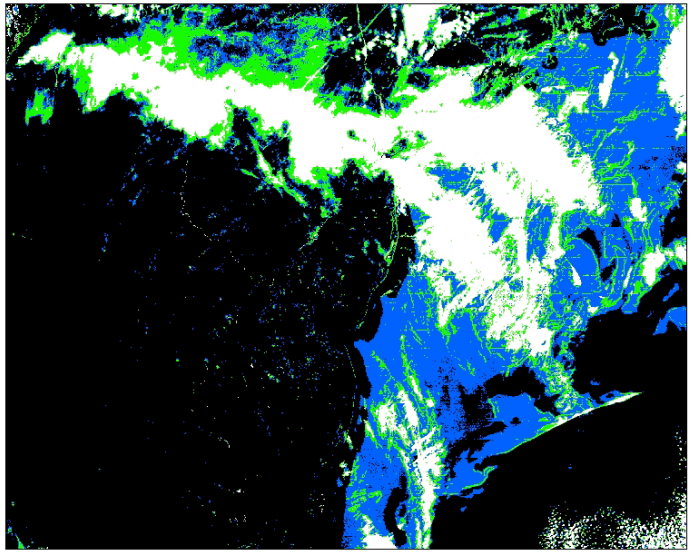
Cirrus Reflectance Flag (with UI<15)



Cirrus Pixel

Non-Cirrus Pixel

MOD06 Cloud Mask



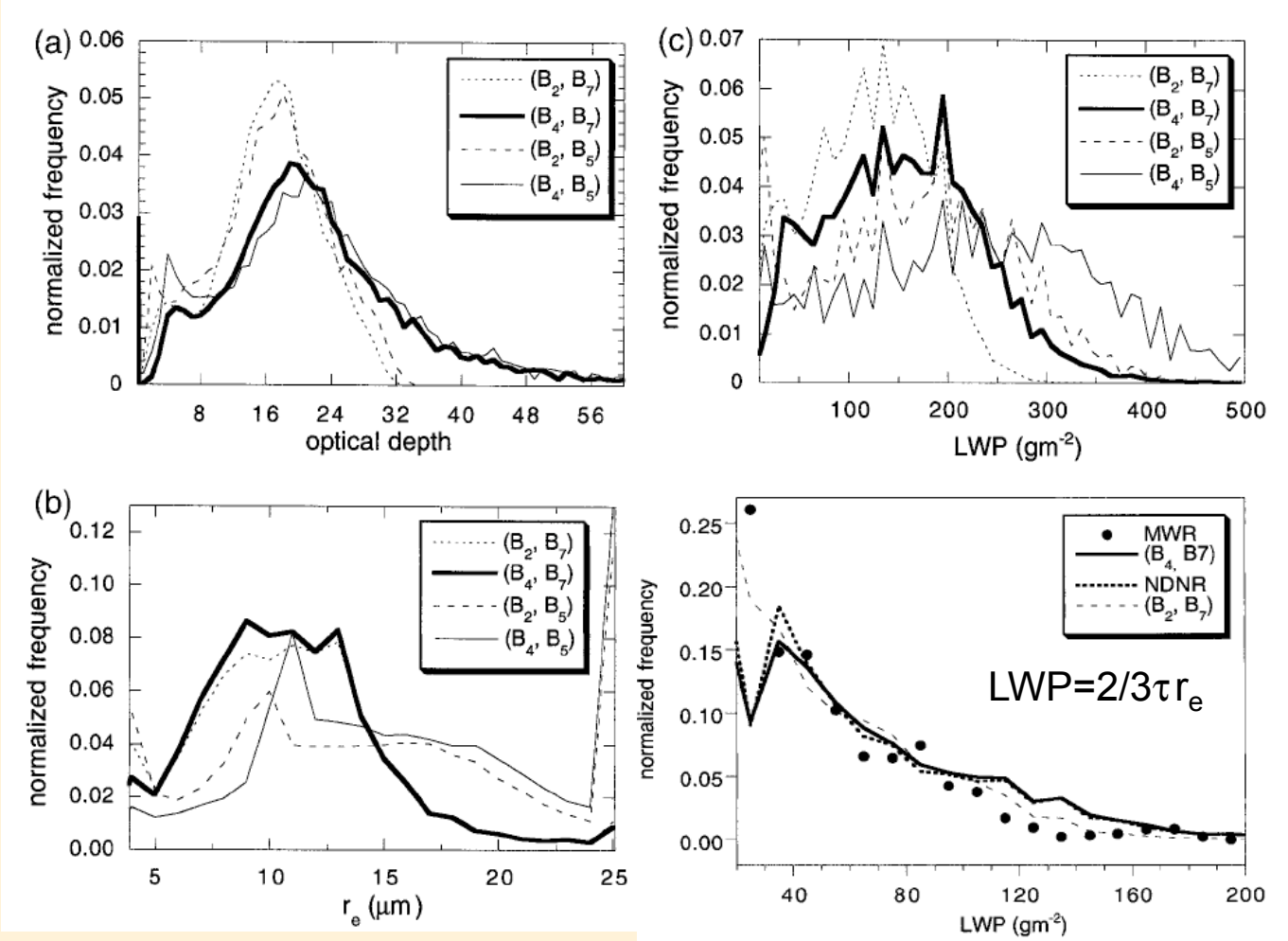
Confident Cloudy

Probably Cloudy

Probably Clear

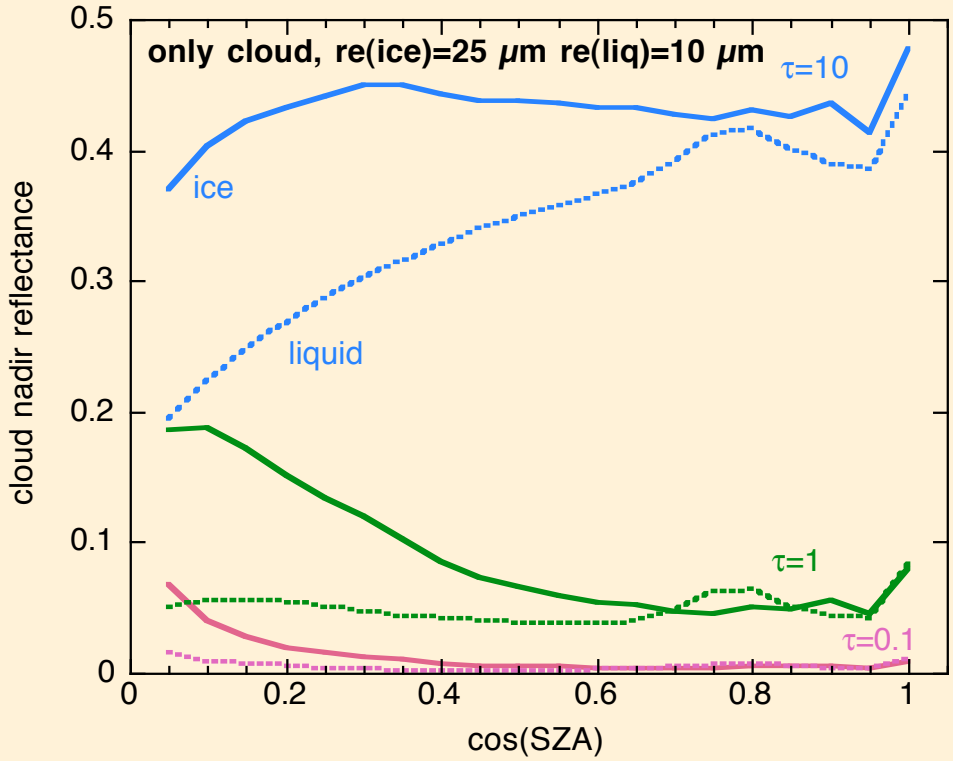
Confident Clear

Landsat cloud retrieval example



Oreopoulos et al. (2000)

Theoretical 1.38 μm studies with a MODIS reflectance simulator (Meyer, Platnick)



<u>TOA 1.38 μm nadir reflectance depends on:</u>

- Solar zenith angle
- Surface albedo (BDRF)
- Total column water vapor
- Profile of water vapor
- Cloud phase, vertical location, optical thickness, effective particle size