

# Cloud Detection for Sentinel 2

Curtis Woodcock, Zhe Zhu, Shixiong  
Wang and Chris Holden

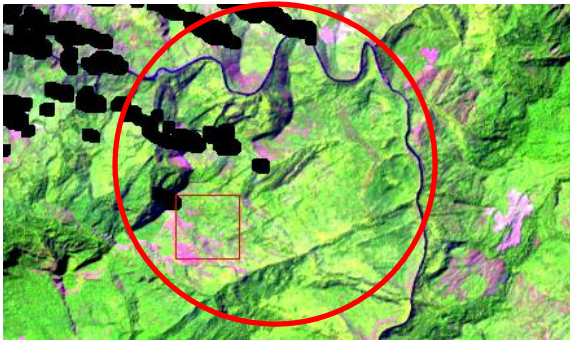
# Background

- 3 primary spectral regions useful for cloud detection
  - Optical
  - Thermal
  - Cirrus bands
- Legacy Landsats have thermal and optical
- Landsat 8 has all 3
- Sentinel 2s have optical and cirrus
- Landsat 8 provides us the opportunity to test other alternatives

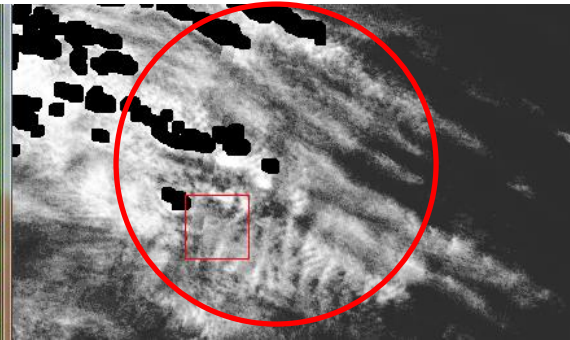
# Outline

- Why cirrus cloud detection is important
- Fmask designed for Landsats 4-7, Landsat 8, and Sentinel 2
- Cirrus cloud spectral effects
- Multitemporal approaches
- Preliminary results with Simulated Sentinel 2 data

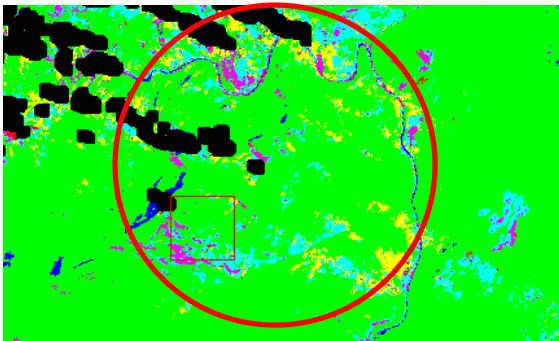
# Why is cirrus cloud detection important?



Landsat 8 false color composite



Landsat 8 Cirrus Band TOA reflectance



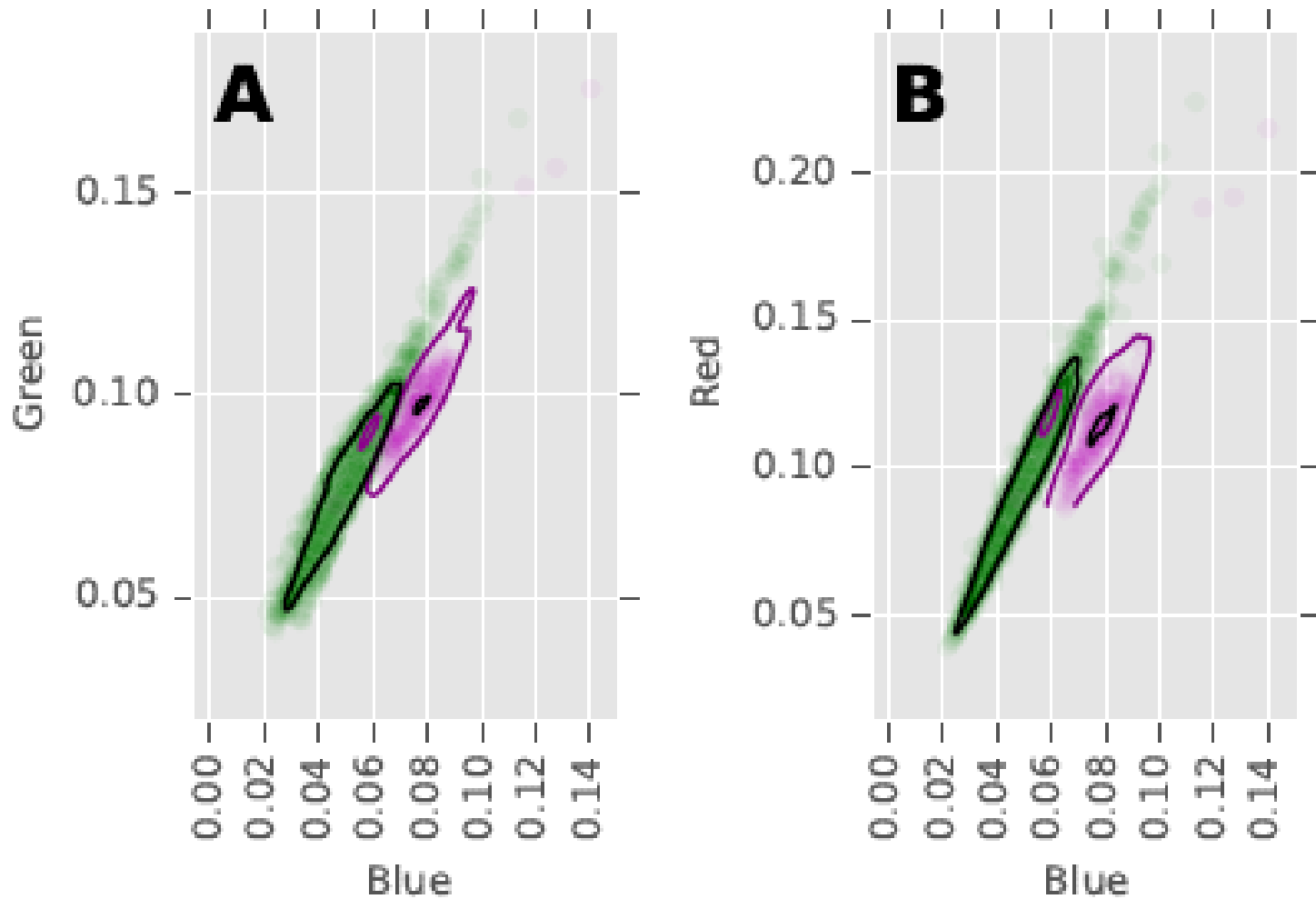
Land cover classification map

## Legend

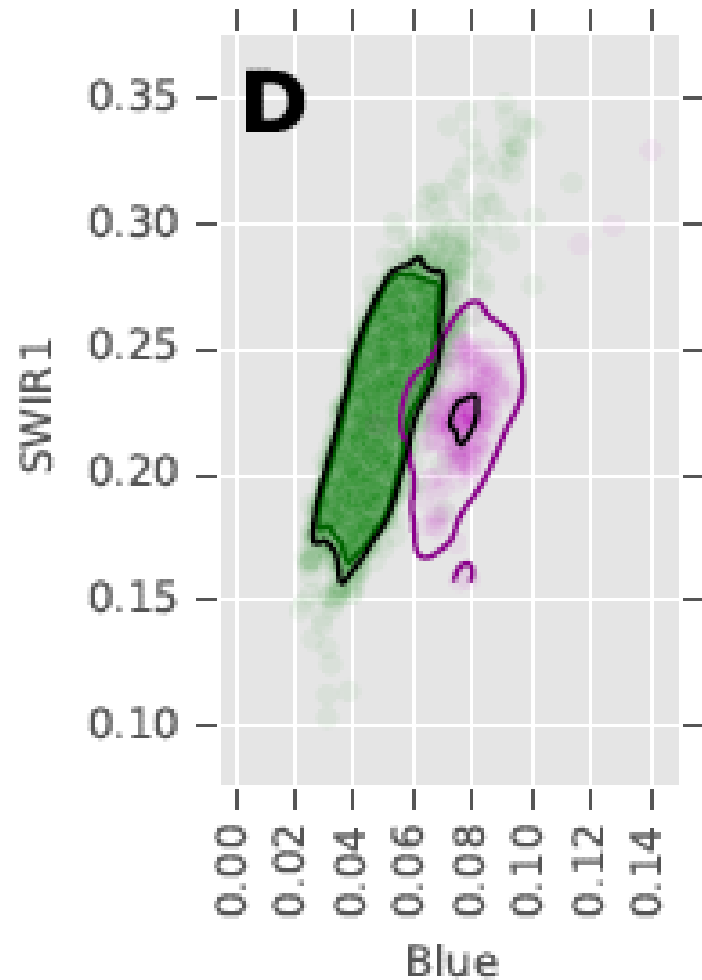
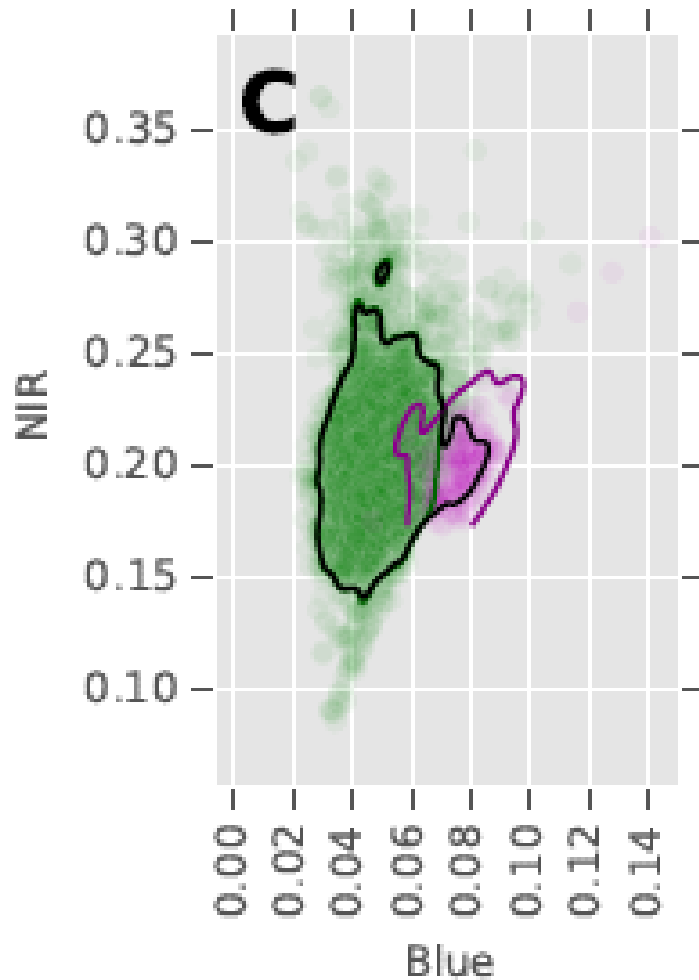
	mined field
	water
	low density built
	agriculture
	forest
	barren
	herbaceous

The land cover inside the red circles are mostly forest and barren, however, due to the presence of the “transparent” cirrus clouds, they are misclassified as herbaceous and mined field

# The effect of cirrus clouds on spectral reflectance (cirrus pixels in pink) (from Chris Holden)



# The effect of cirrus clouds on spectral reflectance (cirrus pixels in pink)





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### Improvement and expansion of the Fmask algorithm: cloud, cloud shadow, and snow detection for Landsats 4–7, 8, and Sentinel 2 images

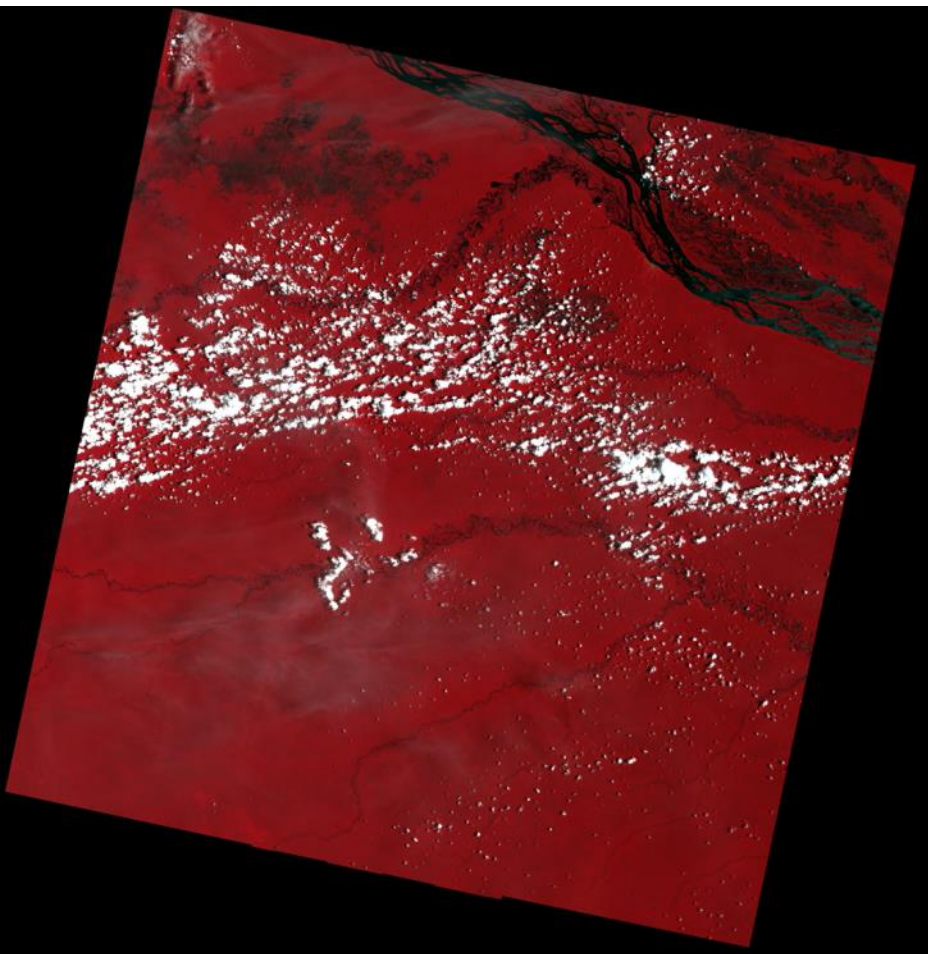
Zhe Zhu<sup>\*</sup>, Shixiong Wang, Curtis E. Woodcock

*Center for Remote Sensing, Department of Earth and Environment, Boston University, 685 Commonwealth Avenue, Boston, MA, 02215, USA*

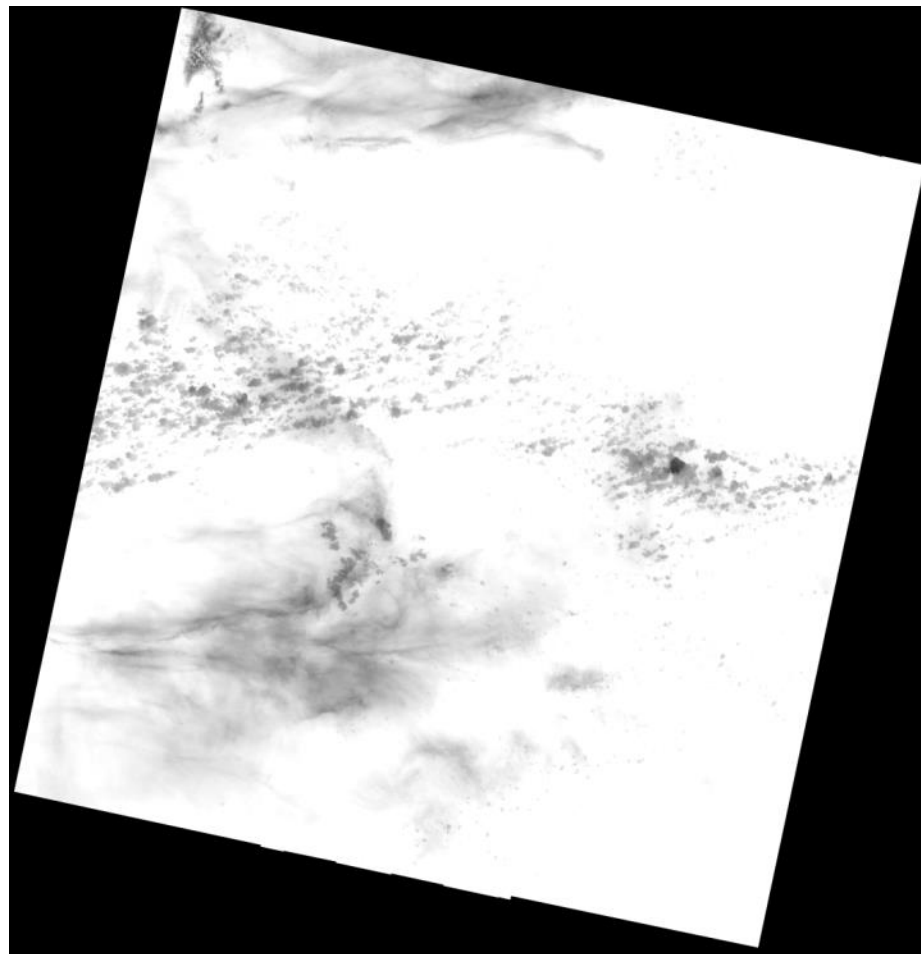


# What do cirrus cloud looks like?

Band 4, 2, and 2 composites



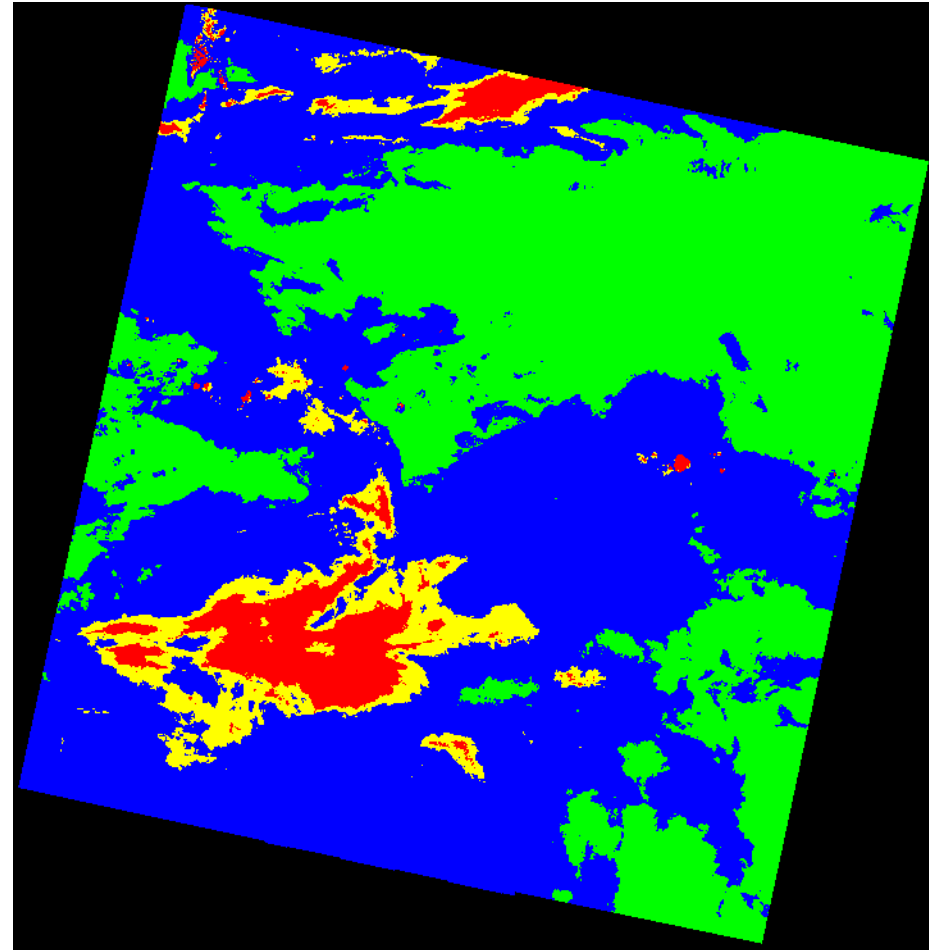
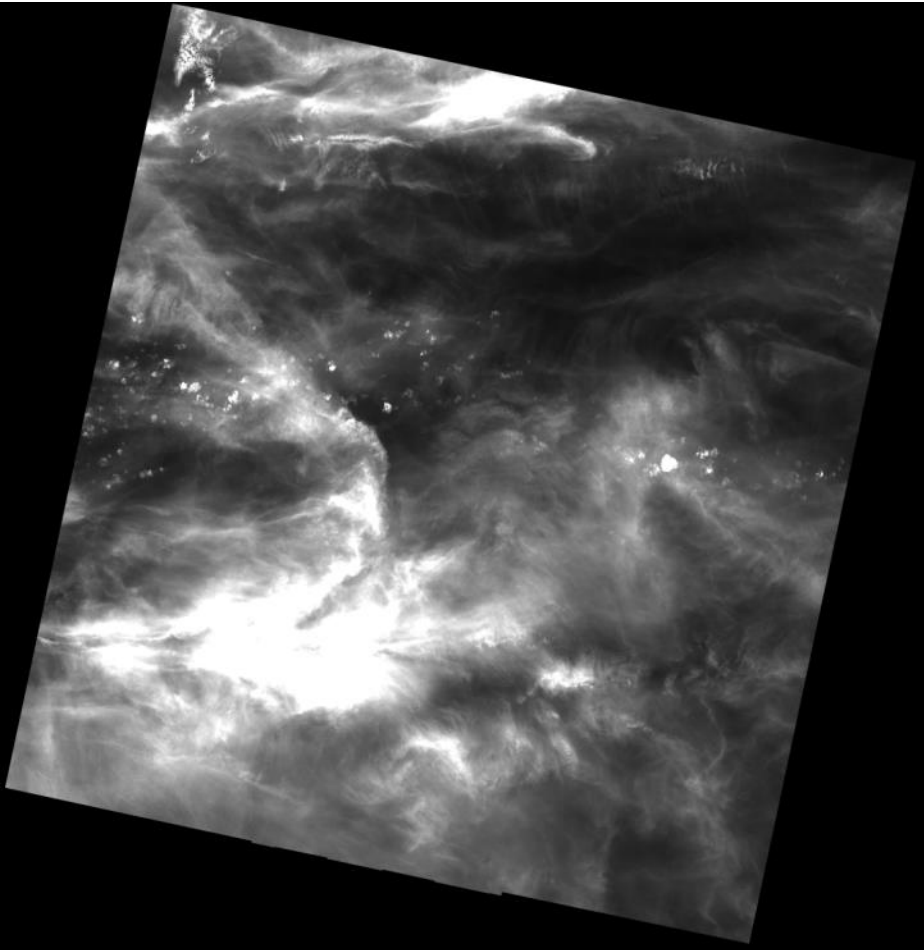
Thermal Band



Amazon p233r61

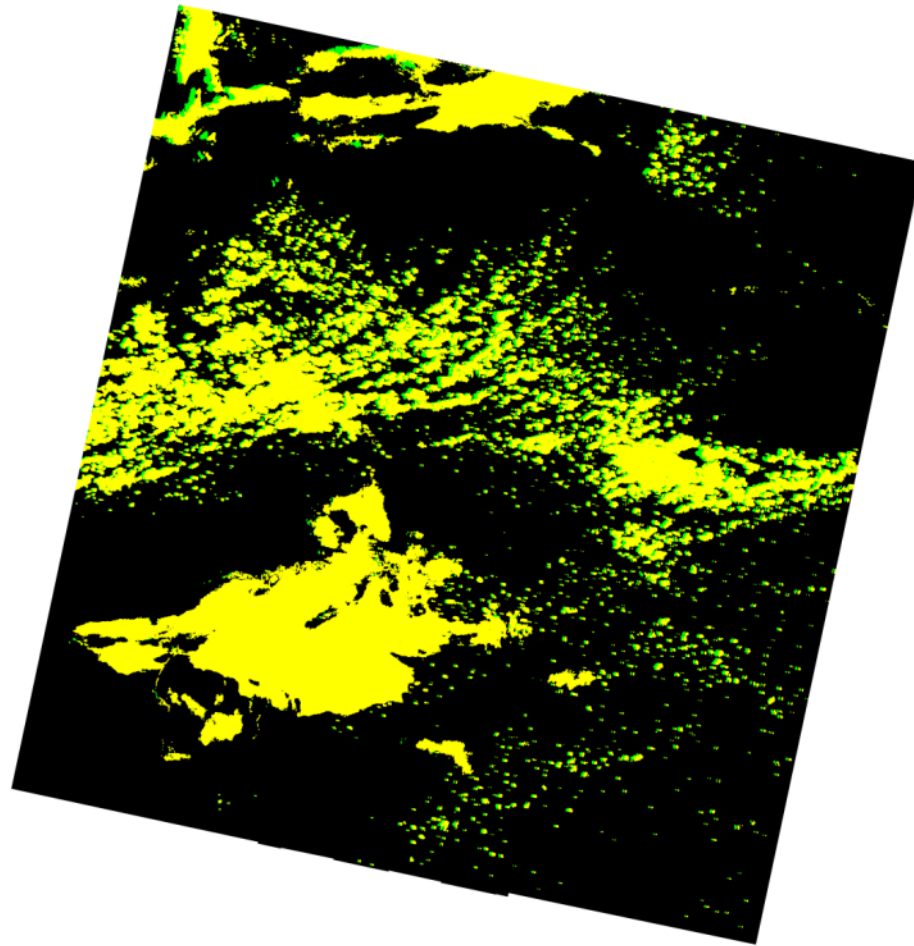


# The Cirrus Band



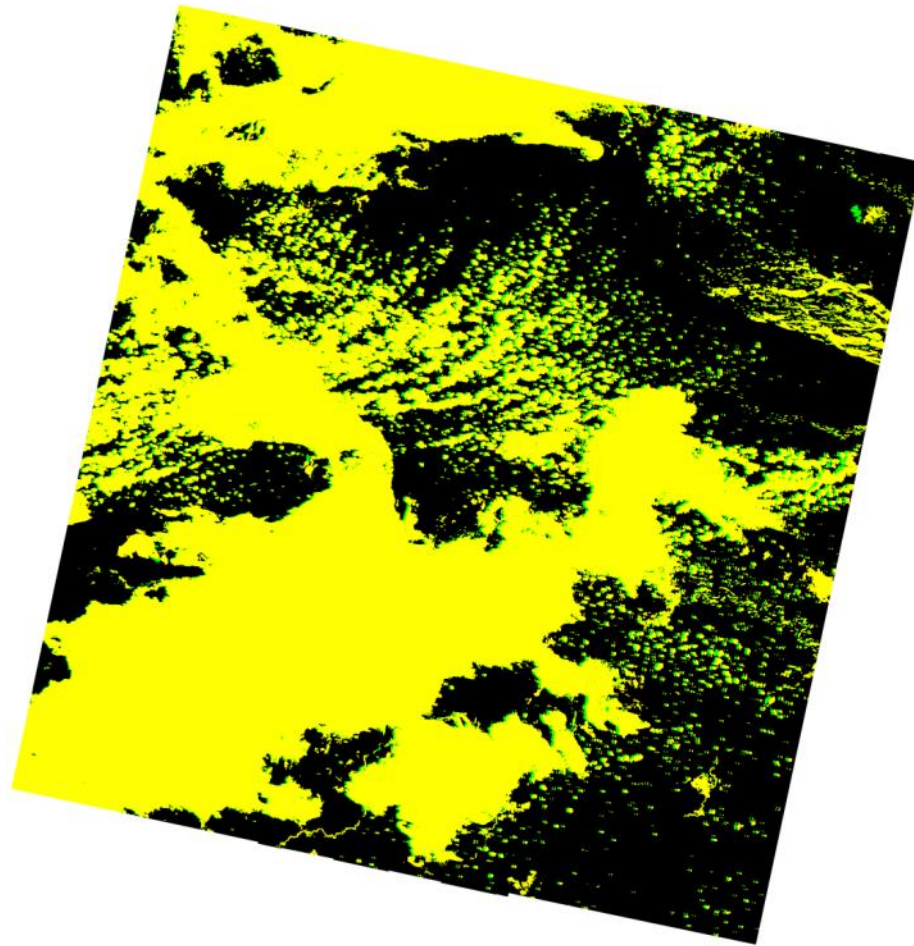
Cirrus band TOA reflectance: 0-0.01 0.01-0.03 0.03-0.04 0.04-1

# “TM/ETM+” Fmask results



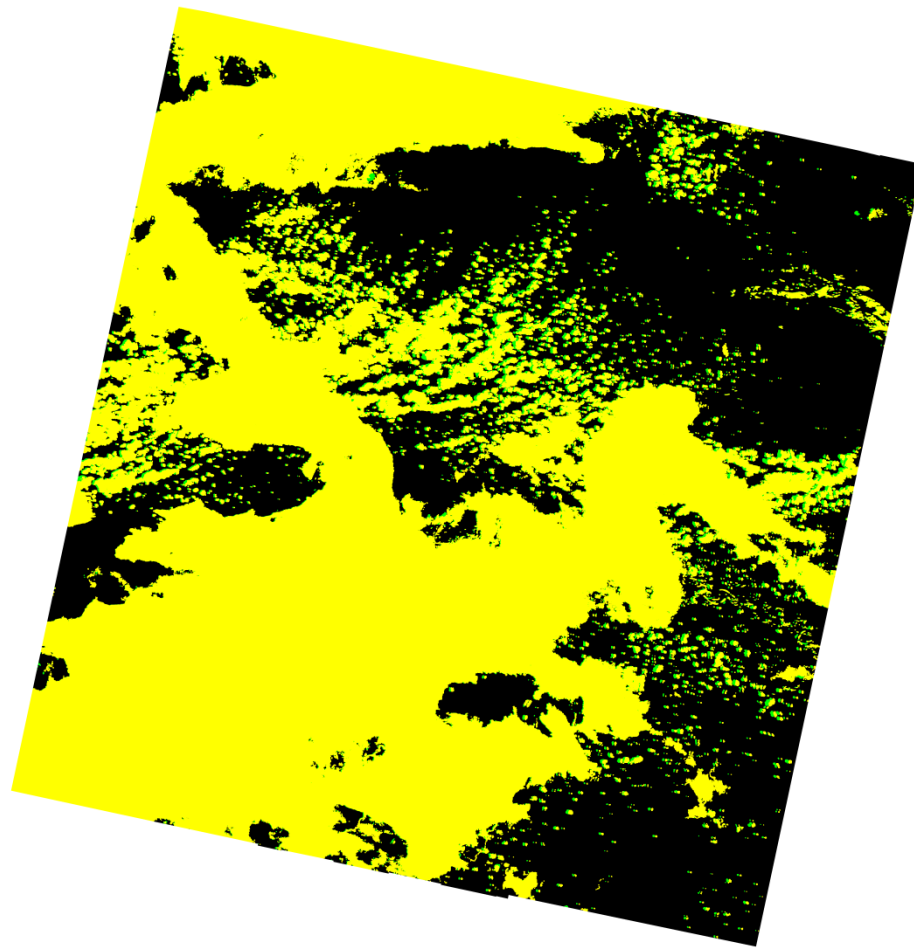
Clear Cloud Shadow Snow/Ice Cloud

# “Sentinel 2” Fmask results



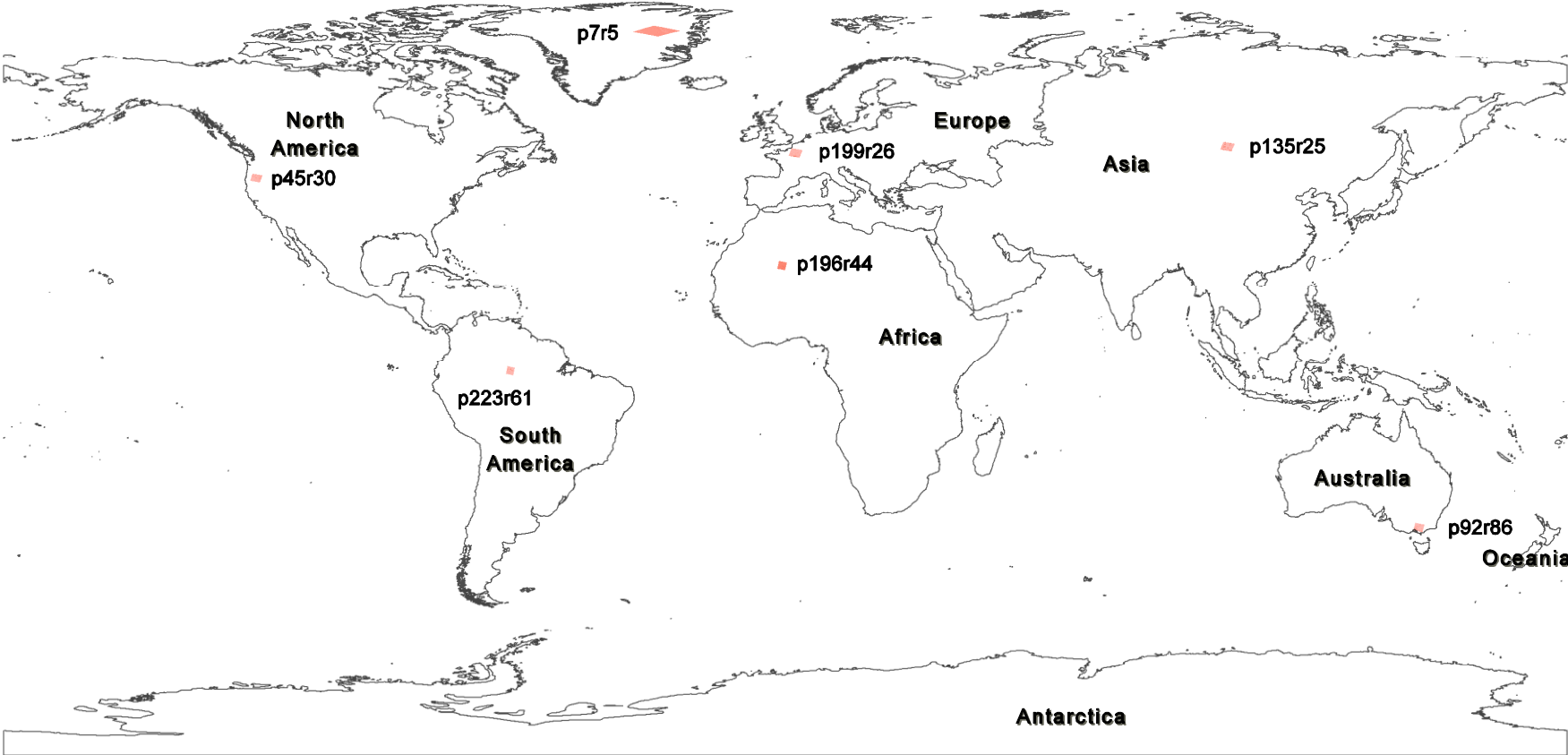
Clear   Cloud Shadow   Snow/Ice   Cloud

# “OLI/TIRS” Fmask results

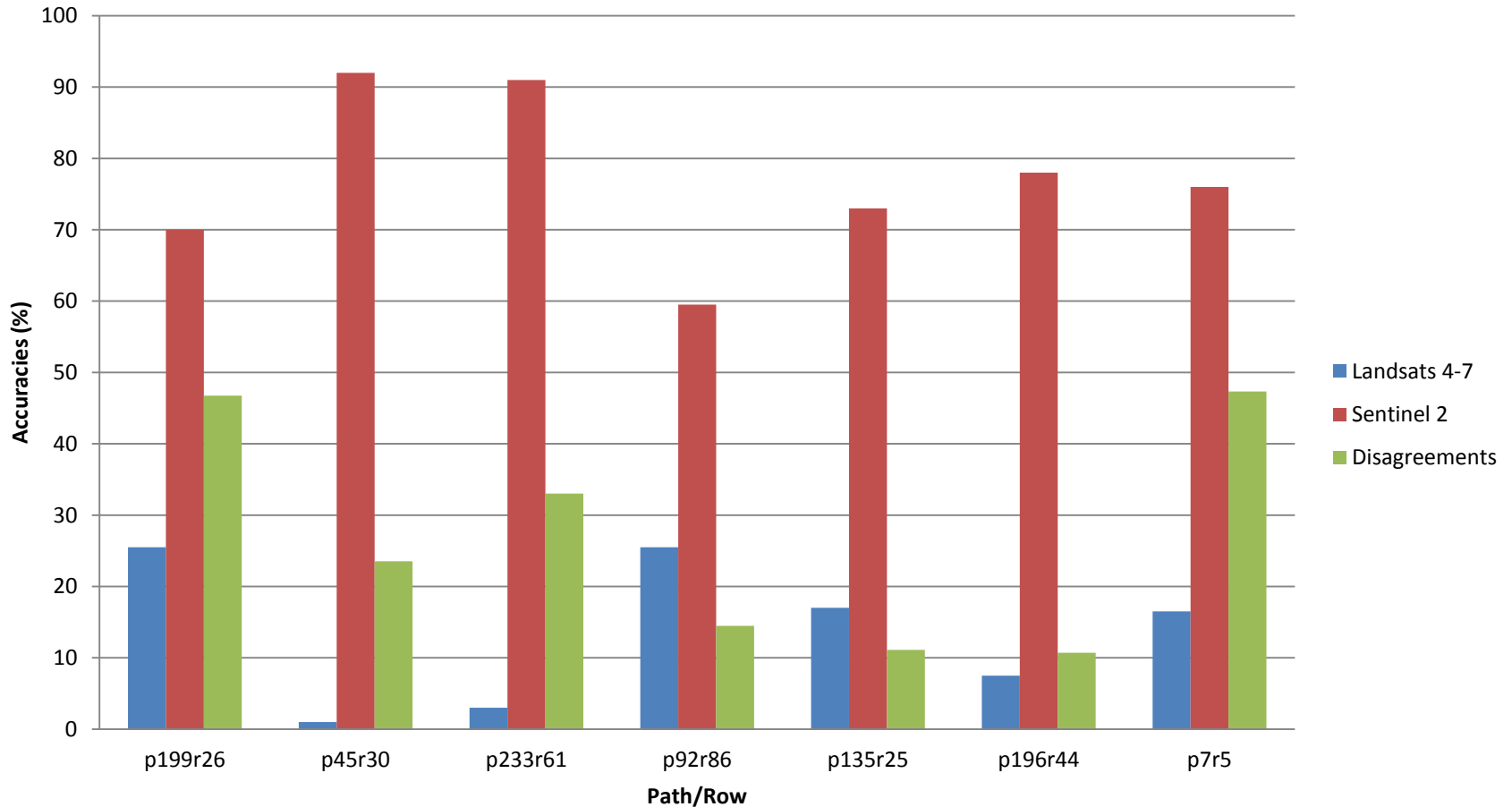


Clear Cloud Shadow Snow/Ice Cloud

# Places have been tested so far

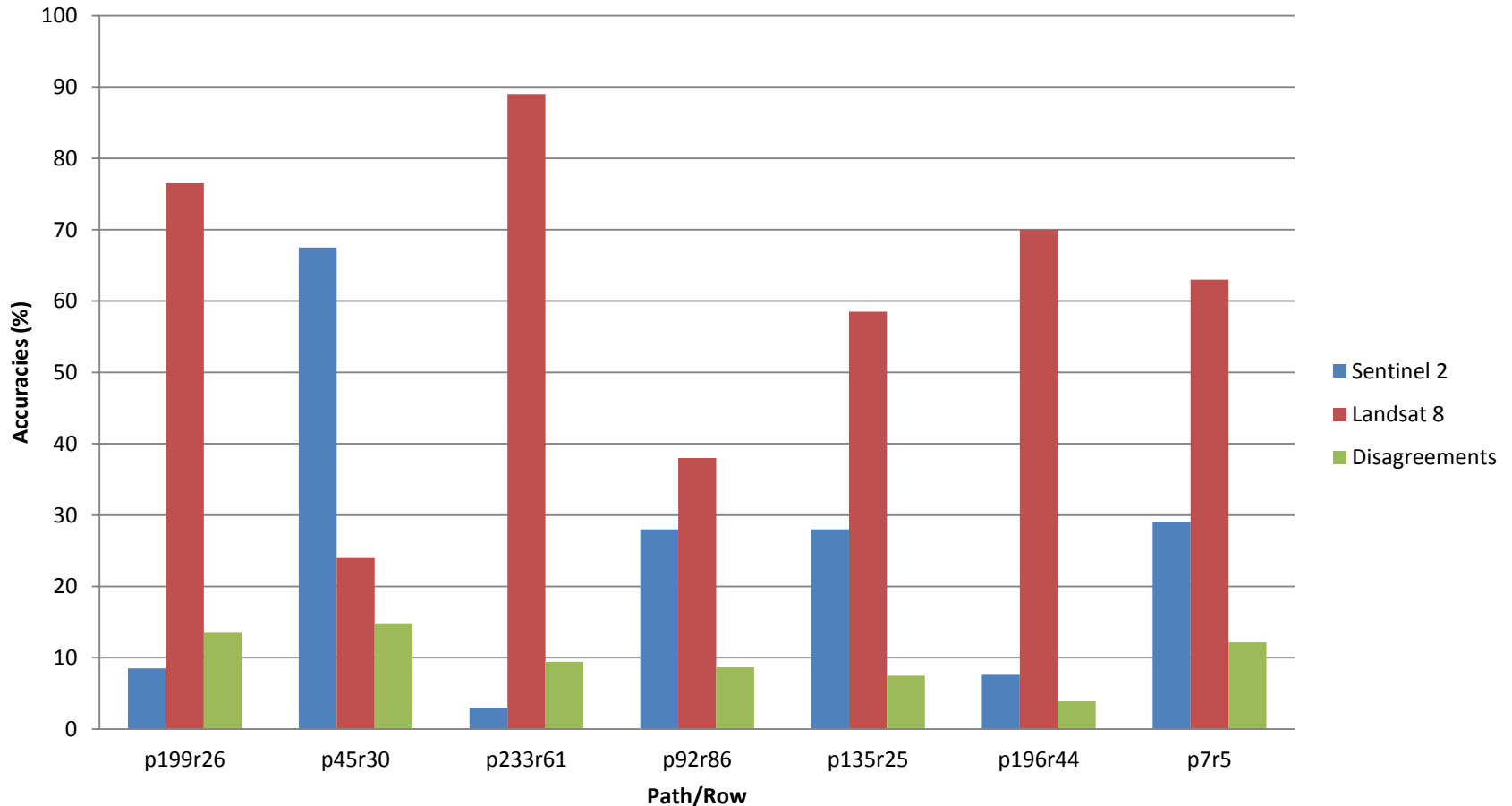


# Fmask results accuracies for all 7 locations between the Landsats 4-7 and the Sentinel 2 scenarios



The blue bars are the overall accuracies for the Landsats 4-7 scenario and the red bars are the overall accuracies for the Sentinel 2 scenario. The green bars show the percent disagreement for Fmask results between the Landsats 4-7 and the Sentinel 2 scenarios.

# Fmask results accuracies for all 7 locations between the Sentinel 2 and Landsat 8 scenarios



The blue bars are the overall accuracies for the Sentinel 2 scenario and the red bars are the overall accuracies for the Landsat 8 scenario. The green bars show the percent disagreement for Fmask results between the Sentinel 2 and Landsat 8 scenarios.



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Automated cloud, cloud shadow, and snow detection in multitemporal Landsat data: An algorithm designed specifically for monitoring land cover change

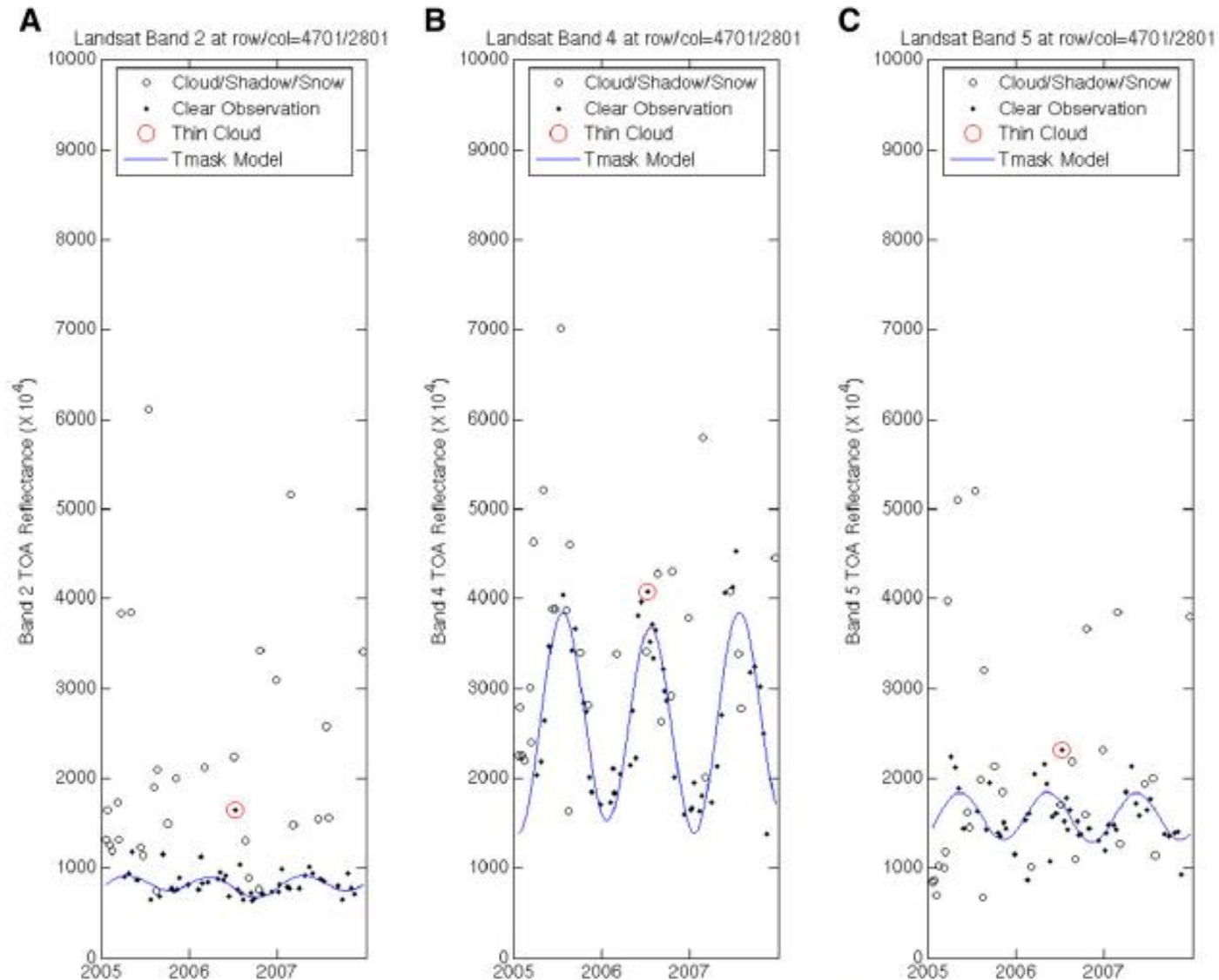
Zhe Zhu <sup>\*</sup>, Curtis E. Woodcock

*Center for Remote Sensing, Department of Earth and Environment, Boston University, 685 Commonwealth Avenue, Boston, MA 02215, USA*





# Examples of clouds found with multitemporal approach



**Fig. 9.** Timesseries of Band 2 (A), 4 (B), and 5 (C) TOA reflectance of the pixel located at the center of the red rectangle in Fig. 8. Clear pixels are black dots. Clouds, cloud shadows, and snow are black circles, and the Fmask mistake is shown in the red circle. The blue lines represent the model-estimated values. Note that the cloud observation missed by Fmask but captured by Tmask changes the spectral signal significantly, especially in Band 2 TOA reflectance.

# Multitemporal solution (Tmask)

(This step does not use the thermal or cirrus bands)

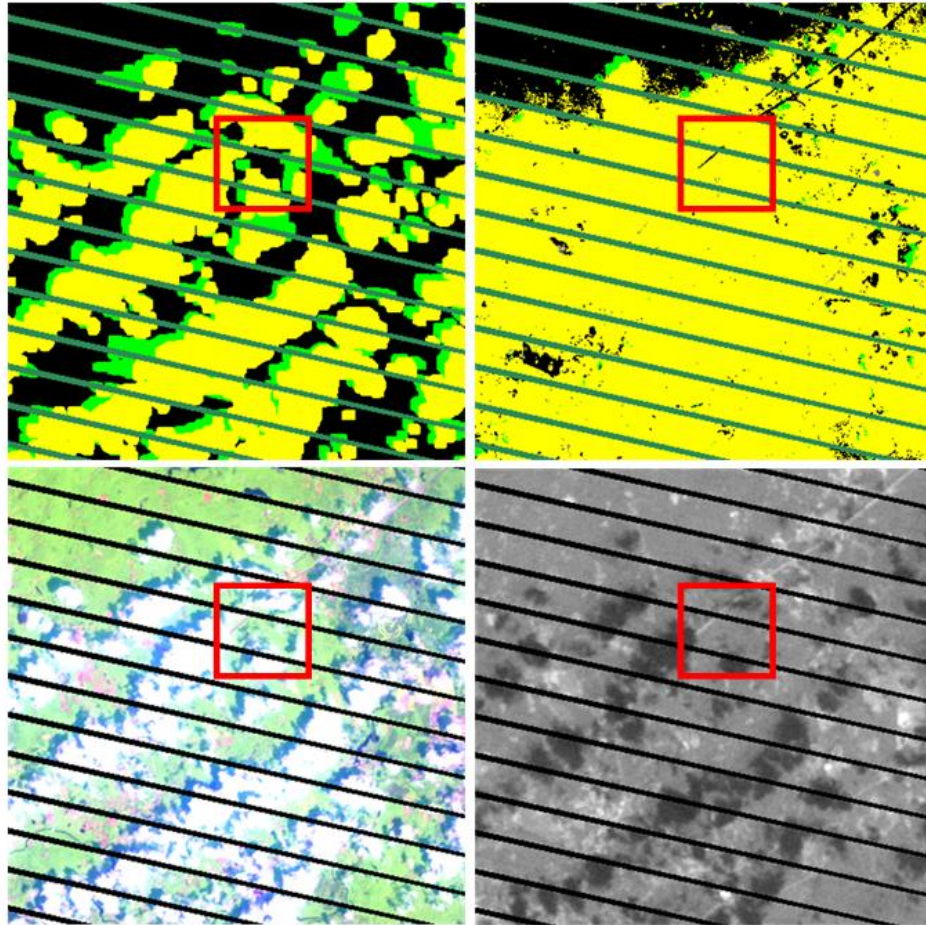


Fig. 8. Comparison of Fmask and Tmask results for a subset of Landsat images at Path 12 Row 31 acquired May 7<sup>th</sup> 2006 – a scenario where two algorithms disagree for extremely thin clouds (Tmask works and Fmask fails).. Note that the extremely thin clouds in the center of the red rectangle are missed by Fmask but captured by Tmask.

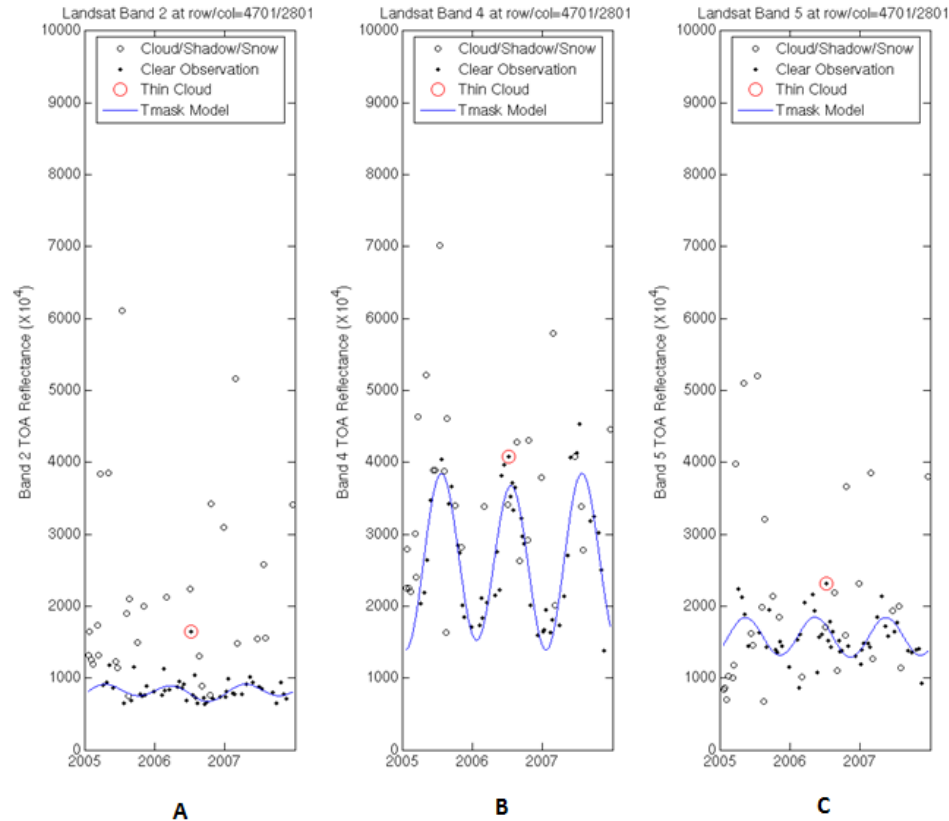
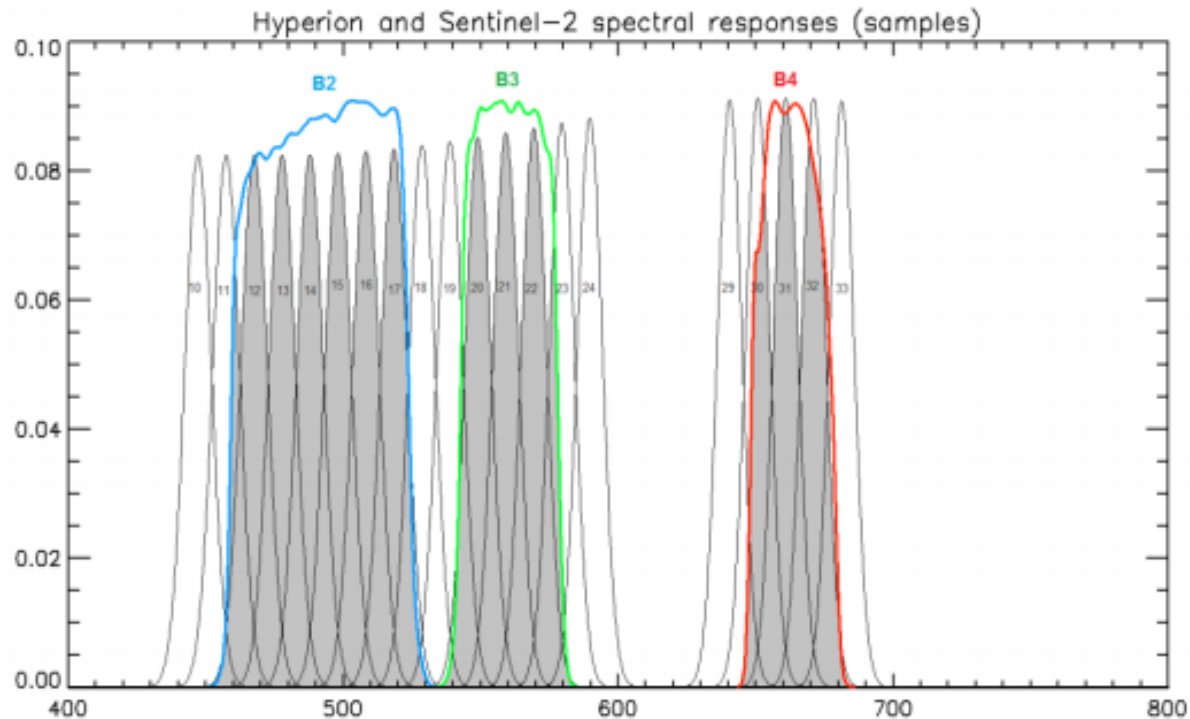


Fig. 9. Times series of Bands 2 (Fig. 9A), 4 (Fig. 9B), and 5 (Fig. 9C) TOA reflectance of the pixel located at the center of the red rectangle in Fig. 8. Clear pixels are black dots. Clouds, cloud shadows, and snow are black circles, and the Fmask mistake is shown in the red circle. The blue lines represent the model-estimated values. Note that the cloud observation missed by Fmask but captured by Tmask changes the spectral signal significantly, especially in Band 2 TOA reflectance.

# Preliminary result with Simulated Sentinel 2 data

- Sentinel-2 simulation dataset was provided by Ferran Gascon that aggregates Hyperion bands to MSI bandpasses.

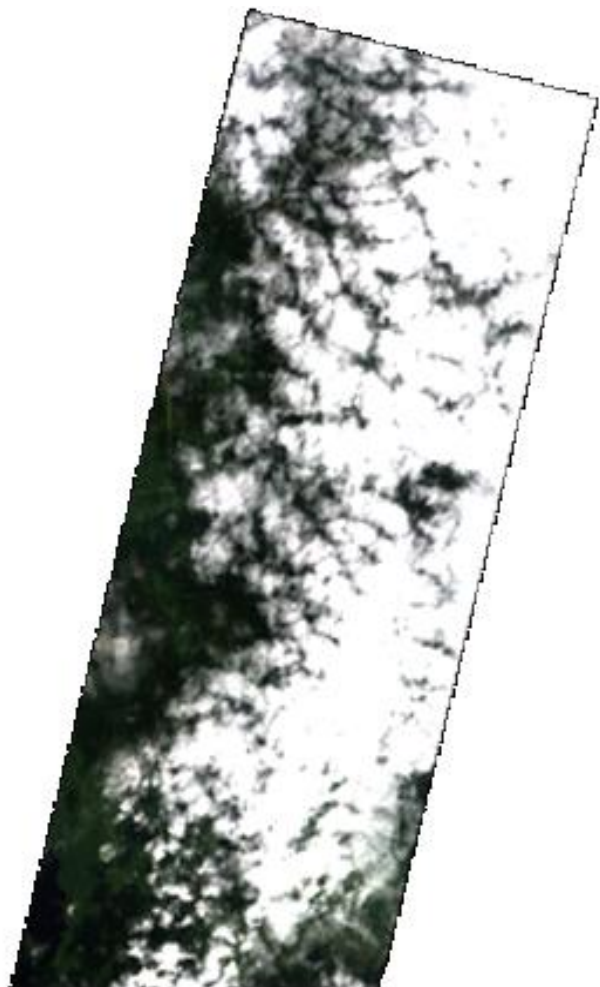


**Figure 1: Hyperion bands involved in Sentinel-2 aggregation process for S2 bands 10 m bands: B2, B3 and B4**

Conversion from MSI radiance to MSI reflectance uses the Thuillier standard solar spectrum, a composite spectrum published by Thuillier et al. : G. Thuillier; M. Hersé; D. Labs; T. Foujols; W. Peetermans; D.Gillotay; P.C. Simon; H. Mandel "The Solar Spectral Irradiance from 200 to 2400 nm as Measured by the SOLSPEC Spectrometer from the Atlas and Eureka Missions" *Solar Physics* 214(1): 1-22 (2003).

- Fmask results were generated base on Zhe Zhu's Fmask algorithm with modifications according to Sentinel-2 specifications.
- Simulation data location: Bangor, Maine
- Acquisition date: 08/25/2002
- Zone: Boreal
- Hyperion original product:  
EO1H0110282002237110PZ





Sentinel-2 4, 3, 2 composite



Sentinel-2 Fmask result

■ Clear land   ■ Clear water   ■ Cloud shadow   ■ Snow   ■ Cloud

# Accuracy Assessment

	Clear land	Clear water	Cloud shadow	Cloud	Total
Clear land	226	1	4	31	262
Clear water	1	4	0	0	5
Cloud shadow	1	0	1	0	2
Cloud	0	0	0	31	31
Total	228	5	5	62	300
Overall Accuracy	262/300		87.30%		

# Conclusions

- 1. Fmask results comparison  
Landsat 8 > Sentinel 2 >> Landsats 4-7
- 2. Fmask is not perfect, but Tmask can further improve the Fmask results.
- 3. Opportunity remaining to continue this work, would love to hear community priorities

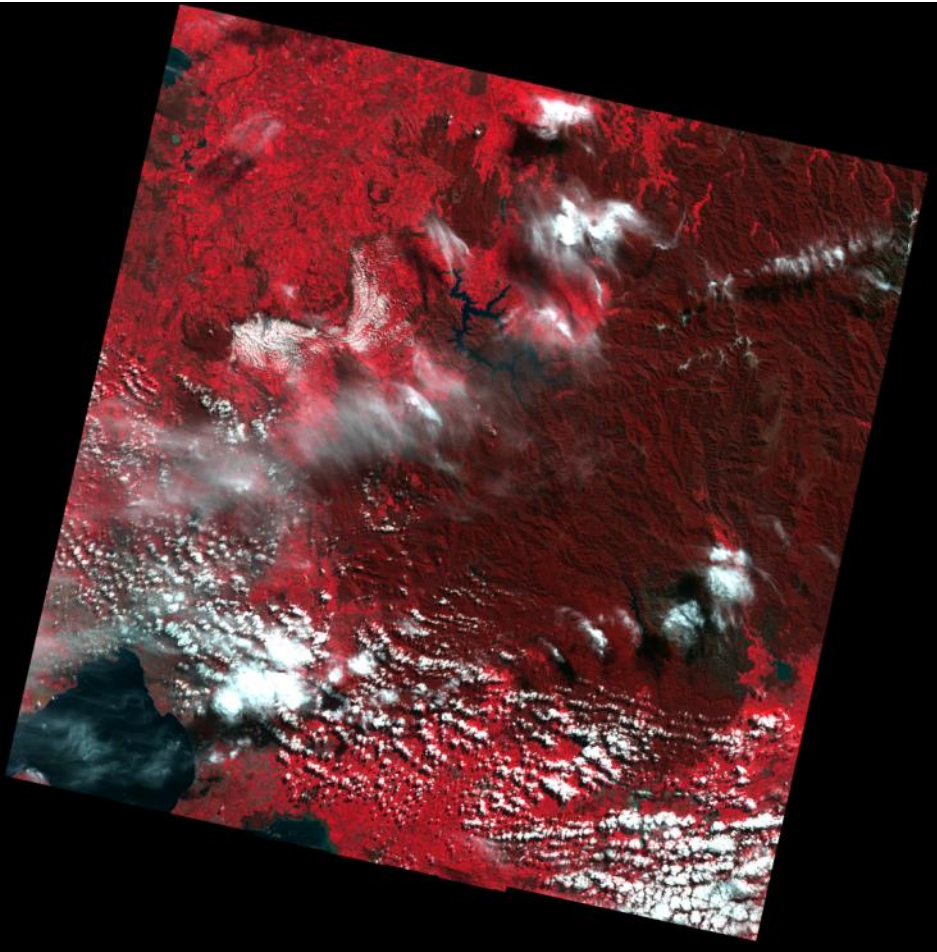
# Backup slides

- Fmask comparison for some other sites
- Some figures for Tmask algorithm that could be used for better illustrating the algorithm

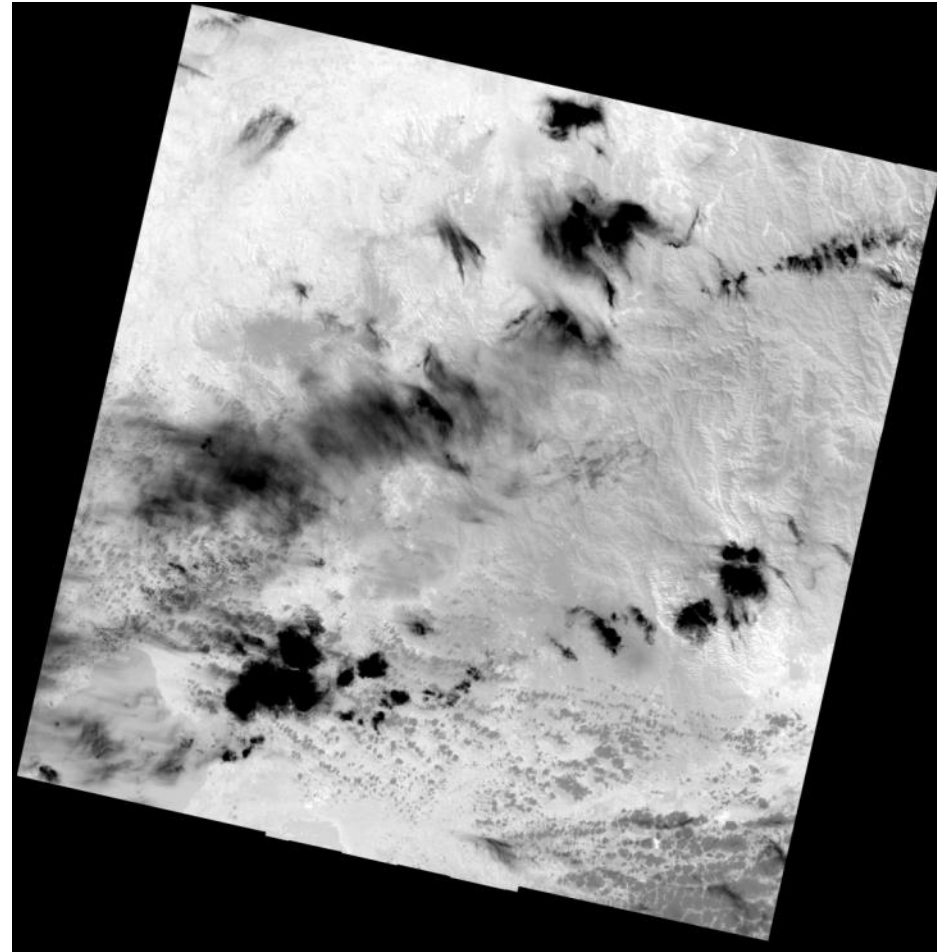


# Australia p92r86

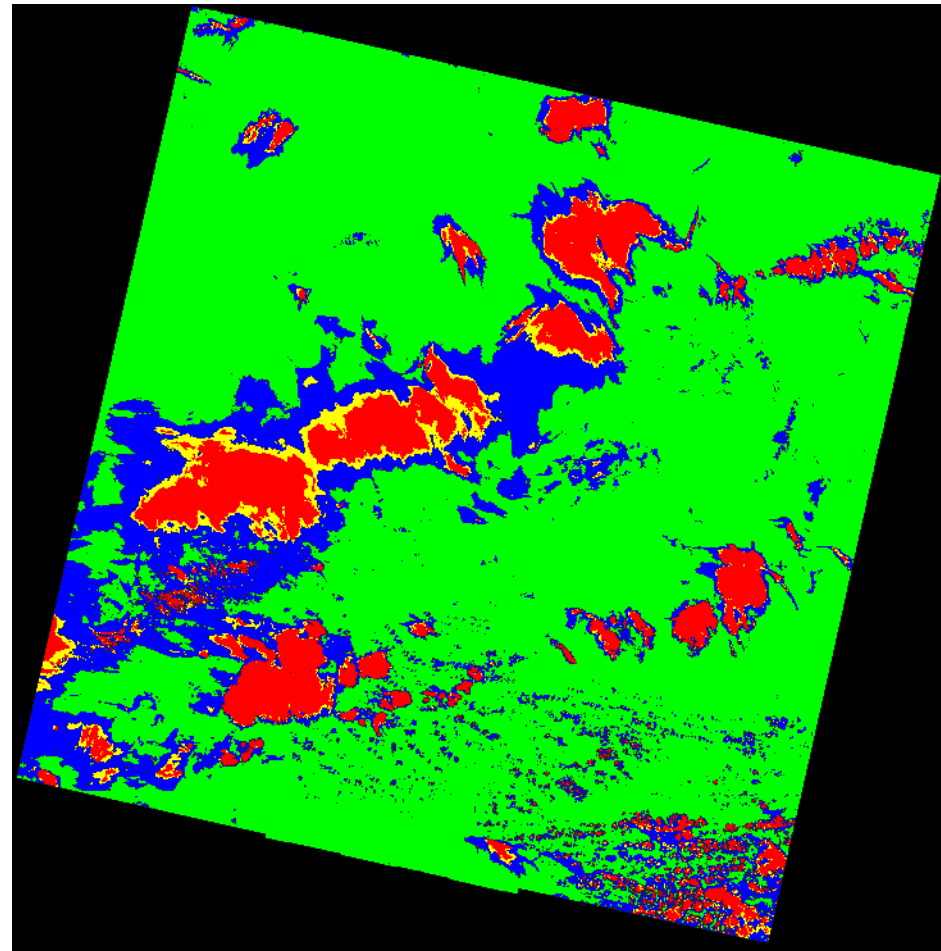
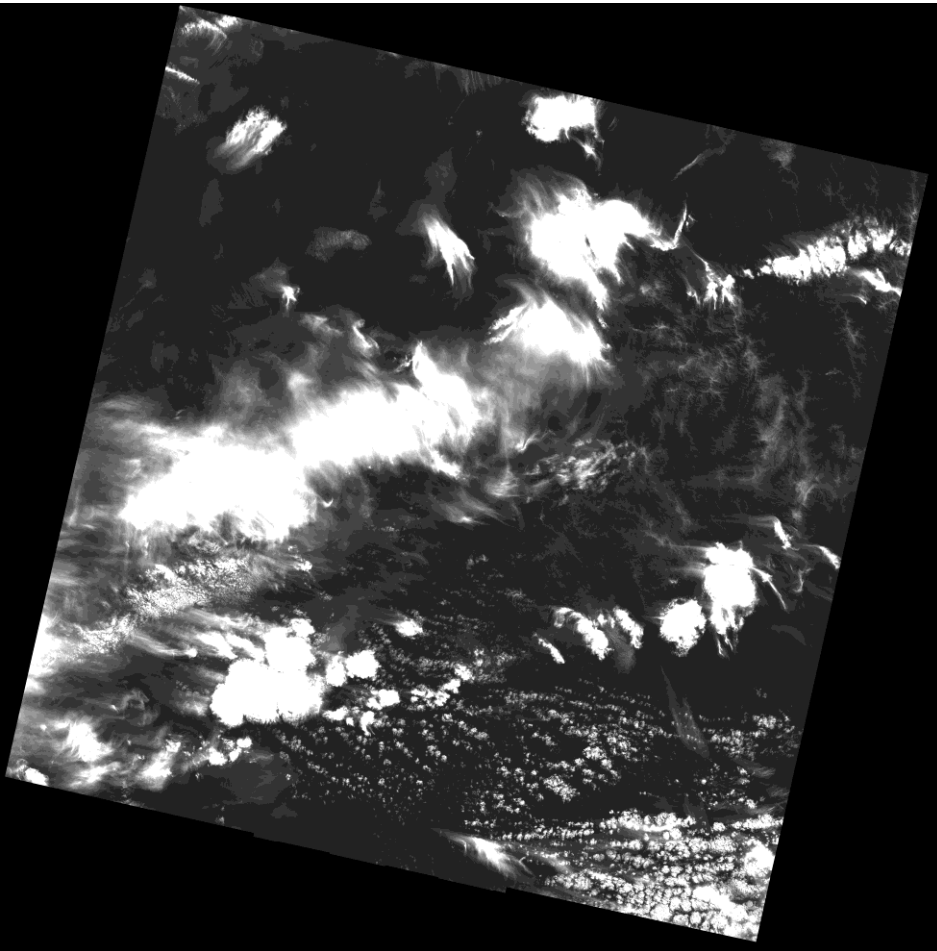
Band 4, 2, and 2 composites



Thermal Band

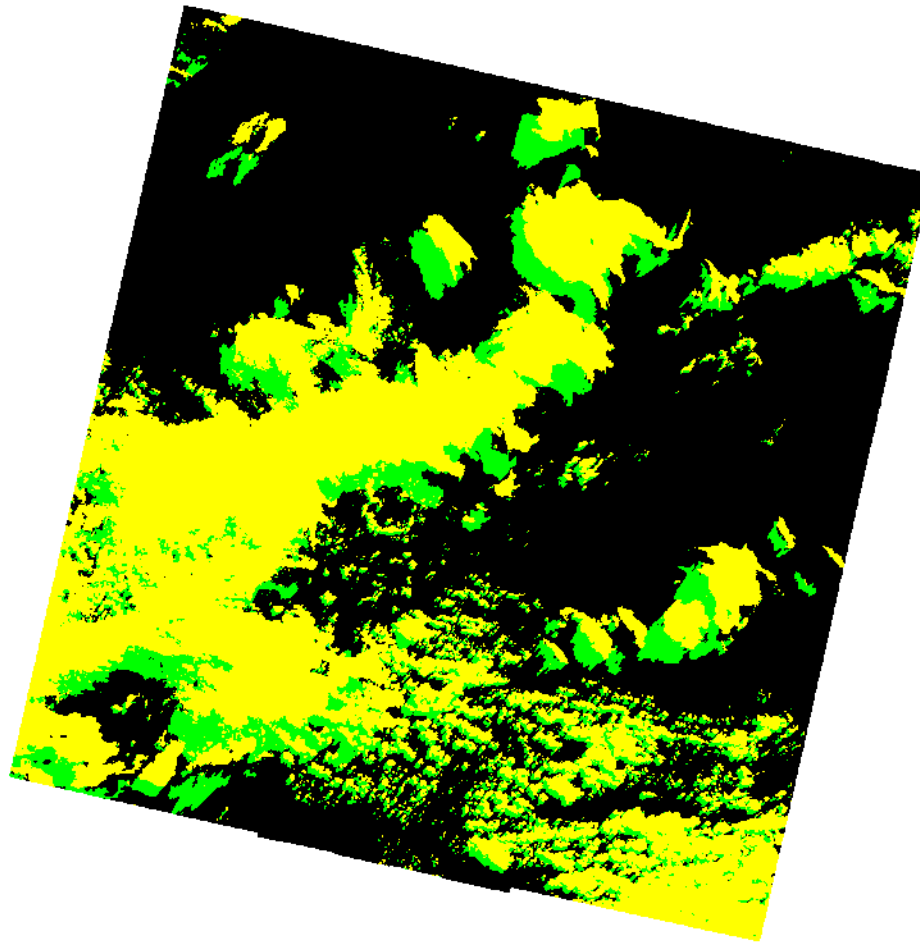


# Cirrus Band



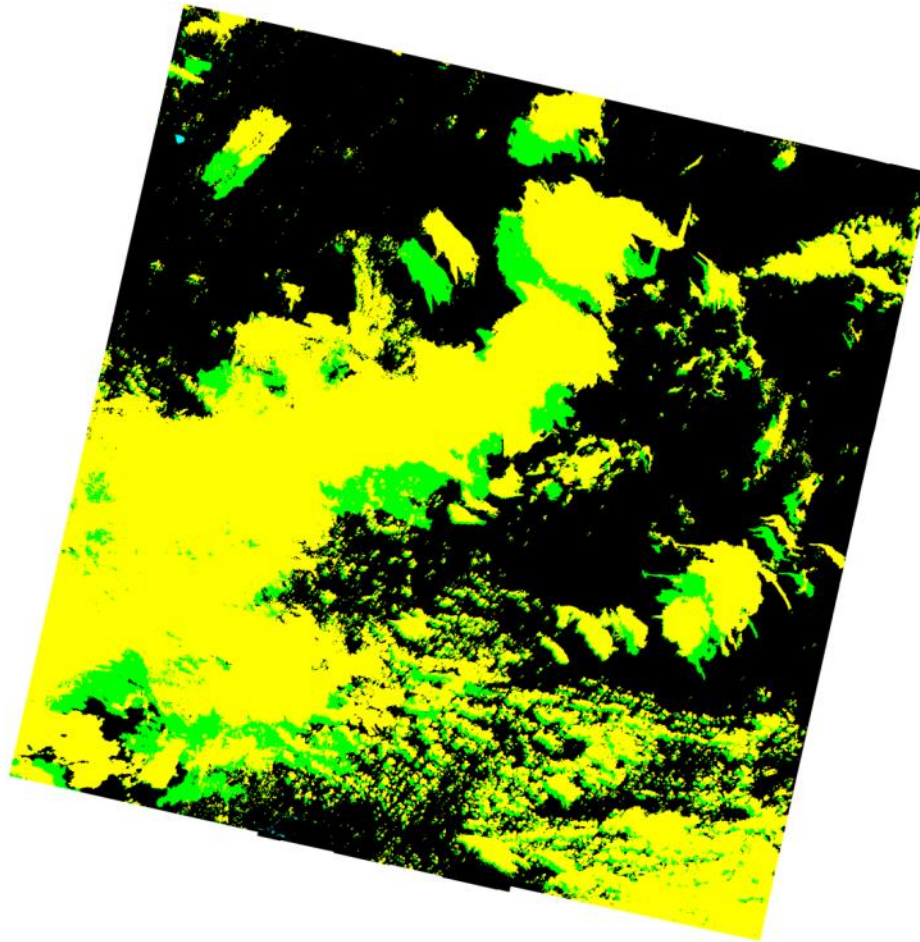
Cirrus band TOA reflectance: 0-0.01 0.01-0.03 0.03-0.04 0.04-1

# “TM/ETM” Fmask results



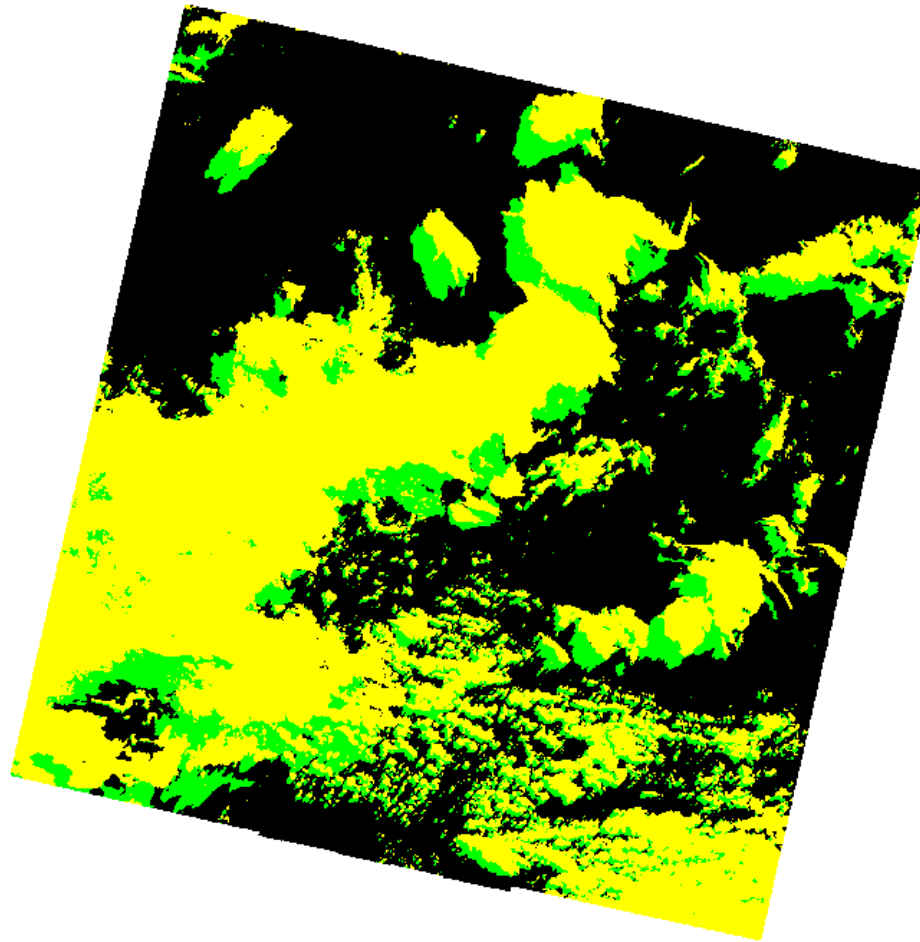
Clear Cloud Shadow Snow/Ice Cloud

# “Sentinel” Fmask results



Clear   Cloud Shadow   Snow/Ice   Cloud

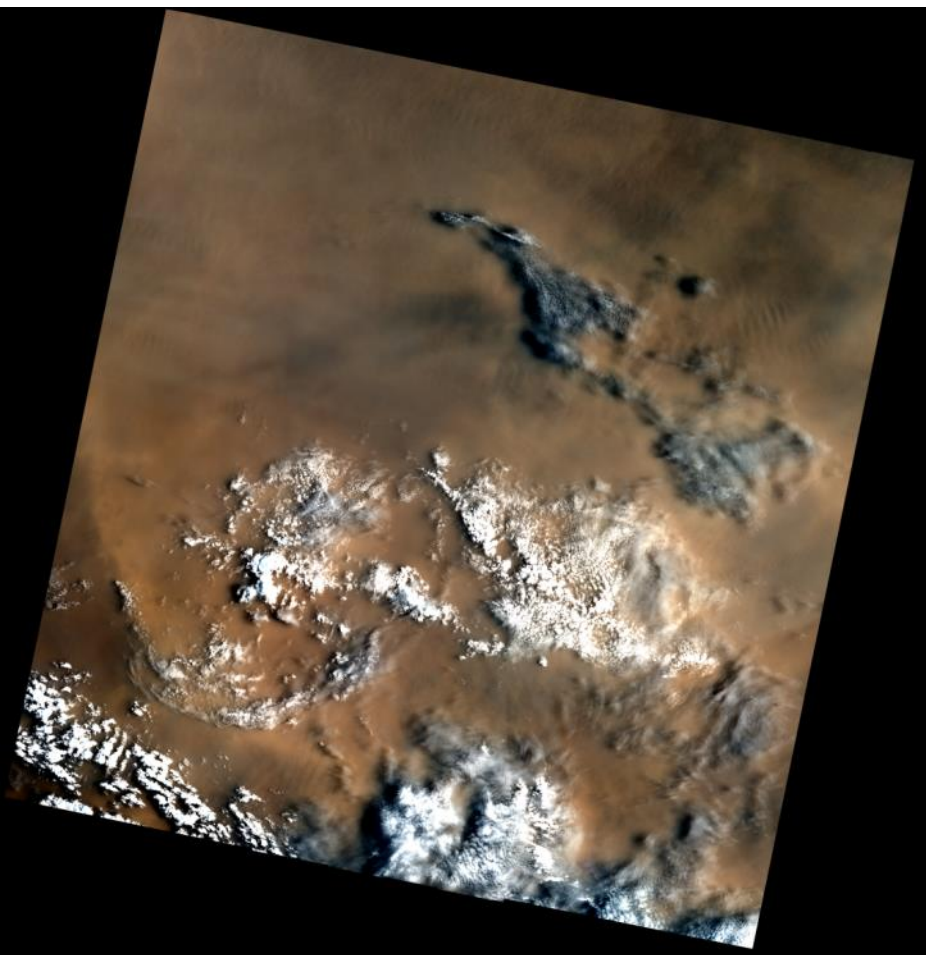
# “OLI/TIRS” Fmask results



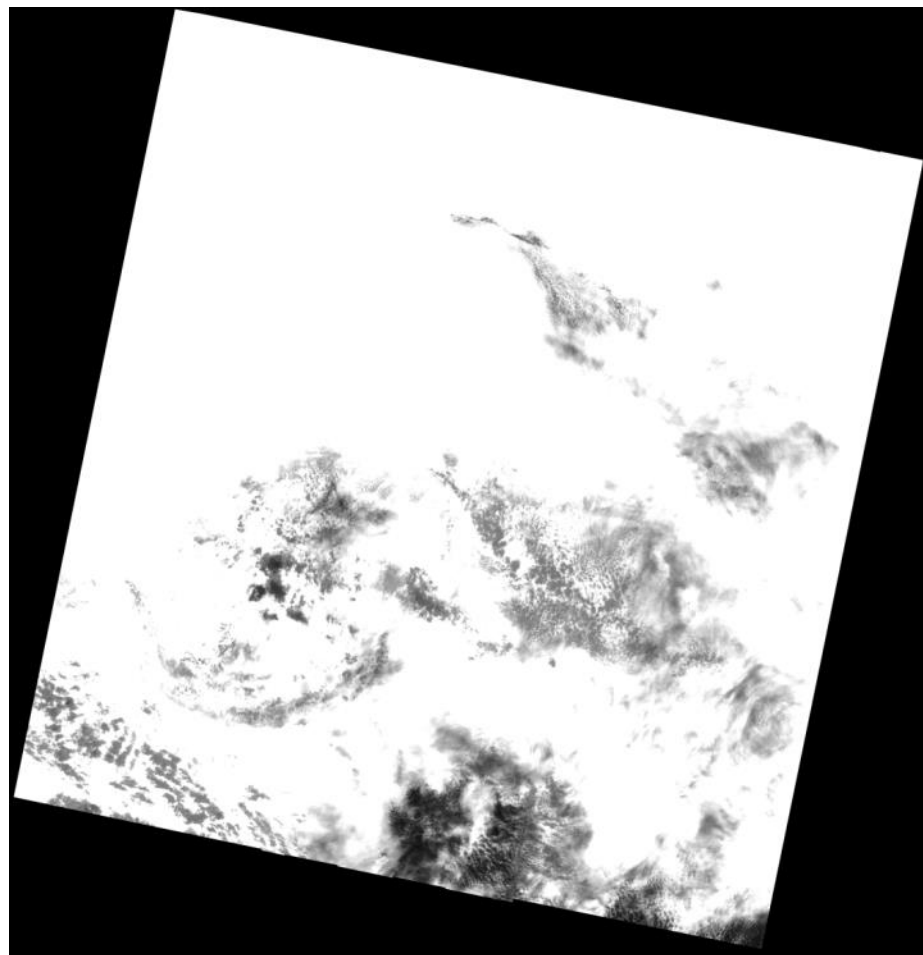
Clear Cloud Shadow Snow/Ice Cloud

# Africa p196r44

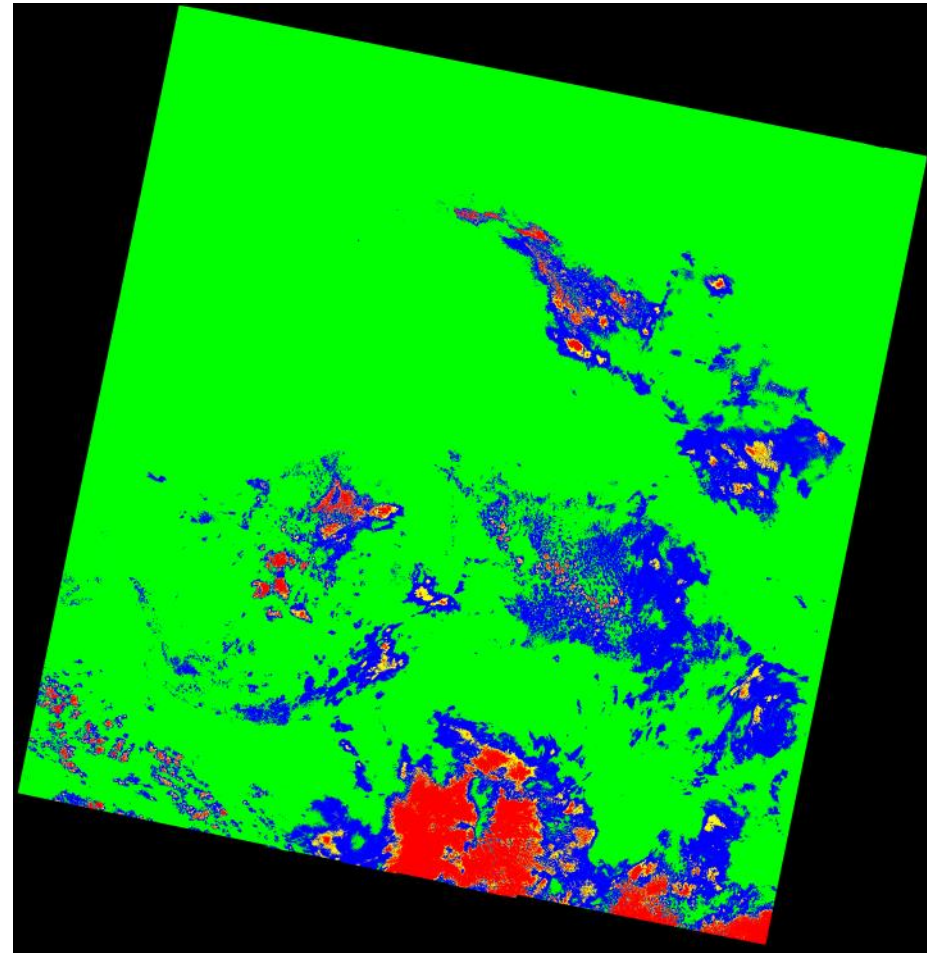
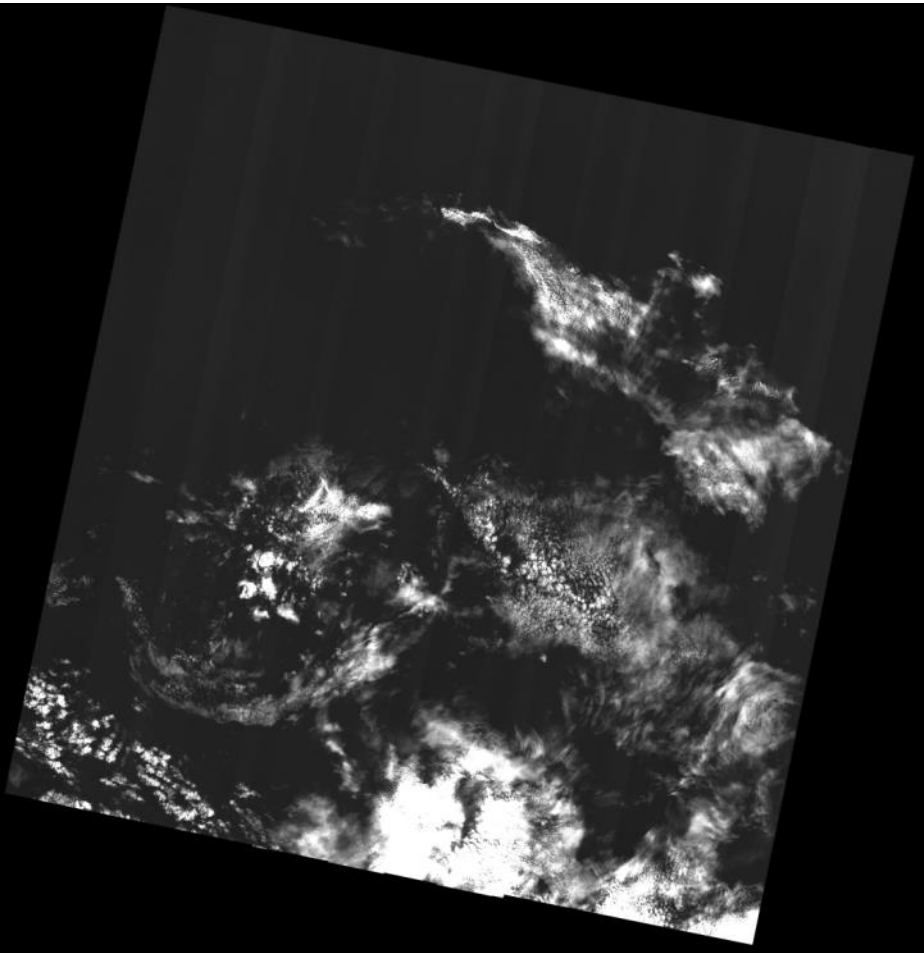
Band 4, 2, and 2 composites



Thermal Band

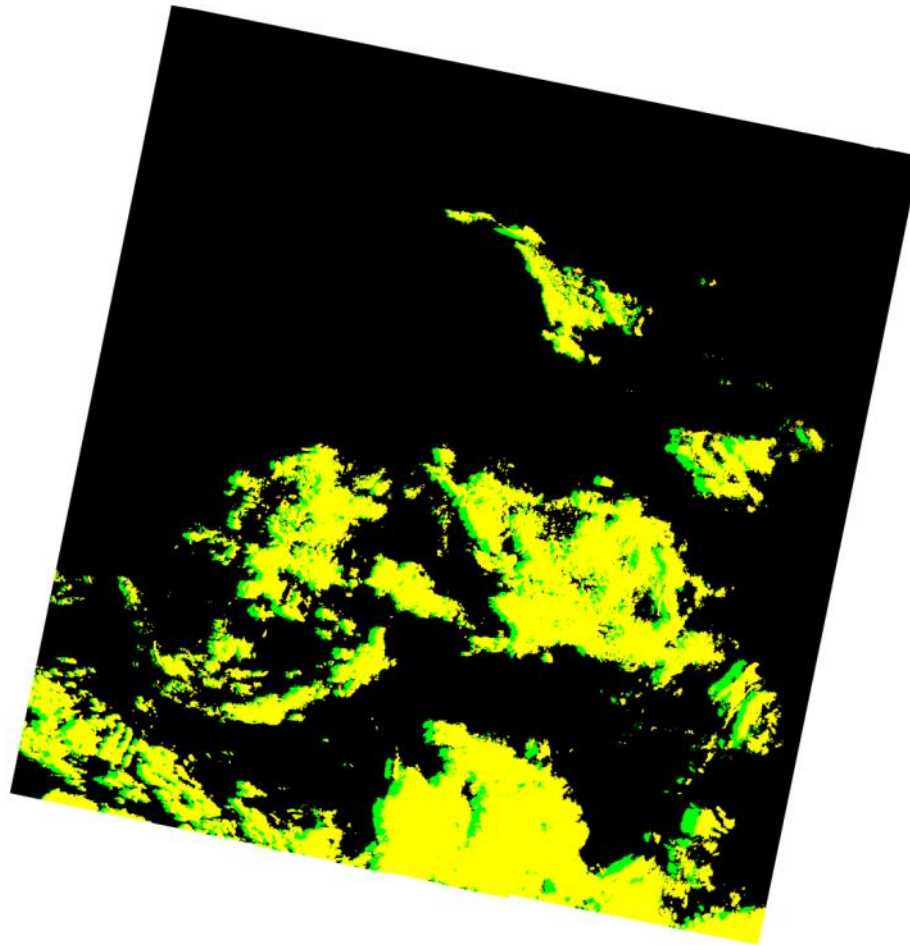


# Cirrus Band



Cirrus band TOA reflectance: 0-0.01 0.01-0.03 0.03-0.04 0.04-1

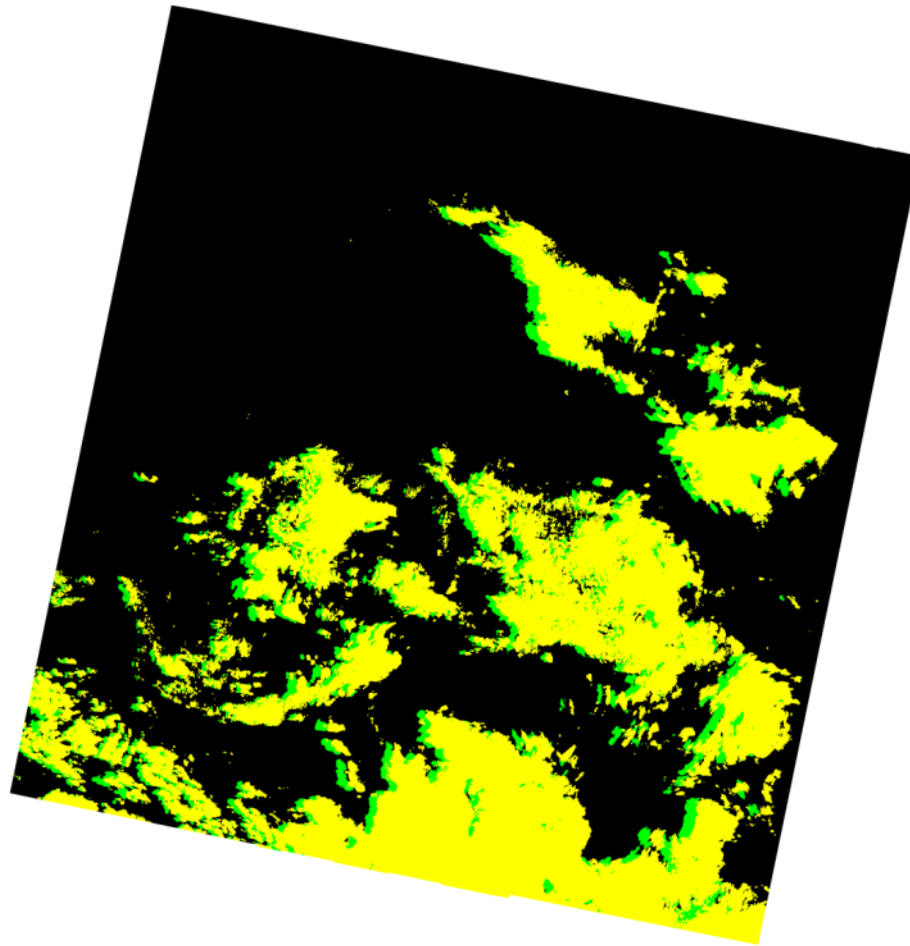
# “TM/ETM+” Fmask results



Clear Cloud Shadow Snow/Ice Cloud

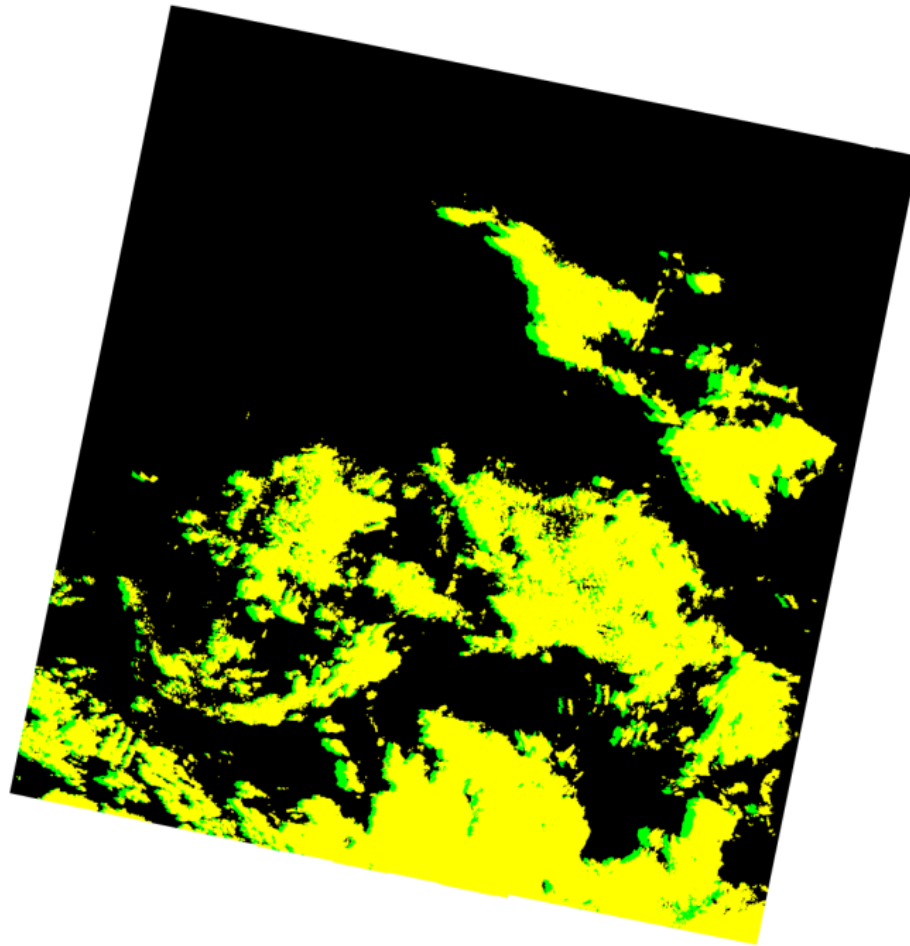


# “Sentinel” Fmask results



Clear   Cloud Shadow   Snow/Ice   Cloud

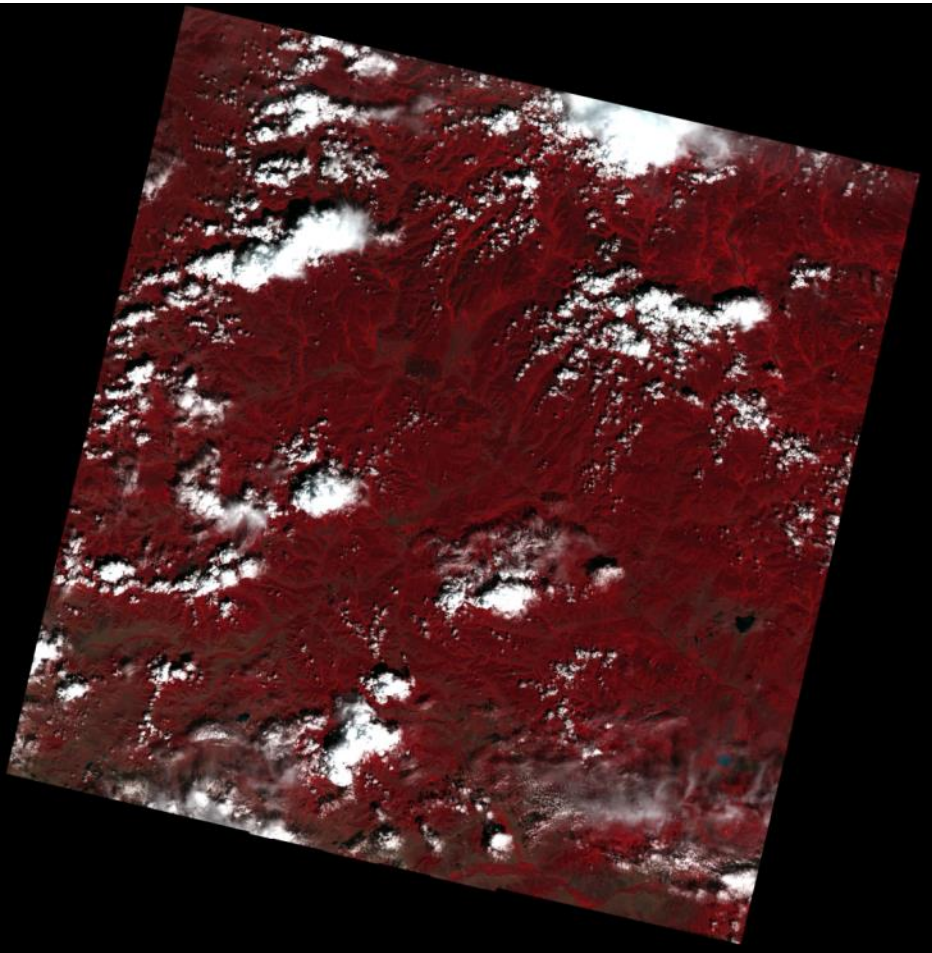
# “OLI/TIRS” Fmask results



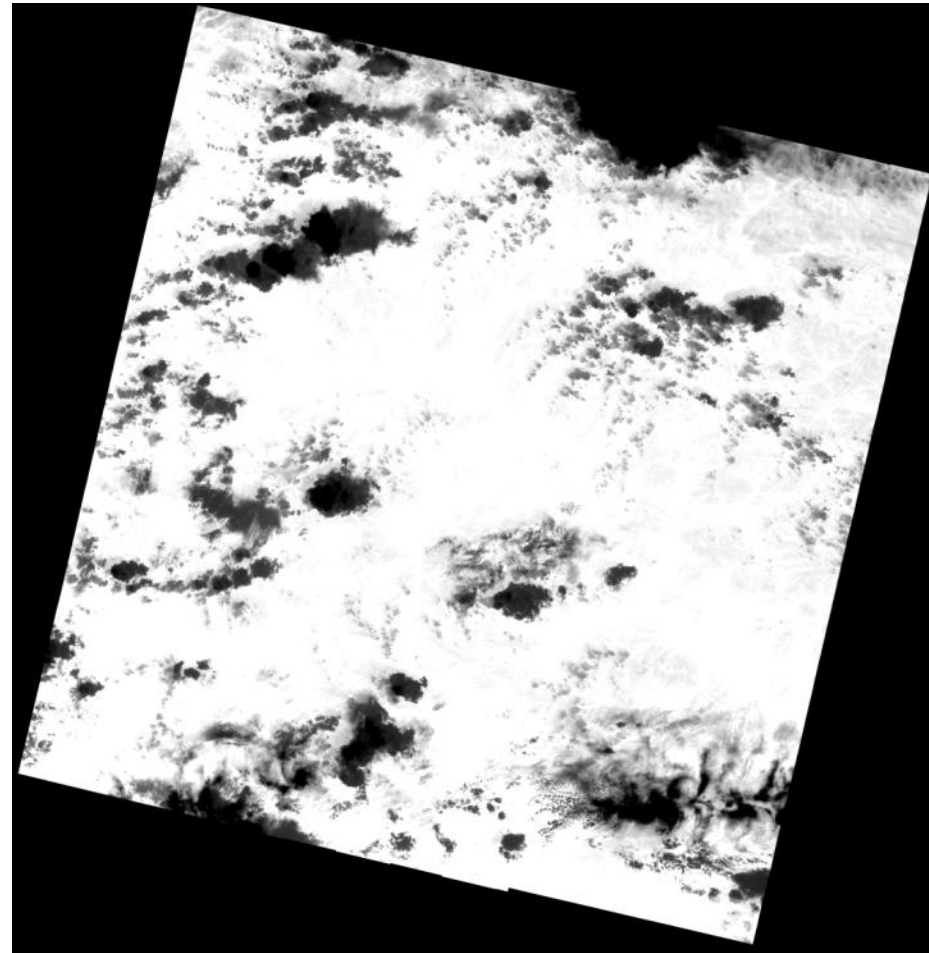
Clear   Cloud Shadow   Snow/Ice   Cloud

# Mongolia p135r25

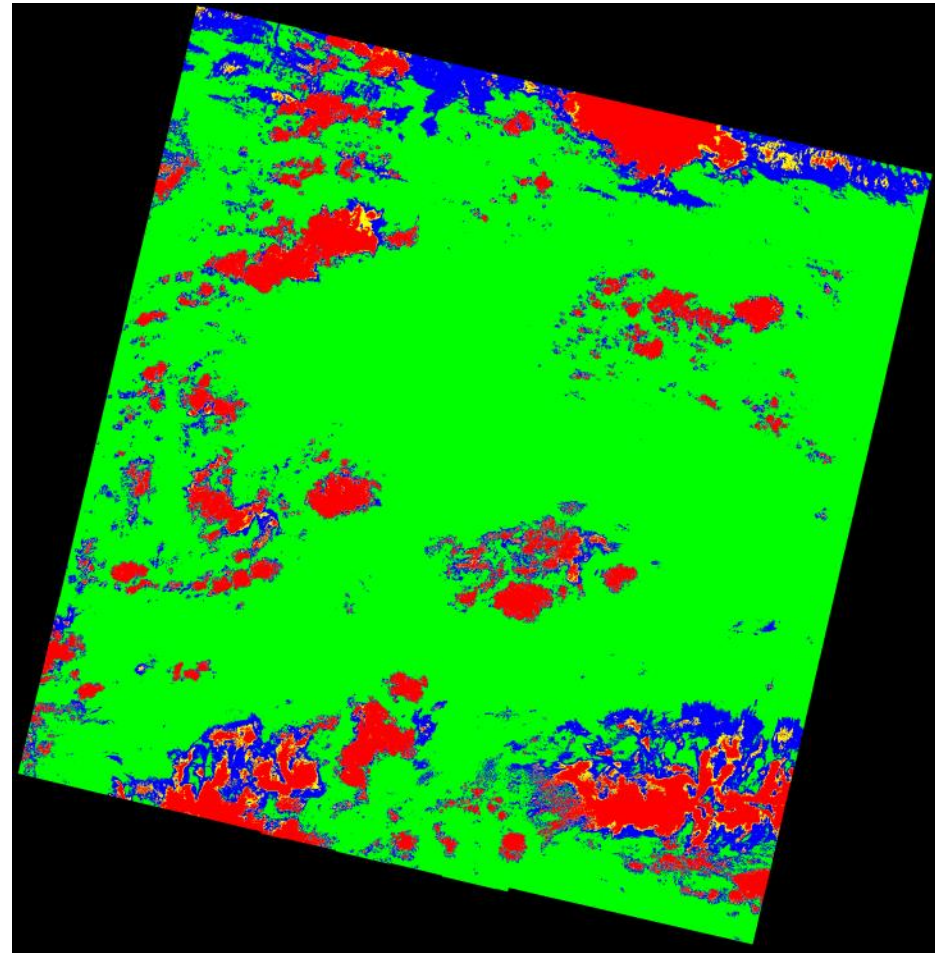
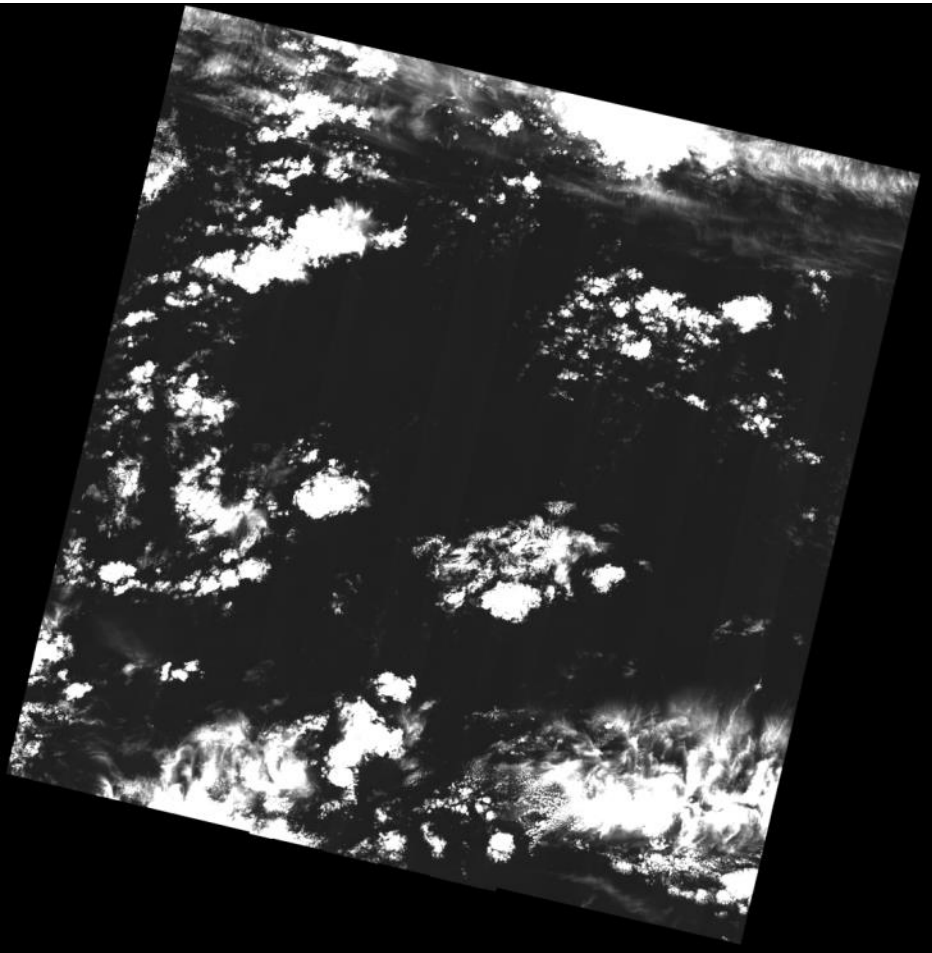
Band 4, 2, and 2 composites



Thermal Band

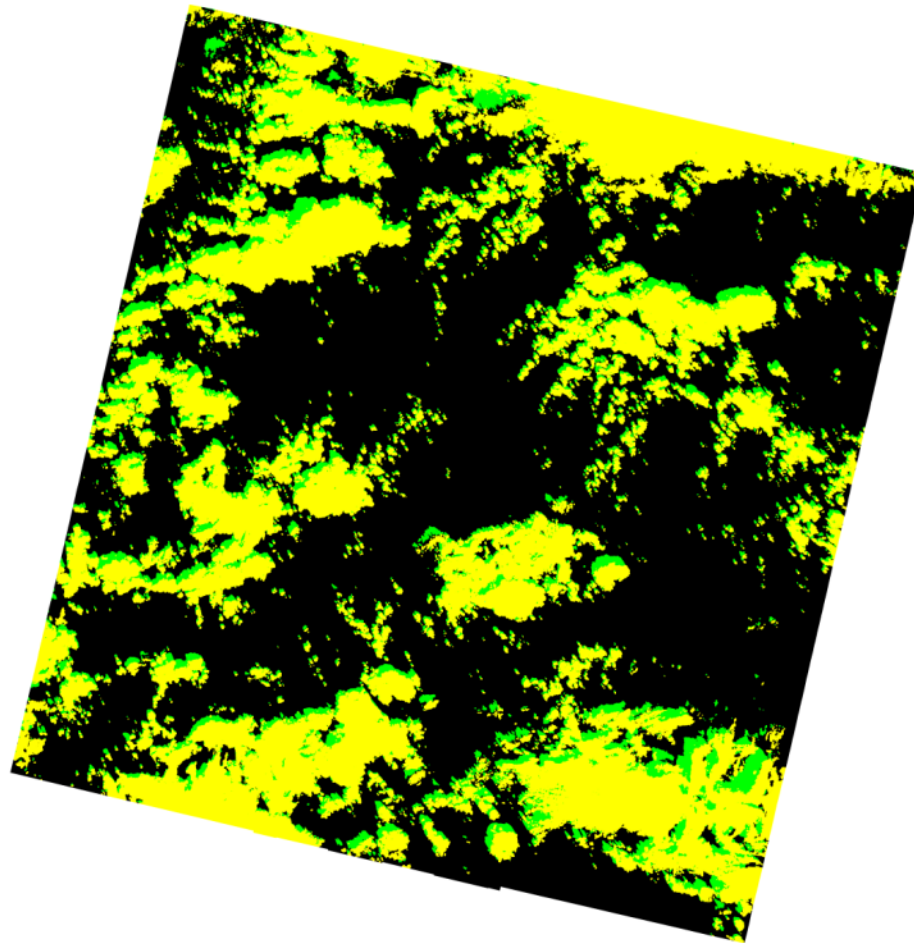


# Cirrus Band



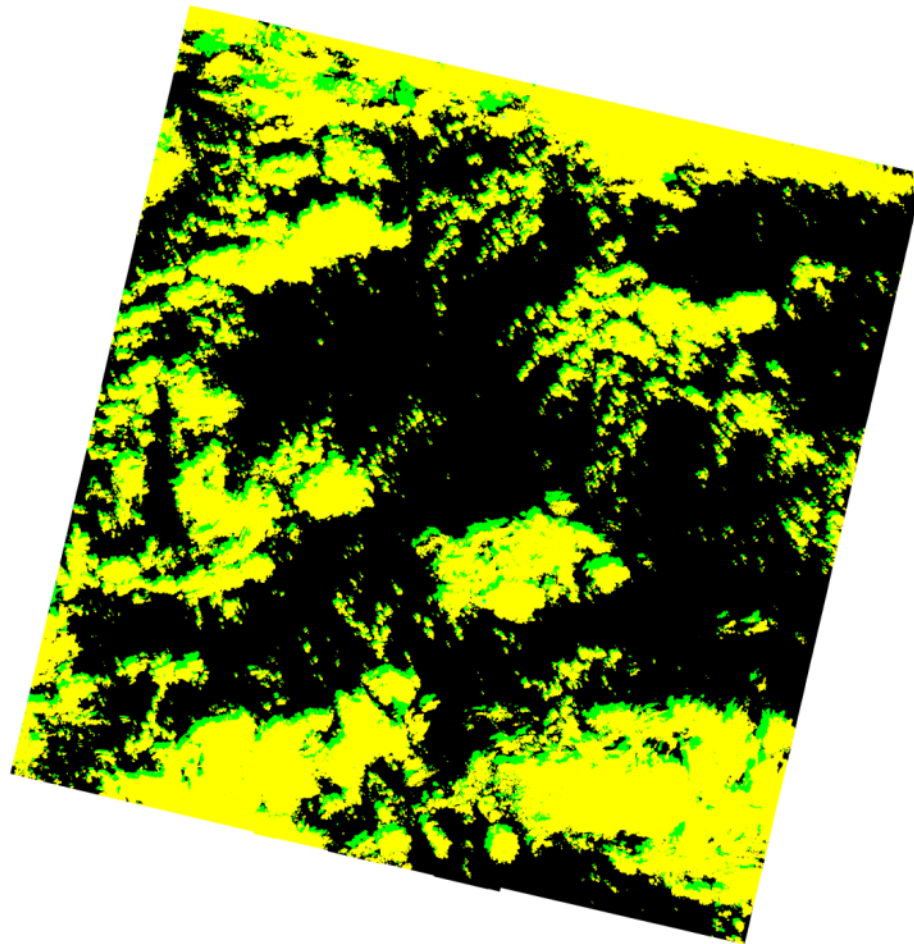
Cirrus band TOA reflectance: 0-0.01 0.01-0.03 0.03-0.04 0.04-1

# “TM/ETM+” Fmask results



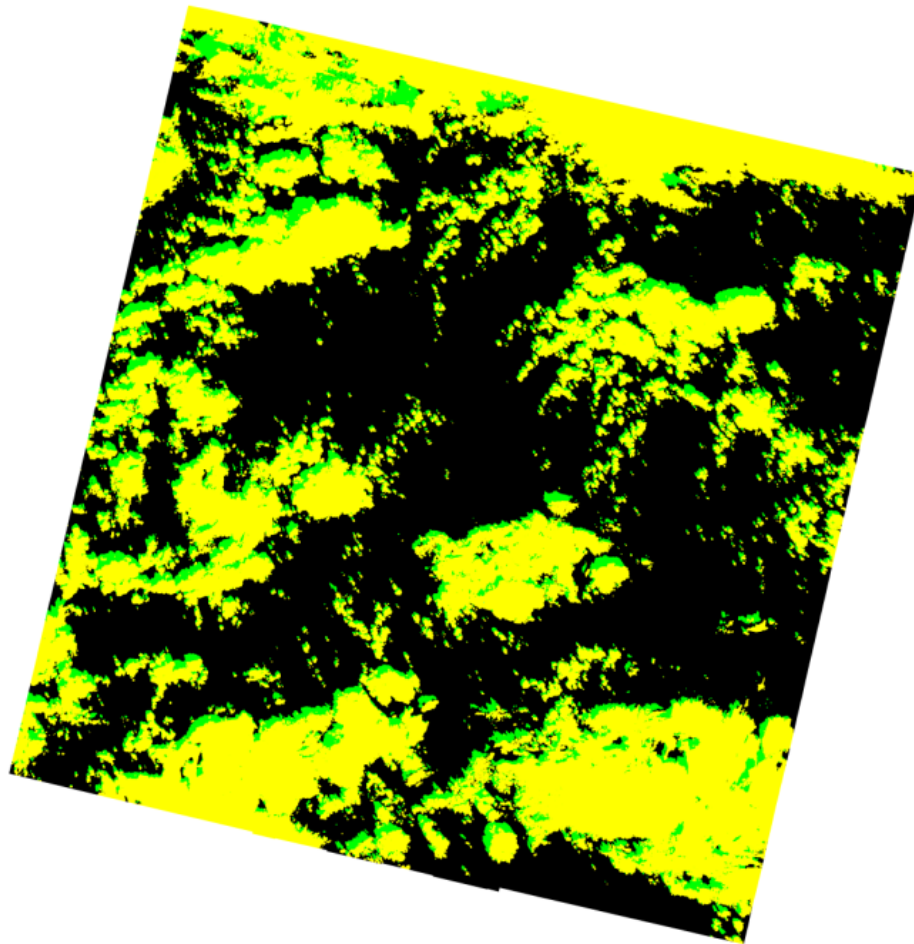
Clear   Cloud Shadow   Snow/Ice   Cloud

# “Sentinel” Fmask results



Clear Cloud Shadow Snow/Ice Cloud

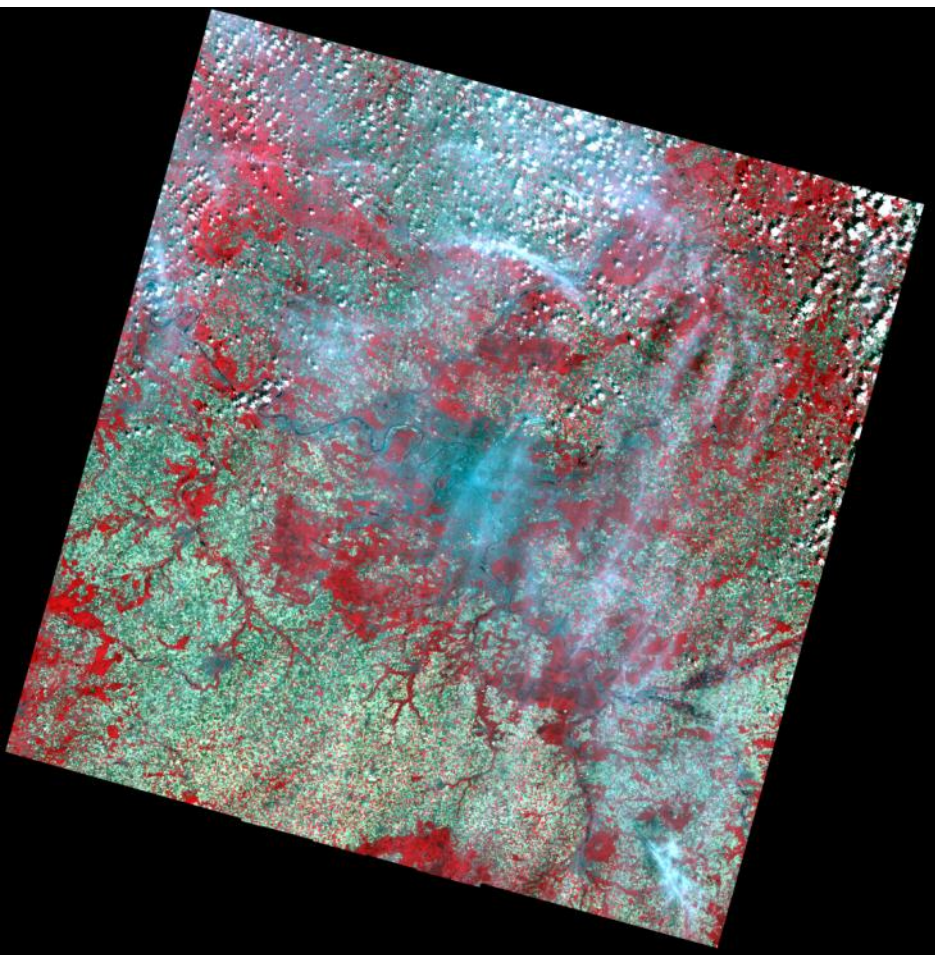
# “OLI/TIRS” Fmask results



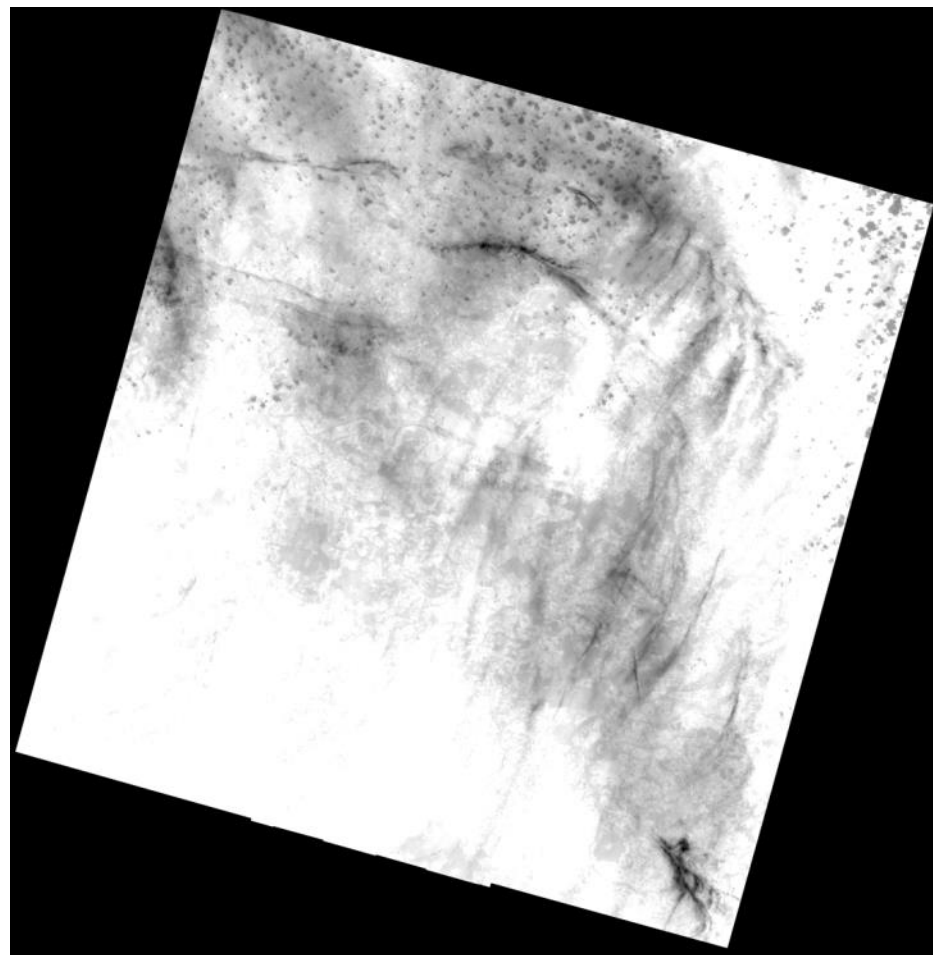
Clear Cloud Shadow Snow/Ice Cloud

# Paris p199r26

Band 4, 2, and 2 composites

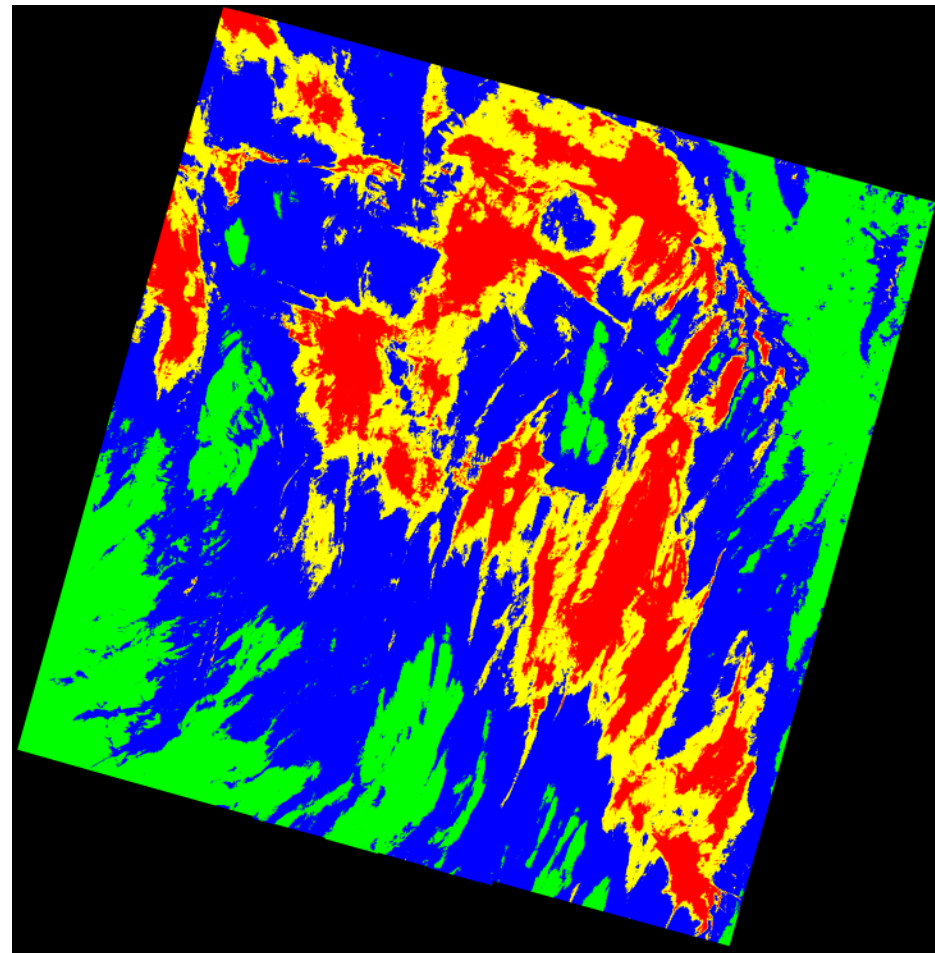
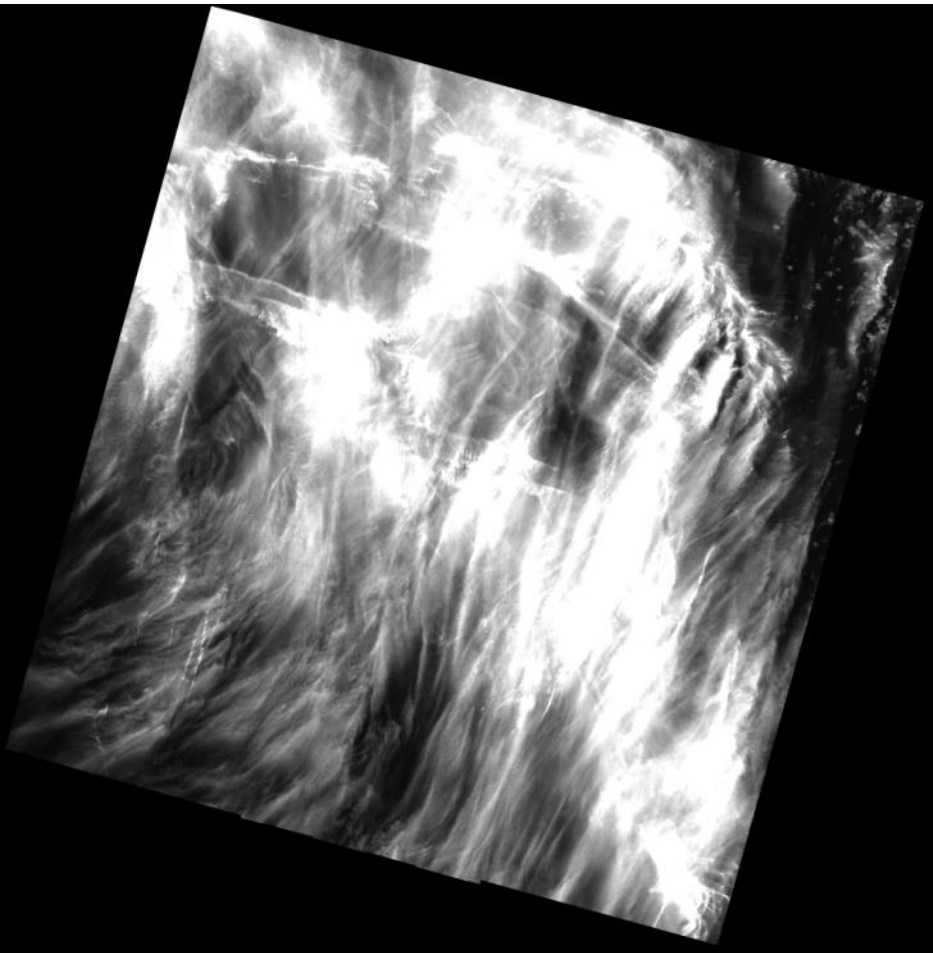


Thermal Band



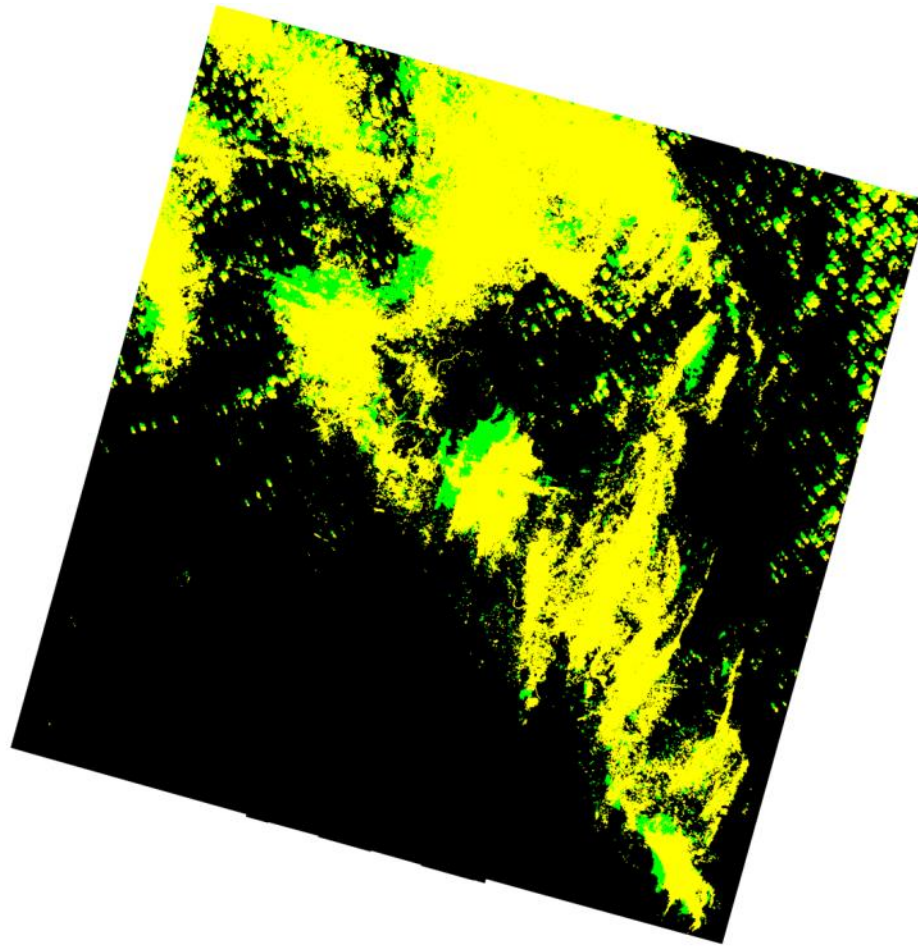


# Cirrus Band



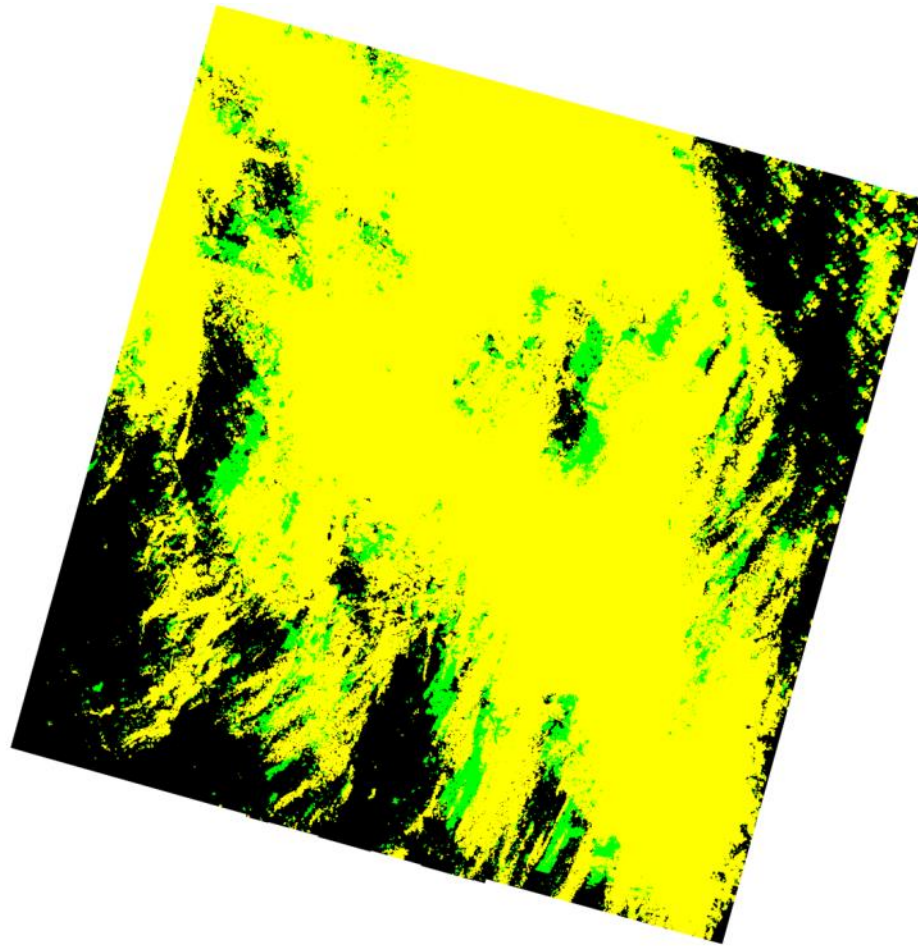
Cirrus band TOA reflectance: 0-0.01 0.01-0.03 0.03-0.04 0.04-1

# “TM/ETM+” Fmask results



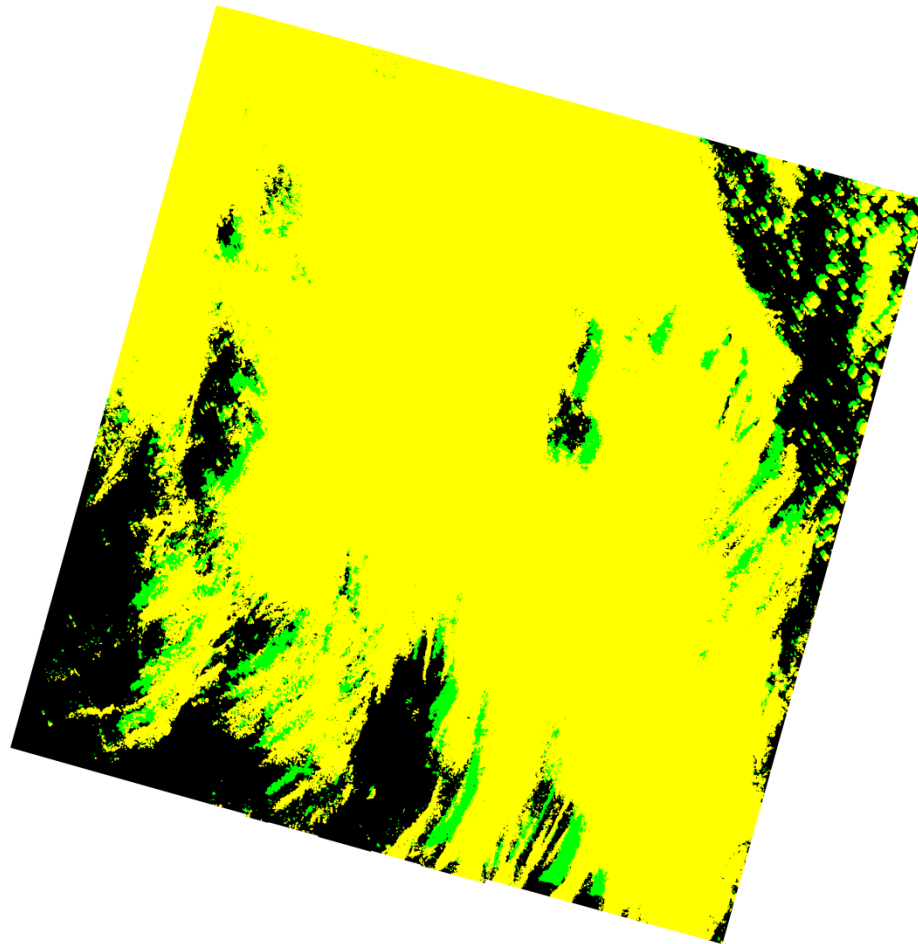
Clear Cloud Shadow Snow/Ice Cloud

# “Sentinel” Fmask results



Clear Cloud Shadow Snow/Ice Cloud

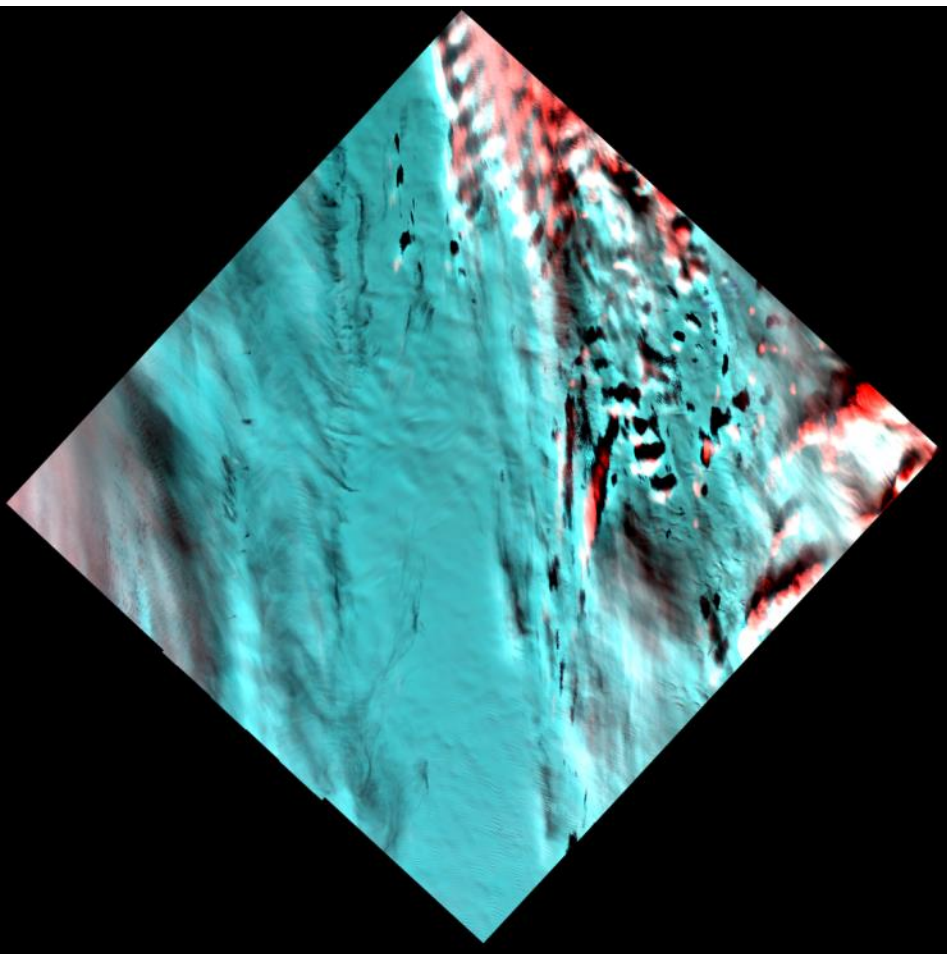
# “OLI/TIRS” Fmask results



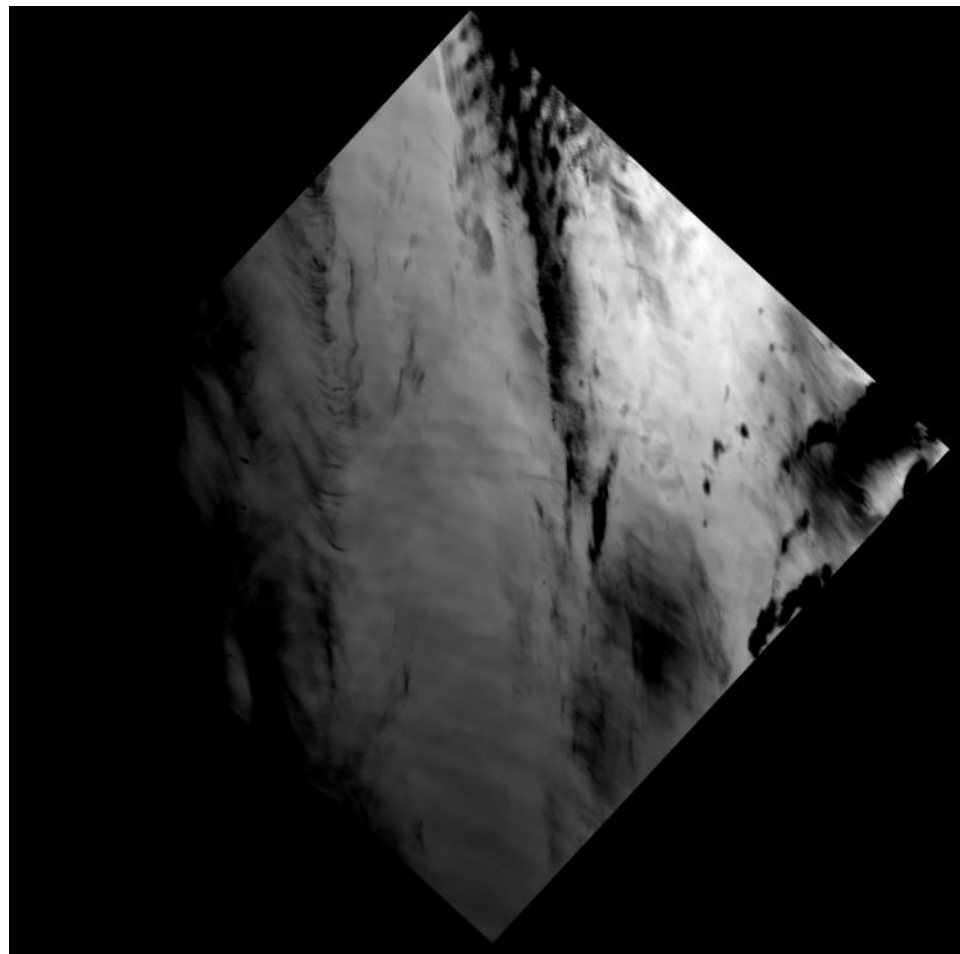
Clear Cloud Shadow Snow/Ice Cloud

# North Polar p7r5

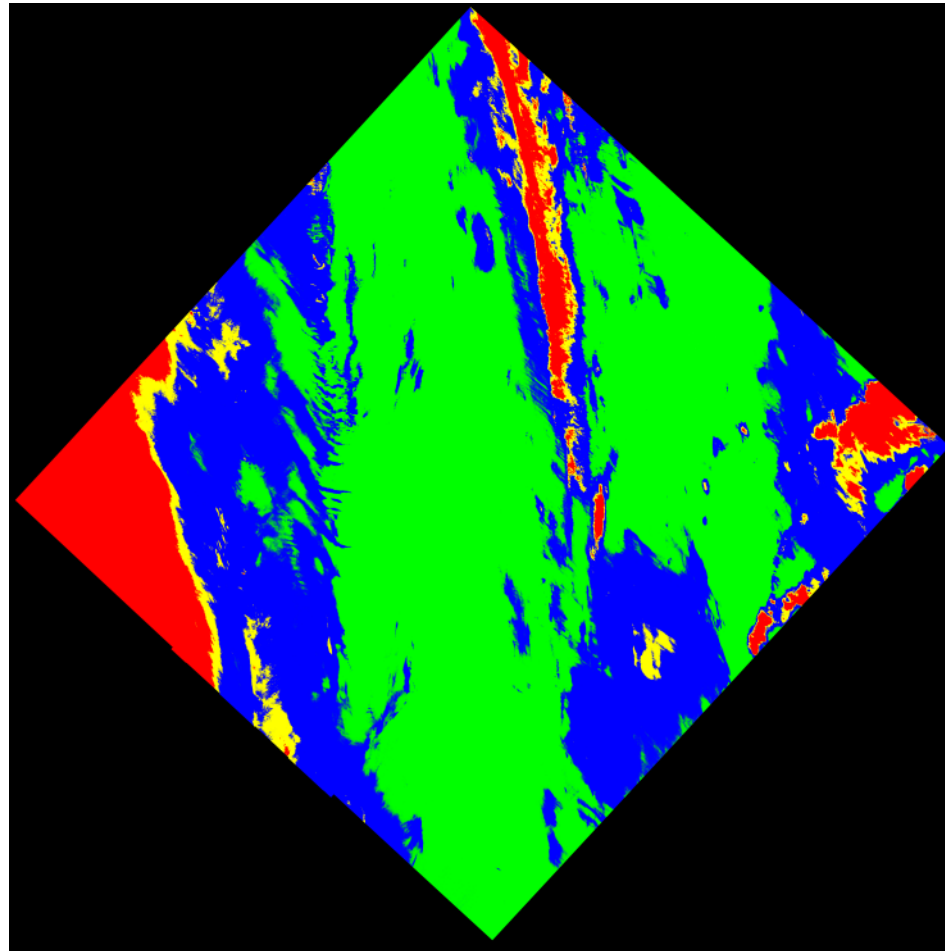
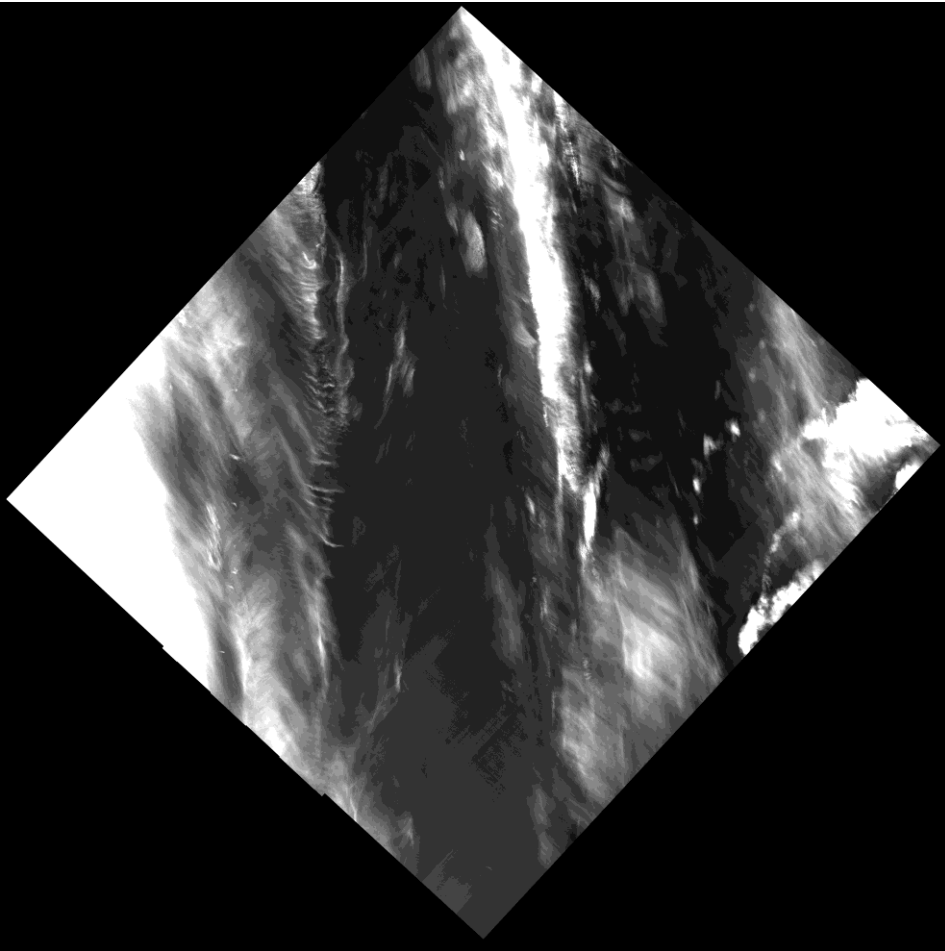
Band 5, 4, and 3 composites



Thermal Band

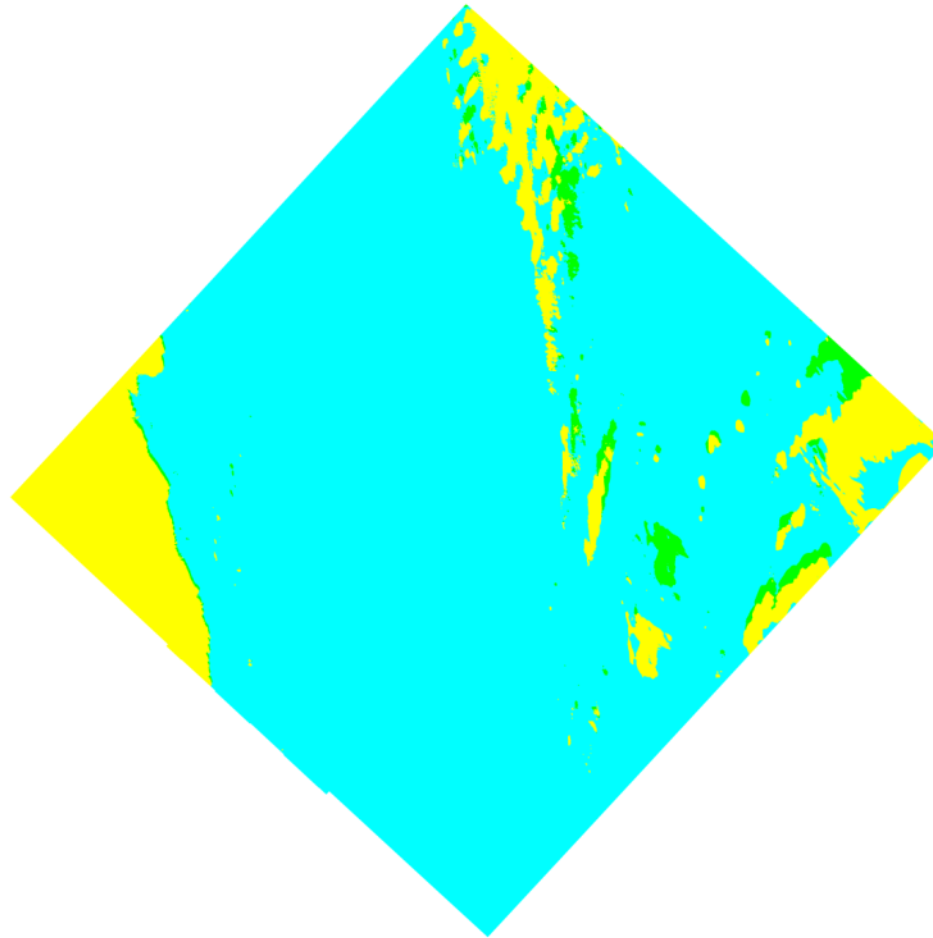


# Cirrus Band



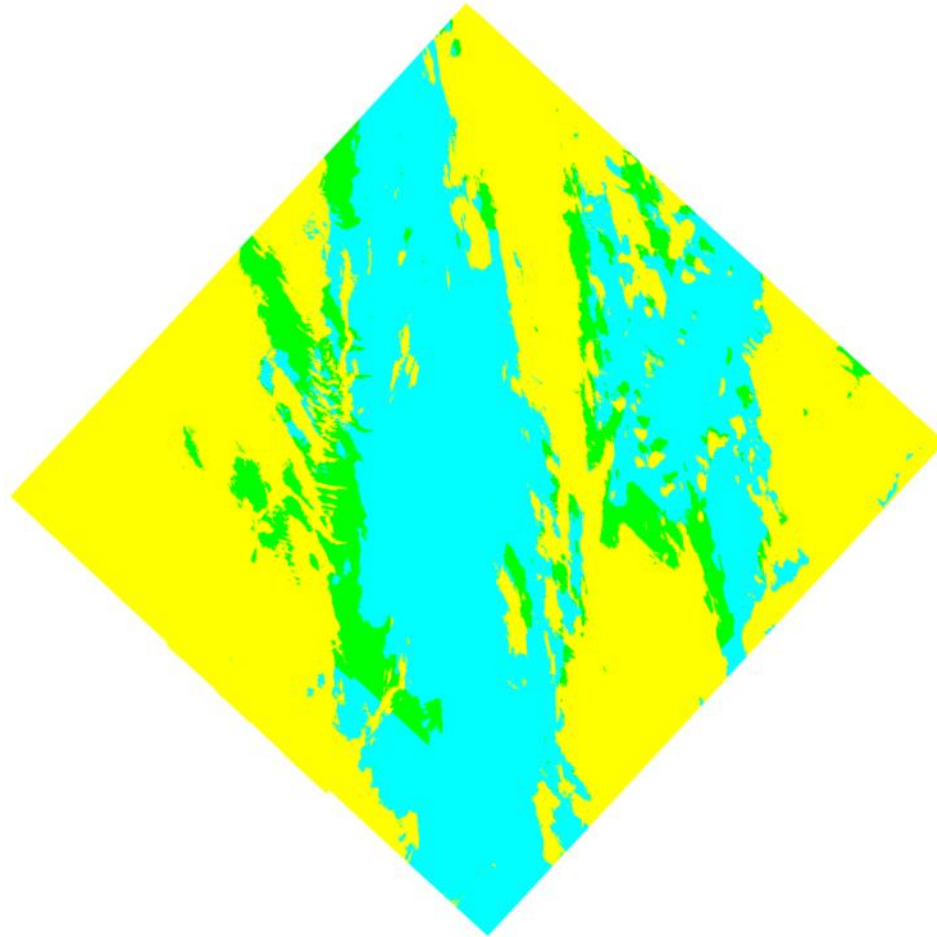
Cirrus band TOA reflectance: 0-0.01 0.01-0.03 0.03-0.04 0.04-1

# “TM/ETM+” Fmask results



Clear Cloud Shadow Snow/Ice Cloud

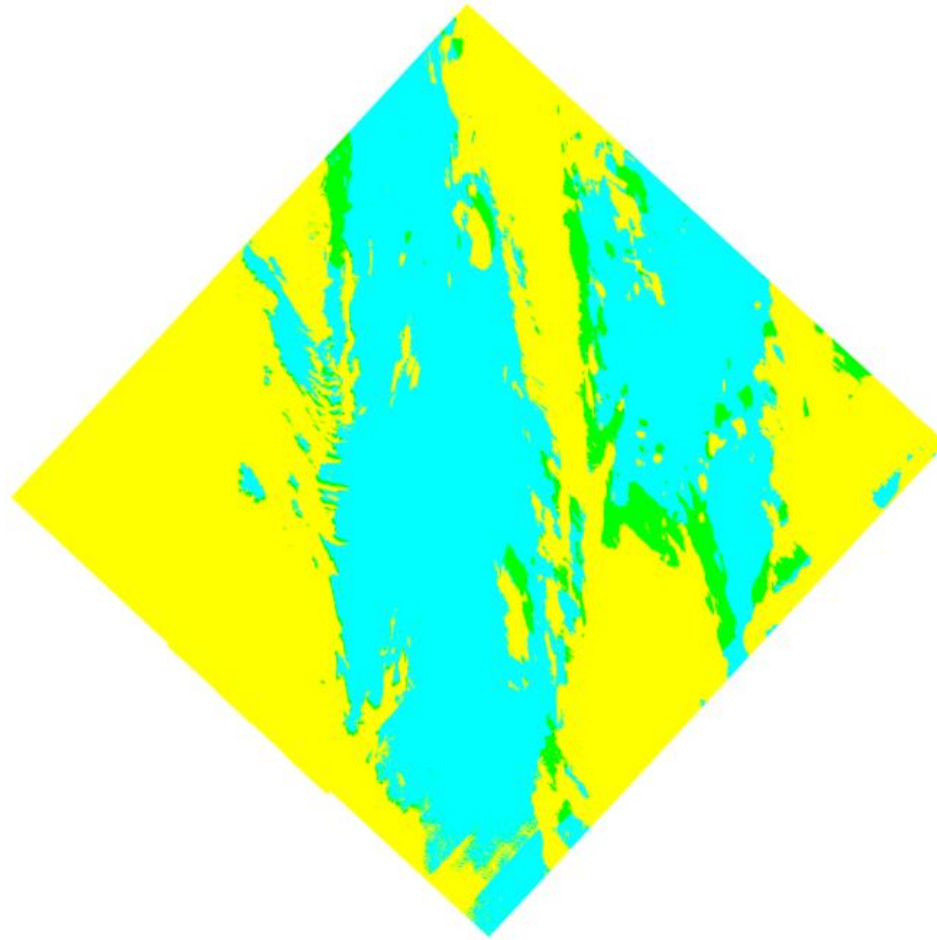
# “Sentinel” Fmask results



Clear   Cloud Shadow   Snow/Ice   Cloud



# “OLI/TIRS” Fmask results

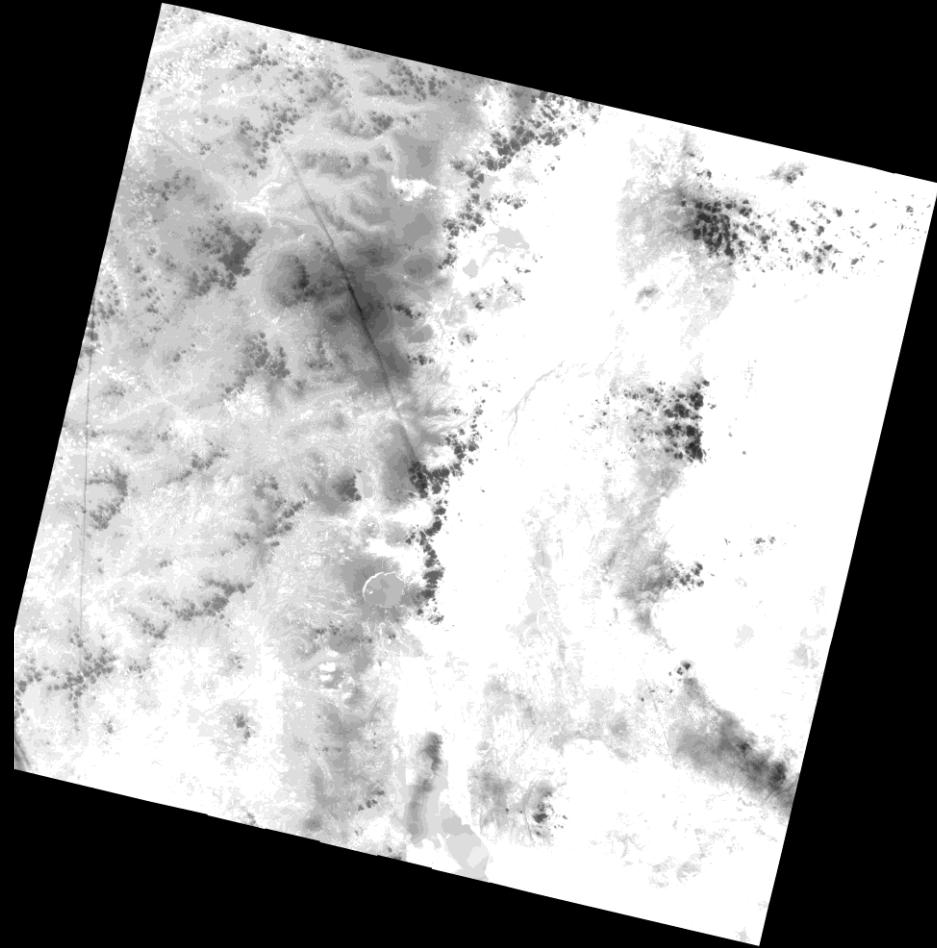
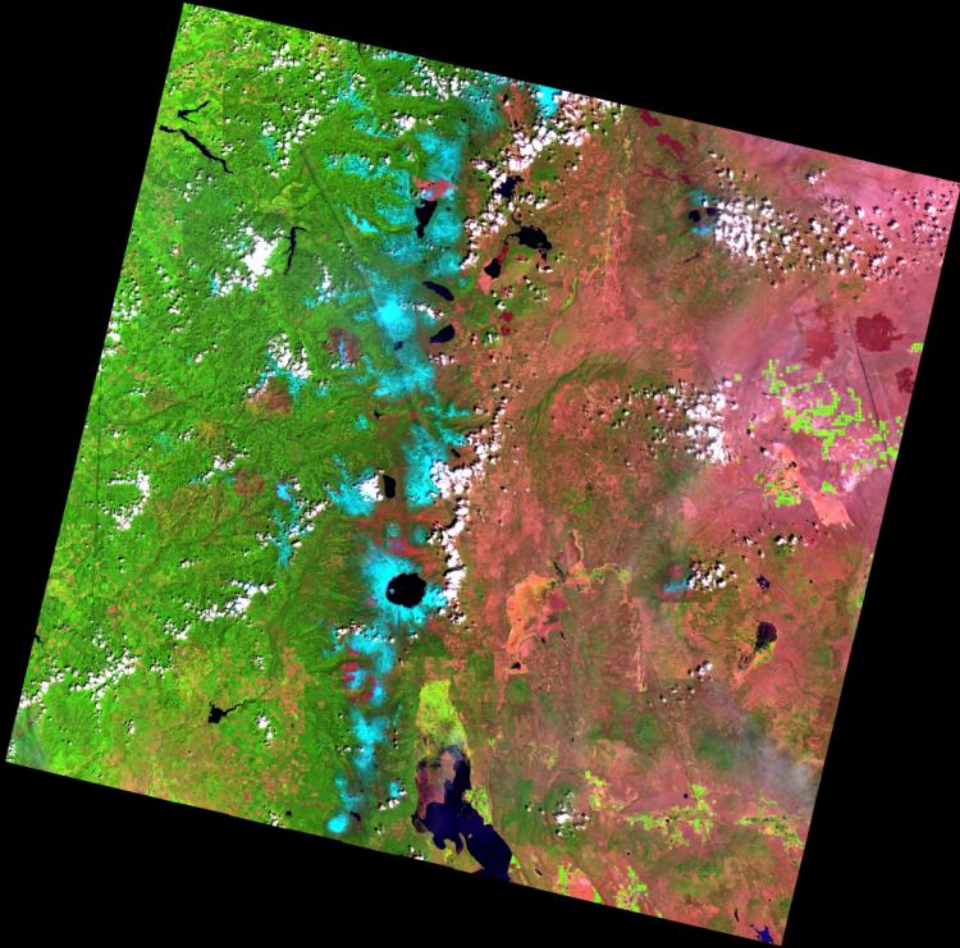


Clear   Cloud Shadow   Snow/Ice   Cloud

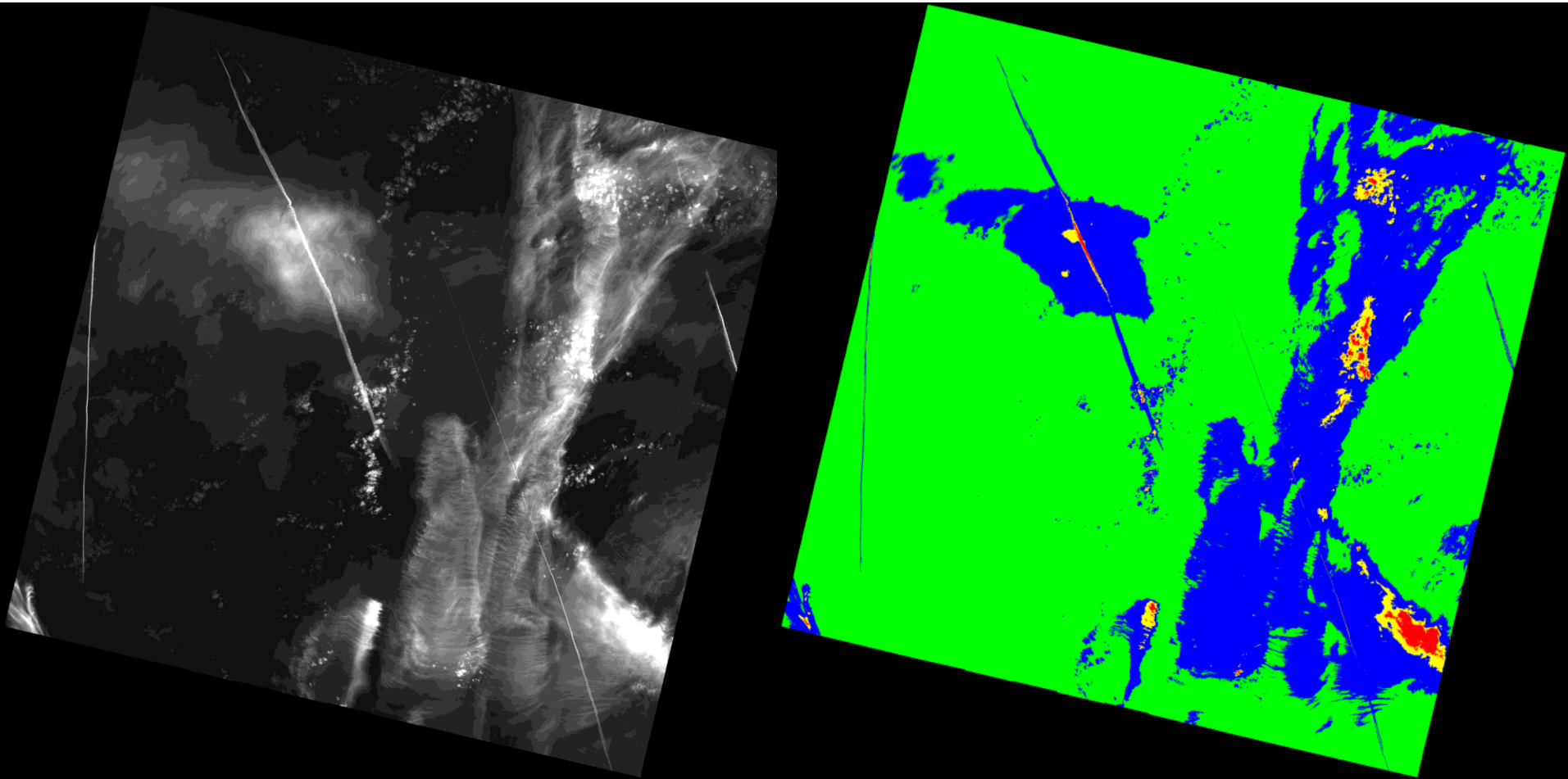
# Oregon p45r30

Band 5, 4, and 3 composites

Thermal Band

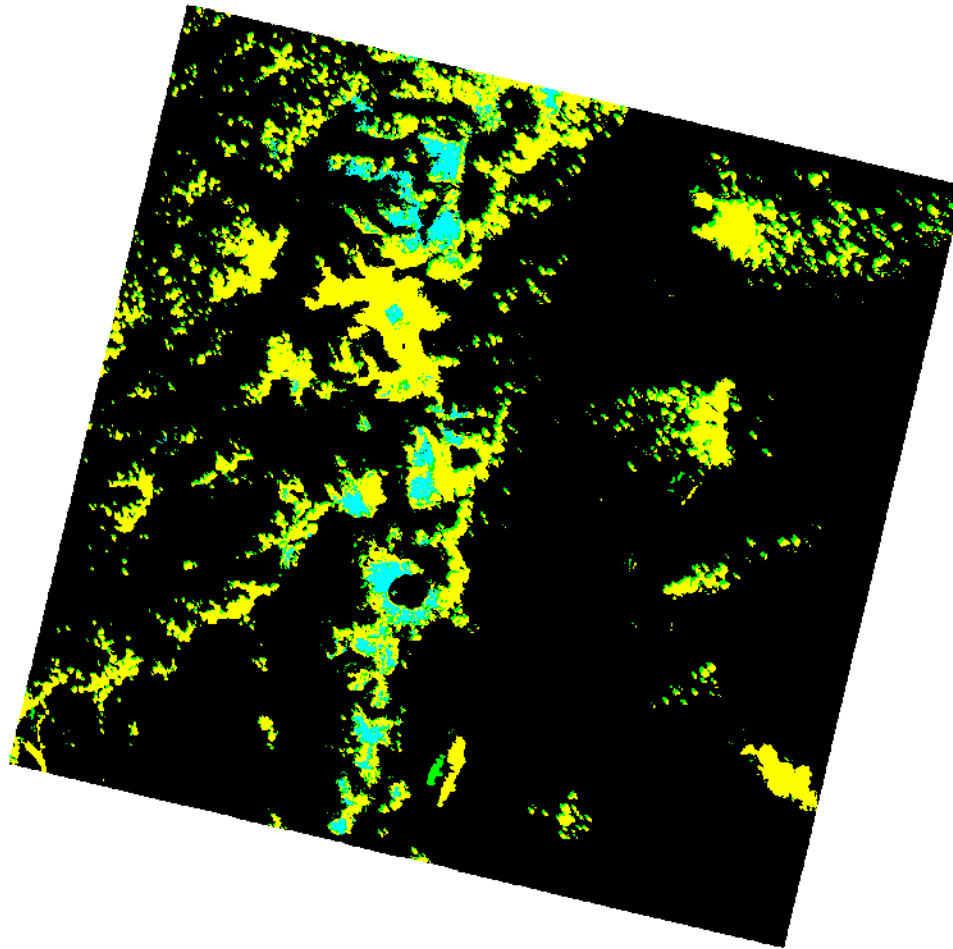


# Cirrus Band



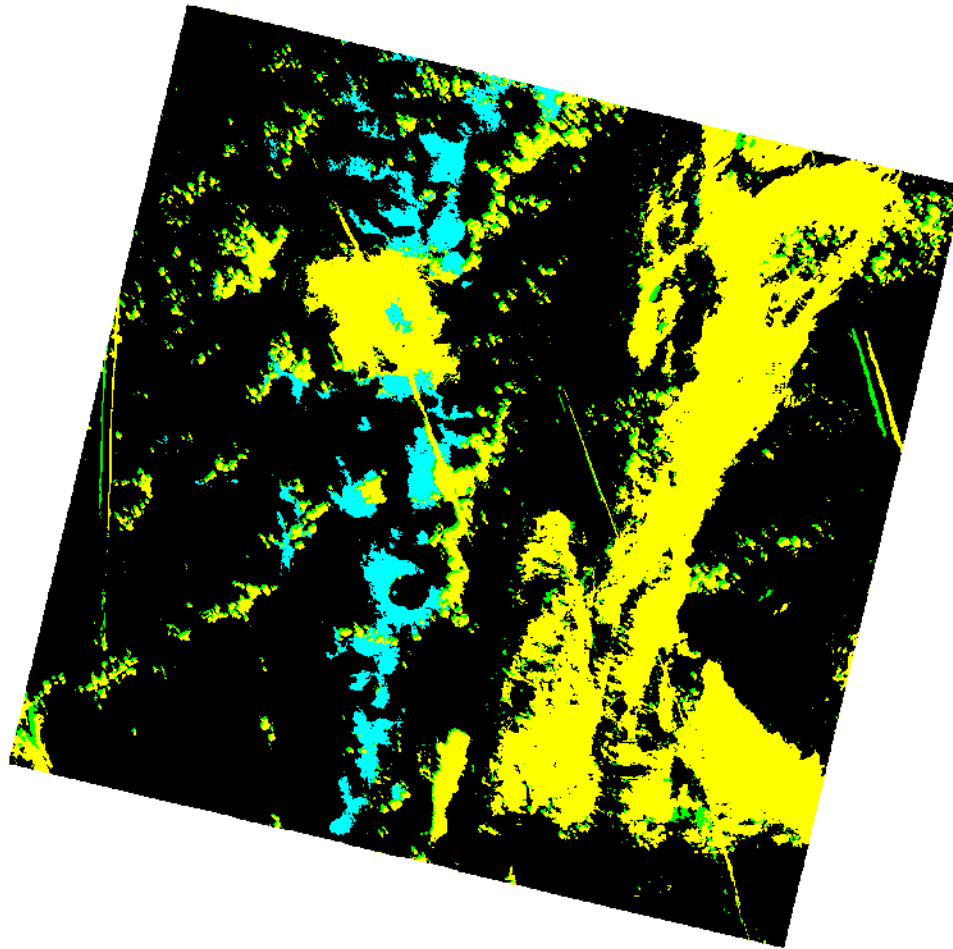
Cirrus band TOA reflectance: 0-0.01 0.01-0.03 0.03-0.04 0.04-1

# “TM/ETM+” Fmask results



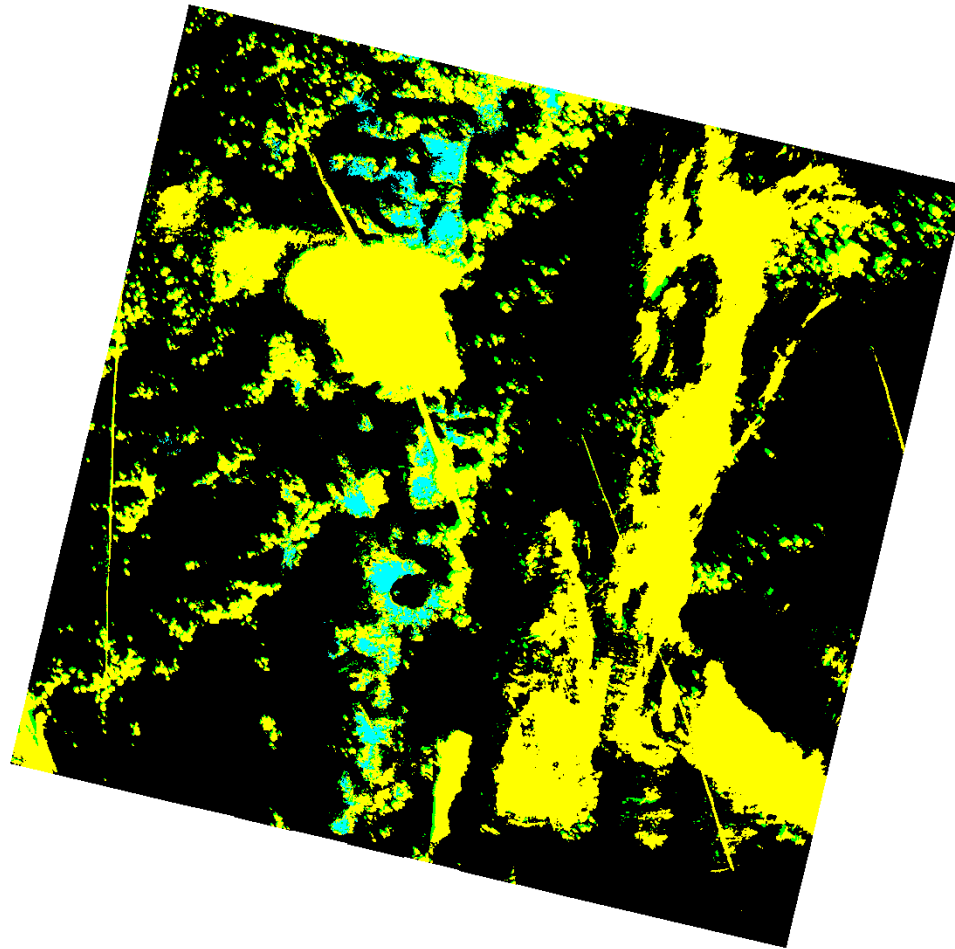
Clear Cloud Shadow Snow/Ice Cloud

# “Sentinel” Fmask results



Clear Cloud Shadow Snow/Ice Cloud

# “OLI/TIRS” Fmask results

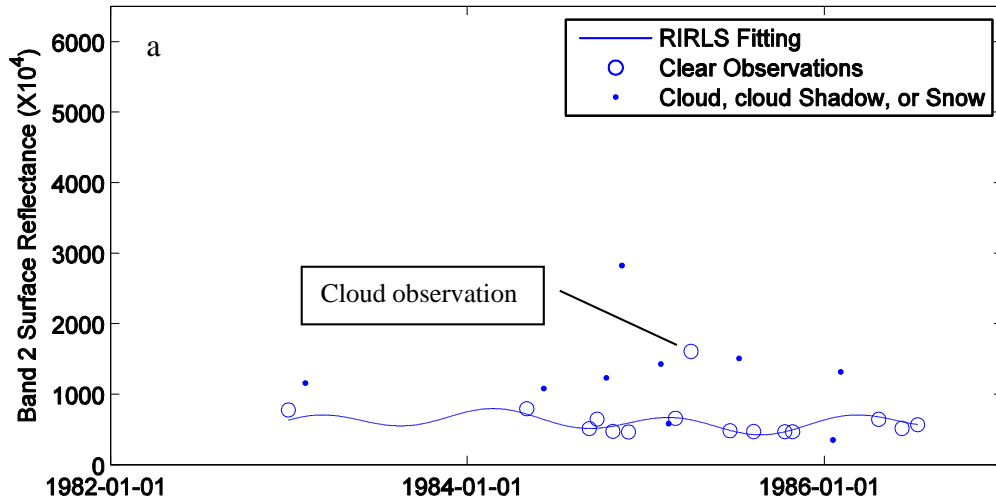


Clear Cloud Shadow Snow/Ice Cloud

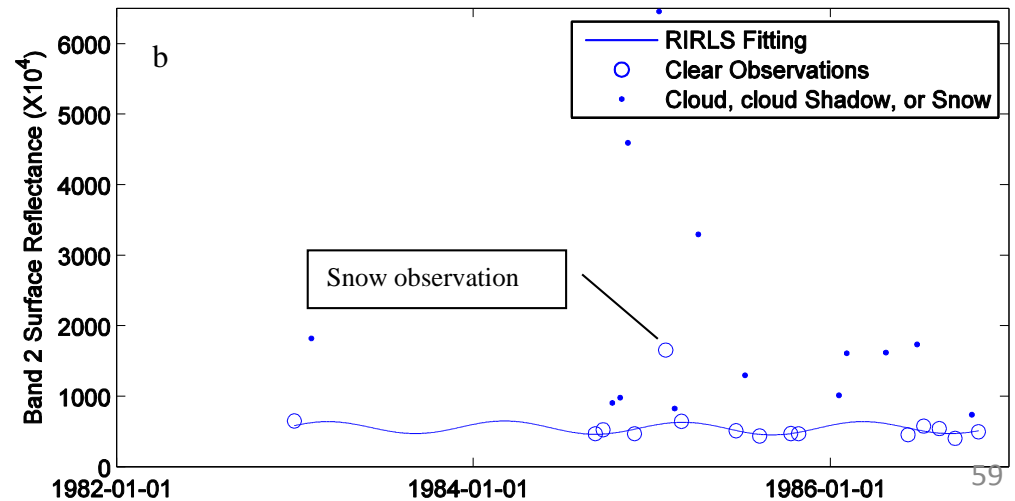
# Two-step cloud and cloud shadow detection

- Step one – “global algorithm”:  
Single-date based cloud and cloud shadow masking (Fmask – freely available)
- Step two – “pixel-based algorithm”:
- Multitemporal cloud and cloud shadow masking based on robust fitting of the “clear” pixels – clouds and shadows are ephemeral outliers

# Part 1: Illustration of multitemporal approach



The presence of clouds and snow will make Landsat Band 2 brighter

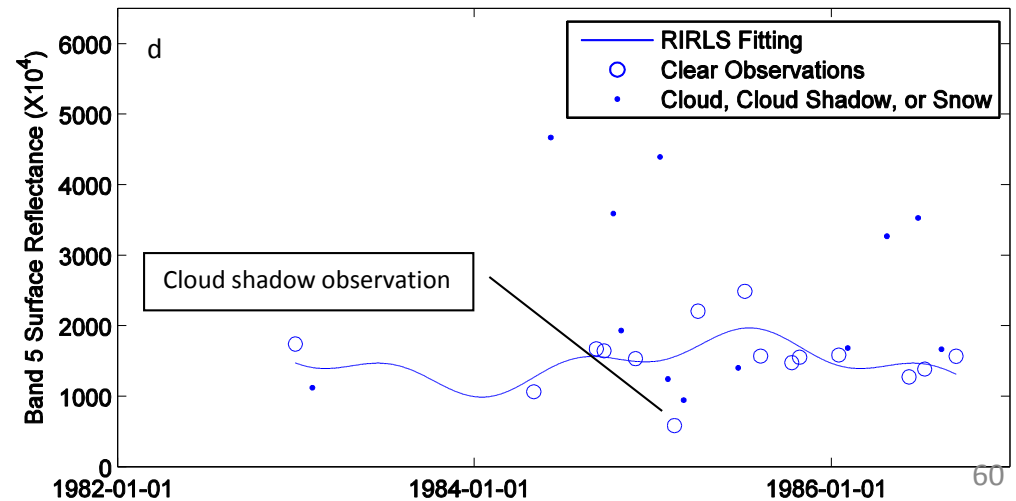




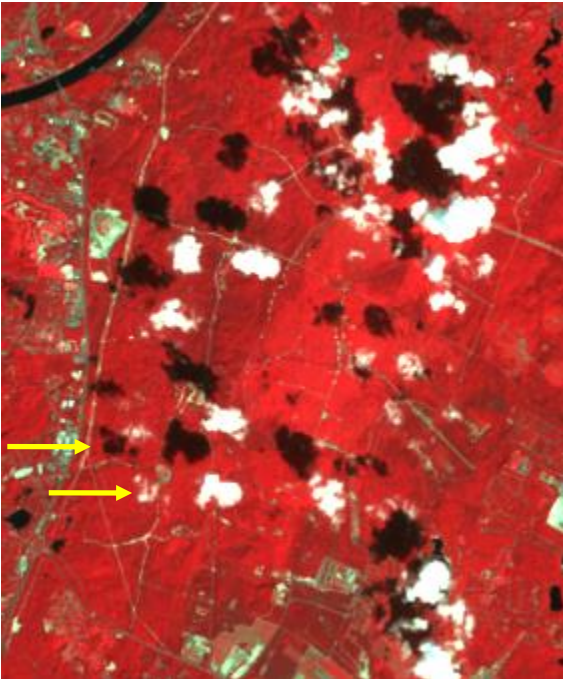
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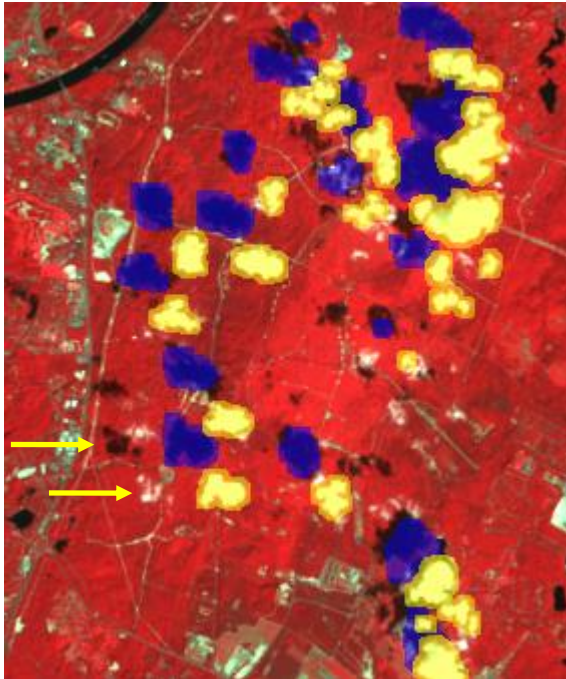
The presence of cloud shadows and snow will make Landsat Band 5 darker



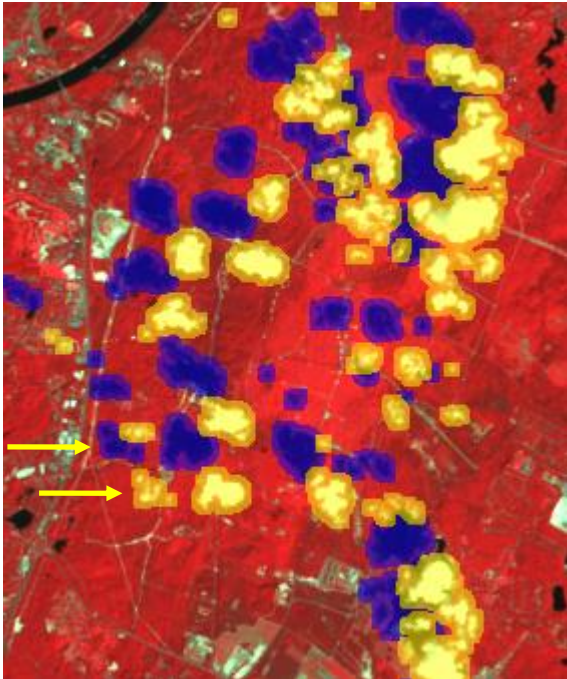
# Illustration of the two-step algorithm



Landsat image



Step 1



Step 2