Cloud Detection for Sentinel 2

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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

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

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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+” Flmask results

Clear  Cloud Shadow  Snow/Ice  Cloud
“Sentinel 2” Fmask results
“OLI/TIRS” Fmask results
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.
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.
Automated cloud, cloud shadow, and snow detection in multitemporal Landsat data: An algorithm designed specifically for monitoring land cover change

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Examples of clouds found with multitemporal approach

Fig. 9. Times series 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 7th 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.

![Hyperion and Sentinel-2 spectral responses (samples)](image)

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

• Fmask results were generated based 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
## Accuracy Assessment

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<th>Clear water</th>
<th>Cloud shadow</th>
<th>Cloud</th>
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<td>Overall Accuracy</td>
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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
“Sentinel” Fmask results
“OLI/TIRS” Fmask results
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
“Sentinel” Fmask results
“OLI/TIRS” Fmask results
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
“Sentinel” Fmask results
“OLI/TIRS” Fmask results
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
“Sentinel” Fmask results
“OLI/TIRS” Fmask results
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
“Sentinel” Fmask results
“OLI/TIRS” Fmask results
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
“Sentinel” Fmask results
“OLI/TIRS” Fmask results
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.
**Part 1: Illustration of multitemporal approach**

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