Mount Lyell Glacier

A Study of Changes in Land Cover between 1999 and 2016

Christopher Prendergast

GIST58, Spring 2021

Contents

1 Introduction

A study was conducted using remote sensing imagery to quantify the change in area of the Lyell glacier in Yosemite National Park, California, USA. This analysis was performed using Landsat 7 imagery captured in late summer when it is easiest to distinguish permanent snow fields from other snow deposits. This paper covers the data sources, analysis methods used, and results obtained from this study.

2 Topic

Mount Lyell is a peak in the Sierra Nevada mountains of California located within Yosemite National Park at the Southeast end of the Cathedral Range. The elevation of the summit in 3,997 meters (13,114 feet). The peak is named after the 19th century geologist Charles Lyell. Mount Lyell is well known as the location of one of the few remaining glaciers in Yosemite. There is also a glacier on the neighboring Mount Maclure which was studied by John Muir and Galen Clark in 1872 (“Lyell Glacier - Yosemite National Park”). Both these glaciers have been shrinking due to the impacts of global climate change. Today, the Lyell Glacier is considered a permanent snow field rather than a living glacier because it has ceased to flow.

2.1 Study Area

The study area included the glaciers on both Mount Lyell and the adjacent Mount Maclure. The extent of the study area was defined by the following WGS84 geographic coordinates which define opposite corners of the area:

Bottom left corner	(-119.3026487600801033, 37.7238425391089152)
Top right corner	(-119.2512447089197281, 37.7606598503118818)

This gave a study area measuring 4.6 x 4.2 kilometers, covering an area of approximately 19.6 square kilometers. The general location of the study area is shown is figure 2. A detailed topographic map of the study area is shown in figure 3.

3 Methods

3.1 Data

The data for this study was selected from ETM+ C1 Level-1 imagery from the Landsat 7 satellite. Mt. Lyell lies on path 42, row 34 and imagery is available for the period between 1999 and 2019. However, images acquired from 2003 onwards must be corrected to compensate for the failure of the Scan Line Corrector in the EMT+ instrument. The following criteria were applied to select suitable imagery for this study.

- Covers the area of the Mt. Lyell glacier.
- Captured on approximately the same day in the second half of September when it was expected that snow cover would be at a minimum.
- Daytime images with 0% cloud cover.
- Period between two images covers the greatest time span available.

These criteria led to the selection of the following two scenes which span a period of 17 years.

Scene	**Date**
LE70420341999270EDC00	September 27th, 1999
LE70420342016269EDC01	September 25th, 2016

3.2 Analysis

The analysis was performed using QGIS 3.16.4 with GRASS 7.8.5 software on a Windows 10 system. The analysis consisted of the following steps:

3.2.1 Virtual Raster Layers

- For each scene, the nine bands were loaded as raster layers and combined into one virtual raster layer corresponding to each year. (See Appendix I for an explanation of the Landsat 7 bands.)
- For the 2016 imagery, the gaps caused by the Scan Line Corrector (SLC) failure were filled using the appropriate mask for each of the nine layers.
- Each virtual raster layer was then clipped to the study area. This gave two layers with identical extents and both with a size of 164 x 149 pixels.
- A true color images (figure 4) was created for each scene clipped represented by a virtual raster layer using bands 3, 2, and 1.
- A false color image (figure 5) was created for each clipped scene using bands 5, 4, and 3. These images highlight the snow areas in a cyan color.
- A false color composite image (figure 8) was created from a combination of both vitrail layers to display the overall change in snow. In this image, the extent of snow in 2016 is displayed in cyan whereas blue indicates the extent of snow loss between 1999 and 2006. The bands from the two virtual raster layers were mapped as follows:

Display Color	**Year**	**Band**
Red	1999	Band 5
Green	2016	Band 2
Blue	1999	Band 2

- A second false color composite image (figure 9) was created from a combination of both scenes to display the overall change in snow. In this image, the extent of snow in 2016 is displayed in yellow whereas orange indicates the extent of snow loss between 1999 and 2006. The bands from the two virtual raster layers were mapped as follows:

Display Color	**Year**	**Band**
Red	1999	Band 2
Green	2016	Band 2
Blue	1999	Band 5

3.2.2 Normalized-Difference Snow Index

- The Normalized-Difference Snow Index (NDSI) was calculated for both years using the clipped virtual raster layers (figure 6). The NDVI was calculated using the following formula:

$$NDVI = (Band2 - Band5)/(Band2 + Band5)$$

Where Band2 is green and Band5 is short-wave infrared.

- The resulting two NDVI layers were reclassified into two classes to display areas with NDVI values above and below the threshold of 0.4 (figure 7). A value greater than 0.4 indicates the presence of snow.

3.2.3 Unsupervised Classification

- An unsupervised classification was performed for each year using the clipped virtual raster layers (figure 10). This classification used the k-means clustering for grids algorithm with 10 clusters and 6 iterations. The results were initially displayed with a platted/unique values symbology. The individual classes were then manually identified and named by inspecting the image. Because the algorithm assigns class numbers in a random fashion the classes for the second image were manually reclassified to match those of the first image.

- The ten classes created by the unsupervised classification were consolidated through manual reclassification into three classes (figure 11). Six classes consolidated into the category "rock" which represents granite slab, talus, and moraine. Two classes were consolidated into "water/shadow." There is confusion in the classification results between water and deep shadow on north sides of ridges. Two classes were consolidated into "snow/ice."

3.2.4 Supervised Classification

- A supervised classification was also performed for each year using the clipped virtual raster images. A vector layer containing the training polygons was created (figure 12). There were four training classes as follows: shadow, water, rock, and ice/snow (figure 13).

3.2.5 Statistics

- Statistics were calculated for the manually reclassified results of the unsupervised classification. For each of the two years, the total area of land cover for the following three categories was calculated: water/shadow, rock, snow/ice. The absolute difference in these values was calculated and plotted as a bar chart (figure 1). In addition, the percentage change was calculated and tabulated.

4 Results

The following results were obtained from the study.

4.1 1999 Land Cover Areas

The statistics calculated for the year 1999 from the unsupervised classification following manual reclassification into three classes were as follows:

	Value	Pixel count	Area (m²)	km²	
Snow/ice	1	2,764	2,487,600	2.49	12.8%
Rock	2	16,929	15,236,100	15.24	78.5%
Water/shadow	3	1,867	1,680,300	1.68	8.7%
		21,560	19,404,000	19.40	100.0%

4.2 2016 Land Cover Areas

The statistics calculated for the year 2016 from the unsupervised classification following manual reclassification into three classes were as follows:

	Value	Pixel count	Area (m²)	km²	
Snow/ice	1	1,273	1,145,700	1.15	5.9%
Rock	2	18,600	16,740,000	16.74	86.3%
Water/shadow	3	1,687	1,518,300	1.52	7.8%
		21,560	19,404,000	19.40	100.0%

4.3 Change in Land Cover from 1999 to 2016

The change between 1999 and 2016 was calculated as follows:

	Area km²			
	1999	**2016**	**Change**	**% Change**
Snow/ice	2.49	1.15	(1.34)	**-53.9%**
Rock	15.24	16.74	1.50	**9.9%**
Water/shadow	1.68	1.52	(0.16)	**-9.6%**
	19.40	19.40	0.00	

In 1999, the area covered by snow and ice was 2.49 km^2. By 2016, this area had fallen to 1.15 km^2. Therefore, there has been a 53.9% reduction in the area covered by snow and ice. In addition, the area covered by water/shadow has decreased by 9.6%. The magnitude of these changes in land cover are illustrated in the following bar chart.

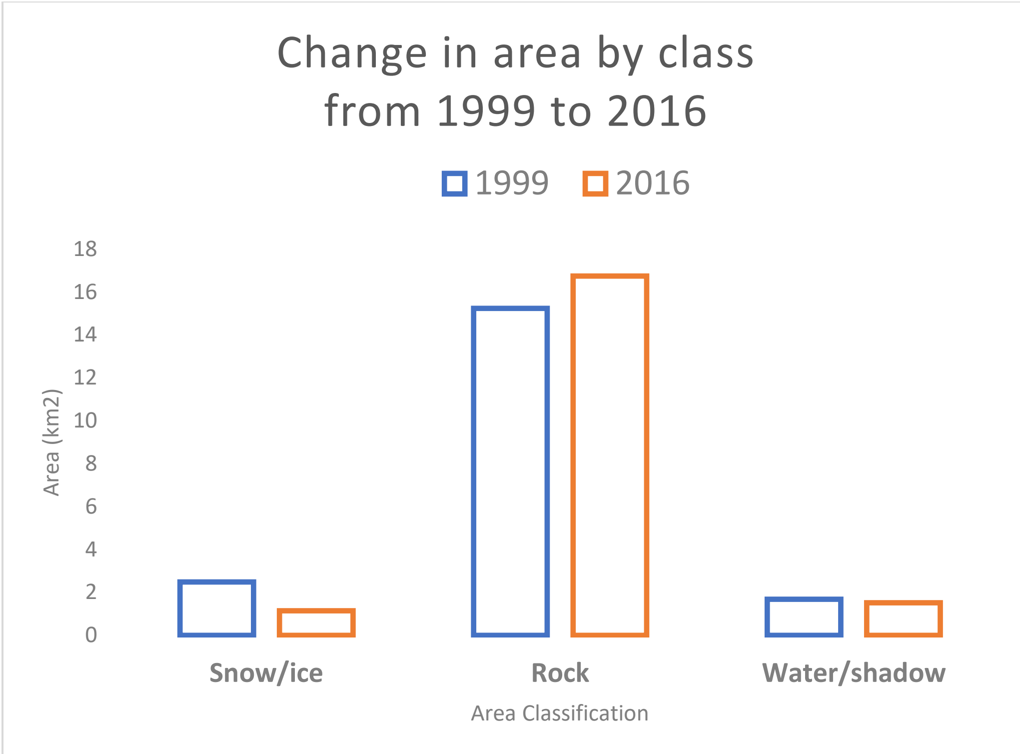


Figure 1 - Change in area of landcover classes from 1999 to 2016.

5 Conclusions

- The glaciers on Mount Lyell and Mount Maclure are receding. Between 1999 and 2016, there was a 53.9% reduction in the area covered by snow and ice.
- The area of water has also declined over the same period. The area classified as water/shadow decreased by 9.6%. Most of this change is due to reduction in water as the area of shadow remains approximately constant.
- The unsupervised classification technique produced better results than the supervised classification technique. Both techniques suffer from a confusion between deep shadow and water. It is possible that with more careful effort, the supervised classification technique could be taught to better discriminate between these two classes.

Figures

Location of Study Area

Figure 2 - Location of study area. (Nzeemin)

Study Area

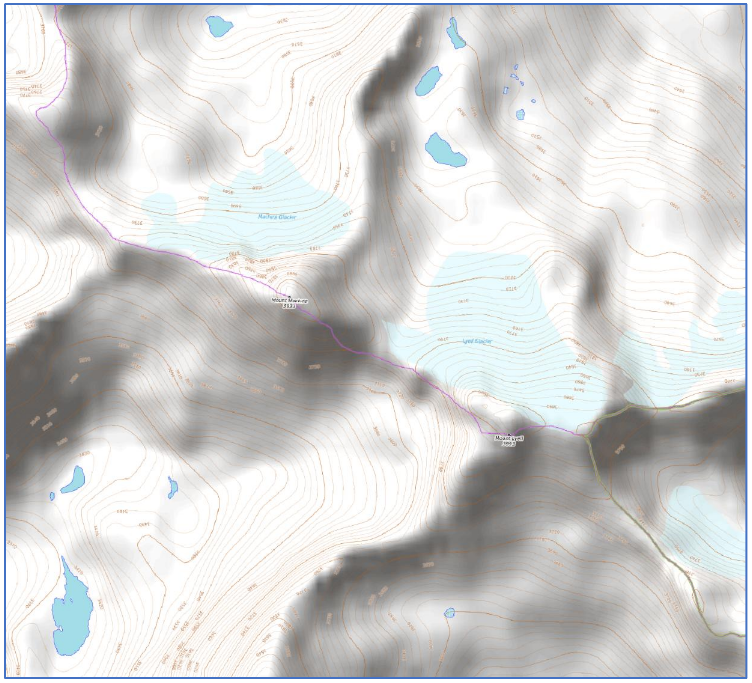


Figure 3 - Study Area, Mt. Lyell, Yosemite National Park, California, USA. (OpenTopoMap)

True Color Imagery

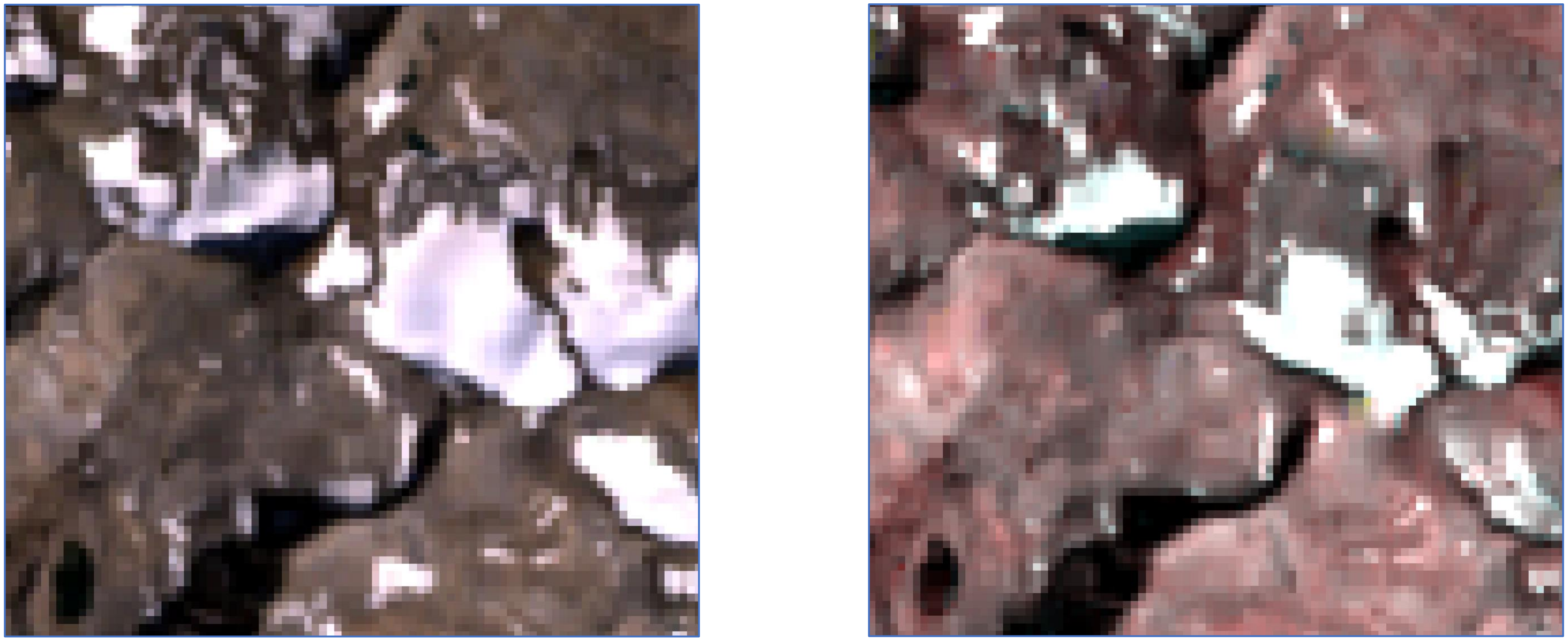


Figure 4 – Landsat 7 ETM+ imagery. "321" true color images. Left: 27th September 1999. Right: 25th September 2016.

False Color ("543") Imagery

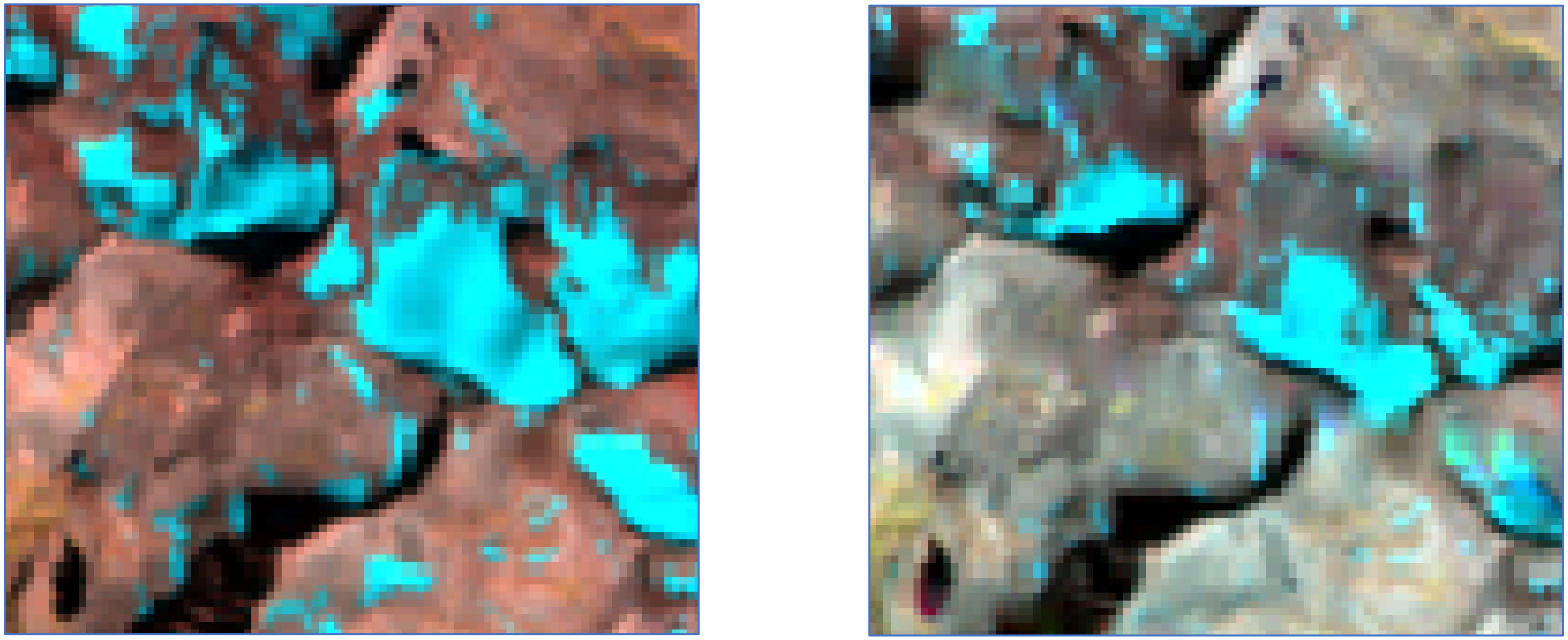


Figure 5 – Landsat 7 ETM+ imagery. "543" false color images. Left: 27th September 1999. Right: 25th September 2016.

Normalized-Difference Snow Index (NDSI)

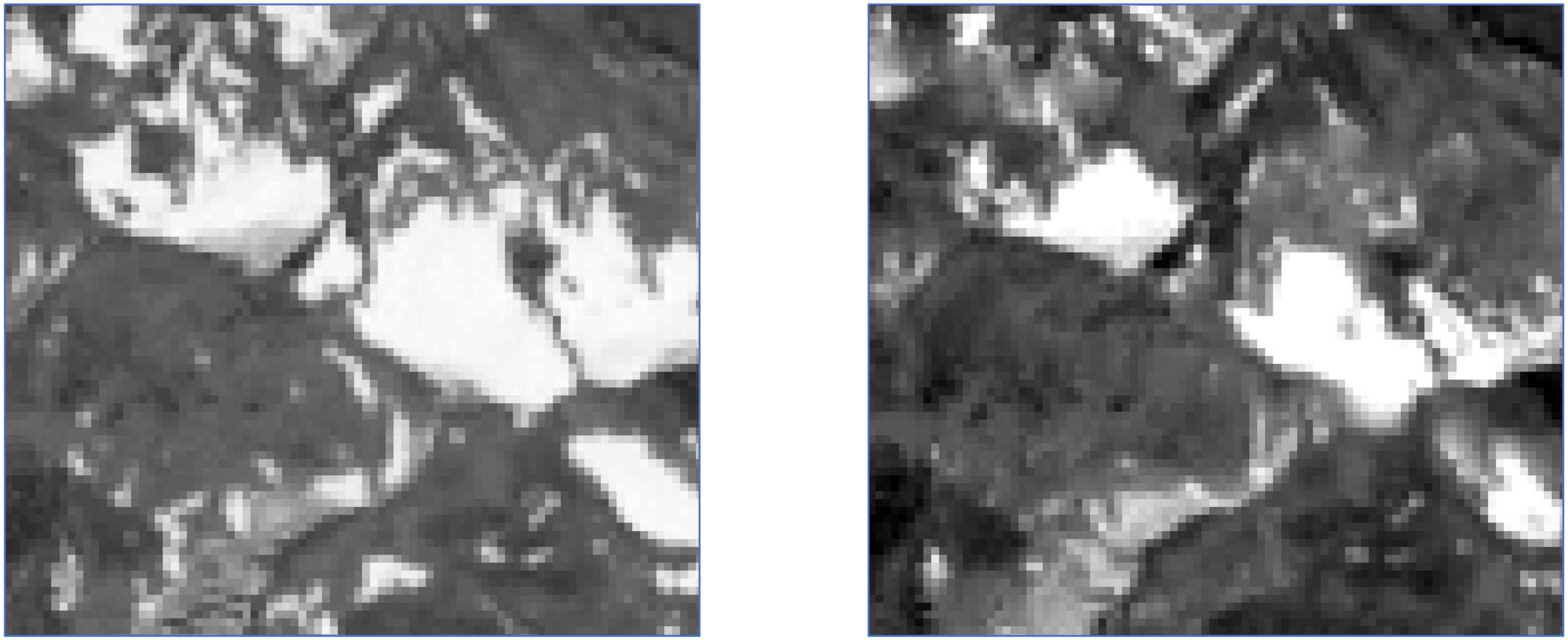


Figure 6 – Normalized-Difference Snow Index (NDSI) derived from Landsat 7 ETM+ imagery. Left: 27th September 1999. Right: 25th September 2016.

Reclassified Normalized-Difference Snow Index

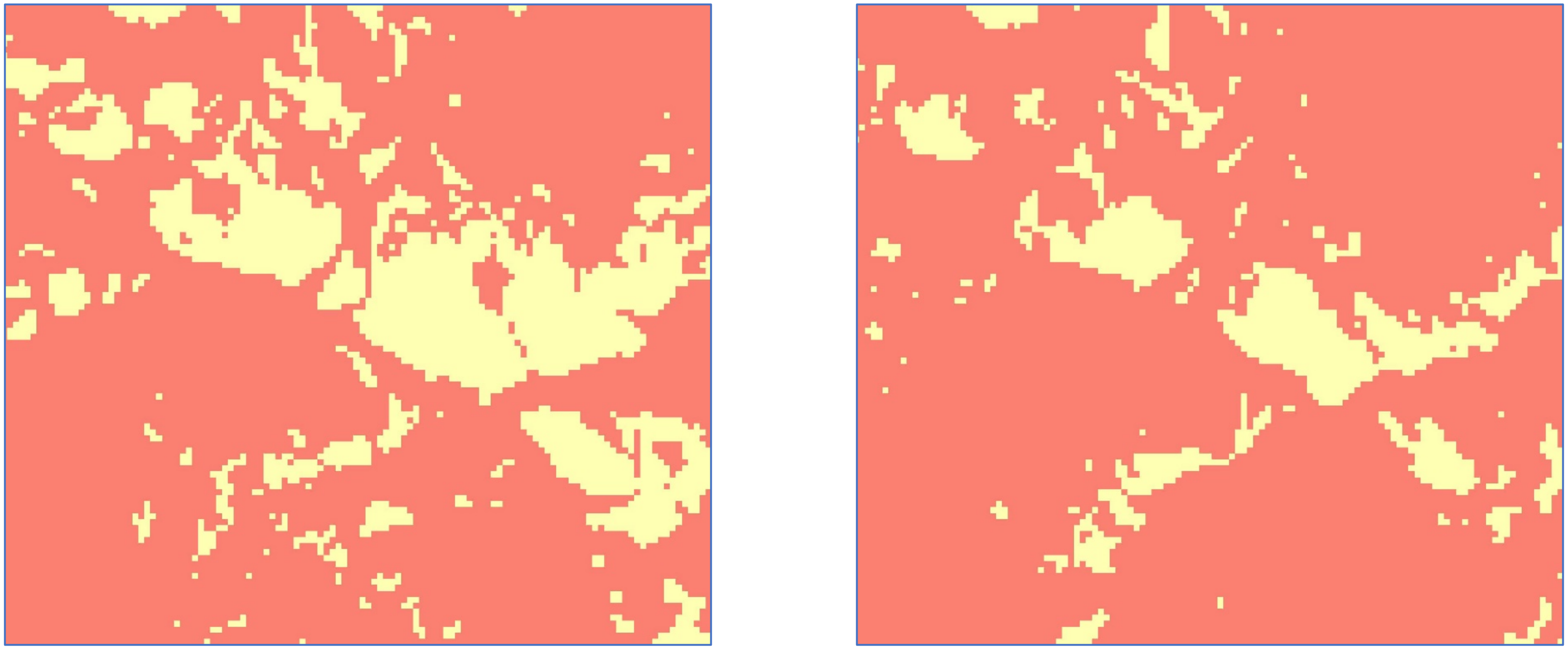
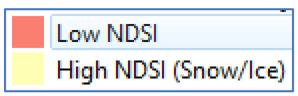


Figure 7 - Normalized-Difference Snow Index (NDSI) reclassified with a threshold value of 0.4. Left: 27th September 1999. Right: 25th September 2016.



Overall Change

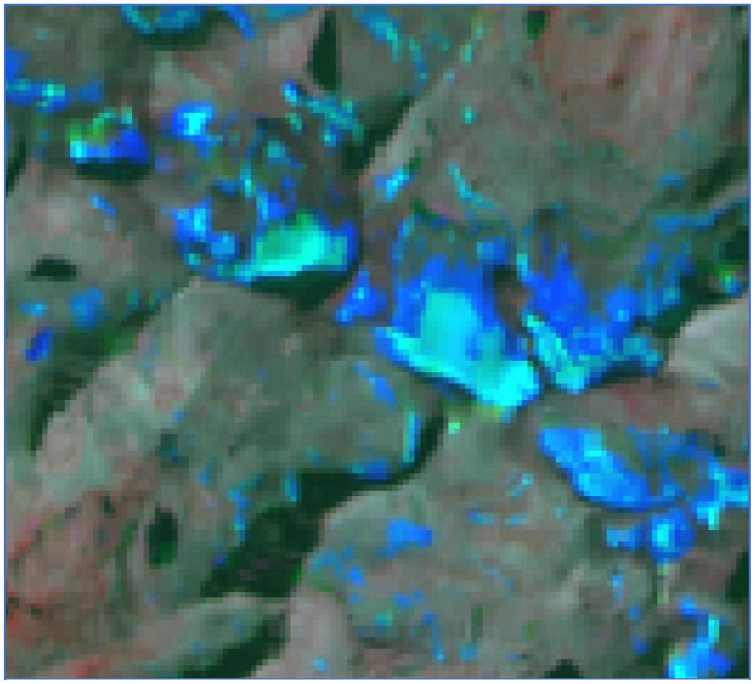


Figure 8 – Overall change false color image.

Overall Change

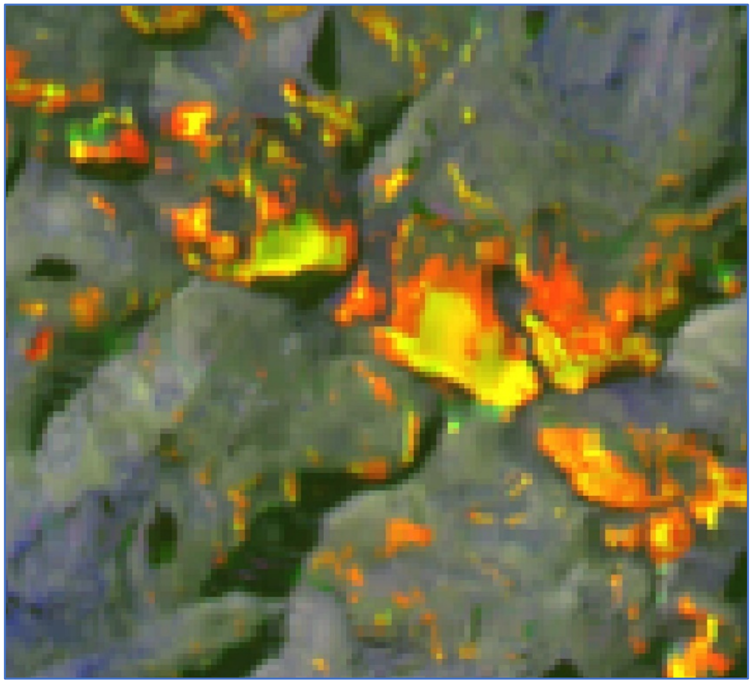


Figure 9 – Overall Change false color image.

Unsupervised Classification (10 clusters)

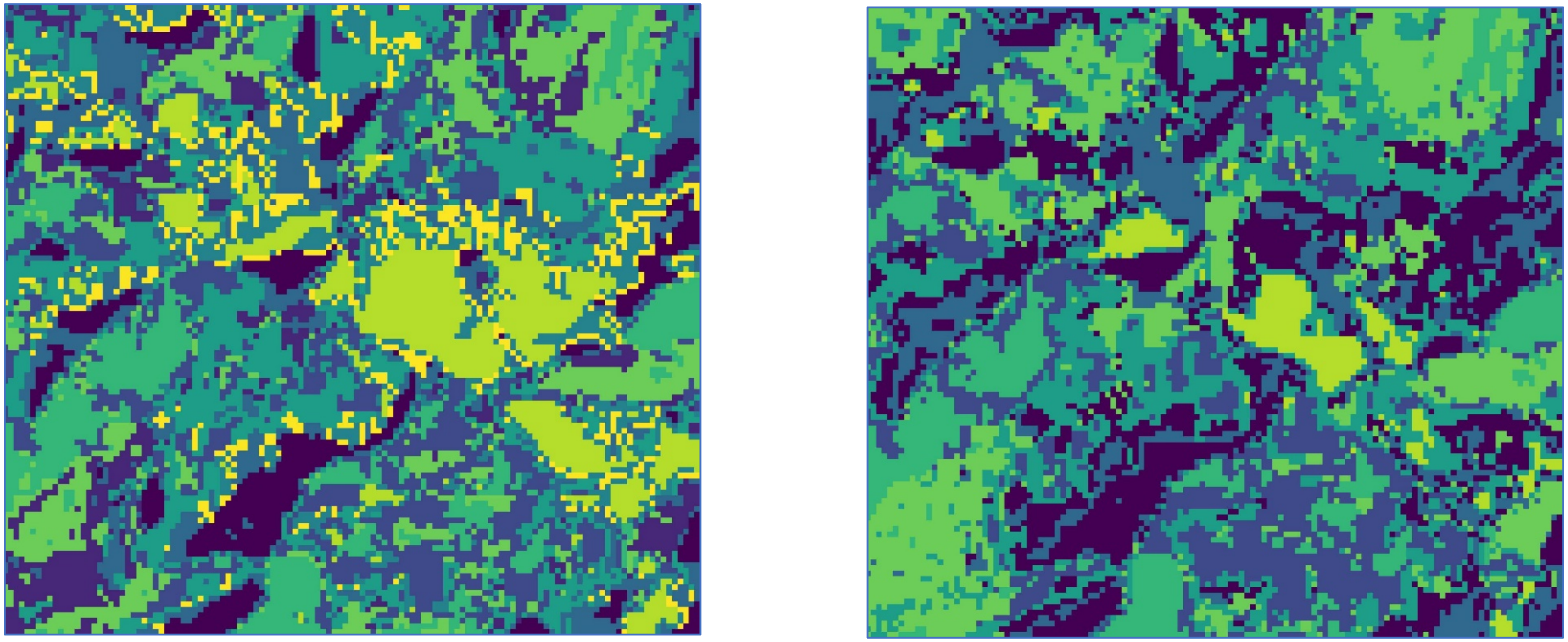
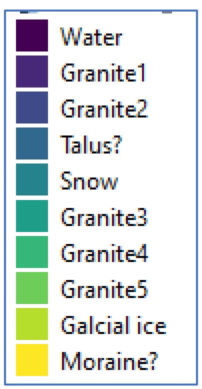


Figure 10 – Unsupervised classification with 10 clusters. Left: 27th September 1999. Right: 25th September 2016.



Unsupervised Classification after Manual Reclassification

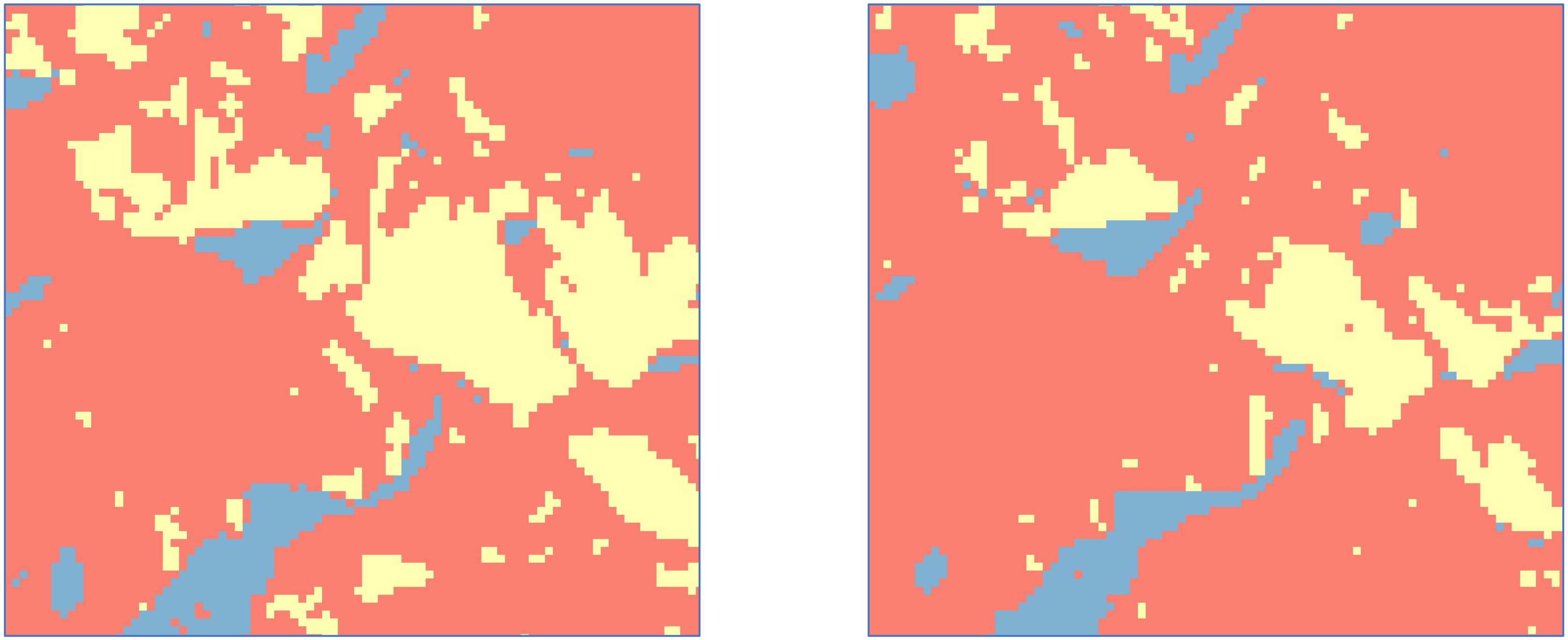
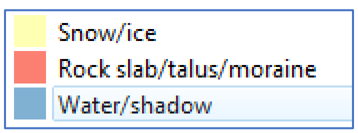
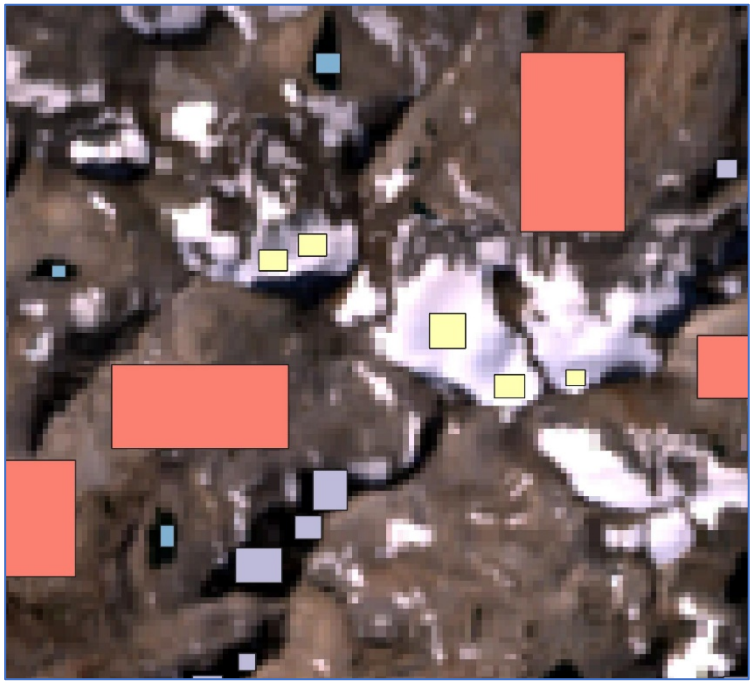


Figure 11 – Unsupervised classification after manual reclassification. Left: 27th September 1999. Right: 25th September 2016.



Supervised Classification Training Polygons



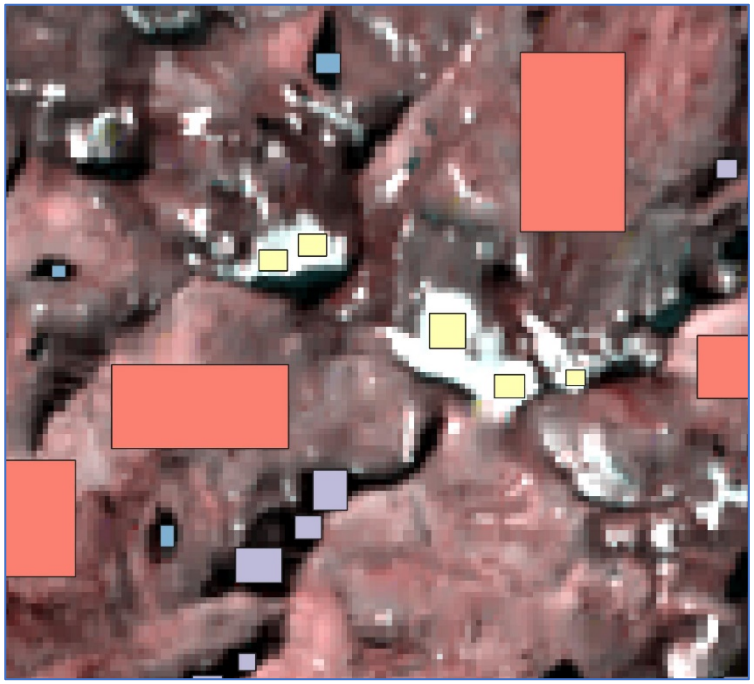
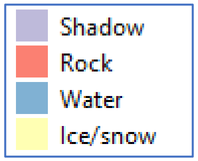


Figure 12- Training polygons for supervised classification. Left: 27th September 1999. Right: 25th September 2016.



Supervised Classification.

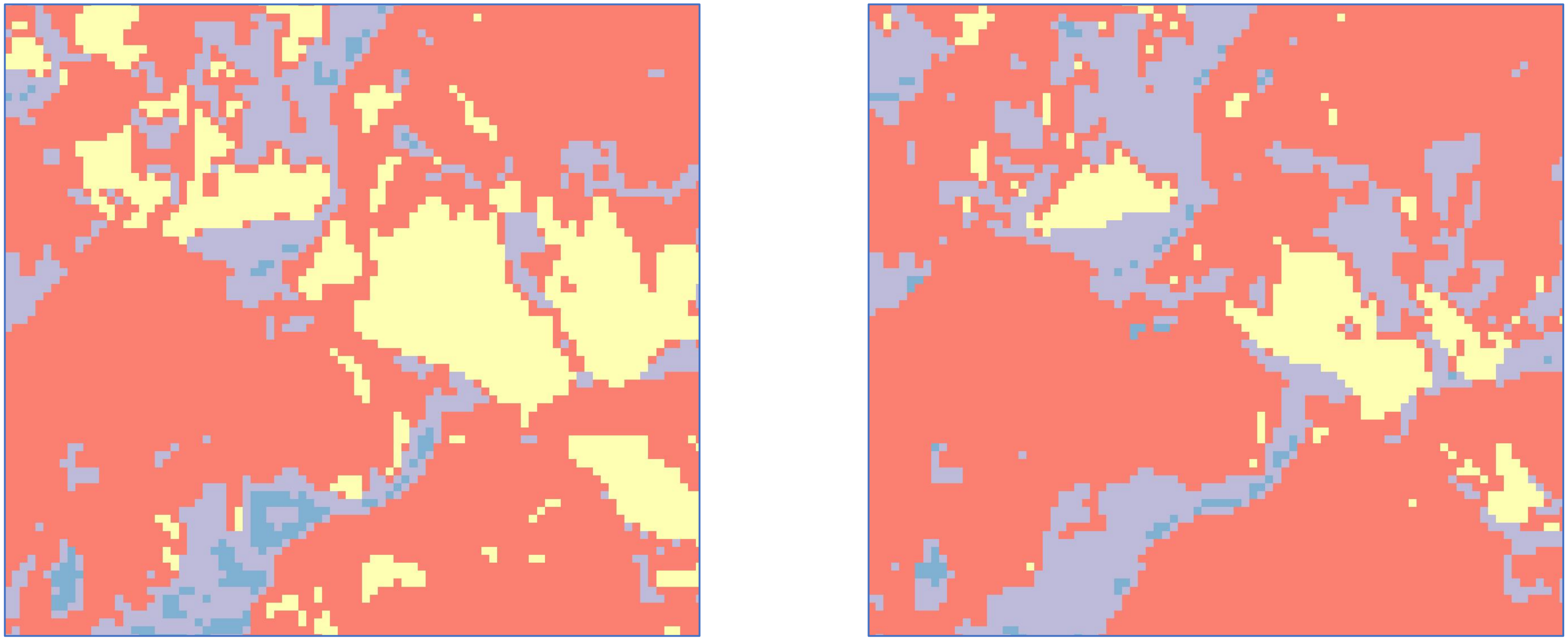
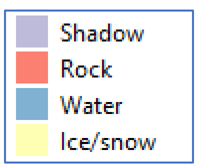


Figure 13 – Supervised classification. Left: 27th September 1999. Right: 25th September 2016.



Works Cited

"Landsat 7." *www.usgs.gov*, www.usgs.gov/core-science-systems/nli/landsat/landsat-7.

"Lyell Glacier - Yosemite National Park (U.S. National Park Service)." *www.nps.gov*, www.nps.gov/yose/blogs/lyell-glacier.htm.

Nzeemin. "Русский: Физическая карта Калифорнии (США)." *Wikimedia Commons*, 14 Oct. 2012, commons.wikimedia.org/w/index.php?curid=22064912. Accessed 24 June 2021.

"OpenTopoMap." *Opentopomap.org*, opentopomap.org/credits. Accessed 24 June 2021.

"Why Do Landsat 7 Level-1 Products Contain Two Thermal Bands?" *www.usgs.gov*, www.usgs.gov/faqs/why-do-landsat-7-level-1-products-contain-two-thermal-bands. Accessed 24 June 2021.

Appendix I – Landsat 7 EMT+ Bands

Landsat 7 carries the Enhanced Thematic Mapper Plus (ETM+) sensor which captures eight spectral bands, including a pan and thermal band. Landsat 7 products are delivered as 8-bit images with 256 grey levels. The bands are as follows ("Landsat 7).:

Band	**Spectral Band**	**Frequency Range**	**Resolution**
Band 1	Visible	0.45 - 0.52 µm	30 m
Band 2	Visible	0.52 - 0.60 µm	30 m
Band 3	Visible	0.63 - 0.69 µm	30 m
Band 4	Near-Infrared	0.77 - 0.90 µm	30 m
Band 5	Short-wave Infrared	1.55 - 1.75 µm	30 m
Band 6	Thermal	10.40 - 12.50 µm	60 m Low Gain/High Gain*
Band 7	Mid-Infrared	2.08 - 2.35 µm	30 m
Band 8	Panchromatic (PAN)	0.52 - 0.90 µm	15 m

* Landsat 7 acquires thermal data in two bands from one detector in both high (Band 6H) and low (Band 6L) gain. The difference in gain settings is important to different types of studies (i.e., clouds vs. deserts). Aside from the resolution differences and saturation on the high and low ends, the two bands provide the same Digital Numbers (DN) for every pixel. ("Why Do Landsat 7 Level-1 Products Contain Two Thermal Bands?")