

# **Using Landsat and NED Images to Learn About Snow in Glacier National Park, MT**

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## **Abstract**

Images with mountain glaciers in Montana were evaluated for the period of summer 1988 and 2001. Landsat imagery superimposed on 1/3" NED elevation data were analyzed using ENVI and ArcGIS. Bright snow spatial coverage was seen to increase while other changes in classification were noted. Photographs of representative areas were compared to satellite and elevation data for better understanding in order to serve as ground truth for classification interpretation. Differences in time of year, snowfall and shadows overwhelmed any long-term climate change effect. Additional analyses of this type should prove useful in assessing the status of perched, mountain glaciers as well as snow-capped peaks.

## **Introduction**

Throughout North America, in general, glaciers are measurably decreasing in both depth and spatial coverage. How fast and to what extent does this trend occur? Glacier National Park, Montana covers approximately 1,600 mi<sup>2</sup>. Within this park are some of the largest mountainous glaciers remaining in the coterminous United States. These include Grinnell, Piegan, and Sexton glaciers. Within a short distance of the Going to the Sun road, built in 1932, the only road through the park, the selected glaciers are among the most studied and photographed. The glaciers are along the continental divide of North America which separates the waters flowing into the Pacific Ocean from those which flow into the Atlantic Ocean. As such, these high-elevation glaciers at latitudes approaching 49° N, the Canadian border, are subject to rapid change with the onset of global warming. Variation in snowfall and summer temperatures will lead to yearly variability in snow cover, but the overall trend is expected to be a decrease and eventually elimination of permanent glacial features atop these protected mountains.

## **Study Area and Data Used**

False-color infrared satellite orthorectified imagery from Landsat 5 Thematic Mapper and Landsat 7 Enhanced Thematic Mapper covering Path 41 Row 26 were obtained from reference 1. This area covers Glacier National Park, Montana, starting at 49° North latitude and between 113 and 114° W longitude. Only mosaics of pictures taken over a few years are available at reference 2. Images used to get an overview of the area covering Glacier Park were from Landsat 7 created in 1999 and 2001. Such images are not useful for temporal analysis since they do not represent one day or one month. Most individual Landsat data costs \$200 per image so only limited, free data could be utilized.

The first individual image from Landsat 5 was displayed using bands 7,4,3 for August 28, 1988 while the second Landsat 7 image also used bands 7,4,3 for July 7, 2001 (Figure 1).



*Figures 1a and 1b. Landsat 5 False-IR 743 Image, August 28, 1998 with Glacier Park overlay (left) and Landsat 7 False-IR 743 Image, July 7, 2001.*

Band 3 covers 0.63 to 0.69  $\mu\text{m}$  (Red) while Band 4 covers the range from 0.75-0.76 to 0.9  $\mu\text{m}$  (Near IR) and Band 7 covers the shortwave infrared spectrum from 2.08-2.09 to 2.35  $\mu\text{m}$  with limited cloud penetration which allows for a discrimination between clouds and snow. Both images used had less than 10 percent cloud cover (reference 1, 4). Landsat data were in UTM Zone 12 projection, WGS 84 datum. GIS shapefile overlays (e.g. roads) were reprojected on the fly.

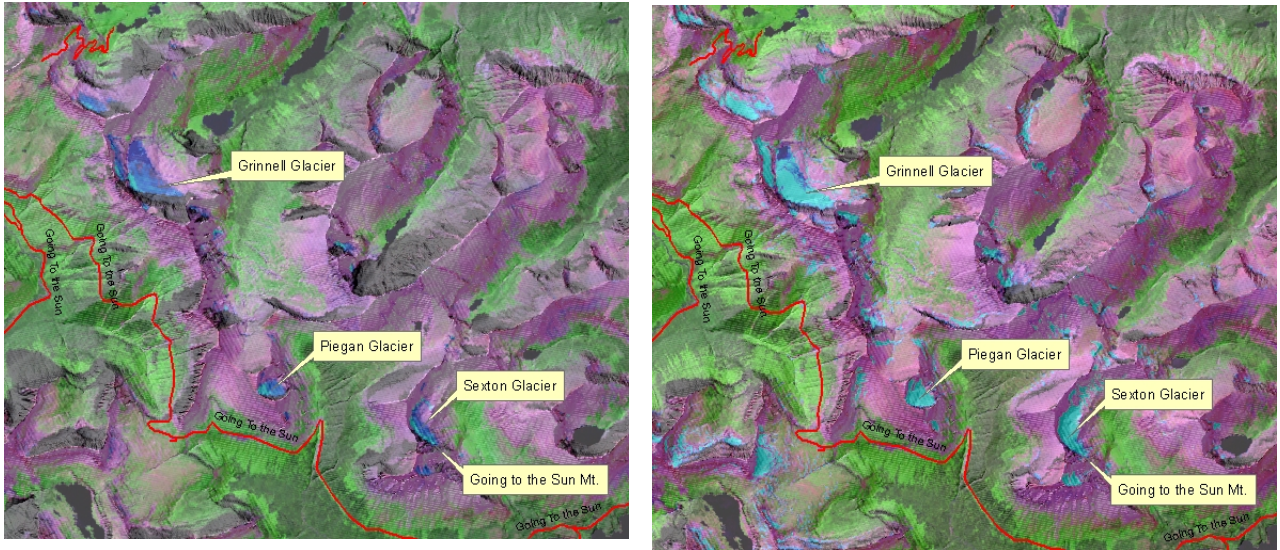
NED data files of the National Elevation Dataset 2001 were downloaded from source 2 and the one covering the region of interest was selected, cropped and overlain on the study area using ENVI and ArcGIS.

## Methods

First, 1" (28.5 m) resolution Landsat and 1/3" (10m) NED data were downloaded from references 1 and 2. First, the coordinate system had to be defined or applied. Next, the region of interest was cropped to include only the tallest mountains with ice. Montana state outline, Glacier national park outline, and road and point feature data were obtained from reference 3 and ArcGis 9.1 was used to place these layers on top of the orthoimagery for identification purposes.

To further clarify the slopes, 1/3" (10m) elevation data, with the hillshading feature of Spatial Analyst applied, were overlaid with 50% transparency on top of the satellite photos (Figure 2).

These overlays provided a good basis for reconciling with ground photographs freely available on the internet. This tourist attraction is the area surrounding the Going to the Sun road through Glacier National Park. Three northeast facing reflective white features were identified from the satellite imagery as Grinnell, Piegan, and Sexton glaciers (Figure 3).



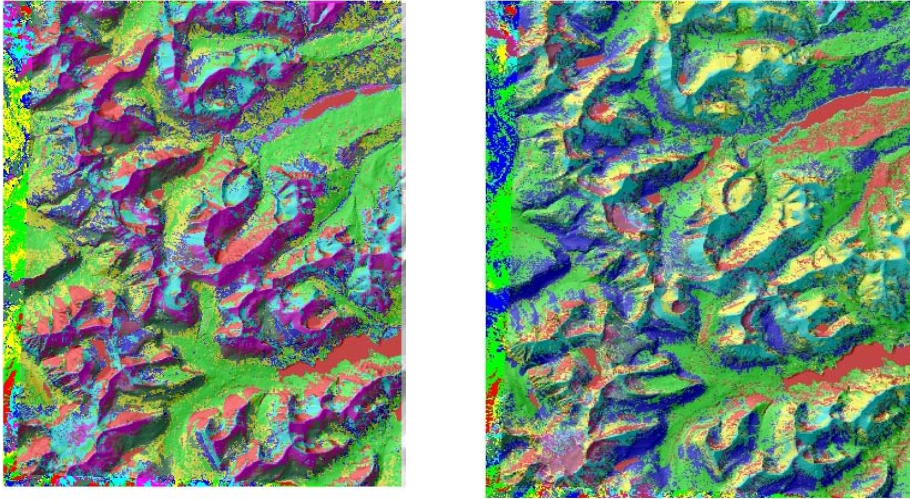
Figures 2a & 2b. Left: August 1988 Landsat overlay on elevation data. Right: July 2001.



Figures 3a, b, c. Left & Center, Piegan Glacier, Right: Sexton Glacier. Sources:  
<http://www.nps.gov/glac/gallery/082501.htm>  
[http://www.summitpost.org/show/mountain\\_link.pl/mountain\\_id/1220](http://www.summitpost.org/show/mountain_link.pl/mountain_id/1220)

Once the features of interest were selected and identified, the unsupervised compute change detection statistics operations of ENVI were applied to the digital number pixel values for an area covering 685 km<sup>2</sup>. After some trials, 8 classes returned satisfactory identification results for each image after 5 iterations (Figures 4). Results are discussed in the next section.

For the NED data, contours of 200m intervals were made of the study area as well as a classified elevation map. This revealed the perched nature of the glaciers and sheltering by tall peaks to the southwest of the glaciers. Also, it revealed the steepness of the cliffs and mountain faces since contours of intervals of less than 200m were too close together for visual interpretation (Figure 5).



Figures 4a, 4b. Classified Images. Left: For August 1988, red = shadow/water, light green = partial shadow (snow or vegetation), blue = mix of bare rock and vegetation, yellow = vegetation, cyan = dark, bare rock, pink = bright snow-covered rock, magenta = dark, rocky slope, dark green = bright grass  
 Right: For July 2001, red = shadow/water, light green = mixed vegetation, snow and rock, blue = bright grass, yellow = mixed vegetation and dark rock, cyan = bright rock, pink = bare rock, magenta = bright snow, dark green = vegetation.

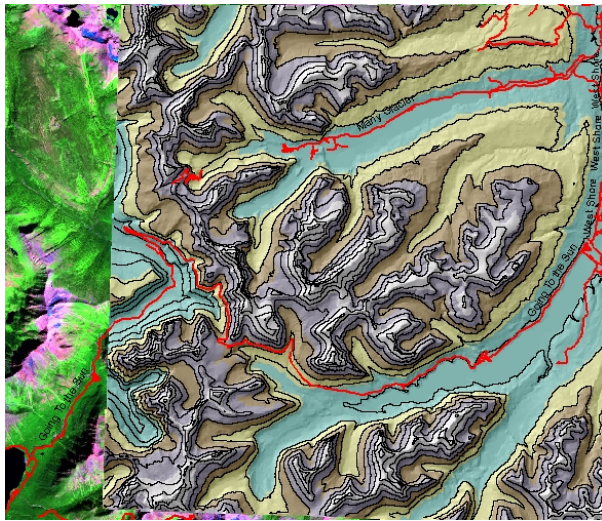


Figure 5: Classified Elevation Data with 200 m contours and roads for region of interest.

Both statistics tables for pixel coverage and spatial coverage in  $\text{km}^2$  were computed for classes of interest. The regions of interest included classes for dark reflectivity (water and shadows), and high reflectivity (white snow) as well as mixed vegetation with high reflectivity. The spatial coverage ( $\text{km}^2$ ) of glacial areas were estimated from this data as well as how much area changed from bright snow to bare rock between the two images.

## Results

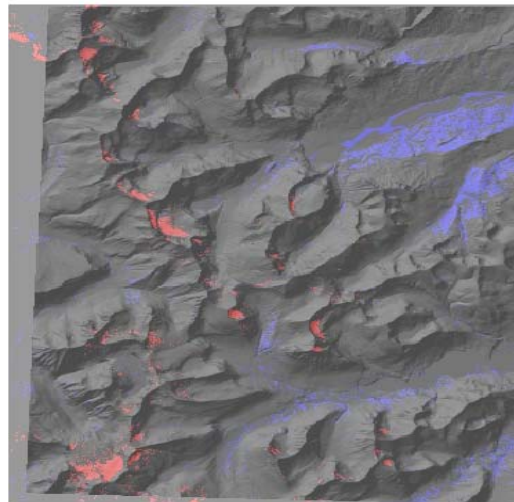
Ice revealed a higher satellite response compared to the surrounding darker, bare rock and alpine vegetation surroundings. This allowed spatial extent of ice to be determined. Over time, a decrease in summer ice coverage is expected and the amount can be estimated; however, for the images studied, this was not supported by the data. It may be possible to detect a change in ice-coated areas over the time scale of a decade and support the trend deduced from ground-based studies, but yearly snowfall variation and time of year must be taken into account with more images per season and per year than were available from Landsat for this study.

A total of 685 km<sup>2</sup> had statistics computed (the region of interest). As shown in Tables 1 and 2, the amount of bright snow was small and approximately 18 km<sup>2</sup> in 2001. No equivalent classification was found in the 1988 image since bright snow was also lumped in with bright rock in the earlier image. This is why the analysis was run backwards in time since it was a one-way match between Class 7 (white snow) in 2001 and Class 6 (white snow with bright rock) in 1988. Of this snow, 7.3 km<sup>2</sup> was also bright in 1988 (40%) while 38% (7.0 km<sup>2</sup>) was only bare rock in 1988 (Class 5). Most of Class 2, vegetation mixed with other surfaces, remained the same (101.4 km<sup>2</sup>) for the study area while the largest change was to class 4: vegetation only (53.0 km<sup>2</sup>). For the darkest pixels, class 1, most remained the same (45.5 km<sup>2</sup>) while the largest change when looking back in time was to class 2 vegetation mixed with other surfaces (24.2 km<sup>2</sup>). Figure 6 shows a zoomed in view of the results of compute change detection statistics for part of the study area. Pink indicates where bright snow was detected in 2001 that was not present in 1988. Blue indicates where there was more shadow or water in 2001 than in 1988.

**Table 1: Pixel Changes from 2001 (More Snow) back to 1988(Less Snow). Equivalent class pairings analyzed were:**

**Class 7 Bright Snow <==> Class 6 Bright Snow & Rock**  
**Class 2 <==> Class 2 Mixed Veg with Other Surface**  
**Class 1 <==> Class 1 Black, Shadow or Water**  
**Final Class 5 = Dark, Bare Rock Final Class 4 = Veg. Only**

	Class 7	Class 2	Class 1	Row Total	Class
Class 1	1827	11522	56057	69406	106104
Class 2	1560	124837	29732	156129	185669
Class 3	40	16686	185	16911	71205
Class 4	1	65239	238	65478	109175
Class 5	8558	519	1760	10837	111778
Class 6	8987	9	1403	10399	106721
Class 7	1237	195	5	1437	66339
Class 8	29	1695	18	1742	86090
Class Tot.	22239	220702	89398		
Class Change	13252	95865	33341		
Image Diff.	84482	-35033	16706		



*Figure 6: Subset of the Change Detection Statistics Mask for the Study Area in MT.*

**Table 2: Areas (km<sup>2</sup>) from 2001 back to 1988**

**Equivalent class pairings analyzed were:**  
**Class 7 Bright Snow <==> Class 6 Bright Snow & Rock**  
**Class 2 <==> Class 2 Mixed Veg with Other Surface**  
**Class 1 <==> Class 1 Black, Shadow or Water**  
**Final Class 5 = Dark, Bare Rock Final Class 4 = Veg. Only**

	Class 7	Class 2	Class 1	Row Total	Class Total
Class 1	1.484	9.359	45.532	56.375	86.183
Class 2	1.267	101.399	24.150	126.816	150.810
Class 3	0.032	13.553	0.150	13.736	57.836
Class 4	0.001	52.990	0.193	53.1845	88.677
Class 5	6.951	0.422	1.430	8.802	90.792
Class 6	7.300	0.007	1.140	8.447	86.684
Class 7	1.005	0.158	0.004	1.167	53.884
Class 8	0.236	1.377	0.015	1.415	69.927
Class Total	18.064	179.265	72.6135		
Change	10.764	77.866	27.081		
Image Diff.	68.6205	-28.456	13.569		

## Summary

Overall, in the image from mid-summer 2001, there was more bright snow detected and more vegetation mixed with other surfaces than in the late-summer 1988 image. Of the bright snow seen in 2001, 40% was the same in 1988 but 38% was just bare rock in 1988. The snow was less lit in 1988 and less reflective, making some of it placed into a different category than white. The lake at the upper right of Figure 6 apparently increased in area over the years. Uncertainties involved when making conclusions from the data include annual snowfall variation from year to year, shadowing by mountains that changes with time of day, delay from early July to late August catches one image at the end of the snowmelt season and one image only partway through the melting process. Long-term effects due to global climate change were not observed in this study as yearly snowfall variation and time of year overwhelmed any long-term effects. It might be possible to also use band 5 Near-Infrared to track snow better as long as distinguishing between the different vegetation types is not the primary factor of concern.

## Acknowledgments

Useful knowledge regarding defining coordinate systems and mapping elevations using ArcGIS is in part attributed to resources and experiences in Kyle Murray's GIS for Water Resources class while knowledge of ENVI was gained through experience in Hongjie Xie's Remote Sensing class. Reference 5 was also a useful starting point.

## References

- 1) <http://www.landsat.org/ortho/default.html>
- 2) <http://seamless.usgs.gov/>
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- 5) *The new remote sensing derived Swiss glacier inventory: I. Methods*, Paul, Kaab et al., 45th International Symposium on remote Sensing in Glaciology, Maryland, 2001, **Annals of Glaciology** 34, 1, 1/01/02, p 355-361