Assessment Monitoring of Suspended Sediment of Alpine Glaciers, using Remote Sensing Techniques

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ABSTRACT

The science of remote sensing of suspended sediments lies in the analysis of satellite imagery to determine the amount of solid contaminant (or sediment) present in a medium (i.e. water, air). This information can then be processed and utilized in studies, such as water quality, air quality, and environmental monitoring. In this project, monitoring of sediment suspended in a body of flowing ice that is later to melt into an outwash fan and subsequent streams is to be monitored to understand the environmental, ecological, and geological importance of this natural process. In order to investigate possible differences in reflectance, we tracked changes in the relative dates (Markham, and Helder 2012). Processing and analysis of the satellite images data was done using the Environment for Visualizing Images, ENVI. This type of research is important because there is need to find alternative means of acquiring data on glacier and assessing their resource value without endangerment of field reconnaissance, similar studies about the possibilities of remote sensing going where it is inaccessible to humans have already been realized (Schneevoigt, et. al., 2008). It will also allow us to determine the best sensor to use for this type of research, between the existing Landsat sensors (e.g. MSS, ETM, TM). Its importance also lays in broadening the fields of study remote sensing can be applied to or can contribute to. We utilized images from 1972 and 2003.

KEYWORDS - Remote sensing Suspended sediments Satellite imagery Landsat sensors ENVI Reflectance

INTRODUCTION

The topic for the project was a study on dynamics of suspended sediment by way or use of Landsat satellite imagery. The major purpose of this research is to examine the capability to determine the quantity of sediment being transported by alpine glaciers through satellite remote sensing. To determine significant differences in the quantity of suspended sediment between the periods of 2003 to the present we will observe and analyze satellite images of the area, specifically during the summer period when ablation occurs.

Remote sensing

Remote sensing is the science of studying and collecting information of an object without any direct contact. Sensors obtain information of the Earth surface features by looking at how they emit and reflect electromagnetic energy. Applied to, it allows the study of a behavior from anywhere in the world (Lillesand and Kiefer, 1999).

Remote Sensing of Suspended Sediments

Sediments are monitored or assessed by the use of remote sensing by means of difference in reflectance, this means that the sediment and the medium in which it is suspended are different in reflectance and can be distinguished from each other in this manner (Markham, and Helder 2012).

LANDSAT

In 1972, NASA launched the first Earth Resources Technology Satellite (ERTS-1); this multispectral data provided a better understanding of our planet. The name was later changed to LANDSAT and it has been a very successful long-term mission. In 1999, NASA launched Landsat 7. Prior to the launch of Landsat 7, two Landsat were in operation, Landsat 4 and Landsat 5. Landsat 6 was launched in 1993 but it failed. Landsat satellites produced some of the most popular and remote sensing images of the earth.

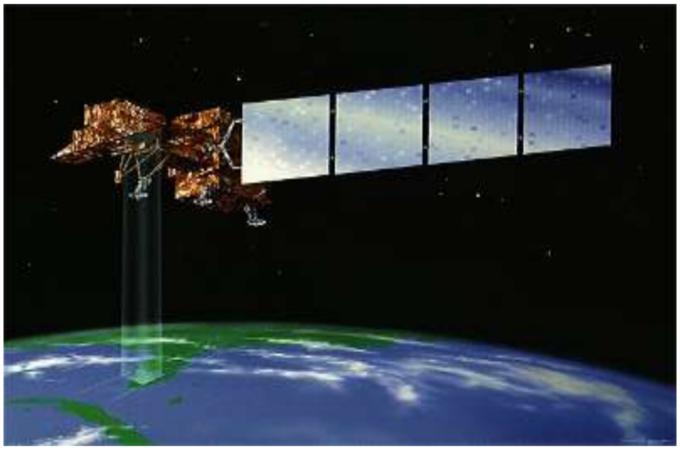


Figure 1. LANDSAT satellite producing remote sensing images of the earth.

LANDSAT Sensors

MSS

Multispectral scanner consists of four spectral bands with 80-meter spatial resolution (Cambell, 2007).

TM

Thematic Mapper consists of seven spectral bands with a spatial resolution of 30 meters for Bands 1 to 5 and 7, and for Band 6 (thermal infrared) of 120 meters (Cambell, 2007).

ETM

Enhanced Thematic Mapper consists of eight spectral bands with a spatial resolution of 30 meters for Bands 1 to 7, and for Band 8 (panchromatic) of 15 meters (Cambell, 2007).

Delani National Park

Denali is located in the central area of the Alaska and also is located in the highest point on the North American continent, called Mount McKinley. This mountain glacier was formed by the subduction of the Pacific crustal plate beneath the North American plate.

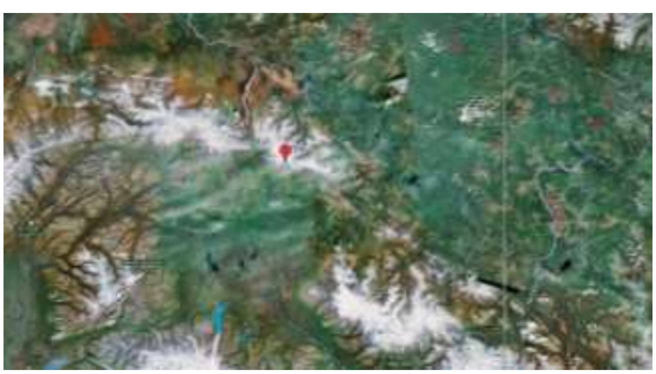


Figure 2. Location of our study site: College Alpine Glacier at Located at Lat: 63 15’ 29” N, and Lon: 145 21’ 17” W and a maximum elevation reaching 9 thousand feet or 2743.2 meters.

Figure 3. Delani National park topographic map of a ablation moraine. It shows the northwestern end of the glaciers covered by an ablation moraine, composed of an accumulation of till. It has an irregular surface with many depressions, some of which contain water, due to melting. (http://www.nationalatlas.gov/100topos/Mount_Mc

Kinley.html).

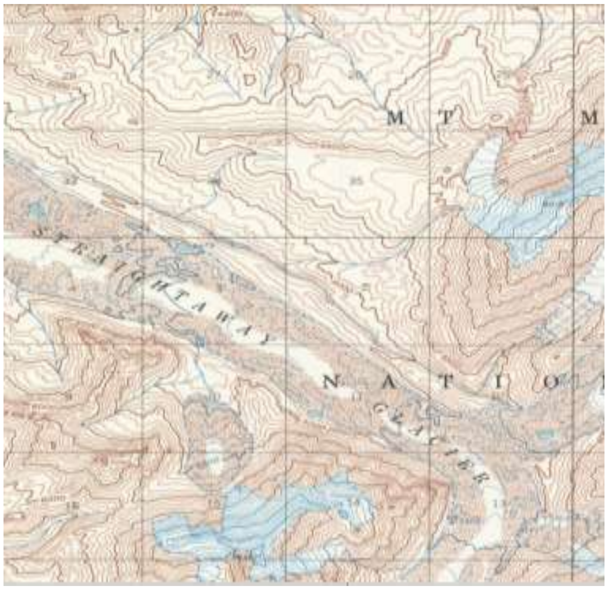


Figure 4. Delani National park topographic map of a lateral moraine. It shows a broad, great lateral moraine. It also shows bands of till and glacial debris running parallel to the direction of glacial flow on the surface. (http://www.nationalatlas.gov/100topos/Mount_McKinley.html).

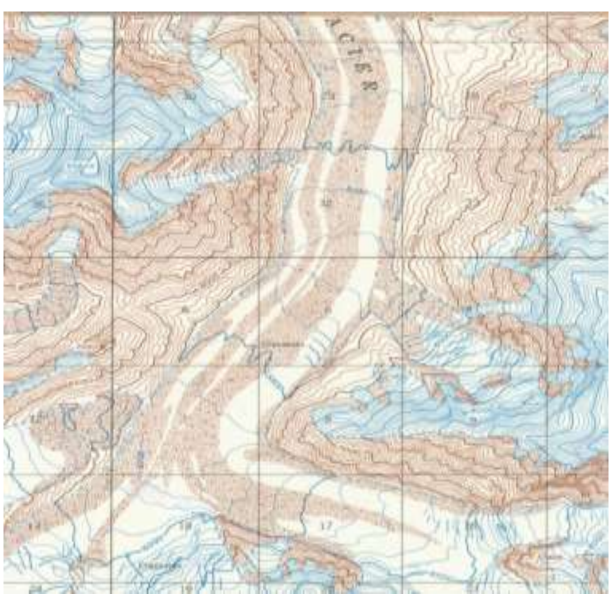


Figure 5. Delani National park topographic map of a medial moraine. It shows a medial moraine down the valley. (http://www.nationalatlas.gov/100topos/Mount_McKinley.html).

METHODOLOGY

Different sensors onboard satellites constantly acquire information about suspended sediments. The satellite assigned to us was Landsat, which has sensors such as the mass spectral scanner (MSS) and the enhanced thematic mapper (ETM). Since 1972 through 2012, Landsat sensors have documented the Earth's transformations. Therefore, it is considered to have the longest remote sensing history of the Earth available. Landsat Multispectral Scanner (MSS) images consist of four spectral bands with 80-meter spatial resolution. Landsat Thematic Mapper (TM) images consist of seven spectral bands with a spatial resolution of 30 meters for Bands 1 to 5 and 7, and for Band 6 (thermal infrared) of 120 meters. Landsat Enhanced Thematic Mapper Plus (ETM+) images consist of eight spectral bands with a spatial resolution of 30 meters for Bands 1 to 7, and for Band 8 (panchromatic) of 15 meters. These sensors were not always use to be calibrated; consequently there were times when many studies of the earth were incomplete. Over the years, these details were improving (Markham and Helder, 2012).

In order to achieve the goals of this research, the first step in the methodology was to identify specific dates or time periods when the acquisition of images from Earth Explorer was possible, from the site of study from each of our sensors. To do this we searched for good locations with available images on the USGS online database, the Earth Explorer and obtained the largest amount of possible images. We acquired images from all three scanners from College Glacier in Denali National Park in Alaska. Located at Lat: 63 15' 29" N, and Lon: 145 21' 17" W. The specific features we looked for were clear examples of alpine glaciers which had well-developed morphological features such as lateral and medial moraines, an outwash plain were ablation or melt occurred and subsequent river from the glacial melt waters.

To these images a series of pre-processing protocols were used in order to better prepare for its analysis. Each image was reduced by sampling and was cleaned by utilizing the dark subtract tool and on two images the destripe feature was used in order to try and reduce the striping.

Each image was then analyzed by comparing the change in expansion and retreat by using the link displays feature.

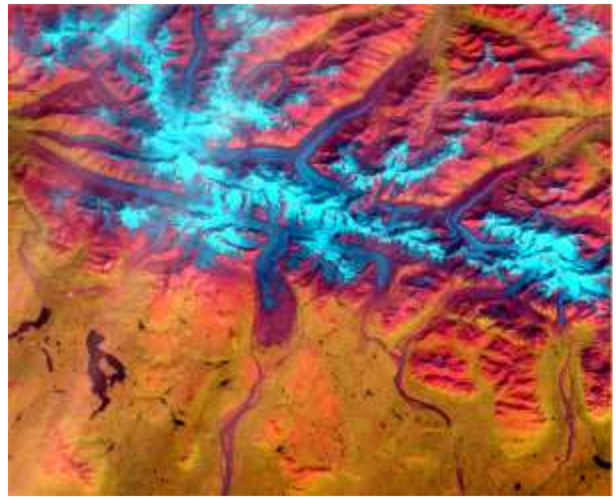


Figure 6. Landsat ETM+ image of College Glacier, Denali National Park, Alaska, from August 1999.

This colored image shows us the alpine glacier formations and their outflow of melt water into the rivers valley below, the dark maroon coloration along the river are sediment deposits from stronger river currents.

In order to estimate or grasp the concentration of sediment suspended in the glacial ice and in its subsequent melt water the formula for suspended Normalized Suspended Material Index (NSMI) was used.

NSMI:

((band red)+ (band green)-(band blue))

/ ((band red)+(band green)+(band blue))

- (Montalvo, 2010) (Fiuza Borges et al. 2011)

This method highlighted the areas of stronger sediment concentration where the shades grey determine the presence and concentration of suspended sediment.

Figure 7. Landsat ETM+ (NSMI) image of College Glacier, Denali National Park, Alaska, from August 1999.

The equation gives us results from -1 to +1 where the negative (black) value expresses clear clean ice and the positive (white) value pertain to sediments or reflective surfaces higher than water in the ranges of the red and green bands.

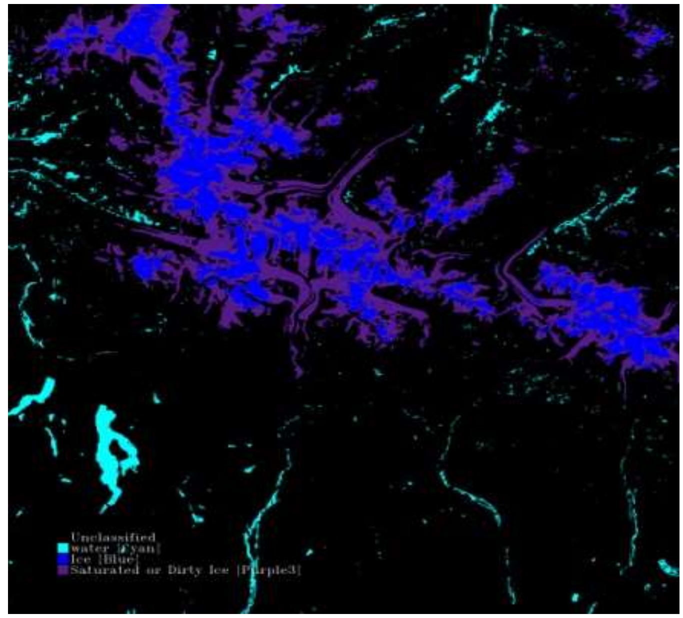


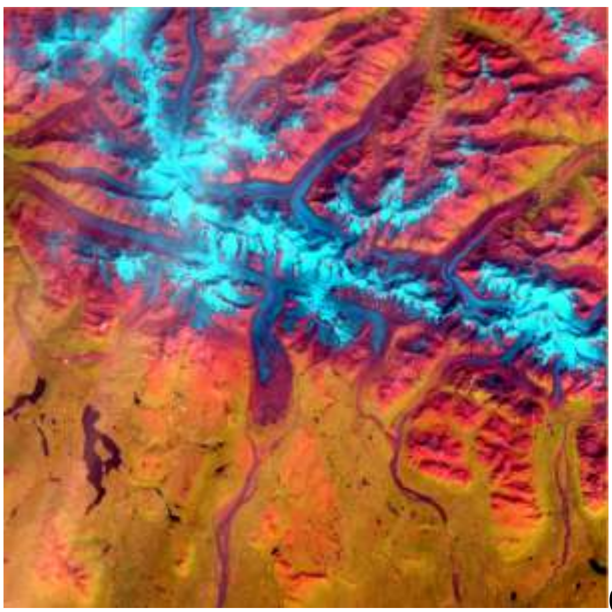
Figure 8. Minimum Distance imagery of College Glacier, Denali National Park, Alaska, from August *1999. Here the water (Cyan), the ice (Blue) and the sediment-saturated ice (Purple) are highlighted.*

Additionally a supervised Minimum distance classification was conducted on the images; this was so we could further highlight the areas of interest, specifically those of clear glacial ice, sediment saturated ice which we termed the limbs of the glacier that had developed moraines which contain the sediment suspended in ice as it flows down the alpine mountains, the suspended sediment in the glacial melt-water and water.

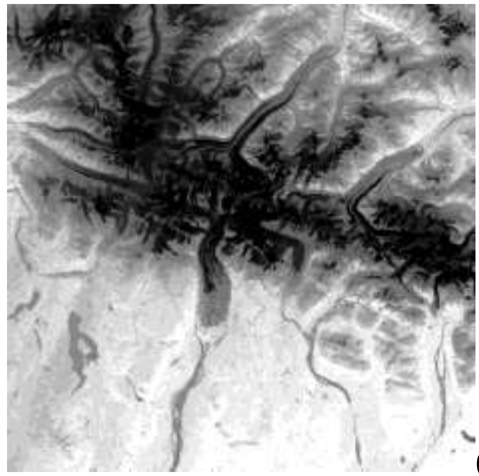
The images were examined to determine which sensor proved useful in determining the flow of sediments suspended in glaciers onto glacial melts waters.

RESULTS AND DISCUSSION

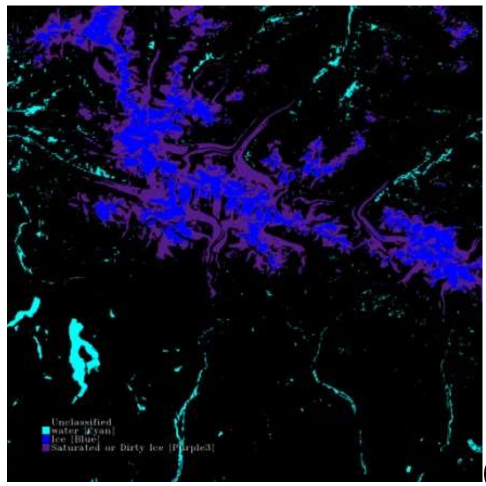
The images obtained reflected a small interval in during the ablation period of the year (July to September) , most of the images obtained where from the Landsat Enhanced Thematic Mapper from 1999 and 2003, images from the Thematic Mapper and the Mass Spectral Scanner where acquired from previous dates due to their recent inexistence.



(a)



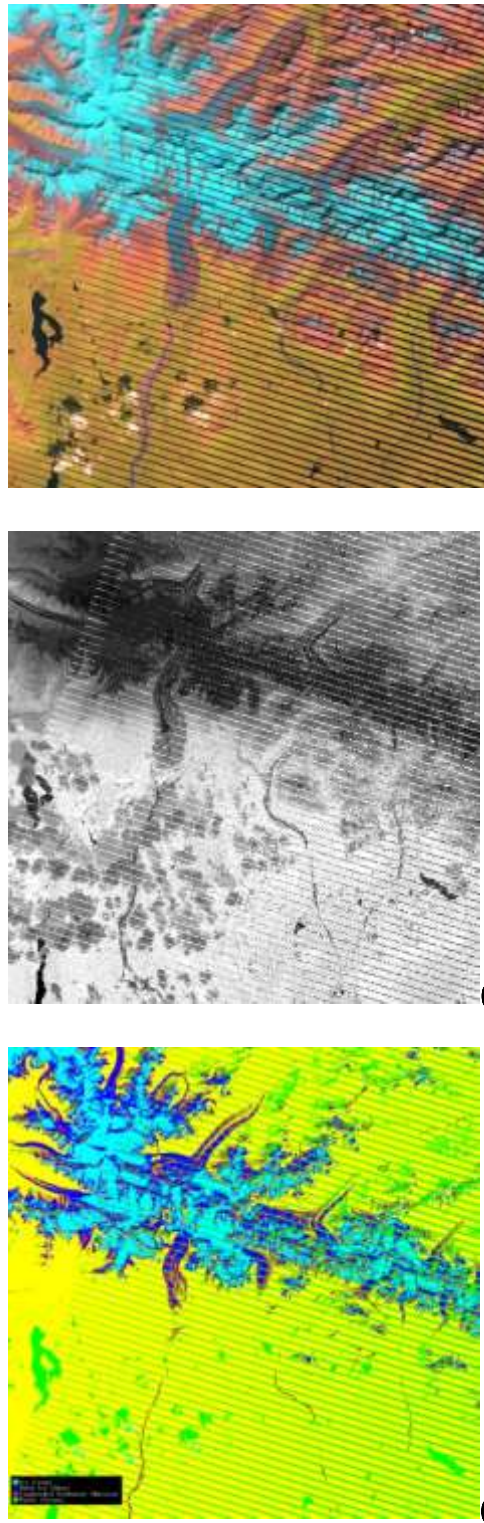
(b)



(c)

Figure 9. (a) Landsat ETM+ image (b) (NSMI) and (c) Minimum Distance imagery of College Glacier, Denali National Park, Alaska, from August 1999. This colored image shows us the alpine glacier formations and their outflow of melt water into the rivers valley below, the dark maroon coloration along the river are sediment deposits from stronger river currents.

These images show us that the ETM allows for a degree of detail use full in monitoring the expansion and contraction of the glacier, but the degree of resolution needed for a spectral scan of river flow is low due to the river flow being so thin, still the image processing allowed for the sediment surrounding the river current to be highlighted. Most notably, sediment around the end of the glacier (end moraines), where it flows down the mountain ravines and melts into the valley is very detailed (*Figure 3-a)*. Here, the sediment is highlighted as it is exposed on top of the glacier (as purple in the Minimum Distance or grey in the NSMI). Although suspended sediment here is identified, it is not quantifiable. Considering the basis for the NSMI (Montalvo, 2010) (Fiuza Borges et al. 2011) the reason the rivers are highlighted as shades of grey is because the streams flowing down from the outwash plain have high concentrations of suspended, the darker the stream the cleaner the stream is of suspended sediment, but considering that, the riverbeds are still viewable in a mixture of shades of grey because there is suspended sediment is present in the stream water. The classified minimum distance image shows us contradictory information as it registered only the water in the stream but not a continuous sediment presence from the base of the glacier to start of the stream.

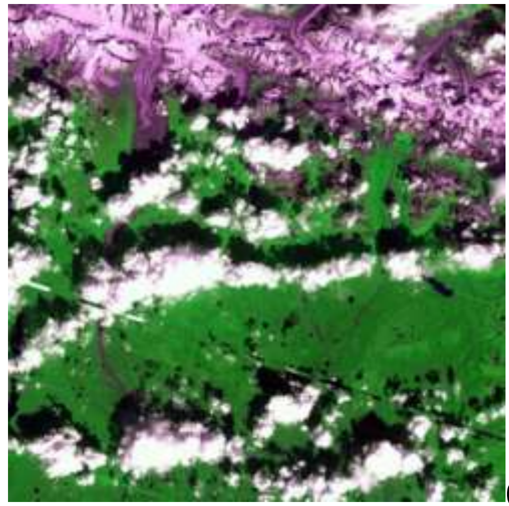


(a) (b) (c)

Figure 10. (a) Landsat ETM+ image (b) (NSMI) and (c) Minimum Distance imagery of College Glacier, Denali National Park, Alaska, from August 2003.

In contrast to the images from 1999 these images from 2003 show us a stronger or higher presence of sediments in the river (used the curser location value to compare the values on both images), such as lighter shades of grey in the NSMI image, signifying a higher reflectance by the sediment and by how the Minimum Distance image classified the entire stream as sediment while it did recognize other bodies of water.

This on its own allows us to hypothesize that the rate and amount of suspended sediment flowing out via glacial melt water is the same? A study made a decade ago (Kumar, et al., 2002) suggest that sediment discharge will vary in contrast to liquid discharge, this varies due to the variability that the glacier will erode and acquire sediment at different rates and quantities during its development. But conclusively the ETM+ does have the capability to monitor glacial features as well as their sediment outflow.


(a)

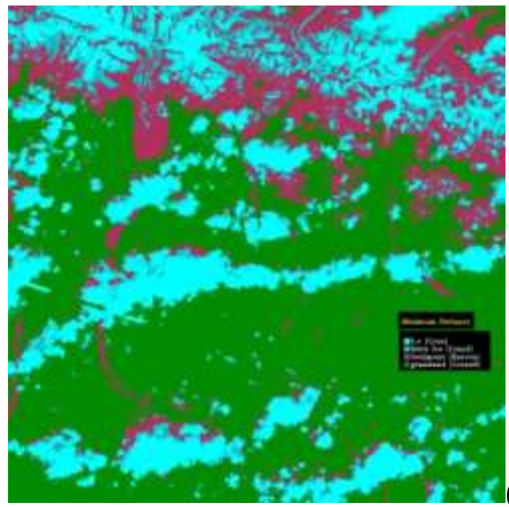

(b)

Figure 11. Landsat Mass Spectral Scanner (MSS) August 1972, (a) is pseudo-color image of College Glacier end moraine; (b) is a Minimum Distance supervised classification.

The MSS image obtained, though obscured by some cloud formations, war a decent image that showed many detailed features, but because it lacked a blue band, the image processing for the NSMI was an unavailable option because it requires q blue band. Though this was but a minor setback, the minimum distance supervised classification yielded interesting results. The class denoted (maroon color) to classify sediment was segmented along the trace of the stream but not at its margins, which suggests that there was suspended sediment present in the body of water. Though the presence of clouds and their shadows did pose a visual problem they did not interfere with the classification of the sediment. But then again the conclusion is that it may be unsuitable to use for this specific monitoring task due to its incompatibility to the NSMI formula, perhaps the use of a different formula may solve this but to monitor the spectrum of water, blue is critical and so its incompatibility continuous.

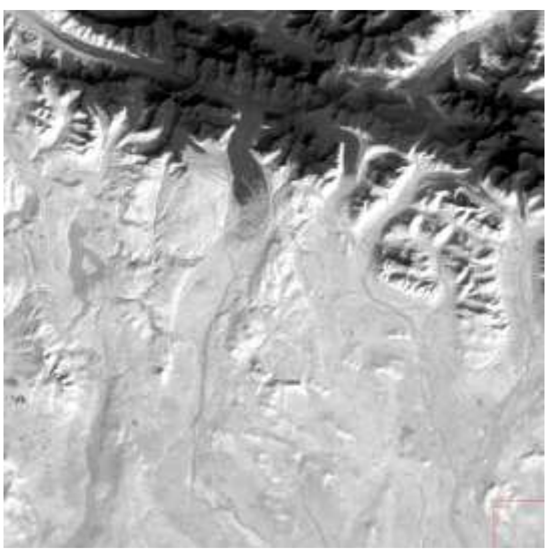


Figure 12. Landsat Thematic Mapper (TM) (band 6) Sep-1995

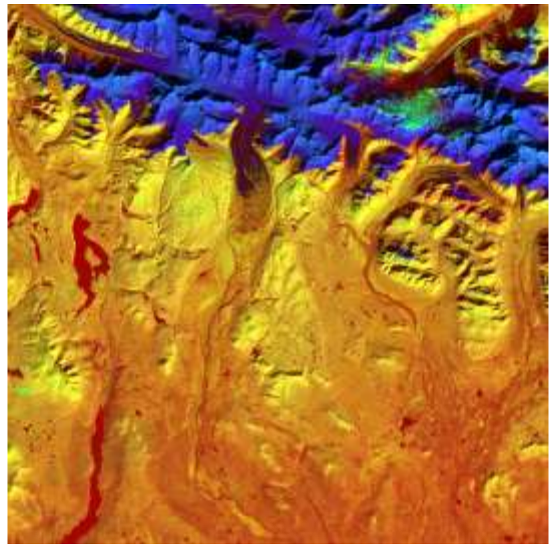


Figure 13. Landsat Thematic Mapper (TM) False color Image Sep-1995.

The TM images we acquired gave us an extremely beautiful detail of the morphology of the area, sadly the image was corrupt and ordering the image would have taken too long to be received. We utilized the TM's 6 band, which records in the far infrared spectrum (figure 7) where we obtained a similar result to that of the NSMI. Here we deduced that the streams created from the river's melt-water are almost indistinguishable from the contrasting surrounding fields, the pixel value for these regions was negative closest to cero, which tells us that sediment is present in the stream but is far less than what we have seen before in the ETM+ images from 2003. Figure 8 allows us to see (orange-red) reflectance from the outwash plane and stream but it not as strong as the surrounding deposits, which leads us to believe that the concentration of sediment flux at this time was low but present.

CONCLUSION

This research also allowed us to determine the best sensor to use for this type of research, between the existing Landsat sensors. Of the three Landsat sensors used the ETM and TM demonstrated the best detail while the MSS lacked a blue band to conduct the NSMI method. Further research can be realized with the development of more specific methods of surveying or band math formulas. The largest draw back for such a study is the small window of time in which the images can be taken so as to get the highest level of detail. Images taken during winter months are useless because the winter winds obscure the surface. But these kinds of problems can be solved as the technologies of remote sensing advance in the future.

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