IDENTIFYING GLACIAL FEATURES WITH SENTINEL-2 DATA

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Abstract

The Tibetan Plateau is a vast elevated plateau in Central and East Asia. It contains thousands of glaciers and other geographical features. Through this area rivers like the Brahmaputra is flowing and making a basin providing about millions of people a home.

The last years global warming has been a focus of public and scientific debate. Not knowing what to expect and what the changes are result in ruling uncertainties which are of major concern because it could cause serious implications for water resources.

During this study the area located in the Upper Brahmaputra in the South-East of the Tibetan Plateau called the Yiong Zangbu catchment will be investigated. To understand what glacial changed have occurred in the past few years data from different years were collected, processed and compared.

The used datasets are ASTER GDEM, HydroSHEDS, GLIMS glacier mask and Sentinel-2 . Sentinel-2 data has been processed and different images are made like true colour and false colour images. Next to that a combination of datasets are used to see whether there is an accuracy issue and to understand what kind of features can be found on which height and what spectral reflectance belongs to it. After processing all the data of two following years differences can be seen. There are lakes that are frozen out within three months. Also glaciers which expanded downwards the hills. This can be a result of strong winters. On the higher parts there was more precipitation, which is helpful while remaining the current glaciers.

Table of contents

1. Introduction

The highest mountain on earth is the Mount Everest with an elevation of 8848m above sea level. It is one of the mountains of the Asian mountain range, the Himalaya, which separates the Indian subcontinents from the Tibetan Plateau. The Tibetan Plateau is a vast elevated plateau in Central and East Asia. It contains thousands of glaciers and other geographical features. It also has a lot of lakes and an active flow system. Through this area rivers like the Ganges, Brahmaputra and the Indus are flowing and making a basin providing about 600 million people a home.

The last years global warming has been a focus of public and scientific debate. Because of pollution and collected greenhouse gasses in the atmosphere the earth is warming up. This will have an influence on the climate, biological lifecycle, natural behaviour. Ruling uncertainties are of major concern because it could cause serious implications for water resources. Having a poor understanding of the main affecting process in combination with the changing climate and extreme topographic relief in this area makes it hard to control.

Since the Tibetan Plateau contains next to the Himalayan mountains a lot of glaciers and has limited data it is interesting to look at the effect of the global warming. To research this effect we need to zoom in into a part of the Tibetan Plateau.

During this study the area located in the Upper Brahmaputra in the South-East of the Tibetan Plateau called the Yiong Zangbu catchment will be investigated. It is located within the orange box that can be seen in figure 1. This part is chosen because of the glacial features and the active flow system of the Brahmaputra. The Brahmaputra is 3848 km long and is an important river for irrigation and transportation with a peak discharge orders of 100 000 m^3/s. A change in the flow system could cause major damages.

To understand what has changed in the past few years data from different years needs to be collected, processed and being compared. First of all there have the be looked at the overall area. Next to that different datasets will be compared. The most important is Sentinel-2 data, optical data, with a variation in ingestion date. This is preferable in order to look at the changes over time. It is also helpful to use other datasets for the elevation, basin outlines and a dataset of glaciers . All these datasets will be processed in a remote sensing program. The combination will help determining the glacial features in this area.

This study begins in chapter 2 with the background area information. In chapter 3 and 4 the used datasets are explained and the methodology is provided. Chapter 5 states the results .This is followed by chapter 6 with conclusions and recommendations.

1.1 Research question

The overall research question of this study is: What kind of glacial features changes can be found in the Yiong Zangbu catchment over time by using Sentinel-2 data in combination with other datasets?

In order to do this it is divided in a few sub question:

- What kind of differences can be seen between the two Sentinel-2 datasets?
- Is it possible to distinguish different glacial features by using Sentinel-2 data?
- How can you distract the real changes from the others?
- Does the information of the different datasets match?

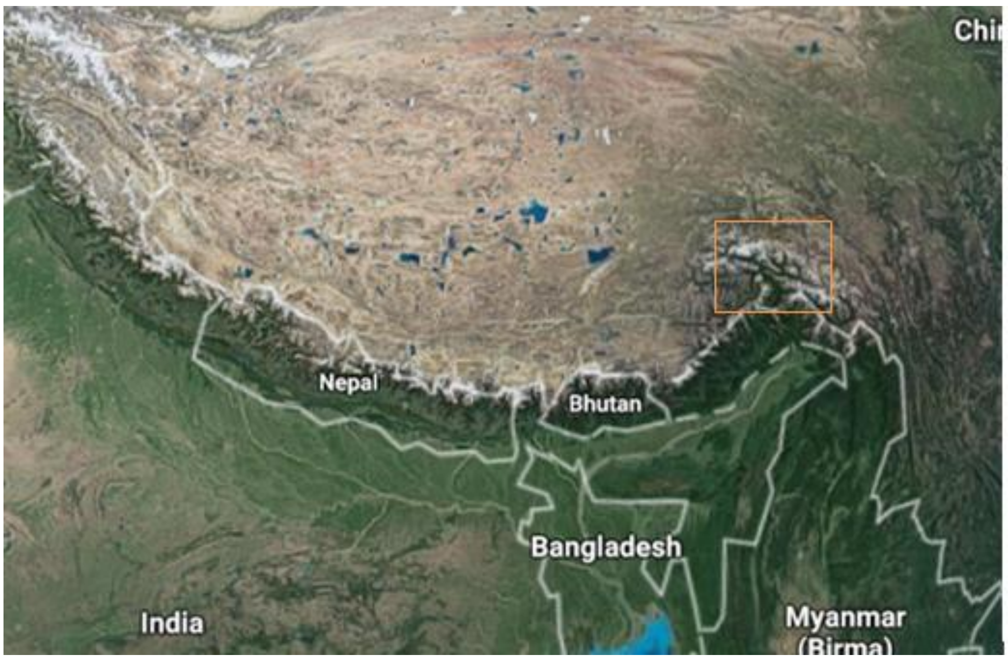

Figure 1: Area of interest in the orange box (Google Satellite)

2. Background

In this chapter the background information of parts will be provided. First the climate and the area of interest is pointed out. The second section deals with the glacier and its features. Next an explanation of remote sensing is given. Finally there is referred back to the sub questions of this study.

2.1 Area of interest

During this study the Yiong Zangbu catchment will be investigated. It is located in the Upper Brahmaputra in the South-East of the Tibetan Plateau. The Tibetan Plateau is a vast elevated plateau in Central and East Asia, as can be seen in figure 2. Sometimes it is called “the roof of the world” because it is the highest and largest plateau with an area of approximately 2.5 million km2 and an average elevation of 4500 m. It also contains a huge amount of glaciers. Therefore, it serves as a water storage, maintains the flow and keeps the water resources under control for Southeast Asia.

The Tibetan plateau has two seasons. The first one is the dry season which occur in the winter. The winter is from November to March and has an average temperature below 0 degrees. The other season occurs in the summer from May to September with a lot of precipitation. The temperature is between 10 and 20°C with strong sunshine. Annual monsoons such as Asian summer monsoon, winter monsoon and the Indian monsoon dominate the precipitation on the Tibetan Plateau. The climate in the West and the North of the Tibetan Plateau is warmer and drier than the South and East (Niu et al, 2004). On top of that the climate varies in the area depending on the elevation. Lover elevation are tropical while there is permanent ice and snow at a high altitude.

Figure 2: The Tibetan Plateau, source of major rivers . Area of interest is within the black box (Yowangdu,2012)

Next to that the Tibetan Plateau contains thousands of lakes and is also the origin of the biggest rivers of Asia such as the Brahmaputra. These rivers provide a living and food security of above 1.4 million people. The Brahmaputra flows through China, India and Bangladesh and is 3848 km long . One of the affecting variables of water levels is glacial melt water in the spring. Since this river can be classified as a braided river, the chance of occurring avulsion and channel migration is high. Therefore the changes in glaciers needs to be monitored in order to understand the hydrologic processes of the Tibetan Plateau. In figure 3 and 4 the study area is given while zooming in.

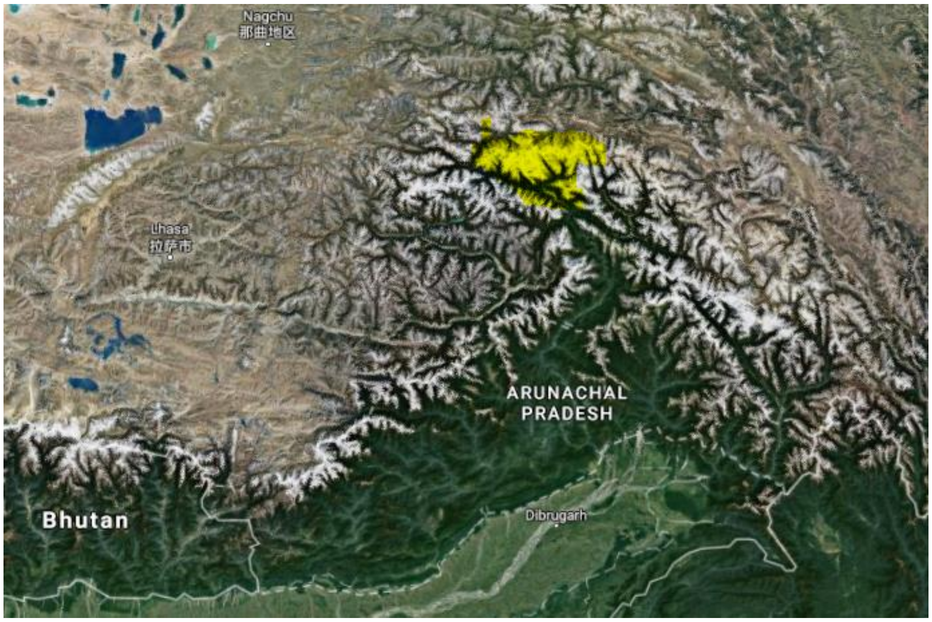

Figure 3: Research area is marked yellow. (Google Satellite)

Figure 4: Yiong Zangbu catchment, Upper Brahmaputra. Orange box is the study area (Google Satellite)

2.2 Glaciers

Glaciers are persistent bodies of dense ice which are constantly moving due to gravity. Due to precipitation of snow and accumulation over the years a glacier can grow or shrink.

The precipitated snow converts to glacial ice in time. It becomes harder by melting and re-freezes again. The stages can be seen in figure 5.

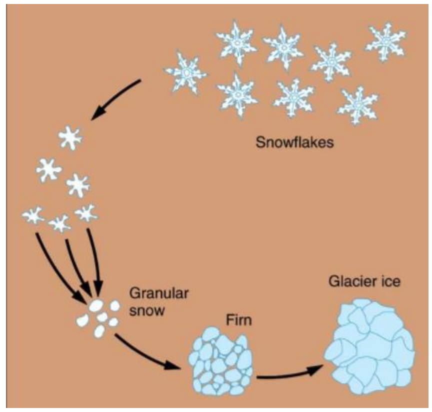

Figure 5: Conversion of snow to glacial ice (studyblue,2017)

Because of precipitation of snow glaciers can be covered with it. This influences the glacial melting behaviour depending on the albedo. Albedo is a measure for reflectance and has a value between 0 and 1. They can also be seen as a percentage of reflectance. When there is zero reflectance all the heat of the sun will be absorbed, while a 100 % reflectance causes no heat absorption at all.

As seen in figure 6, snow is a very good reflector with an albedo between 0.6 and 0.97. The state of snow influences the albedo. Very clean and fresh snow has a high albedo and absorbs almost no heat while dirty snow results in a low albedo value with a higher heat absorbance. Also the albedo of glacier ice varies a lot depending on the dirt.

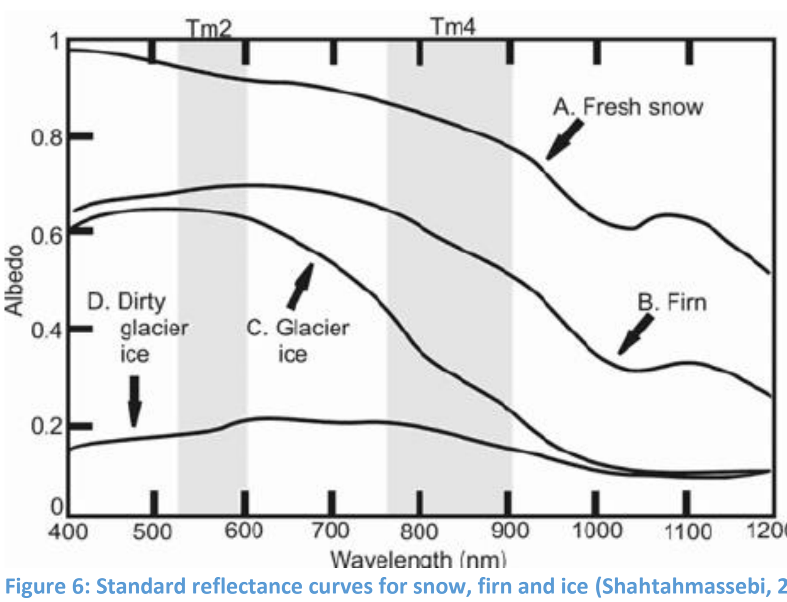

Figure 6: Standard reflectance curves for snow, firn and ice (Shahtahmassebi, 2013)

From this it can be seen that there is an importance difference between snow and ice. Due to this the boundary between snow and ice can be observed, because of the bright white colour of snow. This boundary is called the snowline and varies thorough the year depending on the snow cover trough the seasons.

The equilibrium-line altitude (ELA) on glaciers is the average elevation of the zone where accumulation equals ablation over a 1-year period (Bakke, 2014). During the winter there is not a lot of precipitation and the snowline is almost constant which gives a good approximation of the ELA. The glacier surface above the ELA is mostly snow and the below the ELA mostly ice will be found. The glacier can grow or retreat depending on the ablation. As can be seen in figure 7 on the ELA the accumulation value is equal to ablation value and result in an ELA value of zero. A positive ELA means more accumulation and an advance down the valley. This also means a negative ELA result in an retreating glacier.

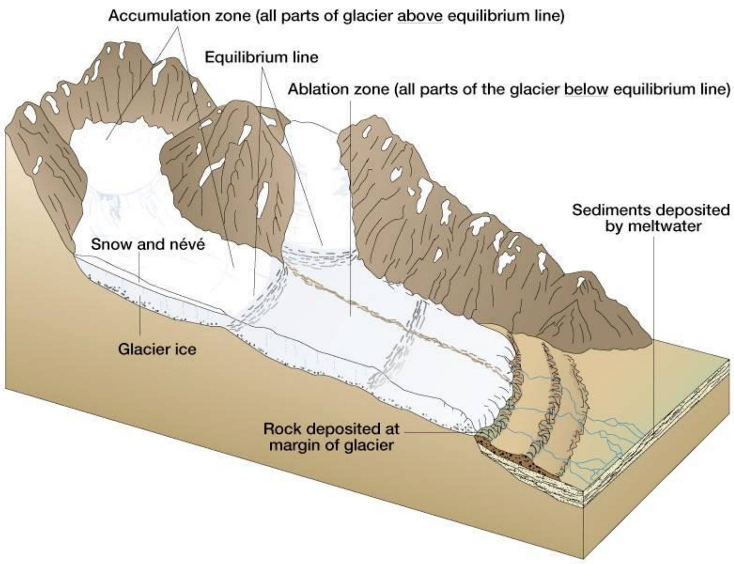

Figure 7: Glacier formation dynamics (Pauly,2015)

2.3 Remote sensing

Remote sensing is acquiring information about an object without making any physical contact with it. This can be done in a lot of different ways, but in this research satellite data is used. Satellite data contains information about the electromagnetic radiation from the earth's surface. Every object and type of land cover has its own spectral signature. Meaning that the absorbed and reflected radiation comes in its region of the electromagnetic spectrum. The prism in the satellite divides the reflected radiation into different band. Sentinel-2 data has 13 bands. In figure 8 an example of the earth's surface reflectance is given depending on the wavelength.

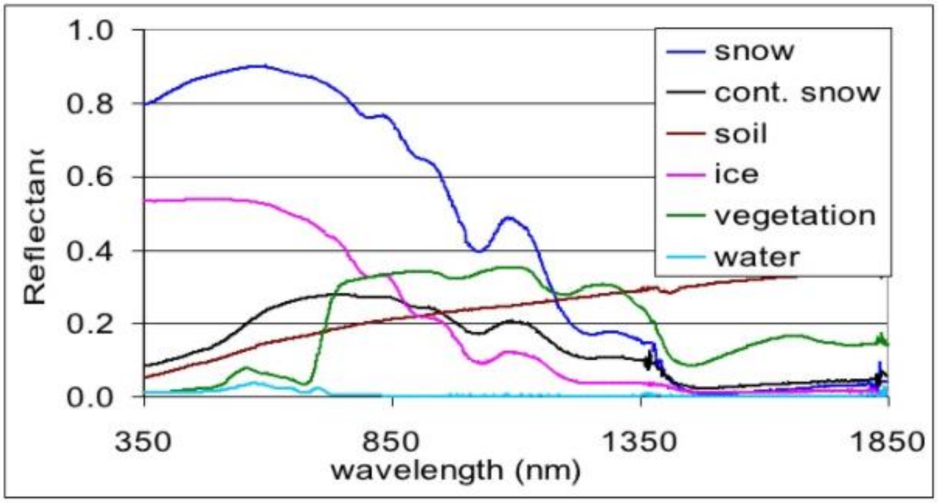

Figure 8: Spectral reflectance of snow ice and other features (Kulkarni,2007)

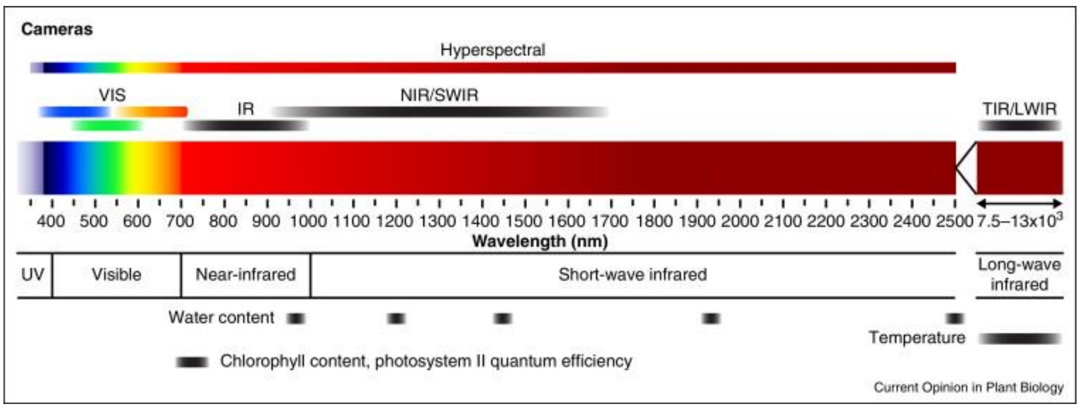

Figure 9: Wavelength spectrum (Fahlgren, 2015)

In figure 9 the wavelengths are shown and divided in part like visible light and infrared. By combining the data of figure 8 and figure 9 it can be seen what reflectance can be detected while measuring in visible region of spectrum. Visible lights make use of the reflectance rate and the white colour. Having clouds in the measured data to detect snow/ice can be a problem since clouds are also white and have approximately the same spectral signatures. SWIR stands for ShortWave InfraRed and is a part of the spectrum which could, in combination with visible light, help distinguishing snow from other objects with a high albedo like clouds. The higher the response the higher is the albedo. Nevertheless materials can be identified by their reflectance spectra. The raw data includes errors and disturbance by the atmosphere. This needs to be corrected, by using atmospheric correction, to get the bottom of atmospheric reflection.

2.4 Conclusion

Knowing this background information gives a base for this research. It can be said that due to spectral data, like Sentinel-2, the glacial features can be found. The reflectance difference causes a difference in spectral data which could help while classifying the different classes. The difference between the two image data with other ingestion date could be seen in the precipitation in that time of the year. If it is during the winter it is expected that more glaciers will be formed, while in the summer more snow will be covering the glaciers.

3. Remote sensing data

This chapter explains the used data in this research. All data that has been used is freely available online. The first optical satellite data is from ASTER GDEM, explained in section 3.1. This is followed by the GLIMS glacier mask in 3.2 and HydroSHEDS in section 3.3. Finally the other optical satellite image from Sentinel-2 is explained in section 3.4.

3.1 ASTERGDEM

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an instrument on board Terra spacecraft which is owned by NASA (National Aeronautics and Space Administration). It was launched into the Earth in 1999, but is started collecting data since February 2000. This instrument was built for a wide range of scientific research areas like hazard monitoring and the change of land cover. Therefore it is build up from 14 different bands with different wavelengths and resolution. These have been used to produce digital elevation models (60 km x 60 km) with a vertical accuracy between 10m and 25m. On June 29,2009 NASA and METI (Minister of Economy, Trade and Industry of Japan) the Global Digital Elevation Model (GDEM) was released. The ASTER GDEM (GDEM1) had a coverage from 83 degrees north latitude to 83 degrees south which includes about 99% of the Earth's surface. (NASA, 2016). The GDEM1 has an overall accuracy of 20 meter. This is reached by using an elevation grid of 1°-by-1° tiles (pixels of 30 x 30 m) maintaining GeoTIFF format (Tetushi et all .,2011). An schematic overview is illustrated in figure 10

On October 17,2011 the ASTER GDEM(GDEM2) was released. It has the same gridding and tile structure as the previous version, but this one includes 260000 additional stereo-pairs, which improve the coverage and reduces the occurrence of artefacts (NASA 2016). The data could be retrieved from NASA EOSDIS(2017).The ASTER GDEM data of the area of interest can be seen in figure 11.

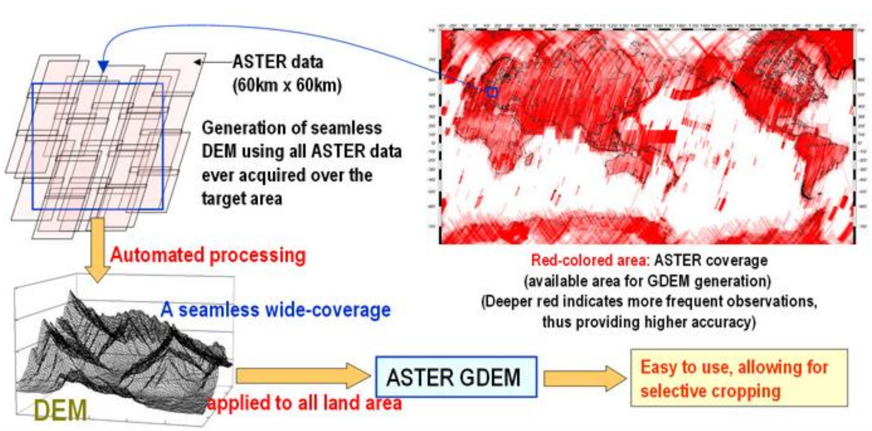

Figure 10: Concept of ASTER GDEM development (Jspacesystems, 2017)

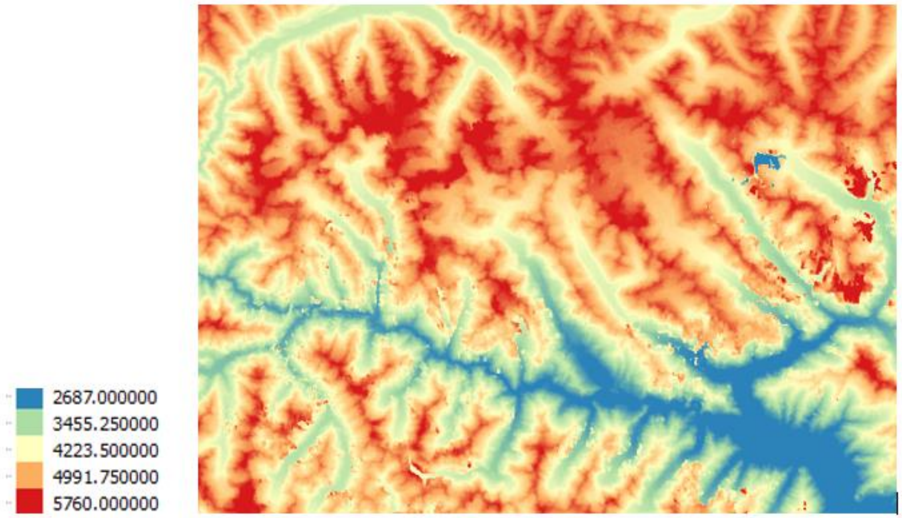

Figure 11: ASTER GDEM data of Yiong Zangbu catchment.

3.2 GLIMS glacier mask

GLIMS is short for Global Land Ice Measurements from Space. It first started as a an ASTER Science Team project. Since there was little information about the amount of glaciers and the changes, the ASTER instrument was adjusted in way to optimize glacier monitoring. This is a global project were approximately sixty institutions word-wide are working together (Raup, 2006). The goal of the project is to inventor the majority of glaciers all over the world-wide. In order to reach the main goal, an international network of collaborators analyse imagery of glaciers in their region of expertise. The quality is varies due to the use of different analysis methods and sources. The GLIMS glacier mask of the Tibetan Plateau was submitted by Li (2003), Chinese Academy of sciences. This glacier mask is a copy of the original data collected and digitized by the Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Science (CAREERI) (Phan, V.H, 2015). The coloured outlines of the GLIMS mask can be seen in figure 12. The GLIMS Glacier Database can be retrieved from NSIDC GLIMS(2017).

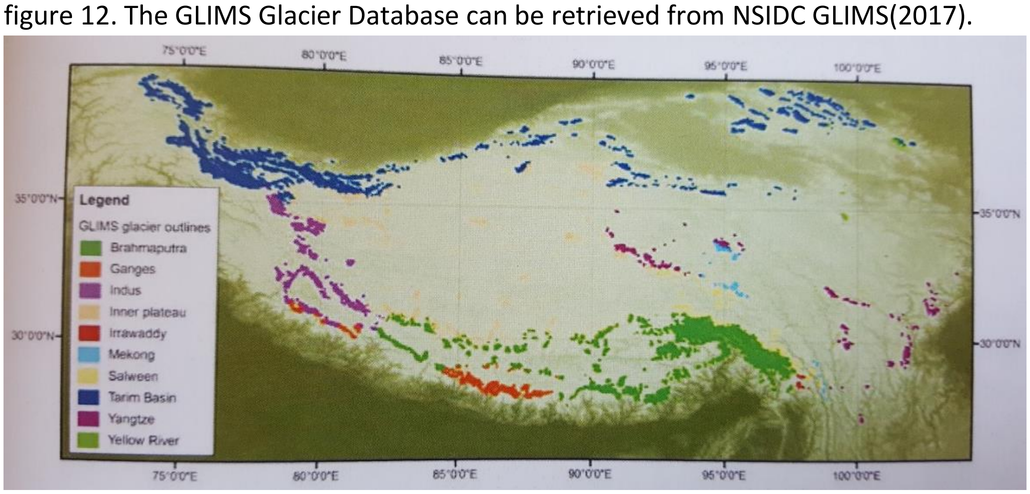

Figure 12: GLIMS glacier outlines colored per basin in the Tibetan Plateau (Phan, V.H, 2015)

3.3 HydroSHEDS

Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales, in short HydroSHEDS, derives a large-scale digital river network and basin maps as a base for analyses and hydrological applications (USGS, 2017). It offers a suite of geo-referenced data sets (vector & raster) at various scales, including stream networks, watershed boundaries, drainage directions, and flow accumulations (Phan, V.H., 2015). An example of such data in level 12 is shown in figure 13. The obtained data which is used by HydroSHEDS is obtained by NASA's Shuttle Radar Topography Mission (SRTM) during a space shuttle flight. The data can be freely downloaded from http://hydrosheds.org/ .

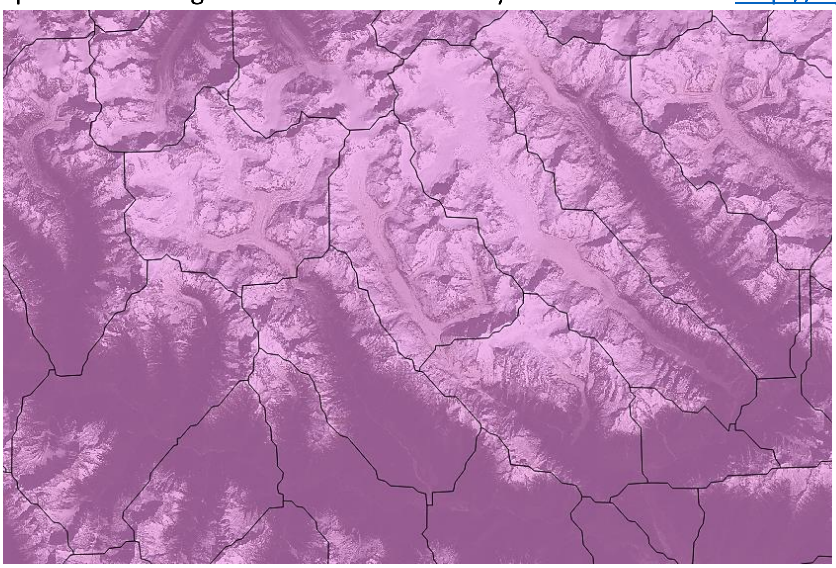

Figure 13: Hydrosheds Yiong Zangbu catchment, level 12 Hydrosheds overlaid on true colour Sentinel-2 (432)

3.4 Sentintel-2

On June 23,2015 Sentinel-2A was launched successfully as a start of the Sentinel-2 program and as a part of the European Copernicus program. It is a multispectral imaging mission with high resolution which could monitor the vegetation and other things such as soil and water cover. This followed by a related satellite, Sentinel-2B, which is launched on March 7, 2017. Sentinel-2B is will be phased 180 degrees against Sentinel-2A. Due to having two satellites with overlapping swaths from adjacent orbits the revisit frequency with different viewing conditions. They will also be revisited every five days under the same viewing conditions. The Sentinel-2 mission will provide a coverage of all continental land surfaces between latitudes between latitudes 56° south and 83° north. Also all European islands, the Mediterranean Sea, closed seas, islands greater than 100 km^2 and coastal waters up to 20 km from the shore will be covered. This is shown in figure 14 (ESA, 2017).

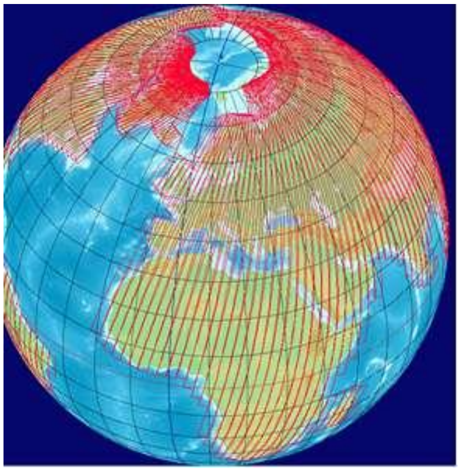

Figure 14: Modelled SENTINEL-2 Coverage(ESA,2017)

The applications for this mission are mostly related to the Earth's surface. A few examples are:

- Water monitoring
- forest and vegetation monitoring
- spatial planning
- glacier monitoring
- environmental monitoring

Sentinel-2 contains a multispectral imager consisting of 13 spectral bands. They are subdivided in the three spatial resolution: 10 meters with four bands, 20 meters with six bands and 60 meters with three bands. The combination of Sentinel-2 's highlights could provide useful information for further investigations. The combination of bands to get the true colour image is very useful while distinguishing ice from snow.
Next to that there are a few product levels : level-0 (raw data), level-1A (decompressed data) , level-1B (least processed data for users), level-1C and level 2A. The granule size depends on the product level such that the first three levels have granules which are 25 km across track and 23 km along track in size. The other two levels have an image which is divided into 100 km tiles in UTM/WGS84 projection (ESA,2017).
When two separate receiving stations needs the continuous acquisition of a Sentinel-2 image it needs to be subdivided into data strips. The levels and their relationships are shown in figure 15. All data is freely available at ESA(2017) .

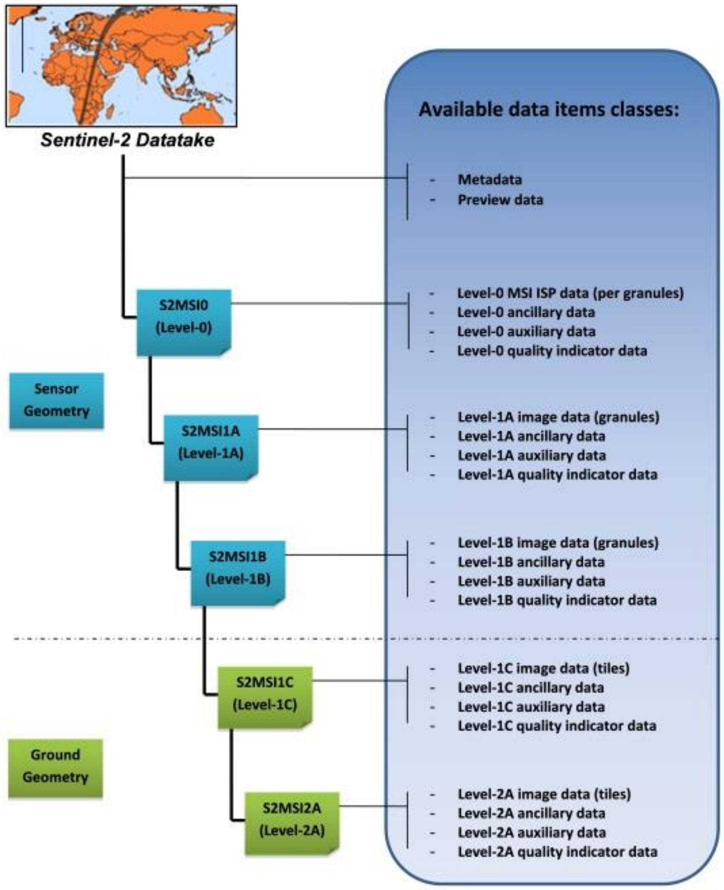

Figure 15: Product breakdown structure

4. Methodology

In order to see whether there are glacial feature differences between the two sentinel images and what the differences are different datasets needs to be loaded, pre-processed and used. First of all, the way of selecting data is clarified. Next the used software is treated. In section 4.3 the way of pre-processing data is explained followed by manual snowline determination in section 4.4. Finally the way of classifying the data in classes is explained.

4.1 Data selection

In order to begin the research data has to be selected and collected. First of all it is important to search what exactly is your area of interest and which lakes and mountains are important to have. Then the first dataset ASTERGDEM needed to be found. This can be retrieved from NASA EOSDIS (2017) . By making sure having the right selection of the area of interest the image data could be selected. The data used in this report is retrieved on November 18, 2016 with the character N30E094.

GLIMS data has been retrieved on May 13,2017 from NSIDC GLIMS (2017) and is easier to select because it is one big dataset with all the glaciers in it.

For HydroSHEDS data can be retrieved from http://hydrosheds.org/. It has to be filtered till you have the area of interest. There will be a lot of levels of the hydrobasin in your data. In this report the levels 9 till 12 are used to make see the hydraulic behaviour within a bigger basin.

Sentinel-2 data also needed to be acquired. This data could be downloaded freely from ESA(2017) . During the selection of this image data it is important to look at the ingestion data. This needed to be after 7 march 2016 because of the launch of Sentinel-2B satellite. Next to that the cloud coverage needs to be taken in account while selecting the data. The first selected dataset had an ingestion date of December 12, 2016. The cloud coverage is lower in comparison with the second selected dataset. The ingestion date is February 18, 2017 and this one has a cloud coverage of 52%. The datasets are roughly the same , but differ due to reflection and cloud coverage. These were the clearest datasets that were found because of the precipitation period in the summer, a lot of snow lays on the mountains which result in extra reflection and less detailed information.

4.2 Software selection

In order to work with the selected data a program is needed to run these datasets. The used program during this study is QGIS. QGIS stands for Quantum Geographic Information System. It is a free and open source program that supports analysis of geospatial data, visualization of it and the editing. This type of GIS provide users the ability of using different layers above each other. During this research the 2.14.8 version of QGIS is used.

4.3 Pre-processing of data

The obtained Sentinel-2 data was gathered in level-1C form. In order to be able to work with it, it needs to be converted to level-2A product. Level-1C contains Top Of Atmosphere reflectance (TOA) which need to be converted to Bottom Of Atmosphere (BOA) reflectance as can be seen in figure 16.

This is also called the atmospheric correction. It needs to be done by the user. The user can choose the wanted spatial resolution 10, 20 and 60 meter. This transformation is done by Sen2Cor. Sen2Cor processes Level 2A data and format it, while performing atmospheric-, terrain and cirrus correction of Top-Of- Atmosphere Level 1C input data. This needs to be downloaded and installed trough a python library, for example Anaconda. Sen2Cor can be found on (http://step.esa.int/main/third-party-plugins-2/sen2cor/ .

Then the Sentinel- 2 data can be converted from TOA to BOA. Because all the data has to be resampled to the given spatial resolution it takes a lot of time. This needed to be done two times in order to do the atmospheric correction for both Sentinel-2 datasets.

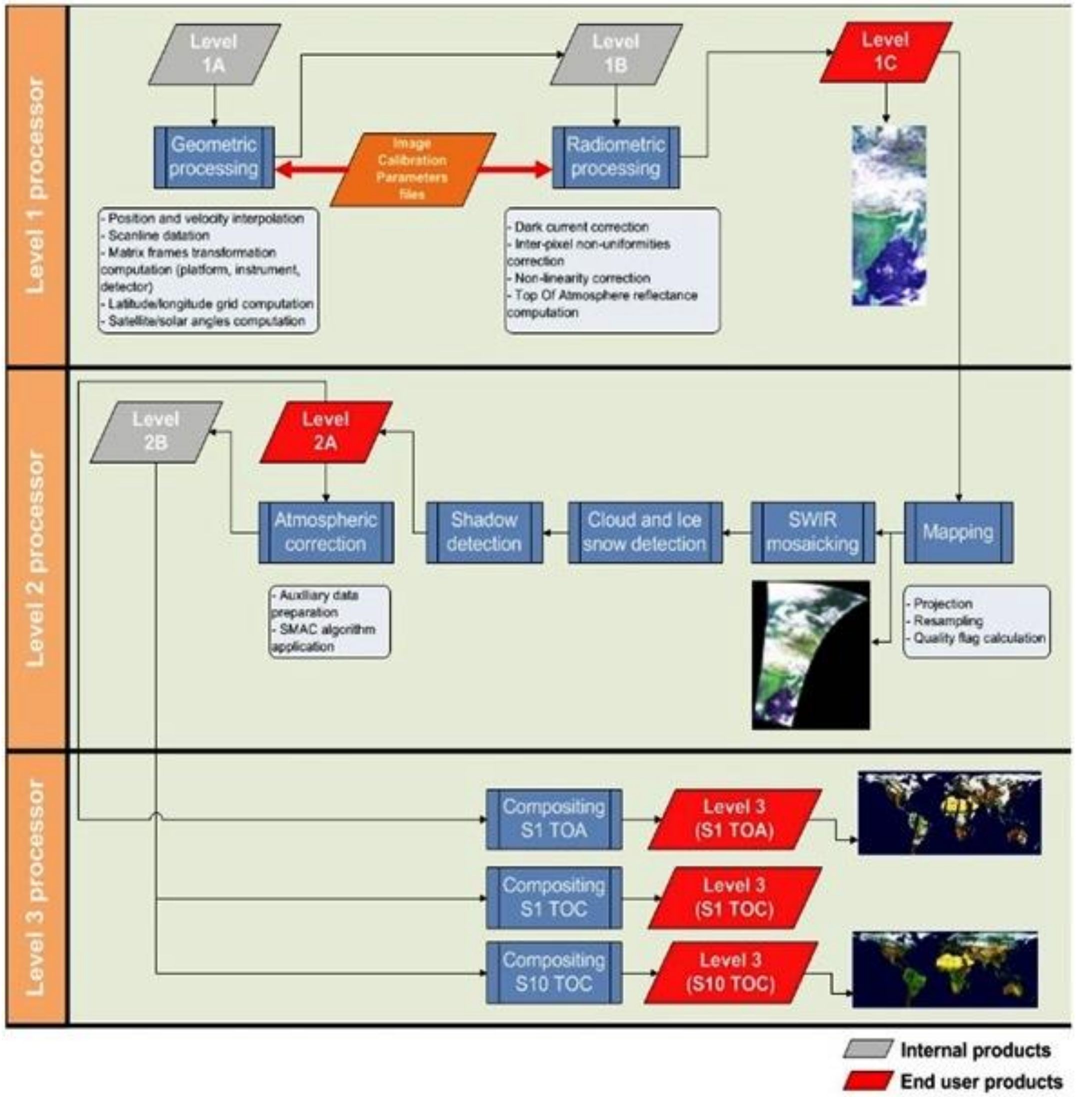

Figure 16: L2A Atmospheric correction, (ESA,2017)

4.4 Manual snowline determination

To have a first look at the glaciers and the snow precipitation in this area there have to be looked at the satellite images. By inspecting a clear dataset there can be looked at the colour differences between snow and ice so that the snowline could be found. It is an easy method, because no software or complicated calculations are needed. Next to the satellite images it is also useful to have a look at ASTERGDEM and the GLIMS mask to have an idea of the elevation and the glacier outlines.

4.5 Classification

First of all the different bands needs to be loaded in QGIS. The different bands will be selected in a particular order to receive a false colour image and a true colour image. Also the RGB will be made. Next to that the Semi-Automatic Classification Plugin (SCP) will be used. First the bands are loaded. Next a training data needs to be made. This is classified in macro classes and the detailed classes. It needs to be taken in account that the classes identity needs to be unique. Normally following numbers are used. Different detailed classes could belong to the same macro class. When making the training data, the classes are defined by the polygon.

Deciding which classification algorithm will be used is also important. Since the classification algorithm classifies the whole image, it compares the spectral characteristics of each pixel to the ones in the land cover classes. There are three different classification algorithms: Minimum distance, Maximum Likelihood and spectral distance. During this research it is chosen to use the maximum likelihood (Congedo,2017). This algorithm is based on the following formula:

$$g_k(x) = \ln p(C_k) - \frac{1}{2}\ln|\Sigma_k| - \frac{1}{2}(x - y_k)^t \Sigma_k^{-1}(x - y_k)$$

where:
Ck = land cover class k;
x = spectral signature vector of a image pixel;
p(Ck) = probability that the correct class is Ck;
|Σk| = determinant of the covariance matrix of the data in class Ck;
Σ−1k = inverse of the covariance matrix;
yk = spectral signature vector of class k.

Furthermore the Sentinel-2 data has 13 bands and different spectral intervals. In order to get the wanted images like a true colour and a false colour image it is needed to know which bands needs to be taken together. Making these combinations is easier while using figure 17.

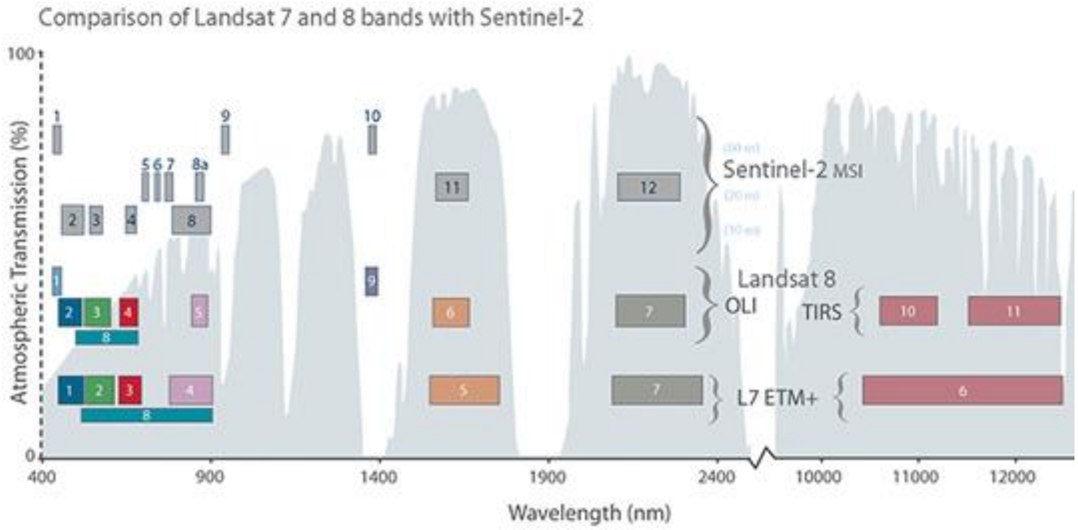

Figure 17: Comparison of Landsat 7 and 8 bands with Sentinel-2

5. Results & Discussion

In this chapter the given data is processed and the results will be provided. The different datasets are used and sometimes also combined in order to see differences or the have a clear image of the meaning of the data.

5.1 Sentinel-2 datasets

First of all it was needed to have a look at the are itself. Therefore the Sentinel-2 datasets are used with the following ingestion dates: dates 10/12/2016 and 18/02/2017. These had been processed and the atmospheric correction has been done. Next different band combinations has been used in order to highlight different features and to have an idea of the area content.

5.1.1 True colour images

In order to get the true colour images of the sentinel-2 data a band has to be found. In this case the 4,3,2 band combination is used. The results of the year 2016 are given in figure 18 and the ones of 2017 can be seen in figure 19. The mountain hills are dark. This could be because of the dense dark vegetation but it could also be the case that there is no vegetation at all on some parts of the mountain hill. There are also some black parts that can be seen in the figures. This is because of the shadow of some mountains which are reflected on other mountains. Next to that a little lake can be noticed in figure 18. Although it is not present anymore based on figure 19. Also a difference of colour can be noticed on top of the mountains. The white colour stands for snow, with some exceptions which can be clouds. And the beige colour could be the glaciers.

Figure 18: True colour image of 2016 , r10 , RGB (4,3,2)

Figure 19: True colour image of 2017 , r10 , RGB (4,3,2)

5.1.2 False colour images

Next to the true colour image also the false colour image needed to me made. This is done by using the following band combination: 11, 8A,4. This is also done two times in order to get the two separate images in figure 20 and 21. The false colour images are better while focusing on the snow and ice detection in the area. As can be seen a lot of red and blue parts are in the figures. The blue colour designates snow and ice. Although, with the colour contrast a slight difference can be made between snow and ice. The lake itself is coloured dark blue and all the other features are coloured red.

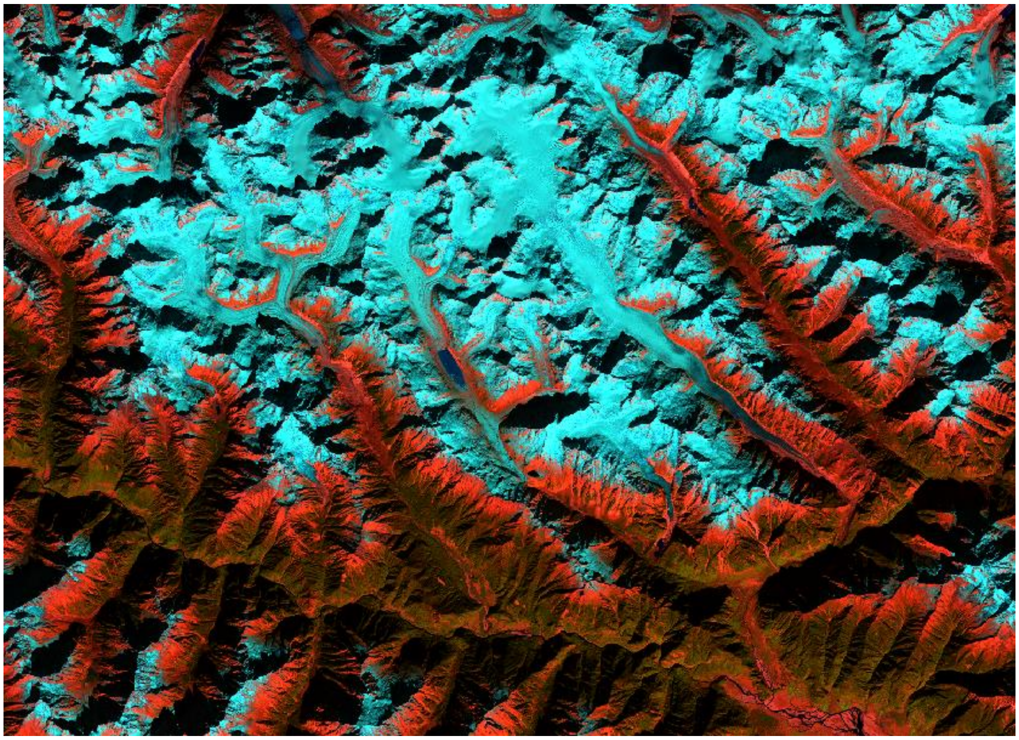

Figure 20: False colour image of 2016 (11,8A,4)

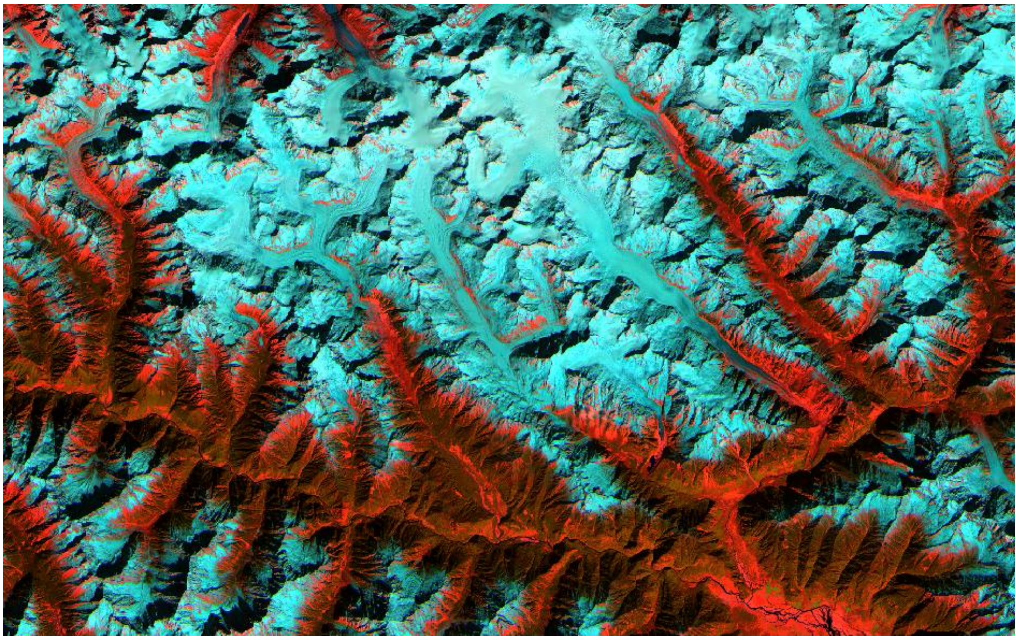

Figure 21: False colour image of 2017 (11,8A,4)

5.1.3 Other band combinations

After making a true and false colour. Another band combination is made. This time the 8,4,3 is made. This looks a lot like the true colour but with more contrast and it also includes the red colour from the false colour images. Like the false colour image the red colour stands for vegetated mountain hills and valleys. In the figures 22 and 23 these are illustrated. It is also remarkable that the different aspects stands more out in these images. It is also easier in this case to approximate the location of the snowlines. This is done in figure 24. Based on the white/ beige colour difference the snowlines are drown. It is just an example on how it is done on the true colour image of 2016.

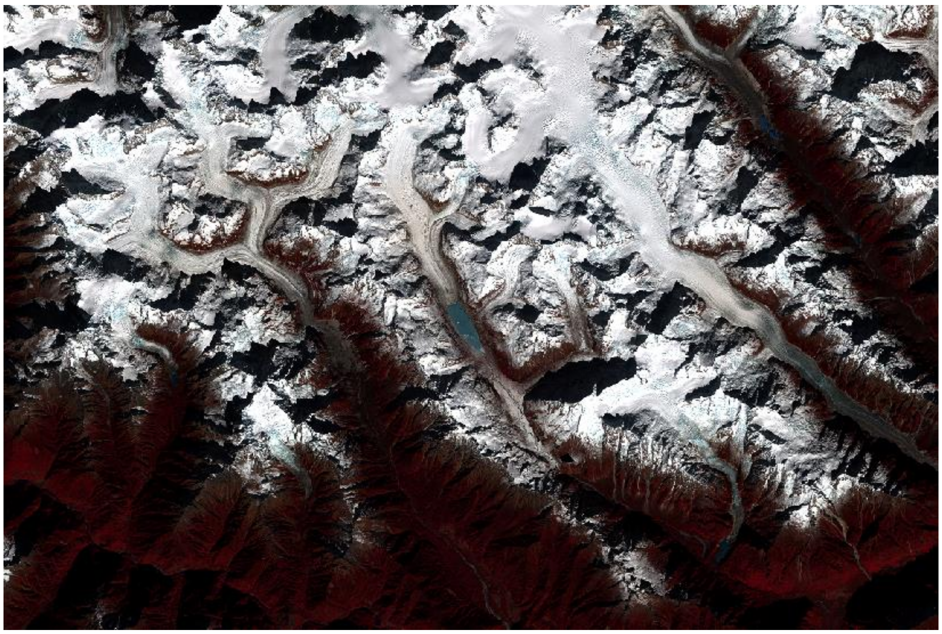

Figure 22: Modified colour image of 2016 with band combination (8,4,3)

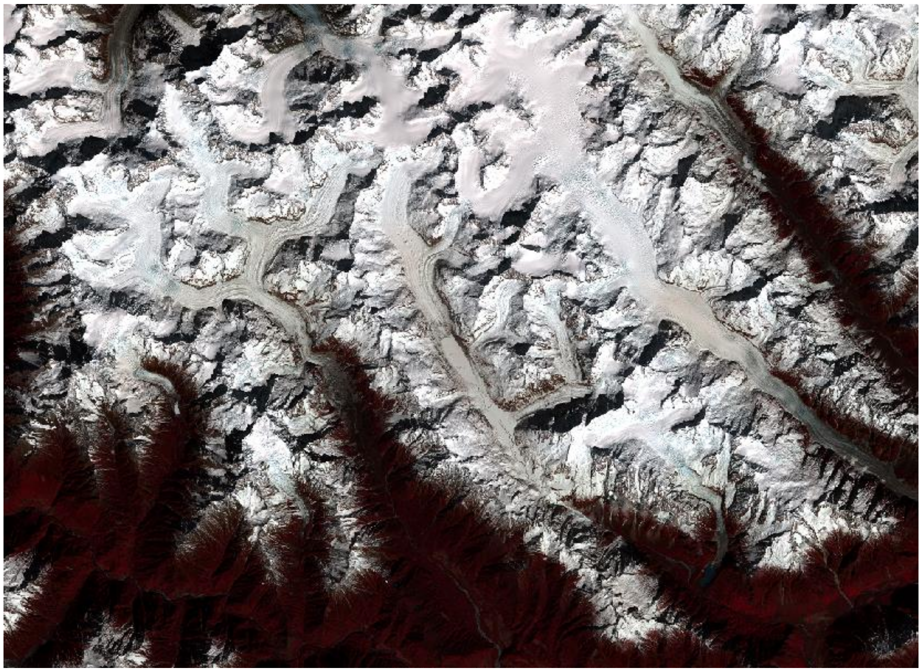

Figure 23: Modified colour image of 2017 with band combination (8,4,3)

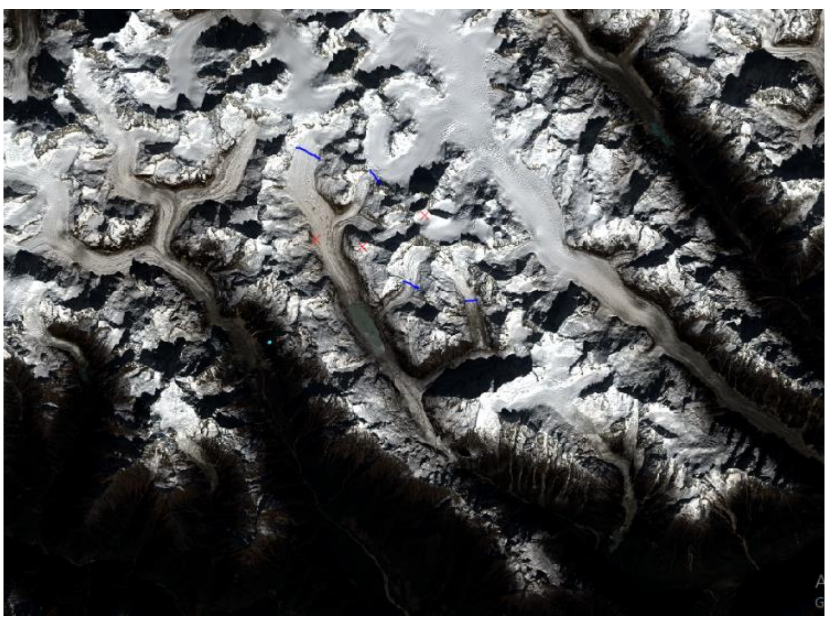

Figure 24: Manual snowline determination

5.2 Combinations of datasets

After processing and analysing the Sentinel-datasets it is important to use the different datasets. Also a combination of these datasets could help while discussing the results and determining the accuracy of the founded results. Therefore the GLIMS glacier mask is overlaying a true colour image of 2017 in figure 25 . The GLIMS glacier mask has a blue colour.

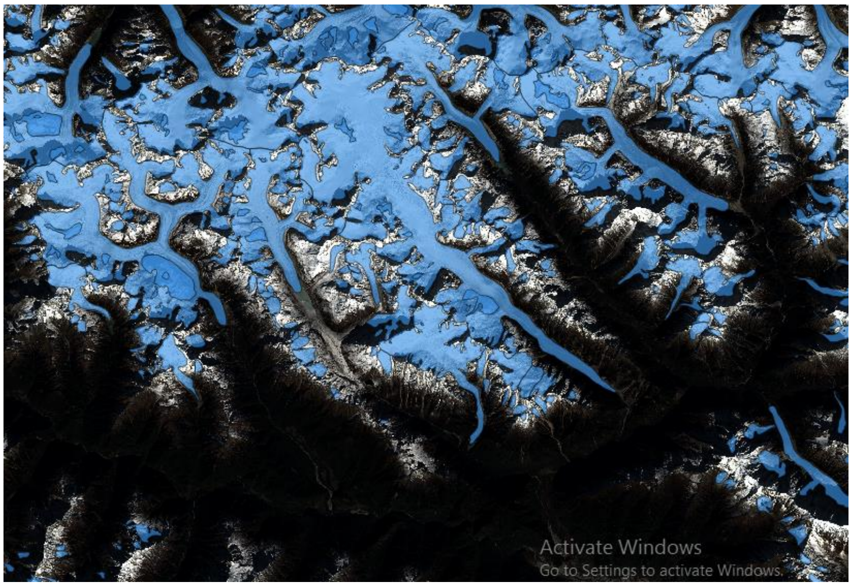

Figure 25: : GLIMS glacier mask over true colour image 2017

It is also very interesting to check whether the basin information from HydroSHEDS is in line with the ones distracted from GLIMS glacier mask. This combination is illustrated in figure 26. The blue colour stands for the glacier mask, while the light purple one points the HydroSHEDS basin out. The black outlines are a combination of the ones from GLIMS and the ones from HydroSHEDS. In this case level 12 of HydroSHEDS is used.

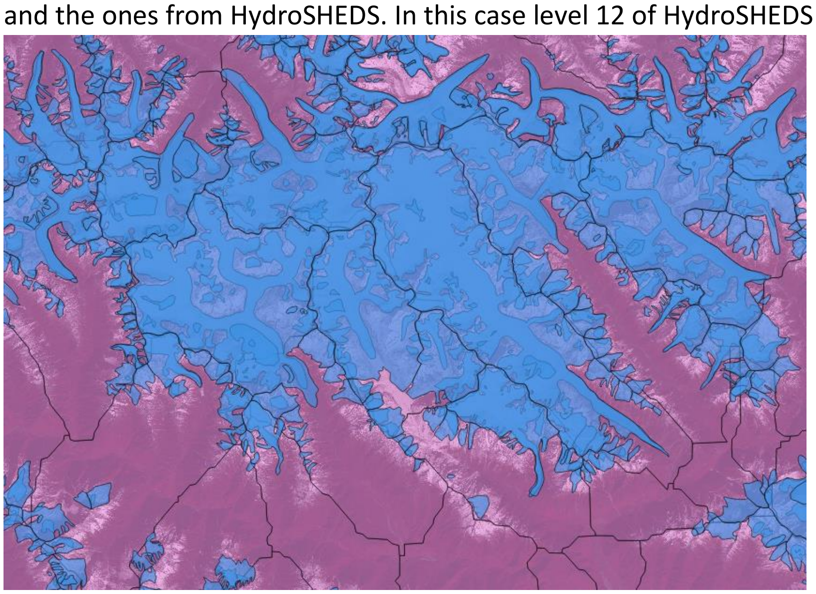

Figure 26: HydroSHEDS level 12, GLIMS and a true color image of 2017

After using the GLIMS glacier mask and HydroSHEDS the ASTER GDEM data is loaded into Qgis. This elevation data is combined with the glacier mask to get an idea about the relation between the height and the forming glaciers with their outlines. As can be seen in figure 27, the highest parts of this area are covered with snow and glaciers. The glaciers sometimes also go downwards in the direction of the valley.

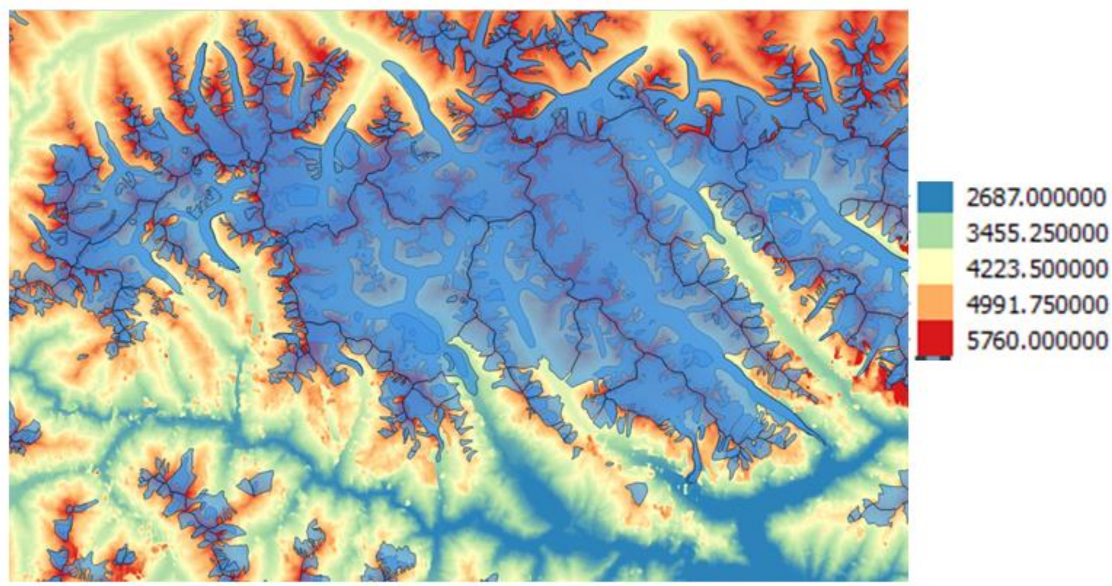

Figure 27: ASTER GDEM data in combination with GLIMS with legend in meters

5.3 Classification of Sentinel-2

After making different images with variating band combinations and comparing the different datasets it is important to make a classification based on the twelve Sentinel-2 data bands. Different major and specific classes are chosen in order to make a as good as possible classification. The chosen training data can be seen in figure 28 and 31. The black squares are the used training data for the different classes. Some cannot be seen in the figure because they are too small. The ROI signature list of the 2016 dataset and 2017 datasets are illustrated in figure 29 and 32. And the actual classifications can be seen in figure 30 and 33 .

Figure 28: Training data for classification of 2016

	S	Type	MC ID	: ID	C Info	Color
1	✖	B	1	1	Mountain	
2	✖	B	1	2	Mountain	
3	✖	B	2	3	Lake	
4	✖	B	2	4	Lake	
5	✖	B	2	7	Snow	
6	✖	B	2	8	Snow	
7	✖	B	2	9	Glacier	
8	✖	B	2	11	Glacier	
9	✖	B	0	12	Shadow	
10	✖	B	0	13	Shadow	

Figure 29: Classification legenda 2016

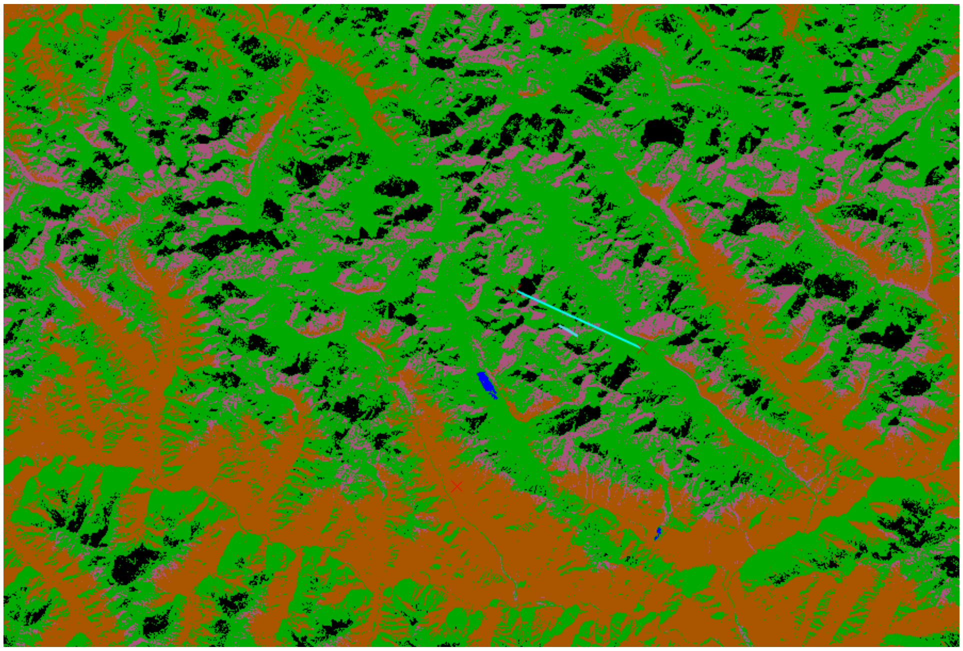

Figure 30: Classification of 12 bands Sentinel-2 Data , 2016

Figure 31: Training data for classification of 2017

B	1	1	Snow	
B	1	3	Snow	
B	1	2	Snow	
B	1	4	ice	
B	1	5	ice	
B	1	7	lake	
B	2	8	Shadow	
B	2	9	Shadow	
B	1	13	Ice	
B	2	14	lake sedimentation	
B	2	15	lake sedimentation	
B	4	16	uncovered side	

Figure 32: Classification legenda 2017

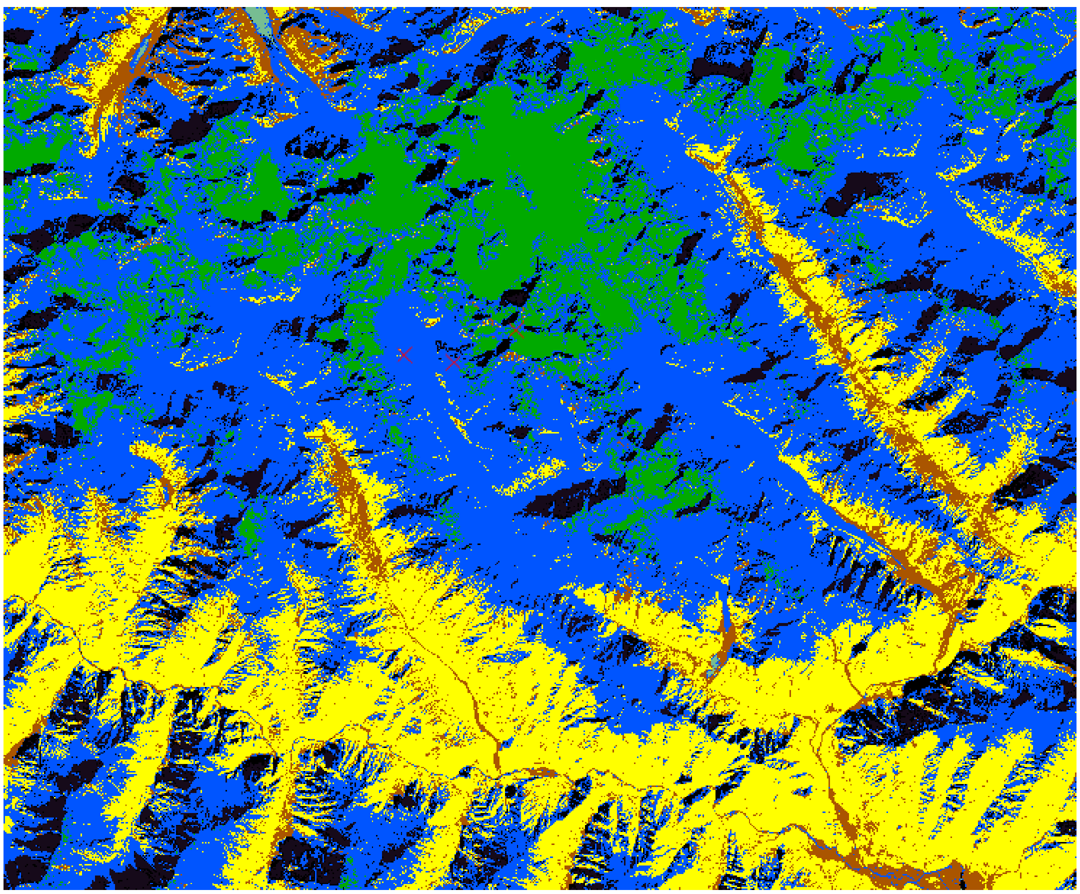

Figure 33: Classification of 12 bands Sentinel-2 Data , 2017

5.4 Difference maps

After making all those images and defining the differences by eye, it is also good to make difference map of the data. First of all a difference map was made for the true colour images. This is illustrated in figure 34. The red dots are the place where the most differences are based on the 4,3,2 bands. Also the difference map of all the 12 bands of Sentinel-2 data is made. This can be seen in figure 35. The same legend is used for both figure 34 and 35.

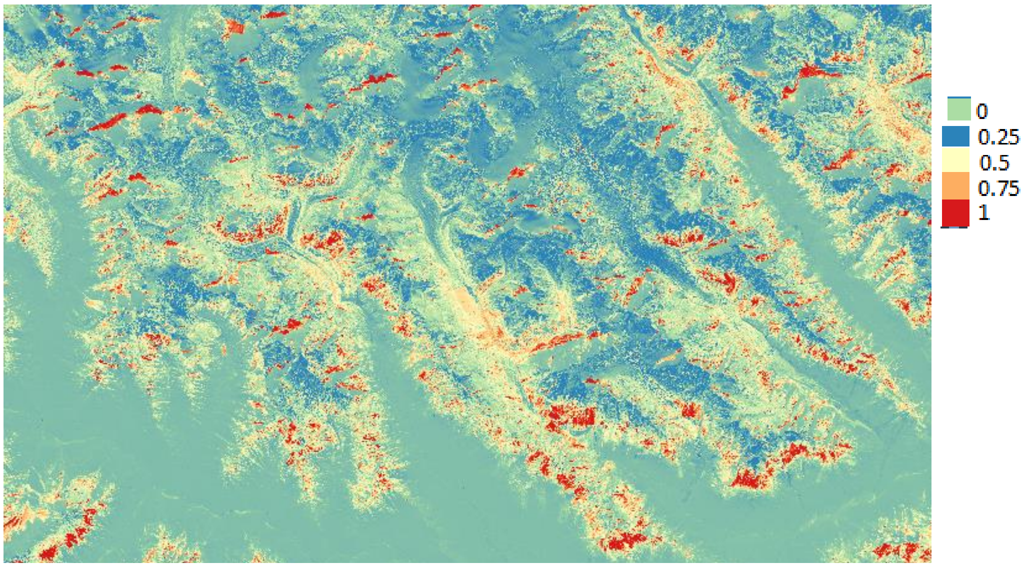

Figure 34: Difference map of true colour images 2016 and 2017

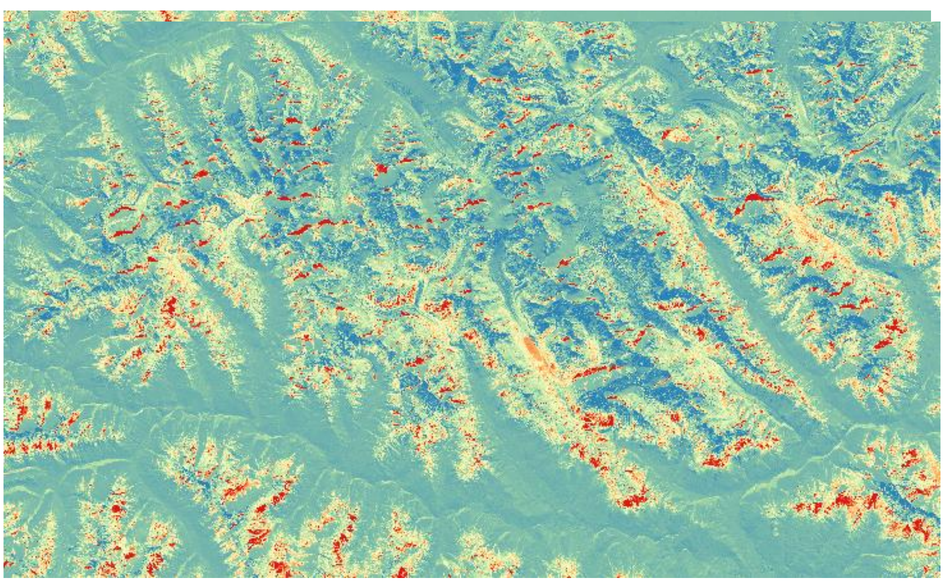

Figure 35: Difference map 12 bands of 2016 and 2017

6. Conclusions and Recommendations

The goal of this chapter is to discuss the collected data in order to get to answer the sub questions which will finally lead to an answer on the research question. Also recommendations are made.

First of all the elevation data was loaded. This gives an insight on the topography of the area. The heights vary between 2700 and 5800 meter. Next to that the HydroSHEDS data was loaded. Level 12 was used in order to get a detailed zoomed in outlines of the basins. It can be seen that different mountain ridges are grouped in one basin. While including the GLIMS glacier mask the glaciers got a blue colour. Also those basin outlines where marked black like the ones from HydroSHEDS. There were slightly some differences but that could be a result of the coordinate reference system or due to accuracy faults.

Next tot that the Sentinel-2 images were loaded. By looking at the produced images of 2016 and 2017 it can be seen that there are a few major changes between the two images. The place of these changes are designated with the orange arrow in figure 35.

Figure 36: Bands 8,4,3 , dataset 2016, with major changes (orange arrows)

These changes are also illustrated in the difference maps. The red and orange marked differences are the ones that count mostly. It can also be seen that the dataset of 2017 contains more "whiteness". This could be clouds or extra precipitation of snow. The lake cannot be seen in the dataset of 2017 and that could be due to low winter temperatures, where the water freezes and become ice. Also the glaciers became bigger in certain areas. But also the snowline went downhill. So it could be said that there was some snow precipitation. This could be a result of coming closer to the end of the winter or due to a monsoon. This can also be concluded from the false colour images.

Also two classification maps are made. The colours for the same classes differ but the legend shows the meaning of the colours. It can be seen that the classification map of 2017 is more detailed than the one for 2016. This is due to a difference in training data. The training data of 2017 is more extended. But both training data are build up from small intervals. This is done in order to minimize the overlapping spectral reflectance of different classes. The shadow parts could not be classified into real data, so that is left as shadow.

It can be said that there are visible changes between 12 December 2016 and 18 February 2017 within the same area. These are found by using Sentinel-2 data and combining the different bands. These can be a result of a strung winter with a monsoon which causes extra precipitation. Nevertheless not all "white areas" are snow. Some of them could also be clouds. In combination with the GLIMS glacier map the glacier outlines could be seen. Also due to shadows some sides of the mountain ranges could not be classified.

What could be recommended for further investigation is making a difference map of the classification. This compared to the difference map of twelve bands of sentinel-2 could result in an estimation of the classification accuracy. It would also be very helpful to try in further researches to program a software that would constantly compare sentinel-2 data with each other and detects the differences. Difference above a certain level could give an alarm. Like when glaciers are melting, the change of floods are higher. Finding this changes in an early stadium will help preventing major disasters.

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