PERMAFROST AREA MONITORING USING POLSAR DATA

GNR 618

Final Project Report

Guided By:

Prof. Gulab Singh

Submitted By:

Group - 8

Karan Chittora (180040050)

Ritvik Sharma (180040083)

Sahil Singh (180040087)

Sumit Suresh Shere (180040108)

INDIAN INSTITUTE OF TECHNOLOGY – BOMBAY

POWAI, MUMBAI – 400 076.

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1. INTRODUCTION

Permafrost is any type of ground—from soil to sediment to rock—that has been frozen continuously for a minimum of two years and as many as hundreds of thousands of years. When the earth remains frozen for at least two consecutive years, it's called permafrost. It can extend down beneath the earth's surface from a few feet to more than a mile—covering entire regions, such as the Arctic tundra, or a single, isolated spot, such as a mountaintop of alpine permafrost. Just as a puddle of water freezes on a frigid winter night, water that is trapped in sediment, soil, and the cracks, crevices, and pores of rocks turns to ice when ground temperatures drop below 32°F (0°C). If the ground freezes and thaws every year, it's considered "seasonally frozen."

1.1 PolSARPro and SNAP

The PolSARPro (Polarimetric SAR Data Processing and Education Toolbox) supports the scientific exploitation of polarimetric SAR data and is a tool for high-level education in radar polarimetry. The tool is a standalone application that performs end-to-end processing without needing other software. PolSARPro is specialized in the analysis of fully-polarimetric data (HH, HV, VH, VV). Not many sensors offer this, but it allows the extraction of scattering mechanisms and many other advanced methods.

SNAP, in turn, is more the allrounder like we can load almost any SAR data, pre-process it, calibrate it, filter it, terrain correct it, and so on.

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1.2 Unsupervised Classification - K-means Clustering

Unsupervised classification is a good way to identify and aggregate pixels with similar features. Unsupervised classification does not rely on user-specified input or predefined classes to be matched. Instead, it automatically determines what classes exist in the data and how best each pixel can be grouped.

Clustering is a type of unsupervised machine learning which aims to find homogeneous subgroups such that objects in the same group (clusters) are more similar to each other than the others.

K-Means is a clustering algorithm that divides observations into k clusters. Since we can dictate the number of clusters, it can be easily used in a classification where we divide data into clusters that can be equal to or more than the number of classes.

1.3 Supervised Classification - Maximum Likelihood Classifier

Supervised image classification is a procedure for identifying spectrally similar areas on an image by identifying 'training' sites of known targets and then extrapolating those spectral signatures to other areas of unknown targets. It requires training data that are typical and homogeneous and the application of a set of methods, or decision rules.

It is based on the idea that a user can select sample pixels in an image that are representative of specific classes and then direct the image processing software to use these training sites as references for the classification of all other pixels in the image.

The algorithm used by the Maximum Likelihood Classification tool is based on two principles:

1. The cells in each class sample in the multidimensional space being normally distributed.
2. Bayes' theorem of decision making

Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Unless you select a probability threshold, all pixels are classified.

2. METHODOLOGY

2.1 Radiometric Calibration

To properly work with the SAR data, the data should first be calibrated. Calibration radiometrically corrects a SAR image so that the pixel values truly represent the radar backscatter of the reflecting surface. It is therefore essential for quantitative use of SAR data.

The image processing, which may be incorporated into signal processing, is the processing stage that converts the complex image data into a geocoded target backscatter or Stoke's matrix map. This process requires the compilation of all the ancillary data into a model of the radar system to relate the image pixel data number to the backscattered power.

For radiometric calibration, the effects of these processes are combined into two gain terms, Ks and Kn, which are incorporated into the mathematical representation of the complex SAR image.

2.2 Polarimetric Processing

Whenever electromagnetic radiation is reflected from a surface, it becomes polarised to a degree, dependent upon the surface structure, texture, and angle of incidence. If the polarisation information from the reflected radiation is extracted from conventional intensity information by an imaging polarimeter it is possible to reveal a detail about the surface that cannot be obtained by any other imaging technique. Hence, polarimetric images provide the means of observing objects and phenomena that are invisible to conventional imaging systems.

In order to properly exploit the information within polarimetric data, we will need processing tools that convert that data into more useable forms for analysis.

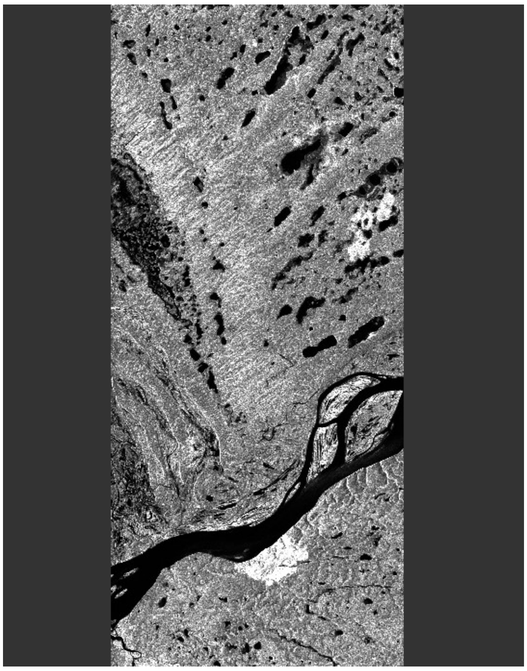
2.3 Polarimetric Matrix Generation

A radar wave of a specific polarization, when interacts with the target surface, experiences change in its polarization state. The wave reradiated from the target surface after this interaction will have response not only in horizontal polarization but also in vertical polarization as well. In terms of SAR polarimetry, these responses from the backscattered wave in each polarization channel are stored in the form of $2 * 2$ scattering matrix given by

$$[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}$$

where each element of the matrix represents the backscatter response of the target in a particular polarization channel. The diagonal elements of the matrix represent the co-pol information, i.e., the transmitted and received radar wave have same polarization, and the off-diagonal terms represents the cross-pol information, i.e., the transmitted and received radar wave have polarization orthogonal to each other. The scattering matrix describes the information of the pure target exhibiting a particular scattering mechanism.

(i)

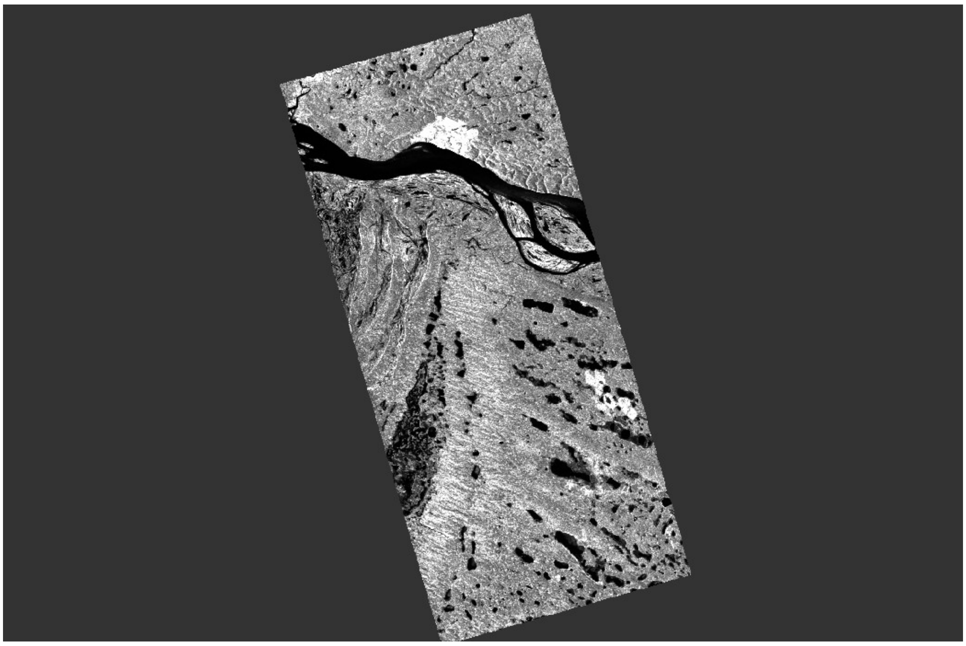


(ii)

T11 Band of the SAR Image after Calibration and Matrix generation
(i) before Multi-looking and (ii) after Multi-looking

2.4 Terrain Correction

Terrain Correction geocodes the image by correcting SAR geometric distortions using a digital elevation model (DEM) and producing a map projected product. Geocoding converts an image from slant range or ground range geometry into a map coordinate system. Terrain geocoding involves using a DEM to correct for inherent geometric distortions, such as foreshortening, layover and shadow.



T11 Band after Terrain Correction

2.5 Polarimetric Decomposition

Polarimetric decompositions allow the separation of different scattering contributions and can be used to extract information about the scattering process. The objective of the decompositions is to express the measured scattering matrix by the radar, i.e. [S], as the combination of the scattering responses of simpler objects

$$[S] = \sum_{i=1}^{k} C_i [S]_i$$

the symbol $[S]_i$ stands for the response of every one the simpler objects, also known as canonical objects, whereas C_i indicates the weight of $[S]_i$ in the combination leading to the measured $[S]$. The three-component scattering model by Freeman and Durden, based on the reflection symmetry, is a helpful tool for the interpretation of the scatterer. However, for PolSAR images including urban areas, the reflection symmetry condition does not hold. Thus, the well-established four-component Yamaguchi model is used.

Image after Yamaguchi Decomposition   Image after Singh i6SD Decomposition

2.6 K-means Cluster Analysis

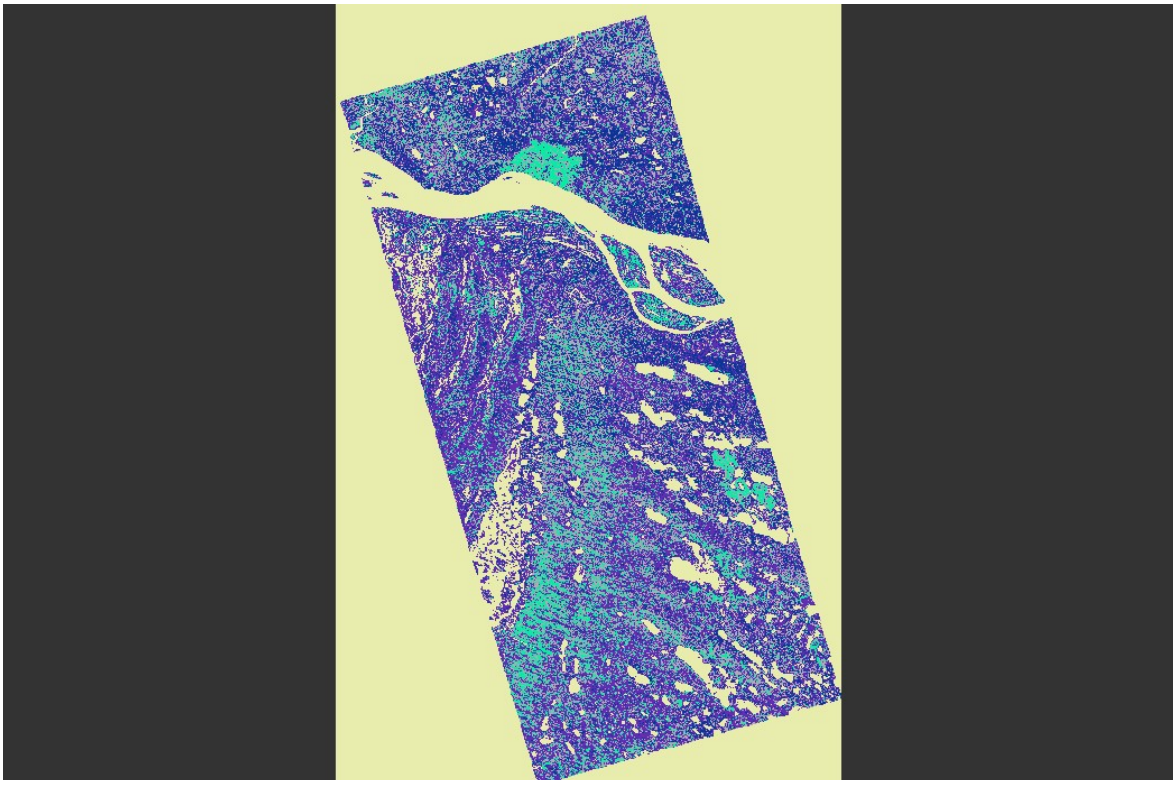
The objective of K-means is to group similar data points together and discover underlying patterns. To achieve this objective, K-means looks for a fixed number (k) of clusters in a dataset.

The K-means algorithm in data mining starts with a first group of randomly selected centroids, which are used as the beginning points for every cluster, and then performs iterative (repetitive) calculations to optimize the positions of the centroids. It halts creating and optimizing clusters when either:

- The centroids have stabilized — there is no change in their values because the clustering has been successful.
- The defined number of iterations has been achieved.

The classifier undertakes various iterations with random cluster centers of the multi-dimensional feature space to find pixels of similar properties.

The output is a product with a single band, where each pixel is assigned to one of the classes (clusters). These clusters do not necessarily represent semantic classes of landcover, but they are homogenous regarding their backscatter characteristics



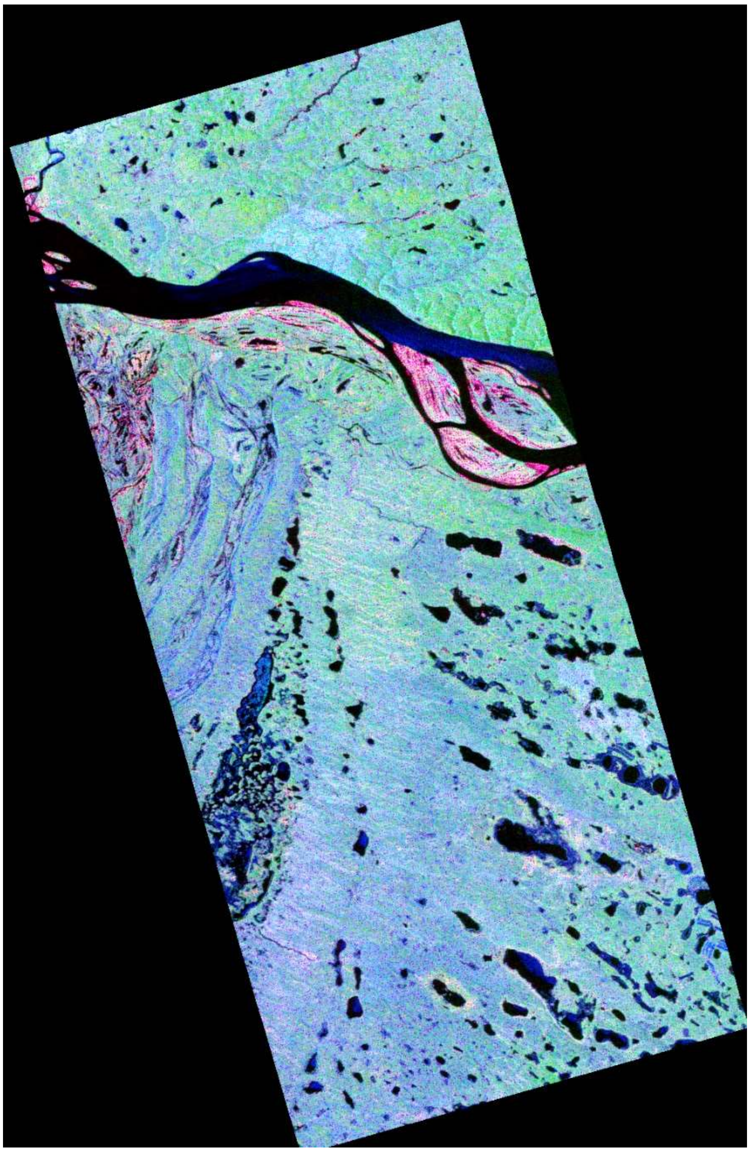
T33 class-indices Image after k-means clustering

2.7 Maximum Likelihood Classification

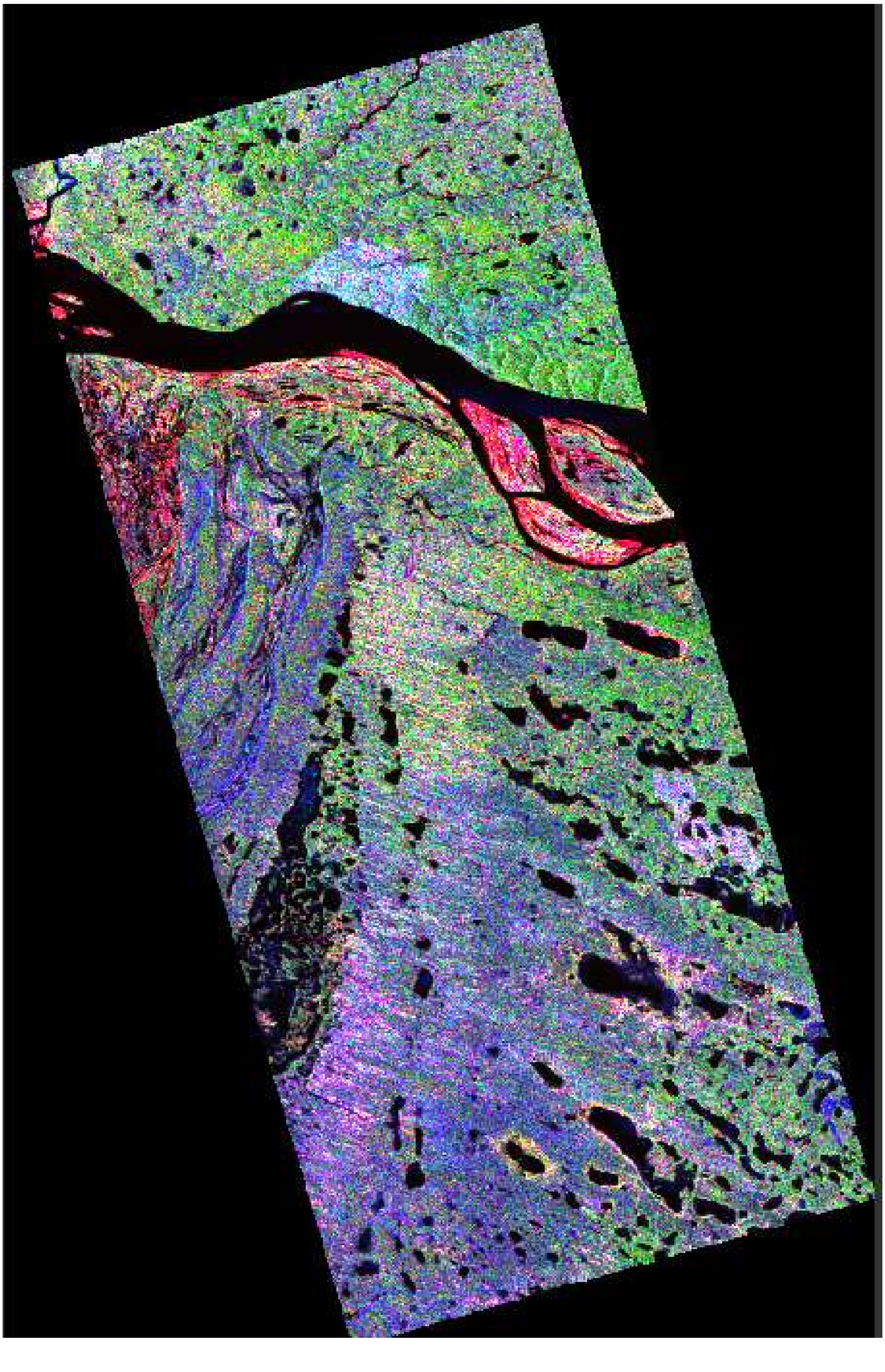
Maximum Likelihood is a supervised classification method derived from the Bayes theorem. Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Unless you select a probability threshold, all pixels are classified. Each pixel is assigned to the class that has the highest probability (that is, the maximum likelihood). If the highest probability is smaller than a threshold you specify, the pixel remains unclassified.

3. RESULTS

The image obtained after the Range-Doppler Terrain Correction needed to be decomposed before classification. We performed Yamaguchi Decomposition in SNAP, but for better output Singh i6SD decomposition was performed in the PolSARPro software. The output obtained after creating a RGB image with Blue, Green and Red input as Odd, Vol and Dbl layers respectively of i6SD decomposed image is shown:



The final image obtained from the T33 Matrix with clear differentiation of various features is shown below:



4. DISCUSSION

The SAR data provided consisted of four polarizations – HH, HV, VH, VV. The data was processed first to make it ready for analysis. The processing was done using SNAP software to make the image easier to analyze using operations like Multi-looking, Terrain Correction, decomposition, etc. Then in the final image obtained, we can clearly classify various landscape features of the Permafrost. There is a large water body passing in the middle. The area above that is surrounded by shrubs, vegetation, ponds, wet snow, etc. in small regions. The reddish colored layer comprises of the land surface or rocks. Below the large water body, the major part is snow covered area along with vegetation and small water bodies like lakes, ponds etc. Both the unsupervised classification and the supervised classification is performed to distinguish the features.

5. CONCLUSION

For this project, we have studied Permafrost using software SNAP and PolSARPro

Permafrost is a permanently frozen layer on or under Earth's surface. It consists of soil, gravel, and sand, usually bound together by ice. Permafrost usually remains at or below 0°C (32ºF) for at least two years. Permafrost can be found on land and below the ocean floor. It is found in areas where temperatures rarely rise above freezing. Permafrost thickness can range from one meter (about three feet) to more than 1,000 meters (about 3,281 feet). Permafrost covers approximately 22.8 million square kilometers (about 8.8 million square miles) in Earth's Northern Hemisphere. Frozen ground is not always the same as permafrost.

The Sentinel Application Platform (SNAP) basic function includes: opening a product, exploring the product components such as bands, masks, and tie point grids. Navigation tools and pixel information functionality also represent some of the basic capabilities.

The PolSARpro software is controlled through a user-friendly, intuitive graphical interface, which enables the user to select a function, set its parameters, and then run it. PolSARPro data processing routines are written in C (> 1000 routines) and the GUI is written in Tcl-Tk.

Experimental results on real PolSAR datasets demonstrate the proposed methods are significantly effective. The Clustering classification model could achieve impressive classification performance compared to the comparison algorithm. The results might be further improved by researching the deep networking order to extract more valid PolSAR classification features.

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