CASE - STUDY

Classification of Glacier Radar Zone and Glacier Velocity Mapping in Pine Islands Using Google Earth Engine and ITS_LIVE

INDIAN INSTITUTE OF REMOTE SENSING

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INTRODUCTION:

Background

The cryosphere is the portion of the Earth where water is in its solid form, either seasonally or annually. The term comes from the fusion of the Greek words cryos (meaning cold, icy) and sphaira (ball, globe). According to (Barry et al., 2011), the term was first introduced in 1923 by Antoni Boleslaw Dobrowolski, a Polish scientist, geophysicist and meteorologist. The components of the cryosphere are snow cover, glaciers, ice sheets and ice shelves, freshwater ice, sea ice, icebergs, permafrost and ground ice. The cryosphere exerts an important influence on Earth's climate, owing to its high surface reflectivity (albedo). This property gives it the ability to reflect a large fraction of solar radiation back into space, and influences how much solar energy is absorbed by land and oceans. Ice on land, in the form of ice sheets and glaciers, plays a further important role in the Earth system through its ability to store vast amounts of water away from the oceans for long periods of time. Any change in the ice volume stored on land, as ice sheets and glaciers grow or shrink, has a direct impact on global mean sea level (Hegerl et al., 2007). The Antarctic has seen less uniform temperature changes over the past 30-50 years, with warming over parts of West Antarctica and no significant overall change over East Antarctica (Jones et al., 1955; Nicolas & Bromwich, 2014). Pine Island Glacier is one of the largest ice streams in Antarctica. It flows, together with Thwaites Ice Stream, into the Amundsen Sea embayment in Antarctica. Improved knowledge of the region's geological structure is important because it provides the template over which the West Antarctic Ice Sheet (WAIS) has waxed and waned over multiple glaciations(Naish et al., 2009; Pollard & DeConto, 2009). These glaciations contribute to the sea level rise and WAIS has a higher contribution compared to Eastern Antarctica and Peninsular Antarctica. In Western Antarctica, particularly the Thwaites and Pine Island glaciers are particularly vulnerable to global warming and are already contributing to rises in sea level. Speedup of Pine Island Glacier over the past several decades has made it Antarctica's largest contributor to sea-level rise.This study aims to explore Sentinel – 1 C Band SAR of glacier facies delineation also known as Radar Glacier Zones for 2015, and explore ITS_LIVE a NASA Programme to track Glacier velocity.

OBJECTIVE

This study is to map the pine glacier's seasonal and yearly

Research Objective:

- To classify different zones of glacier using SAR backscatter seasonal analysis.
- To do a temporal study of glaciers velocity.

Sub objectives:

- Map Radar Glacier Zones (RGZ), using random forest classifier.
- To plot do an inferential study of pine glacier's velocity.

Research Question:

- How useful is Synthetic Aperture Radar in identifying and mapping glacier facies?
- What is the accuracy of Random Forest classifier?
- How has the glacier velocity changed over the year?

LITERATURE SURVEY

Glacier

Glaciers are formed when the accumulation is more than the ablation, in summers the snow will undergo metamorphosis and change into ice which deforms and moves downward under its own weight. This ice mass continues to flow downhill until it reaches a point in the lower altitude where the entire ice supplied from higher altitude melts (Roberto et al., 2008). Pine Island is a special type of glacier called an ice stream. Ice streams are corridors of fast ice flow (ca. 0.8 km/year) within an ice sheet and are responsible for discharging the majority of the ice and sediment within them.(Bennett, 2003).

Pine island glacier

Pine Island Glacier drains much of the marine-based West Antarctic Ice Sheet, and it has a configuration susceptible to rapid disintegration and recession. The ice sheet in this area is grounded up to 2000 m below sea level, making it intrinsically unstable and susceptible to rapid melting at its base, and to rapid migration of the grounding line up the ice stream (Mercer, 1978)

Types of snow pack

Snow is a major contribution to the water balance, climate, and economy of many geographic regions (Kinar & Pomeroy, 2015)

- Snow- It is precipitation in the form of crystals formed by the freezing of water vapours and has low density of about 50-70kg/m3
- Firn – It is the intermediate stage of wetted snow that has survived the entire summer without being transformed into ice, it is found in the region where very less melting takes place. Being the intermediate stage it is denser than snow with density of about 400-830 kg/m3.
- Ice – When the interconnecting air passages in firn are sealed off it becomes highly dense about 830- 917 kg/m3, air is present in the form bubbles and density increases with further compression of the air bubbles

Radar backscatter of different snow pack. The snow covers of glacier i.e. snow pack is not homogeneous it changes with varying altitude. As we move down slope there is rise in temperature which leads to increase in the liquid water content. This changes the dielectric constant of the prevalent snow pack conditions. The electrical properties of the material i.e. the moisture content, surface roughness and volume in homogeneities of the scatters, also the wavelength polarization and incidence angle at the transmitting end affect the radar backscatter signals (Hall et al., 1987). The spectral behaviour of back scattering is used to differentiate the different type of scatters (Rott & Mätzler, 1987). Snow is transparent to microwave radiations; C- band can penetrate up to tens of m in dry snow. Penetration is highly dependent on the liquid water content of the snow pack and the wavelength of the SAR signals, more penetration is noticed for L-band due to higher wavelength. In dry snow scattering will occur mostly at the internal layers due to volume in homogeneities and less at the surface(Rott & Mätzler, 1987). In case of wet snow and glacial ice scattering will take place at the surface as black body properties are approached when surface is wet i.e. high emission and low backscattering. But glacial ice comparatively rough as compared to wet snow giving higher scattering returns in comparison to specular reflection for wet snow facies. Also microwave penetration increases during night due to refreezing of the snow pack. Even if damp snow is under refrozen fresh or dry snow the backscatter values will show very less difference as the backscatter comes from damp snow because of penetration (Thakur, Garg, Nikam, Singh, Chouksey, et al., 2018).The intensity of backscatter increases in lower areas of firn having a similar backscatter to rough glacial ice it is due to the increase in surface roughness of snow at lower altitudes(Rott & Mätzler, 1987). Accurate modelling of the scattering behavior is difficult as surface roughness is comparable to the magnitude of the wavelength there is increase in the amount of scattering with the decrease in the wavelength (Rott & Mätzler, 1987).

Different Zones of the Glacier and their Scattering Mechanism

Glacier facies are distinct zones on the surface of glacier and form accumulation and ablation areas.

- Dry Snow Zone - This zone is found at the top elevation in the glaciers where the mean annual temperature is about -25°C, because of the low temperature no melting takes place even in summers. Dry snow is the mixture of air and snow and compacted under its own weight. In this zone volume scattering is dominant and any variation in the backscatter values is due to the difference in the snow grain size. This zone is found only in the glaciers in Antarctica, Greenland, some glaciers in Alaska and Svalbard at high elevations. The boundary between this zone and next is called dry snow line (Thakur, Garg, Nikam, Singh, Jasmine, et al., 2018).
- Percolation Zone - Surface melting occurs in this zone and water percolates a certain distance into snow where it refreezes leading to the formation of ice lenses and pipe like structures called ice glands. The freezing of melt water releases latent heat of condensation causing further warming of snow. A high value of backscatter in winter months is due to these ice lenses, there is a drop in backscatter values in the melt season as the surface becomes wet. As we move down the glacier we reach a point where all the snow deposited from the end of previous summer has melted this point is called wet snow line
- Wet Snow Zone -Further down the percolation zone entire accumulation of snow has melted and then refreeze leading to a larger crystal size i.e. transformation of snow to ice. The scattering mechanism changes from volume scattering in percolation zone to surface scattering in wet snow zone and there is a striking difference in the backscatter values. This zone has low backscatter values in spring and summer due to melt conditions. The lower part of wet snow consists of slush, where melting is rigorous and appear as damp areas in the SAR images (Thakur, Garg, Nikam, Singh, Jasmine, et al., 2018).
- Superimposed Ice Zone -At lower elevations, huge amount of melt water is produced so that the ice layers merge into a continuous mass this is called superimposed ice. These zones are also found in the wet snow zone buried beneath the firn. The boundary

between wet snow zone and superimposed ice is called snow line or firn line and is determined at the end of the ablation season. Superimposed ice zones are very difficult distinguish from bare ice zones as both are made up of ice but there is a higher degree of smoothness in superimposed ice zone relative to bare ice this can be used as a discriminating factor between the two facies. The lower boundary of the superimposed ice is taken as equilibrium line, and is important in mass balance studies (Chouksey et al., 2021)

- Ablation Area - Lowest part of glacier consists of bare ice; here the total accumulation is lost to melting. In winter season these ice facies are covered with dry snow, less backscatter is observed due to attenuation by dry snow. As snow melts backscatter decrease due to the presence of melt water content. At the end of ablation season when all the seasonal snow has melted higher backscatter returns are observed from the rough bare ice surfaces (Thakur, Garg, Nikam, Singh, Jasmine, et al., 2018)

RGB Seasonal Composite

Polarizations play an important role in SAR remote sensing, cross-polarization (VH or HV) gives information based largely on volume scattering, whereas co-polarized signals (HH or VV) are large contributions from surface scattering (Langley et al., 2008) .Later, investigators used RGB composite of different season SAR data to identify the glacier facies. As there may be a slight difference in their boundaries from field-based analysis, they were commonly called glacier radar zones. Generally, the SAR data of early summer, late summer, and winter are used for generating the composite. The liquid content of snow/ice varies with the season and changes the backscattering; therefore, the SAR composite pixels would show varying tones. Based on these tonal variations, one can easily identify the glacier radar zones. Following radar zones are generally identified based on the backscattering characteristics and tone: Dry snow, percolation refreeze, lower percolation or wet snow, Superimposed Ice, and Clean Ice zones (Arigony-Neto et al., 2007).

Machine learning Classification.

A random forest (RF) classifier is an ensemble classifier that produces multiple decision trees, using a randomly selected subset of training samples and variables. This classifier has become popular within the remote sensing community due to the accuracy of its classifications. The overall objective of this work was to review the utilization of RF classifier in remote sensing. This review has revealed that RF classifier can successfully handle high data dimensionality and multicolinearity, being both fast and insensitive to overfitting (Belgiu & Drăgu, 2016). Random forest can be implemented on google earth engine itself.

STUDY AREA

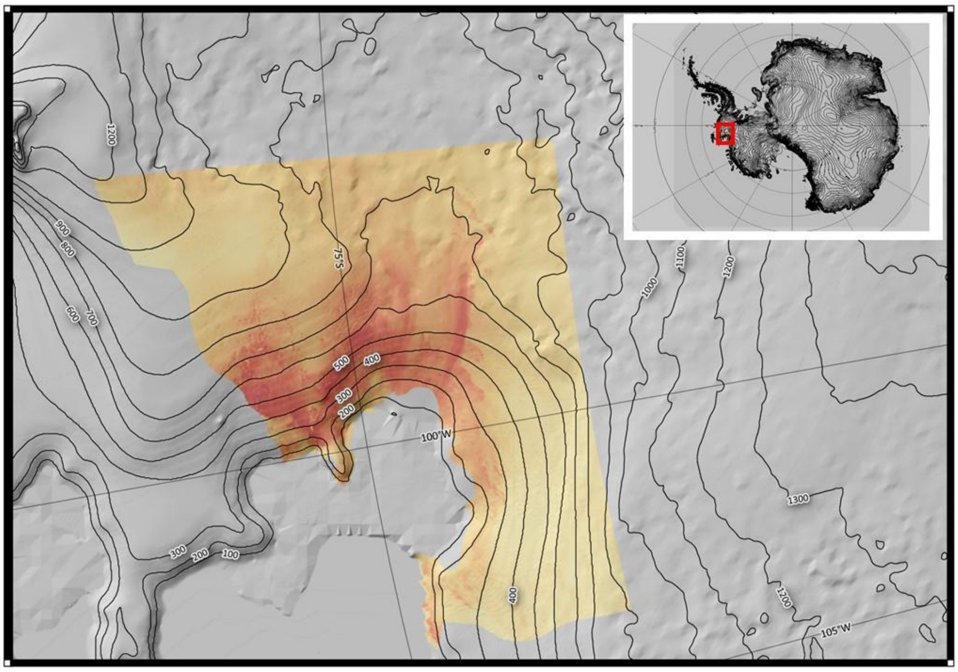

Fig. 1. Pine Island Glacier

Pine Island Glacier (PIG) is a large ice stream, and the fastest melting glacier in Antarctica, responsible for about 25% of Antarctica's ice loss.[3] The glacier ice streams flow west-northwest along the south side of the Hudson Mountains into Pine Island Bay, Amundsen Sea

Antarctica's average annual temperature ranges from about −10 °C on the coast to −60 °C at the highest parts of the interior. Near the coast, the temperature can exceed +10 °C in summer and fall to below −40 °C in winter. Over the elevated inland, it can rise to about −30 °C in summer but fall below −80 °C in winter.

In the southern hemisphere, where Antarctica is, summer and winter are at the opposite time of year to the northern hemisphere. Summer in Antarctica starts in October and ends in March, and winter starts in March and lasts until October. Antarctic seasons change as Earth moves around the sun

DATASET

Satellite imagery:

The Sentinel-1 mission provides data from a dual-polarization C-band Synthetic Aperture Radar (SAR) instrument at 5.405GHz .(ESA, 2022)..

Table 1. Sentinel – 1 Data description.

BANDS Sentinel - 1				
Name	Units	Min	Max	Pixel Size
HH	db	-50*	1*	10 m
HV	db	-50*	1*	10 m
VV	db	-50*	1*	10 m
VH	db	-50*	1*	10 m
Angle	Degrees	0*	90*	20000 m

Sentinel -1 is having four imaging modes IW (Interferometric Wide swath), Interferometric Wide swath (IW) and Extra Wide swath (EW), Strip Map (SM) mode and HH, HH-VV, VV-HH, VV polarizations. Our coverage area is supports IW mode in the ascending and descending pass with HH or HH-VV polarization (European Space Agency (ESA), 2022)

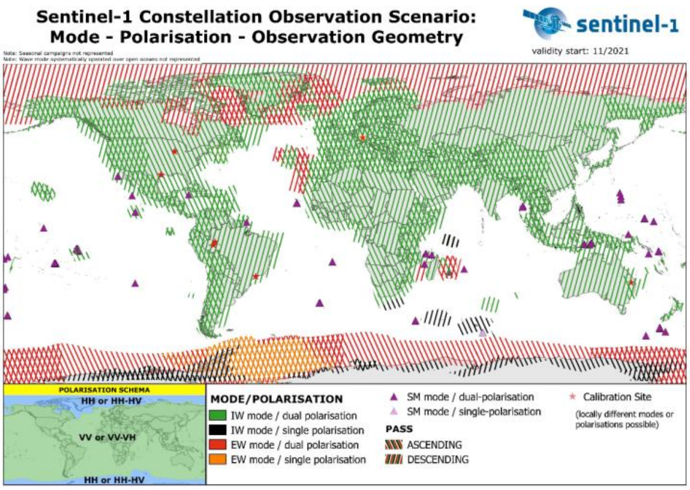

Fig. 1. Sentinel – 2 Coverage in various modes and Polarization

Software and Tools:

Google Earth Engine (GEE), combines a multi-petabyte catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities.

Quantarctica (v 3.2), is a collection of Antarctic geographical datasets for research, education, operations, and management in Antarctica, and let you explore, import, visualize, and share Antarctic data, It works with the free, cross-platform Geographical Information System (GIS) software QGIS (v, 3.22.1-Białowieża) (Matsuoka et al., 2021)

ITS_LIVE, is a NASA MEaSUREs project to provide automated, low latency, global glacier flow and elevation change datasets.

METHEDOLOGY

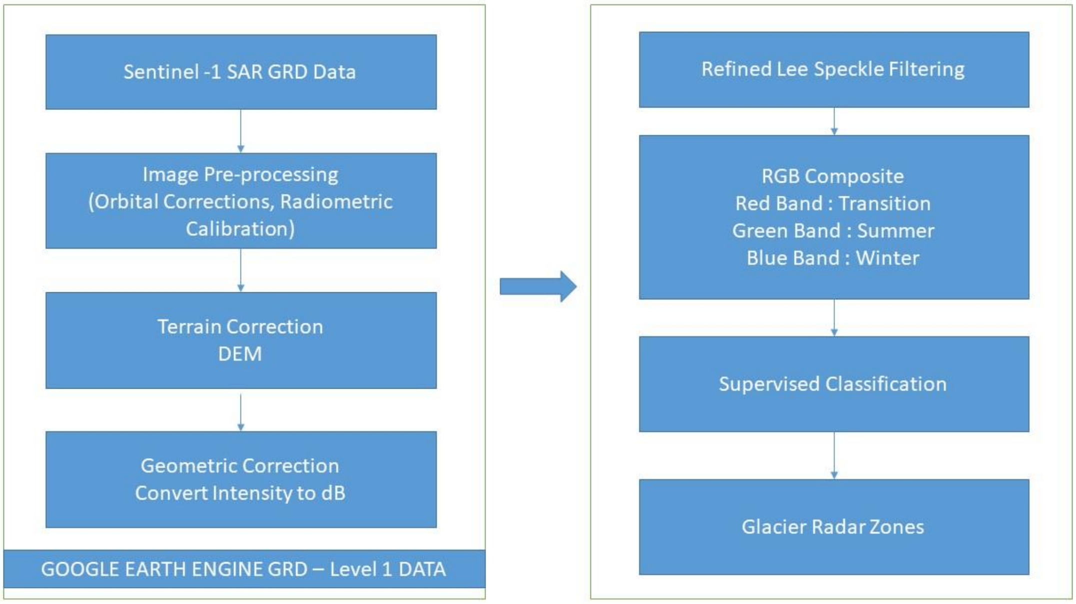

Fig. 3. Work-Flow diagram for Glacier Radar Zones.

Data Acquisition and Processing:

Google Earth Engine was used to acquire sentinel -1 images. Sentinel-1 data is collected with several different instrument configurations, resolutions, band combinations during both ascending and descending orbits as discussed (above), The data-set in google earth engine is called a collection. A Sentinel -1 collection is created and filtered for the area of interest and imaging mode here IW and polarization HH to analyse the surface backscatter

Imagery in the Earth Engine 'COPERNICUS/S1_GRD' Sentinel-1 ImageCollection is consists of Level-1 Ground Range Detected (GRD) scenes processed to backscatter coefficient (σ°) in decibels (dB)

(GEE, 2021) Earth Engine uses the following pre-processing steps (as implemented by the Sentinel-1 Toolbox) to derive the backscatter coefficient in each pixel:

- Orbital corrections - Updates orbit metadata with a restituted orbit file (or a precise orbit file if the restituted one is not available).
- GRD border noise removal - Removes low intensity noise and invalid data on scene edges. (As of January 12, 2018)
- Thermal noise removal - Removes additive noise in sub-swaths to help reduce discontinuities between sub-swaths for scenes in multi-swath acquisition modes. (This operation cannot be applied to images produced before July 2015)
- Radiometric calibration - Computes backscatter intensity using sensor calibration parameters in the GRD metadata

- Terrain correction (orthorectification) - Converts data from ground range geometry, which does not take terrain into account, to σ° using the SRTM 30 meter DEM or the ASTER DEM for high latitudes (greater than 60° or less than -60°).

The data collection was further filtered down yearly and monthly for creating as RGB composite of different season SAR data to identify the glacier facies. (As per the table below.)

Speckle is removed using a Lee filter which has been considered as most superior (Lee et al., 2009), for removing noisy backscatter signals.

Glacier Radar Zones

Glacier zones can be best delineated either through field investigation or by adapting remote sensing techniques. Benson (1962) identified distinct zones on an ice sheet or glacier surface layer based on intense field investigation and regarded them as glacier facies.

differentiated majorly based on the pattern of snow and ice in accumulation and ablation zones

Random Forrest Classification

The Classifier package handles supervised classification by traditional ML algorithms running in Earth Engine. That classifier package includes Random Forest. The general workflow for the classification was:

- Collected training data. Assembled features which have a property that stores the known class label and properties storing numeric values for the predictors.
- The Separation of samples into training and validation set.
- Instantiate a Randomclassifier. Set its parameters if necessary.
- Train the classifier using the training data.
- Classify an image or feature collection.
- Estimate classification error with independent validation data.

RESULTS

The SAR images of different seasons in each year were stacked to generate an RGB composite, as mentioned in the method section. As the liquid water content of a glacier changes due to season, the glacier surface features would reflect different tonal variations. For the example, the SAR images of the different season and RBG composite of the year 2015 is shown in Fig. #. The tonal variation (as discussed in the Method section for each zone) of the backscatter values in the composite was then used for the identification of glacier radar zones.

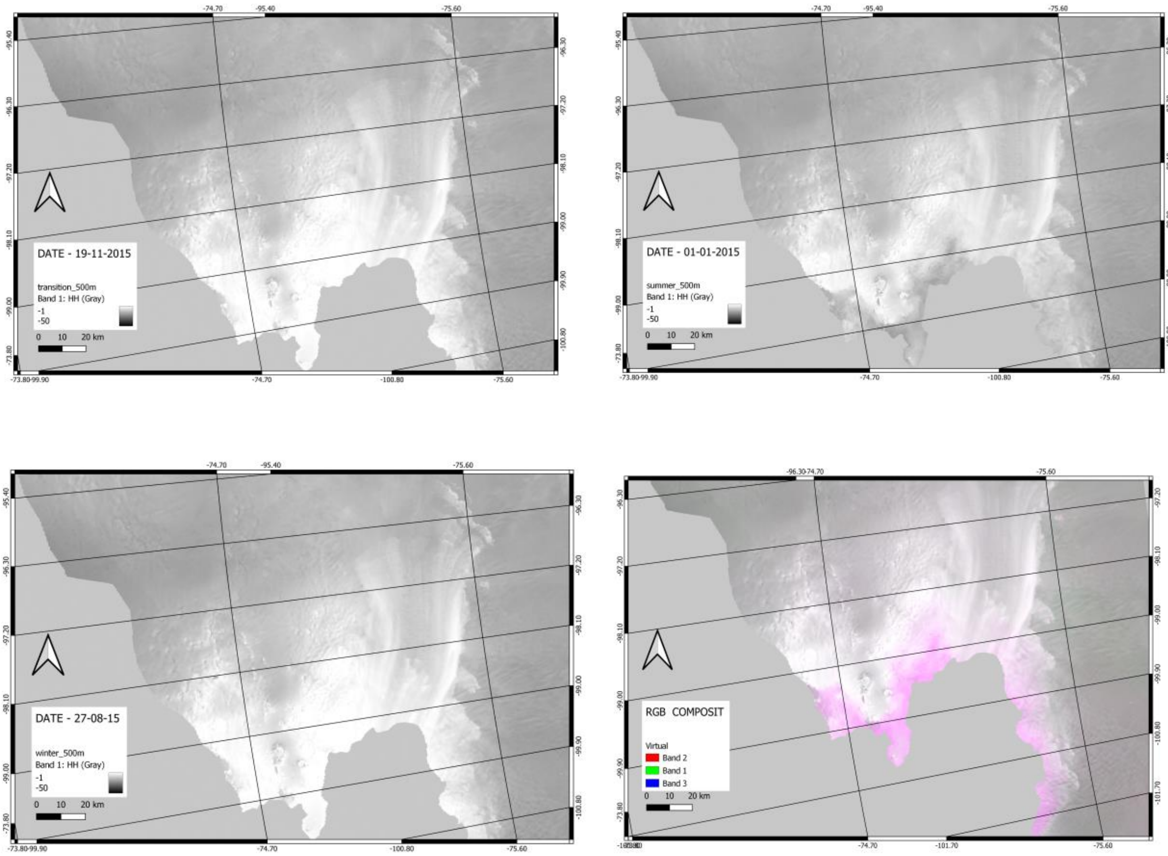

Fig. 3. Backscatter intensity images with HH polarization for Top Left 19.11.2015, Top right 01.01.2015, Bottom Left 27.08.2015, and Bottom right RGB composite image created by using multi-temporal backscatter images by putting the Transition between summer and winter to the red band, summer in green band, winter in blue band.

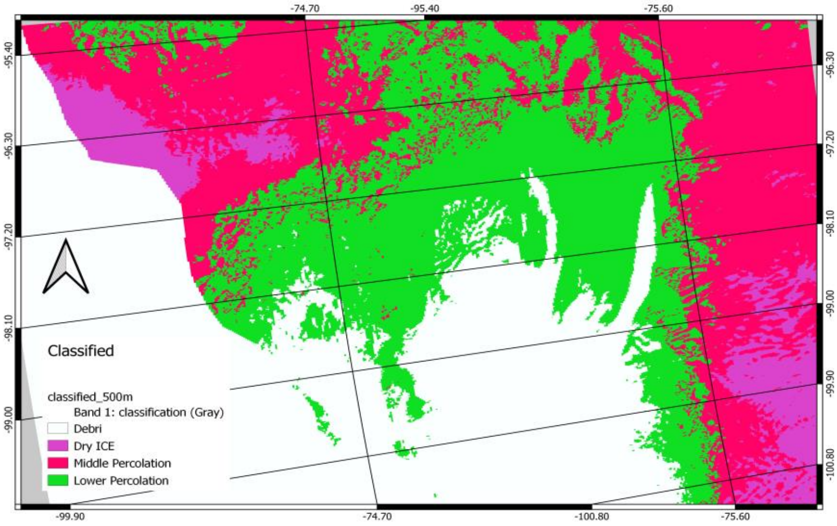

Fig. 4. Classified maps of Pine Island Glacier

The RGB composite of 2015 for Pine Island Glacier showed four zones, debris area (White colour) which are mostly located at the front portion of glacier Dry ice at the elevation (purple colour) middle percolation (pink colour) and lower percolation (Green colour). Google Earth Engine's Random forest classifier was used to classify the RGB composite the results of the same are shown in fig # The temporal changes in the backscatter are shown in fig # for various seasons the. The results of the classification are as shown in Table 2

		Classification (Prediction)					
		0	**1**	**2**	**3**		
Ground Truth (Actual)	**0**	5	0	0	0	**1**	Producer's Accuracy
	1	0	5	1	0	**0.83**	
	2	0	0	3	0	**1**	
	3	0	0	1	1	**0.5**	
		1	**1**	**0.6**	**1**	**0.87**	
		Consumer's Accuracy					

Table 2. Confusion Matrix

Glacier Velocity Trends

The result of glacier velocity for the three geo-location points across the flow of the glacier are shown below which shows that the velocity at the upper regions is much higher compared to the velocity at lower regions and middle part over the period of 2015.

Table 3. Geo-locations for glacier speed tracking.

Point Colour	Latitude	Longitude
	-75.45	-95.69
	-75.26	-99.11
	-75	-101.2

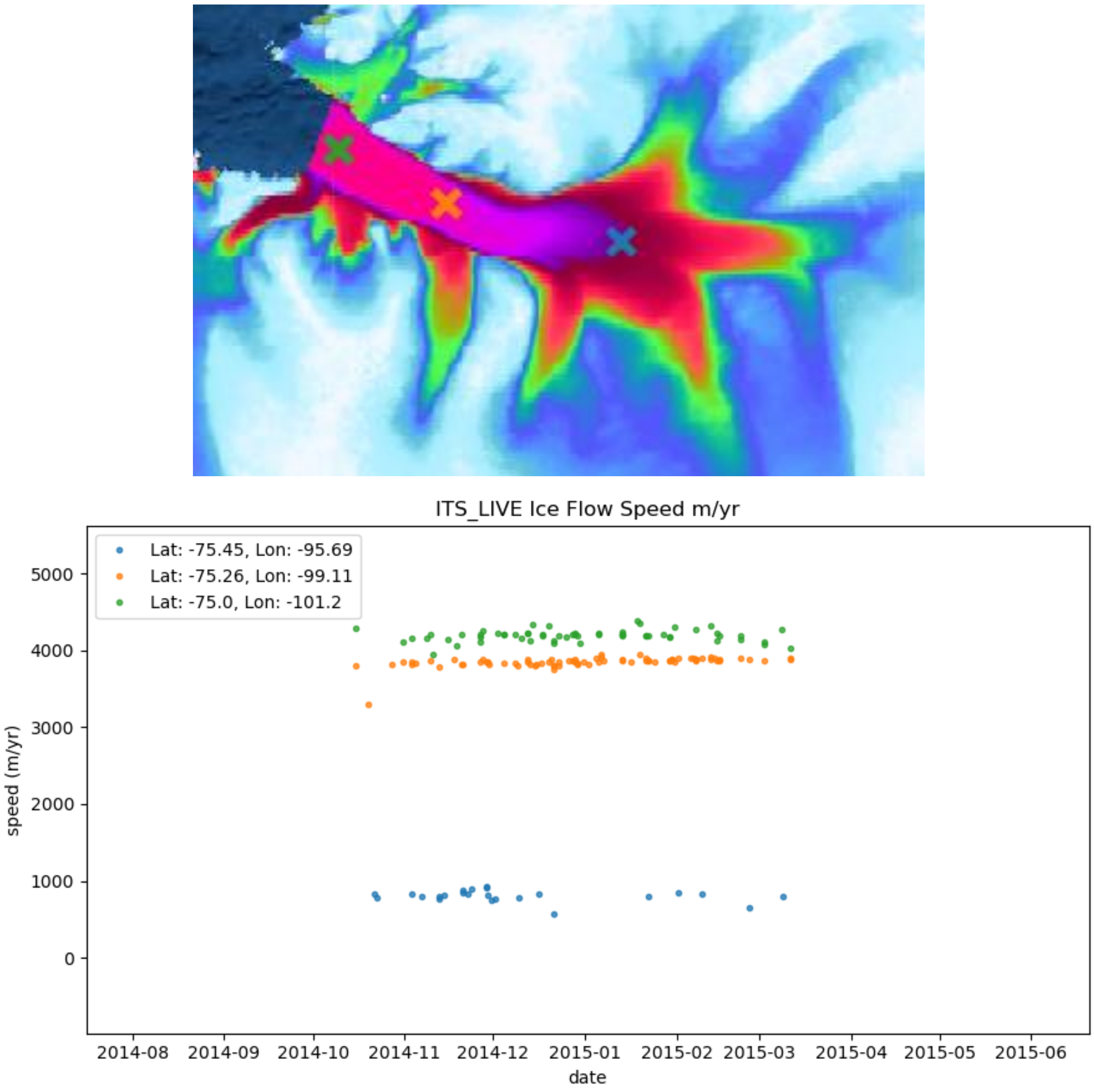

Fig. 5. Top a pictorial representation of glacier velocity, coloured geotags for tracking velocity change over the year - 2015

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