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Application of Remote Sensing to Study the Potential Impacts of 2020 Wildfire Events on the Glaciers of Mount Baker, Washington

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ABSTRACT:

Wildfire activity across the globe has been on the rise in recent years, as climate change continues to warm global temperatures. Wildfires generate ash, soot, and other light-absorbing particles (LAPs) that can be deposited on glacial surfaces. However, understanding the true effects of wildfires on glaciers is difficult to assess, because in situ field measurements can be difficult to obtain. Catastrophic wildfires plagued the Western United States in 2020 and emitted large amounts of LAPs into the atmosphere. LAPs make their way to the surfaces of glaciers through long-range transport through the atmosphere and through wet and dry deposition. Satellite imagery shows that LAPs cause significant snow-darkening of glaciers on large glacial surfaces, like polar ice sheets. However, the methods for using remote sensing technology on smaller, more regional surfaces is less understood. This study uses a time series of 3 Sentinel-2 multispectral images to assess the changes on the glacier surfaces of Mount Baker, Washington in response to the record-breaking 2020 wildfire season in the Western US. This is ongoing research. Preliminary results suggest that the use of NDSII2 calculations is a viable method for visualizing and understanding LAPs on glaciers. Increased wildfire activity in response to climate change will have a significant impact on glaciers across the world and utilizing remote sensing technology to assess those effects will be crucial to monitoring future changes in the cryosphere.

INTRODUCTION

Over 10 million acres of forests burned in the contiguous United States in 2020 (National Interagency Fire Center, September 2021). Smoke plumes from wildfires can travel thousands of miles and light absorbing particles (LAPs), such as black carbon, ash, and soot are deposited across the country, and often onto glaciers. Glaciers in the United States have been on a steady decline over the last 50 years, and the presence of wildfires has been on the rise. As these wildfires burn, LAPs deposited on the surfaces of glaciers result in a decreased albedo. Albedo is the proportion of incident radiation that is reflected by any given surface. Objects that are lighter in color reflect more radiation than objects that are darker, because they absorb less energy. Bright features on Earth, like our ice caps, reflect more heat and radiation than Earth's darker features, like asphalt and forests, that absorb a lot of heat and radiation. Clean glaciers, on average, can reflect from 75-90% of solar radiation. However, when LAPs are deposited on glacial surfaces, it causes those surfaces to darken, thereby decreasing the glacier's ability to reflect incoming radiation. This change in albedo can result in increased melting, as more energy is absorbed into the surface. The use of remote sensing to study these LAPs has been successful on larger scale ice sheets (Pu, et al., 2021), but fewer studies have tested this method on smaller, more regional glaciers, like Mount Baker, Washington.

Literature Review

There have been several studies conducted on the effects of LAPs on glacial surfaces across the world.

Kulkarni et al (2013) conducted a study in the Baspa Basin, Himachal Pradesh, India that suggests that changes in snow albedo in the accumulation area to the deposition of black carbon (BC) can influence the mass balance of glaciers in the area. Monitoring of snow albedo using AWiFS was started in early April 2009, when no fires were present in the region and snow was clean and fresh. Mean albedo for this time was 85 +/- 5%. Forest fires began in the last week of April 2009, and imagery taken in late May 2009 and the spectral albedo measurements had dropped to 62 +/- 5%. Imagery taken in June, after continued major forest fires in the area, showed only a drop in spectral albedo to 60 +/- 5%. Though fires continued to ravage the area between May and June, data shows that initial deposition of LAPs have a much larger effect on albedo than subsequent deposition. Conclusions for this study were strong, and indicated that LAP deposition on glaciers in the area could result in earlier melting of seasonal snow, earlier exposure of ablation areas, and a lower accumulation area, leading to a more negative mass balance.

Research conducted by Pu et al. (2021) studied the degree of snow darkening and increased melting rates of glaciers in New Zealand after 17 million hectares were burned in the Australian 2019-2020 wildfires. Researchers utilized Suomi National Polar Orbiting Partnership (Suomi NPP) satellite data to measure how LAPs are transported, and Moderate Resolution Imaging Spectroradiometer (MODIS)

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data was used to quantify albedo reduction over the entire South Island of New Zealand. Despite in situ measurements not being taken in the field, MODIS satellite data in snow-reflectance calculations was verified with an uncertainty of < 20%. Eight-day composite spectral snow reflectance values from Terra/MODIS from before the first smoke arrival and after the arrival were compared. The snow darkening accelerated snow melt by 0.2 cm/day, an impact that is equivalent to the changes expected to see with a 1.8°C air temperature increase. This impact exceeds the local climate warming of 1.5°C. This study's results are significant, and show just how strong of an effect LAPs have on large glacial areas.

METHODS

Initially, this study intended to use Landsat 8 imagery, however, due to clouds and image availability for 2020, we chose to use Sentinel-2 imagery. The European Copernicus Sentinel-2 mission, launched in June 2015, is composed of two polar-orbiting satellites that are placed in the equal sun-synchronous orbits, 180° to each other. The satellites are each placed at a mean altitude of 786 km. Sentinel 2 carries an optical instrument that measures 13 different spectral bands, ranging from 10 m resolution to 60 m resolution (Table 1). The mission has a swath width of 290 km, with a high temporal resolution, with a revisit time of 5 days at the equator (ESA, 2022).

Sentinel 2 Bands	Central Wavelength (μm)	Resolution (m)
Band 1-Coastal aerosols	0.433	60
Band 2-Blue	0.490	10
Band 3-Green	0.560	10
Band 4-Red	0.665	10
Band 5-Vegetation Red Edge	0.705	20
Band 6-Vegetation Red Edge	0.740	20
Band 7- Vegetation Red Edge	0.783	20
Band 8-NIR	0.842	10
Band 8A-Vegetation Red Edge	0.865	20
Band 9-Water vapour	0.945	60
Band 10-SWIR-Cirrus	1.375	60
Band 11-SWIR	1.610	20
Band 12-SWIR	2.190	20

Table 1: Sentinel 2A Bands with central wavelengths and resolution

Study Site

The study site selected for this research is Mount Baker, Washington, located in the heart of the Cascade Mountain Range, just 80 km west of North Cascades National Park boundary (Figure 1). This site was selected due to its proximity to several large wildfires in the Pacific Northwest of the United States, and because of its large glacier covered area. Mount Baker is home to one of the most glaciated areas in the contiguous United States, second to Mt. Rainer. Mount Baker has 10 glaciers and has a glacierized area of 38.6 km^2 (Figure 1).

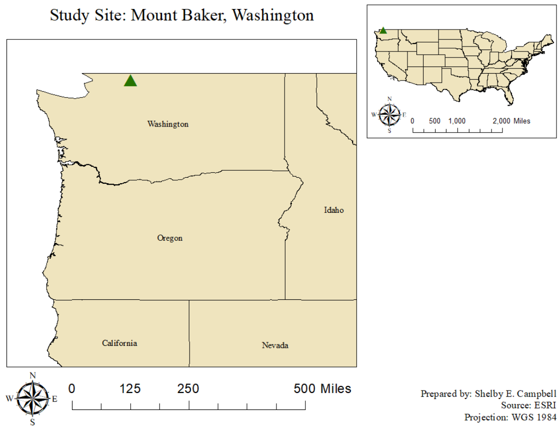

Figure 1: Study Site location of Mount Baker Washington, indicated by the green triangle.

The Sentinel 2A imagery was obtained from the European Space Agency's (ESA) Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home). Three Sentinel scenes were collected: March 18, 2020, September 9, 2020, and October 2, 2020.These 3 dates were selected based on the distribution of wildfire activity across the year. In March, very few fires were present across the United States. September was the most active month for fires, and in October, fire activity began to decrease for the year. The images were received in .img format, and processed in ERDAS Imagine software by stacking Band 2 (blue), Band 3 (green), Band 4 (red), Band 8 (NIR), and Band 11 (SWIR). A shapefile of Mount Baker was produced, and each stacked set of data was clipped to the polygon's extent (Figure 2). After processing and clipping each scene, each scene was processed into a true color image (Figure 3). In order to identify areas with potential LAPs, further image processing was necessary. For this purpose, two different snow indices were calculated. These are: Normalized Difference Snow Index (NDSI, Eq. 1) and Normalized Difference Snow/Ice Index 2(NDSII2, Eq. 2).

$$NDSI = \frac{Green - SWIR}{Green + SWIR} \quad (1)$$

$$NDSII2 = \frac{Green - NIR}{Green + NIR} \quad (2)$$

Using the images generated from the calculations of NDSI and NDSII2, 6 maps were produced as shown in Figure 3.

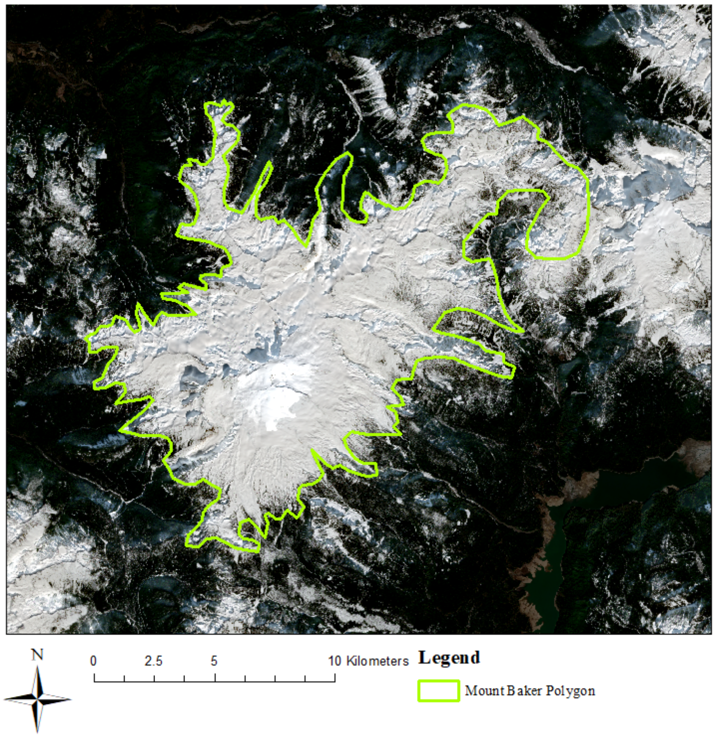

Figure 2: Area of interest over Mount Baker

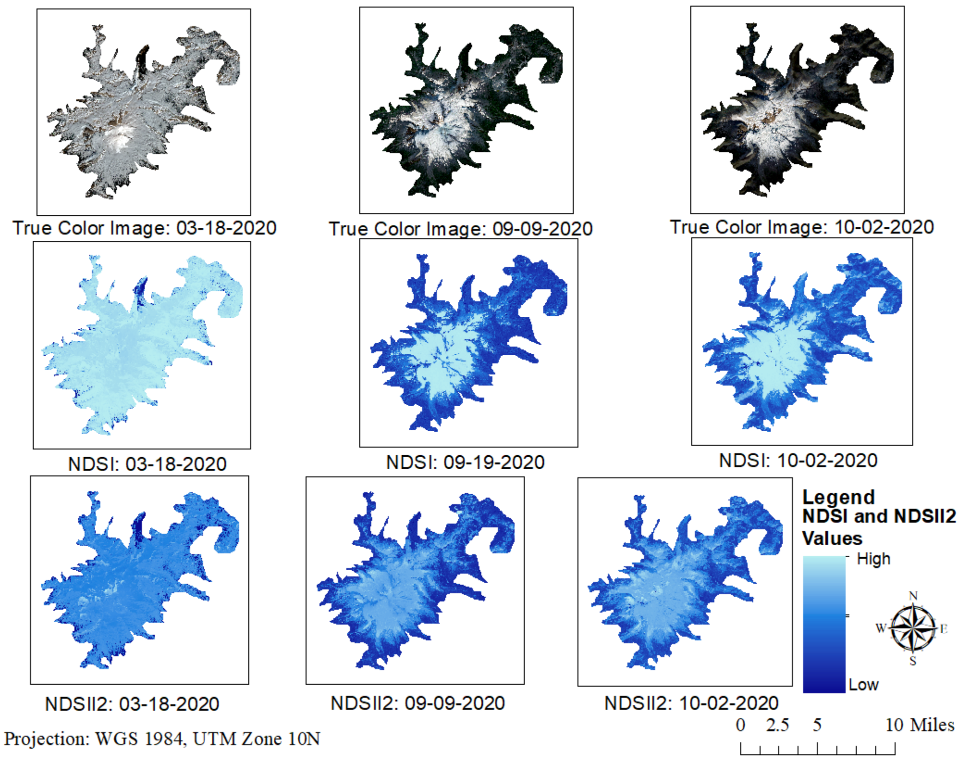

Figure 3: True color images (top), NDSI (middle), and NDSII2 (bottom) maps produced (WGS 1984 datum).

RESULTS

The true color images showed distinct changes in the glacier across the year, but the NDSI images did not show much variation, and proved to be less conclusive. NDSI images were found to be particularly sensitive to differences between snow and rock/vegetation, but was much less sensitive to differences in the snow itself. However, NDSII2 was found to be very useful, and was much more sensitive to differences within the snow. After making initial observations of all 9 maps shown in Figure 3, the true color images and NDSII2 images were further investigated within a specific area of interest, in order to remove distractions of vegetation and rock (Figure 4). Upon closer inspection of the area of interest, the true color images showed an obvious difference between snow and other debris on the glacier throughout the time series, evidenced by the darker pixels (Figure 5). The same observations were made of the NDSII2 images (Figure 6), which also showed the same changes over the year. In the March image, the pixels showed a little distinction between pixels, but the images acquired in September and October showed significant variations in the snow and debris. Whether these pixels are LAPs, or just glacial sediment is not yet determined. Further research is necessary to confirm the identity of these pixels.

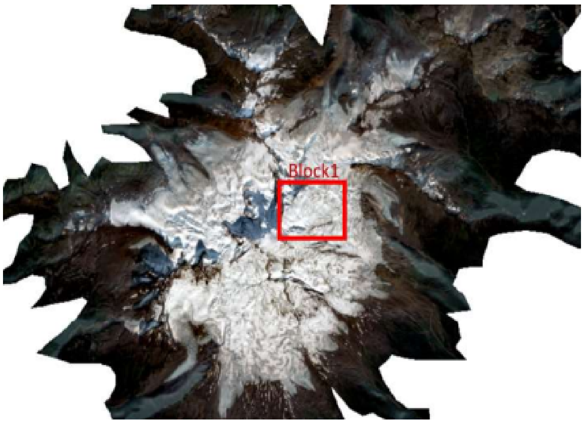

Figure 4: Area of interest for visual inspection

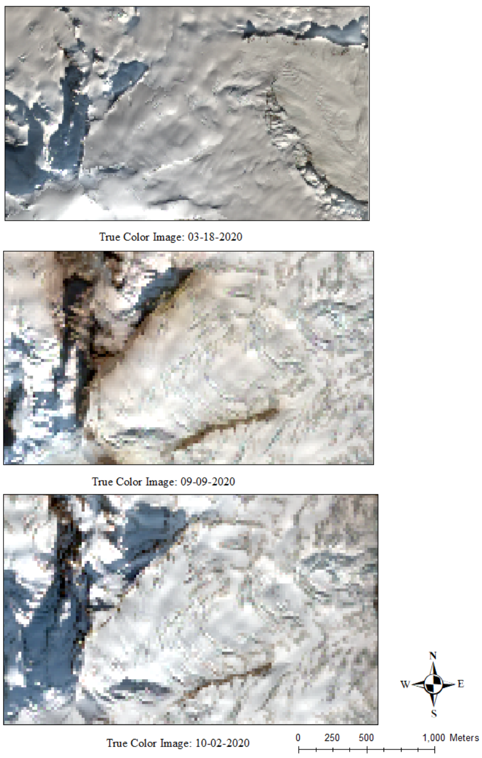

Figure 5: True Color Images (Closer Inspection)

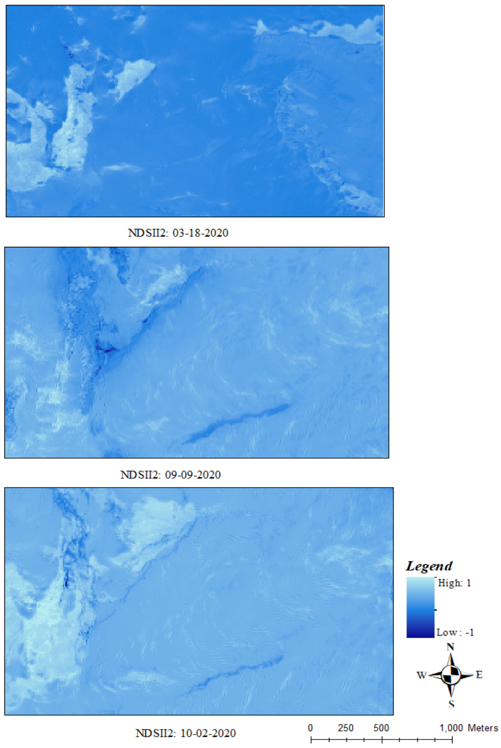

Figure 6: NDSII2 Images (Closer Inspection)

CONCLUSIONS

This study clearly shows the potential for using higher-resolution satellite imagery to observe and monitor light-absorbing particles, sediment distribution, and other glacial changes. As climate change and global warming continue to worsen, finding different ways to monitor the global cryosphere will become more important. In situ measurements are often difficult to obtain in these hostile environments, so having a mechanism for recording and monitoring these changes is crucial. This research is not yet concluded, and further investigations using spectral signature classifications will be utilized to verify whether the pixels are LAPs, or if they are simply glacial sediment.

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