Burnt area mapping using Sentinel images

Summer Internship,
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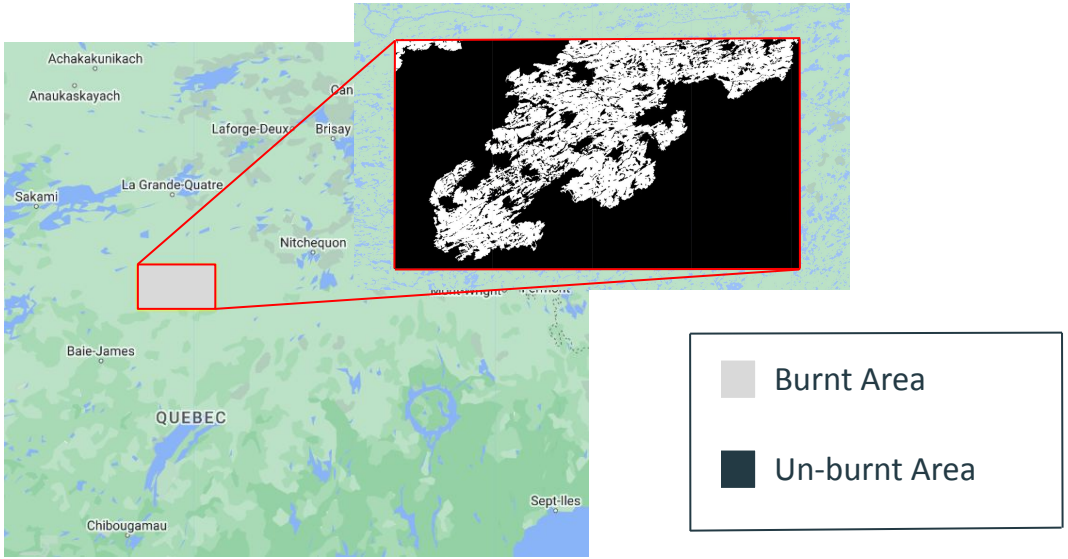
Introduction

- In this study, we assess the potential of Sentinel-1 SAR and Sentinel-2 images for precise forest-burned area mapping.
- Quebec has experienced forest fires in the months of June and July 2023.
- Study area selected was near the Baie-James, the northern part of Quebec.
- The ground truth data collected from the Quebec's Ministry of Forests, Wildlife, and Parks website.
- The shape files are uploaded to the GEE and the binarized images are shown in the figure.



Sentinel 1 Images

- Pre-Fire(February 5 - February 15, 2023) and Post- Fire images(August 20 - August 30, 2023) are collected.
- Data was filtered of containing both VH and VV polarizations.
- Applied terrain correction and RL speckle filter.

Terrain Correction

- Converted the radar image from decibels (dB) to power units for processing.
- Calculated the radar incidence angle, terrain aspect and slope angles and converted to radians.
- Computed slope steepness in range and azimuth directions and local incidence angle.
- Computed the gamma nought, corrected for incidence angle.
- Applied a volumetric model to account for volumetric scattering effect.
- Generated masks for layover and shadow effects to produce a corrected radar image.

Sentinel 1 images

RL Speckle Filter

- Converted the input radar image from decibels to power units for processing.
- Used 3x3 kernels to calculate the local mean and variance of the radar image, providing initial estimates of pixel intensity and variability.
- Sampled 7x7 windows to analyze gradients in four directions, determining the maximum gradient to identify edges and textures in the image.
- Derived the local noise variance from the 7x7 window statistics.
- Adjusted the pixel value using the refined Lee formula that incorporates local statistics and estimated noise variance.
- Replaced the original pixel value with the computed filtered value in the image.

Sentinel 1 images

Log- Ratio

- To extract Sentinel-1 SAR intensity features, the log-ratio index is utilized.
- Computed for both VV and VH polarizations.
- where IXY post-fire and IXY pre-fire are the post-fire and pre-fire SAR intensities of XY (VV or VH) polarization, respectively.

$$\text{log-ratio}^{xy} = 10\log_{10}(I^{XY}_{\text{post-fire}}/I^{XY}_{\text{pre-fire}})$$

Salient Region Detection

- The mean values of the VV and VH log-ratio images are computed
- A Gaussian kernel is defined for horizontal and vertical directions to blur the image.
- Applied the defined kernels to blur the VV and VH log-ratio images separately using convolution.
- Calculated the saliency map based on the Euclidean distance between the mean values and the blurred images.
- Normalized the saliency map values to a range of 0 to 255 for visualization.
- The binary saliency map S is derived by setting a threshold to the saliency image, threshold obtained using an Otsu algorithm.
- The saliency map is then multiplied with the pre- and post-fire difference image leading to filtering background pixels.

Sentinel 2 Images

- Created a function to mask clouds in Sentinel-2 images using the QA60 band.
- Created an image collection from the Sentinel-2 surface reflectance product, selecting only the bands of interest.
- Filtered the Sentinel-2 images to include only those within the defined geometry and date ranges.
- Applied the cloud masking function to each image.
- Defined a function to process an image collection by taking the mean of all images, scaling the pixel values, and clipping the result to the geometry.
- Processed the pre- and post-fire image collections to generate mean images for each period.

dNDVI Calculation

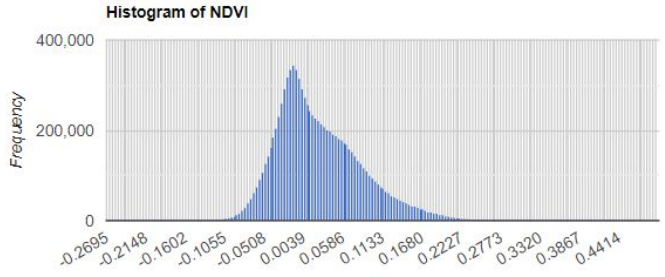
- Defined a function which takes an image as input and calculates the NDVI by applying formula using the Near-Infrared (NIR) and Red bands of the image.
- This function computed the Normalized Difference Vegetation Index (NDVI) using the formula:

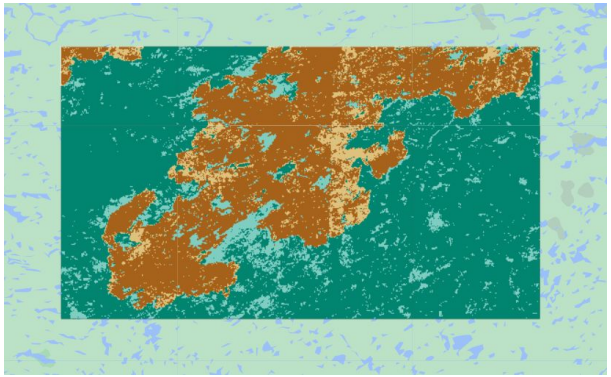
$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})}$$

- Function is applied to both the pre-fire and post-fire processed images to compute the NDVI for each period.
- The change in NDVI (delta NDVI) is computed by subtracting the pre-fire NDVI from the post-fire NDVI.
- This highlighted areas where vegetation health has changed, showed the impact of the fire on vegetation.
- Otsu algorithm applied to the delta NDVI histogram to find an optimal threshold.
- Created a confusion image by combining the classification image and ground truth raster.
- Reduced the confusion image to a fixed histogram and constructed a confusion matrix.
- Calculated precision, recall, and other metrics for the classification.

Results

Threshold obtained = -0.02757





Metrics	Value
Accuracy	0.7723923412235433
Precision	0.5840831168493091
Recall	0.8048851237864406
Kappa	0.5080013315202845

dNBR1 Calculation

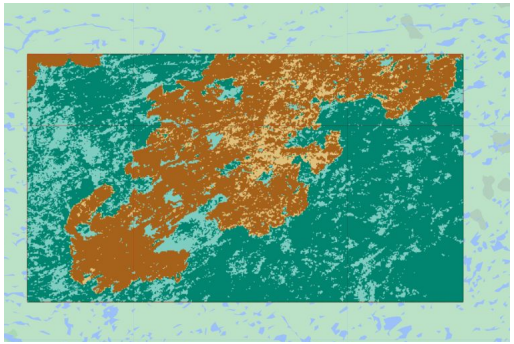
- Defined a function which takes an image as input and calculated the NBR by applying formula using the near-infrared (NIR) and shortwave infrared (SWIR) bands.
- This function computed the Normalized Burn Ratio 1 Index (NBR1) using the formula:

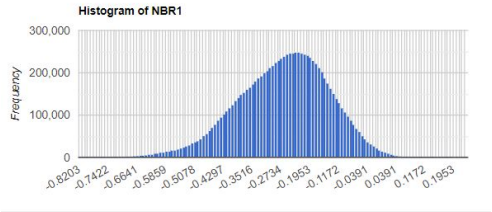
$$\mathrm{NBR1} = \frac{(\mathrm{NIR} - \mathrm{SWIR2})}{(\mathrm{NIR} + \mathrm{SWIR2})}$$

- Function is applied to both the pre-fire and post-fire processed images to compute the NBR1 for each period.
- The change in NBR1 (delta NBR1) is computed by subtracting the pre-fire NBR1 from the post-fire NBR1.
- This highlighted areas where vegetation health has changed, showed the impact of the fire on vegetation.
- Otsu algorithm applied to the delta NBR1 histogram to find an optimal threshold.
- Created a confusion image by combining the classification image and ground truth raster.
- Reduced the confusion image to a fixed histogram and constructed a confusion matrix.
- Calculated precision, recall, and other metrics for the classification.

Results

Threshold = -0.2661789764128568





Metrics	Values
Accuracy	0.728131751247158
Precision	0.526188420346446
Recall	0.8272270252404892
Kappa	0.44065517026721235

Combining the images for Deep Learning

- The Sentinel-2 derived indices (delta NDVI and delta NBR1), Sentinel-1 SAR data (masked VV and VH log ratios), and SRTM DEM-derived terrain metrics (slope and aspect) are reprojected, clipped to a specified geometry, and converted to float data types.
- These layers are concatenated into a composite image along with a ground truth fire map.
- The final composite image is then exported to Google Drive and imported to ArcGIS Pro.
- Using ArcGIS Pro, the image is split into 256x256 pixel patches.

Thank you!