Post-fire analysis near the border of Bolivia, Paraguay, and Brazil for August 2019, using Landsat 8 imagery

Alexa Cristina - final assignment for fourth course in the Geographic Information Systems Specialization, Imagery, Automation, and Applications, from UC Davis and Coursera

INTRODUCTION

Since the beginning of August 2019, NASA satellites have observed several fires near the border of Bolivia, Paraguay, and Brazil (not in the Amazon rainforest). On August 25, 2019, the Operational Land Imager (OLI) on Landsat 8 acquired images of one of the larger fires, which was burning north of the Paraguay River near Puerto Busch.

This project focuses on change detection analysis, estimating burn severity by analyzing Landsat images acquired before and after a fire. A differenced Normalized Burn Ratio (dNBR) can be used to support fire managers, to measure the burn scars to create a baseline for forest regeneration.

The Normalized Burn Ratio (NBR) is an index designed to highlight burnt areas in large fire zones. The formula is similar to NDVI, except that the formula combines the use of both near infrared (NIR) and shortwave infrared (SWIR) wavelengths. Burn severity describes how the fire intensity affects the functioning of the ecosystem in the area that has been burnt.

The analysis is conducted combining automated ArcGIS models and scripts with supervised classification. Based on pre and post fire Landsat scenes archives, we generate a differenced normalized burn ratio (dNBR) raster, then use supervised classification to produce a 4-class thematic burn severity signature file, then we reclassify dNBR, calculate acreage and find largest burnt perimeter using another model.

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STEPS

DOWNLOAD AND DECOMPRESS DATA

- Landsat imagery acquired from USGS earthexplorer.usgs.gov: mid, and post fire archives from 09-AUG-19, 25-AUG-19 and 10-SEP-19
  - LC08_L1TP_227073_20190809_20190820_01_T1
  - LC08_L1TP_227074_20190809_20190820_01_T1
  - LC08_L1TP_227073_20190825_20190903_01_T1
  - LC08_L1TP_227074_20190825_20190903_01_T1
  - LC08_L1TP_227073_20190910_20190917_01_T1
- 7z x LC08_L1TP_227073_20190809_20190820_01_T1.tar.gz
- 7z x LC08_L1TP_227073_20190809_20190820_01_T1.tar -oLC08_L1TP_227073_20190809_20190820_01_T1
- World Countries downloaded from ArcGIS Online, esri-dm, selected by study area

CREATE NEW MAP DOCUMENT

- Set coordinate system for Layers to WGS_1984_UTM_Zone_21N
- Set **Current Workspace** and **Scratch Workspace** to C:\GIS\scratch.gdb
- Create new toolbox FireSeverityTools.tbx
- Add new models ‘Create dNBR’ and ‘Refine dNBR Classified Raster’
- Add new scripts ‘Calculate NBR’ and ‘Landsat 8 Composite Bands’ (used in ‘Create dNBR’)

- Make layers for visualization and burnt areas
- Create 2 dnbr rasters and save them to disk, add multispectral layer stacks (Landsat 8 bands 1–11)
    - The normalized burn ratio (NBR) is defined as the ratio of the difference between the NIR and SWIR bands to the sum of the same bands: NBR = (NIR – SWIR)/(NIR + SWIR)
    - Correct bands for Top of Atmosphere Reflectance
    - When calculating NBR, rescale by 1000, which means that NBR values will lie in the range of ±1000 and dNBR values in the range of ±2000: nbr = Int(Float(band_5_corrected - band_7_corrected) / (band_5_corrected + band_7_corrected) * 1000)
    - The dNBR displays degrees of change between the pre-fire NBR and the post-fire NBR; in our case, pre- and post-fire NBR: dNBR = (pre-fire NBR) – (post-fire NBR), pre- and mid-fire NBR: dNBR = (pre-fire NBR) – (mid-fire NBR)
- Using supervised classification, create signature files and produce **four** plausible burn severity classes from dNBR postfire raster:
    - Unburned: Fir Green
    - Low severity: Tourmaline Green
    - Moderate severity: Solar Yellow
    - High severity: Mars Red
- Add intermediate NBR rasters and multispectral layer stacks (Landsat 8 bands 1–11) as layers
- Set display properties of the multispectral layers to SWIR-NIR-Red (**Band_7, Band_5, Band_4**)

‘REFINE DNBR CLASSIFIED RASTER’ MODEL

- Calculate total burnt area, the repartition per countries and maximum continuous burnt area perimeter
- Reclassify to 1, 2, 3, 4
- Remove 1, 2 classes, keep only moderate and high severity classes
- Convert to polygon, intersect with countries, calculate acres
- Create graphic with burnt acreage per countries
- Buffer features with 100m, dissolve, explode, calculate acres again
- Use summary statistics to get maximum length and acreage for continuous burnt area

CREATE FINAL MAP

- Show differences between pre-fire, mid-fire and postfire classified rasters, the dNBR postfire raster classified by severity, the graphic with burnt areas repartition and maximum continuous burnt areas statistics.

ANALYSIS RESULTS

The fires that started in August 2019 near the border of Paraguay, and Brazil have consumed circa **988069** acres between the **9th of August** and the **10th of September.**

Burnt area acreage is distributed this way: 284,624.678 in Bolivia, 238,324.611 in Paraguay and 465,119.744 in Brazil.

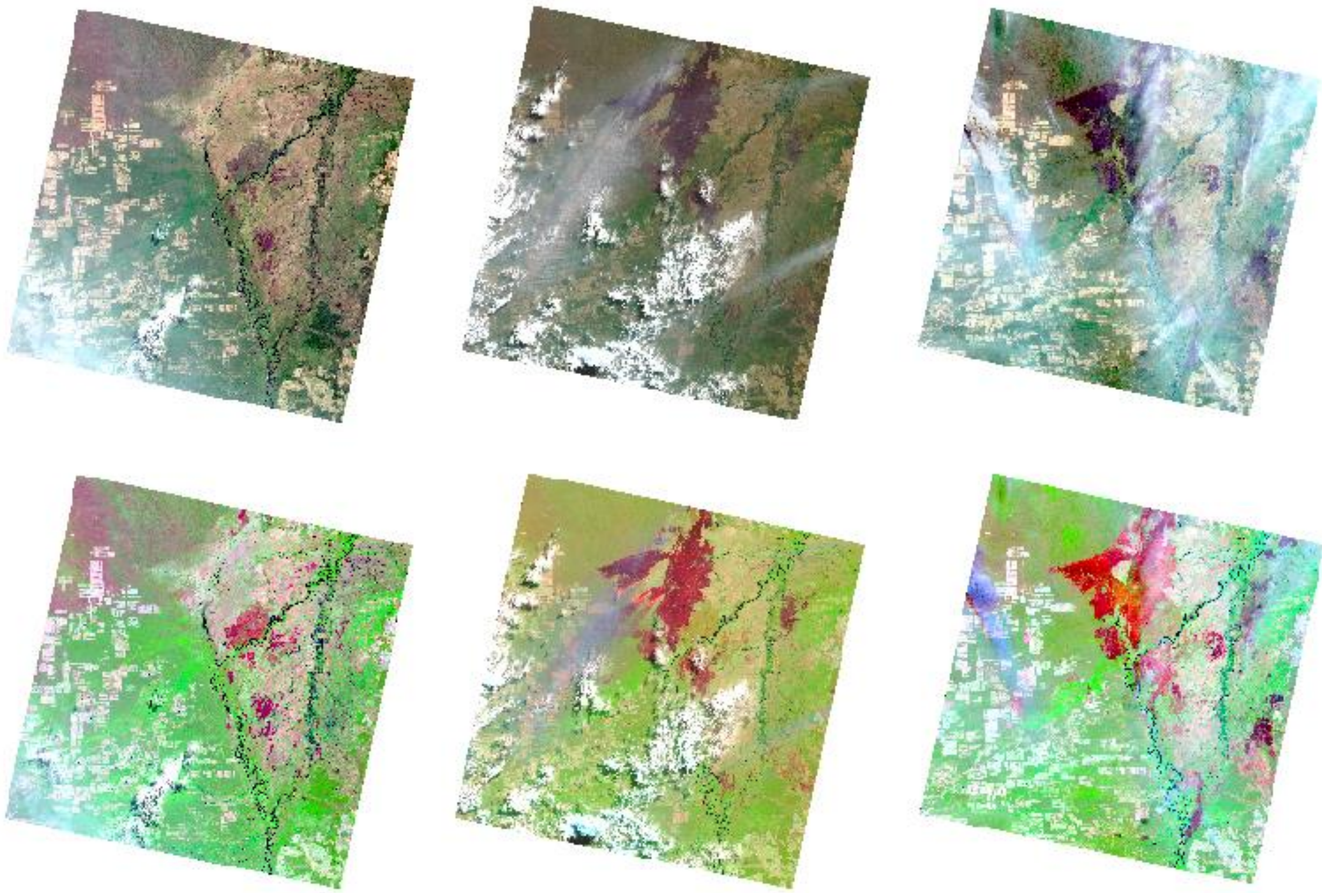
The maximum continuous burnt area of **638673** is equivalent to **491287** soccer fields.

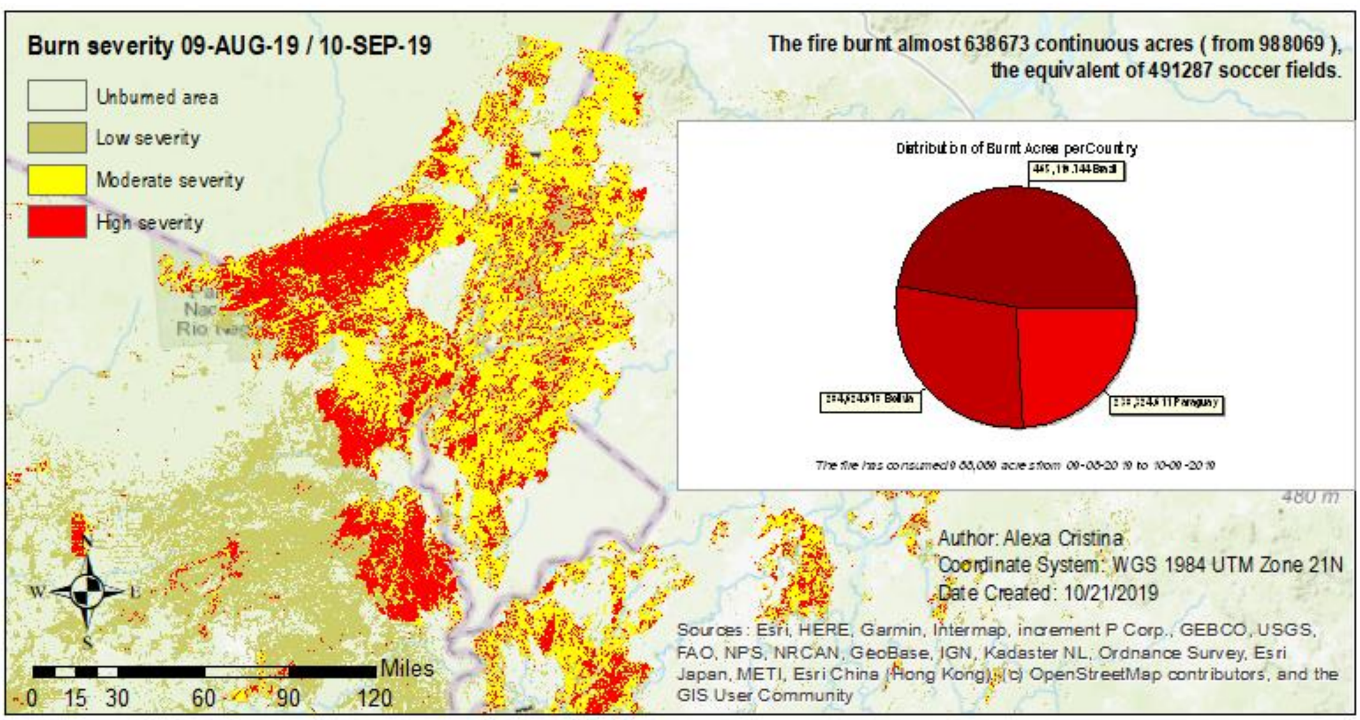
Those results can help fire managers to assess the extent of the damage and represents a baseline for forest regeneration plans.

A broader analysis would involve determining the cause for those frequent fires in the area (eg. deforestation). Also, for better burn severity assessment, we should correlate and compare results with field collected data.

August 2019 fire near the border of Bolivia, Paraguay, and Brazil

Natural Color vs Short Infrared 09-AUG-19, 25-AUG-19 and 10-SEP-19





CALCULATIONS AND OTHER DETAILS

FIRE DATA AND INFORMATION

- lat: -19.759907 decimal degrees
- long: -58.064725 decimal degrees
- fire start date: 09/08/2019
- fire end date: 10/09/2019
- mid-fire date: 25/08/2019

CALCULATING REFLECTANCE VALUE FROM THE SATELLITE DATA

This model implements the formulas published by the USGS for converting the quantized and calibrated scaled Digital Numbers (DN) representing multispectral image data acquired by Landsat 8 Operational Land Imager (OLI, bands 1 to 9) to Top of Atmosphere (ToA) Reflectance.

OLI spectral radiance data can also be converted to TOA planetary reflectance using reflectance rescaling coefficients provided in the landsat8 OLI metadata file (eg. LC08_L1TP_227074_20190809_20190820_01_T1_MTL). The following equation is used to convert DN values to TOA reflectance for OLI image:

- ρλ' = M ρQ cal + A ρ
- ρλ' = TOA planetary reflectance, without correction for solar angle. Note that ρλ' does not contain a correction for the sun angle.
- M ρ = Band-specific multiplicative rescaling factor from the metadata (Reflectance_Mult_Band_x, where x is the band number)
- A ρ = Band-specific additive rescaling factor from the metadata (Reflectance_Add_Band_x, where x is the band number)
- Q cal = Quantized and calibrated standard product pixel values (DN)

Eg. Raster calculator (Arc toolbox >Spatial Analyst tool > Map Algebra tool > Raster Calculator tool)

Band 5 reflectance= (2.0000E-05 * ("sub_tif_Band_5”)) + -0.100000

Where

REFLECTANCE_MULT_BAND_5 = 2.0000E-05

RFLECTANCE_ADD_BAND_5 = -0.100000

sub_tif_Band_5= 5th band (NIR band)

CORRECTING THE REFLECTANCE VALUE WITH SUN ANGLE

- Reflectance with a correction for the sun angle is:
- $\rho\lambda = \rho\lambda\,'/\cos\theta SZ = \rho\lambda\,'/\sin\theta SE$
- $\rho\lambda$ = TOA planetary reflectance
- θSE = Local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (Sun Elevation).
- θSZ = Local solar zenith angle; $\theta SZ = 90° - \theta SE$.

Eg. Band 5 corrected_ reflectance= ("5th_rflctnce") / Sin (49.36816761)

Where:

SUN_ELEVATION = 49.36816761

5th_rflctce =uncorrected reflectance

NORMALIZED BURN RATIO (NBR)

The Normalized Burn Ratio (NBR) is an index designed to highlight burnt areas in large fire zones. The formula is similar to NDVI, except that the formula combines the use of both near infrared (NIR) and shortwave infrared (SWIR) wavelengths.

Healthy vegetation shows a very high reflectance in the NIR, and low reflectance in the SWIR portion of the spectrum (Figure 2) - the opposite of what is seen in areas devastated by fire. Recently burnt areas demonstrate low reflectance in the NIR and high reflectance in the SWIR, i.e. the difference between the spectral responses of healthy vegetation and burnt areas reach their peak in the NIR and the SWIR regions of the spectrum.

To benefit from the magnitude of spectral difference, NBR uses the ratio between NIR and SWIR bands, according to the formula shown below. A high NBR value indicates healthy vegetation while a low value indicates bare ground and recently burnt areas. Non-burnt areas are normally attributed to values close to zero.

The difference between the pre-fire and post-fire NBR obtained from the images is used to calculate the delta NBR (dNBR or ΔNBR), which then can be used to estimate the burn severity.

A higher value of dNBR indicates more severe damage, while areas with negative dNBR values may indicate regrowth following a fire. The formula used to calculate dNBR is illustrated below:

dNBR values can vary from case to case, and so, if possible, interpretation in specific instances should also be carried out through field assessment; in order to obtain the best results. However, the United States Geological Survey (USGS) proposed a classification table to interpret the burn severity, which can be seen below (Table).

ΔNBR	Burn Severity
< -0.25	High post-fire regrowth
-0.25 to -0.1	Low post-fire regrowth
-0.1 to +0.1	Unburned
0.1 to 0.27	Low-severity burn
0.27 to 0.44	Moderate-low severity burn
0.44 to 0.66	Moderate-high severity burn
> 0.66	High-severity burn

Burn severity data and maps can aid in developing emergency rehabilitation and restoration plans - post-fire. They can be used to estimate not only the soil burn severity, but the likelihood of future downstream impacts due to flooding, landslides, and soil erosion.

- Calculating NBR from 4th and 5th bands
- NBR = (NIR – SWIR)/(NIR + SWIR)
- NBR= (Band 5 corrected -Band 7 corrected)/ (Band 5 corrected + Band 7 corrected)

Create the post-fire NBR

- Raster Calculator (Spatial Analyst Tools | Map Algebra | Raster Calculator)
- Float("LC08_L1TP_227074_20190809_band5.tif" - "LC08_L1TP_227074_20190809_band7.tif") / ("LC08_L1TP_227074_20190809_band5.tif" + "LC08_L1TP_227074_20190809_band7.tif")

- nbr = Int(Float(band_5_corrected - band_7_corrected) / (band_5_corrected + band_7_corrected)*1000)

Calculating dNBR from Reflectance

- dNBR = (pre-fire NBR) – (post-fire NBR)
- Raster Calculator
- "LC08_L1TP_227074_20190809_nbr.tif" - "LC08_L1TP_227074_20190825_nbr.tif"
- LC08_L1TP_227074_dnbr_midfire
- "LC08_L1TP_227074_20190809_nbr.tif" - "LC08_L1TP_227074_20190910_nbr.tif"
- LC08_L1TP_227074_dnbr_postfire

LANDSAT IMAGERY

- Pre-fire imagery:
  - https://earthexplorer.usgs.gov/metadata/12864/LC82270732019221LGN00/
  - ID:LC08_L1TP_227073_20190809_20190820_01_T1
  - Path:227
  - Row:73
  - Acquisition Date:09-AUG-19
  - https://earthexplorer.usgs.gov/metadata/12864/LC82270742019221LGN00/
  - ID:LC08_L1TP_227074_20190809_20190820_01_T1
  - Acquisition Date:09-AUG-19
  - Path:227
  - Row:74
- Mid-fire imagery:
  - https://earthexplorer.usgs.gov/metadata/12864/LC82270732019237LGN00/
  - ID:LC08_L1TP_227073_20190825_20190903_01_T1
  - Acquisition Date:25-AUG-19
  - Path:227
  - Row:73
  - https://earthexplorer.usgs.gov/metadata/12864/LC82270742019237LGN00/
  - ID:LC08_L1TP_227074_20190825_20190903_01_T1
  - Acquisition Date:25-AUG-19
  - Path:227
  - Row:74
- Post-fire imagery:
  - https://earthexplorer.usgs.gov/metadata/12864/LC82270732019253LGN00/

- ID:LC08_L1TP_227073_20190910_20190917_01_T1
- Acquisition Date:10-SEP-19
- Path:227
- Row:73
- https://earthexplorer.usgs.gov/metadata/12864/LC82270742019253LGN00/
- ID:LC08_L1TP_227074_20190910_20190917_01_T1
- Acquisition Date:10-SEP-19
- Path:227
- Row:74

Landsat imagery measures ranges of wavelengths of the electromagnetic spectrum, including some that are invisible to the human eye. These ranges are called "spectral bands." The bands from Landsat 8 are described in the following table:

Number	Name	What this band shows best
1	Coastal Aerosol	Shallow water, fine dust particles
2	Blue	Deep water, atmosphere
3	Green	Vegetation
4	Red	Man-made objects, soil, vegetation
5	Near Infrared	Shorelines, vegetation
6	Shortwave Infrared 1	Cloud penetration, soil and vegetation moisture
7	Shortwave Infrared 2	Improved cloud penetration, soil and vegetation moisture
8	Panchromatic	Black-and-white imagery, crisper detail
9	Cirrus	Cirrus clouds
10	Thermal Infrared 1	Thermal mapping, estimated soil moisture
11	Thermal Infrared 2	Improved thermal mapping, estimated soil moisture

Bands 2, 3, and 4 (Blue, Green, and Red) make up the spectrum of light visible to the human eye (the Natural Color band).

Combinations 654, 754, 753 (Red, Near Infrared, and Shortwave Infrared 1 or 2) emphasize the vegetation and penetrate the clouds.

Making forests greener is a simple matter of merging your 4-3-2 image with a 7-5-3 quasi-natural color image that depicts growing vegetation as bright yellow green.

REFERENCES

- https://earthexplorer.usgs.gov
- https://earthobservatory.nasa.gov/images/145522/fire-burns-in-paraguay-bolivia-and-brazil
- https://learn.arcgis.com/en/projects/assess-burn-scars-with-satellite-imagery/lessons/calculate-the-burn-index.htm
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- https://wiki.landscapetoolbox.org/doku.php/remote_sensing_methods:normalized_burn_ratio