# Carbon Estimation Released by Amazon Fire in 2019


Team 10

| | |
|---|---|
| Liujun Wang | 1008015 |
| Hirokazu Saigusa | 972201 |
| Bingkun Chen | 992113 |

## 1.INTRODUCTION

Recently, serious forest fires have been occurring in the Amazon rainforest region. According to data released by the National Space Research Institute of Brazil (2019), there have been 75,336 forest fires in Brazil this year with an increase of 85percent over the same period last year, more than half of which is located in the Amazon rainforest.

Forest fire is one of the main disturbance factors for forest ecosystem which is causing the decrease of vegetation and soil carbon storage. Large amount of carbonaceous gases can be released due to the fire, marking significant impacts on the atmospheric carbon balance and global climate change (*Crutzen and Andreae, 1990*). Therefore, scientific and effective estimation of carbon emissions from forest fire is important to understand its impact on the carbon balance and climate change.

Our project selected three fire locations as study areas and utilised the Difference Normalized Burn Ratio (dNBR) to identify burnt areas. Then, based on the forest fire loss biomass measurement method proposed by Seiler and Crutze (1980), we estimated the fire carbon emissions of the study areas. Finally, the carbon emissions of the three study areas were utilised for the estimation of the total carbon emissions in the Amazon region, so that the impact of the Amazon rainforest fires in 2019 can be evaluated.

There are two types of output for our project: image results and numerical results. The image results show the distribution of carbon emissions from fires in each study area, and the numerical results are the total carbon emissions of each study area and a series of related calculation results. According to research by Crutzen and Andreae (1990), forest fires occur mainly in the form of above-ground vegetation burning. Vegetation burning will release carbonaceous gases, so carbon emissions can be used as an indicator to assess the severity of forest fires. In addition, carbon dioxide gas is the main cause of the greenhouse effect, so the impact on global climate change can be evaluated by carbon dioxide emissions. Therefore, the value of output can be summarized as follows: On the one hand, the results are used quantitatively and qualitatively to assess the severity of the 2019 Amazon rainforest fire. On the other hand, evaluate the impact of this fire on global climate change through identifying the level of $CO_2$ contribution by the fire occurred so far in 2019.

### *Study Area*

Figure 1 shows the location of fires in the Amazon region in 2019. Firstly, we identified the fire areas in the Brazilian Amazon forest. Followingly, we identified high-density, medium-density, and low-density areas considering the distribution of fire by observation of VIIR data that we obtained, then selected three different areas that contain high fire density and less amount of the cloud for our study area (red boxes in Figure 1). The location information of the study area is as follows;

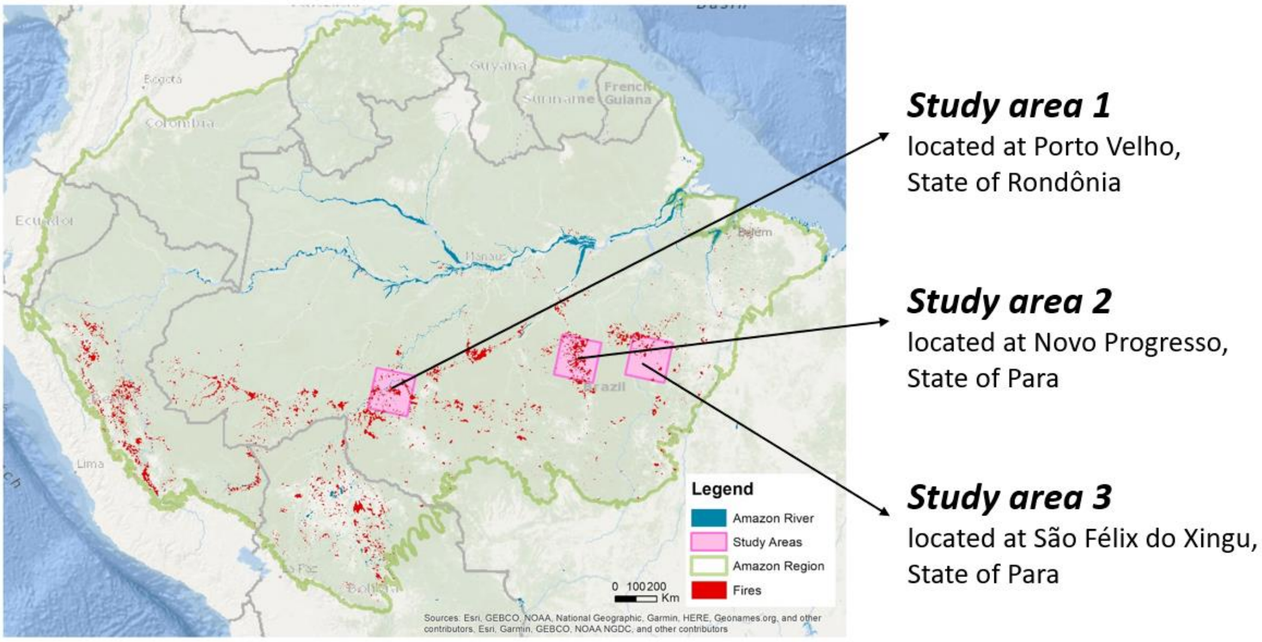



*Figure 1. Fire location detected by VIIRS*

## 2.DATASETS AND METHODS

***Datasets***

There are three datasets processed in this project, which are three Landsat8 Collection 1 Level-1 images, global map of aboveground biomass (GEOCARBON), and VIIRS active fire data. The Landsat8 images were obtained from the EarthExplorer website, which operated by the UGSG (United States Geological Survey). The time range of the data for three study areas is in three months in the year 2019, either from May to August or June to September as the fire events are normally suppressed during the rainy season, which runs roughly from mid-December to May in Amazon area (Nature Tours, 2019). In order to attain the best results, the cloud cover of the downloaded all Landsat8 OLI/TIRS (Operational Land Imager and Thermal Infrared Sensor) C1 Level-1 images were controlled to less than 20percent, whose resolution is in 30 metres.

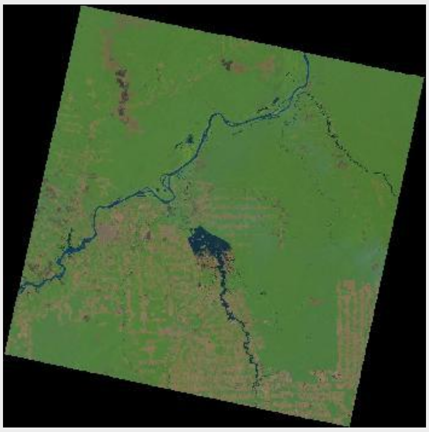
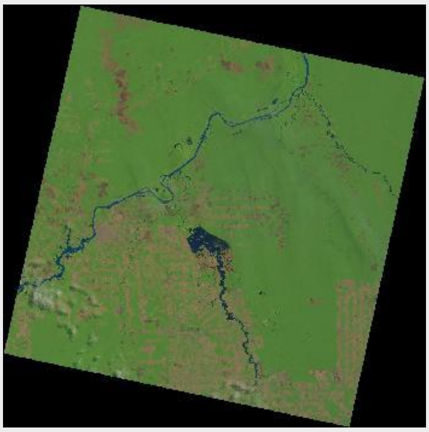
The GEOCARBON image was obtained from Lucid (Land Use, Carbon & Emission Data) website. The data was originally provided by the EU FP7 GEOCARBON project (*Avitabile et al., 2014*). This data shows the aboveground biomass density of the forest (dominance of tree cover) in units of megagram per hectare, and the resolution is in 0.01 decimal degree.

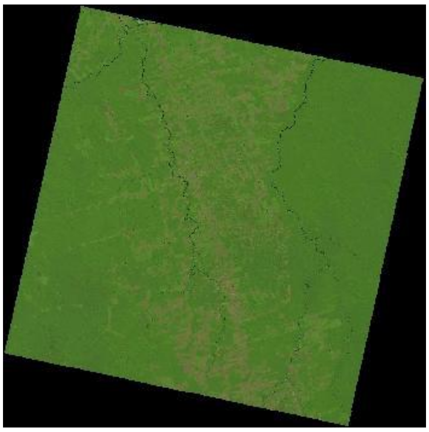
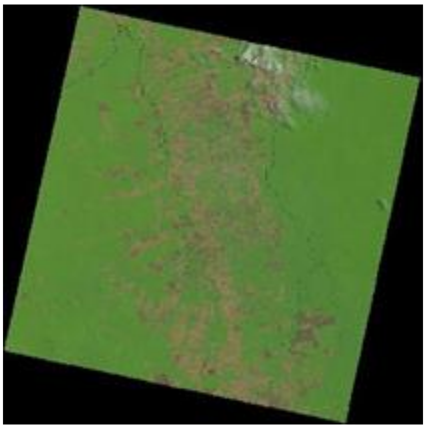
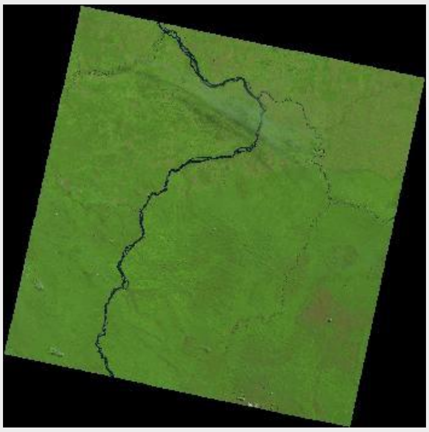
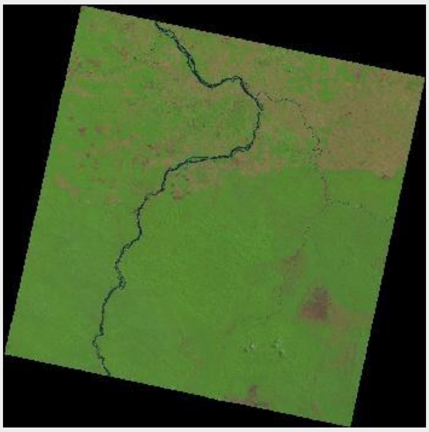
The VIIRS (Visible Infrared Imaging Radiometer Suite) active fire data was accessed from EARTHDATA, which is run by NASA. The original data was from VIIRS I-band in 375 metres resolution. The active fire product used in the project is in txt format, where the latitude and longitude values were built based on the centre of nominal 375 m fire pixel. As the accessible daily data was limited for the last two months, there are 28 text files downloaded from the website covering August 2019.

*Table 1. The datasets and its source in this project*

| Items | Source |
|---|---|
| Study area's Landsat 8 images | https://earthexplorer.usgs.gov |
| Global map of aboveground biomass | http://lucid.wur.nl/datasets/high-carbon-ecosystems |
| Fire location detected by VIIRS | https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/active-fire-data |

*Table 2. Landsat8 OLI/TIRS C1 Level-1 images, including Path/Row, ID, and acquisition date.*

| | |
|---|---|
|  |  |
| Path: 232, Row: 66 (location1) | |
| LC08_L1TP_232066_20190508_20190521_01_T1 | LC08_L1TP_232066_20190828_20190903_01_T1 |
| 08-MAY-19 | 28-AUG-19 |

| | |
|---|---|
|  |  |
| Path: 227, Row: 65 (location2) | |
| LC08_L1TP_232066_20190508_20190521_01_T1 | LC08_L1TP_232066_20190508_20190521_01_T1 |
| 22-JUN-19 | 10-SEP-19 |
|  |  |
| Path:225, Row:65 (location3) | |
| LC08_L1TP_225065_20190507_20190521_01_T1 | LC08_L1TP_225065_20190827_20190903_01_T1 |
| 07-MAY-19 | 27-AUG-19 |

***Methods***

Our basic ideology to analyse the Carbon release is to estimate the coverage of burnt trees in the study area. The Carbon release has a potential relationship with the total burnt area, aboveground biomass density, the ratio of Carbon in biomass, and the burning efficiency of trees (Eq.1) (*Seiler, W. & Crutzen, P.J., 1980*):

$$C_t = A \cdot B \cdot f_c \cdot \beta \qquad (1)$$

(Ct is the total carbon emission; A is the total burnt area; B is the aboveground biomass density; fc is the ratio of Carbon in biomass; β is the burning efficiency)

We used ENVI and ArcMap as the software for processing. The first step we did was to remove clouds from each study area. The Quality Assessment (QA) bands from before fire and after fire files were used to determine the cloud coverage. According to the USGS, the QA band in Landsat collection 1 Level-1 stored the information of surface, atmospheric, and sensor conditions which can influence the pixel's quality (*USGS*, 2019), including the cloud. We decoded the QA band using the Decision Tree in ENVI (Eq.2). Pixel values which higher than or equal to 2800 were interpreted as clouds responding to the high cloud confidence, cloud shadow and high cirrus confidence in attribute table provided by the USGS (2019).

$$\text{(b1 GE 2800) OR (b2 GE 2800)} \qquad (2)$$

Before and after fire decoded BQA files were combined to build the cloud mask. Then, after the before and after fire Landsat images stacking and subset processes, both images were masked under the cloud mask.

The images were displayed into 7, 5, 2 false colour band combination to better visualize the vegetation and waterbody with the help of the SWIR band (*Peters, 2015*). We created several ROIs for forest, other vegetation, waterbody, and other (such as urban and barren land). In order to get the forest covering area as well as to remove the waterbody from the images, Mahalanobis Distance Classification was applied to obtain before and after fire forest and waterbody layers. This supervised classification method is directorial sensitive in distance that is suitable for complex shapes. Images of our study area do not have simple correlation in point clouds (Fig. 2) due to cirrus clouds covering some parts of each study location. In this situation, it is more efficient to choose this classification algorithm method than others (*Ukrainski, 2017*).

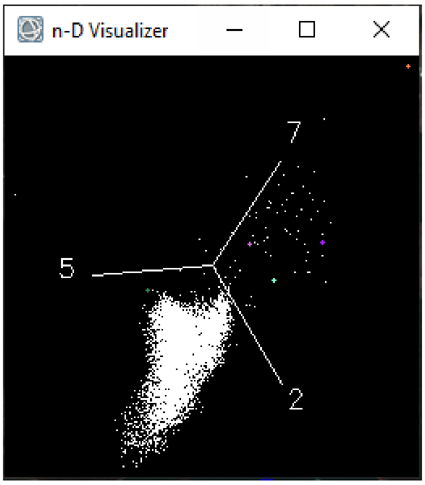



*Figure 2. The n-D Visualizer showing location1 before fire image with complex point clouds*

After several testing progresses, the final output includes 4 classes for both before and after fire images. Among these classes, the waterbody classes were exported and combined together to produce the waterbody mask, and the before fire forest class was exported for later on usage. After applying waterbody mask on before and after images, we calculated the NBR (Normalized Burn Ratio) values from both images with the following equation (Eq.3). Afterwards, we used the Band Math to calculate dNBR image (Difference Normalized Burn Ratio) under the expression "b2-b1" to obtain the burnt area (Eq.4). *(Lopez, 1991; Key and Benson, 1995)*

$$NBR = \frac{(NIR - SWIR)}{(NIR + SWIR)} \qquad (3)$$

$$dNBR = PrefireNBR - PostfireNBR \tag{4}$$

NBR calculation involves the NIR and SWIR bands combination which are appropriate for distinguishing the burnt areas due to reflectance difference (Fig. 3). Landsat8 has two SWIR bands (SWIR 1 wavelength: 1.57 - 1.65 micrometres, SWIR 2 wavelength: 2.11 - 2.29 micrometres), we used the latter band, since the reflectance difference is larger. The output image has the index range encompassing the value from -0.1 to 0.66. According to the USGS FIREMON program publication of burn severity categories (*Key and Benson, 2006*), the best assumption would be that the pixel index higher than +0.1 is considered as burnt area. Colour slice tool was applied to classify the dNBR image, and the burnt area image was exported as GeoTIFF file.

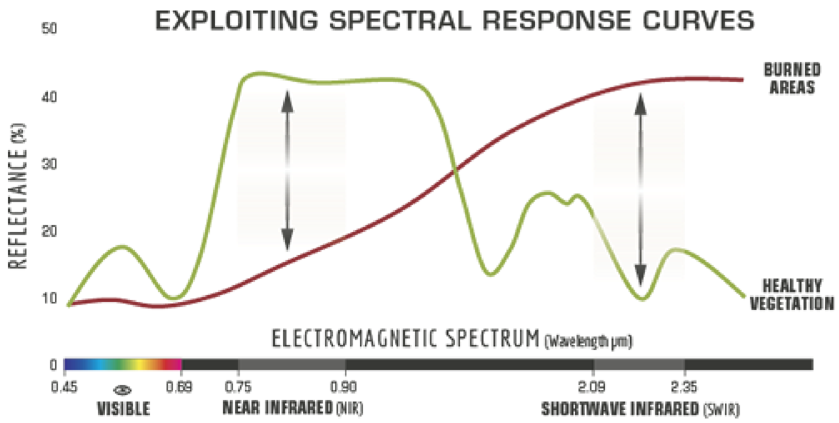



*Figure 3. The reflectance for the burnt areas in the NIR region tends much lower compared to the healthy vegetation but much higher than that in the SWIR. Credit: U.S. Forest Service*

The following steps were completed in ArcMap. Since the burnt area raster might also include the undesirable values which could have no relevance to the forest, the area where is not tree before fire was removed from the burnt area raster using raster calculator with the raster of before fire forest layer. The final burnt area raster shows the predicted burnt locations determined by our model. The total Carbon emission was calculated by the equation at the beginning (Eq.1). Global Aboveground Biomass data was used for aboveground biomass density (B). The raster calculator would run the equation pixel by pixel, so each "burnt pixel" corresponds to each B value. This means only the pixels have the biomass density value and been considered as burnt would be measured as carbon released location. Thus, burnt area (A) would be in the pixel size (30m*30m). The ratio of carbon in biomass (fc) used in this project is 45percent, which has been mentioned in a paper discussed biomass burning (*Levine, et al., 1995*). The burning efficiency would be constrained to certain environments and locations. Consequently, we used 25percent as the efficiency value which came from a previous paper also talked about the amazonian rainforests (*Fearnside, et al., 2001*). The final output from the raster calculator was the total Carbon emission in each study area in tonne unit.

In order to estimate total Carbon emissions from entire Brazil, the carbon emissions from each of the three study areas were applied to our model. We suppose that the ratio of emission will be expressed in the following equation (Eq.5):

$$\frac{F_{in}}{C_{in}} = \frac{F_{Total}}{C_{Total}} \tag{5}$$

($F_{in}$ is the fires located in the study area; $F_{Total}$ is all fires in records in the Amazon region; $C_{in}$ is the Carbon release in the study area; $C_{Total}$ is the Carbon release in Amazon region)

The fire records data we used was from VIIRS, which in txt format. As mentioned in Datasets section, there were 28 files downloaded. These files were compiled into one csv. file and imported into the ArcMap as points (using “Add XY Data” tool). The study area polygons were exported from each Landsat images. Then the points inside of each study area was selected from the entire Brazil fire points data (shapefile) using “Select By Location” tool with within function. We obtained the ratio of fires that happened in each study area by calculating the numbers of points within and dividing the numbers by the total number of fires (points number). Finally, using the fire records ratio and the Carbon release in the study area, we obtained the estimated value of total Carbon emission from Brazil.

Our results would be compared to the entire amount of the world-wide Carbon Dioxide emissions and discuss in the next section for the level of $CO_2$ contribution by this year’s fire.

## 3. RESULTS AND DISCUSSIONS

***Results in each study area***

<u>Location 1</u>

The result imagery of Carbon emission in location 1 shows the burnt area highly corresponding to the fires detected by VIIRS. The burnt locations mostly occur near the croplands and tend to cluster in certain areas as seen in the east north of the study area, which could infer that the fires in this location were mostly in directional and non-natural. The map also shows there were more fires and higher value of carbon emission in the eastern area. It could be caused by different tree types, tree density, and urban development, where the fires are supposed to be relatively in control as being near the city. There are 865,469 pixels classified as the burnt area in study area 1. The number of fire incidents in the study area was counted to be 6,964. And the total Carbon emission in this area is 1838,717 Megagrams (Tons).

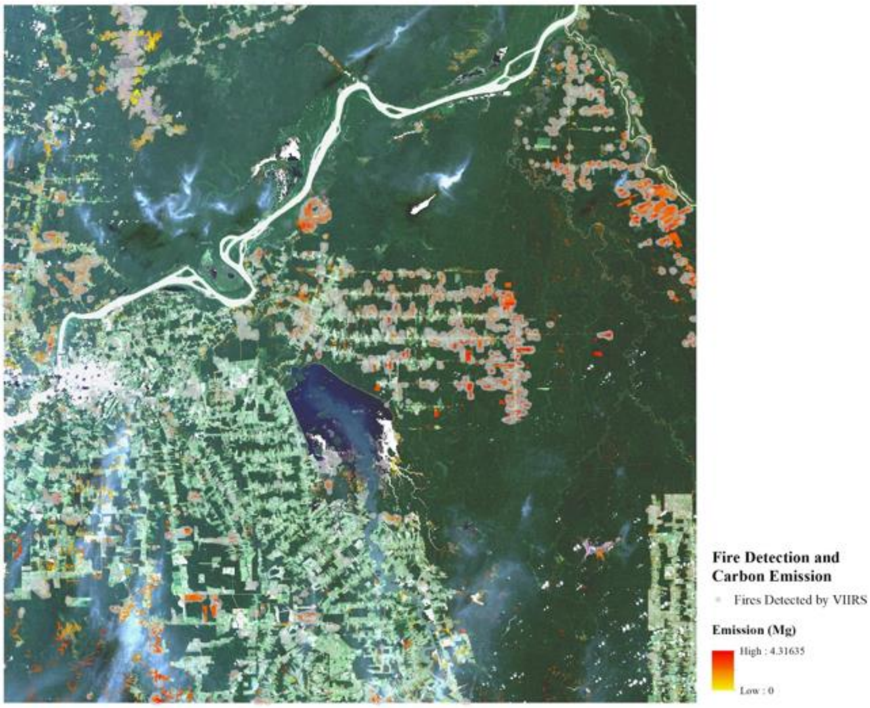



*Figure 4, The result of study area number 1*

*Location 2*

From the dNBR result imagery, the fire area in this zone was observed to be more extensive than the other two locations. The detected burnt areas tend to cluster as a bunch of contiguous blocks, and widely distributed in the observation area. From this result, it can be concluded that this site suffered the most by the fire among the other two study areas. In addition, the carbon emission from location 2 shows that the high carbon emissions are concentrated in the southeastern part of the study area, which can derive from the fact that geomorphological features of the area are mainly composed of forest. The final numerical results show that there are 1,835,954 pixels classified as the burnt area. The number of fire incidents in the study area was counted to be 13,722 and the total Carbon emission in this area is 4,248,584 Megagrams (Tons).

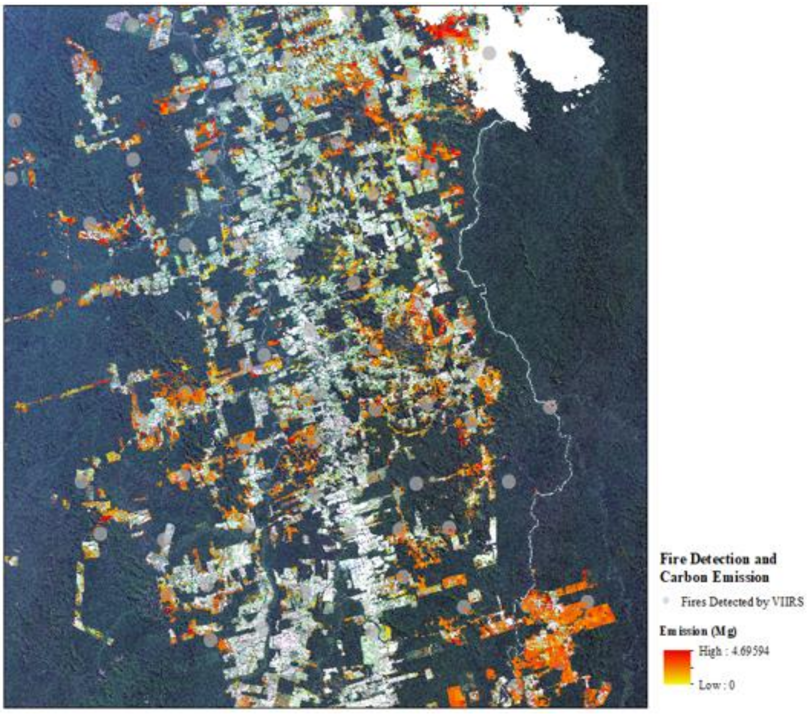



*Figure 5, The result of study area number 2*

*Location 3*

The result imagery of Carbon emission in location 3 shows that the burnt area is mainly clustered in the deep forest area around the centre of the image (See red circle area in Fig.5). The majority of the burnt area pixels are observed as individual dot points, which could suggest that although the study area suffered a number of small size fires, each of fire events was not extensive. The northwest part of the study area showed several sparse burnt areas. The northeast area shows another cluster of fire event. However, a dense cloud extends largely in the area preventing extracting the pixels beneath, which possibly affect the estimation of carbon emission in this study area. There are 156,997 pixels classified in the burnt area. The number of fire incidents in the study area was counted to be 3,116. The total Carbon emission in this area is calculated to be 335,092 Megagrams (Tons).

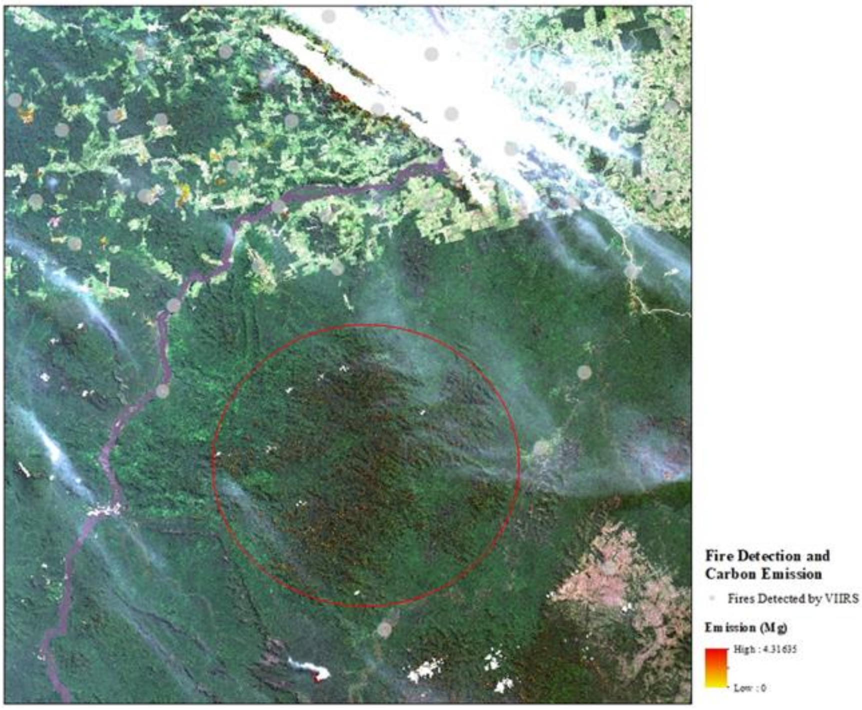



*Figure 6, The result of the study area number 3*

***Comparison of the result to the total carbon emission of Brazil / worldwide emission***

Followingly, based on the carbon emission in each study area obtained in the previous section (Table 3), the total amount of carbon emitted in the fires occured in the study period in Brazilian Amazon area was estimated as 78,7 Megatonnes from location 1 result, 83.1 Megatonnes from location 2 result and 32.1 Megatonne from location 3 result, respectively.

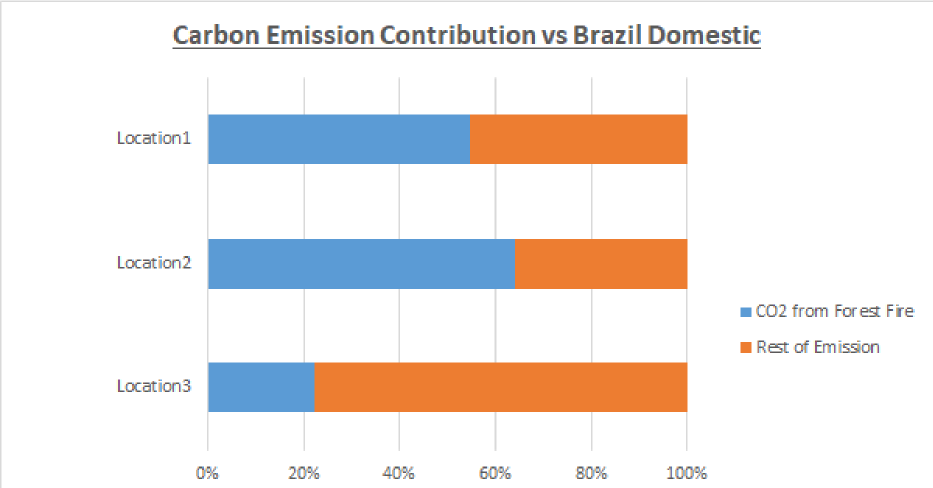
*Table 3, Estimated carbon emission in each study area*

| | Location1 | Location2 | Location3 |
|---|---|---|---|
| C(Mg) | 1,838,717 | 4,248,584 | 335,092 |

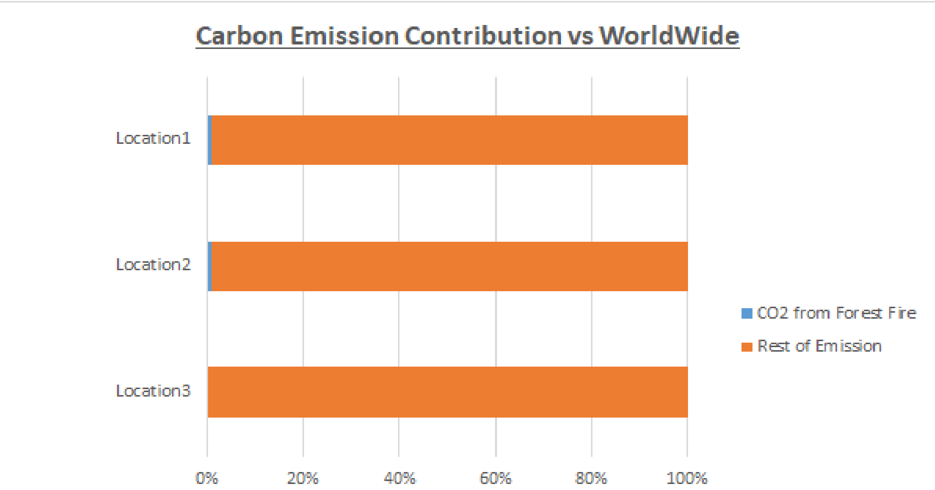
Consequently, the impact of this Amazon fire on the carbon emission of Brazil and that world-wide was estimated comparing in CO2 amount. According to Crutzen and Andreae (1990), approximately 90 percent of Carbon emission is composed of CO2. Utilising this ratio, the CO2 emissions of each site was calculated as; 260 Megatonnes for location 1, 305 Megatonnes for location 2 and 106 Megatonnes for location 3, considering the relative molecular weight of C in CO2. According to World Carbon Atlas (2019), the latest available fixed amount of CO2 emission is of 2017, and the total amount of CO2 emitted annually in Brazil was 476 Megatonne, which is ranked 13 among all countries, and that worldwide was 36,153 Megatonne in 2017. In case that the result of location 1 is relevant, the amount of CO2 released in the Amazon forest fire in 2019 comprises 54.6 percent of Brazil's yearly total emission and 0.7 percent of the world-wide emission. In case study site 2 is relevant, this will be approximately 64 percent of the total amount of that of Brazil annual emission and 0.8 percent of the world-wide emission. The estimate from location 3 result indicates the lowest contribution level, which results in 22 percent of Brazil's yearly emission amount and 0.3 percent of the world-wide emission.

*Table 4, Comparison of CO2 emission in each study site and annual Brazil / world-wide carbon emission*

| | Study Site 1 | Study Site 2 | Study Site 3 |
|---|---|---|---|
| CO2 by Fire (Mt) | 260 | 305 | 106 |
| Brazil Annual Emission 2017 (Mt) | 476 | 476 | 476 |
| Contribution (%) | 54.6% | 64.0% | 22.2% |
| Worldide emission 2017 (Mt) | 36153 | 36153 | 36153 |
| Contribution (%) | 0.7% | 0.8% | 0.3% |




| | Location3 | Location2 | Location1 |
|---|---|---|---|
| CO2 from Forest Fire | 106 | 305 | 260 |
| Rest of Emission | 370 | 171 | 216 |




| | Location3 | Location2 | Location1 |
|---|---|---|---|
| CO2 from Forest Fire | 106 | 305 | 260 |
| Rest of Emission | 36,047 | 35,848 | 35,893 |

## 4. DISCUSSION AND CONCLUSION

### *Discussion and conclusion*

The extent of burnt area and fire severity of each study area that we detected in our analysis varied significantly depending on the sites. One of the reasons for this is potentially due to the difference in topography of each study site such as the height, proximity to urban site, and vegetative composition.

The estimated amount of CO2 is considered to be of high significance. As observed in the result section, even though these estimated amounts were produced in three months, two of the CO2 emission amounts from the study area exceed half of Brazil's total annual CO2 emission. In comparison with the carbon emission data among each countries (*World Carbon Atlas, 2019*), the estimated carbon emission in the 2019 Brazilian forest fire in our analysis is approximately equivalent to that of Kazakhstan (293 Megatonne, ranked 22) in the estimation from the location 1 result, Malaysia (255 Megatonne, ranked 25) in the estimation from the location 2 result and Czech Republic (108 Megatonne, ranked 38) in the estimation from the location 3 result. From this fact, it can be concluded that the forest fires in the Amazon area that occured in our study period was significant enough to provide a large contribution to the world-wide carbon emission.

### *Issues and Limitations / Further works*

This research method considered to involve several issues and limitations. In terms of technical issues, the study areas suffered from the coverage of cloud which extends broad and thick enough to cover the area below, especially in case of location 3. It is considered inevitable because of the fact that the topographical characteristics of Amazon, as well as the fact that the imageries are obtained right after the fire incidents are favourable conditions for cloud formation.

Regarding the carbon estimation formula, the number of study areas are only three locations, which suggests the estimated carbon emission amounts in our analysis do not represent the precise amount emitted. In addition, the model variables employed in our research has limitations; the burn efficiency and carbon biomass ratio are specified in tropical forests, and the percentages were estimated from the research conducted in 1995 (burn efficiency) and 2001 (carbon biomass ratio). The actual Brazilian Amazon area comprises a wide range of vegetation types such as rainforests, croplands and grasslands, and the vegetation composition has been changing in Amazon forests due to the relentless climate change and deforestation.

Finally, although it is not direct limitation to the estimation of CO2 emission, our analysis does not consider the topographical effects such as the altitude of the area and proximity to urban areas, which can be critical to explain the varying significance of the fire among study areas. Considering these factors can improve how informative the model is.

In terms of the cloud coverage, this issue can be alleviated by increasing the number of the study area. For the model variables, incorporating variables from more recent research should improve the accuracy of the model prediction. Finally, in order to expand the informativity of the model, topographic effects should be included in further studies.

## REFERENCES

Avitabile, V, Herold, M, Lewis, SL, Phillips, OL, Aguilar-Amuchastegui, N, Asner, GP, Brienen, RJW, DeVries, BR, Gazolla Gatti, R, Feldpausch, TR, Girardin, C, de Jong, B, Kearsley, E, Klop, E, Lin, X, Lindsell, J, Lopez-Gonzalez, G, Lucas, R, Malhi, Y, Morel, A, Mitchard, E, Pandey, D, Piao, S, Ryan, C, Sales, M, Santoro, M, Vaglio Laurin, G, Valentini, R, Verbeeck, H, Wijaya, A & Willcock, S (2014). Comparative analysis and fusion for improved global biomass mapping. *The International Conference Global Vegetation Monitoring and Modeling* (GV2M). pp. 251-252, International Conference GV2M, Avignon, France

Crutzen, P. J., & Andreae, M. O. (1990). Biomass burning in the tropics: Impact on atmospheric chemistry and biogeochemical cycles. *Science*, *250*(4988), 1669-1678.

Fearnside, P. M., de Alencastro Graça, P. M. L., & Rodrigues, F. J. A. (2001). Burning of Amazonian rainforests: burning efficiency and charcoal formation in forest cleared for cattle pasture near Manaus, Brazil. *Forest Ecology and Management*, *146*(1-3), pp. 115-128.

Global Carbon Atlas (2019). 2017 Global CO2 Emissions [online] Available at: http://www.globalcarbonatlas.org/en/CO2-emissions [Accessed 20 October, 2019]

Key, C. and Benson, N. (2006). Landscape Assessment: Ground measure of severity, the Composite Burn Index; and Remote sensing of severity, the Normalized Burn Ratio. *FIREMON: Fire Effects Monitoring and Inventory System, RMRS-GTR-164*, pp. LA 1-51. USDA Forest Service, Rocky Mountain Research Station, Ogden, UT

Levine, J. S., Cofer R., W., Chahoon, D., R. and Winsted, E., L. (1995). A Driver For Global Change. *Environmental Science & Technology, 29 (3)*, pp. 120A-125A. DOI: 10.1021/es00003a746

National Space Research Institute of Brazil. (2019). Programa Queimadas. [online] Available at: http://queimadas.dgi.inpe.br/queimadas/portal-static/situacao-atual/ [Accessed 20 October, 2019]

Naturetours.com official homepage (2019). Weather & Seasons in the Central Amazon [online] Available at: https://www.naturetours.com/the-amazon-beckons/weather-seasons/ [Accessed 20 October, 2019]

Peters, J. (2015). The Many Band Combinations of Landsat 8, L3HARRIS GEOSPATIAL Official Homepage [online] Available at: https://www.harrisgeospatial.com/Learn/Blogs/Blog-Details/ArtMID/10198/ArticleID/15691/The-Many-Band-Combinations-of-Landsat-8 [Accessed 20 October, 2019]

Seiler, W., & Crutzen, P. J. (1980). Estimates of gross and net fluxes of carbon between the biosphere and the atmosphere from biomass burning. *Climatic change, 2(3)*, pp. 207-247.

Ukrainski, P (2017). How to Pick the Best Supervised Classification Method? *50northspatial*. [online] Available at: http://www.50northspatial.org/pick-best-supervised-classification-method/ [Accessed 20 October, 2019]

U.S. Forest Service (n.a.). How is BARC data generated? *Geospatial Technology and Applications Center (GTAC)*. [online] Available at: https://www.fs.fed.us/eng/rsac/baer/barc.html [Accessed 20 October, 2019]

USGS (2019). Landsat Collection 1 Level-1 Quality Assessment Band [online] Available at: https://www.usgs.gov/land-resources/nli/landsat/landsat-collection-1-level-1-quality-assessment-band?qt-science_support_page_related_con=0#qt-science_support_page_related_con [Accessed 20 October, 2019]

Wasser, L. & Megan, C. (2019). Work with the Difference Normalized Burn Index [online] Available at: https://www.earthdatascience.org/courses/earth-analytics/multispectral-remote-sensing-modis/normalized-burn-index-dNBR/ [Accessed 20 October, 2019]

# Appendix A. The calculation result of each study location

| | Location1 | Location2 | Location3 |
|---|---|---|---|
| Carbon emission (Study Area) (t) | 1,838,717 | 4,248,584 | 335,092 |
| Burnt Area Pixels | 865,469 | 1,835,954 | 156,997 |
| Fires (Study Area) | 6,964 | 13,722 | 3,116 |
| Fires (Brazilian Amazon Total) | 298,225 | 298,225 | 298,225 |
| Carbon emission (Brazilian Amazon Total) (t) | 78,740,864 | 92,335,954 | 32,070,864 |
| Carbon emission in CO2 (Brazilian Amazon Total) | 70,866,778 | 83,102,359 | 28,863,777 |
| CO2(t) (Brazilian Amazon Total) | 259,844,851 | 304,708,649 | 105,833,851 |
| CO2(Mt) (Brazilian Amazon Total) | 260 | 305 | 106 |