Simard’s Fire Spread Model of Peatland in Kalimantan

A. Muid1,2, N. S. Aminah2, M. Budiman2, M. Djamal2

1 Department of Physics, Universitas Tanjungpura, Pontianak, Indonesia
2 Department of Physics, Institut Teknologi Bandung, Bandung, Indonesia
muid@physics.untan.ac.id

Abstract. Peatland fires in Indonesia have become a serious problem because they cause huge losses. Geographical factors of peatlands in the Kalimantan contribute to the difficulty of conventional fire fighting. The current solution is water bombing using a helicopter. Water bombing is expensive and has a high risk for the safety of fire fighters/helicopter crew so must be done with the correct calculation to fire position so that firefighting can work effectively and efficiently. Therefore, mathematical calculation of the fire position is very important. The position of the fire can be determined by knowing the rate of spread of the fire (Rate of Spread / ROS). In this study aims to calculate the rate of fire in peatlands along the Trans Kalimantan road between Palangka Raya and Pulang Pisau, Central Kalimantan using the simard’s model. Land surface temperature (LST) data were obtained from the TERRA MODIS satellite which was downloaded from the website https://modis.gsfc.nasa.gov/data/dataprod/index.php. The results of the calculations for the five triangles obtained that the ROS are 0.03m/s, 0.04m/s, 0.04m/s, 0.04m/s and 0.03m/s for R1, R2, R3, R4 and R5 respectively. The average of ROS is 0.037m/s with a direction of 32.57 degrees.

Keywords: peatlandfire, rate of spread, Simard’s model, Land Temperature Surface

1. Introduction

Southeast Asia is the continent with the largest tropical peatland in the world which is about 56% of the best estimate of tropical peatland area is 441,025 km² which most of them are in Indonesia [1]. Peatlands in Indonesia are estimated between 13.5 - 26.5 million hectares [2]. Utilization of peatlands for human life has raised various problems such as deforestation, subsidence (land subsidence), flooding in the rainy season, drought in the dry season, and the more dangerous peatland fires [3]. Peatland fires produce huge amount of smoke and causes biological effects (flora and fauna), effects on human health (respiratory), effects on climate (global warming), and effects on the economy [4]. Therefore, studies on peatland fire detection are crucial for peatland fire management. Peatland fire is not enough with prevention but it requires further action such as fire fighting. For a firefighting to work effectively it is necessary to calculate the rate of spread (ROS) of the fire.

The rate of fire spread is defined as a measure of the speed at which the fire is developing forward, backward or flanking relative to the direction of the spread of the fire. The rate at which fires spread can also be measured by measuring the increase in the area burned [5]. The rate of spread of fire as the rate at which the fire moves from its original location. The parameters that drive fire are wind, slope and humidity. At the head of the fire, it has a high intensity and the fire moves away from its origin quickly. The spread of fire is similar to chaos theory which can be considered as a non system with characteristic features, such as being sensitive to certain input conditions, fire spread rate and fire intensity which can experience a sudden increase and bimodality in their distributions [6].
Fire behavior can be seen from the large rate of fire spread because the rate of fire spread is the main parameter describing fire behavior. Meanwhile, other parameters of fire behavior are influenced by weather, topography, and materials. Fire spread rate is usually used as an important parameter in fire management and research operations.

A method of measuring the rate of spread of fire has been developed by Abouali et al. which is called the ros calculator [7]. This calculator was built using MATLAB to calculate and construct a contour map of the spread of fire propagation running an algorithm used to process image processing images from the camera used to record the spread of fire. This calculator can be used to analyze the behavior of land fires. This research proposes to prevent the spread of fire by calculating the rate of spread (ROS) of fire. In this paper, another method is used, namely the Simard method. The Simard model is a technique for calculating the rate of fire spread using the time parameter of the fire that reaches three different points (triangles) on the land. If the rate of spread of the fire over several triangles can be calculated, then the average rate of the spread of the entire fire can be calculated [8].

In this study, the temperature data that will be used to calculate the ROS are temperature data obtained from the satellite. The results of the ROS calculation are then analyzed to predict the rate and direction of fire spread. The analysis results are used to determine the position of the water boomong.

2. Experimental Method

In this research, a simulation has also been carried out to calculate the spread of fires. The calculation of the rate of spread of fire on peatlands using Simard's Model. The rate of fire spread (ROS; m / s) is calculated using an equation that applies the principle of triangular geometry. This method calculates the rate of fire spread rate using three points of time when the front of the fire arrives. The three points form a triangle so mathematically if the time of arrival of the front of the fire to the top of the triangle is known, the rate of spread of the fire can be calculated and the direction of the spread of the fire can be calculated. The experiment is to calculate the spread of fires on peatlands in Central Kalimantan on the Trans Kalimantan road, between Palangka Raya - Pulang Pisau, Province of Central Kalimantan. A map of the locations of peatland fires for which the fire rate will be calculated is shown in Figure 1.

For simulation, this research uses daily surface temperature (LST) data derived from remote sensing data using satellites. The peatland surface temperature (LST) was obtained from the TERRA MODIS satellite data available on the website https://modis.gsfc.nasa.gov/data/dataprod/index.php.

Figure 1. Location of Peatland as object of study in Trans Kalimantan Highway, Palangka Raya, Central Kalimantan
This study calculates the ROS rate using the Simard model; it is done in the following steps. The first step is to find data records of the land surface temperature daily of burned peatlands that occurred on August 25, 2002, in the area between Palangka Raya - Pulang Pisau, which geographically is located at the coordinates 02° 10’ – 03° 00’ South Latitude and 113° 40’ – 114° 20’ East Longitude. This data can be obtained from the NASA satellite, which can be downloaded on its website is shown in the Figure 2. The data is provided in the form of a file with the extension *.hdf.

The second step is to select existing data. Data is selected according to the location (coordinates) in accordance with the object of research. In this study, data covering the Kalimantan island area were selected as shown in Figure 3.
The third step is that the file is opened using the Panoply application software as shown in Figure 4.

Figure 4. Opening and data retrieval using Panoply software.

The fourth step is to process the data by importing data and plotting the data using Matlab to get a data visualization as shown in Figure 5.

Figure 5. Importing and Plotting the data to processing on Matlab

The fifth step is to apply a simard model to calculate ROS on a map of the distribution of surface temperature of peatlands as shown in Figure 6.
The rate of spread was calculated using the Simard’s model. This method computes a value of the rate of spread within a triangle knowing the time of arrival of the fire to the triangle's vertexes. The method has been grown for field fire experiments to resolve a problem in ROS estimation. They studied an equation that measures ROS passing through a triangle separately from fire spread direction as shown in Figure 7.

\[ \theta = \tan^{-1} \left( \frac{t_3 - t_1}{t_2 - t_1} \right) \left( \frac{b}{c \sin A} \right) - \left( \frac{1}{\tan A} \right) ; \quad t_2 \neq t_1 \]  

\[ ROS = \frac{b \cos \theta}{t_2 - t_1} \]  

Where:
- \( t_1, t_2, t_3 \) = time that the fire arrive at the first, second and third vertices of triangle.
- \( \theta \) = angle of spread relative to a base line between \( t_1 \) and \( t_2 \).
- \( b \) = length of the base side from which \( \theta \) is measured.
- \( c \) = length to the side which for with \( b \) and the \( A \) angle.
- \( A \) = angle formed by \( b \) and \( c \).

Select a fire origin point on the surface temperature distribution map (August 25, 2002 at 05.30 a.m) by calling it point S1. Determine two fire spots on the surface temperature distribution map on August 25 at 05.50 p.m by
calling them S2 and S3. Calculate the time and distance between S1 and S2, S1 and S3. Calculate the rate of spread of the fire using equations (1) and (2).

3. Result and Discussion
The results of this experiment produce a map of the surface temperature distribution on peatlands in Palangka Raya - Pulang Pisau on 25 August 2002 at 05.30 and 05.50 as shown in Figures 8 and Figure 9. On Figure 8, the map shows temperature and location of the peatland fires that occurred at 5.30 a.m. S1 is area on fire but S2 and S3 have not been burned.

![Figure 8. The map of temperature distribution on peatland during a fire at 05.30 a.m.](image)

![Figure 9. The map of temperature distribution on peatland during a fire at 05.50 p.m.](image)
The map shows a change in temperature at the same location on peatland that occurred at 5:50 p.m. In areas of S2 and S3 it burns. By using the time and distance data obtained, it can be used to calculate ROS. The map shows a fire in S2 area and S3 after 12 hours and 20 minutes at direction are 23.49 degrees from the initial position of fire (S1) with a rate of spread is 0.04m/s.

The area used as the object of research is located in Palangka Raya. Palangka Raya is the capital of the province of Central Kalimantan. Geographically, Palangka Raya is located between 113°30’ – 114°04’ East Longitude and 1°30’ – 2°30’ South Latitude. The total area of Palangka Raya is 284,250 Ha or 2842.5 km². Topographically, the entire Palangka Raya area is below 100 masl. Based on the slope level of the land, Palangka Raya is an area with a flat to gentle slope with a slope ranging from 0 - 40%.

The air temperature in the Palangka Raya region ranges from 22 °C - 32 °C with a relative humidity level of ± 83%. Based on the Koppen climate classification, Palangka Raya has a tropical rainforest (Af) climate. The rainfall in the Palangka Raya region ranges from 2,300-2,700 mm per year. The maximum rainfall occurs in March with monthly rainfall of more than 280 mm per month and minimum rainfall occurs in July with monthly rainfall of 106 mm per month. The highest average temperature is 31.7°C at August and 32.2°C at September [9].

Palangkaraya is an area which land fires occur almost every year. Most of Palangkaraya area is lowland of peatland with shrub vegetation. There is a large river in around of research area. It is possible that the peat has been damaged due to land use changes such as plantations, residensial and agriculture which causes peat water to flow into large rivers. This causes the water level of the peat to drop so that the peat becomes dry, especially during the dry season and dry peat becomes flammable.

Every two months per year in Central Kalimantan is dry season with a mean monthly rainfall of about 100 mm are July and August. the dry month is if mean monthly rainfall less than 100 mm and a wet month is mean monthly rainfall more than 200 mm. the effect of El Niño is an abnormally long dry season as in the case of 1982, 1987, 1991, 1994, 1997 and 2002. The El Niño causes large areas of peatland potential to fire [9,10].

Satellite data has weaknesses in terms of spatial and temporal resolution. Spatially the better resolution is less than 1 km. Temporally, the satellite takes data twice a day so that there is a long interval. The data provided is very large so it requires accuracy in selecting the appropriate data.

The results of calculating the rate of fire spread (ROS) on peatlands in Palangka Raya - Pulang Pisau can be seen in table 1. The results of the calculations for the five triangles obtained that the ROS are 0.03m/s, 0.04m/s, 0.04m/s, 0.04m/s and 0.03m/s for R1, R2, R3, R4 and R5 respectively. The average of ROS is 0.037m/s with a direction of 32.57 degrees.

| ROS | A (degrees) | b (m) | c (m) | t1 (s) | t2 (s) | t3 (s) | r (m/s) | θ (degrees) |
|-----|-------------|-------|-------|-------|-------|-------|--------|------------|
| 1   | 45          | 2000  | 1414  | 0     | 44400 | 44400 | 0.03   | 46.25      |
| 2   | 45          | 2000  | 2236  | 0     | 44400 | 44400 | 0.04   | 23.45      |
| 3   | 45          | 2000  | 2236  | 0     | 44400 | 44400 | 0.04   | 23.45      |
| 4   | 45          | 2000  | 2236  | 0     | 44400 | 44400 | 0.04   | 23.45      |
| 5   | 45          | 2000  | 1414  | 0     | 44400 | 44400 | 0.03   | 46.25      |
|     | Average     |       |       |       |       |       | 0.037  | 32.57      |

4. Conclusion

The rate of spread of fire of peatland can be calculated using Simard’s model. Mathematical calculation of the rate of spread of fire using the Simard’s fire spread model is suitable to the visualization of the temperature distribution map of peatland in Kalimantan.

Calculation of the rate of fire spread using the simard model can be simulated using Matlab. Land surface temperature data can be obtained on the internet, so this method is cheap and easy. The accuracy of the results depends on the accuracy of the temperature data obtained. This method can be developed to predict the position of the fire so that it can be properly extinguished.
5. Acknowledgements

Authors would like to thank Doctoral Dissertation Research Grant RISTEKDIKTI Indonesia for funding this research.

References

[1] J. Rieley and S. Page, “Tropical peatland of the world,” in Tropical Peatland Ecosystems, Springer, 2016, pp. 3–32.
[2] K. Hirose et al., “ASSESSMENT OF TROPICAL PEATLAND MAP IN WEST KALIMANTAN, INDONESIA.”
[3] E. Saputra, “Beyond fires and deforestation: Tackling land subsidence in peatland areas, a case study from Riau, Indonesia,” Land, vol. 8, no. 5, p. 76, 2019.
[4] M. E. Harrison, S. E. Page, and S. H. Limin, “The global impact of Indonesian forest fires,” Biologist, vol. 56, no. 3, pp. 156–163, 2009.
[5] A. L. Sullivan and J. S. Gould, “Wildland Fire Rate of Spread,” in Encyclopedia of Wildfires and Wildland-Urban Interface (WUI) Fires, S. L. Manzello, Ed. Cham: Springer International Publishing, 2018, pp. 1–4.
[6] M. Cruz and M. Alexander, “Modelling the rate of fire spread and uncertainty associated with the onset and propagation of crown fires in conifer forest stands,” Int. J. Wildl. Fire, vol. 26, pp. 413–426, Jan. 2017, doi: 10.1071/WF16218.
[7] A. Abouali and D. Xavier Viegas, “Fire ROS Calculator: A Tool to Measure the Rate of Spread of a Propagating Wildfire in a Laboratory Setting,” J. Open Res. Softw., vol. 7: 24, 2019, doi: DOI: https://doi.org/10.5334/jors.221.
[8] A. J. Simard, J. E. Eenigenburg, K. B. Adams, R. L. Nissen, and A. Deacon, “A general procedure for sampling and analysing wildland fire spread,” For. Sci., vol. 30, pp. 51–64, 1984.
[9] E. I. Putra, H. Hayasaka, H. Takahashi, and A. Usup, “Recent Peat Fire Activity in the Mega Rice Project Area, Central Kalimantan, Indonesia,” 2008, doi: 10.20965/JDR.2008.P0334.
[10] A. Usup, Y. Hashimoto, H. Takahashi, and H. HAYASAKA, “Combustion and thermal characteristics of peat fire in tropical peatland in Central Kalimantan, Indonesia,” 2004, Tropics, vol. 14, no. 1, pp. 1–19.