

Trajectory and Concentration PM₁₀ on Forest and Vegetation Peat-Fire HYSPLIT Model Outputs and Observations (Period: September – October 2015)

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Abstract. Forest and vegetation peat-fire is one of the main sources of air pollution in Kalimantan, predominantly during the dry period. In 2015, forest and vegetation fire in Central Kalimantan and South Kalimantan emit large quantities of smoke leading to poor air quality. Haze is a phenomenon characterized by high concentration of particulate matter. This research objective is to analyze trajectory and dispersion of concentration particulate matter, PM₁₀ in Banjarbaru and Palangka Raya. Dynamics of PM₁₀ (Particulate matter less than or 10 μ m in size) on vegetation peat-fire is done using GDAS (Global Data Assimilation System) output with a horizontal resolution 1° which corresponds to 100 km x 100 km for input model. Climate conditions in the period September to October 2015 at generally during dry season of El Nino year. The Hybrid-single Lagrangian Integrated Trajectory (HYSPLIT) model was used to investigate concentration and long-range movement of this pollutant from the source to the receptor area. We used time-series data on PM₁₀ readings obtained from two stations Banjarbaru (South Kalimantan) and Palangka Raya (Central Kalimantan) belonging to Meteorology Climatology and Geophysics Agency (BMKG). We also used weather parameter such as wind speed and direction. We investigated trajectory run from hotspots information MoF (Sipongi Output Programs) and HYSPLIT. We compared concentration obtained from PM₁₀ observation and its concentrations trend. The dispersion pattern, as simulated by HYSPLIT showed that the distribution of PM₁₀ was greatly influenced by the wind direction and topography. There is a large difference between the concentration of PM₁₀ Palangka Raya and Banjarbaru.

1. Introduction

Forest and vegetation peat-fire (biomass burning) affects significant impacts on human health and climate. This issue was a source smoke haze. This problem has become an emerging disaster issue over last few years, predominantly during the dry period [1]. Smoke haze is a source of disasters such as poor visibility, degradation of local air quality and economic loss [2].

Biomass burning which consists of carbon emission is responsible for increasing particulate matter in El Nino-Southern Oscillation (ENSO) period [3]. During period of smoke haze, the existence of particles of PM₁₀, PM_{2.5} and TSP in air could exceeds the health-safe threshold. Particulate matter emitted by the fires is the dominant pollutant causing exceedances of ambient air quality thresholds on



a regional scale [4]. Particulate PM_{10} was a major driver of the pollutant in the atmosphere from biomass burning [2].

In the El Nino year 2015, Indonesia experienced abnormal drought conditions. The 2015 fire season by September, in much of Kalimantan were blanketed in thick smoke that lasted through October. The thick smoke that blanketed the equator in September-October 2015 was a worst since 1997 with the worst in Palangka Raya [5].

Banjarbaru and Palangka Raya is an important observation point PM_{10} BMKG in Kalimantan. Smoke haze with increasing particulate that affected Banjarbaru 2015 probably derived source of suburban South Kalimantan until the surround of Palangka Raya. In order to reduce these losses, we need a model that can describe the impact of the pollutant distribution area. Dispersion model is very useful to design strategies to reduce emissions and manage ambient air quality [6]. The concentration of pollutants varies by wind direction at a receptor [7].

HYSPLIT (Hybrid Single-Particle Lagrangian Trajectory) is useful to predict the trajectory, dispersion and concentration of pollutants from a point source, line and area [8]. HYSPLIT uses meteorological data to track the movement and concentration either forward or backward in the period and at regular intervals [9].

This research objective is to analyze trajectory and dispersion of concentration particulate matter, PM_{10} in Banjarbaru and Palangka Raya.

2. Materials and Methods

This study uses weather observations data and concentration of particulate matter PM_{10} from meteorological station observations BMKG Palangka Raya and Banjarbaru the period from September to October 2015. We also use weather data model from GDAS (Global Data Assimilation System). Data GDAS1 is downloaded with a horizontal resolution of 1° corresponding to $100\text{ km} \times 100\text{ km}$.

The tool that used for running the simulation is HYSPLIT application (Hybrid Single-Particle Lagrangian Trajectory) version 4.9 to track the trajectory and concentration. Rstudio was running by R version 3.2.3 and Openair to display weather data. GoogleEarth was used to display the location of stations.

The methodology used for this study is divided into these following steps:

2.1. Inventory data

Inventory observation weather data, model GDAS data, observation concentration PM_{10} data and hotspots data. Synoptic weather observation data on the surface of an hourly scale obtained from 2 locations Banjarbaru and Palangka Raya meteorological observation stations period September-October 2015 (Figure 1). GDAS model data was downloaded at the website <https://ready.arl.noaa.gov/ready2-bin/extract/extract.pl/>. Data GDAS1 has a resolution of 1 degree every data network measuring 111.1984 km for every latitude and longitude (Table 1). Data in the form of weekly data that is stored in a bin format consisting of meteorological parameters [10]. PM_{10} observation data was obtained from measurement the automatic instruments. Hotspots data was obtained from the hotspot MoF (Sipongi Output Programs) by the ministry of forestry and environment Indonesia. Hotspots data was given by the website <http://sipongi.menlhk.go.id/hotspot/main> [11]

Table 1. List of BMKG stations measuring air quality in South Kalimantan and Central Kalimantan Province

Province	Stasion	Longitude	Latitude	Altitude	Code Station WMO
South Kalimantan	Banjarbaru	114,841	-3,462	55 m	96687
Central Kalimantan	Palangka Raya	113,944	-2,226	27 m	96655

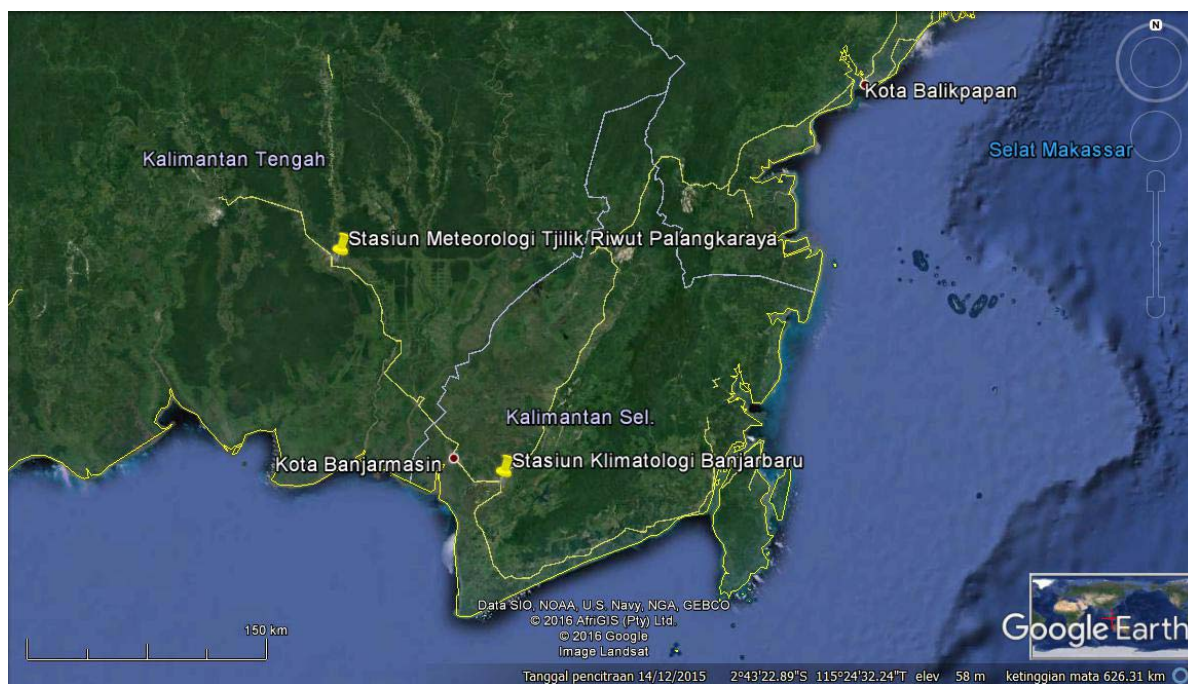


Figure 1. Location weather observation and air quality stations BMKG Palangka Raya and Banjarbaru

2.2. Plotting data

Plotting observation concentration PM_{10} data. Plotting the observation data for PM_{10} in Banjarbaru and Palangka Raya period September - October 2015. This is to determine the peak concentration of PM_{10} during the smoke haze because of forest and vegetation peat-fire. Determining the observation time by selecting multiple time when the peak concentration of PM_{10} were selected by determining the time range of the simulation.

2.3. Simulation of the trajectory and concentration with HYSPLIT

Simulation of the trajectory and concentration HYSPLIT time from September to October, 2015 using the model data GDAS air quality dispersion HYSPLIT performed to estimate the value of meteorological elements such as wind speed and direction to determine its trajectory. Simulation trajectory and concentration HYSPLIT done using the starting point of the source area (hotspots) with the forward trajectory and from the observation point PM_{10} as the area affected.

2.4. Analysis variance

Analysis variance was conducted by quantitative and descriptive methods. This analysis aims to determine patterns and distribution concentrations of pollutants. This analysis was done by looked at the figures of the simulation results (trajectories and concentrations). Analysis variance of concentration was done by quantitative method [7]. We also used trend linear regression for PM_{10} to see forecasting concentration and cumulative frequency distribution concentrations of PM_{10} .

3. Results and Discussion

3.1. Inventory Data

The results of measurement PM_{10} concentrations and meteorological elements such as wind direction and speed shown by both stations BMKG Banjarbaru (Figure 2) and Palangka raya (Figure 3). Figure 2 and Figure 3 shows the concentration of PM_{10} reach the peak. The average result observations for PM_{10} in Banjarbaru and Palangka Raya September-October 2015 shows a quiet different values (Table

2). Banjarbaru average value of PM_{10} concentrations significantly lower than in Palangka Raya. Banjarbaru value is yet below the threshold of $150 \mu g / m^3$. In contrast, the concentration of that particulate in Palangka Raya was a lot above the threshold. It means that during September-October 2015 the average concentration of PM_{10} in Palangka Raya was quite extreme. In fact, during September - October 2015 it was very less rainy in southern part of Borneo because of a strong El Nino. The haze from forest and land fires in Central Kalimantan was the worst incident since 1997, released a lot of particulate matter from the peatlands into the atmosphere.

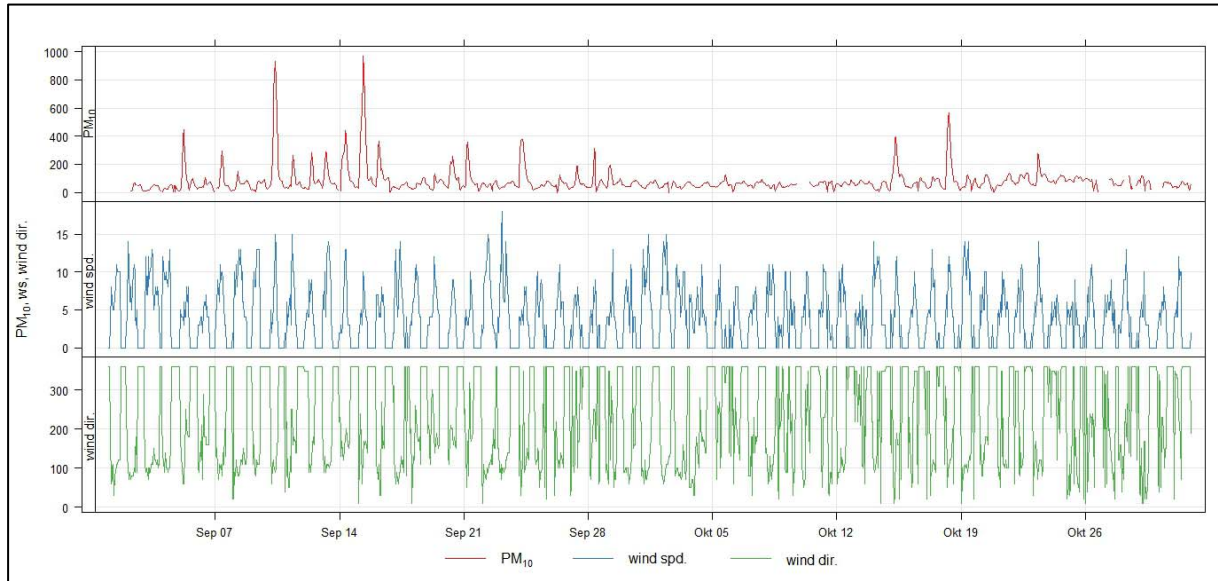


Figure 2. Time series data of concentration PM_{10} , direction and wind speed in Banjarbaru

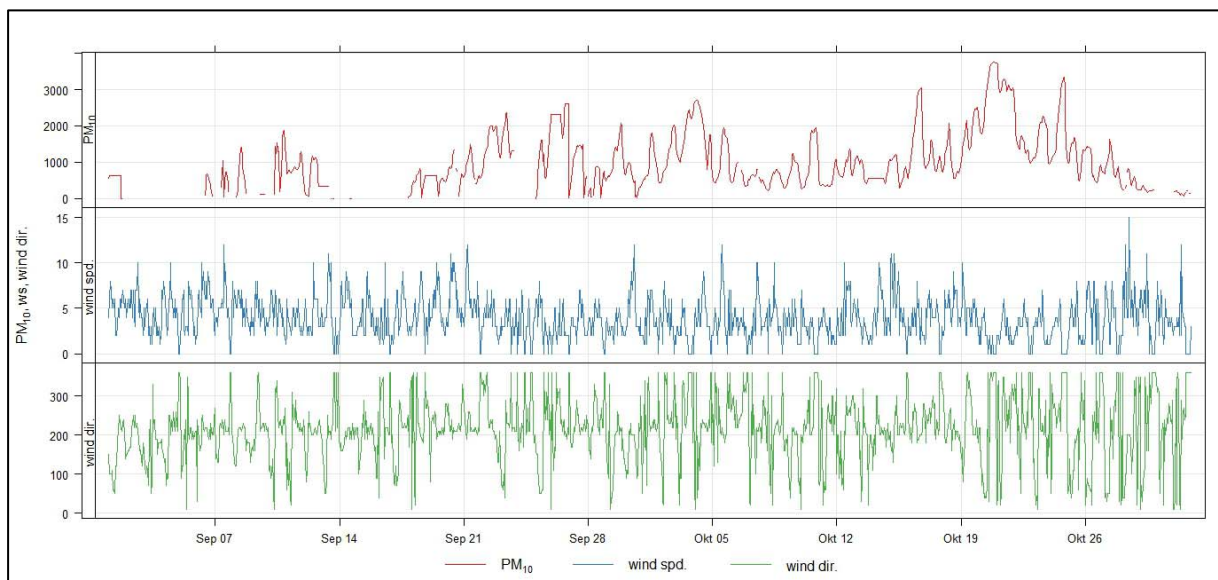


Figure 3. Time series data of concentration PM_{10} , direction and wind speed in Palangka Raya

Table 2. Average concentrations of PM₁₀ observation Banjarbaru and Palangka Raya September-October 2015

Parameter	Stasion	Month/ Year ($\mu\text{g}/\text{m}^3$)		Indonesian Standard
		09 2015	10 2015	
PM ₁₀	Banjarbaru	76.82 $\pm$ 75.17	70.43 $\pm$ 54.5	150 (24 hours)
	Palangka Raya	868.80 $\pm$ 625.5	1167.9 $\pm$ 836.2	

Table 3. The area forest and vegetation fire 2015

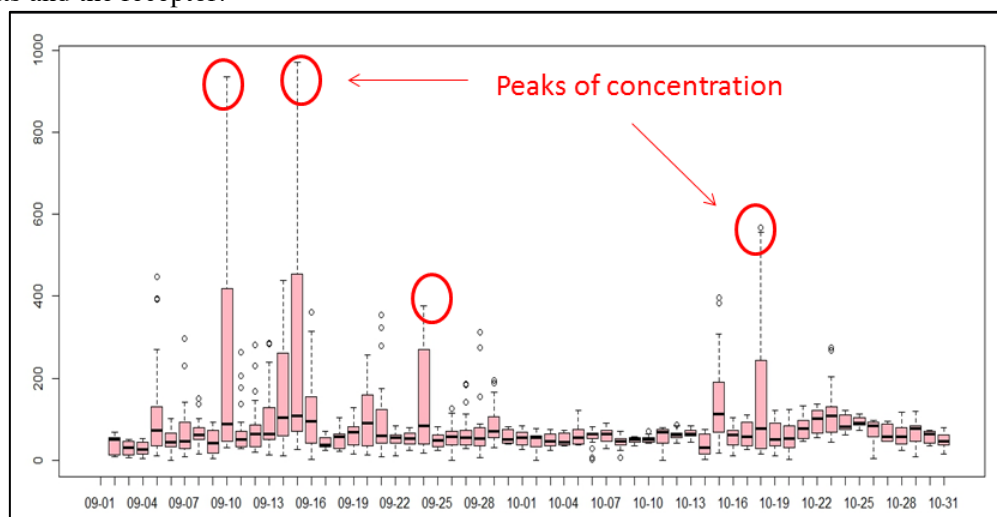
Province	The area forest and vegetation fire (ha)
South Kalimantan	1714.89
Central Kalimantan	122882.9

Source : Sipongi - The ministry of forestry and environment Indonesia, 2016 [11]

South Kalimantan represented by Banjarbaru and Central Kalimantan represented by Palangka Raya. The area of forest and land burned in 2015 Central Kalimantan has larger the area forest and vegetation fire than South Kalimantan (Table 3), so the emissions are released larger in Central Kalimantan. This causes the pollutant concentrations of PM₁₀ in Central Kalimantan larger than South Kalimantan.

3.2. Plotting Data

The result of the calculation in Banjarbaru boxplot (Figure 4) and boxplot in Palangka Raya (Figure 5), could observant will recognize some of the peak point values for PM₁₀. It is presumed at the time an incidence of the peak concentration PM₁₀ in Palangka Raya. Palangka Raya was both of as source pollutants and the receptor.

**Figure 4.** Boxplot PM₁₀ concentration data in Banjarbaru September - October 2015

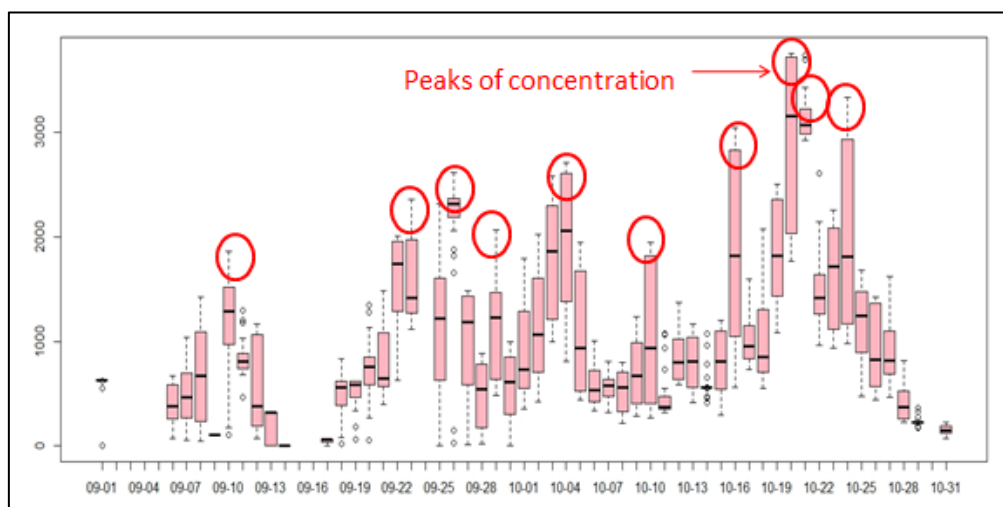


Figure 5 Boxplot PM_{10} concentration data in Palangka Raya September - October 2015

After we find peaks of the PM_{10} concentration, we select some of them to be simulated with HYSPLIT applications. HYSPLIT application could simulate trajectories and dispersion of pollutants PM_{10} . Here are some of peaks concentrations PM_{10} in Banjarbaru and Palangka Raya (Table 4.):

Table. 4 Peaks concentrations of PM_{10}

Location	Peaks concentrations of PM_{10}	
	Concentrations ($\mu\text{g}/\text{m}^3$)	Time
Banjarbaru	934.9	09 September 2015 09:00:00
	970.9	15 September 2015 08:00:00
	375.6	24 September 2015 07:00:00
	567.8	18 October 2015 07:00:00
Palangka Raya	1839.5	10 September 2015 20:00:00
	2357.1	23 September 2015 07:00:00
	2613.5	26 September 2015 21:00:00
	2072.3	29 September 2015 20:00:00
	2708.1	04 October 2015 02:00:00
	1945.1	10 October 2015 20:00:00
	3049.3	16 October 2015 18:00:00
	3760.8	20 October 2015 20:00:00
	3743.1	21 October 2015 00:00:00
	3334.2	24 October 2015 19:00:00

3.3. Simulation trajectories PM_{10}

The simulation result with some sample data peak points concentration by HYSPLIT application has been carried out. Figures 6 and 7 show the simulation HYSPLIT Banjarbaru and Palangka Raya.

HYSPLIT trajectory simulations use a moving frame of reference for the advection and diffusion calculations as the air trajectories [8]. Figure 6 and 7 shows a comparison of the trajectory of pollutants PM_{10} descriptively. Those figure shows us HYSPLIT trajectory results in Banjarbaru on

September (Figure 6) and in Palangka Raya on October (Figure 7). HYSPLIT will track the movement of pollutants to see which direction it moves. Instead, HYSPLIT use GDAS1, weather model data with a period of one week. The Global Data Assimilation System (GDAS) is the system used by the National Center for Environmental Prediction (NCEP) Global Forecast System (GFS) model to place observations into a gridded model space for the purpose of starting, or initializing, weather forecasts with observed data [10].

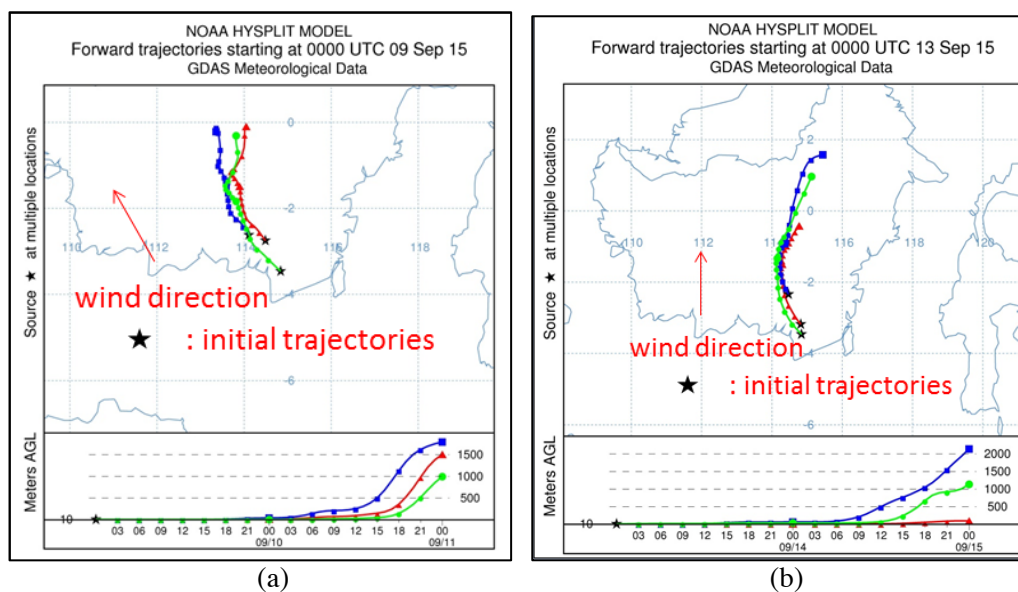


Figure 6. HYSPLIT trajectory simulation results in Banjarbaru (a) 9-11 september 2015, and (b) 13-15 September 2015

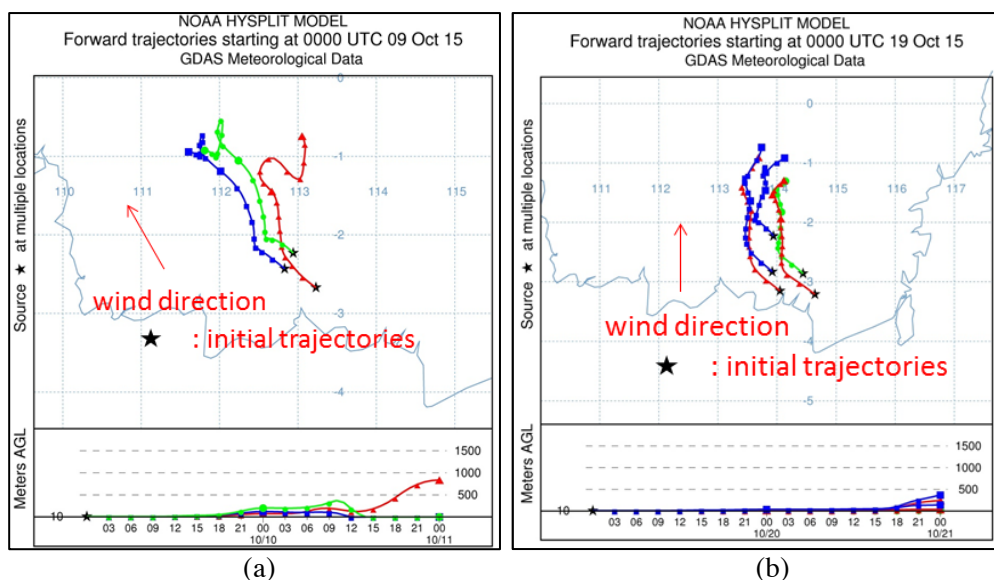


Figure 7. HYSPLIT trajectory simulation results in Palangka Raya (a) 9-11 October 2015, and (b) 19-21 October 2015

Figure 6 to 7 shows us the source of pollutants from some of hotspots bring pollutants PM_{10} from HYSPLIT model tends toward the north and northwest, or in other words, comes from the south and

southeast. The stars show the initial trajectories, sources of pollutants. The direction of the wind is the same as the direction of movement of the synoptic wind through Borneo (Figure 8). Banjarbaru dan Palangka Raya has the same trajectory simulation results. Both of them the directions tend toward the north and northwest. In addition, HYSPLIT trajectory is greatly influenced by wind direction. HYSPLIT is useful to investigate where wind direction that bring pollutants PM_{10} move.

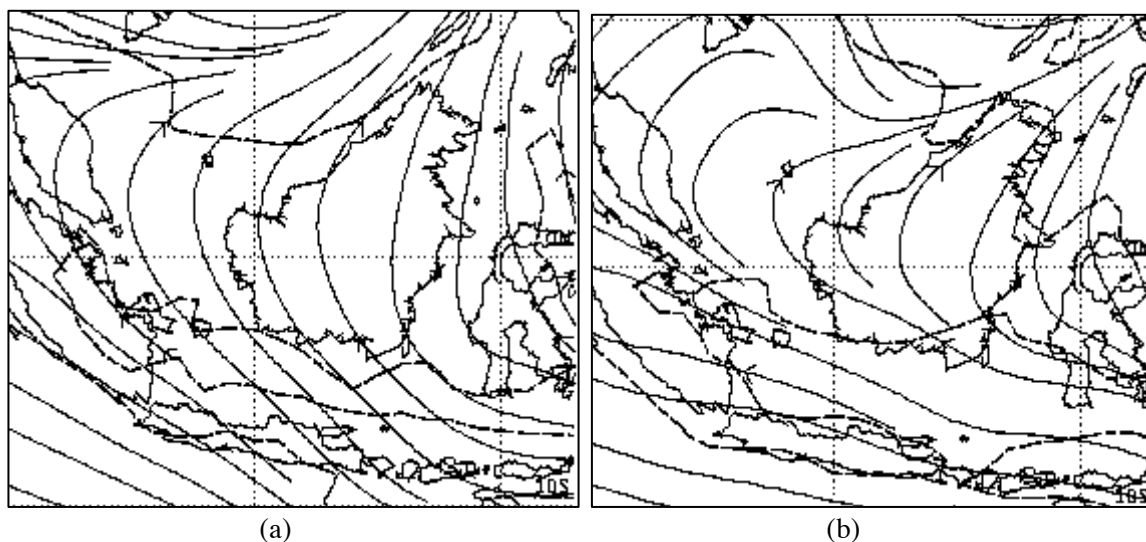


Figure 8. Wind direction through Borneo on September 13, 2015 00 UTC (a) and October 19, 2015 00 UTC (b). The wind moved from the southeast and turn on the equator from the southwest. (Source : <http://www.bom.gov.au/australia/charts/archive/>) [12]

Another factor that must be considered in the model trajectory or direction of the wind is topography. Swachner Muller mountain in the north of Central Kalimantan is an important factor that can deflect the wind in the area (Figure 9). Topography may lead to the spread of pollutants in an area that is not flat (large topographic variations) making it difficult to disperse. So the three factors of weather, topography, and the emissions are important factors in air quality models [6]. HYSPLIT model simulation is also influenced by the local topography.



Figure 9. Topography of Central Kalimantan can make the wind turn wind

3.4. Simulation concentrations of PM_{10}

Simulation pollutants concentration uses a fixed three-dimensional grid as a frame of reference to compute pollutant air concentrations [8]. Simulation of PM_{10} concentration can indicate how much pollutants are dispersed. Through this simulation we can see where pollutants such as particulate matter will be retained as indicated by an area with a high concentration of pollutants. From some of multiple hotspots we can see the sources of the emissions that lead to the emergence of pollutants PM_{10} (Figure 10). We can trace concentrations of PM_{10} where dispersed from the source since the starting point until in the receptor areas where the pollution concentrations are retained.

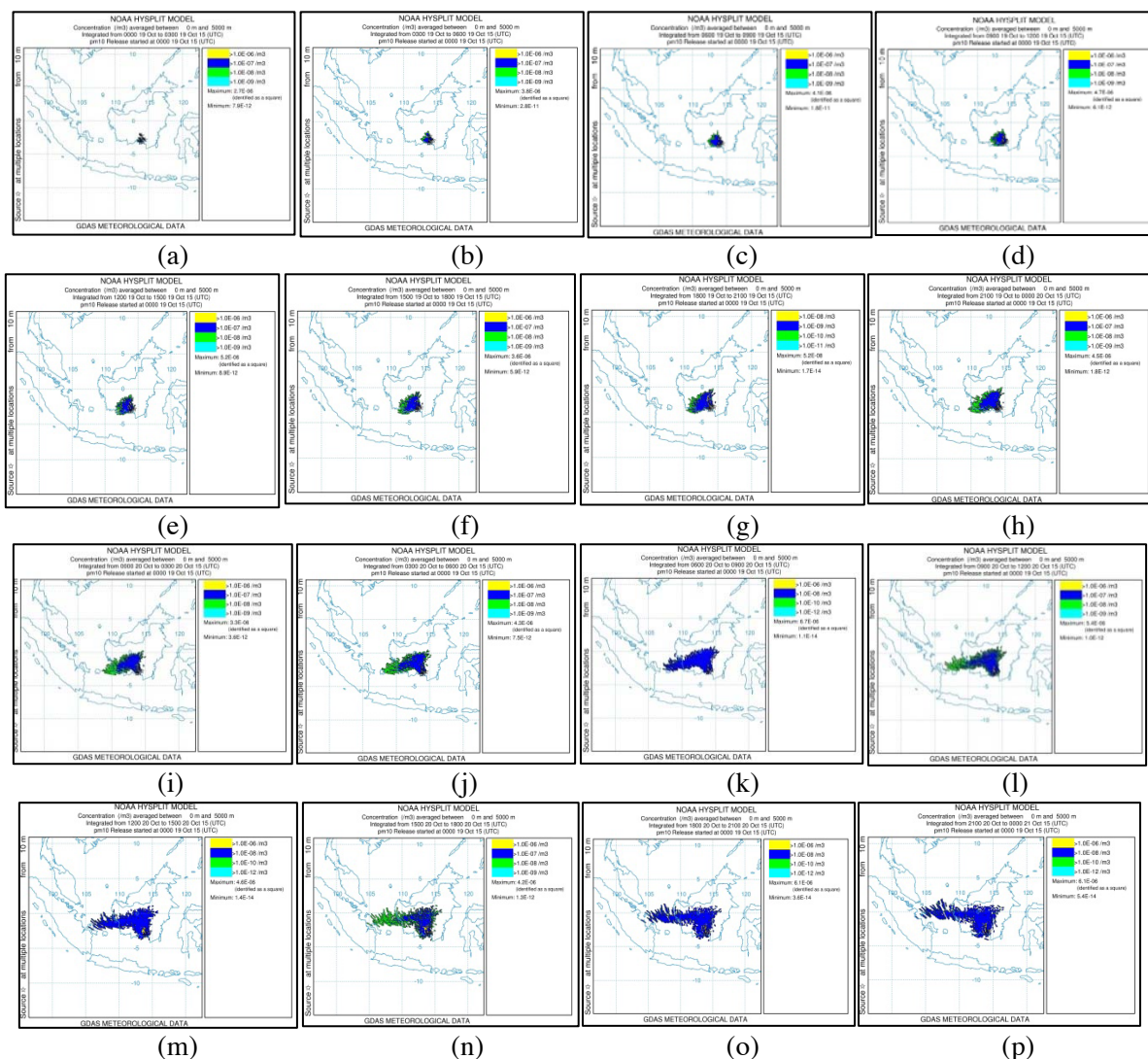


Figure 10. Simulation concentrations of PM_{10} Palangka Raya 19-21 October 2015, 19 October 2015 : (a) 00-03UTC, (b) 03-06UTC, (c) 06-09UTC, (d) 09-12UTC, (e) 12-15UTC, (f) 15-18UTC, (g) 18-21UTC, (h) 21-00UTC, 20 October 2015 : (i) 00-03UTC, (j) 03-06UTC, (k) 06-09UTC, (l) 09-12UTC, (m) 12-15UTC, (n) 18-21UTC, (o) 21-00UTC, 21 October 2015: (p) 00-03UTC

Figure 10 shows the simulated concentration of PM₁₀ in Palangka Raya. Simulation is used on 19-21 October 2015 with a three-hour period. Simulations begins on 9 October 2015 00 UTC until 11 October 2015 00 UTC. Simulation of PM₁₀ concentration can indicate how much pollutants are dispersed. Through this simulation we can see where pollutants such as particulate matter will be dispersed to the eastern of the source. From some of multiple hotspots we can see the sources of the emissions. Concentration with HYSPLIT simulation will be useful with a quantitative analysis pollutants PM₁₀ (Figure 10).

3.5. Analysis variance

Figure 11 and 12 show that there is a trend of increasing concentrations of pollutants both in Palangka Raya and Banjarbaru in the period September- October 2015 on the data hourly, three-hourly and monthly. In Palangka Raya has larger trend of increase compared with Banjarbaru. In fact, at concentrations Banjarbaru three hours in a slight decrease. Wind direction is also a factor that affects will bring many pollutants out of the affected area.

The wind carries pollutants PM₁₀ move. Due to the large particle size of 10 microns, in the strong wind it will not carry over all. However, pollutants will also be a lot of stuck in the source area. Distance from Palangka Raya to Banjarbaru also quite far around 220 km, so the pollutants PM₁₀ will be spend more time in Palangka Raya than in Banjarbaru. Thus, the concentration of pollutants in Palangka Raya higher than Banjarbaru.

Figure 13 shows the cumulative frequency distribution for PM₁₀ for Banjarbaru and Palangka Raya during September – October 2015 (based on real-time measurements). Both of the periods Palangka Raya concentrations of PM₁₀ (September and October 2015) was significantly higher than Banjarbaru. The cumulative frequency distribution of Palangka Raya higher than Banjarbaru.

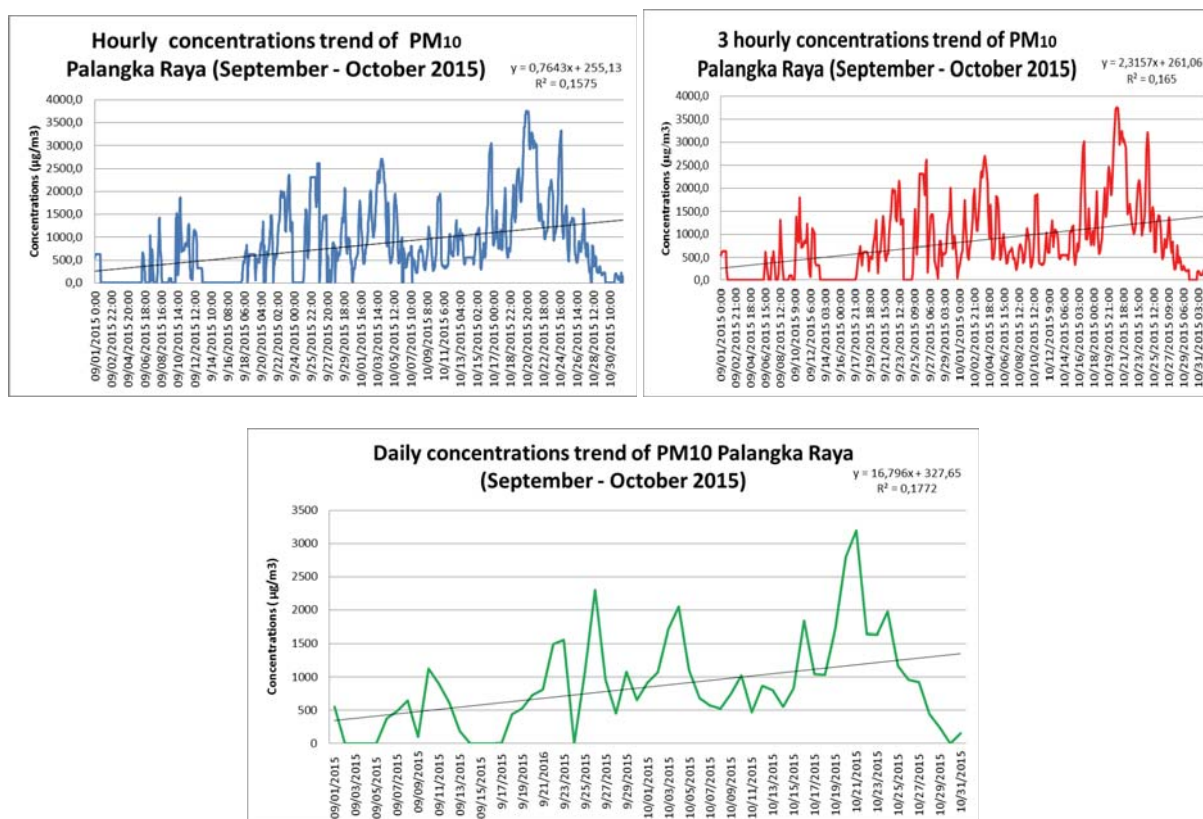


Figure 11. Trend concentration PM₁₀ Palangka Raya (September – October 2015)

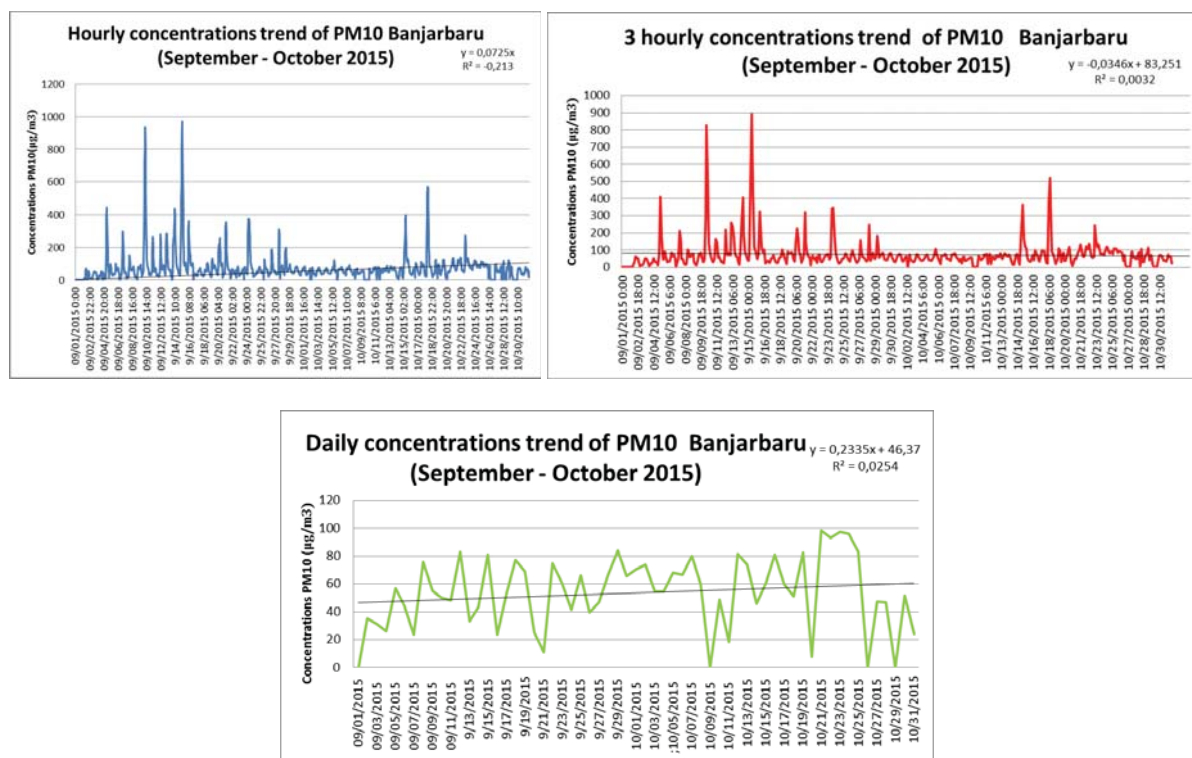


Figure 12. Trend concentration PM_{10} Banjarbaru (September – October 2015)

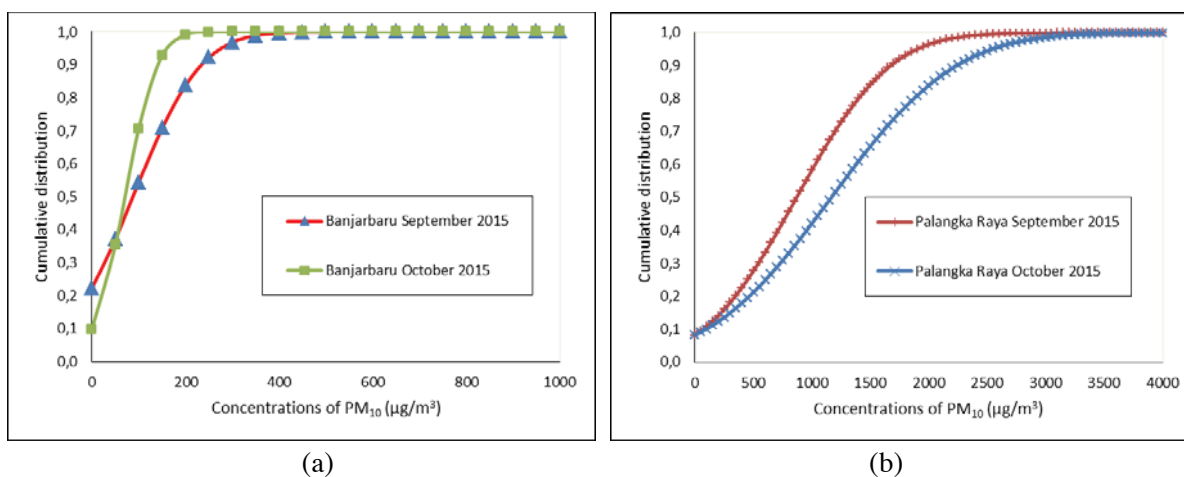


Figure 13. Cumulative frequency distribution concentrations of PM_{10} (a) Banjarbaru (b) Palangka Raya

The assumptions are that the population mean for each period are normally distributed with common but unknown variances. Assuming a larger diameter PM_{10} and weak wind speeds of less than 3 m/s, it can not happen dispersion resulting in the accumulation of pollutants. A cumulative analysis aims to find a cumulation of pollutants due to the measurement of pollutants, with the number of measurements of pollutants measured not only on that day alone but also from pollutants in the days before. Cumulative frequency distribution concentrations of PM_{10} is useful to know the differences cumulative frequency distribution concentrations between Banjarbaru and Palangka Raya.

Hotspots could be useful to determine which became a source of pollutants and areas exposed to pollutants. There are two case studies on the current September-October 2015. In the first case, 13 September 2015 showed the number of hotspots more in Central Kalimantan (Figure 14). The number of hotspots in Central Kalimantan greater than South Kalimantan (Table 5). By contrast, in the second case October 19, 2015 there are more hotspots in South Kalimantan than Central Kalimantan (Figure 15). Hotspots were clustered and numerous is an indication of the affected region. However, from simulation (Figures 6 and 8) the wind was moving from South Kalimantan to Central Kalimantan. Thus, Central Kalimantan is both the source and exposed area, because the wind came from South Kalimantan. Then, the Central Kalimantan PM_{10} concentrations are higher as well get pollutants from South Kalimantan is carried by the wind direction.

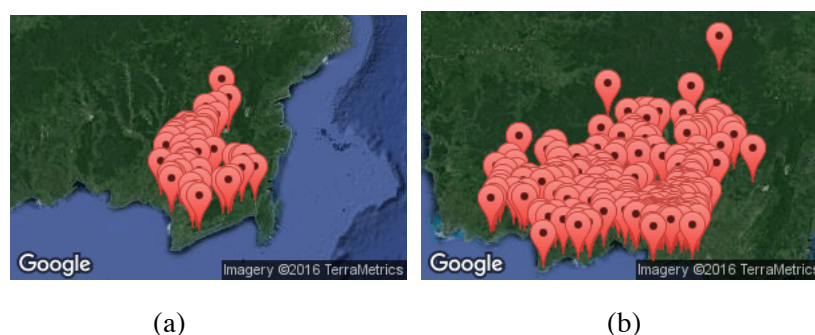


Figure 14. Hotspots in South Kalimantan (a) and Central Kalimantan (b) 13 September 2015[11]

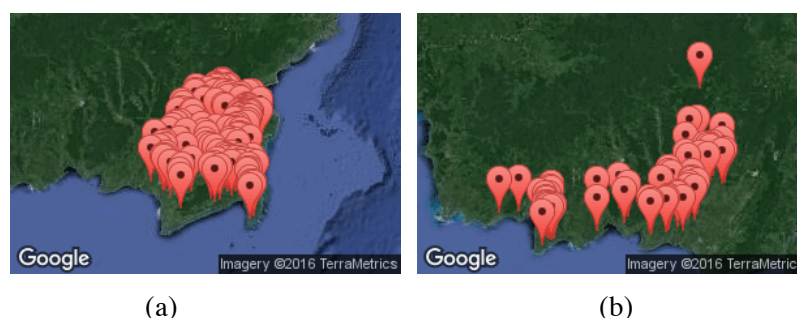


Figure 15. Hotspots in South Kalimantan (a) and Central Kalimantan (b) 19 October 2015 [11]

Table 5. Summary hotspots data

Province	Date	Hotspots
South Kalimantan	13 September 2015	53
Central Kalimantan		240
South Kalimantan	19 October 2015	141
Central Kalimantan		63

4. Conclusions

PM_{10} concentration data from observations are very useful for tracking extreme events by looking at its peak. Simulations using HYSPLIT similar to those seen in the synoptic observations. The dispersion pattern, as simulated by HYSPLIT showed that the distribution of PM_{10} is greatly influenced by the wind direction and topography. Concentration with HYSPLIT simulation will be useful with a quantitative analysis and trend. There is a large difference between the concentration of

PM₁₀ Banjarbaru and Palangka Raya. Area sources of PM₁₀ and areas of exposure is an important area for the dispersion of pollutants and its concentration. Cumulative frequency distribution concentrations of PM₁₀ is useful to know the differences cumulative frequency distribution concentrations between Banjarbaru and Palangka Raya.

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