Trajectory and Concentration PM$_{10}$ 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, PM$_{10}$ in Banjarbaru and Palangka Raya. Dynamics of PM$_{10}$ (Particulate matter less than or 10 μm 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 Langrangian 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 PM$_{10}$ 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 PM$_{10}$ observation and its concentrations trend. The dispersion pattern, as simulated by HYSPLIT showed that the distribution of PM$_{10}$ was greatly influenced by the wind direction and topography. There is a large difference between the concentration of PM$_{10}$ 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 PM$_{10}$, 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 km x 100 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/exract/exract.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.menhk.go.id/hotspot/main [11]

| Province           | Station  | 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        |       |
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.
2). Banjarbaru average value of PM$_{10}$ concentrations significantly lower than in Palangka Raya. Banjarbaru value is yet below the threshold of 150 µg/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 PM$_{10}$ observation Banjarbaru and Palangka Raya September-October 2015

| Parameter | Stasiun    | Month/ Year ($\mu g/ m^3$) | Indonesian Standard |
|-----------|------------|-----------------------------|---------------------|
|           |            | 09 2015                      | 10 2015             |
| PM$_{10}$ | Banjarbaru | 76.82 ± 75.17                | 70.43 ± 54.5        | 150 (24 hours) |
|           | Palangka Raya | 868.80 ± 625.5 | 1167.9 ± 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 PM$_{10}$ 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 PM$_{10}$. It is presumed at the time an incidence of the peak concentration PM$_{10}$ in Palangka Raya. Palangka Raya was both of as source pollutants and the receptor.

Figure 4. Boxplot PM$_{10}$ concentration data in Banjarbaru 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.):

| Location       | Peaks concentrations of PM$_{10}$ | Concentrations (µg/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](image1.png)

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

![Figure 7](image2.png)

**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 PM$_{10}$ 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 PM$_{10}$ 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 PM$_{10}$ (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 PM$_{10}$ 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 PM$_{10}$ 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 PM$_{10}$ for Banjarbaru and Palangka Raya during September – October 2015 (based on real-time measurements). Both of the periods Palangka Raya concentrations of PM$_{10}$ (September and October 2015) was significantly higher than Banjarbaru. The cumulative frequency distribution of Palangka Raya higher than Banjarbaru.

![Figure 11](image1.png)  
![Figure 12](image2.png)  

**Figure 11.** Trend concentration PM$_{10}$ Palangka Raya (September – October 2015)
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]

| 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
PM$_{10}$ Banjarbaru and Palangka Raya. Area sources of PM$_{10}$ and areas of exposure is an important area for the dispersion of pollutants and its concentration. Cumulative frequency distribution concentrations of PM$_{10}$ is useful to know the differences cumulative frequency distribution concentrations between Banjarbaru and Palangka Raya.

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