Diurnal Pattern of PM10 and CO in Riau as a Forest Fire Risk Area

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Abstract. PM10 and CO are air pollutants emitted by fossil fuel combustion and biomass burning have the bad impact on human being. Riau as a forest fire risk area, it is supposed that air quality related to PM10 and CO affected by the fire. This paper studies diurnal pattern of PM10 and CO in Riau during 2015 when a strong El Nino phenomena occurs. The diurnal pattern of pollutant is useful for hazard mitigation of the pollutant especially when its concentration reaches maximum and potent to exceed the threshold value of ambient air quality. The result of the study shows plot scatter of PM10 and CO has got the correlation coefficient of 0.72 when no fire period and 0.91 when fire period. The strong correlation in fire period is caused by the similarity of major sources of biomass burning that ignored other sources. Both diurnal patterns, especially CO shows a bimodal shape when no fire period, and the pattern changes to being flat all of the day when a great forest fire occurs in Riau and its surrounding. The bimodal shape was characterized by two concentration peaks in the morning at 08.00 and in the evening at 20.00 local time that was related on rush hour, atmospheric stability, chemical reaction rate of CO. During one year of el Nino phenomena in 2015, CO concentration is still below national air quality standard although in a great fire period and the diurnal peak concentration, while PM10 concentration in some days in fire period exceeds the national air quality standard.

Keywords: PM10, CO, forest fire, pollution

1. Introduction
The forest fire is one of the environmental problems in Indonesia, especially in Sumatera and Kalimantan islands. Although various efforts of forest fire mitigation and its risks reducing have been carried out, forest fire occurs repeatedly. This event is caused many factors such as economic crisis, the price of log and wood product, CPO prices, the Ministry of Forestry's budget, and supported by natural factors, namely El Nino [1]. Some compounds including air pollutants and greenhouse gases are released to the atmosphere during the forest fire.

The important air pollutants released from the forest fire are PM10 and CO. Carbon elements which have almost half of the dry matter of burning biomass is a source of PM10 and CO formation [2,3]. PM10 is a particulate which has an aerodynamic diameter size of less than 10 µm. It consists of various elements especially carbon and mixed with water vapor appeared as smoke haze. The presence of particulates in the atmosphere reduces air quality because of bad impact on health and climate change [7]. Particulates are poisonous when they enter through the respiratory system and cause death [8]. Particulates reduce the intensity of solar radiation reaching the earth's surface and play a role in cloud
formation which is both climate parameters. Another negative impact is on the transportation sector because of reduced visibility.

Carbon monoxide (CO) is an odorless and colorless gas which has an important role in studying atmospheric chemistry. It is formed by oxidation of carbon compound when fuel content carbon burned incompletely. CO is classified as a gas pollutant because it has the bad impact on human health, photochemical smog contributor, and surface ozone pollutant precursor [4,5,6]. Its character is very reactive to hydroxyl radical (OH), so it has the short lifetime, and finally CO is oxidized to CO$_2$ that is greenhouse gas with warming effect on the atmosphere.

Both PM10 and CO are pollutants which have the same main source of biomass burning in rural areas and fossil fuels combustion in urban areas. Therefore, research on PM10 and CO particulates is often carried out simultaneously [9,10]. Riau is a high-risk forest fire area and its urban area is a developing region that has busy transportation. The two main sources have contributed to the air quality in Riau, especially for CO and PM10 parameters.

There have been many publications indexed journals studying in forest fire impact on economy and ecology [11]. There have been many indexed journal publications studying the impact of forest fires on economics and ecology [11]. In this study, diurnal patterns of PM10 and CO were assessed in fire period and no fire period indicated by the number of hotspots observed in the Riau area and its surroundings. Observations were carried out in 2015 when a strong El Nino phenomenon occurred which produced the largest fires in Sumatra and Kalimantan in the last decade [12]. The understanding of air pollutant diurnal pattern is useful for air pollutant management to minimize the bad impact of air pollutant.

2. Data and Method

This study analyzed PM10 and CO data yield of monitoring air quality using air quality monitoring system (AQMS). The monitoring was located at three places in Pekanbaru city, Riau province, namely in Tampam (0°28.0’N, 101°23.0’E), Kulim (0°27.5’N, 101°32’E), and Sukajadi (0°31.5’N, 101°26.5’E). Sukajadi was an urban area with a dense population and high transportation activities. Whereas Tampan and Kulim were suburban areas which at the first time intended to monitor the impact of forest fires, but finally Tampan area developing to be crowded traffic, so traffic emission affected the observation of PM10 and CO. The monitoring system was also supported by observing meteorological parameters, namely relative humidity (RH) and temperature (T). The type of data its location could be seen in Figure 1. The observation was carried out for one year, January-December 2015 coincided with El Nino Event, and the data was collected every 30 minutes.

Forest fire intensity was identified by the hotspot counts observed by satellite. The hotspot was provided by National Institute of Aeronautics and Space (LAPAN) and could be downloaded at
The hotspot was detected using Terra and Aqua satellites with MODIS sensors (moderate resolution imaging spectroradiometer), and SNPP satellites (Suomi National Polar-orbiting Partnership) with VIIRS (Visible/Infrared Imaging Radiometer Suite) sensors. Hotspot positions were considered to study for the effects of distance at a distance of 100 km, 200 km and 500 km from the monitoring location. Hotspot criteria was selected with a confidence level of more than 80%, which in forest fire management must be taken action to control forest fires. Wind direction was not considered in this study assuming the hotspot was distributed evenly around observation location. Temporal analysis of correlation between the PM10 and CO concentrations and the number of hotspots was grouped every month.

As an important product of biomass burning and fossil fuels, it was necessary to investigate relationship between PM10 and CO. The correlation was distinguished in fire period and no fire period. The relationship analysis was based on Pearson correlation. Diurnal pattern was also distinguished in fire period and no fire period. Fire period was the month when more hotspot detected. No fire period was not only no fire period but also included when just a few hotspots detected in the month. The diurnal pattern of CO and PM10 concentration was calculated by averaging at the same hour each day. Diurnal pattern analysis was associated with emission sources and meteorological parameters including temperature and relative humidity which affect PM10.

Analysis of CO and PM10 quality criteria was based on the national ambient air quality standards in the annex of PP No. 41 of 1999 concerning air pollution control, which was 30 mg / Nm$^3$ for CO for an hour sampling or 10 mg / Nm$^3$ for one day sampling and 150 µg / Nm$^3$ for PM10 for one day sampling. Because the diurnal PM10 and CO pattern was not flat, the daily average was calculated if only the data was more than 80% of the complete data in one day, the daily average both of CO and PM10 were calculated if only the amount of data more than 80% of the complete data in one day, while the monthly both of CO and PM10 were calculated if only the amount of daily average more than 60% of the days in one month.

3. Result and Discussion

3.1. Relationship of PM10 and CO concentrations and hotspot

Hotspot is an area with a relatively hot temperature in comparison to its surroundings where this difference in certain threshold values can be detected by satellites. Forest fires which have high temperature relatively can be detected by satellites as hotspots. However, not all hotspots are forest fires, as well as forest fires if they only occur in a narrow area, they are not detected by the satellite as hotspots. Hotspot is suspected as fire dependence on confidence level. Higher confidence level is more potential as fire and the more hotspot is the greater the potential for burning, so there is a positive correlation between the number of hotspots and the extent of forest fires [13].

The amount of PM10 and CO emissions from forest fire are determined by the amount of biomass burned and emission factors of each compound. The amount biomass burned is multiplication of the mass density of forest biomass, forest area burned, and the fraction of biomass burned. Emission factors of CO and PM10 that consist most carbon compound depend on the combustion process. The combustion process is influenced by oxygen supply in the fire. More oxygen supply is more carbon compound formed as CO$_2$ and the consequently less of CO and PM10, and vice versa. Whether of calm wind, wet biomass and higher density biomass conditions like a tropical forest or peat land are difficult to supply oxygen into combustion process of biomass.

Between hotspot count and area burned is correlated positively, as well as the area burned and the amount of emission [14], consequently, the hotspot count and emission is correlated too. Sukitpaneenit and Kim Oanh NT study of correlation analysis shows that CO and PM10 daily concentrations associated with the hotspot count especially in the rural area has a maximum correlation coefficient ($r$) of 0.59 for CO and 0.65 for PM10 [15]. In this study the relationship between the hotspot count observations with PM10 and CO concentrations is presented in Figure 2. In this figure shows that the hotspot observed by Terra sensor has the best correlation with PM10 and CO concentrations compared to Aqua and SNPP sensors. The monthly hotspot count within an area in radius about 100 to 500 m from location of observation is almost same, especially in radius of 100-200 km from the location. At a
distance of less than 200 km from the location observation which affects the concentration of PM10 and CO, the more hotspots the higher the concentration of PM10 and CO.

PM10 and CO concentrations are observed to be high in August and October, although the hotspot count in these months was detected slightly. The higher concentrations in these months are affected by forest fires in the previous month where many hotspots detected in July and September. This means that the impact of severe forest fires on CO and PM10 concentrations in ambient air continues until the following month around in the forest fire area.

Figure 2. Related hotspot counts and PM10 and CO concentrations

Great forest fires generally occur in Indonesia at the end of the dry season period where weather and biomass are in dry conditions. According to Aldrian and Susanto [16], in normal weather condition, most of Sumatra island, especially Riau and its surrounding areas have two peaks rainfall in March and October. However, the peak of rainfall in March is not as high as October and even rainfall in March is less than rainfall in November and December. July until September is a dry season period when rainfall is very low. Many hotspots were observed during the dry season, i.e July to September. Most hotspots occur in September which is the end of the dry season. It has started increasing rainfall in October cause decreasing hotspot intensity. Based on observing hotspot, the period of fire is from July to September, and the other months are classified no fire period.

The concentration of PM10 in urban area of Sukajadi is lower than in sub-urban area of Kulim, as well as the concentration of CO in the urban area of Sukajadi is lower than in sub-urban area of Tampan. It shows that in Riau as a forest fire risk area, sub-urban areas are more polluted by PM10 and CO pollutants than in urban areas. Local sources of PM10 and CO in urban areas are dominated by burning fossil fuels, while in urban areas other than burning fossil fuels, an important source is burning biomass. The source of biomass burning is borne from cooking traditional and especially during forest fires.

Scatter plot between daily concentrations of PM10 and CO in fire period and no fire shows the strength of correlation both of them presents in Figure 3. The scatter plot has a correlation value ($r = (R^2)^{0.5}$) of 0.73 for no fire period and 0.91 for the fire period. According to Taylor [17] if ($r > 0.68$) then both variables are classified to have a strong or high correlation, whereas according to Ratner [18] the correlation is strong if ($r > 0.7$) or ($r < -0.7$). Based on these two criteria, the correlation between PM10 and CO in Riau has a strong relationship for all conditions. The strong relationship is caused by the same
of the main source emission, both fossil fuels when there are no forest fires and from burning biomass when forest fires occur.

Despite the relationship between PM10 and CO is strongly correlated in all conditions, but it is stronger in the fire period. The stronger correlation is caused the emissions from forest fire process are so great that ignore the other sources of CO and PM10. The strong correlation between PM10 and CO during the fire period in Riau as a forest fire risk area can be applied to estimate if one of the data is known and the other data unknown.

Figure 3. Scatter plot between PM10 and CO daily concentrations

Another difference besides the correlation coefficient of the relationship between PM and CO in the two conditions is a gradient of the correlation equation. The gradient of the correlation equation in the fire period is almost twice the value of the gradient of correlation equation in no fire. It means that there is an increase in emission of PM10 higher than CO when a fire period or the other hand, the emission factor of particulate from forest fire is very high compare from fossil fuel combustion.

3.2. Quality and diurnal pattern of PM10 and CO

PM10 and CO have a bad impact on human health due to their toxic if they inhaled. The smaller size inhaled particulate penetrates the deeper respiratory system, so that only fine particulate be able to reach penetration on blood circulation. CO is toxic for life because it is very reactive with hemoglobin forming carboxyhemoglobin (HbCO). Hemoglobin binds CO of 200 times faster than with oxygen. If the environment is rich in CO, then the body will lack oxygen, while oxygen is a vital matter for life. Because both PM10 and CO are dangerous pollutants, both of pollutants regulated in Government Regulation in PP No. 41 of 1999 which regulates ambient air quality standards. In the annex of the PP No 41 of 1999 is listed national air quality standards (NAQS) for some pollutants. According to the annex, the ambient air quality standard of CO is 30 mg/ Nm$^3$ for an hour sampling and PM10 is 150 µg / Nm$^3$ for one-day sampling.

The hourly average of CO and the daily average of PM10 are shown in Figure 4. Air quality in Riau when no fire is very clean against PM10 and CO and this value can be used as the background value. When the forest fire period indicated by more hotspot observed, the concentration of PM10 and CO rise very high from the background value. Despite CO concentrations very high during great forest fires, the concentration is still below NAQS. Unfortunately, PM10 concentration is very high when forest fires occur. During July-October, there is 28% of days in PM10 conditions above NAQS.

As explained above, that forest fire has a high emission factor. The consequences are air quality of PM10 exceeds national air quality standard. Although people can use masks to reduce the impact of PM10, particles in very small sizes can escape in the filter mask, while the particulate hazard level is higher for smaller sizes. Hence, the particulate is an important concern in mitigating the effects of the forest fire in Riau and its surrounding.
Diurnal pattern of PM10 and CO concentrations in different fire are shown in Figure 5. The concentration of a pollutant in the atmosphere is determined by the number of emissions, and it is influenced by weather conditions that causes pollutant removed from the atmosphere through diffusion, dilution, dispersion, deposition, and chemical reactions. The number of emissions combined with meteorological conditions that removal pollutant generates ambient air concentrations, which it compiles time series data and creates temporal, such as the diurnal, pattern.

Diurnal CO concentration configures a bimodal pattern clearly, while PM10 concentration configurations bimodal pattern slightly when the emission from biomass burning can be neglected because of no fire period. Two peak concentrations occur on the morning at 08.00 and at night at 20.00 local time. The bimodal CO pattern of research conducted by [19] in semi-urban areas in India is caused by transportation activities and planetary boundary layer.

There is different in peak shape concentration in the morning and the evening. The concentration peak in the morning is more sharply than in the evening. The sharp concentration peak in the morning is caused CO is oxidized to form CO$_2$ by solar energy immediately after sunrise [20], through the process:

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\begin{align*}
O_3 + hv & \rightarrow O^\prime (D) + O_2 \\
O^\prime (D) + H_2O & \rightarrow 2 OH \\
2 [CO + OH] & \rightarrow CO_2 + H
\end{align*}
\]

Net: $O_3 + hv + H_2O + 2 CO \rightarrow O_2 + CO_2 + H$

In the day, atmospheric stability condition tends to unstable and the mixing layer is higher than the night. This weather condition causes the pollutant to be mixed vertically well so that the concentration on the surface becomes low. Therefore the concentration in the morning quickly drops and its concentration is low during the day even though traffic activity is still crowded.
Based on the R1-R3 reactions, the net reaction shows that CO removal from the atmosphere need OH hydroxyl produced using solar radiation energy. In the night, there is no solar radiation to support producing OH and according to Voulgarakis [21] that lifetime of OH is very short only on the order of a few of seconds, so the removal of CO from the atmosphere through chemical reactions is ineffective. The lower mixing layer in the night and no significant CO removal through oxidation by OH process in the night makes CO emitted by rush hour in the evening accumulated around the way where observation located. Reduction of CO concentration at night at the location of the observation occurs because it is transported to a large area and decrease traffic activity as a source of CO. Because of the slow process of decreasing CO concentration at the night, the peak concentration in the evening is widened not as sharp as in the morning.

Particulate is not reactive unlike CO, but its concentration can be affected by meteorological factors namely temperature and pressure. Particulate concentrations are positively correlated with temperature and negatively correlated with pressure (Hasheminassab, 2013; Jayamurugan 2013) because of its hygroscopic. Concentration peak of PM10 in the morning is not as high as in the evening, because in the morning when rush hour occurs, the temperature is still low and pressure is high (Figure 6). While in the day when temperature rising, pressure decreasing, and supported the higher mixing layer condition creates low PM10 concentration. Although the mixing layer is low at night, the source of emission is not active, finally PM10 concentration at night becomes as low as during the daytime.
During the fire period, the diurnal bimodal pattern of CO and PM10 turn out to be the almost flat pattern all of the day. The great emission from forest fire can change diurnal pattern under normal condition and neglects the influence of meteorological factors that should reduce the presence of these two compounds. It shows high PM10 and CO emissions by forest fires that affect air quality in Riau not only in the quantity but also in diurnal pattern.

4. Conclusion
The diurnal pattern of CO and PM10 in Riau as a forest fire risk area for one year in the 2015 El Niño event can be distinguished when a fire period and no fire period. During no fire period, the diurnal pattern forms a bimodal pattern, with peak concentrations in the morning around 8:00 and evening at 20:00 local time due to the influence of source activities and weather conditions. In fire period, a great emission during severe fire changes the diurnal pattern to be flat regardless of meteorological factors. The great fire not only changes the diurnal pattern, but also changes the correlation coefficient between PM10 and CO, where the correlation coefficient between CO and PM10 is 0.72 when no fire, and it rises to 0.91 during great fire.

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