Atmospheric Methane Condition over the South Sumatra Peatland during the COVID-19 Pandemic

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ABSTRACT

Recent anthropogenic activities have degraded peatlands, the largest natural reservoir of soil carbon, thereby reducing their carbon uptake from the atmosphere. As one of the primary sources of methane (CH₄) emissions in terrestrial ecosystems, peatlands also contribute to atmospheric greenhouse gases. During the coronavirus disease 2019 (COVID-19) pandemic, Indonesia implemented a lockdown referred to as *large-scale social restrictions* (LSSR) in areas with high case numbers. To evaluate the effects of anthropogenic activity on peatlands, we investigated the CH₄ concentrations in the atmosphere above the tropical peatlands of the Indonesian province South Sumatra before the LSSR (March 2020), during the LSSR (May 2020), and during the corresponding months of the previous year (March and May 2019). Using satellite-retrieved data from NASA, viz., the CH₄ concentration and gross primary production (GPP) measured by the Atmospheric Infrared Sounder (AIRS) on board Aqua and Moderate Resolution Imaging Spectroradiometer (MODIS) on board Terra, respectively, we discovered a decrease of approximately 5.5% in the mean CH₄ concentration (which averaged 1.73 ppm across the periods prior to lockdown) as well as an increase in the GPP (which ranged from 53.3 to 63.9 g C m⁻² day⁻¹ during the lockdown, indicating high atmospheric carbon intake) during the LSSR. Thus, the restrictions during lockdown, which reduced anthropogenic activities, such as land use conversion and biomass burning, and related events, such as peatland and forest fires, significantly influenced the level of atmospheric CH₄ above the peatlands in Indonesia.

Keywords: Atmospheric CH₄, COVID-19, Gross primary production, LSSR, Peatland

1 INTRODUCTION

Methane (CH₄) is a greenhouse gas which leads to global warming event and its impact is greater than carbon dioxide (CO₂) approximately 28-fold (Peng *et al.*, 2016; Knoblauch *et al.*, 2018). Globally, natural peatlands emit around 115 Tg CH₄ y⁻¹ and it was believed as a major source of CH₄ in the atmosphere (Nilsson *et al.*, 2001). Peatlands cover about 3% (4 × 10⁶ km²) of the land area of the earth and store a third of the world's soil carbon (Zhou *et al.*, 2017; Lees *et al.*, 2018). This large reservoir of carbon can affect the atmospheric CH₄ level and changed the atmospheric greenhouse gases of the earth. To date, many peatlands have encountered degradation through anthropogenic activities such as grazing, draining, burning, and conversion to agriculture, industries, and urban areas, which reduce carbon uptake from the atmosphere (Waddington *et al.*, 2010). Therefore, CH₄ emissions from peatlands have taken interest from many researchers all over the world recently (Leroy *et al.*, 2017; Saraswati and Strack, 2019; Huang *et al.*, 2020).

The South Sumatran peatland which is located in the southeast of the island of Sumatra is known as one of the largest tropical peatlands in Indonesia. It covers an area of 1.42 million ha

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(Tampubolon *et al.*, 2019) that encompasses the South Sumatra province of Indonesia at altitudes 2–33 m above sea level. This area is a notable and susceptible peatland that largely drives climate change in the Southeast Asian region. The CH₄ field measurement methods are usually restricted by time and area scales, and cost, but by using the satellite remote sensing method, we can obtain atmospheric CH₄ data over large areas rapidly and at a low cost. Satellites NASA Aqua, GOSAT, and Landsat have been employed in many studies of terrestrial CH₄ emission over wetlands and other ecosystems (Akumu *et al.*, 2010; Parker *et al.*, 2018; Abed, 2020; Yang and Wang, 2020).

Furthermore, several studies regarding air pollutants' status during the COVID-19 pandemic have been extensively studied such as NO₂ (Biswal *et al.*, 2020), SO₂ (Otmani *et al.*, 2020), CO (Nadzir *et al.*, 2020), PM₁₀, and PM_{2.5} (Hashim *et al.*, 2020). However, the atmospheric CH₄ condition during the COVID-19 pandemic, especially in the lockdown period, was still sparse. Pachecho *et al.* (2020) found a major air pollutant such as NO₂ decreased by 23% during the lockdown in Ecuador. This decrease could be due to human activities such as industrial, transportation, and commercial places were largely restricted (Rendana, 2020).

Previous studies by Fang *et al.* (2013) found high methane mole fractions in the air were recorded in Lin'an, China, which ranged from 0.032 to 0.196 ppm. Verhulst *et al.* (2017) have revealed atmospheric CH₄ concentration was very variable over Los Angeles, ranging from 0.08 to 0.15 ppm in 2015. The atmospheric CH₄ emissions are generally affected by vegetation types, climate, and land use (Pelletier *et al.*, 2007). Although CH₄ fluxes in the South Sumatran peatland have been studied (Prayitno *et al.*, 2019), information on the impact of the COVID-19 pandemic on the atmospheric CH₄ status over the peatlands is still sparse.

In the current study, atmospheric CH₄ over the tropical peatlands in the South Sumatra province was measured in three different periods such as before lockdown (referred to as *large-scale social restrictions* [LSSR] in Indonesia), during the lockdown and last year data in 2019. The gross primary production (GPP) value was also examined to understand factors that govern CH₄ fluxes in the peatland. The aim of this study was to analyze the atmospheric CH₄ condition in the South Sumatran peatland during the COVID-19 pandemic.

2 METHODS

2.1 Study Site

The study site is in the South Sumatra province that surrounded by peatland ecosystems (Fig. 1). It is located in the southeast of the main island of Sumatra (2°45'S, 103°50'E) and covers about 91,592 km². In general, the total peatland area of Indonesia is around 20.6 million ha and 35% of the peatlands are situated in the island of Sumatra (Wahyunto and Suparto, 2005). In South Sumatra, peatland areas are classified based on the level of peat maturity such as fibric, hemic, and sapric (Kirana *et al.*, 2016). These areas are found from very shallow peat (0.5–1 m) to very deep peat (> 5 m) (Setiawan *et al.*, 2015). The major land uses found in the peatland are consisted of agricultural activities such as oil palm, rice, rubber, and horticulture. The land use conversion has resulted in a number of hotspots in the peatland areas which increase from year to year. For instance, the hotspot frequency records around 18,852 in 2006 and continues to increase to 26,193 hotspots in 2014. The peatland fire events have contributed to greenhouse gas emissions such as CO₂, CH₄, and nitrous oxide (N₂O) to the atmosphere. These areas are one of the haze contributors in the Southeast Asian region.

2.2 Spatial Distribution of CH₄ in Atmosphere

Satellite retrieval of the trace gas data was applied to estimate the air quality distribution. CH₄ mole fraction in the air was measured by Atmospheric Infrared Sounder (AIRS) aboard NASA's Aqua satellite at 1° × 1° resolution. In this study, we used the AIRS/Aqua daily data product (AIRS3STD V006). The AIRS used 3D analysis of the atmospheric column along with trace gases, cloud, and surface properties. The CH₄ mole fraction in air data was obtained from NASA's website (<https://giovanni.gsfc.nasa.gov/giovanni/>). We chose the CH₄ mole fraction data in several study periods such as before the LSSR (March 2020), during the LSSR (May 2020), and the last year's data in 2019 (March and May 2019). Then, we cropped the area of interest and downloaded the

Fig. 1. The location of study area.

data within the area. The format data of files downloaded were in the form of images (TIFF). Then, the CH₄ raw data were processed using ArcGIS software before they could be used for this study. Several important processes were carried out included resample, interpolation, and reclassify the data. In this study, the CH₄ data from satellites were validated against the air quality monitoring system (AQMS) that was organized by the Ministry of Environment and Forestry of the Republic of Indonesia. The validation results showed a good accuracy between the satellite data and the ground-level data with $R^2 = 0.86$, RMSE = 0.10, and MAE = 0.07. The high accuracy result between the satellite data and the ground-level data indicated the satellite data from the AIRS sensor could be used for this study.

2.3 GPP Estimation

The Moderate Resolution Imaging Spectroradiometer (MODIS)/Terra GPP (MOD17A2H) product is publicly available and ready-calculated; thus, it was used in this study for assessing the GPP in the study area. Qiu *et al.* (2020) have found that the MOD17A2H product had a good agreement with the GPP of flux towers over their forest sites in North America. The MOD17A2H GPP was computed using the light use efficiency (LUE) model proposed by Monteith (1977). The formula for this model was shown in Eq. (1).

$$\text{GPP} = \text{fPAR} \times \text{PAR} \times \varepsilon \quad (1)$$

The fPAR is the fraction of photosynthetically active radiation absorbed by the plant, the PAR is the total photosynthetically active radiation event on the plant and ε is the conversion efficiency of the absorbed energy to the fixed carbon. The formula above has been adopted in NASA's MODIS that allowed scientists to quantify the metabolism of the earth on a daily basis. Therefore, in this study, the GPP data were measured by MODIS aboard the Terra spacecraft at 500 m × 500 m resolution. The data were a cumulative 8-day composite of values based on the radiation use efficiency concept that could be potentially used as inputs to data models to calculate terrestrial energy, carbon, water cycle processes, and biogeochemistry of vegetation. In general, the GPP was the technical term for plant photosynthesis. The high GPP value indicated areas where plants used a higher amount of carbon, while the low GPP indicate areas with a lower amount of carbon.

absorbed. The GPP data were then analyzed at the same periods with atmospheric CH₄ to give a better understanding of CH₄ fluxes from the peatland. In this study, the GPP maps were validated against the land cover map obtained from the Department of Forestry of Indonesia. The validation results obtained a good accuracy between the GPP map and the land cover map with $R^2 = 0.90$, RMSE = 0.09, and MAE = 0.06. Therefore, the GPP data from the MODIS sensor was suitable to be applied for this study.

3 RESULTS AND DISCUSSION

3.1 Atmospheric CH₄ Concentration over the South Sumatran Peatland

Before the LSSR period in March 2020, the mean concentration for CH₄ over the study area was about 1.82 ppm (Fig. 2(c)). The highest concentration was observed in the northern peatlands. In March and May 2019, our study found about a 6% increase in CH₄ concentration over the peatland areas compared with during the same period in 2020 (Figs. 2(a–b)). Fig. 3 showed the monthly average concentrations for CH₄ in 2019 were higher than the concentrations in 2020. The high concentration of CH₄ in 2019 could be caused by the intensive anthropogenic activities during this period. According to Fig. 3, we found a significant increase in CH₄ concentration after June in both years. It might be due to the beginning of the dry season (May–August). During this period, this area frequently experienced forest fire events, especially peatland fires. These events have contributed to high greenhouse gas emissions (CO₂ and CH₄) to the atmosphere. A recent

Fig. 2. Atmospheric CH₄ concentrations before COVID-19 pandemic (a) in March 2019, (b) in May 2019, (c) before the LSSR in March 2020, and (d) during the LSSR in May 2020 in the study area.

Fig. 3. Monthly concentration of atmospheric CH₄ over the South Sumatran peatland before COVID-19 pandemic (dashed line) and during COVID-19 pandemic (solid line) periods.

study has discovered that in Sumatra, the deforestation hotspots were mostly found in southern areas (Singh and Yan, 2021). The majority of hotspots took place in areas with greater human activities.

If we compared with other studies, our results were slightly higher than CH₄ monthly means of 1.74 ppm in western China (Zhou *et al.*, 2004). Furthermore, a study by Thompson *et al.* (2018) has found a higher atmospheric CH₄ concentration of about 1.82 ppm in tropics and subtropics. Based on their assumption, the concentration of CH₄ was strongly influenced by an increase in microbial and fossil fuel emissions. The changes in the microbial emissions were in line with the wetland source responding to variation in precipitation.

There was a notable decrease of CH₄ in the study area from April to June 2020; this was due to the COVID-19 pandemic and mitigation action at those times. Moreover, in natural conditions, the deep peat could be one of the main contributors to the higher emission of CH₄ from the peatlands. In the study area, the deepest-peat (> 5 m) areas were more distributed in the northern peatland thus make these areas possibly emitted a high CH₄ emission. Also, agricultural lands situated around the peatland such as oil palm, rubber, and rice could add CH₄ emissions to the atmosphere (Yulianingsih, 2016). During normal days before the LSSR, anthropogenic activities were intensively carried out in the study area especially in the northern peatlands. These activities included land use conversion from swamp or secondary forests to oil palm, rubber, rice fields, and freshwater fisheries. Converting from secondary forest peatland to agricultural lands tended to increase emissions of CH₄ (58.3%) and CO₂ (25%) to the atmosphere (Inubushi *et al.*, 2003). Additionally, in studies of CH₄ fluxes from drained and deforested peatlands, the CH₄ uptake (2.5 mg m⁻² day⁻¹) was significantly lower than the CH₄ uptake in the undisturbed peatlands (5.6 mg m⁻² day⁻¹) (Sun *et al.*, 2011; Salm *et al.*, 2012).

During the LSSR period, the concentration of CH₄ was found to drop at most of the peatland areas. The mean CH₄ concentration reduced to 5.5%. Fig. 2(d) illustrated the spatial distribution of CH₄ over the study area during the LSSR period. The northeastern peatlands recorded the lowest concentration among peatland areas that was around 1.72 ppm. This result indicated that the restriction of major anthropogenic activities attributed to the reduction of CH₄ levels over the peatland areas. In summary, we assumed the percentage reduction of CH₄ level during the LSSR in the peatland areas was quite significant. This was because, in another study by Chauhan and Singh (2020), they found the CH₄ level decreased only by 0.54% as compared with before lockdown period in India.

Furthermore, we revealed the highest decrease in CH₄ level was observed in the south and southwest of South Sumatra. There was a possible reason for this condition; it might be due to the effect of meteorological factors such as wind direction and velocity. From February to May, the wind pattern in this region mostly blew from the northeast to the southeast that might affect the diffusion of CH₄ gaseous in the study area. A previous study by Battista and de Lieto Vollaro (2017) has found a strong association between major air gaseous pollutants with wind direction and speed, air temperature, and solar radiation in Italy.

3.2 GPP Values over the South Sumatran Peatland

The spatial distribution of the monthly average GPPs before the LSSR (March 2020), during the LSSR (May 2020), and last year's data (March and May 2019) was shown in Fig. 4. The highest GPP values were recorded in the LSSR period at the northwestern peatlands ($63.9 \text{ g C m}^{-2} \text{ day}^{-1}$) while lower values at the northern and northeastern peatlands ($53.3 \text{ g C m}^{-2} \text{ day}^{-1}$) (Fig. 4(d)). It would explain why we obtained the low CH_4 concentration in the atmosphere during the LSSR period; this was due to the high carbon uptake in the study area. To approve this assumption, we run the regression analysis to analyze the association between CH_4 and GPP values as shown in Fig. 5. Our analysis showed the CH_4 and GPP values had good accuracy with $R^2 = 0.89$.

The lowest GPP values were observed in the period before the LSSR and last year 2019 data; the GPP values varied from 0 to $20.9 \text{ g C m}^{-2} \text{ day}^{-1}$ at most of the peatlands (Figs. 4(a–c)). The results were slightly higher than the GPP values of peatlands in the Kalimantan, Indonesia, which were just ranged from 4.62 to $41.09 \text{ g C m}^{-2} \text{ day}^{-1}$ (Wang *et al.*, 2014). However, in the Canadian peatlands, the GPP values were found much lower, which ranged from 5.0 to $8.5 \text{ g C m}^{-2} \text{ day}^{-1}$. This was because the GPP was dropped to zero in winter due to snow cover and low temperatures decreased photosynthesis to zero. The GPP in the subtropical peatlands started to rise as the snow ended which occurred in early April (Lafleur *et al.*, 2003). The GPP values could be associated with the weather condition (Bubier *et al.*, 2003). However, based on the previous study, the statistical proof found that the GPP value in a peatland was not statistically significant with $p = 0.706$ (Connolly *et al.*, 2009). Therefore, the uncertainty of the weather condition effect on the GPP value in a peatland had little effect.

Fig. 4. The GPP values before COVID-19 pandemic (a) in March 2019, (b) in May 2019, (c) before the LSSR in March 2020, and (d) during the LSSR in May 2020 in the study area.

Fig. 5. The relationship between the GPP and CH₄ values.

In tropical peatlands like the study area, the decrease carbon uptake was more caused by the deforestation of vegetation in the peatland thus make the low photosynthetic activity to capture carbon in the air. The GPP was reduced to zero in March and May 2019, and March 2020 (before the LSSR periods) because many vegetated areas have been deforested; thus, it made low temperatures which reduced photosynthesis to zero. During those periods, human activities were intensively carried out which has degraded the peatlands but when the social restriction policy was implemented due to the COVID-19 outbreak, it has improved GPP values in all peatland areas. Another reason, previous studies found that the fPAR from the satellite data could capture GPP well in the growing season from May to October (Wang *et al.*, 2014). Based on our observation, we also found the same result when we found high GPP values in May 2020, while low values observed in March 2020. The high temperature in the area in this early year was believed to accelerate the rate of methanogenesis and this was an impact of raising an ebullition frequency in the peatlands (Schubert *et al.*, 2012).

4 CONCLUSIONS

We analyzed the effect of the COVID-19-related LSSR on the CH₄ concentrations in the atmosphere above the peatlands of South Sumatra. The mean concentration, which averaged 1.73 ppm before the LSSR, fell by 5.5% during May 2020. This decrease in the CH₄ was driven by the increase in the total carbon uptake of the study area, represented by the GPP, which peaked during the LSSR. As anthropogenic activities, such as land cover conversion, biomass burning, and agricultural activities, are primarily responsible for the rise in CH₄ emissions from peatlands, the restrictions during lockdown led to lower levels of atmospheric CH₄ in this region. Our results may assist in formulating a policy for mitigating such emissions in peatland areas.

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