Carbon Emission from Peat Fire in 2015

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Abstract. Peat fire emits a large amount of carbon to the atmosphere. This emission can affect atmospheric composition and also the climate system. This paper discussed the carbon emission from the 2015 peat fire, the largest after 1997 one. Indonesian National Carbon Accounting System (INCAS) published by The Indonesian Ministry of Environment and Forestry was used to calculate the carbon emission from the peat fire. Peat fire emission factors used in the calculation for region of Sumatera and Kalimantan were selected from previous study, while for Papua’s region extrapolation method was applied. Peat area burned was estimated by using Normalized Burn Ratio (NBR) based on hotspot data enquired from MODIS. The cumulative peatland area burned from July – October 2015 in Indonesia was estimated to be about 623,304 ha, where about 270,691 ha (43%), 320,756 ha (51%) and 31,857 ha (5%) were found in Sumatera, Kalimantan and Papua, respectively. By considering only the three biggest gaseous carbon compounds released by biomass burning (CO\(_2\), CO, and CH\(_4\)), therefore total carbon emitted to the atmosphere during these four months peat fire was estimated to be about 0.002 Gtonnes, of which 81% was in the form of CO\(_2\); 16% CO and 2.3% CH\(_4\).

1. Introduction
Peatland is defined as a land composes of organic soils. The land is an area with cumulated half decomposed organic material, ash contents equal or less than 35%, peat depth equal or more than 50 cm and organic carbon contents at least 12% [1]. Indonesia has the largest tropical peatland in the world [2] where about 69.61% of its total area is found in Sumatra and Kalimantan [3]. Tropical peatland is estimated to preserve about 40% of terrestrial carbon [4], but due to traditional slash and burn practices for agricultural and plantation purposes especially in Sumatra and Kalimantan, it has led to large peat fires that released a large amount of carbon to the atmosphere [5], that could affect atmospheric composition and also the climate system. This traditional practice of land clearing is still the cheapest and most efficient way of getting rid of rats, wood debris and grass; the traditional farmers also believe that ash residue from burning can improve the soil pH and fertility [6][7].

In 2015 large peat fires stroked regions of Sumatera, Kalimantan and Papua. Human activities relating to agricultural or plantation purposes were behind the catastrophe [5], while the prolonged drought induced by a strong El Nino enhanced the fires [8]. This 2015 peat fire was the largest after...
the 1997 one. The carbon emissions from peat fire have been investigated by several researchers [5][8][9]. But the results are still inaccurate because the emission was calculated by assuming that peat fire in Sumatra, Kalimantan and Papua emitted the same amount of carbon per-kg of dry peat burned, called emission factor. This study is trying to improve the carbon estimation for the 2015 peat fire by using corresponding emission factor for Sumatra, Kalimantan and Papua peat fires.

2. Materials and Methods

2.1. FIRMS: Hotspot

Daily cumulative hotspots data as indicator of fire used in this analysis were obtained from Fire Information for Resource Management System (FIRMS) website (https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms) retrieved from Moderate Resolution Imaging Spectroradiometer (MODIS) on board of Aqua and Terra satellites. The hotspot from July-October 2015 with confidence level bigger than or equal to 95% was selected for further analysis. Daily cumulative hotspots are used to indicate fires. Only hotspot with level of confidence equal to or bigger than 95% are selected.

2.2. TRMM: precipitation rate (mm/hr)

Precipitation rate is a measure of the rainfall intensity by calculating the amount of rain that would fall over a given interval of time if the rainfall intensity were constant over that time period (American Meteorological Society, 2017). Area averaged daily precipitation rate in unit of mm/hour with spatial resolution of 0.25° × 0.25° from July – October 2015 were acquired from Tropical Rainfall Measuring Mission (TRMM) and downloaded from GES-DISC Interactive Online Analysis Infrastructure (Giovanni) NASA website (https://giovanni.gsfc.nasa.gov/giovanni/) as part of the NASA Goddard Earth Sciences Information Services Center (DISC).

2.3. Methods

Indonesian National Carbon Accounting System (INCAS) [1] has followed the model used by IPCC [10] to estimate carbon emission from the forest and peat fire as follows:

\[ E = a \times F_t \times C_f \times EF \times 10^{-3} \]  

where E is amount of CO₂ or non-CO₂ emission (ton), a is total area burned annually (ha), \( F_t \) is dry fuel mass available for combustion (ton/ha), \( C_f \) is a dimensionless combustion factor and EF refers to emission factor for each gas (g/kg dry mass burned). Dry fuel mass available for combustion (ton/ha) is calculated by multiplying depth of burned peat (m) with bulk density (ton/m³).

Carbon emission from forest and peat fire was limited to peat fire in Sumatra, Kalimantan and Papua. It was calculated for CO₂, CO, and CH₄. These three were the largest gaseous carbon compounds emitted by peat fire and contributed more than 95% of total carbon emitted [11-13]. The other trace gaseous and particulate carbons were neglected.

Emission factor values used to calculate carbon emission from peat fires are listed in Table 1. Emission factor for Kalimantan peat fire was the average of emission factors from three previous studies [12-14]. Because there were no previous studies for Papua and West Papua peat fires, therefore we used emission factor for CO₂ of 1,111 g/kg by extrapolating peat carbon mass fraction of 0.3053 for hemic peat [15] to the regression linear equation of emission factor for smoldering peat fire as shown in Figure 1 [16]. The corresponding emission for CO and CH₄ can be calculated by multiplying their emission ratio, by using CO₂ as a reference species, with the calculated emission of CO₂ by applying the equation below [17]:

\[ E_x = E_{CO₂} \times ER_{x/CO₂} \]  

(2)
where $E_x$ is amount of emission of $x$ (CO or CH$_4$) (ton), $E_{CO2}$ is amount of emission of CO$_2$ and $ER_{x/CO2}$ refers to emission ratio of $x$ with respect to CO$_2$ (mol/mol). For the purpose of this study, therefore $ER_{CO/CO2}$ is 0.153 mol/mol and $ER_{CH4/CO2}$ is 0.029 mol/mol [16].

**Table 1.** Emission factors (g/kg dry peat burned) used for the calculation of carbon emission

|          | Sumatra peat [11] | Kalimantan peat [12, 13, 14] |
|----------|-------------------|-------------------------------|
| CO       | 1,703             | 1,677                         |
| CO       | 210.3             | 221                           |
| CH$_4$   | 20.80             | 13.1                          |

**Figure 1.** Simple linear regression between peat carbon content and emission factor (EF) of CO$_2$ for smoldering combustion [16]

Total peatland area burned was calculated for four months peat fire from July – October 2015 based on normalized burn ratio (NBR) method. This method used hotspot data as an indicator of peat fire from MODIS.

Dry fuel mass available for combustion is a product of depth of burned peat and bulk density [1]. For depth of burned peat, INCAS recommends using 0.18 m for newly burned peat and 0.11 m and 0.04 m for peat burned two and more than two times, respectively [1]. Bulk density used for Sumatra [18] [19], Kalimantan [16] [19] [20] and Papua [15] peats are 0.1716, 0.23 and 0.23, respectively.

Although INCAS recommends using 1 as the combustion factor, which means peat fire is a complete combustion, but in this study, we used 0.8 for Sumatra and 0.7 for Kalimantan and Papua peat fires [11] [13]. It was because peat fire mostly was dominated by smoldering combustion, a type of combustion when no flame is visually observed but apparent thin or thick smokes [16].

**3. Results and Discussion**

Analysis of hotspot and precipitation rate in Sumatera, Kalimantan and Papua based on satellite data was presented in **Figure 2.** In 2015, a strong El Nino hit Indonesia and the region suffered with prolonged drought [9]. The minimum precipitation rate in Sumatera, Kalimantan and Papua were found in July, September and August, respectively. Lower precipitation rate in Sumatera and Kalimantan had triggered higher number of hotspots in both regions (**Figure 2a** and **b**). On the contrary, low precipitation rate did not increase number of hotspots dramatically in Papua (**Figure 2c**). Land clearing for palm oil and pulpwood plantations was reported to be responsible for mostly peat fire incidents in Indonesia [21]. In 2015 Sumatera has the largest palm plantation in Indonesia with area of about 7,139,060 ha (63%), Kalimantan had about 3,639,737 ha (32%) and Papua had about
106,402 ha (0.9%) [22]. It is very interesting fact that proved human activities were the main factors that led to peat fires, since Papua and West Papua both have the smallest palm plantation area [22] and also the smallest population density in Indonesia [23] during that year.

Figure 2. Precipitation rate and number of hotspot during July – October 2015 in a) Sumatera, b) Kalimantan and c) Papua

Figure 3 shows the estimation of cumulative peatland area burned in Indonesia during peat fire in July – December 2015 and their related number of hotspot. The three largest peatland areas burned
were found in Central Kalimantan (197,486 ha), South Sumatra (146,986 ha) and West Kalimantan (74,858 ha) provinces. Total peat areas burned in Sumatra, Kalimantan and Papua were 270,691 ha, 320,756 ha and 31,857 ha, respectively. Based on The Ministry of Environment and Forestry statistic data in 2015 [24], it was reported that since 2010 – 2015 the government has allowed the conversion of forest to plantation/agricultural purposes in Sumatra, Kalimantan and Papua with total area of 3.063 million ha, 1.910 million ha and 1.279 million ha, respectively. Unfortunately, there was no detailed information regarding the proportion of peatland and non-peatland conversion in the data. By assuming that all of these conversions and also the agricultural/farming practices were conducted by slash and burn method, it meant that most fires were found in the existing plantation/agricultural areas. Because of this assumption, therefore for this study we used 0.04 m as a depth of peat burned by assuming that most of peat areas were burned more than two times already and they were located in the existing plantation/agricultural areas.

Table 2 presents the carbon emission calculated for Sumatra, Kalimantan and Papua and their corresponding emission variables. During four months peat fire in Indonesia from July – October 2015, total carbon released to the atmosphere was estimated to be about 1.848 million tonnes or 0.002 Gtonnes C, of which 81% is in the form of CO2 (0.0062 Gtonnes CO2); 16% CO (0.0008 Gtonnes CO) and 2.3% CH4 (0.000065 Gtonnes CH4). Huijnen et al. [9] reported their overestimated carbon emission calculation result during two months peat fire (September – October 2015) to be about 0.227 Gtonnes of which 83% was in the form of CO2 (0.692 Gtonnes CO2), 16% CO (0.084 Gtonnes CO) and 1% CH4 (0.0032 Gtonnes CH4). The reason was probably because the area of forest and peatland burned in Huijnen et al.’s estimation was much larger, covering all the South-East Asia region. Secondly, they also neglected the possibility of peat with different carbon content that would emit different carbon concentration. In this case, they used the same emission factor for Sumatra, Kalimantan and Papua peat fires. Page et al. [2002] reported that during four months (July – October), the 1997 peat fire in Indonesia emitted about 0.81 – 2.57 Gtonnes carbon to the atmosphere which was much higher than the one we calculated for the 2015 peat fire. The reason was because the 1997 peat fire burned much larger peatland areas (about 6.8 million ha), and also, they used the same emission factor for Sumatra, Kalimantan and Papua peat fire.

![Figure 3. Peat area burned in July – October 2015](image-url)
Table 2. Emission and their corresponding variables for peat fire in 2015

| No. | Descriptions                                  | Sumatra | Kalimantan | Papua | Total  |
|-----|-----------------------------------------------|---------|------------|-------|--------|
| 1.  | Total peat area burned (ha)                   | 270,691 | 320,756    | 31,857| 623,304|
| 2.  | Dry fuel mass available for combustion (ton/ha)| 0.0069  | 0.0092     | 0.0092|        |
| 3.  | Combustion factor (dimensionless) CO₂         | 0.8 [11]| 0.7 [13]   | 0.7   |        |
| 4.  | Emission factor (g/kg dry fuel burned) CO₂   | 1,703 [11]| 1,677 [13]| 1,111 |        |
| 5.  | Emission CO₂ (million ton)                   | 2.545   | 3.464      | 0.228 | 6.237  |
| 6.  | Emission CO (million ton)                    | 0.314   | 0.457      | 0.035 | 0.806  |
| 7.  | Emission CH₄ (million ton)                   | 0.031   | 0.027      | 0.007 | 0.065  |
| 8.  | Emission CO₂ eq. (million ton)               | 2.756   | 3.765      | 0.253 | 6.774  |
| 9.  | Emission C (million ton)                     | 0.752   | 1.027      | 0.069 | 1.848  |

4. Conclusion
During the 2015 peat fire, total peat areas burned in Sumatra, Kalimantan and Papua were about 270,691 ha, 320,756 ha, and 31,857 ha, respectively. By considering that peat with different carbon content would emit different carbon concentration, in this case specific emission factors were applied for Sumatera, Kalimantan and Papua peat fires, therefore this study revealed that during July – October 2015 peat fire in Indonesia had released about 0.002 Gtonnes carbon to the atmosphere, of which 81% was in the form of CO₂; 16% CO and 2.3% CH₄.

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