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Reassessment of peatland fires in Central Kalimantan

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Abstract. The El Niño–Southern Oscillation (ENSO) was used to explain fire occurrences in Indonesia's peatlands until 2018. However, the severely spread of 2019 fires although there was no El Nino event (Niño 3.4=-0.04, neutral) in a year, urged us to reassess the peat fires using reliable data and scientific knowledge. Here, we did a series of reassessments of peatland fires in Central Kalimantan by using various data and knowledge about fire, including weather, groundwater levels (GWL), air pollutants, and other parameters related to fire. The reassessment is expected to help respond to peatland fires under rapid climate change. A recent study by the authors has shown the effectiveness of the use of the OLR-MC index as an alternative to ENSO and the peatland fire reassessment model (MODEL-0) based on groundwater level (GWL). As a result of reassessing the generation of various air pollutants from the 2002 fire using MODEL-0, we clearly showed that the air pollutants from the peat components increased rapidly with the onset of the deep peat fire. The findings obtained in this paper are expected to be useful in responding to peatland fires under climate change.

1. Introduction

Peatland fires has been known as a major contribution to emissions of greenhouse gases, fine particulate matter and aerosols, thus contributing to climate change as well as presenting a problem for human health [1]. Due to the thick peatland in Indonesia, peat fires in the country may become more active when the groundwater level drops. The risk of fire on peatland is increased greatly by drainage, which lowers the water table, exposing a greater volume of dry peat to combustion.

Peat fire can be initiated by flaming fires and embers of surface vegetation. The probability of ignition depends on the moisture content, inert content, and other chemico-physical properties [2,3]. Two mechanisms control the spread of smouldering combustion: oxygen supply and heat losses [4, 5]. Studies on smouldering peat fires introduced the overhanging combustion of peat [6]. Their experiment and analysis results lead to an understanding of a physical of the spread and overhang phenomenon in peat wildfires as well as explain the role of moisture and oxygen supply. The spread of smouldering peat fire can be explained by the formation and collapse of overhanging. In addition to overhanging, we add "peat layer fires (underground peat fires)" which spread under topsoil without large openings. We often see "peat layer fires" in an agriculture land and under a paved road with mineral soil above a deep peat layer.

In this paper, we reassess air pollution in 2002 using the peatland fire evaluation model (MODEL-0) introduced in the recent paper [7]. MODEL-0 can classify peatland fires based on the groundwater level (GWL) into three peat fire stages, namely (1) surface fire on peat, (2) shallow peat fire, and (3) deep peat fire, and will predict the occurrence of deep peat fires. Daily changes of air pollutants such as PM10, SO2, CO, NO2, and O3 will be reassessed using these three peat fire stages.

2. Study area

The reassessment is done in the Mega Rice Project (MRP) area and its surrounding. Figure 1 shows the peatland distribution and study area and air pollution measuring sites in the study area. The area was chosen as the study area as it is dominated by peatlands and highly impacted from frequent severe peat fires in Indonesia [7,8,9]. In Figure 1, we illustrate the MODIS on Terra/Aqua hotspots distribution at the study area in 2015.

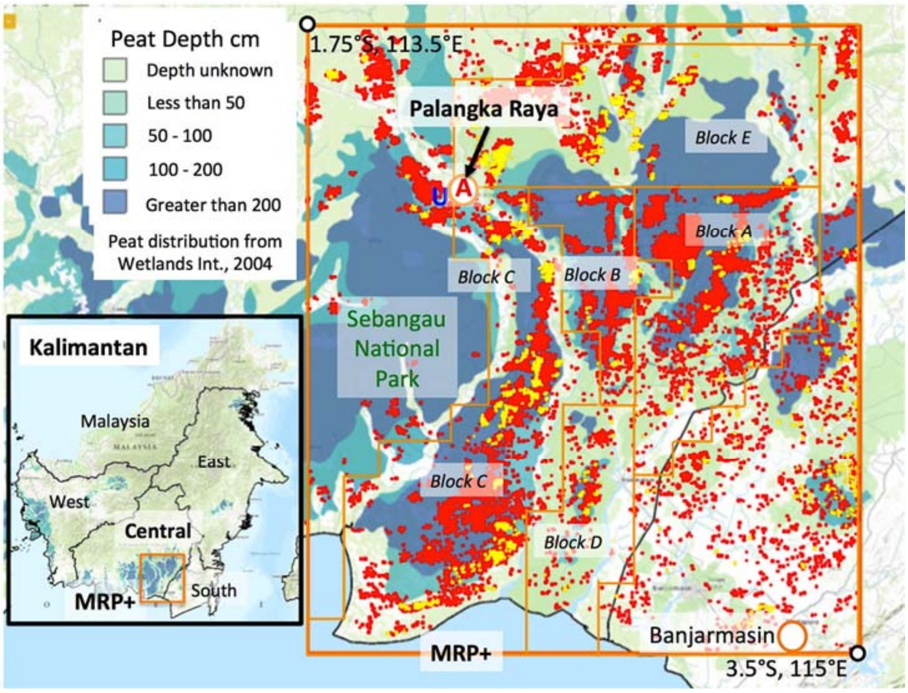

Figure 1. Map of Kalimantan, MRP+, Block A to E, and peatland. MODIS Hotspots are shown by red (detected from DN=170 to 330) and yellow dots (Highest Hotspot 1191, detected on DN=285). U: Groundwater level (GWL) measurement site, A: Tjilik Riwut Meteorology Station (TRMS)

3. Data and Methods

3.1. Air pollution and weather data

Automated continuous analyzers are used to measure PM10, SO_2, CO, O_3, and NO_2 in the three regional air quality center at Tjilik Riwut, Tilung, and Murjani [10]. The Air Quality Center processed all air pollution data automatically from 2000 until around 2010. Unfortunately, most of their gas analyzers were broken in 2011, and air pollution data were unavailable now.

The weather data was measured at the Palangkaraya weather station at Palangka Raya International Airport shown by "A" in Figure 1. Groundwater level (GWL) was measured at "U" in Figure 1. Daily rainfall data was used to evaluate GWL using GWL simulation model (MODEL-0) [7].

3.2. Hotspot (Fire) data and satellite imagery

Hotspot (HS) data from MODIS Terra/Aqua satellites are used to evaluate fires in the study area. The hotspot data are obtained from NASA FIRMS (Fire Information for Resource Management System, https://firms2.modaps.eosdis.nasa.gov).

The Terra/MODIS Corrected Reflectance (True Color) imagery is obtained through the EOSDIS Worldview (https://worldview.earthdata.nasa.gov) and used to grasp haze situation and estimate origin of air pollutants source.

4. Results and Discussion

4.1. Source of air pollutants on deep peatland

Here we did a reassessment of various fire indices by using the OLR-MC index derived from outgoing longwave radiation (OLR) to monitor convective activity over the central maritime continent (MC) region of Indonesia, including Kalimantan Island. The OLR–MC index showed a stronger correlation with active peatland fires than the ENSO index. Therefore, we strongly suggest using the OLR–MC index to analyze future active fires related to both El Niño and climate change [7].

Fig. 2 (a) shows typical peatland fire conditions in the deep peat. Deep peat fires emit greyish smoke form underground peat fire and brownish smokes from surface fire on peat. A mixture of these smokes is called a haze. Smoldering of peat emits various air pollutants (including transient gases) [12] due to low temperature smoldering (peat pyrolysis temperature: about 450-720 K) compared to surface flaming fire (> about 1000 K).

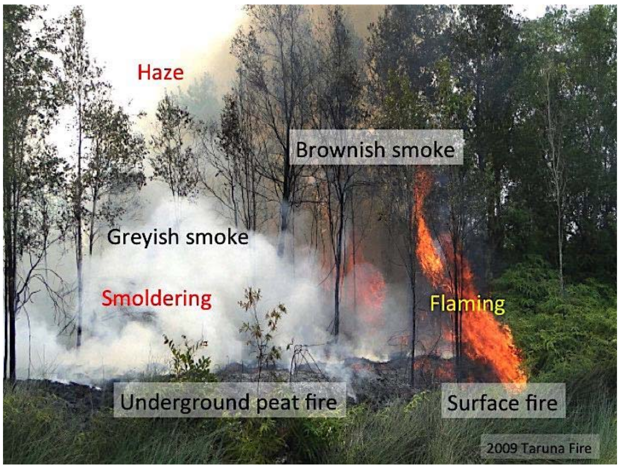

Figure 2 (a) Fire and smoke situation.

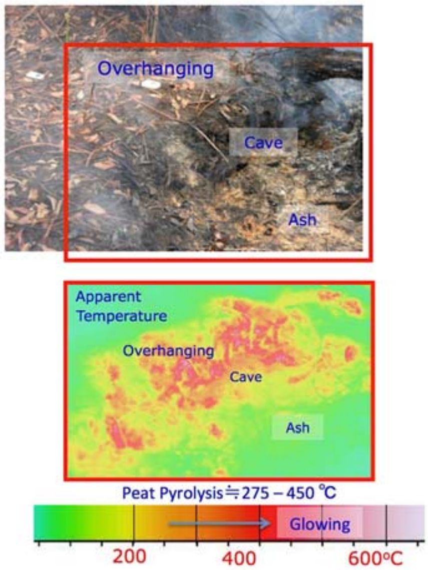

Figure 2 (b) Overhanging and cave in deep peatland fire.

In the deep peat (peat depth more than 0.5 m), active underground peat fires can produce cave (holes under peat surface) and overhanging as shown in **Fig. 2 (b)**. This type of underground peat fire is unique and occurs only in deep peatland areas such as in our study area. Once deep peat fire starts, smouldering peat fires spreads horizontally along the free surface and vertically in-depth [2, 11]. Fire often burns peat soil below the surface horizontally and leaving a cave and overhang (**Fig. 2 (b))**.

Although the overhanging and caves may collapse easily, the lateral spread of the fire continues and may promote new surface peat fires. Thus, underground smoldering peat fires can be sustained by keeping the heat from peat pyrolysis with little heat loss. Our field observation suggests that the indication of peat layer fires is more dominant rather than the cave and overhanging in the third fire stage. The spread of smouldering combustion is controlled by oxygen supply and heat losses [12, 13].

4.2. Fire stages and GWL

The second reassessment is done to observe the relation between fire activity and groundwater levels (GWL). The average fire occurrence trend of El Niño fire year showed three different fire rates (10, 70, and 160 hotspots day^{-1}) on an accumulated HS curve. To find relationship between fire occurrence and GWL, we developed a simple groundwater level (GWL) prediction model (MODEL-0). By assuming evapotranspiration as a constant, MODEL-0 can easily estimate the daily GWL changes using only daily rainfall data.

Peatland fires can be classified into three fire stages based on ground water level (GWL). Field observations are done by several fire researchers [14, 15]. From a comparison of estimated GWL using MODEL-0 and daily fire activity, we found three different fire stages that may define as surface fire, shallow peatland fire, and deep peatland fire. Their GWL boundary values were about -300 mm to -500 mm [7].

Fig. 3 illustrates the peat fire development in 2012. Surface fire started from end of June (Day Number (ND) around 170). Shallow peatland fire started from around DN=178 (July 6) with 27 hotspots (HS) day^{-1}. Deep peatland fire started from around DN=220 (August 8) with 180 hotspots (HS) day^{-1} and lasted until end of October. Classification of these three fire stages is necessary to assess air pollution from peatland fires. At surface fire, most vegetation burns with flames (temperature higher than smoldering combustion). Smoldering peat fire in shallow peatland starts from surface fires. Finally, when the thickness of flammable peat (moisture content less than around 100% [14]) reached about -300 mm measured on August 2, the third fire stage (deep peat fire) begins.

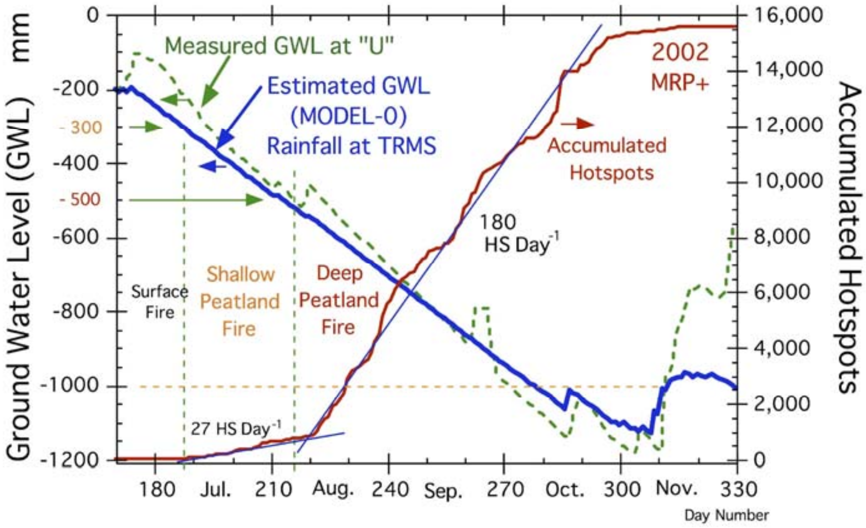

Figure 3. The three stages of peat fire and ground water level.

The gradient of the straight line drawn on the accumulated hotspot (HS) curve in **Fig. 3** shows the fire activity in the three fire stages. The hotspots numbered 180 HS day^{-1} for "Deep peat fire", larger than the average of 160 HS day^{-1} of the last six fire years (2002, 2004, 2006, 2009, 2014, and 2015)) [7].

4.3. Air pollution situation in deep peatland

Daily change of various air pollutants, SO_2, CO, O_3, NO_2, and particulate matter (PM10) are shown in **Fig. 4**. The above air pollutants can be emitted from peat and surface combustion except SO_2. As SO_2 from surface vegetation fire is usually very low, SO_2 will be one of important signs for occurrence of smoldering peat fires. High values of CO, and PM10 in the third fire stage (DN =220-300) are also important sign for occurrence of in the deep peatland fire (lower temperature smoldering peat combustion). NO_2 has two different sources, derived from vegetation fires and combustion in vehicle engines. This is why the NO_2 values are also high from the first and second fire stages (DN =170-220).

The worst air pollution occurred on October 14 in 2002 due to active deep peatland fires in the end of the third fire stage, "3: Deep peatland fire". GWL was lowest about -1000 mm (see **Fig. 3**). Maximum peak concentrations of PM10, SO_2, CO, and O_3 reached 1905, 85.8, 38.3, and 1003 x 10^{-6} gm^{-3} respectively. The O_3 peak may suggest the serious formation of photochemical smog under the high-NO_2 (=42.5 x 10^{-6} gm^{-3}). This may be the world's first record of photochemical smog caused by deep peatland fires.

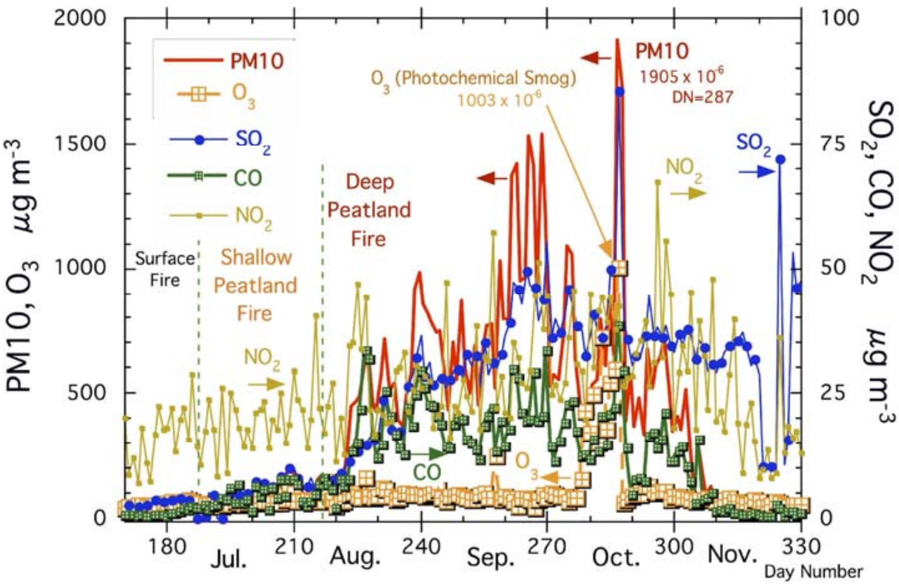

Figure 4. PM10, O_3, SO_2, CO and NO_2.

4.4. Haze, visibility, and hotspot

Lastly, we carried out a reassessment of air pollutants due to fires. This paper describes the results of reassessing the generation of various air pollutants from the 2002 fire. We found that at the end of the third fire stage (deep peatland fires), PM10, SO_2, CO, and O_3 reached their maximum concentrations of 1905, 85.8, 38.3, and 1003 x 10^{-6} gm^{-3}, respectively on October 14, 2002. These maximum concentrations were found following the lowest groundwater level (GWL) on the day at around -1000 mm.

Fig. 5 illustrates daily change of PM10, visibility, and hotspot (HS). Accumulated HS curve shows the fire activity in each fire stages. Dense haze from deep peatland fires may lead to unfavorable meteorological conditions such as calm winds and low air temperature. Sunlight could not reach the ground easily under the dense haze condition in 2002, suggesting that daytime convection flow by the sunlight barely occurred on these days and the haze was confined to the surface due to low air temperature. High PM10 values and low visibilities in third fire stage of “deep peat layer fire” may be due to high fire rate of 180 HS day^{-1}.

PM10 gradually increased during two periods of surface fire (DN=170-187) and shallow peat fire (DN=187-213) as shown in **Fig. 5**. A sharp increase in PM10 from 100 x 10^{-6} g m^{-6} to 400 x 10^{-6} g m^{-3} found in the third fire stage (around August 11 (DN=223)). Very high PM10 (> 500 x 10^{-6} g m^{-3}) lasted until late October. The daily changes in PM10 resemble a jigsaw pattern of hotspots (HS). PM10 reached its maximum of 1905 x 10^{-6} g m^{-3} on October 14 (DN=287), two days after the peak of HS occurred (HSs=1191) on October 12.

Our study showed that the peak of O_3 may indicates the serious formation of photochemical smog under the high-NO_2 (42.5 x 10^{-6} gm^{-3}) derived from peatland fires. Low visibility of less than 2 km persisted at most of the third fire stage (about 70 days from the middle of August to the end of October 2002). Major air pollutants are emitted from unique peat fire types of the overhanging and peat layer fires underground in the third fire stage.

The sharp increase in PM10, SO_2, and CO at the beginning of the third fire stage may be indicated as a sign of deep peatland fires (the overhanging and peat layer fires). This reassessment suggests that PM10, SO_2, and CO measurements are required to monitor the occurrence of “deep peat fire”.

Visibility is found changed in the opposite tendency to PM10. As PM10 increased, visibility was decreased (**Fig.** 5). Visibility is gradually decreased during two periods of surface fire and shallow peat fire. A sharp decrease in visibility from about 7 km to 4 km is observed in the third fire stage (around August 11 (DN=223)). The lowest visibility was nearly 0.16 km on October 13 (DN=286), while less than 2 km visibility lasted for 70 days from middle of August to end of October in 2002. Less than 0.5 km visibility and very slow wind speed of less than 2 m s^{-1} is found for 16 days in late September from DN=260 [10].

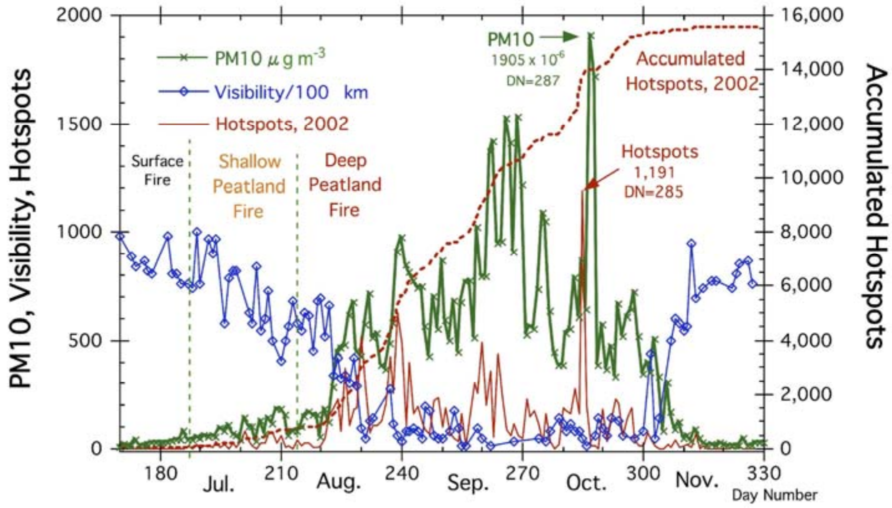

Figure 5. PM10, Visibility, and Hotspots.

Two satellite images in **Fig. 6 (a)** & **(b)** show fire and haze situation of HS peak day (ND=285) and PM10 maximum day (ND=287). **Fig. 6 (a)** shows that active fire distribution and smokes from fires. Most smoke appears to flow from the southeast to the northwest that is the prevailing wind direction during the dry season in Kalimantan. **Fig. 6 (b)** shows that dense smoke (haze) covers central Kalimantan. **Fig. 6 (b)** suggests that MODIS Terra/Aqua satellites could not detect hotspot due to the dense haze (visibility; about 0.16 km). **Fig. 6 (b)** supports the above-mentioned unfavorable meteorological conditions such as calm winds and low air temperature.

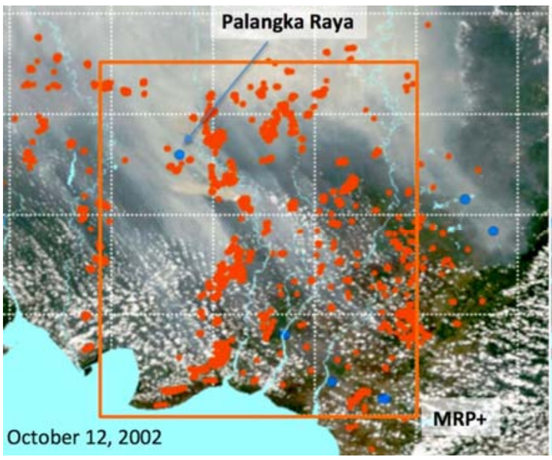

Figure 6. (a) Hotspot peak day (DN=285, Oct 12, 2002) PM10=867 x 10^{-6} g m^{-3}, HSs=1191.

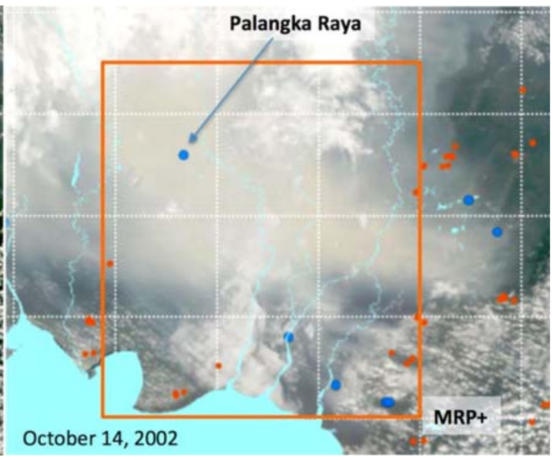

Figure 6. (b) PM10 peak day (DN=287, Oct 14, 2002), PM10=1905 x 10^{-6} g m^{-3}, HSs=13.

5. Conclusions

The main result of the previous reassessment was the introduction of the OLR-MC index and the peatland fire assessment model (MODEL-0). The OLR-MC index is found effective for the 2019 fire that occurred independently of El Nino. The developed peatland fire evaluation model (MODEL-0) can classify peatland fires into three fire stages (surface fire, shallow and deep peat fire) based on the groundwater level (GWL) and can predict the occurrence of deep peat fires.

This paper summarizes air pollution at three fire stages in deep peatland area. Three fire stages help reassess air pollution from deep peat fires. Daily changes of air pollutants such as PM10, SO_2, CO, NO_2, and O_3 clearly showed air pollution characteristics from deep peat fire.

Main conclusions of the study are as follows:

1. At the end of the third fire stage (deep peat fires), PM10, SO_2, CO, and O_3 reached their maximum concentrations of 1905, 85.8, 38.3, and 1003 x 10^{-6} gm^{-3} respectively on October 14, 2002. On this day in 2002, the groundwater level (GWL) was the lowest, about -1000 mm.
2. The sharp increase in PM10, SO_2, and CO at the beginning of the third fire stage was a sign of deep peatland fires (the overhanging and peat layer fires). This reassessment suggests that PM10, SO_2, and CO measurements are required to monitor the occurrence of "deep peat fires".
3. The O_3 peak may indicate the formation of photochemical smog under the high-NO_2 (=42.5 x 10^{-6} gm^{-3}) derived from both peatland fires and engines.
4. Low visibility of less than 2 km persisted most of the third fire stage (about 70 days from the middle of August to the end of October 2002).
5. Major air pollutants are emitted from unique peat fire types of the overhanging and peat layer fires under ground in the third fire stage (deep peat fires).

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