Recent Forest and Peat Fire Trends in Indonesia The Latest Decade by MODIS Hotspot Data

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Abstract

The worse air pollution due to haze from fires occurred in the Southeast Asia during the strongest 1997-1998 *El Niño* event in the last century. The dense haze came from forest and peat fires mainly occurred in Indonesia. Recent fires in Indonesia have become an annual phenomenon nevertheless rapid deforestation rate showed declined trend. In addition, Indonesia formally admitted very large amount of CO_2 emission mostly from fires and deforestation (about 3.01 billion tonnes after the United States). Indonesia is now requested to reduce air pollution due to haze and carbon emissions at the same time. For an execution of REDD+ (Reducing Emissions from Deforestation and Forest Degradation plus) in Indonesia, it is also essential to develop an effective firefighting strategy.

In this paper, recent hotspot data captured by NASA MODIS from 2002 to 2010 was analyzed to grasp the recent fire trend in the whole Indonesia. As Indonesia is not so small country, various grid sizes utilizing latitude and longitude angles from 1x1 to 0.01x0.01 degrees were used for various analysis purposes. Analysis results using one degree grids clearly showed the highest hotspot density areas in Indonesia located in Kalimantan and Sumatra Islands. Among them, One of the Mega Rice Project (MRP) regions (grid center: south latitude 3^o, east longitude 114^o) showed extremely high hotspot density, 0.188 hotspots/km^2/year. Two regions in Riau and South Sumatra of Sumatra Island followed the MRP area and their hotspot densities were 0.111 and 0.106 hotspots/km^2/year, respectively. Other high hotspot density regions were mostly found in deforested area on peat. Analysis results on seasonality of peat fire showed strong correlation with El Niño event. Finally, the authors are now proposing an effective fire forecast method based on recent fire trend in Indonesia.

Keywords: CO_2, haze, hotspot, hotspot density, MODIS, MRP, peat fire, REDD+

1. Introduction

The total land area of Indonesia is 1,910,931km^2 (BPS, 2010), almost 50% (~940,000km^2) cover tropical forest areas which enable carbon sequestration of about 25,500Mt (FAO, 2010; Gibbs *et al.,* 2007) and, partially overlapping, approximately 11% (~200,000km^2) cover peatland areas with a carbon storage of about 55,000Mt (Page *et al.,* 2011; Hooijer *et al*., 2006). Deforestation activities have contributed to a loss of 30% of tropical forests in Indonesia since 1950s, including for instance, the Mega Rice Project (MRP) which converted a large peat swamp forest (PSF) in the southern part of Kalimantan (>10,000km^2) in the mid-1990's (FWI/GWF, 2002; Broich *et al*., 2011; Hansen *et al*., 2009). Other deforested areas of Indonesia were created from 1985 to 2009, which did not include PSF areas (Fig. 1). The deforestation rate for Indonesia declined from the 1.75% for the 1990s to 0.51% in the 2000s (FAO, 2010). However, one of the adverse effects of deforestation on the environment was the uncontrolled forest and peat fires that occurred prior to the period of 2010.

The worst air pollution due to haze from fires in Southeast Asia history, occurred during the strongest the El Niño event of 1997-98, which was the strongest El Niño event on record prior to 2011, The dense haze causing this air pollution was released mainly from forest and peat fires in Indonesia (Heil *et al*., 2006). Page *et al.* (2002) estimated that 810 - 2,570Mt carbon was emitted during the high fire incidence in 1997. Since then, recurring fires in Indonesia have become an annual phenomenon (Langner & Siegert, 2009; Putra *et al*., 2008; Page *et al*., 2009) although the rate of deforestation is declining. The assessment of the Carbon Dioxide Analysis Center (CDAIC) showed the total CO_2 emissions for Indonesia in 2008 was 406,029Mt, an increase of about

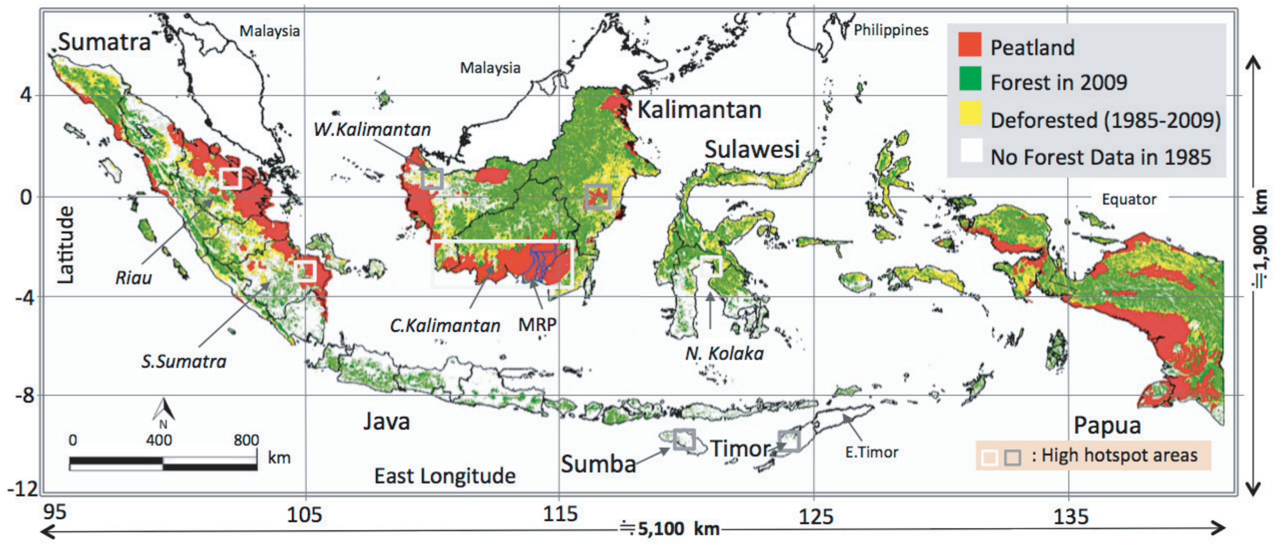

Fig. 1 Peat, forest, and deforested area distribution map for Indonesia.
(Map data derived from GWI/GFW, FAO, Wetland, and BAKORSURTANAL)

280% over the 1990s. This figures includes emissions from fuel consumption, deforestation, and forest fires (UN Statistics, 2011). Further, Indonesia has formally admitted to being the source of emissions of very large amounts of CO_2, mostly from fires and deforestation. Thus Indonesia remains as one of the top carbon emitters, after China and US.

The government of Indonesia is preparing methodology and policies for the REDD+ (Reducing Emissions from Deforestation and Forest Degradation plus) program, which started in 2009 (Ministry of Forestry, 2011). Fires and emissions of CO_2 are clearly a serious challenge for the future implementation of the REDD+ program in Indonesia. Under REDD+, Indonesia should be enhancing carbon storage and decreasing carbon emissions especially from annual fires. To achieve the REDD+ goals, a comprehensive study related of fires and fire characteristics which considering local fire trends in different fire prone areas of Indonesia is necessary.

Several papers related to vegetation fires in the world using MODIS hotspot data have been published. Wildland fires in the Asian region have also been analyzed by many researchers. Asian vegetation fire trends were identified by using fire statistics of individual countries, monthly fire occurrence of the Asian regions, and so on (Vadrevu & Justice, 2011). Spatiotemporal fire occurrence trends in Borneo (Kalimantan) were investigated by Langner & Siegert, 2009. Putra, *et al* (2008; 2011), also analyzed peat fire activity in the MRP area in the Central Kalimantan. This study uses a time series of MODIS hotspot data to intensively investigate fire incidence from national to local scales in Indonesia.

We will conduct the analysis using several sizes of grid cells based on geographical latitude and longitude. However, in the preliminary analysis in this paper, a one-degree grid only was used to understand recent fire trends in Indonesia. We discuss the fire distribution and times of the fires in the ten years surveyed and also the average monthly incidence. The final results will support the pilot project of the initial phase of REDD+ as well as help to develop future fire firefighting strategies to reduce CO_2 emissions and to design the appropriate land use practices in Indonesia.

2. Data and Methods

2.1 Modis daily hotspot data

The NASA MODIS daily hotspot data was used here because there is no other suitable fire data covering the whole of Indonesia which is available for the 2002-2011 study period. The MODIS daily hotspot data (Collection 5.1 active fire product) was extracted through FIRMS (Fire Information for Resources Management System, *http://maps.geog. umd.edu/firms/*).

Hotspot data provided by the NASA MODIS which included data for neighboring countries outside Indonesia was deleted. Representative names were used for groupings in each region (Fig. 2). The temporary boundaries would be different at different levels of analysis depending on the cell sizes. Finer mesh grids have more accurate boundaries or are more nearly at the actual geographical or political border.

2.2 Study region and analysis grid cells

The study used 10 years of MODIS data covering the area from north latitude 6° to south latitude 11° and from east longitude 95° to 142°. A map of the area of the study, the whole of Indonesia, with the forest and peat distribution superimposed, is shown in Fig.1.

Several cell sizes were used in this analysis, all utilizing latitudes and longitudes as the basis for the grid in the identification of locations across Indonesia. Cell sizes with side lengths from 1 to 0.01 degrees were evaluated as shown in Table 1. For simplicity, the cell side lengths were based on latitude and longitude, and the area of cells differs depending on latitude. Representative lengths and areas for various cell sizes are detailed in Table 1. The actual size of various grid cells is shown on

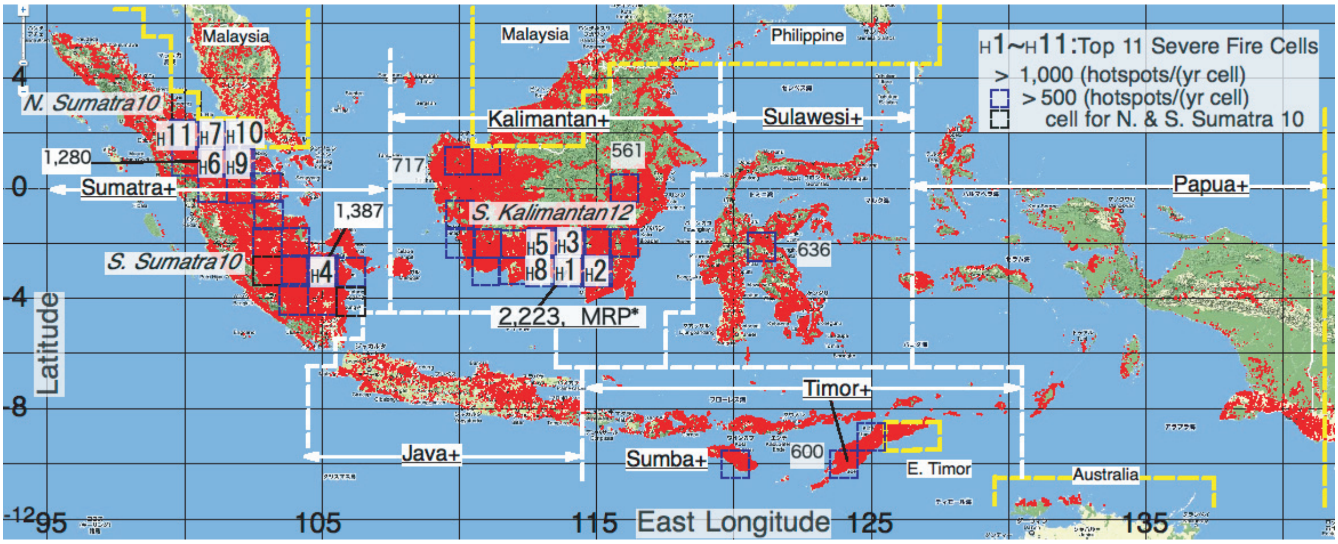

Fig. 2 Hotspot distribution and 11 highest hotspot areas in Indonesia, 2002-2011.

the map of MRP (Mega Rice Project in Central Kalimantan) in Fig. 3, where the five blocks of the MRP (A, B, C, D, and E) are colored differently.

By using this grid cell scheme, hotspots were tallied depending on their latitude and longitude. In this paper, the hotspot density unit uses "cell" instead of km^2, "hotspots/cell" was used to enable a simple comparison with various hotspot values such as annual, monthly, and mean number of hotspots in various regions composed by multiple cells. Conversion from hotspots/cell to a general hotspot density unit of "hotspots/km^2" can be obtained by dividing the number of hotspots in one cell by the cell area of around 12,300 km^2. The inter-cell difference in Indonesia is small less than about 1.5% difference between cell areas at the equator and at 10^o south latitude.

3. Results and Discussions

3.1 Fire distribution in Indonesia

The MODIS hotspot data provided by NASA for 2002-2011 was plotted as shown in Fig. 2. A total of 631,529 hotspots were recorded in the region covered by the study (N 6^o - 11^o, E 95^o to 142^o). About ninety percent of the hotspot cells in Fig. 2 fall fully within the borders of the grid cells covering only areas of Indonesia, the remaining is in the cells overlapping the surrounding countries as shown in Fig. 2. The limits of the cells extending outside Indonesia is an artifact of the one degree sized grid cells used in the analysis here. This paper ignores administrative boundaries to simplify the analysis and for the ease of the data treatment.

In Fig. 2, all coordinate points of MODIS hotspots are indicated with the smallest size of dots. The resulting map shows areas of dense red color regions in Indonesia (regions with high incidences of hotspots) and these can be simply identified on the map in Fig. 2. To show fire prone areas more clearly, several cells with the number of hotspots are marked at the cells as shown in Fig. 2. Eleven cells overlaid by white in Fig. 2 shows cells with fire occurrences above 1,000 hotspots/(yr cell). There are five such cells in south Kalimantan, five in north Sumatra, and one in south Sumatra. These cells are named H-1 to H-11 (in descending order with H-1 showing the cell with the highest fire incidence: H-1, H-2, H-3, H-5, and H-8 in Kalimantan (Fig. 6), H-4 in south Sumatra, and H-6, H-7, H-9, H-10, and H-11 in north Sumatra (Fig. 9).

The cell with the most fires in south Kalimantan, H-1 (also named MRP*), is located at south latitude 2.5^o to 3.5^o and east longitude 113.5^o to 114.5^o (see Fig. 3 for the exact position of this cell) had a mean 2,223 hotspots/yr and a maximum of 5,382 hotspots in 2006. To evaluate the fire incidence in this cell objectively the concept hotspot density will be introduced. The 2,223 hotspots/yr for this cell was converted to an annual mean hotspot density of 0.182 hotspots/km^2 (dividing the number of fires with the area of the cell in km^2) and to a daily hotspot density of 0.497 NASA fire pixels/ (1,000km^2 day) (see more detail in the NASA Earth Observations, *http://earthobservatory. nasa.gov/*). This 0.497 figure is not a very high hotspot density in the NASA scale but it becomes 1.8 pixels/ (1,000km^2 day) when considering that fires only occur during about 100 fire days in July, August, and September. This high daily hotspot density shows that the fire incidence in this particular cell in south Kalimantan is among the most intense fire incidences of any area in the world.

There are four other cells with the cells with the very highest fire incidence in Kalimantan. The second and third (H-2 and H-3) are adjacent to H-1 discussed above. The H-2 cell is to the west of H-1 and H-3 is to the north of H-1.

Six of the cells with the highest fire incidences (>1.000 fires/(yr cell)) were in Sumatra, H-4, H-6, H-7, H-9, H-10, and H-11. The H-4 cell is at south latitude 2.5^o-3.5^o and east longitude 104.5^o-105.5^o. It had 1,387 hotspots/yr or hotspot density of 0.113 hotspots/(km^2yr). This cell is located in middle of the south Sumatra area that includes Palembang (capital of South Sumatra

Province, (Fig. 9). The H-6 area is at north latitude 0.5°-1.5° and east longitude 100.5°-101.5°, in the middle of north Sumatra, and is close to Pekan Baru (capital of Riau Province, (Fig. 9). It had 1,280 hotspots/yr (hotspot density: 0.104 hotspots/(km^{2}yr)). The H-7, H-9, H-10, and H-11 areas are all around the H-6 cell, as shown in Fig. 2.

Based on the eleven H-1 to H-11 cells with the highest fire incidences in Indonesia, the authors defined three fire prone areas "South Kalimantan 12", "South Sumatra 10", and "North Sumatra 10" as shown in Fig. 2. The numbers in Fig. 2 shows the number of fires in the cells with the highest incidence in each area. There were eight areas with fire incidences higher than 500 hotspots/(yr cell) and these are shown as blue rectangles with dotted outlines in Fig. 2. Three were in West Kalimantan, one in central East Kalimantan and the final four in central Sulawesi, Sumba, and Timor (two).

Finally, you will notice the above mentioned cells with high fire incidence (H-1 to H-12) coincide with peatland areas in Kalimantan, Sumatra, and Papua by comparing Fig. 1 and Fig. 2. Peat fire is one of great environmental concern not only for Indonesia but also for the world. Peatland fires emit larger amounts of CO_2 and other air pollutants due to low temperature combustion or smoldering (Usup *et al.*, 2004). Two high fire areas in Sumba and Timor are due to savanna fire (Fisher *et al.*, 2006).

3.2 Fire occurrence trends in Indonesia

3.2.1 Annual fire occurrence

The annual fire occurrence in the six major regions of Indonesia (see Fig. 2) during the most recent ten years (2002-2011) is shown in Fig. 4. The unit of the Y-axis in Fig. 4 and also in all other Figs. (Figs. 5, 7, 8, 10, and 11) related to hotspot in this paper is the number of hotspots. The bar graph in Fig. 4 shows the number of fires in the six regions, from top to bottom: Papua+,

Table 1 Summary of analysis grid cells.

Grid Cell Size (Degree of Lati. & Long.)	Representative Length & Area (One Degree at Equator)		Target	Maximum Number of Grids
	Length (km)	Area (km^2)		
1 x 1	111.3	12,387.7	Whole Indonesia	846
0.5 x 0.5	55.7	3,096.9	Kalimantan, etc.	3,384
0.1 x 0.1	11.1	123.9	MRP, etc.	84,600
0.05 x 0.05	5.6	31.0	Village, etc.	338,400
0.01 x 0.01	1.1	1.2	Plantation, etc.	8,460,000

* Note that the center of cell locate at grid intersects, for example, centered on 1° N and E 101° covers the area north latitude 0.5°-1.5° and east longitude 100.5° -101.5°

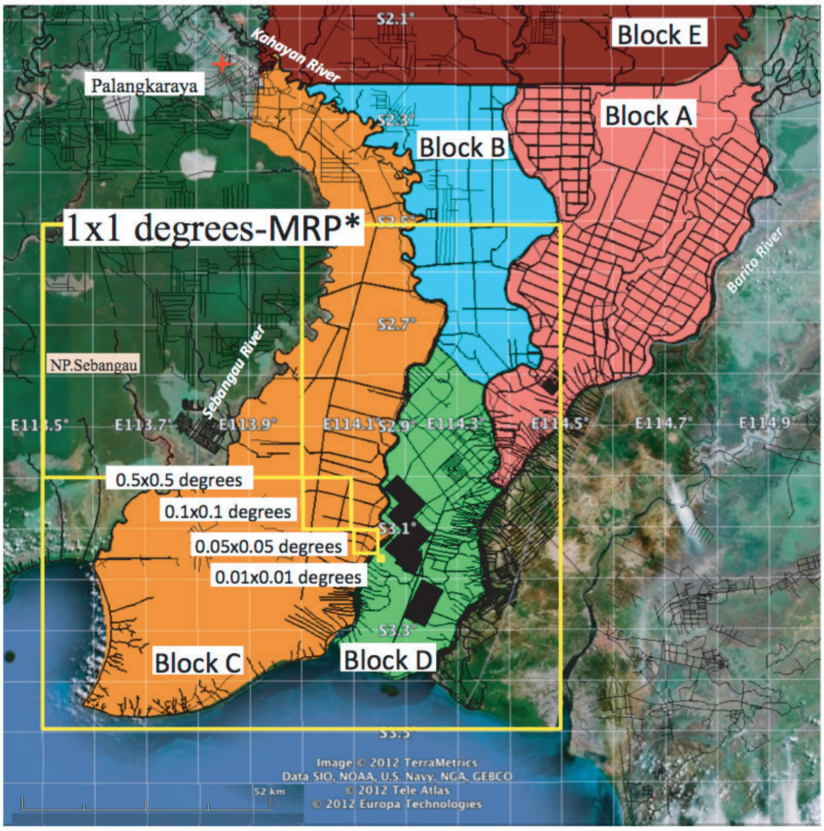

Fig. 3 Five grid cell sizes on the map of MRP.

Java+, Sulawesi+, Sumba+ and Timor+, Sumatra+, and Kalimantan+. Thus, this paper ignores administrative boundaries to simplify the analysis and for the ease of data treatment and puts "+" after each region name like "Sumatra+" to show the expanded region defined in this paper. The bottom section of the bars for Kalimantan distinguishes the number of fires in a cell for the Mega Rice Project (H-1 or MRP*). The total number of cells in the regions were 513: 198 for Papua+, 37 for Java+, 91 for Sulawesi+, 66 for Sumba+ and Timor+, 101 for Sumatra+, and 86 including the MRP* cell for Kalimantan+. The annual mean numbers of fires in the six regions were averaged and the rightmost bar, to the right of the bar for 2011, shows the average annual incidence of fires in the six regions.

The rightmost bar in Fig. 4 shows that the annual mean number of hotspots in Indonesia was about 58,000. About 80% of these fires occurred in only two of the regions, Kalimantan+ and Sumatra+, which were responsible for 23,460 and 21,488 fires (40.6% and 37.2%) respectively. The fire incidence for the other four regions is: Sumba+ and Timor+ with 4,774 fires (8.3%), Sulawesi+ 4,084 (7.1%), Java+ 2,226 (3.8%), and Papua+ 1,799 (3.1%). Fire occurrence in the MRP* cell is at the bottom of this annual mean bar in Fig. 4, and the 2,223 fires in the MRP* cell were very similar to the number in Java+ (an area nearly 40 times larger) and larger than that of Papua+ (area about 200 times larger).

The most fires in the six major regions occurred in two different years, 2006 (Kalimantan+ and Sumatra+) and 2002 (Sumba+ and Timor+, Sulawesi+, Java+, and Papua+). In 2006, there were 54,302 fires in Kalimantan+ and 42,361 Sumatra+. These two regions contribute 84.1% of the total fires in 2006. In 2002, the fire numbers were 9,761 for Sulawesi+, 7,146 for Sumba+ and Timor+, 4,440 for Papua+, and 3,398 for Java+ but their contribution to the total fire numbers of Indonesia was only 27.9%. The proportion of fires occurring in Kalimantan+ was high in both 2006 (47.2%) and 2002 (49.7%). Active fires in 2006 and 2002 occurred under the drought conditions related to the El Niño event. A detailed discussion about relationship between fire activities and drought will be elucidated in chapter 3.3.

The number of hotspots in the ten years varied by a factor of seven between the year with the most fires, 114,977 in 2006 and the year with the fewest, 16,335 fires, in 2010. The following statistical approach provides a more objective discussion of fire occurrence. The fire occurrences in seven out of the ten years were within ±1σ(=68.26%). The remaining three years had ±1σ values of 1.01 for 2002, 1.87 for 2006, and –1.36 for 2010. Statistically, the probability of the occurrence of a year with a high number of fires, such as 2006 is about 6%, suggesting that a year with the number of fires in 2006 will occur roughly every 17 years, if the fire occurrences are assumed to follow a normal distribution.

3.2.2 Seasonality of fires

This chapter will discuss the times that fires occur with monthly means for the ten years period from 2002 to 2011. Figure 5 shows the average fire incidence for each month in the ten years for the different regions of Indonesia. As suggested by Fig. 5 the period of the most frequent fire occurrence in the whole of Indonesia are the three months August, September, and October where the number of fires reached 13,890, 14,589, and 11,264 respectively, for a three month total of 39,743, representing about 70% of the average annual hotspot number (57,800).

From Fig. 5 it is possible to determine the month(s) with the highest fire incidence for the different regions in

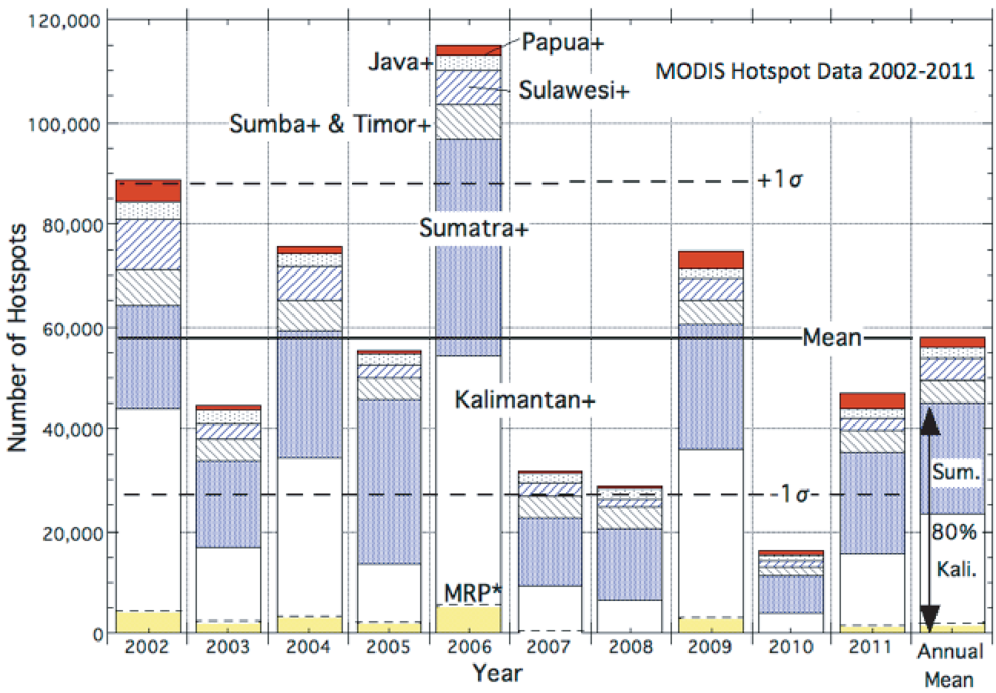

Fig. 4 Annual fire occurrence in whole Indonesia (2002 - 2011).

Indonesia. In Kalimantan+ fires were most frequent in the three months August, September, and October. The months with the most fires for Sumatra+ were August and September, and Sumatra+ had a noticeable number of fires in six other months but only very few fires in April, November, and December. The months with the highest fire incidence for the remaining four regions are also seen in Fig. 5, for Java+, August, September, and October, and for the three regions of Sulawesi+, Timor+ & Sumba+, and Papua+, the highest fire incidence was October. The next chapter will be discussed in more detail the fire trends with the focus of Kalimantan and Sumatra.

3.3 Fire occurrence in Kalimantan and Sumatra

3.3.1 Fires in Kalimantan

Kalimantan was divided into the following five regions for the detailed discussion on fire distribution, the annual changes in fire incidence, and fire period on the main island of Kalimantan ("Kalimantan+" in 3.2 covers a wider area) using the one by one degree cells. The regions were "South Kalimantan 12", West- and East-Kalimantan, South 5, and Central 5. The number at the end of the name indicates the number of cells in its region. West- and East- Kalimantan has 16 and 25 cells, respectively. The boundaries of the five regions are shown with white and yellow broken lines in Fig. 6. The extent of these regions is different from the four provinces of West, East, Central, and South Kalimantan. This occurs because the "South Kalimantan 12" cells comprise three cells from West Kalimantan (rectangles numbered with 656, 634, and 932 hotspots/(yr cell) shown in Fig. 6), one cell from South Kalimantan (with 1,489 hotspots/yr, and one cell from East Kalimantan (with 508 hotspots/yr). Please note the MRP region surrounded by a black dotted line in Fig. 6. The "South Kalimantan12" covers the entire MRP regions with its three cells, H-1 (MRP*), H-2, and H-3 located as shown in Fig. 6.

The fire occurrence from 2002 to 2011 is shown with red dots in Fig. 6. The density of the dots means that the fire distribution is not very clear but it provides a better picture than Fig. 2. Several noticeable fire and fire free areas can be observed in Fig. 6 and in the enlarged insert for the area around Palangkaraya near the top of Fig. 6. Most of fires here are human-caused, and occur along canals, roads, and at the seacoast. Such fires form linear patterns and are simply identified in Fig. 6. The areas with dense hotspots suggest high human activity with deforestation, slash and burn clearing, and plantations. There are 16 cells with more than 500 hotspots/(yr cell) in Fig. 6 that deserve special attention. One is south of Palangkaraya in the enlarged insert in Fig. 6. There are fire free areas even in H-1 (MRP*), the cell with the highest fire incidence in MRP. In the left upper side of the H-1 cell, there is a fire free area. This area corresponds to a tropical swamp forest south of Palangkaraya (the dense green area in Fig. 3).

Figure 7 shows the annual number of fires in the above mentioned five regions of Kalimantan from 2002 to 2011. The bars by year show, from top to bottom the fire incidence in the South 5, East, West, Central and other areas, and finally in South Kalimantan 12 which includes the H-1 cell with the highest number of fires in the MRP area. The rightmost bar shows the average of the annual fire occurrences. Fig. 7 also shows the annual total precipitation of the driest three months from July to September measured at Palangkaraya Airport by using the inversely drawn bars from the top line of Fig. 7 illustrate the relationship between fire activity and rainfall.

From Fig. 7, the annual average is 23,250 hotspots/yr. The annual averages show that 61% of the fires occurred in the South Kalimantan 12 and South 5, with 57.2 %

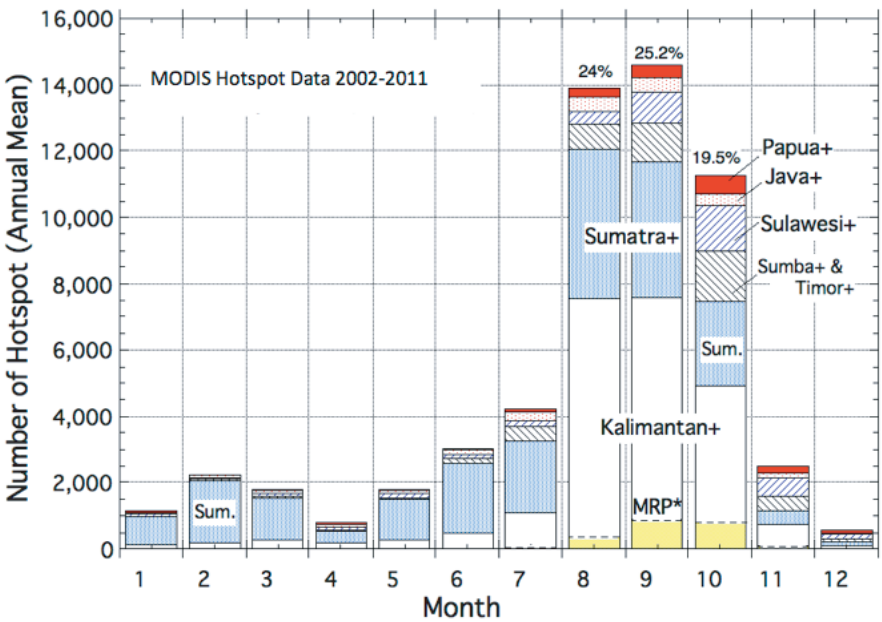

Fig. 5 Fire period in six regions in Indonesia (2002 - 2011).

(13,183 hotspots) and 3.9% (897) respectively. Fires in West Kalimantan accounted for 23.1% (5,314), East Kalimantan for 11.1% (2,567), and Central and others had 5.6 % (1,289) annual fires on average. The average number of fires in the MRP cell, 2,223, very nearly matches the number in all of East Kalimantan, which covers a far larger area (25 cells).

The largest number of fires in the different areas occurred in 2004 in East Kalimantan (5,440 fires); and in 2006 for the other four Kalimantan areas: South Kalimantan12 with 36,101 fires, West Kalimantan with 9,631 fires, South 5 with 2,076 fires, and Central 5 and others with 2,652 fires. In 2006 the ratio of fires reached a very high 66.9% in South Kalimantan12 (including the MRP* cell).

The above mentioned fire activities in Kalimantan could be partially explained by using precipitation measured at Palangkaraya. Figure 7 clearly showed that active fires in 2002, 2004, 2006, and 2009 occurred when total precipitation amount of three driest months in Palangkaraya (Putra *et al.*, 2011) became less than around 100 mm. The largest fires in 2006 mainly due to South Kalimantan12 could be explained by extended drought until October. The precipitation amount for October, 2006 was only 12.6 mm and the lowest monthly precipitation for the last 10 years.

The time of occurrence of fires in Kalimantan will be discussed with Fig. 8, which shows the average monthly fire incidence in the ten years surveyed. In Fig. 8, monthly mean precipitation of the last 10 years in

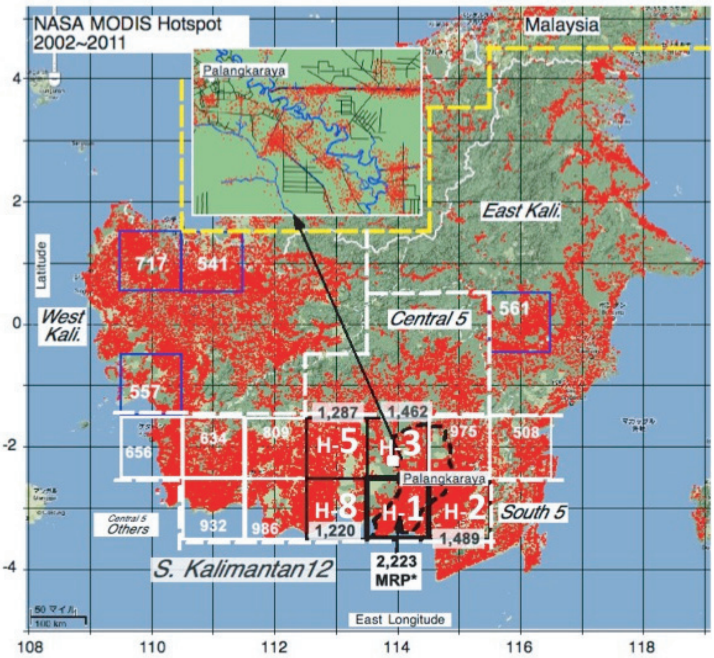

Fig. 6 Hotspot distribution, 5 regions, and 5 highest hotspot areas in Kalimantan.

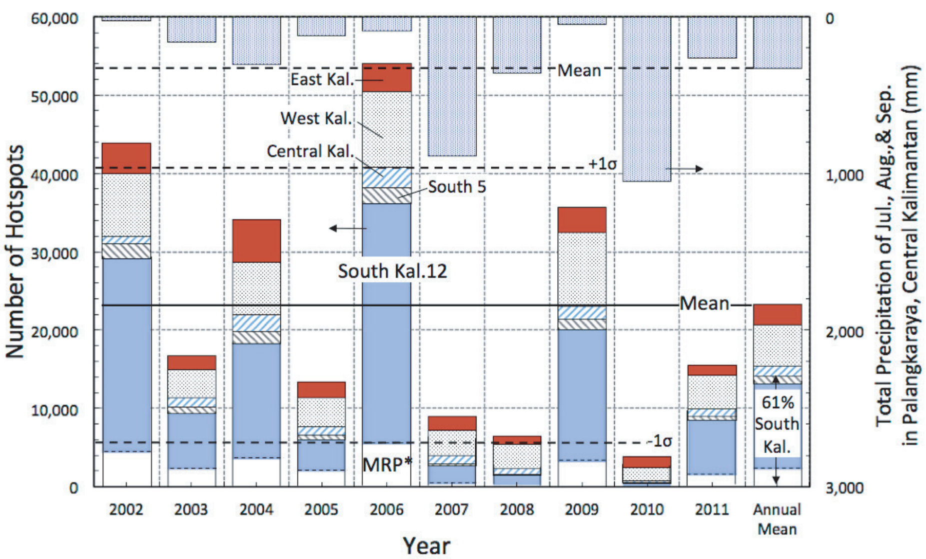

Fig. 7 Annual fire occurrence in Kalimantan and MRP, and dry season precipitation in Palangkaraya (Central Kalimantan).

Palangkaraya is also shown with the inversely drawn bars from the top line of Fig. 8. Figure 8 clearly shows that fires are most common in three months: August, September, and October, similar to the most intense fire period for all of Indonesia (Fig. 5). The number of fires in these three months reached 19,895 (7,471 in August, 7,543 in September, and 4,881 in October), 85.5% of the annual hotspot average (23,250 fires).

Throughout Kalimantan, September was the month with the most fires except in West Kalimantan. In South Kalimantan 12 and South 5, the number of fires in September reached a total of 5,320 fires or 70.5% of the total number of fires in this month. In West Kalimantan, the peak was 3,184 fires in August with only 882 fires in September. Fire numbers in the one H-1 (MRP*) cell were larger than in all of East Kalimantan (24 cells). The number of fires in the H-1 (MRP*) cell from August to October were 3,617, 8,931, and 8,064. These numbers clearly show the need to pay more attention to the very large number of fires in MRP* during September and October.

Monthly mean precipitation trends in Fig. 8 supported active fires during the driest two months, August and September. Fires in October can be explained by the ground water level. As the average lowest ground water level was observed from the bottom of September to the top of October, peat fires continue to be active even in October (Putra *et al*., 2011). South Kalimantan 12 and MRP* remarkably showed this fire trend related to the ground water level in Fig. 8.

3.3.2 Fires in Sumatra

Sumatra was divided into the following four regions for the detailed discussion of the fire distribution, the annual changes in fire incidence, and period with the most fires on the main island of Sumatra (“Sumatra +” in 3.2 covers a wider area) using one by one degree cells like the discussion for Kalimantan above. Sumatra was divided into four regions because the ten provinces in Sumatra are too small for the analysis using one by one degree cells. The four regions in Sumatra were “South Sumatra 10”, “South Others”, “North Sumatra 10”, and “North Others”, with the numbers at the end of the names showing the number of cells; the number of cells for “South Others” and “North Others” 19 and 20, respectively. The boundaries of the four regions are shown with white and yellow broken lines in Fig. 9; Sumatra is divided into two by the equator, and North and South Sumatra will be used here after. South Sumatra has the H-4 cell, which is the fourth highest number of fires in South Sumatra 10 and shown with the number 1,387 (hotspots/yr) in Fig. 9. This cell was also named Palembang to make the fire incidence in this cell more easily comparable with the “MRP*” cell in Kalimantan. Five other “high fire incidence cells,” H-6, H-7, H-9, H-10, and H-11 with 1,280, 1,231, 1,152, 1,080, and 1,001 hotspots/(yr cell) respectively lie in North Sumatra 10, mainly in Riau Province. Among these the H-10 cell had 4,906 hotspots in 2005 and the total for these five cells exceeded 5,700 hotspots/(yr cell). Fires in this region may be partially related to the activities of two companies, Asia Pulp and Paper (APP) and Asia Pacific Resources International Limited (APRIL), during the ten year study period. These companies have several pulp mills and paper plants in Riau, Jambi, and South Sumatra Province.

The fire distribution from 2002 to 2011 are shown with red dots in Fig. 9, but due to the density of the dots, the fire distribution was not completely clear. Most fires appear to occur on the low-lying peatland areas of east Sumatra (see Figs. 1 & 9). There are also other characteristics of the fire distribution that can be observed in

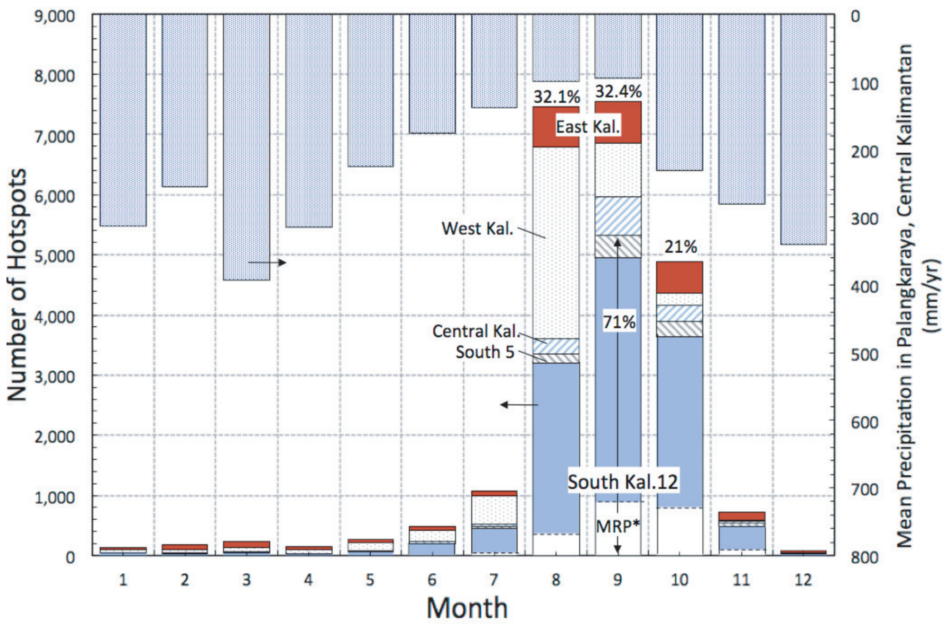

Fig. 8 Fire period in Kalimantan and MRP, and monthly mean precipitation in Palangkaraya (Central Kalimantan).

Fig. 9. Human-caused fires tend to occur along canals, roads, and the seacoast as is also the case in Kalimantan. There is an area of dense fires near Palembang in the H-4 cell in Fig. 9 (marked with the fire incidence there, 1,387). This H-4 cell was named "Palembang" and may be seen to be like MRP* near Palangkaraya, Kalimantan. There are fire free areas in Sumatra in high mountain areas and peatland areas near the coast similar to Kalimantan.

Figure 10 shows the annual number of fires in the four regions of Sumatra distinguished above, from 2002 to 2011, the bars for each year show, from top to bottom, the fire incidence in North others, North Sumatra 10, South others, and South Sumatra 10 which includes the H-4 cell with the highest number of fires in the Palembang area. The rightmost two bars show the average of the annual fire occurrences and the annual largest fire occurrence in Kalimantan in 2006.

The inversely drawn two different bars from the top line of Fig. 10 shows the annual total precipitation of the driest three months from June to August measured at Jambi (South Sumatra, these are shown by a white circle located in the northeast of "H-4" in Fig. 9). The two separated dry months in February and August observed at Pekan Baru (Riau, North Sumatra, and shown by a white circle located in the south of "H-6" in Fig. 9).

From Fig. 10, the annual average was 21,200 hotspots/yr and just smaller than the 23,250 hotspots/yr in Kalimantan. The annual averages show that 51% of the fires occurred in south Sumatra (South Sumatra 10 and South others) and 49% of the fires occurred in north Sumatra (North Sumatra 10 and North others). Fires in North Sumatra 10 accounted for 41.5% (8,799), South Sumatra 10 for 35.7% (7,578), South others for 15.3% (3,249), and North others for 7.5% (1,581). The number of fires in the Palembang cell is 1,387 and very nearly matches the number in North others, which covers a far larger area (20 cells).

The two years with the most fires in Sumatra occurred in 2005 and 2006 however with very different fire distributions within the island. In 2006, the year with the most fires, the total number of fires reached 41,895 and most occurred in south Sumatra, 71.5%, with 22,675 (54.1%) fires in South Sumatra 10 and 7,269 (17.4%) fires in South others. In 2005, the year with the second largest number of fires, the total number exceeded 31,500, most occurring in north Sumatra, 84.6%, with 23,998 (76.2%) in North Sumatra 10 and 2,640 (8.4%) in North others.

The most right hand bar in Fig. 10 allows a direct comparison with the 2006 Kalimantan fire incidence. Comparing the two 2006 bars, both south Kalimantan and south Sumatra show very high fire incidences under the drought conditions due to the El Niño event in that year, 2006. Looking at the two cells, H-1 (MRP*, 5,382 fires in 2006) and H-4 (Palembang, 5,361 fires in 2006) shows that the fire incidences in 2006 here were very similar.

The above mentioned very high fire incidences in Sumatra could be explained by using precipitation measured at Jambi (south Sumatra) and Pekan Baru (north Sumatra). Figure 10 clearly showed two active fire years in 2005 and 2006. In 2005, most fires occurred in North Sumatra 10. On the contrary, most fires occurred in South Sumatra 10 and South Others in 2006. The two different fire trends in 2005 and 2006 may be explained by dry season trends in north and south Sumatra.

The 2005 fires in North Sumatra 10 (north Sumatra) were due to low precipitation in February (39mm, lowest monthly precipitation of latest 9 years from 2002 to

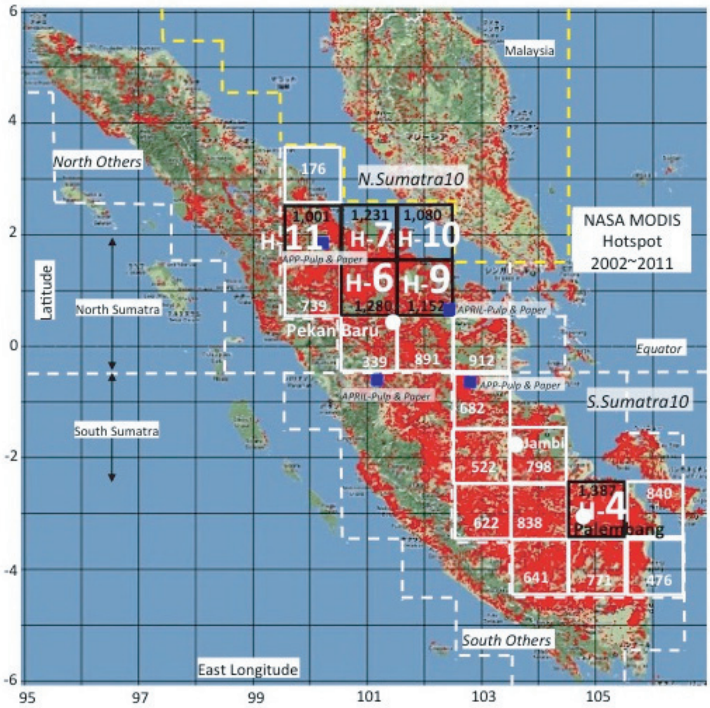

Fig. 9 Hotspot distribution, 4 regions, and 5 highest hotspot areas in Sumatra.

2010) and other dry months. Our analysis showed that the total number of hotspots in North Sumatra 10 in 2005 reached 20,365. The largest monthly number of hotspots was 5,313 in February. The second and third highest numbers were 4,694 in March and 3,183 in August. The 2006 active fires in Jambi (south Sumatra) also may be due to lowest precipitation in the four dry months from July to October (411mm, lowest four months precipitation of latest 9 years from 2002 to 2010).

Figure 11 shows the average monthly fire incidence in the ten years surveyed in Sumatra. The rightmost bar in Fig. 11 shows the September fire occurrence in Kalimantan.

Figure 11 shows that the times of highest fire incidence in Sumatra is not as clear as was found in Kalimantan in Fig. 8. In Sumatra the highest number of fires in August is not much higher than in other months, the contribution of fires in August is only 21% of the whole year, which is smaller than the 32% in September (the month with most fires) in Kalimantan. In addition, north Sumatra showed a different period with the highest fire incidence. This difference, however is not as distinct as the high incidence period in south Sumatra. In North Sumatra there are two fire periods, one is in February and March, another is from June to August. The presence of two periods with many fires may explain why 2005 is the year with the second largest number of fires (Fig. 9) and why August is the month with the most fires in Sumatra (Fig. 10). In south Sumatra, the most fires occurred in August, September, and October, similar to Kalimantan (Fig. 8). The above different fire occurrence patterns in north and south Sumatra can be explained by differences in the precipitation patterns in the two areas.

Two different precipitation types for north and south

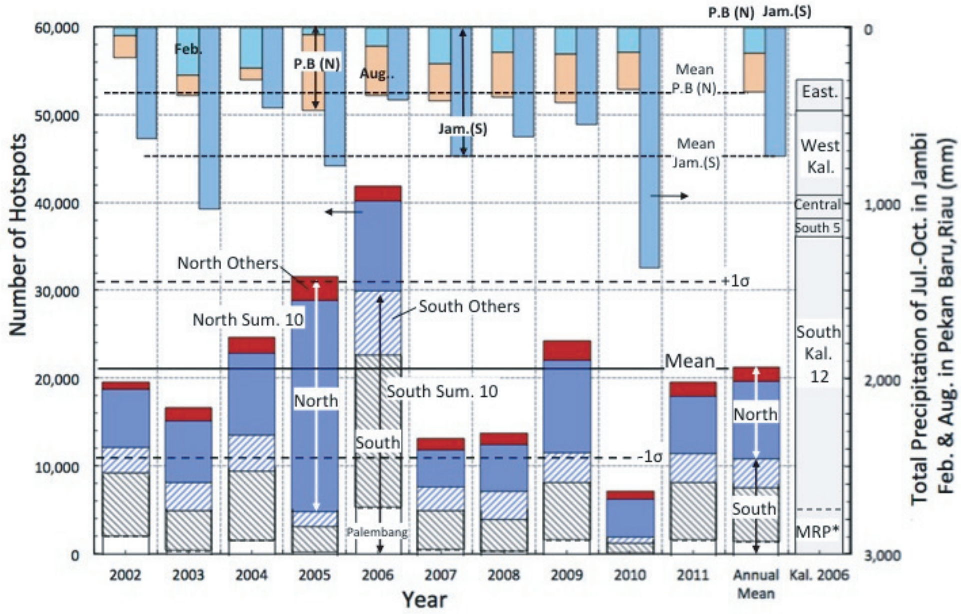

Fig. 10 Annual fire occurrence in Sumatra, and dry season precipitations in Jambi (Jambi, south Sumatra) and Pekan Baru (Riau, north Sumatra).

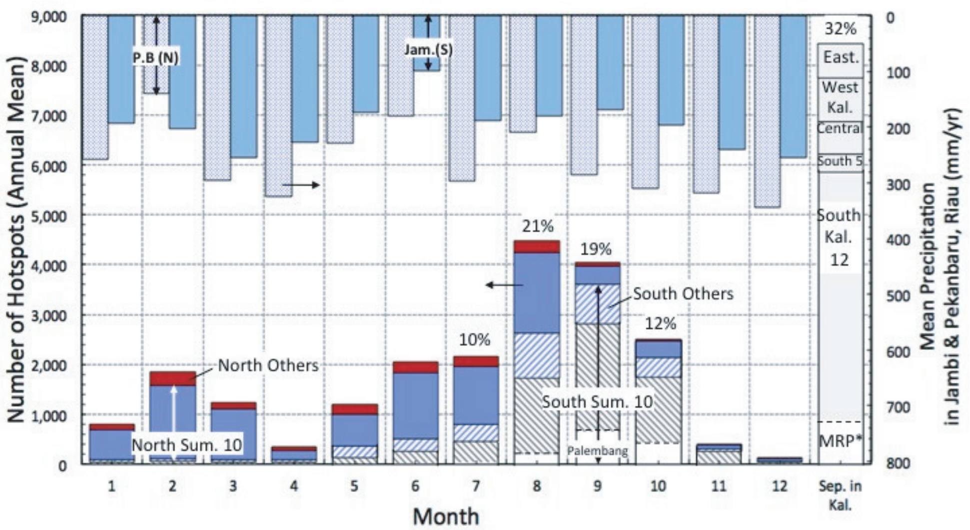

Fig. 11 Fire period in Sumatra, and monthly mean precipitations in Jambi (Jambi, south Sumatra) and Pekan Baru (Riau, north Sumatra).

Sumatra are shown using inversed Y- axis and two bar graphs in Fig. 11. Two climate zones with two different precipitation patterns in Sumatra are described by Aldrian & Susanto, 2003. The monthly mean precipitation trends in Fig. 11 showed that Pekan Baru (north Sumatra) had low precipitation during the months of February, June, and August. Fires in north Sumatra tended to occur mainly in these months. On the other hand, Jambi (south Sumatra) showed only one lowest precipitation month in June but that fires could become active from August to October. This fire trend was similar to south Kalimantan in Fig. 8. South Sumatra and south Kalimantan are in the same climate zone. Fire activities from August to October in south Sumatra in Fig. 11 were weaker than that of south Kalimantan in Fig. 8. This difference may be mainly due to differences in monthly precipitation amount or about 200 mm in south Sumatra and about 100 mm in Kalimantan.

4. Conclusions

The present fire situation, fire prone areas, and the trends in fire incidence for all of Indonesia, for Kalimantan and Sumatra were analyzed using MODIS hotspot data from 2002 to 2011 with 1x1 degree cell. The conclusions can be summarized into the following three parts:

Firstly, the present fire situation and fire prone areas as follows:

1. There were eleven cells where the number of hotspots exceeds 1,000 hotspots/(yr cell) among the approximately 500 cells covering all of Indonesia. These most fire prone areas were found in three regions: south Kalimantan, and south and north Sumatra. (see Fig. 2)
2. The cell with the highest fire incidence (H-1, MRP*) was found in the Mega Rice Project (MRP) area in south Kalimantan. This one cell had both the maximum and the highest mean number of hotspots in the recent ten years, 5,382 hotspots in 2006 and 2,223 hotspots/yr respectively. The maximum hotspot density was 0.438 hotspots/ (km^2yr). (see Figs. 2, 3, 6)
3. The three cells with the highest fire incidence (H-1, H-2, H-3) covered most of the MRP area. (see Fig. 6) The total number of hotspots of these three cells was 5,174 hotspots/yr.
4. The cell with the fourth highest fire incidence (H-4) was in the Palembang area in south Sumatra. The number of hotspots was 1,387 hotspots/yr. (see Figs. 2, 9)
5. In Sumatra, the five cells with the highest fire incidence (H-6, H-7, H-9, H-10, and H-11) were in north Sumatra. (see Figs. 2, 9) The total number of hotspots of the five cells was 5,744 hotspots/yr.
6. Other areas where the fire incidences exceed 500 hotspots/(yr cell) were found in Sumba, Timor, west and east Kalimantan, and central Sulawesi. (see Figs. 2, 6)

Secondly, the trends in the annual fire incidence are as follows:

7. The annual mean number of hotspots in the whole of Indonesia was 57,800 with 78% of these fires occurring in Kalimantan (41%) and Sumatra (37%). (see Fig. 4)
8. In the year with the most fires, in 2006, the total number of hotspots was about twice (115,000) the annual mean (57,800). In 2006, the contribution of Kalimantan (47%) and Sumatra (37%) was 84%. (see Fig. 4)
9. For all of Kalimantan, the annual mean number of hotspots was 23,250 for the ten years. About 61% were recorded in south Kalimantan (South Kalimantan 12 and South 5). In 2006, the year with the most fires, the total number of hotspots was about 2.3 times larger (about 54,000 hotspots/yr) than the annual mean, with the contribution of south Kalimantan 71%. (see Figs. 6, 7)
10. In Sumatra, the annual mean number of hotspots was 21,200, nearly equal for south and north, 51% vs. 49%. The year with the most recorded fires in Sumatra was also 2006, with 41,900 hotspots (about twice the annual mean); 72% of fires in 2006 occurred in south Sumatra. (see Figs. 9, 10)
11. For north Sumatra, the year with the most fires was 2005 (second highest incidence for all of Sumatra). In 2005, the total number of hotspots was 31,500 (84.6%). (see Figs. 9, 10)

Thirdly, the trends in fire incidence by month are as follows:

12. For all of Indonesia the three months of August, September, and October had the highest incidences, with about 70% of fires (39,743) occurring in these three months. The percentages of the average annual number of fires (57,800) in August, September, and October were 24% (13,890), 25% (14,589), and 19% (11,264) respectively. (see Fig. 5)
13. Kalimantan and Sumatra also had high incidences of fires in August, September, and October with 87%, 80%, and 66% of total number of fires in each month, respectively. (see Fig. 5)
14. Kalimantan also had the most fires in August, September, and October. The fire peak for central and south Kalimantan was September and for west Kalimantan was August. (see Fig. 8)
15. In Sumatra, the most intense fire period by month was not easily defined. South Sumatra had the most fires in the three months of August, September, and October while north of Sumatra had two periods with high fire numbers, one in February and March, and the other in June, July, and August. (see Fig. 11)

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