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SPATIAL AND TEMPORAL PATTERN OF FOREST/PLANTATION FIRES IN RIAU, SUMATRA FROM 1998 TO 2000

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ABSTRACT: The Centre for Remote Imaging, Sensing and Processing (CRISP) has been monitoring forest/plantation fires in Sumatra, Indonesia via satellite images since early 1998. Using SPOT images, we have produced detected fire and burn scar distribution maps of Riau Province, Sumatra from 1998 to 2000. With the help of these maps, the spatial and temporal pattern of forest/plantation fire and burn scar distributions in Riau Province, Sumatra for these years are studied. We assess the scale and frequency of the fires, validate the types of fire (plantation or forest or other kinds of fire), identify the frequently fire-affected areas and discuss the methods to improve the accuracy of the results.

1. INTRODUCTION

Every year, forest/plantation fires occur in various parts of Sumatra and Kalimantan, Indonesia. For example, during the periods of May-November 97 and February-April 1998, extensive forest/plantation fires raged in these areas and thick smoke haze covered the region for months, posing a health hazard and causing economic losses estimated in excess of US$ 4 billion. Riau, the second largest province in Sumatra, is one of the regions in Indonesia where forest/plantation fires most seriously occur (see Figure 1). From Riau, fire-caused smoke haze will likely affect Singapore when the wind direction is South-west.

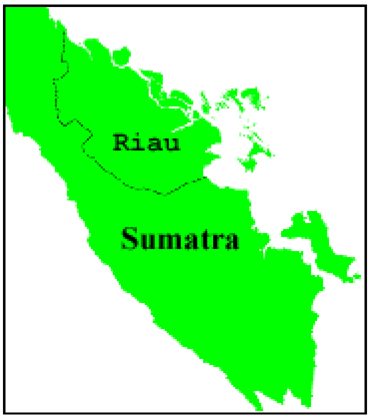


Fig.1 Map of Riau, Sumatra

In response to this situation, CRISP has been monitoring the regional fire situation via satellite images daily since early 1998. Monitoring of forest/plantation fires is carried out using 20m resolution SPOT satellite images. The acquisition areas of the SPOT scenes are planned with guidance from the hot spot images derived from 1km resolution NOAA satellite images of the previous day (Liew et al., 2001). In 1998 and 1999, CRISP used SPOT 1, 2 images for fire monitoring. Since 2000, we have been also using SPOT 4 images (Lim et al., 2000).

Our aim is to investigate the fire situation of the last 3 years from the SPOT data acquired by CRISP. In this paper, detected fires and delineated burn scars of Riau from 1998 to 2000 are analysed. These fire and burn scar distribution maps reveal the spatial and temporal pattern of forest/plantation fires in Riau. Preliminary results will be shown in Section 3.

2. METHODOLOGY

Riau, with an area of 94,562 km^2, can be covered by about 45 SPOT multi-spectral scenes (each scene covers about 60×60 km^2, there are overlaps between scenes). From CRISP's fire monitoring database, distribution maps of detected fires in Riau are plotted for 1998-2000. The burn scar maps of Riau for the same period are generated from mosaics of the SPOT images. In particular, in order to know the fire situation precisely, a full resolution (20m) mosaic of the after-fire period (October–December) in 1998 is produced to obtain the baseline information for comparison. For the other 2 years, quicklook images (with a resolution of about 100m) are used.

2.1 Fire distribution map

During CRISP's daily fire monitoring, when a fire is found, information such as its latitude/longitude, vegetation type at the fire location, and plume length and width are recorded. Here we compile and display this information on a map of Riau according to the latitudes and longitudes of the fires. We classify the fires into big fires and small fires: when the length of the fire plume is greater than 10 km, the fire is considered a big fire. Otherwise, the fire is considered a small fire.

2.2 Burn scar map

After a fire, the original vegetation will be either burnt down or charred and thus its appearance will change from red to black in the SPOT images. These burnt areas are called burn scars.

We generate mosaics of Riau in order to delineate the burn scars. Mosaics of after-fire season (October-December) of 1998, and the before-fire (January-February) and after-fire (October-December) seasons of 1999 and 2000 are produced. The scenes which have least clouds during the given period are chosen for the mosaics.

The burn scars are delineated on the mosaics by visual inspection. The burnt areas can be discriminated by their generally dark appearance in the images. Care is taken not to misclassify cloud shadows, flooded areas and inland water into the category of burn scar since they also appear dark in the images. However, they can be differentiated from burnt areas by their features like the generally smooth texture, while the burn areas are more heterogeneous.

For the year 1998, since the data of this year are used as a baseline, all burn scars (including burn scars from previous years) are delineated. For the year 1999 and 2000, only new burn scars are delineated. This is done by comparison of the mosaic from the after-fire period with the mosaic from the before-fire period of that year. One problem which may affect the accuracy of delineation is the cloud cover. To ensure that delineated burn scars are real burn scars, if an area is covered by cloud, unless under very obvious situation (such as very tidy cloud surrounded by a big burn scar), the area will not be regarded as a burn scar. Thus, clouds appearing in either before-fire mosaic or after-fire mosaic may cause the cloud-covered area to not be classified as a new burn scar area.

Visual interpretation and classification is performed to classify the burn areas into three classes: (A) plantations/agricultural lands; (B) peat swamp forests; and (C) others, mainly secondary forests and bushes. (Liew et al., 1998). Many fires are deliberately set in order to convert forest into land for plantation and agricultural use. If it is obvious that a burn scar is caused by this kind of conversion, this burn scar is also classified in class A.

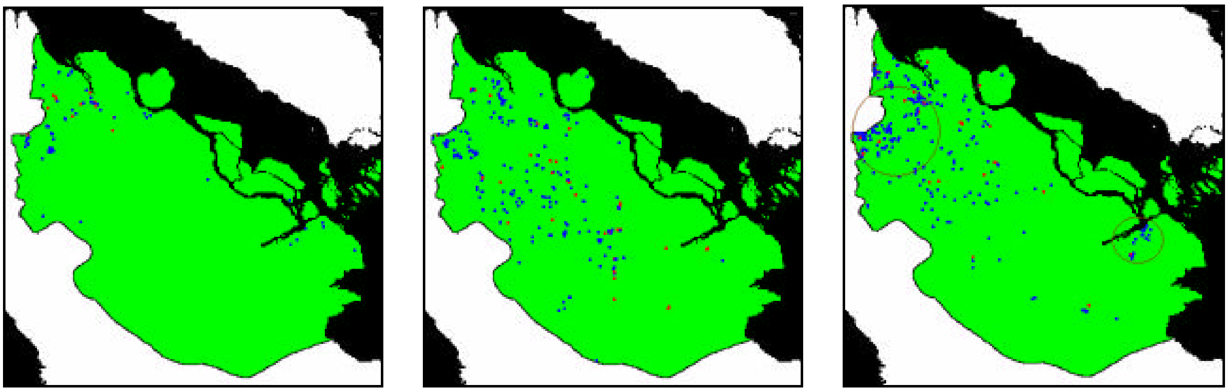
3. RESULTS AND ANALYSIS

3.1 Detected fires

The detected fires are representative samples of the real fire situation. We can detect most fires in Riau when the conditions are favourable. With SPOT 1 and SPOT 2 satellites, any given location in the Southeast Asia region can be observed with a repeat interval of two to three days. Ever since the use of SPOT 4 data in early 2000, together with SPOT 1 and SPOT 2, daily coverage of any given location in the region is made possible (Lim et al., 2000). We program the SPOT acquisition areas with guidance from the hot spot images derived from 1km resolution NOAA satellite images of the previous. Although some fires could be missed in a certain day because the fire location is covered by cloud, if these fires last several days, they still have chances to be detected by SPOT when the cloud condition is improved. The hotspots that appeared consistently on NOAA images on consecutive days are usually big fires and are the main concerns of fire monitoring, so they will most probably be detected during their lifetime of several days.

The maps in Figure 2 show the annual summaries of detected fires. From Figure 2, we can observe that although the numbers of detected fires vary from year to year, fire distributions have a similar pattern. Fires scatter quite broadly while there are several concentrated areas. The most severely fire-affected area in these years is located at the northwest of the province, near the North Sumatra border (left circle in (c) of Figure 2). Another heavily-affected area is located at the northeast corner of the province, along the south bank of Kampar River (right circle in (c) of Figure 2). Large scale fires have been appearing at the same area year by year. Time series of monthly detected fire distribution (not shown here) show that in general the fire-affected areas move gradually from northwest to the east during the fire season.

The seasonal variations of fires can be seen in Figure 3, which shows the numbers of monthly detected fires during 1998-2000. The numbers of detected fires in the same month vary from year to year. There are almost no fires in the beginning and the end of the years. The absolute number of fires is few in 1998, while the fire patterns of 1999 and 2000 are quite similar. In dry seasons, such as July of 1999 and 2000, the numbers of detected fires increased significantly. In other months, there is no clear tendency. The reason may be that many, particularly the largest, fires are associated with human activities, such as the land clearance for oil-palm and plantation. The province has an exceptionally high area (some 70 percent) of land allocated to concession companies and once the valuable timber has been harvested, conversion follows (Anderson et al., 1999). This kind of fires occurs whenever weather conditions permit, regardless of the time of year.



(a) (b) (c)

Fig. 2 Distribution of detected fires; Red: Big fire; Blue:Small fire

(a) 1998: 71 fires (Big: 13, Small: 58), detected by SPOT 1, 2

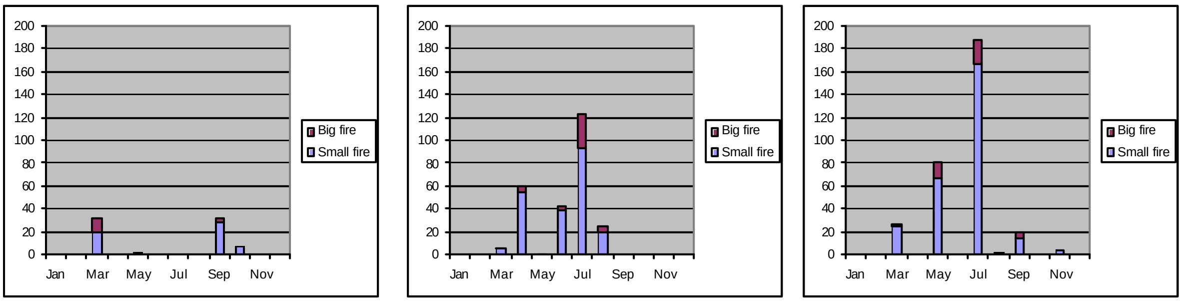
(b) 1999: 255 fires (Big: 42, Small: 213), detected by SPOT 1, 2

(c) 2000: 322 fires (Big: 42, small: 280), detected by SPOT 1, 2, 4.

Remark:

(1) Criterion to distinguish big or small fires is the plume length. When the length is greater than 10 km, the fire is considered a big fire. Otherwise, the fire is considered a small fire.

(2) In 1998 and 1999, CRISP used SPOT 1, 2 images for fire monitoring. Since 2000, we have been using SPOT 4 images as well. SPOT 4 has the ability to detect many small fires since it has an extra Short Wave Infrared band (Lim et al., 2000).Thus the number of fires detected has significantly increased in 2000.



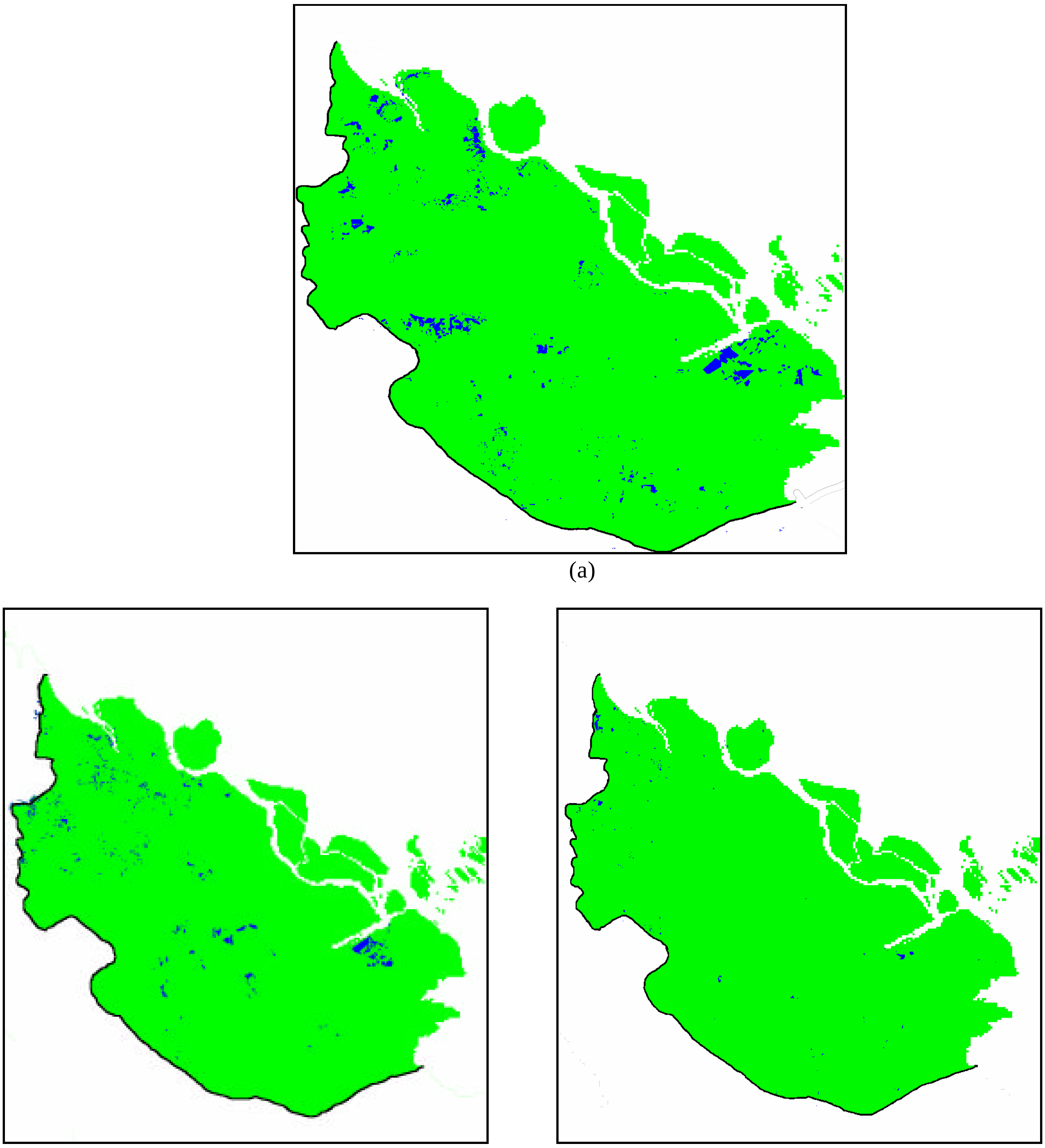
(a) 1998 (b) 1999 (c) 2000

Fig. 3 Numbers of monthly detected fires in Riau during 1998-2000

3.2 Burn scars

Burn scar is also an important index to asses the fire situation. We may miss fires because of the reasons such as cloud cover, or simply fires occurred not at the time when SPOT passed overhead, but burn scars appear as a result of fire. Burn scars exist there for a long period before vegetation grow, thus have a large chance to be detected. We may still miss out some burn scars. For example, clouds may cause the cloud-covered area to not be classified as a burn scar area; new vegetation will grow at the burn scar areas after some time if conditions are favourable, and it is hard, if not impossible, to assess the change of burn scars at all stages. We endeavor to choose most suitable (least cloud cover) images to reduce the influences. Thus, the delineated burn scar maps are also representative of real situation.

Figure 4 shows the burn scar maps for Riau during the period 1998, 1999 and 2000. The burn scar map of 1998 shows that the burn scar area in Riau is 1443 km^2, over 1.5% of the area of whole province. This is an accumulative result of several years. It can be observed that, burn scars scatter quite broadly while there are several concentrated areas. This is similar to fire distribution, but much wider in area, as expected. For the 1999 and 2000 burn scar maps, since they are derived from quicklook images (100m resolution) some small burn scars may be missed out. But they still show similar pattern compared with the 1998 burn scar map.



(a) (b) (c)

Fig. 4 Burn scar maps of Riau

(a) 1998: 1443 km^2 (including old burn scar), (b) 1999: 931 km^2, (c) 2000: 374 km^2

3.3 Combination of detected fires and burn scars

Statistics of detected fires and burn scars in 1998-2000 are shown in Table 1. It can be seen that the percentages of big fires are quite consistent (around 15%-20%) and more than 70% of the burn scars in Riau occur in plantation/agriculture areas. The number of detected fires in 1998 is considerably low, while as mentioned in Section 3.1, the distribution pattern is still similar compared with the distributions of 1999 and 2000. The reason why low number of fires in 1998 is not quite clear and we will discuss this in Section 3.4. In general, there are no significant changes in the scale and frequency of the fires.

Figure 5 shows the combination of detected fires and delineated burn scars in 1999. This figure gives an overview of the fire situation and the fire-affected area of Riau in 1999. We expect to see detected fires co-occur with the burn scars. This can be observed in many places over Riau. We also see that some areas have burn scars only, as explained in Section 3.2. There are also many areas only have detected fires, this may be due to cloud cover in the mosaic (not shown here) or the quicklook (100m resolution) is too coarse to delineate small burn scars.

Table 1. Statistics of detected fires and burn scars in 1998-2000

Year	Number of detected fires in Riau			Year	Delineated burn scars in Riau			
	Big fire	Small fire	Total		Area (km^2)	Burn area classification		
						A	B	C
1998 (SPOT 1, 2)	13 (19%)	60 (81%)	69	1998	1443	70%	25%	5%
1999 (SPOT 1, 2)	42 (17%)	213 (83%)	255	1999	931	82%	14%	4%
2000 (SPOT 1, 2)	34 (13%)	237 (87%)	271	2000	374	75%	20%	5%
2000 (SPOT 4)	8 (16%)	43 (84%)	51					

(a) Statistics of detected fires and delineated burn scars in 1998-2000

Remarks:

(1) A = Plantations/Agricultural lands; B = Peat swamp forests; C = Others (same as defined in Section 2). The percentage under those columns means the percentage of the total burn scar numbers, not the burn scar area;

(2) Note that area of burn scars of Riau in 1998 is the whole area of existing burn scars; while in other years the number is the area of new burn scars.

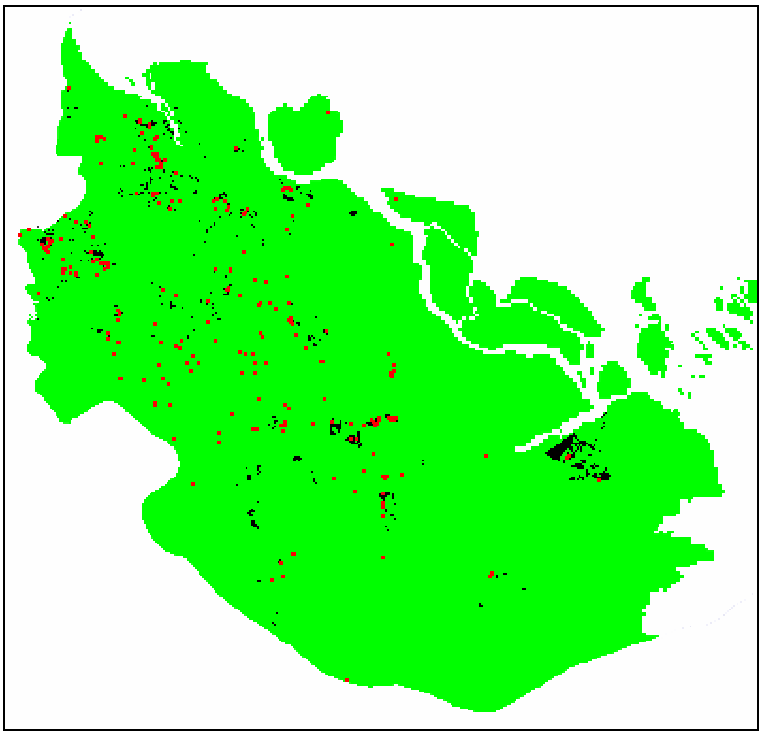


Fig. 5 Combination of detected fire and delineated burn scar in 1999. Black: Burn scars; Red: detected fires; (fire size not scaled with the map)

3.4 Discussion of results

The number of detected fires and the area of burn scars give an indication of the severity of fire situation over the years. Cloud covers may affect the conclusions derived from the data. Some fires may be missed due to cloud cover. In general, during a fire season (usually April to the end of September), there is less cloud because of the dryer weather. The rainy season arrives near to the end of the year and less fires were detected. The increased cloud cover may mask the fire activities, but it can also be argued that fires are less likely to occur during the wet season. The burn scar delineation is mainly based on the after-fire mosaic which is usually more cloud-covered. Thus, we expect that the calculated burn scar area is lower than the actual area. To understand the cloud influence, we first study the cloud situation in Riau during these years. We choose a sample area in central Riau to illustrate the cloud situation. The area is a rectangular area with upper left corner at (0.2°N, 101.8°E) and lower right corner at (0.2°S, 102.2°E). From CRISP's quicklook catalog which contains cloud cover information for each scene, we obtain the cloud statistics shown in Table 2.

The data in Table 2 explains to some extent why fewer fires were detected in 1998, and why in 2000, the burn scar area is relatively low although many fires were detected. 1998 was somewhat wetter than average (Anderson et al., 1999). In

1998, in our sample area, less than 1% of the scenes have a cloud cover which is less than 10%, which means that the weather condition may not be favourable for land clearing by fires. Thus fewer fires were detected. The other possible reason that we detected more fires in 1999 and 2000 could be that the fire monitoring is more and more successful with experience. In 2000, the weather was generally dryer than an average year (see Figure 6), which is suitable for land clearing by fires, and also for detecting fires. However, the cloudy weather (0% of scenes are covered by less than 10% cloud) in the after-fire season prevented accurate delineation of burn scars. The rainfall data (Figure 6) also shows that July is the driest month, while we detected 188 fires (see Figure 3) in July 2000, which is the largest number in that year.

Table 2. cloud statistics during the fire monitoring period of whole year and during the burn scar delineation period

	Scenes acquired whole year			Scenes acquired in after-fire period (Oct.-Dec.)		
	Cloud cover < 10%	Cloud cover < 25%	Total number of scenes (any cloud cover)	Cloud cover < 10%	Cloud cover < 25%	Total number of scenes (any cloud cover)
1998	1 (0.9%)	5 (4.5%)	111	0 (0%)	2 (4%)	47
1999	7 (4.8%)	14 (9.6%)	145	1 (2%)	3 (6%)	47
2000	12 (6.3%)	37 (19.7%)	188	0 (0%)	2 (5%)	42

4. CONCLUSIONS AND FURTHER WORK

We study the spatial and temporal pattern of forest/plantation fire in Riau, Sumatra from 1998 to 2000 using detected fire and delineated burn scar distributions.

The preliminary study shows that the existing burn scar area of Riau in 1998 is about 1443 km^2, which covers more than 1.5% of the whole Riau area. Each year, more than 70% of burn scars in Riau occur in plantation/agriculture area implying that the fires may be associated with human activities. Every year, the fire-affected areas move gradually from northwest during the early part of the fire season, to the east later in the year. In the dry seasons, such as July of 1999 and 2000, the numbers of detected fires increased significantly. Large scale fires have been appearing at the same area year by year. Fires and burn scars scatter quite broadly while there are several concentrated areas. In Riau, the most severely fire-affected area in these years is located at the northwest of the province, near the North Sumatra border Another heavily-affected area is located at the northeast corner of the province, along the south of Kampar River.

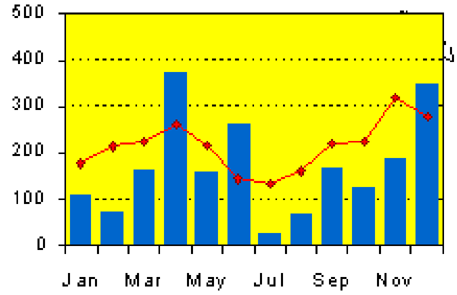


Fig. 6 Monthly rainfall (in mm) of Pekanbaru, Riau in 2000, source: Meteorological Service Singapore (MSS) website. Red marks mean the average rainfall over a period of 2 to 3 decades (exact period not stated on MSS website).

The main problem in burn scar delineation is the extensive cloud cover during the after fire season. The limited spatial coverage of SPOT images (60 km per scene) is not ideal for burn scar delineation over a large area. Mosaics of images acquired over an extended period need to be used. It is possible that vegetation regrowth may have occurred, causing the burnt areas to be missed. The MODIS sensor on board the Terra satellite provides daily wide-coverage data suitable for fire monitoring and burn scar delineation. The thermal bands of MODIS has a higher saturation temperature than those of NOAA-AVHRR, giving practically zero false alarm of fire hot spots. Short period (e.g. 10 days) cloud-free composite images of a wide area such as the whole Sumatra island can be obtained with a resolution of 250m. Such composites can be used for burn scar delineation. Automated burn scar detection may be possible using the reflectance signatures with aids from the many thermal bands (at a coarser resolution of 1 km) available.

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