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Multiple Satellite Detection of Hotspots in Peninsular Malaysia during February and March of 2002

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ABSTRACT

A comparison of the spatial distribution of hotspots detected in Peninsular Malaysia during the short spell of dry conditions that occurred in February and March of 2002 from three different types of satellite programmes such as National Oceanic Atmospheric Administration (NOAA), the Terra Moderate Resolution Imaging Spectroradiometer (MODIS) and Defense Meteorological Satellite Programme (DMSP) satellites was investigated. This period was considered unusual compared to other years, due to the high level of burning activities and the early occurrence of haze compared to the usual burning period from July to September. The spatial patterns of the locations of hotspots detected from these multiple sources were analyzed, although they differed in the overpass times, algorithms, resolutions and cloud coverage that rendered dissimilarities in the hotspots detected. Visual interpretation on the patterns of hotspots showed that Pahang, Johor and Kedah states of Peninsular Malaysia recorded the largest number of hotspots.

INTRODUCTION

The notable 1997 regional transboundary haze crisis that hit the Southeast Asian region including countries such as Singapore, Brunei, Malaysia and Indonesia resulted from the destruction of approximately 10 million hectares of natural forest in Indonesia and incurred an economic loss of over US$10 billion (Boyd, 2002). The problem has not abated, since the recurrence of transboundary haze due to vegetation burning on a large scale has continued since 1997. For the early burning season of February to March 2002, approximately 10,906 hectares of plantations and protected forest reserves were destroyed, which include hundreds of hectares of peat land in Bengkalis, Riau on the island of Sumatra (*The Jakarta Post*, 2002). Most of the fires were left unattended due to the lack of personnel in the local forest department in Sumatra and the inaccessibility of the remote areas. Only surface fires were tackled, while undergrowth fires were left smoldering, as they were difficult to extinguish. The haze in Riau affected the local air quality where visibility was reduced to 20 m in Mantau, Bengkalis (*The Jakarta Post*, 2002).

Although the forest reserves in Malaysia are not as plentiful as in Indonesia, the burning activities that occur can still affect the local environment (Abdullah *et al.*, 2002; Maarof, 2002; Musa and Parlan, 2002; Gawan, 2001; Sangaran, 2001). A total of 543 hectares of land was burnt in Sepang in the state of Selangor in Peninsular Malaysia during February and March of 2002 (*Berita Harian*, 2000a). Approximately 400 hectares of agriculture land and the fringe of forests were burnt by smallholder farmers near Sepang and Kuala Selangor on 15th February and over one hundred hectares of peat land burnt that was strenuous to douse took place during the dry conditions in February (*Utusan Malaysia*, 2002a). In total, 8000 hectares of forest area throughout Peninsular Malaysia was burnt, mostly in the states of Selangor and Pahang (*Utusan Malaysia*, 2002b). Amongst the areas involved were also oil palm plantations of over 3115 hectares near Pekan, Pahang (*Utusan Malaysia*, 2002c).

With the advance of technology, remotely sensed satellites can disclose the active fire counts and spatial areas of burning on a daily basis. It can provide information on the monitoring of different aspects of fires, such as the areas at risk to fires, fire capabilities, burned area, and active fires, smoke plumes or trace gases (WWW1). Data from multiple satellites can be compared to identify the locations of ground truth burning. Remote sensing offers a cost-effective approach to attain an inclusive observation of fire activities in near-real time, particularly over remote, unpopulated areas (WWW2).

Large-scale fire events have been detected by a variety of satellite images that comprise various resolutions and multi-temporal intervals such as SPOT (Liew *et al.*, 1998), National Ocean Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) (Wooster *et al.*, 1998), Along Track Scanning Radiometer (ATSR) hotspot data (Siegert *et al.*, 2000), Landsat TM (Lim *et al.*, 2004) or the European Radar Satellite-2 Synthetic Aperture Radar (ERS-2 SAR) (Buongiorno *et al.*, 1997). Algorithms were also constructed to detect burn scar mapping using moderate spatial resolution satellites (Roy *et al.*, 2002a). Burnt scars using the output of active-fire algorithms have also been investigated for global application from NOAA images (Roy *et al.*, 1999).

The objective of this study was a preliminary comparison of the hotspots detected by various satellites such as NOAA AVHRR, Terra Moderate Resolution Imaging Spectroradiometer (MODIS) and Defence Meteorological Satellite Programme (DMSP) Optical Line Scan (OLS).

The results of this study can help the Malaysian authorities and managers of fires such as the Fire Department, Police and the Department of Environment in evaluating the trends of the burning and to adopt policies that may control or manage future fires.

MATERIALS AND METHODS

Spatial distribution analysis was utilized to establish the distribution patterns of the active fires throughout the day. The area of interest is the Southeast Asian region, with emphasis on Peninsular Malaysia. The period investigated was for the short dry episode in February and March of 2002. The NOAA AVHRR hotspot data was obtained from the Forest Fire Prevention Monitoring Project II (FFPMPII) project that is based in Indonesia. The project is supported by Japan International Cooperation Agency (JICA) and is a collaborative effort with the Department of Forestry, Indonesia. The daily hotspot data is hosted at their website for easy access to the public. The MODIS hotspot data was obtained from the rapid-fire dataset, while the DMSP data was obtained from the Asia-Pacific Network for Disaster Monitoring using Earth Observation Satellite (ANDES) project supported by the Japan Science and Technology Corporation. ANDES is developed as a near-real time operational information system that monitors and mitigate agriculture and forest fires disasters (Sawada, 2002). The data is archived for public use and transferred to East and Southeast Asian countries.

Terra MODIS acquires data in 36 spectral bands that covers the visible, near infrared, short wave infrared, medium wave infrared and thermal infrared (Kaufman *et al.*, 1998). MODIS comprise of 16 thermal bands with high saturation levels suitable for detecting hotspots (Chen *et al.*, 2001). The resolution of the thermal anomalies product is 1 km. The overpass time of Terra is at approximately 1000 am local time. Active fires are detected from the 4 and 11 μm bands, with high saturation temperatures of approximately 450K and 400K, respectively (WWW2). The active fires are detected through the fixed-threshold and a contextual algorithm (Giglio *et al.*, 2003), with different criteria for daytime and nighttime imageries. Each pixel of the MODIS swath is assigned the classes of missing data, cloud, water, non-fire, fire or unknown (WWW3). The performance of the MODIS product is continually examined through quality assessment and validation activities (Roy *et al.*, 2002b).

Fire detection from the AVHRR channel is exploited at the middle thermal infrared channel at approximately 3.7 μm that is sensitive to objects emitting thermal energy at high temperatures of more than 200°C (WWW2). An existence of fire or hotspot lies within the spatial area of 1.1 km^2, without any information on the size, numbers or intensities of fires or burnt area (WWW4). Its moderate calibration and low saturation temperature render the hotspots detected by NOAA AVHRR to inherit many false alarms and a tendency of an underestimation of fire areas or over estimation of the number of fires (Chen *et al.*, 2001).

The OLS is an oscillating scan radiometer designed for cloud imaging with the visible near infrared and thermal infrared bands initially utilized to detect clouds using moonlight, gas flares, lightning, city lights and fires (WWW4). The night time passes occur between 2030 and

2130 local time (Elvidge *et al.*, 2001). The processing algorithms and extractions of fires are described in detail by Elvidge *et al.* (1997). Its spatial resolution of 2.7 km and applications of light emission from night time fires makes this a relatively coarser image than either the NOAA or MODIS images.

Spatial analysis was performed on the active fires detected by the three satellites. Simple centrographic statistics such as the central locations and standard distances or the standard distance deviation were initially calculated. The standard distance deviation (SDD) provides information on the dispersion of the active fire counts around the mean centre. The first-order properties of spatial distribution was carried out where parameters such as the autocorrelation Moran and Geary's C indices can resolve if the hotspots detected by the three satellites exhibit strong correlation tendencies with their neighbours. The neighbourhood patterns and clusters within the overall distribution were then subjected to a second-order spatial analysis, which is a measure of the mean nearest neighbour distance. The nearest neighbour index was calculated to determine if the spread of hotspots were clustered, dispersed or randomly distributed.

Further filtering was performed to identify different groups of clusters of hotspots within the Peninsular Malaysia. The technique employed was the nearest neighbour hierarchical spatial clustering routine that identifies groups of objects that are spatially closer than it would be expected on the basis of chance (Levine, 2002). This technique utilizes a nearest neighbour method that specifies a threshold distance and compares that to the distances of all pairs of points. A minimum of five points per cluster was selected as the cluster threshold for all the group of clusters. Clustering was performed on several levels, where only the clusters that fit the five points limit passes on to the next level.

RESULTS

Weather Conditions

The dry conditions of the El Nino phenomenon during the 1997 haze in Southeast Asia was one of the reasons that aggravated the haze conditions from the large scale biomass burning in Indonesia. The NOAA Climate Prediction Center (NOAA Magazine, 2002) that monitored the Pacific Ocean surface temperatures found an increase of 2°C in February 2002, indicating a progression of an El Nino condition, forecasted as a moderate event that continued until early 2003. This was obtained from evidence of NOAA's global climate monitoring system that consist of data from satellites and moored buoys over the equatorial Pacific Ocean with the purpose of providing real-time atmospheric and oceanic data. *Fig. 1* shows the South Oscillation Index (SOI) over the equatorial Pacific Ocean and the Indonesia sea level pressure anomaly (SLPA) from 1997 to early 2003. The SOI and Indonesian SLPA were in opposite phases during the El Nino periods. The 1997 El Nino was exhibited by negative SOIs compared to the positive magnitudes of the Indonesian SLPA. The starting point of the moderate El Nino began in March 2002, exhibited by weak SOI magnitudes of approximately –2, in contrast to the strongly negative SOI that peaked to –6 in 1997. Thus, the sea surface temperature increase over the Pacific Ocean, a precursor to the El Nino presence was found in February and revealed by the SOI in March.

On a local scale, Peninsular Malaysia was affected by the dry conditions in February and March 2002. It is not clear whether the occurrence of dry condition over Peninsular Malaysia was a precursor to the moderate El Nino event of 2002. The El Nino and the La Nina episodes are extreme deviations of the Tropical Biennial Oscillation theory postulated by Meehl (1997) that encompass the coupled land-ocean-atmosphere climate system. In this climate system, the transition to a relatively strong or weak Asian or Australian monsoon is caused by a variety of large and regional-scale conditions in the seasons preceding the monsoon established by the coupled air-sea interactions of the year before (Meehl and Arblaster, 2002a). Transitions from March to May and from June to September are found to establish the coupled atmosphere-land-ocean interactions for the following year, with an opposite transition in the subsequent year (Meehl and Arblaster, 2002b).

Table 1 shows the list of 18 stations in P. Malaysia that exhibit negative deviations of rainfall from the normal, with an average monthly negative deviation of 67% and a monthly total mean of 40 mm in February. Stations such as Chuping, Pulau Langkawi, Alor Star and Bayan Lepas represent the northwestern region of Penisular Malaysia, while stations Kota Bharu

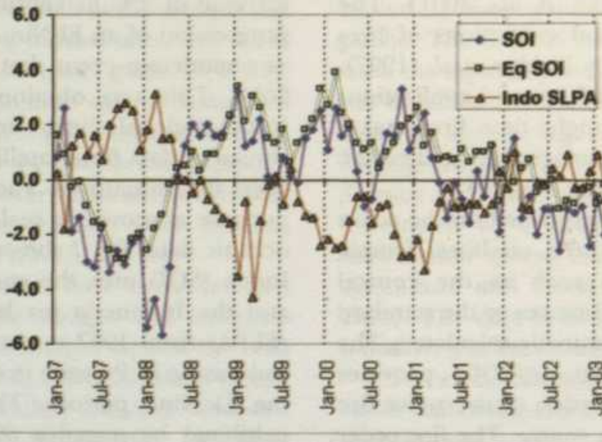

Fig. 1: The Southern Oscillation Index and the Indonesian sea level pressure anomaly from 1997 to early 2003

through to Mersing represent the eastern region. Conditions are slightly wetter in March, where most of the southern stations exhibit negative anomalies of magnitudes below 30%, compared to the northern part of the peninsula in the states of Perlis, Kedah and Kelantan that exhibit negative deviations of more than 60% from the normal, representing very dry conditions. The trend in rainfall patterns was similar to that in February, where the northern and northwestern states received far less rainfall than either the western coast or southern region of Peninsular Malaysia. The average rainfall for the peninsula of 124 mm in March was approximately 24 % below normal.

The temperature deviations from climatological normal showed in Table 1 also illustrate that most of the stations over the Malaysian peninsula exhibit a warming tendency of approximately 20% above normal. The maximum temperatures recorded reached as high as 36.4°C in February and 36.6°C in March at the urban location of Petaling Jaya in Selangor (*Utusan Malaysia*, 2002b). The mean deviations for most of the stations in P. Malaysia were positive, at values of 0.53 and 0.84 in February and March, respectively. Weather parameters such as temperature, evaporation and solar radiation all illustrate above normal conditions, whilst rainfall exhibited negative anomalies, indicating that the Malaysian peninsula was drier and warmer than normal, in which these conditions were conducive to burning where dry vegetation materials were prone to fires and produced smoke easily. Therefore, the burning activities over Peninsular Malaysia were exacerbated by the drier conditions.

Biomass Burning Activities Detected from Multiple Satellite Sources

The hotspots detected by the NOAA and MODIS satellites over Sumatra and Peninsular Malaysia from February and March 2002 indicate that the land clearing activities in Sumatra was dynamic (*Fig. 2*). The highest number of hotspots occurred in early February when the daily number peaked at 1,230 and 1,184 hotspots on the 11th and 12th March, respectively. Most of the hotspots on 11th March were identified in Sumatra, with a total of 875 hotspots in Riau, 45 in North Sumatra and 188 in Peninsular Malaysia. A total of 597 hotspots were detected in Riau, in contrast to 198 hotspots over Peninsular Malaysia on the following day, indicating vigorous burning activity over the two areas during these two days. The number of NOAA AVHRR hotspots detected by the Meteorological Services of Singapore (MSS) was more conservative than the FFPMPII, with the highest hotspots of 550 on 10th March. The number of hotspots registered on the 11th and 12th March was 360 and 310, respectively. Although both centres used the same AVHRR data, their algorithms utilized were different. The mid-morning fires detected by MODIS were the most conservative, with the maximum hotspots occurring on 8th March, totaling 159 hotspots for both Peninsular Malaysia and Sumatra.

TABLE 1
The anomalies of rainfall, solar radiation and evaporation in Peninsular Malaysia from February to March 2002

	% Anomaly Rainfall (mm)		Deviant from Normal Temperature (°C)		Solar Radiation (MJ/m^2)		Evaporation (mm/day)	
	Months							
Stations	Feb	Mar	Feb	Mar	Feb	Mar	Feb	Mar
Chuping	-97	-27	0	1	12	9	17	18
P. Langkawi	-83	-79	1	1	7	6	17	9
Alor Star	-63	-49	1	1	4	4	19	21
Bayan Lepas	-59	-45	1	2	10	7	4	8
Ipoh	-38	-31	1	1	5	3	10	8
Cameron Highlands	-94	-62	0	0	10	9	12	-20
Sitiawan	-23	-1	1	1	6	9	17	11
Subang	-13	-41	2	2	2	-2	11	4
Kluang	-76	-4	0	1	4	8	8	18
Senai	-66	-4	0	0	-5	3	11	24
Kota Bharu	-65	-27	0	0	0	0	9	9
Kuala Krai	-80	-16	0	1	9	12	5	7
Kuala Trengganu	-91	-29	0	0	-5	-3	-4	6
Kuantan	-94	-10	1	1	13	11	18	21
Batu Embun	-81	35	0	1	11	14	6	16
Temerloh	-94	-71	0	1	4	-4	8	9
Muadzam Shah	-57	-49	0	1	5	11	-3	10
Mersing	-26	-46	1	1	10	10	4	-5
Average	-67	-31	0	1	6	6	9	10

Source: Malaysian Meteorological Services (2002)

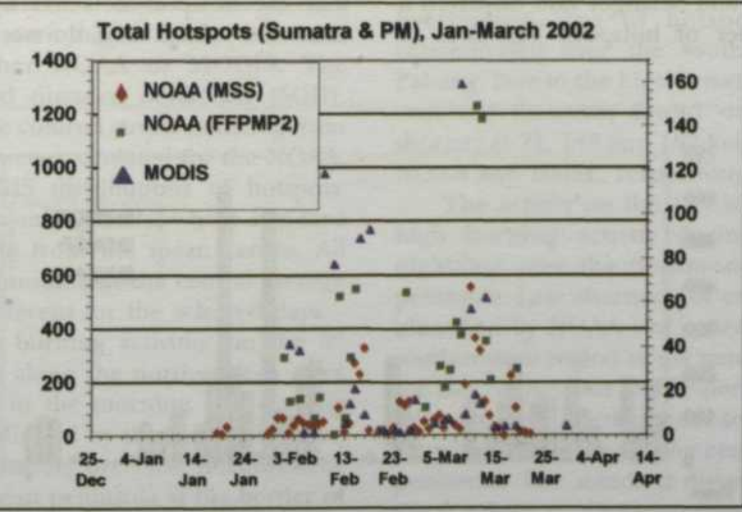

Fig. 2: The activity of burning over Sumatra and Peninsular Malaysia as detected by three types satellites from February to March of 2002

The activity of burning in Sumatra was of a larger scale than in Peninsular Malaysia due to her large-scale development programme of converting vegetated areas into oil palm plantations. This is reflected by the total of only 498 hotspots in February detected by NOAA satellite (*Fig. 3*). Two consecutive days with the highest activity of burning were on the 14th February, with 111 hotspots, followed by the next day that recorded a total of 130 hotspots. In contrast, the DMSP satellite detected a total of 1,044 hotspots during February. Another similar pattern of consecutive days of high hotspots was detected, on the 24th, with a total of 145 hotspots, followed by 198 hotspots on the next day. No hotspots were detected for a total of eight days during this month, which were the 6th, 15th, 16th, 17th, 19th, 20th, and 26th to 29th. The highest single day total hotspots of 85 detected by MODIS were on the 18th February, followed by 81 hotspots detected on the 9th February and 69 hotspots on the 11th. There were six days in March where no hotspots were reported by the FFPMPII project on the 2nd, 3rd, 10th, 15th, 16th and 17th. The latter missing observations were due to the break in record when their office was relocated from Bogor to their present location in Jakarta. Regrettably, vital information was lost when the transboundary haze was at its peak from the 15th to 17th of March.

The state of Pahang exhibited the highest number of hotspots detected at 601, followed by Johore at 365 and Kedah at 235. Terengganu, Negeri Sembilan and Selangor also displayed a substantial number of hotspots. The fires in Selangor received much media coverage due to its close proximity to the capital, Kuala Lumpur, but there was prominent burning of the agricultural waste in February particularly over the northern states such as in Kedah. The burning of the peatland in Pahang emerged as near continuous throughout the two months, with prominence in March 2002.

The trend of burning shown in the two months emerged as if the burning activities only occurred on specific days. One of the factors that hinder continuous detection is the presence of clouds, which consists of thick cumulonimbus clouds characteristic of equatorial regions. Only the nighttime hotspots detected by DMSP showed the near continuous activity of burning over the Malaysian peninsula, although this too was influenced by the presence of clouds. The clearing of agriculture land through burning by the local farmers who prefer to burn during the afternoon and evening is a clear disadvantage for the monitoring or detection of hotspots by the Terra MODIS satellite that has a morning overpass time.

There exists a weak relationship between the hotspots from the three satellites. The correlation coefficient between the hotspots detected by NOAA and DMSP was moderate with a coefficient of 0.4, compared to the lower coefficient of 0.28 between NOAA and MODIS as shown in Table 2. The correlation between MODIS and DMSP was much lower with a coefficient of 0.17. ANOVA analysis confirmed that the hotspots detected by three satellites were not related and do not come from the

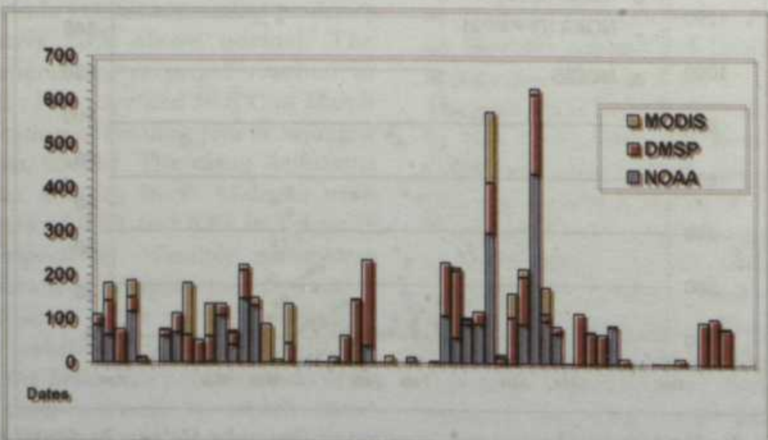

Fig. 3: Hotspots in Peninsular Malaysia as detected by three different satellites such as the AVHRR NOAA, DMSP and MODIS from 1 February to 30 March 2002

same population. This is to be expected as the over pass time of each satellite is different. Terra MODIS detects the morning observation, while NOAA detects the late afternoon burning and DMSP the nighttime fire activity.

TABLE 2
Correlation coefficients between hotspots of the three satellites

Correlation	NOAA	DMSP	MODIS
NOAA	1.000	0.399	0.282
DMSP	0.399	1.000	0.171
MODIS	0.282	0.171	1.000
N cases	59	59	59

Spatial Analysis of Hotspots

Visual interpretation of the spatial distributions of hotspots detected by the three satellites was limited, as comparison when all the satellites were present on the same day could not be performed for the whole month. Only four days experienced this occurrence which were on the 6th, 8th, 11th and 13th March 2002.

Fig. 4 shows the superimposed hotspots from the three satellites. Each of the four days illustrated different patterns of fire distributions that were variable spatially and temporally. The total number of hotspots from the three satellites were moderate on the 6th March, compared to the higher burning activities on the 8th and the 11th March. On both these days, the numbers of DMSP hotspots were higher than the ones detected by either NOAA or MODIS. The different standard distance deviations (SDD), represented by the colored circles radiating from the mean centre were calculated for the NOAA, DMSP and MODIS distributions of hotspots, with their corresponding circles whose standard distances originate from the mean centre. All the four panels showed that the central average locations were different for the selected days.

Much of the burning activities on the 6th March took place along the northwestern coast of the peninsula in the morning and evening time. This was indicated by the central location of the NOAA hotspots over the northwestern part of the Malaysian peninsula at the border of Kelantan-Perak (Table 3). The SDD of 177 km contain most of the hotspots detected over the northern and northwestern states, including approximately 68% of the total NOAA hotspots. Nighttime burning was also concentrated over the northwestern region of the peninsula, with another cluster of high burning over the central state of Pahang. However, the SDD for the hotspots from the DMSP satellite was large at 206 km due to the low number of hotspots totalling 35 compared to the higher density of NOAA hotspots that totaled 125. The SDD for the MODIS hotspots also coincided with the SDD for the NOAA satellite and covered a part of the DMSP circle of dispersed distribution. This reveals that the distribution of hotspots detected from the three satellites all concentrate over the northern to northwestern part of the peninsula.

The DMSP satellite detected high burning in the central and southern states of Pahang, Negeri Sembilan and Johor on the 8th at nighttime in contrast to the occurences over the eastern part of the peninsula. This differed from the clustered distribution of the NOAA hotspots in the southern states of Johor, and eastern and central states of Terengganu and Pahang. Hotspots detected by MODIS were also detected in Pahang, overlying the area detected by NOAA and DMSP particularly over the central eastern coast of the peninsula. This is the location of peat forest that burned for several days as reported in the local media (*Utusan Malaysia*, 2002b; 2002c). The SDDs of burning activities as detected by NOAA, MODIS and DMSP were superimposed over the same area, covering the central to southern parts of the peninsula. The overlapped area of hotspots activity was concentrated over the southeastern state of Pahang. Due to the high density of hotspots, the standard distances found on this day were shorter, at 71, 143 and 162 km, for the MODIS, NOAA and DMSP, respectively.

The activity on the 11th March still showed high burning activity during morning and nighttime over the northwestern coast of the peninsula. Late afternoon or evening burning as identified by NOAA was concentrated over the southwestern region of the peninsula. The SDDs for the NOAA and DMSP derived hotspots for this day also overlapped each other, mainly covering a large area in the central region of the peninsula. The standard distances displayed by the distribution of hotspots from the two satellites were larger than on the 8th March, due to the dispersion of hotspots that were clustered over the northwestern and southwestern region of

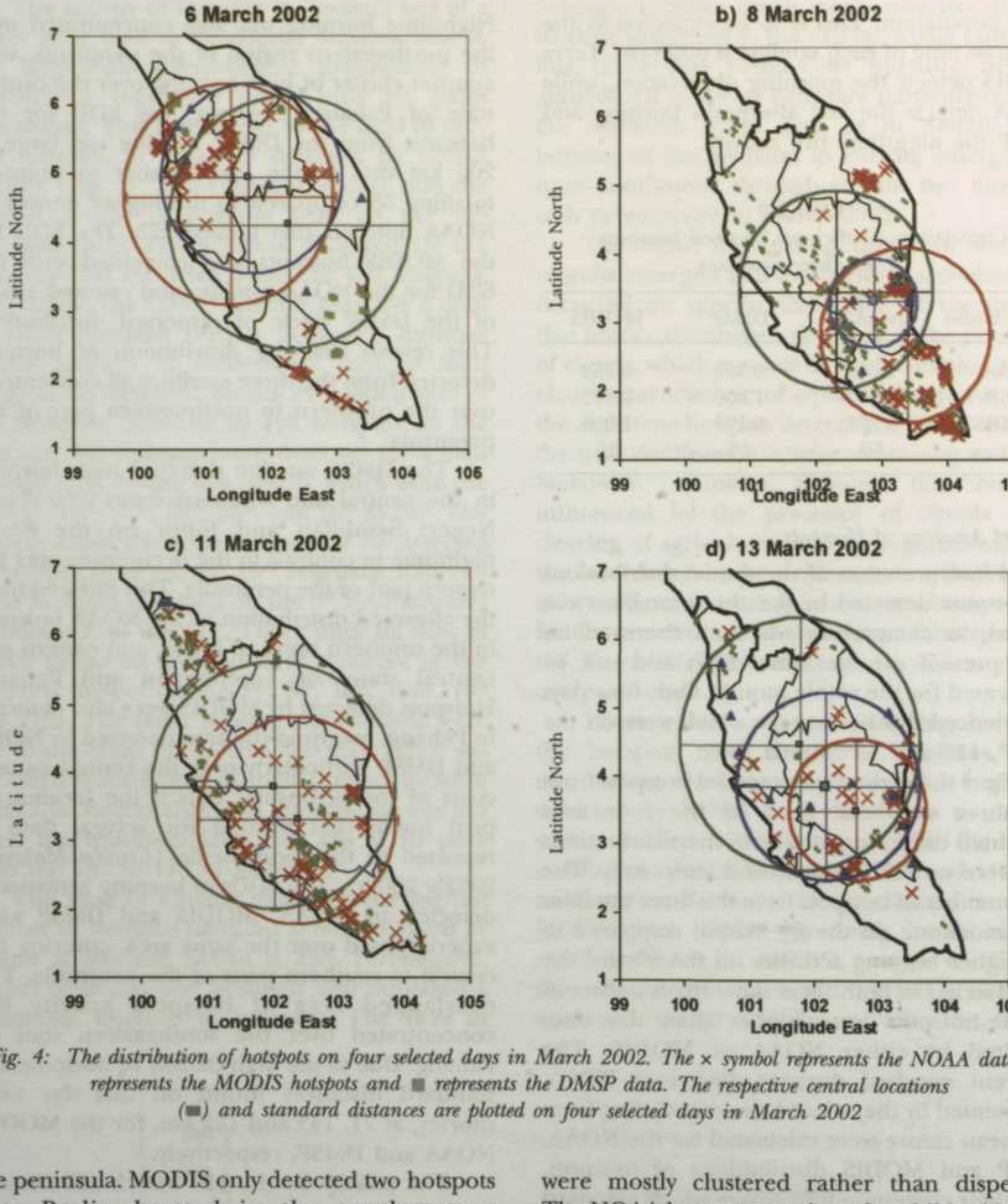

Fig. 4: The distribution of hotspots on four selected days in March 2002. The × symbol represents the NOAA data, △ represents the MODIS hotspots and ■ represents the DMSP data. The respective central locations (■) and standard distances are plotted on four selected days in March 2002

the peninsula. MODIS only detected two hotspots over Perlis, located in the northwestern peninsula. The moderate burning activity in the morning of 13th March was located along the northern part of the western coast and over the central part of the peninsula. Evening burning, detected by NOAA was mainly found over the central region of the peninsula. This is reflected by the overlapped areas of SDDs for each of the satellites, which was located mainly in the central state of Pahang

Table 3 shows that for the selected four days, all the Moran and Geary C indices were positive but less than one, indicating the hotspots were mostly clustered rather than dispersed. The NOAA hotspots consistently exhibited higher values of Moran I, with magnitudes of more than 0.61 for all the four selected days. This suggests that the active daytime hotspots were more spatially correlated or clustered compared to either the morning or nighttime burning activities. This trend was also displayed by the MODIS hotspots, which exhibited moderately high positive Moran indices. This is in contrast to the DMSP hotspots that exhibit lower magnitudes of indices compared to either the MODIS or NOAA satellites, implying that there was less spatial correlation or less clustering compared to either the morning or evening time burning. The second-order spatial analysis that defines the local properties of distribution was investigated, to identify the neighbourhood patterns and clusters within the overall distribution (Table 4). The mean nearest neighbour distance (MNND) varied for different days. The MNND was large on the 6th for the NOAA hotspots compared to the hotspots from other satellites. Only the distribution of hotspots detected by MODIS exhibited a MNND index of more than 1, indicating random dispersion on the 13th March 2002 and a dispersed distribution on the 6th March. This was due to the small number of hotspots detected that are widely dispersed from one another. The nearest neighbour heirarchical (NNH) cluster analysis highlights the difference between the daytime and nighttime spatial variability for the four selected days. The spatial patterns do not indicate that the first-order clusters of daytime hotspots were followed by the first-order clusters of nighttime burning activities as depicted by the NNH1 notation in *Fig. 5*. The placements of the clusters of daytime and nighttime burning were different on all the selected four days. Only two of the second-order clusters were exhibited by the hotspots from the NOAA satellite, as shown on 6 and 13 March. They were grouped from the eight individual first-order clusters on 6 March and from 4 individual first-order clusters on 13 March (*Fig. 5*). No second-order clusters were found from the nine first-order clusters or the sixteen first-order clusters for the DMSP derived hotspots on 11 March. This was due to the hotspots that were dispersed over large distances throughout the peninsula.

However, they highlight the information on the different concentrations of burning activities that may be useful to fire managers such as the local Fire Department as a contingency plan to strategically tackle the concentrated clusters of fires if resources are limited. In this study, five hotspots per cluster were chosen as the threshold criteria. However, the threshold counts could be increased to limit or reduce the groups of clusters within a selected region.

An index of dissimilarity that functions as an indicator of relative change of concentration was presented to study the difference between the paired percentages from the hotspot distributions detected by the satellites. The dissimilarity indices between NOAA and DMSP for the four days investigated were moderate over the states in Peninsular Malaysia, indicating the patterns of distributions were approximately 30% to 70% different over the various states as shown in Table 5. The highest dissimilarity of 69% occurred on the 6th March. The spatial distribution shown in *Fig. 4a* demonstrate that

TABLE 3
The centrographic statistics for the NOAA, DMSP and MODIS satellites

Satellite	Mean Centre Longitude °E	Mean Centre Latitude °N	State	Standard distance (km)	Moran I	Geary C
			a) 06 Mar 2002			
NOAA	101.09	5.01	Perak	113.26	0.61	0.33
DMSP	102.31	4.07	Pahang	203.58	0.65	0.27
MODIS	101.42	5.15	Perak	167.70	0.15	0.89
			b) 08 Mar 2002			
NOAA	103.57	2.41	Johor	117.73	0.73	0.17
DMSP	102.45	3.24	Pahang	130.23	0.34	0.50
MODIS	102.99	3.45	Pahang	64.96	0.55	0.10
			c) 11 Mar 2002			
NOAA	102.70	3.02	Pahang	134.23	0.63	0.22
DMSP	102.13	3.53	Pahang	214.11	0.41	0.52
MODIS	100.38	6.51	Kedah	7.66	NA	NA
			d) 13 Mar 2002			
NOAA	102.87	3.45	Pahang	77.22	0.63	0.19
DMSP	101.74	4.52	Pahang	203.26	0.51	0.44
MODIS	102.50	3.69	Pahang	136.15	0.85	0.17

NA indicates data is not available.

TABLE 4
The second-order local properties of neighbourhood hotspot patterns of the three satellites

Date	Satellites	Mean Nearest Neighbour Distance	Expected Neigbour Distance	Nearest Neighbour Index	Distribution
06 Mar 02	NOAA	5.73 km	20.10 km	0.28	cluster
06 Mar 02	DMSP	3.64 km	30.23 km	0.12	cluster
06 Mar 02	MODIS	101.53km	6.17 km	1.65	disperse
08 Mar 02	NOAA	2.25 km	10.35 km	0.22	cluster
08 Mar 02	DMSP	3.01 km	10.05 km	0.30	cluster
08 Mar 02	MODIS	17.74 km	46.84 km	0.38	cluster
11 Mar 02	NOAA	5.03 km	13.26 km	0.38	cluster
11 Mar 02	DMSP	3.57 km	10.88 km	0.33	cluster
11 Mar 02	MODIS	NA	NA	NA	cluster
13 Mar 02	NOAA	4.78 km	18.51 km	0.26	cluster
13 Mar 02	DMSP	4.50 km	23.04 km	0.20	cluster
13 Mar 02	MODIS	46.00 km	45.35 km	1.01	random

NA indicates data is not available.

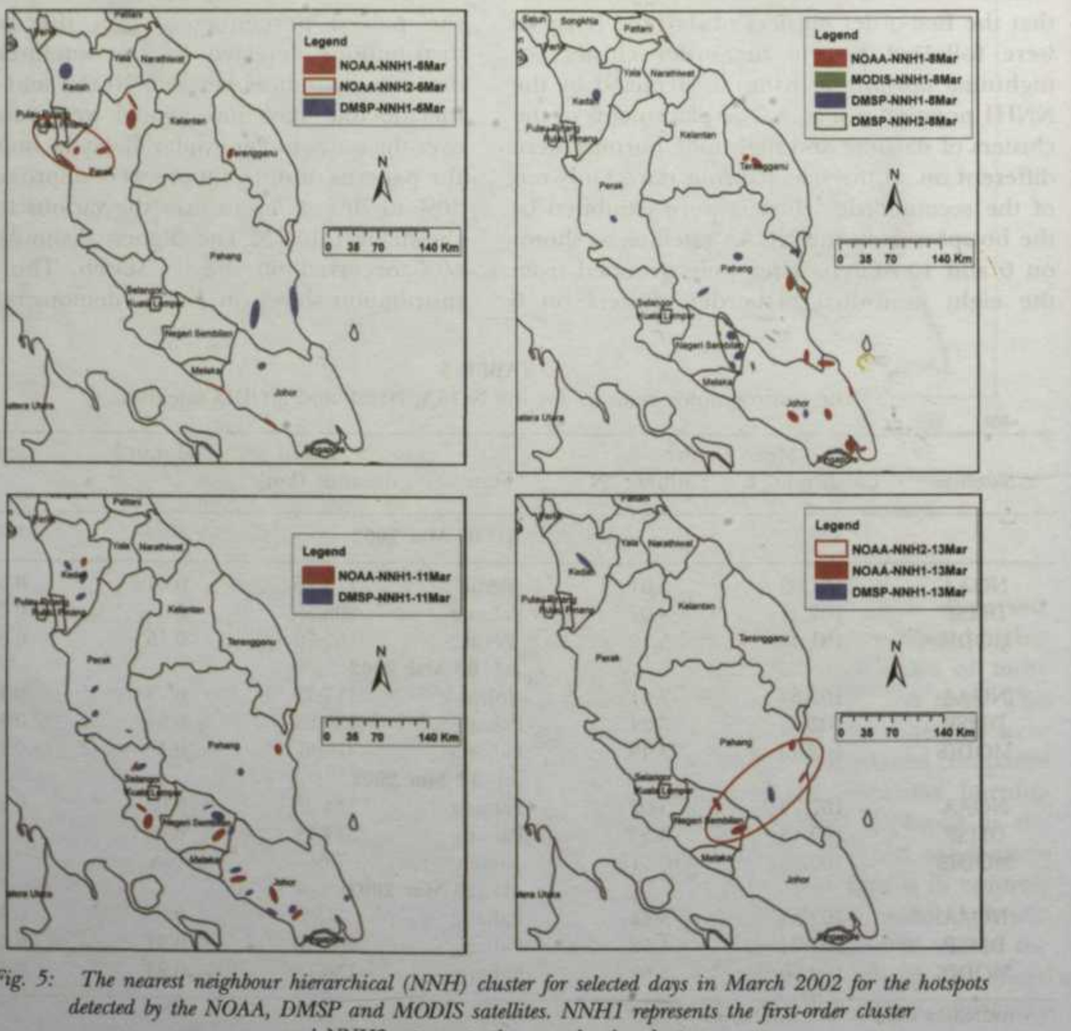

Fig. 5: The nearest neighbour hierarchical (NNH) cluster for selected days in March 2002 for the hotspots detected by the NOAA, DMSP and MODIS satellites. NNH1 represents the first-order cluster and NNH2 represents the second-order cluster

TABLE 5
The dissimilarity indices on selected days between NOAA and DMSP satellites

Dates	Dissimilarity index between NOAA and DMSP and the various states	
06 Mar 02	68.84	Johor, Kedah, Pahang, Terengganu
08 Mar 02	49.69	Kedah, Negeri Sembilan, Perak, Selangor, Perlis
11 Mar 02	32.05	Johor, Kedah, Melaka, Perak, Terengganu
13 Mar 02	47.75	Johor, Kedah, Melaka, Perak, Penang

most of the DMSP hotspots were clustered over the northwest and the southwestern coast of the peninsula, as specified by the mean centre location situated over the central region of the peninsula, with its larger standard distance, indicating the dispersion of its hotspots. In contrast, the NOAA hotspots were located over the northwestern states such as Kedah, Penang and Perak and substantiated by its mean centre and standard distance. Dissimilarity was found mainly in the states of Johor, Kedah, Pahang and Terengganu.

The distribution of hotpots on the 8th March with a high burning activity was illustrated by the concentration of hotspots over the northwestern, central and eastern coast in the states of Kedah, Kelantan and Pahang, but none over the southern or southwestern part of the peninsula. This shows that there exist a 50% difference in the patterns of hotspots between NOAA and DMSP particularly in the states of Kedah, Negeri Sembilan, Perak, Selangor and Perlis. Moderate dissimilarity indices indicating pattern change of hotspots between NOAA and DMSP on the 11th and 13th March mainly occurred over the states of Johor, Kedah, Melaka, and Perak.

One of the factors that hampered continuous monitoring over our equatorial region was the presence of clouds. The NOAA satellite only obtained partial coverage of the peninsula for only ten days within February and March. One of the disadvantages of the Terra MODIS satellite is that the overpass morning time is not coincident with the period of burning activities by the local farmers. MODIS does not always have a fixed area of daily coverage and its detection system requires a far higher saturation brightness compared to NOAA, which causes it to present a more conservative number of hotspots.

CONCLUSION AND RECOMMENDATION

The comparison of the hotspots over the Malaysian peninsula detected by the NOAA AVHRR, Terra MODIS and the DMSP OLS satellites showed that throughout February and March 2002, much biomass burning activities occurred during the drier and warmer than normal conditions over the peninsula. The different satellites with dissimilar overpass times, algorithms and resolutions showed different numbers of hotspots monitored throughout the day. The highest hotspots detected were by DMSP in February, followed by NOAA and the least by MODIS. Statistical relationships analysis for the hotspots from the three satellites was weak, with the strongest correlation between NOAA and DMSP.

There is a tendency of clustering in the burning patterns, particularly over the states of Perlis, Kedah and Pahang during early February in contrast to March. The day to day burning patterns on several case studies highlight a moderate index of dissimilarity, ranging from 30 % to 50% for most of the cases. Conspicuous vegetation fires were found over the paddy fields in the northwestern states of the peninsula in February compared to the logged over forests and peat land in Pahang during March.

In this study, the validation of hotspots with ground truth or sources of errors, resolution limitations or thresholds sensitivities of the hotspot detection from each satellite was not investigated, but raw data from the dataset of each satellite were utilized with the caveats and limitations. Although there may be a mismatch in accuracies, the study has sucessfully compared the spatial patterns of the hotspots derived from different satellites. The commotion of the active fires occurring throughout the day is revealed by the three satellites of differing overpass times. Burning activity that took place in the morning was found to be small, compared to the evening deeds. Nighttime burning as detected by the DMSP satellite may also include the remnants from the evening activity, hence a higher correlation found between the locations of the hotspots detected by the DMSP and NOAA satellites.

In view of the above findings, conceivably an effort to synchronize data from all the satellites currently available and also future ones could be fostered so that a near-continuous 24 hour monitoring of the burning activities can be achieved where resources could be pooled and minimized for the benefit of end users within the Southeast Asian region. This is one of the goals of the Global Observation of Forest Cover – Global Observation of Land Dynamics (GOFC-GOLD) under the Fire Implementation that may foster coöperation between the satellite producers and users (WWW5). Verification of the hotspots with ground truth data is therefore imperative to ascertain the accuracy of the hotspots, with improved algorithms.

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WWW4. Preliminary comparison of GLOBSCAR fire product to MODIS and DMSP-OLS products. *http://www.geog.ucsb.edu~matzke/globscar/globscar_modis_dmsp_compare.html.*

WWW5. GOFC-GOLD fire monitoring and mapping implementation team website. *http://www.gofc-fire.umd.edu/.*