MONITORING OF TROPICAL FOREST FIRE BY SATELLITE REMOTE SENSING

Shoji Takeuchi
Remote Sensing Technology Center of Japan

Chng Lak Seng
Meteorological Service, Singapore

and

Kazuo Joko
National Space Development Agency of Japan

Commission VII

ABSTRACT:
The authors studied the possibility of satellite remote sensing for the monitoring of forest fire occurred at Kalimantan and Sumatera of Indonesia in 1991. Using the daily observation data by NOAA/AVHRR, the spatial distribution and the temporal change of fire smoke and firing spots were detected. The result of the study verified the possibility of real time monitoring of tropical forest fire by the operational reception and processing of NOAA satellite data.

KEY WORDS: Forest Fire, Fire Monitoring, NOAA/AVHRR, Smoke Detection, Hot Spot in Thermal Band.

1. INTRODUCTION

In 1991 there was a large scale of forest fire in Kalimantan and Sumatera of Indonesia. The fire continued to burn during three months, from August to October. The Indonesian government reported that almost 50,000 ha of forested areas were damaged. The smoke due to the fire spread over not only Kalimantan and Sumatera but also Peninsular Malaysia and the atmospheric condition was much influenced by the smoke, for example, the departure and landing of an airplane was severely limited by low visibility condition.

Because of wide distribution of the firing places and difficult accessibility to the firing places, a satellite remote sensing is considered to be the practical and effective way for monitoring of the forest fire conditions. The authors tried to monitor the forest fire using NOAA/AVHRR data, which were received by the receiving station of Meteorological Service of Singapore.

2. RECEPTION AND PROCESSING OF NOAA/AVHRR DATA

2.1 NOAA Data Reception

NOAA/AVHRR data are daily received as well as GMS data by the receiving station of Meteorological Service of Singapore. NOAA/AVHRR data are converted to 8 bits image data after reception and they can be processed by quick image analysis software. The analysis results can be output to slide hardcopy directly. The system also can backup the AVHRR raw image data to CCT or floppy disk.

The CCT and floppy disk archives of AVHRR raw images were then processed by RESTEC image processing facility, in which the radiometric and geometric data correction were performed to AVHRR image data and the film outputs of the results were produced.

2.2 Path Radiance Correction of AVHRR Data

As the preliminary radiometric data correction, the path radiance correction was performed in visible and near infrared bands. The minimum values for every column numbers were searched in the whole area of the raw image and they were approximated by the third order polynomial of column numbers. The profile of the minimum values obtained by the approximation was regarded as the CCT count for zero reflectance of the surface at that column number and the original CCT count was shifted so that the count of the profile became to a fixed value of zero reflectance(in this case 20). This processing was done for every lines of the input raw image.

According to this correction, the raw images were converted to more uniform images concerning to brightness condition in visible and near infrared bands. Especially this correction was very effective for NOAA-10/AVHRR images which were observed early in the morning because the brightness condition of the raw image was much different among column numbers due to very low sun elevation angle.

2.3 Geometric Data Correction of AVHRR Data

The tangent correction was performed to the AVHRR data after the path radiance correction in order to equalize the ground resolution of each pixel. The influence of the curve of earth surface was taken into account when the data of every column numbers were resampled from look angle coordinate to distance coordinate on the earth surface. As the colomn number of the raw image was 1,024, which indicated that the ground resolution at a nadir point is 2.2 Km, the column number of the corrected image was 1,327 so that all pixel sizes in one line became 2.2 Km on the ground.

3. ANALYSIS OF AVHRR IMAGES FOR FIRE MONITORING

3.1 Detection of Smoke by Forest Fire

The smoke pattern due to the fire was detected using the combination of channel-1(visible-VIS), channel-2(near infrared-IR1) and channel-4(thermal infrared(11 µm)-IR3) of AVHRR data. The reflection of smoke in visible and near infrared region is very high as well as that of cloud. However, in thermal infrared region(IR3), the smoke can be hardly detected because of its small liquid water content and low elevation. On the other hand, the cloud can be clearly detected because the elevation of most cloud is very high and this causes very low surface temperature of the cloud. As the CCT count in thermal infrared bands of AVHRR images corresponds to temperature reversely, the clouds are detected as bright(white) patterns in IR3 of AVHRR images.

Therefore, the combination of VIS,IR1 and IR3 can discriminate the smoke pattern from cloud, land and ocean. For example, by the color composite in which VIS correspond to Red, IR1 to Green and IR3 to Blue respectively, the smoke can be detected as yellow color, on the other hand the cloud is colored as white or blue white by the same color composite.

Because there exists sometimes low elevation cloud or fog, the smoke detection described above does not always succeed. In this case, it is necessary to consider the difference of the shape between smoke and cloud/fog.

3.2 Detection of Hot Spot by Forest Fire

The places where the surface temperature became high due to the fire (Hot Spots) were detected using channel-3(thermal infrared(3.7 µm)-IR2). Fig.1 shows the examples of the dump list of IR2 observed at night time. The high temperature region are discriminated by the CCT count lower than about 150 because the CCT count in sea water is just around 150, which is considered to be the highest temperature object at night time except high density urban areas. The extreme example of the CCT count at the hot spots is below 10, which suggests that the surface temperature is higher than that of ocean more than 50 degrees.

4. RESULTS OF MONITORING BY AVHRR DATA

Total eighteen temporal data of NOAA/AVHRR were used for monitoring of the fire conditions in Kalimantan and Sumatera. Fig.2 shows the map of the test site covered by AVHRR data. For the comparison with the results of image analysis, visibility observation data were investigated in Kalimantan, Sumatera and Singapore. The points shown as K1 to K4 and S1 to S3 in Fig.2 indicates the observation points of visibility in Kalimantan and Sumatera respectively.

4.1 Results of the Analysis of AVHRR Temporal Images

(1) Smoke conditions in Kalimantan

The earliest image was taken on Aug. 31. In the color composite image(VIS-R, IR1-G and IR3-B), yellow smoke patterns spread over almost whole area of West-Kalimantan, which suggested that the forest fire had expanded already almost in the whole areas of West-Kalimantan. In the second image taken on Sep. 18, the smoke distribution concentrated in the east side of West-Kalimantan, the north of Banjarmasin, and also the smoke rose up from several points in East-Kalimantan and from the west coast line of Kalimantan.

In the third image taken on Sep.30, The smoke distributions were almost same as those of the image on Sep.18, however, the amount of the smoke was increased than before, which suggested the fire power became more strong.

	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
+	162	172	174	176	178	176	177	174	176	178	177	174	168	172	182	183	183	181	181	174	164	155	157	157	157	157	156	157	156	156
+	161	175	175	174	177	177	176	175	179	183	183	169	158	139	116	176	179	181	181	181	166	156	156	156	157	156	157	156	156	155
+	176	177	177	176	173	173	166	167	169	171	154	154	57	87	160	173	174	182	182	180	179	157	157	156	156	156	157	157	157	157
+	175	177	178	178	170	169	166	171	134	164	166	51	107	172	9	170	175	176	182	180	179	162	158	157	156	156	156	158	157	156
+	177	178	174	176	175	171	164	157	140	165	162	12	166	175	173	173	173	143	167	180	177	171	166	157	157	157	156	157	158	157
+	178	180	174	168	143	158	151	158	151	164	40	180	173	175	174	174	174	157	161	167	154	170	169	162	157	156	157	160	160	161
+	175	179	181	170	168	158	150	157	144	106	156	175	175	176	176	175	176	121	158	172	168	176	169	167	172	169	168	170	171	166
+	182	181	181	171	171	163	157	130	159	176	177	177	176	176	174	174	173	146	166	175	180	171	171	129	172	177	132	181	181	172
+	179	178	179	172	166	162	170	161	10	182	176	178	178	178	175	176	164	167	174	169	171	137	159	145	108	144	179	184	183	177
+	180	179	177	177	163	166	171	165	120	7	162	179	177	178	176	178	173	166	156	129	149	174	169	173	170	84	180	184	183	177
+	176	177	179	179	167	167	156	153	163	99	166	179	178	176	176	178	176	174	122	94	143	124	178	175	174	144	175	178	183	181
+	176	176	179	177	169	169	156	10	174	176	178	177	176	176	176	176	176	176	173	173	175	176	179	177	176	175	174	176	175	182
+	175	175	179	177	174	164	174	149	174	176	178	179	175	179	151	177	176	175	175	175	176	177	178	177	176	175	175	177	174	179
+	6	3	158	164	178	179	176	164	174	175	175	176	178	179	134	179	177	177	177	177	177	177	177	178	177	176	177	176	175	175
+	163	160	10	30	155	181	176	174	173	174	173	173	175	178	177	178	178	176	177	177	178	180	178	178	178	178	179	179	177	176
+	143	114	85	3	179	181	182	178	150	172	172	11	105	171	177	178	178	176	176	177	176	177	177	178	178	179	179	179	179	177
+	177	178	168	169	181	179	178	183	164	172	173	89	156	83	177	177	177	176	177	177	177	176	176	177	177	177	177	179	179	177
+	176	176	181	182	178	179	178	180	176	186	189	167	182	147	172	181	180	176	177	176	177	178	178	177	177	178	178	178	179	178
+	176	177	178	179	178	180	180	172	182	178	186	189	188	191	176	179	180	176	177	176	175	177	177	177	178	177	178	177	178	178
+	170	173	150	164	181	181	183	185	185	169	178	180	186	187	178	178	179	177	177	177	176	169	176	167	167	176	177	178	179	179

Fig.1 Example of dump list of channel-3 (3.7 µm) of AVHRR data taken at night time in the south-east of Sumatera. The areas enclosed by solid lines are considered to be high temperature surface by the fire(hot spots), and the hatched area indicates sea water.

The forth image taken on Oct.7 still indicated the similar smoke distribution and also indicated very strong fire power especially in the north of Banjarmasin. In the fifth image taken in early morning on Oct.8, the huge rising smoke came out from the north of Banjarmasin and spread to the north direction. This smoke pattern suggested that extreme violent fire occurred at a certain place in the north of Banjarmasin.

The sixth image was taken on Oct.17 and in this image only small distribution of smoke was seen in the north of Banjarmasin, where very strong fires were monitored from the previous images. This image suggested that the fire became put out or weak in almost Kalimanan at least by Oct.17. In the last image taken on Oct.28, some extent of smoke pattern was seen again in West-Kalimantan as well as in Sumatera, which suggested the fire became strong and expanded again in Kalimantan after Oct.17.

The AVHRR color composite images taken on Sep.30, Oct.7 and Oct.8 are shown in Plate.1.

(2) Smoke conditions in Sumatera

In the earliest image taken on Aug.31 almost areas of Sumatera were covered by cloud. The second image taken on Sep.15 indicated that the fire smoke rose up from several points near to Palembang. In the third image taken on Sep.23, the smoke distribution became wider than the previous image and especially the fire expanded to the coastal areas in the south of Palembang.

In the forth image taken on Oct.4, the strong smoke rose up from the south-east coastal areas of Sumatera, which indicated that the fire continued to burn and became more strong since Sep.23 in the south-east coast of Sumatera. In the fifth and the sixth images taken on Oct.8 and 9 respectively the violent smoke patterns rose up from the same regions of Sumatera, which indicated the fire power in these areas became maximum around these dates.

In the seventh image taken on Oct.13, only the south part of Sumatera was cloud free and this image indicated the fire still continued to burn in the south-east coast of Sumatera. In the eighth image taken on Oct.17 the smoke patterns were hardly seen, which suggested the fire became very weak or put out in almost areas of Sumatera. However, in the last image taken on Oct.28, the strong smoke patterns rose up again from the south-east of Sumatera, which indicated the fire still continued to burn and became strong again as previously indicated in Kalimantan.

The AVHRR color composite image taken on Oct.8 is shown in Plate.1.

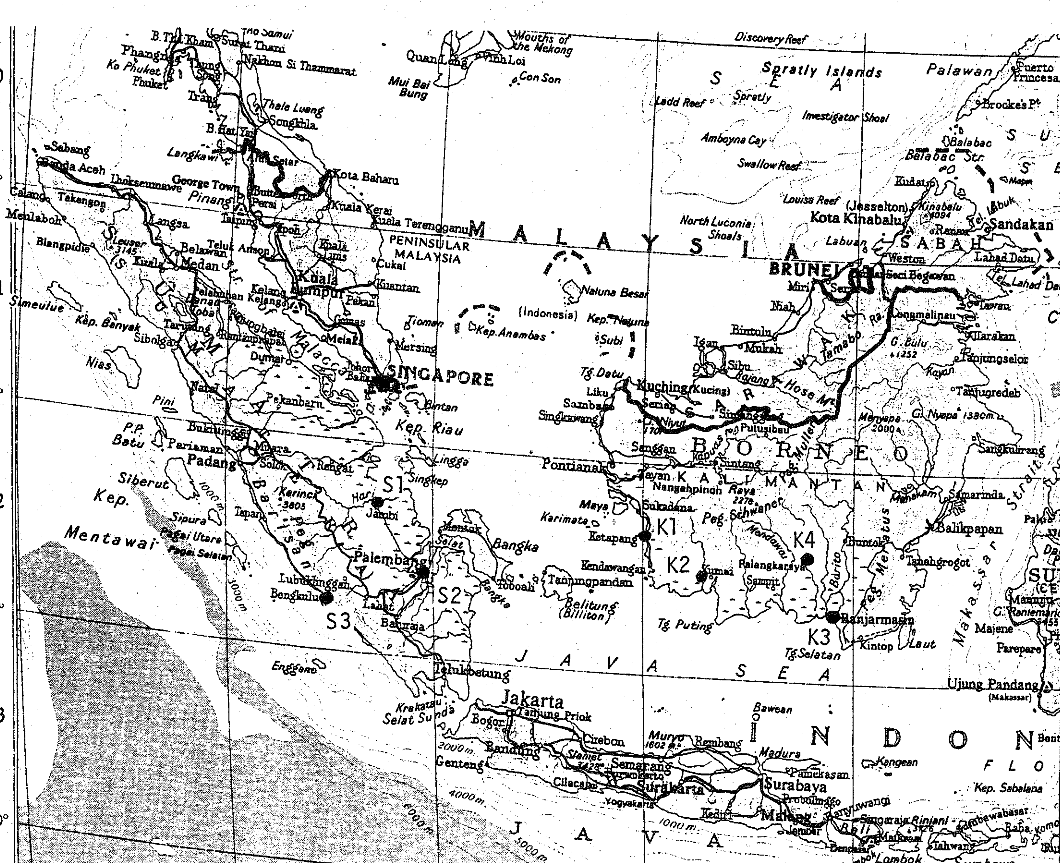
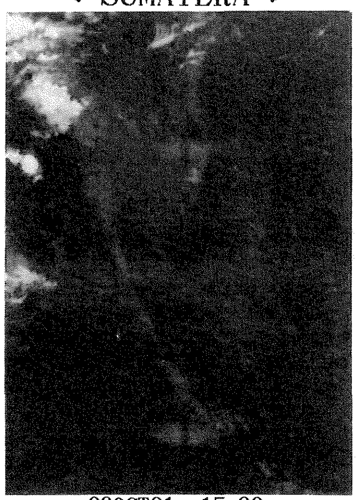


Fig.2 Test site for monitoring by NOAA/AVHRR data. The points of K1 to K4 and S1 to S3 are the observation points of visibility for Kalimantan and Sumatera respectively.

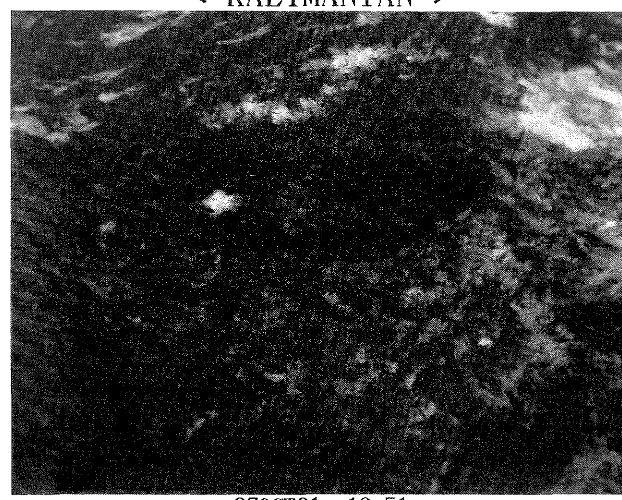
DISTRIBUTION OF SMOKE BY FOREST FIRE IN INDONESIA

< SUMATERA >



08OCT91 15:20

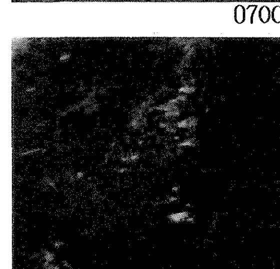
< KALIMANTAN >



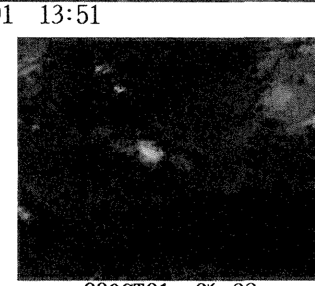
07OCT91 13:51

- NOAA/AVHRR COLOR COMPOSITE IMAGES -

R:VISIBLE(CH-1)
G:NEAR-IR(CH-2)
B:THERMAL-IR(CH-4)



30SEP91 13:32

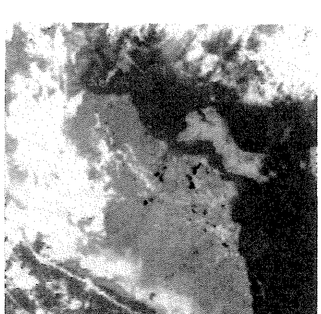


08OCT91 06:33

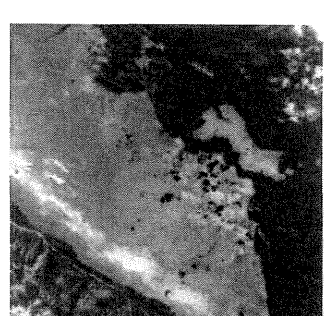
Plate.1 AVHRR color composite images using channel-1(visible), channel-2(near infrared) and channel-4(thermal infrared(11μm)) taken on Sep.30, Oct.7 and Oct.8 in Kalimantan and Sumatera.

HOT SPOTS BY FOREST FIRE IN SOUTH-SUMATERA

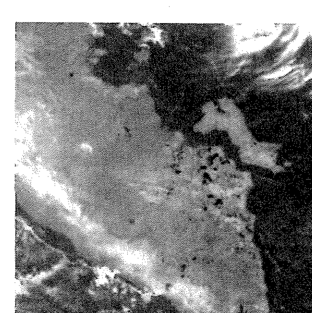
- NOAA/AVHRR THERMAL-IR(CH-3) IMAGES AT NIGHT TIME -



01OCT91 02:15



08OCT91 02:34



09OCT91 02:22

Plate.2 AVHRR channel-3(thermal infrared(3.7 μm)) images taken at night on Sep.30, Oct.7 and Oct.8 in the south area of Sumatara.

(3) Distribution of the hot spots

Total 6 temporal images of AVHRR channel-3(IR2) at night time were used for monitoring of the locations of the hot spots by the fire. The first image was taken at night on Sep.30, the second was taken at night on Oct.4, and the third to sixth images were taken sequentially at night from Oct.6 to 9.

In all images the hot spots were distributed in the south-east coast of Sumatera and the south coast line of West-Kalimantan, although in Kalimantan the detection of the hot spots in the inner region were disturbed by cloud cover except the image taken at night on Oct.4. In Sumatera the distribution of the hot spots were concentrated around Palembang and the extent of the hot spots was considered to be maximum at night on Oct.7.

In kalimantan, only the image taken on Oct.4 was available to investigate the hot spot distribution in West-Kalimantan, the hot spots more than 10 were observed in the north of Banjarmasin, where a very violent rising pattern of the fire smoke was observed from AVHRR image taken early in the morning on Oct.8.

The AVHRR IR2 images taken at night on Sep.30, Oct.7 and Oct.8 in the south area of Sumatera are shown in Plate.2.

4.2 Comparison with Visibility Data

Fig.3 shows the daily change of visibility in Kalimantan , Sumatera and Singapore. The vertical axis means the square root of visibility in Km and the horizontal axis means date. In Kalimantan and Sumatera, the worst visibility data in day time

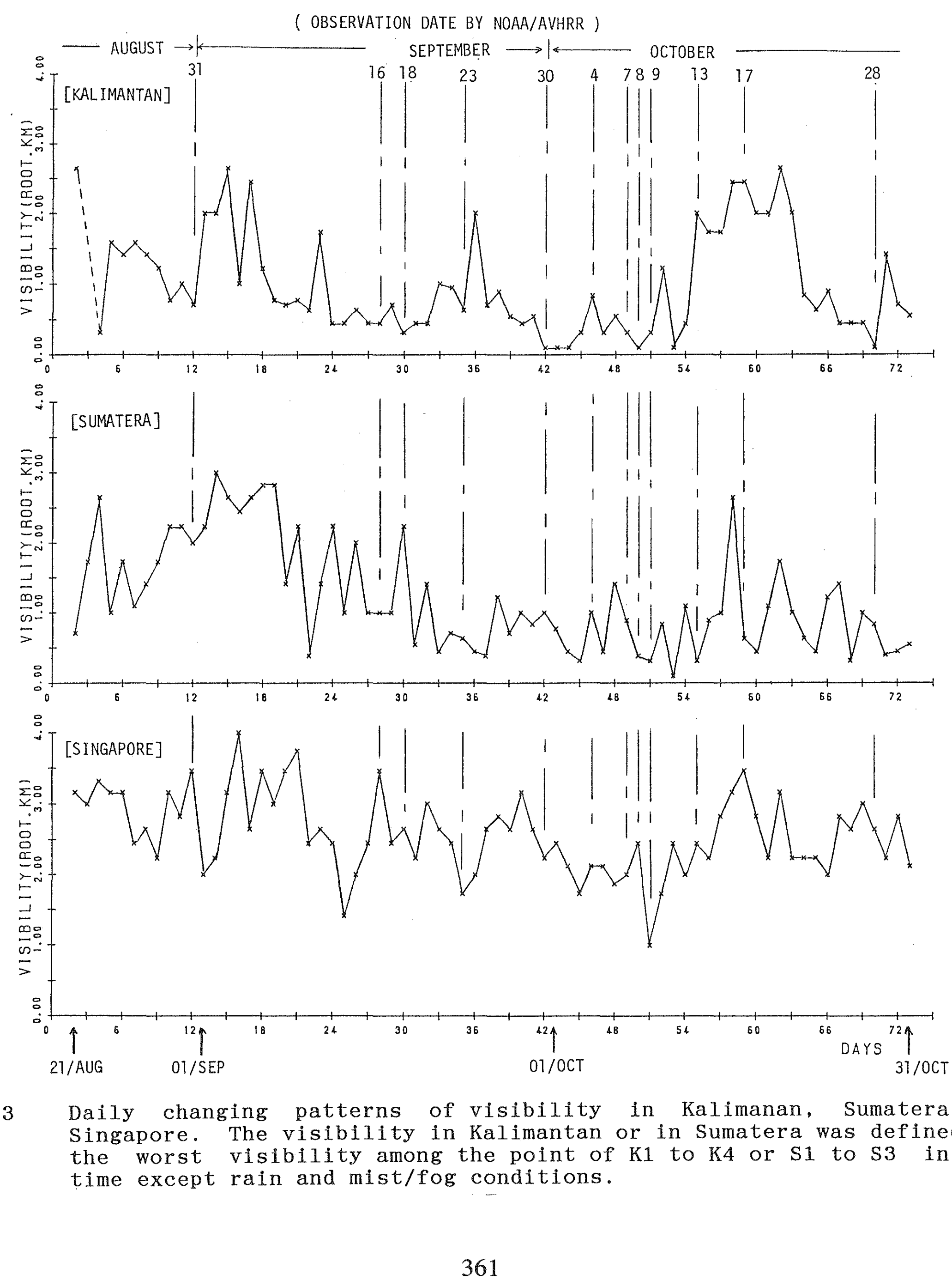


Fig.3 Daily changing patterns of visibility in Kalimanan, Sumatera and Singapore. The visibility in Kalimantan or in Sumatera was defined as the worst visibility among the point of K1 to K4 or S1 to S3 in day time except rain and mist/fog conditions.

except the conditions of rain and mist/fog among the point of K1 to K4 for Kalimantan and S1 to S3 for Sumatera was selected as the representative data in Kalimantan and Sumatera respectively. The dates of NOAA/AVHRR observation are indicated at the top of the graph.

The general changing patters of the visibility in Kalimantan and Sumatera in Fig.3 suggest that the extent and the power of the forest fire reached to maximum just around Oct.7 to 9, although the changing pattern in Sumatera is slightly delayed from that in Kalimantan. This general changing pattern is very much consistent with the results of monitoring by AVHRR images described in 4.1. In addition, the visibility in Singapore also reaches minimum around Oct.7 to 9, which indicates that the influence of the smoke by the fire to atmosphere in Peninsular Malaysia became maximum around these dates.

There are seen relatively high visibility dates around Oct.17 in Kalimantan and Sumatera in Fig.3. This result also consists with the fact that AVHRR image taken on Oct.17 suggested the fires were put out or became weak both in Kalimantan and Sumatera before Oct.17. The weather reports at the monitoring points of visibility sometimes indicated rain or thunderstorm from Oct.13 to 17 and these weather conditions seemed to help to put out the fire.

5. DISCUSSION

Although the test site belongs to the region covered by cloud frequently, NOAA/AVHRR data were proved to be very useful for monitoring of the forest fire conditions. This result seems to be partly due to very abnormal dry condition in Aug. to Oct. in 1991 which was the main reason for the great expansion and long continuation of the fire.

For monitoring of smoke, GMS data are also considered to be useful as well as NOAA/AVHRR because the combination of visible and thermal infrared bands of GMS data can discriminate smoke from cloud by the same principle described in 3.1. Actually, the analysis of GMS data received and processed by Meteorological Service of Singapore clearly indicated the flow of the fire smoke from Kalimantan and Sumatera to Peninsular Malaysia. However, for monitoring of hot spots, only AVHRR data seem to be available because the ground resolution and the wave length of GMS infrared band are not so suitable for detection of the hot spots.

According to the frequent observation and wide coverage, NOAA/AVHRR data seem to be very useful as real time data for preliminary monitoring of the forest fire, for example, for identification of the firing places and estimation of the fire power. The result of this study seems to verify the usefulness of NOAA/AVHRR for these purposes and also the importance of the receiving station of NOAA satellite for carrying out the real time monitoring of the coverage areas by NOAA/AVHRR.

Because the ground resolution of AVHRR is not so high compared with that of Landsat or Spot, the detailed investigation of the damaged conditions of the forest after the fire is difficult to be carried out by AVHRR data. This investigation should be done using Landsat/TM or MOS-1/MESSR.

6. CONCLUSION

The foregoing analyses verified the usefulness of NOAA/AVHRR data for monitoring a wide range forest fire occurred in tropical forest areas. The use of NOAA/AVHRR truly becomes helpful if the analyses of NOAA/AVHRR data are carried out on real time. Therefore, the existence of the receiving station of NOAA satellite seems to be quite important in order to achieve the monitoring of the environment of tropical regions by remote sensing. Also, the analyses of this study actually became possible due to the operational reception of NOAA/AVHRR data by the receiving station of Meteorological Service of Singapore.

ACKNOWLEDGMENT

The authors greatly thank to the staffs of Meteorological Service of Singapore for the cooperation of NOAA data reception and processing. The authors also thank to Mr. Watanabe of Japan Forest Technical Association for the cooperation to this study.