

# Forest fire analysis for several years in Russia by using NOAA satellite

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## Abstract

The main purpose of this work was to construct an efficient algorithm for forest fire detection method using NOAA satellite images. The forest fire analysis using this NOAA satellite has been done by various researchers. However, most of the method can detect the fire but a lot of false fire also appeared in the results and missing of actual fire also happened in some cases. Here we analyzed four satellite based fire detection methods to compare the fundamental differences, problems and effectiveness. To do so we used the data from AVHRR of NOAA-16 of a period of three to six months for Sakhalin and Japan region. Considering their problems and drawbacks an improved fire detection method with statistical analysis has been constructed here. Our method has reduced the false fire detection very significantly as well as detected the actual fire with high accuracy. This method can be applied to a real time forest fire monitoring system for Russia and Southeast Asian region, which is very important for early warning and early detection of fire for reducing the damages of forest fire. And also this study applied Siberian forest fire analysis for several years.

## 1. Introduction

A large-scale forest fire happens frequently in all parts of the world. Forest fire has serious economic implications: destruction of habitats, forests damage, costs of fire fighting and so on. Nowadays it is very important and sensitive issue in Russia and Southeast Asian region since a large scale fire occurs frequently. A huge amount of exhaustion of carbon dioxide by the forest fires is thought to be a cause of global warming. The earth environment is changing because of this global warm and air pollution [1]. At present specialist examines the damage situation after an occurrence of large-scale forest fire and it is thought that wide-ranging monitor by the satellite remote sensing may have lots of advantages in fire fighting.

A wide range real time monitoring by remote sensing satellite is essential for the grasp of the fire occurrence situation. The AVHRR (Advanced Very High Resolution Radiometer) observed on the NOAA satellite series is one of the most widely used satellite sensor for fire detection. Figure 1 shows an outline of NOAA weather satellite observation system operated by National Oceanic and Atmospheric Administration. The AVHRR provides daily data (two scenes for each operational platform) approximately at 1.1km spatial resolution, in five channels (Ch1= 0.58–0.68 $\mu$ m, Ch2=0.723–1.10 $\mu$ m, Ch3=3.55–3.93 $\mu$ m, Ch4=10.5–11.3 $\mu$ m, Ch5= 11.5–12.5 $\mu$ m). Moreover, the long-term availability of AVHRR data provides a good information source for obtaining an indicator of seasonal fire activity on a global scale [2]. In this work we used the NOAA-16 AVHRR data that received in Sendai (Japan) and Novosibirsk (Russia), and transferred to Tohoku University.

Here the problems of the early methods are enumerated so far and an improved fire detection algorithm is developed by using NOAA AVHRR images. Then the proposed method is applied to detect actual fire and compared with the results of fire detection by other methods. This work was performed in two regions, Sakhalin and Japan.

First, NOAA-16 AVHRR data is processed geometric correction and radiometric correction by a program which is provided by NEC [3]. This program processes geometric correction by using TBUS data. But this program cannot process high accuracy geometric correction. Therefore, further geometry correction with higher accuracy is performed by using the method proposed by M. Nakano [4] In this method GCP is created automatically and perspective transformation is used as the geometric correction algorithm.

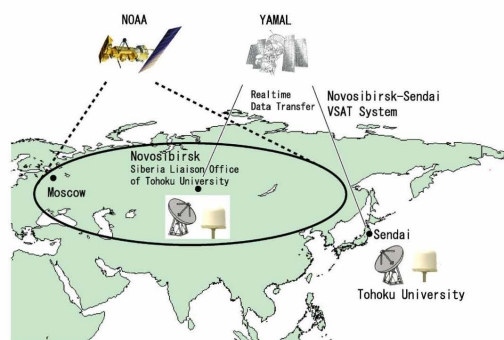


Figure 1 NOAA Satellite Observation System.

## 2. Fire Detection methods with AVHRR Data

AVHRR data has been widely used for fire detection for more than a decade [5] and the accuracy of detection criteria for both large and small fires has rarely been assessed using actual fire data [6] [7] [8]. In general the thermal value of Ch3 is used in most fire detection methods. It is known that the brightness temperature of Ch3 rises due to the fire point [9] [10]. Moreover, the rise like in Ch3 is not seen in Ch4 though the rise of the brightness temperature also happens to Ch4. Most of the classical AVHRR fire detection procedures are based on fixed threshold values deduced by empirical analyses [9] [10] [11] [12] [7]. Limits in the adoptability of threshold methods have been suggested by several authors (see for example Pozo et al. [13], Boles and Verbyla [6], Cuomo et al. [8]).

A contextual approach was devised to take into account the different observational and environmental conditions mainly based on spatial statistics computed from pixels within variable sized windows around candidate fire pixels. The spatial statistics are applied to pixels previously selected as potential fires from multi-spectral threshold tests [14] [15] [6].

Four fire detection methods (proposed by Flasse et. al., [4] Nakayama et al. [15], Boles and Verbyla [6], J. Kudoh[17]) have been studied using NOAA AVHRR images for Sakhalin and Japan region. Sakhalin region is chosen as large scale forest fire frequently happens. Japan region is compared to verify the false detection of fire where the cause of false detection can be made for the rising brightness value of Ch3 by the other factor rather than forest fire. It is thought that the tendency of rising brightness temperature of Ch3 as well as the possibility of false detection was high in this region.

### 2.1 Method of Flasse

Flasse et. al.[14] proposed a contextual algorithm which principles approach were first reviewed by Justice and Dowty [18]. The choice of thresholds used in these contextual approaches was first driven by Kaufman et. al. [9]. Further references were looked for Kennedy et. al. [10]. Flasse algorithm consists of two stages: first the selection of candidate pixels which could be potential fires (PFs) and second the confirmation of PF by comparing with their immediate neighbors as a fire point [14]. A pixel is selected as a PF by considering the following conditions:

$$T_3 \geq 316K \quad (1)$$

$$T_3 - T_4 \geq 10K \quad (2)$$

$$T_4 \geq 250K \quad (3)$$

where  $T_3$  and  $T_4$  (in deg K) are AVHRR brightness temperatures of Ch3 and Ch4 respectively. A PF is classified and retained as a fire when it appears to be different enough from its background. For each PF statistical information is calculated for a variable size context window (from 3 x 3 to 15 x 15 pixels) around the PF and at least 25% of neighboring pixels are considered as fire background. PF is confirmed as fire when

$$T_3 > \mu_{3bg} + 2\sigma_{3bg} + 3K \quad (4)$$

$$T_3 - T_4 \geq \mu_{3-4bg} + 2\sigma_{3-4bg} \quad (5)$$

Here,  $\mu$  is the average value and  $\sigma$  is the standard deviation of the background.

### 2.2 Method of Boles

Usually a forest fire happens in the region, where NDVI (Normalized Deference Vegetation Index) is high e.g. forest. Therefore, Boles first specify the forest by observing NDVI and added Fuel Mask algorithm to the fire condition to reduce the false detection of the places like deserts or sea. Since the NDVI before a fire point indicates a high value, NDVI for past one month is measured and the highest NDVI is assumed as MVC which is used as threshold to the fire condition.

Boles detect a fire by using the expressions mentioned below.

Fuel Mask Algorithm:

$$MVC > 0.3 \quad (6)$$

Detection of PF

$$T_3 \geq 308K \quad (7)$$

$$T_4 > 284K \quad (8)$$

$$T_3 - T_4 > 10K \quad (9)$$

Fire detection

$$T_3 > \mu_{3bg} + 1.5\sigma_{3bg} \quad (10)$$

$$T_3 - T_4 > \mu_{3-4bg} + 1.5\sigma_{3-4bg} \quad (11)$$

$$R_2 > \mu_{2bg} + \sigma_{2bg} \quad (12)$$

where  $R_2$  is reflectivity of Ch2.

Here the false detection may reduced because the place with the possibility of fire occurrence is specified from the situation of past vegetation and a more certain fire may be detected.

### 2.3 Method of Nakayama

Nakayama et. al. improved the part where the standard deviation is used in Contextual algorithm by using the mean deviation. Moreover, it tests the part that will be used as a background. The fire detection is done as follows:

Detection of PF

$$T_3 > 320K \quad (13)$$

$$T_3 - T_4 > 6K \quad (14)$$

$$R_2 < 25\% \quad (15)$$

Background test

$$T_3 < 318K \quad (16)$$

$$T_3 - T_4 < 12K \quad (17)$$

Fire detection

$$T_3 - T_4 > \mu_{3-4bg} + \max(\delta_{3-4bg}, 4K) \quad (18)$$

$$T_4 > \mu_{4bg} + \delta_{4bg} - 3K \quad (19)$$

Here  $\delta$  is the mean deviation of background.

## 2.4 Method of Kudoh

Kudoh et. al. proposed the fire detection method that uses the feature of the fire point obtained from Three Dimensional Histogram of Ch1, Ch3 and Ch5 which is made from past fire information. First of al, 14 years forest fires information from NOAA AVHRR images were accumulated in a Three Dimensional Histogram. Accumulated area was in Far East Russia about 1100 km square region with 681 scenes, 55983 points. Actually the fire is detected from these past AVHRR images by using the method of Flasse. Next, it looks for actual fire point as a result of confirmation by watching the deterioration of NDVI, the presence of smoke and the changes of the temperature in time series. Obtained fire point is collected as fire information and plotted in Three Dimensional Histogram (Kudoh et. al., 2003). To detect a fire the threshold is assumed as the saturation value of 1023 for Ch3 (  $Ch3 \geq 1023$  ). So, Two Dimensional Histogram composed on Ch1 and Ch5 is obtained, which makes some looped area of the accumulated fire corresponding to occurrence number as shown in figure 2. These circles provide reliable fire detection category. Those pixels enter into this category are considered as actual fire. In this category the accuracy of the fire detection goes up by using the number of frequency four or more.

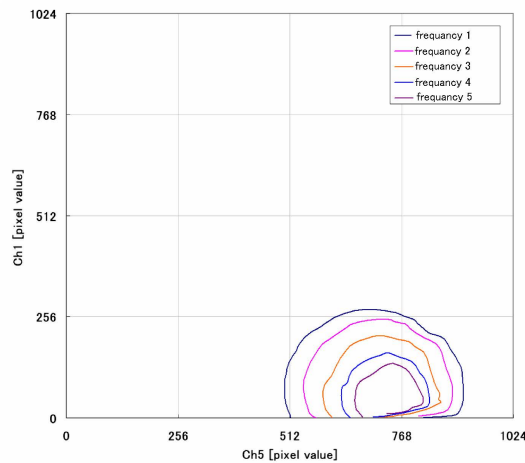


Figure 2 The fire category in Two Dimensional Histogram.

## 3. Comparisons and Problems Finding

To compare the results of fire detection, above four methods were applied in two regions, Sakhalin and Japan. In Sakhalin, the applied period was from June to August, 2003 as a large number of forest fire happened frequently. It is from May to September, 2004 in Japan when a marvelous heat was intense and high temperature was recorded in various places. It is thought that the tendency of rising brightness temperature of Ch3 as well as the possibility of false detection was high in this region especially during those periods. Therefore, the false fire detection by each method will be verified.

### 3.1 Comparison in Sakhalin region

An image of NOAA 16 on June 17, 2003 where a fire broke out in the Sakhalin region has been applied for each method. The obtained result of each method for Sakhalin region is shown in figure 3. Detected fire points indicated by red dots in each image of the figures. It is clear that all method adequately detected the actual fire where a fire breaks out in the center of the image and smoke is generated.

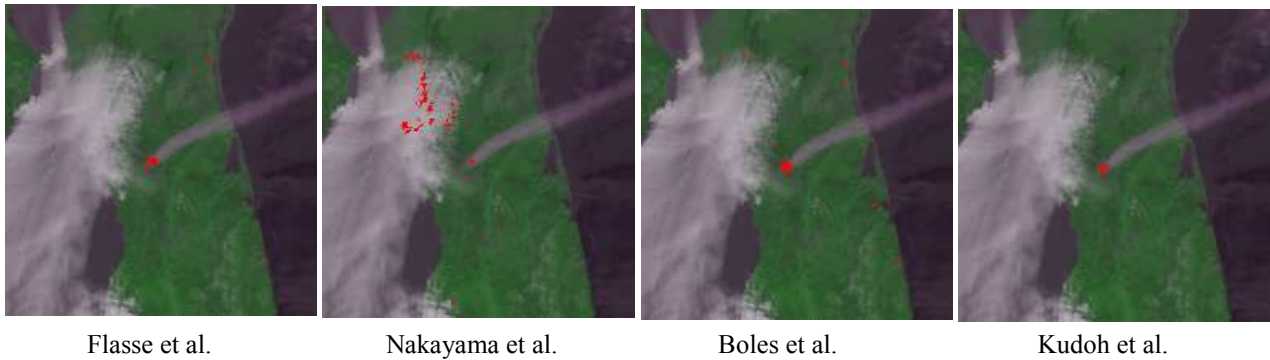


Figure 3 Comparison among the results of early methods in Sakhalin region (NOAA-16 on June 17, 2003).

Moreover, the false detection also happened more or less for each method. False detection is appeared in the sea, here and there for the method of Flasse. Since the fire occurrence place is specified by using MVC in the Boles method, the false detection in the sea is not appeared. However, the false detection in the cloud region stands out probably for the setting of low threshold. The false detection tendency for Nakayama method also looks like Flasse method. In Kudoh method, comparing with others, the false detection is found very few though the actual fire has been detected adequately. It is very clear to understand that in case of Flasse et. al. and Kudoh et. al. the false fire detection is comparatively a little. Next these two methods have been applied for Japan region.

### 3.2 Comparison in Japan region

The results of fire detection for an image of NOAA-16 on 7 July 2004 is shown in figure 4 and figure 5 for Flasse and Kudoh method respectively. Either methods detected huge red fire points which were actually false fire points. As in reality there were happened no forest fire on that time. In case of Flasse method in figure 4, false detection happened in the coastline and the cloud area. In figure 5, Kudoh method showed the false detection mainly in the central area of Tokyo and other area where the value of brightness temperature of Ch3 were very high.

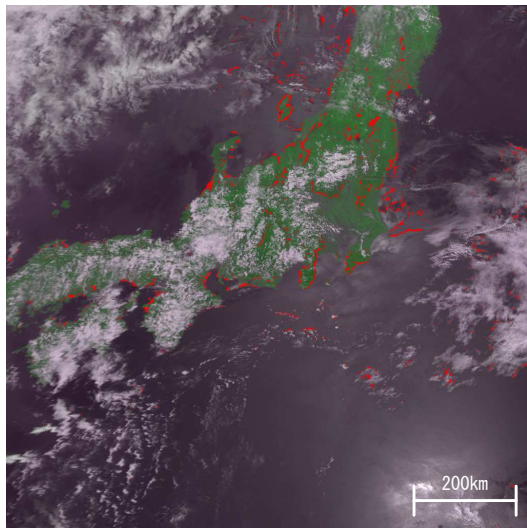


Figure 4 Result of Flasse method in Japan region.

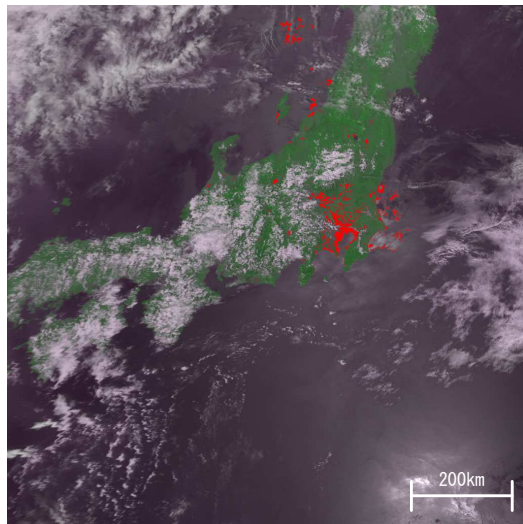


Figure 5 Result of Kudoh method in Japan region.

In the graph of figure 6 shows the comparison of detected fire points for each method applied in Japan region for the image of NOAA-16 on July 7, 2004. In vertical positioned values are the fire points that actually are the false fire points, because the fire that observed with NOAA in the graph has hardly happened in Japan.

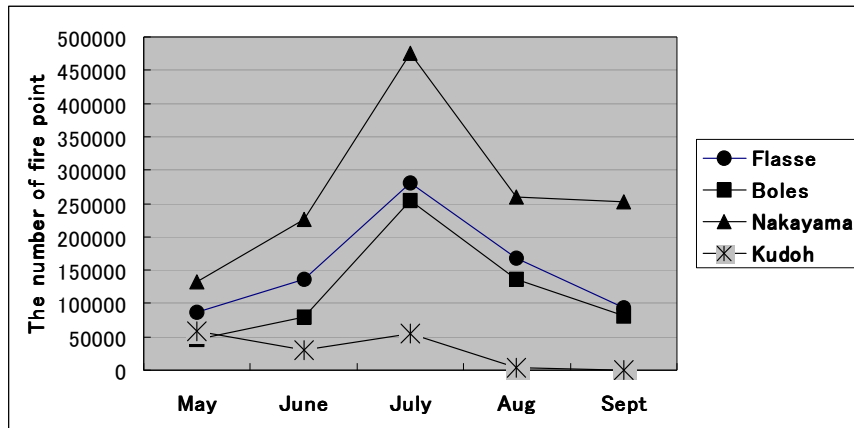


Figure 6 Comparison of detected fire points in Japan region, 2004.

Since fire has been detected based on the brightness temperature of Ch3 in cases of Flasse, Boles and Nakayama, the maximum number of false fire has been detected on the period of July when a high temperature was recorded in Tokyo and other places of Japan. The least false fire has been detected by Kudoh et. al. among the other methods since this method has detected a fire by the threshold processing for Ch3.

To find the reasons of this false detection gray scale images for Ch3 on July 7, 2004 of NOAA-16 in Japan region has been plotted and analyzed as shown in figure 7 and figure 8. Since the method of Flasse have detected a fire by the comparison with the surrounding background, a lot of false detection went out at the part where the brightness temperature of Ch3 is turned such as the coastline and the cloud region as in figure 7. In case of Kudoh et. al. method a fire has been detected by the threshold processing of Ch3. Therefore, a lot false detection is appeared in the part where the value of brightness temperature of Ch3 is very high (figure 8).

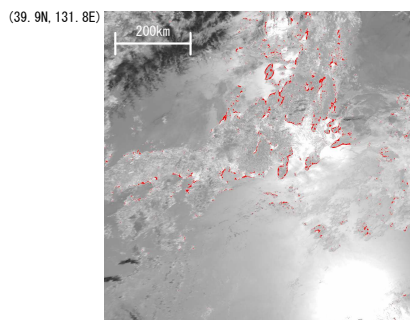


Figure 7 Case of Ch 3 method of Flasse.

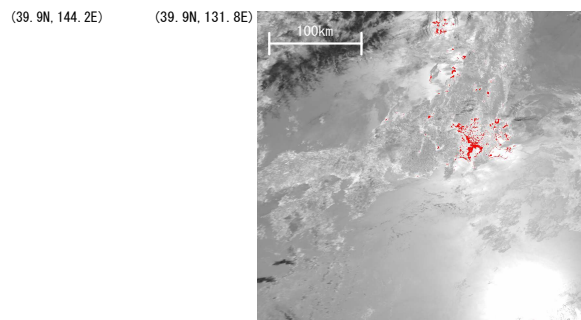


Figure 8 Case of Ch 3 method of Kudoh.

From the above comparisons it is very clear that the accuracy of fire detection is highly dependent on the rising brightness value of Ch3. The brightness value of Ch3 fluctuates largely with the change of temperature with latitude and season. It can goes up by the reasons other than the fire such as 1) the rise of temperature by season in urban area or in desert, 2) the highly developed sun rise which makes reflection of the sun light on the sea. It can be confirmed here in figure 8 that a very high value was produced by the reflection of the sun light on the sea and false fires were detected on those spots.

Moreover, the rise of the brightness temperature of Ch3 is radiated by the rise of the temperature in summer in Tokyo and its surrounding area which is thought to be a cause of the false detection in Japan region in July 2004 by Kudoh method, figure 8. We presumed that the accuracy of fire detection may goes up if these problems can be considered in fire condition.

#### 4. Proposed Method

From all the above comparisons and discussion it is clear that in case of Kudoh method, the difficulties of fire

detection were comparatively low among the other methods. The main difficulties in fire detection were false detection. That means the fire has been detected in places where fires did not appear in real. First of all, it is thought that the false fire detection can be decreased by specifying the region where the possibility of fire occurrence is present (such as forest), using NDVI (used in Boles et. al. method). So, the possibility of the false detection in the sea might be removed. Moreover, the rise of brightness temperature of Ch3 goes up gradually due to seasonal factor (such as in summer) whereas the rise goes up sharply for a forest fire. So it is thought that the fire can be detected more accurately if we consider these natures in fire condition.

#### 4.1 Algorithm

Here we proposed a new fire detection method by improving the Kudoh et. al. technique and by reducing the false fire detection using statistical analysis. Figure 9 shows the flowchart of proposed algorithm. First of all, the image where it wants to detect a fire is called a target image. From the target image, NDVI is observed for past one month and MVC is calculated from the highest value of these NDVI.

It is thought that the false detection of the places such as sea, to which it comparatively rises the temperature of Ch3, can be decreased by considering this MVC to the fire condition. Actually in this step the places with the possibility of fire occurrence (such as forest) are specified from the situation of past one month vegetation.

Then we applied Kudoh method to detect the fire points from those specified places. It was assumed that some false detection might be appeared due to the rise of brightness temperature of Ch3 by the seasonal factor rather than a fire. To remove this false detection a statistical analysis is done over those fire points.

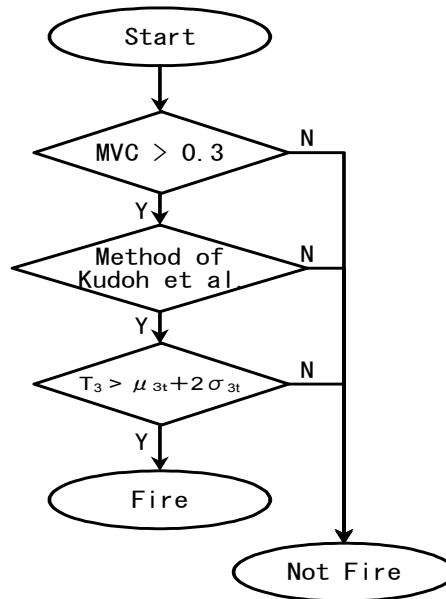


Figure 9 Flowchart of Proposed method.

In statistical analysis a threshold value has been fixed to remove this false detection and added in the fire condition. First of all, from the target image the value of mean and standard deviation of each pixel for past 20 days from the target day has been calculated for Ch3. At this time the part of cloud region in the target image has not been used. Since the brightness temperature of Ch3 for cloud region is lower than the actual ground level, the average value might be lower in calculation. For this purpose it has been avoided the influence of cloud region. Finally a threshold value is obtained from these mean and standard deviation values of Ch3 by considering the equation (20).

$$T_3(x, y) \geq \mu_t(x, y) + 2\sigma_t(x, y) \quad (20)$$

Here,  $T_3(x, y)$  is the value of Ch3 of target image on  $(x, y)$  coordinates,  $\mu_t(x, y)$  is the mean value of Ch3 for past 20 days from target day and  $\sigma_t(x, y)$  is the standard deviation on  $(x, y)$  coordinates. When the value of Ch3 of a pixel was higher than this threshold, it was considered as a fire point.

#### 4.2 Results and evaluation

Our new method is applied in Sakhalin and Japan region by using the same images of NOAA-16 for same period which were used previously in the comparisons on early methods. Then the evaluation has been done by comparing the results of our method with the results of Kudoh method. This verification has been done for both Sakhalin and Japan region as mentioned below.

#### 4.3 Sakhalin region

Figure 10 shows the image of NOAA-16 for the fire detection results of our method in Sakhalin region on June 17, 2003. It is seen in the image of Sakhalin that fire points have detected adequately at the center with smoke as fires mentioned by the red points. Moreover, it is understood that very few false detection appeared in the image of Sakhalin region. No false detection appeared in the sea or cloud region as it was appeared for Flasse or Boles method. The main



difficulties of fire detection have been overcome in this method.

Figure 11 shows the graph of comparison between Kudoh et. al. and our proposed method for fire detection points in Sakhalin on 2003. From this graph it is clear that our method detected the fire for Sakhalin region almost in the same degree as it is detected by Kudoh method. It is confirmed that proposed method can detect the actual fire in the same degree of accuracy as it can by the Kudoh method.



Figure 10 Result of proposed method in Sakhalin on June 17, 2003.

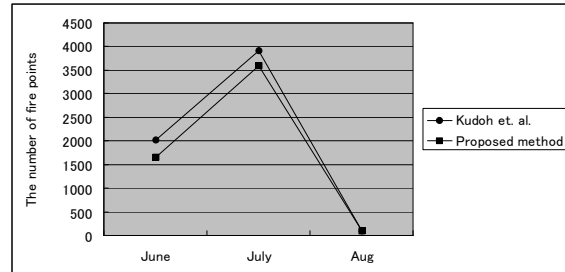


Figure 11 Comparison of the fire points in Sakhalin region, 2003.

#### 4.4 Japan region

The results of fire detection by proposed method for an image of NOAA-16 on 7 July 2004 in Japan region is shown in figure 12. It shows that very few false fire points have been detected here in Japan region by our method. It is clear that the number of false fire points decreased greatly if we compare this result with the result of Kudoh as shown in figure 5.

A high temperature continued by the intense heat in Japan region from May to September 2004. Therefore, a lot of false fire detection was found in Kudoh technique. Figure 13 shows the graphical comparison of fire points found in our method and Kudoh method for Japan region in 2004. The fire points as shown in graph were actually false fire points. Very little false detection appeared in our method. It is clear that in our method the number of false fire points has decreased greatly in the comparison to Kudoh method. Our method is improved by decreasing the number of false fire detection and makes fire detection much more efficiently than early methods. However a few number of false fires appeared as it was not possible to remove all false fire to maintain the high accuracy of actual fire detection.

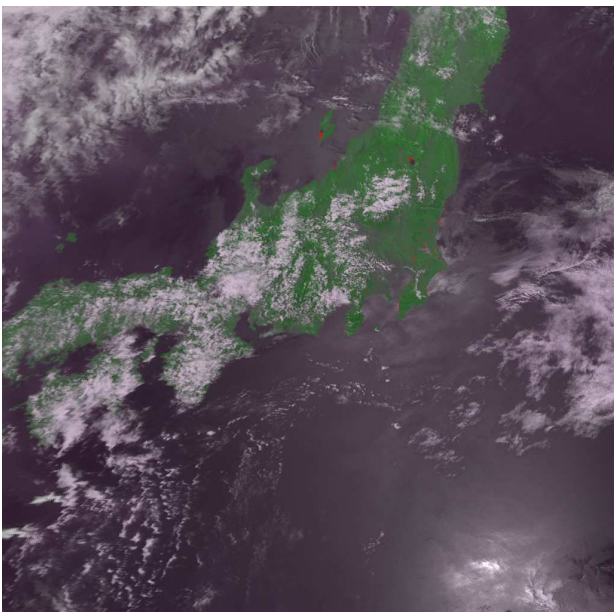


Figure 12 Result of proposed method in Japan on July 7, 2004.

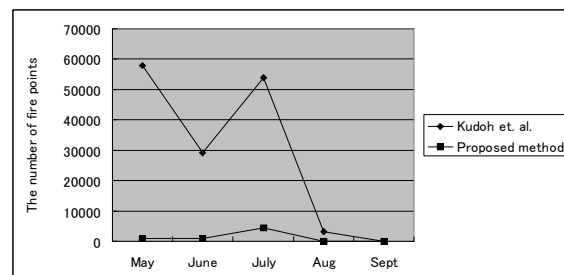


Figure 13 Comparison of false detection points in Japanese region, 2004.

## 5. Applied for Siberian Region

This study applied Siberian forest fire analysis from 2002 to 2004 for every April to September. The analysis area is divided 15 regions including Siberia, Mongolia and north China shown in figure 14. Each region is 1024x1024 size for AVHRR image.

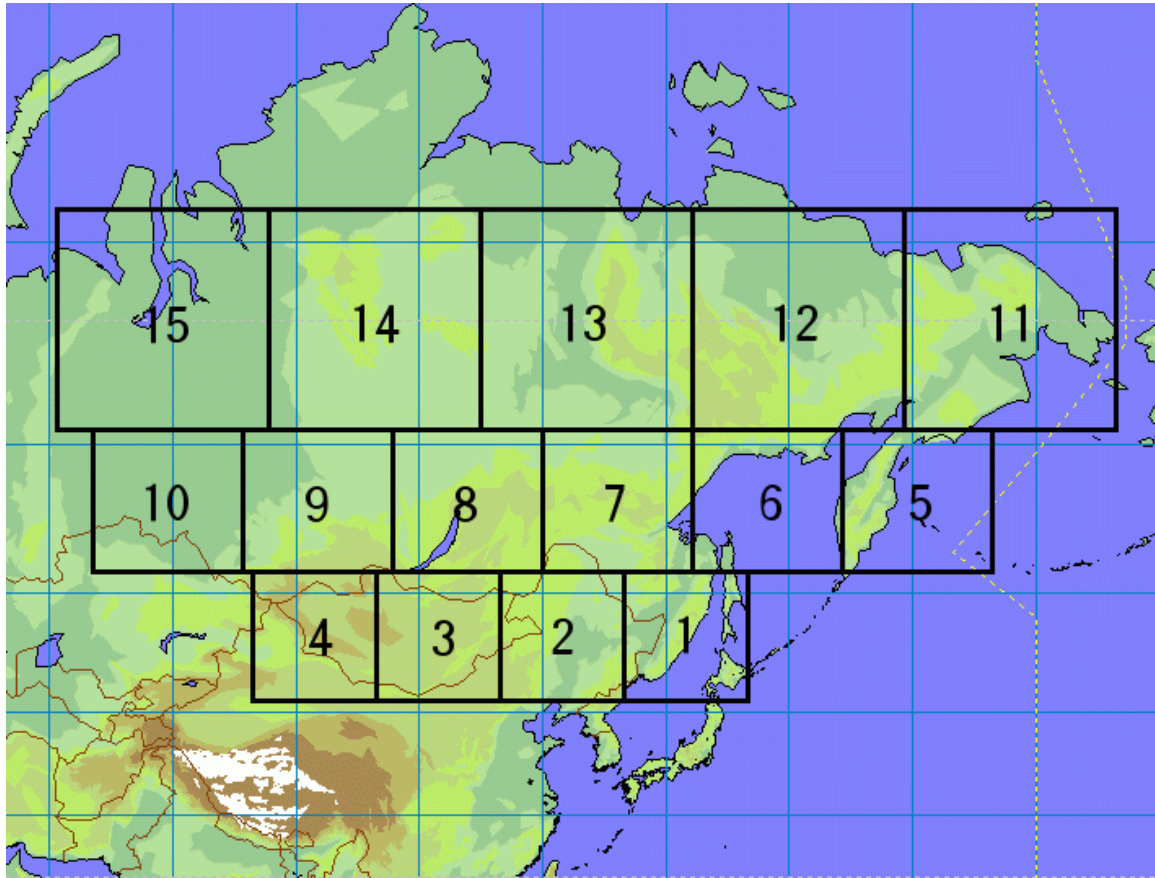


Figure 14 Divided regions map for Siberia forest fire analysis.

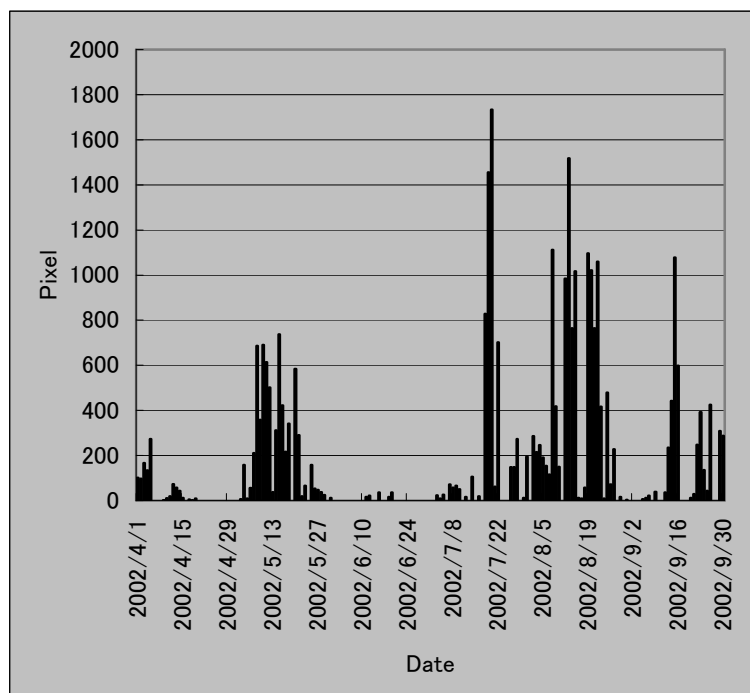


Figure 15 Detected hot spot pixel in Siberia 2002.



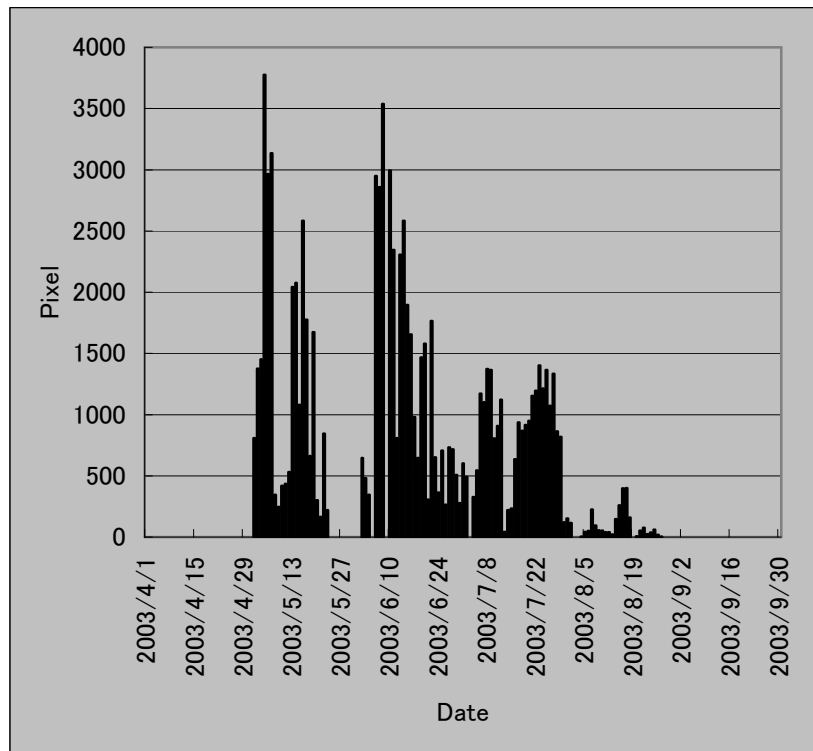


Figure 16 Detected hot spot pixel in Siberia 2003.

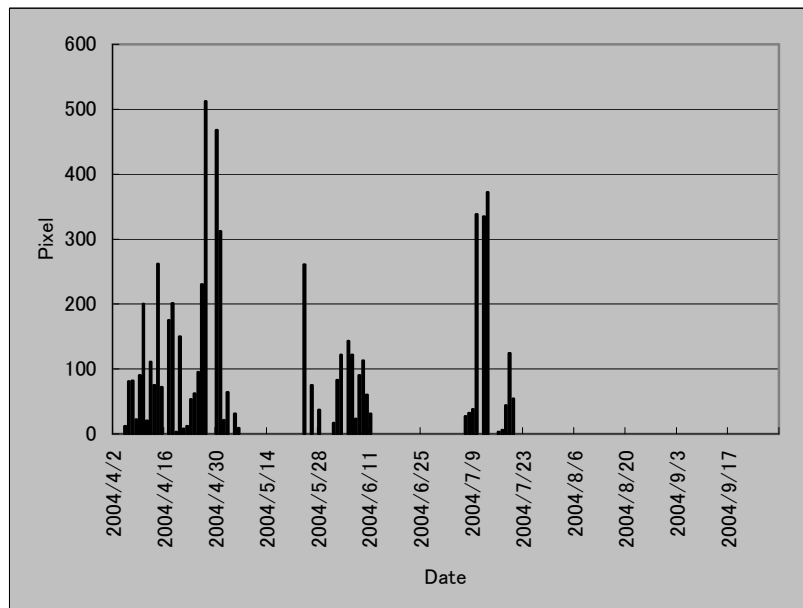


Figure 17 Detected hot spot pixel in Siberia 2004.

The detected hot spot pixel is shown in figure15 – figure 17. This study is continued to more yearly analysis to find the fire pattern, feature, and affecting Japan.

## 6. Conclusions

In this work a new fire detection method using NOAA AVHRR images have been constructed. Our method detected the actual fire with the degree of high accuracy by overcoming the difficulties of actual fire detection. Moreover it reduced the number of false fire detection very significantly. In this work to maintain the high accuracy of actual fire detection it could not be possible to remove 100% false detection. Our method can be used to provide a real time fire monitoring system and can be calculated the burned area more accurately. A future subject is to find out the cause of

these few false fire points that appeared in our results.

## 7. References

- [1]FRA 2000 (Global Forest Resources Assessment 2000 - Main report), FAO forestry paper 140.
- [2]EVA, H., and LAMBIN, E. F., Remote Sensing of biomass burning in tropical regions: sampling issue and multisensor approach. *Remote Sensing of Environment*, 64, 292–315(1998).
- [3]NEC CORPORATION, NOAA receiving and processing manual (in Japanese)(1996).
- [4]M. NAKANO, Y.HARAMOTO, J.KUDOH, An automatic GCP creation method for geometric correction for Multi-time NOAA/AVHRR images, *Journal of the remote sensing society of Japan*, Vol.25, No.2, pp. 191-197(2005).
- [5]LEVINE, J. S. (editor), *Global Biomass Burning*, Cambridge, MA: MIT Press (1991).
- [6]BOLES S. H., and DAVID L. VERBYLA, Comparison of Three AVHRR-Based Fire Detection Algorithms for Interior Alaska, *Remote Sensing of Environment*, 72, 1-16(2000).
- [7]LI, Z., NADON, S., and CIHLAR, J., Satellite-based detection of Canadian boreal forest fire: development and application of the algorithm. *International Journal of Remote Sensing*, 21, 3057–3069 (2000).
- [8]CUOMO, V., LASAPONARA, R., and TRAMUTOLI, V., Evaluation of a new satellite based method for forest fire detection. *International Journal of Remote Sensing*, 22, 1799–1826 (2001).
- [9]KAUFMAN, Y., TUCKER, C. J. and FUNG, I., Remote sensing of biomass burning in the tropics. *Journal of Geophysical Research*, 95, 9927-9939 (1990).
- [10]KENNEDY, P. J. BELWARD, A. S., AND GREGOIRE, J. M., An improved approach to fire monitoring in West Africa using AVHRR data. *International Journal of Remote Sensing*, 15, 2235-2255 (1994).
- [11]RAUSTE, Y., HERLAND, E., FRELANDER, H., SOINI, K., KUOREMAKI, T., and RUOKARI, A., Satellite-based forest fire detection for fire control in boreal forests. *International Journal of Remote Sensing*, 18, 2641–2656 (1997).
- [12]ARINO, O., and MELINOTTE, J. M., The 1993Africa fire map. *International Journal of Remote Sensing*, 19, 2019–2023 (1998).
- [13]POZO, D., OLMO, F. J., and ALADOS-ARBOLEDAS, L., Fire detection and growth monitoring using a multitemporal technique on AVHRR mid-infrared and thermal channels. *Remote Sensing of Environment*, 60, 111–120 (1997).
- [14]FLASSE S.P., CECCATO P., A contextual algorithm for AVHRR.re detection, *Int.J.Remote Sensing*, Vol.17, No.2, 419-424 (1996).
- [15]NAKAYAMA, M.MAKI, C.D.ELIVIDGE, S.C.LIEW, Contextual Algorithm adapted for NOAA-AVHRR.re detection in Indonesia, *Int. J. Remote Sensing*, Vol.20, No.17, 3415-3421 (1999).
- [16]BARBOSA, P. M., GREGORIRE, J., and PEREIRA, J. M. C., An Algorithm for Extracting Burned Areas from Time Series of AVHRR GAC Data Applied at a Continental Scale. *Remote Sensing of Environment*, 69, 253-263 (1999).
- [17]J. KUDOH, and K. HOSOI, Two Dimensional Forest Fire Detection Method by Using NOAA AVHRR Images *IEEE 2003 International Geoscience and Remote Sensing Symposium 2003*, 2494-2495 (2003).
- [18]JUSTICE, C. O., and DOWTY, P. (editor), *IGBP-DIS satellite fire detection algorithm workshop technical report*. IGBP-DIS working paper, 9, 88pp., February 1993, NASA/GSFC, Greenbelt, Maryland, USA