TOPOGRAPHICAL CLASSIFICATION IN THE PREDICTION OF DISASTER ZONES IN FOREST FIRES USING DTM

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KEY WORDS : Forest fire, Topography, Disaster, Wind, GIS

ABSTRACT

There are many forest fires every year in Japan. To prevent forest fires is very important in terms of defense of personal property, preservation of forest and earth environment, etc. There are two methods for the prevention of forest fires. One is to stop an outbreak of fire, and the other is the prevention of fire spread. This paper focuses on the prevention of fire spread. The fire spread of forest fires is strongly influenced by topography and wind. It is the purpose of this paper to develop the topographical classification method in the prediction of disaster zones in forest fires using DTM. In the case study, this paper treated the forest fire in Manba-city and Takehara-city, Japan.

1.INTRODUCTION

The latest development of GIS (Geographic Information System) has led to its diverse use in the prevention of disasters. For such use, however, it is necessary and effective to comprehend what the disastrous phenomena imply. Forest fires happened at Manba-Machi, Gunma Prefecture, Japan in April 1993 on the one hand, and Takehara City, Hirosima Prefecture in August 1994 on the other. Fanned by strong winds, leaping flames spread and expanded in both areas, the damages amounting to the highest ever magnitude in the respective prefectures. In Takehara City, the loss caused by the fire ran into approximately 500 million yen (about 4.2 million dollars), one of the severest forest fires in Japan. In the wood fire at Manba-Machi, the author chartered a helicopter to take aerial photographs of stricken areas and perform an on-the-spot survey and data collection. Also carried out was a minute site survey of the forest fire at Takehara City. The results of these surveys and investigations suggested to us that there was a great topographic influence on the wind direction and velocity in the spread and expansion of fire. This paper describes what topographies have impacts and how they exert certain influences on the spread and expansion of forest fire, and submits a report on the method of topographic classification we developed based on the results of our discussion. The analyses begin with a preparation of detailed map of disaster areas based on the aerial photographs and site surveys. Six topographic factors are then extracted from the numerical topographic maps such as altitude, slant and relief in the regions forming the subject of study including the disaster areas. The quantification theory type III, one of the statistical techniques, is employed to analyze the topographic structure of the regions and prepare a wind force/topographic classification map. Last, the spreading direction, velocity and distance are calculated on the basis of the wind direction and velocity as collected to evaluate the potential risk of the respective regions in the wind force/topography classification map. Application of the techniques described in this paper to the forest fires in Takehara City and Manba-Machi gave good results. The topographical features have great impact on the spread of forest fire. This paper could confirm that the most important information is the topographic geometries representing how steep or moderate the topographies are and in which directions the topographies are slanted. This topographic information, together with the wind direction and velocity turned out to allow us to predict disaster zones of forest fire.

2.OUTLINE OF THE FOREST FIRE

(1)Outline of Manba-city and Takehara-city [1)2)3)]

Manba-city has forestry as the chief industry. There are a lot of manage sugis and hinokis. Topography in the fire damaged area is a steep mountainous region with a height about 1,000min Manba-city.Takehara-city is touched by the bay on the inside and three ways are enclosed by the mountains of height from 200 to 300m.

(2)Outline of the forest fire

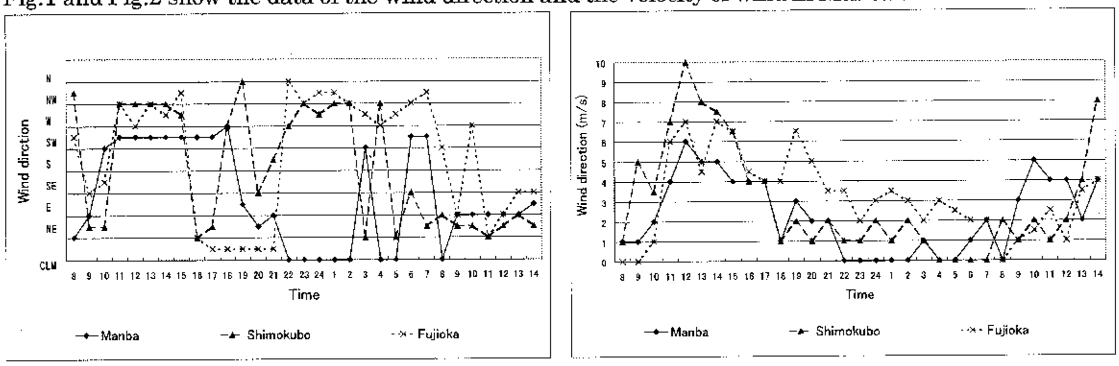
Table 1 shows the outline of the forest fire.

Table 1 Outline of the forest fire

	Manba	Takehara
Topography in the fire damaged area	Steep mountainous region with a height about 1,000m	Three ways are enclosed by the mountain of height from 200 to 300m,and is touched the bay on the inside
Time of fire outbreak	11:35,April 27,1993	15:33,August 11,1994
Time of extinguishing of fire	13:40,April 28,1993	14:00,August 20,1994
Forest type	Sugi(20~45 years of growth) Hybrid(30~45 years of growth) Natural forest 30% Manage forest 70%	Coniferous forest 17% Hybrid forest 83% Natural forest 82% Manage forest 12%
Burnt area	About 100 ha	About 378 ha
Damage amount	About two million dollars	About 4.2 million dollars
Outline of the fire fighting actions	Fire fighting actions were done by the fire brigade on the ground and in the air	Fire fighting actions were done by the fire brigade on the ground and in the air

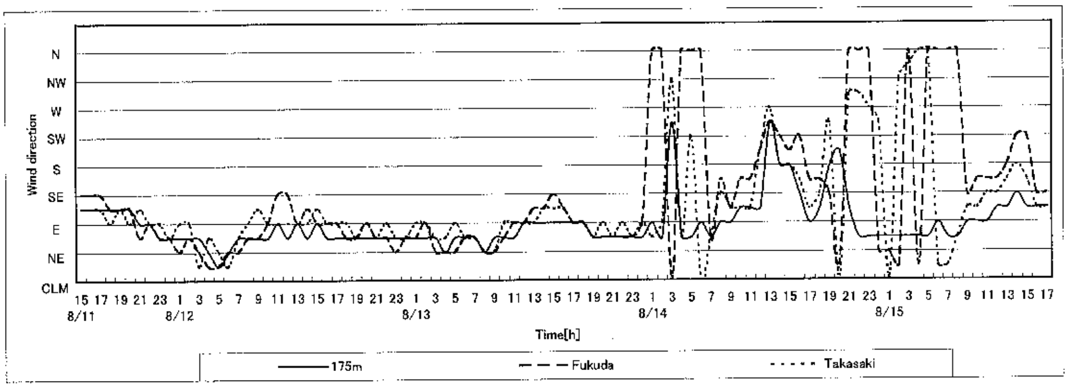
(3)Weather observation information at fire time

Fig.1 and Fig.2 show the data of the wind direction and the velocity of wind in Manba and Takehara.

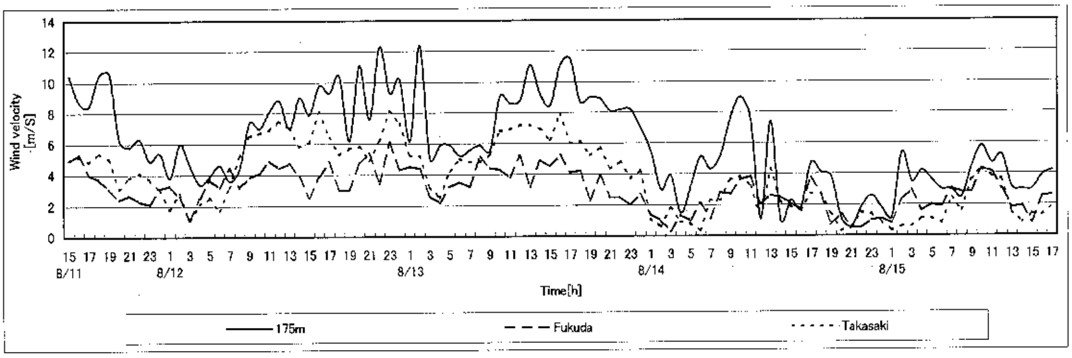


(a)Wind direction (b)Wind velocity

Fig.1 Time change in wind direction and wind velocity of the forest fire of Manba



(a) Wind direction



(b) Wind velocity

Fig.2 Time change in wind direction and wind velocity of the forest fire of Takehara

(4)Figure of the burnt area

Fig.3 shows the burnt area that was made by the home forestry administrative office in Manba. Fig.4 shows the burnt area that was made by Takehara firehouse.

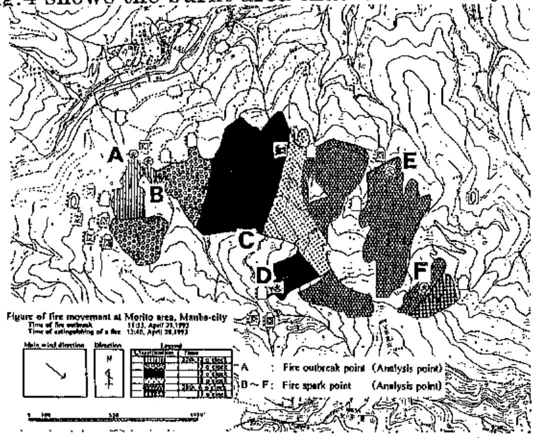


Fig.3 Figure of fire movement (Manba)

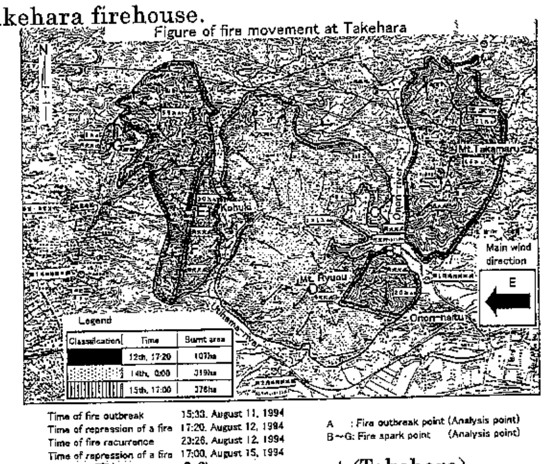


Fig.4 Figure of fire movement (Takehara)

(5)Circumstances of the spread of the fire

①Manba

From my own on-site inspection and movement figure of the fire that was made by the Fujioka firehouse, the circumstances of the spread of the fire are shown as follows. Fig.3 and Table.2 show the circumstances of the spread of the fire. The fire that broke out at point A spread and extended to the southwest. The fire leaped to point B, but the fire was put out at once. The fire that spread to the southwest extended to the ridge and strongly burned in the slope east of the mountain at about one pm. The fire that arrived in this side of the ridge leaped to the mountain on the east side across a valley by strong wind. During this time, the fire leaped to the mountain in the east. The fire which had leaped had burned down the whole slope of west of the mountain on the east side and leaped to point E and spread to the east. At this time from time of fire outbreak was best burning. At the time that fire arrived at the ridge of east side mountain, the wind velocity became weak and the fire certainly did not reach the slope of east of the ridge. Sparks of fire must have been carried by the wind to the ridge.

Table 2 Spreading situation of the forest fire of Manba

Point	Fire outbreak date	Wind direction	Wind velocity (m/s)	Spread time (h)	Repressed time	Note
A	April 27 11:35	NW	8.0	4.0	Time that all fires were repressed. 28th 13:40	Fire outbreak
B	April 27 13:00	NW	7.3	3.0		spark
C	April 27 18:00	W	1.4	9.0		spark
D	April 27 15:00	W	3.5	5.0		spark
E	April 28 6:00	SE	2.2	9.0		spark
F	April 28 11:00	NE	3.8	4.0		spark

②Takehara

Fig.4 and Table.3 show the circumstances of the spread of the fire.The fire broke out from Mt.Takamaru (point A) on August 11,1994 at 15:33, and leapt to the east side slope of Mt.Ryuou (point B) before the wind from the east about 10m/s.The fire would burn 86ha on the Takehara-city side and 21ha on the Mihara-city side by 17:20 on the 12^{th}, and be repressed temporarily.However,the fire which remained under the grass leapt by the strong wind,and the fire rekindled from two places at about 23:30 on the 12^{th}.Afterwards,the fire leapt to the west side of Mt.Ryuou (points E,F,G).The fire burnt 212ha by midnight on the 14^{th}. 59ha was burnt down by 17:00 on the 15^{th}.

Table 3 Spreading situation of the forest fire of Takehara

	Fire outbreak date	Wind direction	Wind velocity (m/s)	Spread time (h)	Change in wind direction (1)	Wind direction	Wind velocity (m/s)	Spread time (h)	Change in wind direction (2)	Wind direction	Wind velocity (m/s)	Spread time (h)	Repressed time	Note
A	August 11 15:33	E	6.8	11.5	12th3:00	NE	4	4	12th 7:00	E	5.6	2.9	12th 9:55	Fire outbreak
B	August 11 23:27	E	4.9	3.6	12th 3:00	NE	4	4	12th 7:00	E	5.6	2.9	12th 9:55	Spark
C	August 12 23:26	E	8.2	24.6	NO change in the wind direction								14th 0:00	Spark
D	August 13 1:00	E	8.1	23	NO change in the wind direction								14th 0:00	Spark
E	August 13 16:00	E	6.7	17	14th 9:00	SE	4.3	11	14th 20:00	E	2.8	13	15th 9:00	Spark
F	August 13 16:00	E	6.7	17	14th 9:00	SE	4.3	11	14th 20:00	E	2.8	13	15th 9:00	Spark
G	August 13 17:10	E	8.7	6.8	NO change in the wind direction									Spark

3.METHOD OF THE TOPOGRAPHICAL CLASSIFICATION SYSTEM FOR THE FORECAST METHOD OF FOREST FIRE DAMAGE

It is the purpose of this chapter to develop the method topographical classification system for the forecast method of forest fire damaged area. In the first place, this paper analyzed the topographical structure of the regions which became the object of this study with some topographical factors, and contracted the land form classification map. Secondly, this paper decided the dangerous condition of each region in the land form classification map according to the direction of the wind.

(1)Sampling of topographic factors

This paper sampled six topographic factors as follows. The analyzed area are within a radius of about five kilometers and seven kilometers including the damaged area in Manba and each Takehara. The sampling area for sampling of topographic factors are a rectangular area of a radius of 2,250 meters and 1,750 meters around a center of given measurement point in Manba and each Takehara. These values are decided by a growth curve.

-Slope form: this factor separates even slope form, dent slope form, and protrude slope form.
-Angle of inclination: the greatest angle of inclination in the rectangular area.
-Direction of slope: this factor separates eight directions.
-Relief amount: Difference of highest elevation and lowest elevation.
-Elevation
-Existed direction of highland: this factor separates eight directions.

(2)Method of the topographical classification system

Table 4 The characteristic quantities of topographic factors in the principal component (Manba)

	Elevation	Slope form	Elevation	Relief amount	Angle of inclination	Relief amount	Elevation	Angle of inclination	Slope form	Relief amount	Angle of inclination	Relief amount	Slope form	Elevation
Characteristic	0 : 450	凸	450 : 590	611 : 5000	7.6 : 15	560 : 611	590 : 780	1.4 : 3	⊿	515 : 560	3.1 : 7.5	0 : 515	凹	780 : 5000
Characteristic quantities	1.54	1.15	1.02	0.43	0.41	0.28	0	−0.10	−0.2	−0.33	−0.90	−1.02	−1.4	−1.85

This paper did quantification 3 to analyze the principal components of the six topographic factors. In this place, this paper used the hypothesis that principal components of topography which influence wind distribution are: a principalcomponent of gentle rise and fall or not, "principal component of land form" ,and a principal component of inclination direction of land by quote from my study results[4] on this subject. Table.4 shows the characteristic quantities of topographical factors as regards land, that is to say slope form, angle of inclination, relief amount, elevation in first principal component arranged in order of size in Manba. From this result, the relief amount becomes small value as the elevation increased; that is to say, become land of gentle rise and fall. In Manba, the first principal component is principal component of land form, and the second principal components and the fourth principal component are principal components of inclination direction of land. This paper made a land form classification map for wind force. Fig.5 shows the land from classification map for wind force of Manba and Takehara.

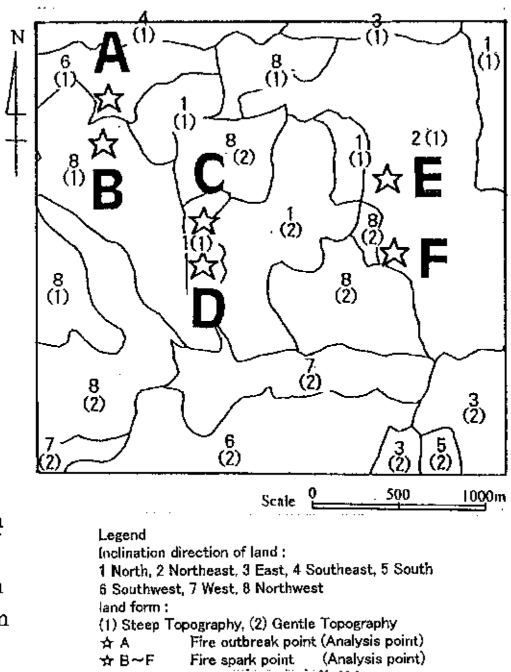


Fig.5 Land form classification map for wind force ,points of fire outbreak and spark of a fire (Manba)

(3)Making forest fire risk district sectional map drawn by analyzing topography

Fire risk on each district sectional areas in the land form classification map for wind force were analyzed based on the wind direction at the fire. Intention of the risk judgment are shown as follows and the risk judgment is shown in Table 5 in Manba.

(a) Relative degree of wind force based on the inclination direction of land were judged by conical land form model shown in Fig.6, that is to say land form was separated by eight inclination directions and the relative fire risk of each districts was judged .

(b)Fig.7 shows the relation between the inclination and the velocity of the wind of geographical features concerning the fire spreading velocity of a fire. It was assumed that the risk of gentle geographical features was higher in Manba where the velocity of the wind was small based on this figure. Oppositely, it was assumed that the risk of steen geographical features was higher in Takehara where the velocity of wind was large.

Table 5. Fire risk judgement analysis based on the topography

Fire risk	Characteristic of district
1	There are highlands on the main wind direction side to the measurement point, and a gentle topography area.
2	There are highlands on the main wind direction side to the measurement point and a steep topography area, as well as highlands on the main wind direction on the opposite side to the measurement point and a gentle topography area .
3	There are highlands on the main wind direction opposite side to the measurement point and a steep topography area, as well as highlands on the main wind direction diagonal opposite side to the measurement point and a gentle topography area beyond which there are not highlands.
4	There are highlands on the main wind direction diagonal opposite side to the measurement point and a steep topography area, as well as highlands on the main wind direction diagonal side to the measurement point and a gentle topography area.
5	There are highlands on the main wind direction diagonal side to the measurement point and a steep topography area, as well as highlands at right angles to the main wind direction to the measurement point and a gentle topography area.
6	There are highlands at right angles to the main wind direction to the measurement point and a steep topography area.

Note: Area of large numerical value of fire risk is more dangerous than area of small numerical value of fire risk.

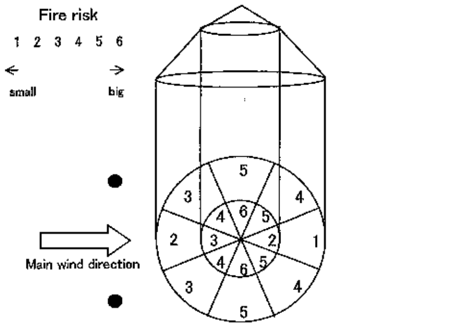


Fig.6 Fire risk judgment analysis based on the topography (schematic diagram) in the Manba

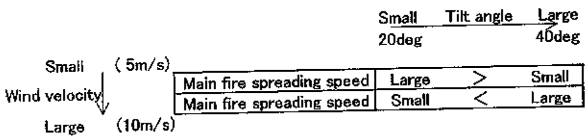


Fig. 7 Relationship between tilt angle and wind velocity for main fire spreading speed

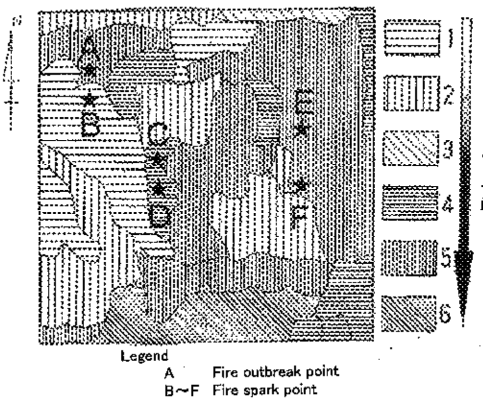


Fig.8 Fire risk district sectional map analyzed according to the topography (wind direction : southeast)

(c)From combination of (a) and (b), relative fire risk judgment was made.

(d)Fire risk showed six grades.

Fig.8 shows fire risk district sectional map drawn by analyzing Fig.5 based on the southeast wind direction in Manba. This method can draw fire risk district sectional map for any wind direction.

4.FORECASTING METHOD FOR FOREST FIRE DAMAGE FORECAST DISTRICT

This paper made the sectional map of fire damage forecast district by analyzing fire spread direction, spread speed, spread times and spread distance, based on the fire risk district sectional map which is based on the topography. The example of Manba is explained as follows.

(1)Calculation of fire spread direction, spread speed, spread times and spread distance[5)6)].

This paper calculated fire spread direction, spread speed, spread times and spread distance. The results are shown in Table 6.

(2)Making of sectional map of fire spread forecast district.

Table 6 Fire spread direction,speed,times and distance (Manba)

	Fire outbreak date	Fire speak time (o'clock)	Fire spreading time (h)	Wind velocity (m/s)	Maximum inclination direction θ_e(deg)	Tilt angle of maximum inclination	Wind direction θ_w (deg)
A	Apr. 27 '93	12	4	8.0	157.5	17.8	135(NW)
B	Apr. 27 '93	13	3	7.3	157.5	18.0	135(NW)
C	Apr. 27 '93	18	9	1.4	157.5	14.1	90(W)
D	Apr. 27 '93	15	5	3.5	180.0	18.1	90(W)
E	Apr. 28 '93	6	9	2.2	180.0	15.7	315(SE)
F	Apr. 28 '93	11	4	3.8	202.5	10.0	225(N)

	Main fire spreading direction θ_E (deg)	Main fire spreading speed V_o (m/h)	Side fire spreading speed V_s (m/h)	Opposite fire spreading speed V_b (m/h)	Main fire spreading distance (m)	Side fire spreading distance (m)	Opposite fire spreading distance (m)
A	142	498	55	10	1992	220	40
B	143	462	62	13	1386	186	39
C	137	134	91	67	1206	819	603
D	137	208	79	37	1040	395	185
E	223	79	43	27	711	387	243
F	217	273	96	42	1092	384	168

A~F : Fire outbreak and fire spark points (Analysis points)

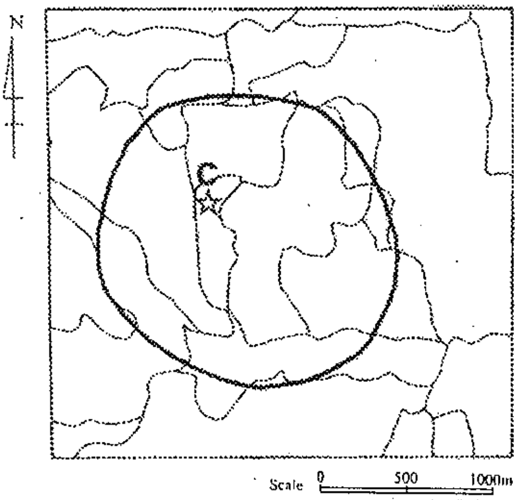


Fig.9 Sectional map of fire spread forecast district (point C)

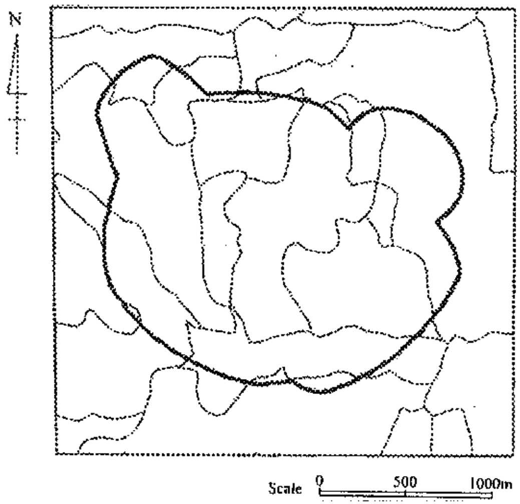


Fig.10 Sectional map of fire spread forecast district (whole area)

Sectional maps of fire spread forecast district were made for fire outbreak point and on each fire spark point. The area was decided by main fire spread distance, side fire spread distance and opposite fire spread distance. By way of example, a sectional map of fire spread forecast district for point C is shown in Fig.9, Fig.10 shows a sectional map of fire spread that combine map from point A to point F.

(3) Making of sectional map of fire damage forecast district.

This paper made a map that combines sectional map of fire spread forecast district and fire risk district sectional map, analyzed based on the topography of each wind direction at the time of fire outbreak and spark from point A to point F. Fig.11 shows the map on point C. This paper assumed that the fire at the fire outbreak point and fire spark points will spread to areas of more fire risk than area of the point. For example in point C, the area that has a high fire risk area than area of point C and area that borders on area of point C exist on the east of point C in Fig.7, so the fire should spread the area east of point C. Fig.12 shows the sectional map of fire damage forecast district at the point C. Fig.13 shows the sectional map of fire damage forecast district that combined the point A to point F into one. Furthermore, there is figure of burnt area in Fig.13.

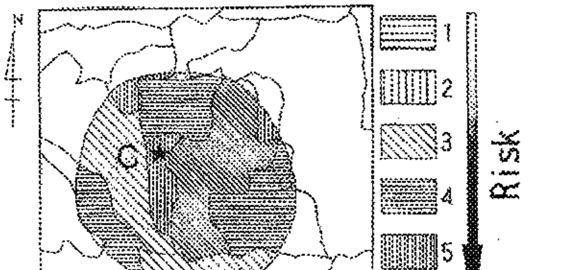


Fig.11 Combined map of sectional map of fire spread forecast district and sectional map of fire risk district (point C, wind direction : west)

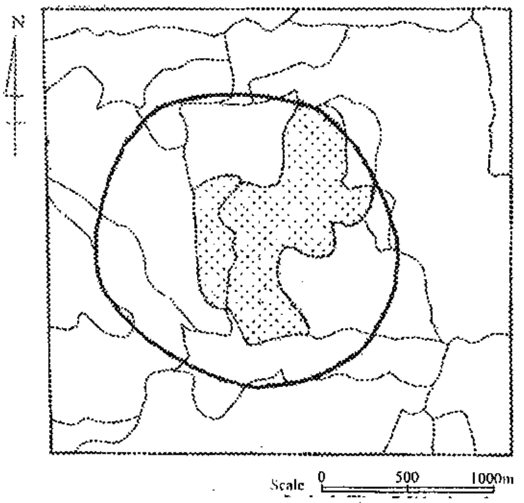


Fig.12 Sectional map of fire damage forecast district (point C)

(4) Discussion and making of sectional map of the final fire damage forecast district.

In the Fig.13, the burnt area is in a sectional map of the fire damage forecast district, but the accuracy is not sufficient. The cause of this error will be the error of establishment of wind direction and the lack of careful consideration to the fire actions. In this paper, wind direction was established by the wind direction at the fire spark time of the point, but the wind direction changed every moment. Especially, wind direction changed remarkably after the fire spark time of point C. Then, this paper investigated for the second time about the wind direction at point C. As a result, just fire spark time at point C is the west wind, but after that wind direction can be seen changed from the west wind to the north-west wind. So this paper corrected the west wind to the north-west wind at the point C. The result is shown in Fig.14. Furthermore, fire of fire spark point B was got under control at once. So this paper thinked that the area of point B was damaged only just the circumference of point B and corrected Fig.14 to Fig.15. Fig.15 shows the sectional map of the final fire damage forecast district.Takehara was analyzed by almost the same method.Fig.16 shows the final map in Takehara.

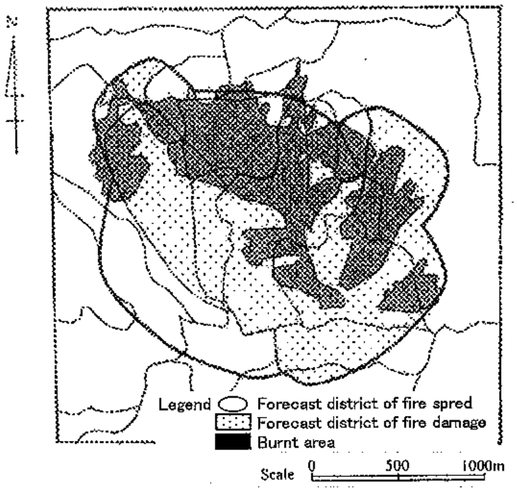


Fig.13 Sectional map of fire damage forecast district (whole area)

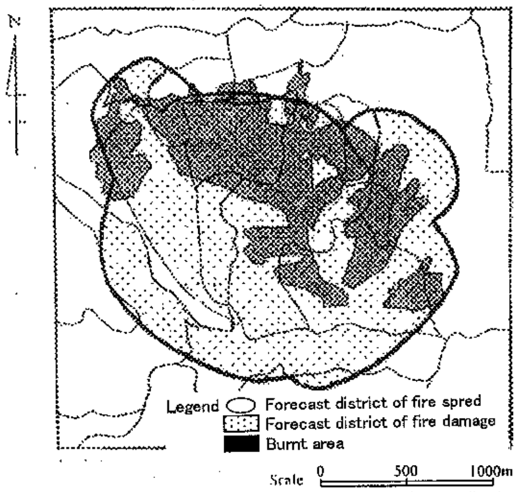


Fig.14 Sectional map of fire damage forecast district (whole area)

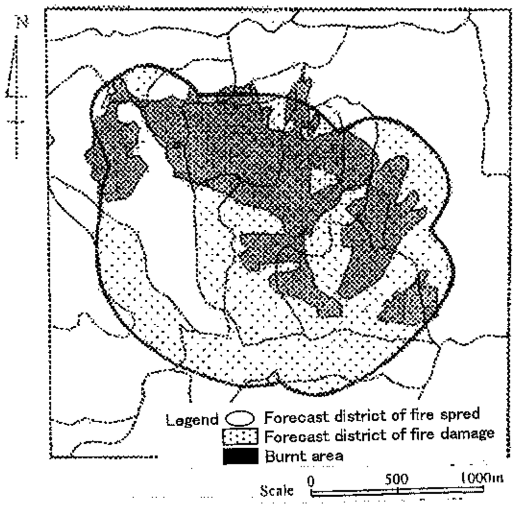


Fig.15 Sectional map of the final fire spread damage district, with consideration to action of fire fighting at point B (whole area)

5. CONCLUSION AND CONSIDERATION

The results of this paper are as follows:

① Although there are some problems, validity for the forecast method of forest fires in this paper could be confirmed. Especially this method can be use for all wind directions.

② The topographical features have great impact on the spread of forest fire.This paper could confirm that the most important information is the topographic geometries representing how steep or moderate the topographies areand in which directions the topographies are slanted.

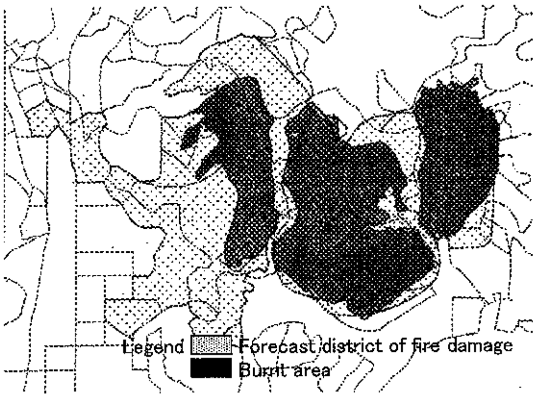


Fig.16 Sectional map of fire damage forecast district (whole area)

These topographic information, together with the wind direction and velocity turned out to allow us to predict disastered zones of forest fire.

③Takehara has improved when an analytical result of Takehara and Manba are compared.It is thought that the reason for this biggest cause is that the wind direction and the value of the velocity of wind in Takehara were able to be decided accurately compared with Manba.I think that setting the wind direction and the velocity are important when this technique is applied for this reason.

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