A CLIMATOLOGICAL STUDY OF LOCAL WINDS (OROSHI) IN CENTRAL JAPAN

by

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A dissertation
submitted to the Institute of Geoscience
University of Tsukuba
in partial satisfaction of the
requirements for the degree of Doctor of Science

1990

ABSTRACT

In order to elucidate the climatological and meteorological characteristics of Ibuki and Suzuka Oroshi (local winds blowing on the Pacific side of Central Japan), pressure patterns on days with Oroshi were classified. They were divided into six patterns, and numbered I to VI. The occurrence rate of Ibuki Oroshi was high in Patterns I and V, and that of Suzuka Oroshi in Patterns II, III, and IV. The wind direction at the 500mb level was NW or WNW for Ibuki Oroshi and W for Suzuka Oroshi.

The occurrence probability of the maximum wind velocity was higher in the day time: 14:00 to 16:00 for Ibuki Oroshi, and early in the morning, 4:00 to 6:00 for Suzuka Oroshi. The occurrence rate for Föhn-like Oroshi was 63%, but for Bora-like Oroshi, only 21%.

Using wind-shaped trees as an index, the Oroshi streamlines were mapped. There are three main Ibuki Oroshi streamlines on the Nohbi Plain: (i) a W wind in the northern part of the plain, (ii) a NW wind through in the central part of the plain, and (iii) a NNW wind along the three rivers on the west part of the plain. On the other hand, a NW wind occupies almost all regions affected by Suzuka Oroshi in the Ise Plain, but there is a NW to NNW wind along the Anou River. The strong wind regions appear at 8-10km intervals in these regions. The NW and NNW winds on the Nohbi Plain are considered to be caused by the effects of lee wave motion.

The lee wave motion effect was also confirmed by an analysis of the wind conditions at surface level, classified by wind direction and velocity on top of Mt. Ibuki (equivalent to the 850mb level). The height of the mountains is about 1,300m, which coincides with the height generally accepted as a suitable height for lee wave motion. Cross-sectional observations along the NW and NNW streamlines of the Nohbi Plain revealed that the strongest wind regions occurred at 20-25km intervals in the case of NW winds and at 10-15km intervals in the case of NNW winds. *Altocumulus lenticularis* clouds often appeared at the upper level. It is also shown that the wavelength becomes longer as the wind velocity on top of the mountain becomes stronger. The average wavelength of an Oroshi was about 14km, when wind velocity was 15m/s on top of Mt. Ibuki. This is also roughly same to the world average.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I. INTRODUCTION

1. Aim of the Present Study

Local winds are the winds that occur under certain synoptic conditions in particular regions surrounded by specific topography. In our country, strong local winds (called Oroshi) can be observed on the Pacific side of Japan on the days with the so-called "west high and east low" pressure pattern of the winter monsoon. Nasu Oroshi, Tsukuba Oroshi and Akagi Oroshi in the Kanto District, and Rokko Oroshi in the Kinki District are examples.

Ibuki Oroshi blow on the Nohbi Plain and Suzuka Oroshi blow on the Ise Plain in Central Japan. Generally, the local winds are given the name of the mountain on the windward side; hence, Ibuki Oroshi is the wind from Mt. Ibuki and Suzuka Oroshi, from the Suzuka mountains.

The Japanese island of Honshu is shaped from north to south in a curve form, and the Nohbi and Ise Plains are located in a relatively narrow part of the main mountain ranges of Honshu on the lee side of the winter monsoon. Accordingly, it is shown that strong local winds would blow there in winter.

The present study was carried out to elucidate the characteristics of Ibuki Oroshi and Suzuka Oroshi. The lee wave motion observed on the Plains was compared with similar patterns all over the world and a con. obtained a general rule on the fall wind (Oroshi) on the plains at the lee side.

2. Previous Studies of Local Wind

(1) Local Winds Outside Japan

The most well known local wind in the world is the Föhn of the Alps in Europe. Föhn can be classified into two types: anticyclonic and cyclonic. The cyclonic type of Föhn is known to blow down the lee side slopes, bringing high temperatures and low humidity (Atkinson, 1981: Yoshino, 1975). Föhn-like winds blow on the Japan Sea side. Chinooks, which blow in the southwestern part of Canada and the western part of the U.S.A. (east of the Rocky Mountains), are also examples of local winds with Föhn effects.

The Bora anticyclonic type has its blocking high over the Iberian Peninsula and the cyclonic type has its cut-off low in the upper area of the Alps. Both Bora bring strong northeast winds to the Adriatic coast. Both of these winds are cold and dry. The difference between Föhn and Bora winds can be attributed to the main air mass crossing over the mountain range: the former is caused by a low altitude air mass and the latter by a high altitude air mass (Yoshino, 1976).

There are usually clouds over the mountain range on the windward side when these winds blow. For example, the white Kapa clouds (cap clouds) over the top of the Dinar Alps are same as the Föhn mauer (föhn-wall) or the Chinook Arch.

Fig. 1-1 Distribution of local strong winds in Japan (Yoshino, 1975).

(2) Local winds in Japan

Many local winds prevail in Japan, because of the country's shape, topography and geographical location. The distribution of local winds in Japan is shown in Fig. 1-1, summarized by Yoshino (1975).

The Japanese local winds are characterized by wind direction, which are roughly opposite on the Japan Sea side and the Pacific side. That is, the local winds on the Japan Sea side blow toward the Japan Sea and conversely, on the Pacific Ocean side they blow towards the Pacific Ocean. This is caused by the different weather situation: the strong local winds on the Japan Sea side blow when the cyclones are passing in the Japan Sea, and in contrast, the strong local winds on the Pacific coast occur mainly during the winter monsoon season when anticyclones blow over Siberia and cyclones blow in the Pacific.

3. Study Area

(1) Situation on a Global Scale

Oroshi, a local strong wind on the Pacific side of the Japanese islands, occurs on the fringe of the anticyclone formed over the Eurasian continent in winter as shown in Fig. 1-2. Accordingly, the change in occurrence frequency of Oroshi in the Kanto Plain has a close relation to that of Bora blowing in Yugoslavia (Yoshino, 1969: Yoshino, 1987). Both Bora and Oroshi occur in association with the outbreak of cold air from the anticyclone which develops on the Eurasian continent. These are the Oroshi winds over the Kanto Plain.

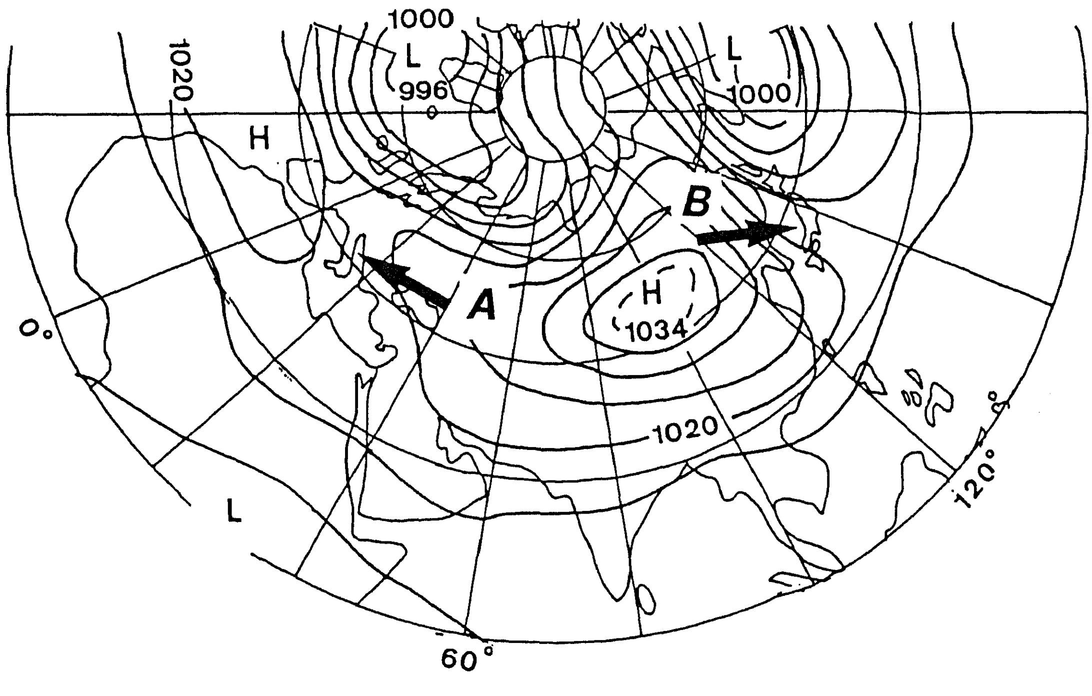


Fig. 1-2 The Oroshi on the Pacific coast of Japan and the Bora on the Adriatic coast of Yugoslavia in relation to the Eurasian anticyclone in winter (Yoshino, 1969).
A: Bora and B: Oroshi.

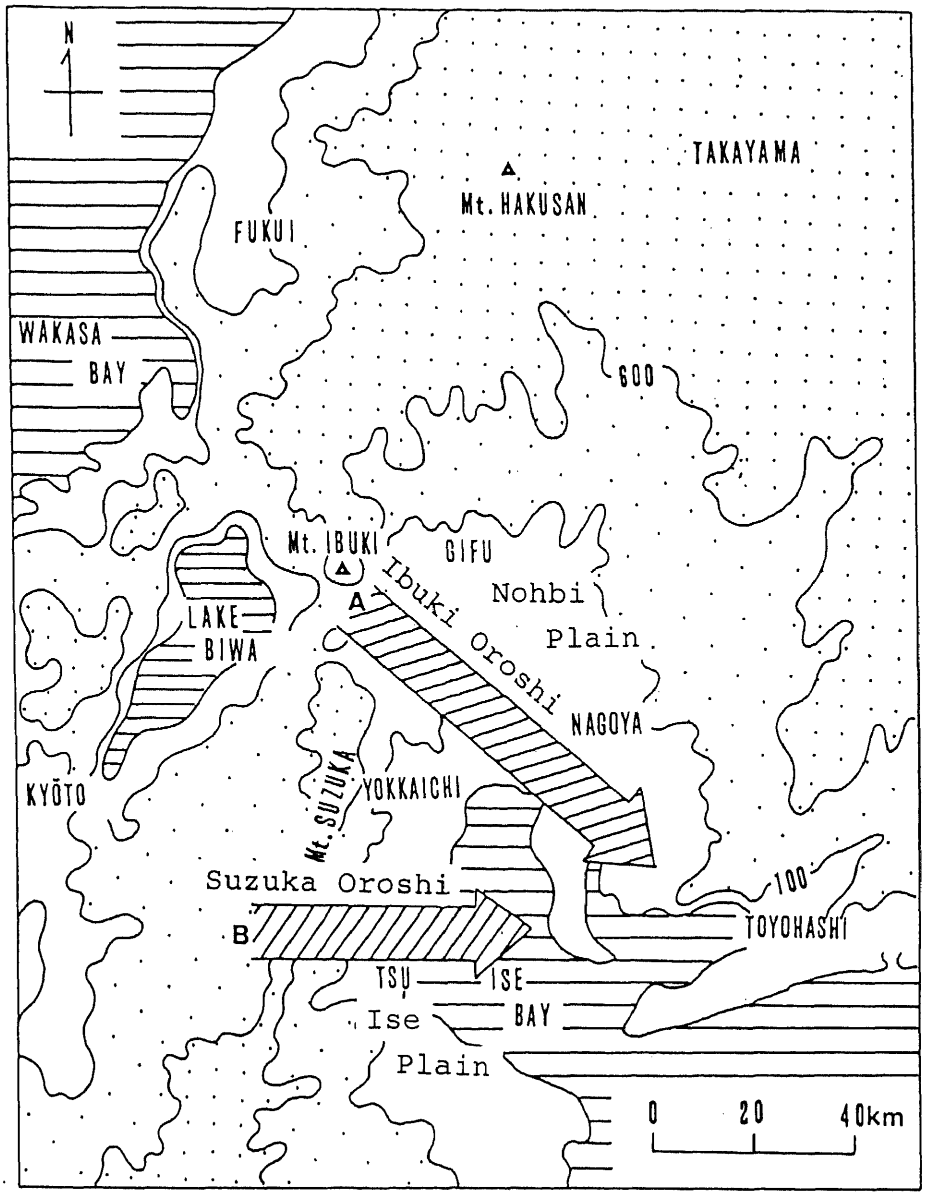


Fig. 1-3 Sketch of local strong winds, Suzuka Oroshi and Ibuki Oroshi on the Nohbi Plain and the Ise Plain in Central Japan in winter.

A: Ibuki Oroshi and B: Suzuka Oroshi.

The Suzuka and Ibuki Oroshi under consideration might have similar characteristics because they both develop on the Pacific side of Honshu.

According to a study by Tamiya (1976), the cold polar air outbreak in East Europe, which is as a trough on the weather map, is one of the necessary conditions for the creation of Bora. Another cold polar air outbreak in East Asia causes Oroshi. The correlation coefficient between the monthly occurrences of Bora and Oroshi is significant in winter months, especially in January.

It can be estimated that the Suzuka Oroshi, Ibuki Oroshi and Bora have similar tendencies, if we consider them on a macro-scale.

(2) Situation on a Meso-scale

Kawamura (1961) has previously studied local air flow, analyzing surface level gradient wind directions in Hokkaido. Kawamura (1966) has also reported local wind system in the Central Japan by the same method.

The Oroshi occurs in association with the outbreak of cold air from the Siberian anticyclone in winter as mentioned above. On the Pacific side in Central Japan from an orographic viewpoint on a meso-scale, the wind system develops on the lee of the mountain range of Honshu. Especially in the case of the Ibuki Oroshi, the winter monsoon cold air coming from the Wakasa Gulf through the Sekigahara Pass prevails on the Nohbi Plain, and Suzuka Oroshi blow down crossing over the Suzuka mountains on the Ise Plain as shown in Fig. 1-3.

CHAPTER II. SYNOPTIC AND AEROLOGICAL ASPECTS OF OROSHI

1. Occurrence Frequency of Oroshi

Fig. 2-1 shows the occurrence frequency of the local wind, the Ibuki and Suzuka Oroshi, which over occurred in the central part of Japan every five-days mean for the past ten years. The period of observation was the five months from November to March, during which time most Oroshi could be observed.

The Oroshi occurrences were marked as days when a maximum average wind velocity of over 8m/s were observed at Nagoya Meteorological Observatory and Suzuka Oroshi at Tsu Meteorological Observatory. A maximum average velocity of over 10m/s was used as a reference.

The upper part of Fig. 2-1 shows the number of days with Ibuki Oroshi, the middle the number of days with Suzuka Oroshi, and the lower the number of the days with both Ibuki and Suzuka Oroshi observed on the same day.

(1) Ibuki Oroshi

The Ibuki Oroshi days per five-days mean have a tendency to increase gradually from the beginning of November, the 61st five-days mean, to March, in the 18th five-days mean. The five-days means in which the Ibuki Oroshi tended to blow more than two days, were the 6th, 11th, 13th and 16th five-days means. The peak with 2.5 days was recognized in the 11th five-days mean at the end of February. This tendency was obvious on the days with a wind velocity over 10m/s. However,

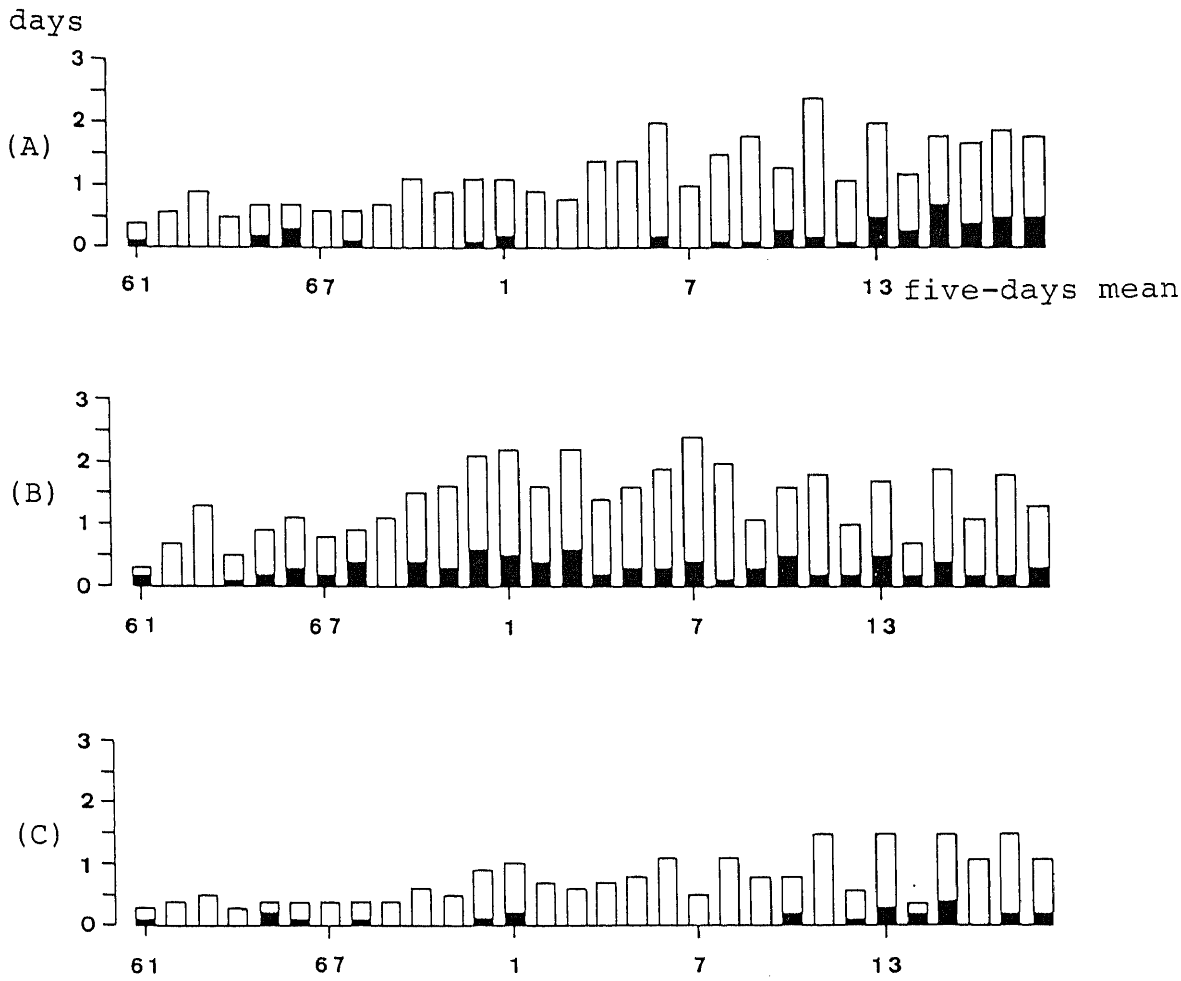


Fig. 2-1 Occurrence frequency (number of days) of the maximum average velocity over 8m/s and over 10m/s (black part) of Ibuki Oroshi on the Nohbi Plain and Suzuka Oroshi on the Ise Plain, 1976-1985.

A: Ibuki Oroshi days, B: Suzuka Oroshi days and C: Ibuki Oroshi and Suzuka Oroshi on the same days.

the rate of appearance was low and only about 10% in the case of strong wind days with more than a 10m/s wind velocity. However, in the observation period during January through February, which corresponds to the 1st-12th five-days mean, there was a tendency such that the 6th five-days mean had high rates of occurrence and decadal change was relatively large.

(2) Suzuka Oroshi

The occurrence tendency of Suzuka Oroshi (shown in the middle part of Fig. 1-2) is different from Ibuki Oroshi. This tendency was resulted from changes in the pressure gradient and wind direction of the upper air layer, and different geographical features of mountains on the windward side, even though both Oroshi blew on the nearby plains of the Pacific Ocean side. The five-days mean, in which Suzuka Oroshi appeared at the highest rate, is from the middle of December, the 69th five-days mean, to the beginning of February, the 8th five-days mean. The five-days mean in which Oroshi blew longer than two days was the 6th five-days mean. In the case of Ibuki Oroshi, only one five-days mean was observed during this period. The peak of occurrence of Suzuka Oroshi is the 7th five-days mean, showing 2.5 days. However, the fluctuation is large after this period and tends gradually to decrease. Suzuka Oroshi had more appearances than Ibuki Oroshi.

For instance, the periods in which Ibuki Oroshi shows more than two days are only three five-days means; and for Suzuka Oroshi, one five-days mean, the 7th. When average five-days means of more than 1.5 days are compared, Ibuki

Oroshi appear in the 9th five-days mean, mainly in February and March, and Suzuka Oroshi appear in the 14th five-days mean from the end of December to March. There is a higher frequency of Suzuka Oroshi than of Ibuki.

(3) Both Ibuki and Suzuka Oroshi at the Same Time

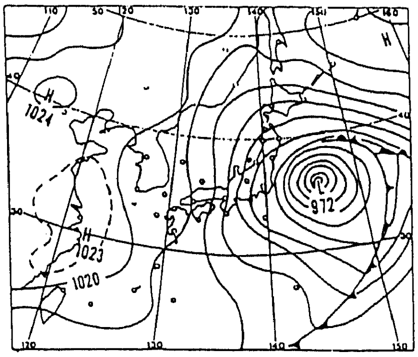
In this part of the study, the frequency of simultaneous occurrence of Ibuki Oroshi and Suzuka Oroshi are analyzed. The average number of days with both Oroshi occurring simultaneously is less than one day in 50 from November to December. From January, it increases slightly, appearing more than one and half days in 50 from the 11th five-days mean at the end of February. However, this tendency does not continue for a long time and the occurrence rate repeatedly goes up and down at intervals of one five-days mean. The running mean of the five-days mean indicates that there was a tendency of winds to appear frequently from the end of February to March,

From the facts mentioned above, it becomes obvious that Ibuki Oroshi on the Nohbi Plain appear frequently from the 11th five-days mean at the end of February through the 18th five-days mean at the end of March, and Suzuka Oroshi on the Ise Plain appear frequently from the 72nd five-days mean at the end of December through the 8th five-days mean at the beginning of February. The Suzuka Oroshi appears at a higher frequency than Ibuki Oroshi from November to March. The frequency of simultaneous occurrence of both winds is low, with an average of about one day for each five-days mean. The main five-days means are from the 11th five-days mean to the 18th five-days mean.

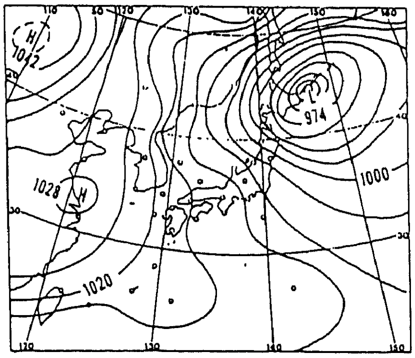
2. Pressure Patterns of Oroshi

The Oroshi days with a maximum average wind velocity over 8m/s were selected, as previously mentioned. These Oroshi periods were investigated for ten years from 1976 to 1985. The selections of Oroshi days were 53 days for Ibuki and 90 days for Suzuka Oroshi during this period. The pressure patterns of these 143 days were classified into 6 main pressure patterns. The days in which both Ibuki and Suzuka Oroshi blew were classified in the same way. The main pressure patterns can be further sub-classified. Therefore, composite maps, which indicate topography and examples of pressure patterns at the surface during Ibuki and Suzuka Oroshi, were completed. In Fig. 2-2, the pressure patterns during Oroshi periods are shown. According to the classification of the pressure patterns by Yoshino and Fukuoka (1967) and Yoshino and Kai (1975), almost all pressure patterns related to Ibuki and Suzuka Oroshi belong to Type I of their classification. Type I is a typical winter monsoon pattern, the so-called "west high and east low" type. In this report, Type I and similar pressure pattern types were further sub-classified into six patterns, from Pattern I to Pattern VI, based on the position of cyclones and the developed anticyclone over the Eurasian continent.

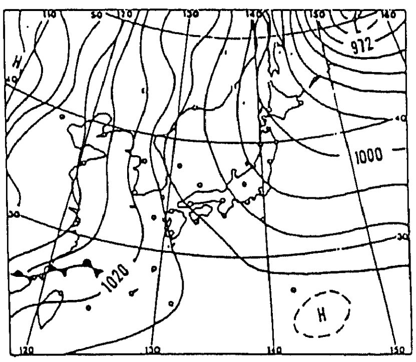
Patterns I, II and III were classified by the latitudinal position of the cyclone though the center of the anticyclones over the continent located similarly in the neighborhood of 120°E.



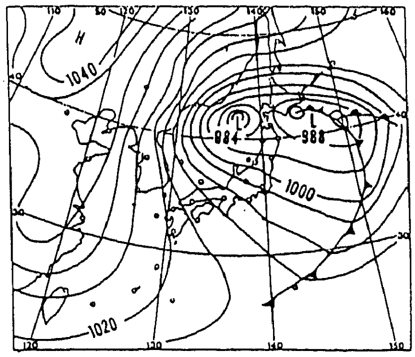
Pattern I
(March 24,1986)



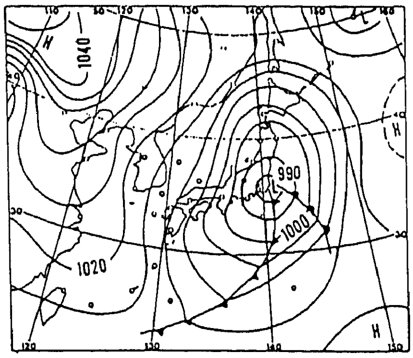
Pattern II
(February 23,1985)



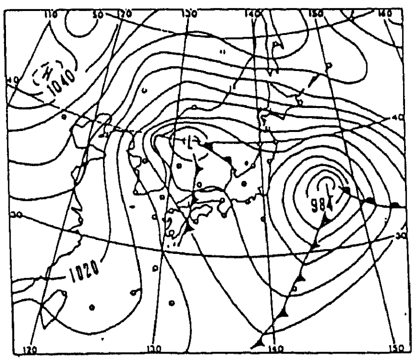
Pattern III
(January 10,1981)



Pattern IV
(January 3,1981)



Pattern V
(March 10,1980)



Pattern VI
(February 18,1983)

Fig. 2-2 Examples of pressure patterns at the surface level during Ibuki Oroshi and Suzuka Oroshi.

The center of the cyclone in Pattern I is located at roughly 35°N off the coast of the Boso Peninsula. In the case of this pattern, the isobars in Central Japan run meridionally as a typical "west high and east low" type.

However, in the case of Pattern II, the center of the cyclone is located in the Sea of Okhotsk, and it covers the area from Hokkaido to the northern part of Honshu. Such a situation results in a tongue like form of anticyclone over southern Kyushu.

Pattern III shows a developed cyclone over the northern Kuril Islands. The pressure gradient over Central Japan is moderate, because the center of the cyclone in this type is located further north than in Patterns I and II.

In contrast to these typical winter pressure patterns of the "west high and east low" type in Patterns I to III, Patterns IV to VI have a close relationship with Type II, the "trough" type, according to the pressure pattern classification by Yoshino and Kai (1975).

The Pattern IV is a double-cyclone type in which cyclones are located between the northern part of Japan Sea and the south-east part of Hokkaido. Therefore, the pressure gradient in the neighborhood of 130°E over the northern Korean Peninsula is steep, providing strong westerlies in Central Japan.

Pattern V shows the cyclone passing along the Pacific coast of Japan. This pressure pattern is a typical "trough" type. The cyclone is located on the east side of Central Japan, and the isobars run more in the north-south direction in Central Japan.

Table 2-1 Mean values of climatic elements (A) in Nagoya on Ibuki Oroshi days and (B) in Tsu on Suzuka Oroshi days (1976-1985).

Patterns	Name of station	Number of days	Frequency (%)	Air temperature (°C) Max.	Min.	Wind direction	Peak gust (m/s)	Precipitation (mm)
I	A	14	26.4	9.5	2.1	NW	10.4	0.8
	B	14	15.6	8.8	2.3	WNW	10.4	0.1
II	A	7	13.2	10.3	1.9	NW	10.5	0.1
	B	18	20.0	7.6	0.4	WNW	10.8	0.1
III	A	5	9.4	6.7	-0.2	NW	10.3	0.0
	B	18	20.0	7.1	0.4	WNW	10.7	0.0
IV	A	10	18.9	9.5	1.4	WNW	10.9	1.3
	B	22	24.4	8.3	1.5	W	11.0	0.5
V	A	15	28.3	12.9	4.0	NW	10.7	3.5
	B	10	11.0	12.1	4.2	WNW	10.6	1.7
VI	A	2	3.8	15.5	6.3	WNW	10.6	8.5
	B	8	9.0	8.8	1.2	WNW	10.7	1.1

The Pattern VI pressure pattern does not occur frequently, but the Suzuka Oroshi blows comparatively frequently within this pattern. This type coincides with the Type II "trough" by Yoshino and Kai (1875), which is a double-cyclone type located both in the Japan Sea and on the Pacific coast of Honshu.

3. The Change of Climatic Elements on the Days with Oroshi

As has been discussed, Ibuki and Suzuka Oroshi blow not always on the same days or with the same frequency, in spite of similar fall winds. In this part of the study, the changes of climatic elements at Nagoya and Tsu are described under the respective pressure patterns. The results are shown in Table 2-1.

In this table, we have selected 53 days with Ibuki Oroshi from the period 1976 to 1985. In contrast, the selected days with Suzuka Oroshi under the same conditions (maximum average velocity over 8m/s) was 90 days. This fact indicates that Suzuka Oroshi has a higher occurrence frequency than Ibuki Oroshi.

In pressure pattern V, Ibuki Oroshi occurs at the highest rate: 15 days, which is 28.3% of the total. This is followed by 14 days for Pattern I and then 10 days for Pattern IV. The occurrence frequency of Pattern I is 26.4%, not much different from Pattern V. In the case of pressure pattern VI, Ibuki Oroshi hardly blows at all: only 3.8% of the time.

In contrast, in Pattern IV, the Suzuka Oroshi blows most frequently: 33 days, which is 24.4%. Secondly, Patterns II and III have 18 days respectively: 20%.

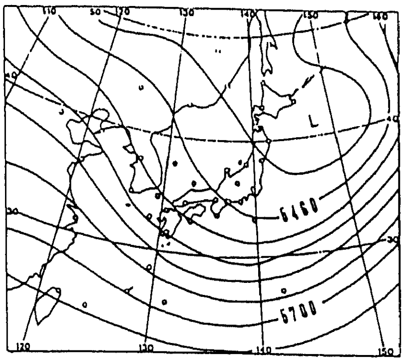
Based on these results, it is suggested that Ibuki and Suzuka Oroshi do not always blow under the same synoptic conditions. However, in the case of Pattern VI, the so-called "double-cyclone" type, the probability of simultaneous Ibuki and Suzuka Oroshi is high. Under Patterns I and V, Ibuki Oroshi blow easily and in Patterns II, III and IV Suzuka Oroshi. Concerning Pattern VI, the occurrence frequency of Suzuka Oroshi was low (9.0%) and the pressure pattern is unusual among local wind pressure patterns in Central Japan.

The prevailing wind direction during the Oroshi days is NW in most cases but it deviated to W on days with Suzuka Oroshi. For example, in Pattern IV, with the highest frequency of Suzuka Oroshi, the wind direction is WNW for Ibuki and W for Suzuka Oroshi.

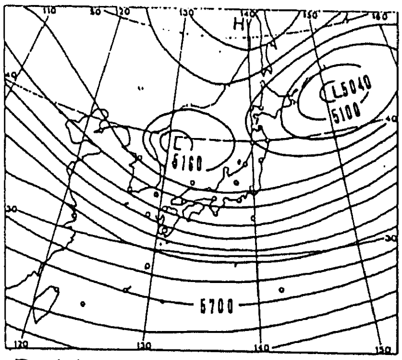
The maximum wind velocity during these pressure patterns does not change widely, because the values shown are the mean values of the blowing days. In the case of Pattern IV Ibuki and Suzuka Oroshi blow with high velocity on the same days, especially in the case of Suzuka Oroshi which produces a westerly wind of up to 11.0m/s. Weak precipitation is seen on the days with Oroshi in this pattern. This tendency can also be seen in Pattern V; we found 3.5mm of precipitation in Nagoya and 1.7mm in Tsu. On the days with Ibuki Oroshi in the case of Pattern VI,much precipitation (8.5mm in Nagoya) was observed. This might be caused by the cyclones accompanying fronts situated not only on the Pacific side but also in the Sea of Japan.

Next, the upper wind stream is considered for these pressure patterns. Fig. 2-3 shows the topography of the 500mb level near Japan for the respective patterns. The arrow in the figure shows the upper wind stream in Central Japan, which was estimated from wind directions at Wajima and Hamada at the 500mb level and which may relate to Ibuki and Suzuka Oroshi.

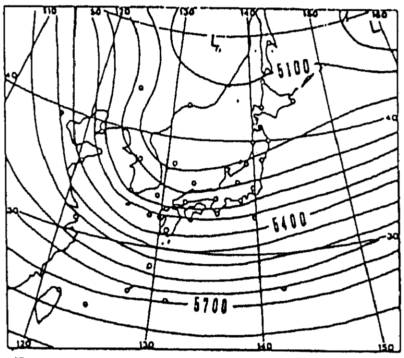
Pattern I, in which Ibuki Oroshi occur 26.4% of the time has a low pressure region in the eastern part of Hokkaido. Accordingly, a NW wind prevails over the area studied. This direction coincides with the wind direction of Ibuki Oroshi. Pattern II, Suzuka Oroshi mentioned above. It is understood that the wind is violent because the isobars of the upper wind stream over western Japan run closely for the low pressure not only in the eastern part of Hokkaido but also over the Japan Sea. A trough is developed westward compared to Pattern I and located around 130°E. The wind direction in the upper air is W in Central Japan. In the case of Pattern III, westerlies meander and a trough is developed near 125°E from the Sea of Japan to the East China Sea. Thus the upper wind stream of Central Japan is westerly at surface level. There is a tendency for Suzuka Oroshi to blow at a high frequency and for Ibuki Oroshi to blow at a low frequency when the upper wind stream is westerly. The occurrence percentage of Ibuki Oroshi in Pattern III was only 9.4%.



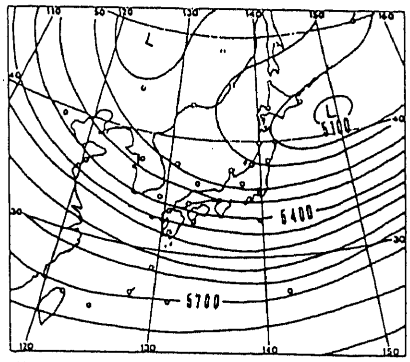
Pattern I
(March 24,1986)



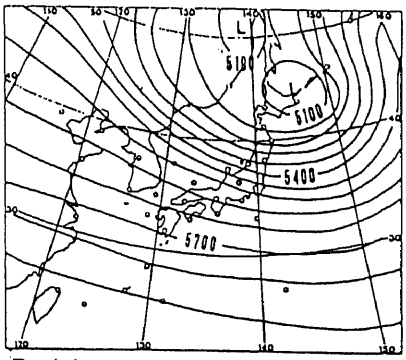
Pattern II
(February 23,1985)



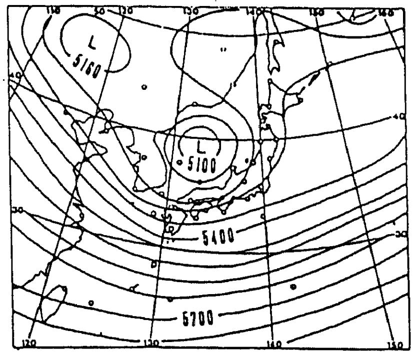
Pattern III
(January 10,1981)



Pattern IV
(January 3,1981)



Pattern V
(March 10,1980)



Pattern VI
(February 18,1983)

Fig. 2-3 Example of pressure patterns at the 500mb level during Ibuki Oroshi and Suzuka Oroshi.

Among these groups of pressure patterns, it is obvious that Pattern IV, which has both a high percentage of Ibuki and Suzuka Oroshi occurrences, shows the middle pressure field. Low pressure is found in the eastern part of Hokkaido and a WNW trough indicates the wind direction of patterns I, II, and III. As shown in Table 2-2, the WNW wind direction of Ibuki Oroshi for Pattern IV shows a similar wind direction at the 500mb level to that of Suzuka Oroshi (W).

The characteristic pressure field at this point is dense isobars in the northeastern part of Japan and at Kanto. The axis of westerlies is situated further north in Pattern III than in Pattern IV. Accordingly, a trough develops at around 145°E and this is further eastward than in the previous pressure pattern groups. Ibuki Oroshi occurs with the highest frequency (28.3%) in Pattern IV.

In Pattern VI, which has a low occurrence frequency, a low pressure system under 5,100m is located on the Japan Sea and a trough is developed around 130°E. For this reason, the direction of the upper air in Central Japan is WSW and a slight southerly wind factor is observed. Almost no Ibuki Oroshi could be observed and the occurrence percentage of Suzuka Oroshi was only 9% in this pattern.

As a result, it is obvious that Ibuki Oroshi tends to blow when the wind direction on the windward side at the 500mb level in Central Japan is NW or WNW. The occurrence frequency of Suzuka Oroshi is high when the wind direction is due west. The upper wind stream was WNW (Pattern IV) when Ibuki and Suzuka Oroshi were blowing at the same time. The location of the trough at the 500mb level is 140°E or eastward by the

Ibuki Oroshi and 140°E or westward for the Suzuka Oroshi in most cases. When a trough develops at 140°E, the occurrence frequencies of Ibuki and Suzuka become high.

CHAPTER III. CLIMATOLOGICAL CHARACTERISTICS OF OROSHI

1. Duration

We have discussed pressure fields and occurrence frequencies of Ibuki and Suzuka Oroshi. It is interesting to discuss when Oroshi blows strongly and how long it will continue. Using the data collected by Nagoya and Tsu Meteorological Observatories when Ibuki Oroshi were blowing on the Nohbi Plain and Suzuka Oroshi on the Ise Plain, we analyzed the time of occurrence of the strongest and longest lasting winds (Owada, et al. 1978). Concerning Ibuki Oroshi, we added and analyzed the data from the weather station on the windward of Mt. Ibuki (1,377m).

(1) Ibuki Oroshi

Using the data observed at the Mt. Ibuki Weather Station, we selected 185 days with Ibuki Oroshi. The conditions of selection were as follows: The maximum wind velocity was over 20m/s at the Mt. Ibuki Weather Station and the range of wind direction was N-W. The wind velocity of 20m/s at the Mt. Ibuki corresponds to 6-7m/s at the Nagoya meteorological Observatory. Table 3-1 shows the occurrence frequency of the time of maximum mean wind velocity for Ibuki Oroshi days.

First of all, the Oroshi with the highest velocity at Mt. Ibuki occurs in the daytime from 14:00 to 16:00. This tendency was the same in Nagoya, located on the leeward .

Table 3-1 The frequency of occurrence of peak mean wind velocity for Ibuki Oroshi days at the Mt. Ibuki Weather Station (1377m), 1964-1972.

J.S.T.	Frequency	
	Mt. Ibuki	Nagoya
0 - 2	14	2
2 - 4	17	3
4 - 6	10	2
6 - 8	11	0
8 - 10	12	4
10 - 12	8	18
12 - 14	19	43
14 - 16	38	73
16 - 18	8	21
18 - 20	20	4
20 - 22	15	8
22 - 24	13	7
Total	185	185

However, the time on Mt. Ibuki was uncertain in comparison with that in Nagoya.

The reason is attributable to the height at the Mt. Ibuki Weather Station (1,377m), situated almost at the 850mb level. It might be that the field on a synoptic scale could be larger than in the local circulation system at this level (Yoshino, 1978). For this reason, we could not observe any maximum among the Oroshi occurrences. They occur not only in the daytime, but also in the evening.

However, there is a striking maximum at 14:00-16:00 observed in Nagoya. The occurrence frequency from 10:00 to 18:00 is more than 80% on 73 days, peak gust velocities were observed between 14:00 to 16:00, which is more than 40%. The Ibuki Oroshi on the Nohbi Plain are effected not only by the pressure gradient on the synoptic scale but also by local cyclones formed in the daytime on the Nohbi Plain because of rising temperatures. The increasing pressure difference between the top of the mountain and the plain creates stronger Ibuki Oroshi.

The frequency of the duration of Ibuki Oroshi is given in Table 3-2. It seldom stops within 4 hours and on average, it continues to blow for 16 hours. The most common frequency of duration of Ibuki Oroshi is 12 to 16 hours; 37 days. The 2nd most common time is 4 to 8 hours. It depends on the velocity of the cyclone or double-cyclone. When the upper wind stream westerlies meander and the cut-off low occurs in succession in the Sea of Japan, the blowing continues for 60 to 70 hours (2 to 3 days).

Table 3-2 The frequency of occurrence and duration hours of Ibuki Oroshi with maximum mean wind velocity over 20m/s at the Mt. Ibuki Weather Station (1377m), 1964-1972.

Duration hours	Frequency
0 - 4	0 (days)
4 - 8	30
8 - 12	28
12 - 16	37
16 - 20	29
20 - 24	17
24 - 28	10
28 - 32	6
32 - 36	2
36 - 40	3
40 - 50	2
50 - 60	4
60 - 70	1
Total	169

(2) Suzuka Oroshi

The occurrence frequency of the maximum mean wind velocity is shown in Table 3-3. In the case of the Suzuka Oroshi, there is no observation data on the windward of the mountainous district, the Suzuka mountains, so only the data from the Tsu Meteorological Observatory was used. The observation period was the 4 years from 1970 to 1973, and the days with a maximum wind velocity of more than 10m/s were chosen.

It is observed from Table 3-3 that the occurrence duration of Oroshi with maximum wind velocity does not show any remarkable characteristics, as was the case with Suzuka Oroshi. However, when we looked for a trend, the maximum wind velocities were found mainly in the early mornings. The highest frequency of occurrence was observed between 6:00 and 8:00 (9 occurrences), but there is only a small difference before or after this period. The frequency of occurrence observed at 4:00 to 6:00 and 8:00 to 10:00 is 8. The occurrence percentage from 4:00 to 10:00 is more than 50%. It becomes obvious that the maximum velocity is not always observed at the time of the highest temperature. It is considered that local cyclone formation by the increasing temperature effect is weak on the Ise Plain. The axis of stronger lee wave motion which is characteristic in the air-flows crossing over the mountain range, does not coincide with the location of Tsu meteorological Observatory on any occasion. It will be mentioned later in a detailed survey of wind distribution.

Table 3-3 The frequency of occurrence of maximum mean wind velocity for Suzuka Oroshi days at the Tsu Meteorological Observatory, 1970-1973.

J.S.T.	Frequency
0 - 2	2 (days)
2 - 4	2
4 - 6	8
6 - 8	9
8 - 10	8
10 - 12	2
12 - 14	4
14 - 16	2
16 - 18	2
18 - 20	2
20 - 22	4
22 - 24	8
Total	53

Table 3-4 The frequency of occurrence and duration hours of Suzuka Oroshi with maximum average velocity over 10m/s at Tsu Meteorological Observatory, 1970-1973.

Duration hours	Frequency
0 - 10	2 (days)
10 - 14	5
14 - 18	6
18 - 22	12
22 - 26	9
26 - 30	2
30 - 34	3
34 - 38	4
38 - 42	3
42 - 46	2
46 - 50	2
50 - 54	2
.	.
.	.
.	.
88	1
Total	53

Continuous duration of Suzuka Oroshi is shown in Table 3-4. The highest frequency of duration was 18 to 22 hours and it occurred 12 times. There was an exceptional occurrence of an 88 hour Oroshi.

2. Bora-like and Föhn-like Oroshi

As mentioned previously, the Bora blows on the Adriatic coast in Yugoslavia and is strong and cold. The Föhn blows in the Alps in Europe and has a warm, dry wind. These two local winds are understood as different phenomena. Therefore, Oroshi is a Bora phenomenon, according to the definition by Yoshino (1976): a Bora-like Oroshi is a local wind where air temperature drops after the beginning, and a Föhn-like Oroshi is a local wind where the air temperature rises after the beginning of Oroshi. These temperature changes can be observed at the foot of the leeward of the mountain.

In this part of study we will investigate whether the Oroshi on the Pacific side of Central Japan have Föhn-like features or Bora-like features. Data from the Hikone Meteorological Observatory was used. On an hourly basis we analyzed wind direction, wind velocity and temperature, which was recorded by automatic instruments. The analyzed period is the 4 years from 1970 to 1973. We used data from Tsu Meteorological Observatory in order to elucidate the change in climatic elements before, after and during the Oroshi.

Table 3-5 The frequency and classification of the three types of Oroshi days at Tsu Meteorological Observatory during the winter monsoon season, 1970-1973.

Types	Patterns	Frequency	Total
Bora	A B	7 (days) 2	9
Föhn	A B	8 18	26
Bora and Föhn	A	6	6
Total			41

(1) Classification of Oroshi Type

Table 3-5 shows Oroshi types classified by the changes of wind and temperature before and after the occurrence of Oroshi. The Föhn type is defined as occurring when the temperature rises, as mentioned above. But the temperature change before and after the Oroshi is so complicated that we classified this type in detail. We defined Föhn Type A as that Föhn phenomenon which continues from the beginning of Oroshi. Föhn Type B is that Föhn phenomenon which is observed from the beginning of Oroshi; but after one or two hours the temperature decreases. The most frequent occurrence type among Föhn Type A and B is Föhn Type B, with 18 occurrences registered. Föhn Type A registered 8 occurrences, which is only 31% of the two Föhn types. In total we observed 26 Föhn type occurrences, which accounted for about 63% of all Oroshi.

The Bora type occurred in only 9 cases and it took 21% of the total. The Bora type Oroshi does not occur so often. The type of Bora are classified as follows: in Bora Type A, the temperature starts to decrease steadily before the beginning of Oroshi. In Bora Type B, the temperature increases one or two hours after the Oroshi starts. Bora Type A has the highest frequency among types of Bora and it amounted to 78%.

There is another type which is classified as neither Föhn nor Bora type. This type was observed in only 6 cases and is termed the Föhn – Bora Type. In this type Oroshi that alternately displays Föhn – Bora characteristics.

This type is common when the Oroshi is neither Föhn nor Bora type.

In the next section typical types are described in greater detail.

(2) Typical Föhn Type and Bora Type Cases

A typical Föhn type case is shown in Fig. 3-1. The upper part of this figure shows the change of wind direction and velocity in terms of time and the lower part shows temperature change. Diurnal variation of the air temperature at Hikone (broken line) on the leeward are shown in relation to temperature. The chain line represents the normal diurnal variation of the temperature curve (mean of normal days from 1970 to 1973 in winter).

Wind velocity started to increase greatly at about 3:00. The velocity was only about 1m/s at 3:00 and reached 6m/s at 4:00 and 9m/s at 5:00. This means that Suzuka Oroshi had started to blow and the wind direction changed to westerly. The temperature at Tsu increased rapidly. That is, the air temperature at 3:00 was about 4°C and it rose to nearly 9°C at 4:00. This means that the temperature rose 5°C only in the hour, which is caused by the Föhn effect. First, temperature decreased, accompanied by a decrease of wind velocity, and after that it showed rising trend again until the highest temperature occurrence. The same trend was observed at Hikone Meteorological Observatory and in the diurnal variation of temperature curve (chain line).

A typical case of the Bora type is shown in Fig. 3-2. In the case of Bora-like Oroshi, a rapid change of temperature cannot normally be observed. This is quite different from the case of Föhn-like Oroshi. The case on October 22 in 1972 is

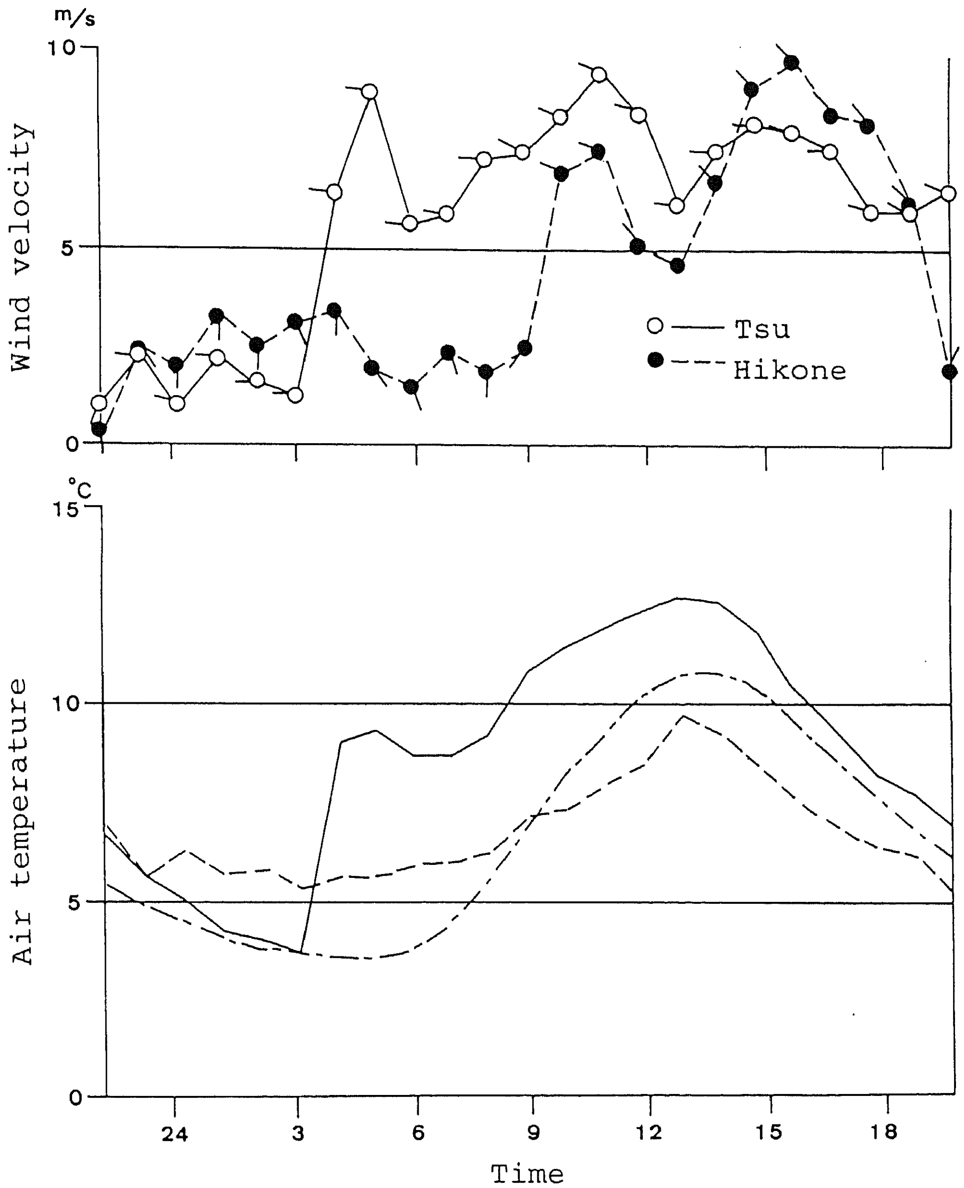


Fig. 3-1 Changes of the wind direction, wind velocity (m/s) and air temperature at Hikone and Tsu during the Föhn-type Oroshi on December 11-12, 1971. Solid line: Tsu, broken line: Hikone, and chain line: normal diurnal variation of temperature curve at Tsu.

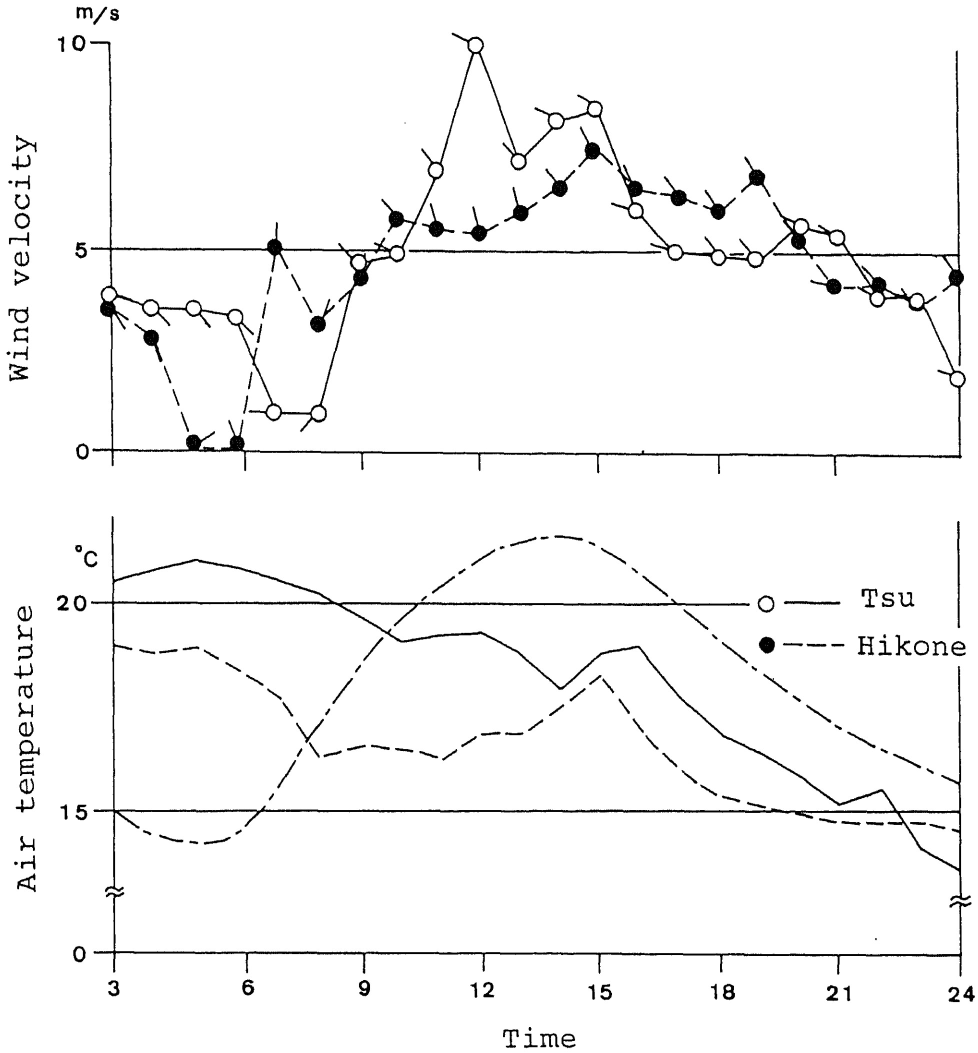


Fig. 3-2 Changes of the wind direction, wind velocity (m/s) and air temperature at Hikone and Tsu during the Bora-type Oroshi on Octover 22, 1972. Solid line: Tsu, broken line: Hikone, and chain line: normal diurnal variation of temperature curve at Tsu.

shown in Fig. 3-2. The temperature was 21°C at Hikone at 6:00. However, the wind velocity began to increase at 8:00 and reached 10m/s at 12:00. The temperature began to decrease in association with this increase in wind velocity and crossed over the diurnal variation curve at 10:00. The highest temperature was observed at 14:00 and it decreased to 17.5°C. This indicates that the air temperature was 2.5°C lower than the air temperature recorded before the Suzuka Oroshi. The temperature change at the time of the highest temperature during the daytime moved against the diurnal variation curve was observed after 16:00, accompanied by a decrease in wind velocity.

The types of Oroshi discussed above are complicated and are therefore further subdivided as shown in Table 3-5. The case (Fig. 3-3) shown here is when both the Föhn and Bora type occurred on the same day. The temperature rose 3°C at the time of the Suzuka Oroshi at 23:00-24:00 and it indicated a Föhn-like Oroshi. However, a temperature decrease was observed from 6:00 when the wind became gradually stronger. The air temperature could be expected to increase at this time, but instead, the air temperature decreased to 6°C from 6:00 to 10:00. We can observe in this case that both Föhn Type and Bora Type Oroshi are seen on the same day.

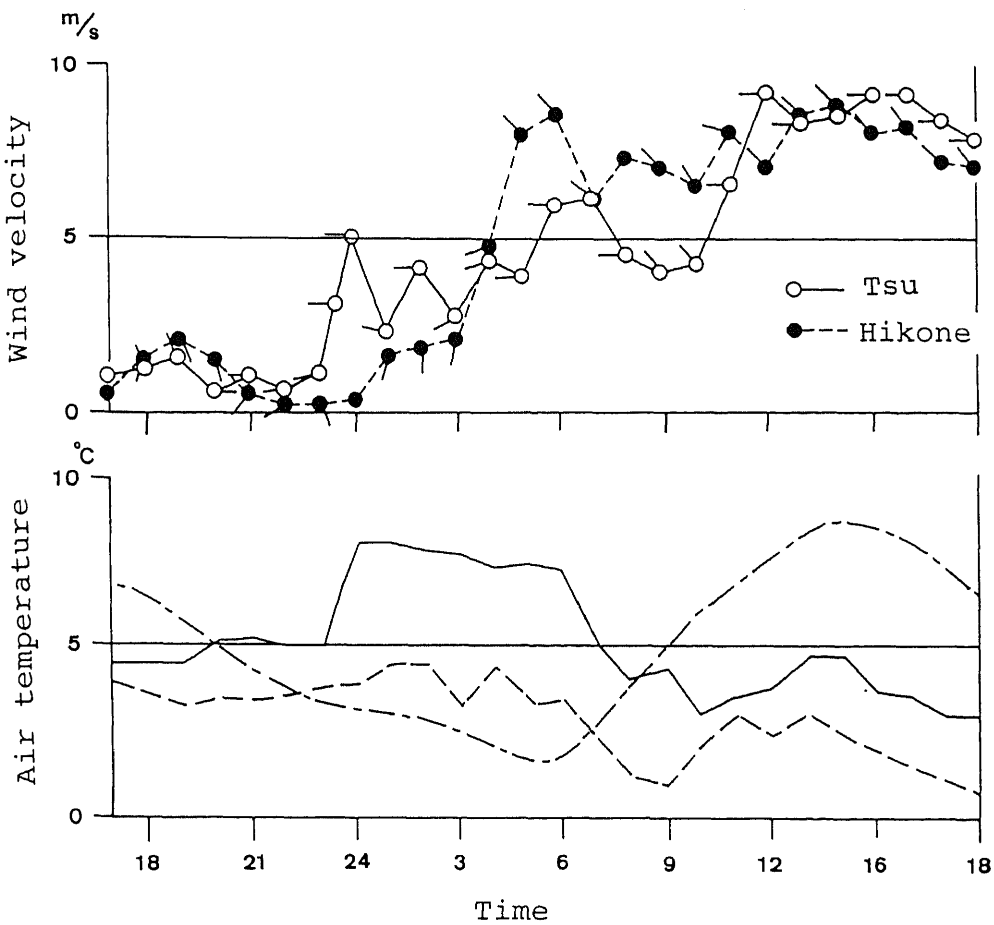


Fig. 3-3 Changes of the wind direction, wind velocity (m/s) and air temperature at Hikone and Tsu during the occurrences of the Bora and Föhn-type Oroshi on February 7-8, 1970. Solid line: Tsu, broken line: Hikone, and chain line: normal diurnal variation of temperature curve at Tsu.

CHAPTER IV. AVERAGE DISTRIBUTION OF OROSHI

1. Study Method

We have discussed the data of Nagoya and Tsu Meteorological Observatory in order to see the difference between Ibuki and Suzuka Oroshi. However, a local wind does not always blow in the same wind direction and velocity in any given area.

In this chapter we clarify the wind direction and the force of wind on the Nohbi and Ise Plains, where Ibuki and Suzuka Oroshi blow. There are quite difficult problems in obtaining long term wind data. Even when long series data can be obtained, they contain varying degrees of accuracy, so it is hard to get data on wind at many points. Wind-shaped trees are used in many cases in order to solve this problem. In this study, the winter wind-shaped trees at the Nohbi and Ise Plains are investigated, because both Suzuka and Ibuki Oroshi are local winds blowing in winter.

2.Ibuki Oroshi on the Nohbi Plain

(1) Study Area

The Nohbi Plain is a large plain of about 1,800 km^2 and is located on the leeward of a narrow part of Honshu. In winter it is subject to a monsoon (west high-east low) pressure pattern as shown in Fig. 4-1. The Northern, Eastern and Western part of the Plain is surrounded by mountains and the Southern Part faces Ise Bay. The Ibuki and Suzuka Mountains are on the west side and the Sekigahara pass is located on between. Ibuki Oroshi is apt to originate from the

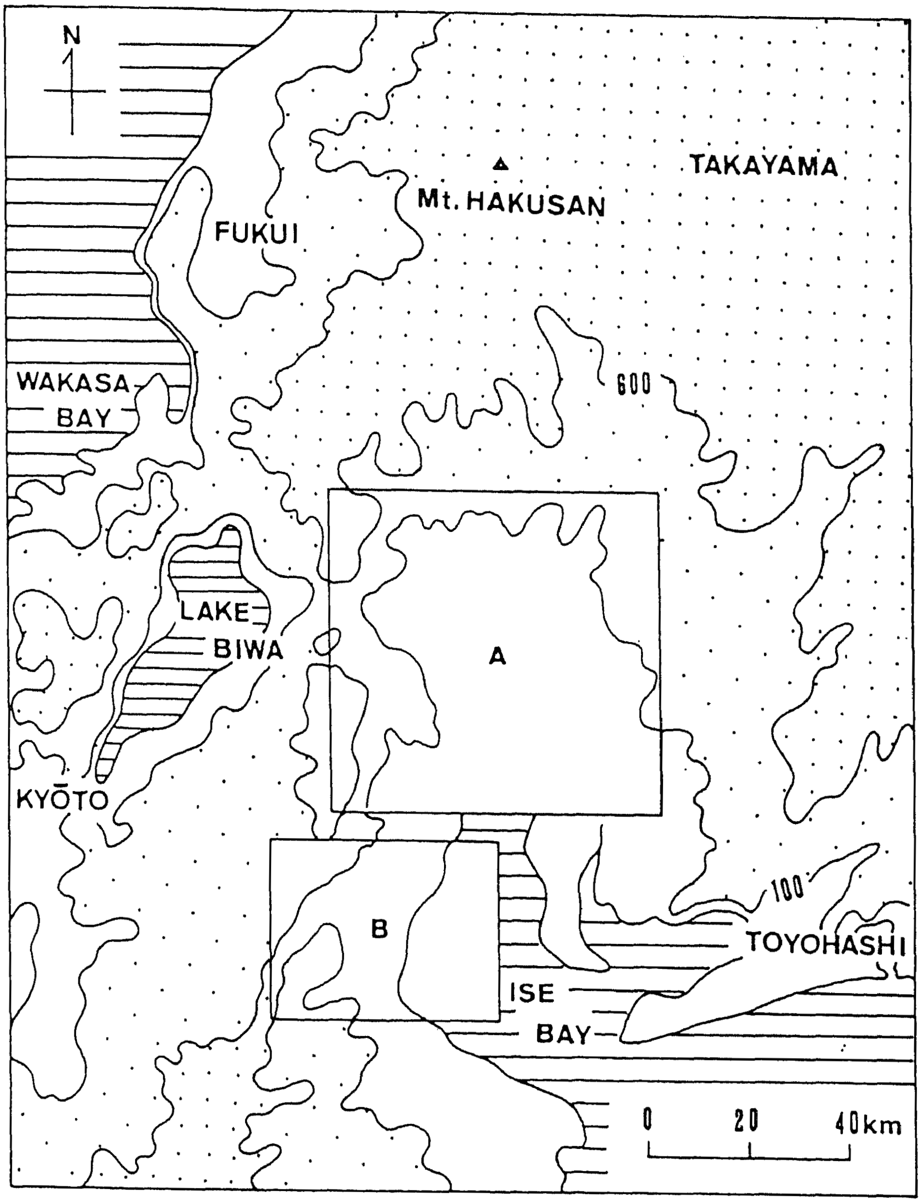


Fig. 4-1 The wind observation area estimated from the wind-shaped trees of the strong Oroshi regions on (A) Nohbi Plain and (B) Ise Plain, Central Japan.
(A) Ibuki Oroshi area as shown in Fig.4–2,3 and (B) Suzuka Oroshi area shown in Fig.4–4,5.

Sekigahara pass. Three rivers, named the Kiso, the Nagara and the Ibi in the northern part of the mountainous regions, flow down to Ise Bay in the western part of the Plain. This area forms one passage for Ibuki Oroshi to blow through.

(2) Streamlines of Ibuki Oroshi

The preliminary investigation was carried out in March, 1973 and 1974, in October,1974 and in March, 1975 (Owada, 1976). There were about 100 observation points in the Nohbi Plain. Automobiles were used as mobile observation, laboratories with instruments at the observation points. A clinometer was used to measure the direction of the wind-shaped trees and deformation scale was record for each trees.

The kinds of trees investigated were mainly Akamatsu (*Pinus densiflora*) and Kuromatsu (*Pinus Thunbergii*). Kuromatsu is dominant in Central Japan. This is because Kuromatsu has resistant power to damage by salty wind.

Fig. 4-2 shows the distribution of wind direction of Ibuki Oroshi obtained by the investigation method mentioned above. The main starting point of Ibuki Oroshi on the Nohbi Plain is not always at Sekigahara (located at the narrow part between the Ibuki and Suzuka Mountains). The upper stream of the Ibi River, which corresponds to the narrow part between the Ibuki mountainous region and Mt. Mikuni, located at the northernmost part, is another starting point. The wind direction on the Nohbi Plain is mainly NNW and it joins with north westerlies from Sekigahara pass. However, a streamline can be observedflowing eastwards along the upper stream of the Kiso River. Streamlines that flow together are divided into two wind flows. One is the wind to Ise Bay along the three rivers, Kiso River, Ibi River and Nagara River on the west side of the plain, and another is where the wind direction

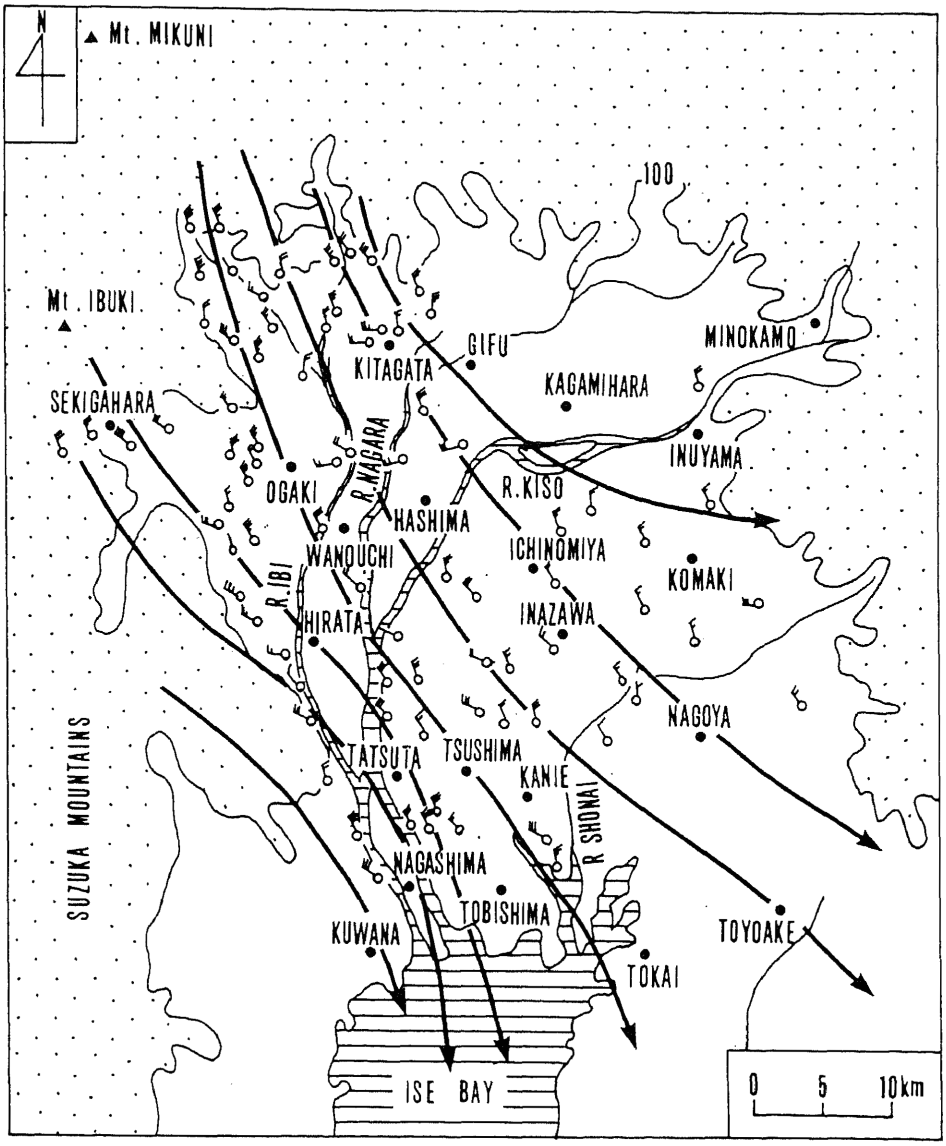


Fig. 4-2 The streamlines of prevailing wind, as estimated by the wind-shaped trees observed at about 100 points on the Nohbi Plain.

becomes NW at the central part of the plain and proceeds to Nagoya. The location of the Nagoya Meteorological Observatory is within this northwesterly streamlines. These results demonstrated that the streamlines of Ibuki Oroshi show three main air flows; westerly winds blowing in the northern part of the plain, northwesterly winds blowing in the central part of the plain and north-northwesterly winds blowing south along the three rivers on the west side of the plain. Next, we discuss the velocity of the winds.

(3) Distribution of Grades of Wind-shaped Trees

Fig. 4-3 indicates the grade distribution of the wind-shaped pine trees, Kuromatsu (*Pinus Thunbergii*). Those were investigated by Owada and Kushioka (1977), which are included in this figure.

The strong wind regions over Grade 3.0 are found in the upper streams of the Ibi River in the northern part of the plain and around Motosu and Miyama at the Neo River, which is a branch of the Ibi River. Hozumi, on the left bank of the Nagara River and Kakamigahara, on the right bank of the Kiso River are also over Grade 3.0. At Tarui a part of the outbreak from the Sekigahara pass to Ogaki, it is over Grade 3.0. The area from Wanouchi to Hirata along the Ibi River and the area from Tatsuta to Nagashima in the area of the Nagara River and the Ibi River are regions that are over Grade 3.0 in the western part of the plain. Streamline in the central part of the plain, there are widely distributed strong wind regions over Grade 3.0 along the left bank of the Kiso River.

The stronger wind region is concentrated in the northern part of the plain. Both the upper stream of the Ibi River, which is located at the narrow part between the Ibuki mountainous region and Mt. Mikuni, and the upper stream of the Neo

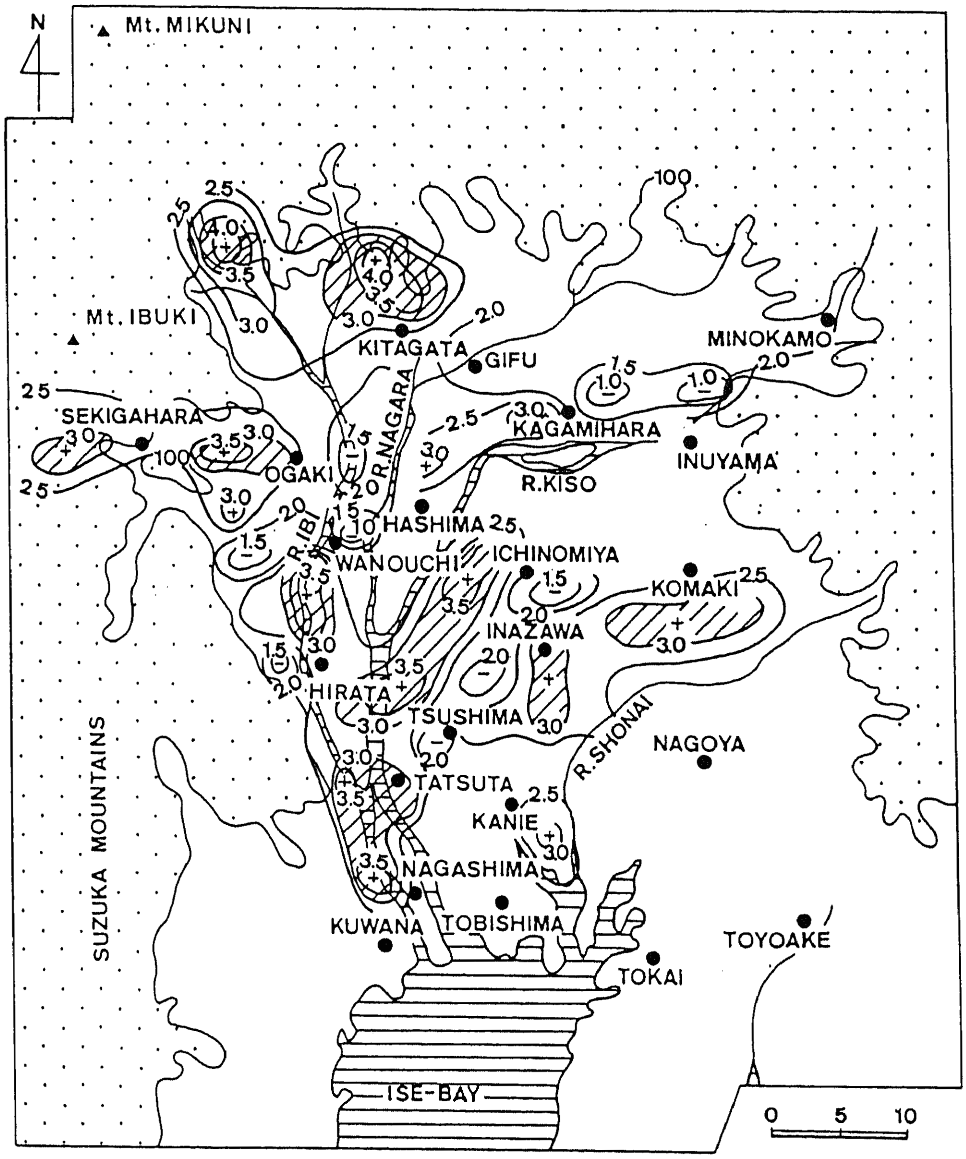


Fig. 4-3 Distribution of grades of wind-shaped trees in the strong Ibuki Oroshi region on the Nohbi Plain.

River (Fig. 4-2) are over Grade 4.0. The mean wind velocity is estimated as more than 5.5m/s by the experimental equations obtained by Owada (1976) by grading wind-shaped pine trees Karamatsu (*Larix leptolepis*) in Hokkaido in relation to monthly mean wind velocity (m/s). Around Ogaki, in the downstream area of the three rivers and in the left bank region of the Kiso River, the mean wind velocity is estimated to be over 5.0 m/s.

Weak wind regions under Grade 1.5 are seen between each of the strong wind regions. They are distributed at roughly equal intervals along the mean streamlines. This is caused by the occurrence of lee waves which originate by the wind crossing over the mountain. The upward components of the lee waves are weak on the surface and the downward components strong. The phases of the estimated lee waves are different from region to region, but roughly speaking, the average distance is 8-10km along the NW streamline from Sekigahara to the central part of the plain. Such lee waves have been observed in many regions in the world which have mountain ranges running long and straight and having a water surface or plains on the leeward. The case in the Nohbi Plain coincides roughly with the world figures summarized by Yoshino (1975).

3. Suzuka Oroshi On the Ise Plain

(1) Study Area

As shown in Fig. 4-1, the Ise Plain is separated from the large Nohbi Plain by the Yohro mountains and stretches from north to south. The east side of the plain faces Ise Bay, and the Suzuka Mountains are to the west. Mt. Ryozen (1,084 m), Mt. Gozaisho (1,210 m) and other 1,000 m level mountains are part of the Suzuka Mountain range. The distance from the foot of these mountains to Ise Bay is 15-20km. However, the Suzuka River flows from the Suzuka Mountains northeast on to the northern part of the plain, and the Anou River flows into Ise Bay on the central part of the plain, north of Tsu.

(2) Streamlines of Suzuka Oroshi

The investigation was carried out in Region B, shown in Fig. 4-1, mainly in January, September and November in 1975 (Owada and Harada, 1978). At about 65 points, observations were carried out. The trees investigated were pine trees on the Nohbi Plain: Akamatsu (*Pinus densiflora*) and Kuromatsu (*Pinus Thunbergii*).

Fig. 4-4 shows the streamlines of Suzuka Oroshi, estimated by analyzing wind-shaped trees on the Ise Plain. Suzuka Oroshi is considered by local people as a westerly wind crossing over the Suzuka Mountains. However, northwest winds blowing over Mt. Nasugahara and the Suzuka Pass southeastwards prevail on the eastern foot of Mt. Suzuka, where the Suzuka River and the Anou River flow into Ise Bay.

Locally, the winds around Kabutogoe do not flow along the valley, but tend to blow over Mt. Nasugahara. This wind streams southwards along the Anou River, proceeding to Tsu City. However, the western part of this wind region is affected by small hills and the wind direction tends to move south-westwards. The Meteorological Observatory is located within northwest wind region of the Suzuka Oroshi. In contrast to these regions, west winds can be observed 7-8km inland from Ise Bay along the Suzuka River on the northern part of the plain. They are northwest winds on the coast. This can be understood as the effect of neighboring topography on the Ibuki Oroshi blowing on the Nohbi Plain. Next, we discuss the wind velocity.

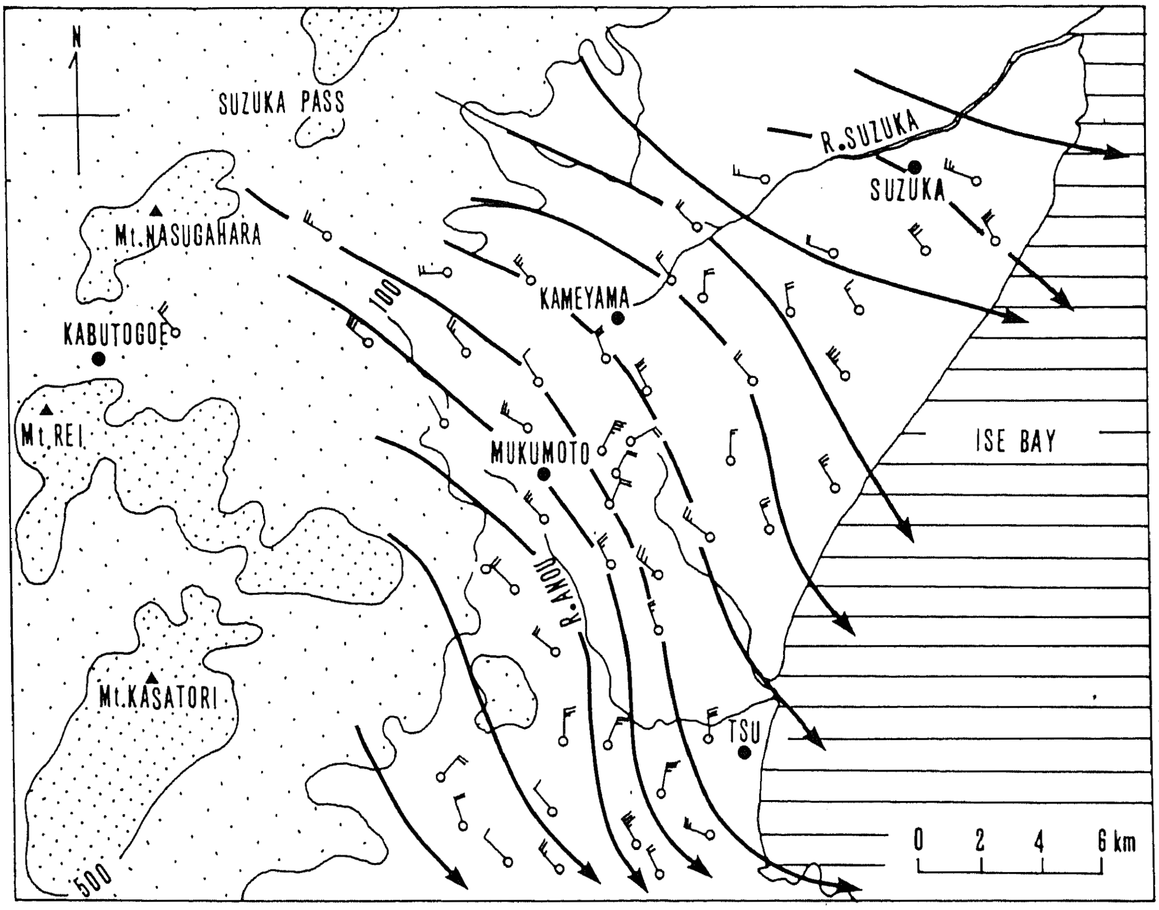


Fig. 4-4 The streamlines of prevailing wind, as estimated by the wind-shaped trees observed at about 65 points in the strong Suzuka Oroshi region on the Ise Plain.

(3) Distribution of Grades of Wind-shaped Trees

Fig. 4-5 shows the distribution of grades of wind-shaped trees on the Ise Plain. The strong wind velocity regions can be seen by the distribution of Grades of wind-shaped trees. The regions are a) from the Suzuka Pass to the south-eastwards region, b) the area from Kameyama to Mukumoto for about 5km on the leeward of Suzuka Pass, c) the area along the shore of the southern part of Suzuka City and d) the surrounding area, of which the city of Tsu is located in the center. These regions are Grade 3.0 on more. In the northern part of Mukumoto, an area 3km southwest of Tsu City and in the small coastal area south of Asuma, Grade 3.5 is seen. These strong wind regions are distributed at certain intervals and in between there are weak wind regions under Grade 2.0. This phenomenon is considered to be caused by the effect of lee wave motion, crossing over the mountains. This is similar to the phenomena mentioned previously on the Nohbi Plain. The phases of these lee waves are about 6-10km on the Ise Plain. Tsu Meteorological Observatory is located within this strong wind region.

4 Summary of Chapter IV

In this chapter an attempt was made to classify the wind direction and force of the Ibuki Oroshi on the Nohbi Plain and Suzuka Oroshi on the Ise Plain. Using the wind-shaped trees as an index, the streamlines of Oroshi were clarified. The kind of wind-shaped trees investigated are mainly Akamatsu (*Pinus densiflora*) and Kuromatsu (*Pinus Thunbergii*).

The results obtained are summarized as follows:

(A) There are three main Ibuki Oroshi streamlines on the Nohbi Plain:

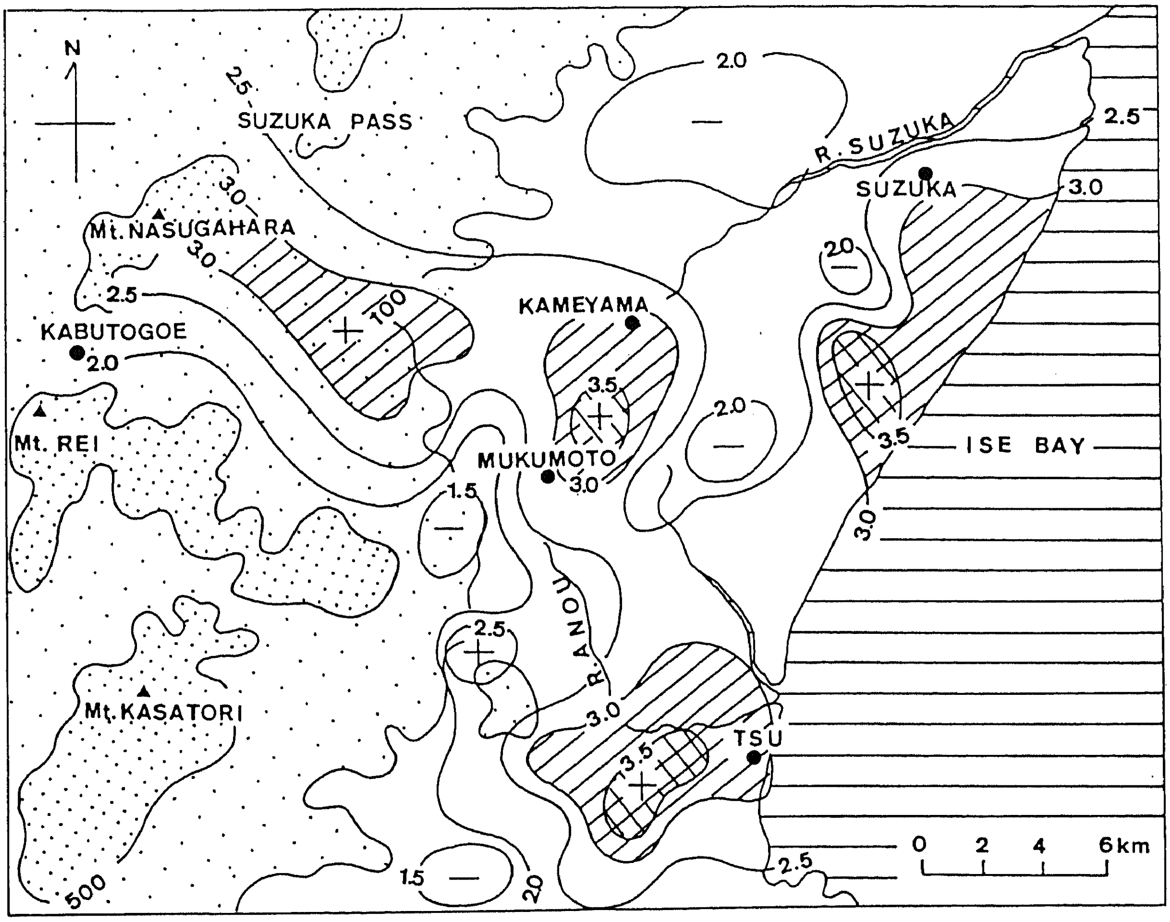


Fig. 4-5 Distribution of grades of wind-shaped trees in the strong Suzuka Oroshi region on the Ise Plain.

(i) a W wind in the northern part of the plain, (ii) a NW wind through the central part of the plain, (iii) a NNW wind along the three rivers in the west part of the plain.

The strong wind regions move along the Ibi River in the northern part of the plain, around Motosu and Miyama at the Neo River, Hozumi on the left bank of the Nagara river, and Kakamigahara on the right bank of the Kiso River. The areas from Wanouchi to Hirata along the Ibi River, from Tatsuta to Nagashima in the area of the Nagara River and the Ibi River are the strong wind regions in the west part of the plain. In the central part of the plain, there is a strong wind region along the left bank of the Kiso River.

(B) The main Suzuka Oroshi streamlines prevail on the Ise Plain: (i) NW winds, blowing over Mt. Nasugahara and the Suzuka Pass southeastwards, prevail on the eastern foot of Mt. Suzuka, where the Suzuka River and the Anou River flow into Ise Bay, and (ii) Locally, the wind flows mainly southwards along the Anou river, proceeding to Tsu City. However, the western part of this wind region is affected by small hills and the wind direction tends to move southwestwards.

The strongest wind regions originate in the Suzuka Pass and move southeast; from Kameyama to Mukumoto, which is on the leeward of the Suzuka Pass, to the area along the shore of the southern part of Suzuka City; and to the surrounding area of which Tsu City is located at the center.

CHAPTER V. LOCAL STREAMLINES CLASSIFIED BY GRADIENT WIND DIRECTION

We are trying to analyze the winds on the Nohbi Plain, because we think that the Oroshi streamline by gradient wind direction changes at the surface level.

1.Data and Method of Classification

There is little data from meteorological stations concerning the wind in these Oroshi areas. Observations have been carried out for a long time only at the Nagoya, Gifu, Tsu Meteorological Observatories as well as at Irago Weather Station and Mt. Ibuki Weather Station. We can also use data from AMeDAS and local Fire Departments. This gives us a total of about 30 regional observation points on the Nohbi Plain from the northern part of the Ise Plain to the Chita and Atsumi Peninsula. This observational region is shown in Fig. 5-1. The analyzed period was three years from 1979 to 1981 and only in winter the monsoon Oroshi occurred (5-2~9). The data previously selected took the days the Oroshi occurred and are divided by a mean wind velocity of over 15 m/s. The data were also taken hourly wind direction and wind velocity recorded by the automatic instruments. The reason we selected a mean wind velocity of over 15 m/s at Mt. Ibuki Weather Station was that the mean wind velocity of the Nagoya Meteorological Observatory is over 5 m/s. The day with Oroshi occurrence was not only determined by the wind velocity but also by the range of wind direction, which was determined from north to west. Other wind directions (easterly and southerly)

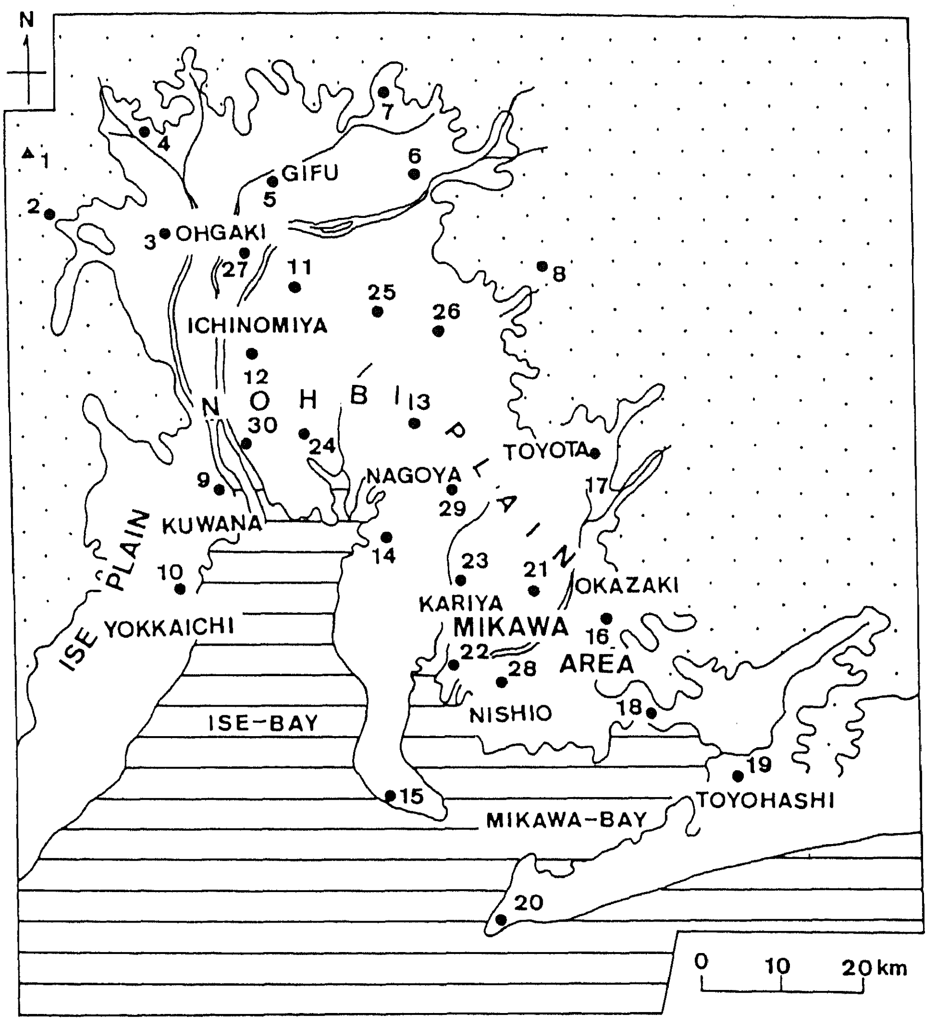


Fig. 5-1 Distribution of observation stations used in this study and topography of the Nohbi Plain, Central Japan.

which were often observed at the time trough or front was passing, were eliminated. The number of selected Oroshi days was 53. The days of Oroshi occurrence were classified by surface level gradient wind direction (NNW, NW, WNW, and W).

2. Distribution of Wind Direction at the Surface Level by Gradient Wind Direction

The streamline at the surface level, when the wind direction on Mt. Ibuki is NNW, is shown in Fig. 5-2. It is classified into four classes by wind velocity. Mt. Ibuki Weather Station is roughly equivalent to the 850mb level, because the difference of wind velocity at the 850mb level affects wind direction and velocity at the surface level.

However, as is obvious from Fig. 5-2, large differences cannot be observed in wind direction. We find only that the streamline fluctuation is larger at the surface level, when winds at the 850mb level are weaker. For example, in the case where the 850mb level wind is over 21.0 m/s, northwest winds can be observed in almost all areas, but in the case of weak winds, there is a westerly streamline on the northern part of the Nohbi Plain, and in the southern part of the Ise Bay. In this case only the streamlines from the wind outbreak points in (a) the narrow parts of the Ibuki Mountains and (b) of the Suzuka Mountains showed a northwest wind direction. Westerly winds blowing in the northern part of the Ise Plain occurred only below 20m/s in the case of the NNW wind at the 850mb level.

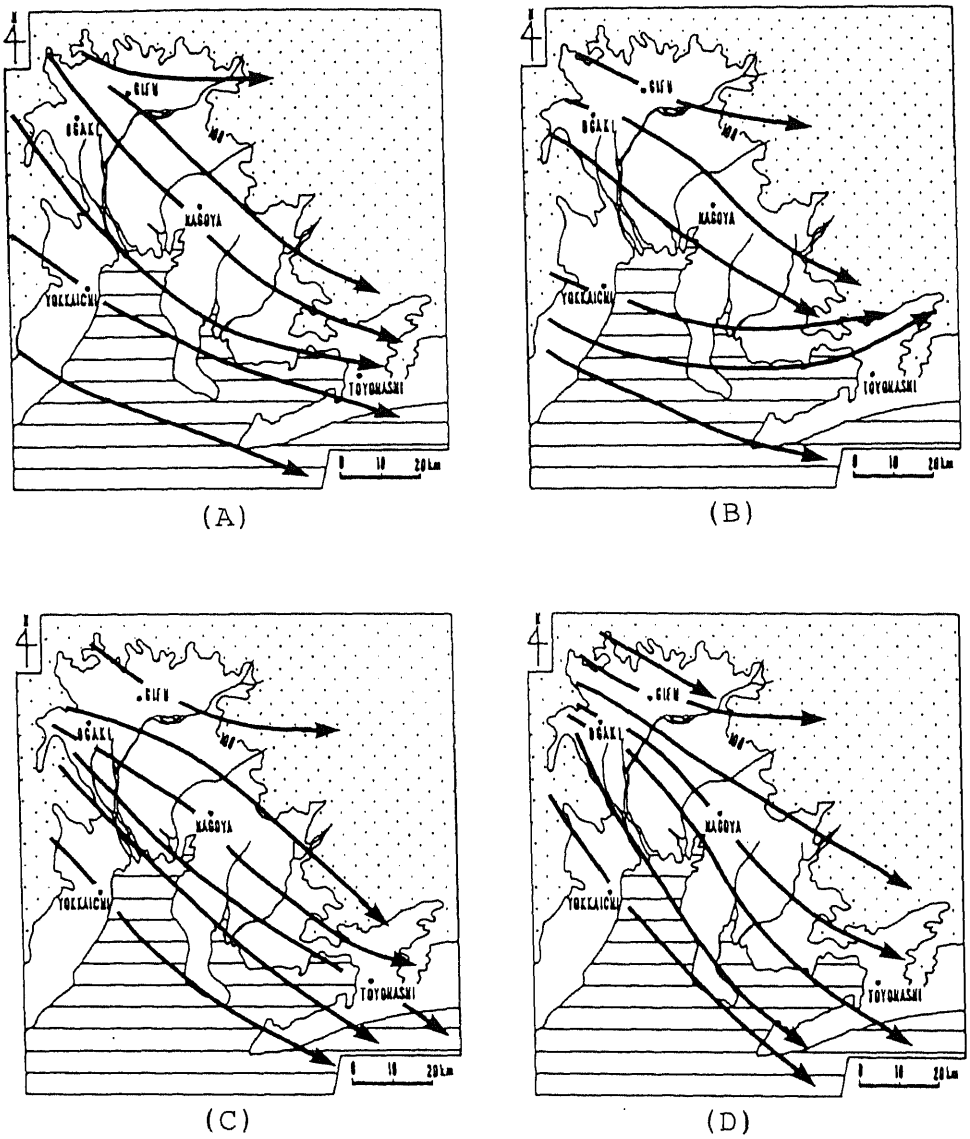
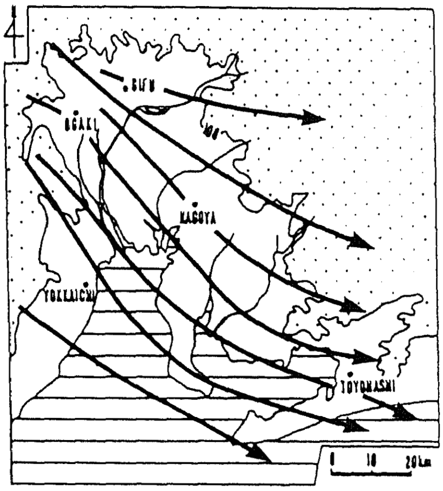


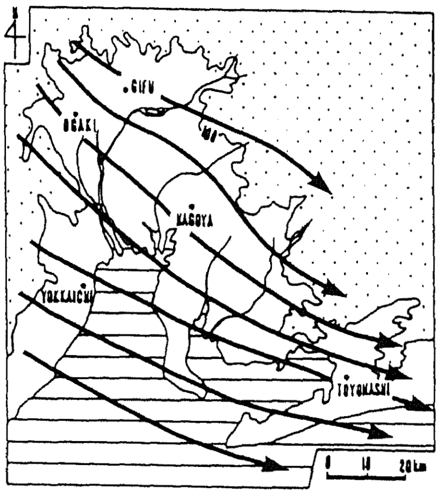
Fig. 5-2 The streamlines of mean wind direction at the surface level on the Nohbi Plain in the case of the strong Ibuki Oroshi. Gradient wind direction is NNW and wind velocity is (A) 15.0-17.9m/s, (B) 18.0-20.9m/s, (C) 21.0-23.9m/s, and (D) over 24.0m/s at the 850mb level under the synoptic situation of monsoon.

When the wind direction on Mt. Ibuki is NW (Fig. 5-3), the westerly component becomes stronger, so that the streamline can easily blow through Sekigahara Pass. However, this wind does not occur as frequently as the NNW wind, and is classified in only three stages. The occurrence of the strongest wind at the 850mb level means that it contains a strong northerly component. In the case of the 850mb level of the NW wind, as clarified in Fig. 5-3, there are several differences between the cases of the strong NW and NNW wind, but much similarity in the case of weak winds. Accordingly, westerly winds blow on the northern part of the Nohbi Plain and the northern part of the Ise Plain.

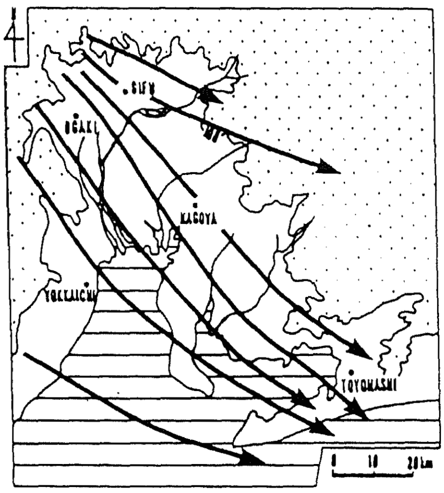
Fig. 5-4 shows the case when the wind direction on Mt. Ibuki is WNW. This wind direction is almost the same to W in Fig. 5-5. In the case of westerly winds, there is a small southerly component. These local streamlines are different from NNW-NW, when westerly winds from the Ibuki and Suzuka Mountains blow into the eastern area of the mountains without changing. The westerly streamline did not converge, and blow southwards along the east side of the mountains as a NNW-NW wind.



(A)

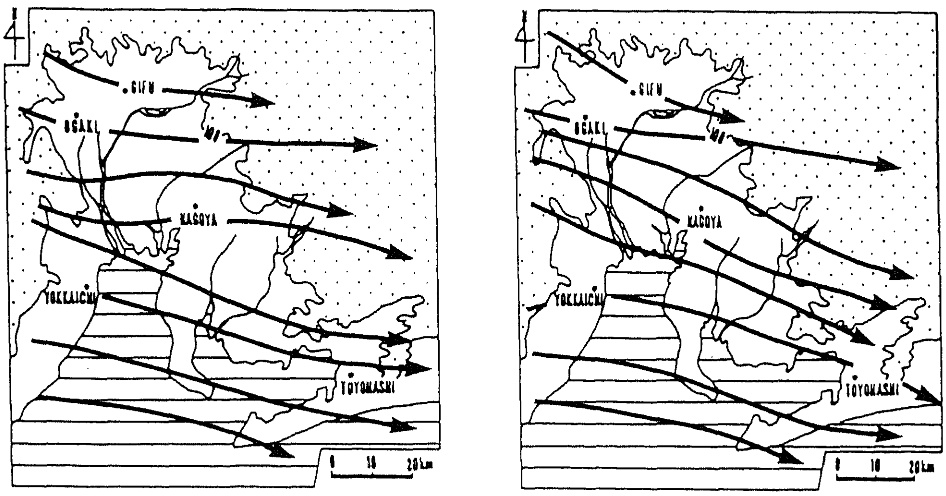


(B)



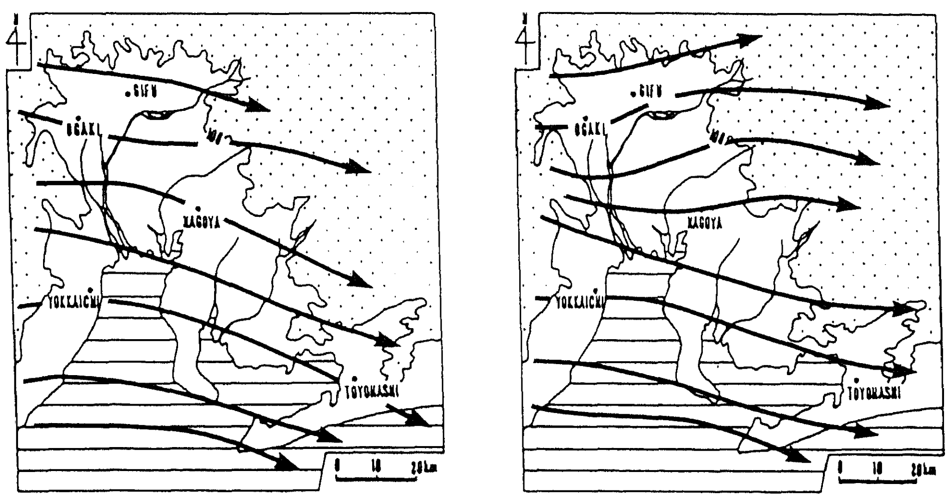
(C)

Fig. 5-3 The streamlines of mean wind direction at the surface level on the Nohbi Plain in the case of the strong Ibuki Oroshi. Gradient wind direction was NW and wind velocity is (A) 15.0-17.9m/s, (B) 18.0-20.9m/s, and (C) over 21.0m/s at the 850mb level under the synoptic situation of winter monsoon.



(A) (B)

Fig. 5-4 The streamlines of mean wind direction at the surface level on the Nohbi Plain in the case of the strong Ibuki Oroshi. Gradient wind direction was WNW and wind velocity is (A) 15.0-17.9m/s, and (B) over 18.0m/s at the 850mb level under the synoptic situation of winter monsoon.



(A) (B)

Fig. 5-5 Same to Fig. 5-4, but the gradient wind direction was W.

3. Wind Velocity Distribution at the Surface Level by Gradient Wind Direction

Figs. 5-6 to 5-9 show the distribution of wind velocity (m/s) on the Nohbi Plain according to the gradient wind direction at the 850mb level. When the wind direction is NNW as shown in Fig. 5-6, the strongest wind region appeared along the northeast streamline that blew in the central part of the plain. However, the streamline did not always correspond to the strongest wind region. In the case where the 850mb level was 15.0-17.9m/s (A) and in the case of 18.0-20.9m/s (B), the strongest wind regions appeared roughly at 20km intervals. This is considered to be related to the occurrence of lee wave motion, which is formed downstream of the air flow crossing over the mountain (as has been detected by the wind-shaped trees shown in Fig. 4-3). The areas with grade greater than 4.0 correspond to the over 6.0m/s. Upper air wind patterns are not so clear. For example, when winds at 850mb level reached 21.0-23.9m/s (C), the strongest wind region appeared to be distributed extensively in a wide area. It was distributed in the northern part of the Chita Peninsula, from the southern part of the plain to Nagoya and Kariya. The wind velocity was over 8m/s in these regions and over 10m/s in the strongest wind region at the head of the Atsumi Peninsula. The strongest wind region in the Atsumi Peninsula is not related to the strongest wind region surrounding northern part of the Chita Peninsula, but is considered as the second lee wave motion region appearing in Mikawa Bay. This second wave motion region is about 40km from the center of the first wave

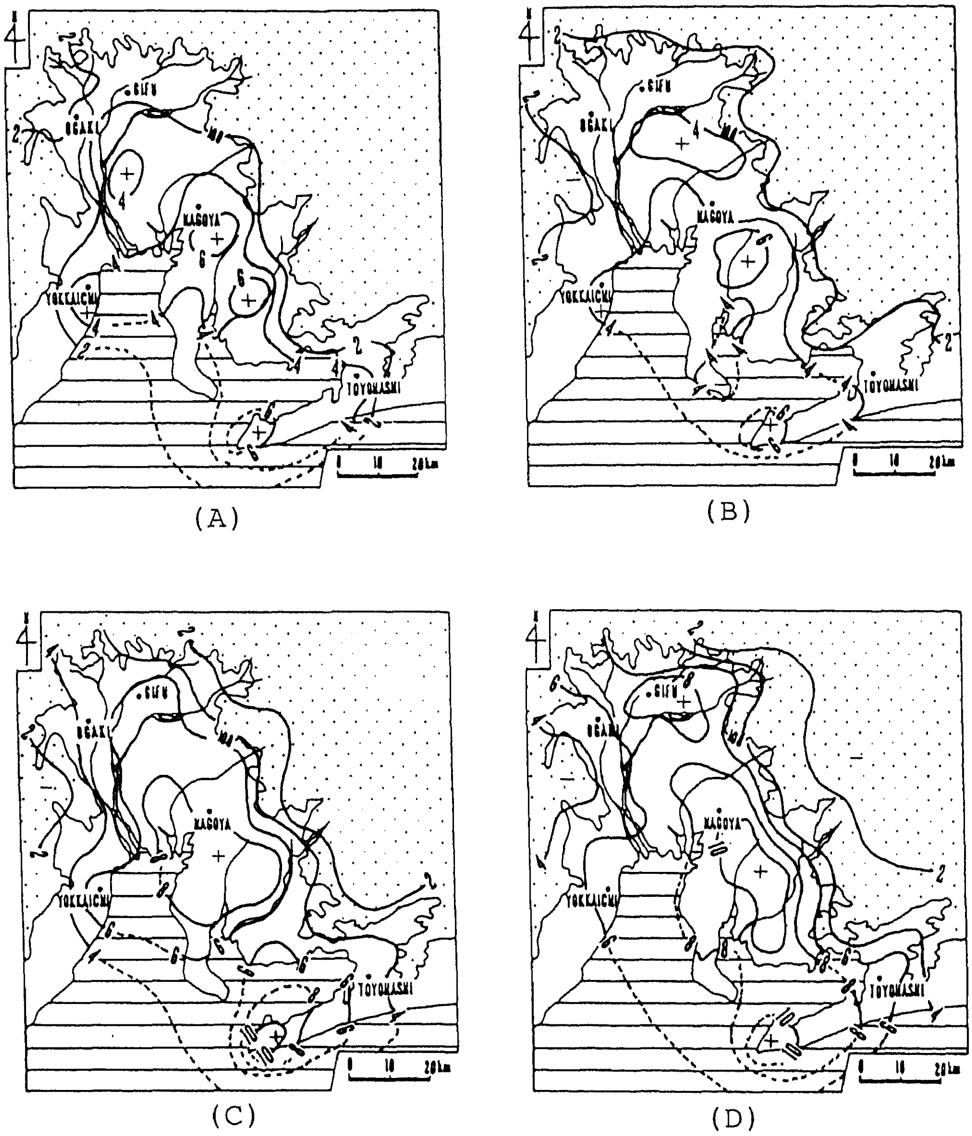


Fig. 5-6 The distribution of wind velocity (m/s) at the surface level on the Nohbi Plain in the case of the strong Ibuki Oroshi. Gradient wind direction was NNW and wind velocity is (A) 15.0-17.9m/s, (B) 18.0-20.9m/s, (C) 21.0-23.9m/s, and (D) over 24.0m/s at the 850mb level under the synoptic situation of winter monsoon.

motion region. We found that the phase of the lee wave motion became longer in proportion to the increasing force of wind at the 850mb level, even if there was a northwest streamline. The wind velocity at the head of Atsumi Peninsula was stronger than in the first wave motion region because the region was the point at which both the northwest wind blowing from the center part of the plain, and the streamline blowing from the Ise Plain.

When the wind at the 850mb level reached over 24.0m/s (D), the strongest wind region occurred in almost the same direction as the surface level by gradient wind direction. This phenomenon occurred strongly in the region from Nagoya to Kariya and proceeding to Nishio, where it reached over 19m/s. At this time, in the eastern part of the plain, around the Mikawa area, it reached over 8.0m/s. This phenomenon also appeared around Gifu between the Kiso River and the Ibi River in the northern part of the plain.

From the data mentioned above, in the case of the NNW gradient wind direction we could not identify a large difference in wind direction distribution depending on wind velocity, but each wind velocity distribution showed some special characteristics. When the Oroshi occurred and when the wind at the 850mb level was weak, the lee wave motion observed had a wavelength of about 20km. However, the strongest wind region became wider and the wave length became longer as the wind velocity on top of the mountain became stronger. Stronger winds apeeared mainly in the northern parts of the plain and on the east side of the plain as the wind velocity on top of the mountain became stronger (over 24.0m/s). This tendency occurs when the winds blow down from the northern part of the Ibuki Mountains rather than from the narrow break between the Ibuki and Suzuka Mountain.

Next, we define the NW wind as shown in Fig. 5-6. The wind direction at the surface level in this case is similar to the NNW weak wind. Therefore, the NW wind on the Nohbi Plain and the WNW wind on the Ise Plain was identified. The head of the Atsumi Peninsula, located between the NW streamline region blowing from the central part of the plain and the WNW streamline, becomes the strongest wind region (over 6.0m/s). However, these strong wind regions do not always appear in the same area, and they change depending on the wind intensity at the 850mb level. In the NW streamline blowing from the central part of the plain, the weak wind is 15.0-17.9m/s (A), and the strong wind regions are distributed from Nagoya to Kariya. When the wind becomes stronger (18.0-20.9m/s) (B), the strongest wind region over 6.0m/s appears in two places: the central part of the plain, including Ichinomiya, and in Nagoya, on the leeward. When the wind becomes strongest at the 850mb level (C), the strongest wind region appears mainly in the Mikawa area including Kariya and Nishio along with the NW streamline from the southern part of the plain. In these regions the wind velocity reaches more than 6.0m/s. The strong wind blows from the right bank region of the Yahagi River to Kariya (over 8.0m/s). When the wind velocity at the 850mb level 20.0m/s, it is obvious that there will be no great change in the distribution of wind velocities at the surface level despite a little difference in wind direction at the 850mb level.

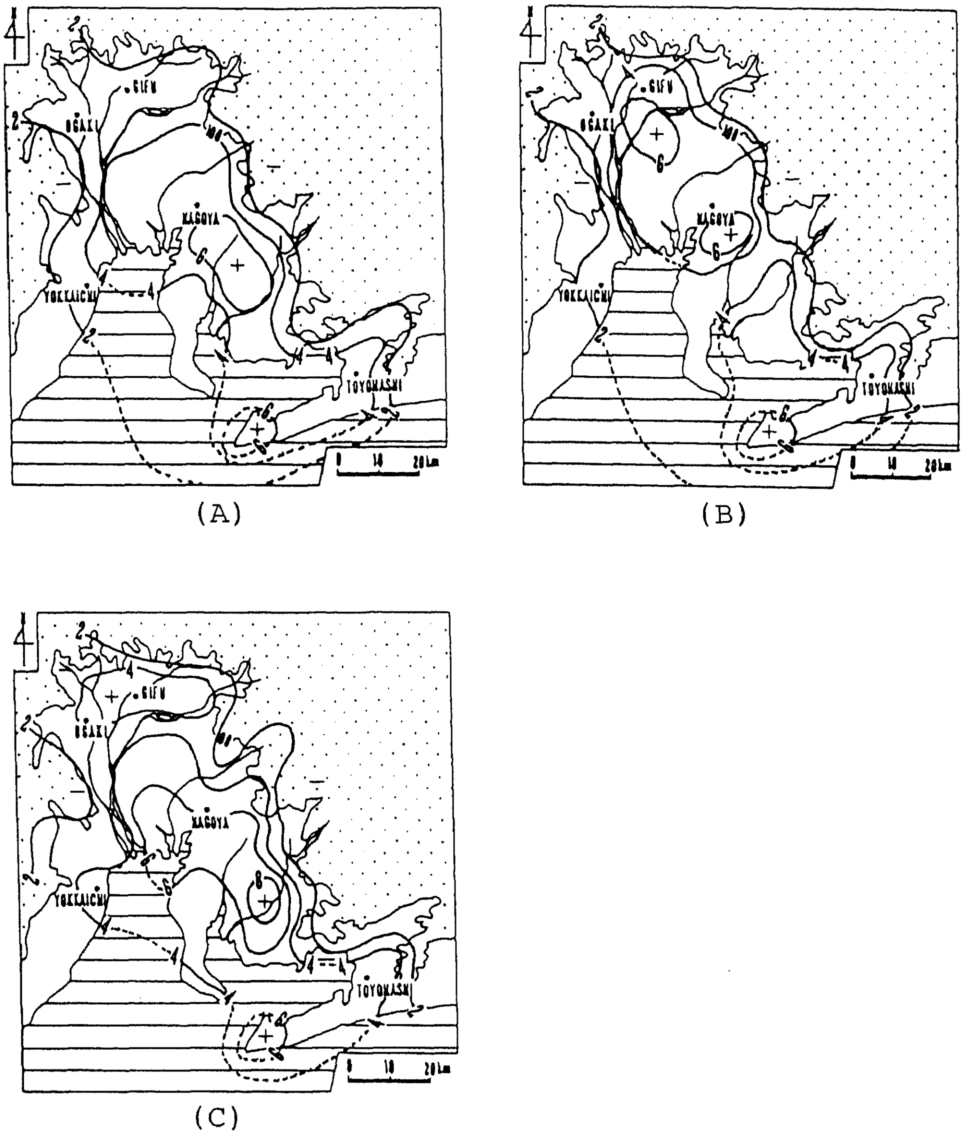


Fig. 5-7 The distribution of wind velocity (m/s) at the surface level on the Nohbi Plain in the case of the strong Ibuki Oroshi. Gradient wind direction was NW and wind velocity is (A) 15.0-17.9m/s, (B) 18.0-20.9m/s, and (C) over 21.0m/s at the 850mb level under the synoptic situation of winter monsoon.

Fig. 5-8,9 shows the case where the wind direction is WNW in the upper and W in the lower. There are a few such cases in contrast with the previously discussed NNW and NW winds. These cases are observed by data from Mt. Ibuki Weather Station.

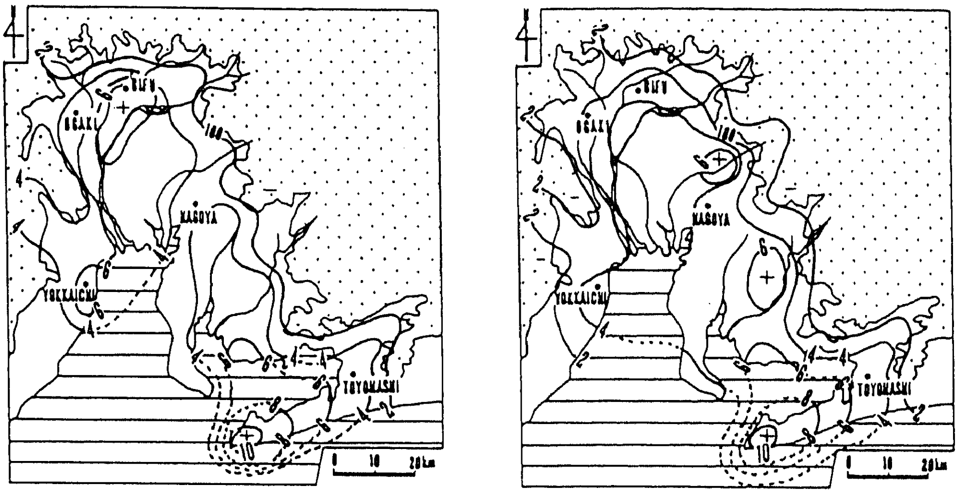
Fig. 5-8 shows the distribution of WNW wind velocity. It is classified into only two steps, as we observed only a slight difference in distribution of wind velocities. The strongest wind regions appeared around Gifu between the Kiso River and the Nagara River at the weak wind time (A). However, when wind velocities at the 850mb level reached over 18.0m/s, the stronger wind region (over 6.0m/s) not only covered the northwest part of the Nohbi Plain but also extdended to the whole of the plain. The areas from Komaki to Kasugai reached over 8.0m/s. The stronger wind region (over 6.0m/s) appeared along the right bank of the Yahagi River. These regions all have the same streamlines, so they are considered to be the effect of lee wave motion. When the pressure gradient wind direction is westerly, the whole area of the Atsumi Peninsula reaches over 10.0m/s. This might have an effect on Suzuka Oroshi, as this is not a NW streamline from Mt. Ibuki, but a westerly wind blowing across Ise Bay.

In the case where the pressure gradient wind direction is W (Fig. 5-9), there is a tendency towards a distribution from WNW to ESE. In the case where the wind velocity was 15.0-17.9m/s (A), a similar tendency is displayed. The distribution of the strongest wind region becomes larger on the northern part of the Ise Plain. However, when the wind becomes stronger as shown in (B), the wind in the northern part of the Nohbi Plain becomes weaker (4.0m/s) and in the strongest wind region the westerly wind blows against the Atsumi Peninsula towards Toyohashi. Therefore, when the pressure gradient wind direction is west, the effect of Suzuka Oroshi is large.

We have previously classified each gradient wind direction of streamline and wind velocity on the Nohbi Plain.

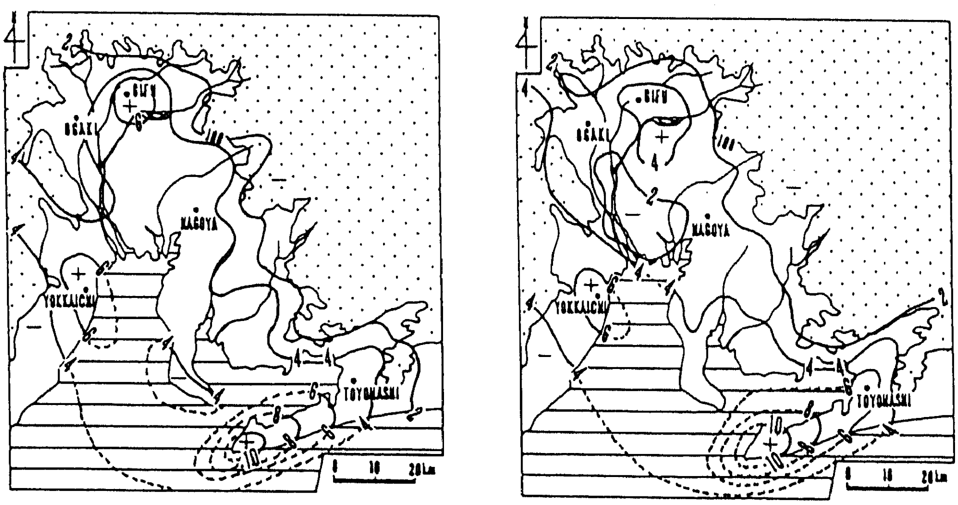
When the winds at the 850mb level are relatively weak the wind at surface level is significantly affected by local topography. When the gradient wind direction is NNW, a NW wind prevails but a westerly wind occupies the head of Chita and Atsumi Peninsula along the southern part of the coast. When the wind at the 850mb level is stronger, a northwesterly wind blows in the region from the northern part of the Ise Plain to the head of the Atsumi Peninsula. When the gradient wind direction is westerly, the streamline of the weak wind changes to NW along the eastern part of the mountainous area converges with the stronger wind.

The intensity of wind at the 850mb level makes a large difference not only to the change of wind direction but also in the distribution of wind velocities. Although the pressure gradient wind direction is the same, the appearance of the strongest wind region was different because of the wind velocity. From the Nohbi Plain through the Mikawa Plain the streamline is NW, but when wind at the 850mb level is about 20.0m/s, the strong and weak wind regions appeared at regular intervals. However, when the wind blows stronger than this, the strongest wind region is concentrated on the southern part of the coast to the Mikawa Plain. That wind reaches 8.0-



(A) (B)

Fig. 5-8 The distribution of wind velocity (m/s) at the surface elvel on the Nohbi Plain in the case of the strong Ibuki Oroshi. Gradient wind direction was WNW and wind velocity is (A) 15.0-17.9m/s and (B) over 18.0m/s at the 850mb level under the synoptic situation of winter monsoon.



(A) (B)

Fig. 5-9 Same as Fig. 5-8, but the gradient wind direction is W.

10.0m/s in the region from Nagoya to the surrounding area of Nishio and Kariya along the Yahagi River. This is caused not by the change of lee wave length of Oroshi crossing over Mt. Ibuki, but by the appearance of the first lee wave motion area from the mountainous area of Central Japan when the pressure gradient wind at the 850mb level blows strongly. Oroshi wind patterns are not simple: winds at the surface level are affected largely by wind direction at the 850mb level and wind velocity. At the same time, the strongest wind region that might be affected by the lee wave motion occurred in regular intervals on the streamline of the NW wind crossing over from Mt. Ibuki. The strongest wind regions were occurred at about 20-25km intervals.

CHAPTER VI. LOCAL CLIMATOLOGICAL STUDY ON LEE WAVE MOTION

1. Observed Results of Lee Wave Motion on the Nohbi Plain

Observational points were selected by using wind-shaped trees as an indicator. The prevailing Ibuki Oroshi on the Nohbi Plain was divided into two categories:

i) NW streamlines blowing in the central part of the plain and

ii) NNW streamlines along the three rivers on the west side.

Observations were carried out along both main streamlines. As shown in Fig. 6-1, observation points along the NW streamline were selected at Goudo-cho, upper stream of the Ibi River (St. 1), Sunomata-cho (St. 2), Kisogawa-cho (St. 3), Bisai (St. 4), Inazawa (St. 5), and in Nagoya (St. 6). On the west side, along the NNW streamline, five observation points were chosen: Tarui-cho (in the Sekigahara Pass) (St. 7), the southern part of Ogaki (St. 8), Hirata-cho (St. 9), Kaizu-cho (St. 10), and Saya-cho (St. 11).

The observations were carried out from 13:00 to 14:00 on February 8, 1975. As shown in Fig. 6-2, there was a "west high and east low" pressure pattern of the winter monsoon season on the day of observation. In this case the developed cyclone was located near the Sea of Okhotsk and an anticyclone over NE China with a center of 1040mb located at 40°N and 110°E and a strong Ibuki Oroshi was blowing on the Nohbi Plain. This pressure pattern belongs to the previously mentioned Pattern II (Fig. 2-2). The occurrence frequency of this pattern is 13.2% (Table. 2-1), but it is one of the typical Ibuki Oroshi pressure patterns. The wind at the 500mb level of Pattern II (Fig. 2-3) is almost westerly, but wind direction at the surface level in Nagoya is NW.

The observation was carried out using portable anemometers (Nakaasa type). The measurement was carried out every minute. The results are shown below.

(1) Wind velocity Distribution along the NW Streamline. Fig. 6-3 shows isopleth based on the observed values along the cross-section Sts. 1-6.

There are differences in wind velocity at all the points. A strong wind of more than 5m/s was observed at Sts. 1, 4 and 5. Wind over 7-8m/s was observed often at St. 5. In the weak wind regions of Sts. 2, 3 and 6, the wind velocity was under 3m/s. In particular, St. 3 has weaker wind. Such differences of wind velocity between observation points are considered as an effect of lee wave motion mentioned above. St. 3 is an upward wind region, St. 1 is located at the foot of the leeward of the mountain and St. 5 is in a downward wind region when the streamline is NW. The distance between strong wind Sts. 1 and 5 correspond to the wavelength about 25km. However, the wavelength is shortened to 20km when the stronger wind at St. 4 registered 6m/s (13:17, 14:12, 15:00). The wavelength became longer as the wind velocity became stronger (Arakawa and Obayashi, 1968).

Comparing the strong and weak wind regions found in Fig. 4-3 with the data in Fig. 6-4, a wind region over 6m/s appears at St. 1, and Sts. 4 and 5 This coincides with the strongest wind regions over Grade 3.0. On the other hand, St. 3 and

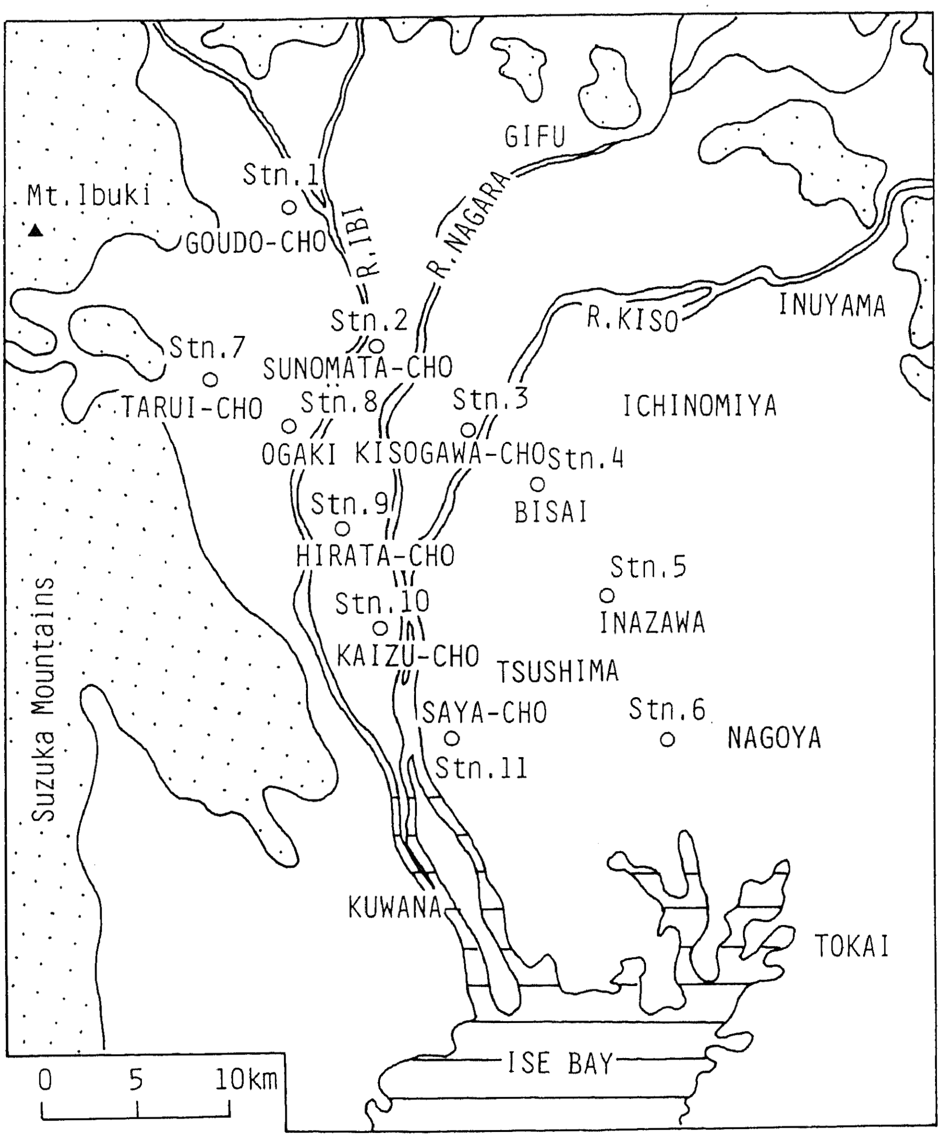


Fig. 6-1 Distribution of observation points in the Ibuki Oroshi region on the Nohbi Plain.

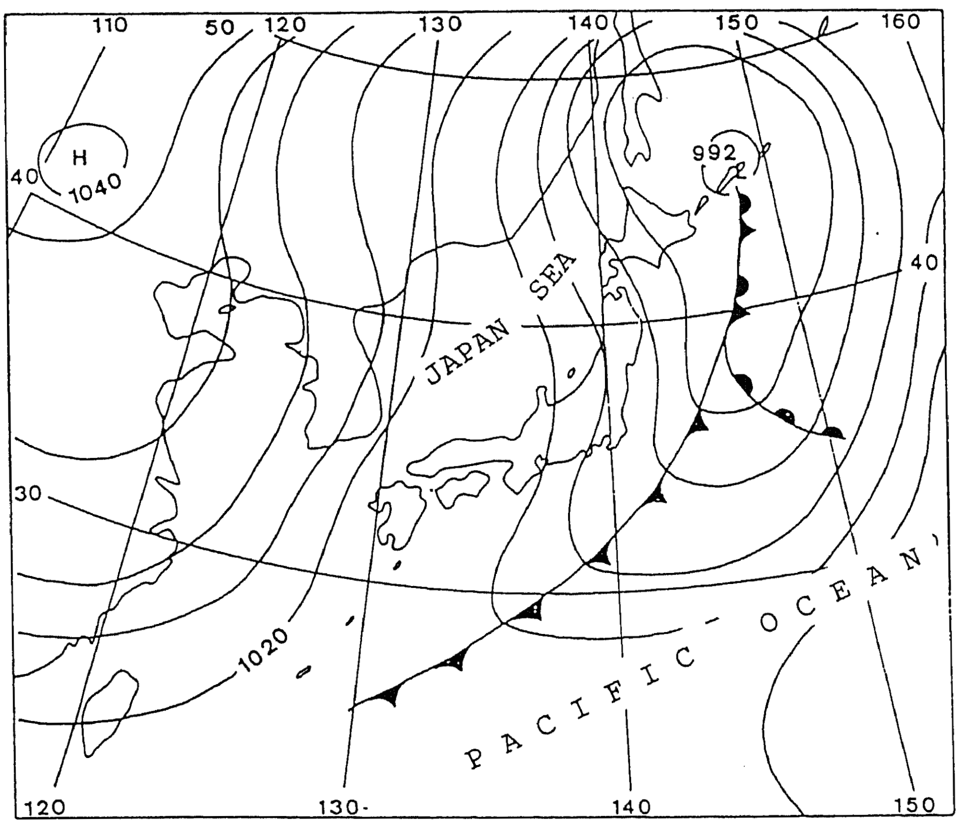


Fig. 6-2 Synoptic situation of observation day on February 8, 1975.

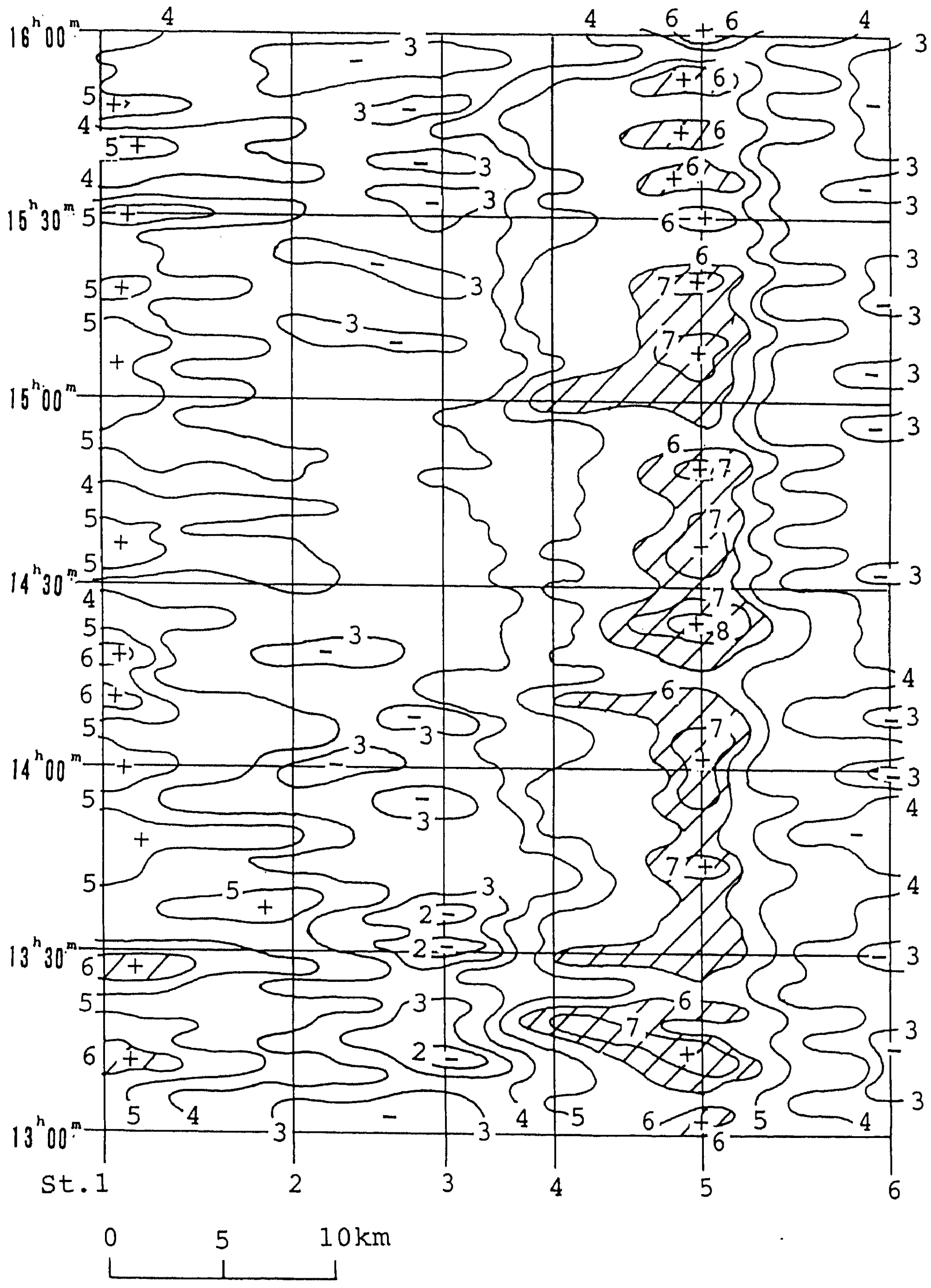


Fig. 6-3 Isopleth of wind velocity (m/s) along the cross-section Sts. 1-6 (Afternoon of February 8, 1975).

St. 6 are the regions with Grade 2.5, and St. 2 is below Grade 1.5.

(2) Wind Velocity Distribution along the NNW Streamline

The NNW streamline includes the regions from Sts. 7-11. Fig. 6-4 shows isopleth based on the observed values along the class-section Sts. 7-11. In the strong wind regions of St. 7, the wind velocity was over 6m/s and often went over 7m/s. The 6m/s wind region at times extends to St. 8 for leeward. The neighborhood of St. 9 at Hirata-cho is the weakest under 5m/s, and sometimes under 4m/s. The wind velocities at Sts. 10 and 11 were very strong, most of the time showing over 6m/s. There is a case of a wind over 7m/s appearing, but this does not occur at Sts. 10 and 11 simultaneously. This may be because the axis of strong wind migrates depending upon the intensity of the wind.

In the case of the NNW streamline along the three rivers in the west of the plain, the strongest wind regions appear at Sts. 7 and 10. Those regions are over Grade 3.0 (see Fig. 4-3). The weak region at St. 9 was under Grade 2.5. This is because the strongest wind region migrated to the leeward as suggested by observational results along the NW cross-section. The NNW streamline along the rivers (Sts. 7-11) contains small regional differences in wind velocity. The strongest wind regions occur at 15km intervals.

The NW wind is strongest at St. 5, and weak at St. 3.

The NNW streamline along the three rivers has a good time correspondence between the strongest and weakest wind regions, and lee wave motion can be clearly observed (see Fig. 6-5).

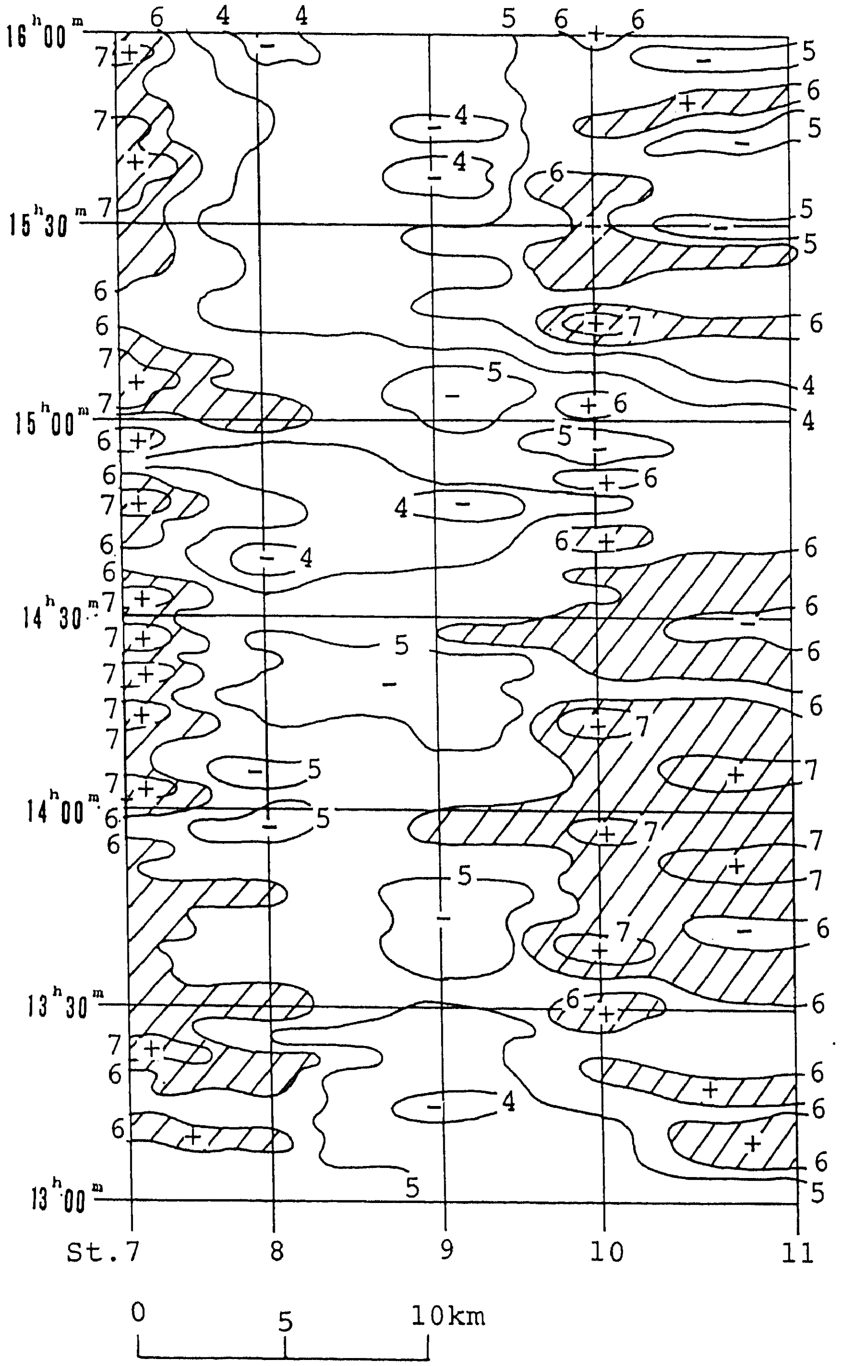


Fig. 6-4 Isopleth of wind velocity (m/s) along the cross-section Sts. 7-11 (Afternoon of February 8, 1975).

The distances between lee waves and occurrence areas of the strongest wind regions correlate well with the evidence revealed by wind-shaped trees. St. 8 is a little different because the wind velocity was higher than the mean wind velocity, and it is also understood that the wavelength difference is brought by lee wave motion. When the wind velocity at St. 7 on the windward was 6m/s, the lee wavelength was 10km, but when it rose to over 7m/s the wavelength reached 15km.

2. Theoretical Wavelength

The average wavelength was obtained from wind-shaped trees in Chapter IV and from meteorological observations in this latter chapter. Here, the wavelength is studied theoretically in order to prove this fact. It was found that the wavelength on the Nohbi Plain was about 10km. However, the strongest wind region obtained from the meteorological observation was not always coincident with the strongest wind region estimated by wind-shaped trees. The wavelength depends on wind velocity.

Theoretically wavelength is expressed by the following equation (Scorer, 1949):

$$\lambda = \frac{2\pi}{l} \qquad (6\text{-}1)$$

where l, Scorer's parameter, is expressed by the equation:

$$l = \frac{1}{u}\sqrt{\frac{g}{\theta} \cdot \frac{\partial \theta}{\partial Z}} \qquad (6\text{-}2)$$

where u is the wind component (m/s) perpendicular to the running direction of the mountain ridge at the height of the summit level; g is the acceleration of gravity; and θ is the potential temperature.

$$\frac{\partial \theta}{\partial Z} = T_z^{0.714} \times \left(\frac{R\alpha}{g}\right)^{0.286} \times 0.286 \times \gamma \times (T_z + \gamma Z)^{-0.714} \qquad (6\text{-}3)$$

where Tz is temperature (°K) of the top of the mountain, R is gas constant, γ is temperature lapse rate (°K/m) and Z is height (m) of the mountain.

$$\theta = T_z^{0.714} \times \left(\frac{R\alpha}{g}\right)^{0.286} \times (T_z + \gamma Z)^{0.286} \qquad (6\text{-}4)$$

Puting θ by equations (6-3) and $\frac{\partial \theta}{\partial Z}$ by (6-4) into equation (6-2), we obtain

$$l = \frac{1}{u}\sqrt{\frac{g}{T_z^{0.714} \times \left(\frac{R\alpha}{g}\right)^{0.286} \times (T_z + \gamma Z)^{0.286}} \times \overline{T_z^{0.714} \times \left(\frac{R\alpha}{g}\right)^{0.286} \times 0.286 \times \gamma \times (T_z + \gamma Z)^{-0.714}}}$$

$$= \frac{1}{u}\sqrt{\frac{0.286\, g\, \gamma}{T_z + \gamma Z}} \qquad (6\text{-}5)$$

The results, the wavelengths expressed by equation 6-5 are shown in Tables 6-1 and 6-2.

When the wind direction on top of Mt. Ibuki was NNW (Table 6-1), the wavelength was expressed in the range from 6.0m/s to 28.0m/s because of the wide wind range of velocity. As a result of that, when the wind velocity on top of Mt. Ibuki is as weak as 6.0-8.0m/s, the theoretical wavelength is 5.5-6.5km. The relation between mean wind velocity Wn at Nagoya Meteorological Observatory and mean wind velocity Wi at Mt. Ibuki Weather Station is expressed by the following equation:

$$Wn = 0.95\ Wi + 0.28 \qquad (6\text{-}6)$$

When we apply this equation to wind velocity on the top of Mt. Ibuki, it was about 15m/s. Thus, when wind velocity on the top of Mt. Ibuki was 14.0-16.0m/s, the wavelength was about 14km. The wavelength is considered to be about 14km on the day of occurrence of Ibuki Oroshi. This is coincident with the wavelength of the NNW wind as shown in Fig. 6-4.

When the wind velocity on top of Mt. Ibuki is over 20.0m/s, the wavelength surpasses 18km, and it reached 24.3km in the case of the strongest wind velocity (28.0m/s). This analysis also fell in line with the previously mentioned results of the meteorological observation of February 8, 1975. The wind direction on top of Mt. Ibuki was NNW, and maximum wind velocity was 18.7m/s. It was 6m/s on the surface level, and it was found at St. 7 as shown in Fig. 6-5. A strong

Table 6-1 The lee wavelength (km) estimated from the climatic element on Mt. Ibuki (1377m).

Wind direction is NNW.

Wind velocity on Mt. Ibuki (m/s)	Lee wavelength (km)	
	theoretical reserch	observation result
6.0	5.5	
8.0	6.5	
10.0	7.9	
12.0	10.9	
14.0	14.3	
16.0	14.0	
18.0	16.0	15 (fig 6.4)
20.0	18.0	
22.0	19.1	
24.0	22.0	
28.0	24.3	

Table 6-2 The lee wavelength (km) estimated from the climatic element on Mt. Ibuki (1377m).

Wind direction is NW.

Wind velocity on Mt. Ibuki (m/s)	Lee wavelength (km)
6.0	5.0
8.0	6.4
10.0	8.8
12.0	9.8
14.0	12.5
16.0	14.6
18.0	14.4
20.0	17.3
22.0	18.0
24.0	22.1

wind region of over 6m/s also appeared at St. 10, and the distance between the strongest wind regions between St. 7 and 10 were about 15km (estimated from Fig. 6-5).

The case of the NW wind on top of Mt. Ibuki is shown in Table 6-2. A slight difference of wind direction on the windward brings out small differences in wavelength. Large changes were not observed. The wavelength of the NW wind became slightly shorter. However, in general, when a local wind blows and wind velocity on the top of Mt. Ibuki is 16.0m/s, the wavelength is 14.6km and it is longer than in the case of NNW. Here, the expression of the wavelength is not only a factor of wind velocity on the windward but also of some other climatic element, so it is impossible to accept as a general tendency.

From the above mentioned facts, the wavelength could be expressed by including the data from the top of Mt. Ibuki into the experimental equation of Scorer (1949). As a result, a significant correlation with high reliability is seen between the calculated values and observed values. It also proves that there is a close relation between the wavelength and wind velocity on top of the mountain. As Arakawa and Obayashi (1968) and Scorer (1953) mentioned, there is a tendency for the wavelength in lee wave motion to become longer when the wind velocity becomes stronger.

Fig. 6-5 shows the relationship between wind velocity on top of Mt. Ibuki and wavelength. There is a positive correlation, and (correlation coefficient) reached 0,992 in the case of the NNW wind. The relationship between the

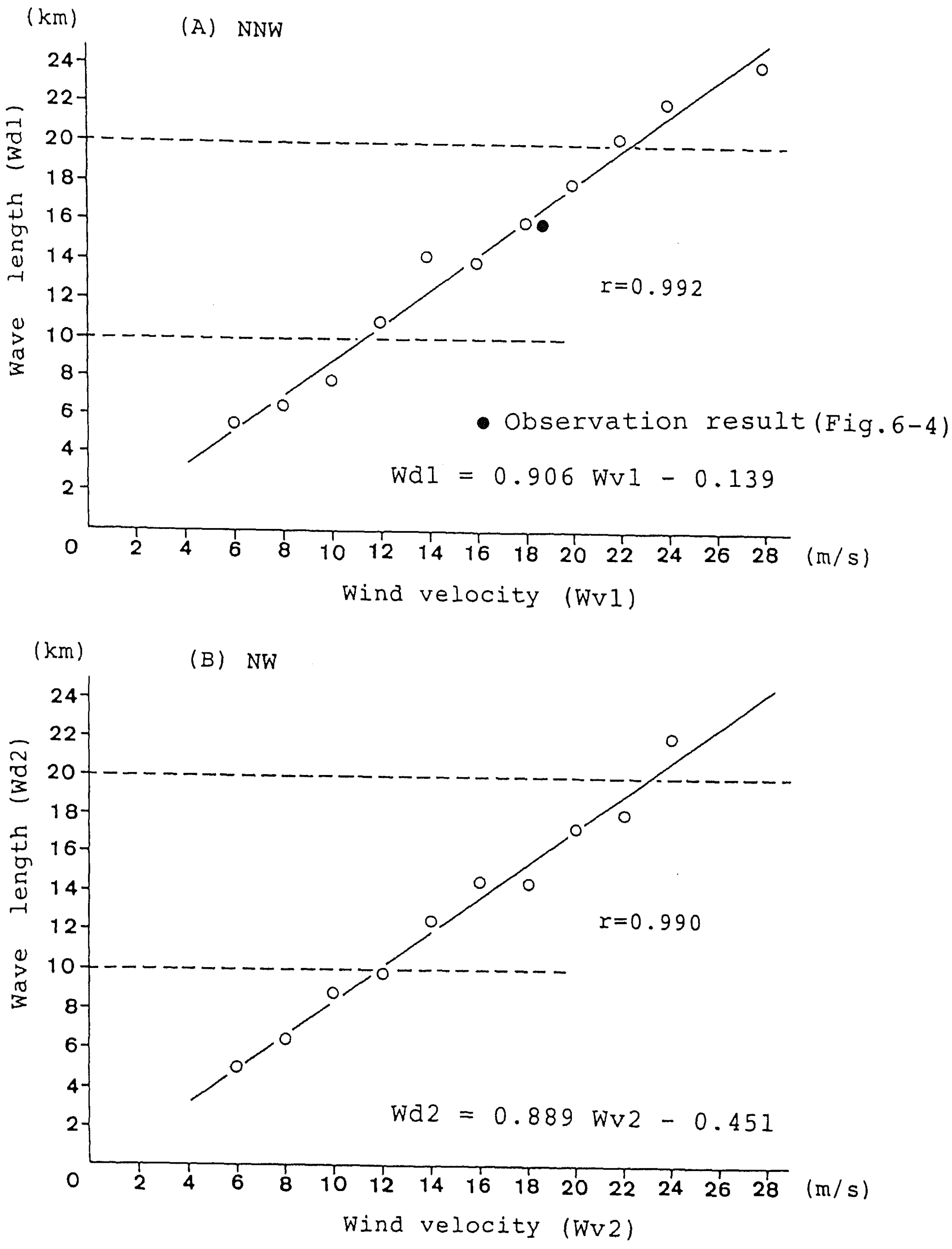


Fig. 6-5 The relationship between wind velocity (m/s) on top of Mt. Ibuki (1377m) and wavelength (km) on the Nohbi Plain. Upper part (A): wind direction is NNW and Lower part (B): NW.

stronger. The maximum wind velocity on top of Mt. Ibuki was 18.7m/s, and the wavelength was about 15km during the present observation (February 8, 1975). Applying this wavelength to the experimental equation of Scorer (1949), it is shown that it is about 16km and the wavelength coincideds with the results of metorological observations.

The mean wind velocity on top of Mt. Ibuki was equivalent to 15m/s on the day of Oroshi occurrence, and the theoretical wavelength was about 14km.

The wavelength of lee wave motion previously estimated has been summarized by Yoshino (1975, 1986) as shown in Table 6-3. Among these wavelengths, the longest is 15-30km at Black Mountain in England, and 11-25km in the Rocky Mountains in the U.S.A. In the Sierra Nevada in the U.S.A., the wavelengths ranged from 4.4-28km. However, a short wavelength range (5-8km) was observed at Crossfell in England, and in the French Alps (5-10km). Thus, the range of the wavelengths of lee wave motion in the world is 5-30km. The wavelength of lee wave motion at Mt. Ibuki obtained in this research was 8-10km, estimated from the wind-shaped trees. It was 10-25km as a result of meteorological observation, and the wavelength obtained from the experimental equation of Scorer (1949) was 14-15km.

From the facts mentioned above, the wavelength of lee wave motion at Mt. Ibuki is rougly equal to the average wavelength in the world.

Table 6-3 Wavelenghts of lee waves observed in various regions (Complied by Yoshino).

Mountains	Wavelength	Literature
Riesengebirge(Sudeten)	8-15km	Koschmieder(1921)
Crossfell, England	5-8	Manley(1945)
Jämtland Mountains,Sweden	8-10	Larsson(1954)
Sierra Nevada, U.S.A	4.4-28	Holmboe et al.(1957)
French Alps	5-10	Gerbier and Bérenger (1960,1961)
Rocky Mountains, U.S.A.	11-25	Vergeiner and Lilly(1970)
British Isles	5-13	Stringer(1972a)
Black Mountains,England	8-10 15-30	Starr et al.(1972)
Dinar Alps, Yugoslavia	10-12	Yoshimura et al.(1974)
Ibuki Mountain	8-15	Owada(1976)

VII. CONCLUSION

This research was carried out in order to clarify the conditions of the local winds called Ibuki and Suzuka Oroshi that blow during the winter monsoon season on the Pacific side of Central Japan. Local winds are winds that occur under certain synoptic conditions in particular regions surrounded by specific topography; Föhn of the Alps in Europe, Chinook on the east side of the Rocky Mountains, and Bora in Yugoslavia are typical examples. Oroshi on the Pacific side of Japan is also an example. Both Oroshi in Japan and Bora in Yugoslavia occur in association with the outbreak of cold air from the Siberian anticyclone in winter that develops in the Eurasian Continent. Oroshi in Japan is the outbreak of cold air of the "west high and east low" pressure pattern in the winter monsoon, which is formed between the Siberian anticyclone and the Aleutian low. As a result, all these winds crossing over the mountain range are usually cold and dry. The Nohbi Plain, where Ibuki Oroshi prevail, is located on the leeward of the mountain range of the narrow Japanese Islands. The Ise Plain has the same topography. Therefore, people who live in these regions have a close relationship with wind, which is a factor in cultivation of agricultural products, house construction, etc. The height of the mountain is 1,200-1,300m in this area, and it plays a role topographically encouraging the formation of mountain waves. In this area meteorological disasters often occur regarding ship navigation and the departure and arrival of aircraft. However, there has been almost no research on Ibuki and Suzuka Oroshi.

In this research, we have clarified the relationships between the Ibuki and Suzuka Oroshi, using local meteorological observations. The results can be summarized as follows:

(i) When we observe the occurrence frequency of the Ibuki and Suzuka Oroshi, every five-days mean for the past ten years, we can see that the number of days of occurrence of Ibuki Oroshi was appeared frequently from the 11th five-days mean through the 18th five-days mean and Suzuka Oroshi was appeared frequently from the 72nd five-days mean through the 8th five-days mean. Suzuka Oroshi appear at a higher frequency than Ibuki Oroshi during the blowing period. The probability of simultaneous occurrence of both local winds is low, and this occurred about once in each five-days mean.

(ii) The Oroshi can be classified into six main pressure patterns named Pattern I to VI. The center of the cyclone in Pattern I is located roughly at 35°N off the coast of the Boso Peninsula. The center of the cyclone in Pattern II is located in the Sea of Okhotsk. Pattern III showed a developed cyclone located over the Northern Kuril Islands. Pattern IV showed a double-cyclone type, and Pattern V is a typical "trough" type. Pattern VI also resembles this type, but the cyclone is located in the Japan Sea and on the Pacific coast of Japan.

(iii) On the day of occurrence of Ibuki Oroshi, the wind direction at the 500mb level is often NW or NNW, and the Suzuka Oroshi often blow. When the wind direction at the 500mb level is WNW, both Ibuki and Suzuka Oroshi occur at the same time. The location of the trough at the 500mb level is 140°E for the Ibuki Oroshi and 130°E for the Suzuka Oroshi in most cases. When the trough develops at 135°E, the occurrence frequency of Ibuki and Suzuka Oroshi is high.

(iv) The occurrence of highest wind velocity of Ibuki Oroshi is between 10:00 to 18:00 (80%), and especially between 14:00 and 16:00 (over 40%).

However, Suzuka Oroshi does not always occur during the daytime; it often occurs from 4:00 to 6:00.

(v) We investigated synoptic conditions on the days of occurrence of Oroshi on the Pacific side of Central Japan to determine whether Suzuka Oroshi are Föhn-like or Bora-like Oroshi. We recognized that the Föhn Type occurred about 63% of the time. The Bora Type occurred only 21% of the time. Both Föhn and Bora Type occurred simultaneously 15% of the time.

(vi) In order to chart typical Oroshi streamline, classification of wind-shaped trees (*Pinus Thunbergii*) was carried out on the Nohbi and Ise Plains. Three main systems of streamlines were found on the Nohbi Plain. Westerly winds blow in the northern part of the plain, northwesterly winds blow in the central part of the plain, and north-northwesterly winds blow south along the three rivers on the west side of the plain. However, on the Ise Plain, northwesterly winds blow in the east foothills of the Suzuka Mountains where the Suzuka River and the Anou River flow into Ise Bay. Westerly winds were observed at the northern part of the plain, but they changed to northwest on the coast.

(vii) We have classified the distribution of pressure gradient wind directions and local streamlines using AMeDAS and data from local Fire Departments. When the upper air flow velocity (850mb) is relatively weak, the wind at the surface level is greatly affected by the local topography. That is, when the pressure gradient wind direction is westerly, streamlines with weak winds change to northwesterly in the eastern mountainous area, and form a convergence region.

(viii) Both mountainous areas on the windward of Ibuki and Suzuka Oroshi have the height of 1,200-1,300m, so that mountain waves easily occur. Therefore, the *altocumulus lenticularis* clouds (which are often observed to the 850mb level of Oroshi regions) are considered to be one of the effects of lee wave motion. We extrapolated the wavelength from wind-shaped trees in order to confirm this lee wave motion. The wavelength was 8-10km.

(ix) By studying the distribution of wind at the surface level, we can see that the strongest wind regions are distributed in certain intervals when wind to the 850mb level is over 20m/s. The strongest wind regions occur every 20-25km intervals on the NW streamline.

(x) This can also be shown through cross-sectional observation along the streamline. Each strong wind region occurred on the NW streamline on the Nohbi Plain at 20-25km intervals. However, the wavelength on the NNW streamline was 10-15km.

(xi) When we try to express the theoretical wavelength of Mt. Ibuki by using the experimental equation of Scorer (1949), the wavelength is over 18km in the case of a 20m/s wind on top of Mt. Ibuki. In the case of the maximum wind velocity of 28.0m/s, the wavelength is 24.3km. The average wavelength (average wind velocity on top of Mt. Ibuki was 15m/s) was about 14km.

(xii) When we look at wavelengths in other parts of the world, we see that the longest wavelength is 15-30km at Mt. Blacks in England, and the shortest one was 5-8km at Crossfell in England, so the range is 5-30km. Thus, the Mt. Ibuki wavelength is of average length.

Acknowledgements

This study is the result of 15 years of work. The author gratefully acknowledges the guidance and advice of Professor Masatoshi M. Yoshino of the University of Tsukuba. The author is also grateful to Professor Takeshi Kawamura, Professor Toshie Nishizawa and Associate Professor Tetsuzo Yasunari of the University of Tsukuba for their suggestions.

The author also thanks Mr. Tatsuhiro Nakamura and Mr. Mitsunori Yamada of the graduate school of Aichi University of Education for their logistic support, as well as Miss Masako Suga for her excellent work in calculation.

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