

## Variation in Wind in the Region around Ise Bay

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### Abstract

In order to examine the wind-driven circulation in Ise Bay, wind distribution in the surrounding region of Ise Bay is examined with reference to its seasonal and daily variations. The wind data during 1987-1996 are observed by AMeDAS of the Japan Meteorological Agency. It is shown that the northwesterly monsoon wind from the Eurasian Continent dominates from November to April in the following year. The northwesterly wind is the strongest in the surrounding region of Ise Bay; its intensity increases in the downstream direction. The northwesterly wind suddenly weakens in May. In summer, a southerly sea breeze together with the divergence over the Ise Bay relatively dominates around Ise Bay. Daily change is also found in the northwesterly wind in winter and southerly sea breeze in summer. The northwesterly wind is relatively strong during the daytime and weak during the nighttime. The summer sea breeze in the western and northern surrounding region of Ise Bay has a maximum peak during the daytime, while the duration of the southerly wind is relatively long in the western region of Ise Bay and no prominent peak in its intensity is detected.

**Key words:** Land and sea breeze, Monsoon, local wind and the Ise Bay

### 1 Introduction

Sea and oceanic circulation is generated by wind stress on the sea surface, thermohaline effect and tidal forces<sup>1,2,3)</sup>. As for wind-driven circulation, to evaluate the wind stress over the sea surface is very important for the estimation of the flow patterns of the sea and ocean circulation.

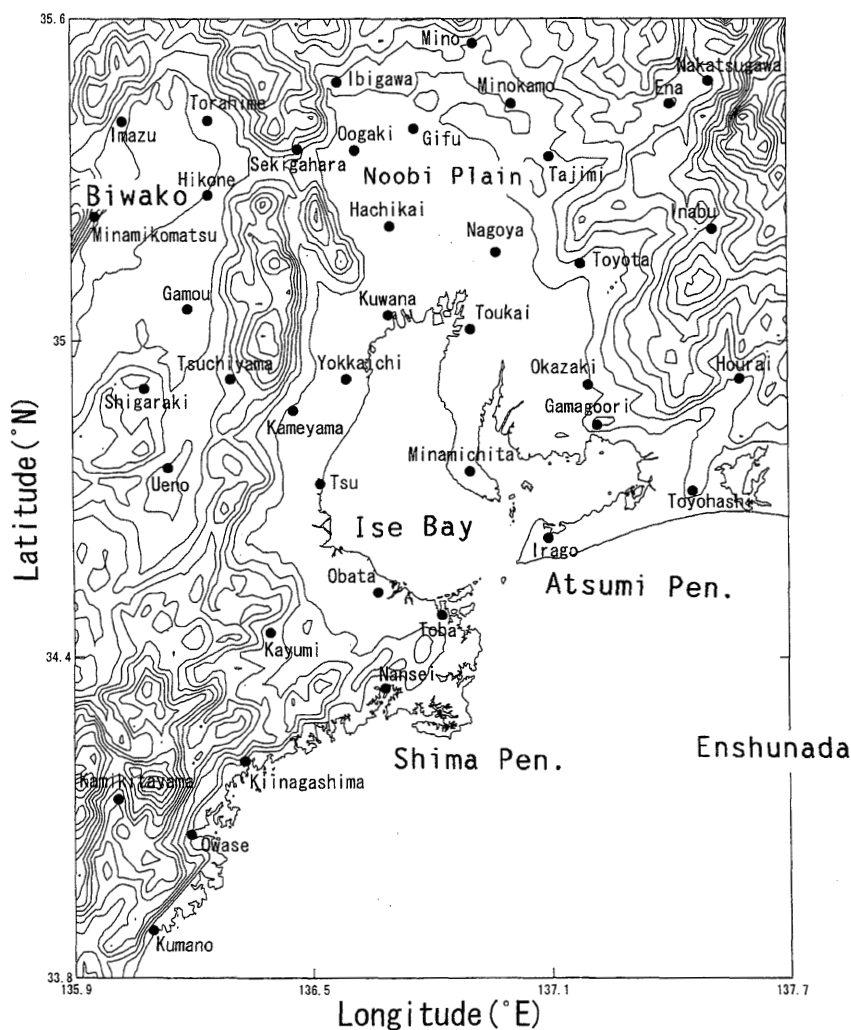
There have been various studies on the wind distribution in the central Japan<sup>4,5)</sup>. In particular, the interaction between sea breeze and valley wind induces the extended sea breeze into land<sup>6,7,8)</sup>. In winter, northwesterly wind caused by the winter monsoon from Eurasian Continent dominates in the central region of Japan. Especially, it was pointed out that strong fall winds come to Ise Bay after going over northern mountains, where there exist two famous fall winds known as Ibuki Oroshi and Suzuka Oroshi<sup>9)</sup>. In summer, southerly sea breeze is relatively dominant and some local fronts are formed over and around Ise Bay<sup>10)</sup>. Mori et al.<sup>11)</sup> shows that the interaction between sea breeze from Ise Bay and that from Enshunada is significant in summer, giving way to deeper intrusions of sea breeze into the Noobi plain.

However, all of the previous studies focused on relatively local meteorological phenomena with short time periods. General characteristics of the annual and daily variations in the wind distribution over Ise Bay have not been well examined so far. In the present study, in order to see the wind-driven circulation in Ise Bay,

long-term wind data over 1987-1996 are analyzed to detect the general tendency of the variation in wind stress over and surrounding regions of the Ise Bay. In the next stage, wind stress over the sea surface of Ise Bay will be estimated and the wind-driven circulation of Ise Bay will be examined.

## 2 Data

Figure 1 shows observational points of the wind. The wind data over 1987-1996 are observed by the AMeDAS employed by Japan Meteorological Agency. Wind is observed every one hour at each observational station shown in Fig. 1 and the accuracy (unit) of the wind speed is  $1 \text{ m sec}^{-1}$ ; the wind direction is observed as relative to 16 directions.



**Fig. 1** Observational stations of AMeDAS in the central region of Japan, used in the wind analyses of the present study. The contour of height above the sea level is also shown with an interval of 10 m.

### 3 Results

Monthly mean wind distribution is shown in Fig. 2. Northwesterly wind, which is caused by the winter monsoon from the Eurasian Continent, generally dominates from November to April in the following near. The northwesterly wind is strongest in the surrounding region of Ise Bay and relatively weak in the mountain areas. Over the Ise Bay, the northwesterly wind is intensified in the downstream direction of wind.

The northwesterly wind suddenly weakens in May around Ise Bay. The sudden change of the wind distribution over Ise Bay in May coincides with the change in vertical water temperature distribution in Ise Bay<sup>12, 13)</sup>. Namely, the vertically homogeneous distribution of water temperature by the formation of the mixed layer in winter is suddenly changed to summer temperature pattern with a seasonal thermohaline in the upper layer. Although the northwesterly wind is suggested to have an effect to maintain the mixed layer

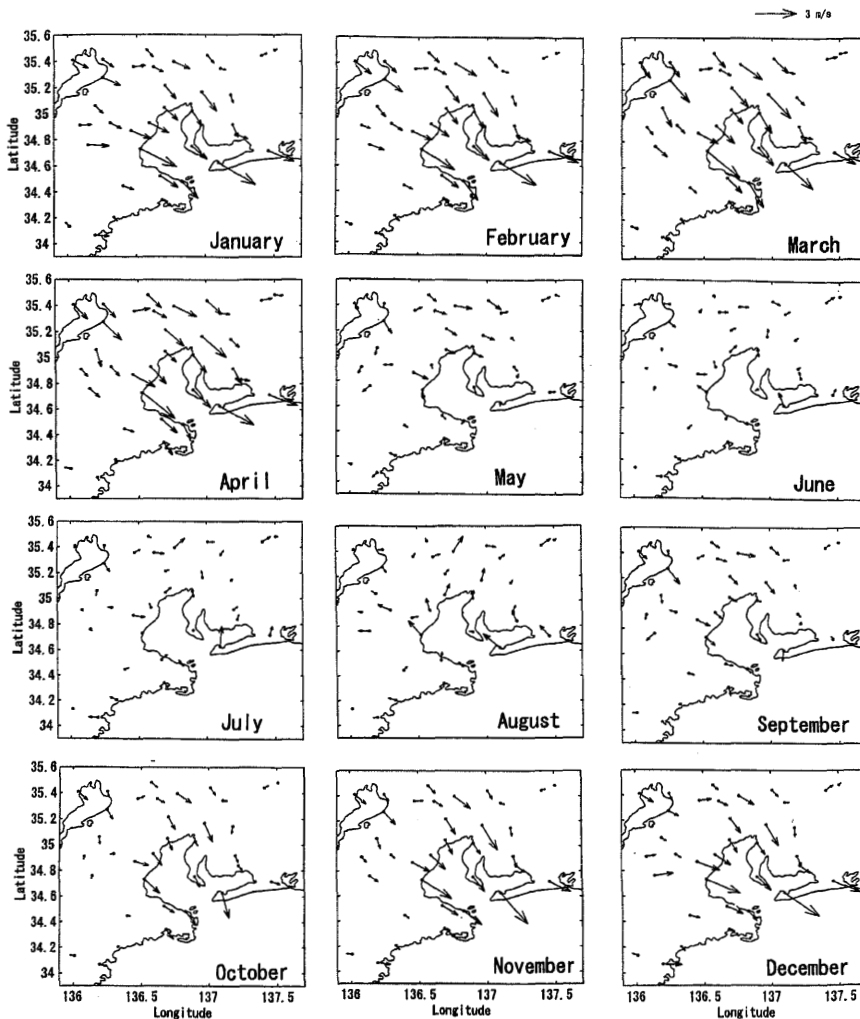


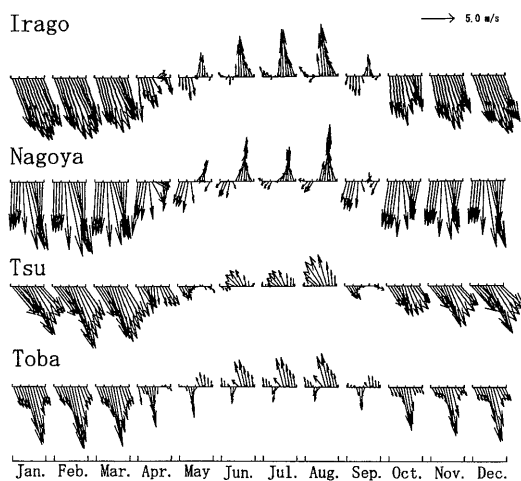
Fig. 2 Monthly mean wind over 1987-1996.

of the bay water up to April, the formation of the seasonal halocline and pycnocline have already been accomplished in April<sup>12, 13)</sup>. Therefore, the mixed layer has not been maintained up to May, because the wind effect seems to be secondary for the formation of the seasonal thermocline. It is thus suggested that the heat budget in the upper layer of Ise Bay is essential for the formation of the seasonal thermocline.

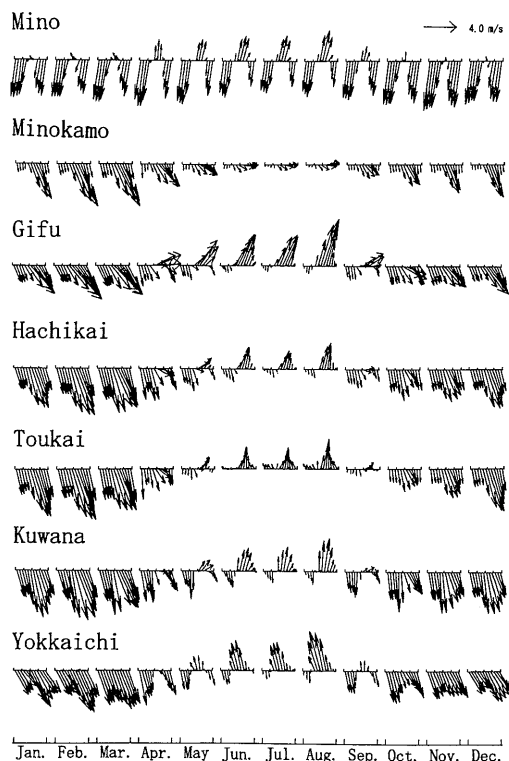
In summer, southerly wind relatively dominates around Ise Bay (Fig. 2). Especially, in August, the southeasterly wind is observed in the western surrounding region of the bay, but the southwesterly wind is detected in the eastern surrounding region. Therefore, the southerly wind diverges over Ise Bay. As the divergence of the wind over Ise Bay influences on the flow condition of the bay, details of which will be discussed in section 4.

The daily and seasonal variations in wind are shown in Figs. 3-6. The northwesterly wind shows a prominent diurnal variation at some places such as Toba (Fig. 3), Minamichita and Okazaki (Fig. 5a), but no clear diurnal variation is found at other places. To see this more clearly, the spatial distribution of the wind during night and day is compared in Fig. 7. It is shown that at day time the northwesterly wind is relatively strong in the coastal area around Ise Bay.

It is also shown from Figs. 3-6 that the southerly sea breeze in the western and northern regions of Ise Bay in summer has a maximum peak in daytime, while relatively long duration of the southerly wind without prominent peak is detected in the western region around the Ise Bay. Namely, at Irigo and Nagoya (Fig. 3), Hachikai, Tokai (Fig. 4), Okawzaki, Gamagori and Toyota (Fig. 5b), northerly wind is observed in



**Fig. 3** Hourly and monthly mean wind over 1987-1996. Each group of arrows show the hourly mean wind for each month. The upward (downward) direction shows southerly (northerly) wind and reference velocity scale is shown in right top.



**Fig. 4** Same as in Fig. 3 but for other stations.

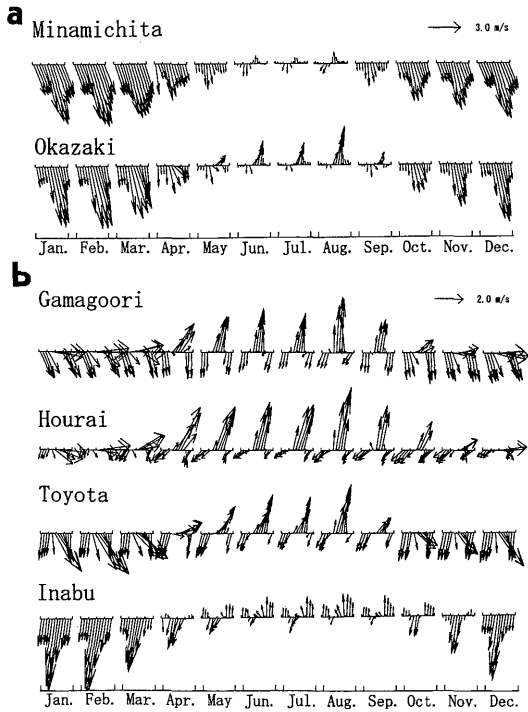


Fig. 5 Same as in Fig. 3 but for other stations.

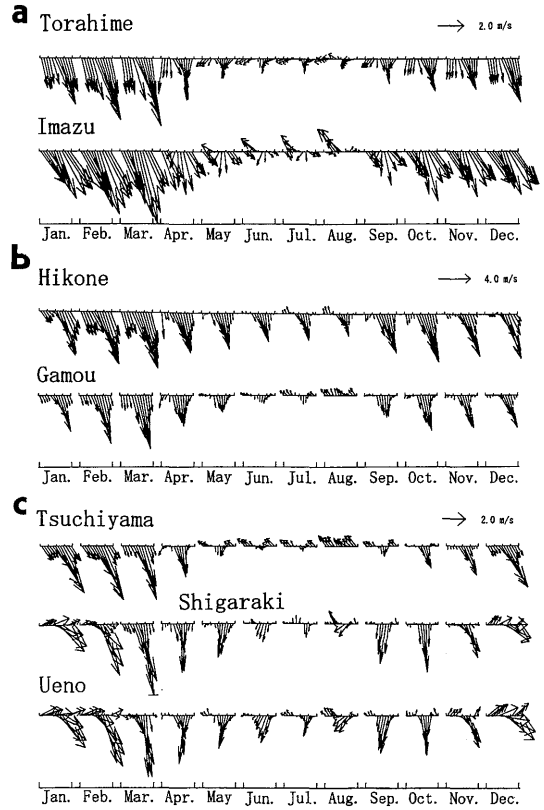


Fig. 6 Same as in Fig. 3 but for other stations.

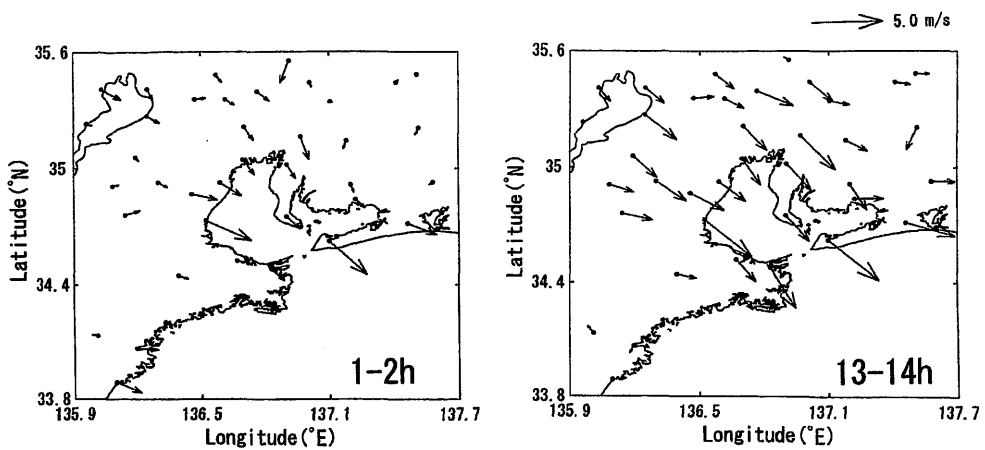


Fig. 7 Hourly mean wind over December to February during from 1 to 2 am (left) and from 13 to 14 (right).

early morning and then it changes later to southerly sea breeze wind. In contrast to this, at Tsu and Toba (Fig. 3), Kuwana and Yokkaichi (Fig. 4), southeasterly wind is prominent all the daytime and the period of the northwesterly wind at night is decreased from Kuwana to Tsu.

To see the difference in southerly sea breeze more clearly, the spacial distribution of wind in summer is shown in Fig. 8. It is shown that the sea breeze begins at 9-10 in morning in the western surrounding region of the Ise Bay, while the sea breeze becomes dominant in the eastern side after 11-12. The southeasterly wind dominates in the western surrounding region of Ise Bay, but southwesterly wind prevails in eastern surrounding region. Therefore, splitting or divergence of the southerly sea breeze into the eastern and western sides of Ise Bay is resulted over Ise Bay.

It is shown from Figs. 6 and 8 that weak sea breeze is observed in the surrounding region of Lake Biwako in summer. If we consider the sea breeze, the wind direction of Imazu and Hikone (Fig. 1) must be opposite. In summer, northerly wind is observed at Hikone and southeasterly wind is seen at Imazu. The sea breeze during 9-14 is also perceived at Minamikomatsu (Fig. 8). However, it is seen from Fig. 8 together with the wind change at Gomou shown in Fig. 6b that the sea breeze is confined to the coastal region of Lake Biwako.

Power spectra of wind at Toba and Irigo are shown in Fig. 9. Almost similar power spectrum is obtained at all the other stations. Significant clear peaks with period of a day and about a year are detected commonly. There exists a weak minimum with a period of 70-100 days. So other peaks with a periods of several days, about a month and a year are perceived in a general tendency.

#### 4 Summary and discussion

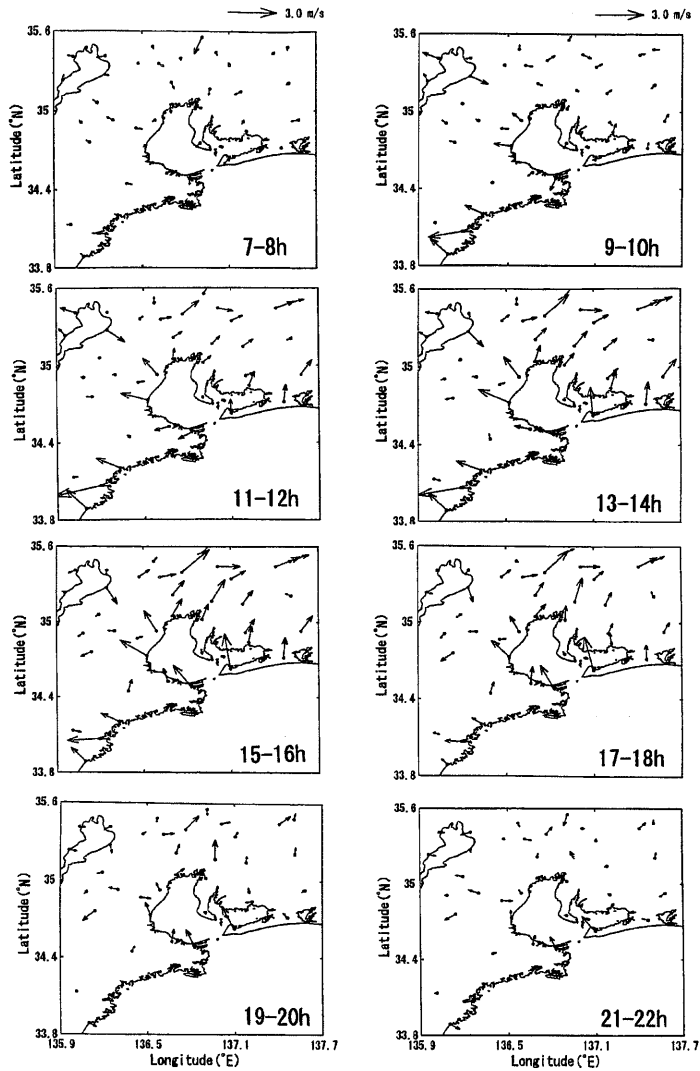
In order to examine the wind-driven circulation in Ise Bay, wind distribution in the surrounding region of Ise Bay, was examined with reference to its daily and seasonal variations.

Northwesterly monsoon wind from Eurasian Continent dominates from November to April in the following year, which is the strongest in the surrounding region near Ise Bay. In summer, southerly sea breeze relatively dominates in the surrounding region of the bay. The southerly wind seems to diverge over Ise Bay.

The daily change is also observed in the northwesterly wind in winter and the southerly sea breeze in summer. At night, the northwesterly wind is relatively strong in the coastal area of Ise Bay, but the northwesterly wind intensifies in the day time. The summer sea breeze in the western and northern regions of Ise Bay has a maximum peak in daytime, while duration of the southerly wind is relatively long in the western region of the bay.

Based on these results, the circulation in Ise Bay is discussed in the following. Over Ise Bay, the northwesterly monsoon wind is more intensified in the downstream direction. If the rotation effect of the earth (Coriolis force) is weak, the divergence of the upper layer of the bay is suggested from the wind distribution and the upwelling of deep layer water in Ise Bay and surface flow toward offshore area are induced. If the rotation of the earth is included, the Ekman transport<sup>1, 2)</sup> flows southwestward and a high sea level area and/or an anticyclonic circulation is generated in the southwestern area in- and off Ise Bay.

In summer, the divergence of wind over Ise Bay is detected for the southerly sea breeze. In case of no rotational effect of the earth, the upwelling of lower layer water into upper layer is suggested, while a cyclonic circulation is formed by stretching of water column<sup>1, 2)</sup> due to the rotational effect of the earth.



**Fig. 8** Two hours mean wind in summer (July to August). Time of average is shown in right bottom of each panel, in which two hours of averaging time, for example 7-8h (hours), corresponds to the period from 7 to 9 am.

However, both suggestions disagree with the observational evidence of Ise Bay. The upwelling is not observed in water temperature, salinity and density distribution<sup>12, 13</sup>, since the large river discharge and surface heating may be more dominant. Furthermore, two anticyclonic circulation is observed in the inner and central areas of Ise Bay and a cyclonic circulation is formed at the southern region near Irago Strait<sup>14</sup>. This cyclonic circulation is formed as the tidal residual circulation by coastal topographic effect of Shima Peninsula<sup>3</sup>. The detailed discussion on this problem will be made by use of numerical model driven by wind stress in near future.

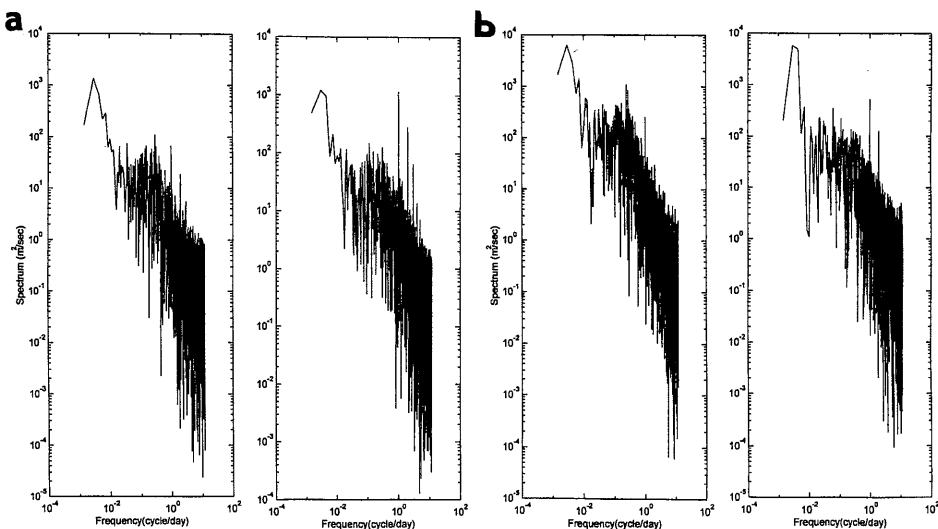


Fig. 9 Power spectra of eastward wind (left) and northward wind (right) at (a) Toba and (b) Irago.

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## 伊勢湾周辺の風の変動特性

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伊勢湾内の風成循環を計算するために、伊勢湾周辺の風の分布について日変動と季節変動に注目して調べた。風のデータは気象庁のアメダスによる 1987-1996 年間のものである。北西の季節風が 11 月から翌年の 4 月まで卓越する。また、北西の季節風は伊勢湾周辺で特に強く、風下に行くにしたがって強まることが示された。北西の季節風は 5 月に急に弱まり、夏季には伊勢湾上で発散する南からの海風が卓越する。また、北西の季節風と南からの海風には日変化が存在し、北西の季節風は昼間に相対的に強く夜間に弱いことが示された。一方、伊勢湾の北域と東域に吹き込む夏の海風は昼間にとりわけ強く、伊勢湾の西域に吹き込む海風は吹く時間が長く強さのピークがない。