HONG KONG OBSERVATORY

Technical Note No. 103

SEA-BREEZE INDUCED WINDSHEAR AT CHEK LAP KOK, HONG KONG

by

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摘要

本篇報告根據 1998 年 9 月 1 日至 1999 年 12 月 31 日期間赤鱲角跑道上的風向及風速數據，研究由海風引致的風切變現象。研究結果顯示，雖然與海風有關的「顯著」風切變事件（定義為風切變強度等如或大於每小時 20 海里的事件）並不常見，但這些事件引致的風切變可達到每小時 23 海里。一般來說，這類風切變事件較多出現於春季及冬季。有利於這類顯著風切變事件發生的天氣條件包括：（一）赤鱲角的最高溫度高於海水溫度，（二）背景風為較大的東至東北風。

ABSTRACT

This note presents a study on the windshear events arising from sea breeze at Chek Lap Kok during the period from 1 September 1998 to 31 December 1999, based on runways winds. The results indicate that while "appreciable" windshear events (defined as windshear cases with strength of 20 kt or more) associated with sea breeze are not frequent, it is possible for the windshear to reach 23 kt during these events. In general, they occurred more often in winter and spring than in the other seasons. Favourable weather conditions inducive to appreciable windshear events associated with sea breeze are (i) higher maximum temperature at Chek Lap Kok than the sea surface temperature, and (ii) relatively high background winds from the east to northeast.

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1. INTRODUCTION

Sea breeze is a common phenomenon in coastal regions like Hong Kong. They refer to the winds that blow from the sea to the land during the day due to uneven heating of land and sea. During the day the sun heats up the land more quickly than the neighbouring sea area. The layer of air above the land warms up and rises. The air over the sea moves onshore to replace the rising air, thereby forming sea breeze. Detailed description of sea breeze can be found in the reviews by Atkinson (1981), Pielke (1984) and Simpson (1994).

The onset of sea breeze is usually accompanied by an abrupt change in winds at coastal locations. The front edge of sea breeze, known as the sea breeze front, is where the sea breeze converges with the background wind. Aircraft flying across a sea breeze front will experience a change in headwind or tailwind. In the aviation community, this change in headwind or tailwind is viewed as a form of windshear.

A number of studies have been made on windshear events arising from sea breeze at Chek Lap Kok (CLK). Examples are Lau (2000) and Lee and Shun (2001). This note reports studies on windshear events under sea-breeze conditions at CLK, based on runway wind observations, and compares these windshear events with windshear cases not related to sea breeze.

2. DATA

At CLK, there are six anemometers, three on each of the two runways. The locations of the anemometers are shown in the inset in Fig. 1. The anemometers on the southern runway (i.e. R1E, R1C and R1W) provide one group of data, and those on the northern runway (i.e. R2E, R2C and R2W) provide another group.

One-minute mean wind data from these anemometers between 1 September 1998 and 31 December 1999 are used to calculate the windshear for these two groups of anemometers as follows:

Southern runway: -

(i) R1E and R1C: windshear across the eastern half of the runway;
(ii) R1E and R1W: windshear across the whole southern runway;
(iii) R1C and R1W: windshear across the western half of the runway.

Northern runway: -

(iv) R2E and R2C: windshear across the eastern half of the runway;
(v) R2E and R2W: windshear across the whole southern runway;
(vi) R2C and R2W: windshear across the western half of the runway

The difference in the along-runway component of wind speed between a pair of anemometers is taken as the windshear value. This corresponds to the change in headwind or tailwind an aircraft will experience while taking off or landing on the runway. The highest windshear value among the three values in each of the two groups above is taken as a measure of the windshear strength on that runway. This represents the maximum windshear along the runway. Negative windshear values are not considered here because the interest of this study is on sea breeze events, which produces positive windshear values.

Windshear cases with strength of less than 20 kt are not uncommon. They are caused by diverse weather conditions. For instance, they occur under light background wind conditions as well as under stronger winds. To study typical weather conditions conducive to significant windshear events associated with sea breeze, those windshear cases with strength of 20 kt or more have been selected for analysis. These events are referred to as 'appreciable' windshear events in the rest of this report.

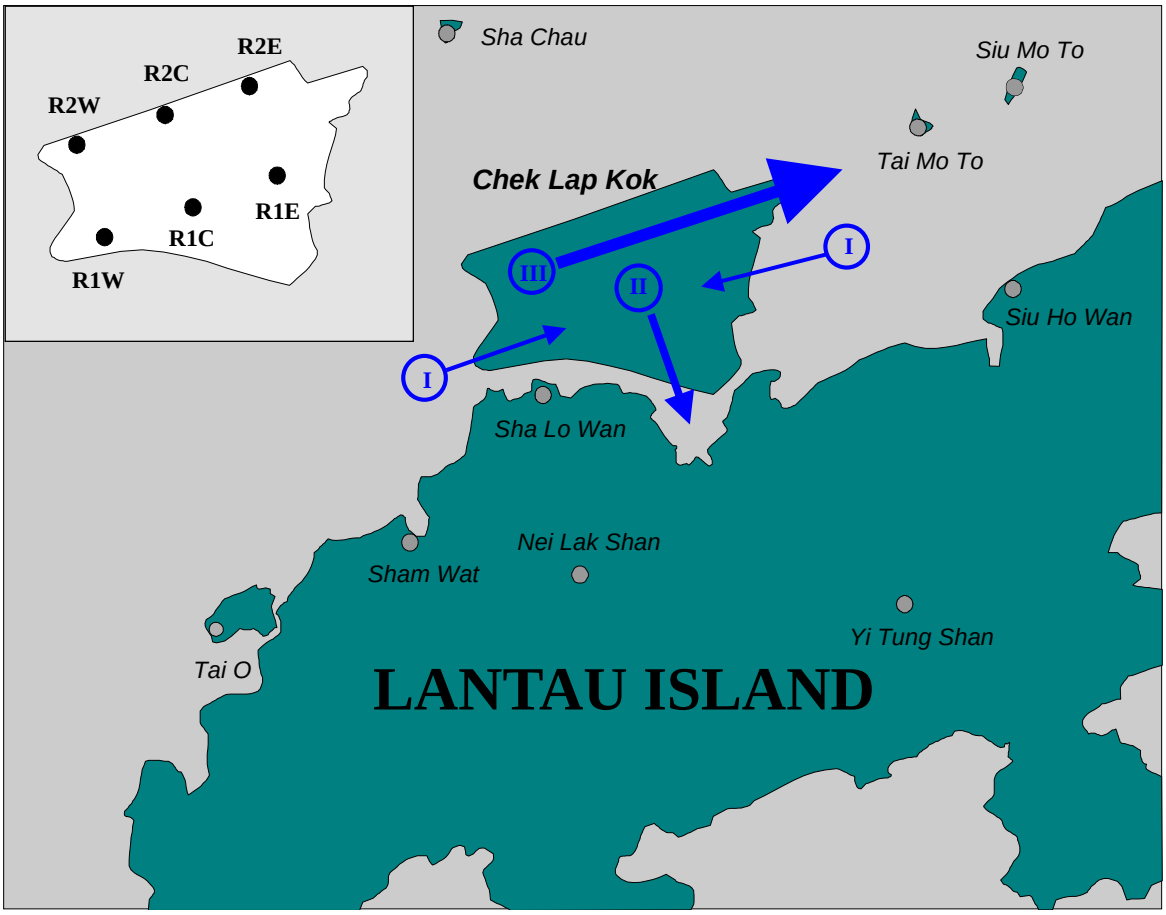


Figure 1. Types of sea breeze at Chek Lap Kok (see text on page 4). Inset depicts the location of the six anemometer sites at Chek Lap Kok.

Appreciable windshear events on either runway are separated into two categories according to whether or not these events were induced by sea breeze. In this study, a windshear event is considered to be sea-breeze induced if: -

(i) the event is associated with a change in wind direction at any one of the six anemometers by more than 90 degrees;
(ii) the change in wind direction occurs during daytime;
(iii) the change in wind direction is not related to thunderstorms or precipitation; and
(iv) the change in wind direction is not associated with the arrival of a monsoon surge.

3. CHARACTERISTICS OF SEA BREEZE AT CLK

On CLK, the favourable background wind conditions for sea breeze to develop are light winds and moderate east to northeasterly winds [Cheng 1999]. Owing to the complex terrain around CLK, sea breeze circulations on CLK could be broadly divided into three types:

Type I

As CLK is an island surrounded by water, sea breeze may converge to the centre of the island from all directions. This corresponds to Type I sea breeze (Fig. 1), which is characterized by easterly winds at the eastern end of the runways and westerly winds on the western end of the runways.

Type II

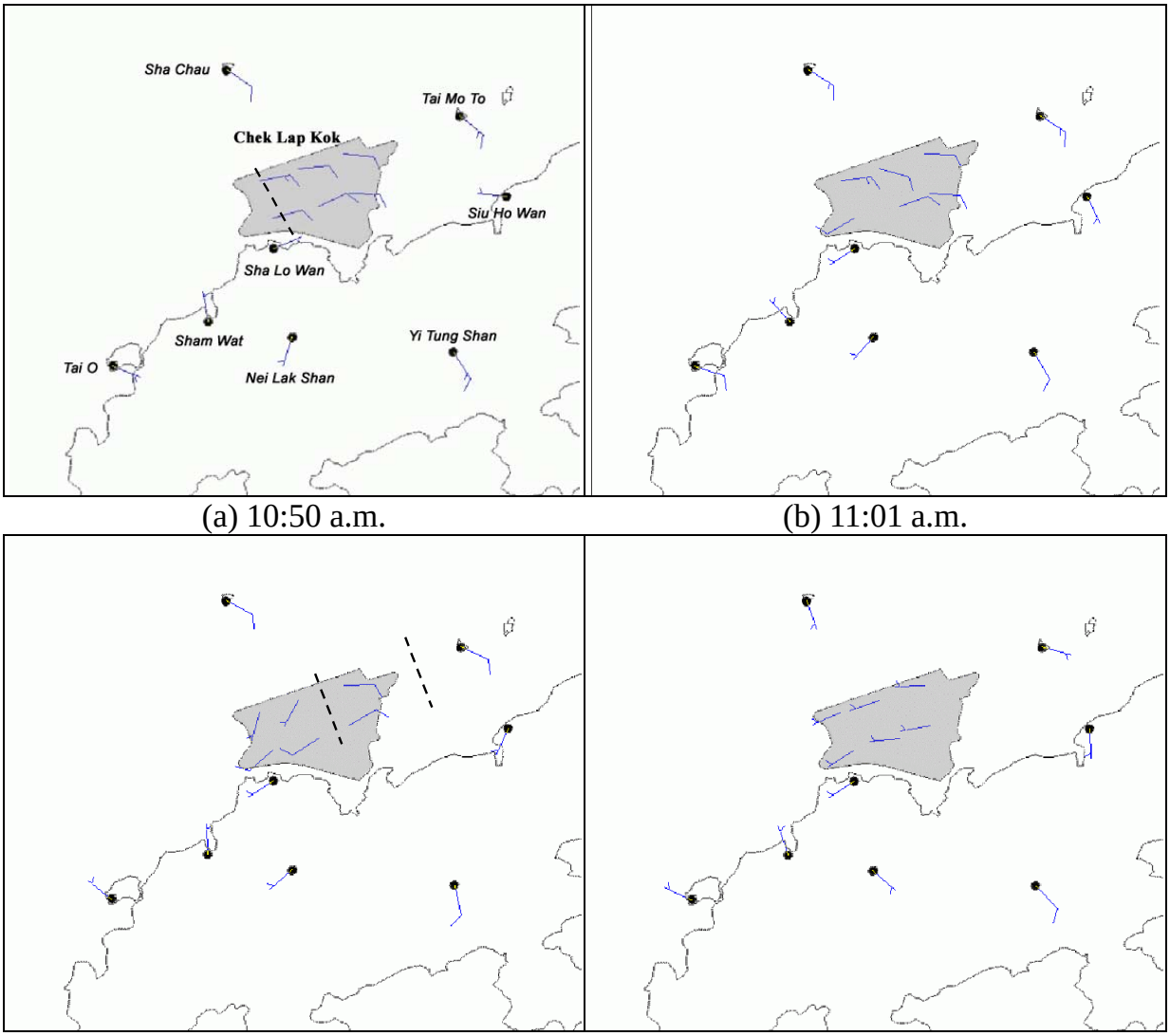
Lantau Island can induce sea breeze that blows across CLK from the north to northwest direction (Type II in Fig. 1).

Type III

The New Territories, being the main landmass in Hong Kong, can generate sea breeze that blows across CLK from the west to southwest (Type III in Fig. 1).

In this note, we focus on Type I sea breeze. The reason is that the sea breeze front associated with this type of sea breeze is located over CLK and may cause windshear across the runways.

Fig. 2 shows an example of Type I sea breeze at CLK. At 10:50 a.m. on 27 January 1999, background easterly winds prevailed over CLK before onset of sea breeze (Fig. 2a). At 11:01 a.m., sea breeze set in over the western part of CLK, as indicated by the dashed line in Fig. 2b. As the sea breeze advanced further east, the sea breeze front moved to the central part of CLK by 11:42 a.m. (Fig. 2c). The sea breeze front progressed further and reached the water east of CLK at 12:47 a.m. at which time general southwesterlies prevailed over the entire airport (Fig. 2d).



(a) 10:50 a.m. (b) 11:01 a.m.

(c) 11:42 a.m. (d) 12:47 a.m.

Figure 2. Passage of a sea breeze front (indicated by a dash line) across CLK on 27 January 1999.

4. RESULTS OF ANALYSIS

Table 1 contains a list of appreciable windshear events between 1 September 1998 and 31 December 1999. Of these, 7 are associated with Type I sea breeze. Table 2 shows the 1-minute mean winds at CLK at the time when appreciable windshear first appeared on those days with Type I sea breeze. It is noted that easterly winds prevailed over the eastern part of CLK while westerly winds associated with sea breeze set in from the west. Opposing winds of about 10-15 knots in magnitude from both sides of CLK resulted in windshear values of 20 knots or more. This means that it is possible for appreciable windshear events to occur when the background winds from the east are about 10-15 knots. This result is consistent with the finding from numerical studies [Bechtold *et al.* 1991, Arritt 1993] that sea breeze convergence is most intense when large-scale background winds blow in the opposite direction of the sea breeze at 5-6 ms^{-1} (about 10-12 knots).

(a) Windshear strength

Table 3 lists the statistics on the occurrence and the maximum windshear value of the appreciable windshear events associated with Type I sea breeze during the period 1 September 1998 to 31 December 1999. The table shows that:-

i) In the above period, the southern runway recorded only 28 minutes of appreciable windshear events associated with sea breeze while the northern runway recorded only 1 minute of such event. For most of the time, the windshear arising from sea breeze events was weaker than 20 kt.

ii) While appreciable windshear events, whether induced by sea breeze or not, were scarce, the maximum windshear recorded for sea-breeze cases was comparable to that of cases not related to sea breeze and might reach 23 kt.

TABLE 1.

DAYS BETWEEN 1 SEPTEMBER 1998 AND 31 DECEMBER 1999 ON WHICH APPRECIABLE WINDSHEAR WAS RECORDED

Date	Sea breeze related (Y/N)?	Total daily rainfall at CLK (mm)	Total bright sunshine at King's Park (h)	Brief description of weather in Hong Kong
6 September 1998	N	37.3	0.6	Showery weather with thunderstorms
30 December 1998	Y	0.0	8.2	**Type I sea breeze**
7 January 1999	N	0.0	7.9	Northeast monsoon
27 January 1999	Y	0.0	8.3	**Type I sea breeze**
23 February 1999	Y	0.0	3.4	**Type I sea breeze**
26 February 1999	Y	0.0	5.5	**Type I sea breeze**
31 March 1999	Y	Trace	10.6	**Type I sea breeze**
1 April 1999	Y	Trace	6.6	**Type I sea breeze**
6 April 1999	Y	0.0	10.6	**Type I sea breeze**
7 June 1999	N	58.3	0.0	Heavy rain brought in by STS Maggie
8 June 1999	N	14.6	0.7	Heavy rain brought by STS Maggie
20 June 1999	N	17.3	2.9	Arrival of southwest monsoon
5 July 1999	N	15.8	5.4	Showery weather
9 July 1999	N	29.5	0.0	Showery weather with thunderstorms
8 August 1999	N	17.8	6.8	Some showers at the time of recorded windshear
23 August 1999	N	281.0	0.0	Heavy rain associated with TS Sam
25 August 1999	N	86.9	0.0	Heavy rain
16 September 1999	N	147.8	0.0	Heavy rain associated with Typhoon York
3 October 1999	N	31.9	6.5	Rain at the time of recorded windshear

TABLE 2.

ONE-MINUTE MEAN WINDS RECORDED AT CLK WHEN APPRECIABLE WINDSHEAR FIRST APPEARED ON THOSE DAYS WITH TYPE I SEA BREEZE IN TABLE 1. THE PAIRS OF ANEMOMETERS THAT RECORDED APPRECIABLE WINDSHEAR ARE HIGHLIGHTED IN BOLD

Date	**Time when appreciable windshear first appeared in the day (Local time)**	**Site**	**1-minute mean winds (speed in knots)**	**Site**	**1-minute mean winds (speed in knots)**	**Site**	**1-minute mean winds (speed in knots)**
30 Dec. 1998	14:44	R2W	196 / 04	R2C	116 / 06	R2E	105 / 10
		R1W	257 / 10	R1C	074 / 09	**R1E**	085 / 10
27 Jan. 1999	11:02	R2W	089 / 12	R2C	110 / 13	R2E	092 / 12
		R1W	238 / 09	R1C	064 / 10	**R1E**	086 / 12
23 Feb. 1999	14:31	R2W	075 / 12	R2C	093 / 12	R2E	093 / 09
		R1W	224 / 11	R1C	231 / 09	**R1E**	084 / 11
26 Feb. 1999	11:14	R2W	088 / 12	R2C	075 / 09	R2E	095 / 12
		R1W	232 / 08	**R1C**	065 / 12	R1E	067 / 10
31 Mar. 1999	11:21	R2W	057 / 13	R2C	066 / 11	R2E	085 / 11
		R1W	238 / 09	R1C	122 / 06	**R1E**	100 / 13
1 Apr. 1999	14:35	R2W	096 / 13	R2C	104 / 13	R2E	110 / 14
		R1W	238 / 06	**R1C**	077 / 15	R1E	094 / 12
6 Apr. 1999	13:18	R2W	222 / 10	R2C	128 / 09	R2E	122 / 12
		R1W	241 / 10	R1C	145 / 08	**R1E**	100 / 12

TABLE 3.
STATISTICS OF APPRECIABLE WINDSHEAR EVENTS ON BOTH RUNWAYS

	Southern Runway	***Northern Runway***
Total no. of minutes from Sep 98 to Dec 99	701280	
No. of minutes with appreciable windshear events related to sea breeze	28	1
No. of minutes with appreciable windshear events not related to sea breeze	20	25
Maximum windshear for sea breeze cases (kt)	23	20
Maximum windshear for cases not related to sea breeze (kt)	24	26

(b) Hourly distribution of occurrence of appreciable windshear

Table 4 shows the hourly distribution of appreciable windshear events associated with sea breeze on the two runways. The table indicates that no appreciable windshear event that was sea-breeze related occurred before 11 a.m. For southern runway, appreciable windshear events that were sea-breeze related occurred between 11 a.m. and 3 p.m. while those for the northern runway occurred between 1 p.m. and 2 p.m. As can be seen in the next section, this late occurrence of appreciable windshear events is related to the strength of the background winds.

(c) Background winds for appreciable windshear events

The background winds in typical sea breeze days are generally light (Cheng 1999). However, on those days with appreciable windshear events arising from sea breeze, the prevailing winds are not light at all. Table 5 shows the daily mean winds at Waglan Island on those days with appreciable windshear cases. It is noted that the background winds were east to northeasterlies with daily mean wind speeds greater than 9 knots. It is believed that the relatively high background winds delayed the time of formation of sea breeze. When sea breeze did set in, convergence of sea breeze with the high background winds would produce the higher observed windshear values.

Also shown in Table 5 is the approximate time of first occurrence of appreciable windshear events on sea-breeze days. While there is no strong relationship between the time of first occurrence of appreciable windshear and the background mean wind speeds, it should be noted, however, that the time of first occurrence of appreciable windshear on 30 December 1998 was the latest among all the sea breeze days but the background wind speed on that day was amongst the highest (more than 20 knots). On that day, the hourly mean wind at Waglan Island was 19 knots from the east-northeast when appreciable windshear occurred. The example illustrates that it is possible for sea breeze to occur under a background wind in excess of 20 knots to produce appreciable windshear.

Table 4.
Hourly distribution of appreciable windshear events induced by sea breeze during the period from 1 September 1998 to 31 December 1999

Time	No. of minutes of sea-breeze induced windshear events on southern runway	No. of minutes of sea-breeze induced windshear events on northern runway
7:00H – 7:59H	0	0
8:00H – 8:59H	0	0
9:00H – 9:59H	0	0
10:00H – 10:59H	0	0
11:00H – 11:59H	16	0
12:00H – 12:59H	3	0
13:00H – 13:59H	4	1
14:00H – 14:59H	5	0
15:00H – 15:59H	0	0
16:00H – 16:59H	0	0
17:00H – 17:59H	0	0

Table 5.
Daily mean winds at Waglan Island on the days with appreciable windshear arising from sea breeze during the period from 1 September 1998 to 31 December 1999

Date	Time of first occurrence of appreciable windshear events in the day	Daily mean winds at Waglan Island (speed in knots)
30 December 1998	14:44	070 / 21
27 January 1999	11:02	050 / 12
23 February 1999	14:31	050 / 14
26 February 1999	11:14	050 / 09
31 March 1999	11:21	080 / 16
1 April 1999	14:35	070 / 15
6 April 1999	13:18	080 / 12

(d) Relationship between time of occurrence and meteorological conditions at CLK

Table 6 lists the time of first occurrence of appreciable windshear, that is, when the threshold of 20 knots was reached, and the meteorological data on the day of occurrence. Here, the time of first occurrence of appreciable windshear refers to the earliest time in a day when appreciable windshear was detected. No strong relationship can be observed between the time of first occurrence of appreciable windshear events and the total daily sunshine duration. However, there was a tendency for earlier occurrence of appreciable windshear when the difference between the maximum temperature at CLK and the sea surface temperature at North Point (sea surface temperature measurements at CLK commenced only after July 2000) is large. In all the sea-breeze cases, the temperature differences were generally 4 degrees Celsius or more.

Apart from the case on 1 April 1999, appreciable windshear was recorded shortly after the sea breeze set in. The lead time was in the range of 5 to 25 minutes. On 1 April 1999, appreciable windshear occurred while the sea breeze was retreating.

Table 6.

List of the time of occurrence of appreciable windshear induced by sea breeze and the associated meteorological conditions during the period from 1 September 1998 to 31 December 1999

Date	Time of first occurrence of appreciable windshear (local time)	Approximate time of onset of sea breeze (local time)	Approximate time when winds over CLK turned to west or southwest (local time)	Approximate duration when sea breeze affected CLK (minutes)	Maximum temperature at CLK - Sea surface temperature at North Point at 2 p.m. (degree C)	Sunshine duration at King's Park (hour)
30 December 1998	14:44	14:34	15:39	65	3.9	8.2
27 January 1999	11:02	10:56	12:41	101	5.9	8.3
23 February 1999	14:31	14:22	15:46	84	6.2	3.4
26 February 1999	11:14	10:49	14:34	225	9.4	5.5
31 March 1999	11:21	11:11	14:04	173	4.8	10.6
1 April 1999 *	14:35	10:00	11:21	81	6.8	6.6
6 April 1999	13:18	13:13	14:17	64	8.2	10.6

* Sea breeze retreated at about 14:35 local time. Appreciable windshear occurred at about 14:36 local time.

(e) Monthly distribution of occurrences of appreciable windshear

Figures 3 and 4 show the monthly distribution of occurrences of appreciable windshear on the southern runway and the northern runway respectively. For each of the months from September to December, the mean value of figures for 1998 and 1999 has been taken to ensure that the results are normalized. Figures 3 and 4 show that: -

i) On the southern runway, appreciable windshear events arising from sea breeze occurred mainly in winter and spring. Other appreciable windshear events were mostly observed in summer and they were related to precipitation, thunderstorms and windy occasions associated with tropical cyclones and monsoon.

ii) On the northern runway, appreciable windshear events arising from sea breeze were not frequent enough to infer any monthly variations in occurrences. Like the case of the southern runway, appreciable windshear events not related to sea breeze occurred more frequently in the summer months.

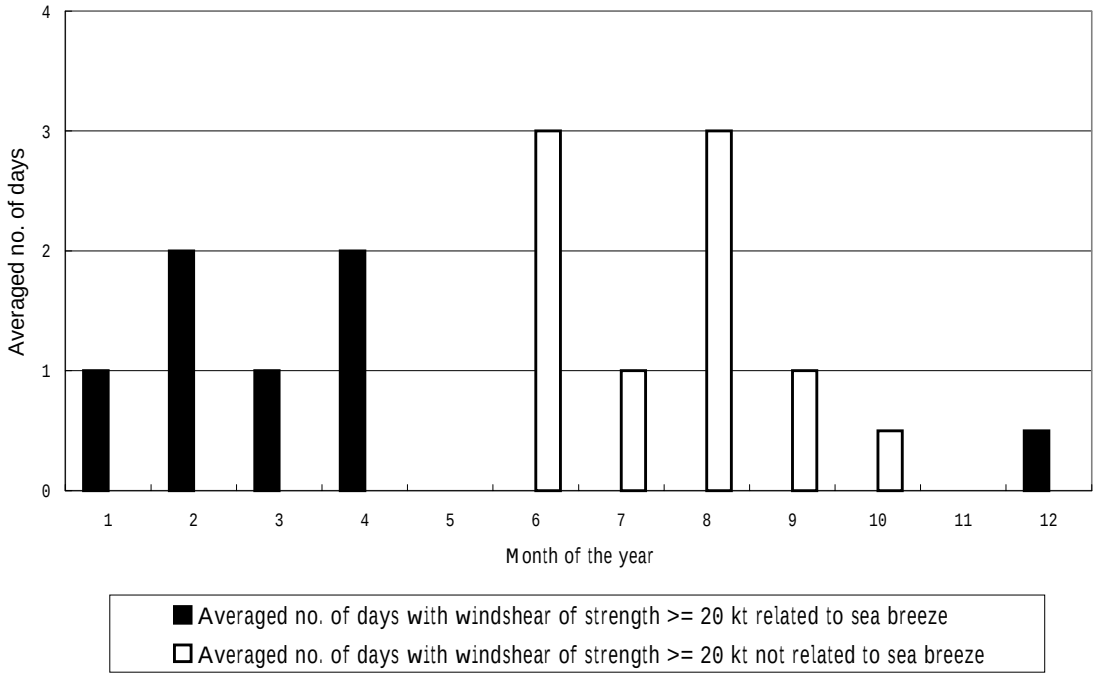


Figure 3. Monthly distribution of appreciable windshear events on southern runway (between 1 September 1998 and 31 December 1999).

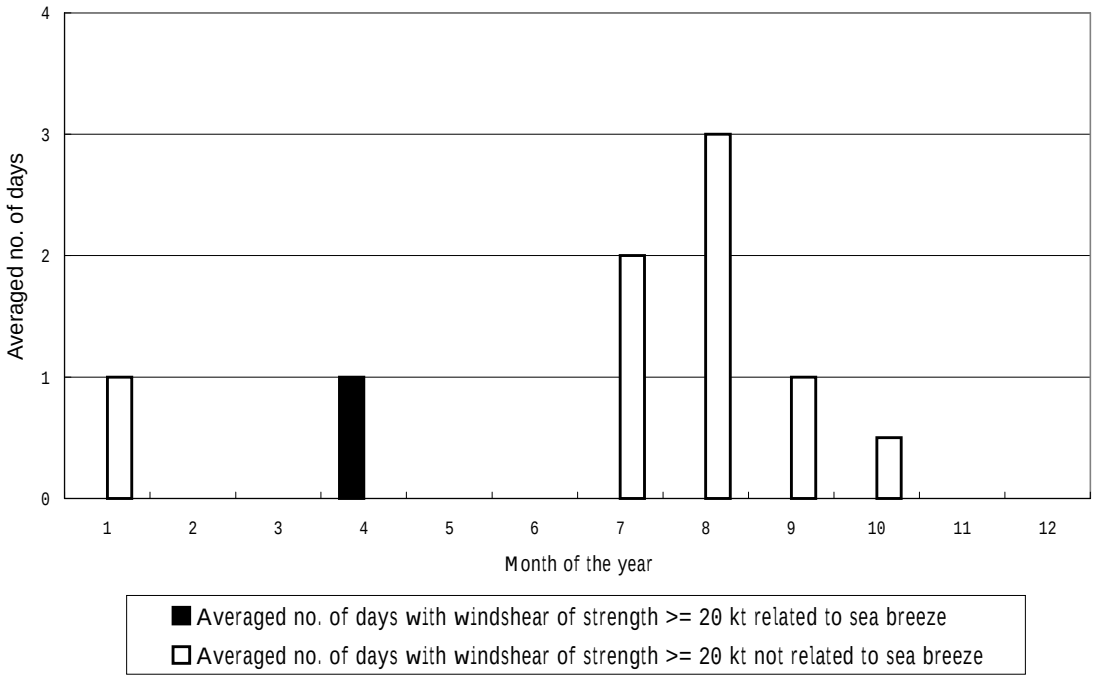


Figure 4. Monthly distribution of appreciable windshear events on northern runway (between 1 September 1998 and 31 December 1999).

Appreciable windshear events associated with sea breeze occurred mostly in winter and spring when the northeast monsoon prevailed. Under the background east to northeasterly flow, the sea breeze that set in from the west converged with the prevailing airstream, giving rise to appreciable windshear.

(f) Large-scale weather conditions conducive to appreciable windshear

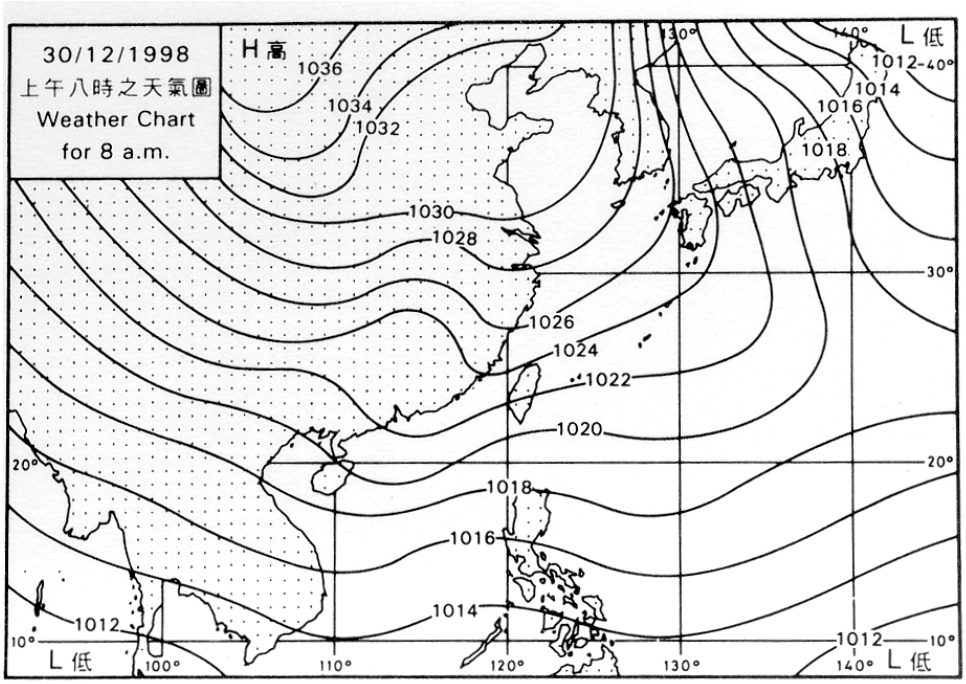
Previous study indicates that the favourable background wind conditions for sea breeze to develop at CLK is light winds or moderate east to northeasterly winds (Cheng 1999). In contrast, the present study shows that it is possible for appreciable windshear events arising from sea breeze to occur when the background wind flow was relative strong from the east to northeast. In these cases, the daily mean wind speeds at Waglan Island were generally higher than 9 knots. Fig. 5 shows the surface charts for those occasions with appreciable windshear arising from sea breeze. A common feature was a dominant ridge of high pressure lying along the coast of southeast China bringing in an easterly airstream to Hong Kong. This is a good signature to watch out for when forecasting appreciable windshear due to sea breeze.

5. CONCLUDING REMARKS

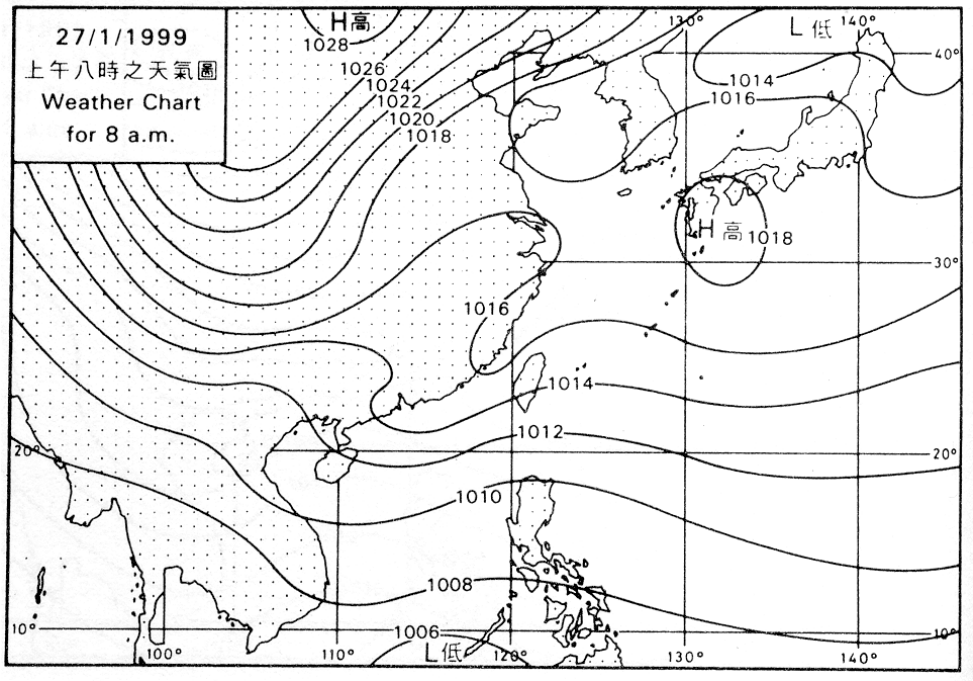
An analysis has been made on appreciable windshear events associated with sea breeze at CLK for the period from 1 September 1998 to 31 December 1999. The results indicate that while appreciable windshear events (defined as windshear cases with strength of 20 kt or more) associated with sea breeze were not frequent, it is possible for the windshear to reach 23 kt during these events. In general, they occurred more in winter and spring than in the other seasons. Favourable weather conditions for appreciable windshear events associated with sea breeze are (i) the maximum temperature at CLK being 4 degrees higher than the sea surface temperature at North Point, and (ii) high background winds from the east to northeast with a daily mean wind speed at Waglan Island of more than 9 knots. These windshear events generally occurred late in the day, after 11 a.m., with appreciable windshear recorded shortly after sea breeze set in over the airport. The lead-time was generally short and was only about 5 to 25 minutes.

A common feature in the synoptic weather pattern identified for these appreciable windshear events associated with sea breeze was the existence of a dominant ridge of high pressure lying along the coast of southeast China. This is a good signature to watch out for when forecasting appreciable windshear due to sea breeze.

It should be noted that only surface winds at CLK were used in this study. The occurrence of appreciable windshear on the runways does not necessarily suggest appreciable windshear aloft, or *vice versa*. To study the windshear above the runways, analysis of the upper air observations such as those from wind profilers and Doppler weather radar will be necessary.

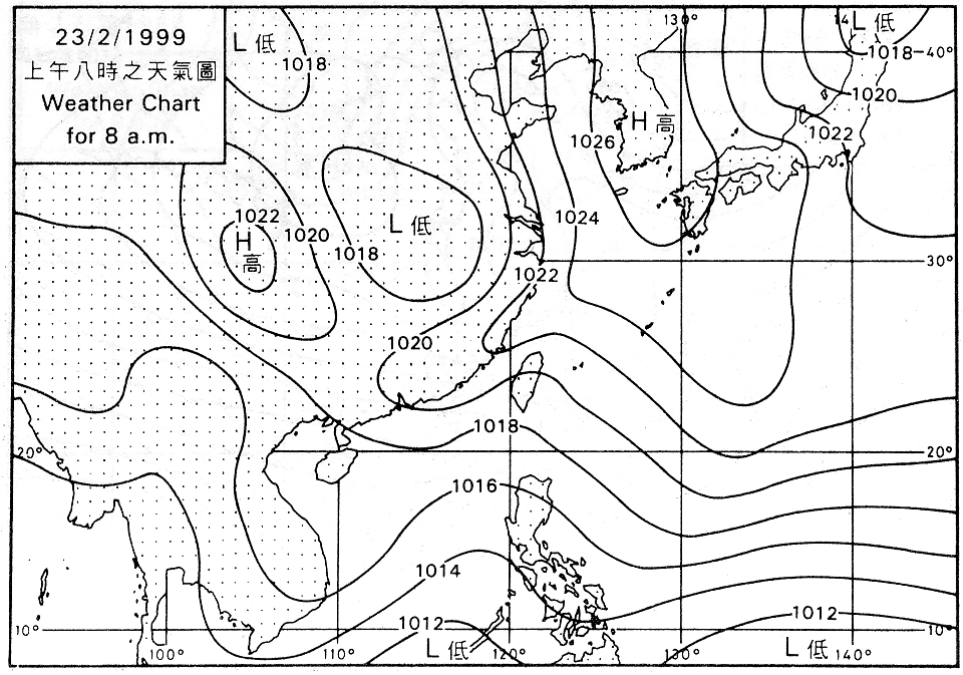


(a) 30 December 1998

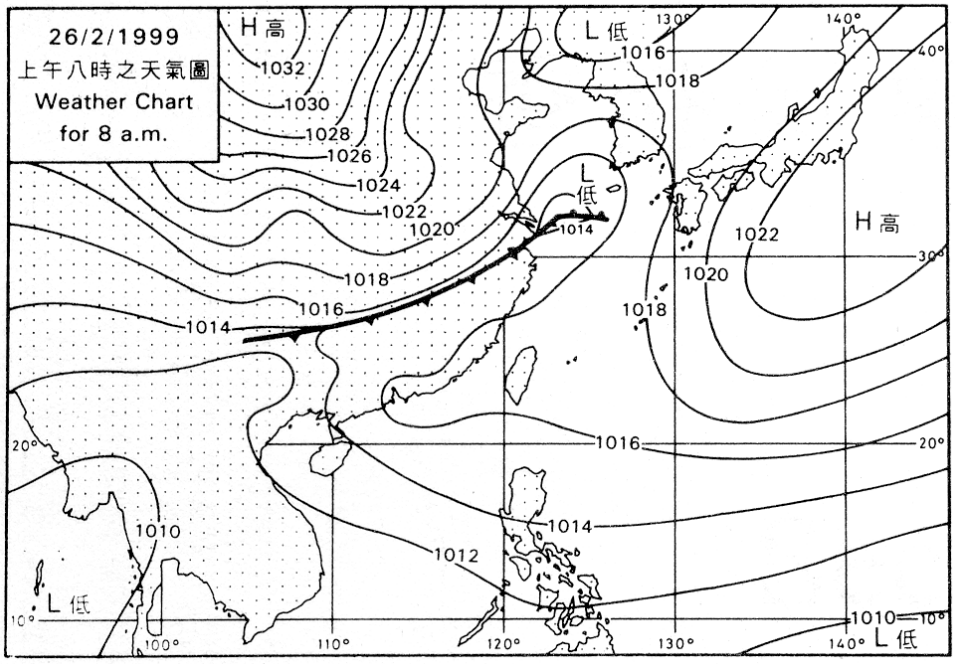


(b) 27 January 1999

Figure 5. Surface charts at 8 a.m. on those days with appreciable windshear events arising from sea breeze: (a) 30 December 1998, (b) 27 January 1999.

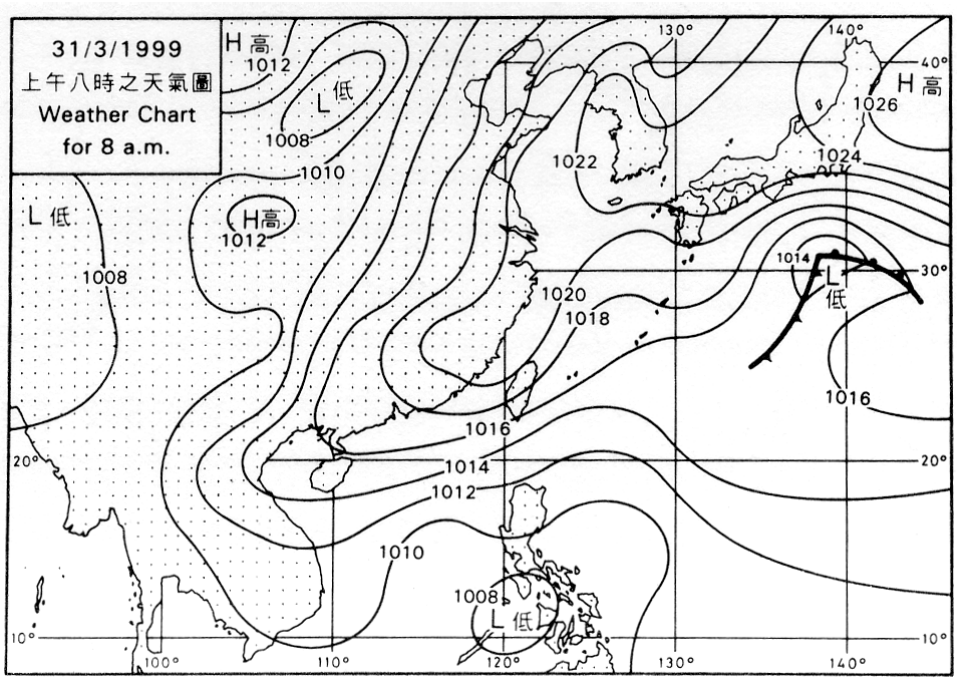


(b) 23 February 1999

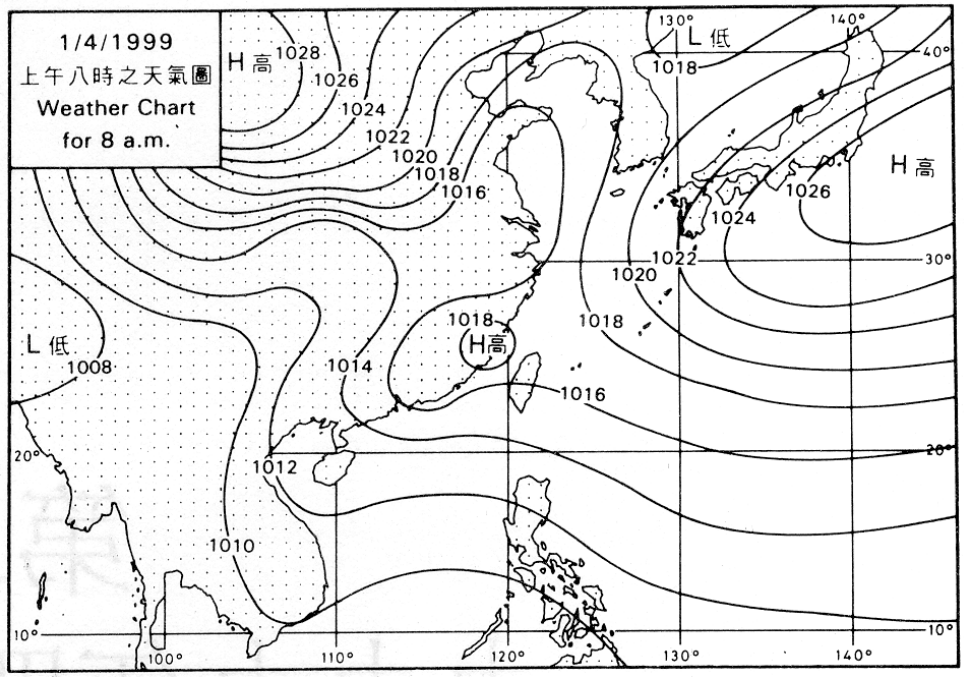


(d) 26 February 1999

Figure 5 (cont'd) Surface charts at 8 a.m. on those days with appreciable windshear events arising from sea breeze: (c) 23 February 1999, (d) 26 February 1999.

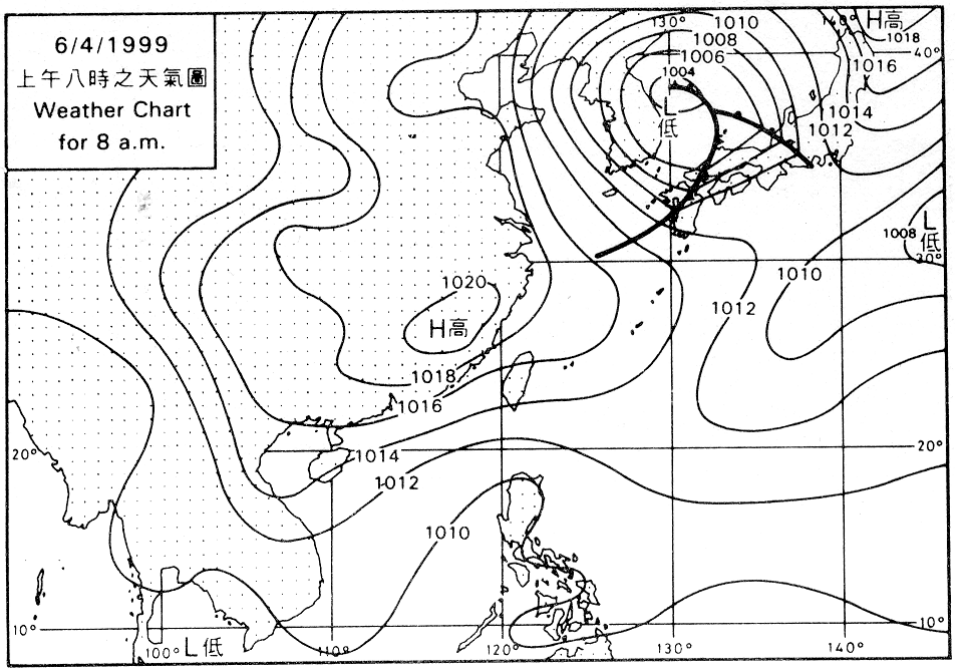


(e) 31 March 1999



(f) 1 April 1999

Figure 5 (cont'd) Surface charts at 8 a.m. on those days with appreciable windshear events arising from sea breeze: (e) 31 March 1999, (f) 1 April 1999.



(g) 6 April 1999

Figure 5 (cont'd) Surface charts at 8 a.m. on those days with appreciable windshear events arising from sea breeze: (g) 6 April 1999.

ACKNOWLEDGEMENT

The author would like to thank Mr. K.P. Wong and his colleagues for preparing the data for this study.

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