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SHORT-RANGE FORECASTING OF NORTHERLY SURGES

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SUMMARY

The purpose of this paper is to improve the short-range forecast capability of northerly surges, particularly by quantifying the usage of $\Delta p(972)$ (pressure difference between Hong Kong and Chenzhou near the Nanling ranges) as a forecast aid. Monthly averages of $\Delta p(972)$ for seven cool seasons (1980/81 - 1986/87) are computed to serve as climatological references. Typical trends of $\Delta p(972)$ in the surge cases of these seven seasons are presented as composite curves. Although monthly variations are not obvious, diurnal differences are quite marked. Surge intensities are also shown to be related to the rate of increase in $\Delta p(972)$. As a forecast index of surge arrival, $\Delta p(972)$ gives the strongest signal at a threshold near 7 - 8 hPa, with typical lead time of 12 - 15 hours. False alarms can be reduced, particularly in the early half of the cool season, by specifying a higher increase rate of $\Delta p(972)$ in the forecast criterion. In late season, easterly surges influence the performance of $\Delta p(972)$ as a forecast index.

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1. INTRODUCTION

Hong Kong in winter is frequented by surges of cold continental air from the north. Previous works have been done on various aspects of these surges, including some useful forecasting guidelines. For example, the "2-day Lake Baikal" rule remains popular among forecasters despite its documented uncertainty (Chu 1978). With the advent of numerical models and their ever-improving performance, medium-range forecast of winter monsoon surges is gaining credibility all the time. In some cases, outlooks have been successfully issued up to one week in advance.

However, in order to capture the trends and changes in local weather elements, forecasters often need a refined timing of the surges, particularly in the shorter term of say 24 hours or less. This will enable forecasters to make timely decisions on strong monsoon signal, fire danger warning and temperature forecasts.

At present, the "24-hour" index proposed by Morrice(1973) is still in use. This index basically covers a forecast range of 18 - 36 hours. Within the 24-hour range and up to the point of surge arrival, there are no well-established monitoring indices from which the timing and effects of the surges can be assessed or revised. One which has been experimented with for some time is the pressure gradient between Hong Kong and Chenzhou (station 57972) just north of Nanling. As yet, no climatological studies and quantification have been conducted for this index. This exercise is therefore intended to fill the gap. Apart from looking at typical behaviour of northerly surges as the cold air advances from Nanling to Hong Kong, attempts will also be made to extract useful forecast guidelines for forecasters' reference.

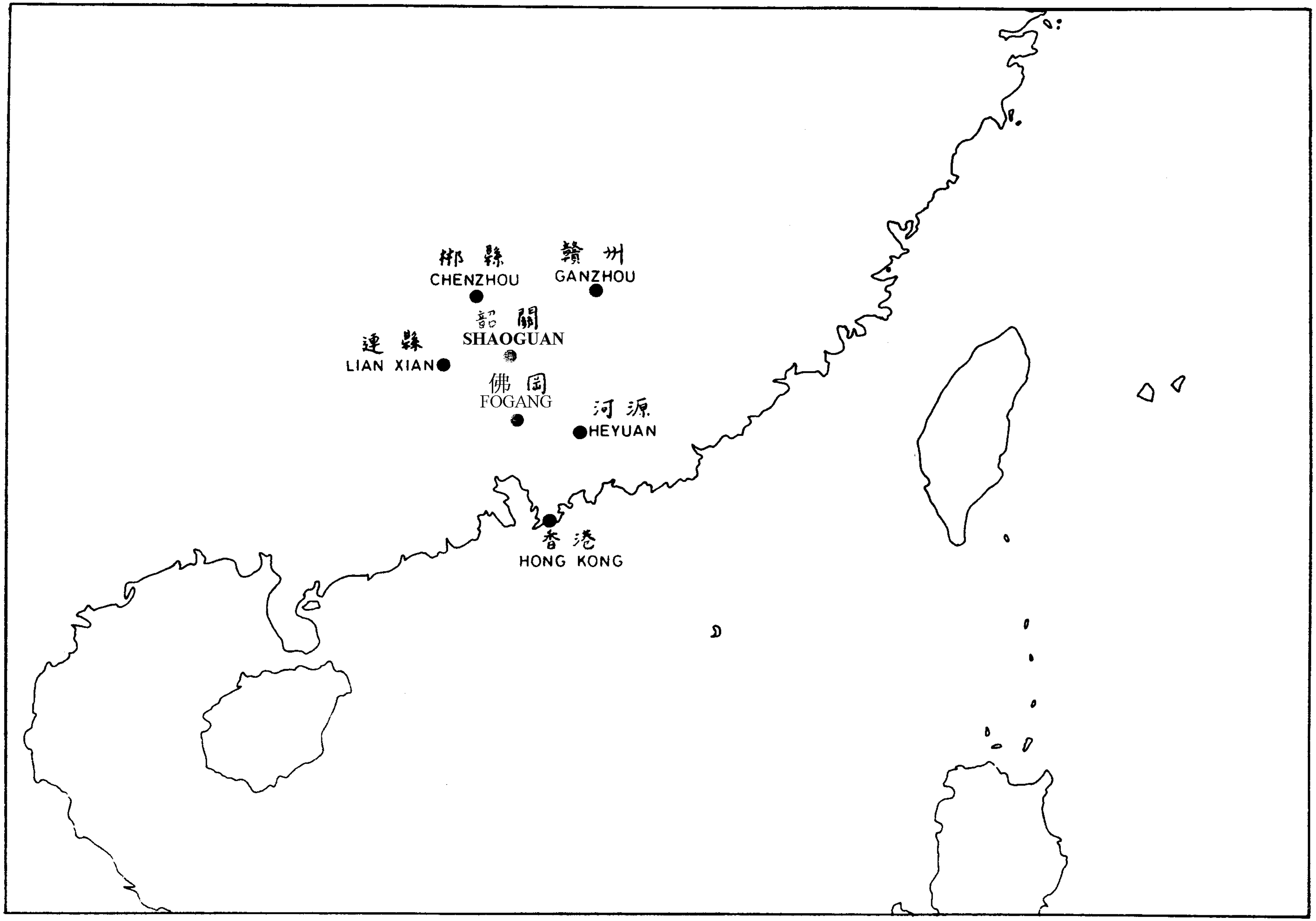

Fig.1. Map of selected stations near Nanling.

2. METHODOLOGY

The choice of Nanling as the reference location is considered convenient on two counts. Firstly, the forecast range of interest is about 24 hours. Assuming an advection speed of 20 km/h, the point of origin will be about 480 km to the north of Hong Kong. This corresponds to the area just north of the Nanling ranges near the latitude of 26N. Secondly, the Nanling ranges are well-known physical barriers against the advance of the shallow pool of cold air. This is often manifested in the building up of a marked frontal region along the ranges in synoptic analyses. For a reasonable timing of surge arrival, close monitoring of the Nanling crossing is, in any case, essential.

Since only data from 1980 onwards can be readily retrieved, results presented in this paper are based on data from seven cool seasons from 1980/81 to 1986/87. The "cool season" is defined as the months from October to March inclusive.

The notation Δp will be used in general to describe pressure difference between Hong Kong and certain selected stations to the north of Hong Kong. This difference is obtained by subtracting the pressure of the former from the latter. Positive values therefore mean higher pressure to the north. If one particular station is referred, the last three digits of the station code will appear in parentheses after the notation. (E.g. $\Delta p(972)$ represents pressure difference between Hong Kong and Chenzhou.) The forecast index as defined in Morrice(1973) will be designated as $\Delta p(M)$. The operational index for easterly surges, i.e. pressure difference between Hong Kong and Shanghai, will be represented by $\Delta p(S)$.

The methodology adopted can be summarised as follows:

(a) compile data set of Δp-values with six stations near and south of Nanling (see Fig.1) for the seven cool seasons;

(b) compile data set of hourly mean winds at Waglan and Cheung Chau at 3-hourly intervals (i.e. hourly mean winds at main and intermediate synoptic hours);

(c) conduct a climatological overview from these data sets to establish a background against which the surge cases can be compared;

(d) identify cases of northerly surges during those seven cool seasons;

(e) from the surge cases, compile composite $\Delta p(972)$-curves and categorise them according to:

(i) time of season (i.e. by month),
(ii) diurnal cycle (i.e. time when surge arrives),
(iii) surge intensity;

(f) study relationship between $\Delta p(972)$-trends and surge onset/intensity;

(g) assess performance of $\Delta p(972)$ as a forecast index for surge arrival time.

To facilitate further discussion, the followings are the definitions of some terms commonly used in this paper:

(a) Northerly surges - The definition is taken from Lam(1976), i.e. four consecutive 3-hourly Waglan wind observations from 340 to 030 degrees and with mean speed of 5 m/s or above. Since winds at Cheung Chau are included operationally for consideration of strong monsoon signal and the exposure of Cheung Chau also renders it more susceptible to northerly onset, the above definition is extended to cover wind analyses at Cheung Chau. A northerly surge is considered to have arrived in Hong Kong if the set criterion is met at either Waglan or Cheung Chau. After objective selection, the surge cases are subjectively screened and filtered according to the following considerations:

(i) cases rejected due to probable influence from tropical cyclones;

(ii) cases rejected when synoptic analyses clearly indicate the absence of any push from the north;

(iii) cases rejected to allow for minor deviations from the set criterion (e.g. due to tendency of winds to veer slightly during daytime and back to northerly in the evening, it may appear that a northerly surge has occurred).

(b) Surge arrival time - Time of the first of four consecutive 3-hourly wind observations as defined in (a) above. If surge arrival times for Waglan and Cheung Chau are different, the earlier of the two will be adopted. In a limited number of cases, having taken into account synoptic considerations, the surge arrival times are subjectively adjusted after ignoring short-lived and minor deviations from the set criterion.

(c) Strong and fresh winds - Due to different exposures for Waglan and Cheung Chau, the following operational criteria are used for descriptive labelling of "fresh" and "strong" winds at the respective locations:

	Waglan	Cheung Chau
Fresh	≥8.5 m/s and <14.5 m/s	≥8.5 m/s and <11.5 m/s
Strong	≥14.5 m/s	≥11.5 m/s

(d) Strong surge - Strong winds are reached at either Waglan or Cheung Chau within 12 hours after surge arrival time.

(e) Fresh surge - No strong winds, but fresh winds are reported at either Waglan or Cheung Chau within 12 hours after surge arrival time.

(f) Moderate surge - Winds fail to reach either strong or fresh criterion during the 12-hour period after surge arrival time.

3. CLIMATOLOGICAL STUDIES

Table 1 shows the average pressure gradient between Hong Kong and the six selected stations near and south of Nanling. It can be seen that Δp-values are generally highest in December while values in March are noticeably lower than the others.

With its northernmost location, Chenzhou (or Chen Xian in conventional atlas) gives relatively high Δp-values as compared with the other stations. The longer travel distance should allow more time for decision-making with regards to forecasts and warnings. For practical purposes, $\Delta p(972)$ is already a widely-used index. As such, results presented hereafter will concentrate on this parameter. Disregarding March, the background level of $\Delta p(972)$ during the winter months stands at about 4 or 5 hPa.

In the study of local winds, winds are resolved into their northerly and easterly components. The results for Waglan are tabulated in Table 2. The easterly component has two peaks within one diurnal cycle: one during the day and the other at night (Table 2(a)). The former can be attributed to enhancement caused by sea-breeze effect. The diurnal behaviour of the northerly component is more straightforward: peaking at 21Z and troughing at 09Z (Table 2(b)). In keeping with the relatively high Δp-values, the magnitude of the northerlies is also largest in December. By combining the northerly and easterly components, directions of the vector mean winds are obtained and tabulated in Table 2(c). The diurnal variation can be clearly seen - winds veering during the day and backing in the evening.

TABLE 1. AVERAGE PRESSURE DIFFERENCES (IN hPa)
BETWEEN HONG KONG AND SELECTED STATIONS NEAR NANLING

Month	57972 Chenzhou	57993 Ganzhou	59072 Lianxian	59082 Shaoguan	59087 Fogang	59293 Heyuan
October	4.1	3.0	2.5	2.1	1.2	0.9
November	4.9	3.9	3.3	2.8	1.7	1.4
December	5.5	4.5	3.9	3.3	2.1	1.7
January	5.2	4.2	3.4	2.9	1.7	1.4
February	4.7	3.8	3.0	2.6	1.6	1.4
March	2.9	2.2	1.5	1.5	0.8	0.8

TABLE 2. AVERAGE WINDS AT WAGLAN ISLAND
AT MAIN AND INTERMEDIATE SYNOPTIC HOURS

(a) Easterly component (in m/s)

	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z
October	6.0	6.4	6.0	5.7	5.8	6.5	6.4	6.1
November	4.5	5.0	4.8	4.4	4.4	4.8	5.0	4.5
December	3.9	4.4	4.4	4.0	3.5	4.2	4.3	4.0
January	4.6	4.8	4.6	4.1	3.7	4.2	4.9	4.6
February	5.2	5.2	4.7	4.4	4.2	4.7	4.9	4.9
March	4.2	4.0	3.6	3.6	3.5	3.8	4.1	4.2

(b) Northerly component (in m/s)

	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z
October	3.5	2.7	1.3	0.9	1.0	1.6	2.4	3.2
November	5.4	4.2	2.5	2.2	3.1	3.6	4.1	5.3
December	5.6	4.4	3.0	2.9	3.9	4.3	5.1	5.7
January	4.5	4.0	2.7	2.3	3.1	4.1	4.7	4.8
February	3.6	3.4	2.9	2.5	2.9	3.5	4.1	4.1
March	2.6	2.4	1.9	1.5	2.0	2.4	2.6	2.6

(c) Direction (in degrees)

	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z
October	059	067	077	081	080	076	069	063
November	039	050	062	064	055	053	051	041
December	035	045	056	055	042	044	040	035
January	046	050	059	061	050	046	046	044
February	055	057	058	061	056	053	050	050
March	058	059	062	068	060	057	058	058

4. CASE STUDIES

A total of 128 cases of northerly surge has been identified following the definition laid down in Chapter 2. Estimated arrival times for these surges adopted for use in this paper are listed for reference in the Appendix. To study the typical characteristics of northerly surges, the 128 cases are categorised in three different ways for analysis - (i) by month; (ii) by time of arrival; and (iii) by surge intensity. Composite curves (effectively average values of all available cases) of Δp(972) are studied in each categorisation so that an overview of the behaviour of northerly surges under differenct circumstances can be obtained. The composite curves cover a period of 36 hours - from 24 hours prior to surge arrival (t-24) to 12 hours after surge arrival (t+12).

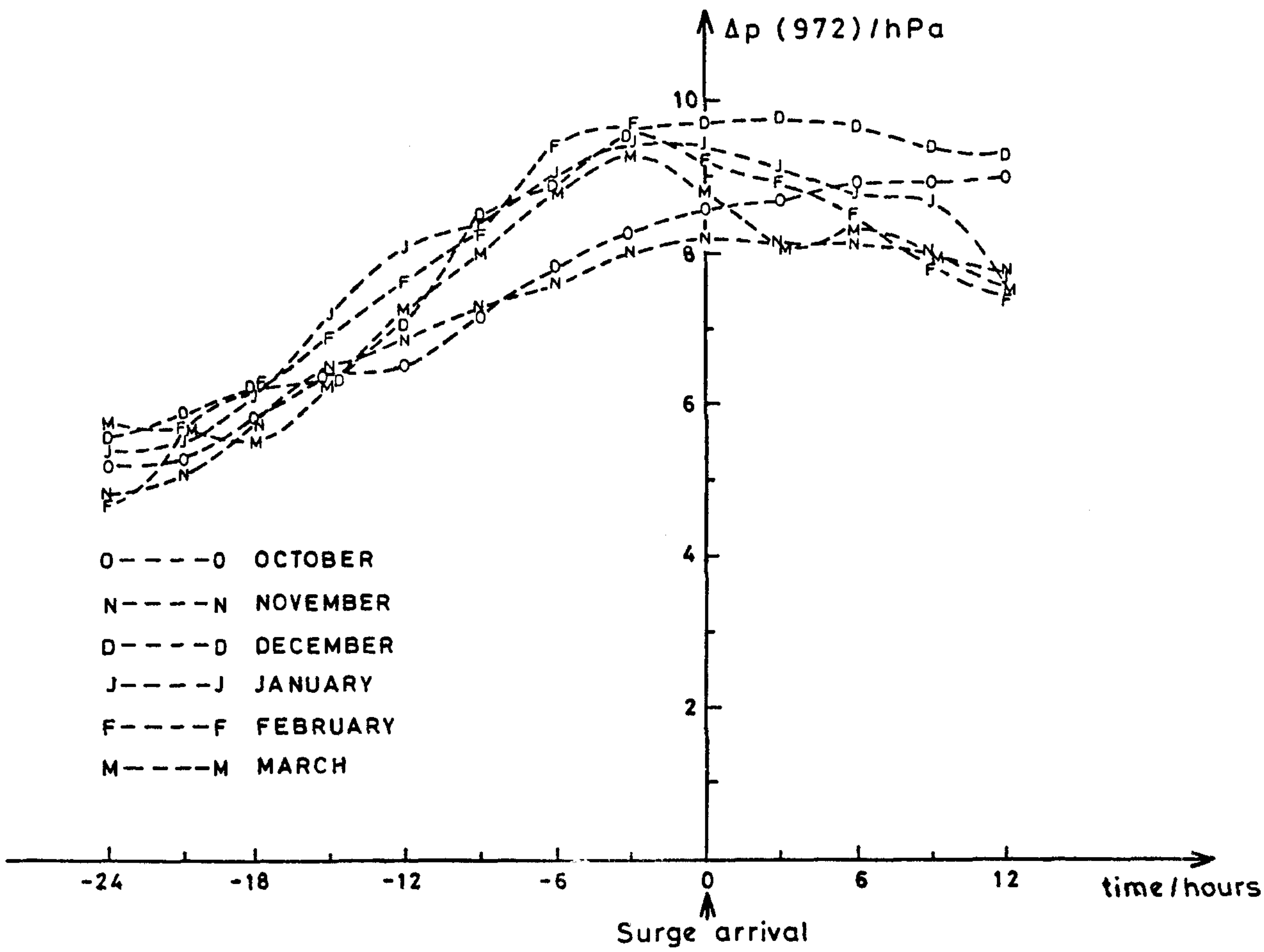

Fig.2. Composite Δp(972)-curves by months (for 7 cool season from 1980/81 to 1986/87).

4.1 Categorisation by months

Fig.2 shows the monthly composite Δp(972)-curves for the seven cool seasons studied. The general trend reveals a gradual rise in Δp(972) within the 24-hour period prior to surge arrival and a levelling-off afterwards. October and November tend to have lower Δp(972)-values during the 12-hour period prior to surge onset. Otherwise, the monthly Δp(972)-trends are generally quite consistent with one another. This seems to suggest that intra-seasonal variations, if any, are not particularly strong. For forecast purpose, a simple application of the Δp(972)-values should therefore be sufficient. In other words, significant improvement is unlikely even if climatological monthly averages of Δp(972) are somehow incorporated into the formulation of forecast indices (for example, by using some kind of departures from climatological monthly averages instead of utilising the observed Δp(972)-values).

Typical Δp(972)-values at surge onset range from 8 to 10 hPa. In fact, a 2-hPa range in Δp(972) is generally the case for the 12-hour period prior to surge arrival. The spread in the monthly averages appears to be smallest in the vicinity of 6 hPa at a time of 18 hours ahead of surge arrival. It is therefore tempting to use this point as a crude first guess of surge arrival time. Standard deviations of the various monthly averages are mostly in the range of 2 - 3 hPa. For the first four months of the cools season, sample variances tend to be smallest at times of 15 - 21 hours before surge arrival. For February and March, the minimum values tend to occur at times much closer to the event itself, typically in the range of 6 -12 hours ahead. The usefulness of Δp(972) as a forecast index, particularly in the range of 12-hour and 18-hour forecast, will be pursued further in the following chapter.

TABLE 3. MONTHLY OCCURRENCES OF NORTHERLY SURGES
(SUM OF 7 COOL SEASONS FROM 1980/81 TO 1986/87)

Month	Moderate	Fresh	Strong	Total
October	4	7	4	15
November	5	13	5	23
December	2	20	8	30
January	9	14	2	25
February	3	13	7	23
March	4	6	2	12
Total	27	73	28	128

The monthly occurrences of northerly surges, with further breakdown into different surge intensities, are tabulated in Table 3. The majority of the surges occur in the months from November to February, with December having the highest frequency. Most of these surges have fresh winds at least. It is also interesting to note that while fresh and strong surges are most frequent in December, surges in January are relatively weak.

4.2 Categorisation by surge arrival time

As has been shown in the previous chapter, winds of northerly component tend to undergo a diurnal variation in strength. It is therefore worthwhile to take a look at the arrival times of northerly surges to see if the same diurnal pattern is observed. From Fig.3, it can be seen that the most favourable time for northerly onset is 5 a.m. in the morning and the least favourable time is 11 a.m. during the day. With the sea-breeze effect introducing a southerly-component wind during daytime, it seems to indicate that this diurnal mechanism is quite capable of upsetting the timing of northerly arrival. Further evidence comes in the form of a secondary peak at 8 p.m. which may be interpreted as a result of the sea-breeze effect relinquishing its control during the evening and allowing the northerlies to come through.

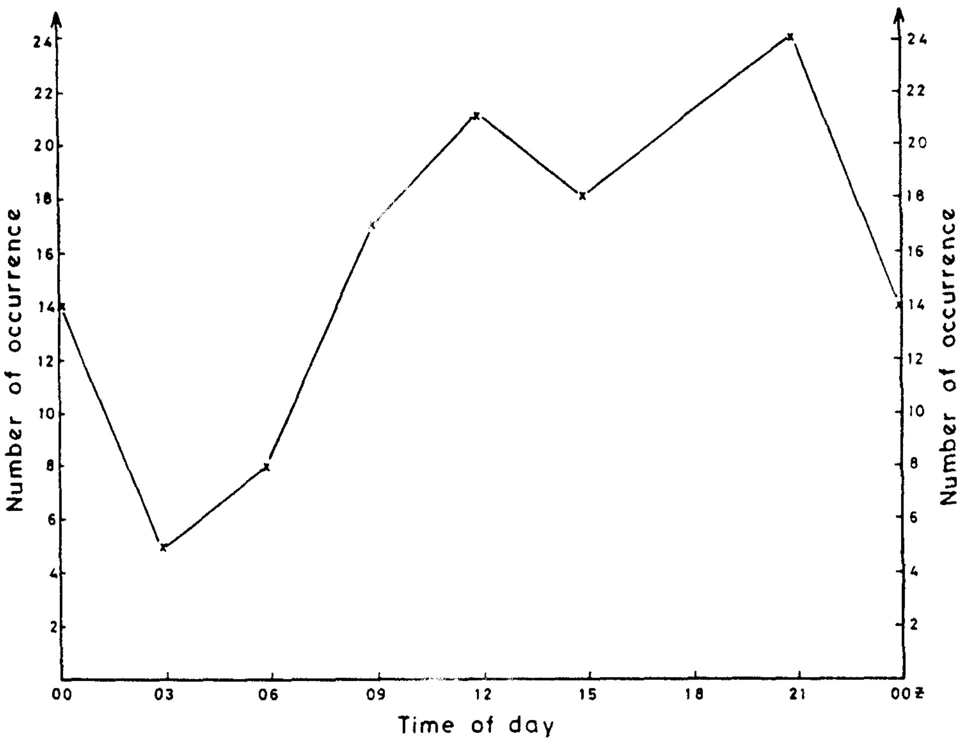

Fig.3. Diurnal distribution of surge arrival times (for 7 cool seasons from 1980/81 to 1986/87).

TABLE 4. DIURNAL OCCURRENCES OF NORTHERLY SURGES (FOR 7 COOL SEASONS FROM 1980/81 TO 1986/87)

(a) Frequency of occurrence at different times of the day

Time	Total	Moderate	Fresh	Strong
00Z	14	3	9	2
03Z	5	1	3	1
06Z	8	1	3	4
09Z	17	3	8	6
12Z	21	4	14	3
15Z	18	2	12	4
18Z	21	5	11	5
21Z	24	8	13	3
Total	128	27	73	28

(b) Chances of occurrence for different periods of the day

Period	Moderate	Fresh	Strong
Morning(00Z + 21Z)	41%	30%	18%
Daytime(03Z + 06Z)	7%	8%	18%
Evening(09Z + 12Z)	26%	30%	32%
Nighttime(15Z + 18Z)	26%	32%	32%

Table 4(a) gives the number of occurrences of northerly surges at different times of the day. Arrivals at the daytime hours of 03Z and 06Z are shown to be most unpopular and constitute only about 10% of the total number of surge cases. A breakdown into surges of different intensities is also listed in Table 4(a), but their preferences for different arrival times are more readily inferred from Table 4(b). To highlight the relative infrequent occurrences of northerly onset at 03Z and 06Z, the day is arbitrarily divided into four separate periods and descriptively labelled as follows: (i) morning (21Z and 00Z), (ii) daytime(03Z and 06Z), (iii) evening(09Z and 12Z), and (iv) nighttime(15Z and 18Z). Note that of the 27 moderate surges and 73 fresh surges, only about 7 - 8% of them arrive during daytime. This is disproportionately low since, if everything is equal, the average chance of occurrence should be somewhere in the region of 25%. For the strong surges, although the chance of daytime arrivals is also on the low side, its departure from average is less noticeable. This reinforces the hypothesis that if the northerly surges are less than strong, they will find it difficult to overcome the sea-breeze effect. Chances of their arrivals during the daytime hours will therefore be significantly reduced.

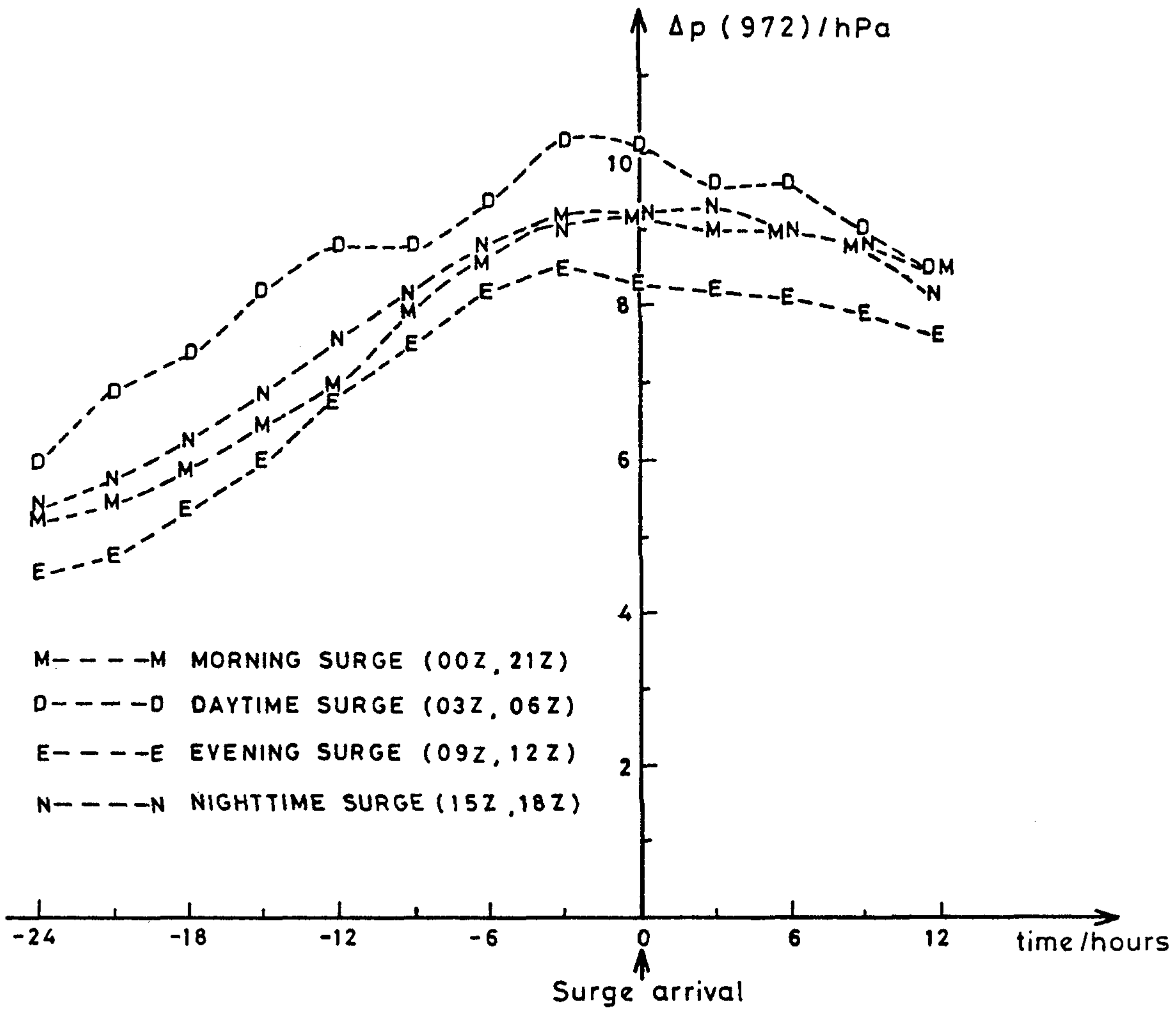

Fig.4. Composite Δp(972)-curves by arrival periods (for 7 cool seasons from 1980/81 to 1986/87).

For a further look at the diurnal characteristics of northerly surges, composite curves of Δp(972)-trend for the four different periods as specified in Table 4(b) are presented in Fig.4. The pre-surge and post-surge trends are, in general, similar to that discussed in Section 4.1. However, surges arriving during daytime appear to have a relatively high Δp(972) background in the pre-surge setting. This may imply that a prevailing northerly situation, sustained by a dominant continental anticyclone for instance, will readily facilitate subsequent onset of fresh or strong northerly replenishment. It is probable that under these circumstances, the diurnal sea-breeze mechanism may be rendered less effective as the synoptic-scale systems hold the upper hand. Howver, this conjecture should be treated with reservation in view of the limited number of cases available for daytime surges.

4.3 Categorisation by surge intensities

If surge arrival times are partially dependent upon surge intensities through the diurnal mechanisms, further analysis by stratification into different surge intensities may serve to reveal some tell-tale signatures in the $\Delta p(972)$-trends. This will help forecasters to assess the likelihood of daytime arrivals and hence falling temperatures during the day. Fig.5 presents the composite curves compiled from the data of the seven cool seasons studied. Strong surges are found to have an average pre-surge ([t-18] to [t-6], say) increase rate of about 1 hPa in three hours; whereas fresh and moderate surges generally have increase rates less than the aforementioned value. Strong winds can also be expected if $\Delta p(972)$ is forecast to reach 10 hPa or above.

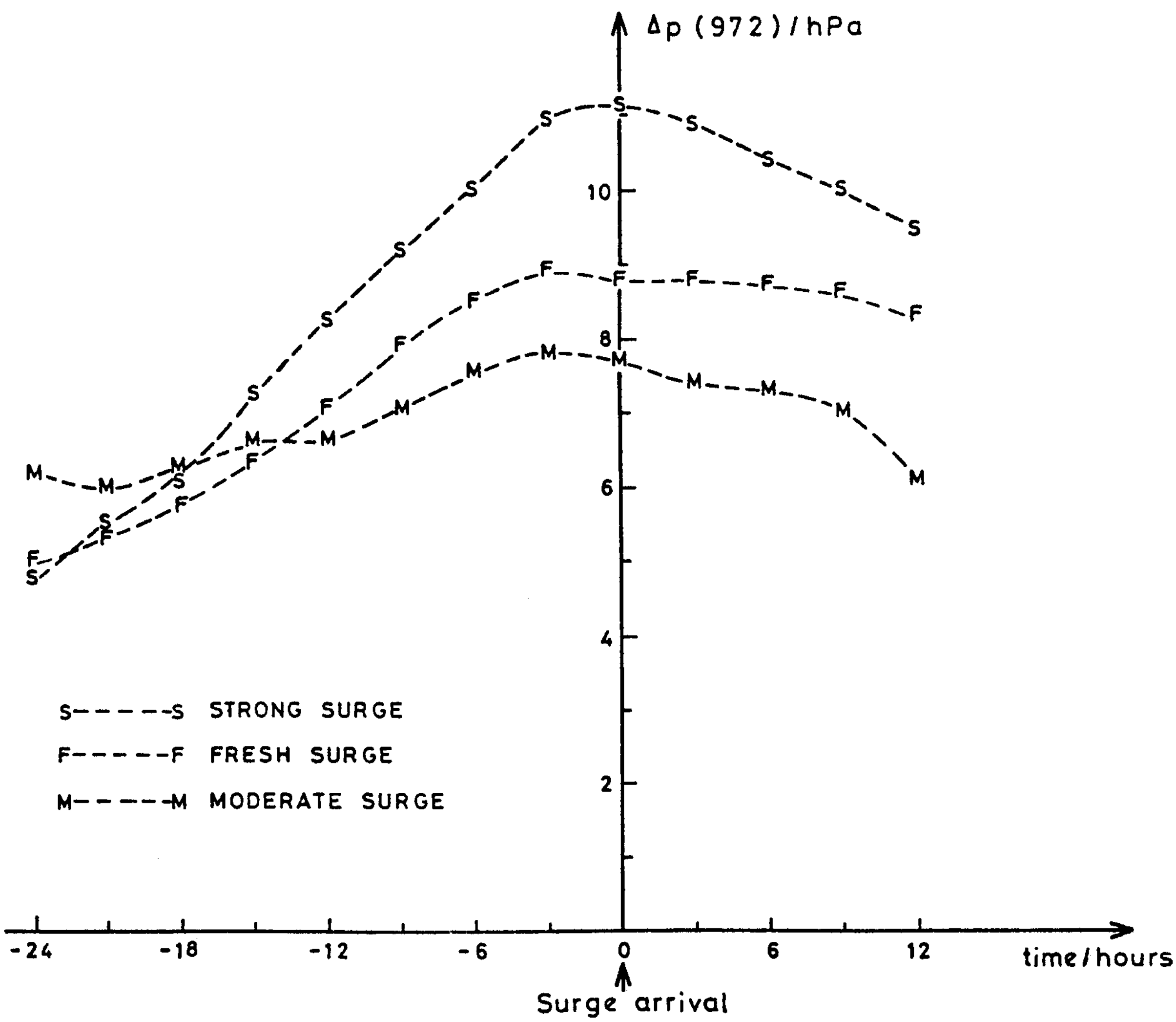

Fig.5. Composite $\Delta p(972)$-curves by surge intensities (for 7 cool seasons from 1980/81 to 1986/87).

5. PERFORMANCE OF $\Delta p(972)$ AS A FORECAST INDEX

5.1 Terminology and methodology

In this chapter, the time series of $\Delta p(972)$ for the seven cool seasons selected will be scanned according to different set criteria. The set criteria will normally consist of two components: threshold value (y) and threshold increase rate (x) of $\Delta p(972)$. For brevity purpose, these criteria will be abbreviated into codes of two digits, say "xy". To assess if a specified criterion is met, the scanning method considers successively groups of three consecutive $\Delta p(972)$-values (say P1, P2, P3). A "signal" is said to have occurred if

(a) $P3 \geq y$ and $P1 < y$;

AND (b) $(P3 - P1) \geq x$. (For the 3-hourly data used in this exercise, x is effectively the rate of increase of $\Delta p(972)$ over a period of six hours. If $x = 0$, this condition is automatically converted to $(P3 - P1) > 0$ since condition (a) implies that $P1 \neq P3$.)

In normal circumstances where $P1 < P2 < P3$, the one closest to the threshold value (x) will be regarded as the point when the signal occurs and its corresponding time is taken to be the "signal time". This remains the general principle in deciding signal time, but some provisions are included to cater for alternative scenarios. In these cases, the eligible candidates for consideration will be restricted. In summary, the occurrence of signals will be determined by the following conditions:

(i) if $P1 < P2 < P3$, the choice is from all three (whichever is closest to threshold value)

(ii) if $P2 \geq P3$, the choice will be between P1 and P2;

(iii) if $P2 \leq P1$, the choice will be between P2 and P3;

(iv) if data for P2 is not available, the choice will be between P1 and P3;

(v) in applying the above conditions, if two $\Delta p(972)$-values are of the same proximity to the threshold value, the time of the earlier value will be adopted as the signal time.

As an illustration of the above methodology, let us consider the following time series of $\Delta p(972)$-values:

19 Jan		20 Jan							
18Z	21Z	00Z	03Z	06Z	09Z	12Z	15Z	18Z (C)	21Z
7.4	6.8	7.2	6.8	7.4	7.1	6.5	5.8	8.2	8.7
				(A)			(B)		

(Sequence A: 03Z–09Z; sequence B: 12Z–18Z; sequence C: 15Z–21Z.)

Example 1: Set criterion = "07" (meaning $\Delta p(972)$ is required to exceed a threshold value of 7 hPa at any increase rate)

Sequence	Signal Time	Applicable Conditions
A	Jan 20 03Z	(ii)
B	Jan 20 15Z	(iii) and (v)
C	Jan 20 15Z	(i) and (v)

Since sequences (B) and (C) have the same signal time, they will be regarded as one signal.

(Notice how the transient increase between 21Z and 00Z is discarded while the weak signal at 03Z is retained. The method is designed with an aim to reduce the "noise" of short-term fluctuation and at the same time not to throw away too many weak signals prematurely. Elimination of such weak signals, if so desired, can be achieved by introducing more stringent criteria, as will be shown in Example 2.)

Example 2: Set criterion = "18" (meaning $\Delta p(972)$ is required to increase at a rate of 1 hPa or more in 6 hours over a threshold value of 8 hPa)

Sequence	Signal Time	Applicable Conditions
B	Jan 20 18Z	(iii)
C	Jan 20 18Z	(i)

Again, both sequences have the same signal time and are taken to represent one signal.

To make discussion easier, the following acronyms will be used:-

(a) TNS - Total Number of Signals identified by the above method for any given criterion.

(b) NSV - Number of Signals Verified, i.e. total number of cases with northerly surges occurring within 24 hours after signal times.

(c) NDS - Number of Duplicated Signals. (From Example 1, if a northerly surge arrives at 03Z on Jan 21, this surge will have been fore-warned by both signals. For ease of reference, the earlier signal is taken to be "original" while the later signal will be regarded as a duplicated signal.)

(d) SSP - Surges Successfully Predicted. (It follows from (b) and (c) that SSP = NSV - NDS.)

(e) NAP (No Alarm Probability) = (128 - SSP)/128. (Recall that the total number of surges in the seven cool seasons is 128.)

(f) FAR (False Alarm Ratio) = (TNS - NSV)/TNS. (Note that NSV and not SSP is used here since duplicated signals are not necessarily noises and can nonetheless be meaningful in reflecting how persistent the push from the north is.)

5.2 Signal verification and lead time

Using results from the previous chapter as guidance, a set of criteria is chosen to evaluate the potential of $\Delta p(972)$ as a forecast index. The signal response for these criteria is tabulated in Table 5.

TABLE 5. SIGNAL RESPONSE FOR DIFFERENT CRITERIA

Criteria	TNS	NSV	NDS	SSP
"05"	366	77	4	73
"06"	333	94	8	86
"07"	301	106	17	89
"08"	237	87	3	84
"09"	189	82	6	76
"15"	289	70	3	67
"16"	269	85	6	79
"17"	241	95	11	84
"18"	201	81	2	79
"19"	162	78	4	74
"25"	161	49	2	47
"26"	152	63	2	61
"27"	135	65	4	61
"28"	112	60	0	60
"29"	103	58	2	56

An interesting observation from Table 5 is the tendency for criteria with threshold value of 7 hPa to have the highest number of duplicated signals. Judging from the climatological background of $\Delta p(972)$, it is reasonable to interprete this as the initial stage of the northerly push near Nanling and the pressure build-up not well-established as yet. In contrast, with threshold value of 8 hPa, the amount of duplicated signals is significantly reduced (and for "28", NDS = 0!). By this stage, the northerly surge is well on its way and a lot of ambiguity is henceforth removed.

Lead time of each signal is simply obtained by calculating its time difference with the corresponding surge arrival time. The frequency distributions of lead time for the whole set of criteria are shown in Fig.6. These are compiled using all verified signals (i.e. sample size = NSV) since it will be unfair to force a choice between original and duplicated signals. Results thus obtained show that irrespective of the threshold increase rate, there is a progressive reduction in lead time as the threshold value increases. The modal lead time is about 18 hours when $\Delta p(972)$ is about 5 - 6 hPa. This will then be reduced by 3 hours for every subsequent 1-hPa rise in threshold value within the range of criteria studied. From the modal values, the overall signal strength is at its peak when $\Delta p(972)$ is in the region of 7 hPa.

The mean lead time also decreases as the threshold value increases. However, notice that the mean lead time is in general not the same as the mode apart from index "29" and criteria with threshold value set at 8 hPA. The threshold of 8 hPa is also where the standard deviation (about the mean) is found to be smallest.

5.3 Forecast potential

The potential of $\Delta p(972)$ as a forecast aid can be measured in terms of FAR and NAP. From Table 5 and using definitions given in Section 5.1, these two parameters are computed and the results are shown in Table 6. Lower values mean better performance. A combined performance ratio (CPR) is also given as the average of FAR and NAP, i.e. assuming these two parameters are of equal importance. In fact, forecasters may wish to assign their own weighting factors according to the actual operational requirement to obtain the appropriate CPR-values.

To give a chance of success better than that by throwing a coin, it is desirable that the various performance indices should have magnitude of less than 0.5. On this basis, results of CPR are rather disappointing and their usefulness seems marginal at best.

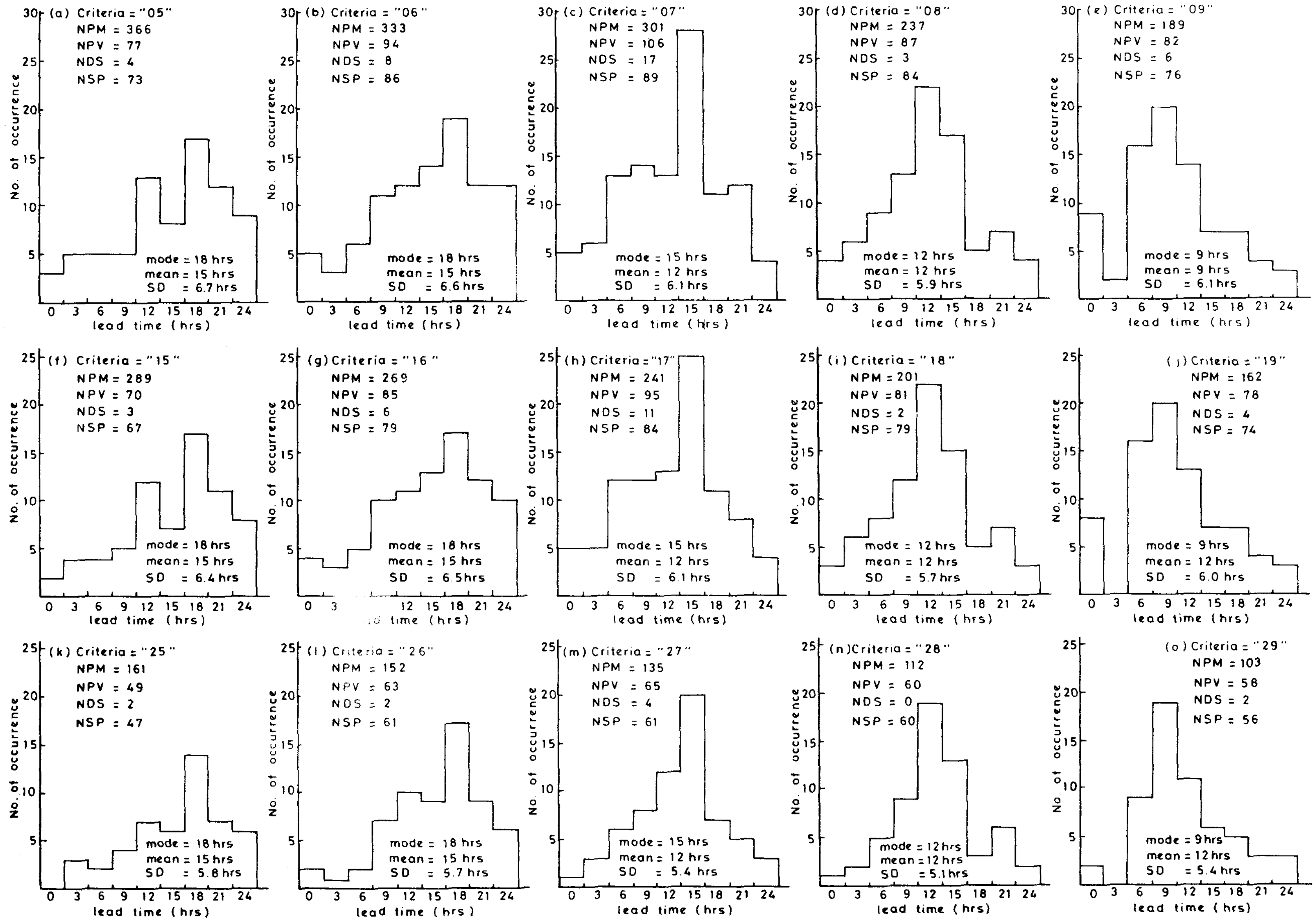

Fig.6. Frequency distribution of lead time
(SD = standard deviation; see text for other details).

Results of FAR are no more promising. Although FAR generally decreases for more stringent criteria, the extent of improvement is limited. Even for the criteria of "28" or "29", which typically represent strong surges as shown in Section 4.3, FAR never drops below 0.4.

On the other hand, NAP does not necessarily improve with increased leniency in criteria. In fact, results are consistent in showing that there is an optimum at the threshold value of 7 hPa where NAP is minimal (irrespective of threshold increase rate). For the criteria of "07", NAP is as low as 0.3. In this respect, $\Delta p(972)$ can be quite useful provided that there is a high tolerance level for false alarms.

5.4 Performance in early and late season

To see whether there are intra-seasonal variations in the performances of the various forecast indices, the surge cases are separated into two groups: early season (October to December) and late season (January to March). Verification exercise is again carried out in similar fashion to obtain the FAR and NAP for the whole set of criteria chosen.

TABLE 6. PERFORMANCE OF DIFFERENT CRITERIA

Criteria	FAR	NAP	CPR
"05"	0.79	0.43	0.610
"06"	0.72	0.33	0.525
"07"	0.65	0.30	0.475
"08"	0.63	0.34	0.485
"09"	0.57	0.41	0.490
"15"	0.76	0.48	0.620
"16"	0.68	0.38	0.530
"17"	0.61	0.34	0.475
"18"	0.60	0.38	0.490
"19"	0.52	0.42	0.470
"25"	0.70	0.63	0.665
"26"	0.59	0.52	0.555
"27"	0.52	0.52	0.520
"28"	0.46	0.53	0.495
"29"	0.44	0.56	0.500

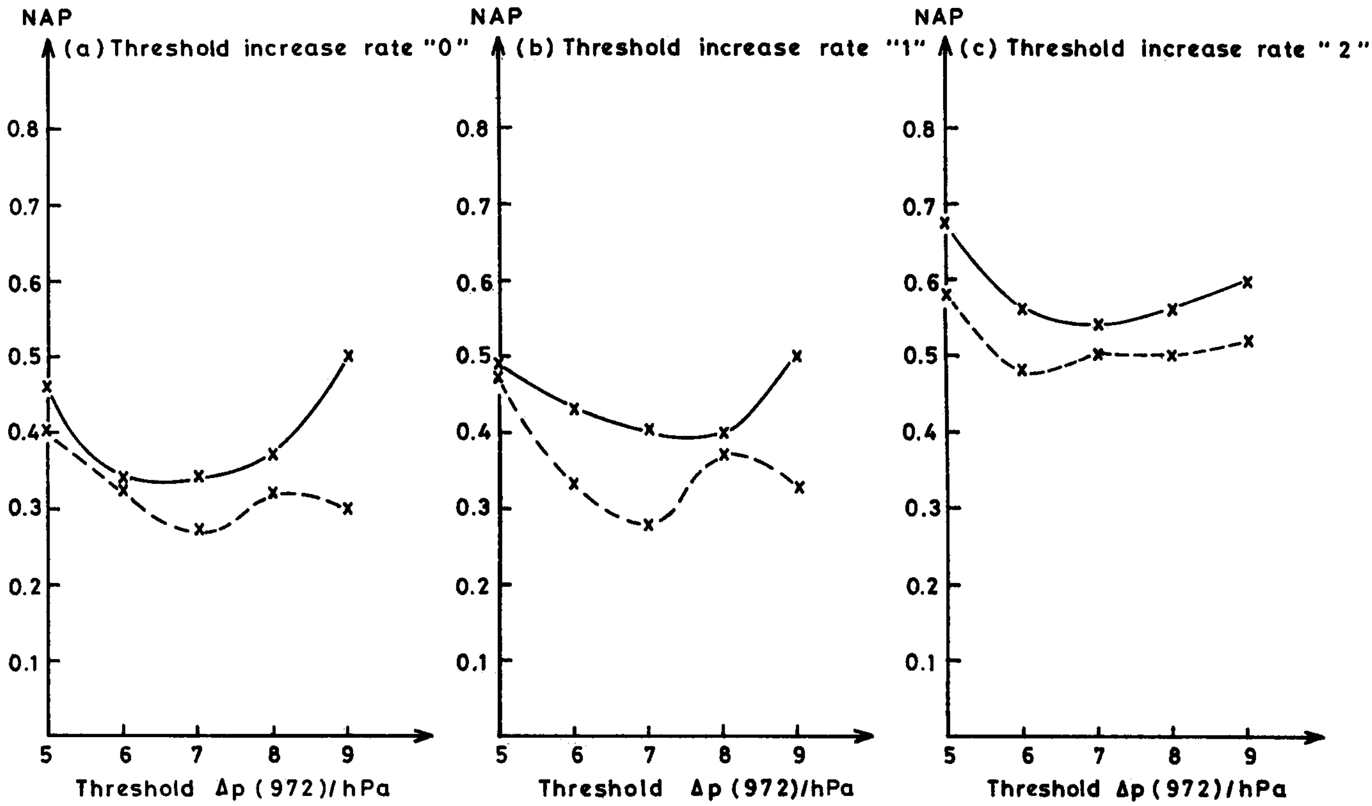

Fig.7. NAP in early (solid line)
and late (dashed line) season.

Results for NAP are shown graphically in Fig.7. Unlike the results for the whole season (see Table 6), the optimum threshold value here is not as well-defined although the threshold of 7 hPa remains the best choice in most cases. Moreover, NAP-values in late season, though showing some erratic fluctuations, are found to be consistently lower than that for early season.

Results for FAR, shown in Fig.8, are even more interesting. Values for late season are now higher than that for early season. But notice how the FAR-values for early season improve with more stringent criteria. The performance of index "28" is particularly impressive, with a reduction of near 50% in FAR in comparison to index "08". This is in sharp contrast to the apparent lack of significant improvement in FAR for the whole season (see Table 6). It can now be seen that this is mainly due to the reluctance of late-season surges to respond to the tightening of forecast criteria. While it is natural to expect FAR to decrease if the northerly push is stronger (as reflected by more stringent criteria showing significant build-up of pressure gradient between Hong Kong and Nanling), it is also obvious that whether the northerlies will actually arrive is dependent upon a multiple of

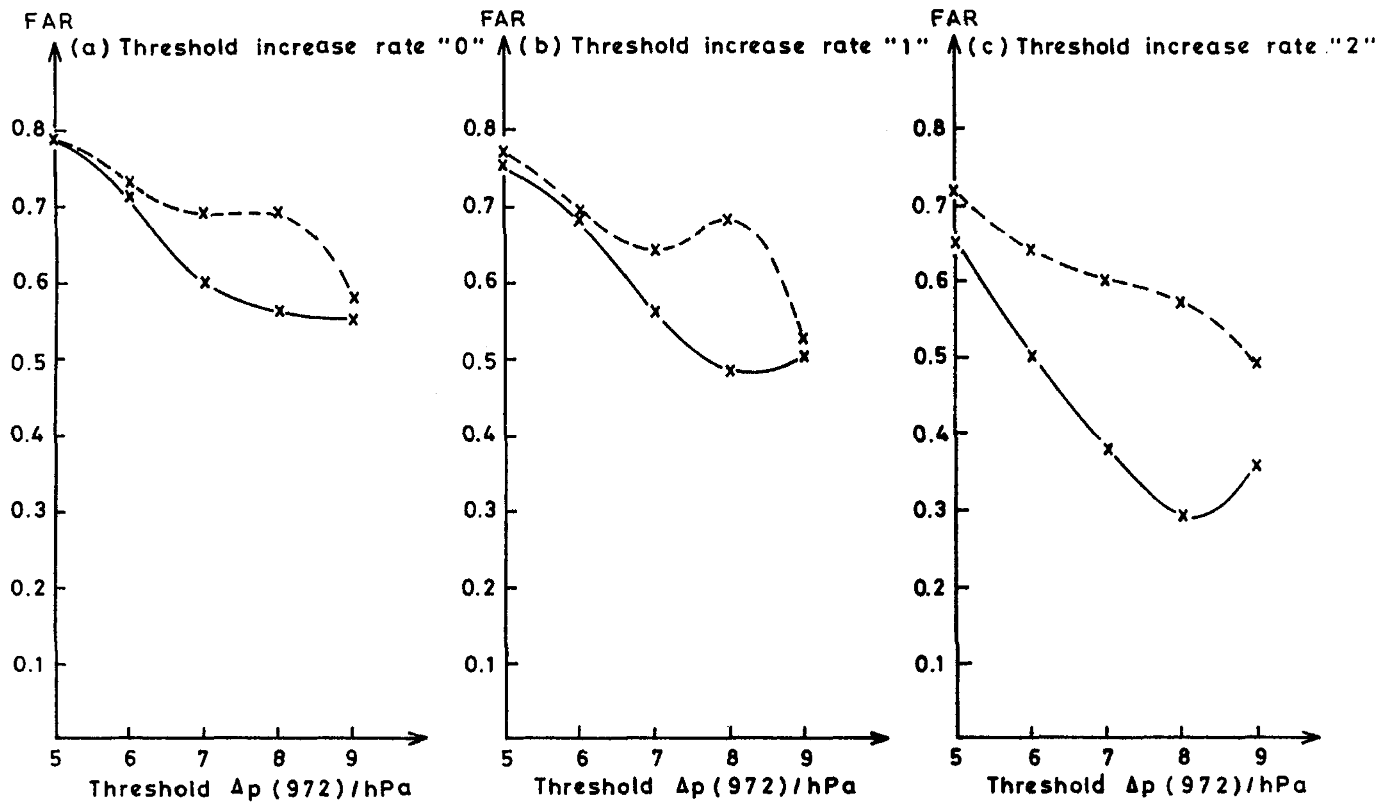

Fig.8. FAR in early (solid line) and late (dashed line) season.

factors. In early season, the intensity of the northerly push seems to be a dominant factor. Stepping up the forecast criterion is therefore quite enough in reducing the FAR. This, however, is no longer true in late season when an intense northerly push across Nanling is not a sufficient consideration to guarantee surge arrival in Hong Kong. Surge onset becomes more dependent on other contributing factors which grow in importance. One probable major factor will be highlighted in the next section.

5.5 Limitations

The capability and limitations of Δp(972) as a forecast index will be assessed from two different approaches.

First of all, we need to understand the problem of no alarms even when the forecast criteria are set at a low level. The best index among the lenient criteria is chosen for a synoptic analysis of the cases of no alarms. In this respect, the index "07" is the obvious choice.

The other approach is to see why false alarms still exist even if the forecast criteria are set stringently. For a representative of the stringent criteria, the choice is between "28" and "29". In the end, the former is preferred over the latter in view of the attractive proposition of "28" in early season (Fig.8(c)). Another advantage of index "28" is its lack of duplicated signals (see Table 5). Furthermore, the lead time of "29" is only 9 hours which leaves forecasters very little time for manouvre. This means that the criterion "29" will be of limited use even if its forecast accuracy can be perfected.

For the index "07", SSP is 89 which means that 39 surge cases apparently have no alarms. An intensity breakdown shows that they consist of 15 moderate surges (56% of total of moderate surges), 14 fresh surges (19% of total of fresh surges), and 10 strong surges (36% of total of strong surges). In other words, this index is quite capable of picking up the fresh surges which form the majority of the surge cases. The large proportion of moderate surges missed are not unexpected considering that the pressure pulses in these cases are naturally quite weak. Furthermore, the majority of these surges occur outside the daylight hours. This seems to suggest that the diurnal effect has not been eliminated completely during the screening process. Nevertheless, since moderate surges often produce only minor effects in local conditions, the extent of NAP here is probably quite acceptable.

What seems most disturbing, however, is the percentage of strong surges with apparently no alert signals. But further analysis of the 10 cases shows that apart from one surge (09Z on 24 October 1980), all the others do have signals. In some cases, the $\Delta p(972)$ background is on the high side and any signals that occur will therefore be above the threshold level. In other cases, the surges do not arrive until 27 to 39 hours after signal times. The delays cause them to be excluded from the verification process. Even then, there are signs of duplicated signals at a level above the threshold value within the 24-hour forecast range. The fact that the majority of these strong surges (7 out of 10) occur in early season further supports the proposed interpretation, since the climatological $\Delta p(972)$ background for the months of October, November and December can be shown to be higher on average (see Table 1). One may therefore be tempted to raise the threshold to capture the signals. However, it should be noted that a blanket stepping-up in criteria (e.g. setting the criterion at "08" instead of "07") will lead to an overall deterioration in NAP (see Fig.7(a)), probably at the cost of missing out a larger chunk of weaker signals. Any tightening of criteria should therefore be done on a selective basis for individual cases. As such, the problem here is not so much about any major weakness in the index.

Rather, it is a matter of prudent application of the index and fine adjustment of the timing in the light of prevailing synoptic situation.

For the more stringent index "28", there are 52 false alarms out of a total of 112 signals. It should be borne in mind that false alarm here simply means that no northerly surges are verified within 24 hours after signal time. As such, these 52 cases include cases of no northerlies whatsoever as well as cases of belated arrivals. It is found that most of them (40 to be exact) occur in late season. For the 12 cases of failure in early season, 3 of them are related to tropical cyclones or significant low pressure areas over the northern part of the South China Sea. Discarding these three special cases, the FAR for early season drops to an even more impressive figure of 0.20.

As discussed in the previous section, there must be some other factors which cause the difference in FAR trends between early and late season. One prime suspect is the effect of easterly surges which are known to be more frequent in late season. As such, the average trends of $\Delta p(972)$ and $\Delta p(S)$ for the 60 successful cases are compared with that for the 49 cases of false alarms (i.e. excluding

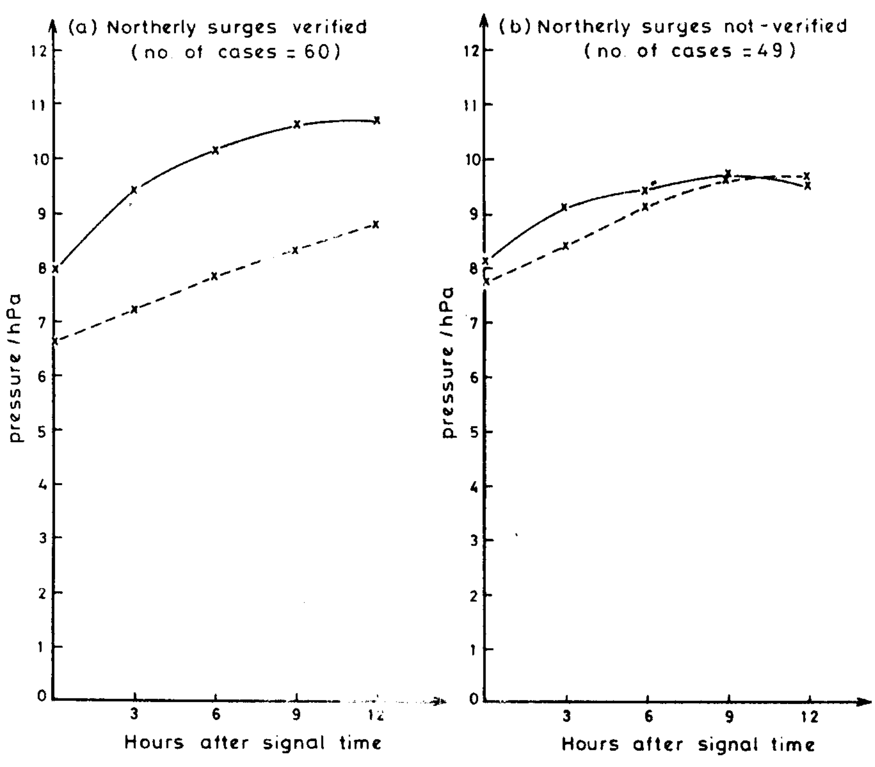

Fig.9. Comparison of $\Delta p(972)$ (solid line) and $\Delta p(S)$ (dashed line).

the three cases relating to tropical cyclones). The period chosen for study is from the signal time of $\Delta p(972)$ to 12 hours after signal time (i.e. theoretically the surge arrival time for index "28"). The results, presented in Fig.9, immediately show that while $\Delta p(S)$-values are generally lower in cases where northerly surges are verified, they are of comparable magnitude to $\Delta p(972)$ in the false alarm cases. This supports the notion that the early advancement of cold air down the coast of southeastern China plays a major role in holding back the northerlies over land.

6. CONCLUSION

The main results and conclusions discussed so far are reiterated below:

(a) Monthly averages of $\Delta p(972)$ for seven cool seasons (1980/81 to 1986/87) are computed to serve as climatological background.

(b) Composites of the northerly surge cases during the same seven seasons show a general rising trend in $\Delta p(972)$ during the 24-hour period prior to surge arrival and then levelling-off afterwards.

(c) Monthly composite $\Delta p(972)$-curves reveal a generally consistent trend. Intra-seasonal differences, if any, are relatively minor.

(d) Case studies suggest the role of the diurnal sea-breeze mechanism in limiting the occurrence of daytime surges, provided the surge intensity is not strong.

(e) Case studies also suggest the likelihood of surge intensity being dependent on the rate of increase in $\Delta p(972)$ within the 24-hour period prior to surge onset.

(f) Study of various forecast criteria shows how the lead time is progressively reduced with increasing $\Delta p(972)$. Signal strength is strongest at a time of 12 - 15 hours before surge arrival.

(g) As a lenient forecast criterion, index "07" is quite acceptable with NAP in the region of 0.3. Typical lead time is 15 hours.

(h) As a stringent forecast criterion, index "28" is the best option, particularly in early season when FAR can be as low as 0.2. Typical lead time is 12 hours.

(i) Northerly surges in late season are less dependent on the intensity of the pressure pulse across Nanling. The effect of cold air advection from the east will seriously jeopardise the chance of northerly onset.

There are also some important but unresolved issues which are summarised below:

(a) Preliminary correlation between $\Delta p(972)$ and northerly wind speed by simple linear regression proves unfruitful. For surge intensity to be reliably forecast, other factors need to be incorporated into future correlation exercises. A suggested list includes the increase rate of $\Delta p(972)$, $\Delta p(S)$, synoptic considerations (e.g. easterly ridge or trough over southern China), and further stratification to allow for diurnal and intra-seasonal variations.

(b) The relationship between surge intensity and daytime surges, which often upset temperature forecast strategy in particular, should also be clarified.

(c) The relative importance and interplay between northerly and easterly surges should be quantified further to give forecasters some definite guidelines in borderline situations.

For a quick assessment, $\Delta p(972)$ can be a useful complimentary tool as a short-range forecast index of northerly surges. Its potential as a continuous monitoring index on the likelihood of northerly onset within 24 hours should not be overlooked. Armed with the current knowledge of its capability and limitations, an overall forecast strategy for the arrivals of northerly surges can be consolidated as follows:

(1) From numerical products and the Lake Baikal 2-day rule, make a first guess of the timing of arrival. Start monitoring the trends of $\Delta p(M)$, $\Delta p(972)$, and $\Delta p(S)$.

(2) Revise the timing based on the $\Delta p(M)$ 24-hour rule.

(3) Monitor closely the $\Delta p(972)$-trend, using the following information on typical lead time to fine-tune the timing:

$\Delta p(972)$/hPa	6.0	7.0	8.0	9.0
Lead time/hours	18	15	12	9

Look out for the threshold values of 7 and 8 hPa where the signals should be most apparent.

(4) At the threshold of 7 hPa, beware of fluctuations in $\Delta p(972)$ which may indicate that the northerly push is hesitant and not yet well-established. Watch out for duplicated signals which may suggest later arrivals.

(5) At the threshold of 8 hPa, the northerlies should be well on its way, particularly if $\Delta p(972)$ increases by the rate of 2 hPa in six hours. In general, the higher the increase rate, the lower will be the chance of false alarms.

(6) If the prevailing $\Delta p(972)$-values are high, thresholds in (4) and (5) may need to be adjusted upwards.

(7) Make an estimate of the surge intensity from the Morrice diagrams or by subjective interpretation of the numerical products. Consider the possibility of strong surges if $\Delta p(972)$ increases at a rate of 2 hPa in six

hours or if $\Delta p(972)$ is likely to reach 10 hPa or above.

(8) If strong surge is unlikely, additional evidences may be required to justify daytime arrival.

(9) Take into account other synoptic factors which may upset the northerly scenario. Monitor closely the advance of cold air down the southeastern coast of China, particularly when $\Delta p(S)$ is of comparable magnitude to $\Delta p(972)$.

If the role of $\Delta p(972)$ in the above strategy is proved to be operationally effective, it may then be worthwhile to develop some kind of model output statistics (say by using grid point forecast pressure of 25.0N 112.5E) to infer the $\Delta p(972)$-trend on a longer-term basis.

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APPENDIX

ARRIVAL TIMES (DAY, HOUR) OF NORTHERLY SURGE CASES
FOR 7 COOL SEASONS (1980/81 - 1986/87)

	Jan	Feb	Mar	Oct	Nov	Dec
1980				12 18Z	01 15Z	08 18Z
				24 09Z	19 21Z	11 12Z
						18 15Z
						22 00Z
						25 21Z
						27 09Z
1981	09 15Z	06 12Z	04 09Z	08 18Z	02 00Z	05 18Z
		25 06Z		22 09Z	06 09Z	13 18Z
				28 15Z	25 15Z	17 21Z
					29 21Z	
1982	04 09Z	10 06Z	08 09Z		09 09Z	05 21Z
	15 18Z	13 12Z			19 09Z	11 00Z
	18 15Z	23 18Z			28 09Z	15 21Z
		28 21Z				24 21Z
1983	01 18Z	02 03Z	03 18Z	22 21Z	12 09Z	17 15Z
	07 15Z	11 00Z	12 12Z	26 00Z	14 21Z	22 00Z
	11 00Z	16 09Z	16 12Z	30 15Z	21 18Z	28 15Z
	17 18Z	24 18Z	28 12Z		29 18Z	
1984	02 18Z	05 09Z		05 21Z	23 18Z	04 21Z
	06 00Z	17 09Z		17 09Z	29 21Z	18 00Z
	18 21Z	25 15Z		26 15Z		20 18Z
	20 09Z	28 06Z				26 06Z
	29 21Z					
1985	03 21Z	18 00Z	04 12Z	02 21Z	08 12Z	06 12Z
	07 12Z	21 09Z	11 00Z	19 18Z	13 12Z	07 12Z
	12 03Z		12 21Z	31 15Z	16 12Z	10 18Z
	24 18Z		30 12Z		23 21Z	13 15Z
	29 03Z				28 18Z	21 15Z
						31 06Z
1986	03 12Z	05 12Z	30 12Z	28 03Z	21 21Z	02 00Z
	25 12Z	09 12Z			23 21Z	06 21Z
		17 21Z			26 21Z	18 06Z
		19 12Z				27 00Z
		27 03Z				
1987	04 15Z	02 15Z	25 06Z			
	07 12Z	27 00Z				
	11 18Z					
	19 06Z					
	23 15Z					