HONG KONG OBSERVATORY

Technical Note No. 90

SYNOPTIC PATTERNS ASSOCIATED WITH WET AND DRY NORTHERLY COLD SURGES OF THE NORTHEAST MONSOON

by

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Published July 1997

Prepared by

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551.589.1(512.317)

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I. Introduction

South China is affected by surges of the northeast monsoon from time to time in winter. The more intense surges give rise to rather cold conditions in Hong Kong. For example, during the cold spell around Chinese New Year in 1996, temperatures fell below 10 degrees at the Hong Kong Observatory (HKO) for seven consecutive days from 18 to 24 February. The weather remained gloomy with rain and the overcast conditions kept day-time temperatures below 12 degrees from 19 to 24 February, thus accentuating the feeling of coldness. Some media reports associated this cold spell directly or indirectly to the deaths of some elderly people. It was therefore an important practical problem at that time to forecast how long the cold spell would last. It was obvious that if the weather remained rainy, the cold air would not be modified by insolation and temperatures might stay low for a longer period of time. On the contrary, if the weather turned fine, insolation would warm up the air and end the cold weather. Accurately forecasting the weather associated with cold surges thus became essential on such occasions.

A surge accompanied by cloudy and rainy weather is often loosely referred to as a wet surge by forecasters in Hong Kong. On the other hand, a dry surge refers to one that is associated with fine weather. A study to differentiate the synoptic patterns associated with wet and dry surges on the south China coast will be useful to weather forecasting in the region.

II. Data

For the purpose of the present study, the coldest surge in Hong Kong of each of the months of December, January and February during 1986-1995 were analysed. Each surge was named by the date on which the lowest temperature was recorded at HKO. As two of these cases (i.e. 31.1.90 and 1.2.90) were actually one cold episode that occurred at the end of a month and lasted till the beginning of the following month, they were counted as one surge only. Thus, there were altogether 29 cases (Appendix 1). On looking through the weather charts and time-cross sections of meteorological elements of these cases, it was found that 28 of them were northerly surges (Lam, 1976). This re-confirmed the notion that northerly surges were in general colder than easterly ones. The only easterly surge of 2.2.93 was not representative of very cold surges and was not analysed here.

The 28 northerly surges were classified into wet, dry and clearing surges according to the following criteria :

(a) Wet surge - Weather remained cloudy with rain after surge arrival and while surface winds were still from the north,.

(b) Dry surge - No rain was recorded at HKO after surge arrival and while surface winds were still northerly,

(c) Clearing surge - Rain recorded at HKO on surge arrival. Rain died out with sunny intervals or periods developing later on and while surface winds remained northerly.

Of the 28 cases, there were 8 wet, 10 dry and 10 clearing surges. The monthly distribution of each kind of surges is given in Table 1. As discussed in the work of Malone (1977), the chance of a northerly surge being dry decreases as the winter progresses. In particular, only 1 out of the 9 surges in February was a dry surge.

Table 1. The monthly distribution of wet, dry and clearing surges.

	Wet	Dry	Clearing	
December	2	5	3	
January	2	4	3	
February	4	1	4	
Sub-total	8	10	10	**Total** : 28

III. 850 hPa Trough Position and the Weather in Hong Kong

Rain brought about by cold surges forms as a result of the undercutting of warm air from the south by cold air from the north. Such undercutting usually manifests itself in the form of an 850 hPa trough. The continuity charts of 850 hPa troughs were therefore plotted for the 28 cases to see whether their positions had any relationship with the weather in Hong Kong. From this analysis, it was found that the 850 hPa trough usually lay over south China before a surge reached Hong Kong. It was also found that whenever the 850 hPa trough stayed to the north of the south China coast during and after the arrival of a northerly surge, the weather in Hong Kong would remain cloudy with rain. If the trough moved south of the coast after the arrival of the surge, rain in Hong Kong would ease off and clouds thin out. In particular, the surge would be a dry one if, before the onset of the surge, the trough had already passed to the south of Hong Kong or had already relaxed such that northerly winds dominated the south China coast.

The continuity charts of the associated 850 hPa troughs and/or the synoptic patterns at that level for a wet, a dry and a clearing surge are shown in Figures 1-3. The case of 1.2.90 was a typical wet surge. On this occasion, the surge arrived at Hong Kong at 21 UTC on 30 January 1990. Figure 1a shows the 850 hPa picture at 12 UTC on 31 January, 15 hours after the onset of the surge. A trough can be seen lying from northeast to southwest over south China. This trough marked the convergence of northeasterly and southwesterly winds. As the 850 hPa trough stayed to the north of Hong Kong from 29 January to 1 February (Figure 1b), the weather in Hong Kong remained overcast with rain during and after the arrival of the surge until 1 February. Rain eased off and clouds thinned out only when surface winds turned easterly on 2 February.

The case 7.12.87 was a good example of a dry surge. Although a 850 hPa trough could be analysed to the north of Hong Kong at 00 UTC on 4 December 1987 (Figure 2a). This trough relaxed from 12 UTC on that day to 00 UTC on 5 December and general north to northwesterly winds dominated the south China coast (Figure 2b). The weather in Hong Kong stayed fine during and after the onset of the surge at 18 UTC on 4 December.

For the case 28.2.86, the surge arrived at Hong Kong on 27 February 1986. The weather in Hong Kong was overcast with rain until 1 March as the 850 hPa trough stayed to the north of the south China coast (Figure 3a). Similar to the wet surge mentioned above, the trough marked the convergence of cold northeasterlies and warm southwesterlies (Figure 3b). As this trough relaxed and northerlies penetrated all the way to the South China Sea on 2 March (Figure 3c), sunny periods emerged on that day.

IV. Movement of the 850 hPa Trough

From the results of Section III, forecasting the weather in Hong Kong associated with a northerly surge therefore reduces to the forecasting of the movement of the associated 850 hPa trough. It is therefore worthwhile to consider the factors affecting the movement of the 850 hPa trough here:

(a) 850 hPa Height Difference

The movement of the 850 hPa trough, in particular whether it will move to the south of Hong Kong from the north, depends very much on the relative strength of the cold air to its north and warm air to its south. To quantify this relative strength, the 850 hPa geopotential height difference between Changsha (Figure 4) and Hong Kong was calculated for the 28 cases. This difference was referred to as ΔZ in this study. Figure 5 is a plot of the values of ΔZ at 12-24 hours before, 0-12 hours before, 0-12 hours after and 12-24 hours after the arrival of the surges. In the diagram, the surges were classified according to whether they were wet, dry or clearing. Noting that the 850 hPa trough remained to the north of the south China coast and the weather in Hong Kong was rainy during the arrival of a clearing surges, ΔZ for these surges will be lumped with those for wet surges.

It is apparent from Figure 5 that the values of ΔZ after surge arrival had little bearing on the position of the 850 hPa trough nor the weather in Hong Kong. It was further observed that ΔZ 0-12 hours before the arrival of all dry surges were positive, hinting that positive ΔZ is a necessary condition for the 850 hPa trough to pass to the south of Hong Kong. Apart from these observations, no specific values of ΔZ could be deduced from Figure 5 as a threshold to forecast definitely the movement of the 850 hPa trough (or the weather in Hong Kong associated with a northerly surge). Nevertheless, the following sets of numbers, which were easy to remember, might be adopted by forecasters in these situations :

(a) if ΔZ was larger than 5 and 15 gpm 12-24 hours and 0-12 hours respectively before its arrival, the surge would likely be a dry one (i.e. 850 hPa trough would pass to south of Hong Kong during or before surge arrival); and

(b) if ΔZ was less than -15 and 10 gpm 12-24 hours and 0-12 hours respectively before its arrival, the surge would likely be accompanied by rain during its onset (i.e. 850 hPa trough would remain to the north of Hong Kong).

The probability of detection (POD) and false alarm rate (FAR) of these two criteria within the 28 cases under study are shown in Table 2.

Table 2. The probability of detection (POD) and false alarm rate (FAR) of Criteria (a) and (b).

Criterion (a)	POD	FAR
0-12 hour	67 %	33 %
12-24 hour	60 %	33 %

Criterion (b)	POD	FAR
0-12 hour	69 %	15 %
12-24 hour	39 %	0 %

For the wet surge of 1.2.90 mentioned in Section III, the variation of ΔZ with time is shown in Figure 6. The surge arrived at Hong Kong around 21 UTC on 30 January 1990. ΔZ was -35 and 1 gpm 21 and 9 hours respectively before the arrival of the surge. These values met criterion (b).

For the dry surge of 7.12.87, the surge arrived at Hong Kong at around 18 UTC on 4 December 1987. ΔZ 18 hours and 6 hours before arrival of the surge were 8 and 22 gpm respectively (Figure 7). These values satisfied criterion (a) above.

As regards the clearing surge of 28.2.86, the time series of ΔZ is given in Figure 8. This surge reached Hong Kong at around 00 UTC on 27 February. ΔZ 24 and 12 hours before arrival of the surge were -3 and 0 gpm respectively. Although the former value was not indicative, the latter value did hint that the surge would be accompanied by rain during its onset. On this occasion, the weather cleared around 03 UTC on 2 March. ΔZ 3 hours before this time (i.e. at 00 UTC on 2 March) was 26 gpm. However, ΔZ was already well above this value 48 hours before (i.e. at 00 UTC on 28 February). Thus this method did not offer guidance for forecasting the improvement in the weather for clearing surge.

(b) 500 hPa Northwesterlies

Southward advancement of surges of the northeast monsoon is usually initiated by 500 hPa perturbations over northern Asia (Lam 1976). Northwesterly winds behind cold troughs at this level are often visualised as the force pushing the cold front at lower levels southwards. Another way of looking at the movement of the 850 hPa trough over south China is therefore to see if 500 hPa northwesterly winds exist over central and south China and, if so, whether they are strong enough to push the 850 hPa trough south of Hong Kong.

For the wet surge of 1.2.90, the 500 hPa chart at 00 UTC on 30 January (Figure 9) indicated that an east-west oriented trough lay just north of 40°N. With the trough in this position, the flow south of 35°N was basically southwesterly. There were no northwesterly winds at 500 hPa over central and south China pushing the 850 hPa trough southwards and the trough remained over south China during surge arrival at Hong Kong at 21 UTC on 30 January. The 500 hPa east-west oriented trough temporarily collapsed and swung southeastwards on 31 January (Figure 10). The 00 UTC chart on that day showed that 500 hPa northwesterly winds behind the trough penetrated to northwestern China as a result. However, the flow over most of central and south China remained southwesterly. The 850 hPa trough was pushed slightly southwards but stayed just to the north of the south China coast on that day (Figure 1b). The 500 hPa east-west oriented trough re-established itself again the next day (Figure 11) when west to southwesterly winds prevailed again at 500 hPa south of 35°N. The northwesterly winds which blew temporarily over central China were not strong enough to push the 850 hPa trough south of Hong Kong. The weather in Hong Kong remained overcast with rain until surface winds turned easterly on 2 February.

For the dry surge of 7.12.87, with a northeast-southwest oriented trough over the Ryukyu Islands, northwesterlies at 500 hPa already existed over China from 25 to 35°N at 00 UTC on 4 December (Figure 12), 18 hours before surge arrival in Hong Kong. As discussed in Section III, the 850 hPa trough started to relax by 12 UTC on 4 December and northwesterly winds prevailed along the south China coast at this level at 00 UTC on 5 December (Figure 2). The weather in Hong Kong was fine during and after arrival of the surge.

For the clearing surge of 28.2.86, a 500 hPa east-west oriented trough existed roughly along 42°N on 26 February and persisted until 28 February (Figure 13a). The flow south of this trough over China was basically westerly. After surge arrival on 27 February, the 850 hPa trough stayed north of the south China coast until 1 March (Figure 3a). The 500 hPa east-west oriented trough showed signs of collapse on 1 March. The trough completely collapsed and swung southeastwards on 2 March. Northwesterly winds behind the trough then managed to penetrate as far south as 25°N (Figure 13b). The 850 hPa trough relaxed at the same time and northerlies at this level penetrated all the way to the South China Sea on 2 March (Figure 3). Sunny periods emerged in Hong Kong on that day.

(c) 500 hPa East-west Oriented Trough

In the course of examining the synoptic patterns, it was noticed that many of the northerly surges were associated with a slow moving east-west oriented trough at 500 hPa over northern Asia near 40-45°N. According to Zhu *et al* (1992), such east-west oriented troughs are usually related to blocking highs in the vicinity of Lake Baikal. In these situations, cold air is accumulated in northern Asia. When the accumulated cold air eventually manages to move south, it would bring an intense surge of the northeast monsoon to China.

The 500 hPa charts for the 28 cases were scrutinised. It was found that 21 of them were associated with east-west oriented troughs over northern Asia. The high proportion of cases connected with such troughs might be explained by the way these cases were chosen. As each case was the coldest surge of a month, it was not surprising that many of them were associated with 500 hPa east-west oriented trough over northern Asia, a favourable synoptic pattern for intense cold air outbreak.

On studying the 21 cases, it was found that if the 500 hPa east-west oriented trough persisted, the flow over central and south China would remain zonal. The 850 hPa trough would stay north of the south China coast and the weather in Hong Kong would remain overcast with rain. If the trough collapsed and swung southeastwards, leading to meridional northwesterly flow over central and south China, the 850 hPa trough could be pushed south of Hong Kong. The weather in Hong Kong would be cleared. The clearing surge of 28.2.86 mentioned above illustrated these clearly.

In order to objectively monitor the collapse of the 500 hPa east-west oriented trough and hence the strength of northwesterly flow over central and south China, a index defined as the difference between Z1 and Z2 was used. Here, Z1 is the mean of the 500 hPa geopotential height of four stations along 30°N (Figure 4) while Z2 is the corresponding mean for four stations along 40°N. This index will be referred to as the "zonal index" in the following discussions. A large zonal index will mean zonal flow between 30 and 40°N and vice versa. Collapse of the east-west oriented trough is usually characterised by a sharp fall in the zonal index.

For the wet surge of 1.2.90, the variation of zonal index is shown in Figure 14. Before surge arrival at 21 UTC on 30 January, zonal index remained in the range of 165 to 240 gpm, indicating the persistence of the 500 hPa east-west oriented trough. As mentioned in Section IV (b), the trough collapsed temporarily on 31 January. The zonal index fell slightly to 125 gpm in response. After the trough re-established itself on 1 February, the index rose to 158 gpm on 2 February. On this occasion, zonal index managed to capture the temporary collapse of the trough. The re-establishment of the trough was also reflected by the index.

For the dry surge of 7.12.87, zonal index was 248 gpm at 12 UTC on 4 January, 6 hours before surge arrival (Figure 15). It fell sharply to 135 gpm at 00 UTC on 5 January and dropped further to 63 gpm 12 hours later. The sharp fall in zonal index indicated that the meridional northwesterly flow over Central and South China was well established by surge arrival.

For the clearing surge of 28.2.86, zonal index stayed at around 200 gpm until 28 February (Figure 16), indicating the dominance of the 500 hPa east-west oriented trough. The trough showed signs of collapse on 1 March as reflected by the fall in zonal index. As the trough completely collapsed at 00 UTC on 2 March, zonal index fell to 125 gpm.

(d) Warm Air from the South

As mentioned above, the movement of the 850 hPa trough associated with a northerly surge depends on the relative strength of cold and warm air. Relatively strong warm air from the south might stop the southward movement of the 850 hPa trough and would be favourable for wet surges. Large negative values of ΔZ before arrival of a surge may be taken as a indication of strong warm air. Besides, warm air from the south might be monitored by the upper winds at Haikou on Hainan Island. For the wet surge of 1.2.90, an anticyclone was situated over the northwestern part of the South China Sea at 850 hPa (Figure 1a). Because of the maintenance of this anticyclone, winds at Haikou remained southwesterly during the entire wet surge episode in Hong Kong (not shown).

V. The Cold Spell during the 1996 Chinese New Year Period

A surface cold front crossed the south China coast in the evening of 17 February 1996, marking the beginning of a prolonged intense northerly surge in Hong Kong. The overcast and rainy weather accompanying the surge, as mentioned in Section I, persisted until the end of the month. The synoptic situation at that time is discussed below with a view to explaining the persistence of rainy weather with reference to the results obtained above.

The continuity chart of the 850 hPa trough (Figure 17) showed that the trough stayed to the north of the south China coast during the entire cold spell which lasted until 24 February.

ΔZ was -53 and -4 gpm 24 and 12 hours before arrival of the surge (Figure 18), consistent with the occurrence of rain during onset of the surge. These large negative values of ΔZ also showed that warm air from the south was rather strong. This surge was also associated with a slow moving east-west oriented trough lying north of 45°N at 500 hPa (Figure 19). This trough maintained itself during the cold spell as shown by the small variation in zonal index (Figure 20) during the period. Zonal index stay above 165 gpm before 25 February and never had a sharp fall, indicating that the 500 hPa flow over central and south China was essentially zonal during the cold spell. In the lack of a push from the north, couple with relatively strong warm air from the south, the 850 hPa trough associated with this surge stayed north of the south China coast during the entire cold episode. The persistence of overcast and rainy weather could therefore be understood.

VI. Conclusions

The coldest surge of each of the months of December, January and February during 1986-1995 were studied. It was found that the majority of these surges belonged to the northerly type. The synoptic patterns of these northerly surges were analysed. It was noticed that the weather in Hong Kong associated with a surge was highly dependent upon the position of the related 850 hPa trough. If the trough stayed to the north of Hong Kong during and after the arrival of a surge, the weather in Hong Kong would remain overcast with rain. On the other hand, if the trough managed to relax or move to the south of Hong Kong, the weather in Hong

Kong would improve. In particular, if the trough had already moved to the south of Hong Kong or relaxed during or before the onset of a surge, the surge would be a dry one.

The forecasting of the weather in Hong Kong accompanying a northerly surge may therefore be reduced to the forecasting of the position of the associated 850 hPa trough. As the trough marked the convergence of cold air from the north and warm air from the south, its movement and hence its position were determined by the relative strength of the two air masses. In this study, this relative strength was quantified by ΔZ, that is, the 850 hPa geopotential height difference between Changsha and Hong Kong. Large positive values of ΔZ before surge arrival indicated that cold air was rather strong and favoured dry surge. On the contrary, negative values of ΔZ suggested warm air was relatively strong and was favourable for wet surge.

Furthermore, it was found that the strength of the push from the north was dependent on whether northwesterly winds existed at 500 hPa over central and south China, preferably south of 30°N. Specifically, if a surge was associated with an east-west oriented trough over northern Asia, organised northwesterly winds usually would not exist over central and south China. The 850 hPa trough could not pass to the south of Hong Kong under such conditions. However, if the east-west oriented trough at 500 hPa collapsed and swung southeastwards, northwesterlies could penetrate as far south as 25°N, generating a northerly push on the 850 hPa trough which might move to the south of Hong Kong. The persistence or collapse of the 500 hPa east-west oriented trough could be monitored quantitatively by the "zonal index". A sharp fall in the index might be a signal for the collapse of the trough.

Acknowledgement :

The authors would like to express their sincere gratitude to Mr. C.Y. Lam for his invaluable comments and suggestions during the preparation of this report.

References :

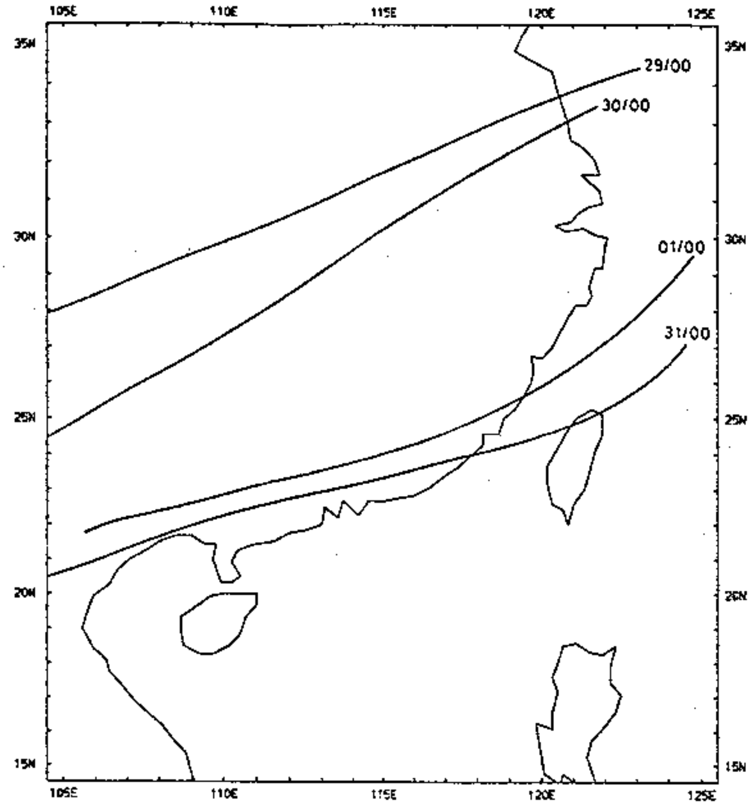
Lam, C.Y., 1976 : 500 millibar troughs passing over Lake Baikal and the arrival of surges at Hong Kong, Observatory Technical Note (Local) No.31.

Malone, D.J., 1977 : Hong Kong Forecasters' Manual, Observatory Technical Note (Local) No. 32.

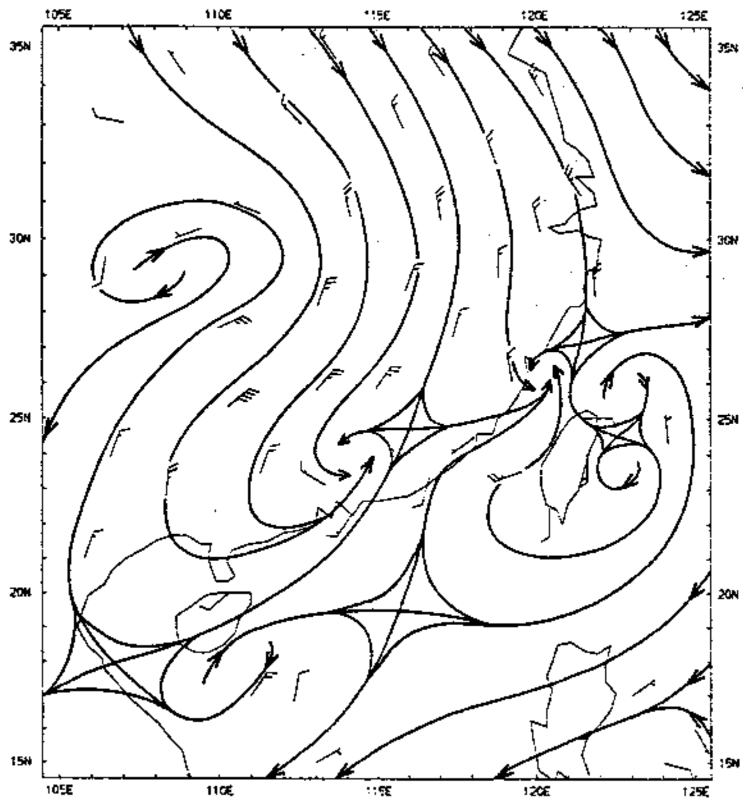
Zhu, K. *et al*, 1992 : Principles and methods in meteorology (in Chinese), Meteorology Press.

Appendix 1 : Cold Surges Studied

1.	6.1.86	northerly dry surge
2.	28.2.86	northerly clearing surge
3.	19.12.86	northerly clearing surge
4.	27.1.87	northerly dry surge
5.	28.2.87	northerly clearing surge
6.	7.12.87	northerly dry surge
7.	19.1.88	northerly clearing surge
8.	19.2.88	northerly wet surge
9.	11.12.88	northerly clearing surge
10.	14.1.89	northerly wet surge
11.	10.2.89	northerly clearing surge
12.	24.12.89	northerly wet surge
13.	31.1.90	northerly wet surge
14.	1.2.90	northerly wet surge
15.	2.12.90	northerly dry surge
16.	15.1.91	northerly clearing surge
17.	20.2.91	northerly clearing surge
18.	28.12.91	northerly wet surge
19.	15.1.92	northerly dry surge
20.	13.2.92	northerly wet surge
21.	16.12.92	northerly clearing surge
22.	16.1.93	northerly clearing surge
23.	2.2.93	easterly surge
24.	17.12.93	northerly dry surge
25.	21.1.94	northerly dry surge
26.	28.2.94	northerly wet surge
27.	22.12.94	northerly dry surge
28.	31.1.95	northerly wet surge
29.	6.2.95	northerly dry surge
30.	30.12.95	northerly dry surge



(a)

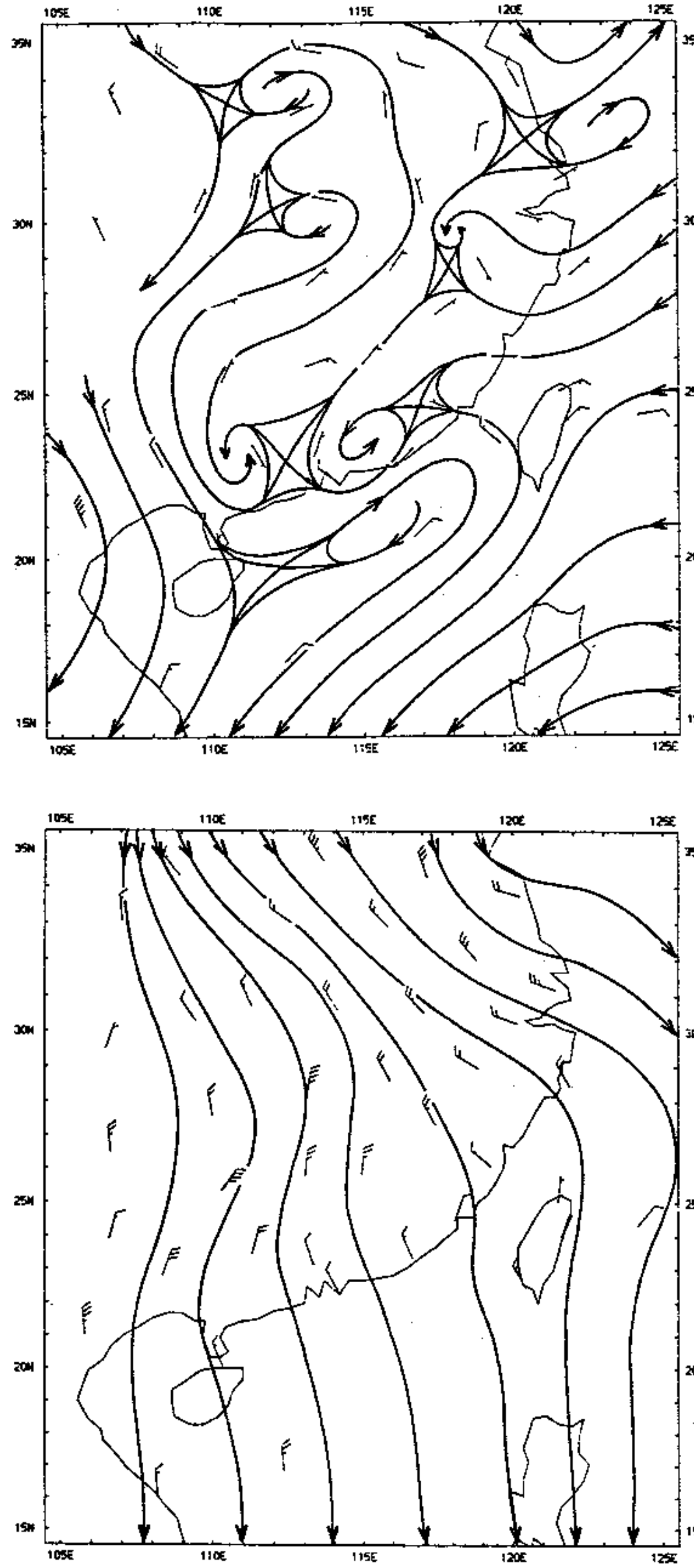


(b)

Figure 1. Wet surge:

(a) Positions of 850 hPa trough during the period 29 January 1990 to 1 February 1990.

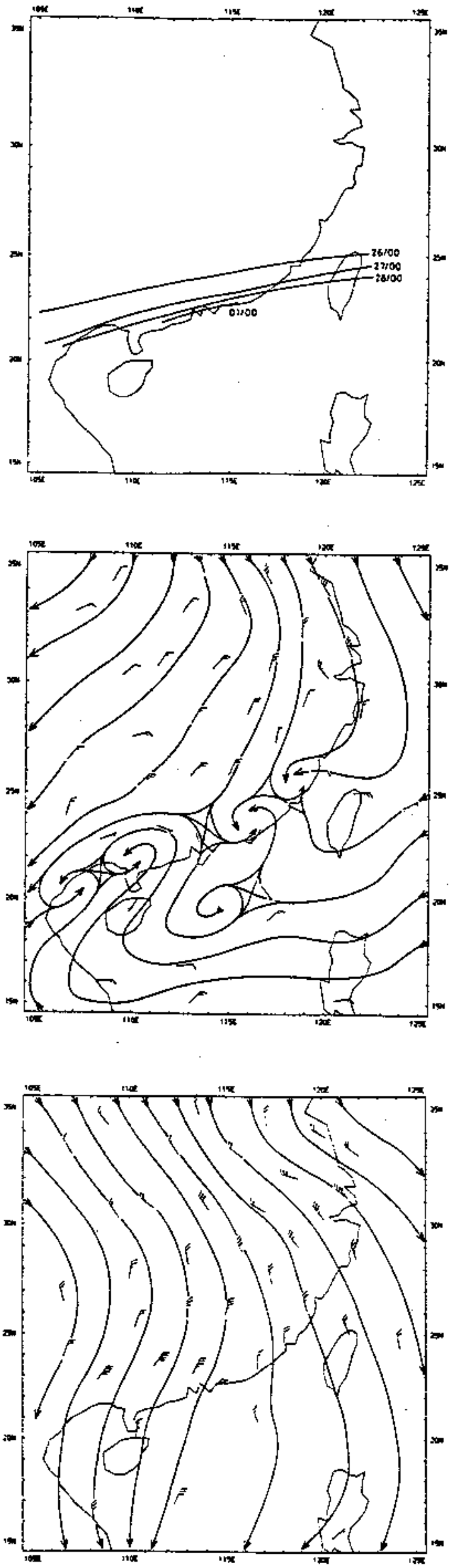
(b) The 850 hPa streamlines at 12 UTC on 31 January. A trough marked the convergence of northerly and southerly winds lying from northeast to southwest over southern China.



(a)

(b)

Figure 2. Dry surge:
(a) 850 hPa streamlines at 00 UTC on 4 December 1987.
(b) 850 hPa streamlines at 00 UTC on 5 December 1987.



(a)

(b)

(c)

Figure 3. Clearing surge:
(a) Positions of 850 hPa trough from 26 February 1986 to 1 March 1986.
(b) 850 hPa streamlines at 00 UTC on 27 February 1986.
(c) 850 hPa streamlines at 00 UTC on 2 March 1986.

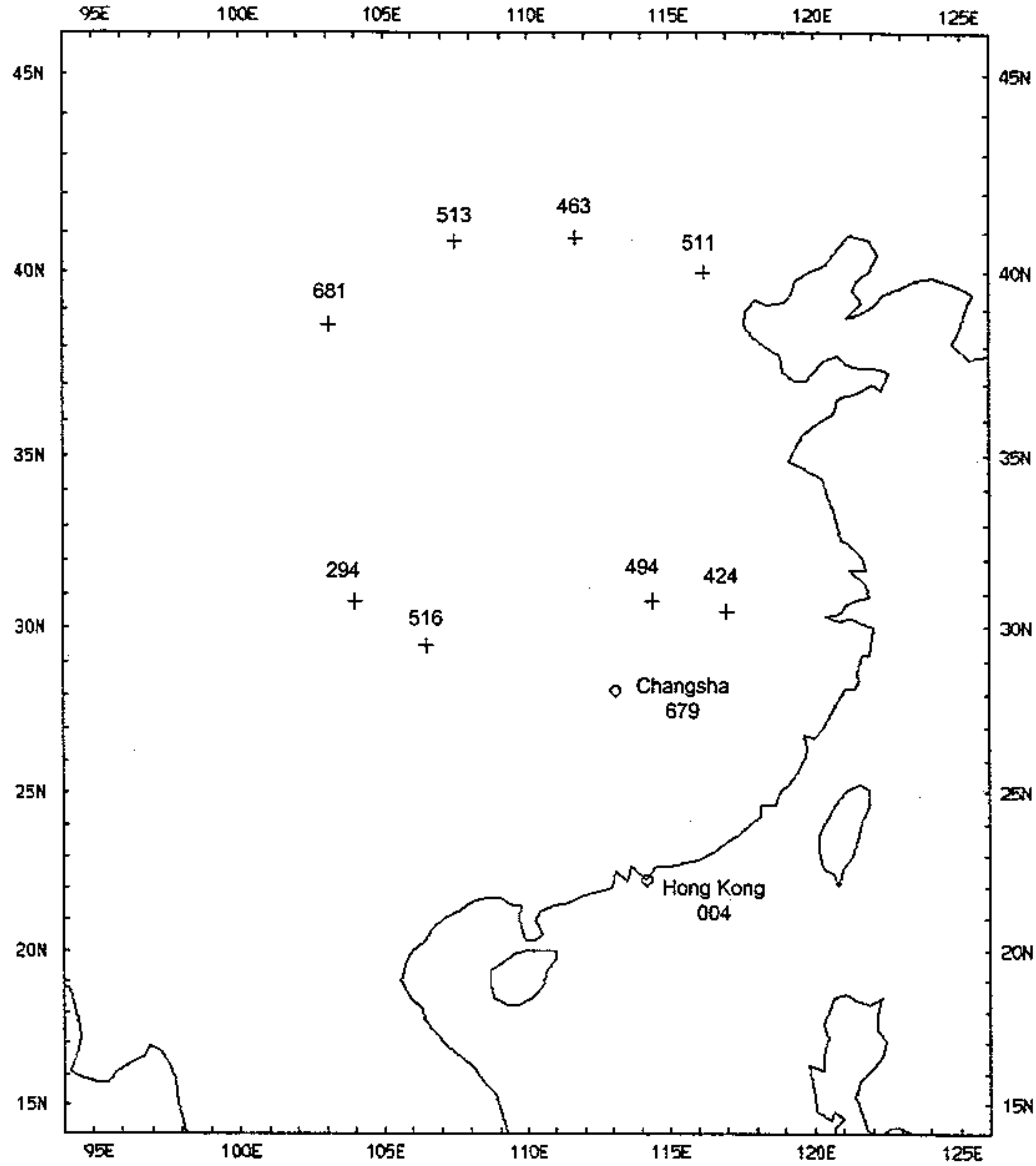


Figure 4. Geographic locations of Hong Kong and Changsha, and the eight stations used in the calculation of zonal index (figures indicating the station codes).

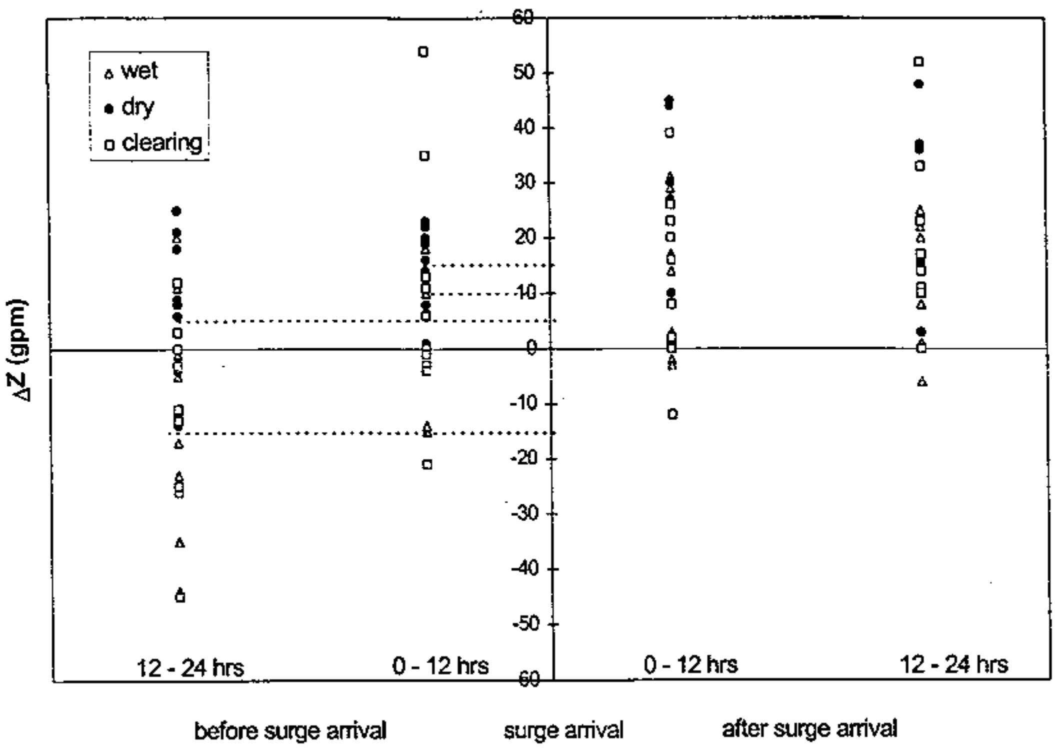


Figure 5. Distribution of ΔZ before and after surge arrival for wet, dry and clearing surges.

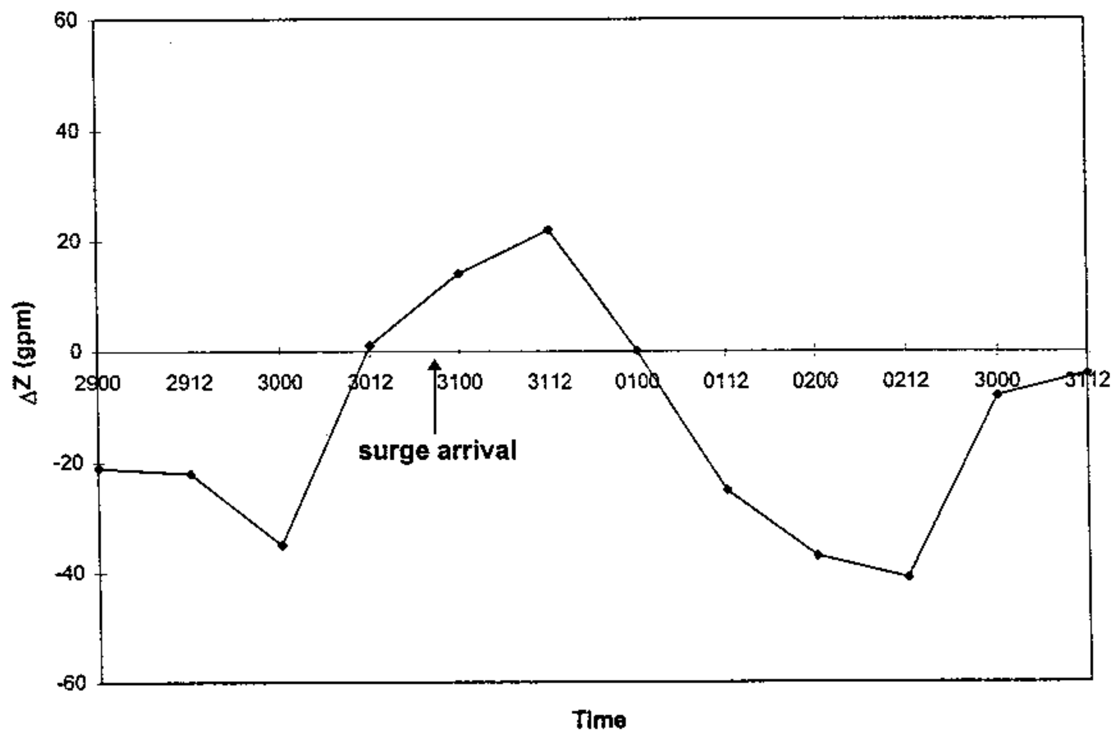


Figure 6. Variation of ΔZ during the period 29 January 1990 to 3 February 1990.

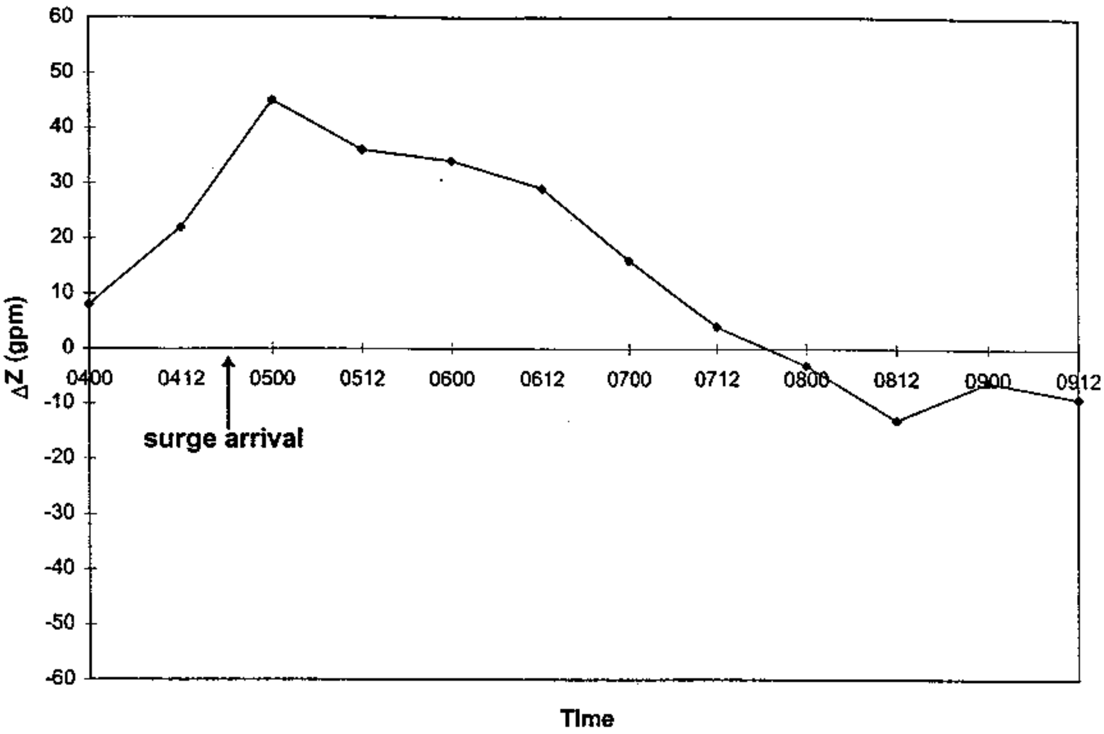


Figure 7. Variation of ΔZ during the period 4 December 1987 to 9 December 1987.

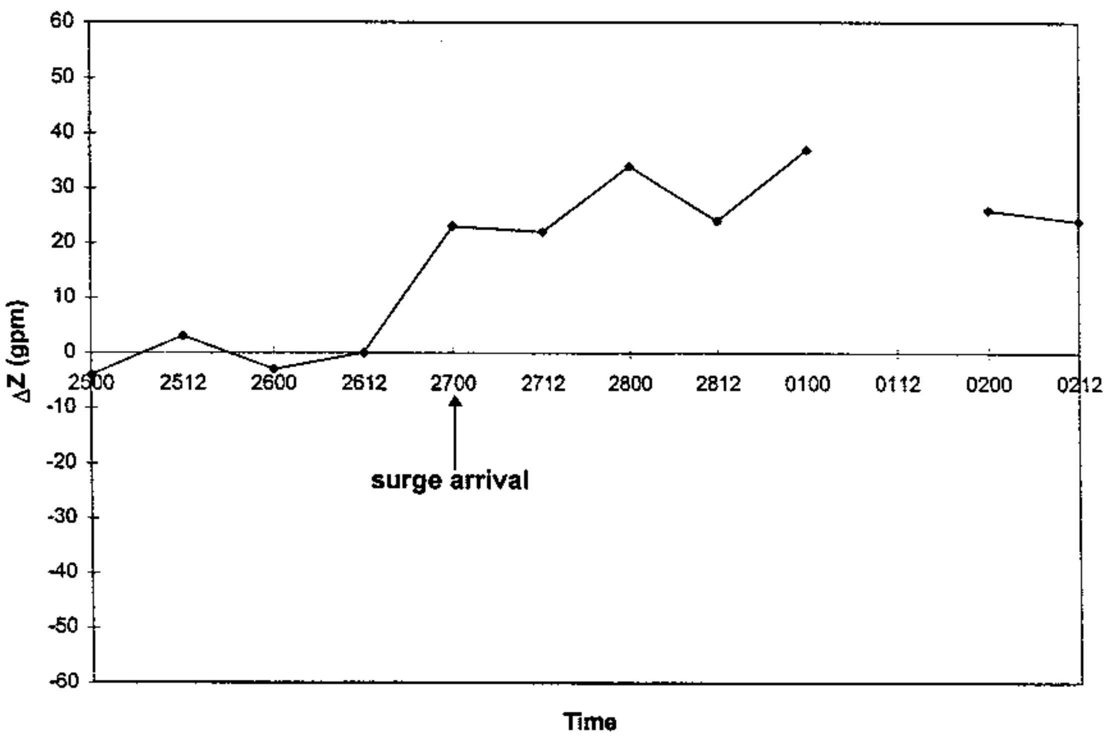


Figure 8. Variation of ΔZ during the period 25 February 1986 to 2 March 1986.

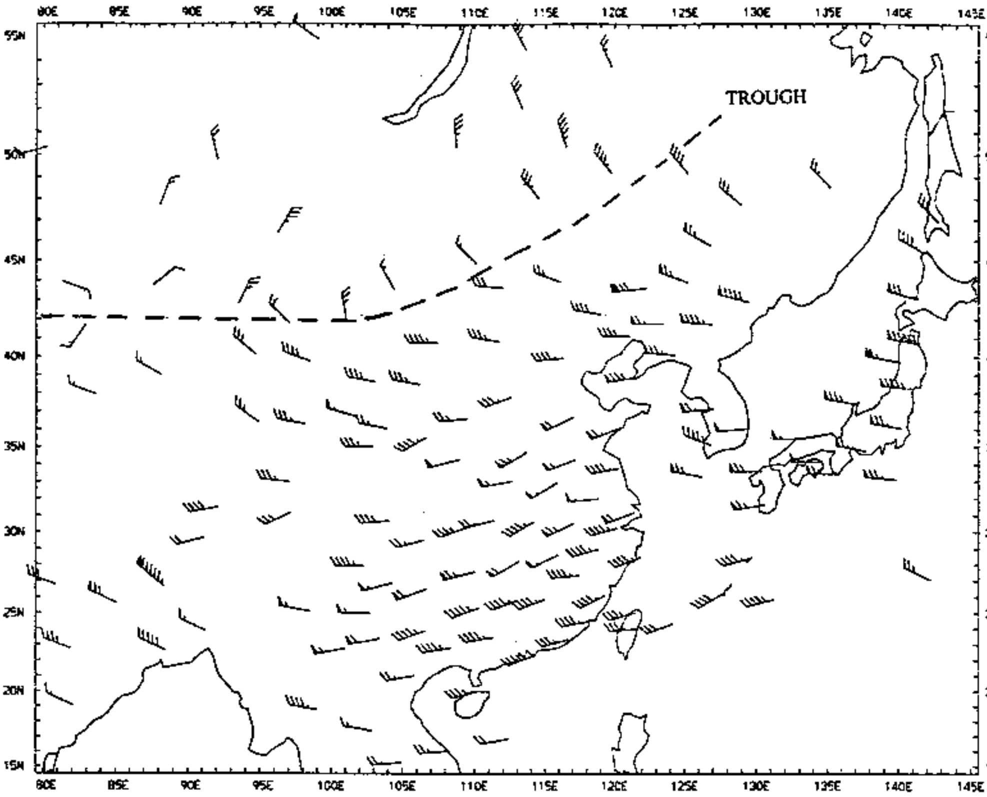


Figure 9. 500 hPa wind field at 00 UTC on 30 January 1990.

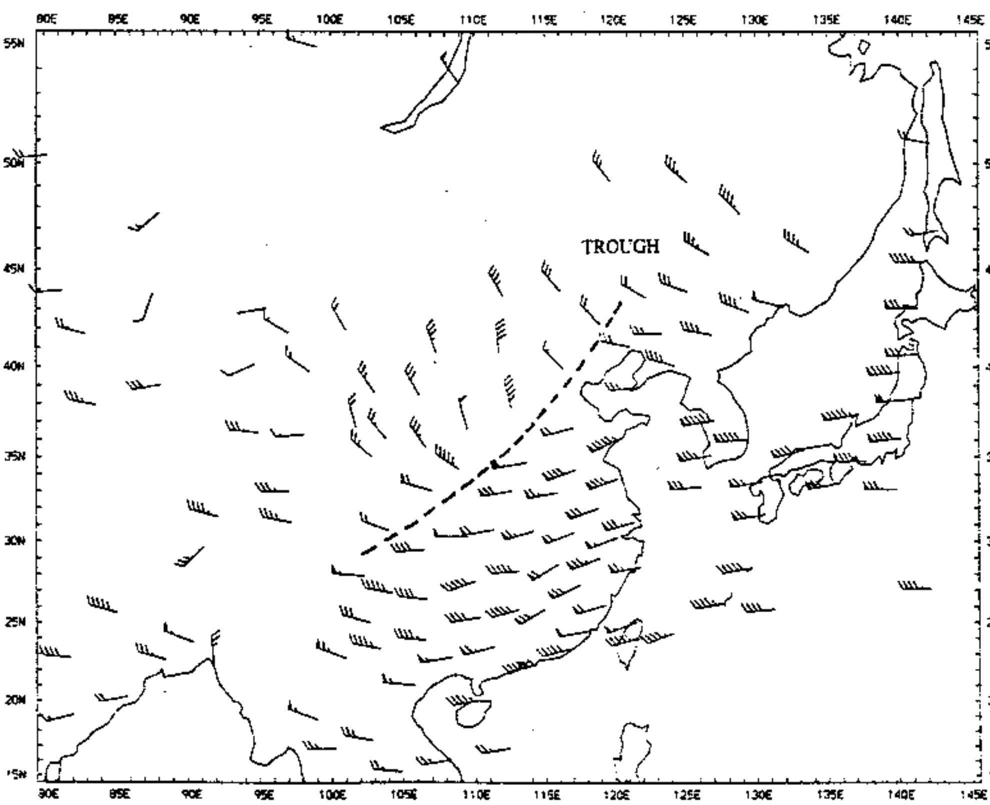


Figure 10. 500 hPa wind field at 00 UTC on 31 January 1990.

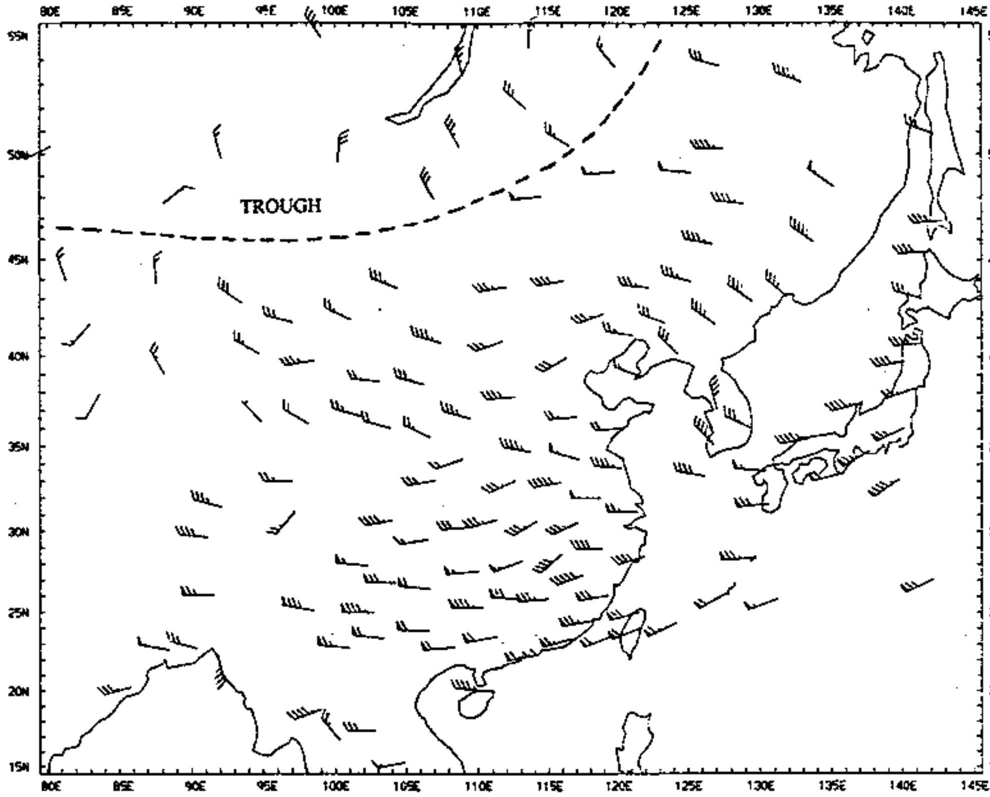


Figure 11. 500 hPa wind field at 12 UTC on 1 February 1990.

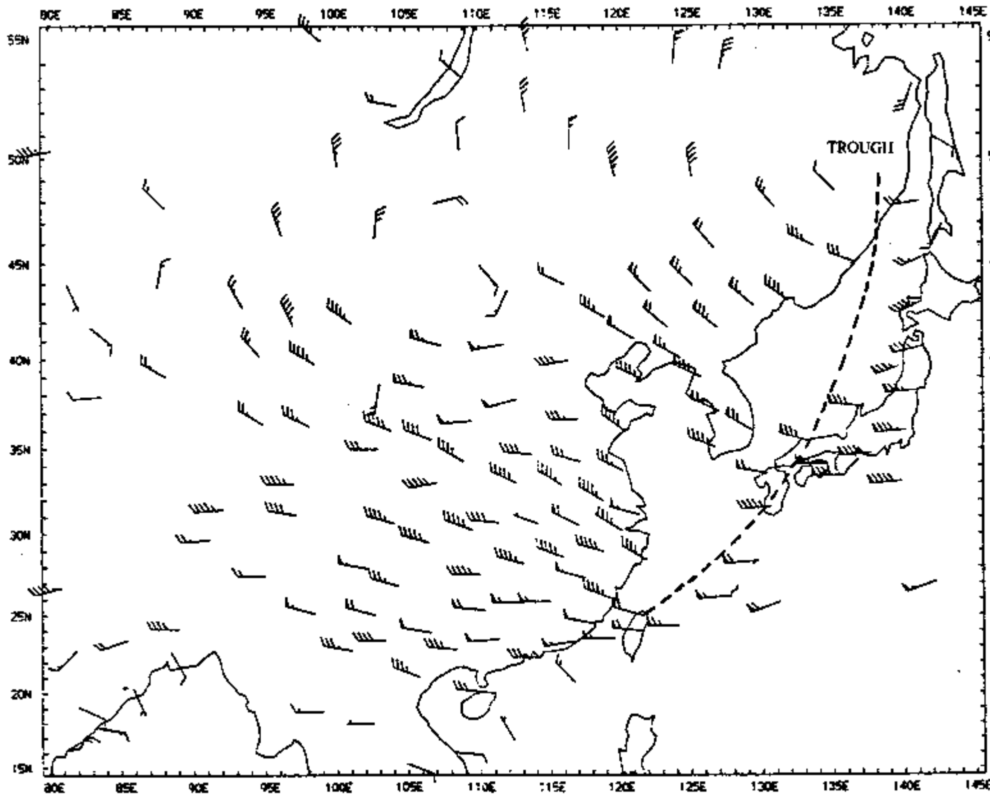
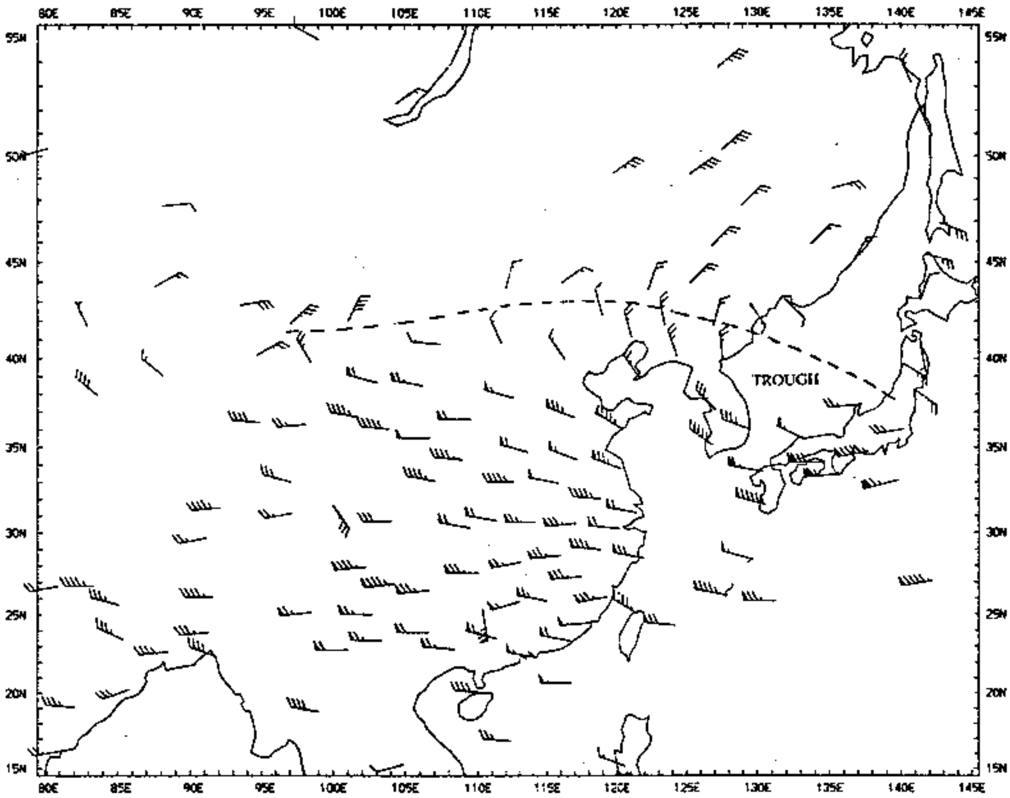
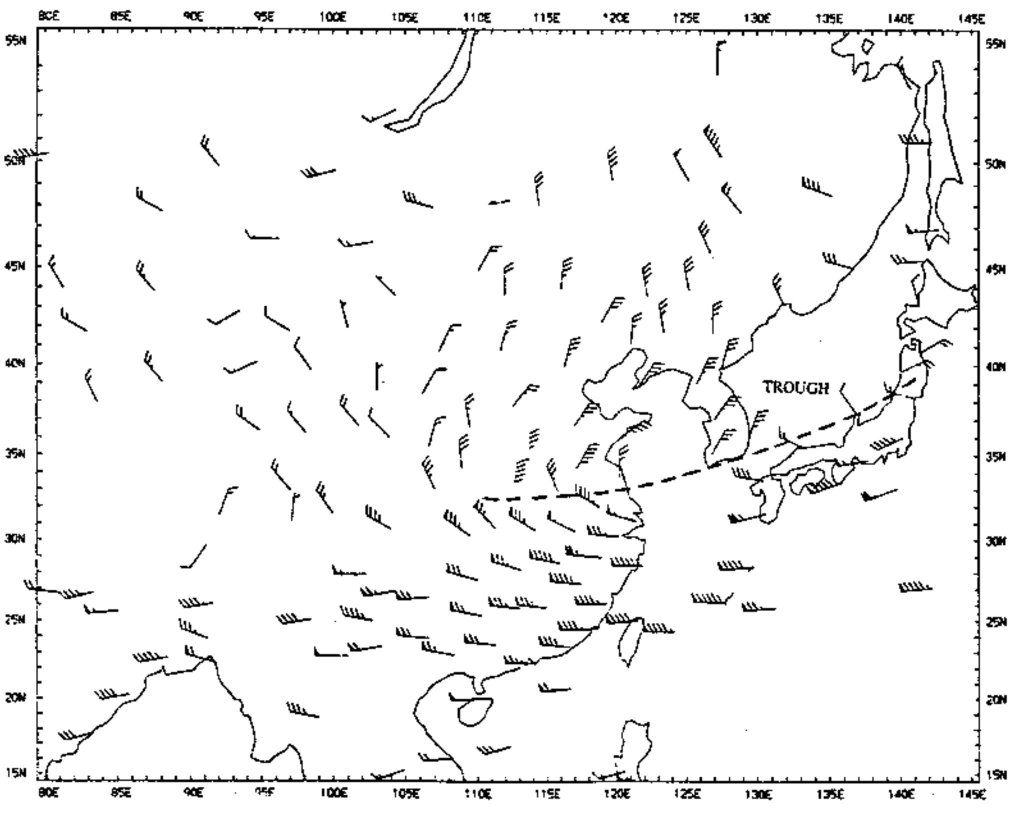


Figure 12. 500 hPa wind field at 00 UTC on 4 December 1987.



(a)



(b)

Figure 13 (a) 500 hPa wind field at 00 UTC on 28 February 1986.
(b) 500 hPa wind field at 00 UTC on 2 March 1986.

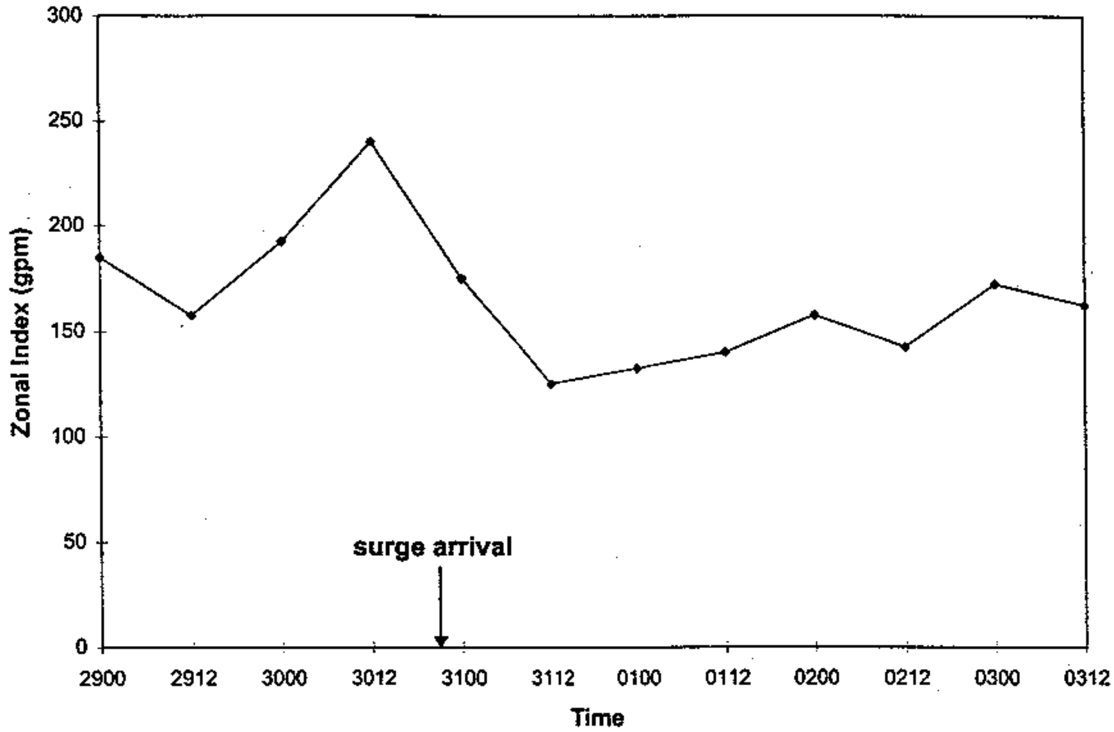


Figure 14. Variation of zonal index during the period 29 January 1990 to 3 February 1990.

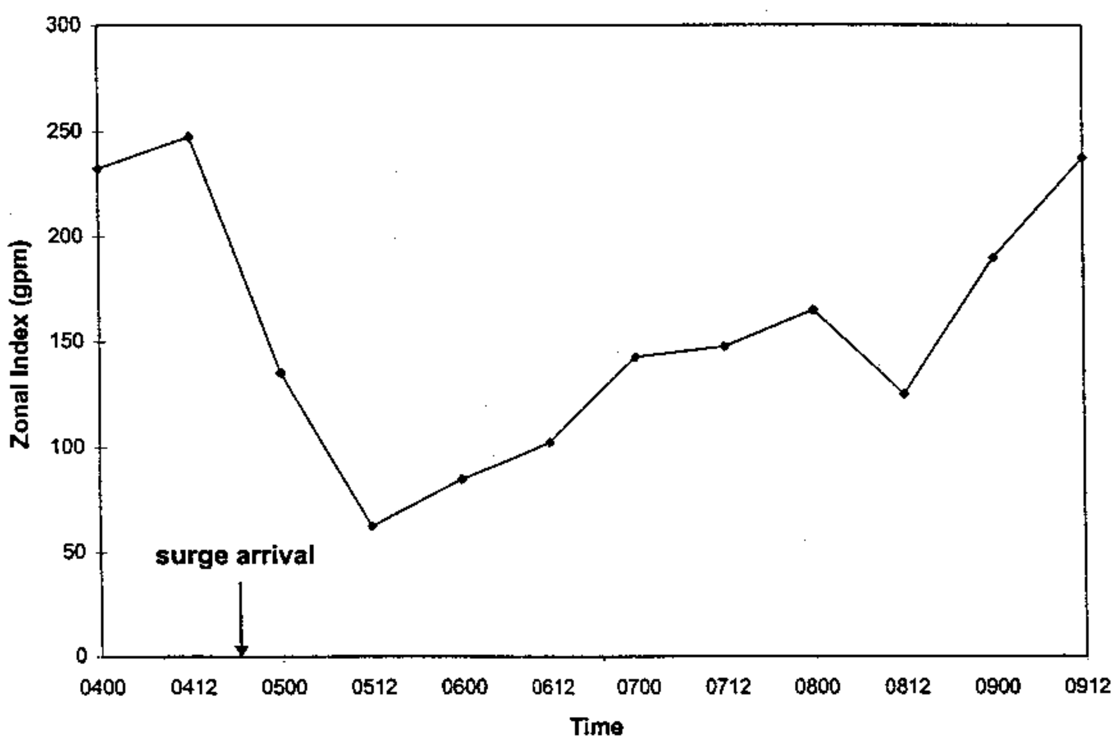


Figure 15. Variation of zonal index during the period 4 December 1987 to 9 December 1987.

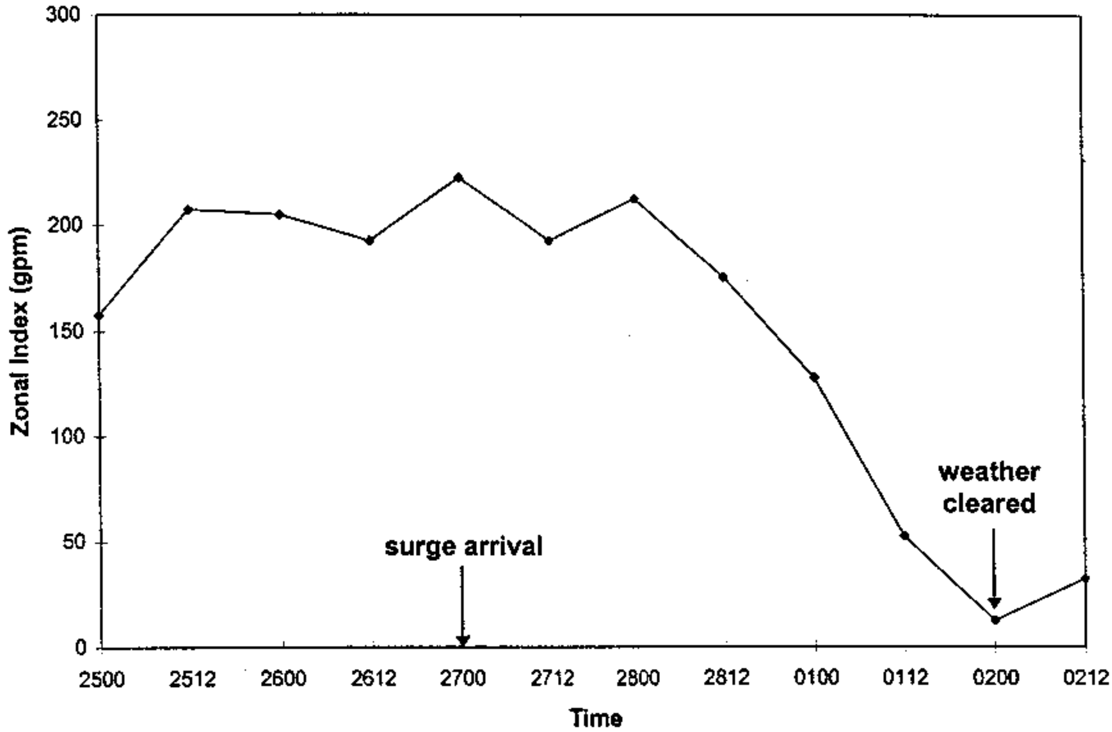


Figure 16. Variation of zonal index during the period 25 February 1986 to 2 March 1986.

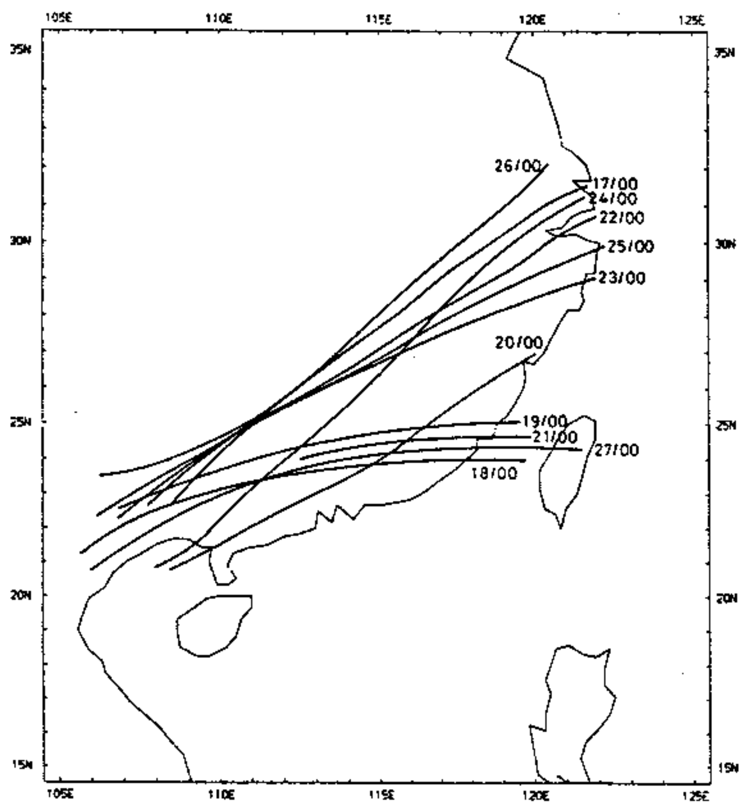


Figure 17. Positions of the 850 hPa trough from 17 to 27 February 1996.

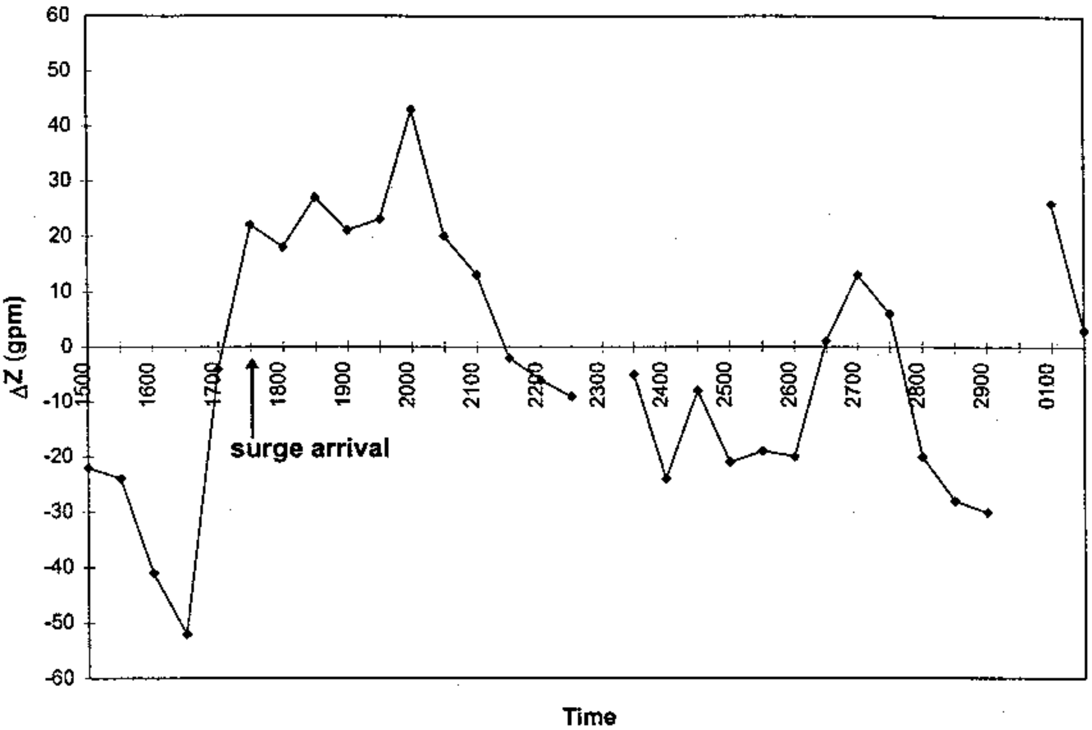


Figure 18. Variation of ΔZ during the cold spell in the 1996 Chinese New Year.

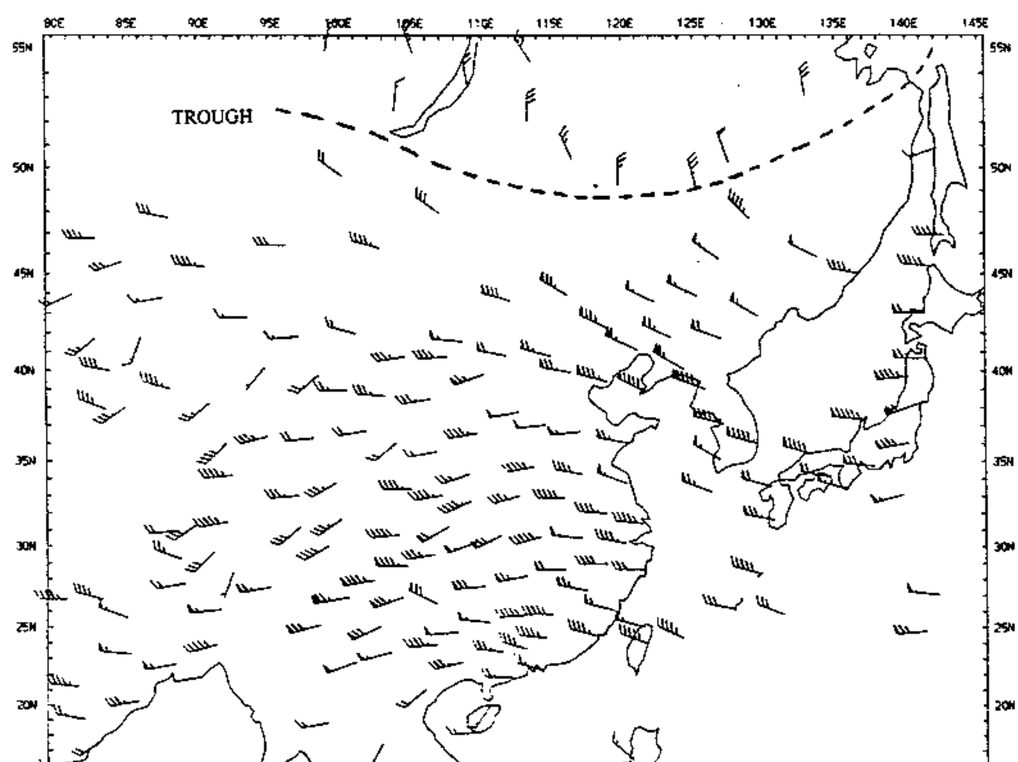


Figure 19. 500 hPa wind field at 00 UTC on 16 February 1996.

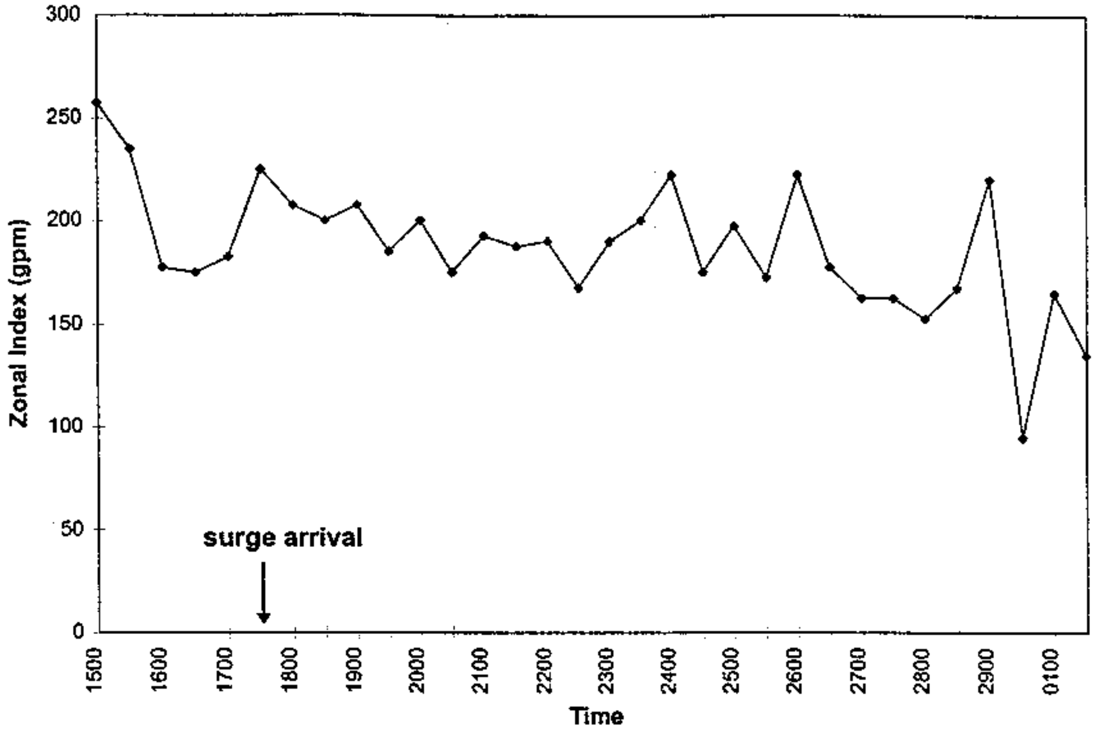


Figure 20. Variation of zonal index during the cold spell in the 1996 Chinese New Year.