Surface Features of Winter Monsoon Surges over South China

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ABSTRACT

The surface features associated with two kinds of winter monsoon surges over south China are studied: the easterly surge (ES) and the northerly surge (NS). Surface meteorological parameters over the region 15°-50°N, 90°-130°E for the surges that occurred in the three winters (October–March) from 1988 to 1991 are analyzed. For the northerly surge, the surface features found are 1) an abrupt temperature drop and wind direction turning from easterly to northerly, which can be related to the passage of a cold front; 2) an increase in the dewpoint depression; and 3) a large north–south pressure gradient. On the other hand, the easterly surge is found to be associated with strong easterly winds up to approximately 40 km h⁻¹, little temperature or pressure change, and a southeasterly motion of a high pressure center from Dahingganling to the Yellow Sea together with a sharp pressure ridge along the east China coast. Furthermore, an ES and an NS are associated with different perturbations (anomalies) in pressure, wind, temperature, and dewpoint depression when compared with the wintertime normal condition. The results suggest a clear distinction between the two surges on the synoptic scale.

1. Introduction

The winter monsoonal character over mainland China may be collectively represented by events of monsoon surge that represent the southeastward advance of the cold Siberia–Mongolia air mass across the east Asian coast. These surges are commonly termed as "cold surge" when rapid temperature drops are associated with the cold outbreak. Nevertheless, the definition of a cold surge is varied (and somewhat arbitrary) and tends to refer to the effects the surge has on the local weather for a specific key location and for practical reasons (Boyle and Chen 1987). For example, Chang and Lau (1979) considered that a cold surge should have at least a 6°C surface temperature drop within 24–48 h over Hong Kong whereas only a 5°C drop was required by Lau and Lau (1984).

According to the Royal Observatory Hong Kong (ROHK), monsoon surges affecting Hong Kong may be either of the northerly type or easterly type (Chin 1969). In a simple sense, the two differ in terms of the wind direction and the degree of transformation of the cold air mass and are basically characterized by evident temperature drops and intense easterly onshore winds, respectively. Therefore, the northerly-type monsoon surge is traditionally regarded as the cold surge.

Both types of surges are directly related to the development of the continental anticyclone over the Siberia–Mongolia region in the wintertime (Chang 1989). In terms of horizontal scale, northerly-type surges affect not only Hong Kong (at about 22°N) but also most parts of China with evident temperature drops so that they can be identified quite easily and various definitions of them are quite consistent. On the contrary, evident effects of the easterly-type surges are only felt along the coastal region and are often not regarded as a monsoon surge in the inland regions of China. Therefore, most studies of the monsoon surges over (south) China in fact refer to the northerly one only in which temperature drops and strengthening in northerlies are emphasized in the identification (i.e., cold surge).

Many studies have been carried out to understand the characteristics associated with the (northerly) cold surge. For example, Chang and Lau (1982) and Lau et al. (1983) investigated the planetary-scale interactions while Chang et al. (1983) studied the gravitational character. The regional circulation characteristics were analyzed by Chu and Park (1984). Ding and Xiao (1992) carried a case study of the northerly surge development in east Asia. Also, Lai (1989) considered the forecasting criteria in Hong Kong. In addition, there are studies concerning the structure and heat budget of the Siberia–Mongolia high such as those by Ding and Krishnamurti (1987) and Ding et al. (1991). On the other hand, no systematic study on the easterly-type monsoon surge has been done. Thus, there is a need to consider the easterly-type monsoon surge (in addition to the northerly) as these surges always occur in Hong Kong and south China (in particular to the coastal regions) during wintertime.

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In the present study, the easterly and northerly types of monsoon surge are treated as completely separate kinds of winter monsoon surges and will be labeled as the easterly surge (ES) and the northerly surge (NS). The surges are defined entirely to the local (Hong Kong) surface weather patterns. The composite synoptic-scale surface patterns associated with each kind of surge are then studied and compared. The purpose of this paper is to identify differences in the surface features through composite analyses between the ES and the NS that affect Hong Kong (and also south China). The upper-air features associated with these two kinds of surges are currently being studied and will be reported in an upcoming paper.

In section 2, a brief description of the data and methodology together with the definitions of the surges will be given. The local and synoptic-scale surface features associated with the NS and ES will be described in sections 4 and 5, respectively, after a brief description of the normal wintertime atmospheric condition in section 3. A comparison of the surges with the normal conditions and a summary of the results together with possible future work in this study will be given in section 6 and 7, respectively.

2. Data and methodology

a. Data

Two sources of data for the period October 1988–March 1991 are used:

(i) data from the Monthly Weather Summary published by ROHK; and

(ii) data from the Global Telecommunication System (GTS) provided by ROHK.

The first source of data gives the daily-averaged surface meteorological parameters in Hong Kong and are referred to in terms of local time. These are used for selecting the surge cases and the analysis of local wind variations at an island offshore (Waglan Island) of Hong Kong. The second dataset is used for studying the synoptic-scale features of the surges, as well as the local variations of pressure, temperature, and dewpoint depression. This dataset consists of daily surface station data [including wind, temperature, dewpoint temperature, and mean sea level pressure (MSLP)] at 0000, 0300, 0600, 0900, 1200, 1500, 1800, and 2100 UTC. The region covered in the synoptic-scale analysis as limited by the data available on the GTS is shown in Fig. 1, together with the location of surface stations and some geographical names to which this paper may refer.
cant effects associated with a surge event over south China generally last for approximately 1–2 days. Further, the cause of the surge may be identified by studying the conditions 1–2 days before. A monsoon surge event is therefore assumed to have a 5-day time span denoted as day −2, day −1, day 0, day 1, and day 2 in sequence, with day 0 being the day the surge arrived in Hong Kong in the identification. Note that the start of day 0 defined in the synoptic-scale analyses lags that defined in Hong Kong time by 8 h. The former is referred to in all the analyses except when discussing local wind patterns at Waglan Island because these latter data are obtained from the ROHK Monthly Weather Summary, which refers to the local time. The winds at Waglan Island are used because Waglan Island is a reference station for wind observations for Hong Kong (Chen 1975), and the wind field recorded in the GTS data source refers to that measured at the headquarters of ROHK, which is largely affected by urban effects. Similarly, wind speed and the prevailing direction referred to in the definition of surges are those measured at Waglan Island.

The definition of an ES is as follows (see Fig. 2):

1) the easterly mean wind component must be greater than that of the monthly normal value by at least 5 km h⁻¹ on day 0;
2) the mean wind speed is maximum on day 0 and is strictly increasing (decreasing) before (after) day 0.

The basic evidence of an ES event is the strong easterly wind (e.g., Morrice 1973). Therefore, maximum easterly winds on day 0 of 5 km h⁻¹ or more stronger than the monthly normal are considered in the definition. Condition 2 is added to ensure that the weather is basically controlled by an individual ES event with insignificant influence by other ES that may have (would) happened some days before (after) the current one. To allow for measurement errors or truncation during averaging, a ±1 km h⁻¹ tolerance is allowed in the above definition.

The definition of an NS is (see Fig. 3)

1) the daily mean temperature T is maximum on day 0 and the decrease in T from day 0 to day 2 must be at least 2°C; or T(day 0) − T(day 1) ≥ 2°C and T(day 2) < T(day 1);
2) the lowest daily mean temperature of the five days is less than the monthly normal;
3) any one of days after day −1 has northerly mean wind speed greater than 29 km h⁻¹ (≈8 m s⁻¹);
4) a discontinuity in the prevailing wind direction: the wind direction on any day before day 0 or day 1 differs from that on any one day after day 0 or day 1 by at least 60°.

A significant temperature drop associated with northerly winds is the primary evidence of a NS event (condition 1). A 2°C drop in daily mean temperature

b. Methodology

1) Definition of the ES and NS

A detailed examination of the time series of wind direction/speed and temperature suggests that signifi-
follows that of Chu (1978) while condition 2 is included to ensure a cold episode. The northerly wind speed greater than 8 m s\(^{-1}\) is found by Lau et al. (1983) to be a good criterion for the verification of the NS. These requirements, other than the magnitude of temperature drop as stated in condition 1, are added to

Fig. 5. The composite MSLP distribution of an NS. Note that the 1026-hPa isobar is thickened to highlight the southward push of the cold air.
Fig. 6. The composite 12-h surface isallobars of an NS. The thickened line is the zero isallobar. Dashed line indicates decrease in MSLP during the past 12 h.
define day 0 of the NS. In addition, the change in the prevailing wind direction (condition 4) is important to ensure that an NS event represents a sudden invasion of cold air from the north and a 60° change is assumed to be significant.

The deficiency of these definitions is that only the local surface conditions are considered to represent (surge) events on the synoptic scale. For the NS, the problem can be neglected when there are enough conditions to define the surge. Although only a single meteorological parameter (wind) is considered in the definition of the ES, it is uncommon that the strengthening of local easterlies is caused by other weathering phenomena except an approaching tropical cyclone. In fact, if the weather patterns are largely affected by a tropical cyclone, the case would be discarded.

In order to study the distinct characteristics of each kind of surge, only independent surge events are selected, that is, those in which the influence on the local surface weather by other events is insignificant. A case is said to be independent if its day 0 has at least a

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**Fig. 6. (Continued)**

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**Fig. 7. Local pressure change relative to day 0 of an NS. The error bars are the standard errors of the 15 cases.**
3-day separation from the day 0 of another event of a different kind.

2) DATA TREATMENT

Independent surge cases from October to March (the period in which winter monsoon surges are most common) in the three winters 1988–1991 are identified. For each kind of surge, according to the availability of the GTS data, the station meteorological parameters are averaged over cases for the five days of a surge event to obtain the composite meteorological characteristics of the ES and NS.

The variables studied in the synoptic-scale analyses for the NS include the MSLP, vector wind, and 24-h temper-
nature change. The same variables, except for the last one, are also analyzed for the ES. Regions along the southeast China coast are focused on when studying the ES. To remove diurnal and topographic effects, averaging of the station data over time and space may sometimes be necessary. Time averaging may be taken either twice (e.g., MSLP) or once daily (e.g., temperature). In the former, the average of the data at 0000, 0300, 0600, and 0900 UTC is denoted as AM of that day and that at 1200, 1500, 1800, and 2100 UTC is denoted as PM of that day. In considering the synoptic-scale wind and temperature patterns, space averaging over stations within 2.5° square are carried out except when dealing with the variations of individual stations.

The atmospheric conditions associated with the surges will be compared with the normal conditions (which are the averaged condition of the three winters) by subtraction of the normal conditions from the patterns associated with the surges. The number of independent ES and NS identified and considered in the composite study are 28 and 15, respectively. The dates of the surges are given in the appendix.

3. Normal condition

The average of the surface weather patterns averaged from October to March for the three winters are taken to be the normal wintertime condition. The daily MSLP distribution (Fig. 4a) shows a relatively small-scale high pressure center of about 1030 hPa located on the windward (western) side of Dahingganling (a mountain range). A large high pressure region can also be observed in the west corner of Mongolia, which is the southern edge of the Siberia-Mongolia cold high that develops in the wintertime. The temperature pattern (Fig. 4b) shows that regions north of 40°N are below 0°C. As expected, surface temperatures over the ocean are generally higher than those over the landmass at the same latitude so that onshore flow (see below) would cause a rise in surface temperature due to advection.

Finally, it is apparent from the surface wind distribution (Fig. 4c) that northeasterly and northerly winds prevail over the coastal regions and the inland of south China, respectively.

4. Northerly surge

a. Mean sea level pressure

The MSLP distribution (Fig. 5) suggests an increase in pressure gradient with no apparent motion of high pressure center core in the Siberia-Mongolia region, which reached approximately 1045 hPa on day −1. An equatorward shift of the isobars over mainland China is also observed as exemplified by the southwestern movement of the 1026-hPa isobar during the NS (which is chosen because it can show the shift over mainland China most clearly).

The evolution of the pressure pattern can be followed even better from the 12-h isallobars (Fig. 6). On day −2 AM, pressure decreased over eastern China and persisted for the rest of day −2 over south China. During this period, pressure continued to rise in Mongolia. The reasons for these pressure changes before the arrival (on day 0) of the NS will be discussed in a future paper. By day 0, the center of maximum pressure rise shifted from the Gobi Desert to the east of Szechuan Basin (30°N, 105°E) and soon into the lee side of the Gweizhou Plateau from day −1 to day 0. Obviously, the shift is related to the motion of the cold air mass, which will be apparent in a later section when temperature changes are considered. Stations along the coast from Ningpo (30°N, 122°E) to Hainan Dao (20°N, 110°E) had similar pressure changes on these two days. On day 1, most regions of China had a pressure drop and no significant change can be observed by day 2, signifying the end of the NS event.

The corresponding pressure changes in Hong Kong relative to day 0 are shown in Fig. 7. The maximum pressure change is observed (approximately +3 hPa) on day 1, which is consistent with the above discussion.

b. Surface wind

The surface wind distribution during day −2 of a NS event (Fig. 8a) shows the prevalence of an onshore flow over most parts of eastern China (especially in regions near the Yellow Sea), which may be related to the pressure drop (see Figs. 6a and 6b). From day −1 to day 0, the most pronounced feature is the large-scale cross-isobaric northerly wind sweeping (surging) through the Central China Plain. At 25°N, a boundary of an abrupt change in wind direction can be observed clearly (Fig. 8b), which is characteristic of a frontal boundary. The regions of northerly winds on day −1 are the same as those with positive pressure rises from day −2 to day −1 over mainland China (the zero isallobar on day −1 consistent with the leading edge of the northerlies). From day 0 to day 1, the northerlies were
accelerating, and in south China the mean surface wind observed on day 1 over Hainan Dao and Xisha Qundao (an offshore island over the South China Sea at 16.83°N, 112.33°E) was about 1.5 times that of day 0. On day 2, the backside of the cold air mass was located at about 30°N such that westerlies were prevalent to the north. Finally, according to the synoptic-scale wind patterns from day −2 to day 2, Hong Kong should re-

FIG. 10. The composite 24-h temperature change of an NS. Dashed lines indicate a decrease in temperature during the past 24 h. The thickened line is the 0°C change.
cord a change in wind direction from more easterly to more northerly and a strengthening in the wind speed (see Fig. 9).

c. Temperature

The 24-h temperature changes on day −2 (Fig. 10a) show a slight increase east of 110°E due to the easterly onshore flow bringing in warmer oceanic air. On day −1, temperatures over northern China dropped when the northerlies strengthened, and the drop was most intense over the Mongolia and the Gobi Desert (Fig. 10b). On the other hand, a warm spell was found over south China before the arrival of the NS, which is consistent with the result of Chu (1978). The changes in temperature and wind direction are characteristic of a cold front passage. If the line of zero temperature change is taken to represent the leading edge of the NS or the cold front boundary, the cold front had reached the Changjiang region by day −1 and was consistent with the pressure and wind patterns described earlier.

On day 0, maximum temperature decreases of approximately 4°C were observed over the Hefei and Nanjing area (30°–35°N, 115°–120°E), while the temperature drop along the south China coast was around 1°C. Meanwhile, while the surface pressure was decreasing in Mongolia (see Figs. 6e and 6f), temperatures rose because of the removal of the cold air mass.

On day 1, a maximum temperature drop of 4°–5°C was recorded in the south China coastal region showing that the cold air mass had arrived. On the following day, both northern and southern China became warmer when the surge of the northerlies came to an end.

The southward shift of the isotherms associated with the motion of the cold air mass can be seen from the movement of the 5°C and 15°C isotherms during the NS (Fig. 11). In addition, the warm spell before the arrival of a NS is apparent from the northward shift of the 15°C isotherms from day −2 to day −1. The temperature variations in Hong Kong (Fig. 12) shows a maximum temperature drop of about 4°C occurred on day 1, which is consistent with the above discussion. Finally, the dewpoint depression over Hong Kong increased from day 0 showing a decrease in the moisture content after the surge event. That is, as may be expected, a northerly wind (or NS) brings drier continental air to Hong Kong.

d. Summary

A NS brings a dry and cold air mass from the north. Strong northerlies and an intense temperature drop characterize a NS event and these have been included in the definition of the NS. Although no clear high pressure center can be observed in the region studied, the source of the cold air mass can be traced back to the northwest of Mongolia and most probably in the West Siberia Plain. When the pressure over the northwest of Mongolia increases to at least 1045 hPa, the high pressure collapses and a surge is initiated and begins its southward track. Cold air pushes southward swiftly and soon reaches the South China Sea within two days (based on the surface temperature change), causing temperature drops of approximately 4°–5°C to most parts of China. On the whole, the characteristics associated with a NS resemble to that of a cold surge commonly described in China.

5. Easterly surge

a. Mean sea level pressure

On day −2, the MSLP pattern resembled the normal condition (compare Fig. 13a with Fig. 4a) except that the high pressure center located on the windward side of Dahingganling was about 2 hPa stronger in the ES. The high pressure center is observed to move south-
Fig. 13. The composite MSLP distribution of an ES.
Fig. 13. (Continued)

Fig. 14. The composite pressure variations in Shanghai and Hong Kong of an ES. The dashed line is the difference between the two stations. Timescale is 3 h.

Fig. 15. The MSLP distribution on day 0 AM of an ES with higher resolution.
Fig. 16. As in Fig. 9 except for an ES.

eastward toward the Yellow Sea on day -1 and was closest to Hong Kong by day 0 when it was just over the Yellow Sea so that the strongest winds are expected at this time. It then weakened and finally moved out of the studied region by day 1 PM. By day 2, the pattern returned almost to normal such that the high pressure center again attained the same value as the normal situation (~1030 hPa). Therefore, it is apparent that the southeastward movement of the high located at the windward side of Dahingganling was responsible for the ES.

Because the pressure difference between Shanghai and Hong Kong is used by forecasters at ROHK as a quantitative indicator of the strength of the easterlies (Chang 1989), the pressure patterns between these two stations are examined in more detail. The southward shift of pressure maxima between the two stations is observed to have a time lag of about 12 h (Fig. 14) with a maximum pressure difference of greater than 8 hPa attained on day -1.

Taking a closer look at the pressure pattern on day 0 AM, a coastal ridging can be observed from Ningpo to Hong Kong (Fig. 15). This is a consequence of the fact that the high pressure center was just over the Yellow Sea on that day. It has been recognized that coastal ridging may be associated with a wave disturbance (e.g., Holland and Leslie 1986). Whether the coastal ridging in an ES contains any wave character will be investigated in the future when the upper-level flow is considered.

b. Surface wind

The local wind variation at Waglan Island of Hong Kong composite for the 28 ES events shows that easterly winds dominated the ES event (Fig. 16). Also, surface winds were more easterly on day 0 with speed up to 43 km h\(^{-1}\) (~12 m s\(^{-1}\)). Although the ES is identified fundamentally from the local wind patterns, similar effects can be observed in regions along the southeast China coast. To show this, the wind speeds of seven stations (including Hong Kong for comparison) are considered (Fig. 17). (Note that the wind over Hong Kong referred to in Fig. 17 was measured at the headquarters of ROHK.) The strengthening in wind speed associated with the wind surge was apparent for stations north of Hong Kong such that wind increased (decreased) by approximately 2–3 m s\(^{-1}\) before (after) the ES. Furthermore, the wind surge was parallel to the coastal line and it became easterly (hence easterly surge) over Hong Kong (Fig. 18). However, the variations in wind speed for stations south of Hong Kong (e.g., Yanjiang) were small.

On the synoptic scale, an anticyclonic flow consistent with the motion of the high pressure center as discussed previously was evident (Fig. 18). Generally, the wind speeds over south China seemed to be weaker when compared with those in the NS event. The effect of the surface wind surge during an ES event faded largely with distance from the coast toward inland so that no apparent variation in wind was recorded in the inland regions of south China.

c. Temperature

Over most parts of the south China, surface temperatures dropped (rose) slightly by less than 1°C before (after) about day 0 and the variations were greater (1°–2°C) in the coastal regions. This can be illustrated from the variations of the temperature (and dewpoint depression) anomaly of the seven stations that were considered previously (Fig. 19). The initial drops in temperature were because of the arrival of the cool air associated with the high. Because the high was not intense (approximately 1032 hPa as compared to 1045 hPa in the NS) and the temperature of the cold air associated was not very low (by considering the surface temperature over the high pressure region), the drops were not large. When the high had moved eastward such that the air that arrived in the coastal region was largely modified by the warmer ocean, temperatures increased thereafter. The southward shift in the temperature patterns can also be observed such that the northernmost station, Dachen Dao, attained the minimum temperature one day ahead of the southern station, such as Hong Kong. Moreover, the minimum temperature attained for the northern stations (Dachen Dao say) were slightly smaller than normal, whereas temperature anomalies for the southern stations were positive during the ES occasion. Another consequence associated with the modification of the air mass was the rise in humidity as represented by the decrease in the dewpoint depression.

Because the temperature variations were not very significant over the inland regions of south China, the synoptic-scale temperature pattern will not be shown (except for the deviations from normal condition on day 0 in the next section).
d. Summary

While the strengthening in winds was most evident and limited to regions along the southeast China coast, an ES is shown to be associated with an eastward motion of a high pressure center that developed over Dahingganling. When the high pressure center moved over the Yellow Sea on day 0, the wind surge arrived in Hong Kong along the coast and became strong easterly over Hong Kong. Most parts of South China also had a rise of 1°–2°C in surface temperature after day 0.

6. Comparison of ES and NS with the normal condition

Local weather conditions were used in the definitions of the surges. However, it is clear from the results in the two previous sections that differences between the ES and NS result from events that occur on the synoptic scale, and the surges are indeed not just regional phenomena.

The NS behaves as a typical cold surge such that a large cold air mass advances from the north within a couple of days. All of the observed surface features are the direct result of the southward passage of cold air. The key to the NS lies in the development of the huge cold high pressure region over Siberia–Mongolia. No evident motion of the high is observed (at least in the region studied) associated with the NS but rather a weakening (breaking down) of the high is observed. On the other hand, the southeastward motion of a weaker (compared to that associated with the NS) high pressure center developed over Dahingganling causes an ES event.

To contrast these two kinds of surges further, the synoptic conditions of the normal wintertime situation are subtracted from those of the surges on day 0. It can be
seen from Fig. 20 that the landmass is warmer and the ocean is cooler in the ES but just the opposite for the NS, with the most significant differences being in the region of 45°N, 110°E. Most parts of China had a 1°–2°C positive temperature anomaly during an ES, whereas the temperature anomaly was positive (negative) south (north) of the leading edge of a NS (on day 0). Furthermore, the surface anticyclone over the Yellow Sea on day 0 in an ES event (see also section 5b) caused a broadscale onshore flow as compared to the normal condition (Fig. 21a). Associated with such an onshore flow is the advection of the warmer oceanic air into the inland of China, which is consistent with the temperature patterns discussed above. To the north of 30°N and east of 110°E, a
Fig. 19. The temperature (solid line) and dewpoint depression (dashed line) anomalies for the seven stations of an ES. Note that daily averaged values are used.

Fig. 20. The differences in surface temperature distribution from the normal condition composite for an (a) ES and (b) an NS on day 0.
southerly wind anomaly is observed in the ES that marks a pronounced contrast with the NS.

Consistent with the temperature and wind anomalies, a large positive pressure anomaly (~11 hPa) can be observed in the Mongolia region and the northwest–southeast pressure gradient anomaly was apparent in the NS case (Fig. 22b). It is apparent that the pressure anomaly is associated with a cold air mass such that the contour of zero temperature anomaly coincides with that of zero pressure anomaly. On the other hand, the anomalous onshore flow follows the pressure gradient such that air flows from a positive to negative pressure anomaly in the ES (Fig. 21a).

Finally, the averaged dewpoint depression anomaly over the region 20°–40°N, 105°–125°E changed from negative to positive in an NS showing that the humidity of the surface was larger than normal before the NS (Fig. 23). The decrease in the humidity after the arrival of the surge was because the air associated with the NS was drier. For the ES, humidity increased because of the onshore flow. On the other hand, the averaged temperature increases slightly and is higher than normal in an ES while it is much lower than normal after an NS.

7. Conclusions

The wintertime monsoonal characteristics over south China can be represented by two kinds of monsoon surges, namely the easterly surge and the northerly surge as termed in Hong Kong. The arrival or identification of the surges can readily be defined from the local surface weather patterns, with a NS being associated with winds turning to the north and daily mean temperature drops of greater than 2°C, whereas intense easterlies fingerprint an ES. From the synoptic patterns, it is observed that a difference of more than 8 hPa in
The distinct natures of the ES and NS are much clearer when compared with the normal conditions. Warm (cold) advection from the ocean (north) to the landmass (south) in the surface such that temperature and humidity rises (drops) characterizes an ES (NS). These observed differences between the ES and NS justify the consideration of an ES as a completely different kind of monsoon surge.

Since only the surface atmospheric conditions are considered, the causes of the monsoon surges cannot yet be understood from this study. Other features must also be investigated in subsequent analyses. These include 1) the upper-level steering flow for the motion of the high pressure center in an ES, 2) the possibility of any wave nature associated with the coastal ridging in an ES, 3) the dynamic and thermodynamic conditions for the atmosphere to sustain a high pressure up to approximately 1045 hPa in an NS, 4) the vertical extent, and 5) the energy exchange processes, etc. All of these will be considered in the next part of this study.

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APPENDIX

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MARCH 1995

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