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Interannual Variation of East Asian Winter Monsoon and ENSO

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ABSTRACT

This paper examines the interannual variation of the East Asian winter monsoon and its relationship with ENSO based on the 1979-1995 NCEP/NCAR reanalysis. Two stratifications of cold surges are used. The first one, described as the conventional cold surges, indicates that the surge frequency reaches a minimum one year after El Nino events. The second one, originated from the same region as the first, is defined as the maximum wind events near the South China Sea. The variation of this stratification of surges is found to be in good agreement with the Southern Oscillation Index (SOI). Low SOI (high SOI) events coincide with years of low (high) surge frequency.

The interannual variation of averaged meridional wind near the South China Sea and western Pacific is dominated by the South China Sea cold surges, and is also well correlated (R=0.82) with the SOI. Strong wind seasons are associated with La Nina and high SOI events; likewise, weak wind years are linked with El Nino and low SOI cases. This pattern is restricted north of the equator within the region of (0°N-20°N, 110°E-130°E), and is confined to the near surface layer. The surface Siberian high, 500 hPa trough and 200 hPa jetstream, all representing the large-scale monsoon flow, are found to be weaker than normal during El Nino years. In particular, the interannual variation of the Siberian high is in general agreement with the SOI.

1. Introduction

The East Asian winter monsoon, which is associated with a strong Siberian high and active cold surges, is one of the most energetic monsoon circulation systems. The dramatic shift of northeasterlies and the outbreak of cold surges dominate the winter weather and local climate in the East Asian region. The winter monsoon and cold surges exert a strong impact on the extratropical and tropical planetary-scale circulations (Chang and Lau, 1982), and influence the SSTs in the tropical western Pacific (Chang et al., 1979). Their general characteristics and the possible linkage between cold surges and tropical atmospheric and oceanic phenomena have been examined in many studies. For example, Chang and Lau (1982) showed that the outbreak of winter monsoon surges forced short term changes in the Hadley and Walker Circulation, the East Asian jetstream and large-scale deep convection over the equatorial western Pacific. Boyle (1986a, 1986b) found the frequency and intensity of the monsoon surges for a given month were related to the intensity of the East Asian jetstream and the extratropical large scale circulation patterns. Lau and Chang (1987) suggested that the interannual variation of the winter monsoon and cold surges may be related to ENSO and tropical intraseasonal oscillations. Ding and Krishnamurti (1987) noted an eastward shift of the tropical planetary scale divergent circulation in association with the cold surges which was very similar to the shift of the divergent circulation between El Nino and La Nina years.

Although the winter monsoon is known to be much weaker during the 1982-83 El Nino event (Lau and Chang, 1987), there has never been a systematic investigation on the relationship between ENSO and the interannual variation of the winter monsoon and cold surges. The purpose of this study is to examine the interannual variation of the East Asian winter monsoon and cold surges and to determine whether there exists a consistent relationship between the winter monsoon and ENSO.

2. Data

We use the twice-daily surface and upper-air fields from the NCEP/NCAR reanalysis (Kalnay et al., 1996) for the period of 1979-1995. The surface quantities include temperature, wind, and sea-level-pressure (SLP); upper air fields are winds at 925 hPa, 850hPa, 700 hPa, and 200 hPa and geopotential height at 500 hPa. The advantage of this data set is that the reanalysis used a "frozen" state-of-the-art analysis/forecast system to perform the data assimilation throughout the whole period, thus circumventing problems with previous NWP analyses due to changes in techniques, models and data assimilation. Also, this dynamically consistent reanalysis offers good horizontal (2.5°x2.5°) and vertical resolution (17 levels).

3. Winter mean circulation and cold surges

The mean winter monsoon circulation has been documented by many authors (e.g., Boyle and Chang 1984; Lau and Li 1984; Lau and Chang 1987; Boyle and Chen 1987) and is briefly discussed here to serve as a background for the rest of the paper.

The dominant surface feature of the winter monsoon is the Siberian high. The winter mean SLP averaged for 1979/80 - 1994/95 is shown in Fig. 1. This surface pressure system, with

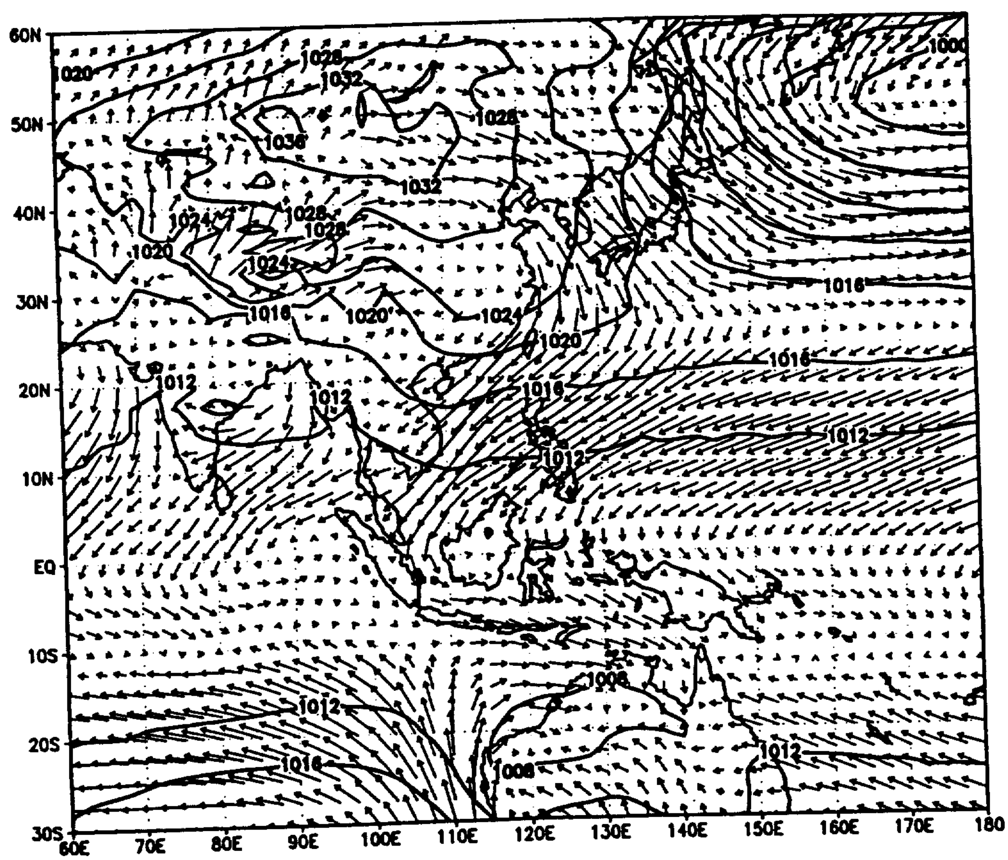

Fig. 1. The averaged East Asian mean sea-level pressure superimposed on the surface (10 meter) wind for winter (DJF) of 1979/80-1994/95. Unit: hPa and ms^{-1}.

central pressure in excess of 1036 hPa, covers the entire East Asian region and yields northeasterly flow over a large part of East Asia. At 500 hPa, the flow pattern is dominated by the coastal East Asian trough. The intensity of this trough is quasi-geostrophically linked to the surface Siberian high. The most prominent feature at 200 hPa is the East Asian jet located near southern Japan. This jet, the strongest on the globe, is associated with intense baroclinicity, large vertical wind shear and strong cold advection. It is maintained by the Coriolis torque acceleration exerted on the ageostrophic wind near the jet entrance region. Its strength is inherently related to the intensity of surface Siberian high and the 500 hPa trough. These features characterize the large-scale three-dimensional winter monsoon circulation.

Fig. 1 also presented the winter mean (DJF) surface wind averaged for 1979/80 - 1994/95. This climatological surface wind represents contribution from both the stationary winter monsoon circulation and the cold surges. North of 30°N, the surface wind blows anticyclonically along the north and east periphery of the Siberian high where the stationary pressure system contributes more to the wind field. South of 30°N where the Siberian high pressure exerts less influence, the wind maximum near the South China Sea can be largely attributed to the cumulative effects of the cold surges. One of the main features of the surface wind is that the westerly flow near Japan bifurcates. The eastward branch merges with the Aleutian low, while the southern branch joins the tradewind belt. Cold air intensity and thickness usually reduce as the airmass moves southward. The monsoon cold air is thus a relatively shallow phenomenon in low latitudes.

The cold surge is the most important transient disturbance embedded within the mean winter monsoon circulation. The occurrence of a cold surge is characterized by a southward movement of a surface anticyclone and an associated abrupt 24-48 hours surface air temperature drop in the affected regions. The typical scenario of a cold air outbreak is: the Siberian high and the major trough near the east coastal region reach a certain intensity. Further west over the continent, an upper level short wave undergoes very strong development as it moves eastward. Eventually the short wave develops into a major trough and replaces the old quasi-stationary trough near the coastal region. During this process, the surface anticyclone moves southeastward and a cold surge occurs (Staff members of Academia Sinica, 1957). It should be pointed out that the build-up and maintenance of the Siberian high pressure is a necessary condition for the occurrence of cold surges. Radiative cooling, persistent cold air advection (usually blocking over Urals) throughout the troposphere and large-scale descending motion all contribute to the maintenance of the cold Siberian high (Ding and Krishnamurti,1987).

4. Interannual variation

In order to investigate the possible linkage between the interannual variation of the East Asian winter monsoon and ENSO, the 1979-1995 winter average Southern Oscillation Index (SOI) is plotted in Fig. 2.

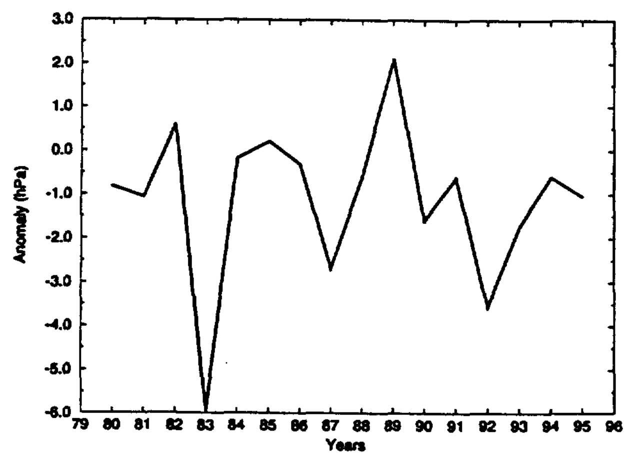

Fig. 2. Southern oscillation index. Anomaly of pressure difference between Tahiti and Darwin.

Although the Southern Oscillation is not a standing phenomenon, the evolution of monsoon circulation during ENSO phases is ignored given that the winter monsoon is not examined on a monthly basis. The two major

El Nino events of 1982/83 and 1986/87 exhibit low SOI. Negative departures of the SOI also occur during the 1989/90 and 1991/92 seasons. The 1988/89 La Nina event has SOI in excess of 2 hPa.

4.1 Cold surges

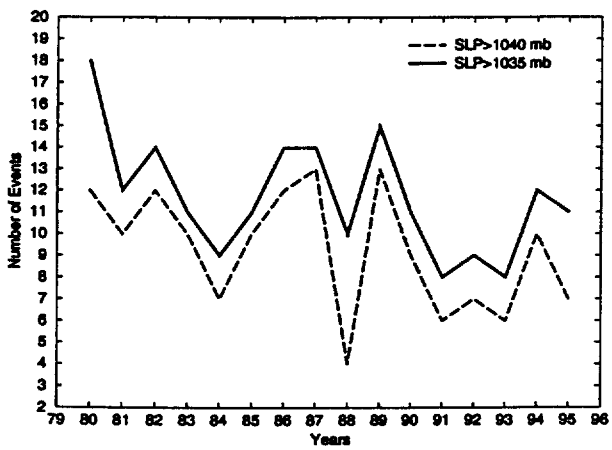

Fig. 3. Cold surge frequency from 1979/80-1994/95. Unit: number of events per season.

The variation of cold surge frequency is first examined. An interesting feature in Fig. 3 is that minimum frequency events occur one year after the El Nino years. To test the robustness of this result, we investigated the sensitivity of the cold surge frequency to the SLP threshold in the cold surge criteria (Zhang et al., 1996). Aside from an expected decline in cold surge frequency with a stricter SLP criterion, the interannual variations were found to be insensitive. Further, the cold surge frequency from Beijing Meteorological Center (BMC) during 1980-1984 shows the same variation pattern as in Fig. 3. Data from BMC also indicates that cold surge frequency reaches a minimum one year after the 1957/58 and 1965/66 El Nino events. This phenomenon agrees with the 1~1.5 year lag response of the northeast China surface air temperature to the SST near the eastern equatorial Pacific suggested by Bao et al. (1989).

As mentioned earlier, the definition of a cold surge is regionally dependent. The cold surges identified above, which are in good agreement with the observations from BMC, typically influence the bulk of East Asia and the coastal regions. However, a subset of these cold surges can reach to the South China Sea. This is illustrated in Figs. 4 (a) and (b), time series of meridional wind in three regions for the 1988/89 season, along with the SLP near the Siberian area. The phases of SLP variation are exactly reversed to those of meridional wind near southern China, which are followed chronologically by the similar variation patterns near Taiwan and in the vicinity of the Hainan Island. The lags between the variation patterns in each region, which represent the southeast propagation of surface anticyclones, are around 1-3 days.

The typical synoptic scenario of the propagation is as follows, before the outbreak of a cold surge, the intensification of the Siberian high simultaneously strengthens the northeasterly flow near southern China. The outbreak of the cold surge pushes the anticyclonic flow southeastward and increases the northerlies near Taiwan region. The wind then subsequently penetrated further into the northern part of the South China Sea and the cold surge ended.

According to the weather forecasters (Li, personal communication, 1996) of Hainan Island (18°N, 110°E), whether a cold surge will affect the Island and the surrounding oceans depends on its path and intensity. When this region is under the influence of a cold surge, the most conspicuous weather phenomenon is the strong northeasterly wind. The seven strong wind events (northerly > 7 m/sec) near the South China Sea in the 1988/89 season, as indicated in Fig. 4 (a), is a subset of the eleven cold surges identified during the season (Zhang et al., 1996). Strong wind events for other years are also examined (not shown). We found that, with no exception, every event is associated with a cold surge outbreak from the extratropics.

Because the surface meridional wind is the most important indicator of the cold surge activity in Hainan area, we define the South China Sea cold surge as the number of days that maximum northerly wind > 7 m/s in the region of (10°N-20°N, 110°E-120°E). Similar definition has been used by Chang and Chen (1992). Based on this definition, the South China Sea

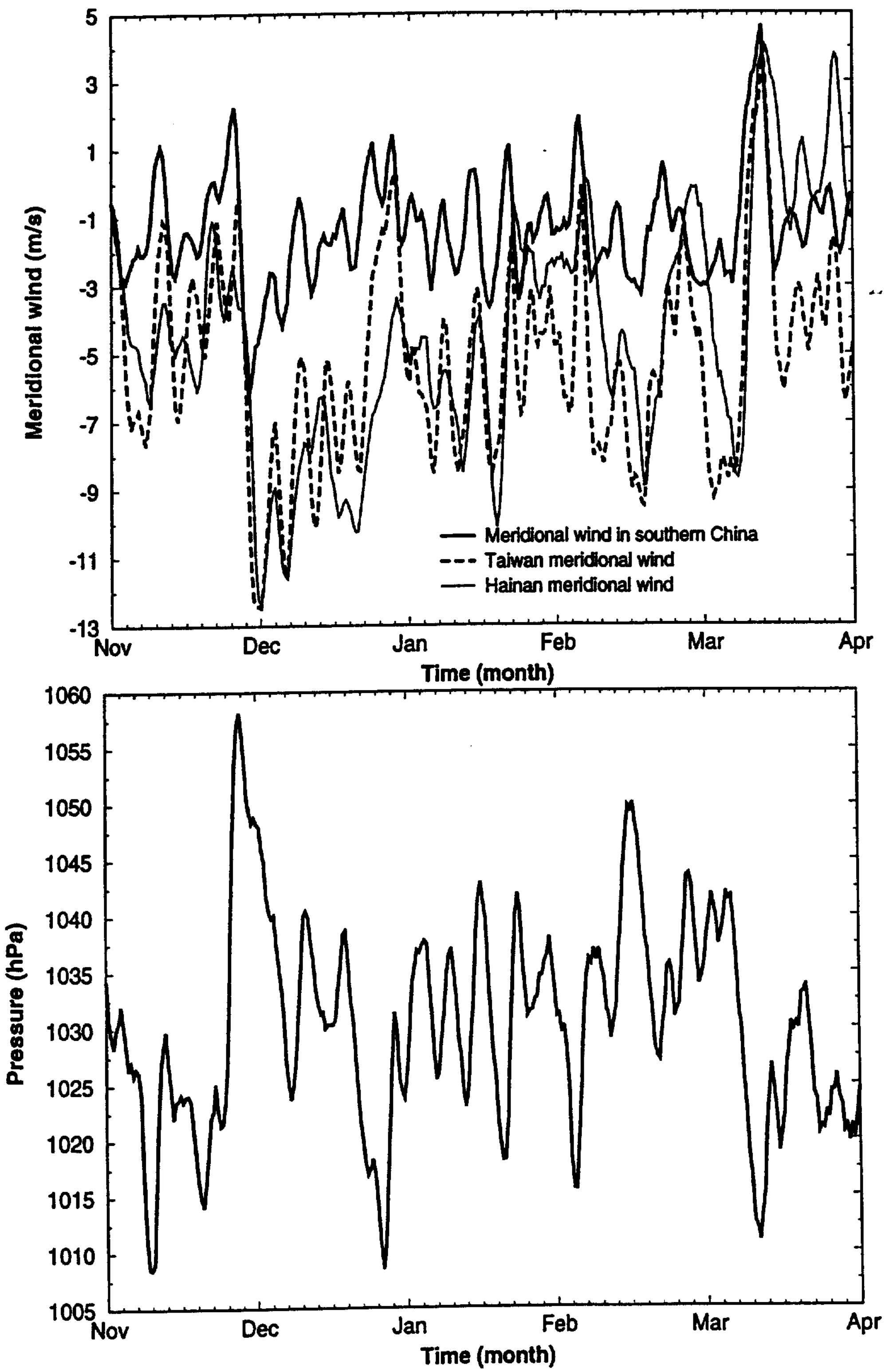

Fig. 4. (a) Twice daily time series of area averaged meridional wind from region near southern China (102.5°E-107.5°E, 45°N-50°N), near Taiwan (120°E-125°E, 22.5°N-27.5°N), and in the vicinity of the Hainan Island (110°E-115°E; 10°N-20°N). Unit: m/sec. (b) Twice daily time series of SLP near Siberia (112.5°E-117.5°E, 25°N-30°N) from November of 1987 to March of 1988. Unit: hPa. A five-point running average has been applied to all the fields.

cold surge frequency is shown in Fig. 5. The interannual variation of cold surge frequency is in good agreement with the pattern of SOI (correlation coefficient = 0.85). Low cold surge

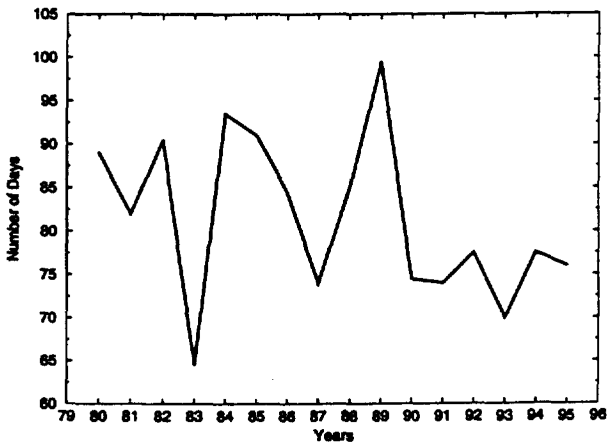

Fig. 5. Cold surge frequency in the South China Sea, number of days the maximum northerly wind near the South China Sea (110°E-120°E, 10°N-20°N) exceed 7 m/s. Unit: number of days per season.

frequencies coincide with El Nino and low SOI events; high frequencies accompany with La Nina and high SOI years. This agrees with observed strong wind record of Hainan Island (Li, personal communication, 1996) for winters of 1950-1980, which indicates that cold air activity is much reduced during the years of 1957/58, 1965/66, 1968/69, and 1972/73, all are El Nino events

4.2 Mean meridional wind

Frequency of the South China Sea cold surges not only bears good relationship with the SOI, but also largely controls the meridional wind variation over the South China Sea and over even larger areas. Fig. 6 shows time series of mean meridional wind for increasingly larger regions. The patterns in all the three regions are similar to that of SOI. In agreement with the cold surges, stronger northerlies occur during La Nina and high SOI seasons, and weaker northerlies occur during El Nino and low SOI years. The correlation coefficient between the SOI and the meridional wind in the South China Sea (10°N-20°N,110°E-120°E) is 0.82. By examining the same time series as in Fig. 6 over many nine-grid-point rectangular boxes near the western Pacific, we found that this SOI-like pattern of the wind does not exist in any of the areas outside the region of (0°N-20°N,100°E-130°E).

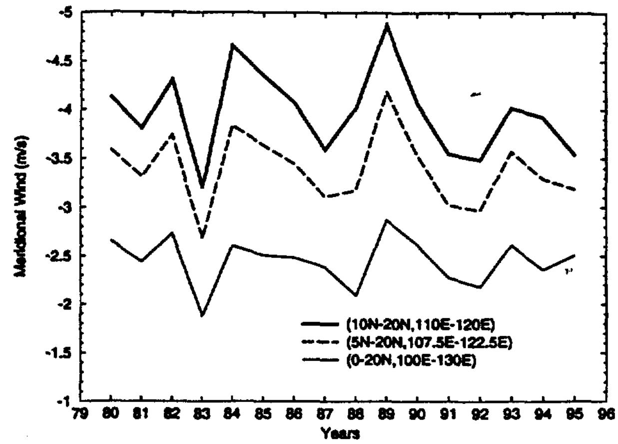

Fig. 6. Winter (NDJFM) area averaged northerly wind over three regions near the South China Sea and western Pacific. Unit: m s^{-1}.

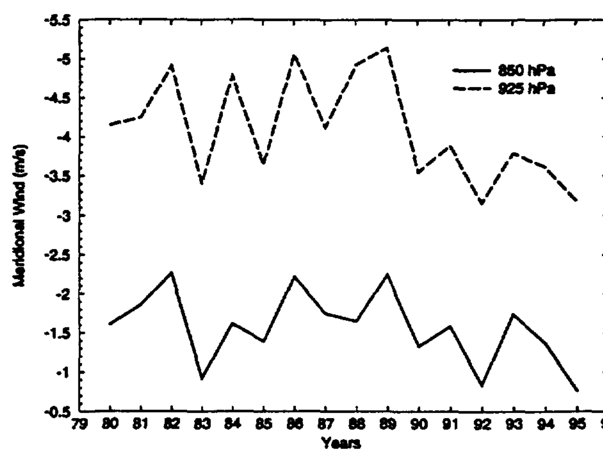

Fig. 7. Winter (NDJFM) area averaged northerly wind over the South China Sea (110°E-115°E, 10°N-20°N) at 925 hPa and 850 hPa. Unit: m s^{-1}.

The meridional wind variation is a shallow phenomenon, occurring primarily at the surface. This is demonstrated in Fig. 7 where the wind variation over the South China Sea is plotted at the 925 hPa and 850 hPa levels. Although the patterns at both levels still bear certain resemblance to the SOI pattern, the biennial oscillation is the dominate mode. At 700 hPa and above (not shown), the geostrophic flow is decidedly zonal over the entire East Asian continent and the wind in the northern part of the South China Sea is under great influence of the split jetstream south of the Tibetan Plateau. The signature of the SOI has been totally lost. Clearly, this SOI-like wind pattern is horizontally restricted within the region of (0°N-20°N,100°E-130°E) and vertically confined to the near surface layer.

Based on the above discussions, it is clear that the variation of area averaged meridional wind near the South China Sea and western Pacific hinges on the variation of the South China Sea cold surges. The South China Sea cold surges share the same origin as the conventionally defined cold surges. The area averaged meridional wind near the South China Sea is thus greatly controlled by the northerlies propagated from the extratropics.

4.3 *Large-scale features*

As mentioned earlier, the surface Siberian high, 500 hPa trough, and the 200 hPa jetstream characterize the winter monsoon large-scale circulation and their strength are inherently related to each other.

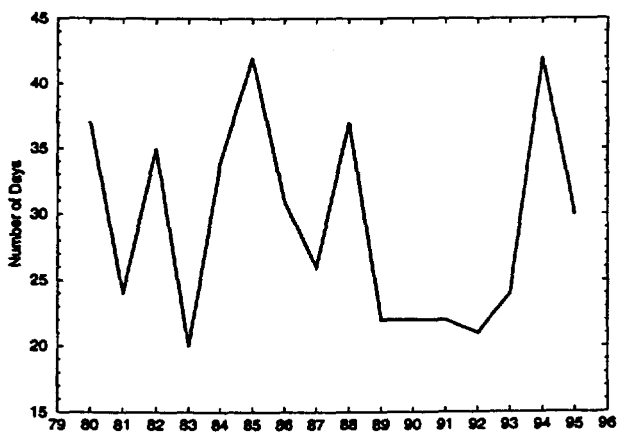

Fig. 8. Number of days that the Siberian high pressure exceeds 1050 hPa in the Siberia region (45°N-55°N, 90°E-110°E). Unit: number of days per season.

Fig. 8 presents the number of days that the central pressure is greater than 1050 hPa in the region of (45°N-55°N, 90°E-110°E). Although this may not be the only measure of the Siberian high intensity, the broad aspect of the interannual variation of this measure agrees with the SOI. The variation patterns indicate that, in general, the Siberian high is stronger (weaker) in La Nina (El Nino) and high (low) SOI years. The mean meridional wind averaged over the southeast periphery (5°N-20°N, 160°E-180°E) of the Siberian high, another way to represent the intensity of the high pressure, shows similar pattern as that of Fig. 8 (not shown).

The variation of the 500 hPa geopotential height anomaly along 135°E is calculated. Although the overall variation pattern (not shown) is not comparable with the SOI, the 500 hPa trough is weaker than normal during the 1982/83, 1986/87 and 1991/92 El Nino events. The 200 hPa East Asian jet is also examined. Although the East Asian jet is subject to propagation or expansion in the east-west direction during different phases of ENSO, the jet intensity (at 140°E) is found abnormally weak during all three major El Nino events (not shown). This result is consistent with the weak Siberian high and 500 hPa trough.

Overall, the large-scale monsoon circulation is weaker than normal during all the three major El Nino events. In particular, the variation pattern of the Siberian high generally agrees with the SOI.

5. Summary and discussion

The study of the East Asian winter monsoon and cold surges from the 1979-1995 NCEP/NCAR reanalysis has revealed several noteworthy features involving their interannual variability. The two stratifications of cold surges are revealing when considering the relationship between ENSO and the interannual variation of the cold air activity. The first stratification yields result that is consistent with the *in situ* observation from BMC. The interannual variation of cold surge frequency shows that minimum surge frequency occurs one year after El Nino events. The second stratification, based on the maximum meridional wind event near the

South China Sea, indicates that the interannual variation of the South China Sea cold surge is in good agreement with the SOI. High cold surge frequency is found during La Nina and high SOI events, low frequency is associated with El Nino and low SOI events.

The variation of mean meridional wind near the western Pacific hinges on the South China Sea cold surges. As in the case of the surges, the interannual variation of the wind is also well correlated with the SOI. Strong wind years are associated with La Nina and high SOI events; weak wind years are found during El Nino and low SOI events. This pattern of variation is restricted north of the equator within (0°N-20°N,100°E-130°E), and confined to the near surface layer. The interannual variation of the Siberian high, measured by means of both pressure and wind, is in general agreement with the SOI. Both the strength of the 200 hPa jetstream and the 500 hPa trough are found to be weaker than normal during El Nino events, although their interannual variation patterns do not agree with the SOI as closely as that of the Siberian high.

Given the close relationship between the SOI and the interannual variation of monsoon meridional wind and cold surges, it is natural to wonder why some of the monsoon related disturbances, either originated from or located in the extratropics, exhibit variation patterns similar to the SOI, and what are the physical mechanisms between the ENSO/winter monsoon interaction.

During a typical El Nino year, the convective activity in the maritime continent is usually reduced. If the cumulus convection in this region is one of the most important monsoon energy sources as suggested by Ramage (1971), the suppression of the maritime convection should be responsible, at least partly, for the weaker than normal extratropical monsoon circulation during El Nino events. With the available observed outgoing longwave radiation (OLR) data from the National Oceanic and Atmospheric Administration, we have computed the OLR anomaly in the maritime continent (110°E-120°E, 5°N-5°S) from 1979-1992. The overall interannual variation pattern (not shown here) is not as close to the SOI as that of the South China Sea cold surges or the Siberian high. However, negative anomaly is found during the 1988/89 La Nina season; likewise, positive OLR anomalies are found during the 1982/83 and 1986/87 El Nino seasons. The correlation coefficient between the OLR anomaly and the SOI is $|R|=0.5$.

On the other hand, evidence indicated that the winter monsoon and cold air activity can greatly affect the tropical convective activity and SST. Slingo (1996, personal communication) found that Indonesian convection is enhanced when cold surges penetrated far into the tropics. Chang et al. (1979) have shown that cold surges are capable of influencing the tropical SST. But whether the cold surges can significantly affect the tropical region, as has been discussed, depends on the intensity and path of the cold surges. It may also relate to the background large-scale circulation. Theoretical studies have suggested (Branstator 1983, Lau and Li 1984) that the interaction between the tropical convection and midlatitude circulation depends critically on the relative position of the convection and extratropical quasi-stationary waves.

It has also been suggested that the interaction between cold surges and convective activities near the maritime continent will in turn modify the extratropical and tropical synoptic and planetary scale circulations (Chang and Lau, 1980). Apparently, further studies are much needed to delineate the mechanism of the interaction between the winter monsoon and convection near the maritime continent.

In summary, the current study has indicated that the interannual variation of the South China Sea cold surges is in good agreement with the SOI. The South China Sea cold surges share the same origin with the conventionally defined cold surges. They also dominate the variation of the area averaged meridional wind near the South China Sea and the western Pacific. The conventionally defined cold surges, on the other hand, reached minimum frequencies one year after El Nino events. However, physical mechanisms mainly responsible for the interaction between ENSO and winter monsoon are still not well understood, especially problems on if and how the winter monsoon cold air activity affects the ENSO through its impact on tropical SST pattern and convective activities in the maritime continent. Simulations of coupled ocean models and GCM simulations with specified observed SST, such as simulations from the Atmospheric Model Intercomparison Project (AMIP), should provide a good opportunity to tackle these problems.

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