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Yi Zhang
Kenneth Sperber
James Boyle

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The Climatology of East Asian Winter Monsoon and Cold Surges from 1979-1995 NCEP/NCAR Reanalyses

Yi Zhang, Kenneth Sperber and James Boyle
Program for Climate Model Diagnosis and Intercomparison
Lawrence Livermore National Laboratory, Livermore, CA 94550 USA

1. Introduction

The East Asian winter monsoon, which is associated with the 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, and may 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). General characteristics of the winter monsoon and cold surges and their possible link with tropical disturbances are revealed in many observational 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 convections over the equatorial Pacific. Boyle (1986a, 1986b) indicated that the frequency and intensity of the monsoon surges for a given month were related to the intensity of the East Asian jetstream and the associated extratropical large scale circulation patterns. Lau and Chang (1987) suggested that the interannual variations of the winter monsoon and cold surges may be related to ENSO and tropical intraseasonal oscillations. Ding and Krishnamurti (1987) illustrated an eastward shift of tropical planetary scale divergent circulation associated with the surges that was very similar to the shift of the divergent circulation centers between non El Nino and El Nino years.

However, little attention has been given to the climatological aspects of the winter monsoon and cold surges. Boyle and Chang (1984) documented the mean winter circulation statistics based on the Navy Fleet Numerical Oceanography Center's (FNOC) gridded analyses. Pan et al. (1985) compiled statistics of cold air outbreak in China with emphasis on local weather forecasting. Ding and Krishnamurti (1987) summarized the climatological tracks of Siberian highs based on the data from winter (DJF) of 1980 to 1984.

The purpose of this study is to compile and document the East Asian mean winter circulation, and present the climatology of cold surges and the Siberian high based on the 1979-1995 NCEP/NCAR reanalyses. Of particular interest is the interannual variation of winter monsoon circulation and cold surge events. Given that the cold surge activity and the Indonesian convection are much reduced during the 1982-83 period (Lau and Chang, 1987), one of our goals is to determine whether there exists a statistically significant relationship between ENSO and the interannual variation of winter monsoon and cold surges.

2. Data and method

We use twice-daily surface and upper-air fields from NCEP/NCAR Reanalysis (Kalnay et al., 1993) for the period 1979-1995. 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 models and data assimilation techniques. Also, this dynamically consistent reanalysis offers good horizontal (2.5^{o}x2.5^{o}) and vertical resolution.

For the purpose of this study, objective criteria to identify cold surges are required. Many cold surge definitions can be found in the literature. A summary of the often used definitions is in Boyle and Chen (1987). Some of the surges are purposely defined in a way convenient for weather forecasting. The definition can be very different depending on the regions of interest. For example, surges defined in the south China sea may have nothing to do with surges defined near Korea. The essence of the cold surge is the outbreak of cold polar air associated with the south-southeastward movement of a surface anticyclone. In designing the surge criteria for a global gridded data, we choose to average the desired

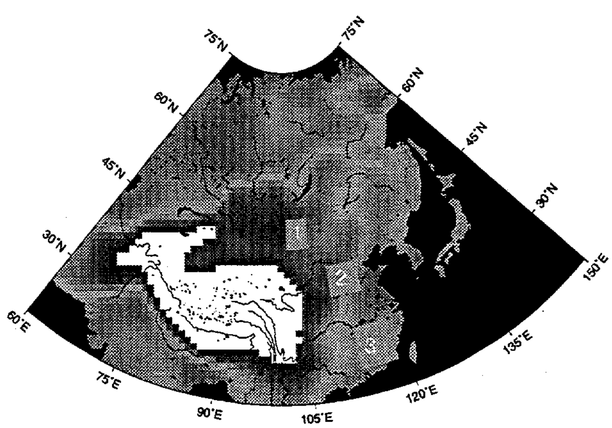

Fig. 1. Location of selected regions. The size of each region is 5^{o}Latx5^{o}Lon.

fields in nine grid points. Fig. 1 shows the East Asian sector. Region 1 is the position of the climatological center of the Siberian high. Region 2 is in the middle of China, and region 3 is in the southern part of China. With the chosen region the following criteria for surge onset is applied to the data set:

(1) A surface anticyclone must be identified north of 35°N at peak intensity prior to the outbreak of the surges, and the average sea level pressure (SLP) at region 1 must be greater than 1035 hPa.

(2) Within 24 to 48 hours of the onset, surface air temperature drops 8-10°C in region 2; or 5-7°C in region 3.

When these criteria are satisfied, a cold surge has been identified. It should be pointed out that the values used in the criteria, based on synoptic experience, are somewhat arbitrary. Since the key characteristics of cold surges are included in the criteria, the overwhelming majority of surges will be identified. Also, since a cold surge affects the temperature and pressure over large areas of East Asia, it is highly unlikely that a non-surge event can be identified as a surge. Comparison of the surges identified from the 1979-1984 period with the surge events documented from the Beijing Meteorological Center indicates that all the strong surges are picked up using these criteria.

3. Statistics of the Siberian high and cold surges

Figures 2 (a) and (b) give the total (1979-95) monthly number of surges and number of days that the Siberian high is greater than 1050 hPa.

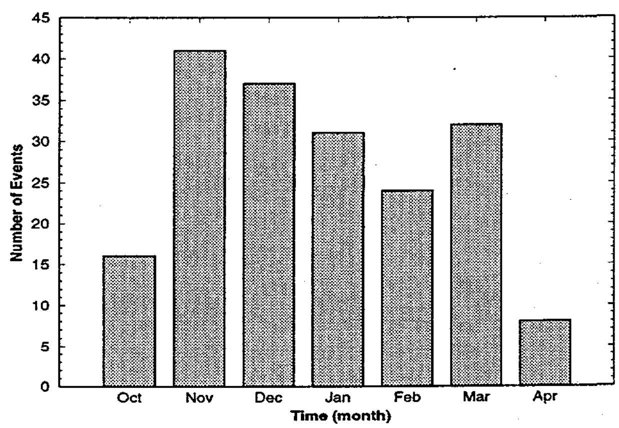

Fig. 2 (a). Total monthly number of cold surges from 1979-1995.

Notice that the Siberian high tends to peak in December and January although the surge frequency reaches its maximum in November. The frequency of surges is also high in March. Despite the suggested close relationship between the intensity of the Siberian high and cold surges (Ding, 1994), the cold surge frequency and the Siberian high reach their maximum in different months, which suggests that these two phenomena may

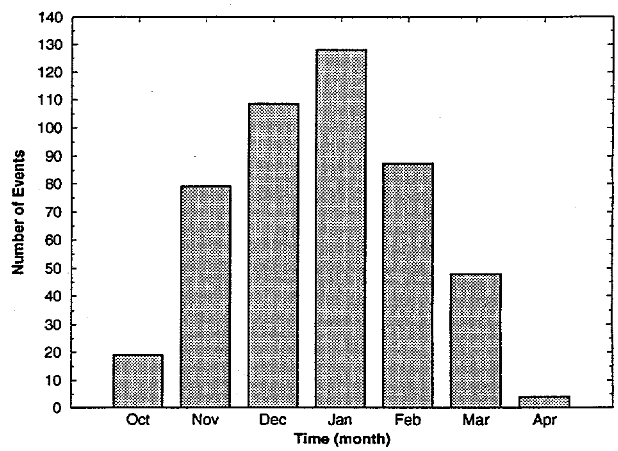

Fig. 2 (b). Total monthly number of days that the Siberian high center pressure is greater than 1050 hPa from 1979-1995.

not as closely related as they were thought to be. The fact that frequency of cold surges usually peaks at March and November is because the Rossby wave patterns undergo active shifting during the large-scale regime transition. Despite abundant sources of cold air and a stronger Siberian high, December and January exhibit relatively low frequency because the wave patterns tend to remain more zonally oriented and unchanged in very cold winters.

Because the prevailing northeasterly wind dominates large areas of East Asia in March and November, and since the cold surge frequency is high in these months, November through March should be considered as the winter monsoon season in East Asia. Climatological studies of surges should encompass the five months period instead of the traditional DJF approach. All the subsequent results are average based on this five-month period.

4. Interannual variations of winter monsoon and surges

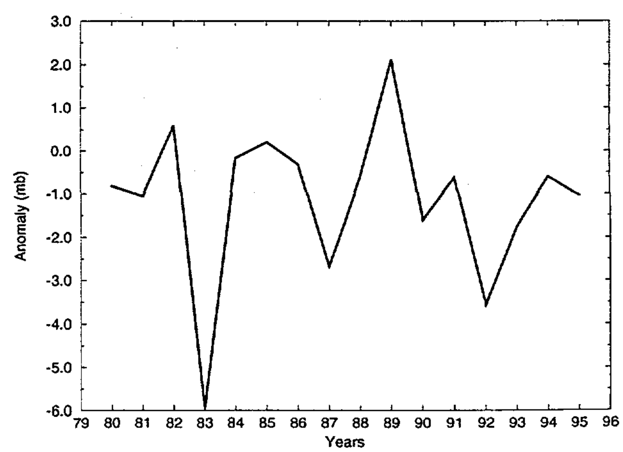

Fig. 3 (a). Southern Oscillation Index. Anomaly of Pressure difference between Tahiti and Darwin.

Fig. 3 (a) is the seasonal averaged anomalies of pressure difference between Tahiti and Darwin, the Southern Oscillation Index (SOI), from 1979-95. The two major El Nino events of 1982-83 and 1986-87 exhibit very low SOI index. The 1989-90 and 1991-92 are also low index events. Fig. 3 (b) is the Siberian high intensity,

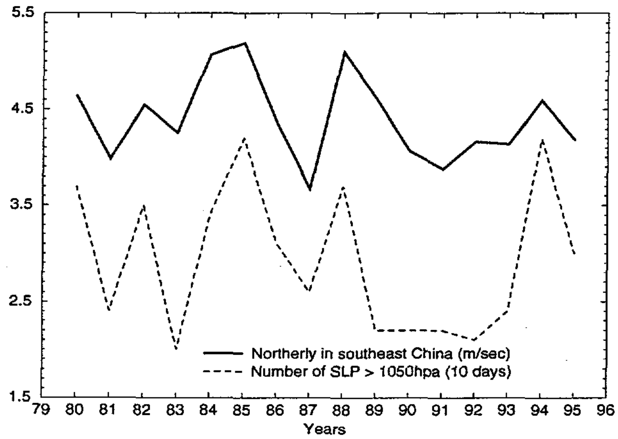

Fig. 3 (b). Northerly wind in Southeast China (117.5°E-122.5°E; 22.5°N-30°N) and number of ten days SLP greater than 1050 hPa.

and northerly wind averaged over the region 117.5°E-122.5°E and 22.5°N-30°N, the southeast periphery of the Siberia high. Both curves are well correlated with the SOI index, a low SOI index is associated with a less intense Siberian high and weak northerly winds. Fig. 3 (c) is a measure of the strength of East Asian jet at 200 hPa. All the low (high) SOI index events are associated with weak (strong) jet intensity. If the intensity of Siberian high, the surface northerly wind and the strength of the jet are indicative of the strength of winter monsoon at all, then it can be stated with confidence based on these figures that the fluctuation of the strength of winter monsoon is related to the interannual variation of the SOI index. High (low) SOI index are associated with strong (weak) winter monsoon and vice versa.

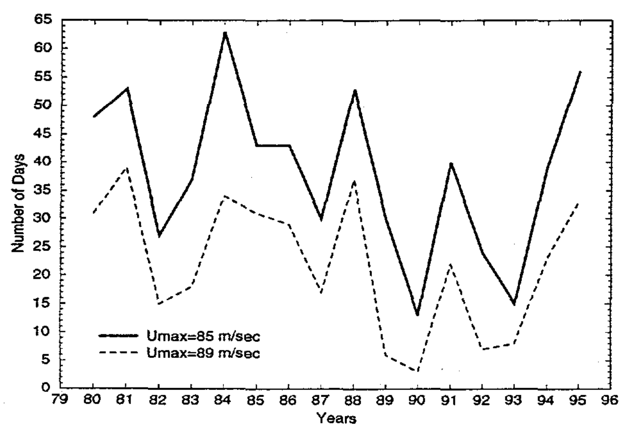

Fig. 3 (c). A measure of the intensity of East Asian jet. Number of days that the 200 hPa u wind is greater than Umax in the jet core region (127.5°E-147.5°E;25°N-35°N).

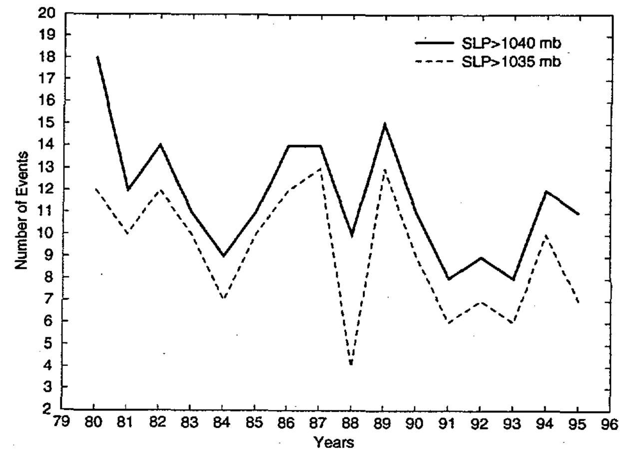

Fig. 3 (d). Interannual variation of cold surge frequency with different SLP threshold.

Fig. 3 (d) is the interannual variation of surge frequency. None of the minimum surge frequencies occurs in a major El Nino event. The surge frequency has been tested using different threshold value of region 1 SLP. The interannual variation of cold surge frequency is shown to be not sensitive to the SLP threshold. One particular interesting feature is that minimum surge frequency occurs one year after low SOI index for all four events. This is consistent with the observed data from Beijing Meteorological Center, surge activity reaches a minimum one year after the 1957-58, 1965-66 and 1972-73 El Nino events. This phenomenon agrees with the 1-1.5 year lag response of the East Asian atmospheric temperature to the eastern equatorial Pacific SST suggested by Bao et al. (1989).

5. Conclusions

The following conclusions are summarized: (1) the Siberian high reaches its maximum strength in January and cold surge frequencies tend to peak in November, (2) interannual variation of East Asian winter monsoon is shown to be related to the SOI index, with low (high) SOI index associated with weak (strong) winter monsoon, (3) a survey of cold surges from 1979-95 indicates that surge frequency is low one year after the El Nino events.

Acknowledgments

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