Relationship between western North Pacific typhoon activity and Tibetan Plateau winter and spring snow cover

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[1] The annual frequency of western North Pacific (WNP) typhoons and the number of landfall typhoons in China are shown to negatively correlate with the Tibetan Plateau snow cover (TP-SC) during the preceding winter and spring. When TP-SC was above normal, fewer typhoons formed in the WNP and made landfall in China, and vice versa. The observed seasonal lag correlation between the TP-SC and the WNP typhoon activity suggests the existence of a seasonal memory of the East Asia – West Pacific regional climate system which provides a means for the seasonal prediction of WNP typhoon activity and typhoon landfall frequency in China. **Citation:** Xie, L., T. Yan, L. J. Pietrafesa, T. Karl, and X. Xu (2005), Relationship between western North Pacific typhoon activity and Tibetan Plateau winter and spring snow cover, *Geophys. Res. Lett.*, *32*, LXXXXX, doi:10.1029/2005GL023237.

1. Introduction

[2] In the winter of 1997–1998, heavy snow blanketed the world's highest mountains, the Tibetan Plateau (TP) [*Xu et al.*, 2002]. The following summer, only 9 typhoons formed over the western North Pacific (WNP), compared to a normal annual of 17 and a maximum of 24 (U.S. National Hurricane Center West Pacific Typhoon Data Archive: http://www.nhc.noaa.gov/). So, the question arises: was it just a coincidence that the increase in Tibetan Plateau snow cover (TP-SC) in the winter of 1997–1998 preceded the least active typhoon season over the WNP? Or, was it a clue for a more robust correlation? Given the large loss of life and economic impacts of land-falling typhoons, it is important to understand the factors and conditions that affect the inter-annual variability of WNP typhoon activity and the annual frequency of landfalling typhoons.

[3] Interannual variability of WNP typhoon activity is known to be influenced by anomalous sea surface temperature (SST) and ambient atmospheric conditions. Active typhoon years in the WNP are often associated with above-normal local SST and vice versa [*Chen et al.*, 1998]. El Niño and Southern Oscillation (ENSO) events are known to strongly modulate the annual hurricane frequency in North Atlantic [*Gray*, 1984], but the influence of ENSO on the WNP typhoon activity shows a more complex picture. The tropical cyclogenesis in the WNP basin as a whole does not show a significant dependence on ENSO [*Chan*, 1985, 2000; *Lander*, 1994]. However, there is a strong ENSO signal at sub-basin scales [*Wu and Lau*, 1992; *Wang and Chan*, 2002; *Chan*, 1985, 2000; *Lander*, 1994]. In El Niño years, fewer tropical cyclones form to the west of 160°E, while more form in the region between 160°E and the dateline. The opposite was found to occur during periods of La Niña. *Wang and Chan* [2002] showed that the WNP TC activities from July to December are noticeably predictable using preceding winter–spring Niño3.4 SST anomalies, while the TC formation from March to July is exceedingly predictable using preceding October–December Niño3.4 SST anomalies.

[4] While ENSO signal has significant prediction value for the interannual variability of WNP typhoon frequency, seasonal prediction of landfalling typhoon frequency in Southeast and East Asia is still a challenge. In this study, we will show that winter and spring season snow cover on the Tibetan Plateau is strongly correlated with the WNP typhoons as well as the landfall frequency of WNP typhoon in China, with the changes in TP-SC preceding the change of WNP typhoon activity.

2. Data

[5] Typhoon frequency is based on the "best track" data from the National Climatic Data Center (NCDC) of the United States National Oceanic and Atmospheric Administration. The data contains the track and intensity of WNP tropical cyclones since 1945. For each storm, the data file contains the 6-hourly (0000, 0600, 1200, 1800 UTC) center locations (latitude and longitude in tenths of degrees), intensities (maximum 1-minute surface wind speeds in knots and minimum central pressures in hpa) and an indicator of whether the system was purely tropical, subtropical or extra-tropical. Typhoon landfall frequencies along the coast of China are derived from the "best track" data, where a "typhoon" is defined as a TC with a maximum sustained wind speed of at least 32 m/s, and landfall is defined as the crossing of the storm center over the coastline.

[6] The snow cover data is derived from the satellite-estimated percentage monthly snow cover within each 1° × 1° grid cell on the TP from 1963 to 2004, available online from the Snow Data Resource Center at the Rutgers University (http://climate.rutgers.edu/snowcover). In this study, 1° × 1° resolution snow cover data for the region (20°–40°N, 75°–115°E) covering the entire TP for the period of 1976–1998 is used. Snow cover data is deemed

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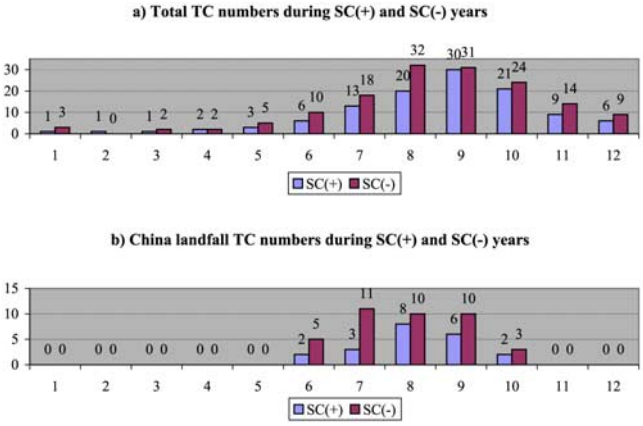

Figure 1. Composite total WNP typhoon and China's landfall typhoon numbers in eight high and eight low TP snow cover years. (a) Monthly landfall typhoon numbers for 8 large snow cover (SC+) years and eight small snow cover (SC−) years; Large (small) snow-cover refers to the condition when the 1–5 year high-pass filtered area-mean snow cover within the rectangular box in Figure 2b is above (below) its 1976–1998 mean. (b) Same as Figure 1a except for total WNP typhoon numbers. Large (small) snow cover is defined as in a), except that for the rectangular box in Figure 2d is used. A FIR high-pass filter with a cutoff frequency of 0.1 is used to extract interannual-frequency snow cover variability.

unreliable before 1975 and uncertain in continuity after 1998 due to a change of NOAA's snow cover mapping system in 1999 (D. Robinson, personal communication, 2004). Geopotential height fields from 1950–2000 are derived from the National Center for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) reanalysis data, archived at NCDC.

3. Relationship Between TP Snow Cover and WNP Typhoon

[7] As shown in Figure 1a, there was a general tendency for the WNP typhoon season to be less (more) active when the snow cover over the Tibetan Plateau was above (below) normal in the preceding winter and spring. Similarly, fewer (more) typhoons made landfall in China (including Hainan and Taiwan) when the preceding winter had an above (below) normal snow cover on the Tibetan Plateau (Figure 1b). In fact, for the eight years with above normal TP-SC, only five typhoons made landfall in China in the early typhoon season prior to August 1, whereas three times the number (15 typhoons) made landfall during the same period for the eight years with below normal TP-SC (Figure 1b). Thus, it appears that large TP-SC suppresses the overall WNP typhoon activity, and reduces the typhoon landfall frequency in China, especially during June and July. Historical records show that, there was, in general, a negative correlation between the number of landfall typhoons in China and the TP-SC in the preceding winter (December–February) (Figure 2a) and spring (March–May) (Figure 2b). The regions with the most significant correlation appear to be near 103°E over the Eastern TP during the winter and near 92°–95°E and 80°E during the spring. The largest magnitude of the correlation coefficient between spring TP-SC and WNP typhoon landfall frequency in China for the 23-year period of 1976–1998 is −0.62 ($p = 0.0012$). This is consistent with the composite trends shown in Figure 1, which indicate that an increase in TP-SC leads to a reduction in annual typhoon landfall frequency in China (including the islands of Taiwan and Hainan), and vice versa. Negative correlation also exists between the winter

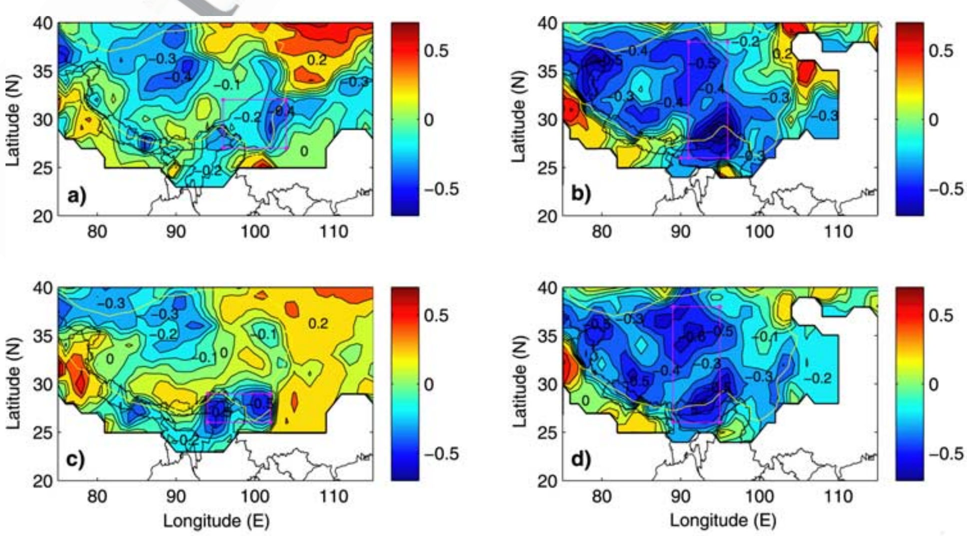

Figure 2. Spatial distribution of TP-SC/WNP typhoon correlation coefficients. (a) Correlation between December–February snow cover and China landfall typhoon frequency; (b) same as Figure 2a except for March–May TP-SC; (c) same as Figure 2a except for total WNP typhoon frequency; (d) same as Figure 2c except for March–May TP-SC. The yellow outline indicates the Tibetan Plateau region.

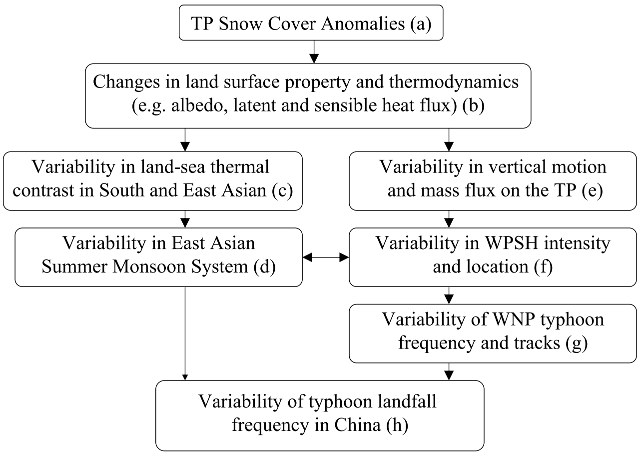

Figure 3. Schematic diagram illustrating the influence of Tibetan Plateau snow cover on the annual frequency of landfall typhoons in China.

and spring TP-SC and the total typhoon number in the WNP (Figures 2c and 2d). The largest correlation between spring TP-SC and WNP total typhoon frequency (R = −0.58, p = 0.0029) occurred near 92°–95°E.

4. Discussions

[8] In Section 3, a statistic relationship between the TP-SC and WNP typhoon activity has been established. This relationship can be explained by the dependence of the complex East Asia regional climate system on the dynamic and thermodynamic processes that occur over the Tibetan Plateau. Based on the results presented in Section 3 and the vast amount of information gathered from existing literature, we propose a mechanism for the link between TP-SC and WNP typhoon activity (Figure 3). As part of the global climate system, Tibetan Plateau exerts a dominant control on the regional weather and climate over East Asia. In winter, the TP acts as a heat sink while, in summer, as a heat source. The variation of the snow cover on the Tibetan Plateau affects the thermodynamic processes in the region by modulating the sensible and latent heat fluxes, as well as by modulating the albedo and hence the radiative energy balance (Figures 3a and 3b). Changes of the thermodynamic processes on the Tibetan Plateau are known to affect the Indian monsoon [*Kripalani et al.*, 2003], the East Asian monsoon [*Zhang and Tao*, 2001] (Figures 3c and 3d), and the winter atmospheric circulation over the North Pacific (Figures 3e and 3f) [*Clark and Sereze*, 2000]. Recent studies have further revealed the relationships between TP-SC and the East Asian summer monsoon (EASM) (Figures 3a–3d) [*Wu and Qian*, 2003; *Zhang and Tao*, 2001], as well as between the EASM and WNP typhoons (Figures 3d–3h) [*Chen et al.*, 2002]. WNP typhoon activity and the timing and persistence of monsoon rainfall in the Yangtze River region are strongly connected [*Chen et al.*, 2002]. When monsoon rainfall persists along the Yangtze River, WNP typhoon activity is usually below normal. On the other hand, the EASM is influenced by the snow cover on the Tibetan Plateau. Above normal TP snow cover leads to a weak surface heat flux, which, in turn, results in a weak land-sea thermal contrast between the TP heat source and the heat sink over the adjacent ocean and, consequently, a late and weak EASM [*Zhang and Tao*, 2001].

[9] The EASM is one of the most dominant climatic signals in the region, which is inextricably coupled to the West Pacific subtropical high pressure system (WPSH) [*Wu et al.*, 2004; *Rodwell and Hoskins*, 2001; *Liu et al.*, 2001]. As part of the EASM system, the WPSH exerts a dominant control on the steering flow of the WNP typhoons (Figures 3f and 3g). A vivid example is 1987–1998. The large snow fall in the preceding winter was found to be a robust precursory signal for a weak monsoon in the following summer. At the same time, only five typhoons formed before mid-September 1998 over the WNP and South China Sea. Only two of the typhoons made landfall, making the June–September period of 1998 the least active typhoon period since 1951. This exceptionally inactive period is related to the abnormal low latitude location of the subtropical high over the WNP [*Luo and Zeng*, 1998]. What was found in 1998 was common in other years with large TP-SC. Figures 4a and 4b show the composite positions of the western edge of the WPSH in July and August during large and small TP-SC years, respectively. In July, as illustrated in Figure 4a, the WPSH generally assumed a more southerly position during large TP-SC years than it did in small TP-SC years. In August, the WPSH generally shifted northwestward in low TP-SC years which steered the typhoons more toward the land, but WPSH shifted northeastward in high TP-SC years which was conducive to northwestward curving typhoon tracks (Figure 4b).

5. Conclusions

[10] We have discovered a strong negative correlation between the extent of snow cover in the preceding winter (DJF) and spring (MAM) on the Tibetan Plateau and the annual frequency of WNP typhoons as well as their landfalling frequency in China. This correlation can be explained by the response of the WPSH to the snow-modulated land surface thermodynamic processes over the Tibetan Plateau. Increased winter snow cover over the TP leads to reduced surface sensible and radiative fluxes and this effect could last well into the spring and early summer. It is followed by a weak summer monsoon and a weak WPSH, which, in turn, leads to a reduced number of

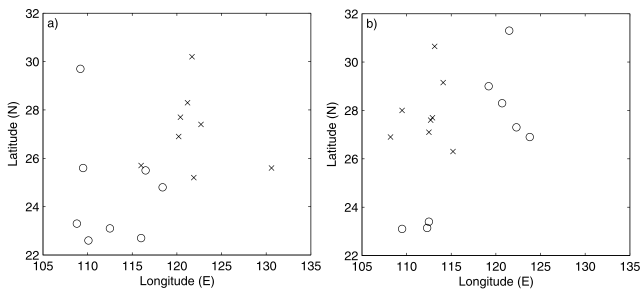

Figure 4. Positions of the western edge of the West Pacific 5880 m geopotential height contour during above and below normal Tibetan Plateau snow cover years. (a) July typhoon period composite; (b) August typhoon period composite.

landfalling typhoons in China, particularly during the early summer (May–July). The observed seasonal lag correlation between TP-SC and landfall typhoon frequency on the coast of China suggests that the annual landfall typhoon frequency in China can be predicted using the amount of winter and/or spring TP-SC as one of the primary predictors. This will be analyzed in a more in-depth study and reported separately.

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