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Dust storm activity over the Tibetan Plateau recorded by a shallow ice core from the north slope of Mt. Qomolangma (Everest), Tibet-Himal region

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[1] Based on a 39.8 m ice core drilled at the East Rongbuk Glacier (27°59′N, 86°55′E 6518 m a.s.l,), north slope of Mt. Qomolangma (Everest), central Himalaya, the changes of dust storm over the Tibetan Plateau (TP) recorded by insoluble particle and its possible connection with the winter (JFM) North Atlantic Oscillation (NAO) are investigated. The results show that the level of dust storm activity exhibits a significant decreasing trend during the past ~50 years. This may be attributed, at least partly, to a decrease in wind speed over the TP and its surrounding regions. The normalized time series of the winter NAO index shows a significant inverse correlation with the mass concentration of insoluble particle implying a possible connection between the winter NAO and the dust storm activity over the TP. **Citation:** Xu, J., S. Hou, D. Qin, S. Kang, J. Ren, and J. Ming (2007), Dust storm activity over the Tibetan Plateau recorded by a shallow ice core from the north slope of Mt. Qomolangma (Everest), Tibet-Himal region, *Geophys. Res. Lett.*, *34*, L17504, doi:10.1029/2007GL030853.

1. Introduction

[2] Dust entrained from China and its surrounding regions is regarded as one of the most important dust sources in the world [*Prospero et al.*, 2002]. High frequency dust storms generated in northern China during the winter and spring play an important role in climate forcing, atmospheric chemistry and ocean biogeochemistry [*Jickells et al.*, 2005]. Spatial and temporal changes of dust storm in northern China have been recorded by weather stations [*Sun et al.*, 2001]. However, there are relatively few stations in western China, especially on the TP.

[3] Ice cores preserve dust information including aeolian origin, windblown long distance from the continents [*Thompson et al.*, 2000; *Zdanowicz et al.*, 2000]. The vast extent of glaciers in the mountains of central Asia provides a means to measure the depositional flux of atmospheric dust over a wide geographic area. However, there are few studies that have documented the aeolian dust record of central Asia using ice cores from the TP and Himalayas [*Thompson et al.*, 2000]. Here we focus on a new shallow ice core record from the East Rongbuk (ER) Glacier of dust deposition from the arid and semi-arid regions of central Asia (Figure 1).

[4] Over the middle and high latitudes of the Northern Hemisphere (NH), especially during the cold season months (November–April), the NAO is the most prominent and recurrent pattern of atmospheric variability [*Hurrell*, 1995].This study aims to address the trend of dust storm activity over the TP and the potential linkage with the winter NAO.

2. Methods

2.1. Ice Core Drilling and Analytical Procedure

[5] In September of 2002, a 39.8 m ice core was recovered from the ER Glacier, ~5 km of northeast of the summit of Mt. Qomolangma (Everest) (Figure 1). The high snow accumulation (50 cm w.e.a^{-1}) at the drill site allows for preservation of seasonal signals, enabling the ice core to be annually dated [*Hou et al.*, 2003]. The ice core was sampled into 712 samples at ~5 cm resolution. The outer ~2 cm of each sample was removed for stable oxygen isotope analysis using pre-cleaned stainless bistouries. The inner portion of the ice core was collected in pre-cleaned polyethylene sample containers, for further chemical and insoluble particle analyses. All sampling procedures were performed in a cold (−5°C) clean room. Insoluble particles were analyzed using a 256-channel Coulter Counter (Coulter Counter Multisizer e III ©) in a class 100 clean room. Samples were melted immediately prior to particle analysis. 2.5 ml samples were extracted from the sample containers using a pipette and diluted 1:4 with NaCl electrolyte for particle counting. The instrument was set to detect particles with an equivalent spherical diameter large than 2.0 μm. Each concentration and size distribution value represents the average of at least three independent measurements of each sample. The total mass of insoluble dust was calculated from the volume size distribution assuming an average density of 2.5 g/cm^3.

2.2. Dating

[6] Seasonal variations of $\delta^{18}O$ in the southern TP are dominated by the 'amount effect', with relatively low $\delta^{18}O$ in the summer and high $\delta^{18}O$ during the winter and spring [*Tian et al.*, 2003]. Previously an 80.4 m ice core collected from the ER Glacier was dated using the distinct seasonal fluctuations of $\delta^{18}O$ [*Hou et al.*, 2003]. Using this method,

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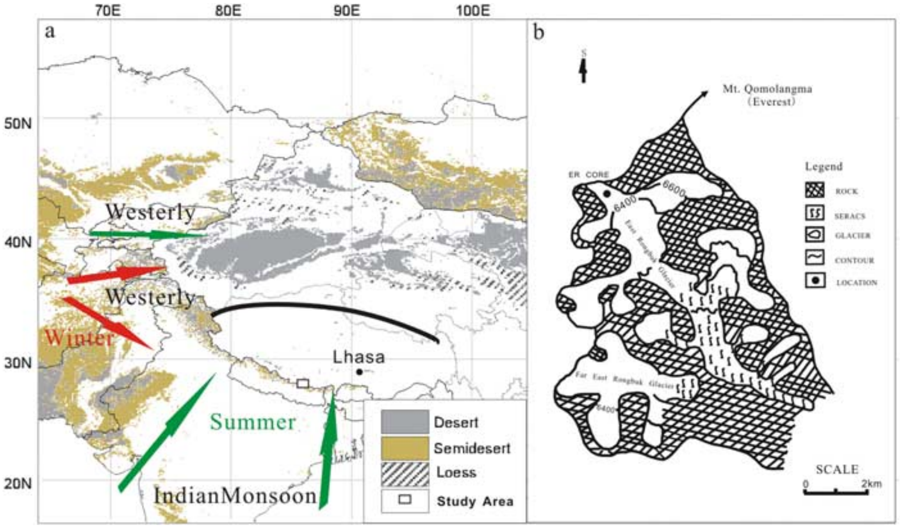

Figure 1. (a) Location map of the study area in the central Himalayas and distribution of dust sources and general patterns for winter and summer circulation systems. The thick line represents the northern border of the summer monsoon (34°–35°N in the middle of the plateau). (b) Map of the ER Glacier showing the ice core drilling site.

the 39.8 m ice core was annually dated, and spans the period 1951–2001 A.D. (Figure 2). The result was further verified by double β activity horizons produced by the atmospheric thermonuclear tests in the early 1950s to the early 1960s. We identify the $\delta^{18}O$ peak between the depth 31 m and 32 m of the ice core as 1963 A.D. where the β activity peak was observed.

3. Results and Discussion

3.1. Record of Dust Storm Frequency

[7] Figure 3 shows the profile of insoluble particle concentrations versus time, indicating similar variations between mass and number concentrations; thus, we only focus on the change of mass concentrations. The number-weighted annual mean mass concentrations show a decreasing tendency from 1951–2000 A.D. (Figure 3c). Particle concentrations are high in the mid-1950s to 1970s, after which concentrations decrease to levels in the 1990s that are only half of those in the 1950s and 1960s. This variation is similar to: the dust storm record from Lhasa (Figure 3d) in southern TP; the dust storm record from weather stations over the TP [*Qian et al.*, 2004]; and the reconstructed long-term trend of dust storms in northern China based on weather stations (Figure 3e) [*Qian et al.*, 2002]. Although these time series do not correlate at annual scales due to differences in statistic methods, they do share a common decreasing feature.

[8] The occurrence of dust storms over the TP is principally between December and April, with the location of dust storm activity moving northward during the dust storm season [*Fang et al.*, 2004]. This seasonal movement is closely related to the position of the westerly jet over the TP. When the axis and center of westerly jet moves from south to north over the TP from winter to summer, the southern branch of the westerly jet gradually weakens, whereas the northern branch intensifies (Figure 1). Superimposed with the impact of the complicated topography on the TP, the convergence center of air currents also moves accordingly from south to north over the TP from winter to spring, giving rise to a corresponding northward movement of the center of dust storms [*Fang et al.*, 2004]. Thus dust concentrations in the ER Glacier are generally high in the winter and spring [*Kang et al.*, 2004], and the dominant dust sources are mainly located in the arid and semi-arid regions of central Asia [*Wake et al.*, 1993]. Because the record of dust in the snow could reflect regional to northern hemispheric signals [*Wake and Mayewski*, 1994] and the common change feature between the dust record and the frequency of dust storm, it seems that the insoluble particle

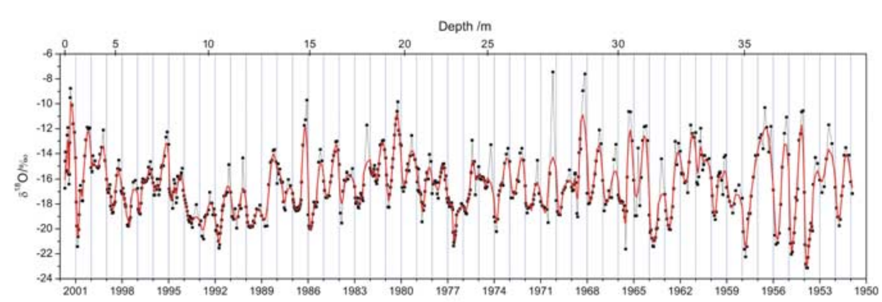

Figure 2. Annual dating of the ER shallow ice core based on seasonal variations of $\delta^{18}O$ (dotted line). The thick line represents the 3-point running mean.

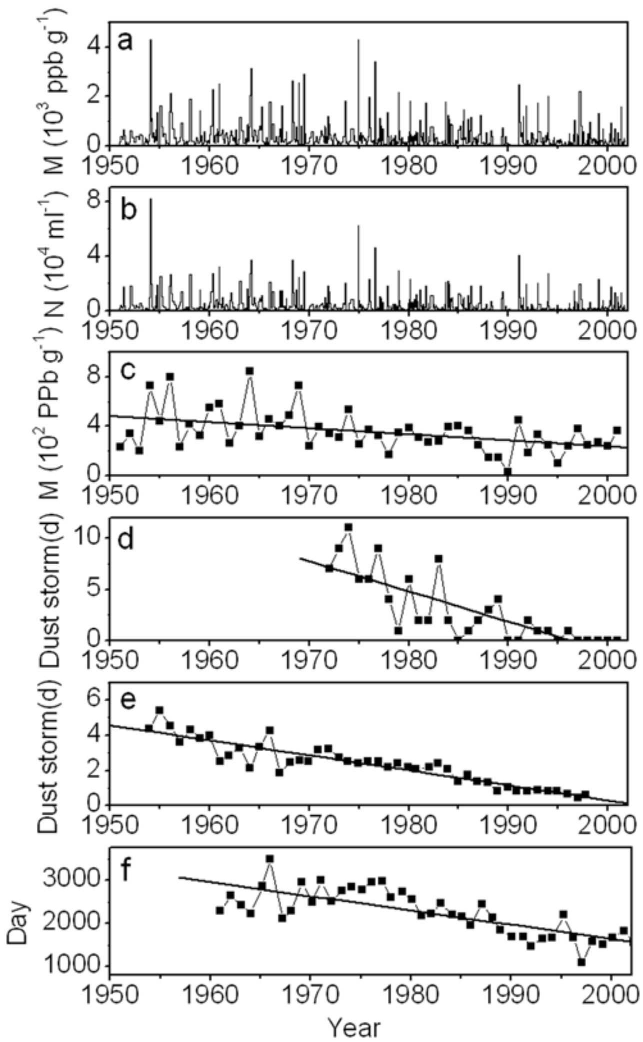

Figure 3. Profiles of (a) particle mass and (b) number concentrations in the ER shallow ice core and (c) number-weighted annual mean mass concentrations, (d) with comparison to Lhasa dust storm frequency from 1972–2001, (e) dust storm frequency to the north of the Yangtze River of China from 1954–1998, and (f) annual occurrence of spring gale days recorded at 175 stations in northern China. Heavy lines denote linear trend, all exceeding the 99% significance level.

concentrations of the ER ice core may represent the frequency of dust storm over the TP.

3.2. Atmospheric Circulation Changes

[9] Previous studies suggest that the main climatic factor controlling dust storm frequency in northern China attributes to the dynamical impact of strong wind [*Zhao et al.*, 2004]. The eruption and trajectory of air-born dust are mainly governed by the wind in the low and middle troposphere. The annual number of dust storm days in northern China is correlated positively with annual mean wind speed and negatively with annual precipitation [*Sun et al.*, 2001]. *Qian et al.* [2002] also suggest that wind anomalies are strongly associated with dust weather frequency. The annual occurrence of spring gale days (instantaneous wind speed $\geq$17.0 m/s) recorded at 175 stations (including parts of stations on the TP) in northern China is shown in Figure 3f [*Zhou et al.*, 2006], indicating a decreasing trend after 1975 similar to the profile of ice core particle concentrations.

[10] Using NCEP reanalysis data [*Kalnay et al.*, 1996], Figure 4a plots the mean wind field changes of the 500 hPa during January to March for 1951–1975 which shows west wind over the TP and its surrounding regions, and Figure 4b plots interdecadal changes (1976–2001 minus 1951–1975) of the 500-hPa horizontal winds and 600-hPa temperature during January to March. It is clear that the horizontal winds over the TP and its surrounding regions show a significant decreasing trend. Based on these temporal and spatial similar changes, it seems that the particle concentrations in the ER ice core could be significantly related with wind speed. Also it is clear that the regions of the decrease of wind and temperature are highly related (Figure 4b), and the wing field appears abnormal cyclone over the TP and its surrounding regions. This indicates that the decreasing intention of wind field during past 25 years over the TP and its surrounding regions might have an inherent relation with air temperature. The decrease of air temperature results in abnormal cyclone in upper troposphere and abnormal anticyclone in low troposphere [*Yu et al.*, 2004]. *Kang et al.* [2006] also found the increase in pressure over the TP and its surrounding regions in the winter during past decades and suggested that it may block the westerly jet and further decrease the break out of the dust storm.

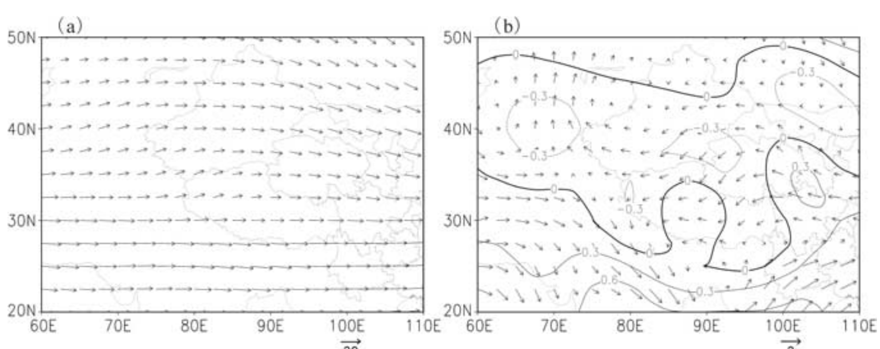

Figure 4. (a) Mean winter (JFM) horizontal winds at 500 hPa for 1951–1975. (b) Interdecadal changes (1976–2001 minus 1951–1975) of winter (JFM) 500-hPa horizontal wind and winter (JFM) 600-hPa temperature (unit: °C).

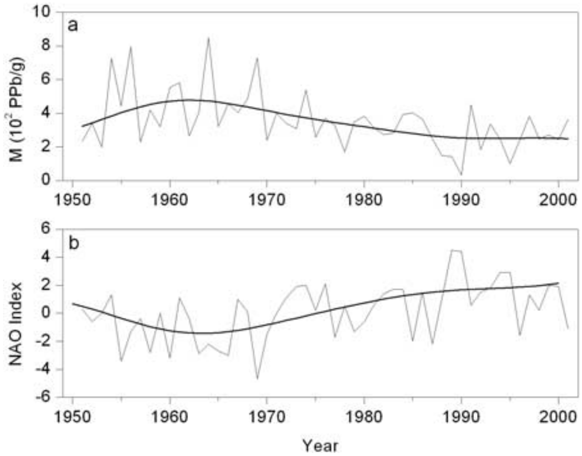

Figure 5. Comparison (a) the particle mass concentration and (b) the normalized time series of the winter (JFM) NAO index. The solid thick line represents the 11-yr running mean.

3.3. Correlation With NAO

[11] The NAO was found to have a strong influence on the Asian climate (e.g., winter monsoon, air temperature) on seasonal to decadal time scales [*Gong et al.*, 2001; *Yu and Zhou*, 2004]. In order to analyze the impact of the winter (January–March: JFM) NAO on dust storm activity over the TP, we examined the association between mass concentration and the winter NAO index. The normalized time series of the winter NAO index and the concentration of insoluble particles are inversely correlated ($p = 0.01$, $r = -0.46$) (Figure 5).

[12] Although there is a significant correlation between the winter NAO index and the mass concentration of insoluble particle, the mechanisms behind such a correlation are not clear. The winter NAO index is not correlated with NCEP temperature and precipitation over the central Himalaya (not shown). The inverse relationship between the winter NAO and our ice core insoluble particle record may reflect the influence of the winter NAO on the environmental and climate conditions in the dust source area, rather than the Himalayan region. During the past several decades, the winter NAO was strong, and had a significant influence on the Eurasian surface temperature [*Hurrell*, 1995]. Significant cooling over northern Africa and the Middle East associated with a positive winter NAO index has been suggested by *Hurrell et al.* [2003]. *Yu and Zhou* [2004] and *Li et al.* [2005] found that the cooling signal propagates eastwards from northern Africa to the TP and southern Asia during January and March. Therefore the winter NAO may influence the low and middle tropospheric atmospheric circulation over the TP and its surrounding regions through its control over regional temperature variability. In this point, the decreasing of dust storm frequency after 1975 over the TP may be connected with the change of winter NAO index.

[13] The mechanisms of dust storm outbreaks over the TP and northern China are different. Dust storm outbreaks over the TP are associated with the movement of westerly jet, whereas in northern China they are generally related to cold air outbreaks associated with the Siberian High [*Sun et al.*, 2001]. However, there is a close connection between the NAO/AO and the Siberian High [*Gong et al.*, 2001]. We check the relationship between winter (JFM) Siberian High Index (40°N–65°N; 80°E–120°E) and insoluble particle concentration, resulting in a correlation coefficient of 0.35 ($p = 0.05$). Thus, we can compare our data with dust storm records in northern China.

4. Conclusions

[14] An insoluble particle record from a shallow ice core recovered from the ER Glacier on the northeast ridge of Mt. Qomolangma (Everest) suggests a reduction in the activity of dust storm during the past 50 years. This reduction is attributed to a decrease in wind speed over the TP and its surrounding regions. The annual mass concentration of insoluble particles is inversely correlated with the winter (JFM) NAO index. This large-scale climatic control on the dust export is affected through change in air temperature that influences the strength of wind over the TP and its surrounding regions.

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