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Variation of strong dust storm events in Northern China during 1978–2007

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ABSTRACT

Dust storms have a great significance for global mineral aerosol cycle, marine ecosystem, air quality and human health. Dust storm frequency (DSF), often used as a primary index for understanding a regional characteristic of dust storms. However, DSF couldn't describe the frequency and the outbreak areas of a dust storm event (DSE) which was defined as a dust storm occurred at three or more meteorological stations during the same weather process, because a DSE might occur at several meteorological stations and continue for several days. We defined a new index DSE considering the factors including wind speed, wind direction and spatial variation during a dust storm process. To clarify which index of DSF or DSE is better to describe the characteristics of dust storms, we have used the data sets of dust storm from 319 meteorological stations to calculate the frequency of DSE, and the outbreak area and the duration of each DSE in 1978–2007, as well as to compare the differences between DSE and DSF in spatiotemporal distribution in Northern China. The results showed that the high-value locations of occurrence numbers of DSE and DSF were almost overlapped; from 1978 to 2007, the total values of DSE and DSF decreased from 558 to 201 and from 1273 to 467, respectively, but the mean values of outbreak area and duration of DSE have wavily increased since 1991. These implied that the differences existed between DSE and DSF in describing the characteristics of a regional dust storm, and DSE was a better index for a dust storm to identify the fact of occurrence frequency and outbreak area. The implication of this study was that the values of DSE and DSF have a decrease trends with increase of extreme precipitation events and decrease of mean wind speed under the global warming scenarios, but strong dust storms, which is defined as the outbreak area of an event >105 km^2 here, probably bring greater risk in future.

1. Introduction

Dust storm is a kind of severely disastrous weather phenomenon which produces a huge number of mineral dusts to be transported very far by wind. The mineral dusts not only have actively contributed to marine ecosystem productivity (Zhuang et al., 1992; Jickells et al., 2005) and obviously inhibited to occurrence of acid rain (Sha et al., 1996; Terada et al., 2002), but also have caused air pollution (Chang et al., 1996; Borbély-Kiss et al., 2004) and damaged human health (Hefflin et al., 1994; Yang and Meng, 2008; Goudie, 2009, 2014). Therefore, dust storm has become a research hotspot in recent years. Globally, North Africa, Asia, Australia and North America are high incidence areas of dust storms, from where 4.50×10^8 tons of mineral dust was annually transported to oceans (Jickells et al., 2005). The arid and semiarid areas in Northern China including sandy and gravel deserts, as a part of Asian dust storm source, annually released 1.00×10^8–4.60×10^8 tons of mineral dust (Laurent et al., 2006), of which 6×10^6–1.2×10^7 tons and 6.7×10^7 tons mineral dust were transported to the North Pacific Ocean and the China Sea, respectively (Uematsu et al., 1983; Gao et al., 1997), accounting for a large proportion in the global mineral dust transport (Harrison et al., 2001).

Three indices, which are dust storm frequency (DSF) defined as the days of dust storm at a meteorological station in a period (Wang et al., 2005; Indoitu et al., 2012), the total suspended particle concentration (C_{TSP}) during the dust storm (Zhang et al., 2010) and mineral dust emission (MDE) during the dust storm (Shao and Dong, 2006), are commonly used to assess the intensity, harmfulness and environmental impact of dust storms. This set of indices can roughly be used to describe the variations in temporal series and spatial distribution of dust storms; and the source distribution, intensity, harmfulness and environmental impact of dust storms; as well as the effect on human health in downwind area (Goudie and Middleton, 2001;Goudie, 2009, 2014). However, to accurately determine the intensity, outbreak area, duration and dust transport amount of a dust storm, it is necessary to introduce the new index of dust storm event (DSE), which was defined as a complete

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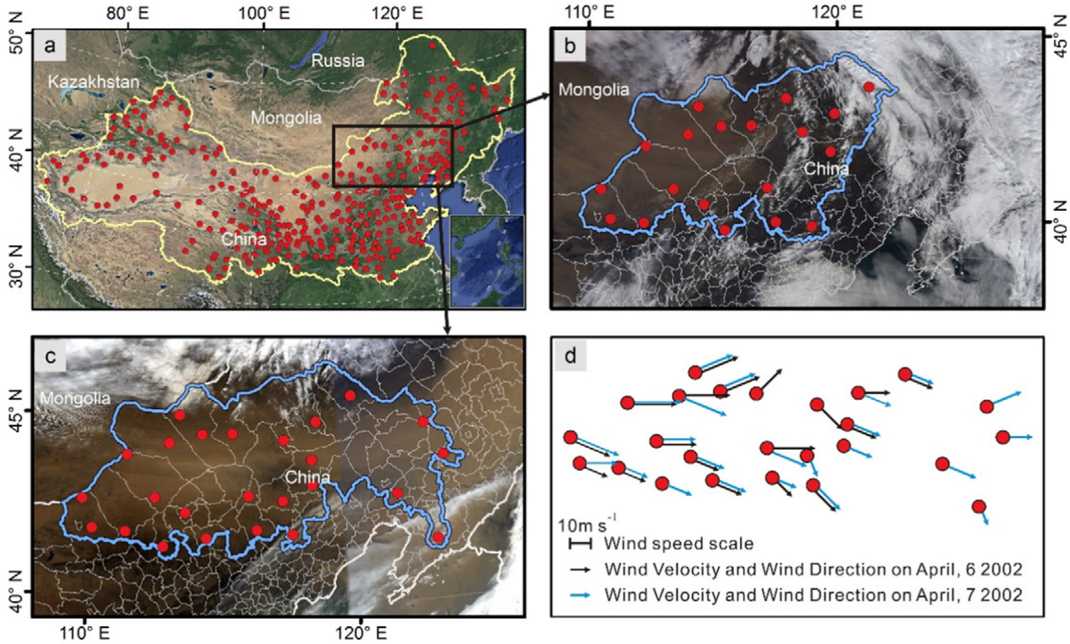

Fig. 1. The study area and an example of DSE. (a) Locations of 319 meteorological stations (red circles) in the study area (yellow lines) and the region of the example of DSE (black rectangle). (b) and (c) Locations of meteorological stations (red circles) and the outbreak areas of a DSE (blue lines) on April 6 to 7, 2002, respectively. The satellite images were from Moderate Resolution Imaging Spectroradiometer (MODIS). (d) The complete process of DSE on April 6 to 7, 2002.

dust storm process from the beginning to the end in a weather process. A dust storm process refers to a dust storm occurs at three or more neighboring meteorological stations at the same observation time according to the Chinese standard of dust storm grades (AQSIQ and SAC, 2006). The DSE is specifically designated to indicate a large-scale and longer-lived dust storm under the control of systematic weather process. The advantages of using the DSE concept are: (i) The statistic value of DSF was derived from daily data of an independent meteorological station, and couldn't distinguish the deference between local dust storm caused by local weather process and DSE caused by large-scale weather system. Yet, only the large-scale and longer-lived dust storms have the greatest effects on both ocean and land ecosystems through the deposition of mineral dust (Sun et al., 2001). (ii) Uncertainties have existed in the estimation of MDE inflicted by soil wind erosion by using current models (Alfaro et al., 2004). On the basis of occurrences and durations of dust storm events (DSEs), and observation data of dust concentrations in air during DSEs, the estimation accuracy of MDE can be significantly improved (Zhang et al., 1998). (iii) The spatial resolution of C_{TSP} is so low that it cannot be used to accurately assess the harmfulness and environmental impact of dust storms due to the observation stations of C_{TSP} much less than those of dust storm. (iv) To evaluate the harmfulness of a dust storm, especially a single DSE, requires the supporting data of duration and outbreak area of a DSE, because the duration might last several days and the outbreak area might be widespread.

The limitations of C_{TSP} and MDE made them not to be used as the primary indices for assessing the harmfulness and environmental impact of large-scale and longer-lived dust storm dust storms, the previous studies mainly focused on the spatiotemporal variation characteristics of the DSF, and showed that the values of DSF were in an overall decreasing trend (Qian et al., 2004; Wang et al., 2004), but the works have rarely been done on the DSE. The purpose of this study is to clarify the differences between DSE and DSF, and the spatiotemporal variation characteristics and outbreak areas of DSEs in Northern China during 1978–2007; and explore the tendency of DSEs, DSF, C_{TSP} and MDE under global change scenarios.

2. Method

2.1. Data sources

In the meteorological records of China, dust storms are generally defined by the horizontal visibility of 1 km or less at the observation

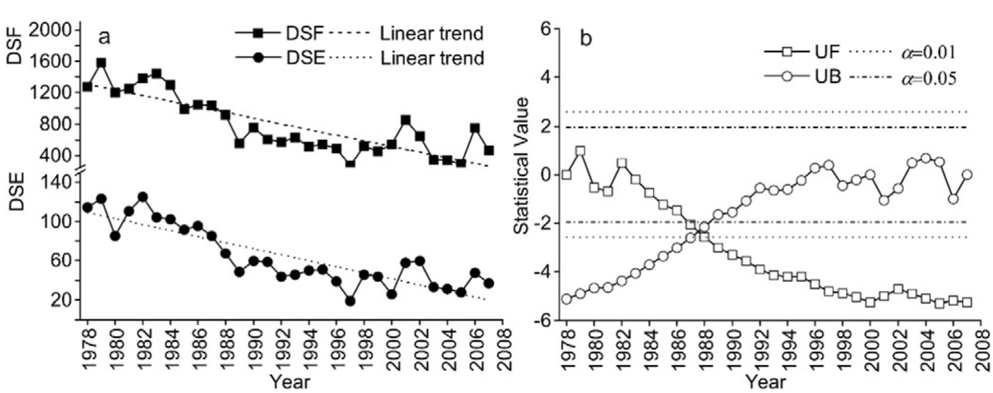

Fig. 2. Annual variations and Mann-Kendall test of DSF and DSE in Northern China from1978 to 2007. (a) Annual variations of DSF and DSE. (b) The result of Mann-Kendall test, UF (squares) and UB (circles) represent the statistical indicators for Mann-Kendall test.