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Changes of the probabilities in different ranges of near-surface wind speed in China during the period for 1970–2011

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ABSTRACT

Slowdown in near-surface wind speed (SWS) has been revealed over China in the last 30 years, but changes of probabilities in different wind ranges and probability distribution of SWS are still not involved. In this paper, the changes of probabilities in different wind ranges and probability distribution of SWS from 1970 to 2011 were studied. The results show: (1) The annual mean SWS declined at a rate of -0.15 m s^{-1} decade^{-1}, meanwhile, the monthly mean variation of probabilities for six wind ranges showed a bimodal fluctuation. (2) The long-term trends of probabilities of 0.3–1.5 m s^{-1} and 1.6–3.3 m s^{-1} increased, while the probabilities of 3.4–5.4 m s^{-1}, 5.5–7.9 m s^{-1}, and $\geq$8.0 m s^{-1} declined over the 42-year period. (3) The probability of SWS beyond 3.0 m s^{-1} was lower in large city than that in small city, meanwhile, the probability density function curves in similar sized city in different climate zones were not consistent, which implied that the probability distribution of SWS could be affected by both urbanization and climate characteristics.

1. Introduction

Near-surface wind speed (SWS) is influenced by climate changes and changes in land surface characteristics (Najac et al., 2009). Consequently, it's important to study the changes in SWS as a reflection of climate change and anthropogenic influences (Wu et al., 2016). In former studies, a significant decrease in SWS was found in recent decades in the northern mid-latitudes and some local areas (Vautard et al., 2010; McVicar et al., 2012). Vautard et al. (2010) showed that the SWS declined by 5–15% over almost all continental areas in northern mid-latitudes, and that the strong winds slowed faster than weak winds. Wever (2012) found the annual mean SWS declined 1.2% in Europe for the period 1982–2009, which in Netherlands showed a decreasing rate of 3.1% decade^{-1}, associating a decline of the frequency of daily maximum wind in the last 20 years (Cusack, 2013). Najac et al. (2012) reported that the evident slowdown in SWS was found in central and southern France, in which the most significant reduction of SWS reached 4.8% in central France. The decrease in SWS was also observed in 73% stations in Turkey during the period 1975–2006 with a mean rate of -0.14 m s^{-1} decade^{-1} (Dadaser-Celik and Cengiz, 2014). In addition, a decrease in SWS was also observed in Spain and Portugal from 1961 to 2011 (Azorin-Molina et al., 2014, 2016a, b), in Czech from 1961 to 2005 (Brazdil et al., 2009), in England during the period 1980–2010 (Earl et al., 2013), in Western Canada and most parts of southern Canada for 1953–2006 (Wan et al., 2010), in America for 1971–2000 (Greene et al., 2012), in Sweden for 1959–2013 (Minola et al., 2016).

The reduction in SWS was also reported in China (Jiang et al., 2010; Fu et al., 2011; Zha et al., 2017). Xu et al. (2006) revealed that annual mean SWS decreased 28% for 1969–2000. Jiang et al. (2010) revealed that the decreasing trend of SWS was more evident in regions with higher SWS than that with lower SWS. Guo et al. (2011) discovered that the decreasing trend of annual mean SWS in China reached -0.18 m s^{-1} decade^{-1}, and that the main contribution to the decrease in SWS came from the reduction of strong wind events. Liu et al. (2014a) pointed out the annual mean SWS decreased by more than 20% in most regions of China from 1966 to 2011, at the same time, SWS decreased up to 80% in some regions in Northwestern China, the reaches of Songhua River and Yangtze River, and the Southeastern China. Wu et al. (2016) reported that a significant slowdown of SWS at a rate of -0.13 m s^{-1} decade^{-1} was found in Eastern China Plain (ECP) region. Some other studies also discovered the pronounced decrease in SWS over China in the last 30 years (Mashowald et al., 2007; McVicar et al., 2010; Lin et al., 2013, 2015).

The significant reduction in SWS over land has been reported in the last 30 years in a number of former studies (Peterson et al., 2011; Tobin et al., 2014; Berrisford et al., 2015), but wind speed variable with time

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and space and depended on local conditions (Pop et al., 2016). Hence, the potential causes of slowdown in SWS remained uncertain. Some studies considered that the reasons for the variability in SWS were attributed to the changes of driving force. Vautard et al. (2010) found that the changes of atmospheric circulation could explain 10–50% of the slowdown in SWS in northern mid-latitudes. The impact of North Atlantic Oscillation (NAO) on the SWS was significant over Europe in recent 30 years (Earl et al., 2013; Azorin-Molina et al., 2014, 2016a). In addition, the changes of SWS could also be induced by El Niño-Southern Oscillation (ENSO) (Enloe et al., 2004), Arctic Oscillation (AO) (Clifton and Lundquist, 2012), East Asian Monsoon (EAM) (Xu et al., 2006), pressure-gradient force (PGF) (Klink, 1999, 2007; Clifton and Lundquist, 2012), inter-decadal tropical cyclones (Sooraj et al., 2009; Welker and Faust, 2013), the rise of air temperature (Fujibe, 2009, 2011; Dadaser-Celik and Cengiz, 2014; Kim and Paik, 2015), and the increase of anthropogenic aerosol emission (Jacobson and Kaufman, 2006; Bichet et al., 2012). More potential causes of the reduction in SWS have been summarized by McVicar et al. (2012).

It is interesting that reduction in SWS was more significant over land than that over ocean (Vautard et al., 2010, 2012; Bichet et al., 2012). Therefore, some studies advocated that long-term decrease in SWS was not mainly induced by driving force, which could be induced by the rise of surface roughness attributed to land use and cover change (LUCC). Schwiesow and Lawrence (1982) suggested that wind profile below 200 m inland had an expected deceleration at lower levels owing to the increased surface roughness. Tamura and Suda (1989) supposed that the reduction of wind speed mainly caused by the increasing of the ground roughness in Japan. Klink (1999) discovered that higher surface roughness in cities relative to rural areas decreased urban wind speeds. Tanentzap et al. (2007) pointed out that the effects of forest regeneration around the mining town of Sudbury in Northern Ontario, Canada, resulted in a 34% reduction in the wind speeds measured at Sudbury Airport from 1978 to 1995. Furthermore, Bichet et al. (2012) simulated an evident decline in SWS when increasing the surface roughness using a coupled global model. Vautard et al. (2010) proposed that 25–60% declines of SWS could be induced by actual rise of surface roughness. Wever (2012) found an increase of surface roughness in Europe could account for the 70% decrease in SWS during the period 1981–2009. Wu et al. (2016, 2017) advocated that the distinct reduction in SWS in ECP was mainly caused by LUCC, and Zha et al. (2016) further discovered that probability of SWS beyond 3.8 m s^{-1} was 1.8%, but which increased to 20.6% when excluding the effects of LUCC in ECP region.

The decreases in SWSs and the potential causes were discussed in China in former studies, but the specific variations in probability within different wind ranges remained unclear, as well as the influences of different city scales on the probabilities of different wind ranges. He et al. (2010) considered that knowledge of probability distribution of SWS is essential for surface flux estimation and wind risk assessments, at the same time, which is especially important for many applications in wind power climatology (He et al., 2012). Therefore, in this study, we will further investigate the probability distribution of SWS and the differences of wind speed probability in different sized cities. After the introduction, the data and methods are presented in Section 2, the results are described in Section 3, followed by discussion in Section 4, and conclusions are presented in Section 5.

2. Data and methods

2.1. Data

Daily mean wind speed dataset at 653 stations are obtained from the China meteorological data Sharing Service System. The wind speed was measured with anemometer 10 m above the ground, at the same time, the siting, installation and observation of the anemometer conformed the standard of the World Meteorological Organization's Guide to Global Observation System and China Meteorological Administration's Technical Regulations on Weather Observation (CMA, 2003; Feng et al., 2004; Xu et al., 2006; Fu et al., 2011; Guo et al., 2011). The detailed information about the siting, installation and observation of the anemometer presented by Tao et al. (1991), Kaiser et al. (1993) and CMA (2003). In addition, Liu (2000) used the standard normal homogeneity test (SNHT) method to examine the credibility of annual mean SWS in China in the last 40 years. Detailed information about the SNHT method can be found in Alexandersson (1986). Liu (2000) revealed that 20% stations showed the inhomogeneous annual mean SWS, at the same time, changes of instrument mainly occurred during the period 1967–1970, which included replacement of wind measurement instrument, relocation of the station and changes in the observation height. The replacement of wind measurement instrument accounted for 70.2% of inhomogeneity in SWS, and the station relocation and changes in the observation height accounted for 15.7% and 14.1% of the inhomogeneity in SWS, respectively. However, Liu (2000) also pointed out that 80% stations showed the annual mean SWS were homogeneous, and the SWS dataset in China was credible. Furthermore, the wind speed data used in this study was examined and calibrated by Chinese National Meteorological Information Center (NMIC). The quality control methods used by NMIC included the homogeneous test, the extreme test and the temporal consistent test.

In addition, according to the instruction of dataset, we found that there were 59 national standard meteorological stations were adjusted as the ordinary stations from 1991 to 2006, and the missing data was found in other 14 stations before 2000. In order to obtain a homogeneous wind speed record at each anemometer station, the above-mentioned 73 stations were removed from the total 653 stations. Finally, 580 stations were used in this study. The 580 stations used in this research were selected according to the following criteria: (1) It is a national standard meteorological station; (2) Wind speed data observed since 1970; (3) The station did not relocate in the study period; (4) The total days of missing data account for less than 1% of the length of total data series. The terrain height and 580 stations in China are shown in Fig. 1. Furthermore, this wind speed dataset was also used by Zha et al. (2017), who compared the spatio-temporal characteristics of SWS to that of the European Centre for Medium-Range Weather Forecasts Reanalysis from January 1989 onward (to be extended back to January 1979) (ERA-Interim) dataset, and revealed that the two wind speed datasets showed the consistent inter-annual and seasonal changes. Therefore, the SWS dataset used in this study is considered to be a credible dataset (CMA, 2003).

Typhoon track data during the period 1970–2011 obtained from the Joint Typhoon Warning Center (JTWC) was also used to removing the tropical cyclone data in the instrumental wind speed data. An affected station by typhoon was selected if it was enclosed within a circle with radius of 2° latitude and longitude centered at middle of the typhoon (Wu et al., 2016, 2017; Zha et al., 2016, 2017). To analyze the influences of different sized cities on the wind speed ranges, we classified the stations used the population size which based on the 2005 year for each city, 580 stations in China were further classified into large cities, medium cities and small cities by population size more than 1,000,000, between 500,000 and 1,000,000, and under 500,000, respectively (Wu et al., 2012). Some previous studies also pointed out that the population size was an effective indicator of urbanization, which was used to classify different city levels (Xu et al., 2006; Jiang et al., 2010; Guo et al., 2011). To focus on the difference in the rough underlying surfaces between different cities and to better highlight the impacts of different scale cities on SWS, the differences in SWS between 154 large cities and 255 small cities were predominantly discussed. The spatial distribution of the large city and small city stations are shown in Fig. 1.

2.2. Methods

According to the criteria of CMA, the SWS can be divided into 13 ranges (CMA, 2003), which includes five and eight ranges for SWS lower and higher than 8 m s^{-1}, respectively. The 13-range criterion is usually