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Potential transport pathways of dust emanating from the playa of Ebinur Lake, Xinjiang, in arid northwest China

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ABSTRACT

In this paper, the HYSPLIT model, driven with reanalysis meteorological data from 1978 to 2013, was used to understand the potential transport characteristics of dust and salt dust emanating from the playa of Ebinur Lake in arid northwest China. Daily air parcel trajectories were computed forward for 8 days from an origin centered over Ebinur Lake at 100 m above ground level. Air parcel trajectory density plots were mapped for seven levels: 0–100 m agl., 100–500 m agl., 500–1000 m agl., 1000–1500 m agl., 1500–2000 m agl., 2000–3000 m agl., and 3000–5000 m agl. These show that potential dust transport pathways have clear seasonal differentiation. The potential transport distance of dust and salt dust is greatest in spring and summer. In autumn and winter, the potential transport of the high-density air trajectory is below 1000 m traveling a shorter distance. Potential dust transport pathways showed notifying directivity in different seasons and heights. Southeast in spring and summer, and north to northeast in autumn and winter are the two main potential transport channels of dust and salt dust. Accordingly, dust and salt dust from the playa of Ebinur Lake may influence the atmospheric processes and biogeochemical cycles of a vast region. The main area of influence of dust and salt dust is close to the source area, and will significantly accelerate the melting of snow and ice in the Tianshan Mountains. This highlights the urgent need to combine remote sensing, isotope and other methods to further research the transport characteristics of dust and salt dust from the playa of the Ebinur Lake.

1. Introduction

The natural geographical environment shaped the unique lakes found in arid regions with different hydrology and ecology, compared with lakes in humid areas, which determine their sensitivity to climate change and human processes (Hu et al., 2007). As an important part of the regional water cycle, terminal lakes in arid regions constantly receive salt and nutrients through surface water and groundwater as a unique sink in the long evolution process. However, over the past decades, many terminal lakes have undergone drastic desiccation because of climate change and human processes, and Lop Nor on the eastern edge of the Tarim Basin of China (Li et al., 2008) and Hamoun Lakes in the Sistan Basin of Iran (Rashki et al., 2013) have even dried up. When this occurs, a playa is created, which is a dry waterlogged depression or a dry lake bed in an arid or semi-arid region with loose sediment of high salt content (Briere, 2000; Barth, 2001). This leads to the accumulation of evaporite salt minerals with the continuous evaporation of highly mineralized groundwater under the strong evaporation (Goudie and Wells, 1995). Wind abrasion of sediment of the playa results in frequent dust and salt dust storms, which severely endanger the ecological environment of lakes and adjacent areas (Micklin, 2007; Liu et al., 2011b).

Playas (dry lake beds) are widely distributed in the arid and semiarid areas of northwest China and Central Asia, where they are an important dust source. Examples include Lop Nur in the eastern Tarim Basin, Ebinur Lake (Abuduwaili and Mu, 2006) and the Manas Lake area in the Junggar Basin, Aiding Lake in the Turpan Basin (Wang and Wu, 2003), the Aral Sea (O'Hara et al., 2000; Baidya Roy et al., 2013), and Balkhash Lake (Bond et al., 1992) in Central Asia. The dust and salt dust storms formed by wind erosion of the playa contain a great deal of high-density and fine-particle sizes of sulfate, chloride, and heavy metal elements (Liu et al., 2011a). These will influence soil salinization, pose a serious threat to plants and animals, and accelerate ice melting after long-term suspension as aerosols in the atmosphere (Abuduwaili et al., 2010; Abuduwaili et al., 2015).

The playa is very small when compared with the main dust source, such as a desert, but it is more destructive because of the high salt content. Wind erosion of the playa of Ebinur Lake in the southwest of Junggar Basin has caused serious dust and salt dust hazards (Abuduwaili et al., 2008). Although not the dominant type of global

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dust, salt-rich dusts from playas may be important to the radiative properties of dust plumes, atmospheric chemistry, windborne nutrients, and human health (Reynolds et al., 2007). The role of salt-rich aerosol particles in atmospheric processes is important in bio-geochemical cycling, rain formation, climate research, and in the remote sensing of reflectance (Israelevich et al., 2002; Sreekanth, 2014). However, to date, little is known about the spatial transport pathways of dust and salt dust originating from the playa of Ebinur Lake. In this paper, we use a HYSPLIT model for the first time to provide new insights into the potentially seasonal transport characteristics of dust and salt dust emanating from the playa of Ebinur Lake. The present study may help to further understand the long range transport and deposition of dust and salt dust from the dry lake bed, as well as provide a motivation for the rational use and protection of arid terminal lakes.

2. Regional environments and salt dust hazards

Ebinur Lake basin lies in the southwest border region of the Junggar Basin (Fig. 1), in Xinjiang in arid northwest China. It is located at 43°48′–45°52′N, 79°88′–85°22′E with an area of 50,321 km^2, of which mountains, plains, and lakes account for 24,317 km^2, 25,762 km^2, and 542 km^2, respectively (Abuduwaili and Mu, 2006; Ma et al., 2014). The lowest water collection point of the basin is Ebinur Lake.

Ebinur Lake basin is surrounded by mountains on the southern, western, and northern sides, and connected to the plain of the Junggar Basin in the east (Fig. 1). The southern edge of the basin is the western part of the north Tianshan Mountains, namely the Borokhoro Mountain, with a ridge line at an altitude of 3500–3500 m. The highest peak at 5500 m above sea level is the highest point of Ebinur Lake basin. The Alatao Mountain, on the northern branch of the Tianshan Mountains, is located at the northwest end of this basin, where the highest peak is at an altitude of 4569 m. The northern side has the low Mayile Mountain with an altitude of 2609 m above sea level. Ebinur Lake is located in the middle of the basin, facing the 10-km wide valley between the Alatao and Mayile mountains in the northwest (a narrow pass 10–20 km wide and 50 km long between the Balkhash–Alakol Depression). The Ebinur Lake basin has a typical temperate continental climate characterized by lack of rain (precipitation 100–200 mm), and a strong evaporation capacity (potential evaporation 1500–2000 mm). The annual average wind (17 m/s or higher) occurs on 164 days, up to 185 days per year (Wu et al., 2009; Ma et al., 2011). Frequent dust and salt dust storms that match the special terrain are remarkable characteristics of this region.

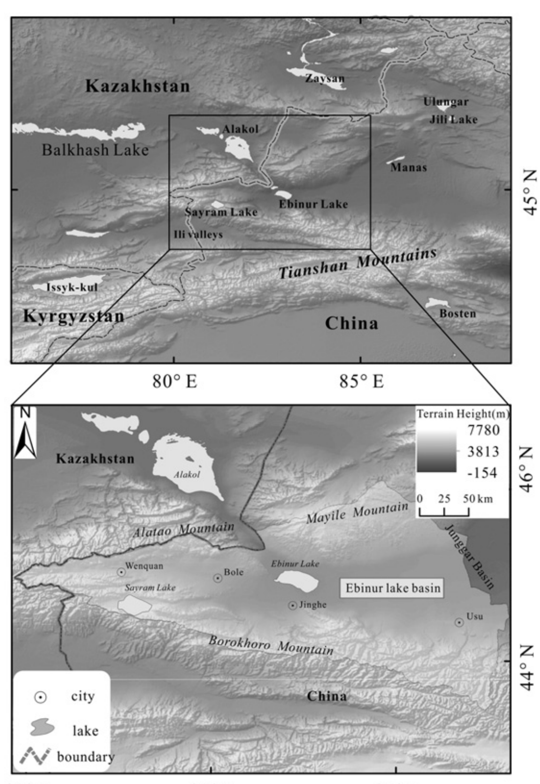

Fig. 1. Geographical location of the Ebinur Lake basin.

Since the 1950s, and especially after 1978, Ebinur Lake has shrunk dramatically in volume owing to climate change and human influence, leaving a saline playa greater than 500 km^2 (Mu et al., 2002). Millions of tons of dust and salt dust are emitted annually into the air from the playa (Abuduwaili and Mu, 2006). Winds from the northwest transport salt dust to the surrounding areas and the entire oasis economic zone on the northern slopes of the Tianshan Mountains, which has caused severe environmental issues and resulted in large economic losses.

3. Data and methods

The HYSPLIT model is a complete system for computing simple air parcel trajectories, as well as complex dispersion and deposition simulations (Stein et al., 2015). The initial development was a result of a joint effort between the Air Resources Laboratory of the National Oceanic and Atmospheric Administration and Australia's Bureau of Meteorology. The model has more complete functions of transport, dispersion, and settlement patterns processing a variety of meteorological factors, physical transport processes, and different types of emission sources (Draxler and Hess, 1998; Draxler et al., 1999; Draxler and Rolph, 2003; Rolph, 2016), and was widely used for the analysis of atmospheric pollutant transport (Wang et al., 2010; Alam et al., 2011; Escudero et al., 2011). The meteorological dataset from the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) global re-analysis was used to drive the HYSPLIT version 4.8 model to compute forward air trajectories beginning daily at 08:00 (Beijing Time) from Ebinur Lake. The forward trajectories were run from December 1978 when Ebinur Lake underwent a dramatic decrease in volume to November 2013. Seven levels (0–100 m agl. (above ground level), 100–500 m agl., 500–1000 m agl., 1000–1500 m agl., 1500–2000 m agl., 2000–3000 m agl., and 2000–5000 m agl.) were selected to analyze the trajectory pathways according to the method described in detail by McGowan and Clark (2008). Using clustering analysis in the HYSPLIT model, the potential transport paths of dust from the Ebinur Lake basin were analyzed, and the potential transport direction in different seasons and the proportion of the air parcel trajectories were estimated.

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite was launched in April 2006, which carries the dual polarization Lidar CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) sensor. CALIPSO is a two-wavelength polarization Lidar that performs global profiling of aerosols and clouds in the troposphere and lower stratosphere, and can observe the vertical distribution of aerosols in any terrain, in thin clouds, and clear sky conditions (Winker et al., 2003; Huang et al., 2008; Winker et al., 2009). The present study used CALIPSO data to verify the potential height.

4. Results

4.1. Potential transport pathways in spring (March–May)

Spring is the season with the greatest dust activity in the Ebinur Lake basin, as in many other arid and semi-arid places in northwest China (Liu et al., 2013; Huang et al., 2015) and Central Asia (Indoitu et al., 2012; Ge et al., 2016). The potential transport characteristics of the air parcel in Fig. 2 show that the highest density of trajectories is centered on the Ebinur Lake basin and the Tianshan Mountains in northwest