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Seasonal and diurnal variations in dust characteristics on the northern slopes of the Tien Shan – Grain-size, mineralogy, chemical signatures and isotope composition of attached nitrate

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ABSTRACT

A dust monitoring program was initiated in the summer of 2010 to (i) improve the informative value of aeolian components of varved lake sediments in Central Asia for palaeoclimatic interpretations, (ii) evaluate the impact of aeolian influx on modern lakes in the region and (iii) obtain data for a future comparison with dust east of the high mountain belt formed by the Alay, Pamir, Tien Shan and Altai mountains. We collected the coarse (>2.5 μm) dust fraction on the northern slopes of the Tien Shan 42°40′49.69″N, (74°41′37.36″E, 1740 m asl) using a high-volume slit-impactor at 3-day sampling intervals. We present data on the mineralogical composition, particle-size distribution, soluble salts and nitrate isotope composition of the collected dust. The short-term and seasonal changes in dust concentration and composition are discussed in the context of high temporal resolution measurements of meteorological parameters and particle counts for 31 grain-size bands.

Throughout the study period, $CaCO_3$ was a major dust constituent (average particle frequency 14%). Between July 2010 and October 2012, the average content of soluble salts was 10 wt.%; mole percentages of water-leachable anions were 60% NO_3, 30% SO_4, 10% Cl. Ca was the dominant leachable cation (>90%). The collected dust comprised (i) gypsum which forms pedogenically in the topsoils of arid regions and (ii) secondary gypsum originating from the interaction of sulphuric acid aerosols with $CaCO_3$ in the atmosphere. Variable proportions of (i) and (ii) and the extent of $Ca(NO_3)_2$ formation (verified by chemical mass budgets) were documented in the Ca/Sr and Ca/SO_4 ratios of the aqueous leachates.

The isotopic compositions of the dust nitrate in the majority of the samples clustered between −10 and +10‰ for $\delta^{15}N[NO_3]$ (VSMOW) and +50 and +100‰ for $\delta^{18}O[NO_3]$ (Air). The $\delta^{18}O[NO_3]$ values of a majority of the collected samples exhibited a weak positive correlation with the NO_3 load of the collected dust ($R^2 = 0.148$). The time series of the $\delta^{15}N[NO_3]$ values varied around a basement level of −6‰, which indicates that NO_x from mobile sources is a major precursor of the dust-NO_3. The distinct, positive departures from these values correlated with increases in the content of soot. We conclude that the related $\delta^{15}N[NO_3]$ peaks reflect increased NO_x contributions from coal burning. The possible origin of the dust was evaluated using satellite images and backward trajectory calculations for a few example monitoring intervals. Data synthesis in the context of hemispherical atmospheric circulation models, including the data for 2013, the results from ongoing chemical and isotope analyses of the non-soluble solid residues of the collected materials and the statistical handling of an extended data set will further elucidate the relationships involving atmospheric circulation, atmospheric dust load, dust sources and the characteristics of the study region.

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1. Introduction

The arid climate belt extending from the western Sahara to the deserts and semi-deserts of Central Asia and northern China is a major dust source for the entire Northern Hemisphere (e.g., Engelbrecht and Derbyshire, 2010). The study of natural archives of aeolian deposition, such as loess (e.g., Kukla, 1987; Tungsheng, 1988; Pye, 1995; Xiao et al., 1995; Vandenberghe et al., 2006; Roe, 2009), dunes (e.g., Grunert and Lehmkuhl, 2004), lacustrine sediments (e.g., Schettler et al., 2006; Zhu et al., 2013), marine sediments (e.g., Rea and Leinen, 1988; Nagashima et al., 2007) and ice cores (e.g., Biscaye et al., 1997; Mayewski et al., 1997) has the potential to yield information on palaeoclimatic changes related to (i) local environmental conditions, (ii) environmental changes in the source areas of the dust, (iii) changes in the hemispherical atmospheric circulation, (iv) changes in local wind strength and (v) variations in the local importance of wet and dry deposition of mineral aerosols.

An ongoing monitoring project running under the structural Global Change Observatory (GCO) program of the GeoForschungsZentrum Potsdam (GFZ) involves the investigation of annually laminated lacustrine sediment records from Kyrgyzstan and the sampling and analysis of dust. The integrated studies aim to improve the information value of aeolian components in lacustrine sediments regarding (i) the reconstruction of palaeoclimatic changes and (ii) the impact of the aeolian influx on the nutrient budget and general hydrochemical characteristics of lakes. The identification and analysis of the aeolian components in the retrieved sediment cores includes microscopic analyses to identify the seasonal character of the sedimentation and the analysis of the grain-size distribution of the silt fraction. Therefore, the sampling of mineral aerosols has focussed on the trapping of silt-sized particles in large quantities at a high temporal resolution for the purpose of a wide range of analytical determinations.

Our study complements monthly gravimetric monitoring of PM 2.5, elemental carbon, water-soluble organic carbon contents and organic species extracted from quartz-fibre filters as markers of the source of the anthropogenic organic dust fraction. This monitoring was performed at the eastern edge of Lake Issyk Kul (Teploklyuchenka) and at our monitoring site between July 2008 and July 2009 (Miller-Schulze et al., 2011). A few analytical data from previous projects on the grain-size distribution and mineralogical composition of dust collected at Teploklyuchenka are given in Adushkin et al. (2012). At both monitoring sites, the monthly PM 2.5 values varied around 10 $\mu g/m^3$. The organic matter contents of the collected dust ranged between 11 and 38%. Emissions from gasoline and diesel engines and from burning biomass are inferred to be major components of anthropogenic dust contamination (Miller-Schulze et al., 2011).

Here, we report the first results on (i) the dust mass concentration based on particle counting; (ii) the particle-size distribution; (iii) the mineralogical dust composition based on SEM–EDX analyses; (iv) the ionic composition of the water-soluble dust fraction and (v) the stable isotopic composition of nitrate. The dust was collected at 3-day sampling intervals at an altitude of 1740 m asl between July 2010 and December 2012. Changes in the atmospheric dust load at the ground-based monitoring station are discussed in the context of local meteorological monitoring data and changes in the hemispherical circulation (backward trajectory calculations). The presented data improve the relatively sparse knowledge on (i) the physico-chemical and nitrate isotope characteristics of dust, (ii) the seasonal changes in the atmospheric dust load and dust composition and (iii) the relationships between dust composition and dust sources at the northern margin of the Central Asian High Mountain Belt (cf., Formenti et al., 2011).

Debate is on-going regarding the substantial proportion of fine particles (fine silt and clay) in Chinese loess, which is widespread in China along a belt from the northern foothills of Kunlun Shan and Qinling Shan (Hexi Corridor), reaching its greatest thickness along the middle reaches of the Huang He on the Central Loess Plateau (Fig. 1a) (e.g., Tungsheng, 1988). Although there is broad consensus that (i) the deserts and semi-deserts of NW China which receive fluvial input from the high mountain areas represent the major source regions of the Chinese loess and (ii) the majority of the mineral aerosols is transported during seasonal dust storms to the loess accumulation areas, there is still debate about the substantial proportion of fine particles in the loess. In part, these fine particles may represent a 'background component' carried by the zonal westerlies over long distances (cf., Vandenberghe et al., 2006 and references therein) from source areas east of the high mountain belt of the Pamir, Alay, Tien Shan and Altai (Fig. 1a) towards Chinese loess accumulation areas or as far as the northern Pacific Ocean. However, polymodal particle-size distributions with substantial clay- and fine silt components have also been found in dust collected during dust storms (Qiang et al., 2010). A future comparison of our results with those obtained in similar studies on the Chinese mainland will help identify the postulated 'remote' dust component in the dust load over China and in natural dust archives east of the Central Asian High Mountain Belt.

2. Study region

2.1. Climate and meteorological conditions

The region of Central Asia that includes the territories of the republics Turkmenistan, Uzbekistan, southern Kazakhstan, Kyrgyzstan and Tadzhikistan is located in the interior of the Eurasian continent at a low latitudinal position within the temperate zone and is far from the oceans and surrounded by high mountain ranges along its southern margins (Fig. 1a). Remote air masses from the North Atlantic Ocean, the Mediterranean, Siberia and the Arctic origin reach the region. The air temperatures strongly decrease in winter and increase in summer due to the continental position of the region. During the winter, cold arctic air masses temporarily intrude into the region. These air masses are not blocked by high mountains in the western part of Central Asia and western Siberia. Cyclonic activity evolves along the western branch front of the 'Asian High' at temperate latitudes. In March and April, the cyclogenesis intensifies across the southern Caspian Sea, whereas in summer, it dislocates in the Pamir–Alay mountain range.

In summer, continental hot air masses, low cloud cover and dry weather conditions prevail which causes a strong heating of the soil surfaces of the desert and semi-arid lands that occupy large areas in the foreland of the high mountain ranges. The heating and the subsequent ascent of warm air favours the intrusion of air from outside the region. Because the region is most open to the north and west, surface airflow particularly originates from these areas. However, there is a considerable variety of air-flow and pressure patterns during all seasons because Central Asia is not an area of deeply developed pressure cells (Lydolph, 1977). Bugaev et al. (1957) classified 12 types of surface airflows and their frequencies for the summer and winter half years (Suppl. Fig. 1). The Caspian Sea influences the regional climate, whereas the influence of the Aral Sea is minor and mainly local in character.

2.2. Geographical and geological setting

The Tien Shan is an active intra-continental mountain belt that extends over 2500 km in the E–W direction across Central Asia.