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New inventory of dust sources in Central Asia derived from the daily MODIS imagery

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Abstract. This paper presents the first inventory of dust emission sources in Central Asia and western China (35-50ºN, 50-100ºE) derived from the twice daily MODIS imagery from 2003-2012. The high-resolution (1 km) dust enhancement product was generated and used to produce maps of dust point sources and gridded data sets of dust emission frequencies. The most active dust emissions were observed in the eastern part of the Tarim basin (Lop Nur salt lake) followed by the Aralkum. A high frequency of dust emissions was recorded in the regions which were not reported in literature to date: the upper Amudarya region in northern Afghanistan and the Pre-Aral region (from the Ustyurt Plateau to the Betpak Dala desert). Dust emissions were associated mainly with the fluvial features (dry river beds and lakes), agricultural activities and fire damage to vegetation. In the eastern and northern parts of the study region and in the Aralkum, dust emissions peaked in spring while in the western and southern parts, they peaked in summer. The Aralkum exhibited a consistent growth in the frequency and intensity of dust emissions and similar but weaker trends were observed in the Karakum and Kyzylkum.

1 Introduction

Deserts of Central Asian deserts are an important source of dust in the extra-tropical latitudes, where economic activity and health of millions of people are affected by dust storms. Although the significance of Central Asian dust sources were repeatedly highlighted in dust studies in global scale (e.g. [1-4]), only a few studies investigated the spatio-temporal distribution of Central Asian dust sources in detail (e.g. [5-7]). Studies considering larger areas used remote sensing products such as Atmopshric Optical Depth (AOD). While AOD is a useful indicator of the presence of dust in the atmosphere and enables detection of the dust-emitting regions, it does not provide detailed information on the location, activity and characteristics of dust sources because of the displacement of dust by atmospheric circulation. The previous studies, attempting to characterise sources of dust in Central Asia in more detail, relied on weather station records and dust deposition rates as the primary source of data and were hampered by the scarcity of meteorological stations, unaccessibility of many areas and difficulties in organising continuous sampling.

As a result, to date there was no detailed information about dust sources in Central Asia, land-surface properties resulting in dust emissions, and meteorological controls over the emissions. This lack of knowledge hampers our understanding of the dust cycle in Central Asia, dust storm and general meteorological forecast and land-use management. This paper presents the first large-scale inventory of dust emissions and dust sources in Central Asia and north-western China (35-50ºN, 50-100ºE) detected with high spatial resolution. It reports locations and characteristics of dust sources and analyses their spatial and temporal variations.

2 Data and methods

The data for this study were derived from analysis of the daily MODIS Terra and Aqua imagery for the 2003-2012 period. Both satellites are operating on the sun-synchronous, near-polar circular orbits and cross the equator at approximately 10:30 a.m. and 1:30 p.m. local time respectively.

While it is relatively easy to detect the mineral aerosols over ocean and water surfaces in true-colour satellite optical imagery, detecting dust over the land surface and particularly over the deserts using visible channels is difficult because of the similar reflectivity of mineral aerosol and the background desert surface in the visible part of the spectrum. This problem can be resolve using dust enhancement techniques. These techniques are based on brightness temperature difference (BTD) between the hot ground surface and cooler elevated dust plumes. We use a BDT technique reported in [8] for enhancing desert dust storms in MODIS L1B top-of-atmosphere (TOA) radiance data. Unlike traditional BTD binary results (dust/non-dust mask), this dust enhancement product (DEP) is a colour composite image, in which the dust is enhanced as shades of pink while clouds/land appear cyan/green. This allows a more accurate interpretation of the features in the scene, spatially over regions with complex surface reflectivity and the selected method showed a better performance in comparison to other dust enhancement techniques developed for MODIS [9]. The ability of DEP algorithm to separate dust and clouds is specifically useful for detection of dust in the higher latitudes where cloud contamination of the scene is more frequent than lower latitude dust source regions such as the Sahara and the Middle East.

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An example of a DEP image is presented Figure 1, comparing the visual appearance of dust in MODIS true-colour and in the DEP image. Dust plume, highlighted as pink in DEP images, can be clearly distinguished from other features of the scene, hence can be used to determine the location of dust point sources which contributed to dust plume formation.

Two DEP images were produced for each day from Terra and Aqua overpasses over the region. The approximately 3 hours time difference between the two satellite overpasses enabled the investigation of the development of individual dust plumes between the two snapshots and establishing locations of the eroding point sources at the head of each dust plume.

To identify and locate the dust producing areas within arid and semi-arid regions of Central Asia, we generated and visually inspected daily DEP images from the 2000-2012 period, located and recorded positions of Dust Point Sources (DPS) for every single dust outbreak that has occurred during this time period in this region and was visible on the MODIS imagery together with a range of meteorological variables. These data formed an inventory of dust emission sources in Central Asia which, for the first time, enabled characterisation of dust sources at the sub-basin scale, and investigation of temporal variability of their activation, surface characteristics of source regions, and synoptic conditions conducive to dust emission.

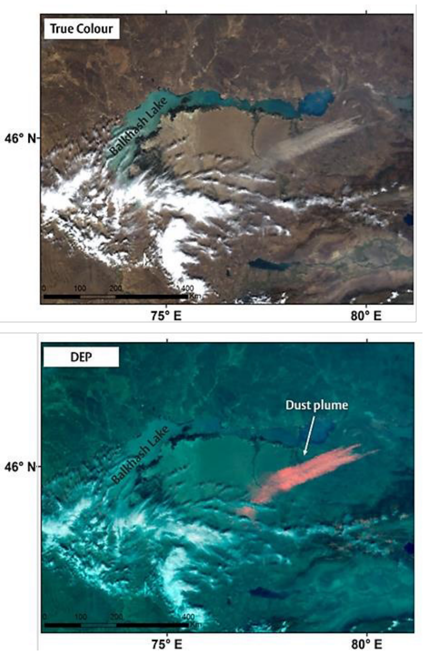

Figure 1. Comparison between MODIS true-colour and the DEP images for a dust event in the Lake Balkhash region, September 2006.

The DEP technique has a number of limitations. Firstly, false enhancement of dust was possible over cold terrain. This limitation was more prominent in winter and in the early morning observations [9]. Secondly, the temporal resolution of observations was relatively coarse in comparison with temporal resolution provided by the geostationary satellite data. Two images per day did not enable capture of dust outbreaks if either clouds were present or if the onset of dust emission was after the satellite overpass and the emission did not last long enough to be captured in the following day's observation. Thirdly, only the upwind dust point sources can be precisely located and any additional contributing sources lying under the dust plume could not be detected. To account for these limitations, all the detected dust point source (DPS) activations were rated and given 'Quality Flags' 1-3 whereby 1 corresponds to the most reliable data (no clouds or overpassing dust plumes on the imagery) to 3 whereby DPS could be detected but their visibility on the imagery was poor.

3 Results

The obtained positions of DPS were mapped and grouped into 12 regions on the basis of their location, characteristics, seasonal cycles and predominant land surface features (Figure 2).

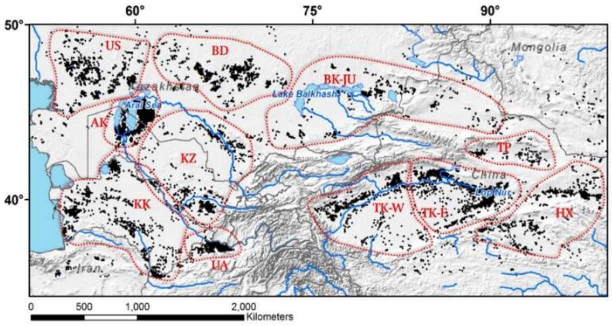

Figure 2. Distribution of DPS (shown as black dots) in Central Asia. The region acronyms stand for: Ustyurt Plateau (US), Betpak Dala desert (BD), Aralkum (AK), Kyzylkum (KZ), Karakum (KK), Upper Amudarya (UA), Balkhash and Junggar basins (BK-JU), Western Taklamakan desert (TK-W), Eastern Taklamakan (TK-E), Turpan depression (TP), and Hexi Corridor (HX). Background is shaded relief generated using GTOPO30 digital elevation model.

Analysis of spatial distribution of the DPS records showed that there is a clear link between the fluvial systems and concentration of DPS records, in particular in the Tarim basin, where the majority of DPS were detected along the floodplains of the Tarim River in northern margins of the Taklimakan desert. The same pattern was apparent in the Karakum-Kyzylkum region, with high density of observed DPS along the fluvial plains of the Amudarya and Syrdarya rivers. A large number of DPS were also associated with the major alluvial fans in the region such as those formed at the outlet of the Murghab, Tedzhen and Balkh rivers.

To further investigate the spatial distribution of the detected DPS, DPS were gridded over a one degree grid covering the study area. A number of DPS per grid box and number of days with DPS in a grid box (dusty days) were calculated. The most active sources were located in the eastern part of Tarim basin, where the average number of dusty days exceeded 50 per year. To the east of the Tarim basin, several active dust sources were detected along the Hexi (Gansu) Corridor. The strong alternating easterly and westerly winds were often channelled

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thorugh this narrow passage between the mountains deflating dust particles from numerous fluvial pans. Importantly, a very small number of DPS were identified in the southern margins of the Taklamakan desert which featured as an active source of dust in the previous assessments based on the analysis of AOD [1, 2]. This false detection resulted from the accumulation of transported dust over the southern part of the Taklamakan where atmospheric dust was banked up against the mountains [10, 11].

The second most active region was the Aralkum with over 30 dusty days per year in the central part of the dry lake bed. The dry surface of the former Aral Sea is a well-known human made desert which is becoming the dominant source of dust storms in the region. A lower but still significant number of dusty days were recorded in the south-western Aralkum, where active sources extend along the channel of the Dry River Uzboy, which over 800 years ago, flew from the Sarygamysh Lake towards the Caspian Sea, carrying water surcharge from Aral Sea and western branches of Amudarya River to the eastern coasts of Caspian Sea [12]. The upper Amudarya region in northern Afghanistan (UA in Figure 2) is another very active dust source region that experienced a high number of dust outbreaks and which was not previously discussed in literature.

Agricultural activities are believed to be the main contributor to dust emissions from the southern Kyzylkum. In particular, the occurrence of numerous DPS correlates well with land areas under dryland farming in Samarkand region, Uzbekistan. Poor farming techniques can leave the ground vulnerable to wind erosion, especially if the storms strike at a particularly vulnerable time, e.g. the fallowing period when vegetation cover is minimum [13].

Strong links between extensive degradation of vegetation, caused by wild fire episodes in the Pre-Aral and Balkhash regions, and increasing number of DPS records were uncovered.

Analysis of dust emission events showed that the northern and eastern regions as well as the Aralkum experience different seasonal cycle of dust emissions in comparison with the western and southern regions. In the Taklamakan, emissions occur throughout the year but their frequency starts increasing in February, peaks in March and April and gradually falls during the following months until October. In the Balkhash and Junggar basins, as well as Turpan depression, there was very little or no dust activity in January and February due to permanent snow cover, but as snow covers disappeared both regions become very active in March and April. On the other hand, dust sources in the Hexi Corridor, which is located further south, are active during the cold months but remarkably inactive between June and October.

Apart from the Aralkum desert, maximum number of dusty days in all source regions in the western part of Central Asia occured in summer. The months, in which the maximum number of dusty days were recorded, varied. Dust emission in the Upper Amudarya region peaked in June, whereas in the Betpak Dala, Ustyurt, Kyzylkum and Karakum they peaked in August and September. In the Aralkum (Figure 3), the maximum number of dust events occurred in April and May, with more than 70 dusty days in each month during the ten year time period (Fig. 3). The intensity of dust storms was also highest in these months. This result contrasts the previous studies which suggested that dust activities peak in Central Asia in summer [1; 6; 14].

An increase in the number of dusty days was observed in the Aralkum during the study period from 18 in 2004 to more than 60 in 2012 in line with the rapid desertification in the eastern Aralkum following the separation of the two parts of the Aral Sea in 2005. A drop in the number of dusty days in 2011 was probably linked to the temporary rehabilitation of the eastern lake in 2010. A small but statistically significant increase in dust activity was registered in the Karakum-Kyzylkum region.

In other regions, there were no significant trends in the frequency of dust emissions between 2003 and 2012 but most were characterized by inter-annual variability resulting from varying meteorological conditions, agricultural activities and fire activity.

4 Discussion and conclusions

This analysis revealed several previously unidentified or under-reported aspects of dust storm formation in Central Asia, which can be summarized as follows:

(1) Aralkum has become one of the most important sources of dust in Central Asia where a marked increase in dust emission, evident from the AOD and DPS data, occurred in the 2003-2012 period. With the prevailing dust transport towards the populated regions of western Asia and the Caspian in the west, dust emissions from this region can potentially affect not only ecosystems but human well-being. Detailed modelling of dust transport from this region is required and knowledge of dust source locations will be an important input to the future modelling studies.

(2) We found a very high density of DPS in the Aralkum and the Upper Amudarya region, compared to other dust source regions. The Upper Amudarya region was highlighted as an important source of dust for the first time by this study with more than 10 DPS per 1000 km^2.

(3) A number of other regions, previously overlooked in literature, were identified as significant sources of dust, most importantly the Pre-Aral region encompassing the Ustyurt Plateau and the Betpak Dala desert.

(4) Fire has had a significant effect on developing dust emitting surfaces in the Pre-Aral and Balkhash regions. Nearly 80% of dust sources in these regions were characterized by the strong degradation of vegetation cover due to wildfire events.

(5) A distinctive shift was noted in the location of dust hotspots obtained from the analysis of DPS in comparison to the use of AOD observations. This highlighted an important drawback of the methods based on the estimations of atmospheric dust loading, such as MODIS AOD [1] and TOMS Aerosol Index [2; 15]. The latter methods tend to identify dust sources incorrectly based on the presence of transported dust in the atmosphere. This artefact was more pronounced over areas affected by strong winds such as the Aralkum, where transported dust

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led to detection of very active dust sources away from the dry lakebed or the southern Taklamakan where topography forces the accumulation of dust in the atmosphere.

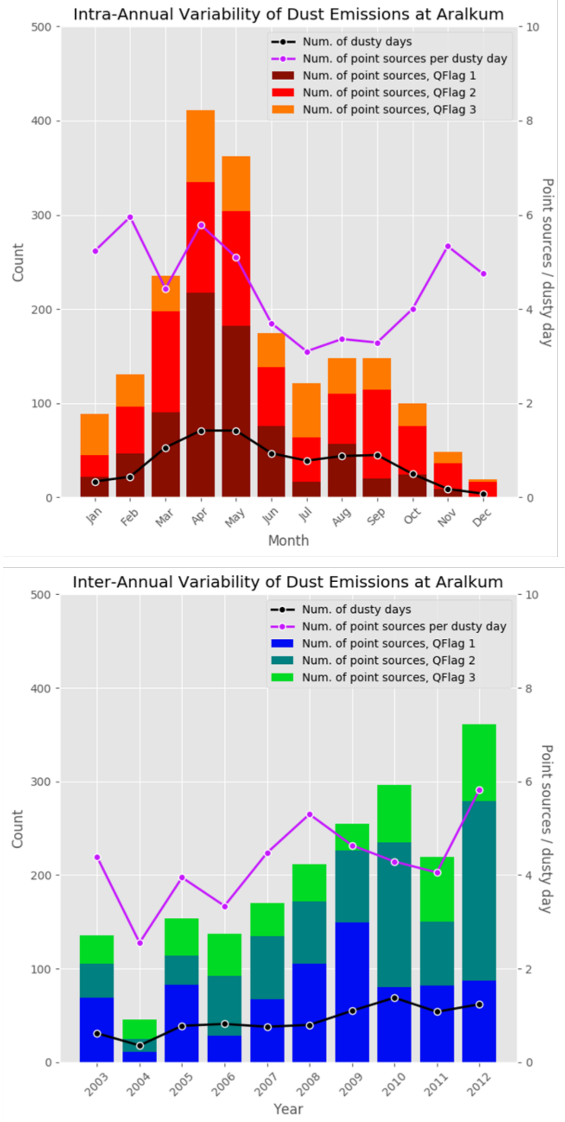

Figure 3. Inter-annual and intra-annual variation in dusty days and DPS in the Aralkum.

References

1. Ginoux, P., Prospero,J.M., Gill, T. E., Hsu, N.C., Zhao, M., Rev. Geophys., 50, 1-36 (2012)
2. Prospero, J.M., Ginoux, P., Torres, O., Nicholson, S.E., Gill, T.E., Rev. Geophys., 40, 2-1-2-31 (2002)
3. Goudie, A.S. Prog. Phys. Geog. 7, 502-530 (1983)
4. Middleton, N., Goudie, A.S., Wells, G., Aeolian Geomorphology, ed. W. G. Nickling, 237-259 (1986)
5. Indoitu, R., Kozhoridze, G., Batyrbaeva, M., Vitkovskaya, I., Orlovskiy, N., Blumberg, D., Orlovsky, L., Aeol. Res., 17, 101-115 (2015)
6. Groll, M., Opp, C., Aslanov, I., Aeol. Res., 9, 49-62 (2013)
7. Orlovsky, L., Orlovsky, N., Durdyev, A. J., Arid Environ.,60, 83-97 (2005)
8. Miller, S.D., Geophys. Res. Lett., 30 (20), 2071 (2003)
9. Walker, A.L., Liu, M., Miller, S.D., Richardson, K.A., Westphal, D.L., JGR, 114, D18207 (2009)
10. Rittner, M., Vermeesch, P., Carter, A., Bird, A., Stevens, T., Garzanti, E., Ando, S., Vezzoli, G., Dutt, R., Xu, Z., and Lu, H., EPSL, 437, 127-137 (2016)
11. Uno, I., Harada, K., Satake, S., Hara, Y., Wang, Z. J., Met. Soc. Japan, 83 (3), 219-239 (2005)
12. Velichko, A., Spasskaya, I., The Physical Geography of Northern Eurasia, ed. M. Shahgedanova (2002)
13. Gillette, D.A., Passi, R.J., Geophys. Res., 93(D11), 14,233–14,242 (1988)
14. Orlovsky, L., Dourikov, M., Babaev, A., J. Arid Environ., 56, 579-601 (2004)
15. Washington, R., Todd, M., Middleton, N.J., Goudie, A.S., Ann. Assoc. Amer. Geog. 93, 297-313 (2003)