Comments from anonymous Referee #1

Major comments

Question 1: The title of the paper is "Dust deposition and ambient PM_{10} concentration in central Asia: Spatial and temporal variability", while the paper only focus on Xinjiang province, China. However, the Central Asia is generally referred to the core region of the Asian continent which usually including Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan in the modern context. The title of the paper, therefore, should be reconsidered regarding study region and avoid possible confusion.

Reply: We have revised the paper to indicate that Xinjiang Province is located in east Asia. While Xinjiang Province is technically located at the western fringe of east Asia, the geography of the Province is very similar to central Asia. The title has been changed to "Dust deposition and ambient PM_{10} concentration in northwest China: Spatial and temporal variability".

Question 2: In the Introduction, the author cites Simonson (1995) and Pye (1987) to show that dust plays an important role in climate change and environmental quality. The paper cited here, which is published in 1990s and relatively outdated. Since then, the dust deposition data have been enriched, as listed in the Table.1. What is the current circumstance of dust deposition research? What is still unknown? I would suggest author include more recent paper in this field to strengthen the introduction section.

Reply: New citations have been added to the Introduction to support the discussion of the importance of dust in climate change and environmental quality. Citations added to the Introduction include:

Chen, S., Huang, J., Zhao, C., Qian, Y., Leung, L. R., and Yang, B.: Modeling the transport and radiative forcing of Taklimakan dust over the Tibetan Plateau: A case study in the summer of 2006, J. Geophys. Res. Atmos., 118, 797–812.

Chen, S., Zhao, C., Qian, Y., Leung, L. R., Huang, J., Huang, Z., Bi, J., Zhang, W., Shi, J., Yang, L., Li, D., and Li, J.: Regional modeling of dust mass balance and radiative forcing over East Asia using WRF-Chem, Aeolian Res., 15, 15–30.

Huang, J., T. Wang, W. Wang, Z. Li, and H. Yan, 2014: Climate effects of dust aerosols over East Asian arid and semiarid regions, Journal of Geophysical Research: Atmospheres, 119, 11398–11416, doi:10.1002/2014JD021796.

Huang, J., Fu, Q., Su, J., Tang, Q., Minnis, P., Hu, Y., Yi, Y., and Zhao, Q.: Taklimakan dust aerosol radiative heating derived from CALIPSO observations using the Fu-Liou radiation model with CERES constraints, Atmos. Chem. Phys., 9, 4011–4021, doi:10.5194/acp-9-4011-2009, 2009.

Lin, Y., and Feng, J.: Aeolian dust contribution to the formation of alpine soils at Amdo (Northern Tibetan Plateau), Geoderma, 259-260, 104-115, doi:10.1016/j.geoderma.2015.05.012, 2015.

Shao Y P.: Physics and modeling of wind erosion, Dordrecht, Kluwer Academic Publishers, 225-278, 2000.

Varga, G., Cserháti, C., Kovács, J., and Szaliai, Z.: Saharan dust deposition in the Carpathian

Basin and its possible effects on interglacial soil formation, Aeolian Research, 22, 1-12, doi:10.1016/j.aeolia.2016.05.004, 2016.
Zheng, Y., Zhao, T., Che, H., Liu, Y., Han, Y., Liu, C., Xiong, J., Liu, J., and Zhou, Y.: A 20-year simulated climatology of global dust aerosol deposition, Science of The Total Environment, 557-558, 861-868, doi:10.1016/j.scitotenv.2016.03.086 , 2016.

Question 3: The paper did not provide any discussion regarding dust source for deposition and PM_{10} in this region and thus the analysis was based on the unstated assumption that the only two dust sources are Taklimakan desert and Gurbantunggut desert. However, this might not be the case all the time, since long-range transport of dust from central Asia could also contribute to the dust deposition in Xinjiang province, despite the two large local dust sources. Without the analysis of dust source in the first place, the attempt to explain the spatial and temporal characteristic of dust deposition and ambient PM_{10} seems unwarranted. I would recommend the authors give a brief discussion of dust sources in the revised manuscript.
Reply: A brief discussion on dust sources in central and east Asia has been added to Section 3.4 (page 6) to include the following: Deserts in central Asia are a source of atmospheric mineral dust (Miller-Schulze et al., 2015). Under the strong westerly circulation, atmospheric dust can be transported a few hundred kilometers to the east and be deposited through wet scavenging and dry settling (Shao, 2000; Chen et al., 2014). Despite the Taklimakan and Gurbantunggut Deserts being local sources of dust in Xinjiang Province, long-range transport of dust from the central Asian Aralkum, Karakum, Caspian and Kyzylkum Deserts (Indoitu, et al., 2012) could also contribute to the dust deposition and ambient PM_{10} concentration in neighboring Xinjiang Province. Since the 1980s, the Aralkum Desert in Uzbekistan and Kazakhstan has become one of world's youngest deserts and a potential source of salt dust in east Asia (Indoitu, et al., 2012; Groll, et al., 2013; Opp, et al., 2016).

Question 4: In this study only one factor are considered and examined in Section 3.4, which is dust days, while the subtitle of the section mentioned "factors." Although dust event might be of the dominant factor, other factors should also be taken in account or at least be mentioned in the analysis. For instance, it is widely recognized that the wind speed and direction could be very influential to dust transport. In the manuscript, although data of wind speed and direction is mentioned in the section 2.2(Line 31), the analysis regarding this data was not provided in the manuscript. In addition to the wind, precipitation could also be a controlling factor. Further analysis of the other factors should also be provided in the manuscript.
Reply: We have considered precipitation and wind speed as climatic factors affecting PM_{10} concentration and dust deposition. The linkage between precipitation and wind speed and PM_{10} concentration and dust deposition are discussed in first and second paragraph of Section 3.4 in revised manuscript.

Minor comments

Question 1: Page 1, Line 17 : : :(particulate matter 10 m in aerodynamic diameter): : : Please rephrase the sentence in the parentheses.
Reply: Revised as "particulate matter in aerodynamic diameter ≤10 μm".

Question 2: Page 1, Line 26-27 : : :The arid climate likely influenced the high dust deposition and PM_{10} concentration in the region: : : This sentence is uncorroborated by the manuscript.
Reply: This sentence was deleted.

Question 3: Page 1, Line 29 This study suggests that sand storms are a major factor affecting: : : Please change "are" to "is".
Reply: This sentence was revised as "This study suggests that sand storm is a major factor affecting the temporal variability and spatial distribution of dust deposition in northwest China."

Question 4: Page 2, Line 7-8: An understanding of atmospheric dust sources, emissions, and deposition is therefore essential to improve regional air quality. This sentence is not logically related to the information given before it. The discussion prior to it can't lead to the conclusion that this kind understanding can be helpful to improve regional air quality.
Reply: This sentence was revised as "An understanding of atmospheric dust sources, emissions, and deposition is therefore essential to improve our knowledge of dust impact on regional air quality".

Question 5: Page 2, Line 30 : : : that spans the 21st century. The sentence is overstated, since only 2000-2013 was analyzed in the study, which certainly did not span 21st century.
Reply: The description of "that spans the 21st century" has been deleted.

Question 6: Page 3, Line 31 Daily meteorological data, including surface wind speed and direction
: : : Even though the surface wind speed and direction are mentioned in the data description, the analyses relating to them are not given in the manuscript.
Reply: This sentence was revised as "Daily meteorological data including dust days, surface wind speed and precipitation, were collected from the China Meteorological Administration". We do include information regarding wind speeds in Section 3.4.

Question 7: Page 5, Line 2 This industrial belt includes Changji and Urumqi. High dust deposition in the industrial belt was due to industry, coal burning and vehicle exhaust. This explanation is possible, with the anthropogenic source of dust is considered. Please further strengthen this conjecture with relevant papers. In addition to the Changji and Urumqi, Hami, which is also a city located in northern Xinjiang, also had a high dust deposition value as depicted in Figure.2. Why?

Reply: We revised it as "This industrial belt includes Changji and Urumqi. High dust deposition in the industrial belt was due to local industry, coal burning and vehicle exhaust (Matinmin and Meixner, 2011; Zhang et al., 2014b). Therefore, the mixing of the anthropogenic aerosol with transported desert dust contributed to deposition in Changji and Urumqi (Li, et al., 2008)."

New references have been included in this section as:

Li, J., Zhuang, G., Huang, K., Lin, Y., Xu, C., and Yu, S.: Characteristics and sources of air-borne particulate in Urumqi, China, the upstream area of Asia dust, Atmospheric Environment, 42(4), 776-787, doi:10.1016/j.atmosenv.2007.09.062, 2008.

Mamtimin, B., and Meixner, F.: Air pollution and meteorological processes in the growing dryland city of Urumqi (Xinjiang, China), Science of the Total Environment, 409, 1277-1290, doi:10.1016/j.scitotenv.2010.12.010, 2011.

Zhang, X.X., Chen, X., Guo, Y.H., Wang, Z.F., Liu, L.Y., Paul, C., Li, S.Y., and Pi, H.W.: Ambient TSP concentration and dustfall variation in Urumqi, China, Journal of Arid Land, 6(6), 668-677, doi:10.1007/s40333-014-0069-6, 2014b.

Hami is located in eastern Xinjiang Province. The city has a population of over 0.5 million and lacks industry characteristic of Changji and Urumqi. The high dust deposition at Hami is due to dust storms originating in the Turpan Depression, not industry.

Question 8: Page 6, Line 17 .. data suggest that particulate matter is the main air pollutant in Xinjiang. The PM_{10} constituent accounted for 48.7% and 48.2% of the API in the Kuytun and Urumqi. It is necessarily suggest the particulate matter is the main air pollutant?

Reply: Yes! We re-checked the API daily data of the six selected stations (see section 3.3). "The PM_{10} constituent accounted for 48.7%, 78.4%, 96.2%, 91.5%, 99.5%, and 99.6% of the API in the respective above cities." As for Kuytun, excellent air quality (API<50) accounted 51.3% (Fig.8), therefore, particulate matter is the main air pollutant.

Question 9: Page 6, Line 31—Page 7, Line 1-11 This decline in dust deposition or PM_{10} concentration could be due to a decrease in frequency of severe dust days versus frequency of dust days from 2000 to 2013 in the region: : :. Nevertheless, in examining the relationship between average annual dust days and dust deposition or PM_{10} concentration across stations, the frequency of dust days was closely related to dust deposition (R^2=0.93) (Fig.10) and ambient PM_{10} concentration (R^2=0.89) (Fig.11). There was a significant 10 increase in dust deposition (7.91 t km^{-2} day^{-1}) and PM_{10} concentration (2.06 g m^{-3} day^{-1}) associated with an increase in dust days. In this paragraph, the relationship between dust deposition/PM_{10} concentration and dust day frequency at each station is investigated. The result, admittedly, is evident show there is a connection. According to the definition of different dust days, which can be found in section 2.2(page4, line1-5), blowing dust and dust storm constitutes days in which

dust is emitted at the station, while dust-in-suspension constitutes days in which dust is not emitted at the station. However, the scatter plot fails to distinguish the inherent difference between these three dust events. Moreover, since the dust is not emitted at this station during dust-in-suspension days, the conclusion given by author, that there appeared to be a close association between frequency of dust-in-suspension events and dust deposition, become unconvincing.
Reply: We examined trends in dust-in-suspension, blowing dust, and dust storms from 2000-2013. Note that there was no trend in blowing dust or dust storms from 2000 to 2013. Over this same time period, there was a significant decrease in frequency of dust-in-suspension. Although we did not show these trends in the paper, the trend for fewer dust-in-suspension coincides with the decline in dust deposition and PM_{10} concentration from 2000 to 2013. Based upon similarity in trends, there appeared to be some connection between dust-in-suspension and dust deposition.

Question 10: In page 10, Figure 2, please add units for dust deposition in the legend within the figure. In page 17, Figure 5, please add units for PM_{10} concentration in the legend within the figure.
Reply: We added units for dust deposition and PM_{10} concentration in Figure 2 and Figure 5 in revised manuscript.

Comments from anonymous Referee #2

Question 1: P. 2, l. 10-11: The authors motivate their study by stating that Pye (1987) suggested a lack in reliable dust deposition data. This reference is almost 30 years old. I would suspect that more data has been collected since. In fact, the authors list several newer references for data on dust deposition in their Table 1. In my opinion a more comprehensive overview and discussion on currently available dust deposition data is needed.

Reply: We have revised the paper with a more comprehensive overview and discussion on currently available dust deposition data in the Introduction (Page 2, Line 11-25). New citations have been added to the Introduction to support the above discussion. Citations added to the Introduction include:

Duce, R.A., Liss, P.S., Merrill, J.T., Atlas, E.L, Buat-Menard, P., Hicks, B.B., Miller, J.M., Prospero, J.M., Arimoto, R, Church, T.M., Ellis, W., Galloway, J.N., and Hansen, L.: The atmospheric input of trace species to the world ocean, Global Biogeochem. Cycles, 5, 193-259, doi: 10.1029/91GB01778 , 1991.

Ginoux, P., Chin, M.. Tegen, I., Prospero, J.M., Holben, B., Dubovik, O., and Lin, S.: Sources and distributions of dust aerosols simulated with the GOCART model, Journal of Geophysical Research, 106(17), 20255-20273, doi: 10.1029/2000JD000053, 2001.

Ginoux, P., Prospero, J.M., Gill, T.E., Hsu, N.C., and Zhao, M.: Global-scale attribution of anthropogenic and natural dust sources and their emission rates based on MODIS Deep Blue aerosol products, Reviews of Geophysics, doi: 10.1029/2012RG000388, 2012.

Huneeus, N., Schulz, M., Balkanski, Y., Griesfeller, J., Prospero, J., Kinne, S., Bauer, S., Boucher, O., Chin, M., Dentener, F., Diehl, T., Easter, R., Fillmore, D., Ghan, S., Ginoux, P., Grini, A., Horowitz, L., Koch, D., Krol, M. C., Landing, W., Liu, X., Mahowald, N., Miller, R., Morcrette, J.J., Myhre, G., Penner, J., Perlwitz, J., Stier, P., Takemura, T., and Zender, C. S.: Global dust model intercomparison in AeroCom phase I, Atmos. Chem. Phys., 11, 7781-7816, doi:10.5194/acp-11-7781-2011, 2011.

Mahowald, N.M, Kohfeld, K.E., Hansson, M., Balkanski, Y., Harrison, S.P., Prentice, I.C., Michael, S., and Rodhe, H.: Dust sources and deposition during the last glacial maximum and current climate: a comparison of model results with paleodata from ice cores and marine sediments, J. Geophys. Res. 104, 15895-916, 1999.

Mahowald, N.M., Engelstaedter, S., Luo, C., Sealy, A., Artaxo, P., Benitez-Nelson, C., Bonnet, S., Chen, Y., Chuang, PY., Cohen, DD., Dulac, F., Herut, B., Johansen, A.M., Kubilay, N., Losno, R., Maenhaut, W., Paytan, A., Prospero, JM., Shank, L.M., and Siefert, R.L.: Atmospheric iron deposition: global distribution, variability, and human perturbations, Annu. Rev. Marine. Sci, 1, 245-278, doi: 10.1146/annurev.marine.010908.163727, 2009.

Prospero J.M.: Long-range transport of mineral dust in the global atmosphere: impact of African dust on the environment of the southeastern United States, Proc. Natl. Acad. Sci. 96, 3396-3403, doi: 10.1073/pnas.96.7.3396, 1999.

Zhang, X.Y., Arimoto, R., and An, Z.S.: Dust emission from Chinese desert sources linked to variations in atmospheric circulation, 102(D23), 28041-28047, doi:10.1029/97JD02300, 1997.

Question 2: P. 2, l. 25-26: What are the processes governing dust emissions, transport,

and deposition in Asia? And what data was used by Shao et al. (2011) and Groll et al. (2013) as the basis of their findings (note that the reference should be Shao et al. (2011) rather than Shao (2011))? I think these questions need more attention in the paper, especially to support interpretation of the spatial and temporal variability observed in Xinjiang Province. How is the data presented in the manuscript on hand different/better than the data used in earlier studies? What drives the trends and spatial variability? These questions appear mostly unanswered in the present paper.
Reply: The Eurasian atmospheric circulation is governing dust emissions, transport, and deposition in central Asia. Compared with earlier studies, the data presented in this manuscript were observed at 14 environmental stations in Xinjiang, northwest China during 2000-2013 with a monthly temporal resolution, which would be helpful to improve our knowledge of dust impact on regional air quality. The 14-year continuous deposition data was collected according to Chinese national standards, which fills the gap in the central Asian arid region where observations are scarce. The atmospheric circulation such as cyclones (Shao et al., 2013) primarily drives and influences the trends and spatial variability of dust deposition and ambient PM_{10} concentration. We added this discussion in Section 3.4.

Question 3: Are the 14 environmental monitoring stations the same as the air-quality monitoring stations where the API is obtained from?
Reply: Yes, the 14 environmental monitoring stations are the same as the air-quality monitoring stations where the API is obtained from.

Question 4: P. 4, l. 3: "Dust-in-suspension constitutes days: : :". Present weather reports refer to the time of observation, not to the whole day. What category is used for a day in p. 7, l.4 if the 3-hourly data shows two different reports on the same day, e.g. blowing dust and dust in suspension? The authors have chosen to not show the results of their present weather report analysis (p. 7, l. 6). However, it would be interesting to see the outcome and compare to earlier studies using a similar method (see first reference in my comment 8).
Reply: We used the most severe dust category if two or more observations were made on a single day. For example, if both blowing dust and dust in suspension were observed at one meteorological station during a single day, we categorized this event as a blowing dust day. A comparison of our method to methods used in earlier studies is provided in Fig. S1 (in the Supplement).

Question 5: P. 5, l. 2: It is stated that high dust depositions in the industrial belt were caused by "industry, coal burning and vehicle exhaust". What are the underlying references or data used to support this statement? Or is this a hypothesis? Does the API data used later in the paper provide any evidence in that regard?
Reply: We revised the text as "This industrial belt includes Changji and Urumqi. High dust deposition in the industrial belt was due to local industry, coal burning and vehicle exhaust (Matinmin and Meixner, 2011; Zhang et al., 2014b). Therefore, the mixing of the anthropogenic aerosol with transported desert dust contributed to

deposition in Changji and Urumqi (Li, et al., 2008)."

Both Fig. 2 and 8 (API data used later in the paper) provide evidence that dust deposition in Changji and Urumqi is due to industry or vehicles.

New references have been added to this section as:

Li, J., Zhuang, G., Huang, K., Lin, Y., Xu, C., and Yu, S.: Characteristics and sources of air-borne particulate in Urumqi, China, the upstream area of Asia dust, Atmospheric Environment, 42(4), 776-787, doi:10.1016/j.atmosenv.2007.09.062, 2008.

Mamtimin, B., and Meixner, F.: Air pollution and meteorological processes in the growing dryland city of Urumqi (Xinjiang, China), Science of the Total Environment, 409, 1277-1290, doi:10.1016/j.scitotenv.2010.12.010, 2011.

Zhang, X.X., Chen, X., Guo, Y.H., Wang, Z.F., Liu, L.Y., Paul, C., Li, S.Y., and Pi, H.W.: Ambient TSP concentration and dustfall variation in Urumqi, China, Journal of Arid Land, 6(6), 668-677, doi:10.1007/s40333-014-0069-6, 2014b.

Question 6: P. 5, l. 31: Based on their data, the authors "suggest a positive relationship between dust deposition and PM_{10} concentration". This is to be expected as - apart from wet scavenging through precipitation – dust deposition is caused by gravitational settling and turbulent diffusion. Both processes are dependent on dust concentration, i.e. the higher the dust concentration, the higher the dust deposition. I think a more detailed discussion of the observation results on the basis of the physics underlying dust deposition would be needed here. Correspondingly, I would suggest to present dust deposition as a function of PM_{10} concentration in Fig.7 (and discuss results accordingly) rather than vice versa.

Reply: We have briefly discussed the physics of dust deposition in Section 3.2 in the revised manuscript (Page 6, Line 9-16). Moreover, we changed the x-axis and y-axis of Fig. 7 to present dust deposition as a function of PM_{10} concentration, and added discussion in this section.

Question 7: P. 6, l. 20-21: The authors state that "weather appears to be a dominant factor" driving dust concentration and deposition in arid regions. This is very vague and only very few details are discussed in the following. It seems clear that atmospheric and land-surface conditions are decisive for local dust entrainment and that atmospheric flow determines dust transport. A more detailed discussion of the predominant regional circulations in Xinjiang province would also help interpretation of the spatio-temporal variability of dust deposition in the area.

Reply: A more detailed discussion of the predominant regional circulation in Xinjiang province has been added in Section 3.4 (Page 7, Line 5-9) to interpret the spatio-temporal variability of dust deposition in the study area.

Question 8: Section 3.4: How do the results obtained in this paper (e.g. trends) compare to earlier studies on dust variability in central Asia (see for example Shao et al. (2013, doi:10.1002/jgrd.50836) and Xi and Sokolik (2015, doi:10.1002/2015JD024092)). I think more consideration need to be given to previous works, even though they might not deal with the exact same area.

Reply: The results obtained in this paper are based on the measurement from observation, which reflect the regional dust characteristics. The high PM_{10} concentration in 2001 and 2002 over study region (Fig. 6) is in accordance with Shao et al. (2013) as described “years of high dust activities in east Asia”. Moreover, the decreasing trend of PM_{10} concentration and dust deposition in the study is consistent with Shao et al. (2013) as described “declining dust activities in east Asia since the late 1970s”.
Further consideration of earlier studies has been given, and we added the following citations to the discussion section:

Shao, Y., Kolse, M., and Wyrwoll, K.: Recent global dust trend and connections to climate forcing, Journal of Geophysical Research, doi: 10.1002/jgrd.50836, 2013.

Xi, X., and Sokolik, I.N.: Dust interannual variability and trend in Central Asia from 2000 to 2014 and their climatic linkages, Journal of Geophysical Research, doi: 10.1002/2015JD024092, 2015.

Question 9: P. 7, l. 19-20: “These results suggest that dust source[s] in central Asia affect regional air quality and [are] a potential contributor of global dust.” Other studies (e.g. Shao et al., 2011, doi: 10.1016/j.aeolia.2011.02.001, and references therein; Huneeus et al., 2011, doi: 10.5194/acp-11-7781-2011; Ginoux et al., 2012, doi: 10.1029/2012RG000388) have shown that some of the world’s major dust sources are located in central Asia. Please rephrase the statement so that it becomes clear in what way the present results support earlier findings, and it what way they may differ.
Reply: In above papers by Shao et al., 2011; Huneeus et al., 2011; and Gnioux et al., 2012; they suggested that uncertainty in dust deposition is an important problem in current research because of a limited number of observations. This uncertainty severely influences the accurate estimation from models. Our observation confirmed that the study area is a potential dust source region as described by Shao, et al. (2011) and Ginoux et al. (2012). We rephrase the statement in the Conclusion (Page 8, Line 19-21).

Question 10: P. 7, l. 31: “: : :this work can aid in adjusting model parameters: : :”. While measured dust depositions can certainly be used to evaluate dust model outputs, it does not seem that this is a direct follow-up on the present manuscript or an objective of this study. In my opinion, this work can rather – if further detailed discussions are added – support understanding of dust deposition along with its spatio-temporal variability in the study area (of course this could then also support model development and evaluation in the future) and I would suggest to motivate the paper as such.
Reply: We’re now preparing the next manuscript of modeling on dust deposition in the study area.

Dust deposition and ambient PM_{10} concentration in ~~central Asia~~northwest China: Spatial and temporal variability

Xiao-Xiao Zhang[1, 2], Brenton Sharratt[3], Xi Chen[1], Zi-Fa Wang[2], Lian-You Liu[4], Yu-Hong Guo[2], Jie Li[2], Huan-Sheng Chen[2], and Wen-Yi Yang[2]

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Abstract. Aeolian dust transport and deposition are important geophysical processes which influence global bio-geochemical cycles. Currently, reliable deposition data are scarce in central and east Asia. Located ~~in~~at the ~~eastern part~~boundary of central and east Asia, Xinjiang Province of northwestern China has long played a strategic role in cultural and economic trade between Asia and Europe. In this paper, we investigated the spatial distribution and temporal variation in dust deposition and ambient PM_{10} (particulate matter ~~≤10 µm~~ in aerodynamic diameter ≤10 µm) concentration from 2000 to 2013 in Xinjiang Province. This variation was assessed using environmental monitoring records from 14 stations in the province. Over the 14 years, annual average dust deposition across stations in the province ranged from 255.7 to 421.4 t km^{-2}. Annual dust deposition was greater in southern Xinjiang (663.6 t km^{-2}) than northern (147.8 t km^{-2}) and eastern Xinjiang (194.9 t km^{-2}). Annual average PM_{10} concentration across stations in the province varied from 100 to ~~156~~196 µg m^{-3} and was 70, 115 and 239 µg m^{-3} in northern, eastern and southern Xinjiang, respectively. The highest annual dust deposition (1394.1 t km^{-2}) and ambient PM_{10} concentration (~~582~~352 µg m^{-3}) were observed in Hotan which is located in southern Xinjiang and at the southern boundary of the Taklamakan Desert. Dust deposition was more intense during the spring and summer than other seasons. PM_{10} was the main air pollutant that significantly influenced regional air quality. Annual average ~~ambient PM_{10} concentration~~ dust deposition increased logarithmically with ~~dust deposition~~ ambient PM_{10} concentration ($R^2 \geq 0$.~~88). The arid climate likely influenced the high dust deposition and PM_{10} concentration in the region.~~81). While the annual average dust storm frequency remained unchanged from 2000 to 2013, there was a positive relationship between dust storm days and dust deposition and PM_{10} concentration across stations. This study suggests that sand ~~storms are~~storm is a major factor affecting the temporal variability and spatial distribution of dust deposition in ~~central Asia~~northwest China.

Key words: Dust deposition; PM_{10}; Desert; Atmospheric environment; ~~Central~~East Asia

1 Introduction

Airborne dust generated by aeolian activity is an environmental concern in central and east Asia (Huang et al., 2011; Chen et al., 2014). Historically, aeolian activity and airborne dust influenced civilization along the ancient Silk Road which connected Asia and Europe (Zhang, 1984; Dong et al., 2012; Groll et al., 2013). Today, airborne dust is recognized as a factor affecting global radiation and warming (Stanhill, 2005; Carslaw et al., 2013; IPCC, 2013; Huang et al., 2009; Chen et al., 2013; Huang, et al., 2014) and air quality in distant lands (Tsoar and Pye, 1987; Xu et al., 2007; Uno et al., 2009; Li et al., 2012). Deposition of airborne dust also plays a significant role in soil formation and biological diversity in arid and semi-arid regions (Simonson, 1995~~).~~; Lin and Feng, 2015; Varga et al., 2016). An understanding of atmospheric dust sources, emissions, and deposition is therefore essential to improve our knowledge of dust impact on regional air quality.

Dust in the atmosphere and its subsequent deposition are vital indicators of aeolian activity and environmental quality. ~~Pye (1987) indicated that~~Deposition has been measured directly at only a few sites, therefore, reliable dust deposition data are lacking around the world~~.~~ (Pye, 1987; Mahowald, et al., 1999; Prospero, 1999; Mahowald, et al., 2009; Zhang et al., 2010; Huneeus et al., 2011; Shao et al., 2011). Annual dust deposition ranges from 10 to 200 t km^{-2} on continents and one to two orders of magnitude lower over oceans (Pye, 1987~~).~~; Duce et al., 1991; Ginoux, et al., 2001; Ginoux, et al., 2012). It's estimated that annual average dust deposition rate upon desert areas ranged between 14-2100 t km^{-2} (Zhang, et al., 1997). Observations of dust deposition have been made over deserts with an enhanced awareness of its significance. Table 1 lists observations of dust deposition in desert regions and other regions of the world prone to aeolian activity. High dust deposition occurs in Asia, with an annual deposition of 8365 t km^{-2} in the Aral Sea Basin (Wake and Mayewski, 1994; Groll et al., 2013). ~~Shao~~Ginoux et al. (2001) compared dust deposition at 16 sites with simulation result, predicted the annual global dust deposition was approximately 1842 megatons. Shao et al. (2011) estimated that over 2000 megatons of dust is emitted from the Earth's surface into the atmosphere annually~~.~~, and participates with global biogeochemical cycle. Zheng et al. (2016) estimated that annual average global dust deposition was approximately 1161 megatons. Recent investigations suggest that dust deposition during one dust storm can be 10 to 25 times higher than the annual average (Liu et al., 2004; Goudie, 2014). However, uncertainties remain in estimating the dust deposition budget of the earth system because of the lack of observational data and inaccuracies of parameters in numerical simulations (Ginoux et al., 2001; Huneeus et al., 2011; Shao et al., 2011; Ginoux, et al., 2012; Zhang et al., 2014a).

Located in east Asia and at the ~~eastern part~~boundary of central Asia, Xinjiang Province of northwestern China has long played a strategic role in cultural and economic trade between Asia and Europe. Xinjiang Province experiences severe sand and dust storms and is highly susceptible to desertification (Chen, 2010). Xinjiang Province is one of two major source regions of atmospheric dust in China, the other region being western Inner Mongolia (Xuan, 1999; Xuan et al., 2000). Long-range transport of dust from the region strongly affects air quality in ~~eastern~~east Asia (Derbyshire et al., 1998; Uno et al., 2009). In fact, dust from the region can be transported across the Pacific Ocean and thus impact air quality in North America (Husar et al., 2001; Osada et al., 2014). Indeed, particulate matter associated with dust transport can severely deteriorate air quality (Sharratt and Lauer, 2006; Shoemaker et al., 2013). Over the past decades, many observations have been made of processes that govern dust emissions, transport, and deposition in Asia (Shao~~,~~ et al., 2011; Groll et al., 2013). Little is known, however, concerning dust deposition and concentrations in Xinjiang Province. In fact, temporal and spatial variations in dust deposition and concentration have not been characterized despite the importance of dust transport from the region. To improve our understanding of the fate and transport of airborne dust in central and east Asia, there is a need for continuous and long-term records of dust deposition and concentration. The purpose of this study is to characterize the spatiotemporal distribution of dust deposition and particulate matter concentration in Xinjiang Province~~ that spans the 21st century.~~. This characterization will strengthen our comprehension on aerosol transport in ~~central~~east Asia and provide aerosol data for modelling dust transport in global desertification regions.

2 Methods

2.1 Study area

Xinjiang Province is located in northwest China and is the largest inland province which covers an area of more than 1.6 million km^2 (Fig. 1). The Taklamakan and Gurbantunggut Deserts are located in the province. The Taklamakan Desert, located in the southern region, is the world's largest shifting-sand dune desert. The Gurbantunggut Desert, located in the northern region, is the largest fixed-dune desert in China. The province is in part characterized by extreme aridity and aeolian desertification. The average annual precipitation varies from more than 700 mm in high-altitude forests and mountains to less than 50 mm in the deserts. Annual potential evaporation can exceed 2000 mm in desert regions (Chen, 2010). Sand and dust storms occur throughout the year, but are most common in spring. In this study, the province was divided by latitude and longitude into three regions, those being northern Xinjiang, eastern Xinjiang and southern Xinjiang (Table 2).

2.2 Experimental Data

Dust deposition and PM_{10} concentration were measured at environmental monitoring stations maintained by the Xinjiang Environmental Protection Administration, a division of the Ministry of Environmental Protection (MEP) in China. Data collected at 14 stations (Fig. 1 and Table 2) were used in this study and represent a spatial distribution within this region.

Dust deposition was determined by the gravimetric method and documented at monthly intervals. Glass cylinders were used to monitor dust deposition. Three cylinders (replicates) were installed to monitor dust deposition at each station. The cylinders (0.15 m in diameter, 0.3 m tall, and open at the top) were partly filled with an ethylene glycol ($C_2H_6O_2$) – water solution prior to deployment. The solution enabled trapping of dust in a liquid media at temperatures below 0°C and also minimized evaporation from the cylinder. Cylinders were mounted vertically on a tower at approximate 10 m above ground. The mass of dust collected by the cylinders was determined after washing the contents out of the cylinders and oven-drying the contents at 105℃. Dust deposition rate was calculated as the mass of dust per unit area per unit time and expressed in units of t km^{-2} mon^{-1} (MEP, 1994). Monthly and yearly dust deposition data were available through the MEP for the 14 stations from 2000-2013.

Ambient PM_{10} concentration was measured with high volume samplers designed to collect particulate matter by filtration. The samplers were installed at 1.5 m above the ground and equipped with fiberglass filters for trapping PM_{10}. PM_{10} concentration was determined based upon gravimetric filter analysis and flow rate of each sampler. Daily PM_{10} concentration data were obtained by the arithmetic mean of four samplers with the sampling time being >18 h for each sampler. PM_{10} was expressed in μg m^{-3} (MEP, 2011). Annual PM_{10} data were available through the MEP for the 14 stations (Xinjiang Statistical Bureau, 2014).

Daily meteorological data, including dust days, surface wind speed and direction and dust daysprecipitation, were collected from the China Meteorological Administration. A dust day was defined by visibility according to World Meteorological Organization protocol; days in which visibility was <10 km at any observation time throughout the day constituted a dust day. The World Meteorological Organization further classifies dust days as dust-in-suspension, blowing dust, and dust storms (Shao and Dong, 2006). Dust-in-suspension constitutes days in which dust is not emitted at the station at the time of observation and visibility is <10 km, blowing dust constitutes days in which dust or sand is emitted at the station and visibility is 1-10 km, and dust storms constitutes days in which dust or sand is emitted at the station and visibility is <1 km. Observations of visibility and wind characteristics at each station were taken at 3 hour intervals throughout the day.

Daily air pollution index (API) data were obtained from air quality monitoring statistics published by the MEP (http://datacenter.mep.gov.cn). These data were used to illustrate the impact of airborne dust versus other air pollutants on air quality. The API is calculated according to the daily concentration of three main air pollutants (U.S. EPAUSEPA, 2006; Wang et al., 2013), namely PM_{10}, SO_2 and NO_2. The API is calculated as:

$$API=\max(API_i), \quad (1)$$

$$API_i = \frac{API_u - API_L}{C_u - C_L} \times (C_i - C_L) + API_L, \quad (2)$$

Where API_i is the index for pollutant i (i.e., PM_{10}, SO_2, and NO_2), API_u and API_L are the upper and lower limits of the index for a specific category of air quality (i.e. excellent, slight, moderate, moderately severe, and severe), C_i is the observed concentration of pollutant, and C_u and C_L are the upper and lower limits of the pollutant for a specific category of air quality. Information regarding the determination of the API index can be obtained from the MEP (MEP, 2012a, 2012b). Based on the API, air quality was classified as: excellent with an API of 0 to 50, slight pollution with an API of 50 to 100, moderate pollution with an API of 100 to 200, moderately severe pollution with an API of 200 to 300, and severe pollution with an API of 300 to 500. For the purpose of this study, we used only API data collected in 2010 since annual deposition and PM_{10} concentration appeared to typify that which occurred between 2000 and 2013 in eastern, northern, and southern Xinjiang Province.

Temporal trends in dust deposition, PM_{10} concentration and dust days were evaluated by testing the significance of the slope estimate using a t test at a probability level (P-value) of 0.05.

3 Results and discussion

3.1 Dust deposition

Detailed information on dust deposition during 2000-2013 was obtained from 14 environmental monitoring stations (Table 2). Annual average dust deposition across all stations in Xinjiang Province was 301.9 t km^{-2}. The highest annual deposition occurred in Hotan and Kashgar in southern Xinjiang while the lowest deposition occurred in Karamay in northern Xinjiang. Based upon spatial characteristics in annual dust deposition, deposition increased from north to south across the province (Fig. 2). The annual average dust deposition was 147.8, 194.9 and 663.6 t km^{-2} in northern, eastern and southern Xinjiang, respectively. Generally, the origin of mineral dust could be attributed to both natural and anthropogenic sources (Miller-Schulze et al., 2015). Although dust deposition was relatively low (<150 t km^{-2}) for the majority of stations in northern Xinjiang Province, dust deposition was at least 50% higher for stations within the industrial belt on the northern slope of the Tianshan Mountains. This industrial belt includes Changji and Urumqi. High dust deposition in the industrial belt was due to local industry, coal burning and vehicle exhaust. (Matinmin and Meixner, 2011; Zhang et al., 2014b). Therefore, the mixing of the anthropogenic aerosol with transported desert dust contributed to deposition in Changji and Urumqi (Li, et al., 2008). Figures 3 and 4 depicted the temporal variation in dust deposition from 2000-2013. The highest annual deposition occurred in 2012 in southern Xinjiang, 2002 and 2012 in eastern Xinjiang, and 2001 in northern Xinjiang. Over the 14 year period, dust deposition varied with time across Xinjiang Province. The slope estimate of the relation between average dust deposition and year (-6.4±0.1 t km^{-2} yr^{-1}) was significant at $P=0.05$. This trend was most apparent in northern Xinjiang (slope estimate was -5.6±0.1 t km^{-2} yr^{-1}) and least apparent in southern Xinjiang (slope estimate was -1.9±0.1 t km^{-2} yr^{-1}). High dust deposition occurred in spring in eastern and northern Xinjiang and in spring and summer in southern Xinjiang (Fig. 4). Dust deposition peaked in April in eastern and northern Xinjiang and in May in southern Xinjiang. This corresponds to the onset of wind erosion caused by intensifying zonal flow and rising air temperatures before the arrival of the summer monsoon (Song et al., 2016). The maximum monthly average dust deposition was 97.5 t km^{-2} in southern Xinjiang, which was 6.9 and 8 times more than the deposition in northern and eastern Xinjiang, respectively.

3.2 PM_{10} concentration

The annual average PM_{10} concentration in Xinjiang was 125 μg m^{-3} based upon data collected at 14 stations from 2000-2013. Ten stations (71 percent) in our study had an annual average PM_{10} concentration above the People's Republic of China Class II residential standard of 70 μg m^{-3}. The highest annual average PM_{10} concentration (~~582~~352 μg m^{-3}) occurred in Hotan in southern Xinjiang while the lowest average PM_{10} concentration (46 μg m^{-3}) occurred in Tacheng in northern Xinjiang. The annual average PM_{10} concentration appeared to increase from northern to southern regions (Fig. 5). Annual average PM_{10} concentration in Xinjiang ranged from 100 to ~~156~~196 μg m^{-3} (Fig. 6) across years. The annual average PM_{10} concentration was 70, 115 and 239 μg m^{-3} in northern, eastern and southern Xinjiang, respectively. The high annual concentration in southern Xinjiang is of the same magnitude as found in other desertification regions of the world such as South Asia, Middle

East, and western Sahel desert (WHO, 2015). These high concentrations of suspended particulates, especially finer particulate, may influence the health of sensitive populations who are susceptible to respiratory illness (Goudie, 2014).

Over the period of record (2000-2013), there was a trend for decreasing PM_{10} concentration in Xinjiang Province. The slope estimate of the relation between annual PM_{10} concentration and year (-4.2±0.1 μg m^{-3} yr^{-1}) was significant at P=0.05. This trend was most apparent in southern Xinjiang (slope estimate was -11.8±0.1 μg m^{-3} yr^{-1}). On the contrary, PM_{10} concentration appeared to increase with time in eastern and northern Xinjiang (slope estimates were 1.3±0.1 μg m^{-3} yr^{-1} and 3±0.1 μg m^{-3} yr^{-1}, respectively). The slope estimate, however, was not statistically different from zero and indicated no apparent trend in PM_{10} concentration with time in northern Xinjiang. A decrease in both dust deposition and PM_{10} concentration over 2000 to 2013 suggests a positive relationship between dust deposition and PM_{10} concentration. This relationship is supported by data in Fig. 7. Dust particles are delivered back to the surface by both dry and wet deposition (Shao, 2000). In arid and semi-arid region of central Asia, the deposition process is mainly dominated by dry deposition because of less precipitation, which is comprised of gravitational settling, turbulent diffusion and molecular diffusion (Zhang and Shao, 2014; Xi and Sokolik, 2015). Those physical processes from the air to surface are complex and dependent on dust concentration with a representation of the higher the dust concentration, the higher the dust deposition (Slin and Slin, 1980; Wesely and Hicks, 2000; Petroff, et al., 2008; Zhang et al., 2014a). Fig. 7 showed that dust deposition significantly increased with high PM_{10} concentration above 200 μg m^{-3}. A logarithmic function fit the data better than a linear function, suggesting that changes in atmospheric PM_{10} concentration are smaller at higher rates of deposition with a correlation coefficent $R^2 \geq 0.81$. This trend could be due to deposition of larger or more massive particles under more severe dust or sand storms. While PM_{10} concentration may rise under more severe wind erosion events, the limited supply of PM_{10} in sand (major soil type in the province) will likely suppress a rise in PM_{10} concentration in the atmosphere under more severe erosion events. Nevertheless, from 2000 to 2013, the decline in both dust deposition and PM_{10} concentration across Xinjiang could be due to less frequent or intense dust storms because dust deposition in major cities of northern China was found to be closely related to the frequency of sand and dust storms (Zhang et al., 2010).

3.3 Influence of atmospheric dust deposition on local air quality

Daily ambient air quality has been reported by MEP since 2000. Airborne dust is one of three pollutants influencing the API, thus the relative contribution of dust to the API was of interest. Accordingly, we made a comparative analysis to identify the impact of airborne dust on air quality in Urumqi and Kuytun in northern Xinjiang, Turpan and Hami in eastern Xinjiang, and Kashgar and Hotan in southern Xinjiang (Fig. 8). In 2010, there were 178, ~~176,~~ 286, ~~346~~351, 334, 363, and ~~363~~360 days in which PM_{10} was the main constituent of the API in Kuytun, Urumqi, Turpan, Hami, Kashgar and Hotan, respectively (Fig. 8). The PM_{10} constituent accounted for 48.7%, ~~48.2%,~~ 78.4%, ~~94.8~~96.2%, 91.5%, 99.5%, and 99.~~5~~6% of the API in the respective above cities. These data suggest that particulate matter is the main air pollutant in Xinjiang. Severe PM_{10} pollution (API >300) occurred mainly in spring, which was closely associated with the seasonality of strong winds and dust storm activity (Li et al., 2004). Stations in southern Xinjiang (Kashgar and Hotan) had higher API's caused by elevated PM_{10}

concentrations throughout the year. This can be attributed to the violent and persistent eaolian activity around the Taklamakan Desert (Pi et al., 2014). Consequently, PM_{10} is an important pollutant which dominates ambient air quality in Xinjiang.

3.4 Factors influencing dust deposition and PM_{10} concentration

Many factors influence ambient particulate concentration and dust deposition, but weather appears to be a dominate factor in arid regions (Zhang et al., 1996; Zhang et al., 2010). The Eurasian atmospheric circulation greatly affects weather in central Asia (Kang, et al., 2013). Strong winds associated with this atmospheric circulation cause large amounts of dust to be emitted into the atmosphere.In fact, dust activity is highly correlated with variability in global climate and atmospheric circulation (Gong, et al, 2006; Mao et al., 2011; Shao et al., 2013). The Eurasian atmospheric circulation greatly affects weather in central and east Asia (Zhang et al., 1997; Kang, et al., 2013; Xi and Sokolik, 2015). Dust activities are primarily driven by the strength of cyclone and the Siberian High affecting the study region (Park, et al., 2011; Shao et al., 2013). Strong winds associated with this atmospheric circulation cause large amounts of dust to be emitted into the atmosphere. Deserts in central Asia are an important source of atmospheric mineral dust (Miller-Schulze et al., 2015). Under the strong westerly circulation, atmospheric dust can be transported a few hundred kilometers to the east and be deposited through wet scavenging and dry settling (Shao, 2000; Chen et al., 2014). Despite the Taklimakan and Gurbantunggut Deserts being local sources of dust in Xinjiang Province, long-range transport of dust from the central Asian Aralkum, Karakum, Caspian and Kyzylkum Deserts (Indoitu, et al., 2012) could also contribute to the dust deposition and ambient PM_{10} concentration in neighbouring Xinjiang Province. Since the 1980s, the Aralkum Desert in Uzbekistan and Kazakhstan has become one of world's youngest deserts and a potential source of salt dust in east Asia (Indoitu, et al., 2012; Groll, et al., 2013; Opp, et al., 2016).

Climate also directly influences the atmospheric environment of arid and semi-arid areas (Wei et al., 2004; Zu et al., 2008; Huang et al., 2014). The annual average precipitation in north, east and south Xinjiang is 237, 94, and 87 mm, respectively. Dust emission was negatively correlated with precipitation (Gong, et al., 2006). Therefore, the lack of precipitation contributes to dust emissions. In fact, regions with lower precipitation have higher PM_{10} concentrations and dust deposition in Xinjiang Province. Daily average wind speed in north, east and south Xinjiang is 2.5, 2.2, and 1.8 m s^{-1}, respectively. In contrast to precipitation, regional differences in wind speed fail to account for differences in PM_{10} concentrations and dust deposition.

Spatial differences in dust deposition and PM_{10} concentration across Xinjiang Province may also be due in part to differences in frequency of dust days in the region. Dust storms normally occurred in all seasons in southern Xinjiang. The magnitude of wind erosion and dust day frequency in southern Xinjiang is nearly twice as large as in northern and the eastern Xinjiang (Wang et al., 2006). Figure 9 displays the variation in dust day frequency in Xinjiang Province from 2000 to 2013. The data indicate that the annual average frequency of dust days fluctuated from 15 to 52 days. The frequency of dust days in the southern region ranged from 41 to 133 days while the frequency of dust days in eastern and northern regions ranged from 2-

45 days and 0-3 days, respectively, across years. The slope estimate of the relationship between dust days and years (0.11 day yr^{-1}) indicated no apparent trend for an increase or decrease in dust days from 2000 to 2013. Thus, despite no temporal trend in dust days, we observed a decline in dust deposition and PM_{10} concentration across years. This decline in dust deposition or PM_{10} concentration could be due to a decrease in frequency of severe dust days versus frequency of dust days from 2000 to 2013 in the region. We are unaware of any previous study which has examined dust day severity in Xinjiang Province, thus we used data available through the China Meteorological Administration to assess trends in dust day severity. Dust days were characterized according to dust-in-suspension, blowing dust, and dust storm events. Although there was no trend in the frequency of blowing dust and dust storm events from 2000 to 2013, there was a trend for fewer dust-in-suspension events from 2000 to 2013 (~~data not shown).~~Fig. S1 in the Supplement). Thus, there appeared to be a close association between frequency of dust-in-suspension events and PM_{10} concentration and dust deposition. Nevertheless, in examining the relationship between average annual dust days and dust deposition or PM_{10} concentration across stations, the frequency of dust days was closely related to dust deposition (R^2=0.93) (Fig.10) and ambient PM_{10} concentration (R^2=0.89) (Fig.11). There was a significant increase in dust deposition (7.91 t km^{-2} day^{-1}) and PM_{10} concentration (2.06 µg m^{-3} day^{-1}) associated with an increase in dust days.

4 Conclusions

The atmospheric environment of central and east Asia is severely affected by the airborne dust, thus this study was undertaken to quantify dust deposition and ambient PM_{10} concentration in ~~the region~~east Asia. Data collected at 14 environmental monitoring stations from 2000-2013 in Xinjiang Province, China confirmed that annual average dust deposition ranged from 255.7 to 421.4 t km^{-2}. Annual average PM_{10} concentration varied from 100 to ~~156~~196 µg m^{-3}. The highest dust deposition was observed in Hotan in the southern Taklamakan Desert with 1394.1 t km^{-2}, which is ten times that in China's Loess Plateau (Liu et al., 2004). The highest ambient PM_{10} concentration was also observed in Hotan with ~~582~~352 µg m^{-3}, which far exceeds the World Health Organization's long-term exposure standard (WHO, 2014). These observation results provide a concrete evidence on the study area as "dust region" described by Shao et al. (2011) and Ginoux et al. (2012), and suggest that dust source in ~~central~~east Asia affect regional air quality and is a potential contributor of global dust. The spatial distribution and temporal variability in dust deposition and ambient PM_{10} concentration showed significant variation and a trend for lower deposition and concentration with time. The inner-annual dynamic of dust deposition varied significantly with seasonality. Spring and summer had the highest dust deposition (1.3 times the average), followed by autumn and winter. The highest intensity of dust deposition was observed in May, followed by April, June and July.

In dust source areas such as Xinjiang, China, windblown sand and dust affect air quality, especially during the spring season. The analysis of the data indicated no trend in frequency of dust days from 2000 to 2013. A positive relationship existed, however, between dust days and dust deposition as well as airborne PM_{10} concentration across stations. The effect of weather on dust deposition and ambient air quality cannot be expressed by a simple correlation and should not be extrapolated based on the currently limited evidence. This study provides information on the potential spatial-temporal dust deposition and ambient dust aerosol variation in ~~central~~east Asia. Although longer term datasets are needed to address trends over longer time periods, this work can aid in adjusting model parameters in simulating dry dust deposition or PM_{10} concentration in desertification regions of ~~central~~east Asia.

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Tables

Table 1. Observations of dust deposition in desertification regions.

Continent	Location	Period	Dust deposition t km^{-2} yr^{-1}	Citation
America	Kansas, USA	1964-1966	53.5-62.1	USDA (1968)
	New Mexico, USA	1962-1972	9.3-125.8	Gile and Grossman (1979)
	Arizona, USA	1972-1973	54	Péwé (1981)
Europe	Spain	2002-2003	17-79	Menéndez et al. (2007)
Africa	Nigeria	1976-1979	137-181	McTainsh and Walker (1982)
	Niger	1985	164-212	Drees et al. (1993)
	Libya	2000-2001	420	O'Hara et al. (2006)
Oceania	Australia	2000-2001	5-100	Cattle et al. (2009)
Asia	Israel	1968-1973	57-217	Yaalon and Ganor (1975)
	Kuwait	1982	2600	Khalaf and Al-Hashash (1983)
	Saudi Arabia	1991-1992	4704	Modaihash (1997)
	Lanzhou, China	1988-1991	108	Derbyshire et al. (1998)
	Loess Plateau, China	2003-2004	133	Liu et al. (2004)
	Urumqi, China	1981-2004	284.5	Zhang et al. (2010)
	Iran	2008-2009	72-120	Saeid et al. (2012)
	Uzbekistan	2003-2010	8365	Groll et al. (2013)

Table 2. Dust deposition and PM_{10} concentrations at 14 stations in Xinjiang.

No.	Station	Region*	Latitude	Longitude	Population** (million)	Annual dust deposition (t km^{-2})	Annual PM_{10} concentration (μg m^{-3})
1	Urumqi	NJ	43.832°N	87.616°E	2.26	229.4	141
2	Changji	NJ	44.017°N	87.308°E	0.36	295.7	76
3	Shihezi	NJ	44.306°N	86.080°E	0.62	107.7	61
4	Bole	NJ	44.900°N	82.071°E	0.27	133	48
5	Karamay	NJ	45.580°N	84.889°E	0.29	81.1	54
6	Tacheng	NJ	46.691°N	82.952°E	0.17	84.9	39
7	Yining	NJ	43.912°N	81.329°E	0.53	142.7	78
8	Kuytun	NJ	44.426°N	84.903°E	0.30	108.1	66
9	Hami	EJ	42.818°N	93.514°E	0.48	209.8	84
10	Turpan	EJ	42.957°N	89.179°E	0.28	180.1	145
11	Korla	SJ	41.727°N	86.174°E	0.57	231.8	131
12	Hotan	SJ	37.113°N	79.922°E	0.33	1394.1	352
13	Kashgar	SJ	39.471°N	75.989°E	0.57	516.9	236
14	Aksu	SJ	41.170°N	80.230°E	0.51	511.5	238

* Xinjiang Province was classified into three regions: northern Xinjiang (NJ), eastern Xinjiang (EJ), and southern Xinjiang (SJ).

**Population in 2013 as reported by the Xinjiang Statistical Bureau.

Figures

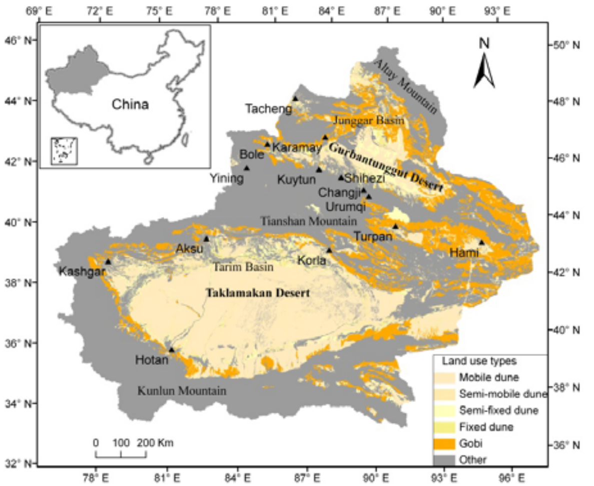
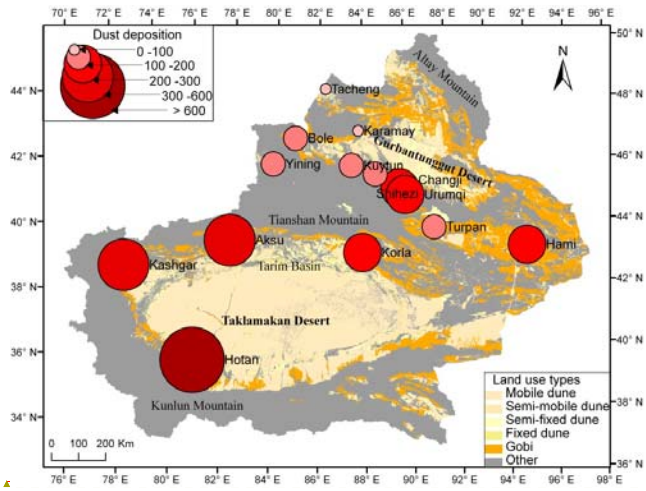


Figure 1. Location of Xinjiang Province in China (gray area outlined on inset map). Dust deposition and concentrations were measured at stations signified by small triangles. Land use types are identified across the province according to Wang et al., 2005.



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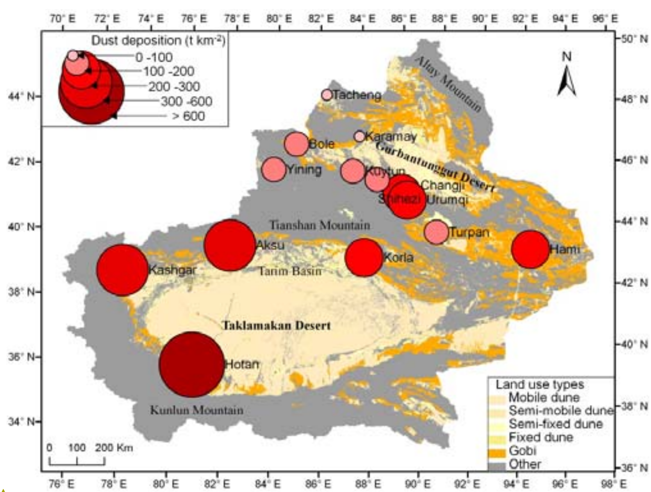

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Figure 2. Annual average dust deposition ~~(t km^{-2})~~ reported at 14 stations in Xinjiang Province from 2000-2013. Land use types across the province are identified according to Wang et al. (2005).

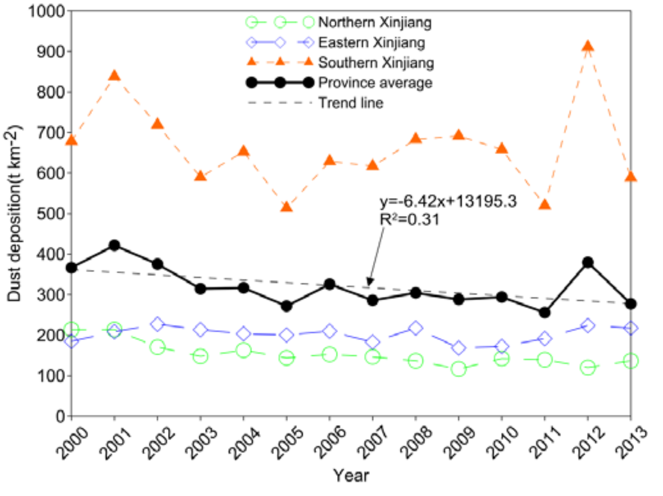


Figure 3. Annual average dust deposition in Xinjiang Province from 2000 to 2013. Dust deposition in northern, eastern and southern Xinjiang is the average deposition at 8, 2 and 4 stations, respectively.

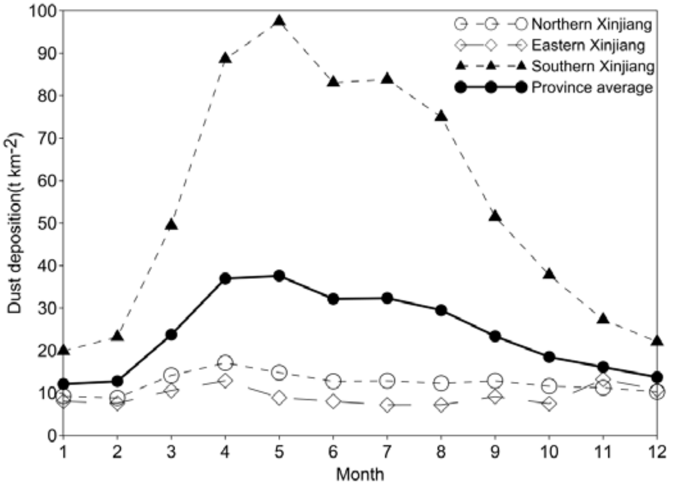
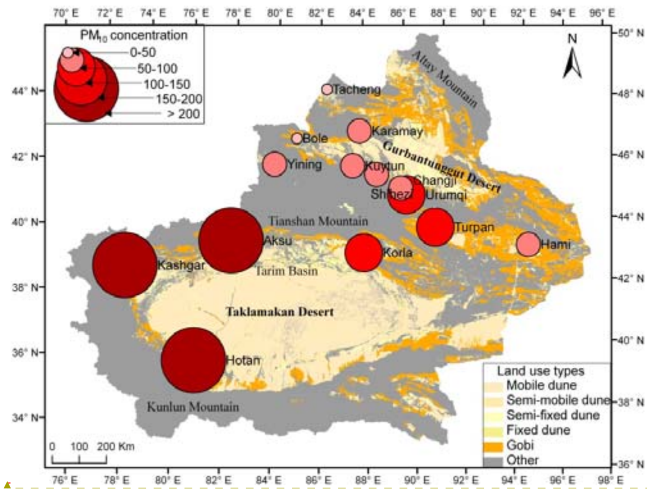


Figure 4. Monthly average dust deposition in Xinjiang Province from 2000-2013. Dust deposition in northern, eastern and southern Xinjiang is the average deposition at 8, 2 and 4 stations, respectively.



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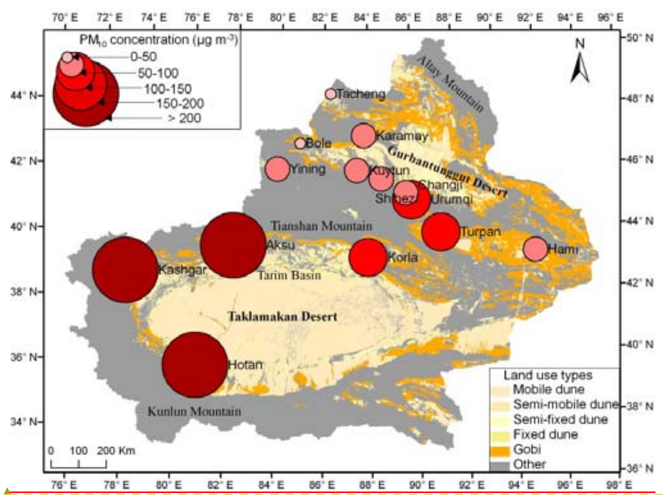

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Figure 5. Annual average PM_{10} concentration ~~(μg m^{-3})~~ reported for 14 stations in Xinjiang Province from 2000-2013. Land use types are identified across the province according to Wang et al., 2005.

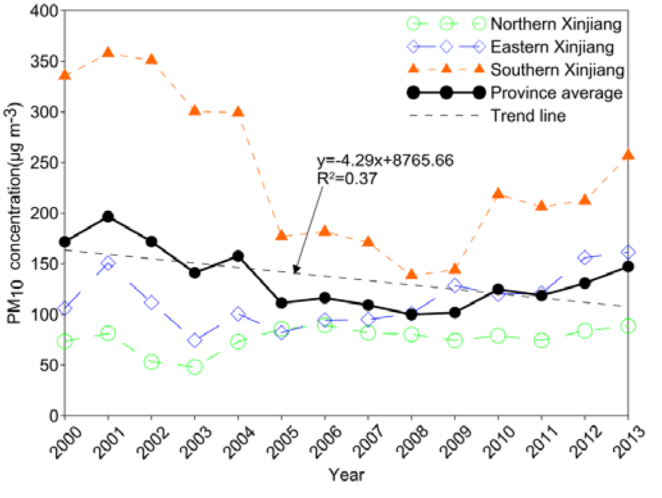

Figure 6. Annual average PM_{10} concentration in Xinjiang Province from 2000 to 2013.

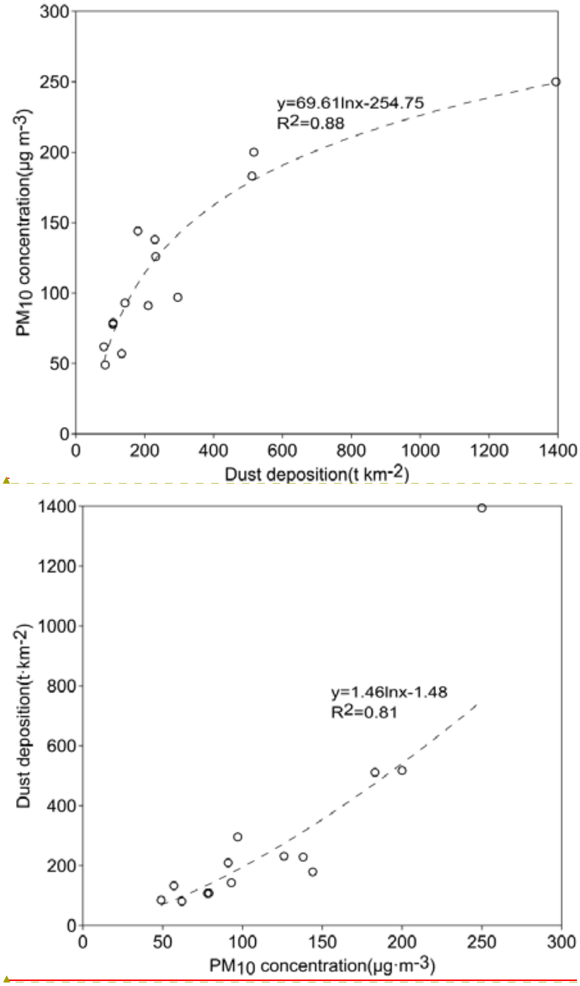

Figure 7. Relationship between annual dust deposition and PM_{10} concentration in Xinjiang Province. Each point represents data averaged across 2000 to 2013 at one station.

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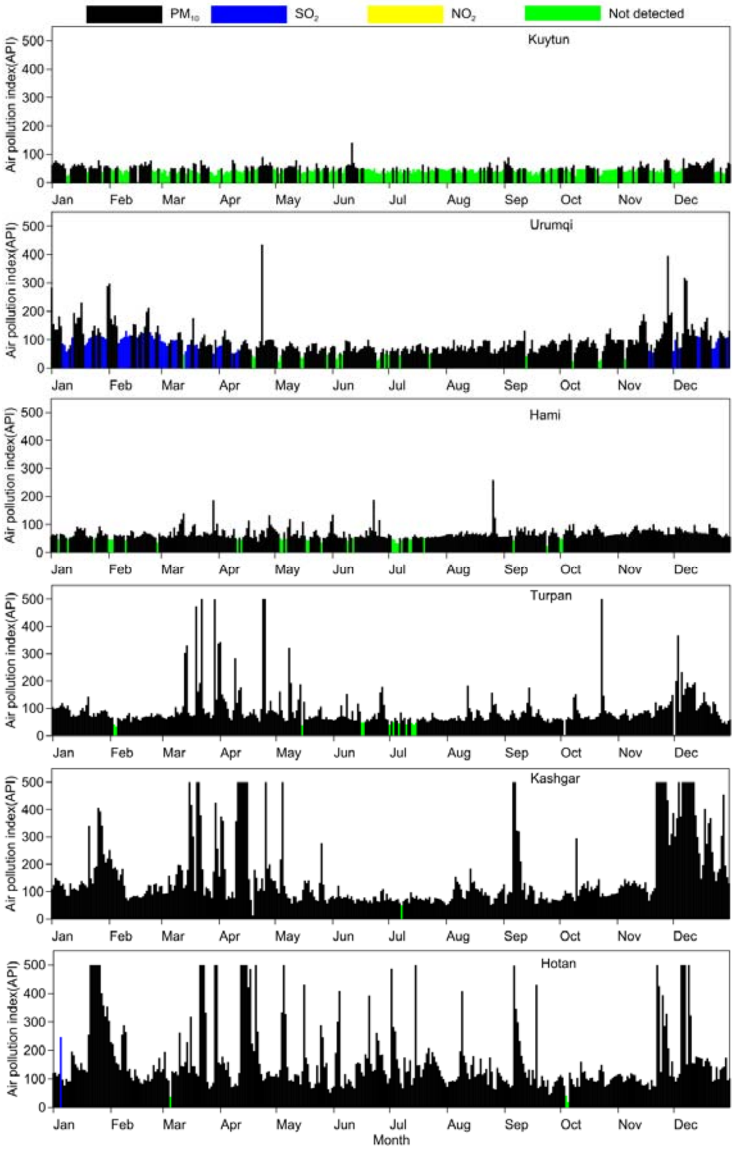

Figure 8. Daily air pollution index for Kuytun and Urumqi in northern Xinjiang, Hami and Turpan in eastern Xinjiang, and Kashgar and Hotan in southern Xinjiang in 2010. The main air pollutant contributing to the daily API is identified for each station. Not detected indicates excellent air quality (API<50).

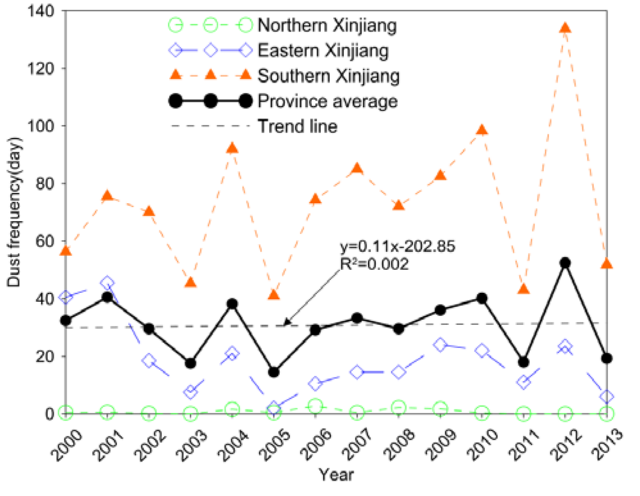

Figure 9. Dust day frequency in Xinjiang Province from 2000 to 2013.

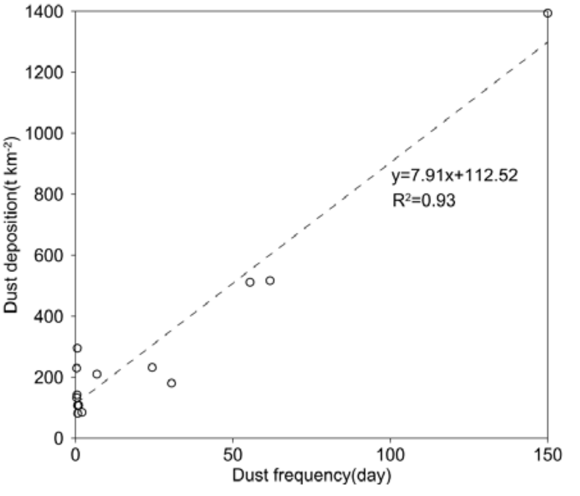

Figure 10. Relationship between annual dust deposition and dust day frequency in Xinjiang Province. Each point represents data averaged across 2000 to 2013 at one station.

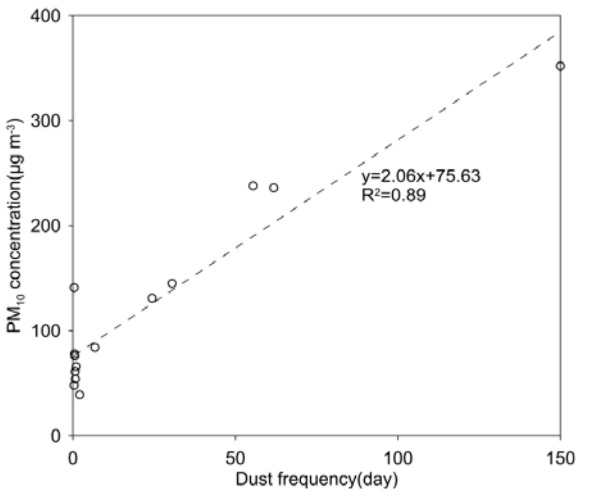

Figure 11. Relationship between PM_{10} concentration and dust day frequency in Xinjiang Province. Each point represents data averaged across 2000 to 2013 at one station.

Supplement Material

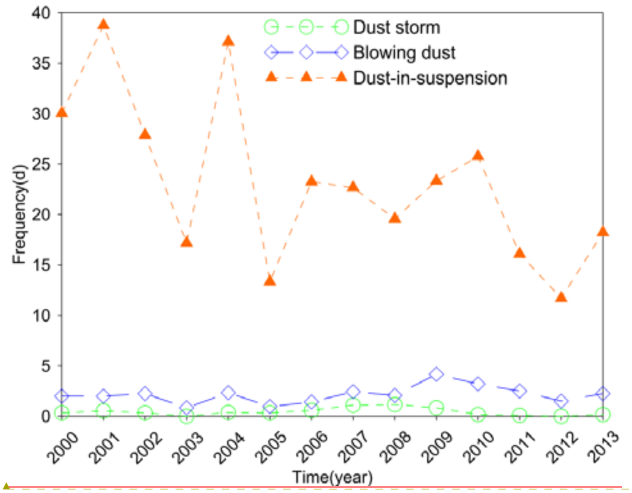

Figure S1. Frequency change of dust storm, blowing dust and dust-in-suspension day in Xinjiang Province from 2000 to 2013.

带格式的: 字体: (默认) +西文正文, (中文) +中文正文, 8 磅

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