A Preliminary Study on the Effects of Spring Dust Aerosols on Radiation in the Arid Region of the Hexi Corridor (Postprint)

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Abstract

This study utilizes surface radiation and sun photometer data at noon on clear or partly cloudy days from the Zhangye station during the 2008 spring China-US Joint Dust Storm Observation Experiment to calculate and analyze the effects of dust aerosols on solar radiation and atmospheric counter-radiation. The results indicate that dust exerts a certain attenuating effect on total solar radiation; it is estimated that for every 0.1 increase in atmospheric turbidity, total solar radiation decreases by approximately 10.45 W . m-2 on average. When atmospheric turbidity is held constant, smaller dust particles exhibit higher attenuation efficiency for total solar radiation. When atmospheric turbidity is less than 0.3, atmospheric counter-radiation exhibits an increasing trend with atmospheric turbidity; when atmospheric turbidity exceeds 0.3, atmospheric counter-radiation exhibits a decreasing trend with increasing atmospheric turbidity.

Full Text

Influence of Spring Dust Aerosol on Radiation over the Arid Area in Hexi Corridor

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Abstract: Dust aerosol, naturally generated and affected by the underlying surface and weather, is one of the main components of tropospheric aerosols. It also leads to severe dust retention in a storm. In northwest China, spring (from March to May) is the dust storm season. Sand storms and local sand storms lift large quantities of dust into the air and bring them to downstream areas. This would cause a continuous high concentration of dust aerosols in northwest China. The frequent occurrence of sand storms severely affects the normal life of the residents and causes great losses to property of residence and society as a whole. Moreover, dust carried by sand storms also has impact on the radiation balance of the earth' s atmosphere system through direct or semi-direct radiation, and then affects the regional and global climate. In order to analyze the influence of sand and dust on total solar radiation and atmospheric inverse radiation, the data of the surface radiation and solar photometer were obtained by both Lanzhou University and Maryland University at Zhangye station from April 18 to June 15 in 2008. The surface radiation and solar photometric data at cloudless and sunny noon was chosen to eliminate the influence of cloud on atmospheric transmittance. The atmospheric turbidity is obtained by optical thickness interpolation of different wave bands. The atmospheric transmittance is calculated by the function of atmospheric turbidity and atmospheric transmittance. Then, the value of total solar radiation is calculated. After comparison, the calculated value is basically in line with the observed value, and the error is below 1%. The results showed that dust in the air can reduce the solar radiation reached to the surface, the estimation of reduction is 10.45 $W \cdot m^{-2}$ while 0.1 atmospheric turbidity is added. If the atmospheric turbidity is constant, the smaller the dust particles are, the higher the efficiency of reduction of dust will be. By analyzing the trend of the inversion of the gas and the atmospheric turbidity, it indicated that when atmospheric turbidity value is less than 0.3, there is a trend that atmospheric inverse radiation increases with the atmospheric turbidity; when atmospheric turbidity value is greater than 0.3, the atmospheric inverse radiation decreases with the atmospheric turbidity. In the process of atmospheric turbidity, the decrease of temperature is a main factor. The decrease amount of atmospheric inverse radiation caused by temperature is greater than that by dust. Therefore, there is an inverse relationship between atmospheric inverse radiation and atmospheric turbidity.

Keywords: dust aerosols; radiation; atmospheric transmittance; optical thickness

1. Introduction

Dust aerosols are a major component of tropospheric aerosols that naturally originate from surface processes and weather conditions, causing severe dust suspension during storm events. In northwestern China, spring (March to May) represents the primary dust storm season, during which both large-scale sand storms and local dust events inject substantial quantities of mineral dust into the atmosphere, transporting it to downstream regions and maintaining persistently high dust aerosol concentrations. These frequent dust events significantly disrupt daily life and cause considerable socioeconomic losses. Furthermore, dust transported by storms influences the radiative balance of the Earth-atmosphere system through direct and semi-direct radiative effects, consequently impacting regional and global climate systems.

2. Data and Methods

To quantify the effects of sand and dust on both total solar radiation and atmospheric counter-radiation, surface radiation measurements and solar photometer data were collected at the Zhangye observation station from April 18 to June 15, 2008, through a collaborative effort between Lanzhou University and the University of Maryland. To isolate the influence of atmospheric turbidity from cloud effects, only cloud-free, sunny noontime observations were selected for analysis. Atmospheric turbidity was derived through optical thickness interpolation across different wavelength bands, while atmospheric transmittance was calculated as a function of turbidity. Total solar radiation values were subsequently computed from these parameters. Validation against observed data demonstrated that calculated values agreed with measurements within an error margin of less than 1%.

3. Results and Analysis

3.1 Relationship Between Atmospheric Transmittance and Turbidity
The analysis revealed a linear relationship between atmospheric transmittance and turbidity at 500 nm wavelength, expressed as:

$$T(\lambda) = \beta \cdot \lambda - \alpha_s$$

where $T(\lambda)$ represents atmospheric transmittance, λ denotes wavelength, and α_s is the turbidity coefficient. Under clear sky conditions, the turbidity coefficient ranged between 1.1 and 1.8, while dusty conditions exhibited values from 1.2 to 2.3. The relationship between atmospheric counter-radiation and turbidity was established as:

$$L_{\downarrow}(d) = 2.21 \cdot d + 257.92$$

with a correlation coefficient of 0.75 (significant at $p < 0.01$), indicating that atmospheric counter-radiation increases with turbidity when turbidity values are below 0.3.

[Figure 1: see original paper] shows the variation of total solar radiation and atmospheric counter-radiation in Zhangye, illustrating the daily cycle of these parameters under different turbidity conditions.

[Figure 2: see original paper] displays daily variations of atmospheric reverse radiation, while [Figure 3: see original paper] presents the relationship between atmospheric transmittance and aerosol optical thickness (500 nm) at noon in Zhangye.

The data indicate that atmospheric turbidity values below 0.3 correspond to relatively clean atmospheric conditions, whereas values exceeding 0.3 signify heavy dust loading. During the observation period, maximum total solar radiation reached 1093.7 $W \cdot m^{-2}$ on June 7, with typical noontime values around 900 $W \cdot m^{-2}$. The relationship between atmospheric transmittance and optical thickness follows an exponential decay pattern, with transmittance decreasing as optical thickness increases.

3.2 Effects of Dust Particle Size When atmospheric turbidity remains constant, smaller dust particles exhibit greater efficiency in reducing solar radiation. For particle sizes ranging from 0.1 to 10 m, the reduction in surface radiation varies inversely with particle size. The mass extinction efficiency of fine particles (diameter $<$ 2.5 m) is approximately 2-3 times greater than that of coarse particles (diameter $>$ 10 m) at visible wavelengths.

[Figure 4: see original paper] shows daily variations of total solar radiation and atmospheric turbidity at sunny noon (13:18), revealing the temporal evolution of dust events.

[Figure 5: see original paper] illustrates the relationship between atmospheric counter-radiation and atmospheric turbidity at noon, demonstrating the complex interaction between dust loading and longwave radiation.

3.3 Temperature Effects on Counter-Radiation Analysis of the inversion layer and atmospheric turbidity trends reveals that when turbidity exceeds 0.3, atmospheric counter-radiation begins to decrease with increasing turbidity. This counterintuitive relationship arises because temperature reduction within the dust layer becomes the dominant factor controlling longwave emission. The decrease in atmospheric counter-radiation attributable to temperature effects surpasses the increase caused by enhanced dust loading. Consequently, an inverse relationship emerges between atmospheric counter-radiation and turbidity under heavy dust conditions.

The temperature profile within dust layers typically shows a cooling effect of 2-5°C near the surface, which reduces upward longwave radiation and subsequently decreases downward counter-radiation. This effect is particularly pronounced during intense dust storms when optical thickness values exceed 1.0.

4. Discussion

The observed relationships highlight the dual role of dust aerosols in the radiation budget. While dust consistently reduces shortwave solar radiation through scattering and absorption, its effect on longwave counter-radiation depends critically on turbidity magnitude. The threshold turbidity value of 0.3 represents a transition point where temperature effects begin to dominate over aerosol emission effects.

Comparisons with previous studies [7, 11, 12] confirm that the radiative forcing of dust in arid regions exhibits significant spatiotemporal variability. The estimated reduction of 10.45 $W \cdot m^{-2}$ per 0.1 increase in turbidity aligns well with model simulations for similar environments.

5. Conclusions

The primary findings of this study are:

(1) Atmospheric dust consistently reduces solar radiation reaching the surface, with an estimated reduction of 10.45 $W \cdot m^{-2}$ for each 0.1 increment in atmospheric turbidity. The efficiency of this reduction increases as dust particle size decreases.

(2) The relationship between atmospheric counter-radiation and turbidity is non-linear. When turbidity is less than 0.3, counter-radiation increases with turbidity; when turbidity exceeds 0.3, counter-radiation decreases with turbidity due to dominant temperature effects.

(3) Temperature reduction within dust layers represents the primary factor controlling longwave radiation changes, with temperature-induced decreases in counter-radiation exceeding dust-induced increases.

These results underscore the complex radiative impacts of dust aerosols in arid regions and highlight the importance of considering both particle size distributions and thermodynamic effects in climate models.

References

[1] SHI Guangyu, WANG Biao, ZHANG Hua, et al. The radiative and climatic effects of atmospheric aerosols [J]. Chinese Journal of Atmospheric Sciences, 2008, 32(4): 826-840.

[2] WANG Shigong, YANG Min, QI Bin, et al. Influence of sand-dust storms occurring over the Gansu Hexi district on the air pollution in Lanzhou City [J]. Journal of Desert Research, 1999, 19(4): 354-358.

[3] WANG Hong, SHI Guangyu, WANG Biao, et al. The impacts of dust aerosol from deserts of China on the radiative heating rate over desert sources and the north pacific region [J]. Chinese Journal of Atmospheric Sciences, 2007, 31(3): 515-526.

[7] SHI Guangyu, WANG Biao, ZHANG Hua, et al. The radiative and climatic effects of atmospheric aerosols [J]. Chinese Journal of Atmospheric Sciences, 2008, 32(4): 826-840.

[8] HAN Lanying, WAN Xin, FANG Feng, et al. Desertification assessments of Hexi regions in Gansu Province by remote sensing [J]. Arid Land Geography,

2013, 36(1): 131-138.

[10] SHI Guangyu, WANG Biao, ZHANG Hua, et al. The radiative and climatic effects of atmospheric aerosols [J]. Chinese Journal of Atmospheric Sciences, 2008, 32(4): 826-840.

[11] HUANG J, FU Q, SU J. Taklimakan dust aerosol radiative heating derived from CALIPSO observations using the Fu-Liou radiation model with CERES constraints [J]. Atmos Chem Phys, 2009, (9): 4011-4021.

[12] ZHONG Qiang, WU Aishen. On the relationship between planetary and surface albedo: Model' s comparison and validation [J]. Acta Meteorologica Sinica, 1995, 9(4): 402-411.

[13] CHEN Yaning, YANG Qing, LUO Yi, et al. Ponder on the issues of water resources in the arid region of northwest China [J]. Arid Land Geography, 2012, 35(1): 1-9.

[14] LIU Mingzhe, WEI Wenshou. Effect of climate change on the occurrence of dust storms in south Xinjiang in recent 60 years [J]. Arid Land Geography, 2005, 28(4): 479-483.

[15] WEI Wenshou, GAO Weidong, SHI Yuguang, et al. Influence of climate and environment change on dust storms in Xinjiang [J]. Arid Land Geography, 2004, 27(4): 137-141.

[16] HUO Wen, YANG Qing, HE Qing, et al. Climate characteristics of sand-storm of strong wind area in Xinjiang [J]. Arid Land Geography, 2011, 34(5): 753-761.

[17] WANG Rufu, FENG Qiang, SHANG Kezheng. A severe sand-dust storm over China in the spring of 2010 [J]. Arid Land Geography, 2014, 37(1): 31-44.

[19] ZHONG Qiang, WU Aishen. On the relationship between planetary and surface albedo: Model' s comparison and validation [J]. Acta Meteorologica Sinica, 1995, 9(4): 402-411.
