Monitoring Dust Concentrations over Desert and Cropland during Dust Storms Using Visibility Sensors

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Abstract. Directly measuring the dust concentration during a dust storm is very important for studying dust emission and wind erosion processes. The Mira visibility sensors were introduced for directly measuring dust concentrations over desert and cropland during dust storm events. The output of the sensor was compared with that of optical particle counter. We found that the Mira visibility sensors can directly measure the particle numbers concentrations. Characteristics of dust concentrations at the two ground surfaces during dust storms were analyzed. By using the Mira visibility sensors and optical particle counters and other meteorological elements in Dunhuang, China, dust emission processes and characteristics over desert and oasis during dust storms was discussed.

1. Introduction
Dust and dust storms have a considerable effect on visibility [1], air quality [2], human health [3] and the climate system [4]. Even though these dust storm effects had been broadly studied, the processes at the sources such as the frequency, duration, intensity or aerosol number-size distribution had not been adequately described. In order to clarify the process of dust outbreak and the relationship between ground surface conditions, such as surface vegetation cover, soil water content, temperature, etc., and dust outbreak and to obtain basic data for applying it to dust outbreak model in the course of parameterization and verification, as a part of the Japan-China Cooperation Project on aeolian dust experiment on climate impact (ADEC), continuous field observation of dust concentration and meteorological elements on different surfaces such as sandy desert and agricultural field were induced [5]. Two automatic observation stations have settled in Dunhuang, China. One of the stations was settled on a Gobi Desert in March 2001 and another has settled on a cropland inside the Dunhuang oasis in September 2001. Directly measuring the dust concentration during a dust storm is very important for studying dust emission and wind erosion processes. However, it is very difficult to measure. Unfortunately, the size distribution of emission fluxes has seldom been measured in natural source areas and, for lack of sufficient field data, it has often been assumed in the past to be independent of meteorological conditions prevailing during emission [6, 7]. A visibility sensor was introduced for directly measuring dust concentration at the two sites. The output of the sensor was compared with that of optical particle counter. Characteristics of dust concentrations at the two ground surfaces during dust storms were analyzed.
The purpose of this study is to test if the visibility sensor can be used for directly measuring dust concentrations during dust storms and give out the observational results of dust concentration variations at ground surface during dust storms in Dunhuang, China and to clarify the process of dust concentration change during the dust storm.

2. Study Area and Data
Figure 2-1 shows the locations and topographies of the observation sites. Station 1 has settled in a flat moveable sandy desert or Gobi Desert with moveable sand area near the famous Mogao Grottoes 20 km apart from Dunhuang Oasis. The land surface of the Gobi Desert site was covered by gravel (about 2-10 mm in diameter) and removable sand and dust particles. Station 2 has settled in an agriculture field in the central part of Dunhuang Oasis. This site is a cotton field during May to November and the other time is bare soil and under vary dry condition after the ploughing work, including harrowing, leveling, plowing, fertilizing and seeding. Both sites located in very flat area as shown in Fig. 3. The flat area has a diameter of over 2 km. However, the oasis site is inside of windbreak network. The grid of the network is about 200-500 m*200-500 m. The station is settled in the center of a grid about 400 m*400 m.

Figure 2-1. Location and topography of the observation sites.

Dust concentrations were measured using an optical particle counter (OPC) (Yamatronics, Japan) and a visibility sensor, the MIRA Visibility Sensor 3544 (Aanderaa Instruments, Norway), which is designed to fulfill the demand for a small, low power (DC) unit to be operated with Aanderaa Measuring Stations. The sensor consists of an aluminum body containing all necessary solid-state electronics and two vertical legs. It is furnished with a standard Aanderaa meteorological sensor foot. It is a rugged, watertight, corrosion free and solid-state sensor with minimum maintenance requirements. In one leg of
the body, an infrared (IR) light emitting diode is installed at an angle of 25 degrees. The opposite leg contains an IR photo detector as shown in Fig.2-2. The diode and the photo-detector are protected against clogging by a cover.

**Figure.2-2.** The Mira visibility sensor.

CR10X Measurement and Control Systems (Campbell Scientific, Inc.) are used for all meteorological elements (wind, air temperature, humidity, pressure, radiation, soil temperature and water content, heat flux etc.), except visibility. The energy balance between the incoming spectral short-wave and long-wave radiation, from 0.3 to 50 μm, relative to the surface reflected short-wave and outgoing long-wave radiation were measured by The CNR 1 Net Radiometer (Kipp & Zonen INC.). The station in desert is a 10m tower with 4 levels wind and air temperature and humidity observations at 1m, 2m, 4m and 10m and 2 levels (3 levels from September of 2001) of visibility observation. The station in oasis is a 4m tower with 3 levels as shown in Fig.2-3.

**Figure.2-3.** View of the experimental sites.

Dust concentrations were measured using an optical particle counter (OPC) (Yamatronics, Japan) and a visibility sensor, the Mira Visibility Sensor 3544 (Aanderaa Instruments, Norway), which is designed to fulfill the demand for a small, low power (DC) unit to be operated with Aanderaa Measuring Stations. Due to the visibility sensor is designed to detect fog and haze, we define a Dust Concentration Index (DCI) for use it to detect dust as

\[
DCI = \frac{(a - N)}{a}
\]

Where the coefficients \(a = 1022\), the maximum raw data reading and \(N\) is the raw data reading. DCI will be between 0 (no heavy dust event) and 1 (the heaviest dust event as visibility = 0). Fast sampling mode of the visibility sensor was used. In this mode, the light beam is transmitted every 6 seconds and average data for 10 minutes was recorded.
All the elements (wind, temperature, humidity, radiation and pressure) above the ground is sampled every 10 second. Soil temperature and moisture (TDR) are sampled every 10 minutes. One minutes sampling data are averaged and recorded for 10 minutes intervals during ordinary observation period and sampling data are recorded during IOP period (Intensive Observation Period). Maximum and minimum of wind and their standard deviation within the recording 10 minutes intervals were also recorded. The details of the observation stations and observation system has introduced by Du et al. [8]  

3. Results  

3.1. Use of visibility sensor for measuring dust concentration  
Figure 3.1 shows a comparison of DCI and particle numbers concentration for a dust event on April 8-9, 2002. It is obviously that DCI has a very good relationship to the dust numbers concentration. For the total particles numbers lager than 0.5μm, DCI changes with the particle numbers concentration exponentially and it changes proportionally with the particle numbers concentration larger than 5.0μm as shown in Fig.3-2 (observation period was from April to September 2002). That is,  

\[
\text{Particles numbers larger than } 0.5\mu m = 2934.1e^{3.2452 \times \text{DCI}} \tag{2}
\]

\[
\text{Particles numbers larger than } 5.0\mu m = 197370 \times \text{DCI} + 44489 \tag{3}
\]

Figure 3.1. Comparison of DCI and dust particle numbers on Apr. 8-9, 2003 over desert in Dunhuang, China  

Figure 3.2. Relationship between DCI and dust concentration over desert in Dunhuang, China (data from Apr. to Sep. 2002)  

3.2. Dust storm process  
Most dust storms in spring in Dunhuang are probably generated by cold frontal systems with dry squall lines. As shown in Fig. 6, air pressure, wind speed and relative humidity were the lowest of the day before the dust storm passing the station on April 13, 2002. Cloud appeared (radiation decreased compared with that on April 12) and wind direction changed several hours before dust storm. When dust storm passing the station, strong wind speed appeared and DCI at 9m became bigger than that at 2m. Air Pressure increased and temperature decreased with relative humidity increasing with time after the dust front passing. The process of a dust storm can be divided into 4 stages in Dunhuang, China as follows.  

3.2.1. Pre-emission stage. Pre-erosion stage lasts several hours before the dust storm comes. In this stage, wind speed becomes weak and weak (usually lower than 4m/s (sometimes below 1.0m/s)) and wind direction changes (usually clockwise). Air pressure decreases to lowest value and there will be some cloud appears.
3.2.2. Dust outbreak stage. This stage only lasts about one hour occurred when cold front passing. As wind speed suddenly increasing, DCI increase very quickly. The most important features of this stage are the variation of roughness length and friction velocity and the dust concentration (DCI) at 9m is larger than that at 3m. Dust concentration in the air (DCI) increases exponentially with wind speed or friction velocity when strong wind blown (wind speed at 10m is over about 6m/s or friction velocity is over about 0.2m/s). Due to saltation occurs in the sandy desert surface, wind profile and roughness length change with wind speed.

3.2.3. Dust passing stage. Dust passing stage can last from one hour to over 10 hours. During this stage, air pressure, air temperature and soil temperature decrease and humidity increase with strong wind blows. Sometime wind speed may decrease or increase for several meters as shown in figure 6. DCI at 9m is lower than that at 3m.

3.2.4. Calm down stage. This stage lasts several hours too. DCI decrease as wind speed decrease. Sometime DCI decreased very quickly due to rainfall occurred. Usually air temperature and surface soil temperature will be about several degrees lower that that before the dust event as shown in Fig.3-3
Figure 3.3. Variations of Several Elements during a Typical Case of Dust Storm from April 12 to 15, 2002 in Dunhuang China, including DCI, Solar Radiation, Pressure, Wind Speed and Direction, Air Temperature and Humidity.
3.3. Difference of dust concentration between desert and bare cropland

Figure 3-4 shows a comparison of dust concentrations both the particle numbers concentration and the Dust Concentration Index (DCI) between desert and bared cropland. It shows that although the DCI over the cropland was higher than that over the desert during the dust storm, dust concentration observed by the optical particle counter did not show much difference between the two sites. However, during the calm down stage of the dust storm, numbers of small particles such as 0.5μm to 1.0μm over the cropland was much more than that over the desert as DCI shows.

![Comparison of Dust Concentrations (up: DCI; down: particle numbers) between Desert and Cropland on Apr. 13, 2002 in Dunhuang, China](image)

Optical particle counter observation also shows that higher particle numbers concentration over cropland when there is no dust emission. This is because there are many fine dusts on the surface of the cropland, especially on the field road in the oasis in Dunhuang. These fine particles contribute the higher dust concentration over the cropland.

4. Conclusions

The Mira visibility sensor can be used for directly measuring dust numbers concentration during dust event after approving by other instruments such as optical particle counter. It has very high response and can measure dust concentration directly with an interval of less than one minute. By changing its output to dust concentration index (DCI), it will proportional increase with particle numbers concentration larger than 0.5μm and exponential increase with the particle numbers concentration larger than 5.0μm.

By using the Mira visibility sensor and optical particle counter with other meteorological elements in Dunhuang, China, dust emission processes by a dust storm can be divided into 4 stages as 1) pre-emission; 2) outbreak; 3) passing and 4) calming down stages.

During a dust storm, dust concentration over cropland is almost the same as that over desert. However, concentration of fine dust (smaller than 1.0μm) over cropland for the other period is higher than that over desert in Dunhuang, China.

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