The effects of sand dust storms on greenhouse gases

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In Asia, sand dust storm (SDS) occurs nearly every year, especially in northern China. However there is less research about the relationship between SDS and greenhouse gases (GHGs). In this paper, we select 4 times of SDS that occurred in the spring of 2009 and 2010 in Asia. We monitor the areas covered by the SDS using MODerate resolution Imaging Spectral radiometer (MODIS) data, and then we use Greenhouse gas Observing Satellite (GOSAT) data to check how the SDS affect the concentration of CO_2 and CH_4. Compare the concentration of CO_2 and CH_4 on SDS days with the monthly mean values of the SDS happened month. We also compare the concentration of CO_2 and CH_4 on the SDS days with the value before and after the SDS. After analysis, we found that the SDSs increase the concentration of CO_2 and CH_4 in the atmosphere. When the SDS occurred, the concentrations of CO_2 and CH_4 increased and reached peak values on the last or penultimate days of the storm and then decreased to their normal values. Atmospheric flow is the main reason of CO_2 concentration increase, the lack of free radicals (OH) during SDSs and the presence of CH_4 sources in southeast of China are the main reasons of CH_4 increase. We also found that in arid and semi−arid areas, the SDSs had little effect on the concentration of these two GHGs.

1. Introduction

A sand dust storm (SDS) is a meteorological phenomenon in which strong winds draw an enormous amount of sand and dust from near the ground surface into the sky, making the air foul and causing visibility less than 1 km (Di *et al.* 2008). There are four major SDS-prone areas in the world: North America, Australia, Central Asia and the Middle East (Qian *et al.* 2006).

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SDSs are natural events that occur widely around the world, especially in subtropical latitudes and dry savannas. SDSs are most common in mid-latitude dry-lands. However, the most severe SDSs occur where there are anthropogenic land disturbances in dry-lands under conditions of severe drought. Major storms occur when prolonged drought causes the soil surface to lose moisture and where there are strong winds. The results of SDSs can impact climate and air temperature and can also influence ocean cooling. Dust can affect soil formation; create geomorphologic formations such as wind erosion depressions, wind column, Jadin and wind residual hill in dry-lands, and remove cover from desert surfaces. Moreover, SDSs can accelerate soil erosion and encourage desertification (Tsolmon *et al.* 2008). Early research has shown that Asian dust can be transported across the Pacific Ocean and reach as far as the western US (Hong *et al.* 2004). SDSs not only impact the environment, they also affect our health: several studies have shown that microorganisms mobilized into the atmosphere along with desert soils are capable of surviving long-range transport on a global scale. Dust-borne microorganisms in particular can directly impact human health via pathogenesis, that is, the exposure of sensitive individuals to cellular components and the development of sensitivities through prolonged exposure (Garrison *et al.* 2006, Martiny *et al.* 2006, Tsolmon *et al.* 2008).

SDSs occur nearly every spring in China, especially in the northern China. Ding and Liu (2011), using a time sequence, analyzed 344 ground stations from 1954 to 2005 and found that the number of SDSs in the northern China have been decreasing. Xinjiang and Inner Mongolia have had the fastest reduction; other regions show the same reduction trend, and only a few regions have experienced the opposite trend. They also found that the spatial distribution of SDSs had close relation with the climatic fluctuation, vegetation coverage, water loss and soil erosion, human activities and other factors also affect the spatial distribution of SDSs. Ma *et al.* (2011) analyzed the relationship between SDSs and global warming over the past 46 years in northern China and found that over the past 46 years the average days of SDS decreased significantly with the increasing of the average temperature. They also analyzed the reasons that affect SDS frequency from natural and human factors and found that the decreased of Mongolia cyclone is the direct reason of SDS decrease in China. Recent studies of SDS mainly focus on three issues: the method used to monitor SDS, the composition of dust and how the sand dusts affect the atmosphere.

Remote sensing is an established method for the detection and mapping of dust events and has been used to identify dust source locations with varying degrees of success (Baddock *et al.* 2009). Multi-satellite observations such as MODerate resolution Imaging Spectral radiometer (MODIS), Total Ozone Mapping Spectrometer (TOMS), Sea-viewing Wide Field-of-view Sensor (SeaWiFS), Advanced Very High Resolution Radiometer (AVHRR), and the Chinese Feng Yun (FY) series have been used in Asian SDS monitoring (Miller 2003, Qu *et al.* 2006, Tsolmon *et al.* 2008, Baddock *et al.* 2009). Surface reflectance of dust is usually very bright in the red part of visible spectrum and in the near infrared, but is much darker in the blue spectral

region. Based on these features Hsu *et al.* (2004) proposed a new approach to retrieve aerosol properties over surfaces such as arid, semi-arid, and urban areas.

Aerosol impact on climate has recently raised a new wave of interest with the purpose to assess natural and anthropogenic climate effect. There are many reasons to believe that aerosol contribution to climate formation is comparable with the impact of greenhouse gases (GHGs) (Kondratyev and Varotsos 1995, Wang *et al.* 2010, Ma *et al.* 2011). On the effects of SDSs on the atmosphere, Wang *et al.* (2010) analyzed the impact of sand dust on the concentration of sulfur dioxide (SO_2) in Xiamen Island, China, in 2008, and found that the concentration of SO_2 increased the day after sand dust, after two days the concentration fell back to its former value. Liu and Jiang (2004) and Xu *et al.* (2003) stated that when an SDS occur, the air visibility is reduced, air quality deteriorates, and the concentration of total suspended particulates (TSP), or respirable particulate matter with a diameter less than 10 μm (PM_{10}), increases. In addition, the air pollution indexes (SPI) increases, and the concentration of SO_2, nitrogen oxide (NO_x) and carbon monoxide (CO) changes.

Great interest has been paid on greenhouse effect as the overemphasized contribution of it to the global climate change (Kondratyev and Varotsos 1995). The rising atmospheric CO_2 concentrations accompanying global warming are now important research topics in global environmental studies. There are many nutrients in dust; for example, iron is found in dust but is a nutrient missing in oceans. When the dust fall into the oceans, the increase of nutrients in seawater can causes algal blooms, which can absorb more CO_2 by photosynthesis. The absorption of CO_2 can further reduce the Earth's temperature. Moreover, sand dust can shield solar radiation directly, which can prolong cold periods on Earth (Lv 2002). Sand dust affects the radiation balance of Earth's atmosphere directly, thus affecting climate (Qian *et al.* 2006). Sand dust is a kind of aerosol that can reflect solar radiation and thus reduce global temperature. Sand dust can offset 20% of Earth's increasing temperature value resulting from industrial emission GHGs (Zhu *et al.* 2004). SDSs also have a significant impact on the global climate system: the dust flowing in the air generated by an SDS is an important component of aerosol, and dust moving with the air can change the amount of radiation, generating climate change at a regional or global level. The 'parasol effect', 'ice core effect', and 'iron fertilization effect' are the result of SDSs (Zhu *et al.* 2010).

At present, with the development of the world economy and increasing population, the concentration of GHGs continues to rise. GHGs, such as SO_2, CH_4, O_3 and NO_x, have been studied by numerous researchers (Stewart and Hessami 2005, Monteny *et al.* 2006, Gonzalez *et al.* 2010). As we know green vegetation plays an important role in CO_2 cycle. A growing forest naturally removes GHGs from the atmosphere and reduces the magnitude of global climate change. Global vegetation and soils removed carbon from the atmosphere at a rate (mean±66% confidence interval) of $4.7\pm1.2 \times10^6$ kg y^{-1}, fossil fuel emissions $8.7\pm0.5 \times10^6$ kg y^{-1} and deforestation emissions $1.2\pm0.7 \times10^6$ kg y^{-1} (Gonzalez *et al.* 2010). Prior to industrialization, the Earth's

atmosphere contained about 280 ppm of CO_2 (280 CO_2 molecules for every million molecules in the atmosphere). This CO_2 was maintained in the atmosphere via volcanic and biological activities (Gaetano 2006). Global warming is becoming an important social issue in addition to being of scientific interest (Ma *et al.* 2004). On 17 Dec 2009, the 'Climate Change Summit' held in Copenhagen renewed interest in GHGs research worldwide. Because of the lack of monitoring data regionally, GHGs studies only focus on small areas, such as Beijing (Gu *et al.* 2002, Wang *et al.* 2003, He *et al.* 2005) or Huai'an of China (Yin *et al.* 2009), and these studies all focus on diurnal or seasonal variations.

The launch of Greenhouse gases Observing Satellite (GOSAT 'IBUKI') can provide concentration data of CO_2 and CH_4 on global scale which help the studies of GHGs. GOSAT is the world's first spacecraft to measure the concentrations of CO_2 and CH_4, the two major GHGs, from space. The spacecraft was launched successfully on January 23, 2009 by Japan, and has been operating properly since then.

Until now, there has been no report about the relationship between SDSs and GHGs. In this paper, we used MODIS L1B (32 bit float data that have already projected to latitude and longitude coordinates) data to detect when and where the SDSs occurred; for the first time, we used GOSAT data to analyze how the SDSs affected the concentration of CO_2 and CH_4 in the atmosphere. Analyze the reasons of the concentration of CO_2 and CH_4 changes. This paper also enriches the research of atmospheric changes and the effects of SDSs on GHGs.

2. Materials and methods

As a key research instrument of the NASA Earth Observing System (EOS) missions, MODIS was successfully launched onboard the Terra and Aqua satellites. MODIS senses the Earth's entire surface in 36 spectral bands, spanning from the visible (0.415 μm) to the infrared (14.235 μm) regions of the spectrum with spatial resolutions of 1 km, 500 m, and 250 m at nadir. Therefore, MODIS products can be useful to determine dust storm properties and to monitor dust transport (Ghedira *et al.* 2009).

Several methods have been developed to identify signals related to the radiative effect of atmospheric aerosols. Klüser and Schepanski (2009) derived a new Bitemporal Mineral Dust Index (BMDI) from Meteosat Second Generation (MSG) infrared observations over land and found that the BMDI shows a good capability for dust detection and dust load estimation over land and deserts. However, BMDI dust detection is limited in scenes with high atmospheric humidity, such as coastal regions. Kudoh (2010) used the Modified Soil Adjusted Vegetation Index (MSAVI)/Normalized Difference Vegetation Index (NDVI) of AVHRR, Brightness Temperature Differences (BTD) and Normalized Difference Dust Index (NDDI) to extract dust storms, and obtained satisfactory results. Ghedira *et al.* (2009) used an Aerosol Optical Depth (AOD) map to detect and monitor dust over Sudan on 12 May 2009 and found that an AOD index greater than 0.9 can be

used as an indicator of heavy dust presence. Qu *et al.* (2006) used the NDDI to monitor Asian dust storms and found that the simple NDDI index is able to identify SDSs and clouds easily and that the NDDI can be used to detect SDSs over bright surfaces where the MODIS AOD product is not available. Han *et al.* (2005) used the threshold of the absolute value of Band5 minus Band6 of MODIS and the Normalized Difference Snow Index (NDSI) to construct the branches of decision trees to monitor sand dust and found that the methods are of valuable practical use. Band3 of MODIS was also used by some researchers in monitoring SDSs (Kudoh 2010, Miller 2003, Hsu *et al.* 2004). Baddock *et al.* (2009) compared and evaluated five principal methods of dust source identification and found that the approaches using BTD are the most consistently reliable techniques for dust source identification in the Lake Eyre Basin, Australia. Huang *et al.* (2007) found that, based on microwave polarized BTD ($\triangle T_b = T_{bv} - T_{bh}$) among two channels of 89 GHz and 23.8 GHz and infrared BTD between channels at 11 and 12 μm, the integrated approach is better than the method based solely on infrared BTD in storm detection, especially for dust systems covered by ice clouds. BTD is the most widely used method of sand dust detection (Ackerman 1997, Pierangelo *et al.* 2004, Huang *et al.* 2007, Chaboureau *et al.* 2007, Schepanski *et al.* 2007, Tsolmon *et al.* 2008, Baddock *et al.* 2009). Calculating BTD is straightforward, and keeping the full range of values (rather than applying a dust threshold) is often preferable for both dust plume and source detection. The procedure does not appear to be very sensitive to observed mineralogical variability either within or between plumes; thus, all dust, regardless of source, is enhanced provided it can be differentiated thermally from the ground surface (Baddock *et al.* 2009).

In this paper, Terra and Aqua/MODIS L1B data were used to detect SDSs. Preprocessing was performed for the L1B data. The preprocessing included georeference and sensor calibration, but not atmospheric correction. This correction was not performed because, in terms of SDSs, the effects of dust aerosols on the attenuation of direct solar radiation is much greater than other factors, such as Rayleigh scattering, and the distribution of dust aerosols is uneven. The result is that atmospheric correction models, such as 6S and MODTRAN, may not fit the sand dust spectra (Han *et al.* 2005). We also employed the most widely used method of BTD (equations (1)−(3))to detect SDSs in this paper.

$$\mathrm{BTD} = T_{32} - T_{31} \tag{1}$$

$$T = \left[\frac{hc}{k\lambda}\right] \frac{1}{\ln[2hc^2\lambda^{-5}L^{-1}+1]} \tag{2}$$

$$L = \frac{2hc^2\lambda^{-5}}{\left[e^{\frac{hc}{k\lambda T}}-1\right]} \tag{3}$$

Here: L = blackbody radiance ($W \cdot m^{-2} \cdot Sr^{-1} \cdot \mu m^{-1}$)

T = the brightness temperature from a central wavelength

c = light speed (2.998×10^8 m $\cdot s^{-1}$)

λ= the sensor's central wavelength (μm)

h = the Planck constant (6.626×10^{-34} J ·s)

k = the Boltzmann constant (1.380×10^{-23} J ·K^{-1})

Because of the bright underlying surfaces over SDS's location of origin (i.e., desert, arid and semi-arid regions), it is a difficult task to detect dust and sand storm properties using conventional visible and near-infrared wavelengths (Ghedira *et al.* 2009). Thermal channels and the visible and near-infrared data of Terra and Aqua/MODIS were used together to distinguish between the bright underlying surfaces and the sand dust. BTD was used to detect sand dust and desert land, and then band3, band5 and band6 of MODIS were used to identity dust from desert (see figure 1).

The GOSAT is the world's first spacecraft designed to measure the concentrations of CO_2 and CH_4 from space. Molecules of CO_2 and CH_4 in the atmosphere absorb light of particular wavelengths; hence, the amounts of CO_2 and CH_4 in an optical path can be calculated by measuring how much light is absorbed by these molecules. Use this principle, GOSAT calculated column abundances of CO_2 and CH_4 from the observational data.

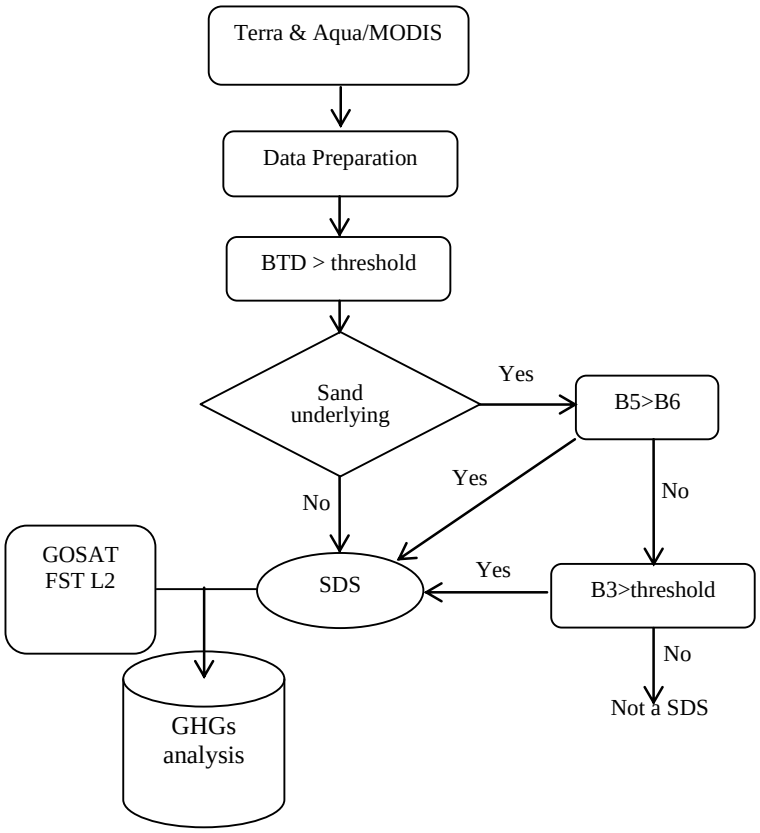

Figure 1. Flow diagram for dust storm detection in this paper

In this paper, we selected 4 times of SDS episodes that occurred in 2009 and 2010 in Asia. GOSAT FTS (Fourier Transform Spectrometer) SWIR L2 (store column abundances of CO_2 and CH_4 retrieved from the radiance spectra in the bands 1 through 3 of FTS) data were then used to analyze how SDSs affected the concentration of GHGs. The data from GOSAT FTS SWIR L2 are point data; thus, we calculated the mean value of the points in and around the sand dust cover areas. Preprocessing of the MODIS data was conducted using ENVI 4.7 software. The GOSAT FST data processing was conducted in ArcMap 10.0.

3. Results

3.1 Dust storm detection

Using the technique flow in figure 1, we examined the 4 times of SDSs-covered areas in the spring of 2009 and 2010 in Asia (see figures 2−5):

The first SDS we monitored occurred on April 23−25, 2009 (see figure 2). From figure 2, we see that the SDS originated in southern Mongolia and western Inner Mongolia of China and strengthened when it passed through the Badain Jaran and Tengger deserts. Because of the sink of dust along the transform route, the dust storms became increasingly weaker. The dust storm covered more than 10 provinces of China, and it also affected South Korea and Japan.

The second SDS we monitored was the most serious since 2009 (see figure 3). This SDS occurred on March 19−21, 2010. From figure 3 we see that the dust storm originated in Mongolia and strengthened over the Wulanbuhe desert and Hobq desert. This SDS affected more than 13 provinces of China. Moreover, the dust reached the Taiwan province of China. South Korea and Japan were also affected.

The third SDS occurred on March 29−30, 2010 (see figure 4). This SDS originated in Taklimakan desert, and it affected the provinces of Xinjiang, Qinghai, Gansu, Ningxia and Inner Mongolia. This SDS did not affect southeast of China, and all of these affected provinces are covered by the Gobi or sandy terrain.

The last SDS we monitored originated in the Taklimakan desert (see figure 5). This SDS affected approximately 7 provinces in the central part of China. Some reports stated that this was the most serious SDS in Gansu province in the past 9 years.

3.2 CO_2 and CH_4 concentration changes

In order to monitor the concentration of GHGs in the atmosphere on SDS days, we compared the concentrations of CO_2 and CH_4 on SDS days with the monthly mean values of the corresponding areas. As we mentioned before, the GOSAT FTS SWIR L2 are point data, we can extract the corresponding areas by

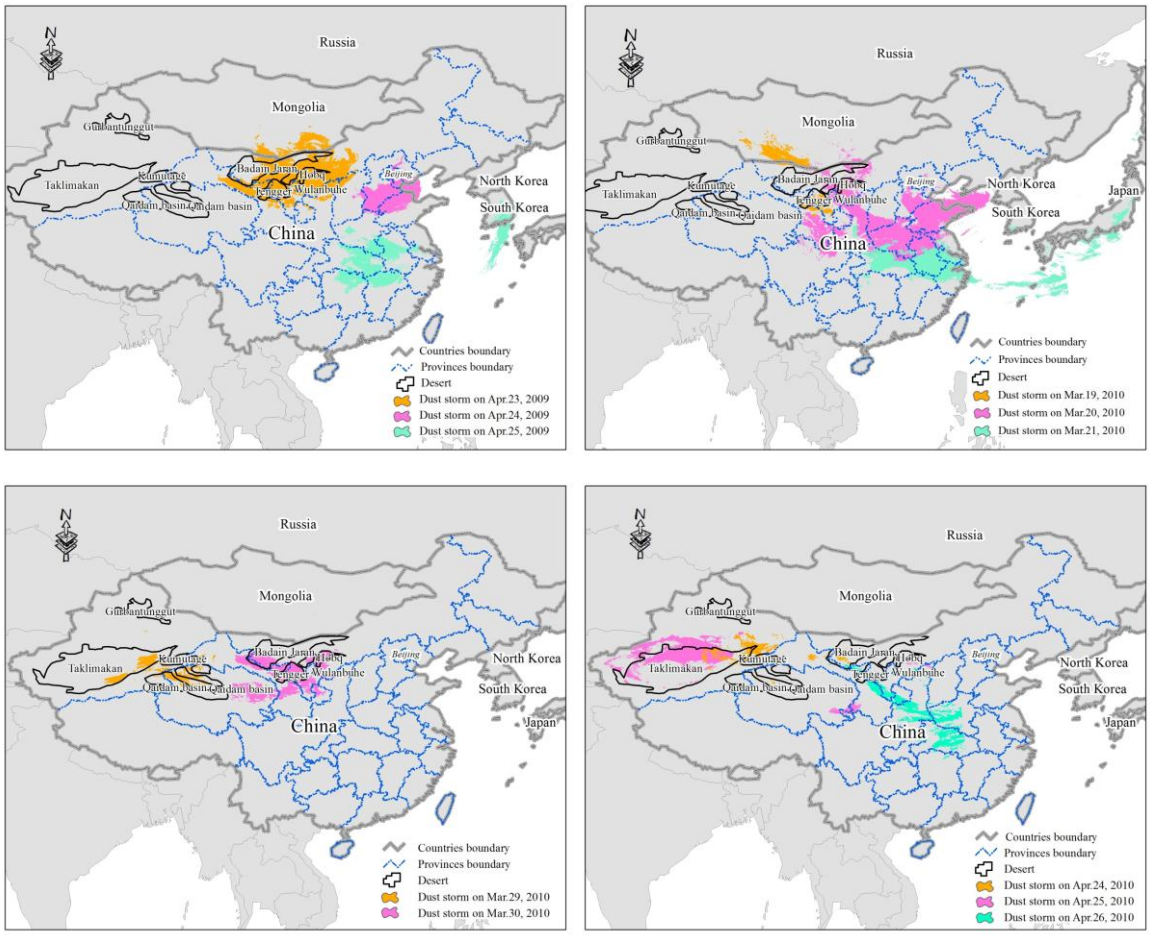

Figure 2. Areas covered by SDSs on Apr.23−25, 2009. The SDS originated in southern Mongolia and western Inner Mongolia of China and strengthened when it passed through the Badain Jaran and Tengger deserts. The dust storm covered more than 10 provinces of China, and it also affected South Korea and Japan. Figure 3. Areas covered by SDSs on Mar.19−21, 2010. The SDS originated in Mongolia and strengthened over the Wulanbuhe desert and Hobq desert. This SDS affected more than 13 provinces of China. Moreover, the dust reached the Taiwan province of China. South Korea and Japan were also affected. Figure 4. Areas covered by SDSs on Mar.29−30, 2010. This SDS originated in Taklimakan desert, and it affected the provinces of Xinjiang, Qinghai, Gansu, Ningxia and Inner Mongolia. Figure 5. Areas covered by SDSs on Apr.24−26, 2010. This SDS originated in Taklimakan desert and affected approximately 7 provinces in the central part of China. Some reports stated that this was the most serious SDS in Gansu province in the past 9 years.

ArcMap 10 easily: first, we selected all the points of CO_2 and CH_4 concentrations in the study area (contain Mongolia, China, North Korea, South Korea and Japan) of the SDSs happened month in 2009 and 2010; then in ArcMap 10, we exported the points that overlay with the SDSs layers and obtained the corresponding area points; At last we calculated the monthly mean concentrations of CO_2 and CH_4 respectively. We can see from figure 6 that the monthly mean values of CO_2 concentrations are nearly identical at approximately 380 ppm. However, the CO_2 concentration on the SDS days is greater than the monthly mean concentration, and the value on April 24−26, 2010 reached 385.76 ppm. From figure 7, we can see that the monthly mean concentration of CH_4 is between 1.73 ppm and 1.76 ppm and that all the SDS day concentrations are greater than the monthly mean values. The concentration of CH_4 reached 1.82 ppm on April 23−25, 2009. From figure 6, we also see that the monthly mean concentration of CO_2 in March 2010 are greater than the other monthly mean values, this is mainly because that the SDS covered areas were mainly desert or Gobi with little vegetation, without the respiration of vegetation the concentration of CO_2 has great value. We also found that the concentrations of CO_2 in March were higher than in April. This is because that with the spring coming, the vegetation covers increasing which can absorb CO_2. The lowest monthly mean concentration of CO_2 appeared in April 2009; this is because that this SDS mainly covered south of China where with higher vegetation. From figure 7 we can see that for the monthly mean concentration and the values on the SDS days on March 29−30, 2010, the concentrations of CH_4 are lower than the other times of SDSs. This is caused by a lack of CH_4 sources in desert and Gobi.

Although atmospheric CH_4 concentration is about 200 times less than CO_2, it contributes approximately 15% to current 'greenhouse' forcing in the atmosphere. This is because CH_4 is about 30 times more effective as CO_2 in absorbing IR radiation, and is about 45 times more effective as a greenhouse gas overall than CO_2 when the longer atmospheric residence time of CH_4 is taken into account (Ojima *et al.* 1993). So monitoring the concentration of CH_4 in atmosphere is also important.

Wetlands are among the primary sources of atmospheric CH_4, of which 1.10×10^{11} kg are from the anoxic decomposition of organic matter in natural wetlands each year. Flooded rice fields and Peatlands are also primary sources of CH_4 (Jackel *et al.* 2001, Ojanen *et al.* 2010). These sources account for 15–30% of the total annual CH_4 emissions, and dry-land emits the smallest amount of CH_4 in all the land cover types (Jiang *et al.* 2009). From figure 4 we can see that, the SDSs on March 29–30, 2010 mainly originated from and affected areas that are both in northwestern China, where the land cover is mainly desert or Gobi, and the concentration of CO_2 and CH_4 changed just a little compared with the monthly mean value (see figure 6 and figure 7). From the analysis above, we can state that SDSs can increase the concentration of CO_2 and CH_4, but in the area with little vegetation cover, the increasing is not obvious.

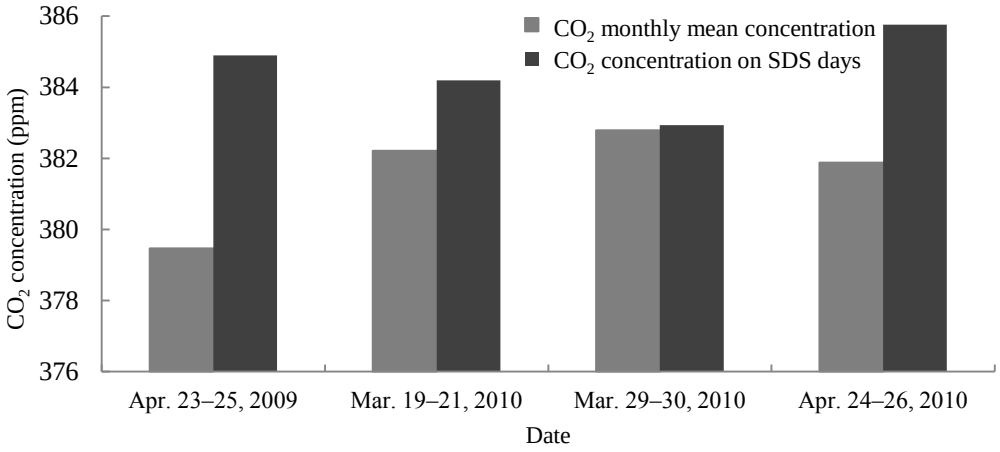

Figure 6. The concentration of CO_2 on SDS days and the mean values of SDS month.

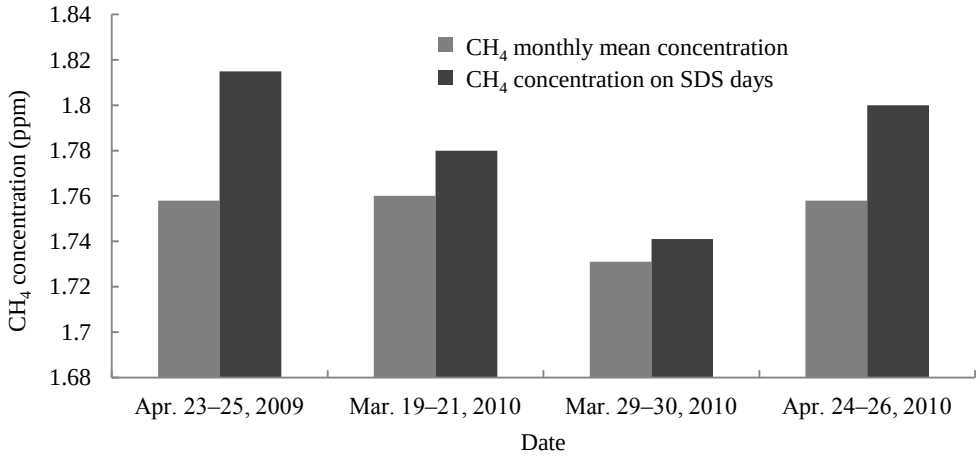

Figure 7. The concentration of CH_4 on SDS days and the mean values of SDS month.

To further understand how SDSs affect GHGs, we analyzed the concentration changes of CO_2 and CH_4 before and after SDSs (see figures 8−11). In order to increase the accuracy, on the SDS days, we used the mean value of the points that were covered by the SDS happened day; the values of before and after SDSs, we used the mean value of the points that were covered by the onetime of SDS (the same as the corresponding area that mentioned before). We can see that CO_2 and CH_4 levels exhibit a similar trend: they all clearly increase when the SDS occurs; they then reach the peak value on the last day of the SDS and then decrease to the normal value. This result shows that SDSs contribute to the greenhouse effect by increasing the concentrations of CO_2 and CH_4 in the atmosphere.

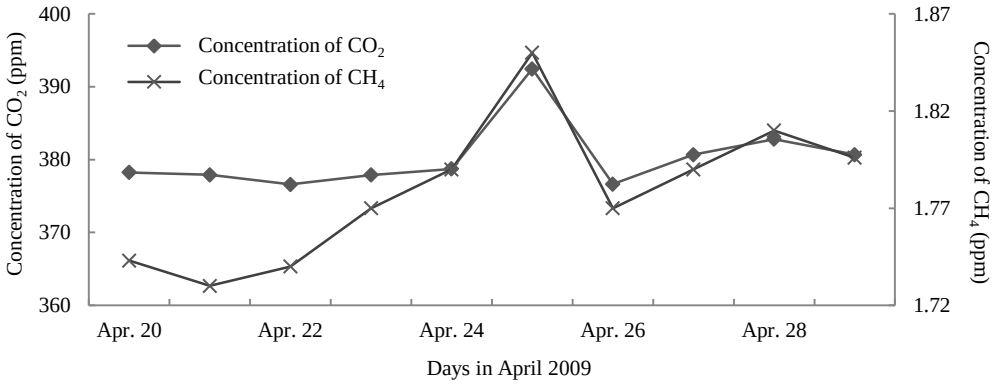

Figure 8. The concentration changes of CO_2 and CH_4 before and after the SDS of 23−25 April 2009.

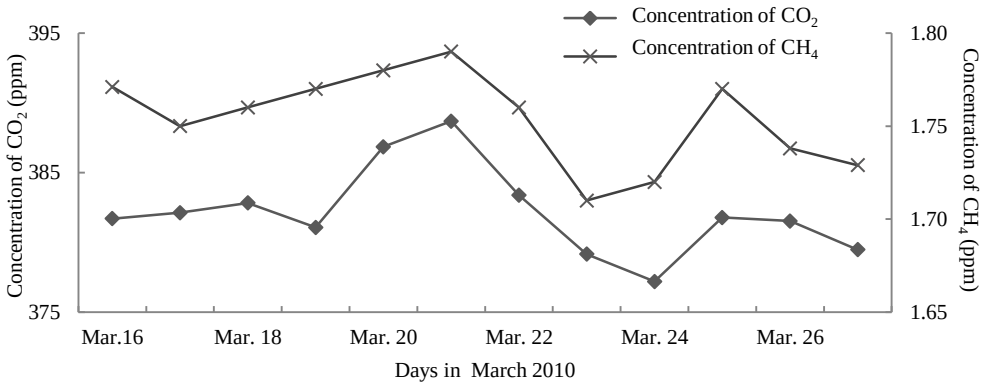

Figure 9. The concentration changes in CO_2 and CH_4 before and after the SDS of 19−21 March 2010.

Some researchers have found that soil carbon (C) plays a major role in contributing to atmospheric concentrations of GHGs such as CH_4 and CO_2 (Duan *et al.* 2001, Mahdi *et al.* 2005). Desertification is one of the most serious environmental and socioeconomic problems in many arid and semi-arid regions of the world (Gomesa *et al.* 2003). It not only results in soil degradation and severe decreases in the potential productivity of land (Gad and Abdel 2000), but it can also increase the emission of soil C and N as GHGs (Dale and Peter 2001, Breuer *et al.* 2006). Over the past 40 years, in China the total CO_2 amount released by desertification was 1.50×10^8 kg, while the CO_2 amount sequestered by desertification reversing processes was 5.9×10^7 kg C. The net CO_2 amount released from the desertified lands of China corresponded to 9.1×10^7 kg C, or approximately 68.42% of the 1.33×10^8 kg C of annual CO_2 released in the global temperate and frigid zones (Duan *et al.* 2001). SDSs are the most serious consequence of desertification; thus, we can conclude that SDSs may increase the concentration of GHGs through the dust flow in the atmosphere.

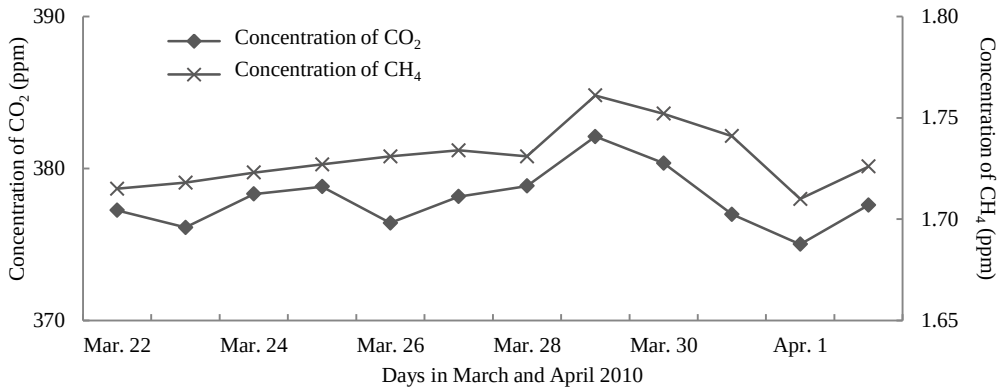

Figure 10. The concentration changes in CO_2 and CH_4 before and after the SDS of 29−30 March 2010.

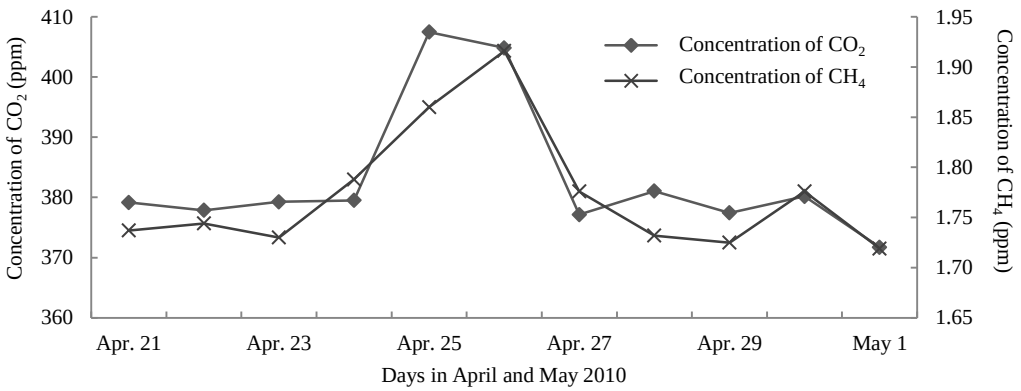

Figure 11. The concentration changes in CO_2 and CH_4 before and after the SDS of 24−26 April 2010.

Based on the GOSAT data, we found that northwestern China (Xinjiang, Gansu and western Inner Mongolia) and southern Mongolia had mean CO_2 concentration of 380.06 ppm in March and April 2010, and the mean concentration in southeastern China (Shandong, Henan, Hebei, Hunan, Anhui and Jiangsu provinces) was 376.59 ppm. The SDSs not only transform the sand dust but also the atmosphere. All of the matters in the atmosphere were transferred from northwestern to the southeast of China when SDS happened, causing the concentration of CO_2 in the sand-dust-covered areas increase.

The concentration of CH_4 has the opposite trend to CO_2, in northwestern China and southern Mongolia, the average value of CH_4 was 1.73 ppm and in southeastern China, the concentration was 1.76 ppm in the March and April 2010. But along with the moving of dust storm from northwest to southeast, the concentration of CH_4 was increasing. This increase in CH_4 has been partly attributed to the increasing sources of CH_4 such as rice paddy cultivation, wetland and fossil fuel processing in southeast of China. Some researchers have found

that CH_4 can be offset by oxidation that largely takes place in the atmosphere through reaction with the free radical (OH) (Crutzen and Gidel 1983, Cicerone and Oremland 1988). OH in the atmosphere is generated photochemically through short wavelength radiation, such as the reaction of electronically excited O atoms with H_2O and organic molecules. The radiation will decrease when the SDS occurs. This weakens the formation of OH. Furthermore, dust can integrate the H_2O of atmosphere easily, which also causes the decreasing of OH.

4. Summary and conclusions

CO_2 and CH_4 are the major GHGs in the atmosphere affected directly by human activity. Over the past several centuries, atmospheric CO_2 and CH_4 concentrations have increased rapidly (Cicerone and Oremland 1988, Gaetano 2006). In this paper, we used MODIS data to monitor 4 SDSs covered areas in the spring 2009 and 2010, and then we used GOSAT data to detect how SDSs influence the concentration levels of CO_2 and CH_4. After we compared the CO_2 and CH_4 concentration on sand dust days to the mean value of the corresponding dust-storm month, we found that the SDS days had higher values than the monthly average. After analyzing the concentration before and after SDSs, we found that the SDSs increase the concentration of CO_2 and CH_4. When the dust storms occurred, the concentrations of CO_2 and CH_4 increased and reached peak values on the last or penultimate days of the storm and then decreased to their normal values. Atmospheric flow from north to south of China is the main reason of CO_2 concentration increase; the lack of OH radicals during SDSs and the presence of CH_4 sources in southeast of China are the main reasons of CH_4 increase. We also found that in arid and semi-arid areas, the SDSs had little effect on the concentration of CO_2 and CH_4.

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