China Dust-storm Monitoring Using Meteorological Satellite

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Abstract: Dust-storm is one of the heaviest hazardous weather which frequently affects most part of northern China in spring. Satellite multi-spectral observations can provide significant information for detecting and quantitative determining the property of dust-storm . An algorithm to monitor dust-storm automatically was developed based on satellite observation. The algorithm utilizes split widows technique and spectral classification technique and also developed a new dust remote sensing product Infra-red Difference Dust Index (IDDI) proxy dust-loading dataset using GMS-5.

Keywords: Dust-storm, split windows technique, IDDI

1. Introduction

Dust-storm is one of the biggest hazardous weather over north part of China in spring. As social and economic developments, Its impact become more and more greater, and therefore there are great needs of monitoring dust-storm outbreaks as well as retrieve their optical properties in recent years. Long-term daily monitoring of dust load over land and ocean using satellite is a very important way for the global and regional environment and climate. The generation of dust ,its transport, and its deposition are significant process for ecological studies. As a result, it is important to monitor the frequency, the magnitude, and the trajectory of dust storm at global and regional scale.

Several studies have successfully retrieved information concerning dust concentrations and distributions over the oceans using visible-wavelength AVHRR and METEOSAT data. The ocean surface exhibits a high degree of homogeneity and reflectance is low for visible radiation, so dust clouds appear as bright regions superimposed on the dark ocean background. Optical thickness may be calculated from the visible reflected radiance, and converted into estimates of aerosol concentration. The retrieval of similar information over land areas has proved problematic. UV-absorbing aerosols, including desert dust, over both land and ocean regions on a global scale has been achieved using the Total Ozone Mapping Spectrometer (TOMS) on the Nimbus 7 satellite, using the fact that UV surface reflectivity is low and nearly constant over both land and water.

Spatial and temporal continuity of data are necessary if the large-scale impact of dust loadings on climate over periods ranging from hours to months is to be assessed. So the use of geostationary meteorological satellite data seems to us more relevant such as GMS, FY-2. These satellites can systematically monitor the interest region of north china and Northeast Asia. It is therefore very suitable for our purpose. But we must integrate many kinds of remote sensing analysis techniques to our project. First split widows technique is based on negative brightness temperature difference (BTD) between 11μm and 12μm of dust , which differ from most of cloud and ground surface. The BTD can be simulated using MODTRAN radiative transfer model. Secondly Spectral classification technique uses the multi-spectral channel signal of dust-storm which discriminate it from other targets. And the last technique is the Infra-red Difference Dust Index (IDDI) proxy dust-loading using many observation data. All of theories will be described detailedly bellow.

2. Dust detection technique

2.1 IR split widows technique

Neglecting the atmospheric effects and aerosol scattering , Measured infrared radiance over a narrow spectral bandpass can be approximated as

$$I_\lambda \approx B_\lambda(T_s)\cdot exp(-\tau_\lambda) + (1-exp(-\tau_\lambda))\cdot B_\lambda(T_a) \qquad (1)$$

Where B_λ is Plank function; T_s and T_a are surface temperature and an effective temperature of the aerosol layer, respectively, τ is the aerosol optical depth. Upwelling thermal infrared radiation between 11 and 12μm from the earth's surface is selectively scattered and absorbed by airborne particles. Volcanic silicate ash can be discriminated by using the dual thermal infrared bands found on meteorological satellites because ice and liquid water particles preferentially absorb longer wavelengths while silicates preferentially absorb shorter wavelengths. So silicate particles cause a negative brightness temperature difference (BTD<0). Using BTD to discriminate the volcanic cloud from meteorological clouds is called the "split windows" method. Dust storm contain large amounts of dust and sand particles, which appear the similar different absorption characteristic to the volcanic silicate in the thermal region. We simulated the BTD signal of dust aerosol using MODTRAN radiative transfer model and the result as the figure 1. This figure shows that no matter what the surface temperatures are, as the surface visibility goes smaller, the BTD goes lower, and this trend becomes inverse when surface visibility is very poor. We can detect the existence of dust aerosol by using BTD when the optical depth is not very thick.

2.2 Spectral classification technique

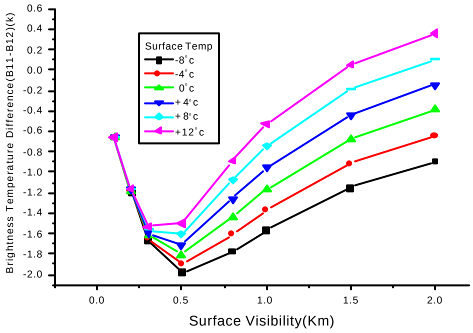

Fig1.The relationship between surface visibility and temperature differences a function of ground surface temperatures for middle latitude winter atmosphere

The difficulty to locate high dense dust-aerosol regions is the identification of dust-storm region from open and cirrus cover regions. The dust, open and cirrus regions are indicated by a, b, and c respectively in figure 2. Although there is no significant difference between a and b in visible image, the radiative temperature for a is significant lower than b due to the height of dust cloud. Comparing visible and infrared images, it is not difficult to distinguish them. As for cirrus cloud, because of its semi-transparent, there are great similarities between dense dust-aerosol region and cirrus cloud region in both visible and infrared images. But because water vapor channel is sensitive to water vapor contents in high level and the atmosphere should be saturated when cirrus appear, the cirrus always look brighter than dust. Comparing visible, infrared and water vapor channels, we can distinguish dense dust-aerosol region from open and cirrus cover regions.

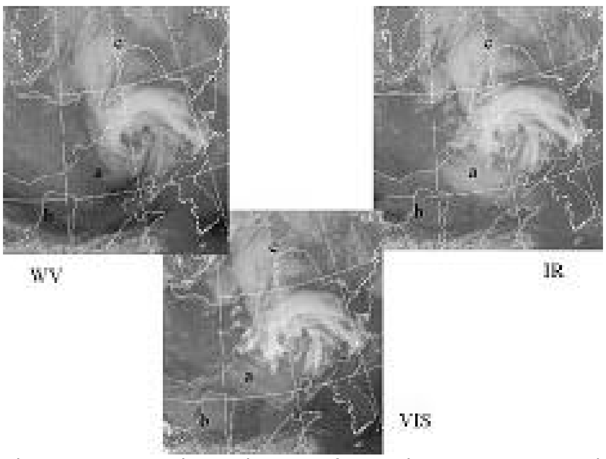

Fig2. WV, IR and VIS images for a dust- storm event (a: dust-storm; b: open region; c: cirrus)

2.3 Infra-red Difference Dust Index(IDDI)

The presence of a dust layer will reduce the infrared radiance of satellite targets in arid and semi-arid regions where the flux of sensible heat from the ground surface to the atmosphere is high. Several processes contribute to the lowering of the IR radiance. Firstly, the dust layer will reduce incoming solar radiation, cooling the land surface and thus reducing the outgoing longwave radiation (OLR) from the land. Secondly, if the dust particles are of a size comparable to the wavelengths of the measured IR radiation, some of the IR radiation emitted by the land will be absorbed by the dust layer, attenuating the OLR signal. The component of the measured IR signal originating from the dust layer will therefore represent a lower temperature than that characterising the land surface. The higher the altitude of the dust layer, the lower this temperature will be. The temperature depression (with respect to clear-sky IR radiance) resulting from the presence of dust in the atmosphere may be used as an index of dustiness. Modeling studies suggest that a dust layer between the surface and the 500 hPa level, with an optical depth ranging from 0.5 to 3 results in a measured IR temperature depression of 10-30 K.

Infra-red Difference Dust Index (IDDI) has been developed at the Laboratoire d' Optique Atmosphérique (LOA) de Lille, at L' Université des Sciences et Technologies de Lille in France (Legrand *et al.*, 2001). The IDDI is a record of the reduction in brightness temperature of the Earth-atmosphere system due to the presence of aerosols. Over the arid and semi-arid regions of northern China and Mongolia , the dominant aerosol types are soil-dust particles originating in the Desert, so the IDDI may be interpreted as representing airborne dust of desert and semi-desert origin over these areas. The next stage is to create reference images representing clear-sky conditions for consecutive, non-overlapping periods whose duration is short enough to eliminate seasonal effects but long enough to ensure that clear sky or near clear-sky conditions characterise at least one measurement for each pixel. In order that these criteria are fulfilled, a 10-day reference period is used. For a given pixel, the maximum in the values of BT within a given reference period is assumed to represent the value characteristic of the target area in question in the absence of cloud and dust haze for that period. Daily "difference images" are then constructed by subtracting the measured daily values from the values of the reference image for the period in question. In the case of the brightness temperature data, difference values indicate the temperature depression for each pixel due to the presence of atmospheric aerosol particles or cloud. In order to use the IDDI as a means of measuring atmospheric dust, cases where the reduction in BT is due to the presence of cloud must be identified and either masked or removed. These monthly means of IDDI have been constructed from "instantaneous" daily IDDI taken at different time. The figure 3 show the monthly means of IDDI in northern China April, 2001. The result indicate the mean spatial distribution and relative strength of dust event. The IDDI is a new by-product of dust storm monitoring operation system.

3. Data process and Result

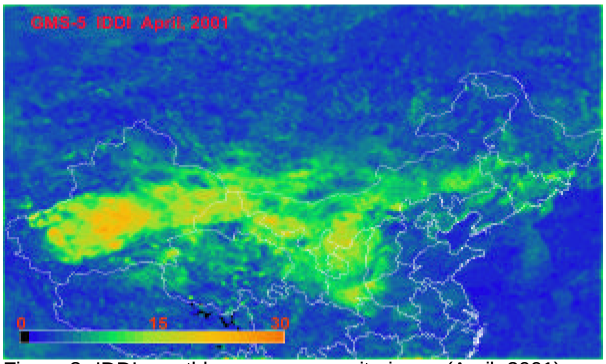

Figure 3 IDDI monthly mean composite image(April, 2001)

We use all channels' data of GMS-5 to monitor the dust event of northern China in Spring . First the disk image of GMS is projected to a northern China area in the same latitude/longitude grid and calibrate the digital value to brightness temperature(IR) or reflectance(VIS). We call the raw data as "origin image"(OI) and calculate the BTD using the OI . A clear and clean (hot) IR reference image(RI) is constructed with the collection of these hottest value, picked out for every pixel from the series covering 10 days. And then a difference image(DI) , exhibiting the clouds and dust information, is created by subtracting every OI from its corresponding RI. The next step in the processing consists of identify cloud in the OIs. We adapt several techniques to identify the cloud pixel. These techniques include the high reflectance method in VIS channel, the spatial coherence method, IR BTD threshold method, correlation method of water vapor channel and IR channel. The detailed description of the cloud masking will be introduced in other paper. The IDDI image can be derive from the DI and cloud masking. The last step of dust event monitoring is combine the BTD, IDDI and the spectral classification parameter. We define the dust level area of based on the IDDI value, which is 10-20k, 20-30k,higher 30k corresponding to weak, middle strong and heavy dust event respectively. Figure 4 is the result of dust event monitoring at 1:32 April 7, 2001. it show the result of single time in one day. If we cumulate all the times of monitoring result, we can get the occurrence frequency of all dust storm during some time such as one month (or one year). Figure 5 show the Occurrence frequency of all dust storm monitored by GMS-5 in 2001. We can see the several typical dust source region including Taklamakan, Tengeli, Maowusu, and Henshandake desert, and transportation path from the sources. These visual and value results can be used to find the source of dust emission, monitoring the dust seasonal activity, and their year-to-year change and long-term evolution.

4. Discussion

This paper introduce a integrated technique to monitoring the dust storm in China using geostationary meteorological satellite GMS. The set operation system of dust storm monitoring is completely automatic system on PC windows. We've got the monitoring result of dust storm in China in recent three years since 2001. From these result, we can see the year-to-year change of the distribution and strength of the dust event in northern China and around areas. But GMS have finished its flight mission since May, 2003. We will apply this algorithm to the data of the next geostationary satellite FY-2C of China, which will be launched in 2004. The validation of result is our next task about this work.

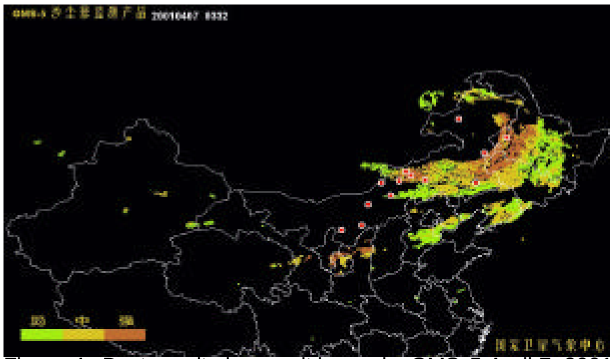

Figure 4 Dust monitoring result image by GMS-5 April 7, 2001, GMT Time:, the Green, Yellow and brown area stand for the weak, middle strong and heavy dust event respectively. And the ground observation report(red point with white circle) is pointed in image

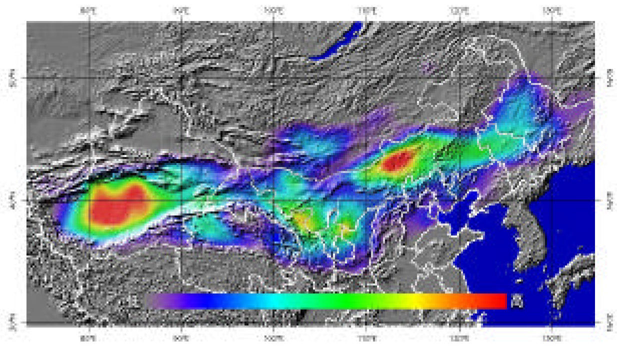

Figure 5 Occurrence frequency of all dust storm monitored by GMS-5 in 2001

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