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DUST REMOTE SENSING WITH GEOSTATIONARY SATELLITE FY-2C

Summary and purpose of paper

The paper introduces the product for dust storm detection at CMA: Infrared Difference Dust Index (IDDI) is produced based on FY-2C VISSR observation and has become operational process of CMA/NSMC.

DUST REMOTE SENSING WITH GEOSTATIONARY SATELLITE FY-2C

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1. Introduction

FY-2C multi-spectral observations contain information for dust-storm detection. An algorithm of automatically monitoring dust-storm was developed based on FY-2C satellite. The algorithm uses split widows technique and spectral classification technique. Split widows technique is based on negative brightness temperature difference (BTD) between 11μm and 12μm, which differs from most of clouds and the ground surface. The BTD can be simulated using MODTRAN radiative transfer model. Spectral classification technique uses the dust-storm signal contained in multi-spectral channel to discriminate it from other targets. The two techniques are combined to identify the dust cloud and to track the dust transport path and estimate the effected area. In addition, we try to retrieve the quantitative property of dust including particle sizes, optical depth and total masses of particles with BTD. For doing this, a large number of simulations were conducted using radiative transfer model. Result shows that a correct microphysical model is required to generate BTD value and it is not a single linear relation between BTD and the total dust optical depth. We also produced a dust remote sensing product Infra-red Difference Dust Index (IDDI) proxy dust-loading dataset using FY-2C. The IDDI is a record of the reduction in brightness temperature of the Earth-atmosphere system due to the presence of dust aerosols which can be interpreted as representing airborne dust loading. Currently, dust detection is operational with FY-2C.

2. Method

The basic theories for remote sensing airborne dust and corresponding detection technique are followed.

2.1 IR split widows technique

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

$$I_\lambda \approx B_\lambda\ (Ts)\cdot\cdot exp(-\tau_\lambda)+\ (1\text{-}exp(-\tau_\lambda)\ \cdot B_\lambda(Ta)$$

where B_λ is Plank Function; Ts and Ta are surface temperature and the effective temperature of the aerosol layer, respectively, τ is the aerosol optical depth. Upwelling thermal infrared radiation between 11μm 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). Dust storm contains large amount of dust and sand particles, similar different absorption characteristic occurs to the volcanic silicate in the thermal region.

We simulated the BTD signal of dust aerosol using MODTRAN radiative transfer model and the result given in 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 with the BTD when the optical depth is not very thick. From this simulation, it shows that BTD between band 11μm and 12 μm is negative. BTD of thermal split window channels depend on the density of air dust.

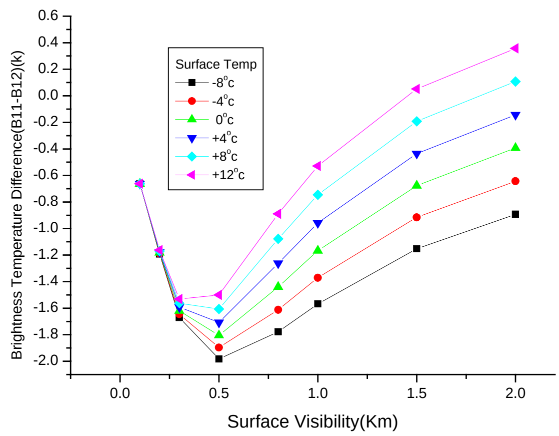

Figure 1. The relationship between surface visibility and temperature differences a function of ground surface temperatures for middle latitude winter atmosphere

2.2 Multi-spectral classification technique

The difficulty to locate high dense dust-aerosol regions is in the identification of dust-storm region from open and cirrus covered regions. The dust, open and cirrus regions are indicated with a, b, and c respectively in figure 4. Although there is no significant difference between a and b in visible image, the radiative temperature for a is significantly 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-transparency, there is great similarity between dense dust-aerosol region and cirrus cloud region in both visible and infrared images. But because water vapor channel is sensitive to high level water vapor content, and the atmosphere should be saturated when cirrus appears, the cirrus always look brighter than dust. Comparing the visible, infrared and water vapor channels, we can distinguish dense dust-aerosol region from open and cirrus cover regions.

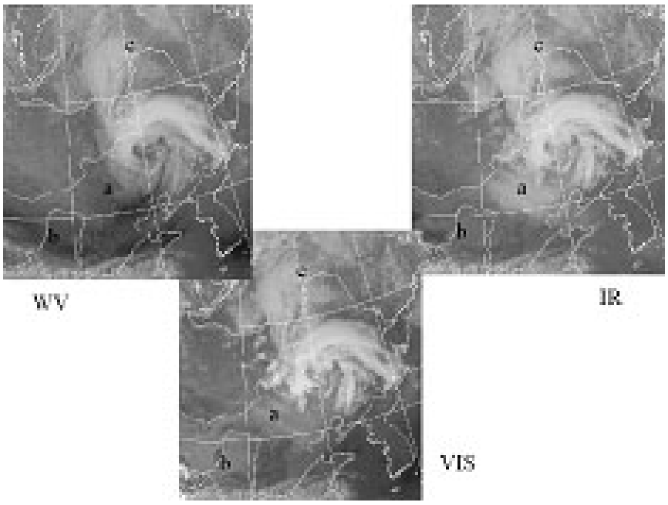

Figure 2. WV, IR and VIS images for a dust target (a: dust-storm; b: open region; c: cirrus)

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 long-wave radiation (OLR) from the land. Secondly, if the dust particles are of the size comparable to the wavelengths of the measured IR radiation, land IR radiation will be absorbed by dust layer and attenuate the OLR signal. The component of measured IR signal originating from the dust layer will therefore represent as a lower temperature than that of the land surface. The higher the altitude of the dust layer, the lower this temperature will be (neglecting the effect of temperature inversions). Figure 3 shows mechanisms explaining the depression of thermal infrared radiance outgoing to space in the presence of a dust layer over land.

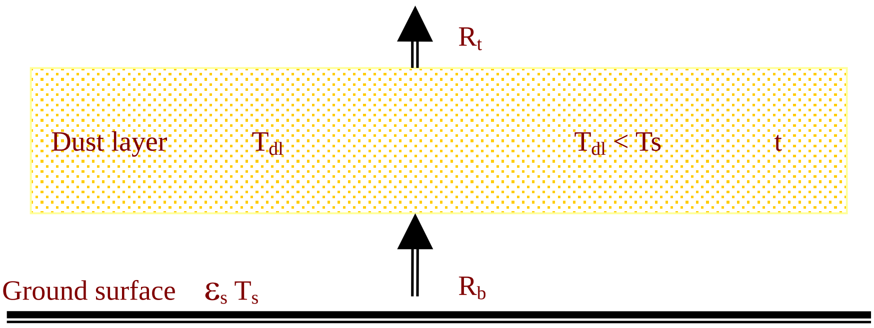

Figure3 Mechanisms explaining the depression of thermal infrared radiance outgoing to space in the presence of a dust layer over land

Infra-red Difference Dust Index (IDDI) is defined by :

$$IDDI = T_{BB} - T_s$$

where T_{BB} is the observed brightness temperature by sensor from space, Ts is the underlying background surface brightness temperature which is obtained in clear sky at the same condition.

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., 1994).

3. Processing and Dust Case

The operational program framework is following for dust detection based on FY-2C. The main program is composed of those parts as Data Input and Calibration Module, Reference Image Production Module, Cloud Mask or Check Module, Synoptic data Reading Module, Dust Identification Module and Result Output Module. Dust Identification Module is the core module in this algorithm, but other Modules are also important for exact dust detection information.

We use all bands' data of FY-2C to monitor dust event of north China in spring. Firstly full disk image of FY-2C is projected to a Northeast Asia area using the equivalent latitude/longitude grid and calibrate the digital value to brightness temperature(IR) and reflectance(VIS). We call the raw data as "original 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. And then dust event detection and discrimination is combine the BTD, IDDI and the spectral classification parameter. Finally we produce dust occurrence area image (RGB or Grid data)and corresponding IDDI value product. We define the dust level area of based on IDDI value, which is 10-20k, 20-30k,higher 30k corresponding to weak, middle strong and heavy dust event respectively. The figure 4 is the result of dust event monitoring at 04:00 April 19, 2005. Based this, we can also make the occurrence animation of every dust event from all time results.

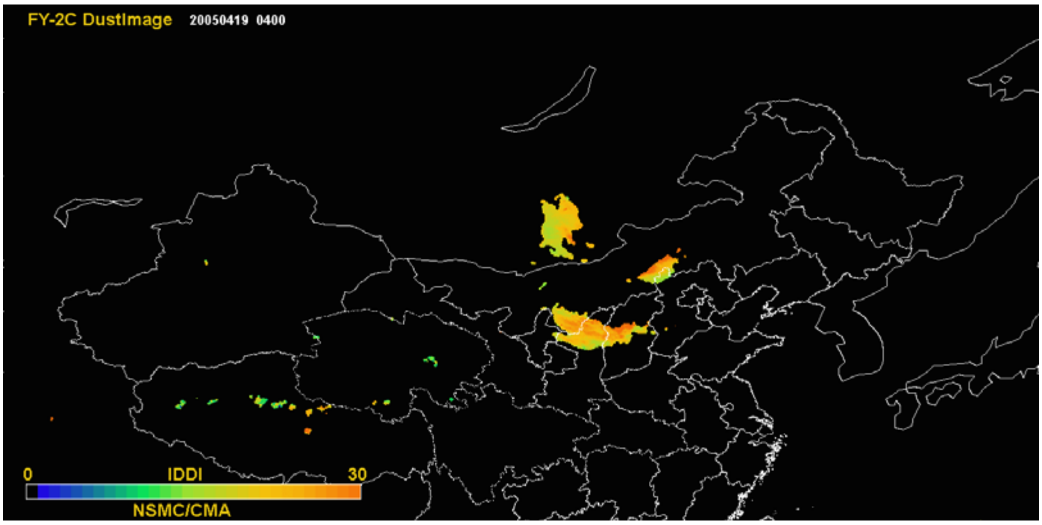

Figure 4 FY-2C Dust detection result IDDI image(2005.4.19, GMT04:00)

We made comparison using the PM10 data. During the dust weather day, PM10 observation can validate the results from satellite observation. From the PM10 value distribution, we see the dust outbreak which is consistent with FY-2C IDDI spatial distribution. Figure shows two dust cases in April 28-29, 2005.

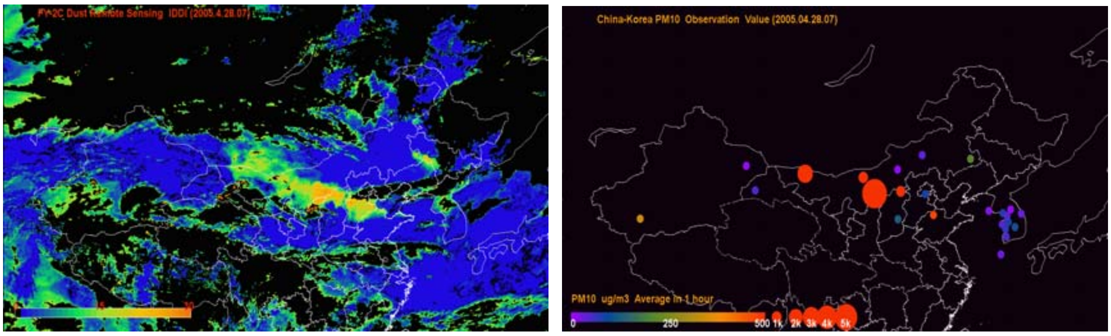

Figure 5 FY-2C IDDI value compare with Ground observed PM10 value at the same time(2005.04.27 07:00)

4. Discussion and future plan

To make it short, the algorithm of dust detection based on FY-2C is effective for detecting dust event in northeast Asia. We can monitor the occurrence and evolution of every dust event. We also obtain distribution and occurrence frequency of dust events in every spring from a serial of FY-2C observations.

There is still improvement needed for the algorithm. First, it is necessary to improve the cloud mask algorithm and reduce cloud contamination. Secondly, there is a daily cycle of TBB, Ts and IDDI so that a new idea is to develop thresholds for dust identification. We shall not use a fixed threshold for the whole day, instead, we apply dynamic thresholds corresponding to different observation time. It is based on the diurnal circle of the Ts and IDDI.

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