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## EXTRACTION OF THE DISTRIBUTION OF YELLOW SAND DUST AND ITS OPTICAL PROPERTIES FROM ADEOS/POLDER DATA

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### ABSTRACT

The yellow sand dust (called "Kosa" in Japan) transported from the deserts in the northern part of China often covers over East Asia in the late winter and spring. "Kosa" phenomena were observed on April 13 and 14, 1997 at meteorological stations in Japan. The ADEOS/POLDER data just taken on April 13, 1997 was used to estimate the distribution of hazy Kosa clouds and the optical properties of yellow sand dust.

The long-range transport of yellow sand dust was simulated to estimate the transport paths and the global mass distribution of yellow sand dust, because it is difficult to extract the optical properties of the widely spread hazy Kosa cloud from the satellite-level data. The result of the long-range transport simulation shows that the regions of the high concentration of yellow sand over the Sea of Japan obtained from the simulation almost correspond to the hazy Kosa regions appeared in the POLDER image. In order to estimate the optical properties of yellow sand dust in hazy Kosa regions over the Sea of Japan, several points were selected from the hazy regions in the POLDER image. The observed reflectances by the POLDER in each point were compared with those obtained from the simulation of the radiative transfer in the atmosphere-ocean system. As a result, it is shown that at the 565nm channel, the refractive index of yellow sand dust is in the range from 1.45 to 1.6, and the optical thickness of atmosphere  $\tau(565\text{nm})$  is 0.42 to 0.56.

### 1 INTRODUCTION

The yellow sand dust (called "Kosa" in Japan) transported from the deserts in the northern part of China is regarded as the main source of atmospheric aerosols for East Asia in the late winter and spring. The dust particles in the atmosphere have significant effects on retrieving the surface information such as the ocean color and the surface albedo from satellite-level data, because the radiance received by the satellite sensor includes the skylight scattered diffusely by the yellow sand dust. The optical properties of yellow sand dust and the structure of the dust layer have been studied by means of Lidar observation from ground stations (Arao 1986, Kai 1988). However, it is as yet very difficult to extract the optical properties of the widely spread hazy Kosa cloud that will consist of the yellow sand dust from the satellite-level data such as NOAA AVHRR and Japanese meteorological satellite (GMS) data.

"Kosa" phenomena were observed on April 13 and 14, 1997 at meteorological stations in Japan. The concentration of the suspended particulate matter in the air measured at ground stations in the Ishikawa prefecture at the side of the Sea of Japan was high (Tanimoto, 1997). The ADEOS/POLDER data just taken on April 13, 1997 was used to estimate the distribution of hazy Kosa clouds and the optical properties of yellow sand dust.

First of all, composite color POLDER images were generated to visually identify the hazy Kosa regions on POLDER images. It was, however, difficult to clearly distinguish between normal clouds and hazy Kosa clouds on their color POLDER images. Therefore, we simulated the transport paths and the global mass distribution of yellow sand dust for East Asia by using the long-range transport model including dry and wet depositions to extract the regions where it looks like Kosa clouds from POLDER images (Kusaka, 1998). The starting date and source regions for the transport simulation were determined by referring to the weather chart and the surface wind velocity (wind velocity at the height of 10m) given by ECMWF (European Center for Medium range Weather Forecasts). The results of the long-range transport simulation show that (1) the source locations of yellow sand particles observed on April 13 in Japan are the Takula Makan desert and the dry region in the north of Beijing, China, and (2) the high concentration regions obtained from the simulation almost correspond to the hazy Kosa regions appeared on the POLDER image.

Next, the optical properties of yellow sand dust spreading widely over the Sea of Japan were estimated. Several points

were selected from the hazy Kosa regions appeared on the POLDER image. The POLDER sensor observes target reflectances quasi-simultaneously up to 13 different viewing angles in a single satellite pass. For each point, the reflectances against different viewing angles were extracted from POLDER data at the 565nm and 765nm channels. The observed reflectances by the POLDER in each point were compared with the results obtained from the simulation of the radiative transfer in the atmosphere-ocean system. The computer code 6S (Vermote, 1997) was used to simulate the absorption and the scattering processes in the atmosphere. In this simulation, it was assumed that the sea surface is calm, and the size distribution of yellow sand is represented by the Junge power-law.

Finally, it is shown that at the 565nm channel, the refractive index of yellow sand dust is in the range from 1.45 to 1.6, and the optical thickness of atmosphere is 0.42 to 0.56.

## 2 IDENTIFICATION OF YELLOW SAND CLOUDS

### 2.1 Composite Color POLDER Images

POLDER level-1 data (Breon, 1997) used here are PIL1TBG1006545AD\_N50\_00\_N30\_00 (April 13, 1997). The scenes of sequence numbers 36-40 were extracted from them. The POLDER observes the polarized intensity as well as the radiance at 9 channels. The ground resolution of POLDER data is 6km by 7km. We generated composite color images using 6 non-polarized channels (443NP, 449NP, 565NP, 763NP, 765NP and 910NP channels), and checked carefully whether “Kosa”-like clouds are visible on their composite color images. The high concentration belts of “Kosa”-like clouds were clearly visible in the composite color image generated by the combination of 443NP, 565NP and 765NP channels. Fig.1 shows the geometrically corrected POLDER image (Blue:443NP, Green: 565NP, Red: 765NP) of the sequence No.38 taken on April 13. We can see that the hazy belts of “Kosa”-like clouds stretch from the western part of Korea to the Sea of Japan. However, it is not clear that the “Kosa”-like clouds actually consist of yellow sand whirled up in the desert of the northern part of China. We next estimate the distribution of yellow sand clouds appeared on POLDER images using the long-range transport simulation of yellow sand dust.

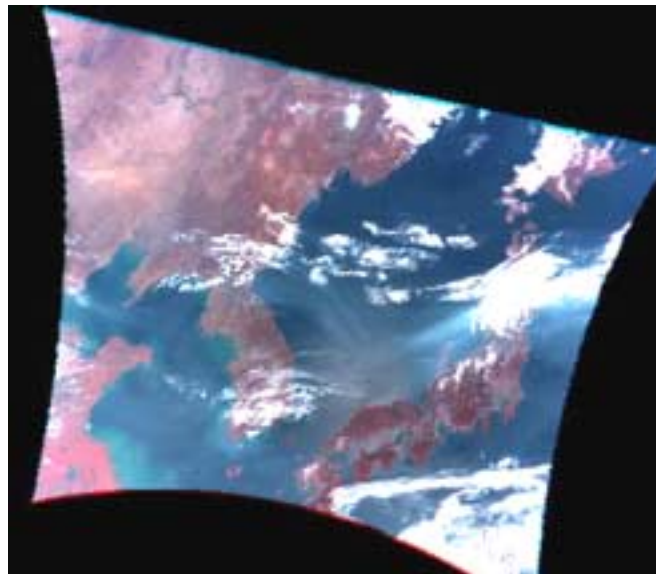


Figure 1 The geometric corrected POLDER image for East Asia (Blue: 490nm, Green: 565nm, Red: 765nm) taken on April 13,1997. The hazy belts of yellow sand dust are visible over the Sea of Japan and the Yellow Sea

### 2.2 Long-range Transport of Yellow Sand Dust

The long-range transport of yellow sand dust was simulated using the computer software (Mirage 3.0) developed by EDF and Aria technologies, France (ARIA, 1996). The Mirage 3.0 allows us to compute the diffusion and depletion of yellow sand dust as well as the trajectories of an air mass. The trajectories of the air mass were computed by tracing the wind field in the upper air given by the ECMWF, and the diffusion and depletion of yellow sand dust were computed using the estimated wind-flow trajectories. We have performed case studies for the long-range transport simulation of yellow sand. The most difficult and important problem for the transport simulation is to determine the initial conditions such as the source locations and starting date for the numerical simulation. In this study, the starting date and source locations for the numerical simulation were determined by referring to the weather chart and the surface wind velocity

(wind velocity at the height of 10m) in the ECMWF data. It is known that the yellow sand will be curled up by the surface wind with the velocity more than about 5 m/s (Water Research Institute, 1991).

The following three conditions were imposed to select the source regions of yellow sand:

- (1) The low atmospheric pressure is passing over desert areas.
- (2) The surface wind velocity is larger than 5m/s.
- (3) There is no precipitation during several days.

According to the weather chart, the low atmospheric pressure was appeared in the northern part of China on April 6, 7 and 8, 1997. We used the u-v velocity in the ECMWF surface data to identify the surface areas satisfying the condition (2), and use the precipitation per day in the forecast data given by the ECMWF to check the condition (3). Figure 2 shows the areas where the surface wind velocity is larger than 5 m/s on April 8. In Figure 2, the regions designated by red circles are the Takula Makan desert and the dry region in the north of Beijing, China, and satisfy the conditions (1) – (3) as mentioned above. The two areas, therefore, were chosen as source regions of yellow sand, and April 8 was chosen as the initial date for the numerical simulation. However, it is very difficult to investigate how high yellow sands are winded up at dry regions, and so dust particles were released at three altitudes, 700hpa (3.0km), 750hpa (2.5km) and 850hpa (1.5km). Flow-trajectories of them were computed every an hour from 00 GMT April 8 to April 15. Since flow-trajectories depend on the initial location, we computed flow-trajectories by changing source locations within dry regions shown in Figure 2. Figure 3 shows the trajectories at 00:00GMT of April 12, 13 and 14 in the case that air masses were released at the height of 750hpa over the Takula Makan desert (38N, 83E). Figure 4 shows the trajectories at the same time as Figure 3 in the case that air masses were released at the height of 850hpa over the dry area in the north of Beijing (43N, 116E). We can see that trajectories of air masses shown in Figure 4 correspond to the belt of thin clouds, extending from the north of the Korea peninsula to the Sea of Japan and to the Japan islands, in the POLDER image shown in Figure 1. Trajectories shown in Figure 3 also correspond to the hazy cloud passing over the southern part of the Korea peninsula in the POLDER image.



GMT 06:00 April 8, 1997

Figure 2 Two regions, Takula Makan desert and dry region in the north of Beijing, with the surface wind velocity larger than 5 m/s on April 8

In order to compute the diffusion and depletion of yellow sands, a constant mass flux of yellow sands was released during periods in which the low atmospheric pressure is passing over dry regions at the northern part of China. In the case of the Takula Makan desert, yellow sands were released during 12 hours, and were released during 6 hours in the case of the dry area in the north of Beijing. The size of yellow sands was assumed 2.5  $\mu\text{m}$ . Figure 5 shows the simulated concentration of yellow sands on April 13 over East Asia in the case that yellow sands were released at the altitude of 750hpa in two dry regions as mentioned before. In Figure 5, the concentration distribution of yellow sands larger than 60  $\mu\text{g}/\text{m}^3$ , which is the mean concentration of the suspended particulate matter in the air measured at the Ishikawa prefecture, Japan on April 13, is shown. As seen from Figures 1 and 5, hazy regions appeared in the POLDER image correspond to the high concentration areas obtained from the long-range transport simulation of yellow sands. Therefore, we consider that hazy clouds shown in the POLDER image of Figure 1 consist of yellow sands.

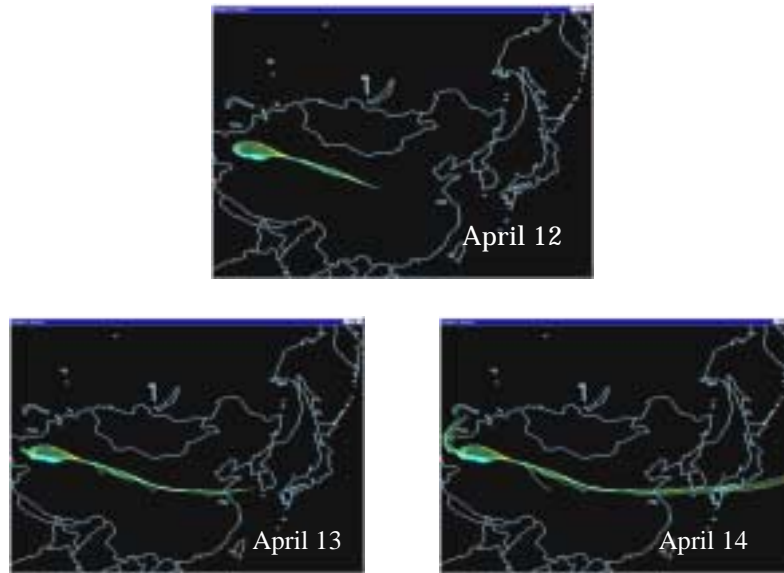


Figure 3 Flow-trajectories at 00:00GMT of April 12, 13 and 14 in the case that air masses were released at the height of 750hpa over the Takula Makan desert

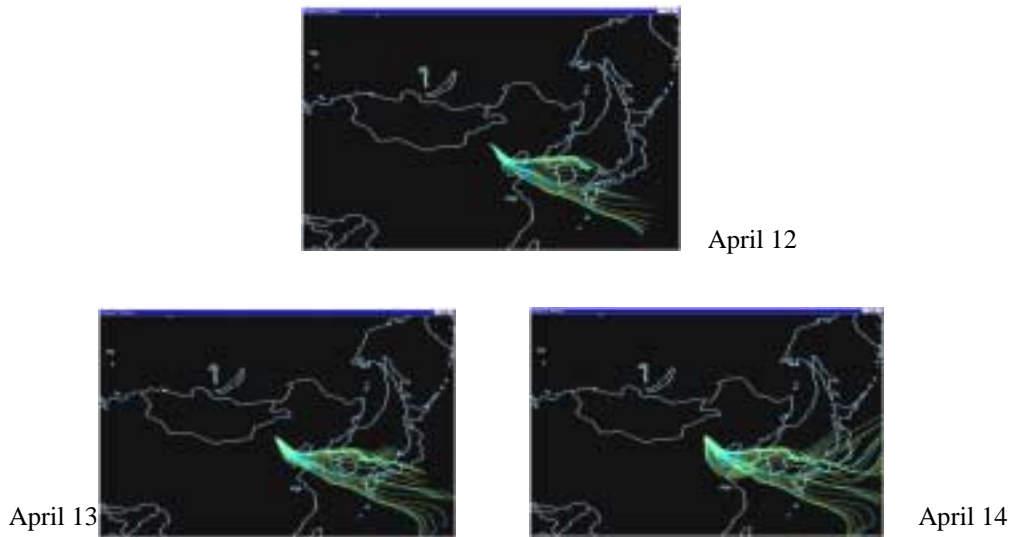


Figure 4 Flow-trajectories at the same date as Figure 3 in the case that air masses were released at the height of 850hpa over the dry land in the north of Beijing

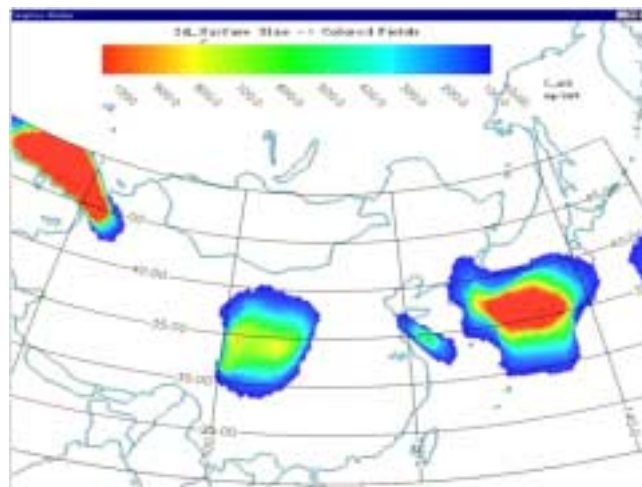


Figure 5 Concentration distribution of yellow sands larger than 60 µg/m<sup>3</sup> obtained from the transport simulation

### 3 OPTICAL PROPERTIES OF HAZY CLOUDS

The results of the transport simulation showed that the haze including yellow sands cover widely over the Sea of Japan. The optical properties of atmospheric aerosols including the yellow sand dust over the sea surface are estimated from the POLDER data (Sequence No. 38) taken on April 13.

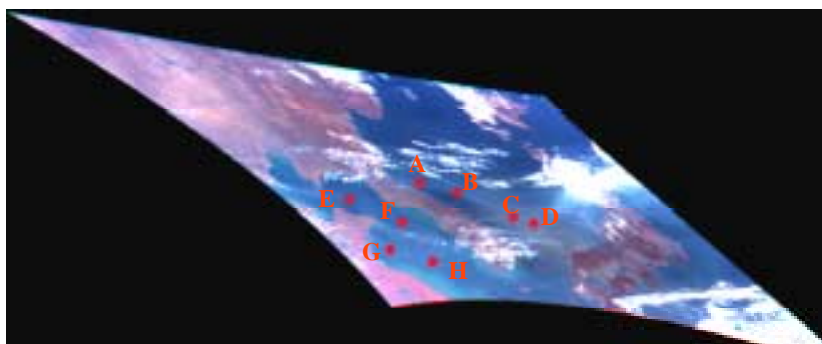


Figure 6 POLDER image given by the POLDER reference grid. The locations of the selected points, A, B, ---, H are shown on it.

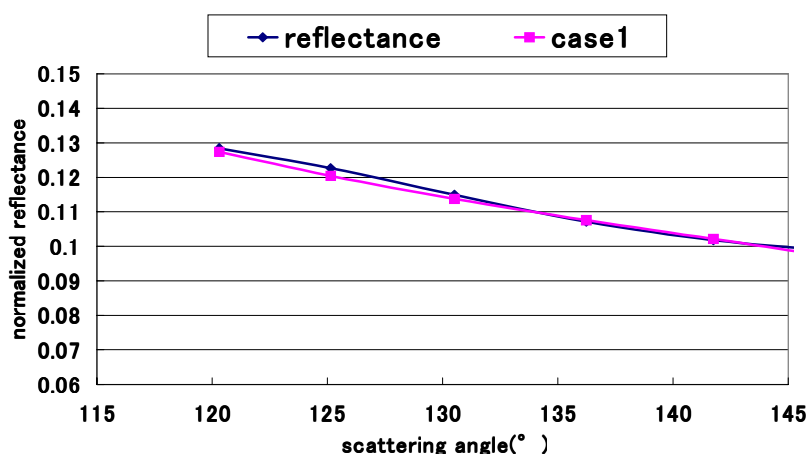


Figure 7 The observed reflectance (black line) and the reflectance (blue line) derived from the estimated optical parameters of yellow sand dust at the point B

Some points were selected from the high concentration belts of yellow sands appeared in the POLDER image. Figure 6 is the composite color POLDER image given by the POLDER reference grid, and the locations of the selected points, A, B, ---, H are shown on it. The reflectances up to 13 different viewing angles are measured at each point. The measured reflectances versus scattering angles were compared with those obtained from the simulation of the multiple scattering in the atmosphere-ocean system (Vermote, 1997) at each point. It was assumed in the simulation of the multiple scattering that the number size distribution for the yellow sand dust is described by the Junge power-law function,  $dN(r)/dr=c(r_0/r)^a$ , where  $a$  is an arbitrary constant,  $r$  the radius, and the absorption of light by yellow sands is taken no account. Given a certain  $a$  in the Junge function, the refractive index,  $nr$ , of yellow sand dust and the optical thickness of yellow sand dust  $\tau_y(550\text{nm})$  were changed as follows:

$nr$  : 1.3 to 1.6, interval  $\Delta nr=0.05$

$\tau_y(550\text{nm})$  : 0.1 to 0.5, interval  $\Delta \tau_y=0.05$ .

In cases of  $a=5$  and  $5.5$ , the values of  $nr$  and  $\tau_y$  in which the square errors between the observed reflectances and the simulation ones are minimum were determined. Figure 7 shows the result of the point B at the 565NP channel (central wavelength 564.5nm). In this case, it was found that  $a=5.5$ ,  $nr=1.55$ ,  $\tau(565\text{nm})=0.52$ , where  $\tau(565\text{nm})$  represents the total optical thickness of atmosphere at the 565NP channel. Optical parameters of the yellow sand dust at other points were determined in the same way as the case of the point B. The results are shown in Table 1. As seen from Table 1, optical parameters of yellow sand dust are somewhat different from one point to another, but we have 1.45 to 1.6 for the refractive index of yellow sand dust, 0.42 to 0.56 for the optical thickness of atmosphere at the 565NP channel.

(565nm)	A	B	C	D	E	F	G	H
a	5	5.5	5	5	5	5.5	5.5	5
nr	1.55	1.5	1.55	1.5	1.5	1.45	1.6	1.55
$\tau(565\text{nm})$	0.519	0.515	0.563	0.563	0.423	0.467	0.468	0.519
$\rho$	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

Table 1 The optical parameters of yellow sand dust clouds at 565nm.  $\rho$  is the reflectance of the sea surface.

#### 4 CONCLUSIONS

The distribution of hazy "Kosa" clouds was identified on the ADEOS/PODER image over the sea surface taken on April 13, 1997 using the long-range transport simulation of yellow sands. Optical properties of yellow sands were estimated at the points sampled from the hazy "Kosa" clouds.

The following results were obtained.

- (1) It was found from the long-range transport simulation that source regions of yellow sands observed on April 13, 1997 in Japan were the Takula Makan desert and the dry region in the north of Beijing, China, in which yellow sands were winded up by the strong surface wind on April 8.
- (2) The high concentration regions over the Sea of Japan obtained from the long-range transport simulation almost correspond to the hazy clouds appeared on the POLDER image. This means that the hazy clouds, which mainly consist of yellow sands, extend widely over the Sea of Japan.
- (3) By comparing the observed reflectances with theoretical ones evaluated from scattering processes in the atmosphere-ocean system, it was found that the refractive index of yellow sand dust is in the range from 1.45 to 1.6, and the optical thickness of atmosphere is 0.42 to 0.56 at the 565NP channel.

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