Response to reviewers

"Spatial distribution of dust's optical properties over the Sahara and Asia inferred from Moderate Resolution Imaging Spectroradiometer"

We would like to thank the Anonymous Referee#3 for the constructive comments. According to the comments, we modified the manuscript and we believe that the revised paper is improved. Our point-by-point responses and actions for the comments are listed as below. The comments from reviewers are *emphasized*, and our responses and actions are shown in blue. Modified part in the revised manuscript is shown in red. English correction by several native speakers is shown in green**.** The original sentences removed in the revised manuscript are shown as orange.

This manuscript present a method based on "critical surface reflectance" to estimateaerosol single scattering albedo along with aerosol optical depth. The nine-yearMODIS data were analyzed to plot the spatial distribution of aerosol optical propertiesover the Sahara and Asia. Uncertainties are also investigated in order to validate the estimated results. Generally, a lot of work has been done in this research, and the manuscript is well written. The following is my concerns:

1. In page 8 line 1, "three month periods of" should be removed.

Thank you very much. We remove that phrase in the revised manuscript.

2. Did authors consider the spatial variation of ozone concentration in the radiative transfer model when the look-up tables were calculated?

The spatial variation of ozone concentration was not considered in the original manuscript, and the vertical ozone profile of "US standard model" was used. Based on WMO (2011), we find that the annual average of total-column ozone at the southern part of Sahara is about 270DU, while that of the northern part is about 310DU. We performed sensitivity tests with the total-column ozone of 270DU and 310DU, and found that the spatial distributions of ω_0 and τ_a are almost the same as shown below.

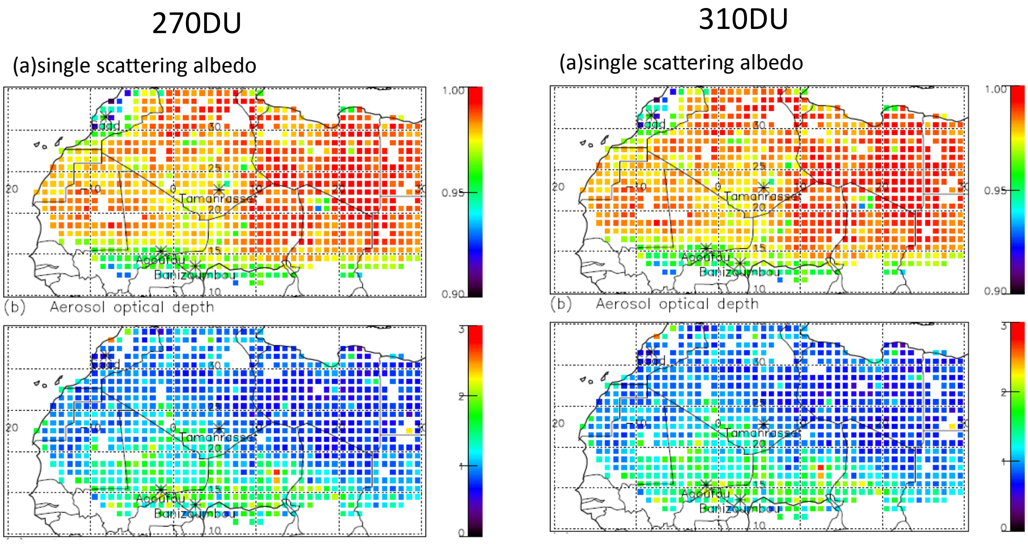


Figure: Aerosol single scattering albedo (ω_0) and optical depth (τ_a) using the total-column ozone of 270DU (left) and 310DU (right) for ch. 1.

In the revised manuscript, we give an explanation as follows.

[P31121_L25] Section 3.1.1 Sources of uncertainty

In addition to the uncertainties in aerosol model discussed above, the spatial variation of ozone concentration can be a source of uncertainty in our radiative transfer simulation. The annual average of total-column ozone over the northern part of Sahara is about 270DU, while that over the southern part is about 310DU (WMO, 2011). We performed a sensitivity test with the total-column ozone of 270DU and 310DU, but the uncertainty was quite small and did not affect the total uncertainty discussed above (not shown).

We also add the reference below.

[Reference]

World Meteorological Organization, Scientific Assessment of Ozone Depletion: 2010, WMO Global Ozone Research and Monitoring Project - Report No. 52, 2011.

3. The color in Fig. 3 is confusing.

We change the color in Fig. 3 (large ω_0 -> red). We also add the color bar in Fig. 3.

4. The spatial distribution of the estimated aerosol optical property uncertainties over Asia would be also interesting if are shown as Fig. 4.

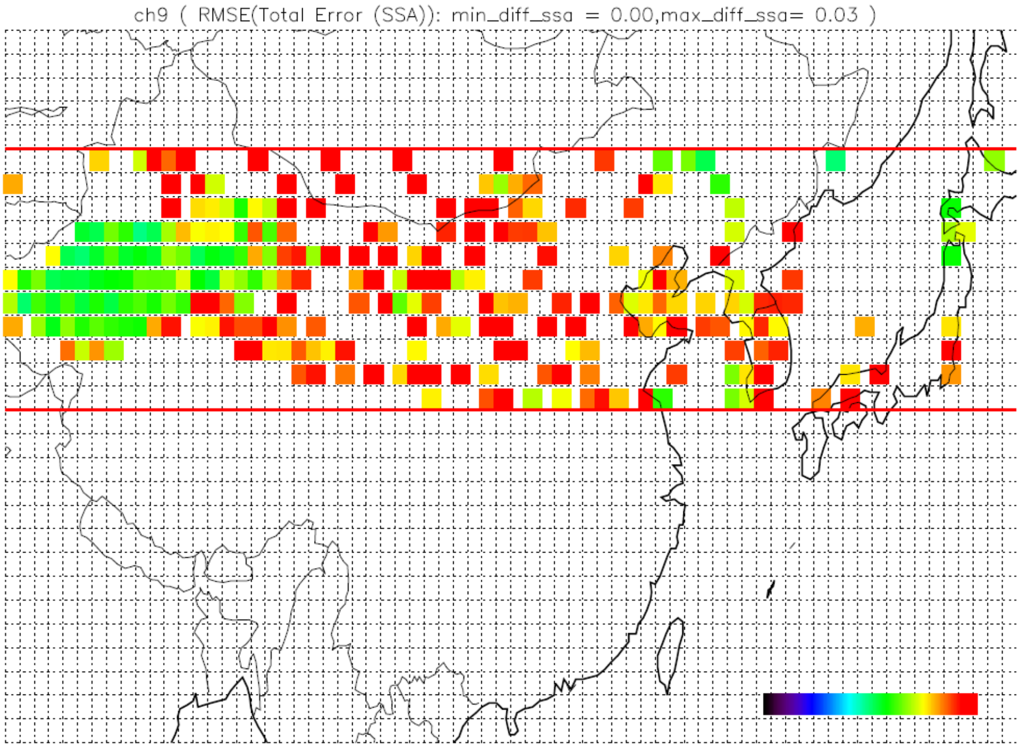
In the revised manuscript, we include the estimated aerosol optical property uncertainties over Asia in Fig. 5. We add an explanation to the revised manuscript as follows.

[P31122_L14] Section 3.1.2

The spatial distribution of the total uncertainties in the estimation of ω_0 and τ_a over the Sahara and Asia are shown in Fig. 4 and Fig. 5, respectively.

[P31122_L19] Section 3.1.2

In Asia, the total uncertainty in ω_0 is larger in the east of Takla Makan desert compared to that over the Takla Makan desert region (Fig. 5). This is because uncertainties by the variation in the surface reflectance (categories (1) and (2)), and that by the dust altitude (categories (11)), are large over there. Similarly to the case of the Sahara, uncertainty in ω_0 by the variation in the surface reflectance is large over the regions where τ_a is small. On the other hand, uncertainty in τ_a is large over the Takla Makan desert.



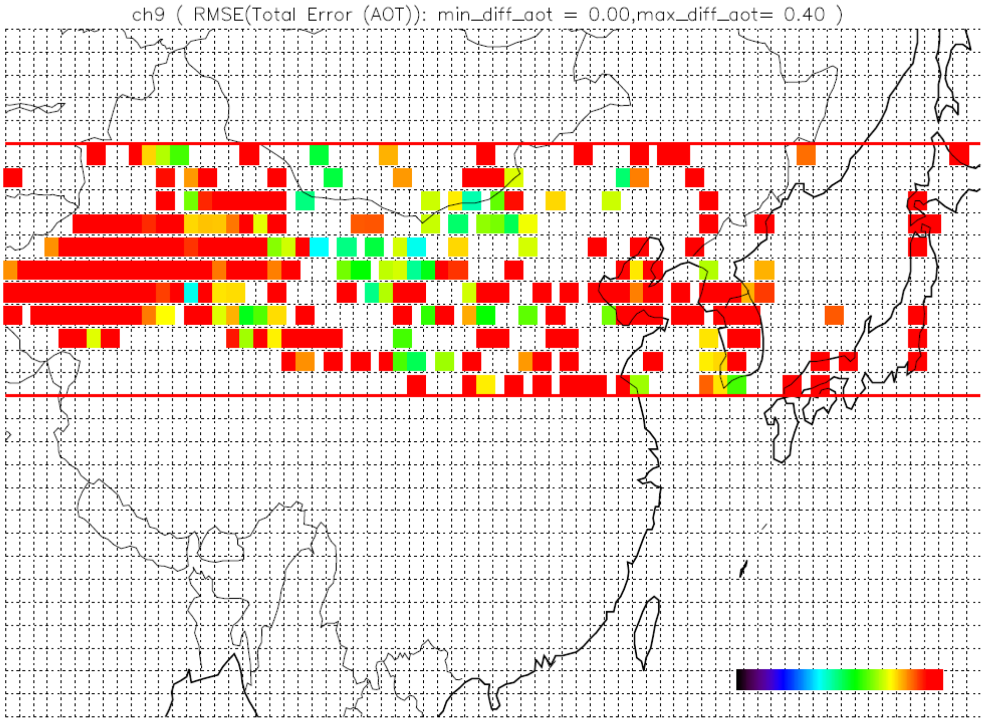


Fig 5 Same as Fig.4 but for over Asia.

5. In the equations of 7 and 8, p represents the scattering phase function, however I believe the p in equation 7 is quite different from it in equation 8, because these two formulas are descriptions for haze and clear conditions, respectively.

Thank you very much for your comment. That's right. In the revised manuscript, the scattering phase function *p* is not used, but instead ρ_0^t and $\rho_{0\_clear}^t$, the TOA reflectances of the atmosphere if the ground is non-reflecting for the hazy and clear conditions, respectively, are used. This is because the original equation (4) is only valid for the small aerosol optical depth, as pointed out by the reviewer #1 comment 8), and thus we removed this equation. However, Eq. (10) and (11) of the original manuscript can be derived without using Eq. (4). The difference of ρ_0^t and $\rho_{0\_clear}^t$ includes the difference of p between hazy and clear conditions. Please note that Section 2.5 in the original manuscript is now moved to the Appendix.

[P31117_L26] Section 2.5, Removed

If the solar zenith (θ_0) and viewing angles (θ) are small enough (Chandrasekhar,1960):

$$\rho_0^t = \pi \sec\theta_0 \sec\theta \omega_0 \frac{p}{4\pi}\tau$$

(4)

where *p* is the scattering phase function, normalised such that its integral over all angles equals 4π. τ is the total optical depth of the gaseous and aerosol scattering.

[P31118-P31119] Section 2.5

By substituting Eqs. (4)-(5) to Eq. (3):

$$\rho^t = \rho_0^t + \frac{\rho_g}{(1 - s\rho_g)} \exp\{\{-\tau_a[1-\omega_0(1-\beta^a)] - \tau_m/2\}\{\sec\theta_0 + \sec\theta\}\} \quad (6)$$

The TOA reflectance during clear conditions can be formulated in the same manner:

$$\rho_{clear}^t = \rho_{0\_clear}^t + \frac{\rho_g}{(1 - s\rho_g)} \exp\{\{-\tau_{a\_clear}[1-\omega_0(1-\beta^a)] - \tau_m/2\}\{\sec\theta_0 + \sec\theta\}\} \quad (7)$$

where τ_{clear} and τ_{a_clear} are the total and aerosol optical depths during clear conditions, respectively, and $\rho_{0\_clear}^t$ is same as ρ_0^t but during clear conditions. The relationship between $\Delta\rho^t$ and ρ^t_{clear} is then calculated using Eqs. (6) and (7):

$$\Delta\rho^t = \rho^t - \rho^t_{clear} = \alpha\rho^t_{clear} + \beta \qquad (8)$$

α and β in Eq. (9) are calculated as follows:

$$\alpha = \exp\left[-(\sec\theta_0 + \sec\theta)\left(\tau_a - \tau_{a\_clear}\right)\left[1-\omega_0\left(1-\beta^a\right)\right]\right] - 1 \qquad (9)$$

$$\beta = \rho^t_0 - \left\{-\exp\left\{-(\sec\theta_0 + \sec\theta)\left(\tau_a - \tau_{a\_clear}\right)\left[1-\omega_0\left(1-\beta^a\right)\right]\right\}\right\}\rho^t_{0\_clear} \qquad (10)$$

* According to this modification, the numbers of equations are changed in the revised manuscript.

6. The large differences of AOD between estimated from the MODIS data and the AERONET may be less helpful to reduce the uncertainty of dust aerosol radiative effects on climate system.

We add a caveat on the AOD estimated from MODIS to the revised manuscript as follows.

[P31125_L7] Section 3.2.3

Therefore, the τ_a estimated from MODIS may not be useful information of dust's optical properties. In addition, this overestimation of τ_a may affect the estimation of ω_0, so we check this relationship in Fig. 6.