Simulating performance of CHIMERE on a late autumnal dust storm over Northern China

Supplementary Materials

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1 Dust emission equation in CHIMERE

1.1 The [Marticorena and Bergametti, 1995] (MB) scheme

In this dust scheme, the vertically integrated saltation flux is estimated by using the equation from White [1]:

$$F_h(D_p) = K\frac{\rho_{air}}{g}u_*^3(1-\frac{u_{*t}}{u_*})(1+\frac{u_{*t}}{u_*})^2, \tag{S1}$$

where K is a constant which equals 1 and the air density (ρ_{air}) is considered as 1.227 kg m^{-3} following the parameterizations of Marticorena and Bergametti [2]. u_* is friction velocity calculated using the roughness length, z_0, and u_{*t} is threshold friction velocity, depending on the soil particle diameter size D_p and z_0. The flux is calculated only if $u_*>u_{*t}$. Then the corresponding vertical dust flux is estimated by using vertical-to-horizontal dust flux ratio (α) with a constant value of 2×10^{-6} and is then projected into three modes (fine, coarse and big modes) using constant percentages (0.2, 0.6 and 0.2).

1.2 The [Alfaro and Gomes, 2001] (AG) scheme

The equation of horizontal dust flux in this AG scheme is the same with MB scheme. While α is computed based on the partitioning of the kinetic energy of individual saltating aggregates and the cohesion energy of the populations of dust particles. This algorithm assumes that dust emitted by sandblasting is characterized by three modes whose proportion depends on the wind friction velocity. Three dust modes, which are considered as independent of the soil types, described the three modes using log-normal distributions with diameters d_1=1.5 μm, d_2=6.7 μm and d_3=14.2 μm, and their associated standard deviation, respectively σ_1=1.7, σ_3=1.6 and σ_3=1.5. In order to apportion the available kinetic energy between the three modes, a constant cohesion energy e_i is associated to each mode values. The numerical values of e_i were determined by adjusting the predicted aerosols size distribution to those measured in wind tunnel under different wind conditions, using an iterative least square routine. The recommended values are used: e_1 =3.61, e_2 =3.52 and e_3 =3.46 g cm^2 s^{-2}. The kinetic energy is expressed as a function of the soil particle diameter after Alfaro et al. [3] and Shao and Lu [4]:

$$e_c = \rho_p\frac{100\pi}{3}D_p^3(u_*)^2, \tag{S2}$$

It is compared to the cohesion energy of the three aerosol modes in order to compute the proportion $p_i(D_p)$ of these three modes to the total dust size distribution (Table S1). In addition, according to the description of Alfaro et al. [3], Equation S2 is only used when u_*<0.27 m s^{-1}, the equation for 0.27 m s^{-1}< u_*<0.55 m s^{-1} is showed as

$$e_c = \rho_p \frac{100\pi}{3} D_p^3 (9.1(u_* - u_{*t}) + U_{h,t})^2, \quad \text{(S3)}$$

where $U_{h,t}$=0.54 m s^{-1}.

TableS1 Fraction (p_i) of the kinetic energy (e_c) of individual saltating aggregates used to release particles from each of the three possible aerosol modes of binding energies e_i

	p_1	p_2	p_3
$e_c < e_3$	0	0	0
$e_3 < e_c < e_2$	0	0	1
$e_2 < e_c < e_1$	0	$(e_c - e_2)/(e_c - e_3)$	$1- p_1$
$e_1 < e_c$	$(e_c - e_1)/(e_c - e_3)$	$(1\ p_1)(e_c - e_2)/(e_c - e_3)$	$1- p_2- p_1$

Vertical-to-horizontal dust flux ratio (α) in this scheme can be written as:

$$\alpha(D_p) = \left(\frac{\pi}{6}\right) \rho_p \beta \sum_{i=1}^{3} \frac{p_i(D_p) d_i^3}{e_i}, \quad \text{(S4)}$$

1.3 The [Kok 2014] (KOK) scheme

The vertical dust flux in KOK was acquired directly without converting from horizontal flux to vertical flux [5]

$$F_d = C_d f_{bare} f_{clay} \frac{\rho_a (u_*^2 - u_{*t}^2)}{u_{*st}} \left(\frac{u_*}{u_{*t}}\right)^{C_\alpha \frac{u_{*st} - u_{*st0}}{u_{*st0}}}, \quad \text{(S5)}$$

f_{bare} is the fraction of the surface that consists of bare soil, f_{clay} is the soil clay fraction and ρ_a is air density. u_{*st} is this friction velocity but for a standard atmospheric density ρ_{a0}=1.225 kg m^{-3}:

$$u_{*st} = u_{*t} \sqrt{\frac{\rho_a}{\rho_{a0}}}, \quad \text{(S6)}$$

u_{*st0} represents u_{*st} for an optimally erodible soil and was chosen as u_{*st0}=0.16 m s^{-1}. The dimensionless coefficient C_α is chosen as 2.7. The dust emission coefficient C_d represents the soil erodibility as:

$$C_d = C_{d0} \times \exp\left(-C_e \frac{u_{*st} - u_{*st0}}{u_{*st0}}\right), \quad \text{(S7)}$$

with the constant dimensionless coefficients C_e=2.0 and C_{d0}=4.4×10^{-5}.

1.4 friction velocity u_* and threshold friction velocity u_{*t}

The friction velocity, u_*, is estimated under neutral conditions, as follows:

$$u_* = U \frac{k}{\ln(z/z_0)}, \quad \text{(S8)}$$

with U the 10 m mean wind speed, k=0.41, the Karman constant, z the height above ground level where the wind speed is estimated by the meteorological model, in CHIMERE, z=10 m, and z_0 is the roughness length.

The threshold friction velocity, u_{*t}, in CHIMERE can be calculated using the two schemes:

[Iversen and White, 1982] (IW) scheme:

$$u_{*t}(D_p) = \begin{cases} \frac{0.129K}{\sqrt{1.92B^{0.092} - 1}} & 0.02 < B < 10 \\ 0.129K\left[1 - 0.858\exp(-0.0617(B - 10))\right] & B > 10 \end{cases}, \quad \text{(S9)}$$

where $K = \sqrt{\frac{\rho_p g D_p}{\rho_{air}}}\left(1 + \frac{0.006}{\rho_p g D_p^{2.5}}\right)$. The friction Reynolds number $B = \frac{u_{*t} D_p}{\nu}$, $B = 1331 D_p^{1.56} + 0.38$, the former one is used in the second time step whereas the latter is used at the start of the calculation. u_{st} is the threshold friction velocity over smooth surfaces, D_p is the diameter of the soil particle, ν is the kinematic viscosity of air, ρ_p is the particle density, ρ_{air} is the air density and g is the gravitational acceleration.

[Shao and Lu, 2000] (SL) scheme.

$$u_{*t}(D_p) = \sqrt{a_n(\frac{\rho_p g D_p}{\rho_{air}} + \frac{\gamma}{\rho_{air} D_p})} \quad , \tag{S10}$$

where the constant parameters a_n=0.0123 and γ= 300 kg m^{-2}. The particle density ρ_p=2.65×10^3 kg m^{-3} is chosen to be representative of quartz grain clay minerals.

2 Vertical distribution of KOK scheme

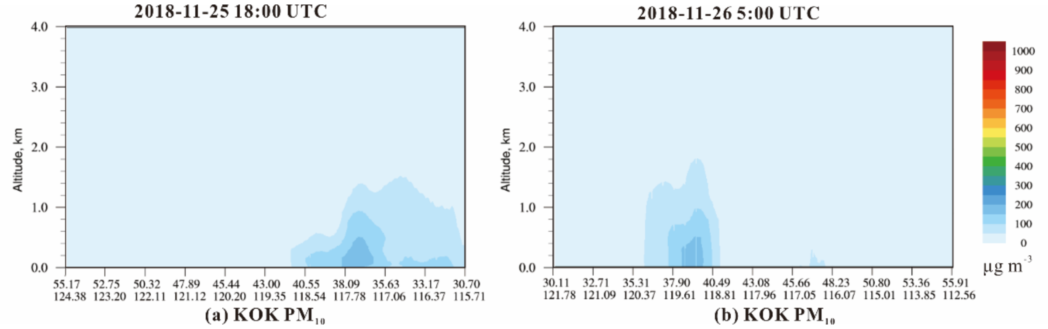

Figure S1. Vertical distributions of aerosol extinction coefficient from the CALIPSO and CHIMERE simulated PM_{10} concentrations at 18:00 UTC on Nov. 25 (left panel) and at 5:00 UTC on Nov. 26 (right panel).

3 Vertical-to-horizontal dust flux ratio (α)

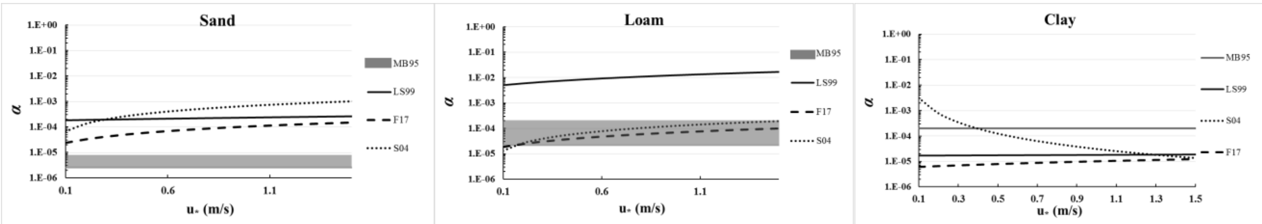

Fig. S2 vertical-to-horizontal dust flux ratio (α) for sand, loam and clay as a function of friction velocity (u_*) following Marticorena and Bergametti [2] (MB95), Lu and Shao [6] (LS), Shao [7] (S04) and Foroutan et al. [8] (F17).

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