

Electronic Supplementary Material to: In Situ Measurement of Dust Particle Transport to the Tropopause Layer over the Northern Tibetan Plateau*

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1. Supplementary methods

In addition to the physical and chemical schemes (Table S1) and the input datasets (Table S2) used in the WRF–Chem simulations, several adjustments were applied.

1.1. Dust emission scheme adjustments

The Model for Simulating Aerosol Interactions and Chemistry (MOSAIC) aerosol scheme in the WRF–Chem model is designed to simulate a wide range of aerosol species, including sulfate, nitrate, ammonium, organic carbon, black carbon, and sea salt (Zaveri et al., 2008). MOSAIC incorporates the chemical and physical processes of aerosols, such as gas-phase chemistry, nucleation and coagulation. The scheme aims to divide aerosol particles into eight size bins: 0.039–0.078 μm , 0.078–0.156 μm , 0.156–0.312 μm , 0.312–0.625 μm , 0.625–1.25 μm , 1.25–2.5 μm , 2.5–5 μm , and 5–10 μm .

The GOCART dust emission scheme (Ginoux et al., 2001), coupled with the MOSAIC aerosol scheme, was selected. Like for other aerosol types in MOSAIC, the scheme relies on eight dust particle size bins to effectively describe dust emission and transport processes. The dust emission flux (F) is expressed as follows:

$$F = CS s_p u_{10m}^2 (u_{10m} - u_t), \quad (\text{S1})$$

where C ($\mu\text{g s}^2 \text{ m}^{-5}$) is the dust emission factor, which is typically an empirical constant. In this study, this factor was adjusted on the basis of the aerosol optical depth and set to $2.4 \mu\text{g s}^2 \text{ m}^{-5}$. Moreover, S denotes the wind erosion index, which represents the fraction of a grid cell susceptible to wind erosion. s_p denotes the mass fraction of each dust particle size bin. u_{10m} is the horizontal wind speed at 10 m. u_t is the threshold wind speed for dust emission at 10 m.

1.2. Adjustment of dust refractive index

The Rapid Radiative Transfer Model for General Circulation Models (RRTMG) longwave and shortwave radiation schemes were chosen in this study. To better represent the absorptive and refractive properties of dust, the shortwave refractive index for dust in the RRTMG scheme was adjusted to $1.55 + 0.006i$ (Wu et al., 2009; Liu et al., 2016; Di Biagio et al., 2019). The adjusted refractive index was employed in the Mie scattering calculations to determine optical properties, such as aerosol extinction coefficients. These optical properties are essential for the calculation of radiative transfer and feedback.

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2. Supplementary tables

Table S1. The physical and chemical schemes chosen for this simulation.

Physical and chemical processes	Configuration
Microphysics	NSSL 2–moment 4–ice (Mansell and Ziegler, 2013)
Long/shortwave radiation	RRTMG (Iacono et al., 2008)
Land surface	Noah (Chen and Dudhia, 2001)
Boundary layer	YSU (Hong, 2010)
Cumulus parameterization	Tiedtke (Zhang et al., 2011)
Aerosol chemistry	CMBZ–MOSAIC 8bin (Zaveri and Peters, 1999 ; Zaveri et al., 2008)
Dust emission	GOCART (Ginoux et al., 2001 ; Hu et al., 2020)

Table S2. WRF–Chem input datasets.

Category	Data
Meteorology	ERA5 (Hersbach et al., 2020)
Boundary conditions	WACCM (Gettelman et al., 2019)
Anthropogenic emissions	EDGAR-HTAP (Crippa et al., 2023)
Biomass burning emissions	FINN (Wiedinmyer et al., 2006, 2011, 2023)
Biogenic emissions	MEGAN (Morichetti et al., 2022)

3. Supplementary figures

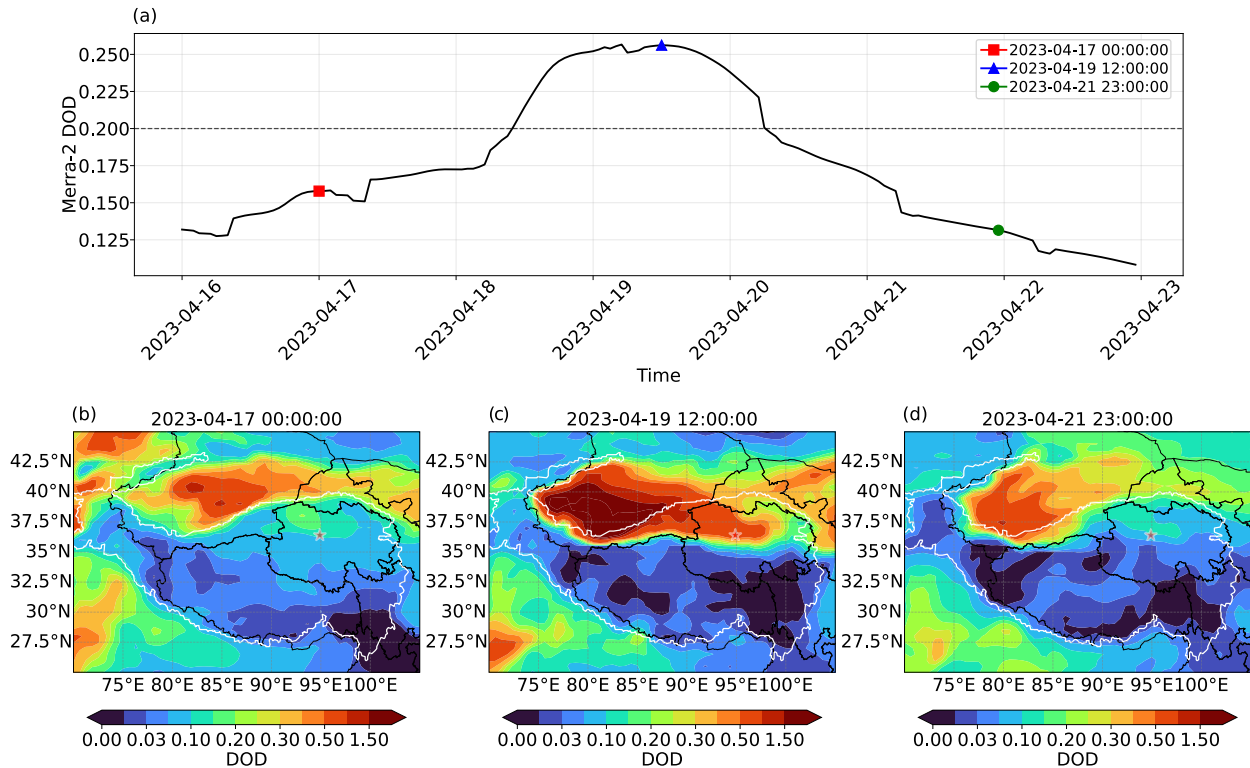


Fig. S1. (a) Time series of the MERRA-2 DOD averaged over the region 25°–45°N and 70°–105°E. (b) Spatial distribution of the MERRA-2 DOD over the region at 0000 UTC 17 April 2023, with the Golmud sounding site marked by a red star. The white solid line represents the boundary of the TP. (c, d) As in (b) but at 1200 UTC 19 April 2023 and 0000 UTC 21 April 2023, respectively.

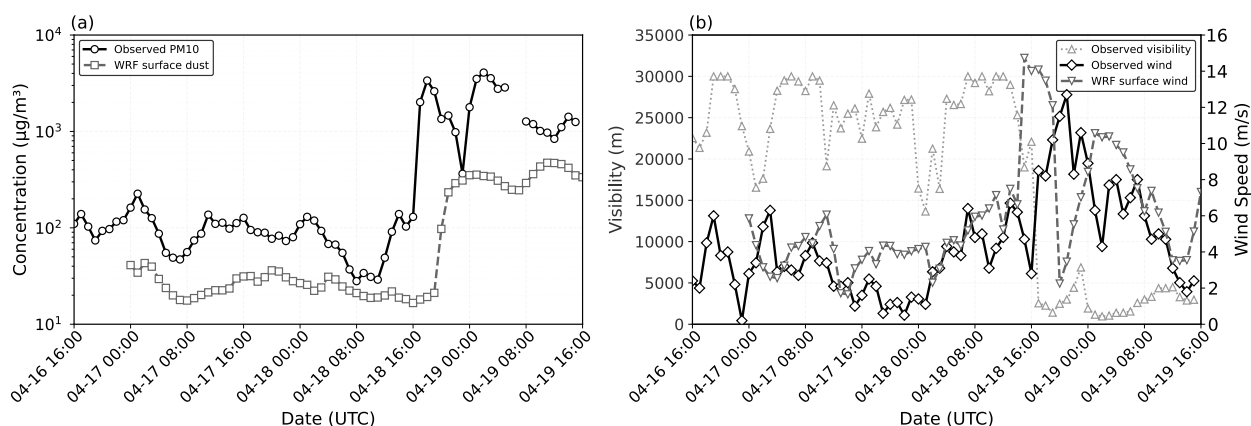


Fig. S2. (a) Time series of surface PM_{10} concentration observed at Golmud (black solid line) and simulated surface dust mass concentration from the model (dark gray dashed line). (b) Time series of surface wind speed observed at Golmud (black solid line), surface visibility observed at Golmud (gray dashed line), and simulated surface wind speed from the model (dark gray dashed line).

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