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Supporting Information for

Assessment of dust size retrievals based on AERONET: A case study of radiative closure from visible-near-infrared to thermal infrared

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1 The estimation of dust vertical distribution based on the aerosol depolarization ratio

The dust vertical distribution is represented by the dust backscatter profiles $\beta_d(z)$, which is estimated from the collocated MPLNET V3 L15 aerosol profiles of attenuated backscatter coefficients $\beta(z)$ and depolarization ratio $\delta(z)$ using the a priori dust (δ_d) and non-dust DPR (δ_{nd}) based on the following equation:

$$\beta_d(z) = f_d(z) \cdot \beta(z);\ where\ f_d(z) = \frac{(\delta(z) - \delta_{nd})(1 + \delta_d)}{(1 + \delta(z))(\delta_d - \delta_{nd})}$$

δ_d is assumed to be ranging from 0.2 to 0.3, while δ_{nd} is assumed to be ranging from 0.02 to 0.07. The upper bound and lower bound of $f_d(z)$ are calculated based on the upper bound (0.3 and 0.07) and lower bound (0.2 and 0.02) of δ_d and δ_{nd}. The final $f_d(z)$ are obtained from the average of the upper bound and lower bound of $f_d(z)$. Afterward, the $\beta_d(z)$ is further normalized to be the vertical distribution of dust as:

$$\widehat{\beta_d}(z) = \frac{\beta_d(z)}{\sum_z \beta_d(z)}$$

2 Statistical definition of the bias index to the radiative closure

We defined a bias index χ as $\chi = \left(1 - \frac{P_{BTD}}{P_{ZERO}}\right) \times 100\%$; where

$$P_{BTD} = \int_{-NEDT}^{NEDT} p_{BTD}(X = x)\, dx$$

$$P_{ZERO} = \int_{-NEDT}^{NEDT} p_{ZERO}(X = x)\, dx$$

$p_{BTD}(x)$ is the normalized probability mass function (PMF) with $\sum_x p_{BTD}(x) = 1$. It is approximated according to the mean (μ) and the standard deviation (σ) of the discrete probability mass distribution of BTDs based on AERONET PSD and the adjusted PSD. $p_{ZERO}(x)$ is the normalized PMF with the μ of $p_{BTD}(x)$ shifted to zero, which is used as a proxy for the well-matched TIR radiative closure with the estimated errors from the σ of the BTD distributions.

The normalized PMF is defined as

$$p(x) = f(x) \Big/ \sum_x f(x)$$

where $f(x)$ is the Gaussian distribution defined as

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

By integrating p_{ZERO} spaning within the AIRS detector noise (represented by the noise equivalent delta temperature (NEDT)), we obtain the probabilities of the LBLDIS BT to match with AIRS BT within the AIRS observational uncertainty among the random error without bias, which is represented by P_{ZERO}.

Afterward, By integrating p_{BTD} spaning within the AIRS NEDT range, we have the probabilities of the LBLDIS BT to match with AIRS among the random error with potential bias due to the assumed dust PSD, which is represented by P_{BTD}.

If $P_{BTD} = P_{ZERO}$, the $\chi = 0\%$, which means there is no bias contributed by the assumed dust PSD. If $P_{BTD} = 0$, it means there is no probability for the LBLDIS BT to match with the AIRS BT with the assumed dust PSD, leading to $\chi = 100\%$. In this way, we can quantify how much bias exists when using the AERONET PSD in the test of TIR radiative closure, and how much bias is reduced if we adjust the PSD to be coarser by adding on a super-coarse mode PSD.

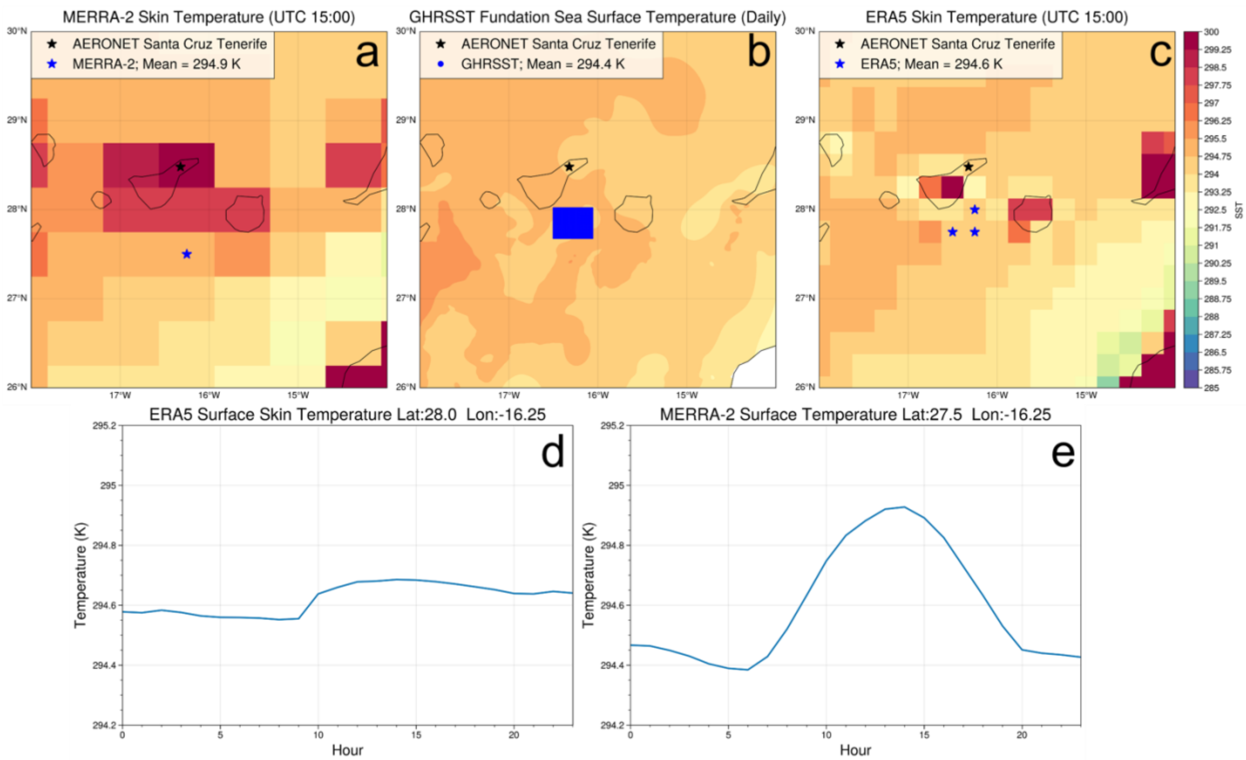

Figure S1. The distribution of surface temperature represented by skin temperature from MERRA-2 at 15:00 UTC (a), foundation sea surface temperature from GHRSST (b) and skin temperature from ERA5 at 15:00 UTC (c) on June 19, 2022. The black stars represent the geolocation of Santa Cruz Tenerife. The blue stars and dots represent the collocated grid cells with the AIRS cloud-free dust pixels indicated in Figure 1a. (d) and (e) are the mean diurnal variabilities of skin temperature from the collocated grid cells of ERA5 (d) and MERRA-2 (e) from 0:00 UTC to 24:00 UTC on June 19, 2022.

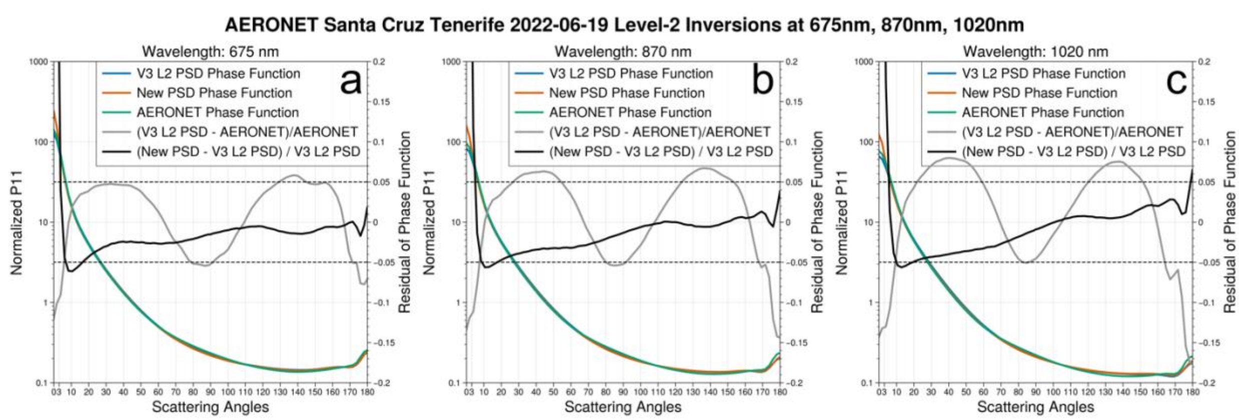

Figure S2. AERONET V3 L2 (green) and IITM-calculated dust phase functions and residuals (grey and black curves for the right y-axis) at 675 (a), 870 (b) and 1020 nm (c) based on the AERONET

PSD (blue) and the adjusted dust PSD (red). The AERONET PSD and adjusted dust PSD are shown in Figure 2a in the main manuscript.

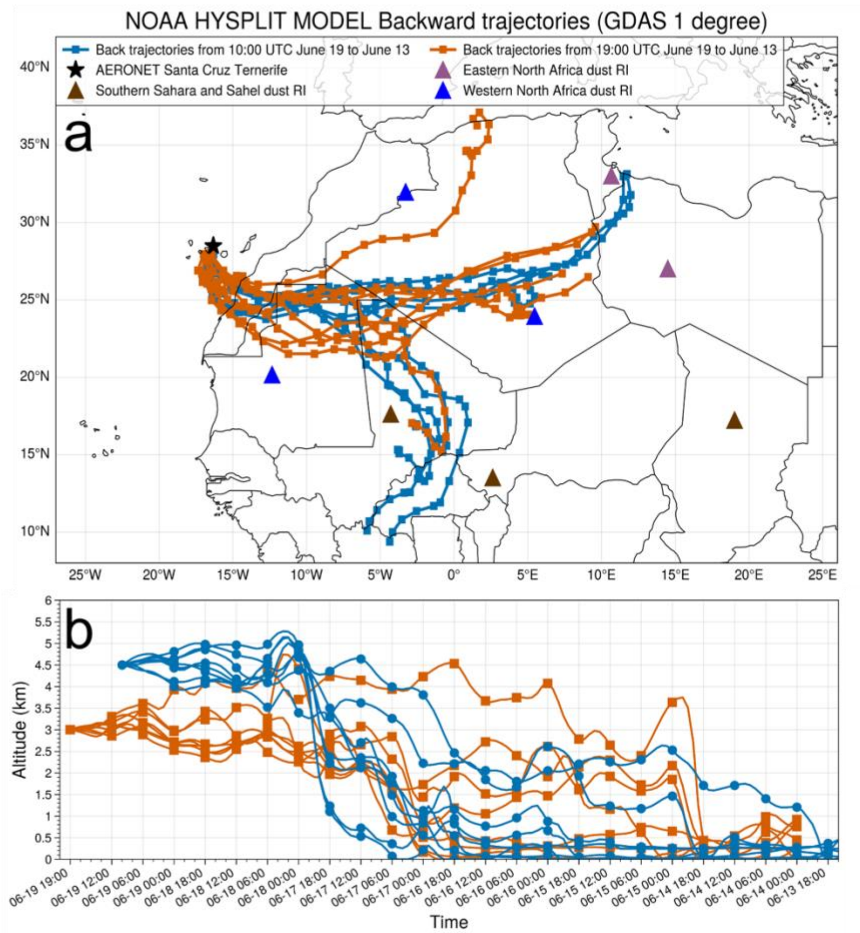

Figure S3. The horizontal (a) and vertical (b) ensemble HYSPLIT back trajectories originated from AERONET Santa Cruz Tenerife (black star) at 10:00 UTC (red solid curves) and 19:00 UTC (blue solid curves). The blue, purple and brown triangles in (a) represent locations where dust CRIs were sampled over Western and Eastern North Africa, Southern Sahara and Sahel, respectively (Di Biagio et al., 2017).