Referee #1

Comment A1

The manuscript by Xu and coauthors presents new model developments within the IPSL Earth System Model framework, aimed at including vegetation dependence on desert dust emissions. Simulated fields are validated against observational datasets. The topic is of interest for the aerosol and climate modelling communities. Both the manuscript and the underlying scientific work are well crafted. This work is suitable publication after minor revisions, from my perspective.

Response

We sincerely thank the reviewer for the positive assessment and constructive suggestions. We have carefully addressed all comments in the revised version, with detailed point-by-point responses provided below.

Comment A2

Specific comments

67-68. Perhaps not many "original" studies such as, e.g. Marticorena and Bergametti (1995), but many "CMIP-class" models already include this effect, e.g. UKESM (Woodward et al., 2001: https://doi.org/10.1029/2000JD900795), CESM (Zender et al., 2003: https://doi.org/10.1029/2002JD002775), MPI (Stanelle et al., 2014: https://doi.org/10.1002/2014JD022062D) among others.

Response

Thanks for this insightful comment. The sentence has been revised in lines 68–71 to explicitly acknowledge these CMIP-class models:

"To date, only a limited number of process-oriented studies have explicitly investigated the effects of vegetation on dust emission as a primary focus. Nevertheless, such effects have already been incorporated in several Coupled Model Intercomparison Project (CMIP)-class models, such as UKESM (Woodward et al., 2001), CESM (Zender et al., 2003), and MPI (Stanelle et al., 2014), among others."

References:

Stanelle, T., Bey, I., Raddatz, T., Reick, C., and Tegen, I.: Anthropogenically induced changes in twentieth century mineral dust burden and the associated impact on radiative forcing, J. Geophys. Res. Atmos., 119, 13526–13546, https://doi.org/10.1029/2014JD022062, 2014.

Woodward, S.: Modeling the atmospheric life cycle and radiative impact of mineral dust in the Hadley Centre climate model, J. Geophys. Res. Atmos., 106, 18155–18166, https://doi.org/10.1029/2000JD900795, 2001.

Zender, C. S., Bian, H., and Newman, D.: Mineral Dust Entrainment and Deposition (DEAD) model: Description and 1990s dust climatology, J. Geophys. Res. Atmos., 108, 4416, https://doi.org/10.1029/2002JD002775, 2003.

Comment A3

155. Why only January? What about the Southern Hemisphere, for instance?

Response

The January temperature criterion was originally implemented for Northern Hemisphere sources to exclude frozen ground and ice-covered surfaces; thus, it does not fully capture Southern Hemisphere seasonality. We acknowledge this simplification and a month-by-month check will be implemented in future model versions.

The text has been revised in the Methods (lines 161–163) and Section 4 (lines 816–819):

In Methods:

"(1) Non-frozen or ice-free surface: Dust mobilization is restricted to surfaces not bound by ice or frost (Schulz et al., 2009). In this study, this is quantified by excluding regions where the mean January surface air temperature is below 0 °C, which mainly reflects Northern Hemisphere winter conditions and was originally optimized for major Northern Hemisphere sources;"

In Section 4:

"...the use of a January temperature threshold—originally designed for Northern Hemisphere sources—may not fully capture the seasonal freezing cycles in the Southern Hemisphere. While this simplification does not affect our assessment of vegetation-induced effects (due to the methodological consistency across all simulations), it contributes to regional biases that we aim to address in future versions through a full month-by-month temperature check."

References:

Schulz, M., Cozic, A., and Szopa, S.: LMDzT-INCA dust forecast model developments and associated validation efforts, IOP Conf. Ser. Earth Environ. Sci., 7, 012014, https://doi.org/10.1088/1755-1307/7/1/012014, 2009.

Comment A4

156. How is a "potential dust source area" defined?

Response

The "potential dust source area" is a predefined input mask in the model that constrains dust emission to regions where the climatological annual precipitation is less than 300 mm (Schulz et al., 2009).

We have revised the main text in lines 164–166 as: "(2) Precipitation-limited source areas: The grid cell must be located within a predefined potential dust source area, where climatological annual precipitation is less than 300 mm (Schulz et al., 2009), representing regions with limited annual moisture supply as potential dust emitters;"

References:

Schulz, M., Cozic, A., and Szopa, S.: LMDzT-INCA dust forecast model developments and associated validation efforts, IOP Conf. Ser. Earth Environ. Sci., 7, 012014, https://doi.org/10.1088/1755-1307/7/1/012014, 2009.

Comment A5

157. Which variable is a "surface wetness proxy"?

Response

This proxy represents the moisture balance (net water-equivalent depth, mm) in the uppermost soil layer.

We have clarified this in lines 167–170:

"(3) Completely dry surface: Dust emission is restricted to a completely dry surface, quantified by a surface wetness proxy (water-equivalent depth, mm) that represents the moisture balance in the uppermost soil layer. Emission is permitted only when this proxy falls below a value of 10^{-10}, which serves as a numerical threshold to enforce a dry surface condition and does not represent a physically meaningful soil moisture value."

Comment A6

191. Considering that fr >=1 by definition, there are three possible cases for the application of equation 4.4, from my understanding:

(1) u < ut < ut*fr , leading to no dust emissions

(2) u > ut*fr > ut , leading to dust emissions from both "pure" bare soil and bare soil between vegetation patches

(3) ut < u < ut*fr , resulting in positive emissions from "pure" bare soil but apparently negative emissions from bare soil between vegetation patches, which would pose some problems. Please clarify this aspect.

Response

We used the MAX function in the model code to ensure that each term in Eq. (4) only contributes to the total dust emission flux when its specific threshold (u_t and $u_t \times f_r$) is exceeded, thereby preventing unphysical negative values.

We have revised Equation (4) (line 208) to explicitly include the max operator:

$$F_{\text{dust}} = (1 - A_v)\times\text{MAX}[C\times u^2\times(u\text{-}u_t),0]+A_v\times\text{MAX}\left[C\times u^2\times\left(u\text{-}f_r\times u_t\right),0\right]$$

We have also revised the corresponding text in lines 216–218 for clarity:

"Emissions from the first term of Eq. (4) that represents the contribution from surfaces without vegetation protection, occurs only when the default threshold velocity (u_t) is exceeded. Conversely, emissions from the second term accounting for the vegetation effect, are determined by a modified threshold velocity ($u_t \times f_r$), ..."

Comment A7

16 (Supplement). Regridded how? Via bilinear interpolation?

Response

The regridding was performed using bilinear interpolation. We have clarified this in the Spplement (lines 16–17): "…, using a bilinear interpolation approach."

Comment A8

252. Do you mean that deep convection follows the "Standard Physics" while turbulent mixing parameterizations follows the New Physics" scheme?

Response

We clarify that both the deep convection and turbulent mixing parameterizations follow the "New Physics" scheme (Boucher et al., 2020). The term "Standard Physics" was a remnant from a previous version and has been corrected.

The revised text (lines 289–290) now reads: "The deep convection and turbulent mixing parameterizations follow the "New Physics" scheme (Boucher et al., 2020), …"

Reference:

Boucher, O., Servonnat, J., Albright, A. L., Aumont, O., Balkanski, Y., Bastrikov, V., Bekki, S., Bonnet, R., Bony, S., Bopp, L., Braconnot, P., Brockmann, P., Cadule, P., Caubel, A., Cheruy, F., Codron, F., Cozic, A., Cugnet, D., D'Andrea, F., Davini, P., de Lavergne, C., Denvil, S., Deshayes, J., Devilliers, M., Ducharne, A., Dufresne, J.-L., Dupont, E., Éthé, C., Fairhead, L., Falletti, L., Flavoni, S., Foujols, M.-A., Gardoll, S., Gastineau, G., Ghattas, J., Grandpeix, J.-Y., Guenet, B., Guez, L. E., Guilyardi, E., Guimberteau, M., Hauglustaine, D., Hourdin, F., Idelkadi, A., Joussaume, S., Kageyama, M., Khodri, M., Krinner, G., Lebas, N., Levavasseur, G., Lévy, C., Li, L., Lott, F., Lurton, T., Luyssaert, S., Madec, G., Madeleine, J.-B., Maignan, F., Marchand, M., Marti, O., Mellul, L., Meurdesoif, Y., Mignot, J., Musat, I., Ottlé, C., Peylin, P., Planton, Y., Polcher, J., Rio, C., Rochetin, N., Rousset, C., Sepulchre, P., Sima, A., Swingedouw, D., Thiéblemont, R., Traore, A. K., Vancoppenolle, M., Vial, J., Vialard, J., Viovy, N., and Vuichard, N.: Presentation and evaluation of the IPSL-CM6A-LR climate model, J. Adv. Model. Earth Syst., 12, e2019MS002010, https://doi.org/10.1029/2019MS002010, 2020.

Comment A9

296. Was this calculation done online or rather calculated a posteriori based on monthly output?

Response

The simulated DAOD at 550 nm was calculated *a posteriori* (offline) based on the monthly outputs of dust load. We have revised the text in line 335–336: "The simulated DAOD at 550 nm was calculated *a posteriori* based on monthly model outputs using the following equation:"

Comment A10

329. Are those scaling factors applied to dust emissions? If so, in the case of the 4-mode configuration you would imply changing the overall size distribution at emission. Please comment on that.

Response

The scaling factors used to tune the DAOD were indeed applied *a posteriori* (offline) to the dust emissions. To reach the target global DAOD (Ridley et al., 2016), we applied the same scaling coefficient exclusively to Mode 2 and Mode 3, which collectively account for ~80% of the optical depth in the 4-mode configuration.

As noted, this modifies the relative mass contributions of the modes at emission (e.g., changing the 1, 4, 31, and 64% distribution (without scaling factors) to 1, 5, 36, and 59% (with scaling factors) for Modes 1–4, respectively). However, this adjustment only rescales their respective emission magnitudes and does not alter the intrinsic microphysical properties (e.g., MMD, σ) of individual modes.

We have added the following explanation in the text (lines 369–376): "… and *b* specifically for Mode 2 and Mode 3, while Mode 1 and Mode 4 were left unchanged in the 4-mode configuration. This strategy is based on the fact that Mode 2 and Mode 3 contribute most significantly to the global DAOD (together accounting for ~80 %), whereas Mode 1 and Mode 4 have a smaller contribution (Di Biagio et al., 2020). To ensure consistency throughout the dust cycle, these global scaling coefficients were systematically applied offline to the monthly model output (including dust emission, DAOD, surface PM concentration, and deposition) as part of an *a posteriori* calibration. Although applying such scaling coefficients to emission slightly modifies the relative mass contributions of different size modes within the 4-mode configuration, the intrinsic microphysical properties of each mode (e.g., MMD and σ) remain consistent with the original parameterization."

References:

Di Biagio, C., Balkanski, Y., Albani, S., Boucher, O., and Formenti, P.: Direct Radiative Effect by Mineral Dust Aerosols Constrained by New Microphysical and Spectral Optical Data, Geophys. Res. Lett., 47, e2019GL086186, https://doi.org/10.1029/2019GL086186, 2020.

Ridley, D. A., Heald, C. L., Kok, J. F., and Zhao, C.: An observationally constrained estimate of global dust aerosol optical depth, Atmos. Chem. Phys., 16, 15097–15117, https://doi.org/10.5194/acp-16-15097-2016, 2016.

Comment A11

332. How was the overall calibration process carried out in order to determine the optimal scaling coefficients (considering all three variables)?

Response

The calibration was conducted in a two-stage process (1) constraining the scaling coefficients so the global mean annual DAOD fell within the benchmark of 0.030 ± 0.005 (Ridley et al., 2016); and (2) identifying the optimal coefficient that yielded the best collective statistical metrics for DAOD, surface PM, and total deposition.

For instance, in the 4-mode configuration, a coefficient of 1.24 was selected over 1.44 because it yielded better collective metrics across all variables (Table S2), although both fell within the Ridley et al. (2016) range.

We have revised the text (lines 377–381) for clarity: "The calibration process prioritized maintaining the global mean annual DAOD within the target range of 0.030 ± 0.005, while simultaneously optimizing the model's overall statistical performance against independent observational datasets for DAOD, surface PM, and total deposition. Sensitivity analysis (Table S2) revealed that the optimal scaling coefficients are 0.74 for *a*, and 1.24 for *b*. Other coefficients produced a higher global mean annual DAOD and resulted in weaker correlation with observations in the 4-mode configuration (Table S2)."

Reference:

Ridley, D. A., Heald, C. L., Kok, J. F., and Zhao, C.: An observationally constrained estimate of global dust aerosol optical depth, Atmos. Chem. Phys., 16, 15097–15117, https://doi.org/10.5194/acp-16-15097-2016, 2016.

Comment A12

341. These processes apply to dust atmospheric dispersion in general, not specifically to PM10. This sentence seems out of place here.

Response

We agree with reviewer and have revised the text (lines 385–386) to more accurately reflect the factors governing surface concentrations:

"Surface dust PM concentrations are determined by the combined effects of vegetation-modulated emissions and subsequent atmospheric transport and deposition processes."

Comment A13

374. I do not understand this distinction, since I could not find any subsequent budget segregating e.g. global land vs oceanic dust deposition.

Response

The distinction was introduced to evaluate model performance across different deposition environments (Figs. S27–S28), as the physical processes and observational uncertainties vary between terrestrial and oceanic sites. We did not intend to imply a separate budget analysis.

We have revised the text (lines 434–435) to clarify this purpose: "To evaluate the model's performance across different deposition environments, we distinguished between observations from terrestrial and oceanic stations, where the corresponding grid cells were identified using a global land mask (NASA, 2025)."

Comment A14

491. It is not clear at which point those scaling factors were applied, i.e. online at the stage of dust emissions, or rather offline, on the monthly history files?

Response

The global scaling coefficients were applied offline to the monthly history files as an *a posteriori* adjustment.

We have explicitly clarified this offline approach in both the Methods (lines 372–374) and Results (lines 566–568).

In Methods:

"To ensure consistency throughout the dust cycle, these global scaling coefficients were systematically applied offline to the monthly model output (including dust emission, DAOD, surface PM concentration, and deposition) as part of an *a posteriori* calibration."

In Results:

"Through the *a posteriori* application of the global scaling coefficients (Sect. 2.3.3) to the monthly history files, ... All subsequent analyses were conducted using these offline-adjusted results."

Reference:

Ridley, D. A., Heald, C. L., Kok, J. F., and Zhao, C.: An observationally constrained estimate of global dust aerosol optical depth, Atmos. Chem. Phys., 16, 15097–15117, https://doi.org/10.5194/acp-16-15097-2016, 2016.