Reply to the comments of Editor

Comment 1: Please address comments provided by the reviewer. I also have this concern: this study claims that using E20 dry deposition scheme improves model prediction of PM concentration from which it is concluded that E20 is a more accurate scheme. There are several issues related to such a statement: (1) are the differences in predicted PM concentrations between using different deposition schemes significant? I noticed that in some cases the error percentages from using different dry deposition schemes only changed marginally.

Response: We thank the editor for the comment. The performances of various dry deposition schemes can be significant different for PM_{10}, but marginally different for $PM_{2.5}$ simulation. Hence, the improvement of CMAQ by E20 dry deposition scheme was particularly for PM_{10} simulation, that most represented during East Asian Dust episodes. We added the statement as "It's worth noting that E20, in particular, showed exceptional performance in the PM_{10} simulation compared to other dry deposition schemes under the refined dust scheme. This underscores the potential effectiveness of E20 in managing PM_{10} particulate matter. However, the $PM_{2.5}$ simulations showed only marginal changes, regardless of whether it was a surface or high-altitude simulation." **Page 11, line 282-285 in the revised manuscript.**

"Similar to the trend of $PM_{2.5}$ simulations in Taiwan (as shown in Fig. 4), the spatial distribution of the modeled $PM_{2.5}$ was identical to that of all dry deposition schemes. The result implies the significant impact of dry deposition on the EAD simulation's dust model, displaying the positive relationship between dust deposition and PM_{10} concentrations (Zhang et al., 2017)." **Page 13, line 333-337 in the revised manuscript.**

We modified the statement in the abstract as "We proposed implementing the E20 dry deposition approach, particularly in PM_{10} simulation, narrowing the uncertainty of the CMAQ dust emission treatment." **Page 2, line 32-34 in the revised manuscript.**

Comment 2: (2) Because there are compensating errors between different processes in the model, can the improved model-prediction of PM concentration be solely attributed to the chosen dry deposition scheme? For example, if dust emission is biased low, then using a deposition scheme with low Vd would give a better prediction of PM concentration, and vice versa. This does not mean such a deposition scheme is more accurate than others. In other words, can the conclusion presented here be generalized? I would recommend the authors to either add more uncertainty analysis/discussion to support their conclusion and/or rephase their conclusion by considering the factors mentioned above.

Response: We appreciate the editor's constructive comments and suggestions. We agree with the editor that the performance of dust emission could influence the PM prediction with a certain level of V_d. The higher dust emission (or considered as low bias) leads to lower V_d and, eventually, higher dust loading. The present work intentionally simulated the strong dust intensity of multiple dust storms in Spring 2021 and a regular EAD episode in January 2023. The purpose is to investigate whether or not the distinct dust emission intensity could impact aerosol deposition and concentrations. The result shows that the spring 2021 simulation generated higher dust emissions than January 2023, which caused lower V_d during Spring 2021 compared to the one during January 2023 (Figure 7). Under both strong and regular dust emissions phenomena, E20 seems to outperform the PM_{10} simulation. We modified the discussion/analysis as "As shown in Figure 7a, the results during the spring of 2021 are similar to those for January 2023 in comparing the dry deposition schemes. Notably, the V_d of the coarse mode for E20_2023 and E20_2021 was lowest compared to the other dry deposition schemes. Contrary, the accumulation and coarse mode by P22 were the highest. The result was consistent with the best simulated PM_{10} by E20 in 2023 and 2021 displayed in Table 4 and 5, respectively. The lowest V_d of the coarse mode particle was responsible for reducing the PM_{10} simulation underestimation, consistent with the simulation by Ryu and Min (2022). The slow V_d means the total loss of aerosol to the surface has been minimized, leading to increased aerosol concentration. In addition, the spatial distribution of dust emissions could significantly influence the aerosol deposition velocity. The total dust emission in Spring 2021 was of a much higher magnitude and wider spatial distribution than in January 2023 (Fig. 7b, c). This led to a slow V_d in the coarse mode, particularly, causing more dust loading during the multiple dust storms in Spring 2021 than the regular dust episode recorded in January 2023. This finding is consistent with Zeng et al. (2020), which emphasized the sensitivity of different dust emissions on dry deposition schemes. However, it's important to note that the research was only conducted in one particular short period. On the other hand, this work has highlighted the distinct dust emission according to EAD intensity impacting the various dry deposition schemes. These implications are crucial for understanding the behaviour of aerosols in the atmosphere and their significant impact on air quality." **Page 14, line 350-366 in the revised manuscript.**

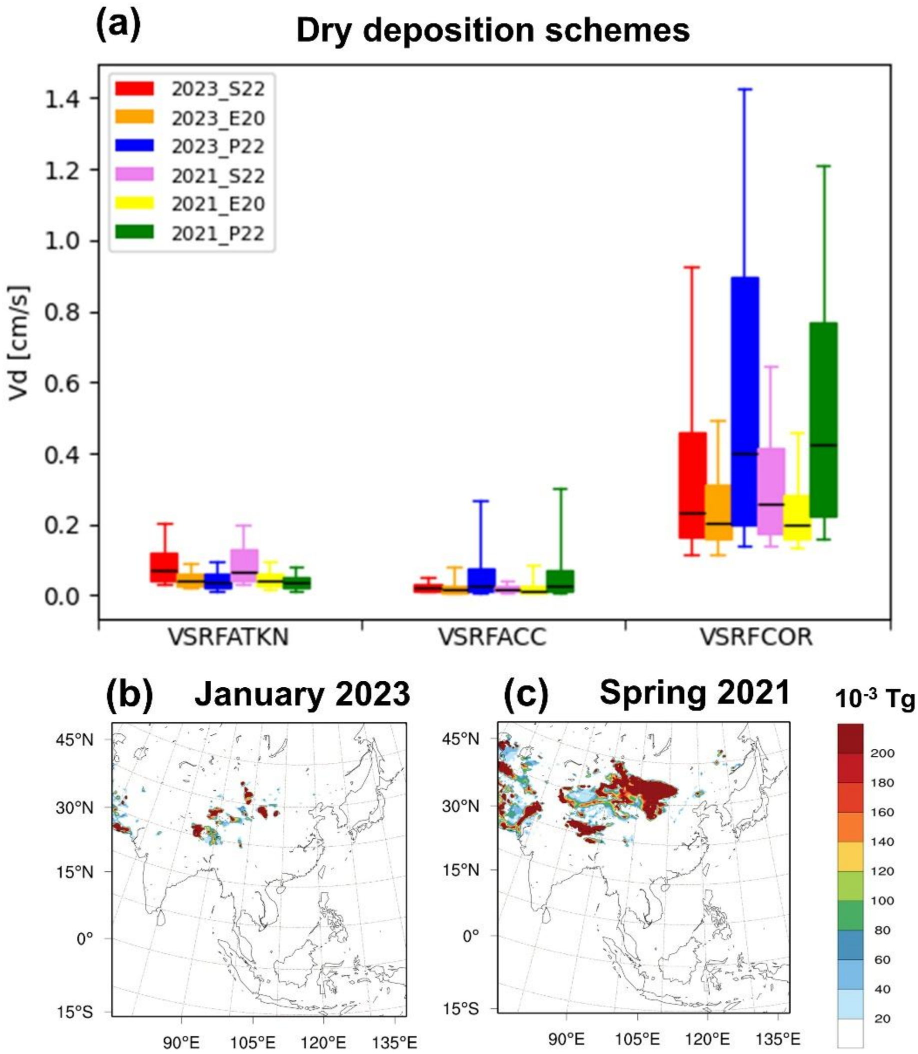

Figure 7: (a) 10-days (2023) and 40-days (2021) averaged dry V_d predicted by CMAQ for the Aitken, accumulation, and coarse particle modes using the 2023_S22 (red), 2023_E20 (orange), 2023_P22 (blue), 2021_S22 (violet), 2021_E20 (yellow) and 2021_P22 (green) particle dry deposition schemes. The variability illustrated by the boxes and whiskers corresponds to spatial variability in annually averaged values throughout the CMAQ domain. The simulated total dust emission by CMAQ_Dust_E20 in (b) January 2023 and (c) Spring 2021.

Also, the present research intends to test the dry deposition scheme's response to the dust emission model as constant variables. Even though we simulated the two different dust emission intensities, the different dust emission schemes' reactions to the dry deposition scheme in the CMAQ model remain uncertain. As a result, we propose the potential future studies, which will explore the sensitivity of the various dust emission parameterizations impacting the dry deposition schemes. We modified the conclusion as "We noted that the improved model simulation for EAD relied on dust emission, dust deposition, and transport processes. The dust emission treatment was proven sensitive to the CMAQ model performance in East Asia (Dong et al., 2018; Liu et al., 2021; Kong et al., 2024). In addition, the CTM performance can be attributed to the dust emission schemes and the dry deposition schemes (Zeng et al., 2020). In other words, different dust emission schemes may impact the V_d and dust loading, which reacts differently to model performance. The present research, which is a complex examination, is of significant importance as it primarily focuses on which dry deposition scheme can improve the most recent updated dust emission model. Therefore, the sensitivity of the dust emission parameterizations or approaches, including surface roughness, land surface, soil texture, and types on the dry deposition scheme, underscores the need for a comprehensive understanding and is proposed for future studies.

Finally, it is necessary to point out that the dry deposition on the EAD is closely associated with the PM_{10} concentration (Zhang et al., 2017). Nevertheless, it has been shown that there are other atmospheric processes related to the air quality over the Western Pacific, including transboundary haze, biomass burning, and local emission (Chuang et al., 2020; Ooi et al., 2021; Chang et al., 2022). These complex phenomena could cause variations of $PM_{2.5}$, ozone, and the corresponding primary pollutant. Hence, the role and response of the dry deposition scheme in the CMAQ should be paid attention to in the future for compressive understanding and model improvement. This research enhances our understanding of dust emission and dry deposition models and provides valuable insights for improving air quality models, which is crucial for environmental and public health management." **Page 20, line 515-534 in the revised manuscript.**

Reply to the comments of RC4

Comment 1: Abstract："The result showed that the dry deposition parameterization could significantly impact the CMAQ dust emission treatment". It seems that dust emission has no direct relationship with dry deposition parameterization. So this sentence can be replaced by "The result showed that the dry deposition parameterization could significantly impact the CMAQ dust concentration in the air"

Response: We thank the reviewer for the suggestion. The sentence has been revised as suggested. We modified as "The result showed that the dry deposition parameterization could significantly impact the CMAQ dust concentration in the air." **Page 1, line 17-18 in the revised manuscript.**

Comment 2: "It is revealed that the increase of wet deposition due to the surface resistivity (Rb) leads to a significant increase in dust mass concentration but a minor increase in black carbon (BC)." The sentence can not be understood clearly. Here, wet deposition was related to the surface resistivity (Rb)?

Response: We thank the reviewer for pointing out the problem. The statement specifically emphasized the significant influence of surface resistivity on the dust and minor on black carbon concentrations. We revised the sentence as "It is revealed that the increase of the surface resistivity (R_b) leads to a significant increase in dust mass concentration but a minor increase in black carbon (BC)." **Page 2, line 31-32 in the revised manuscript.**

Also, we have modified the conclusion. We revised the sentence as "By comparing the base P22 scheme to the revised scheme (P22E01-P22E03), the dust aerosol increased significantly and marginally by the black carbon." **Page 20, line 510-511 in the revised manuscript.**

Comment 3: P 148 "Vs" seems to be "Vg"

Response: We thank the reviewer for the comment. The symbol has been corrected. We changed the symbol as "V_g". **Page 6, line 148 in the revised manuscript.**

Comment 4: P162 "Since the present study is primary focused on the impact of dry deposition scheme on CMAQ dust model" here, "model" should be "modeling"

Response: We thank the reviewer for the warm reminder. The term has been revised. We corrected as "…modeling…". **Page 7, line 163 in the revised manuscript.**

Comment 5: P187-193, E22 and P22 refers to dry deposition of Emerson et al. (2020) and Pleim et al. (2022) . Why S22 stands for Shu et al. (2011) scheme? The author stated that "Indeed, both CMAQ_Off_S22 and CMAQ_Dust_S22 used the dry deposition mechanism by Shu et al. (2011)." I can not find the paper of Shu et al. (2011) in the reference list. Shu et al.(2022) and Pleim et al. (2022) are also missing.

Response: We thank the reviewer for the warm reminder. The reference Shu et al. (2011) has been removed, and replaced by Shu et al. (2022). The related references have been included to the reference list. We added the references as

“Pleim, J. E., Ran, L., Saylor, R. D., Willison, J., and Binkowski, F. S.: A New Aerosol Dry Deposition Model for Air Quality and Climate Modeling, J. Adv. Model. Earth Syst., 14, 1–21, https://doi.org/10.1029/2022MS003050, 2022.” **Page 26, line 678-680 in the revised manuscript.**

“Shu, Q., Murphy, B., Schwede, D., Henderson, B. H., Pye, H. O. T., Appel, K. W., Khan, T. R., and 534 Perlinger, J. A.: Improving the particle dry deposition scheme in the CMAQ photochemical modeling 535 system, Atmos. Environ., 289, 119343, https://doi.org/10.1016/j.atmosenv.2022.119343, 2022.” **Page 26, line 695-697 in the revised manuscript.**

Also, the sentence has been revised. We corrected the sentence as “Indeed, both CMAQ_Off_S22 and CMAQ_Dust_S22 used the dry deposition mechanism by Shu et al. (2022).” **Page 8, line 191-192 in the revised manuscript.**

Comment 6: It was suggested that the author should give more detailed description and main difference about the three dry deposition schemes of S22, E22 and P22, which can be included in a Table.

Response: We thank the reviewer for the constructive suggestion. We have included the detailed description of the 3 dry deposition schemes of S22, E20 and P22 in Table 1. We added as

"**Table 1.** Detailed mechanism expression relating the three dry deposition schemes.

Schemes	Surfaces	S22 (CMAQv5.3 and beyond)	E20	P22
V_d		$f_{veg}V_{d\ vegetated} + (1-f_{veg})V_{d\ smooth}$	$f_{veg}V_{d\ vegetated} + (1-f_{veg})V_{d\ smooth}$	$f_{veg}V_{d\ vegetated} + (1-f_{veg})V_{d\ smooth}$
R_b	Vegetated	$\frac{1}{f_{veg}((\max(\mathrm{LAI}, 1.0))u_*(E_B + E_{Im})}$	$\frac{1}{\mathrm{wet} * E_{Tot\ veg} + (1-\mathrm{wet}) * E_{Tot\ veg} * R1}$	$\frac{1}{f_{veg}((\max(\mathrm{LAI}, 1.0))u_*(E_B + E_{Im})}$
R_b	Smooth	$\frac{1}{u_*(E_B + E_{Im})}$	$\frac{1}{\mathrm{wet} * E_{Tot\ smth} + (1-\mathrm{wet}) * E_{Tot\ smth} * R1}$	$\frac{1}{BAI.u_*(E_B + E_{Im})}$
E_B	Vegetated	$Sc^{-2/3}$	$C_B Sc^{-2/3}$	$C_{IB} Sc^{-2/3}$
E_B	Smooth	$Sc^{-2/3}$	$C_B Sc^{-2/3}$	$f_{wc}\frac{u_*}{U_{10}} + (1-f_{wc})C_{IB}Sc^{-2/3}$
E_{Im}	Vegetated	$\frac{St^2}{St^2+1}$	$C_{Im}(\frac{St}{St+\alpha})^{1.7}$	$f_{micro}\frac{Sth^2}{Sth^2+1} + (1-f_{micro})\frac{St1^2}{St1^2+1}$
E_{Im}	Smooth	$\frac{St^2}{St^2+400}$	$C_{Im}(\frac{St}{St+100})^{1.7}$	$10^{-3/St}$
E_{In}	Vegetated	0	$C_{In}\left(\frac{d_p}{A}\right)^{0.8}$	0
E_{In}	Smooth	0	0	0

$V_{d\ vegetated}$ = deposition velocity over the vegetative surface: $V_{d\ vegetated} = \frac{V_g}{1-\exp(-V_g(R_a + R_{b\ vegetated}))}$

$V_{d\ smooth}$ = deposition velocity over the smooth surface: $V_{d\ smooth} = \frac{V_g}{1-\exp(-V_g(R_a + R_{b\ smooth}))}$

f_{veg} = grid scale vegetation-coverage fraction
E_B= Brownian diffusion efficiency
E_{Im}= Impaction efficiency
E_{In}= Interception efficiency
Sc= Schmidt number
St= Stokes number
wet = Wet surface
$E_{Tot\ veg}$= veg_ustar*($E_B + E_{Im} + E_{In}$)
$E_{Tot\ smth}$= 3.0*ustg*($E_B + E_{Im}$)
R1 = Bounce correction term by Slinn (1982).
C_B= Brownian collective coefficient: 0.2
C_{Im}= Impaction collective coefficient: 0.4
C_{In}=Interception collective coefficient: 2.5
α = Empirical constant
LAI = Leaf area index
BAI = Building area index
C_{IB}= 1.0/3.0
f_{wc}= Whitecap surface fraction
f_{micro}= Total impaction fraction from the microscale features
$u_*$and U_{10}= Frictional velocity and wind speed at 10 m (ms^{-1})

$St1$ and Sth = Obstacle characteristic dimensions for the leaf hairs and microscale roughness on leaves"

Comment 7: P187 "the present research conducted five simulation scenarios, namely CMAQ_Off_S22, CMAQ_Dust_S22, CMAQ_Dust_E20 and CMAQ_Dust_P22", here, five or four?

Response: We thank the reviewer for the comment. We revised the sentence as "To ensure the precision of the multiple dry deposition parameterizations, the present research conducted four simulation scenarios, namely CMAQ_Off_S22, CMAQ_Dust_S22, CMAQ_Dust_E20 and CMAQ_Dust_P22." **Page 8, line 186-188 in the revised manuscript.**