Geosci. Model Dev. Discuss.,
https://doi.org/10.5194/gmd-2019-310-RC2, 2019

Geoscientific Model Development Discussions
Open Access
EGU

Interactive comment on "WRF-Chem v3.9 simulations of the East Asian dust storm in May 2017: modeling sensitivities to dust emission and dry deposition schemes" *by* Yi Zeng et al.

Sandra LeGrand (Referee)

sandra.l.legrand@usace.army.mil

Received and published: 19 December 2019

General Comments:

This study presents an investigation of dust simulation sensitivity to three dry dust deposition schemes and two adaptations of widely used dust emission schemes using the Weather Research and Forecasting model coupled with chemistry (WRF-Chem). The authors successfully demonstrate that airborne dust concentration and transport simulation can be sensitive to dry deposition process parameterization. Moreover, their findings make a compelling case that future efforts should focus on improving dry dust deposition schemes (in addition to dust emission schemes) and that more field mea-

Printer-friendly version

Discussion paper

surements of dry deposition are needed to reduce uncertainties in dust simulation.

The authors did a good job introducing and comparing the deposition scheme physics in section 2.3 and should be commended for finding/reporting several undocumented discrepancies in the various WRF-Chem model versions. Overall, this paper brings attention to a process that is often overlooked in dust transport model assessment and is of value to the modeling community.

However, critical gaps remain in the authors' methodology that need to be addressed before publication moves forward.

The current approach supports the authors' assessment that GOCART and Shao2011 produce markedly different dust emission flux patterns, BS95 removed the most dust from the atmosphere, Z01 removed the least dust from the atmosphere, and the S11Z01 combination produced the best simulation of average PM_{10} and AOD for this case study. These results, however, may only be applicable to this case study and particular WRF-Chem configuration.

For example, the authors did not include or allude to an analysis of how well the model simulated the general meteorological conditions driving the dust events. How well did the model winds (surface and aloft), synoptic conditions, etc. verify against observations? This is a necessary step to be able to discern whether simulation outcomes (good or bad) are actually due to dust scheme physics or an artifact of erroneous forcing conditions.

Also, it is unclear which dust emission scheme correctly captured the emission phase of this dust event (with respect to magnitude, spatial footprint, and temporal patterns). Assuming the Taklimakan and Gobi Deserts are the primary sources of dust, the scatter plots from Figure 7 seem to indicate GOCART did a better job with dust emission from the Taklimakan Desert and that there's little difference between the results of the two dust emission schemes for the Gobi Desert region. Figure 2 shows maps of the total simulated dust loading from the two dust emission schemes. GOCART clearly produces widespread low-level dust emission, while Shao2011 emits stronger dust plumes from localized sources, mostly from the Gobi Desert region. The AOD comparison in Figure 8 is for midway through the dust event. It is unclear if dust originated in the Taklimakan Desert and was transported, if the Taklimakan Desert region in the AOD observation is cloud obscured, or if the dust in the Gobi Desert is entirely local.

Furthermore, because the authors have chosen to evaluate the dust emission and deposition schemes simultaneously, it's difficult to draw more generalizable conclusions about deposition scheme performance. Z01 may appear to be the best dry deposition scheme, but the slower deposition rate in Z01 may be compensating for the dust emission schemes not producing enough dust in the first place, issues with boundary layer mixing, or simulated winds that were too weak.

An overview of how well the model (or each simulation depending on whether or not aerosol feedbacks were affecting weather evolution) captured the general atmospheric conditions of the case study event is needed. This could be part of the main text or added as an appendix. This is particularly important given the strong influence of wind flow/turbulence and boundary layer mixing on the deposition process.

Dust emission observations are difficult to obtain (or in some cases non-existent). Understanding the evolution of the weather forcing conditions in combination with the dust emission simulation results, and possibly even qualitative assessment of true or false-color satellite imagery, would enable the authors to make inferences as to which dust emission treatment was more accurate for this particular case study. Timeseries plots comparing PM_{10} observations to simulated PM_{10} values from grid points in/near the source regions may also offer some insight.

Given the focus on deposition, this paper really should include an assessment of the simulated vertical dust distribution. For example, the authors could add a comparison of simulated vertical dust distribution to CALIOP LiDAR observations from the CALIPSO satellite (Winkler, 2009; available via the NASA Earth Data Portal at https://search.earthdata.nasa.gov/) in order to demonstrate that simulated dust was in good agreement with observed plume heights before making assumptions about fall rate accuracy.

Hopefully, these issues can be easily addressed with additional plots and documentation. Papers by Ma et al. (2019), Letcher and LeGrand (2018), Rizza et al. (2017), and Nguyen et al. (2019) offer good examples of approaches for general dust case study descriptions, forcing weather evaluations, and/or vertical dust distribution assessments.

Specific Comments:

1. P3 L59: "Large-size" is a relative term. Please provide a value for a frame of reference. For example, "... large-size aerosol particles (e.g., diameters > X µm), such as dust."
2. P3 L69, P13 L282, P17 L398, P18 L401: "A lot" is somewhat colloquial for use in an academic paper.
3. P3 L71: Please adjust the text to make it clear that the papers by Yuan et al. (2019) and Chen et al. (2017) are also WRF-Chem studies.
4. P4 L75: Why is it important to evaluate the dust emission and deposition schemes simultaneously? Wouldn't it be better to select a case study with well-simulated dust emissions from a single dust emission scheme when assessing model sensitivity to deposition scheme configuration? Model performance assessment for different pairings of dust emission and deposition schemes over an extended period of time may be of value to some readers, but evaluating the two aspects of the dust transport process simultaneously for a single case study event introduces extra degrees of freedom that make it difficult to ascribe model performance to a particular root cause.

5. P4 L82-84: The authors reference a study by Zhang et al. (2019) that found that the WRF-Chem GOCART model underestimated dry deposition in northwest China by more than an order of magnitude compared to observations. Interestingly, the study by Zhang et al. (2019) was done using WRF-Chem v3.7.1. An error was recently discovered in how the GOCART gravitational settling code was implemented in WRF-Chem that also affects the calculation of the dry deposition rate (see code commit change comment in the WRF source code repository by Alexander Ukhov; https://github.com/openwfm/WRF-Fire-merge/commit/2ffdebf4ac311a5b1ef8cd0c639e0d857b550fdb). Given that this error wasn't corrected until the release of WRF-Chem v4.1, the findings from Zhang et al. (2019) may no longer be representative of GOCART in the current WRF-Chem release. It would be good if the authors note that here for reader awareness.

6. P5 L101: "The model setups are listed..." wording is odd. Suggest changing to "A summary of the settings used to configure the model are listed..."

7. P5 L103 and Table 1 – Please add the radiation time step to your model description. Simulated wind speeds and dust emission flux appear to be very sensitive to this parameter when using RRTMG (not well documented). Also, please include the land use dataset (*lu_index*) used for this study in the configuration description given that some of the deposition scheme parameters have dependencies on land use categories.

8. P5 L107-109: Suggest combining the following sentences to avoid redundancy: "The MOSAIC aerosol scheme uses sectional approach to represent aerosol size distribution. The MOSAIC 4-bin aerosol scheme divides aerosol particles into four size bins by aerosol diameter: 0.039-0.156, 0.156-0.625, 0.625-2.5, 2.5-10.0 µm." Suggest changing to: "The MOSAIC 4-bin aerosol scheme divides airborne particles into four size bins by their effective diameter (0.039-0.156, 0.156-0.625,

0.625-2.5, 2.5-10.0 µm) to represent aerosol size distribution."

9. P5 L112: Suggest deleting "from dust emission schemes" to avoid redundancy.

10. P6 L122-123: This statement as written (also stated in other peer-reviewed publications) misrepresents the findings from the Shao et al. (2011) paper. Shao et al. (2011) concluded that their simplified scheme produced similar results to the Shao (2004) scheme when compared to observations from the Japan-Australian Dust Experiment (JADE). The same Shao et al. (2011) paper also notes that these findings shouldn't be generalized due to the conditions of the JADE experiment. Recommend the authors simply note that they chose to use the most simplified version of the University of Cologne (UoC) dust emission schemes for their experiment or confirm Shao2004 and Shao2011 produce similar dust emission flux outcomes for their particular case study.

11. P6 Section 2.2.1: The GOCART emission scheme description is rather sparse compared to the Shao scheme descriptions. The authors reference the paper on MOSAIC by Zhao et al. (2010), which offers a similar brief overview of the GOCART dust emission scheme and references the original Ginoux et al. (2001) paper. However, closer examination of the code (subroutine *mosaic_source_du* in *module_mosaic_addemiss.F*) indicates *dust_opt=13* (at least in v3.9) also includes the modifications to the original GOCART dust emission scheme (*dust_opt=1*) documented by LeGrand et al. (2019; Section 3.2.1) with the exception of the C parameter (default C value is set to 1×10^{-9} kg s^2 m^{-5} consistent with the original Ginoux et al. (2001) paper). It would be good if the authors could expand this section given the general lack of documentation on the WRF-Chem *dust_opt=13* setting (currently not included in the WRF-Chem user's manual). Also, the paper by Zhao et al. (2010) explored more than one modal size distribution configuration. It would be beneficial to readers for the authors to describe how the emitted dust particle size distribution used in *dust_opt=13* is

prescribed.

12. P6 L142: "... we cut the size bins for MOSAIC aerosol scheme from Shao2011 directly." Please be clearer on how the emitted dust size bins were configured for both the GOCART and Shao2011 simulations. The UoC emitted dust size bins have diameter ranges of < 2.5, 2.5–5, 5–10, 10–20 µm in v3.7.1 and 0.2–2, 2–3.6, 3.6–6, 6–12, 12–20 µm in v3.9. UoC emitted dust size bins from v3.9 match the emitted dust size bins from GOCART *dust_opt=1*. Emitted dust size bins in GOCART *dust_opt=13* appear to be modified to ignore dust particles larger than 10 µm and match the 4-bin distribution used by MOSAIC (MOSAIC bins also noted by authors on P5 L109). Does this statement imply the authors modified the MOSAIC module aerosol size bins to incorporate 5 bins and larger particles (particles up to 20 µm) for the simulations configured with Shao2011? Also, the use of the word "cut" here is a little colloquial.

13. P7-10 Section 2.3: Please introduce what is meant by important terms like "rebound effect," "collection efficiency from interception," "Schmidt number," and "Stokes number" to help readers understand why differences in these parameters matter for the deposition process.

14. P9 L190 and L196: Please provide ranges for the α and A parameters. Does use of Z01 have a dependency on WRF-Chem being configured with a particular land use dataset given the dependency pf γ, α and A on the land use category (LUC)?

15. P10 Section 2.4: Please include the number of vertical levels used and the time step in the model description section.

16. P10 L214-215: This section needs a figure showing the model domain or a reference to one of the other figures showing the whole model domain. Suggest expanding Figure 4 (WRF-Chem EROD parameter) to include the whole model

domain, changing Figure 4 to Figure 1, and referencing the EROD parameter in the dust emission scheme description section.

17. P10 L219-221: The authors note that meteorological conditions are reinitialized every 24 hours, provide two examples of studies that also used this approach, and comment that this approach has been verified to obtain better meteorological fields. The references provided, however, don't really support this statement. For example, Su and Fung (2015) reinitialize their meteorological fields ever 4 days, and neither study explored the use of different "spin-up" approaches on their results. Reinitialization or "daisy-chain" spin-up is a common practice used by numerical weather modelers. As long as the resultant weather fields used in the experiment were representative, the justification statement (L220-221) is unnecessary.

18. P11 Section 3 (Results): MOSAIC incorporates aerosol feedbacks. The six tests most likely were subject to different weather forcing conditions as the simulations evolved. How notable were those differences?

19. P11 L241-242: The authors utilize AOD simulation results at 1300 local time to compare with the daily MODIS AOD product. The actual model domain encompasses multiple time zones though (e.g., Fig. 1). Are the model values used for the analysis based on the central point of the model domain (UTC + 8 hours), or was there some other approach used to create a composite simulation product? A comparison of a single simulation time period to the daily product may be fine if the model correctly captured the timing of the forcing conditions. Was this the case? If not, it may be better to compare the daily MODIS product to the simulation time period that best matches the state of the atmosphere when the observations were collected or use simulated daily averaged-AOD values for the comparison.

20. P11-12 L245-256: Which dry deposition scheme was used for the dust emission

analysis? MOSAIC includes aerosol feedbacks, which could affect the surface winds driving the dust emission simulation. The authors state that they reinitialized the meteorological conditions every 24 hours, but that could still allow enough time for the forcing conditions to be affected. Were the wind fields the same in both emission scheme tests?

21. P12 L258: Why was this time period chosen? Is it the highest magnitude of dust emission for the simulation event?

22. P12 L263-264 and L268-269: Unless the authors have altered the code, Shao2011 as implemented in WRF-Chem uses the EROD parameter from the original GOCART dust emission scheme as a mask. Dust emission is permitted where the erodibility factor is greater than zero via a binary (0 or 1) multiplier (e.g., LeGrand et al., 2019; section 3.3; implemented in *module_uoc_dust.F*). Note, areas classified as zero in the default pre-calculated erodibility factor dataset in WRF-Chem over land are either relatively high points in the terrain (maximum elevation in the surrounding $10^{\circ}\times10^{\circ}$ area) or determined to have vegetation coverage according to a static 1987 annual average land cover dataset derived from $1^{\circ}\times1^{\circ}$ resolution AVHRR data (see Kim et al., 2013). Was this erodibility factor masking treatment included in the code implemented by the authors into MOSAIC? If not, this is an important distinction to document.

23. P12 L257-258 and P36 Figure 3: What grain size(s) were used to diagnose u_{*t} and u_t (Fig. 3c through 3f)? Are the dust emission fluxes presented in Fig 3. (g and h) representative of the emission flux for that grain size or the total dust emission flux?

24. P12 L269-270: The authors' comment that differences in dust emission flux produced by the two dust emission schemes are due to differences in threshold conditions required for dust emission and differences in formulas and parameters used for calculating dust emission. In other words, the two dust emission

schemes are very different from each other and produce different results? This has been well documented in other publications and doesn't add to the discussion. Suggest removing this sentence. The narrative flows into the next paragraph without it.

25. P12 L272-275: GOCART is also dependent on mean wind shear. Intermittent turbulence is not considered in the GOCART dust emission process either. Dust emission under low wind speed in GOCART from the Taklimakan Desert is likely due to the threshold velocity error described in LeGrand et al. (2019). The erodibility factor values in the authors' model domain max out at 0.35. The application of the erodibility factor decreases the dust emission flux.

26. P13 L280-285: This is an important aspect of the experimental design and needs to be moved to the methodology section/incorporated into Section 2.2. Details about the Shao2011 configuration used in this study should be consolidated to Section 2.2; they should not split between the main text and the appendix.

27. P13 L294-295: Please provide a reference for the statement "As desert dust mass is mainly concentrated in the large particle size range. . ." and the upper bound of the range. Is this statement appropriate for all desert regions or just East Asia? Also please include the value of the reference diameter (5 µm) in the main text as well as the figure caption. The "coarse" and "accumulation" characterization of emitted dust from MOSAIC needs to be described prior to this discussion. These are somewhat ambiguous terms in the dust literature. Suggest defining these terms in section 2.2.

28. P15 L350: Suggest replacing the phrase "better than" with "more physically meaningful" here (also in the abstract). "Better physics" does not always translate to better numerical model simulations.

29. P16 L373: "Extremely high AOD" is a little too vague here. Are the observed AOD

values considered extremely high for this type of event in East Asia? Suggest replacing the sentence intro with "The highest AOD values for this case study were observed in. . ."

30. P17 L376-377: Wording here is a little odd. Suggest changing to "Simulated AOD values from the S11Z01 configuration produced the closest match to the observed daily MODIS AOD with respect to magnitude and spatial pattern (Fig. 8g).

31. P17 L382-383: Was the cloud cover an issue? Were there any areas masked out for clouds in the MODIS AOD observations that may have actually been high in dust concentration?

32. P18 L408-409: Reference needed for the statement ". . . dust emitted from [the] Gobi Desert is the most important source of dust weather in northern China."

33. P18 L409-410: The paper by Su and Fung (2015) provides an analysis of a single case study event in East Asia. This study offers valuable information, but a single case study is not sufficient evidence to make general claims about model performance over a region. Recommend removing the statement about the Shao2011 scheme being documented to give better performance than GOCART over East Asia from the text. It's unnecessary.

34. P19 L424: Why is there an ellipsis (. . .) in Eq. A2?

35. P19 L431-432, P30 L446-447, L463-464, P33 Table B1, P35 Table B3: Suggest adding a subscript to β from Eq. A4 since the β symbol is also used to represent a different parameter in one of the deposition schemes.

36. P30 Table 3: Columns for *dust_opt* and *dust_schme* are unnecessary. The value used to activate the Shao2011 dust emission module by the authors may not be the one used by the WRF-Chem source code managers. Listing an arbitrary

Printer-friendly version

Discussion paper

setting in Table 3 could cause confusion to readers if this new approach is eventually implemented into the baseline code with different activation options later. Suggest noting that GOCART is *dust_opt=13* and that Shao2011 is *dust_opt=4* with *dust_schme=3* in the text in section 2.2 and removing these columns from the table.

37. P33 Table B1: The values for the third row seem to be missing.

38. P37 Figure 2: The diameter of the emitted dust is less than 10 µm in the *dust_opt=13* version of GOCART. Unless the authors have modified the code, the upper range of the emitted dust size bins from *dust_opt=3* is 20 µm (in both v3.7.1 and v3.9).

Noted Typos:

1. P14 L302 and P40 Fig 5: Be consistent with symbol case. The particle diameter is represented by a lower case d in all previous equations.

2. P11 L241-242: Use of "p.m." is unnecessary with 24-hour clock time.

3. P12 L253: Use of acronym GD for Gobi Desert before it's been defined (on P13 L277).

4. P12 L254: Use of acronym TD for Taklimakan Desert before it's been defined (on P12 L271).

5. P16 L372: "...with MODIS [is provided] in Fig. 8."

6. Punctuation is an issue. Several commas missing from compound sentences throughout the text.

7. Missing the word "the" before desert names throughout the text.

References

Chen, S., Huang, J., Qian, Y., Zhao, C., Kang, L., Yang, B., Wang, Y., Liu, Y., Yuan, T., Wang, T., Ma, X. and Zhang, G.: An overview of mineral dust modeling over East Asia, J. Meteorol. Res., 31(4), 633-653, doi:10.1007/s13351-017-6142-2, 2017.

Ginoux, P., Chin, M., Tegen, I., Prospero, J. M., Holben, B., Dubovik, O. and Lin, S.-J.: Sources and distributions of dust aerosols simulated with the GOCART model, J. Geophys. Res., 106(D17), 20,255-20,273, doi:10.1029/2000JD000053, 2001.

Kim, D., Chin, M., Bian, H., Tan, Q., Brown, M. E., Zheng, T., You, R., Diehl, T., Ginoux, P. and Kucsera, T.: The effect of the dynamic surface bareness on dust source function, emission, and distribution, J. Geophys. Res.-Atmos., 118(2), 871-886, doi:10.1029/2012JD017907, 2013.

LeGrand, S. L., Polashenski, C., Letcher, T. W., Creighton, G. A., Peckham, S. E. and Cetola, J. D.: The AFWA dust emission scheme for the GOCART aerosol model in WRF-Chem v3.8.1, Geosci. Model Dev., 12(1), 131-166, doi:10.5194/gmd-12-131-2019, 2019.

Letcher, T. W. and LeGrand, S. L.: A Comparison of Simulated Dust Produced by Three Dust-Emission Schemes in WRF-Chem: Case Study Assessment, ERDC/CRREL TR-18-13, U.S. Army Engineer Research and Development Center, Hanover, New Hampshire, USA, doi: 10.21079/11681/28868, 2018.

Ma, S., Zhang, X., Gao, C., Tong, Q., Xiu, A., Zhao, H. and Zhang, S.: Simulating performance of CHIMERE on a late autumnal dust storm over Northern China, Sustainability, 11(4), 1074, doi:10.3390/su11041074, 2019.

Nguyen, H. D., Riley, M., Leys, J. and Salter, D.: Dust storm event of February 2019 in Central and East Coast of Australia and evidence of long-range transport to New Zealand and Antarctica, Atmosphere, 10(11), 653, doi:10.3390/atmos10110653, 2019.

Rizza, U., Miglietta, M. M., Mangia, C., Ielpo, P., Morichetti, M., Iachini, C., Virgili, S. and Passerini, G.: Sensitivity of WRF-Chem model to land surface schemes: Assessment in a severe dust outbreak episode in the Central Mediterranean (Apulia Region), Atmos. Res., 201, 168-180, doi:10.1016/j.atmosres.2017.10.022, 2018.

Shao, Y.: Simplification of a dust emission scheme and comparison with data, J. Geophys. Res., 109(D10), doi:10.1029/2003JD004372, 2004.

Shao, Y., Ishizuka, M., Mikami, M. and Leys, J. F.: Parameterization of size-resolved dust emission and validation with measurements, J. Geophys. Res., 116(D8),

doi:10.1029/2010JD014527, 2011.
Su, L. and Fung, J. C. H.: Sensitivities of WRF-Chem to dust emission schemes and land surface properties in simulating dust cycles during springtime over East Asia: Simulated Dust Cycles Over East Asia, J. Geophys. Res.-Atmos., 120(21), 11,215-11,230, doi:10.1002/2015JD023446, 2015.
Winker, D. M., Vaughan, M. A., Omar, A., Hu, Y., Powell, K. A., Liu, Z., Hunt, W. H. and Young, S. A.: Overview of the CALIPSO mission and CALIOP data processing algorithms, J. Atmos. Oceanic Tech., 26(11), 2310-2323, doi:10.1175/2009JTECHA1281.1, 2009.
Yuan, T., Chen, S., Huang, J., Zhang, X., Luo, Y., Ma, X. and Zhang, G.: Sensitivity of simulating a dust storm over Central Asia to different dust schemes using the WRF-Chem model, Atmos. Environ., 207, 16–29, doi:10.1016/j.atmosenv.2019.03.014, 2019.
Zhang, X.-X., Sharratt, B., Lei, J.-Q., Wu, C.-L., Zhang, J., Zhao, C., Wang, Z.-F., Wu, S.-X., Li, S.-Y., Liu, L.-Y., Huang, S.-Y., Guo, Y.-H., Mao, R., Li, J., Tang, X. and Hao, J.-Q.: Parameterization schemes on dust deposition in northwest China: Model validation and implications for the global dust cycle, Atmos. Environ., 209, 1-13, doi:10.1016/j.atmosenv.2019.04.017, 2019.
Zhao, C., Liu, X., Leung, L. R., Johnson, B., McFarlane, S. A., Gustafson, W. I., Fast, J. D. and Easter, R.: The spatial distribution of mineral dust and its shortwave radiative forcing over North Africa: modeling sensitivities to dust emissions and aerosol size treatments, Atmos. Chem. Phys., 10(18), 8821–8838, doi:10.5194/acp-10-8821-2010, 2010.

Interactive comment on Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2019-310, 2019.