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Interactive comment on "The AFWA Dust Emissions Scheme for the GOCART Aerosol Model in WRF-Chem" *by* Sandra L. LeGrand et al.

Anonymous Referee #2

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The authors describe and compare the current dust emission options in WRF-Chem and discuss similarities and differences between the different options. The objective of the paper is to document the AFWA-dust emission module in WRF, but strong emphasis is given also on the GOCART and UoC dust modules with the goal to compare the implementations and document so-far undocumented aspects. While this is useful, it does not seem to have happened with interaction/consultation of the persons responsible for the implementations, which is - at least - surprising and which might have helped to clarify certain aspects.

The paper is overall well written and organized. However, there are several shortcomings/incorrect statements, in particular regarding the description of the UoC implementation. I also see some problems regarding the terminology and code versions used

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for the simulations. I recommend revision of the manuscript, considering the following comments:

GOCART-WRF Implementation:

- The authors discuss the change of an expression for the saltation threshold in the GOCART-WRF implementation from one for wind velocity to one for friction velocity. It is important to note here that both equations for threshold velocity (Eqs. 2 and 5) were originally expressions for threshold friction velocity, only the coefficient A in Eq. 2 was adapted, supposedly to mimic a wind speed rather than friction velocity. The deficits discussed in section 3.1.2 could therefore be easily overcome by either doing a similar empirical adjustment or by using one of the stability functions to convert between u* and u readily available from the surface layer physics in WRF. The authors further discuss that the use of such a threshold friction velocity would be "physically invalid" (P9 L16), because it is designed to represent the initiation of saltation (P8 L26) while saltation is not explicitly represented in the GOCART-WRF scheme. This argument does not hold, because the merging of saltation and dust emission to one empirical relationship in the parameterization does not contradict the assumption that dust emission is initiated by saltation. This is also stated by the authors themselves (P5 - L15-19): "The impacts of saltation bombardment processes on mobilization are not necessarily omitted - rather they are internalized in the relationship between wind speed and emissions". For this reason, I suggest still to highlight the issue of comparing u* with u in the current implementation also mentioning that a correction like it was done before could easily be added, but to remove the discussion about the unphysical use of the equation (in an empirical parameterization) at the end of Section 3.1.2, the purpose of which seems to be mainly to motivate the introduction of the AFWA module. This is unnecessary. The formulations in this motivating paragraph, i.e. P9 L14-L22, to me also seem to be too strong statements in terms of the novelty of the implementation keeping in mind that it is not a new emission parameterization, but the incorporation of existing and well-known parameterizations in WRF. Apart of that, I recommend to add references to Eqs. (2) [Bagnold, 1941; Ginoux et al. (2001)].

- P6 L15 The authors state that the impact of a soil moisture correction factor > 1 is small, because soils moisture does not normally assume such small values "in most numerical weather models". It would be more relevant here to discuss this in the framework of WRF which does seem to allow for such small values (P28 L23-24).

- P8 L7-9 The mismatch between predicted and observed threshold friction velocities for small particles in the Bagnold-parameterization is well-known and dates back to the mid/late 20th century. Iversen and White (1982) provided the next well-referenced parameterization for u*t including a minimium of u*t for particles of about 100 micrometers in diameter (Iversen and White, 1982 is also the basis for the MB95 expression used in the AFWA implementation), followed by Shao and Lu (2000), who put the expression on pure physics-based footing. Reference to a modeling study from 2003 does therefore not seem appropriate here.

- P8 L18-19 It is explained here that the coefficient in Equation 15 (0.129) is given as 0.0013 in the model due to rounding and unit conversion. However, checking the source code, I see a factor of 0.13 (L. 273 in module_gocart_dust.F and L.511 in module_gocart_dust_afwa.F, WRF-Chem V4.0). Please clarify.

AFWA implementation:

- P9 L26 The MB95 parameterization represents saltation bombardment only.

- Repetition of Eq. (5) seems unnecessary here.

- P9 L12 - See previous comment on the factor 0.0013

- Please add reference to Eq. (10)

UoC implementation:

- P14 L7 The namelist variable is called dust_schme and not dust_scheme.

- P14 L12 ["Both schemes simulate the physics of dust emission"] This is not correct. While the Shao schemes used in the UoC module are physics-based parameterizations, the AFWA module makes use of the Marticorena and Bergametti parameterization, which is semi-empirical. See also my later comments on "physics-based schemes" and the technical term "schemes" under "Terminology".

- P14 L15 Which dust emission bins are referred to here, the bins to calculate the emissions or the bins passed on to the WRF transport routines? The former are not the same between the UoC and AFWA modules and the latter are consistent with the GOCART-WRF and AFWA implementations only from WRF V3.8.1. Before that the UoC implementation was using different bins (see Flaounas et al., 2017)

- Note that while Eq. (17) might give similar output like Eq. (5), it is not empirical.

- P14 L25 The value of 1.65 x 10ˆ-4 kg sˆ-2 is documented in Darmenova et al. (2009)

- P15 L18 I strongly recommend not to merge coefficients here, as this can give an equation a different appearance. Please list all coefficients separately for consistency with the original references.

- P15 L7-8 The UoC implementation uses the vegetation fraction provided by the WRF-model. This can easily and should be updated for case studies to obtain more accurate results. The specific vegetation product used is therefore not a feature of the UoC dust emission module, but of the parent WRF model.

- P16 L2-3 The statement here is unclear and misleading. Supply-limited saltation is not accounted for in either of the implementations in WRF. While the EROD function is meant to represent the availability of erodible sediment, it does by no means account for supply limitation in its physical meaning within the saltation process. Rather, it represents the "most probable locations of sediment" (Ginoux et al., 2001).

- P16 L7-9 This sentence is not clear to me.

- P16 L10 the variable dpsds is not calculated using Eq. (22). Eq. (22) gives the probability density function for airborne sediment particle-size distribution p_s(d) ("psds" in the code) (e.g. S11). Please modify Eq. (22) accordingly for consistency with S11. "dpsds" is the probability for each bin and follows according to the definition of probability density functions. There is therefore no need to introduce such an internal variable here.

- P16 L14 d is diameter, not bin.

- P16 L15-16 ["Limitations..."] This seems to be a general statement and not specific to the UoC implementation.

- P16 L19-20 ["prior to correction for soil moisture and ground cover"] This is not correct, the corrections are applied first.

- P17 L7 ["other tuning parameters"] While soil characteristics like the ones mentioned can be used to tune a model, they are not per se tuning parameters, but have a physical meaning.

- Eq. (25) I do not understand how the authors derived this equation. It is inconsistent with the one implemented in the UoC-S01 module. See also my comment further down on Section 3.3.2, Point 6. Apart of that, it needs to be Q(d_s) rather than q(d_s).

- Eq. (27) Q(d_s) rather than q(d_s)

- P18 L16 The authors discuss here about a vegetation correction applied on both saltation and dust emission flux in the model and speculate that this correction "may be in error". The correction effectively reduces the surface area from which (a) sand particles and (b) dust particles can be emitted. Considering emission as a two-part process, application of the correction twice, i.e. for Q and F separately, is therefore plausible.

- P19 L6 The authors claim that "measurements of these soil characteristics are generally unavailable", referring to the use of soil particle-size distributions. This is surprising given that a complete set of parameters representing particle-size-distributions for the

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12 USDA soil-texture classes is provided with the implementation. Availability is therefore not an issue and can be considered similar to that of other "difficult-to-obtain" soil-related parameters, e.g. porosity or clay fraction as used in the AFWA implementation.

- P19 L10-18 The description of how the soil particle-size distributions are obtained is not clear. The use of the FAO soil map is again, like vegetation cover, that provided by the WRF modeling framework and should not be considered as a feature of the implementation. The term "soil modes" is also misleading in the context of probability density functions, for which a "mode" has a statistical meaning. The soil parameters available in the UoC implementation are assigned to the 12 USDA soil texture classes for each of which particle-size distributions can be computed. Further, the particle-size distributions are calculated in the subroutine psd_create and not in the subroutine h_c. The latter determines the moisture correction of the threshold friction velocity. However, I believe that the names of individual subroutines should not be discussed here.

- In the original paper S04, c_y varies from 1 x 10ˆ-5 to 3 x 10ˆ-4. Note that exponential notation (1 x 10ˆ-5 rather than 1e-5) is preferable.

- Sec. 3.3.2, Point 2 - documented in Darmenova et al. (2009), see comment above

- Sec. 3.3.2, Point 3 - The roughness correction represents drag partition, while the application of (1-cf) correct for the area covered by vegetation. The factor is discussed in Darmenova et al. (2009).

- Sec. 3.3.2, Point 4 - The use of the Kawamura/White saltation flux equation is documented in Shao et al. (2011), in which also the Shao (2004) scheme is used.

- Sec. 3.3.2, Point 5 - See earlier comment on "soil modes"

- Sec. 3.3.2, Point 6 - This point is also incorrect. First, Eq. (25) is not the one implemented in the model. In the relevant subroutine (vhlys), it is stated clearly that the subroutine computes Eq. (8) from Lu and Shao (1999). Comparing the implementation with Eq. (8) in the original paper shows that the two are in perfect agreement. The supposed difference of a factor of 1/d mentioned by the authors disappears understanding that Eq. (8) in Lu and Shao (1999), gives V/b rather than V and that b is approximately equal to d as explained in Shao (2001). The reason why the Equation from Lu and Shao (1999) is implemented here is likely the fact that the new Equation in Shao (2001) is more complicated and subject to further testing as is discussed at length in Shao (2001). Second, Eq. (36) [also Eq. 36 in Shao, 2001] is also in perfect agreement with Eq. (8) in Lu and Shao (1999), which can easily be show using mathematical conversions and inserting beta, while the Equation given by the authors (their Eq. (25)) is incorrect.

- P21 L21 The Shao schemes available in the UoC module do not include aerodynamic (dust) entrainment. In Shao et al. (2001), Section 5 it is stated: "Here we are mainly concerned with the latter case" referring to saltation-based dust emission

- P21 L27 Eq. (7) in Shao (2004) does not represent sigma_p. Eq. (7) describes gamma (cf. Eq. (23) in the present paper).

Test case and comparison:

- P22 L13 The references given here belong to WRF-Chem, not to the dust emission schemes. I suggest moving them to an earlier position.

- If the UoC saltation flux bug fix was released in January 2018, this was well before submission of the manuscript. The version used for evaluation in this paper should therefore be the one with the bug corrected. There is no point in using a version that is known to be wrong and that is outdated. If the authors wish to test the effect of this bug fix on the results, they can do so in an appendix, but the version in the main text should be the version "as is", i.e. including the bug correction.

- In Section 3.2, an implementation error is mentioned for the AFWA implementation. It is not clear whether the version used in the comparison is the one with or without

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the error correction. The same as mentioned in the previous comment for the UoC scheme applies here, too, with the only difference that the correction for the AFWA scheme does not seem to be included in the current release, but will be in a future version.

- P23 L20-21 ["The atmospheric dust observed..."] Please add reference, e.g. a figure, or give additional explanation.

- P24 L25-26 It is sufficient to give the color coding in the figure caption.

- P25 L28, P27 19 I suggest adding one or two more references for the "spurious dust lofting" in the GOCART-WRF implementation if available, keeping in mind that - if it depends on u*t vs. ut - this could be relatively easily fixed.

- P26 L9-10 The larger spatial extent in the results of the GOCART-WRF scheme are visible most of the time in Fig. 5, but not at 10 UTC on 25 Jan for which the MODIS data is shown in Fig. 4.

- P27 L24 (and relevant subsequent passages) The binary use of the EROD function cannot cause a reduced area of active dust emission in the UoC parameterization: dust emission is possible wherever EROD > 0, i.e. wherever dust emission is possible in the AFWA implementation.

- P27 L29 The version using the bug fix should be used here - see earlier comment.

- P28 L5 Is the threshold friction velocity meant with "soil threshold parameter"? In that case it would depend on particle size and not be a single value.

- P28 L16 The coefficients used in the soil moisture correction are not only different due to different units. Different sets of coefficients are also used for each of the 12 soil texture classes (Klose et al., 2014; based on Shao and Jung, 2000, unpublished manuscript)

- Fig. 8, If the same meteorology is used for all runs, it would be sufficient to show wind speed only once.

- Fig. 9, All corrections - Why are there no values shown north-west of the Caspian Sea for the UoC implementation?

- P 29 L12-21 See previous comments on bug fix.

- P29 L32/Fig. 9 Please explain why S/(rough+cfˆ2) is plotted here.

Terminology:

- The terms scheme, parameterization, and model are used almost interchangeably here. This is problematic, in particular in the context of the GOCART, AFWA and UoC "schemes", which in my opinion are neither scheme nor parameterization nor model, but only the implementations of existing parameterizations/schemes in a model (which would be WRF-Chem in this case). I think it is important to use consistent terminology throughout the paper.

- The authors use the expression "emission mode" at several locations (e.g. P4 L3, P4 L15, P5 L20). I am not aware of any common use of this expression in the dust emission/aeolian community. I would therefore strongly recommend to abstrain from this expression. Most likely it is being confused with the modes of particle motion, which are, e.g., saltation, suspension, creep (Bagnold (1941), Shao (2008), Kok et al. (2012)). Please revise.

- P5 L16-18 The explicit separation of saltation and dust emission fluxes in a parameterization does not necessarily make it a physics-based parameterization. If the saltation flux and/or dust emission flux are represented by empirical relationships rather than basic physics, it will still be (semi-)empirical. The text should be modified accordingly.

Minor comments:

P1 L13 - particles rather than particulates

P2 L5 - Reference for GOCART model needed here, in particular the dust component that is of relevance for this paper.

P2 L9 - "enabling their vertical movement" is not correct here speaking of dust emissions - Please revise, e.g. ""enabling dust transport in the atmosphere"

P2 L11 - As the present paper is concerned with dust emission, the addition of Ginoux et al. (2001) as a reference here would be appropriate.

P3 L9-10 - Implementation described in Darmenova et al. (2009)

P3 L22-23 - aerodynamic lift, saltation bombardment, and particle disaggregation are not forces, but processes. The half-sentence introducing those is misleading.

P9 L25 saltation bombardment

P9 L29 "effective particle size" rather than "effective aerosol size"

P22 L18-19 reference to NOAA/NCEP (2000) in parentheses

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