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Comment on acp-2022-228

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Referee comment on "The simulation of mineral dust in the United Kingdom Earth System Model UKESM1" by Stephanie Woodward et al., Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2022-228-RC1, 2022

This article describes the dust scheme in the UKESM1, while calculating changes in the dust cycle between the pre-industrial and present day, as well as under future scenarios. In the UKESM1, vegetation can change in response to a changing climate, thereby modifying dust emission. Under future warming, dust sources contract, associated in part with a reduction of the bare soil fraction, resulting in less dust. To highlight the sensitivity of dust to vegetation changes, the authors contrast the absence of significant dust changes in a model version without the vegetation feedback. The expansion of vegetation in the future and its effect upon dust has been discussed in previous articles (e.g. Mahowald and Luo GRL 2003, where greening is due to fertilization by rising CO2 concentrations, and which should be cited), but the change remains uncertain, so estimates by additional models are important. The article is clearly written, and I enjoyed reading it, although I would like to see some points clarified before I recommend publication. The authors can contact me at ron.l.miller@nasa.gov if they have any questions.

Major Comments

1. Differences between the two model versions with (UKESM1) and without (HadGEM3-GC3.1) the Earth System feedbacks are partly the result of differences in tuning of dust model parameters, rather than differences in the range of physical processes represented by each model. These parameters are identified in the article (line 132) but little information is given about the observations used for tuning. More discussion of the tuning is important because differences in the direct radiation effect (DRE) between UKESM1 and HadGEM3-GC3.1 are attributed to differences in tuning and the impact upon the present-day size distribution (line 563).

2. The agreement of both model versions with observations is described as "encouraging" (line 560) and used to question the necessity of including preferential sources that are

absent in UKESM1 but commonly present in other models (cf. also line 490). However, the importance of preferential sources is typically demonstrated using the frequency of occurrence (FoO) of AOD above a certain value, and noting that regions of frequent dustiness (high FoO) are highly localized, suggesting that dust emission itself is confined to limited regions (Prospero et al. Rev. Geophys. 2002). This is the motivation for the preferential source maps of Ginoux (2001, 2012) along with Zender (2003) and Tegen (2002), even if their physical criteria that identify sources vary. For the authors to demonstrate that their model does not need preferential sources, they would have to show that their FoO, which is not diagnosed for either model, is consistent with the observed values. The authors need not diagnose FoO, but they should note that their choice of observations for evaluation does not distinguish the effect of their preferred source omission.

3. The future experiments suggest that the expansion of vegetation in the late 21C will reduce dust emission, but it is essential to show that this feedback is simulated with the correct amplitude. Some observations suggest that dust models are failing to simulate large decadal variations in source strength and dust emission (e.g. Yoshioka et al J. Climate 2007, Mahowald ACP 2010). These studies should be noted, because they raise the possibility that the change in dust between the pre-industrial and present day is larger than simulated by current models, suggesting that the models and their projections of future dust emission are lacking an important dust-climate feedback.

Minor Comments:

22 "0.289 W m-2" missing minus sign?

35 "Climate models have long included dust schemes (e.g. Tegen and Fung, 1994...)" I'm not sure how 'climate model' is defined but Tegen and Fung describes an offline chemical transport model driven by GISS AGCM winds. The integration of a dust scheme into the actual GISS AGCM was described by Tegen and Miller JGR 1998.

55 "such as the size distribution" I find this confusing because it is a consequence of model differences rather than a model difference per se. I suggest limiting the description to the latter. I am guessing that the HadGEM3- GC3.1 experiment holds vegetation fixed? Are there other differences that might be important? (Some of the discussion below that addresses my comment could be moved here.)

90 "inhibited" Do you mean 'prevented'?

93 "equation (1) was derived from instantaneous measurements at single locations." Is this true? I believe that equation (1) is based upon averaging over a time scale related to the passage of several turbulent eddies, corresponding to at least a few minutes.

94 "Corrections are therefore needed..." The parameter k1 is uniform with space and time, even though rapid fluctuations might be specific to certain conditions. e.g. Lunt JGR 2002 and Cakmur JGR 2004 relate gustiness to the surface sensible heat flux, which is typically strongest at midday and within arid regions. This use of k1 should be discussed in this context.

98 "Dry threshold friction velocity (U*td) values were obtained from Bagnold (1941)" Could you give more information about your threshold dependence upon diameter? My memory is that Bagnold proposed a threshold that increased with particle diameter, whereas subsequent measurements showed a minimum near 75 um diameter and a subsequent increase of the threshold for smaller particles. (e.g. Greeley and Iversen 1985).

128 "In UKESM1 the total marine dust deposition flux is passed into the ocean" During atmospheric transport, is there any processing of the iron in dust into bioavailable forms? (e.g. Myriokefalitakis GMD 2022)

161-163: please give more specific information about what observational criteria were used that resulted in different values of the tuning parameters between the two models.

194 "the global load in UK_PD is 30% higher than in H3_PD." Could you comment on regional differences (Fig. 1c and d)? In key dust emitting regions like parts of the Sahel, the difference between model versions can be up to a factor of 2.

195 "The UK_PD load of 19.5 Tg is in good agreement with the AeroCom mean of 19.2Tg (Textor et al, 2006)." A more observationally based estimate of the load is given by Kok et al. Nat. Geosci. 2017: 23 (14–33) Tg. This is strictly an estimate for PM20, but the addition of larger particles probably increases this value only slightly.

200 "dust-dominated AERONET" Note that AERONET measures AOD. Also, how were dust dominated sites identified? (Maybe move discussion near line 245 to here?)

207 "and the position of the Subtropical Front" Is this the atmospheric Subtropical Front? How is this identified? By the position of the subtropical jet?

209 "The similarity in the level of performance between UKESM1 and HadGEM3-GC3.1 is noteworthy" Could you quantify this performance, e.g. with a correlation coefficient for both surface concentration and AOD between the two models?

225 "UKESM1 dust was tuned to give better agreement with the size distribution data from the FENNEC campaign (Ryder et al., 2013) than was shown in HadGEM3-GC3.1" Why wasn't the FENNEC data used to tune HadGEM3-GC3.1?

240 why is the UK_PD AOD consistently smaller than that due to H3_PD?

246 "Capo Verde off the west African coast" Does the AOD at this location include the effect of sea salt, which like dust, has large diameters and a small AE?

259 "(MCS) produce similar levels of dust to those seen in the dry season." Please cite Caton-Harrison et al. JGR 2019 and 2020.

263 "N96 climate model" What is the approximate resolution of N96?

277 "The high bias on the southwest side of the Himalayas and low bias on the northeast side suggest the model may be failing to transport aerosol over the steep orography there." Couldn't some of this bias be due to other aerosol species that contribute to the MODIS retrievals?

297 "this collection of deposition" Albani et al. JAMES 2014 makes available a similar collection that acknowledges differences in the sampled particle size range. Is the size range from the Huneuus set used here uniform across all the sites?

304 "noticeable bias is in Antarctica and the Southern Ocean" Is the overestimate of deposition related to the underestimate of surface concentration in these regions (Figure 2a)?

306 "and hence roughness." How is roughness related to deposition?

324 "being positive over the brightest surfaces" Is this an albedo effect as implied by the sentence? The positive forcing could also result from large LW emission toward the surface by the dust layer over bright surfaces where vegetation is sparse and emission is large.

356 "feedback between dust DREs and emissions" see also Miller et al. (2004) doi:

10.1029/2004JD004912.

371 "SW DREs are approximately halved due to the size distribution change, mainly because of reductions in the load of finer particles in bins 2 and 3 (0.2–2.0 μm)..." It's hard to keep track which model is being referred to :) I'm guessing that the UK model has the larger particles? Given this fundamental difference in particle size, a figure describing it would be helpful.

382 "6 The response of dust to changing climate" Maybe have two subsections: 6.1 for PI to PD and 6.2 for PD to the future?

393 "The effect of climate change excluding the vegetation response (but including land-use change) is estimated from the difference between HadGEM3-GC3.1 simulations H3_PD and H3_PI." It seems potentially inconsistent to use the H3 model to diagnose the land-use effect in the UK model, given the different tunings. In fairness to the authors, the global averages in Figure 9 seem to argue that the H3 model can be used to diagnose the effects of land use and climate change in the UK model, although regional differences between Fig. 9c and d can be significant (e.g. over India and parts of the Sahel).

466 "The global load reduction of 23% associated with “Fossil-fuelled development” is somewhat larger than the 19% reduction of the “Middle of the road” pathway." Why don't these changes scale linearly with the radiative forcing? (4.5 v. 8.5 W/m2)? This seems like an important question if the future change in dust is predictable.

490 "It was not found necessary to limit dust emissions by imposing any sort of preferential source terms". See major comment 2.

510 "Even globally homogeneous LW–SW compensation has been shown to affect climate (Tilmes et al., 2016), and in the case of dust regional effects will be important." One reason is that the DRE at the surface, which is usually farther than the TOA value from zero, will perturb the hydrologic cycle (e.g. Miller et al 2004 doi:10.1029/2003JD004085 or Miller et al 2014 doi:10.1007/978-94-017-8978-3_13)

533 "(haboobs)" Also note that this fraction will vary seasonally and be most important in summer (Caton-Harrison et al. JGR 2019 and 2020).

536 "The omission of dust aging " what mechanisms of aging are referred to here? What effect does this have on particle lifetime?