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Reply to comment by N. M. Mahowald et al. on "Relative importance of climate and land use in determining present and future global soil dust emission"

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[1] We appreciate the interest in the question, which percentage of soil dust aerosol is derived from anthropogenically disturbed soils compared to natural desert sources. This remains a very uncertain but most important factor in the study of the processes controlling the dust aerosol distribution and its effects. While we agree with the comment by *Mahowald et al.* [2004] that the results of *Tegen et al.* [2004] might be to a certain extent model dependent, we find that the method used by *Mahowald et al.* [2004] to derive information about the relative percentage of dust emission from cultivated soils using dust storm frequency data cannot be directly compared to the method used in our original publication. *Tegen et al.* [2004] compared a global climatology of dust storm frequencies (DSFs) with modeled dust emission events to estimate how much of the dust is blown from soils that are either cultivated or used as grazing land on a global scale. We found that the observations show a small but significant increase in DSF in agricultural areas where vegetation covers more than 10% of the ground. However, while, in order to match the observations, modeled dust emissions from agricultural areas had to be increased, just a small increase resulting in 5–7% of the global dust emissions originating from those areas was sufficient. The use of two different data sets of cultivation distributions [*Klein Goldewijk*, 2001; *Ramankutty and Foley*, 1999] led to similar results.

[2] In their results, *Mahowald et al.* [2004] used the same DSF data set together with a global dust transport model to test with a different method if those results were dependent on the model or methodology. With this they find that the correlation between DSF and modeled events of reduced visibility caused by dust is statistically indistinguishable for a series of dust emission scenarios with dust emission increases in cultivated areas varying between 0% and 50% of global emissions.

[3] *Mahowald et al.* [2004] are correctly stating that statistical testing should be carried out to confirm this type of results. We repeated our analysis with model scenarios increasing dust emissions from cultivated land for the cultivation distribution from *Klein Goldewijk* [2001] by further reducing the threshold wind friction velocity required to initiate dust emission, and used the Student's t test to check when the differences between the measured and modeled DSF would be statistical significant. We find that for a global percentage of 15% of dust from agricultural soils the disagreement becomes statistically significant at a significance level of 0.05, i.e., the modeled emission events from agricultural lands are significantly higher than the observations at the same locations, thus giving an upper limit for the result of the analysis.

[4] The results from the two studies are not directly comparable because *Mahowald et al.* [2004] and *Tegen et al.* [2004] compare their model results to different subsets of dust storm frequency data. *Mahowald et al.* [2004] determine the correlation between all DSF observations and their model results, while *Tegen et al.* [2004] excluded DSF data from stations in areas with a vegetation cover of less than 10%. This was not explained in the original paper. This exclusion is based on the fact that for those stations with very little or no vegetation DSFs in agricultural areas based on the *Ramankutty and Foley* [1999] distribution, are lower in comparison to DSFs in natural, undisturbed regions. This is opposite to the relationship found in areas with higher vegetation cover and is most likely due to a bias in the location of cultivated sites in arid regions. The cultivation and vegetation cover data sets are available on 0.5 degree resolution, but any cultivated patches within a grid cell in an arid region would obviously be located where favorable conditions for vegetation exist, are artificially irrigated, or are located in places that are protected from dust storm events by their topographic setting. However, including the grid cells with vegetation cover of less than 10% does not change the results given by *Tegen et al.* [2004] when using the cultivation distribution by *Klein Goldewijk* [2001]. Thus the results indeed depend to a certain extent on the cultivation data set used in the analysis. If the station data from areas with low vegetation are included, the DSF observations and model results may not necessarily give significantly different correlations in cultivated and uncultivated sites for the diverse model scenarios, but we cannot judge if this would be the case for the cultivation distribution used by *Mahowald et al.* [2004]. Although the comparison of modeled and observed DSFs was only made for grid cells with vegetation cover higher than 10%, the lowered thresh-

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olds were applied for all agricultural grid cells, including the low-vegetation regions. While this introduces another uncertainty, it results most likely in an overestimate of dust emission from cultivated sites, and thus does not change the conclusions of the original publication.

[5] It cannot be decided with this study whether the different methods of constructing emission scenarios - on one hand lowering of the wind threshold to increase the number of dust emission events in agricultural regions [*Tegen et al.*, 2004], on the other hand increasing the dust emission factor for agricultural areas in the *Mahowald et al.* [2004] study (a method used, e.g., by *Tegen and Fung* [1995]) - makes a significant difference in the results. However, comparing the observed DSFs directly to modeled visibility reduction events is a more quantitative method compared to comparing to modeled emission events. The use of modeled events of reduced visibility rather than the number of dust emission events gives surprisingly good results when compared to the observations, even if the modeled visibility reduction had to be enhanced by a factor of forty. If the resolution of the dust transport model is sufficiently high (e.g., in regional models) the direct comparison with visibility should be the preferred method for such comparison, once contributions of other visibility reducing factors can be excluded.

[6] *Tegen et al.* [2004] did not show to which extent the results are model dependent. The results of global dust emission models spread widely, as, e.g., small differences in surface wind fields can lead to great differences in computed dust emissions due to the non-linear dependence of dust fluxes on surface wind velocities. Also, uncertainties in dust emissions are caused by insufficient knowledge of surface properties in key dust source regions. We can only partly address this problem by repeating our analysis using different surface wind fields as input into the dust emission model. (From the sensitivity studies with different dust models and wind reanalysis fields presented by *Luo et al.* [2003] it appears that, in the Saharan and Asian dust source regions, wind fields from different reanalyzes cause larger differences in the modeled dust optical thicknesses than the use of different model formulations with identical wind fields). The use of the surface wind product from the NCEP reanalysis rather than the ECMWF ERA15 reanalysis fields results in very similar percentages of dust emissions from anthropogenic soils, i.e., 8% compared to the original 7%, supporting the findings by *Tegen et al.* [2004]. Still, these results remain to be tested with an independent dust model.

[7] Finally we agree that further progress on this topic requires regional to field scale studies, both modeling and measurements. In particular, it is unlikely that the currently available global models will be able to provide estimates on how much dust, in addition to agricultural sources, is released from small-scale but possibly important anthropogenic sources like dirt roads, construction and military activities in deserts.

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