GEOPHYSICAL RESEARCH LETTERS, VOL. 31, L24105, doi:10.1029/2004GL021272, 2004

Comment on "Relative importance of climate and land use in determining present and future global soil dust emission" by I. Tegen et al.

Natalie M. Mahowald,[1,2] Garymar D. Rivera Rivera,[1,3] and Chao Luo[4]

Received 16 August 2004; revised 21 October 2004; accepted 22 November 2004; published 30 December 2004.

INDEX TERMS: 0305 Atmospheric Composition and Structure: Aerosols and particles (0345, 4801); 0322 Atmospheric Composition and Structure: Constituent sources and sinks; 0365 Atmospheric Composition and Structure: Troposphere—composition and chemistry. **Citation:** Mahowald, N. M., G. D. R. Rivera, and C. Luo (2004), Comment on ''Relative importance of climate and land use in determining present and future global soil dust emission'' by I. Tegen et al., *Geophys. Res. Lett.*, *31*, L24105, doi:10.1029/2004GL021272.

1. Introduction

[1] *Tegen et al.* [2004] presented a study of the contribution of land use sources to the overall desert dust loading using dust storm frequency data and their model of atmospheric desert dust [*Tegen et al.*, 2002]. As noted by *Tegen et al.* [2004], previous studies have shown that attribution of anthropogenic influences are very sensitive to models and meteorology [e.g., *Mahowald et al.*, 2002; *Luo et al.*, 2003]. Here we constrain the land use fraction of emission with observations of dust storm frequency following *Tegen et al.* [2004] to evaluate the sensitivity of this fraction to the model, meteorology and methodology. While *Tegen et al.* [2004] find that dust storm frequency (DSF) observations are best matched with a 5–7% contribution of anthropogenic sources to global emission, here we find that anthropogenic contributions ranging from 0 to 50% result in agreement with dust storm frequencies that is statistically indistinguishable.

2. Methodology

[2] The dust storm frequency dataset used for this study is identical to that used by *Tegen et al.* [2004] and was kindly provided by them. It represents the average of dust storm days per year averaged over the 1950–2000 time period when data are available at 2249 stations. Dust storm days are defined as days in which the visibility is less than 1 km. For this study, we assume that each station is independent of nearby stations, which will overestimate our estimate of number of degrees of freedom.

[3] *Tegen et al.* [2004] defined as day with a dust storm any day in which the emission of dust were greater than zero in a given grid box, thereby ignoring transport impacts, which they attempted to remove by eliminating stations with substantial transport. In order to test the sensitivity of their result to this assumption, we use both a source test as well as a concentration test to define when there is a dust storm. Our source test is identical (when emissions are greater than zero in a grid box), while we use two concentration criteria. For the first concentration, we assume that there is a dust storm event when the concentration would result in a visibility less than 1 km. We calculate that visibility will be less than 1 km following standard air pollution techniques [*Godish*, 1997] to be ~4.7e-6 kg/kg for standard conditions. In the data, if there is an observation at the meteorological station any time within the day when the visibility goes below 1 km, it counts as a dust storm day. In order to account for the large spatial and temporal heterogeneities in concentration within one grid box, we use 40 times the concentration for criteria 1, and 20 times the concentration for criteria 2. We chose these two values to give us slopes between the model and data that are on either side of 1.0, and allow us to test the sensitivity to our assumptions about spatial and temporal heterogeneity within a grid box to the resulting slope and correlation coefficient. Model results suggest that grid-averaged concentrations can vary by a factor of 2–10 during one day [e.g., *Luo et al.*, 2004, Figure 2]. Satellite pictures of desert dust plume show that plumes can be as small as a few km wide (while our grid box is 180 km × 180 km) (e.g., http://earthobservatory.nasa.gov/NaturalHazards/natural_hazards_v2.php3?img_id=12178) suggesting that these 20x and 40x factors relating daily and grid-box averaged values to a maximum value observed within the box are reasonable. Factors between 5 and 100 yield qualitatively similar results for the correlation coefficient statistical significance.

[4] Additionally, instead of the *Tegen et al.* [2004] model we use the models results from *Luo et al.* [2003] and *Mahowald et al.* [2002] which use the Model of Atmospheric Transport and Chemistry (MATCH) [*Rasch et al.*, 1997; *Mahowald et al.*, 1997], National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis [*Kistler et al.*, 2001] and the dust entrainment and deposition model [*Zender et al.*, 2003] which has been shown to compare well to observations for a 0–50% land use source [*Luo et al.*, 2003]. Daily averaged model results for 7 years are included in this study (1984–1991, with 1987 missing due to accidentally missing daily values).

[5] The final difference (and perhaps the most important) is that the *Tegen et al.* [2004] study changed the wind threshold velocities over different vegetation types to best

---

[1] National Center for Atmospheric Research, Boulder, Colorado, USA.

[2] Also at Institute for Computational Earth System Science, University of California, Santa Barbara, California, USA.

[3] Also at Department of Geological Sciences, University of Texas at El Paso, El Paso, Texas, USA.

[4] Institute for Computational Earth System Science, University of California, Santa Barbara, California, USA.

0094-8276/04/2004GL021272$05.00

Table 1. Slope and Correlation Coefficients for Model Results (Between 0–50% Land Use) and Observations of Dust Storm Frequencies[a]

Fraction Land Use	Slope (obs = a model + b)			Correlation Coefficient With Probability of Being Statistically Significantly Different Than the Highest Value (H)		
	Source Criteria	Conc. Criteria 1	Conc. Criteria 2	Source Criteria	Conc. Criteria 1	Conc. Criteria 2
0%	0.671	1.147	0.687	**0.545** (33)	**0.743** (H)	**0.719** (5.1)
10%	0.737	1.187	0.727	**0.554** (H)	**0.743** (8.9)	**0.721** (H)
20%	0.737	1.192	0.739	**0.554** (H)	**0.738** (31)	**0.714** (38)
30%	0.737	1.183	0.735	**0.554** (H)	**0.732** (54)	**0.705** (72)
40%	0.737	1.161	0.723	**0.554** (H)	**0.726** (72)	**0.693** (91)
50%	0.737	1.130	0.707	**0.554** (H)	**0.717** (87)	0.681 (98.5)

[a] Three criteria for dust storms are used for the model results: source criteria and two concentration criteria described in the text. (H) refers to the highest correlation, while the number in parenthesis is the probability that the result is statistically significant. Bold numbers show the values which are not statistically significantly different (at the 95%) than the highest value.

match the data, while we change the relative amount of preferential source areas for land use sources between 0 and 50% by 10% increments, and find the best fit between the observations and the data. In this study, we use model results that have previously been presented in more detail [e.g., *Mahowald et al.*, 2002; *Luo et al.*, 2003], and we use the *Ginoux et al.* [2001] source as our natural source. For the land use source, we use the *Matthews* [1983] database to indicate where the land use is, and assume that sources occur only in ‘desert regions’ from the BIOME3 model [*Haxeltine and Prentice*, 1996]. To go from a 0% to a 50% source, we keep total global emissions constant, but vary our global emission factor for the natural and cultivation source such that the emissions are 0 to 50% from land use. Thus the differences between this study and *Tegen et al.* [2004] include model, meteorology and methodology. Both the *Tegen et al.* [2004] and our methodology have uncertainties associated with them, and are reasonable but different approaches.

3. Results

[6] Table 1 shows the correlation coefficient and slope between the model and observed number of dust storm days at each station. Notice that using a concentration criteria results in a better correlation and slope for all the different scenarios. Ideally we want a slope of 1.0, which is achieved somewhere between our criteria 1 and 2 (see Table 1) The highest correlation is for the case when land use is 0 or 10% or 10–50% of the total source (depending on the criteria used). Notice that results for 10–50% land use for the source scheme are identical in our case because of the linear addition of land use, and the dust storm days being defined as any day with source above 0. Also included in Table 1 is the probability that the correlation coefficients are statistically significantly different than the highest value [*Press et al.*, 1992]. This shows that for most cases, 0–50% land use are not statistically significantly different than the highest correlation at 95 percentile (although they are almost statistically significant). Note that we do not have Gaussian distributions, which is a criteria for statistical significance tests; if we use rank correlations instead, for which we know the distribution and which has a clear statistical significance test, we obtain qualitatively similar results [*Press et al.*, 1992]. Notice that the correlations between the model and observations are quite close for the different cases, and this is seen in the probability that each is different than the highest being low for most cases (Table 1). The data is not able to discriminate between the different cases, probably due to the strong similarity in the dust sources and concentrations between 0–50% land use sources [*Mahowald et al.*, 2002; *Luo et al.*, 2003].

4. Conclusions

[7] Here, we use different model, meteorology and methodology to suggest that land use is between 0–50% of the total dust source to the atmosphere, in contrast to the results of *Tegen et al.* [2004]. As previously argued [*Mahowald et al.*, 2002; *Luo et al.*, 2003; *Mahowald and Luo*, 2003], estimating the importance of land use from global models is difficult because of the overlap between human and natural sources and the downwind transport of dust. Sources of dust are thought to be very small scale, and it may be that constraining the portion that are due to land use requires field work, not global studies using models or satellite data.

[8] **Acknowledgments.** This manuscript benefited from comments by Ron Miller, Ina Tegen and Karen Kohfeld. We would like to thank Ina Tegen and her coauthors for making the dataset available to us for this analysis. This work was supported by NASA-IDS (NAG5-9671), NASA-NIP (NAG5-8680), and NSF-Biocomplexity (OCE-9981398). GDRR was supported by the Significant Opportunities in Atmospheric Research and Science (SOARS) program of the University Corporation for Atmospheric Research, with funding from the National Science Foundation, the U.S. Department of Energy, the National Oceanic and Atmospheric Administration, and Goddard Space Flight Center, NASA. NCAR is supported by the National Science Foundation.

References

Ginoux, P., M. Chin, I. Tegen, J. Prospero, B. Holben, O. Dubovik, and S. J. Lin (2001), Sources and distributions of dust aerosols simulated with the OCART model, *J. Geophys. Res.*, *106*, 20,255–20,273.

Godish, T. (1997), *Air Quality*, CRC Press, Boca Raton, Fla.

Haxeltine, A., and C. Prentice (1996), BIOME3: An equilibrium terrestrial biosphere model based on ecophysiological constraints, resource availability, and competition among plant functional types, *Global Biogeochem. Cycles*, *10*, 693–709.

Kistler, R., et al. (2001), The NCEP-NCAR 50-year reanalysis: Monthly means CD-ROM and documentation, *Bull. Am. Meteorol. Soc.*, *82*, 247–267.

Luo, C., N. M. Mahowald, and J. del Corral (2003), Sensitivity study of meteorological parameters on mineral aerosol mobilization, transport, and distribution, *J. Geophys. Res.*, *108*(D15), 4447, doi:10.1029/2003JD003483.

Luo, C., N. Mahowald, and C. Jones (2004), Temporal variability of dust mobilization and concentration in source regions, *J. Geophys. Res.*, *109*, D20202, doi:10.1029/2004JD004861.

Mahowald, N. M., and C. Luo (2003), A less dusty future?, *Geophys. Res. Lett.*, *30*(17), 1903, doi:10.1029/2003GL017880.

Mahowald, N. M., P. J. Rasch, B. E. Eaton, S. Whittleston, and R. G. Prinn (1997), Transport of ^{222}Radon to the remote troposphere using MATCH and assimilated winds from ECMWF and NCEP/NCAR, *J. Geophys. Res.*, *102*, 28,139–28,151.

Mahowald, N. M., C. S. Zender, C. Luo, D. Savoie, O. Torres, and J. del Corral (2002), Understanding the 30-year Barbados desert dust record, *J. Geophys. Res.*, *107*(D21), 4561, doi:10.1029/2002JD002097.

Matthews, E. (1983), Global vegetation and land use: New high-resolution data bases for climate studies, *J. Clim. Appl. Meteorol.*, *22*, 474–487.

Press, W. H., S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery (1992), *Numerical recipes in Fortran: The Art of Scientific Computing*, Cambridge Univ. Press, New York.

Rasch, P. J., N. M. Mahowald, and B. E. Eaton (1997), Representations of transport, convection and the hydrologic cycle in chemical transport models: Implications for the modeling of short-lived and soluble species, *J. Geophys. Res.*, *102*, 28,127–28,138.

Tegen, I., S. P. Harrison, K. Kohfeld, C. Prentice, M. Coe, and M. Heimann (2002), The impact of vegetation and preferential source areas on global dust aerosol: Results from a model study, *J. Geophys. Res.*, *107*(D21), 4576, doi:10.1029/2001JD000963.

Tegen, I., M. Werner, S. P. Harrison, and K. E. Kohfeld (2004), Relative importance of climate and land use in determining present and future global soil dust emission, *Geophys. Res. Lett.*, *31*, L05105, doi:10.1029/2003GL019216.

Zender, C., H. Bian, and D. Newman (2003), The mineral dust entrainment and deposition model DEAD: Description and 1990s dust climatology, *J. Geophys. Res.*, *108*(D14), 4416, doi:10.1029/2002JD002775.

C. Luo, Institute for Computational Earth System Science, University of California, Santa Barbara, CA 93106, USA.

N. M. Mahowald and G. D. R. Rivera, National Center for Atmospheric Research, PO Box 3000, Boulder, CO 80307, USA. (mahowalk@ucar.edu)