Short communication

Sensitivity of desert dust emissions to model horizontal grid spacing during the Bodélé Dust Experiment 2005

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ABSTRACT

The impact of model horizontal grid spacing on meteorology and dust emissions in the Bodélé depression was investigated during the well-documented period of the Bodélé Dust Experiment 2005 (BoDEx 2005). Five horizontal grid spacing ranging from 100 km to 5 km were tested. The main conclusion of these sensitivity tests is that the meteorology of the Bodélé depression is quite insensitive to model horizontal grid spacing below 50 km in agreement with Todd et al.'s (2008b) results. Below 50 km, dust emissions also appear relatively insensitive to model mesh size, the influence of model horizontal grid spacing on dust emissions tending towards an asymptotic behavior as model mesh size is reduced.

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1. Introduction

Mineral dust aerosols are an important, but still poorly understood, component of the Earth's climate system (e.g. Forster et al., 2007). For instance, the model intercomparison made by Todd et al. (2008a) highlighted great discrepancies between 5 regional models concerning the mineral dust emission estimates from the world's greatest single mineral dust source in the world, the Bodélé depression, during the Bodélé Dust Experiment 2005 (BoDEx 2005, Washington et al., 2006; Todd et al., 2007). These authors found at least one order of magnitude range in model estimates of key quantities including dust concentration, dust burden, dust flux, and aerosol optical thickness. As explained by Todd et al. (2008a), their study was a model intercomparison "of opportunity" so that all 5 regional dust models had differing options and configurations. In particular, model horizontal grid spacing varied from 26 to 7 km. According to the review by Mass et al. (2002), clear benefits (more realistic simulated structures, improved meteorological numerical forecasts) are obtained when increasing model horizontal grid spacing in region where orographic flows or diurnal circulations are important, which is the case in the Bodélé depression. It can be then assumed that the discrepancies observed in Todd et al. (2008a) model intercomparison are at least partly explained by the differences in model horizontal grid spacing.

This paper aims at investigating the impact of an increase of the model horizontal grid spacing on the simulation of dust emissions in the Bodélé region using a coupled meteorological-dust aerosol model during the BoDEx 2005 campaign. In a first part, the model used in this study and the sensitivity tests are described. Then, results from the simulations are discussed from and compared to in-situ measurements.

2. Model and sensitivity tests

The paralleled version 6.0 of the Regional Atmospheric Modeling System (RAMS, Cotton et al., 2003) is used coupled online with the Dust Production Model (DPM) originally developed...
by Marticorena and Bergametti (1995) and recently improved by Laurent et al. (2008) for Africa as described in Bouet et al. (2007).

In this study, RAMS is initialized and laterally nudged by the European Centre for Medium-range Weather Forecasts (ECMWF) operational analysis fields T511L60. The modeled domain is a grid centered on Faya Largeau (Chad, 18°N;19°E) extending from 14.3°N to 21.6°N and from 13.2°E to 24.8°E. Five model horizontal grid spacing are tested: 100 km, 50 km, 25 km, 10 km, and 5 km. The topography used in RAMS is derived from the United States Geophysical Survey (USGS) database at about 1 km grid spacing. Topography is then smoothed as model horizontal grid spacing increases: Tibesti and Ennedi Massifs culminate at a lower altitude, and small scale topographical features disappear. The vertical column is divided into 30 steps with an increasing spacing. The vertical layer between the surface and 1000 m is described by the first 10 levels, with the first one centered on 23.9 m, in agreement with the recommendations of Todd et al. (2008b). The upper layers are described by 20 levels, with the highest level at about 22 km above the surface. RAMS also includes a detailed soil (surface and subsurface) model (Walko and Tremback, 2005).

During the BoDEx 2005 campaign, an intense dust storm occurred from 10 to 12 March 2005. The simulation then starts on 5 March 2005 0000UTC and ends on 15 March 2005 0000UTC so that it includes dust-free (5–8 March 2005) and dusty days (9–12 March 2005).

Comparison between modeled and experimental fields is achieved using the data set collected during the BoDEx 2005 campaign in Chicha (16.88°N;18.55°E) (see Washington et al., 2006).

3. Results and discussion

3.1. Influence of model horizontal grid spacing on the meteorology of the Bodélé

Todd et al. (2008b) have already conducted numerical experiments on the influence of model horizontal and vertical grid spacing as well as the Planetary Boundary Layer (PBL) scheme on the meteorology of the Bodélé depression during BoDEx 2005. These authors found that during this period it was relatively insensitive to model horizontal grid spacing, but was highly sensitive to the PBL scheme, and required high resolution for vertical grid spacing in model low levels. Our results are consistent with those obtained by Todd et al. (2008b) so that this discussion is presented in Appendix 1 as supplementary material.
3.2. Influence of model horizontal grid spacing on emitted dust mass flux

A comparison between emitted dust mass fluxes simulated at Chicha using model horizontal grid spacing from 100 km to 5 km is presented in Fig. 1a from 5 to 12 March 2005. For all model horizontal grid spacing except 100 km, dust emissions are simulated on 10, 11 and 12 March 2005, which is in agreement with the observations (Washington et al., 2006). During the dusty days, when model mesh size is 50 km or below, a marked diurnal cycle is simulated for dust mass flux with a maximum in the midmorning-early afternoon. As dust emission is dependent on the third power of this parameter in the DPM, this is in agreement with the diurnal cycle modeled for surface wind velocity. Significant differences are observed for the simulated dust mass fluxes: dust emissions are more intense when the model horizontal grid spacing is reduced. However, differences in simulated dust peaks are weaker (i) on 12 March 2005, and (ii) between 50 and 25 km, and between 10 and 5 km. This can be explained by the differences between simulated 2-m wind speed. Indeed, when comparing the differences between simulated 2-m wind speed for the different horizontal grid spacing in Fig. A2a, the same pattern is obtained: a weaker difference in simulated 2-m wind speed is observed between 50 and 25 km on the one hand and between 10 and 5 km on the other hand as it is observed for the simulated dust mass flux. This result was not intuitive as dust mass flux is proportional to the third power of the surface wind speed with the proviso that dust emission threshold is overcome. One explanation is that in every case, surface wind speed is not only just above dust emission threshold (7 m s⁻¹), but differences in surface wind speed are also so small that it does not significantly affect dust mass flux.

From in-situ measurements, Todd et al. (2007) estimated that the daily mass flux during this dust episode was about 1.2 ± 0.5 Tg day⁻¹ in the exposed diatomite area (from 17°N to 17.5°N and from 16.5°E to 18.5°E), i.e. a total dust mass emitted from the Bodélé depression ranging between 2.1 and 5.1 Tg cumulated over the 3 dusty days. Table 1 reports the dust mass emitted from the whole model domain and from the exposed diatomite area from 10 to 12 March 2005. The emitted dust mass (M) was computed according to:

\[ M = F \times nx \times ny \times \Delta x \times \Delta y \times 86,400 \times 3 \]  

where \( F \) is the dust mass flux averaged over the considered area and from 10 to 12 March 2005 (in µg m⁻² s⁻¹), nx and ny the number of pixels in x and in y directions constituting the considered area, \( \Delta x \) and \( \Delta y \) the model horizontal grid spacing respectively in x and in y directions (in m).

When using a model horizontal grid spacing of 100 km, dust emissions from the Bodélé depression is clearly underestimated compared to Todd et al.’s (2007) estimates (Table 1). Results from all other model horizontal grid spacing are in broad agreement with the estimates provided by Todd et al. (2007). When model mesh size is decreased from 100 km to 50 km, simulated dust mass emitted from the whole domain increases by about 75% whereas it only increases by 10% when model mesh size is reduced from 50 km to 25 km or from 25 km to 10 km (Table 1). When model mesh size is diminished from 10 km to 5 km, no substantial increase in dust emissions is observed (about 3%) according to Table 1 for the whole domain).

Finally, if the simulated dust mass flux emitted from the whole model domain is plotted as a function of the reverse of model horizontal grid spacing as in Fig. 1b, the influence of model horizontal grid spacing on dust emissions tends towards an asymptotic behavior as model mesh size is reduced. Our results suggest that, even though model configurations were not constrained during the intercomparison by Todd et al. (2008a) during BoDEx 2005, model horizontal grid spacing is likely to account for only a small proportion of this uncertainty in intercomparison of simulated dust emissions fluxes.

4. Conclusions

This study aimed at investigating the impact of model horizontal grid spacing on meteorology and dust emissions in the Bodélé depression during BoDEx 2005. Five horizontal grid spacing were tested: 100 km, 50 km, 25 km, 10 km, and 5 km.

The meteorology of the Bodélé depression appears insensitive to model horizontal grid spacing when it is lower than 50 km during the studied period, which is in agreement with Todd et al. (2008b). Significant differences are observed in daily dust mass flux, and are directly related to the differences in surface wind speed. However, no significant change is noted in simulated total dust emissions when model horizontal grid spacing is reduced from 50 km to 5 km as the influence of model horizontal grid spacing on dust emissions tends towards an asymptotic behavior as model mesh size is reduced. Finally, the poor dependence of simulated mineral dust production to model horizontal grid spacing suggests that the large scale of simulated mineral dust production obtained during the intercomparison by Todd et al. (2008a) does not result from the different model horizontal grid spacing.

This study though factual illustrates a severe and well documented dust storm that occurred during springtime in the Bodélé. The annual cycle of dust in the Bodélé follows a semiannual cycle with peaks in the boreal spring and fall driven by regional circulation (Washington et al., 2006). Bouet (2007) investigated the influence of model horizontal grid spacing during summertime and found a great influence of model horizontal grid spacing both on meteorology of the Bodélé and the associated dust emissions. Then, further investigation should be conducted over longer period in this region to generalize this conclusion.

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Appendix. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.atmosenv.2011.12.037.
References


