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# Sensitivity of hourly Saharan dust emissions to NCEP and ECMWF modeled wind speed

Laurent Menut<sup>1</sup>

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[1] The impact of atmospheric aerosol concentrations on climate remains uncertain. This is due to the lack of understanding of the physical processes involved and also to uncertainties on the data used to model them. In the case of modeled dust emissions, the key parameters are the surface wind speed and the soil characteristics. Dust emissions are issued from inhomogeneous land surfaces and depend on local changes in wind speed. Nevertheless, their representation in models is crude since the local variability of the emission is not taken into account due to the model resolution. This simplified physical representation is problematic since the first emission process, saltation, is triggered by a threshold on the wind speed value. For most model studies, the global meteorological fields used are issued either from NCEP or ECMWF models, but the impact of the forcing was never quantified. In this study, we examine the emission fluxes variability based on the selected meteorological data set. The difference between the two emission fluxes can reach a factor of 3. This bias is not systematic and is highly variable on the timescale of an hour within different areas over western Africa. The impact of the sandblasting scheme is also studied; the variation arising by using two different schemes do not exceed 20%.

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## 1. Introduction

[2] The amount of mineral dust emitted over arid and semi-arid areas is directly linked to the surface wind speed and the surface characteristics (soil mineralogy, vegetation). The two processes leading to injection of mineral matter into the atmosphere are saltation and sandblasting. These processes were extensively studied in wind tunnel experiments [Gillette, 1977; Alfaro *et al.*, 1997, among others] and in real conditions during field campaigns [BodEx, among others, Washington and Todd, 2005]. These works lead to a complete description of the dust emissions processes [Marticorena and Bergametti, 1995; Alfaro and Gomes, 2001; Shao and Lu, 2000]. With these parameterizations, the dust emission flux may be estimated as a function of wind speed and soil mineralogy.

[3] In the framework of climate modeling, the estimation of dust emissions is a crucial point. Dust is the most emitted aerosol in the atmosphere and has been identified long ago as having a significant impact on the Earth radiative budget. Up to now it is still unclear whether dust has a cooling or warming effect on climate, since (1) processes such as radiative effect, long-range transport, deposition, scavenging, etc., are poorly known (2) when using dust emission models, the uncertainty of input data is too high, e.g., wind speed. The implementation of local parameterizations of

emission processes into large scale models need to take into account several issues, among which (1) the representation of complex mosaic surface textures and mineralogies, with various vegetation types into large scale model cells (2) the way wind speed is modeled (parameterization, temporal and spatial resolution).

[4] Thus even if the dust emission process was correctly known, a great uncertainty would remain in model results. In this paper, we will try to evaluate the uncertainty related to the initial stage of the modeling process, namely the quality and the variability of modeled wind speed and emissions parameterization.

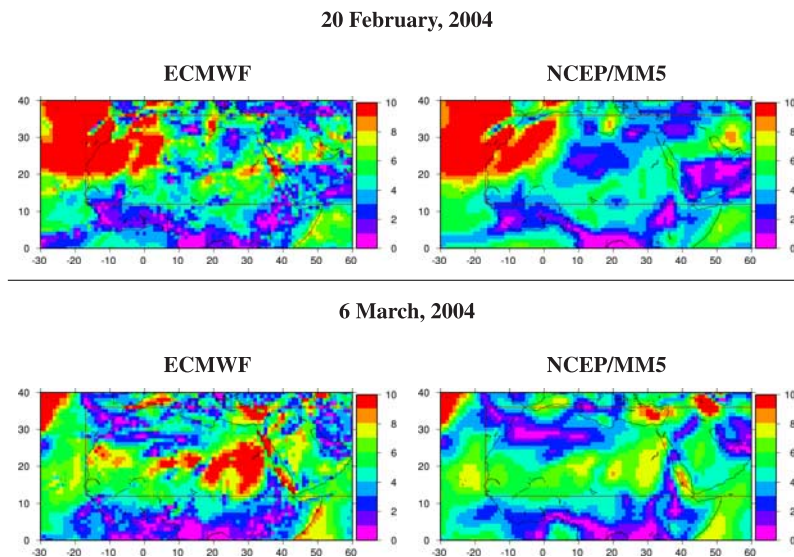
[5] The goal of this paper is to estimate the spread in simulated emissions forced by wind speed fields modeled by two well-known meteorological models (ECMWF and NCEP presented in section 2). This is achieved by calculating dust emissions over western Africa, with an hourly time step for the period February–March 2004. In addition, and in order to compare the impact of emission schemes on final dust fluxes, we also use the Marticorena and Bergametti [1995] and Alfaro and Gomes [2001] parameterizations (presented in section 3). In section 4, the different calculated fluxes are compared in order to evaluate which factor has the greater impact.

## 2. Direct Comparisons of NCEP and ECMWF Meteorological Fields

### 2.1. Wind Fields Used for the Case Study

[6] Previous studies have already compared the meteorological fields derived by NCEP and ECMWF global models.

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**Figure 1.** Wind speed ( $\text{m s}^{-1}$ , 10 m above ground level) maps issued from ECMWF (left) and NCEP-MM5 (right) meteorological fields. Maps are for 20 February and 6 March 2004 at noon.

Surface fluxes were compared in *Josey* [2001], where low biases probably due to small differences in the wind fields were pointed out. *Meisner et al.* [2001] compared sea surface wind speed to SSMI-NSCAT measurements and concluded that the differences between the two analyzed meteorological data sets are very low over sea (less than  $1 \text{ m s}^{-1}$ ).

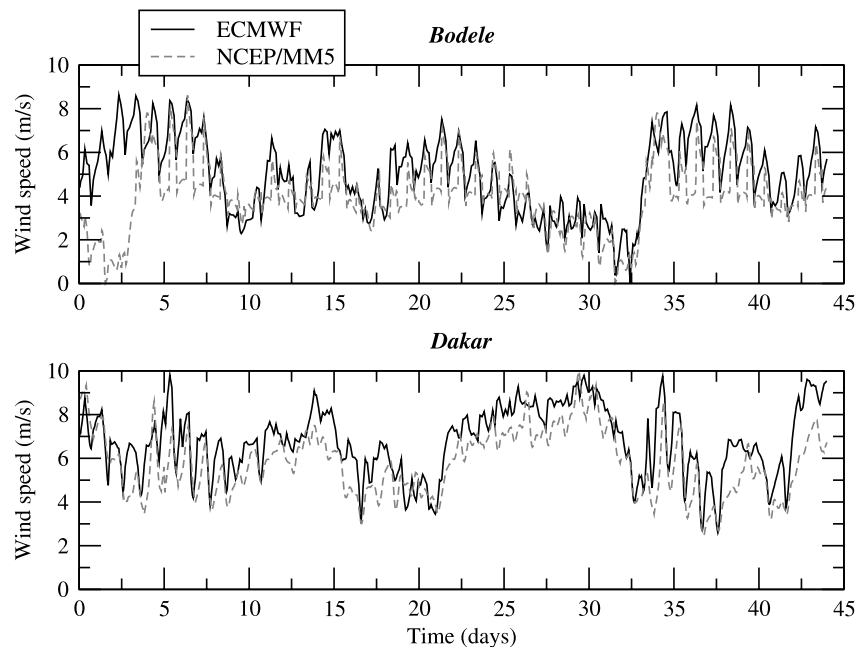
[7] This study uses NCEP and ECMWF wind fields. Since data concerning dust soil types have a horizontal resolution of  $1^\circ \times 1^\circ$ , wind data of the same resolution are needed. The NCEP wind data are provided at  $1.125^\circ \times 1.125^\circ$  horizontal resolution and they are used as forcing for the MM5 model [*Dudhia*, 1993] in order to obtain a  $1^\circ \times 1^\circ$  wind field. On the other hand, the ECMWF analysis fields

are provided with a horizontal resolution of  $0.25^\circ \times 0.25^\circ$ . They are thus averaged over the  $1^\circ \times 1^\circ$  domain grid.

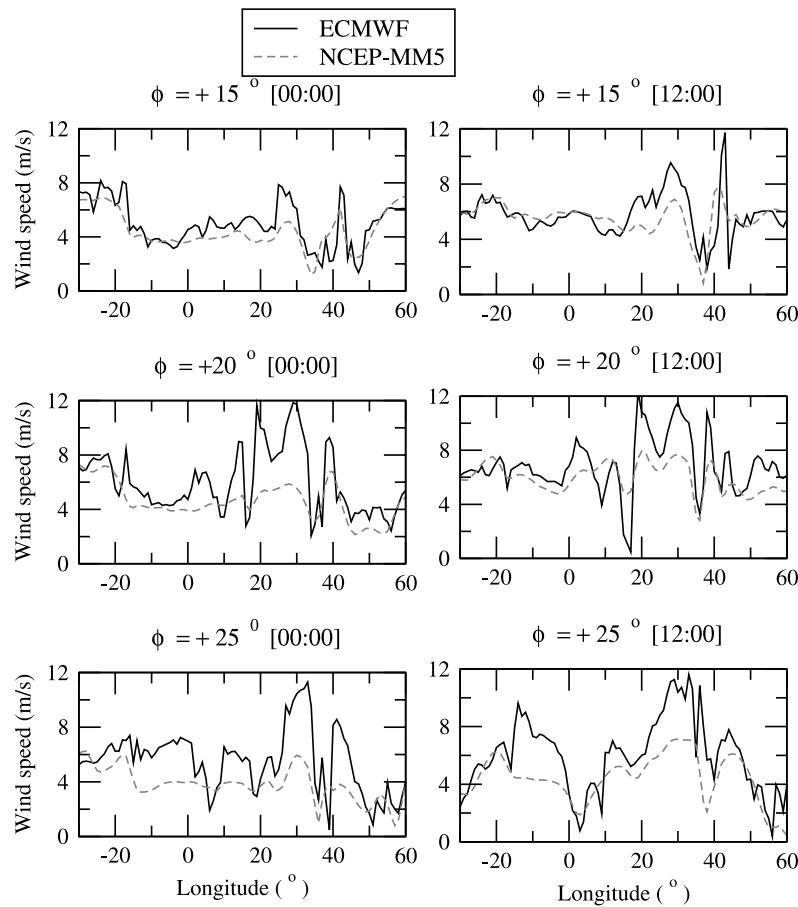
[8] Inherent differences between NCEP and ECMWF models lead to different wind fields despite the consistency in horizontal resolution. Wind fields are directly compared in the following manners: (1) horizontal maps, (2) time series for specific locations and (3) iso-latitude sections.

## 2.2. Horizontal Patterns

[9] Figure 1 presents 10 m wind speed horizontal maps over northern Africa for 20 February and 6 March 2004. Both days correspond to large dust emission events, observed by the SEAWIFS satellite and extensively discussed



**Figure 2.** Time series of wind speed over the whole period (from 31 January 2004 to 15 March 2004 in days) and for specific locations: (top) Bodele and (bottom) Dakar.



**Figure 3.** Iso-latitude comparison of modeled wind speed issued of ECMWF and NCEP-MM5 data for  $\phi = +15^\circ\text{N}$ ,  $+20^\circ\text{N}$ , and  $+25^\circ\text{N}$  and for the 6 March 2004 00:00 (left) and 12:00 UTC (right).

in Schmechtig *et al.* [2004]. The two models simulated the same wind flow patterns and the wind speed values are strongly correlated. The absolute values are very close over the sea and the major differences are observed mainly over land (i.e., where dust are emitted). The NCEP-MM5 fields exhibit lower values than ECMWF. Finally, although the patterns are close, the ECMWF fields present a higher horizontal variability while the NCEP-MM5 wind field is smoother.

[10] This first and simple comparison showed that, if dust are emitted in the same way by the two meteorological forcings, they will be certainly transported in a similar manner. When a meteorological model is used for dust modeling, the first important point is to produce realistic surface wind speed to have the better emissions calculation as possible.

### 2.3. Comparisons of Wind Speed

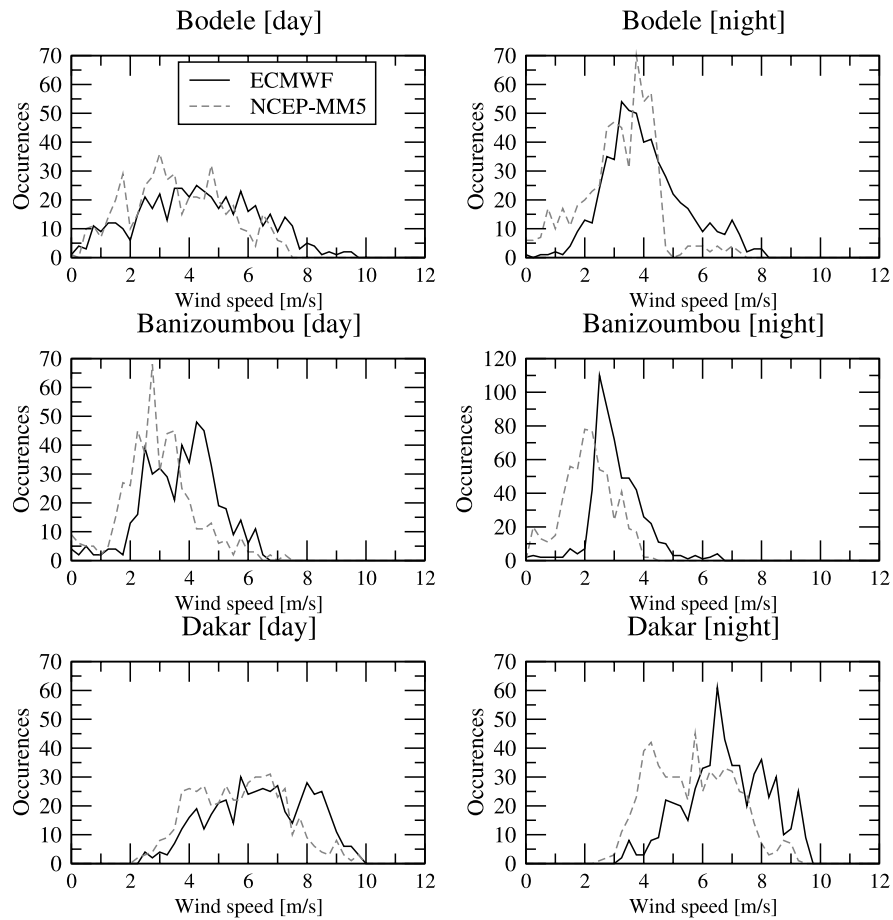
[11] The first direct comparison consists in time series over Bodele and Dakar. These locations are chosen because Bodele (Chad) is the most important dust source in western Africa and Dakar (Senegal) is located at the coastline and under the wind of the main dust transports events usually leading to huge dust plumes over the Atlantic sea. In addition, Dakar is a AERONET station and thus a well known site for dust studies.

[12] Results are displayed in Figure 2. Wind speed values are lower with NCEP-MM5 than with ECMWF, but the main day-to-day variability of the two meteorological data sets is similar (except during the first four days in Bodele). However, since the NCEP-MM5 underestimation is not systematically diagnosed, we cannot conclude to a model bias. In addition, Figure 3 presents values for the 6 March 2004, 12:00UTC. Wind speed values are extracted for three constant latitudes:  $\phi = +15^\circ\text{N}$ ,  $+20^\circ\text{N}$  and  $+25^\circ\text{N}$ . The enhanced spatial variability of ECMWF can be clearly observed. The most important difference is located at  $\phi = +20^\circ\text{N}$  and longitude  $\lambda \approx -10\text{W}$  and  $\approx +30\text{E}$  where ECMWF diagnose wind speed up to  $10 \text{ m s}^{-1}$  but NCEP values do not reach  $7 \text{ m s}^{-1}$ .

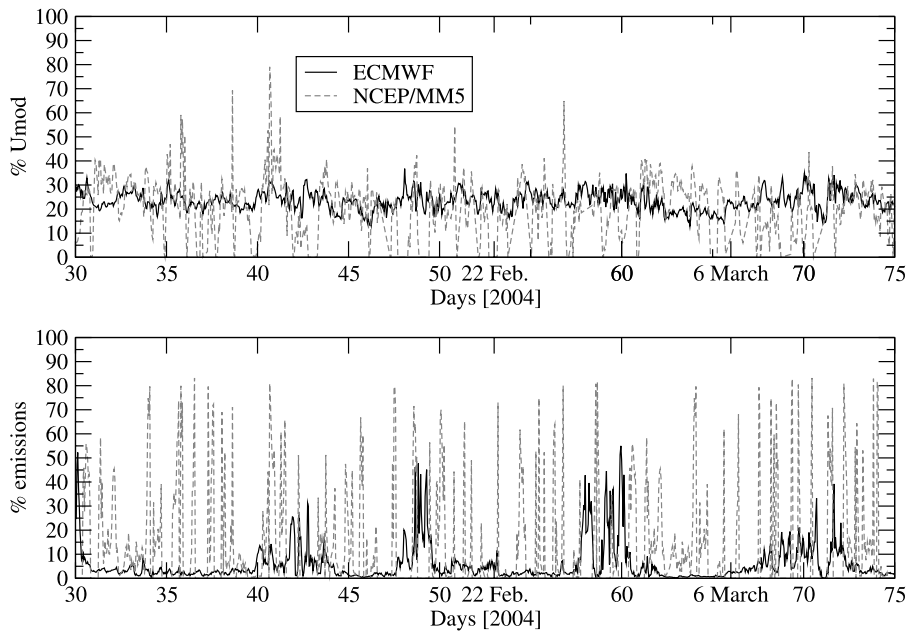
[13] These differences may not be a problem for climatological studies or long-range transport, but in the framework of dust emissions (depending on wind speed threshold), they have to be carefully taken into account: a meteorological forcing may produce a large amount of dust emissions and the second one not.

### 2.4. Day and Night Wind Occurrences

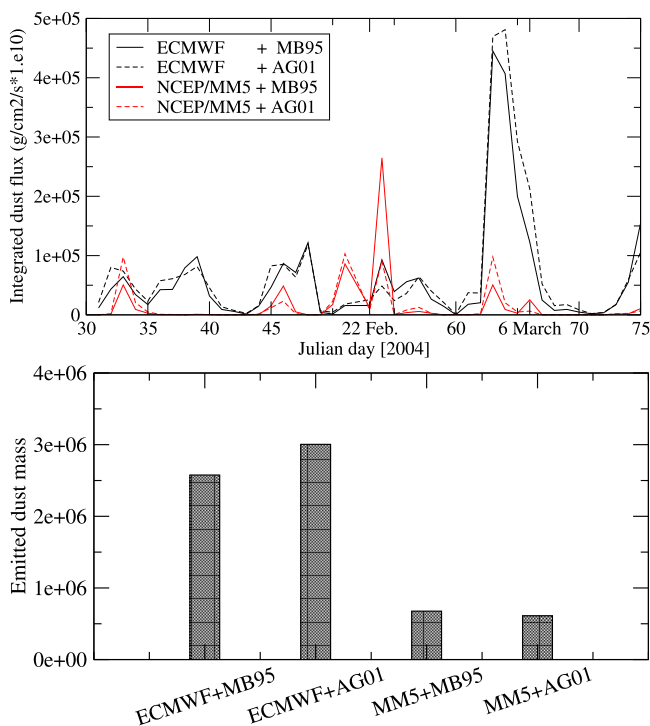
[14] To quantify the differences between the two meteorological forcings, we plotted the distribution of wind speed with a bin size of  $1 \text{ m s}^{-1}$  between 0 and  $12 \text{ m s}^{-1}$  for three sites: Bodele (Chad), Banizoumbou (Niger) and Dakar (Senegal). To have a better view of potential differences,



**Figure 4.** Distribution of wind speed for three sites, Bodele (Chad), Banizoumbou (Niger), and Dakar (Senegal), and two periods (day and night). Data are hourly sorted from 31 January 2004 to 15 March 2004.



**Figure 5.** (top) Percentage of wind speed values in the interval  $|U|^T < |U| < |U|^T + 1$  (m/s) compared to all wind speed values leading to saltation flux. (bottom) Percentage of vertical flux due to the wind speed in the former interval.



**Figure 6.** (top) Daily dust emissions fluxes integrated over the whole domain. Units are in  $\text{g}/\text{cm}^2/\text{s}$ . (bottom) Same data but integrated over the whole domain and the whole period. Units are in g.

we splitted the results between night and day (i.e.,  $07:00 < t < 19:00$  UTC for the latter).

[15] Results are displayed in Figure 4 and show that during the day, wind speed is higher than during the night due to convection, except in Dakar where land-sea breeze effects induced high wind speed values during the night too. Between the two meteorological data sets, ECMWF clearly exhibits more frequently high wind values than NCEP/MM5. These differences in the maximum value may have an important effect on deduced dust emissions fluxes.

### 3. Estimation of Dust Emissions Fluxes

#### 3.1. Saltation and Sandblasting Schemes

[16] The dust emissions fluxes are calculated using two well-known parameterizations: the parameterization of *Martcorena and Bergametti* [1995] and the dust production model proposed by *Alfaro and Gomes* [2001].

[17] The parameterization by *Martcorena and Bergametti* [1995] estimates saltation fluxes using wind speed values and a complete description of the soil texture: soil mineralogy, surface humidity, information on vegetations and rocks on the surface. In order to estimate vertical dust fluxes, i.e., sandblasting fluxes, *Martcorena and Bergametti* [1995] proposed constant factors fitted on numerous experiments. More details may also be found in the work of *Martcorena et al.* [1997].

[18] The parameterization by *Alfaro and Gomes* [2001] also used the saltation formulation as proposed by *Martcorena and Bergametti* [1995]. But in this case, the sandblasting fluxes are explicitly estimated, leading to

knowledge on the size distribution of the dust fluxes. In this study, *Alfaro and Gomes* [2001] dust production model is implemented with the numerical optimization described by *Menut et al.* [2005].

[19] The common point with these two schemes is the saltation formulation: this is the process under the influence of a threshold value of the wind speed expressed as a threshold on the friction velocity (thus also depending on the roughness elements of the surface [*Iversen and White*, 1982; *Shao and Lu*, 2000]).

[20] If we are studying only wind speed values, a difference between, for example,  $6.9$  and  $7.1 \text{ m s}^{-1}$  is only of the order of a few percent. However, in the case of saltation process, and if the threshold value is  $7 \text{ m s}^{-1}$ , the impact is much more important: the second calculation may diagnose a large amount of emitted dust when the first one estimates no flux at all. This threshold is realistic for very small surface in reality: only where the wind speed value is the same and with the same surface. To use only one wind speed value in a grid cell of  $1^\circ \times 1^\circ$  resolution is not realistic. In order to avoid errors in our study, a wind speed distribution was added to the dust emissions calculations.

#### 3.2. Use of a Wind Speed Distribution

[21] The interest of the specific Weibull distribution to represent wind speed variability was extensively discussed by numerous authors such as *Pavia and O'Brien* [1986], *Pryor et al.* [2005], and *Cakmur et al.* [2004]. In order to build a distribution for a chosen wind speed value, representing the mean value for a specific area and period, the probability density function is expressed as:

$$p(|U|) = \frac{k}{A} \left( \frac{|U|}{A} \right)^{k-1} \exp \left[ - \left( \frac{|U|}{A} \right)^k \right] \quad (1)$$

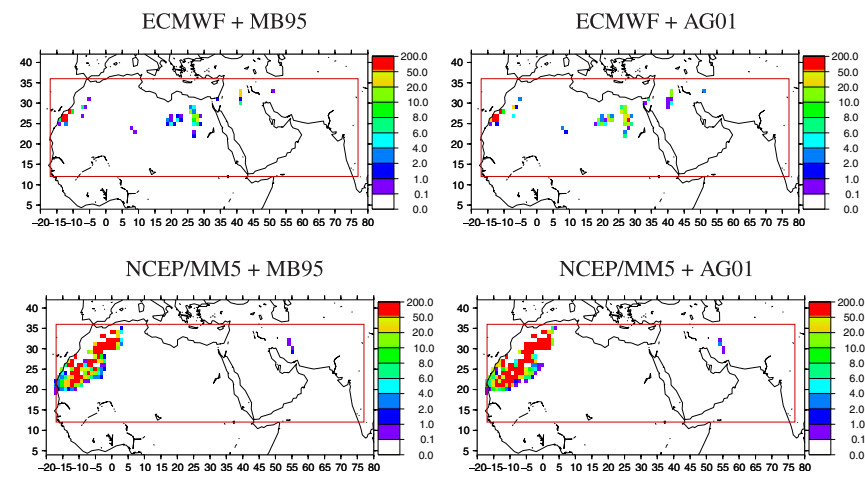
where  $k$  is a dimensionless shape parameter (in our case  $k = 4$ ) and  $A$  is a scale parameter related to the mean of the distribution (in our case the modeled wind speed for each cell and each modeled hour).

[22] It is important to estimate the occurrence of “sensitive” situations, i.e., the number of times where the wind speed were near the “threshold” value or not. If the mean wind speed used is always higher from this value, the Weibull distribution would have no impact. However, if the mean wind speed value is always close to the threshold value (i.e.,  $\pm 1 \text{ m s}^{-1}$ ), the implementation of a Weibull distribution becomes important and would change the emissions fluxes.

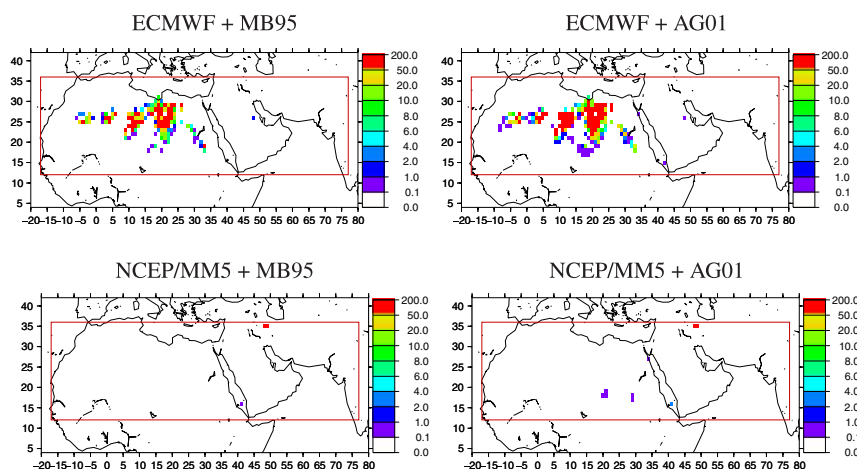
[23] To estimate this distribution is rather complex because, for one wind speed value, the dust vertical flux also depends on the soil texture itself, the drag partitioning and the soil particle diameter [*Martcorena and Bergametti*, 1995].

[24] We estimate the occurrence of wind speed values  $|U|_{\text{model}}$  greater than the threshold wind speed  $|U|^T$  for each soil of the model surface database. The calculation is done for each model grid cell where dust is emitted (i.e., not over the sea). We count the occurrence of wind speed values close to the threshold as  $N_w = \sum |U|$  if  $|U|^T < |U| < |U|^T + 1$ . We also count the occurrence of wind speed values  $|U|$  up to the threshold value as  $N_{wTOTAL} = \sum |U|$  if  $|U|^T < |U|$ . Figure 5 (top) shows the percentage given by  $N_w/N_{wTOTAL} \times 100$ . On

20 February 2004



6 March 2004



**Figure 7.** Dust emissions fluxes maps for the two schemes and the two meteorological forcings on 20 February 2004, 12:00 UTC and 6 March 2004. Units are in  $\text{g}/\text{cm}^2/\text{s} \times 1.0 \text{ e}10$ .

average, 21 (NCEP) and 23% (ECMWF) of the wind speed values are just above the threshold values of each grid cell. Those 21% and 23% (Figure 5, bottom) are responsible for 12% and 5% of the total dust flux for NCEP/MM5 and ECMWF respectively.

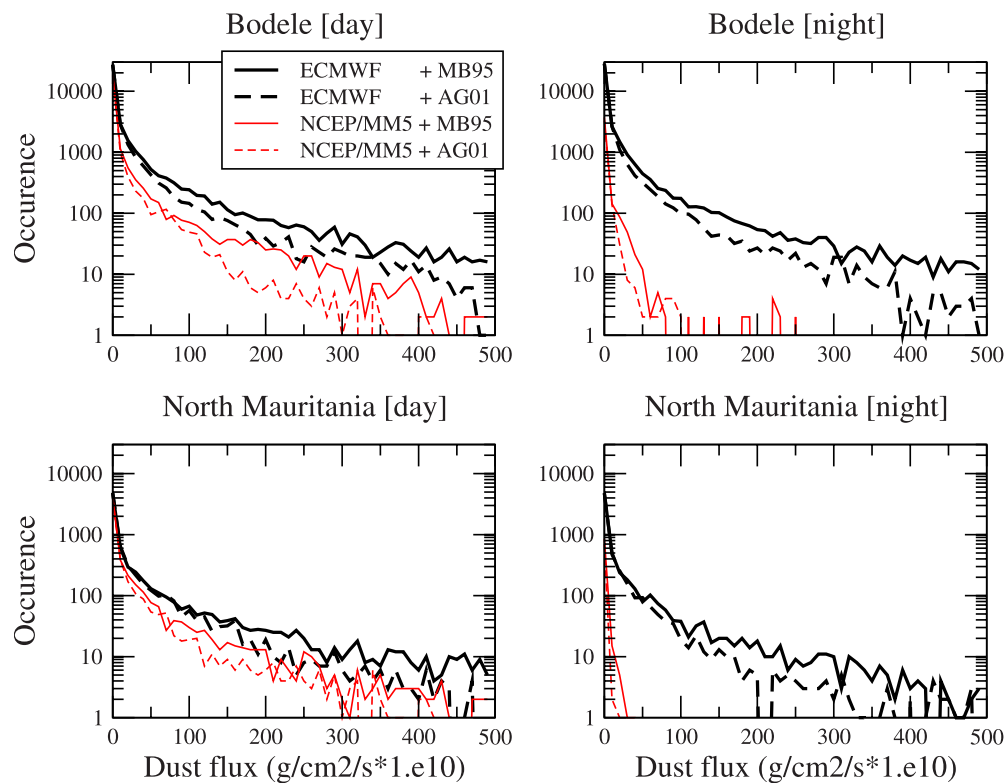
#### 4. Variability of Dust Emitted Fluxes

[25] The main question is if the most important factor for dust emissions estimation (and thus accuracy) is the wind speed or the emissions scheme. To answer this question, we first calculate integrated dust fluxes over the whole horizontal domain (western Africa) hour per hour for the two months of February and March 2004. The results are integrated to give monthly averaged fluxes as usually expressed by dust models. Results are splitted between day and night for the selected sites.

##### 4.1. Integrated Fluxes Over the Domain

[26] We first estimate the total amount of dust emitted for the whole period, i.e., from 31 January to 15 March 2004.

Results in the Figure 6 show that a large variability occurs day to day over a period of 45 days. In the top panel, each value represent the flux spatially integrated over the whole emissions domain and temporally integrated day by day. For each meteorological model, ECMWF and NCEP/MM5, the results are close and have a similar behavior in time with the two emissions schemes. However, if we compare fluxes obtained with the same emission schemes but two different meteorological data sets, the results are completely different: the integrated emissions fluxes are not correlated in time and are different in intensity. In the bottom part of the figure, we integrated temporally the fluxes presented in the top part of the figure. This leads to four values only, representative of all emitted fluxes for the whole period and over the whole domain. The largest differences are observed between the two meteorological forcings: with the same emission schemes, a factor of 3 is observed. For the same meteorological data sets, differences are only of the order of 20% between the two.



**Figure 8.** Number of dust fluxes estimated for various intensity classes, from 0 to 500  $\text{g}/\text{cm}^2/\text{s} \times 1.0 \text{e}10$  using 50 bins and for the whole period.

#### 4.2. Hourly Dust Emissions Fluxes Maps

[27] In order to refine our previous results and to examine their spatial variability, the hourly emission fluxes are displayed on a map, Figure 7. Two different dates are presented: the 20 February 2004 when a huge dust plume, issued from the Dakar region, flew to the South of Europe (Spain and France). The other example is the 6 March 2004 when a large dust plume, coming from the center of northern Africa, flew over the Atlantic sea (this latter case is longer discussed in *Menut et al.* [2007]).

[28] The first conclusion with this panel of figures is that, for the same meteorological forcing, the fluxes estimated with the two emissions parameterizations are very close. However, different meteorological fields show distinctly different dust emission behaviors: for the first day (20 February 2004), when the ECMWF forcing diagnoses very low surface fluxes, the NCEP/MM5 forcing estimates a large amount of emitted dust. On the other hand, for the second day (6 March 2004), we observe the opposite effect: important dust emissions are diagnosed with the ECMWF forcing when NCEP/MM5 diagnoses no dust. These figures show a large dust emission variability both in space and time. This illustrates the huge impact of the problem of this “threshold” emissions parameterization. It also highlights that it is not possible to quantify a bias on a meteorological data set in order to retrieve the same kind of emissions with another one.

#### 4.3. Distribution as a Function of Area and Time

[29] For well-known source areas (Bodele and North Mauritania), we estimate the distribution of emission fluxes as a function of their intensity. Results are presented in the

Figure 8 and values are splitted between night and day but calculated over the whole period.

[30] With the two meteorological data sets, the results are similar during the day. The largest differences in calculated emissions fluxes occur during the night: with the NCEP/MM5 data sets, nighttime wind speed has a nonnegligible impact on the total emissions fluxes.

### 5. Conclusion

[31] For the modeling of mineral dust emissions, the key parameters are the surface wind speed and the soil characteristics. If the physical processes leading to dust emissions is now well-known, their parameterization in models remains difficult. Due to the threshold aspect of the saltation, the emissions fluxes become very sensitive to the description accuracy of the soil and the wind speed. In this paper, we quantify the spread on modeled dust emissions fluxes by using two different meteorological data sets and two dust production models. Dust emissions fluxes are hourly calculated over the whole western Africa and during more than one month (February and March 2004).

[32] The global meteorological fields of NCEP or ECMWF models were considered, since they are the most frequently used meteorological data sets in dust studies. The difference between emissions fluxes using the two models can reach a factor of 3. This factor is not systematic and varies a lot when we examine the results with an hourly time step and area by area in western Africa. In order to have a more realistic representation of the wind speed sub-grid variability, we used a Weibull distribution and showed that 21 and 23% of the wind speed values are just above the



threshold values of each grid cell. We count the percentage of emissions and we showed that those 21% and 23% are responsible for 12% and 5% of the total dust flux for NCEP/MM5 and ECMWF respectively. We can thus conclude that the use of the Weibull distribution leads to a more realistic representation of the real wind speed, but is not a very sensitive factor for emissions calculation. The sensitivity exercise was extended to two different sandblasting schemes: in this case, the variability is lower and does not exceed 20% between estimated dust emissions fluxes.

[33] In conclusion, we showed that the modeled mean wind speed is the dominant factor in the system, and that the influence of the emissions schemes is lower (for the two considered here). If we look at hourly values, these differences are not systematic (except for the night when wind speeds of NCEP/MM5 are very low). When ECMWF allows to diagnose a huge emission event on 6 March 2004, NCEP/MM5 remains relatively moderate. On the other hand, NCEP/MM5 diagnoses an important event on 22 February not significant in ECMWF. Then, even if modelers are able to relatively safely compare dust budget over a large area and with a time step of a month, the problem remains with an hourly time step. This shows that the daily forecast of dust concentrations is a very complex procedure and that an uncertainty of several order of magnitudes exists for dust emissions, mainly depending on modeled wind fields near the surface. Finally, it is clear that a link between a possible wind speed bias and its impact on emissions cannot be found. The problem remains complex, as a small difference in wind speed may become a huge difference in modeled emissions fluxes.

[34] **Acknowledgments.** Myrto Valari and Vincent Noel (Laboratoire de Météorologie Dynamique) are acknowledged for their valuable comments and suggestions on this paper.

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