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Comparison of CLASSIC bin dust scheme to UKCA modal dust scheme within the Met Office UM

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Abstract.
This document describes the work done so far to evaluate the newly implemented UKCA dust aerosol scheme against the CLASSIC UM dust scheme and observations. The UKCA scheme treats the mineral dust in two lognormal modes, and thus has a coarser size resolution than the CLASSIC dust scheme in which the dust is carried in 6 size bins. Initial tests show that the UKCA model is able to produce realistic accumulation mode aerosol loading but the coarse mode loading is strongly underestimated compared to the CLASSIC scheme. The UKCA also underestimates total dust loading compared to observations from the University of Miami data set. The differences in the simulated loading between the schemes remains significant and will be the subject of future research.

1 Introduction

The Met Office Unified Model (UM) has a 'bin' treatment of mineral dust aerosol whereby the dust emission flux is divided into six size categories and each of these sections is transported independently in the model (see Woodward, 2001). As the transport and deposition rates of atmospheric aerosol are size dependent, the 6 sections (or bins) have different lifetimes and distributions, with the smaller size bins having a longer lifetime and thus are able to travel further from the source regions. This bin dust scheme is part of the CLASSIC (Coupled Large-scale Aerosol Simulator for Studies In Climate) aerosol scheme in the UM, as described in Jones et al. (2001).

As part of the UK Chemistry and Aerosol (UKCA) project (Morgenstern et al., 2009), a new aerosol module has been implemented in the UM, which is a simplified version of the GLOMAP aerosol scheme that has been used widely within the TOMCAT offline transport model (Spracklen et al., 2005, 2007, 2008). The GLOMAP-mode aerosol module (Mann et al., 2010) treats the as 7 lognormal modes, each with a number concentration and internally-mixed composition of several components (e.g. sulfate, dust, BC, OC and sea spray). This approach leads to a realistic treatment of the distribution of cloud condensation nuclei (Spracklen et al., 2010) with primary and secondary CCN (e.g. Merikanto et al., 2010).

However, GLOMAP-mode carries dust in modes rather than bins, whereas the existing dust emissions scheme (Wooward et al, 2001) has been coded to give the emissions into the 6 CLASSIC dust bins. Consequently, to drive GLOMAP-mode with the existing UM emissions, they need to be mapped onto the aerosol modes in UKCA. Additionally, the dust transport and deposition rates are now determined by modes each covering a wider size range than the CLASSIC dust bins, and the overall dust distribution may be affected. In this work we describe work done to evaluate the global distribution of mineral dust simulated by UKCA with the existing UM emissions and compare to that of the bin-resolved CLASSIC dust scheme.

2 Methodology

The CLASSIC mineral dust scheme, as detailed in (Woodward, 2001, from now on called W01), calculates the mass flux of mineral dust as a function of wind speed, taking addition factors (e.g. soil moisture and vegetation) into account. The total mass flux is then divided into 6 separate emissions fluxes (for the 6 size categories) based on the fraction of soil / silt / clay in the emitting grid box.

The UKCA treats the aerosol size distribution in 4 size categories: nucleation, Aitken, accumulation and coarse modes. For each size category (except nucleation) there exists a hydrophilic and a hydrophobic mode. Of the 7 modes of the UKCA scheme, the W01 mineral dust is of the size of the accumulation and coarse modes, with an additional flux at approx 20 μm, which is at the upper limit of the coarse mode and is best considered as a 'supper coarse' mode. As mineral dust is hydrophobic on emission it is reasonable to directly emit the mineral dust into the accumulation and coarse hydrophobic modes.

2.0.1 Emitting dust into the modal scheme

In the subroutine *ukca prim du*, the 6 dust emission fluxes (as calculated using W01) are passed in, they are then used to calculate the number and mass of new particles added to the accumulation and coarse modes. We use the 6 separate dust fluxes to emit into the modes in an attempt to keep the size-resolved flux (dependent on soil type) calculated in W01.

A number of different setups have been tested to emit the bin dust into the modal scheme. At present, the size emission fluxes are put into two modes as follows:

- Accumulation: All the mass flux in bins 1 and 2 and half the emission flux of bin 3
- Coarse: Half the emission flux of bin 3, all the mass flux of bins 4 and 5

We currently neglect the mass flux in bin 6 as it is 'super coarse' and although it is a significant fraction of the total emitted dust mass the lifetime is so short that it does not significantly contribute to mass outside of the grid box in which it is emitted. When bin 6 is emitted to the coarse mode, it increases the mean size of the coarse mode such that the lifetime of the mode becomes much too short. It is possible to implement a non-advected super-coarse mode for radiation calculations if this is found to be necessary.

The splitting of the dust between modes is controlled by the *FRACDUEM* array, there is some flexibility in the division of the dust between the modes.

2.1 Comparison of the CLASSIC and UKCA dust fields

The UKCA can be run with both the CLASSIC and the UKCA aerosol schemes running simultaneously (but without interactions), this allows the comparison of simulated dust fields within the same simulation, so the two simulated dust fields have identical meteorology and the total mass of dust emitted is identical.

There are a number of differences between the two schemes that cannot be easily resolved:

- Deposition schemes: The UKCA has been developed with it's own deposition schemes to treat the dry and wet deposition of aerosol species, these schemes have been adapted from the GLOMAP model (Spracklen et al., 2005). CLASSIC also treats aerosol sedimentation, dry deposition and scavenging due to convective and large scale rain, but the schemes were developed independently of those of the UKCA. Differences in treatments of wet and dry deposition can be sufficient to result in significant differences in aerosol lifetime, even if the size distribution of the aerosol is the same (e.g. Textor et al., 2006)
- Order of process calls: The order of process calls is the UKCA and CLASSIC schemes is different, which may affect the dust loading as if, e.g. deposition is calculated before vertical mixing in one scheme (but not the other) it would affect the amount of vertical transport and thus the aerosol distribution.

2.1.1 Global burden and distribution

To compare the two schemes, the bins of the CLASSIC scheme have been grouped in to the same size categories as the UKCA modes - accumulation and coarse - using the grouping as the emission fluxes (accumulation = bins 1 + bin 2 + (0.5 * bin 3) and coarse = (0.5 * bin 3) + bin 4 + bin 5). Figures 1 to 3 show the annual mean global distribution of mineral dust as simulated in the UM. The two schemes simulate similar distributions of accumulation mode aerosol with column burdens of 25–100 mg m^{-2} over the Sahara and values of 5–25 over much of N. America and Asia. Burdens of 0.25–1.0 are simulated by both schemes over the northerly region of the Southern Ocean. The surface distribution is also similar, although the UKCA scheme shows a shorter atmospheric lifetime with many far fields sites in the NH showing a value of < 0.1, whereas the CLASSIC scheme predicts values of > 0.1 throughout most of the NH.

The coarse mode aerosol distributions agree less well with the UKCA simulating much lower dust values in both the column and the surface plots. The CLASSIC scheme predicts a dust burden of > 5 mg m^{-2} over most of the NH, but the UKCA scheme shows values of 1–5 mg m^{-2} in the NH away from the dust emission regions.

The total dust load is simply the sum of the accumulation and coarse burdens (Figure 1). These fields compare better than the coarse mode alone, possibly due to compensating errors (i.e. regions where UKCA underestimates coarse mode and overestimates accumulation mode). For reference, Figure 4 shows the annual mean column dust burden for the year 2000 as simulated by the AeroCom models (median of all models). The AeroCom median values generally lie between the two schemes - CLASSIC overestimates burden compared to AeroCom and UKCA underestimates burden compared to AeroCom.

The zonal distribution of mineral dust is shown in Figures 5 and 6; accumulation mode dust has a similar distribution in both schemes but whereas CLASSIC predicts coarse mode concentrations of > 1 μg m^{-3} in many regions above 5 km, UKCA always predicts concentrations < 1 at these altitudes. It is clear from this plot that there is much less vertical transport of coarse mode dust in the UKCA scheme compared to the CLASSIC scheme.

2.1.2 Aerosol deposition and lifetime

The CLASSIC and UKCA aerosol schemes both include (separate) treatments of wet scavenging due to convective and large-scale rain, dry deposition and aerosol sedimentation. Differences in the two schemes therefore can arise for two reasons: (i) differences in the size distribution between the modal and bin treatments and (ii) differences between the parametrisation of the deposition schemes. Figures 7 to 12 show global annual mean deposition fields for the two schemes. Table 1 shows the burdens and deposition budgets for the two schemes (dry then wet in the order: total aerosol, accumulation mode only, coarse mode only), Table 2 shows an overview of the burden for selected AeroCom models and Table 3 shows the budget of the separate bins in the classic aerosol scheme.

The clearest difference of the deposition in the UKCA and CLASSIC schemes is the difference in the relative importance of wet and dry deposition: in both schemes dry deposition is the more important removal method, but in CLASSIC is accounts for 65% of the total mass removed and in UKCA it accounts for $>90\%$ of the total mass removed. The UKCA has a higher total dry deposition flux (3553 Tg yr^{-1} compared to 2545 Tg yr^{-1}) and a smaller wet removal flux (352 Tg yr^{-1} compared to 1387 Tg yr^{-1}).

The global distribution of the deposition fluxes are similar between the schemes, the total dry deposition flux looks similar from Figure 7 although the UKCA has higher maximum fluxes (largest global mean flux of 11997 cf 2630) especially in the Sahara, thus it seems that the larger deposition rate of the coarse mode aerosol in the UKCA scheme is due to a few very large fluxes rather than a constant over-prediction.

The wet deposition flux of the coarse mode is much larger in the CLASSIC scheme with large values over the Sahara and the surrounding region, as there is little warm rain formation in this region it is possible that this is due to differences in the ice scavenging between regions.

2.2 Comparison to observations

These simulations were done with the UM version HadGEM3 which is not yet tuned to provide fully realistic dust burdens (*pers. communication S. Woodward*). This limits the extent to which comparing to observational datasets is useful - the model may preform well or badly simply due to a poorly constrained emission flux. However, comparing to observations gives us an idea of the extent to which the two schemes differ in the context of observed dust concentrations.

Figure 13 summarises how well the two schemes compare to annual mean observations in the University of Miami data set. The CLASSIC scheme shows a much better comparison to observations both far field and closer to source. Although there is significant scatter, the CLASSIC scheme seems to simulate realistic values and captures the decrease in aerosol loading with distance from source. Except for one location with a correctly simulated high concentration, UKCA significantly underestimates mineral dust aerosol compared to both the CLASSIC scheme and the observations. Much of the mass of the aerosol is in the coarse mode, thus the previously mentioned underestimation of coarse mode mass is a significant contributor to this error.

Figure 14 shows the comparison of the two schemes to the DIRTMAP datasets, here UKCA underestimates deposition compared to observations and CLASSIC. The total mass of dust deposited in UKCA is actually larger than that of the CLASSIC scheme, implying that there is an overestimation of deposition in the UKCA close to source which removes too much aerosol, resulting in low concentrations even a short distance downstream and thus a lower deposition at the DIRTMAP sites (which are mostly out of the active dust producing regions).

3 Conclusions

The UKCA and CLASSIC dust schemes within the UM have been compared. There accumulation mode dust concentrations compare fairly well between the two schemes, but the coarse mode concentrations are quite different. In particular UKCA underestimates the concentration of far field coarse mode dust, which could arise either from differences in the wet deposition between the two schemes or, potentially from differences in the order in which key processes are called. Future work will explore the sensitivity of the simulated dust fields to these two factors. Future work will also consider the inclusion of a third, non-advected super-coarse mode which might be necessary for radiation calculations.

References

Jones, A., Roberts, D., Woodage, M., and Johnson, C.: Indirect sulphate aerosol forcing in a climate model with an interactive sulphur cycle, J. Geophys. Res. - Atmos., 106, 20 293–20 310, 2001.

Mann, G. W., Carslaw, K. S., Spracklen, D. V., Ridley, D. A., Manktelow, P. T., Chipperfield, M. P., Pickering, S. J., and Johnson, C. E.: Description and evaluation of GLOMAP-mode: a modal global aerosol microphysics model for the UKCA composition-climate model, Geoscientific Model Development, 3, 519–551, doi:10.5194/gmd-3-519-2010, http://www.geosci-model-dev.net/3/519/2010/, 2010.

Merikanto, J., Spracklen, D. V., Pringle, K. J., and Carslaw, K. S.: Effects of boundary layer particle formation on cloud droplet number and changes in cloud albedo from 1850 to 2000, Atmospheric Chemistry and Physics, 10, 695–705, doi:10.5194/acp-10-695-2010, http://www.atmos-chem-phys.net/10/695/2010/, 2010.

Morgenstern, O., Braesicke, P., O'Connor, F. M., Bushell, A. C., Johnson, C. E., Osprey, S. M., and Pyle, J. A.: The influence of chemical composition and mixing state of Los Angeles urban aerosol on CCN number and cloud properties, Geoscientific Model Development, 2, 43–57, doi:10.5194/gmd-2-43-2009, 2009.

Spracklen, D., Pringle, K., Carslaw, K., Chipperfield, M., and Mann, G.: A global off-line model of size resolved aerosol processes; I. Model development and prediction of aerosol properties, Atmospheric Chemistry and Physics, 5, SRef–ID: 1680–7324/acp/2005–5–2227, 2005.

Spracklen, D. V., Pringle, K. J., Carslaw, K. S., Mann, G. W., Manktelow, P., and Heintzenberg, J.: Evaluation of a global aerosol microphysics model against size-resolved particle statistics in the marine atmosphere, Atmospheric Chemistry and Physics, 7, 2073–2090, http://www.atmos-chem-phys.net/7/2073/2007/, 2007.

Spracklen, D. V., Carslaw, K. S., Kulmala, M., Kerminen, V. M., Sihto, S. L., Riipinen, I., Merikanto, J., Mann, G. W., Chipperfield, M. P., Wiedensohler, A., Birmili, W., and Lihavainen, H.: Contribution of particle formation to global cloud condensation nuclei concentrations, Geophys. Res. Lett., 35, doi:10.1029/2007GL033 038, 2008.

Spracklen, D. V., Carslaw, K. S., Merikanto, J., Mann, G. W., Pickering, S., Ogren, J. A., Andrews, E., Baltensperger, U., Weingartner, E., Boy, M., Kulmala, M., Laakso, L., Lihavainen, H., Kiveks, N., Mihalopoulos, N., Kouvarakis, G., Jennings, S. G., Birmili, W., Wiedensohler, A., Weller, R., Laj, P., Sellegri, K., Bonn, B., , and Krejci, R.: Explaining global surface aerosol number concentrations in terms of primary emissions and particle formation, Atmospheric Chemistry and Physics, 10, 4775–4793, 2010.

Textor, C., Schulz, M., Guibert, S., Kinne, S., Balkanski, Y., Bauer, S., Berntsen, T., Berglen, T., Boucher, O., Chin, M., Dentener, F., Diehl, T., Easter, R., Feichter, H., Fillmore, D., Ghan, S., Ginoux, P., Gong, S., Grini, A., Hendricks, J., Horowitz, L., Huang, P., Isaksen, I., Iversen, I., Kloster, S., Koch, D., Kirkevåg, A., Kristjansson, J. E., Krol, M., Lauer, A., Lamarque, J. F., Liu, X., Montanaro, V., Myhre, G., Penner, J., Pitari, G., Reddy, S., Seland, Stier, P., Takemura, T., and Tie, X.: Analysis and quantification of the diversities of aerosol life cycles within AeroCom, Atmospheric Chemistry and Physics, 6, 1777–1813, http://www.atmos-chem-phys.net/6/1777/2006/, 2006.

Woodward, S.: Modeling the atmospheric life cycle and radiative impact of mineral dust in the Hadley Centre climate model, J. Geophys. Res. - Atmos., 106, doi: 10.1029/2000JD900 795, 2001.

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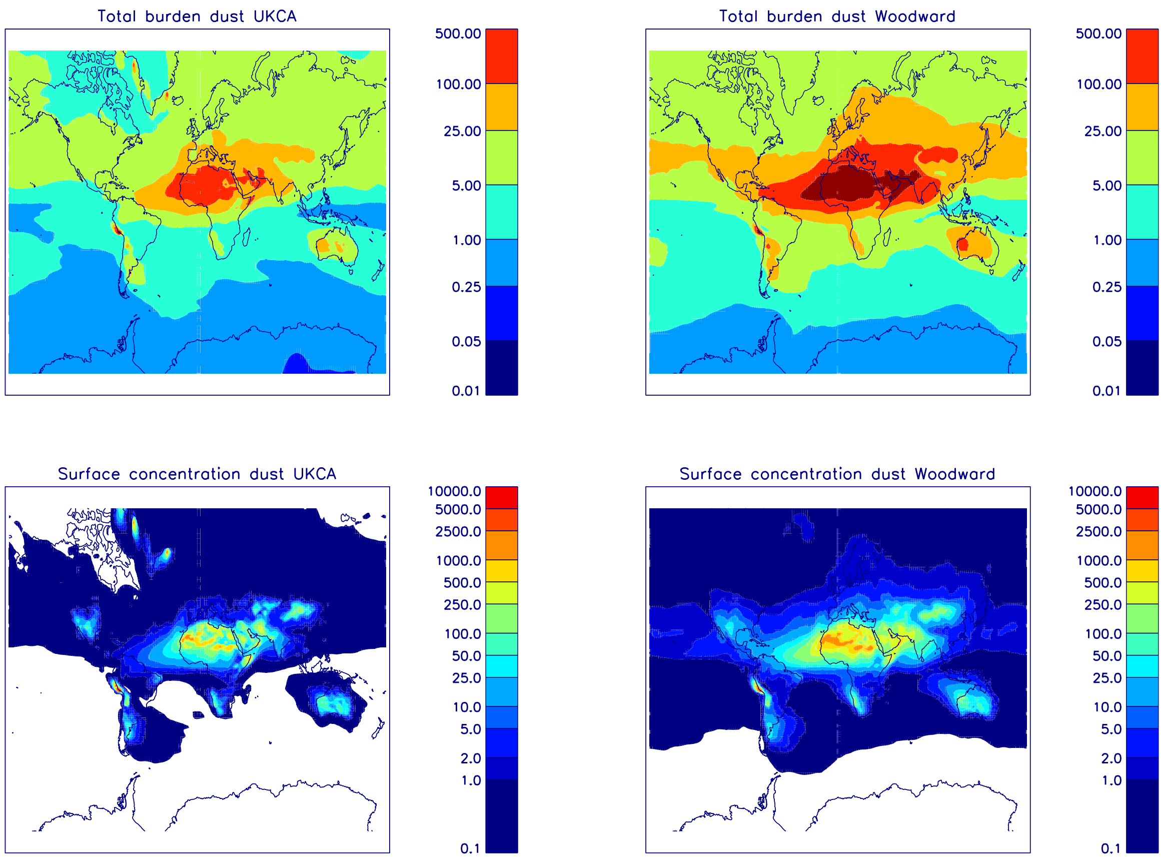

Fig. 1. Top Row: Column burden of mineral dust aerosol (mg m^{-2}) as simulated by the UKCA (right) and CLASSIC (left). Bottom row: Surface concentration of mineral dust (μg^{-3}) as simulated by the UKCA (right) and CLASSIC (left).

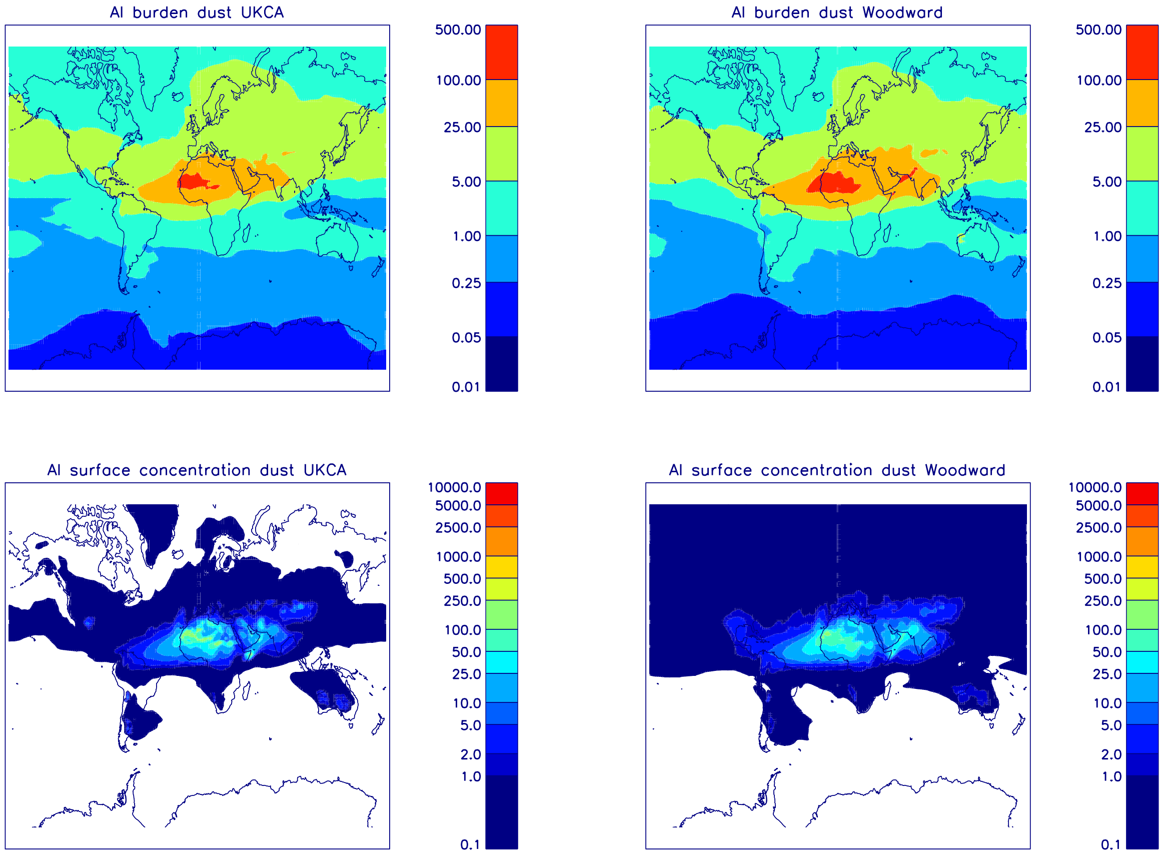

Fig. 2. Same as previous, but accumulation mode aerosol only

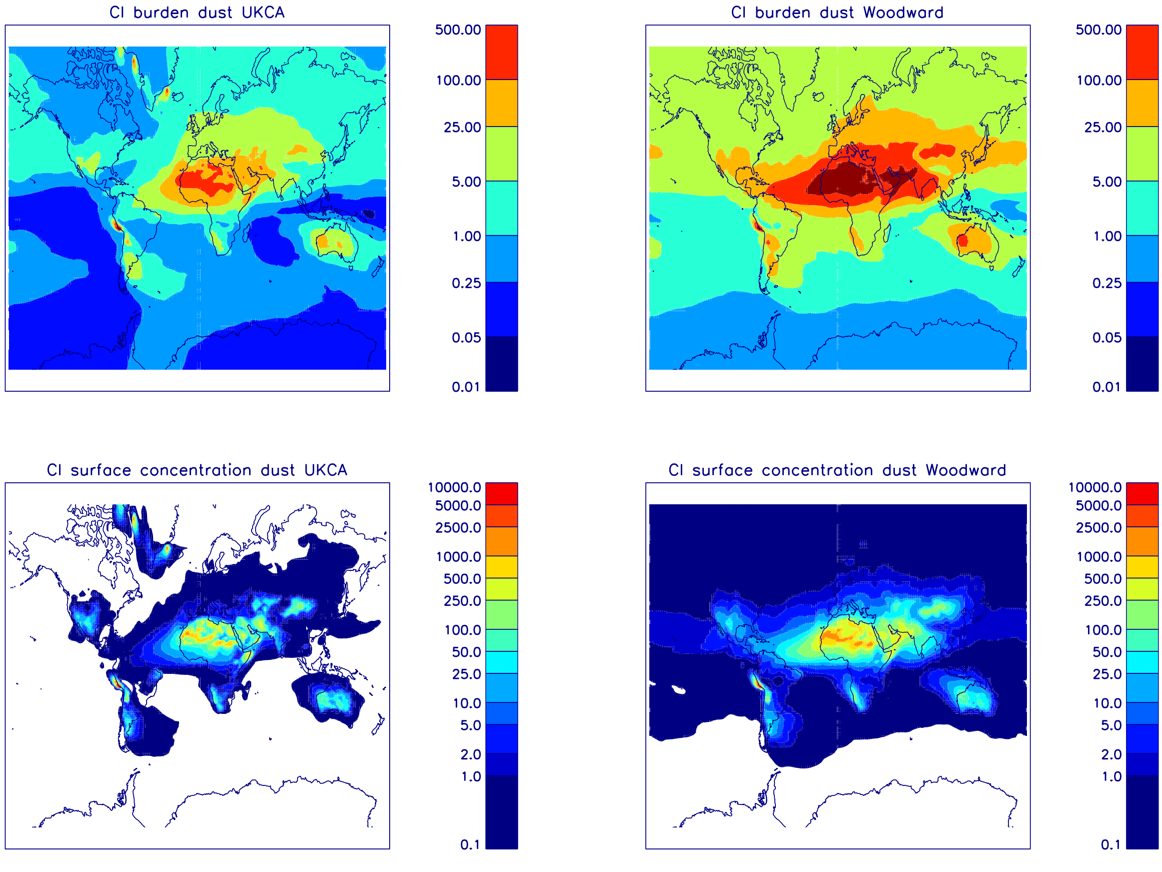

Fig. 3. Same as previous, but coarse mode aerosol only

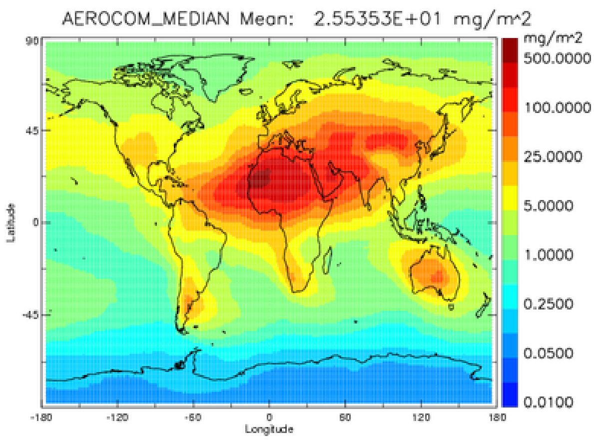

Fig. 4. Column distribution of mineral dust, median of the AeroCom models for the year 2000 (http://nansen.ipsl.jussieu.fr/cgi-bin/AEROCOM/aerocom/aerocom_work_annualrs.pl)

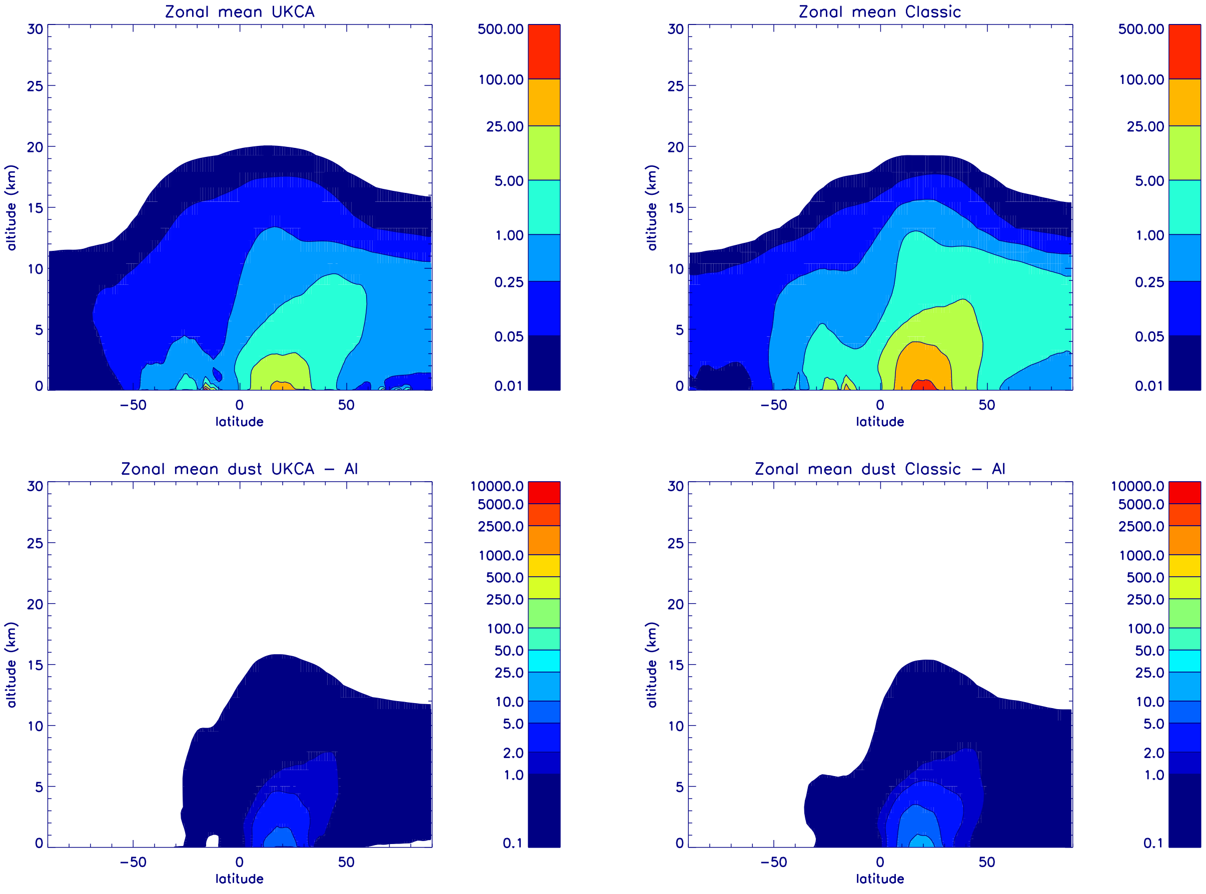

Fig. 5. Zonal mean distribution of mineral dust aerosol as simulated by the UKCA (left) and CLASSIC (right). Top row: Total dust, Middle row: accumulation only, bottom row: coarse only.

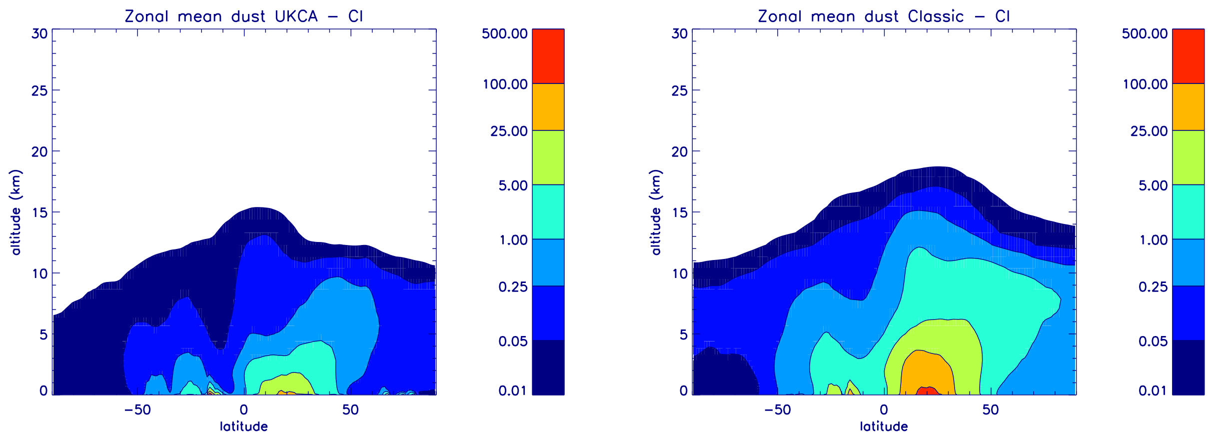

Fig. 6. Zonal mean distribution of mineral dust aerosol as simulated by the UKCA (left) and CLASSIC (right). Top row: Total dust, Middle row: accumulation only, bottom row: coarse o nly.

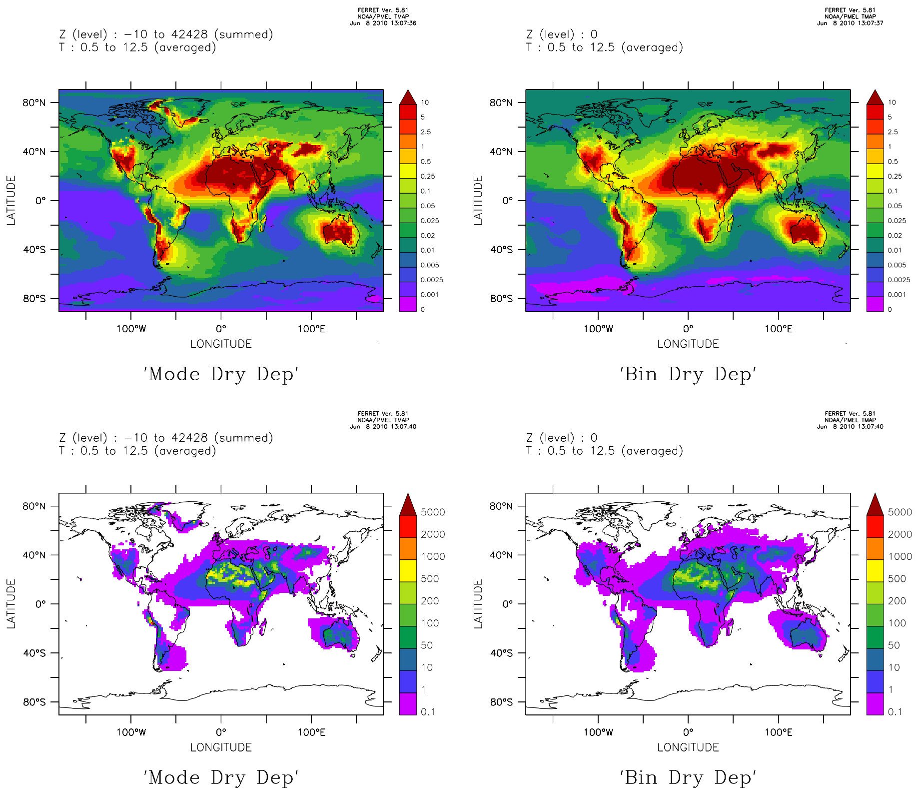

Fig. 7. Dry deposition of mineral dust aerosol (g m^{-2} yr^{-1}) with the UKCA (left) and CLASSIC (right) schemes. Top row and bottom row are the same but have different scales

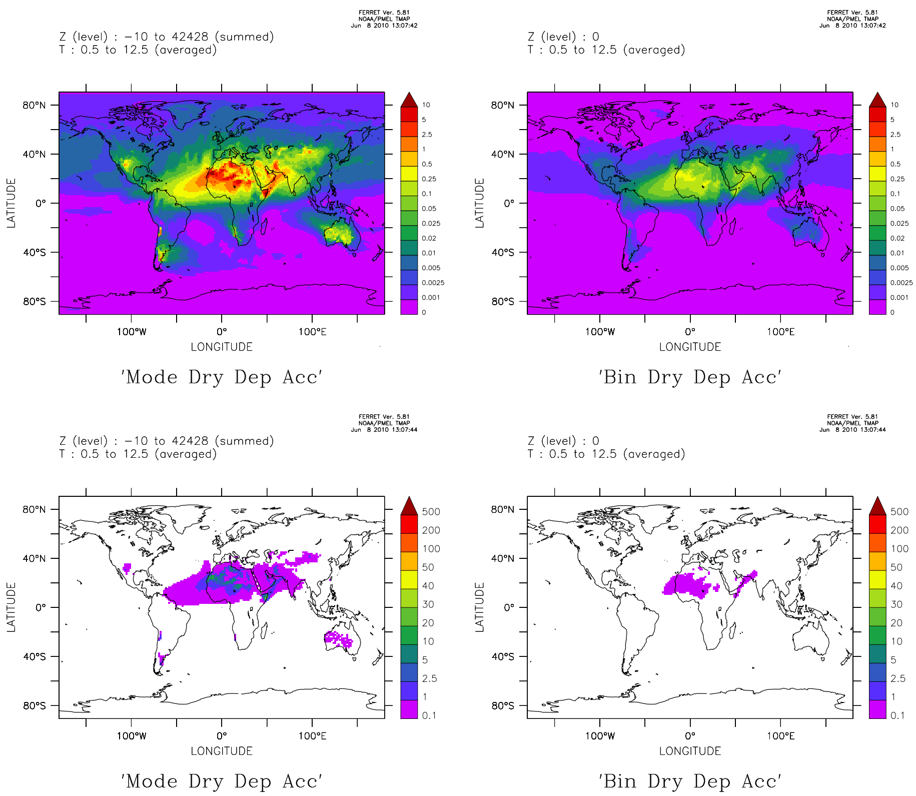

Fig. 8. Dry deposition of accumulation mode mineral dust aerosol (g m^{-2} yr^{-1}) with the UKCA (left) and CLASSIC (right) schemes. Top row and bottom row are the same but have different scales

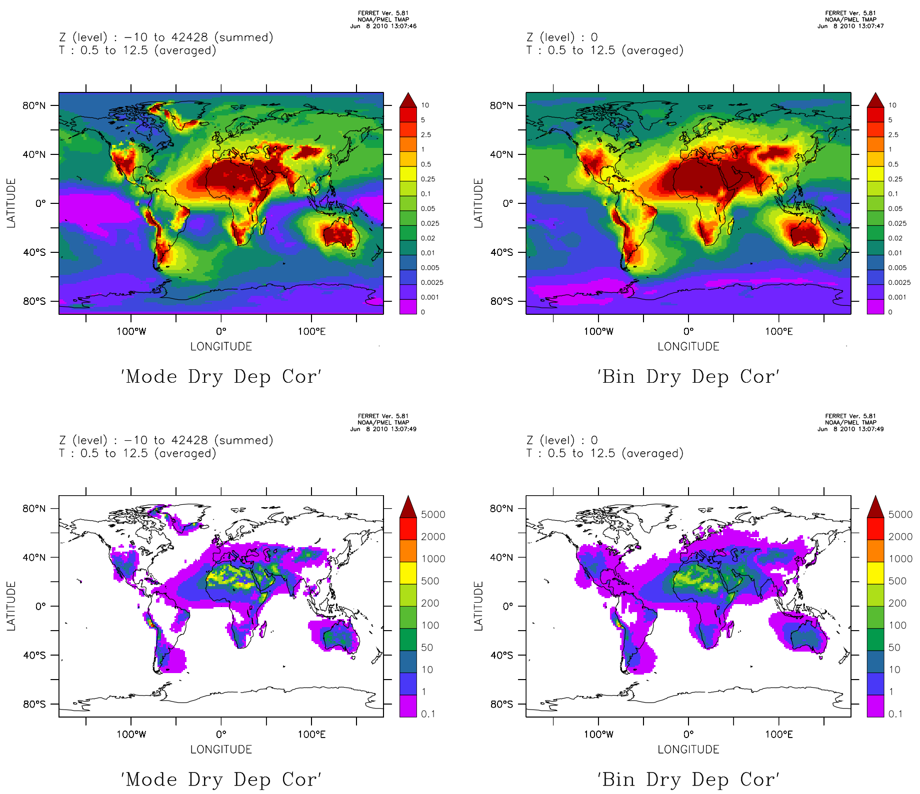

Fig. 9. Dry deposition of Coarse mode mineral dust aerosol (g m^{-2} yr^{-1}) with the UKCA (left) and CLASSIC (right) schemes. Top row and bottom row are the same but have different scales

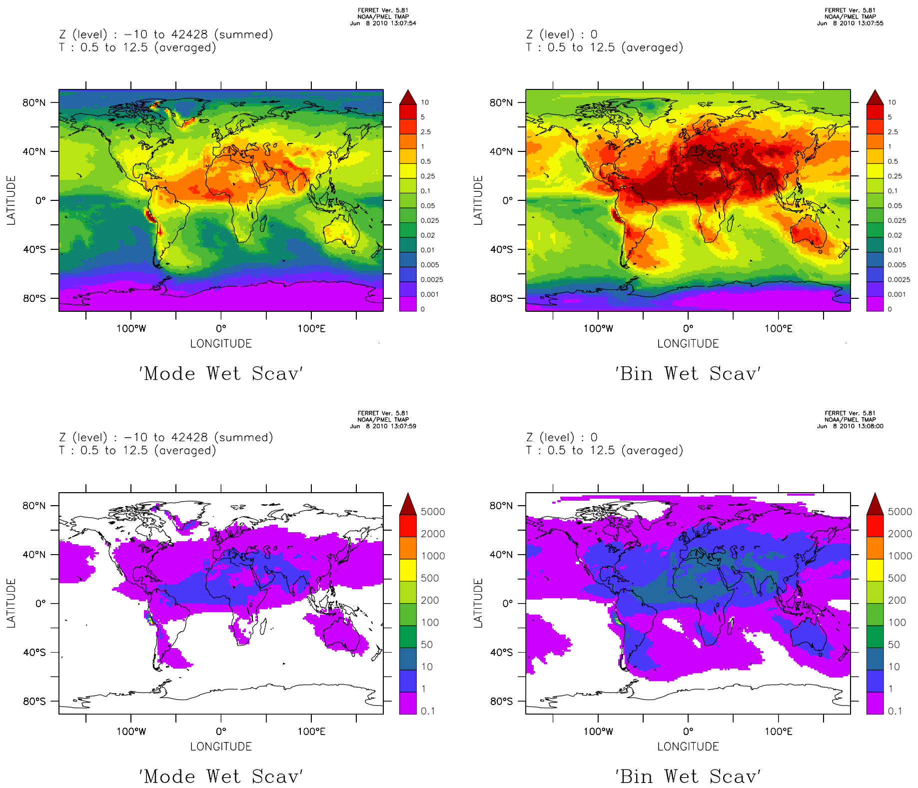

Fig. 10. Wet deposition of mineral dust aerosol (g m^{-2} yr^{-1}) with the UKCA (left) and CLASSIC (right) schemes. Top row and bottom row are the same but have different scales

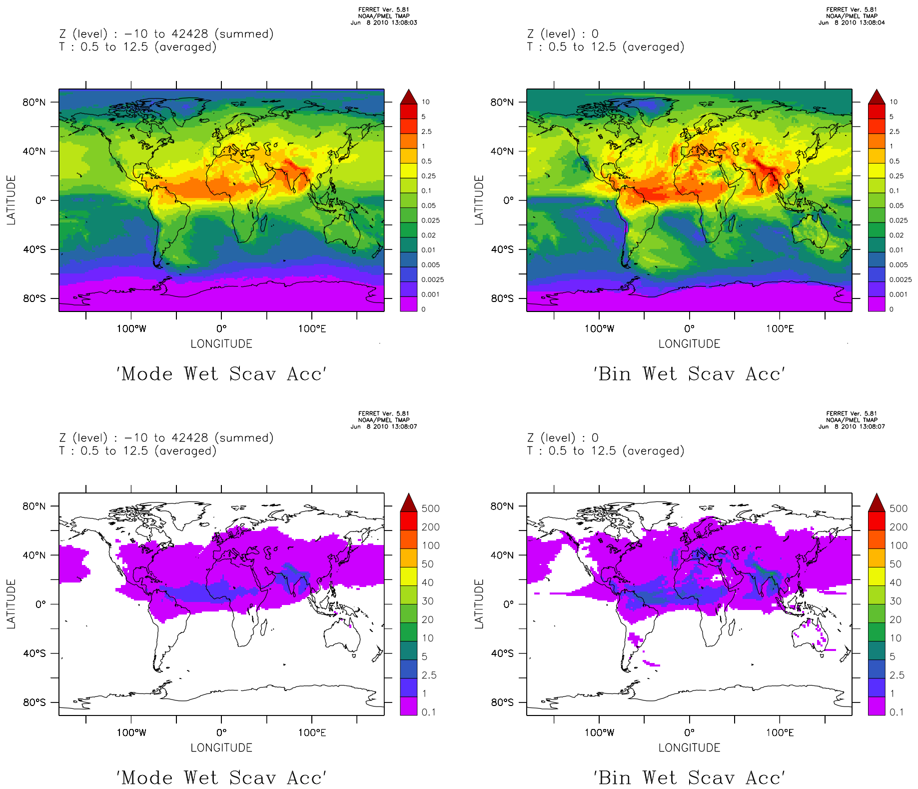

Fig. 11. Wet deposition of accumulation mode mineral dust aerosol (g m^{-2} yr^{-1}) with the UKCA (left) and CLASSIC (right) schemes. Top row and bottom row are the same but hav e different scales

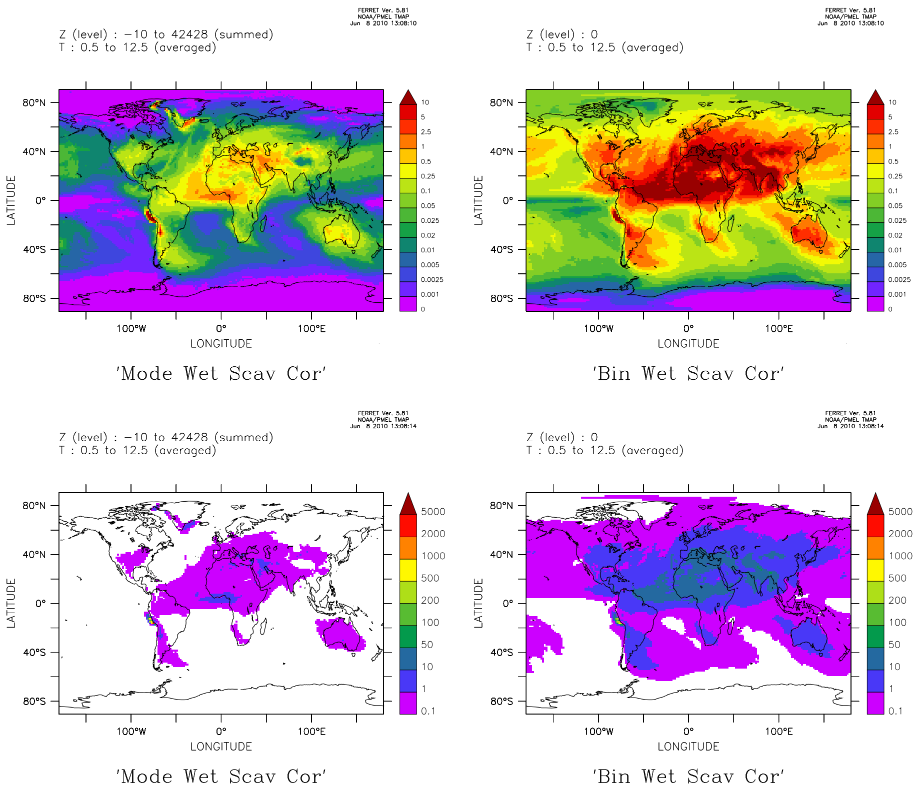

Fig. 12. Wet deposition of Coarse mode mineral dust aerosol (g m^{-2} yr^{-1}) with the UKCA (left) and CLASSIC (right) schemes. Top row and bottom row are the same but have diff erent scales

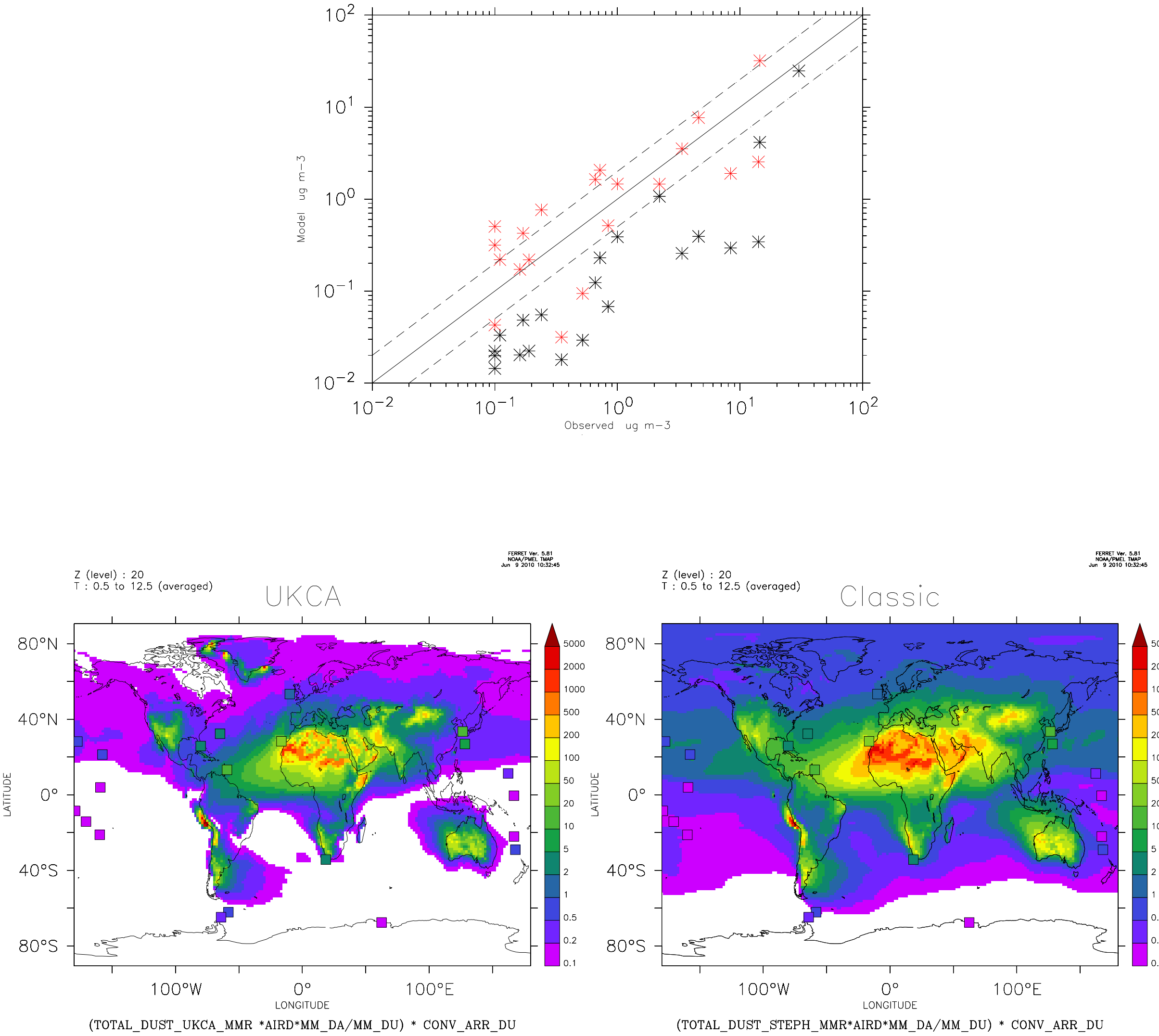

Fig. 13. Comparison of simulated dust fields with the CLASSIC (red) and UKCA (black) schemes to the University of Miami dataset. Bottom row, same but with University of Miami data overplotted on global maps

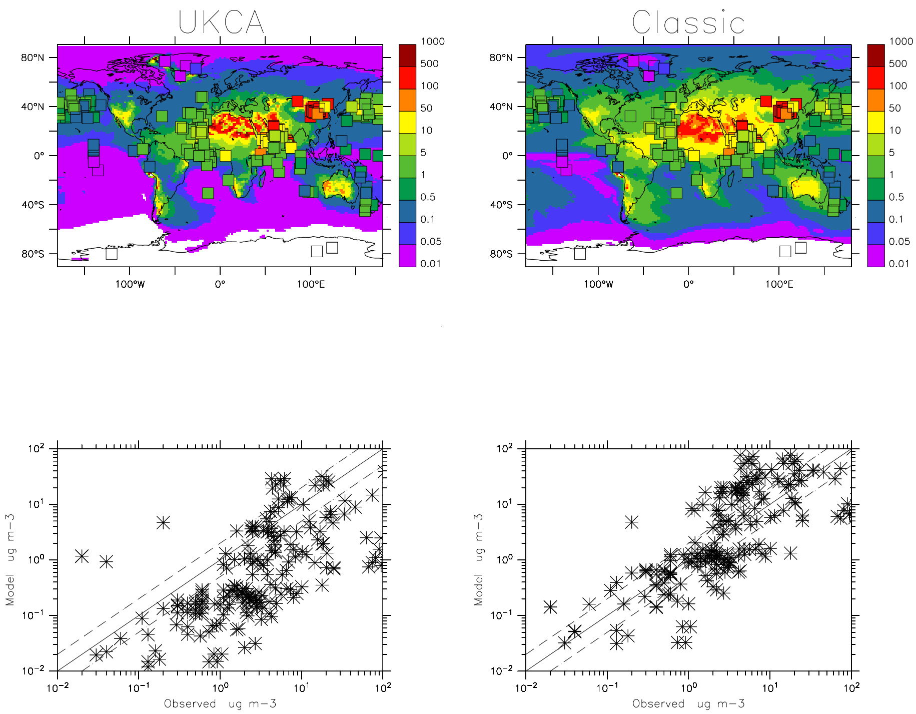

Fig. 14. Comparison of simulated dust fields with the DIRTMAP dataset

Table 1. Summary of burdens and lifetimes in UCKA and CLASSIC

Category	UKCA Total	UCKA Acc	UKCA Cor	CLASSIC Total	CLASSIC Acc	CLASSIC Cor
Emission	3936.00	146.00	3790.00	3936.00	146.00	3790.00
Burden	8.10	3.97	4.20	36.00	5.30	30.72
Wet	352.50	91.14	261.40	1387.00	138.50	1260.00
Dry	3553.00	50.88	3502.00	2524.00	4.05	2520.00
Diff = Emis - (Wet +Dry)	30.50	3.98	26.60	25.00	3.46	10.00
Diff/Emission	0.01	0.03	0.01	0.01	0.02	0.00
WET/(DRY + WET)	9.03	64.17	6.95	35.46	97.16	33.33
Lifetime (wet) days	8.39	15.90	5.86	9.47	13.97	8.90
Lifetime (dry) days	0.83	28.48	0.44	5.21	478.24	4.45
Lifetime (net) days	0.76	10.20	0.41	3.36	13.57	2.97

Table 2. Summary of burdens and lifetimes from AeroCom

Category	GISS	HAM	UMI	ULAQ	TM5	PNNL	MOZGN	KYU
Emission	1525	671	1711	2102	1704	2060	2402	4035
Burden	29.1	8.27	19.459	29.578	9.326	22.139	21.279	17.367
Wet	463	378	627	287	299	1357	430	637
Dry	1044	305	1087	1814	1404	685	1969	3388
Diff = Emis - (Wet +Dry)	18	-12	-3	1	1	18	3	10
Diff/Emission	0.012	-0.018	-0.002	0.000	0.001	0.009	0.001	0.002
WET/(DRY + WET)	30.72	55.34	36.58	13.66	17.56	66.45	17.92	15.83
Lifetime (wet) days	22.94	7.99	11.33	37.62	11.38	5.95	18.06	9.95
Lifetime (dry) days	10.17	9.90	6.53	5.95	2.42	11.80	3.94	1.87
Lifetime (net) days	7.05	4.42	4.14	5.14	2.00	3.96	3.24	1.57

Table 3. Summary of burdens and lifetimes of the 6 bins (note bin 6 is neglected in all other analysis)

Category	b1	b2	b3	b4	b5	b6
Emission	0.9972	27.79	234.5	994.9	2677	7650
Burden	0.041	1.18	8.27	20.49	6.09	1.19
Wet	0.962	26.64	221.9	714.6	420	61.48
Dry	0.0187	0.2857	7.481	266.6	2249	5601
Diff = Emis - (Wet +Dry)	0.0165	0.8643	5.119	13.7	8	1987.52
Diff/Emission	0.017	0.031	0.022	0.014	0.003	0.260
WET/(DRY + WET)	98.09	98.94	96.74	72.83	15.74	1.09
Lifetime (wet) days	15.56	16.17	13.60	10.47	5.29	7.06
Lifetime (dry) days	800.27	1507.53	403.50	28.05	0.99	0.08
Lifetime (net) days	15.26	16.00	13.16	7.62	0.83	0.08