Reply to the Interactive comment on « Dust emission size distribution impact on aerosol budget and radiative forcing over the Mediterranean region : a regional climate model approach » by P. Nabat et al.

Anonymous Referee #2

Reply : We would like first to thank the reviewer for the evaluation of our work and his positive comments. We have adressed all the comments and questions in detail, and clarified the mentioned points. Please find below our point-by-point replies highlighted in bold. Corrections in the text are indicated in italics.

This manuscript deals with the application of a new parameterization scheme of the dust size distribution to the emitted vertical flux in the RegCM-4 model, in order to estimate the aerosol budget, and radiative forcing over the Mediterranean region. Calculations of aerosol budget (load, dry and wet deposition), properties (e.g. Aerosol Optical Depth, AOD, asymmetry factor, single scattering albedo) and radiative forcing are carried out with the coupled-chemistry regional climate model RegCM-4.
The total radiative effect of dust aerosols on the Earth's energy budget still remains a source of uncertainty in simulating present climate and predicting future climate changes. This uncertainty is induced from the high spatial and temporal variability of aerosols amount and properties due to their short lifetime, which is strongly determined by the size distribution of atmospheric particles. Therefore, the realistic representation of dust size distribution in climate and air quality models is of great importance.
The main originality of the submitted work is the application of a new method, proposed by Kok (2011), parameterizing the size distribution of the emitted dust vertical flux, in the RegCM-4 aerosol module. In order to investigate the improvements resulted from the use of the new scheme, a comparison between simulations with the new method and the one already used by RegCM, is performed by authors. Additionally, a comparison with observational data is made for some calculated aerosol properties such as AOD. The new dust size distribution scheme results in more realistic estimates compared to measurements.
In the framework of the main objective, the submitted work treats too many things. For instance, simulations are performed on different time scales: daily (episodic), seasonal (intra-annual variability) and long-term (decadal) scale. Simulation of dust events allows the assessment and the evaluation of emission and transport processes whereas, long-term simulations present climate interest. Moreover, estimation of the aerosol radiative forcing over the Mediterranean region over a relative longer time scale (2000-2009) with a coupled-chemistry regional climate model (RegCM-4) constitutes another originality of the present work.
Reply : We admit our paper treats many things and covers different time scales. However, in such a study including the evaluation of a new dust size distribution, using case studies at the daily scale is a compulsory step. It enables us to evaluate the model to represent realistic extreme events beyond average climate. The seasonal scale is also essential in the evaluation given the strong seasonal cycle of dust aerosols over the Mediterranean. Finally the long-term scale enables us to present the consequences of this new distribution from a climatic a point of view, which is as you said, an originality of the present work and what RegCM-4 is basically designed for. We think these different time scales are combined in a relevant way (avoiding a too long paper) in order to assess the evaluation of dust emission and to estimate the dust radiative forcing over the Mediterranean. Besides, the other reviewer has highlighted the simulations for « different time scales that

address both seasonal and inter-annual variability » making the work « comprehensive ».

In overall, the submitted paper is interesting, well written and organized and it can be published in the ACPD Journal after taking into account the following comments.

The Taylor diagram, as authors note in the text, is a useful tool that allows a quick and concise statistical evaluation of how well different patterns correspond each other. Indeed, the comparison-validation that is performed in the paper between the spatial distribution of simulated and MODIS AOD along with Taylor diagram, clearly proves the improvements in model estimations resulted from the use of the new parameterization scheme. However, authors could attempt a more detail and thorough comparison between simulated and MODIS AOD. For instance, they could calculate the differences (absolute of relative) between simulated (both REF and NEW) and MODIS AOD for each grid-cell. This kind of comparison can be performed at least for the seasonal means of AOD for the year 2008. Such a comparison allows a very detail and accurate evaluation of model outputs taking always into account the error of MODIS AOD data, and mostly would reveal the improvement in the spatial distribution of AOD, induced by the new parameterization scheme. Since the manuscript is already extended enough as it contains a lot of results, there is no space to insert additional figures. Authors could however, give in the discussion the range of the calculated differences and how these are reduced for the NEW simulations.
Reply : We thank the reviewer for his positive remarks about the use of Taylor diagrams. We acknowledge that a map showing differences between both simulations (REF and NEW) and MODIS could have been included in the paper. However, as mentioned in the review, there is no space to add another figure. In order to estimate more precisely the improvement of the model, we have calculated these differences for the seasonal means and added the following quantifications.

Section 5.1
For winter *(page 17853, line 4): a slight underestimation especially in REF in the Eastern Mediterranean. The average difference with MODIS over the sea is -0.019 for REF and only -0.007 for NEW. Over Northern Africa, AOD is clearly overestimated in Algeria, with a bias reaching 0.27 compared to Deep Blue data, reduced in 0.14 in NEW. The underestimation between 20 and 25°E by REF is also corrected by NEW.*

For spring *(page 17853, line 18): Over the Mediterranean Sea, the average difference with MODIS AOD is reduced from 0.043 in REF to 0.017 in NEW.*

For summer *(page 17853, line 25): (…), although it is too widespread in REF around Sicilia, giving a maximal difference over the sea with MODIS of 0.12 instead of 0.06 for NEW. … (line 666) which is corrected in the NEW simulation (0.3), reducing the average bias over the Northern African continent from -0.091 in REF to -0.055 in NEW.*

For autumn *(page 17854, line 10) : The average difference over the sea with MODIS is indeed 0.023 for REF, improving to -0.010 for NEW. Over Africa, Deep Blue data and the NEW simulation are in good agreement with values ranging from 0.2 to 0.35. In REF, AOD is out of this range in Tunisia (0.5) and in Egypt (0.15).*

In general, in the results discussion authors do not insist so much on the quantitative

comparison of simulations with observations and even the statistics presented through Taylor diagrams is not discussed. For instance, in section 4.1 (case study 1) only numbers for standard deviation are given whereas the improvement of RMS with the NEW simulation is noted without giving any number. Respectively, in section 4.2 (case study 2) it is pointed out the amelioration of the correlation coefficient for the NEW simulation, again without cite the respective numbers.
Reply : We agree our paper can have in general more quantitative comparisons, and we have taken this comment into account in the corrected version. More precisely, we have added the following text for answering to the remark about the discussion of Taylor diagrams in case studies 1 and 2.
Section 4.1 ***(page 17848, line 9): The RMS difference is consequently reduced in NEW (1.32) compared to REF (3.09).***
Section 4.2 ***(page 17850, line 10) The correlation coefficient (figure 4e) is higher for the NEW experiment (0.56) than for REF (0.48), and an improvement is also noticed for the standard deviation (0.25 for NEW, 0.24 for MODIS and 0.27 for REF) and the RMS difference (0.97 for NEW instead of 1.09 for REF).***

In tables 1 and 2 authors can add next to the "total" AOD value the corresponding mean AOD value issued from MODIS data, averaged over the study domain.
Reply : Tables 1 and 2 report different parameters (including AOD) for dust aerosols only, and MODIS cannot derive dust AOD. That is the reason why RegCM simulations have been performed with all aerosols : we are able to compare total simulated AOD to retrieved AOD. Figures 1 and 4 enable this comparison. Consequently, this information cannot be added to tables 1 and 2. However, we have added it in the text :
Case 1 (section 4.1): ***(page 17848, line 27) dust AOD has decreased substantially in the NEW simulation. On average over the affected region, total AOD from NEW is 0.30 against 0.46 for REF, while MODIS AOD is 0.24.***
Case 2 (section 4.2): ***(page 17850, line 17) Therefore, the difference in dust AOD is smaller than in the first case, but AOD has still decreased in the NEW simulation. On average over the affected zone, NEW AOD (0.30) is now closer to MODIS AOD (0.24) than REF AOD (0.40).***

In the section 2.2, second paragraph, authors should clearly state that they have used the MODIS-Aqua Deep Blue data and specify which collection (5.0 or 5.1), which Level and with what spatial resolution.
Reply : Corrected.
Section 2.2 ***(page 17842, line 21): For this study, we have used the Level-3 aerosol products (collection 5.1, standard and Deep Blue algorithms) at the 1x1 degree resolution.***

Page 17851, section 4.3, line 15, authors write: "Three stations have been chosen in different places over the Mediterranean basin, ...". The stations should be added in parenthesis, e.g. (Blida (Algeria), representing a location in the vicinity of dust sources, Barcelona located in the west Mediterranean and Crete in the eastern basin).
Reply : Corrected.
Section 4.3 ***(page 17851, line 16): These stations are Blida (Algeria, 36.5°N, 2.9°E), representing a location in the vicinity of dust sources, Barcelona (Spain, 41.4°N, 2.1°E), located in the Western Mediterranean, and Crete (Greece, 35.3°N, 25.3°E) in the Eastern basin.***

In Fig. 9 and 10, colour bars indicating the scale of AOD values are missed.

Reply : Colour bars have been added.

In Fig. 11, clarify if values of aerosol concentration (mg m-3) are averages over the year of 2008.

Reply : It was already mentioned in the caption. We have now added it in the text as a clarification.

Section 5.1 ***(page 17854, line 25): The effect of the different size distribution on the simulated dust burden is presented in figure 11, with averages of every dust bin integrated concentration over the year 2008.***

At the end of page 17854 (lines 17-28) authors state "In contrast, with the new size distribution, the column burden of the larger dust (> 1.0m) is substantially increased.". According to Fig. 11, this increase is particularly strong for the dust bin 2.5 – 5 m. This could be pointed out in the discussion.

Reply : Added in the discussion.

Section 5.1 ***(page 17854, line 27): In contrast, with the new dust size distribution, the column burden of the larger dust (> 1.0m) is substantially increased, especially for the third dust bin (2.5 – 5µm).***

Specify what the temporal resolution of the simulations performed over the year of 2008 and the period 2000-2009, is.

Reply : Added in the new version.

Section 2.1 ***(page 17842, line 8): Outputs for all the simulations performed in this study are provided every 6 hours.***

Authors could attempt a comparison of the intra-annual variability of SW radiative forcing with the one reported by Benas et al. 2011 (Benas et al.: Aerosol shortwave daily radiative effect and forcing based on MODIS Level 2 data in the Eastern Mediterranean (Crete). Atmospheric Chemistry and Physics, 11, 12647-12662, 2011) noting however that this work refers to Crete AERONET station and calculations are performed with a radiation transfer model based on Terra and Aqua MODIS data.

Reply : This article by Benas et al. (2011) has indeed studied the aerosol direct shortwave effect in Crete over a similar period (2000-2010). Their results show an average direct effect of -26 ± 16 W/m² at the surface. They underline the contribution of dust aerosols during spring, and anthropogenic aerosols in summer, which causes a maximal negative radiative impact of aerosols between April and August. This seasonal cycle is coherent with our study using the RegCM-4 model, but the average direct effect over Crete is stronger than in RegCM-4 (-13 W/m²), probably because of this lack of sulfate aerosols in RegCM-4 (discussed in section 5.1).

Section 5.2 ***(page 17856, line 26): This maximum in shortwave direct effect is coherent with the study of Benas et al. (2011) in Crete. Over the period 2000-2010, calculations performed with a radiation transfer model based on Terra and Aqua MODIS data has shown a similar seasonal cycle, despite a stronger aerosol direct radiative forcing over Crete (-26 ± 16 W/m² against -13 W/m² for RegCM-4) probably due to the lack of sulfate aerosols in RegCM-4 (see section 5.1).***

In section 5.2 (page 17856, lines 15-16) authors cite "During the dry period, namely from June to October, the absence of rain favours a strong aerosol maximum.". Actually, it is the synoptic conditions prevailing over the Mediterranean this period of the year that favour the accumulation of aerosol particles in the atmosphere. Specifically, during this period, the subtropical Atlantic high (Azores) prevails over the Mediterranean basin being enhanced and causing subsidence. It results thus, in an extremely stable atmosphere and

in absence of rainfall, conditions that favour the aerosol accumulation in the atmosphere.
Reply : Corrected in the new version.
Section 5.2 ***(page 17856, line 15): During the dry period, namely from June to October, the synoptic conditions prevailing over the Mediterranean favour the accumulation of aerosol particles in the atmosphere. Specifically, during this period, the subtropical Atlantic high (Azores) prevails over the Mediterranean basin being enhanced and causing subsidence. It results thus, in an extremely stable atmosphere and in absence of rainfall, conditions that favour the aerosol accumulation in the atmosphere.***

Authors underline in the text that one of the objectives of this work is to estimate the aerosol direct SW and LW radiative forcing, with estimations on a decadal scale (2000-2009) being important for climate reasons. Additionally, they note that it is the first time that such calculations are performed for the Mediterranean basin with a coupledchemistry regional climate model. For the above reasons, I suggest authors to summarize in a table the calculated values of aerosol direct SW and LW radiative forcing averaged over the period 2000-2009 and at least, over the whole study area (meaning that they could give values for Africa, Mediterranean Sea and Southern Europe separately and/or for each season depending on the paper extent). This could be helpful for the readers and easier to make comparisons with other studies.
Reply : A table including annual averages of SW and LW radiative forcing calculted with both simulations (REF and NEW) over the three regions (Northern Africa, Mediterranean Sea and Southern Europe) has been added.
Section 5.2 ***(page 17856, line 21): Table 3 summarizes their annual and seasonal averages over Northern Africa, the Mediterranean Sea and Southern Europe.***

RF		Northern Africa	Mediterranean Sea	Southern Europe
SW	Surface	-14.9 (-9.7/-20.2/-18.5/-11.4)	-13.6 (-7.9/-19.5/-15.3/-11.5)	-10.3 (-5.8/-13.6/-12.4/-9.2)
	TOA	0.1 (-1.1/0.7/1.2/-0.6)	-5.5 (-3.8/-8.2/-5.5/-4.7)	-3.1 (-2.3/-4.6/-2.5/-3.0)
LW	Surface	5.8 (4.2/8.6/6.5/4.1)	1.7 (1.1/3.1/1.3/1.3)	0.8 (0.5/1.2/0.7/0.7)
	TOA	1.0 (0.3/1.5/1.6/0.6)	0.6 (0.4/1.0/0.5/0.4)	0.3 (0.1/0.6/0.3/0.2)

Table 3 : Annual (first line of each cell) SW and LW direct radiative forcing averages (W/m²) at the surface and TOA for the NEW simulation over Northern Africa (from 25°N to the sea), the Mediterranean Sea and Southern Europe (from the sea to 47.5°N). Seasonal averages (DJF / MAM / JJA / SON) are indicated on the second line of each cell for the same regions and parameters.

In section 5.2 (page 17857, lines 10-18) authors compare the calculated SW aerosol radiative forcing for the whole study area over the period 2000-2009 with respective estimations from the work of Papadimas et al. (2011) noting the exact region considered in the work of Papadimas et al. (2011) and that they use MODIS data. They should additionally specify that this work refers to the period 2000-2007, it uses MODIS Terra (collection 5 and 5.1) Level-3 data and computations are performed with a spectral radiative transfer model. Finally, the reference to this work should be corrected since it is

now available to ACP (Papadimas et al.,: The direct effect of aerosols on solar radiation over the broader Mediterranean basin, Atmos. Chem. Phys., 12, 7165–7185, 2012).
Reply : These precisions have been added and the reference has been updated.
Section 5.2 *(page 17857, line 10): These values are in quite good agreement with SW aerosol radiative forcing from the article of Papadimas et al. (2012), calculated with a spectral radiative transfer model from MODIS Terra (collection 5 and 5.1) Level-3 data. In the latter study, the direct SW radiative effect over the broader Mediterranean basin (29-46.5°N, 10.5°W-38.5°E) over the period 2000-2007 is estimated (…)*

Though authors in the abstract and the introduction emphasize the impact of the new parameterization method on the dust deposition due to its effect on marine biochemical activity, the respective discussion is not equivalent. Specifically, the information that I miss is the validation of the model deposition estimates with measurement, in case that these are available for the study area. Such a comparison could show how realistic are the deposition values resulted from the NEW scheme. The same is valid for the revealed seasonal cycle though it seems completely normal.
Reply : We agree that an additional evaluation of the model deposition would be another opportunity to evaluate the new dust emission scheme. However an extensive validation of deposition should be the subject of a complete study that is beyond the scope of this paper. We just wanted to assess the first order potential impact on emissions. We modify the abstract to be more balanced with the lack of investigation on the deposition part and biogeochemical impact.
Besides, such measurements are not available over the Mediterranean basin to our knowledge for the investigated year 2008. However, the ChArMEx project (http://charmex.lsce.ipsl.fr/) will help in providing more measurements in the following years, so that we could carry out studies to validate simulated dust deposition.
Conclusion *(page 17860, line 7) : In order to carry out studies to validate simulated dust deposition, the ChArMEx project (the Chemical Aerosol Mediterranean Experiment, http://charmex.lsce.ipsl.fr/) will also help in providing more measurements in the following years.*

At the last paragraph of the section 5.3 (page 17858, lines 18-19) authors state "Its seasonal cycle, similar in the three regions, ...". Focusing on decadal simulation since it can be considered more representative, the seasonal variation over the southern Europe is single with maximum in February indicating the important role of winds, whereas for the other two regions a secondary maximum in autumn can be noticed (early in autumn (September) in Africa and late autumn (November) over the Mediterranean Sea). The secondary maximum seems consistent with the dust episodes in autumn and the respective maximum of the wet deposition.
Reply : Corrected.
Section 5.3 *(page 17858, line 18): Its seasonal cycle is regulated by the aerosol content and the winds. The highest deposition values occur during the first four months of the year : because of the circulation in winter associated with stronger winds and higher precipitation, the residence time of aerosols is more important in summer than in winter. The role of winds is particularly important in southern Europe, where the maximum is earlier (February) than in Africa and over the sea (April). Besides, a secondary maximum in autumn can be noticed in Africa in September, and over the Mediterranean Sea in late autumn (November). This*

secondary maximum seems consistent with the dust episodes in autumn and the respective maximum of the wet deposition.

Conclusions are rather qualitative and they miss some numerical results. For instance, it can be cited what is the improvement in AOD values with the new size distribution scheme always compared to the previous one and MODIS measurements. Also, the estimated increase in dust deposition can be mentioned, and finally the computed with the RegCM-4, aerosol SW and LW radiative forcing over the Mediterranean can be reported since it is one of the main findings of this work.

Reply : Numerical results have been added to the conclusion. The abstract has also been completed.

Conclusion :

(page 17859, line 19) The average bias in spring over the Mediterranean Sea compared to MODIS AOD has been reduced from 0.043 in REF to 0.017 in NEW.

(page 17860, line 2) The new dust emitted size distribution has increased dry deposition by 57% on average over the year 2008 because of the emission of more coarse dust aerosols.

(page 17859, line 26) The average SW RF over the Mediterranean Sea reaches -13.6 W/m² at the surface, and -5.5 W/m² at TOA. The LW RF is positive over the basin : 1.7 W/m² on average over the Mediterranean Sea at the surface, and 0.6 W/m² at TOA. It is stronger at the surface than at TOA, notably over Northern Africa (5.8 against 1.0 W/m²), because of (…)

Some minor remarks

Stay consistent with the full name (RegCM-4) of the current version of RegCM especially in the discussion part of the paper, where some times it is cited as RegCM and some others as RegCM-4.

Reply : Corrected in the new version.

In section 4.1, page 17849, line 26 you cite the SSA. Define the acronym in section 2.2, page 17843, line 8, where the single scattering albedo is cited for first time.

Reply : Corrected in the new version. (it is in fact cited for the first time page 17841, line 12)

References :

Benas, N., Hatzianastassiou, N., Matsoukas, C., Fotiadi, A., Mihalopoulos, N., and Vardavas, I. : Aerosol shortwave daily radiative effect and forcing based on MODIS Level 2 data in the Eastern Mediterranean (Crete), Atmos. Chem. Phys. Discuss., 11, 19881-19925, doi:10.5194/acpd-11-19881-2011, 2011.

Papadimas, C. D., Hatzianastassiou, N., Matsoukas, C., Kanakidou, M., Mihalopoulos, N., and Vardavas, I.: The direct effect of aerosols on solar radiation over the broader Mediterranean basin, Atmos. Chem. Phys., 12, 7165-7185, doi:10.5194/acp-12-7165-2012, 2012.