

Reply to Interactive comment on “A 4-D climatology (1979–2009) of the monthly aerosol optical depth distribution over the Mediterranean region from a comparative evaluation and blending of remote sensing and model products” 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 addressed 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 paper compares several satellite data, model output, and model-data assimilation products of AOD over the Mediterranean region (including Europe and N Africa). By evaluation of each product with AERONET from 2003 to 2009 and evaluation of vertical profiles from the models or assimilated products with CALIOP, a “best” set of satellite and model results is chosen to construct a 4-D climatology of AOD and its five components (sulfate, black carbon, organic carbon, dust, and sea salt) in this period over the Mediterranean region. For period before 2003, the 4-D climatology is extrapolated based on the sulfate trends from the LMDz-OR-INCA model assuming other aerosol components remains the same as the 2003-2009 average. The purpose of this reconstruction of long-term AOD over the Mediterranean region is for use in regional climate models for aerosol radiative forcing and aerosol-climate studies.

I would like to first commend the authors for their significant amount of efforts pulling 11 satellite products, one global model, one regional model, and two global assimilation (reanalysis) products together in this work. However, there are several fundamental issues in this work that have to be addressed/corrected. The major comments are listed below, followed by specific comments. At this stage, I do not recommend publication in the present form, unless those major comments are adequately addressed.

Major comments:

1. Satellite data: a) It seems the authors did not use the updated or correct version of SeaWiFS. SeaWiFS retrieves AOD over both land and ocean and covers period from late 1997 to the end of 2010 (e.g., Hsu et al., ACP 2012). b) TOMS data covers time period beyond 1992 to the end of 2001, although there are data gaps and platform change (e.g., Torres et al., JAS 2002). Both TOMS and SeaWiFS data are publicly available. You should replace those used in your paper with more complete data.

Reply : a) The proposed SeaWiFS dataset covers land and ocean indeed, and is based on the MODIS deep blue (DB) algorithm that is already used in the comparison in the Terra and Aqua MODIS data sets. It represents a significant improvement compared to the dataset we had previously used. Consequently we have added the SeaWiFS DB product (named SeaWiFS-2 in the revised version) to the comparison in the paper.

Page 8478 line 9 : More recently, a newly-developed AOD retrieval algorithm over land and ocean has been applied to SeaWiFS measurements (Hsu et al., 2012). This new product has been included in the present intercomparison, and will be called SeaWiFS-2 in this paper.

b) TOMS/NIMBUS-7 has worked until April 1993, 1992 is the last complete year (Torres et al., 2002). Then TOMS was launched onboard the Earth-Probe satellite in July 1996, retrieving aerosols until 2005. However, data are usable only until 2000 because of a degradation of the instrument after 2000. Consequently, we have added in the present work the TOMS data between 1997 and 2000, so that the TOMS data set now covers the periods 1980-1992 and 1997-2000, like in the study of Moulin and Chiapello (2004).

Page 8479 line 4 : After the end of Nimbus-7 in April 1993, TOMS was launched onboard the Earth-Probe satellite in July 1996, retrieving aerosols until 2005. Because of a deterioration of the instrument after 2000, only data between 1997 and 2000 has been included in the present work.

2. Models: I don't see any point to use Tegen et al. (1997) aerosol. Besides the reason it does not play any roles in the reconstruction, it is a very old, out dated field, although Tegen et al. 1997 is the first study to compare modeled AOD with satellite (AVHRR) data. In that work, five major aerosol components were simulated with different models using emissions in the 1980s, because at that time no single global model was able to do all of them. The models have evolved rapidly since Tegen et al. 1997 and now many global models have the aerosol capability. I would suggest use the recent results from the AeroCom study. If multiple models are too much, then at least you can use the AeroCom median to replace Tegen et al. 1997.

Reply : The aim of the study is (1) to provide a comparison and an evaluation of the different existing aerosol data sets over the Mediterranean, and (2) to present which one is the more appropriate for aerosol-climate studies. We agree with the reviewer that the climatology from Tegen et al. (1997) is a relatively old dataset with several disadvantages. However, it is still used in several global and regional climate models (e.g. Farda et al., 2010, Zubler et al., 2011), as well as numerical weather prediction models (e.g. Tompkins et al., 2005). Thus we believe that the Tegen climatology is worth being evaluated against the other products.

Besides, following the reviewer's remark, we have now added a more recent dataset in the new version, coming from the ACCMIP exercise (Lamarque et al., 2013), which is more recent than the AeroCom study. Moreover, it should be mentioned that the AeroCom exercise has been limited to one year (2000), whereas ACCMIP has included longer simulations, with compulsory time-slices (1980 and 2000). The ACCMIP mean over the 2000s has been added in our comparison. In addition, the ACCMIP models have also been used to assess the aerosol trend between 1979 and 2009.

Page 8482 line 9 : The Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP) has gathered several chemistry-climate and chemistry-transport models, in order to study the long-term changes in atmospheric composition between 1850 and 2100. This exercise includes longer simulations than AeroCom, with compulsory time-slices (notably 1980 and 2000). The mean of models which have interactive aerosols, namely CICERO-OsloCTM2 (Skeie et al., 2012), GFDL-AM3 (Naik et al., 2012), GISS-E2-R (Shindell et al., 2012), GISS-E2-R-TOMAS (Lee and Adams, 2010), HadGEM2 (Collins et al., 2011), LMDz-OR-INCA (Szopa et al., 2012), MIROC-CHEM (Watanabe et al., 2011), NCAR-CAM3.5 (Lamarque et al., 2012) and NCAR-CAM5.1 (Liu et al., 2012), has been included as a participant in the present intercomparison. The AOD trends between ~1980 and ~2000 have also been investigated for each of these models.

3. Components: Several issues regarding the aerosol components: - I don't quite understand how the CALIOP components are used in the vertical but the selected model components are used for column AOD. How consistent are they? Do you just use the vertical shape of CALIOP and distribute the model column values to the shape? - The CALIPSO aerosol types are not equivalent to aerosol chemical composition models simulate. For example, "marine" aerosol is not just sea salt, and the "polluted dust", which is completely ignored in this work, contains multiple components. Even "smoke" and "dust" can include minor non-smoke and non-dust components. These aerosol types cannot be used quantitatively as pure components – they are just masks to indicate dominant components. If you use them literally and quantitatively as aerosol chemical components, errors have to be estimated.

Reply : In this work, we have used the CALIOP profiles to tentatively constrain the aerosol

vertical distribution over the Mediterranean basin. For the time and to our knowledge, this remote sensing technique represents by far the best way to assess the vertical profiles of particles at regional scales, and it includes an aerosol speciation. Such information on the aerosol type is not available from surface lidar (EARLINET) or sun-photometer (AERONET) observations. This is why we choose using CALIOP data in the present study in spite of uncertainties linked with the CALIOP aerosol classification as mentioned by the reviewer. Some studies (e.g. Mielonen et al., 2009 ; Costabile et al., 2013) have tried to separate different aerosols using optical properties such as single scattering albedo and Angstrom coefficient, but this would require a complete study which is out of the scope of this paper.

As CALIOP retrieves aerosols along narrow swaths, we have defined 16 regions in which we have gathered all the data from CALIOP between 2006 and 2010, in order to get monthly averages for each aerosol type. We only take the vertical shape of CALIOP, and then distribute the AOD from the 2D-reconstruction product.

We are aware of the problem in the association between CALIOP and model types, and we have tried to associate both products at best given their limitations.

Our final product is a first attempt of reconstruction over the Mediterranean basin, and taking into account CALIOP profiles in this reconstruction makes it probably better than the other existing products (RegCM-4, MACC, ...). It is very difficult to estimate errors in the vertical distribution related to the use of CALIOP. For a given CALIOP aerosol type, region and month, there is an intrinsic variability in the profile which could be used as a minimum approximation of the error.

Page 8492 line 17 : For the time and to our knowledge, the CALIOP instrument represents the best way to assess the vertical profiles of particles at regional scale, including an aerosol speciation. Such information on the aerosol type is not available from surface lidar (EARLINET) or sun-photometer (AERONET) observations.

Modification of the end of the paragraph 3.4 :

As a consequence, it is useful to take into account seasonal and geographical variability in our reconstruction with CALIOP data. In order to have vertical profiles representing the different aerosol types and regions, we resort to monthly means over different regions of the Mediterranean basin defined in Figure 1 and Table 4. This allows to have enough CALIOP retrievals to calculate a significant mean, so that regions cannot be too small. Regions proposed in Figure 1 take into account climatic and geographical characteristics of the Mediterranean basin. In particular, sea and land surfaces are separated. For each region, all the data from CALIOP between 2006 and 2010 have been gathered, in order to get these monthly averages for each aerosol type. Only the vertical shape from CALIOP has been used, to distribute the AOD from the bidimensional reconstruction product. As the retrieval period of time is still short (only 2006-2010), the interannual variability in vertical distribution is not taken into account.

A “best” model is chosen for its best match with the MODIS AOD, but there is no indication of the confidence in model components. For example, MACC matches MODIS AOD the best, largely because the MODIS AOD is assimilated, not necessarily because the model itself gives a reliable estimate of AOD or its components. - None of the models include ammonium nitrate and secondary organic aerosol, which can be quite important over Europe (thus Med Sea). In addition, it seems volcanic aerosols are not included either. At least such missing components should be acknowledged and associated error of omitting them estimated. - There is very little evaluation of aerosol speciation from the model. The only comparison is given for the vertical shape (not the quantity) with CALIOP aerosol type. There are no shortage of systematic surface observations in Europe; why not compare the model concentrations with these data to have some idea of how models do?

Reply : The problem is to find a method allowing us to differentiate different aerosol

components in the final product. Some studies (e.g. Lee and Adams, 2010 ; Shindell et al., 2013) have determined the dominant mass type in different locations around the world, and evaluated AOD in regions which have the top decile of one aerosol type mass density for example. This is not feasible in our regional study (except maybe for dust over the Sahara desert) as the Mediterranean area is affected by mixtures of different aerosols. Besides, we could use the separation between fine and coarse mode available for example in the MODIS data set (Remer et al., 2005), considering fine aerosols are essentially sulfates, BC and organic aerosols. However, in this case we would ignore the fine fraction of dust aerosols. Even though surface observations indicate a limited average contribution of dust in the fine aerosol fraction (e.g. 10-15% for PM1.5 at Finokalia on Crete Island according to Sciare et al., 2008) the AERONET-derived particle size distribution indicate that the submicron mode represents on average a third of the total particle volume in the Mediterranean atmospheric column during dust events (Mallet et al., 2013). Moreover, uncertainties are still important in this kind of product (Yu et al., 2009), showing no consensus on an observationally-constrained anthropogenic AOD.

It is the same problem for the absorption aerosol optical depth (AAOD), which could be estimated for the black carbon and dust aerosols. However dust aerosols are more or less absorbing depending notably on their size and hematite content, and some organic aerosols are not exclusively scattering (Mallet et al., 2013).

As a result, our approach is limited to the evaluation and comparison of the total AOD data from each model. MACC has got the best scores against AERONET ground-based measurements, but since its AOD seems to be underestimated over the Sahara compared to all other satellite retrievals, we decided not to take dust aerosols from this model product. We have preferred using dust aerosols from the RegCM-4 model, forced by the ERA-INTERIM reanalysis and including a complete dust interactive scheme validated in several studies (e.g. Solmon et al., 2008, 2012 ; Nabat et al., 2012).

We hope the coming ChArMEx campaign in summer 2013 could help us bringing validation data for our models, notably through case studies.

Page 8499 line 23 : No means has been found to evaluate properly the separation between the different aerosol types. Previous studies (Lee and Adams,2010 ; Shindell et al., 2013a) have determined the dominant mass type in different locations around the world, which is more difficult in this regional study (except for dust over the Sahara desert) as the Mediterranean area is affected by mixtures of different aerosols. The separation between fine and coarse mode available for example in the MODIS data set (Remer et al., 2005) could be used considering fine aerosols are essentially sulfates, BC and organic aerosols. However, the fine fraction of dust aerosols would not be taken into account in this case. Moreover, uncertainties are still important in this kind of product (Yu et al., 2009), showing no consensus on an observationally-constrained anthropogenic AOD.

The same problem is raised for the absorption aerosol optical depth (AAOD), which could be estimated with the black carbon and dust aerosols. Dust aerosols are however more or less absorbing depending notably on their size and hematite content. Some organic aerosols are not exclusively scattering (Mallet et al., 2013) As a result, the method used in the present work has been to evaluate and compare the total AOD data from each model, highlighting the limitations for some components (e.g. sulfates in RegCM-4, dust aerosols in MACC). The final reconstruction is a first attempt to have an AOD climatology over the Mediterranean basin, that has none of the mentioned limitations.

With regards to the other aerosol species, we acknowledge that ammonium nitrate and secondary organic aerosol are missing, which is the case in most climate models (Shindell et al., 2013). Only 2 models in the ACCMIP exercise include nitrate aerosols and nitrate does not

seem to be abundant over the Mediterranean compared to sulfates (e.g. Sciare et al., 2008). We have added this remark in the text.

Page 8499 line 27 : Another point to mention is the consideration of the other aerosol species. Secondary organic aerosols and ammonium nitrates are notably missing in this comparison, which is also the case in most of climate models (Shindell et al., 2013). Only 2 models in the ACCMIP exercise include nitrate aerosols, and nitrate does not seem to be abundant over the Mediterranean compared to sulfates (e.g. Sciare et al., 2008). Nitrates, which could have a potential impact on global climate in future (Bellouin et al., 2011), and other aerosol types, could be included in the next comparative exercises when most models include them.

Volcanic aerosols are indeed not included in the comparison, but we have proposed to use the Amman et al. (2007) dataset to include historical eruptions. Two eruptions are included over the 1979-2009 period : El Chicón (1984) and Pinatubo (1991).

4. Long-term trends:

The assumption of no interannual variability of BC, OC, dust, and sea salt from 1979 to 2002 is not realistic at all. The 4-D data reconstructed in such way is not useful and can be very misleading for models. Not only sulfate over Europe has reduced significantly in this period, anthropogenic BC and OC have also reduced. If the LMDz uses you use Lamarque et al. (2010) emission, it must not just use SO₂ but also use BC and OC emissions. Why not include those trends? Also, biomass burning changes from year to year, and Africa has experienced wet or dry periods during those decades, directly effecting dust emissions and transport to the Med Sea. - The large volcanic eruptions occurred in the last 3 decades are important part of the aerosol variations, not just in the stratosphere, but in the troposphere as well, especially in the upper troposphere. But they are completely ignored in this work, and authors even attributed the observation of those large volcanic AOD to “high bias”.

Reply : LMDz-OR-INCA and the other ACCMIP models use the emissions from Lamarque et al. (2010). The following table presents the differences in AOD of different aerosol components between the 2000-2010 and 1980-1990 periods calculated by the different ACCMIP models over Europe : no significant trend is found in BC and OR aerosols over Europe, contrary to sulfate aerosols. That is the reason why we have only included the sulfate aerosol trend in our final AOD reconstruction. This absence of trend in organic and black carbon aerosols has now been argued in the new version.

Model	SU	OR	BC	SD	SS
CICERO	-0.14	-0.01	-0.00	0.00	0.00
GFDL	-0.14	-0.00	-0.00	-0.01	0.00
GISS	-0.19	-0.00	-0.00	0.00	0.00
HadGEM2	-0.10	-0.00	-0.00	0.00	0.00
LMDz-OR-INCA	-0.12	-0.00	-0.00	-0.00	0.00
NCAR-3.5	-0.10	-0.00	-0.00	-0.01	0.00
NCAR-5.1	-0.05	-0.01	-0.00	0.00	0.00
Mean	-0.12	-0.00	-0.00	-0.00	0.00

Table 1 : AOD differences for each aerosol type in the different ACCMIP models between ~2000 and ~1980.

Moreover, we should precise that our product over the period 1979-2009 does not intend to reproduce the year to year changes, but only the trends. No satellite product is available over the whole period, and the year to year variability may not be very realistic in ACCMIP

models, since these free-running models have not been forced by reanalyses, so that the exact chronology of events is not reproduced. On the contrary, the MACC reanalysis has a realistic chronology as it includes data assimilation, but this product only dates back to 2003. In fact, the best product would be either a long reanalysis including data assimilation, or ACCMIP models forced by climatic reanalyses to have a real chronology. None of these two possibilities does exist for the moment, which explains why we have developed our reconstruction (precised in Section 4.1).

With regards to volcanic aerosols, we agree with the reviewer some volcanic aerosols have been also in the troposphere and not only in the stratosphere (corrected in the text). But their effect remains rather limited in time and space and in relative AOD.

5. Errors and uncertainty range: Given so much assumptions and different ways of data combinations in this reconstruction, I am surprised that there is no error and/ or uncertainty range estimated for the 4-D products. Such estimates are must.

Reply : We agree this kind of product must be provided with estimations of uncertainties. As far as total AOD is concerned, we have provided a map of uncertainties (figure below, added in the paper), based on the standard deviation on the overall average AOD over the ensemble of the four satellite products covering the whole domain including continent and ocean (MODIS/AQUA, MODIS/TERRA, MISR/TERRA and SeaWiFS-2). Uncertainties are high over Near-East and northern Africa, whereas they are weaker over Europe. Given that there is no satellite product for specific aerosol type, and that some models have shown clear limitations with some aerosol types (e.g. RegCM-4 for sulfates), it is not feasible to provide similar information for each aerosol type. However, the figure below for total AOD reveals that uncertainties seem to be more important in dust-emitting regions.

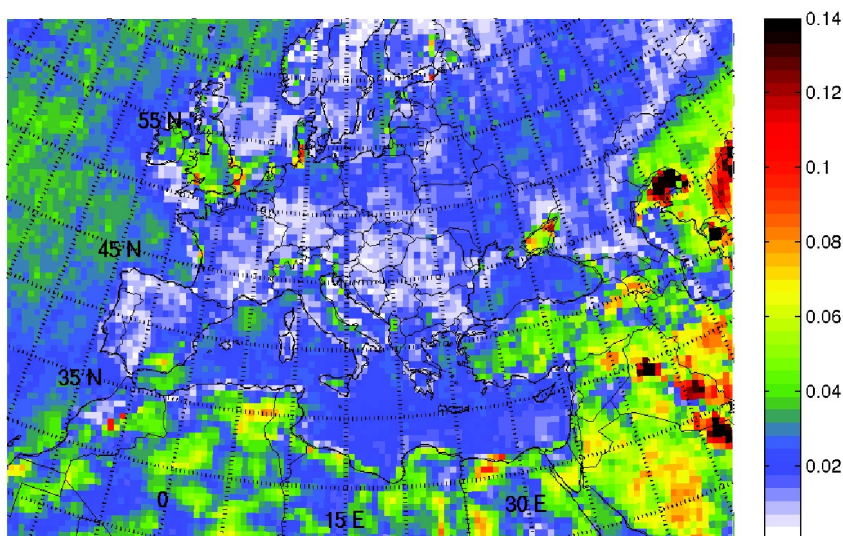


Figure 1 : Estimation of error in total AOD (calculated with 4 different satellite products)

The error range associated with this estimation has also been added to figure 16 (below), for seasonal and interannual total AOD.

With regards to the AOD trends, an error range has been added using the different ACCMIP models. A confidence interval at the level 0.05 has been calculated around the trend from the LMDz-OR-INCA model, and plotted in figure 16 of the paper (below), representing the annual averages of the different data sets between 1979 and 2009.

Page 8499 line 22 : Given these uncertainties, the final reconstruction is provided with an estimation of error based on the four satellite products covering the whole domain (AQUA/MODIS, TERRA/MODIS, TERRA/MISR and SeaWiFS-2). Figure 19 (top) presents the standard deviation of the ensemble of these four data sets. Uncertainties are high over Near-East

and northern Africa, whereas they are lower over Europe.

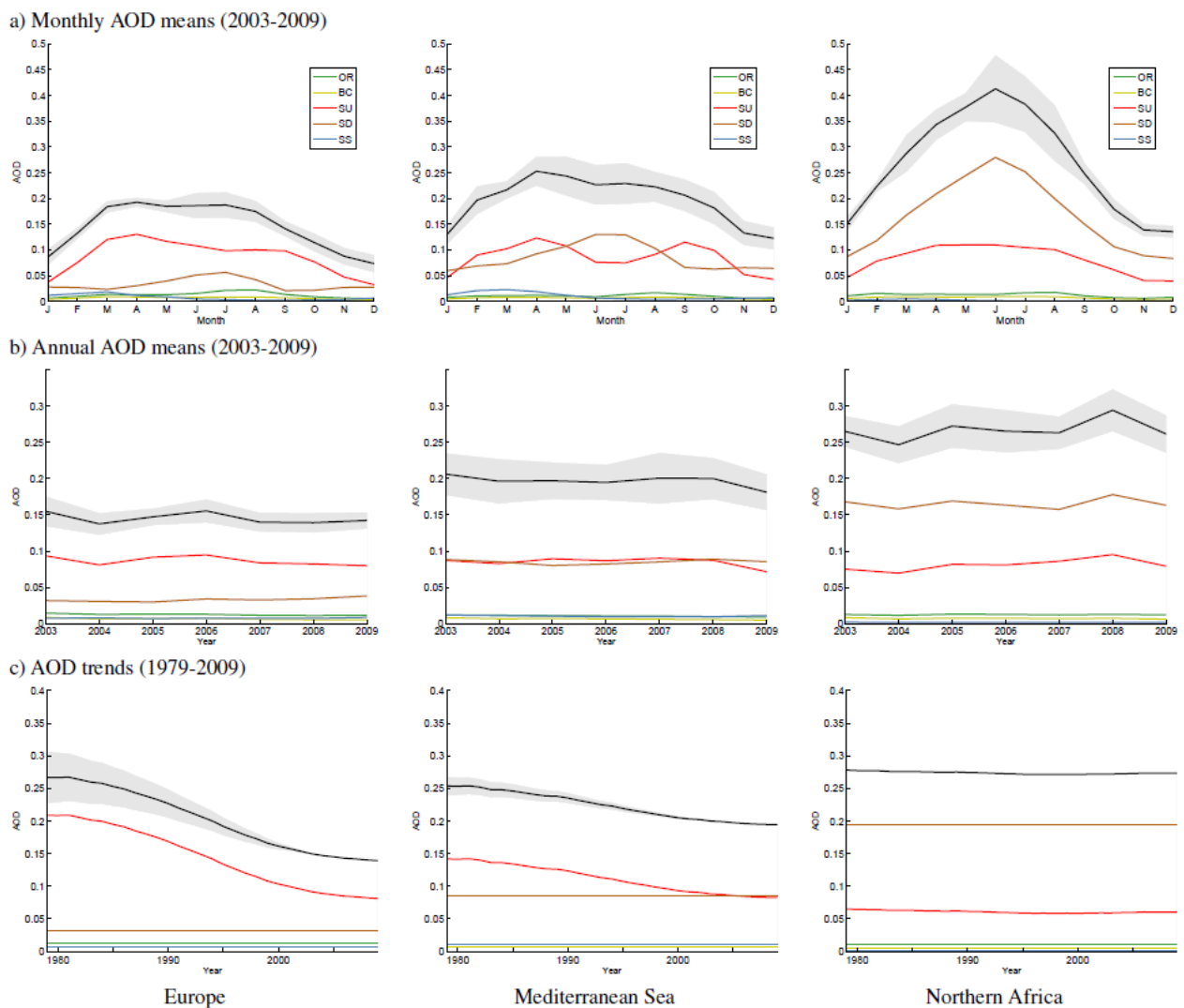


Figure 2 : Seasonal (a) and annual (b and c) AOD averages in the reconstruction field over Europe (left, region 8+9+10), the Mediterranean Sea (middle, region 5+6) and Northern Africa (right, region 1+2) for the five aerosol species (in color) and total AOD (in black). Top (a) and middle (b) plots concern the 2003-2009 period, bottom plots (c) the 1979-2009 period. The confidence interval at the level 0.05 is indicated in gray.

6. At the end, I am not sure how useful this 4-D reconstructed product is – there are so many assumptions involved in reconstructing the component AODs and vertical profiles without a clear picture of possible range of errors, there is no evaluation of SSA and asymmetry factors, there are important aerosol components missing in this reconstruction, and there are lack of realistic aerosol component trends prior to 2003. The usefulness of such products should be objectively assessed.

Reply : Aerosols play an important role for the simulation of present and future climate, Hohenegger and Vidale (2005) have shown the sensitivity of the model to aerosol forcing. We effectively acknowledge that our 4-D reconstruction presents limitations, notably in the choice of the models for each aerosol type. However it represents a significant improvement compared to the climatologies previously used in climate models (e.g. Tegen et al., 1997). A number of climate models which do not have aerosol interactive schemes need this kind of climatology to take into account a realistic aerosol field. That is the reason why we need an aerosol climatology adapted to climate models and as realistic as possible, which is the aim of the present study. In that frame, we are currently preparing an article based on the RCM

ALADIN-Climat model (no interactive aerosol scheme for the time being), forced by this new 4D AOD reconstruction. Comparisons between aerosol radiative forcing and climate feedbacks will be investigated when using old-climatology and this reconstruction. This reconstruction could also be useful for the Coordinated Regional Climate Downscaling Experiment (CORDEX), which the equivalent of the CMIP exercise for regional climate models. One of the regions considered in CORDEX is indeed the Mediterranean region, and most of the participant models do not have interactive aerosol schemes and consequently need this kind of climatology.

Besides, this new AOD product could also help to validate interactive aerosol schemes.

All these points were not clearly explained in the first version of this paper, and have been clarified in the new version.

Moreover, estimations of errors have been provided (see reply to point 5), as well as details about aerosol optical properties (SSA, asymmetry factor). Table 5 has indeed been modified to include realistic effective radius and refractive indices used for the Mie calculations giving SSA and asymmetry factors for visible and infrared wavelengths. An associated error range (10 % around the effective radius) has also been provided in the calculated SSA and g.

7. For comparison purpose, the maps for different satellite datasets and models should show the same time period. Otherwise it is difficult to assess the differences, because aerosols do change from year to year. You should use all periods to “reconstruct” the AOD, but for comparison purpose, it is appropriate to use the common time period. This applies to Fig. 2, 3, and 12.

Reply : Following the comment of the reviewer, we have plotted the average AOD from the different sensors over the common time period (2006-2007, figure below). It turns out that there are very few differences with the original figure 2 of the paper, which has been calculated over the total period of each data set. Consequently and if the reviewer agrees, we have decided not to include this figure in the new version, in order to reduce the number of figures in the paper. The average over the common time period is however mentioned in Table 2, and we have also added this remark in the text.

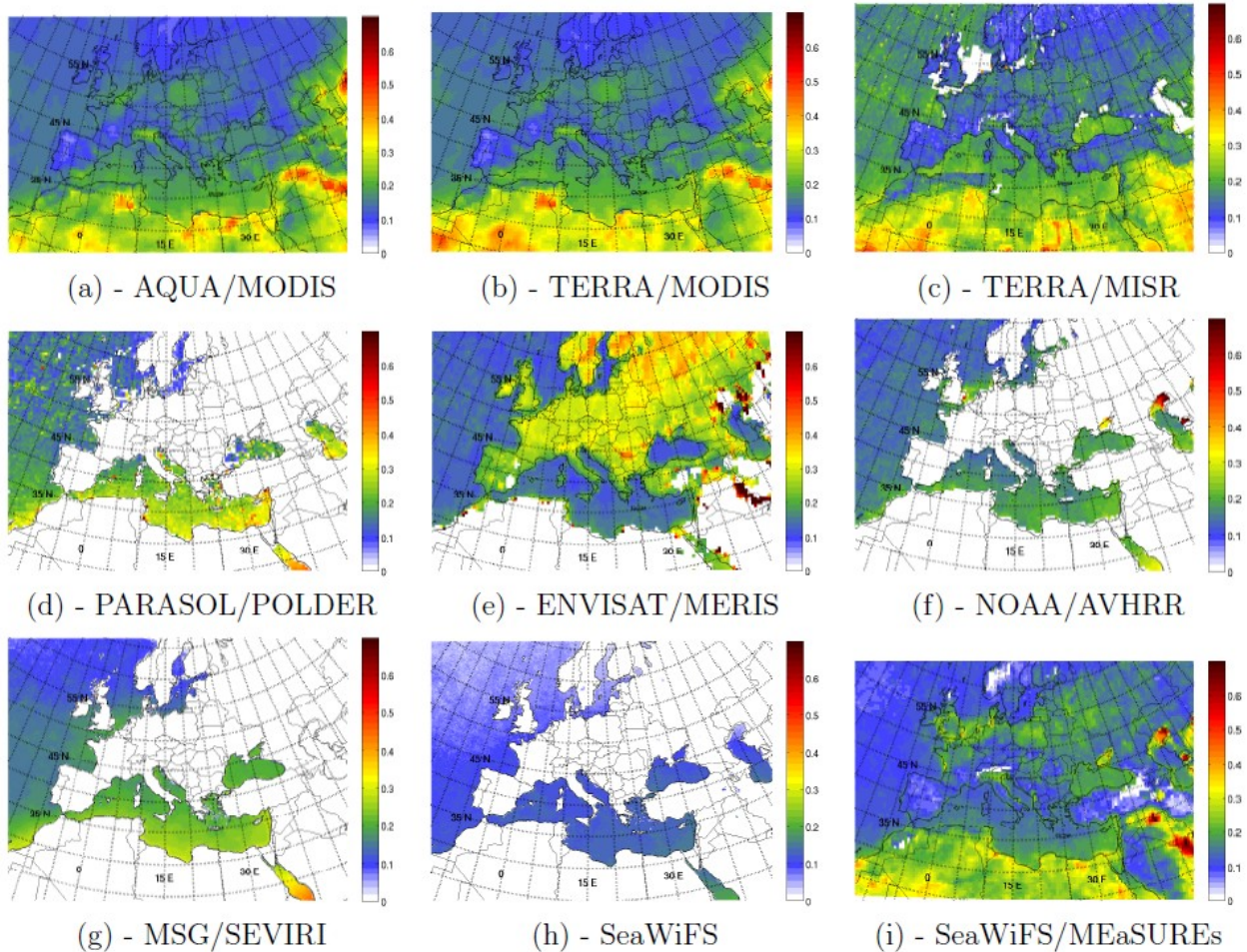


Figure 3 : Mean Aerosol Optical Depth (AOD) at 550 nm from different satellite sensors over the Mediterranean region for the 2006-2007 period.

Specific comments:

P 8473, line 1: it is not “either scattered or absorbed”; it should be “scattered and absorbed”.

Reply : Corrected.

P 8473, line 7-8: Not all those various authors had derived satellite AOD. Satellite AODs are retrieved by various satellite teams.

Reply : Corrected.

Page 8473 line 7 : Various authors have already used AOD derived by several satellite teams from satellite data over the Mediterranean, using for example MODIS ...

P 8473, line 21: What does “a relative agreement” mean? Give some measures (e.g., within x%; within +- y).

Reply : Corrected.

Page 8473 line 21: Kinne et al. (2006) have found a relative agreement in global mean AOD, evaluated between 0.11 and 0.14 in the different AeroCom models, against 0.135 for AERONET and 0.15 for satellite composites. Differences are larger at the regional scale.

P 8474, line 26: “second time” – when was the first time?

Reply : Removed.

Page 8474 line 26 : We have also used the CALIPSO/CALIOP ...

P 8474, line 27: “long period” – be more specific.

Reply : Corrected.

Page 8474 line 27 : the CALIPSO/CALIOP product to assess the vertical distribution of aerosols over five years (2006-2010).

P 8476, line 19: Remove “relatively good”. This is a subjective description. Also, the 1deg x 1 deg MODIS data is a gridded product (Level 3), not the standard product which is at 10-km resolution.

Reply : Removed.

Line 19 page 8476 : at a 1°x1° resolution.

P 8479, line 22: Why do you have to use one of these three sensors? I think you should use all of them (plus SeaWiFS) by weighing the errors.

Reply : The idea was to estimate the best product in terms of aerosol optical depth over the Mediterranean basin. We do not mean that we wanted to keep only one data set, and the text has been modified in that sense. The results have shown AQUA/MODIS has the best scores against AERONET measurements, consequently we have chosen to take only this one for the final product. The idea to take the other ones to estimate the error in AOD has been applied (see previously).

Page 8479 line22: be based on one or several of these four sensors.

P 8481, line 15-16: I don't understand this sentence “. . .the choice of the projection does not have any influence on the aerosol atmospheric content”. Why not? Using different emission projection will surely affect the aerosol atmospheric content, unless all the projections have the same emission.

Reply : Not all the projections have the same emission, but the four RCP do not show differences between themselves in aerosol concentration between 2000 and 2010 (Szopa et al., 2012, see notably figure 9). Clarified in the text.

Page 8481 line 16 : as AOD is similar in the four scenarios between 2000 and 2010 (Szopa et al., 2012).

P 8481, line 17: Do you mean the chronological aerosol from LMDz is fictitious? “Fictitious” has a rather negative meaning as “false”, “untrue”, etc. If you do mean that LMDz generates fictitious results, you should not use it at all!

Reply : We do not mean that the aerosols from LMDz are false, but that their temporal chronology is not real (random) as there is no relaxation towards reanalyses. For example, a maximum in 1988 does not mean a real maximum took place exactly in 1988. Climate models are only able to reproduce statistics (variance, extremes, ...). We have modified the text to make it clearer.

Page 8481 line 17 : no relaxation towards reanalyses is applied leading to an unreal (random) chronology in the aerosol events : only the statistics (variance, extremes, ...) in AOD are correct.

P 8481, line 23-25, AeroCom: You are already doing model intercomparisons in this paper. You should at least use the AeroCom median, which is available.

Reply : Already answered in point 2, we have added the ACCMIP mean.

P 8482, line 12: How long is “very long”? Years?

Reply : Corrected.

Page 8482 line 12 : the multi-year simulation (1850-2010) of LMDz-OR-INCA

P 8483, first paragraph under “3.1 Methodology”: The description of what are shown in the Taylor diagrams and box-whisker figures would be most appropriate to move to the place where you present the figures.

Reply : We have described the Taylor diagrams in the specific section 3.1 Methodology since

detailed explanations were needed. We do not want to mix this methodologic information with scientific results, in order to keep a clear message. However, and following the reviewer's remark, we have added a reference to the section 3.1 at the beginning of the results using Taylor diagrams.

Page 8483 line 23 : in Taylor diagrams, as detailed in Section 3.1

P 8484, line 21: “a north-south AOD gradient is well established” – only parasol, and perhaps SEVIRI, displayed some N-S gradient. From the figure, one cannot see any gradient from other satellites over the Med Sea.

Reply : From the figure 2, a north-south AOD gradient in all satellite data sets is observed (except effectively for SeaWiFS and MERIS sensors). In order to be more precise in this new version, we have calculated the north-south and west-east gradients for each data set, and presented the results in the following table (also added in the paper). These values now clearly indicate the presence of a north-south AOD gradient in most data sets, and have been added in the text.

Data set	AOD North-South gradient $10^{-2}/^{\circ}$ (%)	AOD West-East gradient $10^{-3}/^{\circ}$ (%)
AQUA/MODIS	0.65 (3.5)	0.16 (0.8)
TERRA/MODIS	0.65 (3.3)	0.16 (0.8)
TERRA/MISR	0.49 (2.4)	0.11 (0.5)
PARASOL/POLDER	1.45 (6.4)	0.43 (1.7)
MSG/SEVIRI	0.85 (4.7)	0.22 (1.2)
SeaWiFS	0.28 (2.6)	0.10 (0.9)
SeaWiFS-2	0.63 (4.0)	0.17 (1.0)
ENVISAT/MERIS	0.18 (12.1)	0.05 (0.3)
NOAA/AVHRR	0.50 (2.9)	0.09 (0.5)
TEG97	0.32 (1.7)	0.17 (0.8)
GEMS	0.39 (1.6)	0.10 (0.4)
MACC	0.38 (1.6)	0.11 (0.5)
RegCM-4	0.81 (6.9)	0.03 (0.3)
LMDz-OR-INCA	0.84 (3.7)	0.09 (0.4)
ACCMIPmean	0.50 (2.3)	0.03 (0.2)

Table 2 : AOD average gradients (North-South and West-East) over the Mediterranean Sea in the different data sets.

P 8486, line 5: “inferior” is not used appropriately. There is no “superior” or “inferior” AOD, but “higher” or “lower”.

Reply : Corrected.

Page 8486 line 5 : but slightly lower.

P 8486, line 6: “lower” is better than “weaker”. I don’t see a lower AOD in RegCM4 from the figure - it is actually higher in eastern Europe than MODIS and MISR.

Reply : Precisions about the location of these regions have been added.

Page 8486 line 6 : In Europe, RegCM-4 AOD (0.127) is lower than in satellite data sets, particularly in western Europe (Benelux, Germany, Po Valley), suggesting ...

P 8486, line 8: “slight difference”? The difference over the Atlantic Ocean is quite significant!

Reply : The Sea designed here the Mediterranean Sea (corrected in the new version). Over the Atlantic Ocean, these significant differences may be due to the fact that this region is closer to the limit of the domain, thus missing in RegCM-4 simulation aerosols produced over the Atlantic Ocean outside the domain (also added in the text).

Page 8486 line 8 : the slight difference over the Mediterranean Sea... . Over the Atlantic Ocean, low AOD simulated in RegCM-4 compared to satellite data sets may be due to the proximity of this region to the limit of the domain, thus missing in RegCM-4 simulation aerosols produced over the Atlantic Ocean outside the domain.

P 8486, line 11-12: Why do you attribute the “overestimation” to sulfate?

Reply : The sulfate scheme of the GEMS model had a bug in the conversion from SO₂ to SO₄ (Morcrette et al., 2011), which has been corrected in MACC. The correction of the bug has decreased the sulfate AOD, which could explain the overestimation of GEMS AOD over Europe.

Page 8486 line 12 : linked to an overestimation of sulfate aerosols over Central Europe, related to a bug in the conversion from SO₂ to SO₄ corrected in the MACC version (Morcrette et al., 2011).

P 8486, last line: “Mediterranean AOD is indeed controlled by the dust. . .” – this is a conclusion without the evidence. From which dataset this conclusion is from?

Reply : References have been added in the new version.

Page 8486 line 28 : Mediterranean AOD is indeed controlled by the dust emissions over Northern Africa (Moulin et al., 1998) and anthropogenic aerosols in summer over central Europe (Barnaba and Gobbi, 2004).

P 8487, line 8: “negative bias” – against what?

Reply : Corrected.

Page 8487 line 8 : The same variations but with a positive difference compared to MODIS and MISR are shown by PARASOL, as well as by SEVIRI, SeaWiFS-2 and AVHRR with a negative difference.

P 8487, line 16: Give quantitative numbers of this “very good agreement” (e.g., withinx%). In general, such subjective phrases should not be used.

Reply : Corrected.

Page 8487 line 16 : Over Europe, differences between MODIS (on AQUA and TERRA), and MISR do not exceed 0.02 for every month revealing a very good agreement between these sensors, SeaWiFS-2 shows similar AOD variations and values except a minimum in June, while MERIS AOD is higher on average.

P 8487, line 19: “a positive bias” – compared to what? GEMS is lower than MERIS. If both GEMS and MACC assimilate MODIS, why are they different from MODIS and different from each other?

Reply : Assimilation does not impose the AOD values in the model, so that the aerosol scheme also matters, which can explain differences between GEMS and MACC. Corrected in the text.

Page 8487 line 19 : with a positive difference compared to MODIS and MISR.

P 8487, line 23: Not all models show the same variations. The seasonal max appear in different months.

Reply : Corrected.

Page 8487 line 33 : The models show different variations and values with a maximum situated between April and July

P 8488, line 12: Change “a weaker spread” to “ a less spread”.

Reply : Corrected.

P 8488, line 17: What kind of error is “important”? “Large errors” is more accurate.

Reply : Corrected.

Line 17 page 8488 : The other satellite sensors show larger errors in averaged AOD...

P8488, line 26: Change “weakest” to “smallest”.

Reply : Corrected.

P 8489, line 3: Are you talking about scores, or standard deviation, or something shown in the figure? If it is score, what kind of scores are you talking about, and how are they calculated?

Reply : We are talking about the scores mentioned in the Taylor diagrams (standard deviation, correlation and RMS difference). Added in the text.

Page 8489 line 3: The other data sets show lower scores in the Taylor diagram

P 8490, line 11: MACC agrees with MODIS because it assimilates MODIS. Its comparison with MODIS is not an independent evaluation (i.e., use MODIS to generate the product then compare with MODIS).

Reply : We know the comparison between MACC and MODIS is not a completely independent evaluation, and have added it in the text. However, like the other data sets, MACC has been evaluated against AERONET ground-based measurements in Section 3.2, which are completely independent from MACC. Besides, the MACC team has chosen to assimilate MODIS in their product, which is likely to be a relevant choice as we have shown in the present study that MODIS has got the highest scores against AERONET measurements.

Page 8490 line 11 : MACC and GEMS reanalyses have the best RMSE and correlations, even if it should be noted that the evaluation against MODIS data is not completely independent because of data assimilation in these reanalyses

P 8490, line 16 regarding Figure 8: There are too many lines in each panel, making the figures hard to read and digest. Please separate the regions into different panels.

Reply : This separation between different panels has been done for figure 16 in the revised version. To avoid an excessive number of figures, we have kept the different lines in figure 8, but we have increased the size of the figure.

P 8490, line 26: You should also look the seasonal cycle from the satellite data to convince the readers that RegCM4 also simulate the seasonal cycle correctly.

Reply : This has been mentioned in the previous paragraph.

P 8491, line 28: Change “inferior” to “less than”.

Reply : Corrected.

P 8492-8493, first paragraph in “3.4 Vertical dimension”: It is not clear how CALIOP vertical profiles are actually used, and how those “relative distribution” are translated into absolute distribution. Also, which group does the “polluted dust” from CALIOP belong?

Reply : See the answer in point 3 of major comments.

P 8493, line 12-16: I don’t understand how you determine the top of the aerosol altitude of 5000m or 6000m. This seems arbitrary and not even correct; for example, the models have dust all the way up.

Reply : Indeed models have aerosols on the whole atmospheric column. In order to precise the

altitude range for dust aerosols notably, we have now considered the major part of dust AOD (90%). This precision has been added in the text.

Page 8493 line 12 : The major part of dust AOD (90%) is situated between the surface and 4700 m for CALIOP (4000 m for MACC and 5000 m for RegCM-4),...

P 8494, line 14-15: What does “significant aerosol vertical profiles” mean?

Reply : We have removed the word « significant ».

Page 8494 line 14-15 : vertical profiles representing the aerosol types and regions,

P 8495, line 25-27, “high AOD value” in 1992: This is not high bias of AVHRR data - this is the real volcanic aerosol from Pinatubo. If the satellite data do not show such a large volcanic AOD, they would have serious problems! It is the model that does not include any volcanic aerosols. This is the problem of model, not data.

Reply : Answered in point 3 of major remarks.

P 8496, line 15-21, LMDz trends: What are the emissions of SO₂, BC, OC used in LMDz-INCA model? Have you examined the trends of aerosols in addition to sulfate? Is sulfate the only species in the model showing a decreasing trend? If it uses Lamarque et al. emission, then it should show changes of all anthropogenic aerosols from 1979 to present, not just sulfate.

Reply : Answered in point 4 of major remarks.

P 8497, line 2-3, CALIOP for the period of 2003-2009: CALIOP only available since the second half of 2006. What did you use for 2003 to the first half of 2006?

Reply : We do not take into account the interannual variability in the aerosol vertical distribution as data from CALIOP began in 2006. For each year of the period 2003-2009, we use monthly averages.

Figures: As I already mentioned earlier, the comparisons in Figure 2, 3, and 12 should use the same time periods. The fonts in all figures are generally too small, particularly in Fig. 4 as they are essentially illegible.

Reply : Corrected.

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