

## ***Interactive comment on “Modelling and assimilation of lidar signals over Greater Paris during the MEGAPOLI summer campaign” by Y. Wang et al.***

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Received and published: 11 February 2014

We thank the reviewers for their useful comments on the following manuscript:

Journal: ACP

Title: Modelling and assimilation of lidar signals over Greater Paris during the MEGAPOLI summer campaign

MS No.: acp-2013-536

MS Type: Research Article

Special Issue: Megapoli-Paris 2009/2010 campaign

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### **Part I**

## **Response to Referee 3’s comments**

### **General comments:**

*The paper comes after a previous publication on the assimilation of lidar observations in a CTM (Wang et al. 2013 in ACP) where the assimilation is based on an empirical relationship between aerosol concentrations and lidar measurements of the European lidar network (EARLINET). The present paper is different since it is proposed to assimilate the lidar signal instead of mass concentration to improve the PM10 or PM2.5 simulations. The work plan is well defined and the scope of the paper is relevant for publication in ACP. I agree with the comments of reviewer 1 and 2 saying that the paper needs major improvements before publication. The paper is also very difficult to read because the links between the different results and also the different sections are poorly discussed.*

In order to illustrate the links between the different results/sections, a figure describing the methodology used for lidar signal modelling from outputs of the air quality model and for comparisons to measurements was added in the manuscript. Moreover, the following statement was added at the beginning of section 3: “Figure 2 describes the methodology used for lidar signal modelling from the outputs of the air-quality model and for comparisons to measurements (aerosol concentration measurements, AOD data and lidar vertical profiles)”. We believe this additional figure will make the manuscript clearer.

Furthermore, statistics of comparisons to measurements were added for lidar signals. The same statistics were used for PM mass concentrations and AOD and compared to criterion defined in the literature. Using common statistics allows us to link the different

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results.

### Specific comments:

1) *I do not understand why the data of the MEGAPOLI campaign provide a better benchmark for the assessment of the assimilation method compare to the previous paper using a longer time period and larger area. This should be better explained in section 2.2. It is said it will be done in a forthcoming paper but better to be more convincing about the added value of the present approach.*

Because no lidar network performed regular and simultaneous measurements before 2012, an Observing System Simulation Experiment (OSSE) was built over Western Europe in the previous paper. In that OSSE, we defined lidar networks of fictitious lidar stations, which were based on lidar sites of a subset of EARLINET stations. However, real lidar network measurements were not available and therefore not used. We created and assimilated synthetic lidar observations (vertical profiles of PM<sub>10</sub> mass concentrations).

The difficulty in assimilating lidar network measurements is that lidar networks such as EARLINET do not provide regular and simultaneous measurements. Three-days continuous measurements were performed recently (in July 2012) and these measurements will be used in an article in preparation. This manuscript is mostly devoted to present the preprocessing stage of data assimilation (DA) and a validation of the lidar observation operator ( $H$  in Equation 15). This purpose is illustrated in the abstract and the introduction: “In this study, we investigate the ability of the chemistry transport model (CTM) POLAIR3D of the air quality modelling platform POLYPHEMUS to simulate lidar backscattered profiles from model aerosol concentration outputs. This investigation is an important preprocessing stage of data assimilation (validation of the observation operator)” and “This paper aims at evaluating the lidar signals simulated

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by POLYPHEMUS and at testing new DA algorithms for assimilating lidar signals. We used measurements performed during the the MEGAPOLI summer experiment, when a ground-based mobile lidar (GBLM) was deployed around Paris on-board a van. Measurements from a ground-based *in situ* lidar at Saclay were also performed on 01 July 2009. The evaluation of lidar signals can also be regarded as a preprocessing stage of DA (validation of the observation operator)” (L.85-90). To test our algorithms of lidar signal simulations and assimilations, we used lidar data of the MEGAPOLI campaign. For clarity, the following sentence was added in the introduction: “We used measurements performed during the MEGAPOLI summer experiment, when a ground-based mobile lidar (GBLM) was deployed around Paris on-board a van” (L.86-88).

2) *The section 3.1 on the assessment of the reference altitude  $z_{ref}$  is not very well justified, it comes in the lidar OSSE development section , I agree that it is needed for calculating the scattering ratio in the model but the method to derive  $z_{ref}$  is only relevant to the lidar data analysis. This is a very well known procedure in lidar data processing and the added value of this paper is not obvious on this topic. I agree with reviewer 1 that if an improved technique is proposed is should be compared to other approaches commonly used. What is the scattering of the different calibration factor derived when applying this technique ?*

The proposed method for the calibration of the lidar signal is designed to “automatically estimate the normalisation altitude  $z_{ref}$  from the lidar vertical profile” (L. 234-235). Such method would be required for operational forecast using the assimilation of lidar signals. In section 3.2, we have stated “Although the molecular zone is often determined visually from lidar vertical profiles, this method is not efficient to treat large amounts of lidar profiles” in this paper (L. 232-234).

We do not use any OSSE in this paper. Section 3 is designed to present the lidar observation operator, and an efficient method to estimate  $z_{ref}$  is crucial in the method in order to simulate the lidar signals that are to be compared to measurements and to be assimilated.

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Because  $z_{\text{ref}}$  (in the molecular zone) is derived from the lidar signal, it depends on the information contained in each lidar profile, e.g. the altitudes of aerosol layers. Overall,  $z_{\text{ref}}$  varies on the different measurement days. For example, as shown in Fig. 3,  $z_{\text{ref}}$  is estimated to be about 2850 m at 13:00 UTC 01 July, 3500 m at 16:00 UTC 04 July, 3000 m at 12:00 UTC 16 July, 2900 m at 15:00 UTC 21 July, 2850 m at 14:00 UTC 26 July and 3750 m at 14:00 29 July. On each measurement day, since the lidar measurements were performed during a very short period and the aerosol structure at high altitudes (e.g. higher than 2500 m above the ground) changed slightly, the estimated  $z_{\text{ref}}$  varies very slightly (see Figures 4 to 9).

3) Section 4 called model evaluation is the weakest part of the paper. The comparison results provided in Table 2 and 3 on the model simulations of PM<sub>10</sub>, PM<sub>2.5</sub> and AOD are not discussed while they show a large variability. The bias in PM<sub>10</sub> compare to PM<sub>2.5</sub> is not obvious to understand. It is also difficult to assess the role of the horizontal variability, and of the the small number of observations (6 diurnal cycles and 2 stations for AOD, 4 for PM<sub>2.5</sub>). Only PM<sub>10</sub> data can be considered fairly representative of the horizontal variability. It would be helpful to have some horizontal map of the daily maximum of PM<sub>10</sub>, PM<sub>2.5</sub> and AOD from the model simulations and PM<sub>10</sub> horizontal distribution from the campaign surface network. The bias between model runs and data on PM<sub>10</sub> was already mentioned in Royer et al. 2011 but with smaller values while the same campaign data are considered. It is not clear as it stands where is the added value of section 4 on model evaluation when considering the results already published in Royer et al. 2011.

We do not want to go to the details of the daily variabilities, but only evaluate the model using criteria to show that the simulation corresponds to a state-of-the-art simulation of aerosols. The horizontal and daily variabilities were detailed in Royer et al. (2011). However, as suggested, the horizontal map of the simulated AOD has been added in Figures 4 to 9 for the horizontal variability of aerosols.

The underestimation of PM<sub>10</sub> is very common in air quality modelling. It is partly be-

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cause PM<sub>10</sub> are more affected by deposition and resuspension than PM<sub>2.5</sub>. That is why the explanation of the underestimation (L. 285-289) is based on emissions of coarse PM (particulate matter with a diameter higher than 2.5  $\mu\text{m}$  and lower than 10  $\mu\text{m}$ ).

The simulation setup is different from Royer et al. (2011). As specified in section 2.2, the number of vertical levels is different: "a finer vertical resolution is used with 23 vertical levels from the ground to 12000 m, instead of nine vertical levels in Royer et al. (2011)". The meteorological fields are also different. Our meteorological inputs are obtained from the work of Couvidat et al. (2013) which take into account the effect of urban heat on meteorology. Furthermore, the modelling of secondary organic aerosols is different (a model less complex is used here). Therefore, a statistical evaluation of the results was performed, to show that our simulations meet the performance criteria defined in the literature.

4) In this paper the assesment of the model runs in this paper should be based on the comparison with lidar profile as discussed in section 5. A discussion on the difficulty of the model to reproduce the upper altitude aerosol layer near above 2 km should be added. Generally speaking this section on lidar does not read very well because the differences are mentioned but without an overall synthesis of the discrepancies. Discussions about the temporal change are difficult to follow because the X axis scales of FIG. 4 to 9 are always changed. Why not trying to compare the plume distribution derived from the mobile lidar to illustrate the model ability to reproduce the horizontal variability ?

There are 2 out of 6 measurement days where the model can not reproduce the high-altitude aerosol layer near above 2 km. As suggested, a discussion on the difficulty of the model to reproduce these layers was added: "It is mostly because boundary conditions do not provide information about this aerosol layer due to the large-scale model uncertainties" (L. 321-322) and "... (large-scale model uncertainties)..." (L. 340).

As suggested, an overall synthesis of the statistics was added in the manuscript at

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the end of section 5: "For all measurement days, we also computed the statistics (i.e. RMSE, correlation, MFB and MFE) between observed and simulated lidar vertical profiles. The scores are shown respectively in Figures 4, 5, 6, 7, 8 and 9. Overall, RMSEs are below 1.63, the MFB ranges from -38 % to 8 % and the MFE ranges from 3 % to 38 %. Currently, there is no criterion to evaluate the comparisons for lidar signals. The criterion of Boylan and Russell (2006) was designed for PM concentration and light extinction. Because the scores of the lidar comparisons are extremely good compared to the criterion of Boylan and Russell (2006) with low errors and bias, the criterion of Boylan and Russell (2006) may not be restrictive enough for lidar signals".

For readability, we modified the X axis scale so that it is fixed for each measurement day.

The horizontal variability was studied by Royer et al. (2011). Here, we focus on the vertical variability to be able to evaluate the lidar signal modelling. But for each of measurements, we compared profiles at different horizontal locations. The positions of these locations are now well identified in Figures 4 to 9.

*5) I am not very familiar with the data assimilation numerical techniques but my question is how the assimilation impact the PM10 distribution in the lower layers when the lidar shows upper altitude layer due to long range transport not seen by the model ? A more physically meaningful constraint could be to modify the boundary conditions from the large scale domain which probably control the occurrence of these upper altitude layers.*

In the simulation, the assimilation modified only the initial conditions of the forecast. After the assimilation of lidar signals at high altitudes, aerosol mass concentration corrections are treated by the model, e.g. transported by the wind and vertically mixed by the turbulence.

Yes, you are right. In this paper, boundary conditions are obtained from nested simulations over Europe and France. In theory, if the model simulates better high-altitude

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aerosol layers in simulations over Europe and France, the created boundary conditions should be more accurate. However, the difficulty in reducing the uncertainties in simulations over Europe and France is that there are high uncertainties in their input data (e.g. boundary conditions, emissions and meteorological data). Furthermore, DA at high altitudes could reproduce high-altitude aerosol layers in simulations over Europe and France. However, real measurements at high altitudes (e.g. lidar measurements) over Europe or France were not available. Therefore, we can not improve simulations over Europe and France, and obtain more accurate boundary conditions for the simulation over the Greater Paris area.

#### **Technical details:**

*Figure 1 is very difficult to read especially to identify the stations measuring PM2.5*

Figure 1 was replotted with the legend. For readability, we changed the colour for the stations measuring PM<sub>2.5</sub> concentrations.

*Figure 4 to 9 (not blue points only red and black lines)*

We replotted Figures 3 to 9 with black solid lines for lidar observations.

*In figure 4 to 9 add a panel with a map showing the position of the different profiles.*

As suggested, we added an additional panel showing the horizontal distribution of the simulated AOD and the positions of the different profiles in Figures 4 to 9.

*Add the full date in the first column of the tables*

It is done.

*Why only 4 days for the AOD observations in Table 3 ?*

There is no available AOD data on 21 and 29 July 2009 at stations: Paris and

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Palaiseau. Therefore, we showed only the statistics for 4 days (i.e. 01, 04, 16 and 26 July 2009).

## References

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