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Interactive Comment

Interactive comment on "Assimilation of lidar signals: application to aerosol forecasting in the Mediterranean Basin" *by* Y. Wang et al.

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We thank Referee 2 for his useful comments on the following manuscript:
Journal: ACP
Title: Assimilation of lidar signals: application to aerosol forecasting in the mediterranean basin
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General summary:

Some points that needs to be addressed concern the generality of the results given that only one case study was presented, as well as the impact of changing the boundary conditions on the DA results.

As shown by Roustan et al. (2010) who have performed sensitivity analysis for aerosol and gas-phase concentrations over Europe using the model used in this paper (POLAIR3D/POLYPHEMUS), simulated concentrations of PM are sensitive to boundary conditions (BC). Depending on the global scale model used to provide BC and on the simulated period/year, changing BC could improve or deteriorate aerosol forecasts. If BC are improved, aerosol forecasts may be improved in the simulation without DA, and the impact of DA may be less important. However, depending on period/year and place, changing BC may also deteriorate aerosol forecasts leading to a higher impact of DA. Because simulations of PM strongly depend on other input data, e.g. meteorological fields (Dawson et al., 2007) and emissions (de Meij et al., 2006; Napelenok et al., 2006), the impact of DA may also be more or less important if other input data are changed. The modifications of DA would vary with period/year and place. Therefore, for simplification, this paper presents only one set of input data.

Specific Comments:

1) *p.5 l.127: Could also add these to the list of references on lidar DA:*
Campbell, J.R., Reid, J.S., Westphal, D.L., Zhang, J., Hyer, E.J., Welton, E.J., 2010. CALIOP aerosol subset processing for global aerosol transport model data assimilation. Journal of Selected Topics in Applied Earth Observations and Remote Sensing 3, 203-214. doi:10.1109/JSTARS.2010.2044868.
Zhang, J., J. R. Campbell, J. S. Reid, D. L. Westphal, N. L. Baker, W. F. Campbell,

ACPD
14, C6294–C6302, 2014

Interactive
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and E. J. Hyer, 2011: Evaluating the impact of assimilating CALIOP-derived aerosol extinction profiles on a global mass transport model, Geophys. Res. Lett., 38, L14801, doi:10.1029/2011GL047737.

These two citations are added as follows: "lidar extinction coefficients (Campbell et al., 2010; Zhang et al., 2011)" (P. 7 L. 25-26).

2) *p.6 l. 177 Are the boundary conditions on dust derived from the EMEP inventory? Please explain. In the case of the regional models, DA results strongly depend on boundary conditions (BC). For example, it would be interesting to investigate how the use of different BCs (from global models, or different inventories, or different reference year, etc.) would influence the DA results. Please comment on this in the text*.

Boundary conditions (BC) are climatological conditions obtained from averaging BC from the MOZART4 model over the years 2004-2008. This point was stated at P. 9 L. 16-19 as follows: "Boundary conditions are climatological conditions obtained from averaging boundary conditions from MOZART4 (Model for OZone And Related chemical Tracers version 4) (Emmons et al., 2010) over the years 2004-2008". Moreover, we explained at P. 9 L. 20-26 as follows: "Anthropogenic emissions of gases and aerosols are generated with the EMEP inventory for 2009... In the simulation, Saharan dust is only forced by boundary conditions".

In regional models, the simulation strongly depends on input data, e.g. BC (Roustan et al., 2010), meteorological fields (Dawson et al., 2007) and emissions (de Meij et al., 2006; Napelenok et al., 2006). BC are often obtained from the global models. Therefore, they strongly depend on the uncertainties of global models. In this paper, BC are from the MOZART4 model over the years 2004-2008. They are not specific BC for the month of July 2012. However, if specific BC are used, concentrations may be better modelled and the impact of DA would then be less important. However, because uncertainties on global models and BC are high, it is not certain that concentrations may be better modelled. Furthermore, uncertainties are not only limited to BC but also to meteorological fields and emissions. For clarity, the following statement is added at P. 11 L. 10-16: "In regional models, uncertainties are linked to input data and parameterizations, e.g. initial and boundary conditions (Roustan et al., 2010), meteorological inputs (Dawson et al., 2007) and emissions (de Meij et al., 2006; Napelenok et al., 2006). DA may be used to improve input data as initial conditions as done in this paper using observations. Replacing other input data, such as BC or emissions by another set of data which are also uncertain, may either improve or deteriorate the aerosol simulations depending on period/year and place, leading local variations in the impact of DA".

3) *p.8 l.232 Were the observations averaged over 1 hour? Did you try different averaging intervals? What about in the vertical?*

Yes, the lidar observations were averaged over one hour. In this paper, we did not try different averaging intervals. However, Wang et al. (2014) assimilated data every 10 mins at the scale of Paris, because averaging or assimilation intervals depend on the modelling scale. They are larger in this paper (simulations over Europe) than in the simulation over Paris. In the vertical, assimilated data were interpolated from the high resolution lidar profiles (see Tab. 1).

4) *p.9 l.275 The analysis of the case study using backward trajectory can only go so far as far as the species attributions: can the authors use different tools (for example global aerosol models) to assess what type of aerosols were likely present at the lidar stations during the campaign period?*

We focus mainly on the forecast of aerosols, e.g. mass concentrations of PM_{10} and $PM_{2.5}$. We checked if Saharan dust strongly impacted the continent of Europe P. 14 L. 1-10. In this paper, backward and forward trajectories are used to show the impact area of assimilating lidar data P. 14 L. 20-24. They are not used to assess the aerosol types. This is done using POLAIR3D/POLYPHEMUS. For clarity, the following statement is added at P. 14 L. 11-12: "To check that the penetration of the Saharan

ACPD
14, C6294–C6302, 2014

dust plume over the continent of Europe was limited and to assess where analysed concentrations are transported to after assimilation, ...".

5) *p.10 l.306 Would you have had the same improvements if more dust was already present in the BCs? The influence of the BCs should not be neglected. This is part of assessing the goodness of the background.*

Yes, we believe we would have had the same improvements if more dust was already present in BC, because the penetration of Saharan dust plume over the continent of Europe was limited and did not affect most of the ground-based concentrations, as discussed in section 3.3. Using BC from another global models may not improve the simulations as all global models are attached to uncertainties. This paper presents the first application of assimilating lidar signals. It was expected to demonstrate the usefulness of lidar network for aerosol forecasts. Therefore, only one set of input data is tested. Assessing the impact of uncertainties on DA may be the topic of further papers.

6) *p.11 l.321 : Add "should" before "24-hour".*

At P. 16 L. 12, "should" was added before "24 h".

7) *p.11 l.324 : Why did you choose 60 hours for the total forecast length?*

Actually, we took 108 hours as the forecast length. Since improvements are not significant after 60 hours, we showed only the first 60-hour forecast in this paper.

8) *p.12 l.374 What is the vertical resolution of the data? Did you perform any averaging? If yes, did you look at the sensitivity to the choice of averaging interval (the same question applies to the temporal averaging, see question above). Why did not not assimilate from the surface? Are there intrinsic problems with the use of the ground-based lidar observations close to the surface? Please comment*.

The vertical and temporal resolutions of the data are shown in Tab. 1. Moreover, they are detailed at P. 12 L. 11-13 that "The vertical resolution of measurements ranges

ACPD

14, C6294–C6302, 2014

from 3.25 m to 30 m (depending on the lidar system). The temporal resolution of measurements ranges from 30 s to 300 s (depending on the lidar system)". Assimilated data were interpolated with a time resolution of 1 hour from high temporal resolution lidar profiles. We did not perform any averaging in the vertical.

We did not assimilate lidar data from the ground level, because data are not available between the surface and several hundred meters due to overlap problems (see Figures 2 and 3). Please see answers to comments 6) and 7) of Anonymous Referee 1.

9) *p.13 l.404 Please summarize the results in a table, section 5.1 is hard to read. Please do the same for sections 5.2 and 5.3*.

For clarity, we summarised the statistics of sections 5.1, 5.2 and 5.3 in Tab. 4.

10) *p.13 l.417 How do you assess the significance of the improvements?*

For clarity, the following sentence "Against the observations at BDQA stations on the southern side of 44° N (dashed line in Fig. 1), ... The improvements are significant" is modified to "Against the observations at BDQA stations on the southern side of 44° N (dashed line in Fig. 1), ... The improvements of DA are more significant by comparisons to measurements at BDQA stations southern of 44° N than at all BDQA stations" (P. 20 L. 8-9).

11) *p.14 l.431 From these results it appears that the radius of influence of the lidar measurements is rather small. Could you comment on how what type of density of lidar stations would be desirable? Where would having more lidar stations bring the highest benefits? It is probably situation-dependent. Could you comment on using a denser network such as the ceilometer network?*

The radius of influence of the lidar measurements is not very small. As tested in this paper (see section 4.2), the assimilation correlation length should be less than 200 km. We took 100 km as the reference assimilation correlation length which defines a radius of influence of about 500 km by the Balgovind approach (similar to exp(-x/L), x stands

ACPD
14, C6294–C6302, 2014

for the distance and L stands for the assimilation correlation length).

Wang et al. (2013) have investigated the number of required lidars and how to define an optimal lidar network for PM_{10} forecasts over western Europe using synthetic data. They have studied lidar networks of 12 stations, 26 stations and 76 stations. 76 lidar stations lead to the best scores (RMSE and correlation). Moreover, Wang et al. (2013) have investigated the optimal locations of lidar networks. They found that spacing regularly the lidars improves PM_{10} forecasts over Europe. Since Wang et al. (2013) used synthetic data (i.e. the vertical profile of aerosol mass concentrations), the results should be generalised to the ceilometer network.

What type of accuracy is needed from the lidar measurements to have a significant impact on the surface PM concentrations?

Lidar measurements as those performed here are accurate enough to have a significant impact on surface PM concentrations. Since uncertainties in the lidar signal are low (less than 5 %), reducing uncertainties in the simulation and changing the algorithm used for assimilating lidar signals may further improve surface concentrations.

12) *p.15 l.478 Can this be generalized?*

Yes, but it also depends on the modelling scale, the vertical resolution, the density of lidar network etc. Moreover, most validation observations were provided by the French network (i.e. BDQA) in this paper.

13) *p.15 l. 484 Remember the possible role played by the BCs, you only experimented with one set of BC and one case*.

Please refer to answers to comments 2) and 5) of Anonymous Referee 2.

Figures

Figure 2-3 It would be good to see the model equivalent of the lidar PR2 before and after assimilation alongside the observations.

Such comparisons are shown in Fig. 11 of Wang et al. (2014). They were used to validate the improvements at high altitudes. In this paper, we focus mainly on the validation using surface PM measurements to study the impact of assimilating lidar signals at ground level.

Figure 13 Could you also show the time series for AOD at a few stations rather than only the scatterplot. Are the obs matched to forecast time?

As you suggested, a figure of the time series of observed and simulated AODs at two stations Rome and Bucharest is added in the paper. Also, the following statement is included in section 5.4: "Figure 13 shows the time evolution of the AOD measurements and AODs of the 36-hour forecasts without DA and with DA at AERONET stations Rome (41.84° N,12.65° E,130 m a.g.l.) and Bucharest (44.35° N, 26.03° E, 93 m a.g.l.). The impact of assimilating lidar signals lasts about 36 hours, which corresponds to the findings of sections 5.1 and 5.2".

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ACPD

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