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Discussions

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 1 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 comments

It is not clear to me why and how this simple and partly misleading lidar information leads to forecast improvements. More explanations are required.

This paper is based on the algorithm developed by Wang et al. (2014). As mentioned in the abstract, it presents a new application of assimilating lidar signals (range corrected lidar signals, i.e. PR^2) to aerosol forecasting. The algorithm for assimilation of lidar signals was described in detail in Wang et al. (2014). For clarity, the following sentences are added in Section 2: "Wang et al. (2014) developed an aerosol optical property module to simulate the aerosol optical properties (AOD, backscatter and extinction coefficients) and lidar signals (PR^2) from the model aerosol concentration outputs. They also detailed the OI approach for assimilating lidar signals from the model aerosol concentration outputs" (P. 9 L. 27-29 and P. 10 L. 1) and "Concentrations can be impacted by lidar DA far from the place where lidar signals are assimilated, because analysed mass concentrations are transported by winds and diffusion (turbulence)" (P. 11 L. 7-9).

Details

1) *Page 13066, lines 20-22: The model is able to interpret attenuated backscatter, i.e., this complex mixture of backscattering and extinction? Otherwise, if the model interprets attenuated backscatter as backscatter then the use of the lidar data can lead to very bad results, i.e., when ignoring the extinction effect on the range-corrected lidar signals. We need more details how the lidar data are used! Reference to Wang et al. (2013) is not sufficient.*

Yes, our model, POLAIR3D of the air quality modelling platform POLYPHEMUS, is able to simulate attenuated backscatter. Wang et al. (2014) have developed an aerosol optical property module in POLAIR3D to model aerosol optical properties (e.g.

backscatter and extinction coefficients) and lidar signals (range corrected lidar signals) from the model aerosol concentration outputs (see Fig. 2 in Wang et al. (2014)). For clarity, the following sentences are added in Section 2: "Wang et al. (2014) developed an aerosol optical property module to simulate the aerosol optical properties (AOD, backscatter and extinction coefficients) and lidar signals (PR^2) from the model aerosol concentration outputs. They also detailed the OI approach for assimilating lidar signals from the model aerosol concentration outputs" (P. 9 L. 27-29 and P. 10 L. 1).

The reference "Wang et al. (2013b)" is updated to "Wang et al. (2014)" at P. 8 L. 12 and L.16.

2) *Page 13067, line 19: The modelling domain covers western and part of eastern Europe, only!! This is strange (sorry for this emotion, but I was a bit upset)! How can you provide high-quality aerosol forecasting in the Mediterranean Basin if the Mediterranean is not totally covered by the model? The most interesting and highly polluted area (and thus source of aerosols even in the central and western Mediterranean) is the Eastern Mediterranean! Why is this part excluded? Please give detailed information.*

The assimilation experiment was designed to assess the improvements of assimilation of lidar signals for real-time forecasting over western Europe (http://cerea.enpc.fr/en/prevision.html). As shown in Fig. 1, validation data are sparse. The french network (i.e. BDQA) provides most validation data. For clarity, this paper's title is modified to "Assimilation of lidar signals: application to aerosol forecasting in the west mediterranean basin".

3) *Page 13069, line 20 to page 13070, line 25: Even as a modeller, please do not ignore the reality! So, please provide an improved Table 1 and Figure 1! The list of participating stations in Table 1 is incomplete. CUT, Limassol, Cyprus measured this 9-12 July episode in the framework of the project as well. I asked them by e-mail! Even if not included in this paper and model study, the reality (full list of network stations) should be reflected in Table 1. CUT, by the way, is also one of the stations*

with 1640nm photometer channel, thus one of the modern AERONET stations. Please provide a better Figure 1, showing the full Mediterranean and then insert, may be, a box with the modelling domain. To be clear here, I will not accept this paper, if Table 1 and Figure 1 are not improved according to my suggestions!

The lidar stations Limassol (i.e. CUT), Messinia and Payerne are now included in Tab. 1. For clarity, the following statement is added at P.12 L.7-9 and in the caption of Tab. 1: "Data received by Payerne and Messinia stations are not available. Also, data received by Limassol station are not used in this paper, because Limassol is outside of the model domain" and "Limassol was not included, because it is outside of the model domain. Payerne and Messinia were not included, because data were not available".
Also, as suggested, Figure 1 is improved as follows:
1. Limassol, Messinia and Payerne lidar stations are included.
2. The full Mediterranean is shown.
3. A rectangle to show the modelling domain is inserted.
For clarity, the caption of Fig. 1 is modified as follows: "Map of the different measurement sites providing measurements between 9-12 July in the domain of interest (the rectangular area delimited by the black box). The red triangles show the locations of French air quality network (BDQA). The cyan squares show the station locations of the EMEP-Spain/Portugal network. The cyan triangles show the locations of stations around Barcelona. The green squares show the locations of EMEP-Europe stations. The green diamonds show the locations of AERONET stations. The dark blue/black star markers show the locations of ACTRIS/EARLINET stations. The black star markers show lidar stations without data between 9-12 July or outside of the forecast domain. The yellow star marker shows the location of the Corsica lidar station. The dashed line shows the latitude of 44° N which is used to split the French stations in Sect. 5.1".

Again, does the model explicitely use the backscatter AND extinction information, or is the attenuated backscatter just interpreted as backscatter? Please state that clearly!.

We used the attenuated backscatter. Please refer to answers to comment 1) of Anonymous Referee 1.

4) *Page 13070, line 23: The lidar color plots are rather poor, contain almost no information. Almost nothing is seen in these figures, some plumes, mostly decreasing signals, no PBL tops. Why are the lidar data so poor? Are the lidars so bad? I am really surprized that such low quality observations can lead to improvements of aerosol fortecasts.*

We re-plotted Figures 2 and 3 with hourly-averaged vertical profiles of PR^2, to better show the atmospheric structure. Also, the captions of Figures 2 and 3 are respectively modified to "Hourly-averaged range corrected lidar signals (PR^2) from 06:00 UTC 9 July to 06:00 UTC 12 July at Athens, Clermont-Ferrand, Evora, Granada, L'Aquila and Potenza lidar stations" and "Hourly-averaged range corrected lidar signals (PR^2) from 06:00 UTC 9 July to 06:00 UTC 12 July at Barcelona, Bucharest, Corsica and Madrid lidar stations". Indeed we cannot easily visually determine the PBL top at some stations (e.g. Athens) in Figures 2 and 3. But the PBL top can be easily visually determined at Evora, Barcelona and Bucharest stations. That is likely because of the different overlap of the different lidar systems and different atmospheric conditions at stations.

Although the PBL top is not sometimes easily visually determined due to the overlap problem, lidar observations provide aerosol information at high altitudes, which improves the aerosol simulation using DA.

5) *Page 13071, line 12: Why do you use 355 nm AOD? The AOD at 340 nm (used to get the 355 nm AOD) is not just free of uncertainties, because strongly controlled by Rayleigh extinction (and correction of this effect). Why not using 500 or 532 nm AOD? Please explain! May be the reason is, ... as it is often found in measurement-model inercomparisons... , the modelled AOD matches much better the measurements at short wavelengths than at 500, 532, or 550 nm AOD? Please explain, why you use this a bit complicated wavelength (even the Angstroem exponent is uncertain at these*

short wavelengths).

In our opinion, the wavelength 355 nm is not attached to more significant concentrations than 532 nm. Although extinction coefficients include a strong contribution of molecules at this wavelength, they can be easily corrected by calibration uncertainties. As shown in Chazette et al. (2010), AERONET gives a maximal absolute uncertainty of about 2% for AOD, which is wavelength dependent. Moreover, in the current implementation of our DA algorithm, only one wavelength may be used. This is mentioned in the following statement at P. 8 L. 12-13: "Wang et al. (2014) developed for the first time DA algorithms to directly assimilate normalised range corrected lidar signals (PR^2) at one wavelength (i.e. 355 nm)". Measurements were performed at 355 nm at most stations, because the lidar measurements at 355 nm are eye-safe (e.g. aviation near the city) and more sensible to aerosol pollution. Keeping the wavelength of AOD match with the one of lidar reduces the computational cost in simulations.

Again, Cyprus (CUT, AERONET/EARLINET station) belongs to AERONET too. Again, Figure 1 is really bad, even Crete (in the center of the Mediterranean) is almost not on the map. As mentioned, please improve Figure 1 significantly.

CUT (34° 40' N, 33° 02' E) is one of AERONET stations. However, it is out of our modelling domain ([15° W, 35° E] × [35° N, 70° N]). It is why CUT AERONET station is excluded. FORTH CRETE (35 N, 25 E) does not provide the Level 2.0 (cloud-screened and quality-assured) AOD data for the year of 2012. Please refer to the AERONET website http://aeronet.gsfc.nasa.gov/new_web/aerosols.html. Therefore, FORTH CRETE is excluded. For clarity, the caption of Fig. 1 has been modified as follows: "Map of the different measurement sites providing measurements between 9-12 July in the domain of interest (the rectangular area delimited by the black box)...".

6) *Page 13073: How can lidar data in terms of attenuated backscatter with all the problems introduced by overlap problems in the near field (in the lowest 500-1500 m above ground) improve ground-based PM2.5 and PM10 forecasts? Please explain. I*

have no idea, how this is possible.

To avoid overlap problems, the lidar data below chosen altitudes were not used in this paper (see Figures 2 and 3, the overlap altitude depends on the lidar system). Assimilating lidar data improves aerosol mass concentrations at high altitudes (above the overlap altitudes), e.g. 1000-3500 m above ground level. The improved aerosol concentrations at high altitudes are transported to the ground by diffusion (turbulence) and winds during the simulation of the chemistry-transport model, leading to improvements of ground-based concentrations. This is now explained in section 2: "Concentrations can be impacted by lidar DA far from the place where lidar signals are assimilated, because analysed mass concentrations are transported by winds and diffusion (turbulence)". This impact of DA on concentrations nearby the locations of lidar is shown in Section 5.1 and 5.2. The ground-based PM_{10} and $PM_{2.5}$ stations can be impacted by assimilation of lidar data: "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. These southern stations are impacted by DA of the Corsica, Spain and Portugal lidar data" and "the surface stations around Barcelona are also strongly influenced by the Evora and Madrid lidar sites due to wind fields, because Barcelona is on the leeward side of these lidar sites during the lidar campaign in July 2012 (see Fig. 6). The improvements due to lidar DA associated with a long-range transport pollution from Evora and Madrid are also validated". About this point, please also refer to Wang et al. (2013) and Wang et al. (2014) who have demonstrated the usefulness of assimilation of ground-based lidar data for aerosol forecasts.

7) *Page 13076: line 5-28: What is now the most important lidar information when using attenuated backscatter? Please state! Is it the observed aerosol layering (geometrical properties) or the optical properties of aerosols which may be used to estimate volume and mass concentrations of the particles? Please provide more details on this! And again, how did you overcome the large uncertainties in the lidar data in the lowest*

tropospheric heights?

In our case, we assimilate PR^2, instead of extinction, backscatter coefficients or mass concentrations estimated by the optical properties. Therefore, both the optical and geometrical properties of aerosols are important for assimilation of lidar signals. To avoid overlap problems (uncertainties in the lowest tropospheric heights), the lidar data at each station below chosen altitude were not used in this paper (see Figures 2 and 3). For example, the lidar data at Athens station below 600 m a.g.l (see Fig. 2) were not used. In this section, we discussed the choice of the assimilation altitude range: "First, as the normalisation of range corrected lidar signals is done at high altitude, the lower the altitude is, the higher the error in the simulated lidar signal is" and "Second, the numerical computations of the lidar operator H and its tangent lidar operator H (see Eq. 1) are very costly". Therefore, we need a moderate assimilation altitude range.

8) *Pages 13077 and 13078: There are no explanations why the forecasts improve, all the results do not help. The reader will almost learn nothing without further information.*

For clarity, the following sentences are added in Section 2: "Wang et al. (2014) developed an aerosol optical property module to simulate the aerosol optical properties (AOD, backscatter and extinction coefficients) and lidar signals (PR^2) from the model aerosol concentration outputs. They also detailed the OI approach for assimilating lidar signals from the model aerosol concentration outputs" (P. 9 L. 27-29 and P. 10 L. 1) and "Concentrations can be impacted by lidar DA far from the place where lidar signals are assimilated, because analysed mass concentrations are transported by winds and diffusion (turbulence)" (P. 11 L. 7-9).

9) *Figure 7: What is the truth? (what is the true curve or the curve most close to the reality)? May be I missed the point?.*

Figure 7 shows the time evolution of the RMSE (root mean square error) and the correlation of aerosols, rather than the aerosol mass concentration evolution. There is no "truth". There are statistics calculated against observations to estimate how the simulation performed, i.e. how close they are to observations. The lower the RMSE is and the higher the correlation is, the better the simulation for aerosol forecasts is.

10) *Figures 10 and 11: Again, what are the true curve?*

Please refer to answers to comment 9) of Anonymous Referee 1.

11) *Figures 12 and 13: I do not see any improvement when using these attenuated backscatter data from lidar!*

The improvements shown by scatter plots in Fig. 12 are not very significant. However, the statistics (RMSE, correlation and bias) show improvements. It is discussed in section 5.3 as follows: "The PM$_{10}$ correlation and RMSE are slightly improved. During the assimilation and forecast periods (72 h), the RMSE averaged over all six experiments is 6.9 μg m^{-3} without DA and 6.3 μg m^{-3} with DA (see Tab. 4). Compared to the simulations without DA, DA (“Lidar DA”) increases the correlation from 58 % to 63 % (see Tab. 4). Meanwhile, the Mean Bias Error (MBE) decreases from 3.1 to 2.3 μg m^{-3} (see Fig. 12)." (P. 21 L. 6-10).

According to the statistics in Fig. 14, the improvements are not significant for all AOD. However, AODs are significantly improved in the simulation with DA for high AOD observations. This is discussed and explained in section 5.4 as follows: "As shown in Fig. 14, AODs are significantly improved in the simulation with DA for high AOD observations (few cases). When the observed AODs are larger than 0.4 ($N = 262$), the RMSE (resp. MBE) is 0.23 (resp. 0.2) without DA against 0.20 (resp. 0.13) with lidar DA. It is because large AODs could be associated with transport of particles above the boundary layer, which is not well simulated by the model (probably due to large-scale model uncertainties) but followed by the lidars (Wang et al., 2014). It may also be that assimilation of lidar signals improves the estimation of aerosol mass concentrations more efficiently when aerosol concentrations are high, e.g. during air pollution events, that is when the lidar signal is strong" (P. 22 L. 4-12).

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