Atmos. Chem. Phys. Discuss., 13, C1334–C1344, 2013
www.atmos-chem-phys-discuss.net/13/C1334/2013/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Continuous atmospheric boundary layer observations in the coastal urban area of Barcelona, Spain" *by* M. Pandolfi et al.

M. Pandolfi et al.

marco.pandolfi@idaea.csic.es

Received and published: 16 April 2013

We would like to gratefully thank W. Thomas for his useful comments.

GENERAL COMMENTS:

(1) Nonetheless, the authors should strive for making clear the main goal of the paper. This is, in my view, the missing element. The results presented in this paper are somewhat foreseeable. The Western Mediterranean is mainly affected by air masses originating from the South-West/East (the NAF scenario) and the West (the ATL scenario) while regional contributions become stronger during stable weather conditions. This is or was already known. Therefore, one could, to some extent, expect and estimate the way the mixing layer heights would vary when moving from one scenario

to the other. To some degree one may conclude also the behaviour of the aerosol backscatter during these scenarios. The authors quantified these changes but results are not a surprise which limits in some way the value of the paper. There were already several studies in the past dealing with similar issues (following the list of references and especially with respect to the paper of Sicard et al. 2011) and it is therefore even more important to make clear why this paper contributes significantly to the scientific discussion.

Answer: Previous publications on aerosol optical properties over Barcelona by lidar have dealt mainly with a climatological analysis (summer vs. winter, monthly averages) of PBL height, AOD, mean extinction and backscatter vertical profiles (from 1 km a.g.l.), lidar ratio and Angstrom exponent. In these publications the lack of a clear annual cycle for PBL AOD and PBL height have been partly related with the typical summer conditions in the WMB characterized by regional recirculation of airmasses and combined sea breeze and upslope flows which may prevent the vertical development of the PBL. However, a direct comparison between PBL AOD and height vs typical atmospheric scenarios in the WMB were not presented in these previous publications.

In our manuscript we show how the mean PBL height and backscatter coefficient vary as a function of the three typical scenarios (NAF, ATL, REG) affecting the WMB. This analysis allowed us for example to observe, discuss and present the limited development of PBL when African air masses are over Barcelona. Saharan dust episodes in the WMB are more frequent and intense in summer and might also contribute to lower the PBL in summer. Thus, we show that the PBL under NAF episodes had characteristics considerably different compared with ATL and REG scenario (which also differ between them having on average the same PBL heights but strongly different backscatter, RH, and ground PM1 concentrations). We also show with data from ceilometer and radiosoundes the effect of strong winds from the Mediterranean Sea on the development of PBL over Barcelona during the afternoon. This analysis is new for Barcelona given that this is the first time that daily cycles of PBL height and backscatter are presented for Barcelona as a function of atmospheric scenarios during a whole month. Furthermore, we present and discuss (for the first time for Barcelona) the relationship between backscatter, RH (ground and vertical RH measurements) and ground PM1 concentrations and the relationship between backscatter and atmospheric stable/unstable/neutral conditions as a function of the height. The variation with height of RH strongly affects the vertical profile of backscatter over our coastal site and this could also be a possible reason why aerosol models and radiative transfer models still suffer from large uncertainties when applied to the WMB region.

These and other novel aspects of our manuscript have been better presented in both the introduction and the conclusions.

(2) It would be helpful to formulate the open scientific question to be answered at the beginning of the paper. Then the reader is guided through the paper and results shall give the answer to the question opened at the beginning. A conclusion (which is missing !) could discuss possible applications of the knowledge gained. This kind of red line would be very helpful to judge the authors contribution to the scientific work level made. In other words, it should be clear after reading the paper why this paper has actually been written.

Answer: Following the suggestion of the Referee, the last part of the Introduction was modified as followed:

“In this study, we analyse one month of measurements of PBL height and optical properties continuously performed for the first time over Barcelona (Spain), using the vertical-pointing 1064-nm wavelength CHM15K ceilometer within the framework of the SAPUSS (Solving Aerosol Problems Using Synergistic Strategies) project (Dall’Osto et al., 2012). Main aims of this work are to provide valuable insights on PBL structure, evolution and optical properties over Barcelona based on the continuous ceilometer measurements and radiosonde data. We present and discuss the daily cycle of the PBL height and aerosol backscatter at selected heights under three typical atmo-

ACPD
13, C1334–C1344, 2013

spheric scenarios affecting the WMB and detected during the duration of the campaign, namely: stagnant Regional (REG), warm African (NAF), and cold Atlantic (ATL). Ground meteorological data and ground PM1 concentrations are also presented and correlated with the measured aerosol optical properties as a function of the atmospheric scenarios. The effect of overlying warm African air masses and of strong winds from the sea within the whole PBL on PBL growth and evolution are discussed. Additionally, ceilometer measurements were correlated with radiosonde data to study the effect of relative humidity on aerosol backscatter vertical profile over the coastal area of Barcelona. Finally, the aerosol backscatter coefficient vertical profile and its relationship with unstable/stable atmospheric conditions are also discussed."

Moreover the following DISCUSSION AND CONCLUSION section was added:

"4 DISCUSSION AND CONCLUSIONS During the SAPUSS (Solving Aerosol Problems Using Synergistic Strategies) project a vertical-pointing 1064-nm wavelength CHM15K ceilometer was deployed with the aim of determining the boundary layer structure, evolution and optical properties over the coastal area of Barcelona. Ceilometer data have been thoroughly analyzed in order to provide valuable insights on 1) the impact that three typical atmospheric scenarios (African dust outbreak, Atlantic advection, Regional recirculation) in the WMB have on the PBL over Barcelona and 2) the possible explanations for the observed increase of aerosol backscatter with height within the SML irrespective of the thermodynamic states of the atmosphere. Findings can be summarized as followed:

(1) PBL maximum height and daily variations (DV) were strongly dependent on air mass types, ranging from the highest PBL-strongest DV (ATL) to the lowest PBL-weakest DV (NAF). The observed differences in PBL structure over Barcelona were due to the concomitance of different factors. The presence of warm African air masses above colder local air changed the temperature profile thus lowering the height of the inversion. As a result the mean SML height during NAF was 25% lower than for the ATL scenario. Previous studies conducted in Barcelona have related the lack of a clear PBL height

ACPD
13, C1334–C1344, 2013

annual cycle to the typical summer conditions of the WMB characterised by weak pressure gradients and the development of breeze circulation patterns which may prevent the vertical development of the PBL (Sicard et al., 2011). Even though the breeze pattern is a recognized cause affecting the growth of PBL at coastal sites, the higher occurrence and intensity of African dust episodes in the WMB in summer (10-20% of the days, Pey et al., 2010b) may also contribute to prevent the development of the PBL. This result is also a motivation to further investigate about the possible relationship between PBL height and African dust episodes.

(2) The analysis of the relationship between the SML heights estimated from ceilometer (SMLh_ceil) and radiosoundings (SMLh_rad) at 12:00 UTC revealed another interesting characteristic of PBL under NAF. On average during SAPUSS, the SMLh_rad were lower than the SMLh_ceil by around 166 m and 249 m during REG and ATL, respectively, whereas during the NAF scenario the difference was small (-42 m). We argued that a possible reason for the good agreement between SMLh_ceil and SMLh_rad during NAF was the presence of abrupt changes in the vertical profiles of backscatter and potential temperature at the SML top caused by the differential advection of air masses above Barcelona during NAF. These abrupt changes reduced the uncertainties in SML top retrieval from the two techniques. The mean slopes of the lidar backscatter and potential temperature profiles at the top of the SML during NAF were -0.038$\pm$0.007 Mm-1sr-1/m and +0.018$\pm$0.007 $^{\circ}$K/m, respectively, at 12:00 UTC. By comparing these values with Fig.5, we can observe that the potential temperature and backscatter first derivatives during NAF were in the upper range and out of range, respectively, of values reported in Figure 5. These values corroborate the hypothesis that the differential advection caused abrupt physical and thermodynamic changes at the SML top which accounted for the good agreement between SMLh_ceil and SMLh_rad during NAF.

(3) Aerosol backscattering coefficients (BSC) were highly variable, with the highest values influenced by both African dust intrusions (NAF) and regional anthropogenic pollution (REG). The compression of the SML under NAF favoured the transport of the

ACPD
13, C1334–C1344, 2013

Interactive Comment

Saharan dust down towards the surface layers by dry deposition. As a consequence, the NAF scenario registered the highest mean $\beta 500$ and $\beta 800$ measured during the campaign which were 20% and 15%, respectively higher than under REG and 50% and 46%, respectively, higher compared with ATL.

(4) In the portion of the atmosphere characterised by neutral thermodynamic stability conditions ($d\Theta/dz \sim 0$) at midday, the BSC increased in parallel with RH with altitude. By contrast, under the stable stratified conditions ($d\Theta/dz > 0$) above the SML, BSC decreased with falling RH with height. The increase in BSC with altitude was also detected under unstable atmospheric conditions ($d\Theta/dz < 0$). This analysis revealed that at midday the aerosol backscatter over the coastal site of Barcelona increases with height from near ground to the SML top irrespective of the thermodynamic states of the atmosphere. At midday the portion of the atmosphere characterized by neutral thermodynamic stability conditions ($d\Theta/dz \sim 0$) is assumed to be well mixed and represents the volume of air into which pollutants can be dispersed. The increasing backscatter with height within the SML at midday was due to the increase with height of RH, which through aerosol swelling, increase the effective aerosol cross-section. When lidar data are used to estimate the PBL AOD from extinction measurements, common assumption is to assume the extinction to be a flat extrapolation at ground of the extinction profile at the range of full overlap. On the base of 1 month of radiosundings performed during SAPUSS, we observed that the RH at Barcelona monotonically increases with height by around 40% from ground to the SML top. Thus, the observed strong RH dependence of backscatter vertical profile should be taken into account for PBL AOD calculation from lidar extinction data. In summary, continuous on-line measurements of the spatial and temporal distribution of the PBL characteristics and aerosol optical properties are valuable. Further studies are necessary to improve our knowledge on the relationship among African dust outbreaks, temperature vertical profile and PBL height."

(3)The authors should spend some more time discussing the way retrieving aerosol backscatter coefficients from the uncalibrated raw data of the Jenoptik instrument. Paragraph 2.2.1 is ways too short to give the reader an idea about how the retrieval was performed under which additional assumptions and/or the usage of additional data.

Answer: Indeed, an inversion procedure based on Klett is performed and provides the profiles of extinction and backscatter by assuming a LIDAR ratio. The thorough description of this procedure including assumptions and errors in case of clouds or haze can be found in Section 4.1 and A.1.2 of: Martucci, G., J. Ovadnevaite, D. Ceburnis, H. Berresheim, S. Varghese, D. Martin, R. Flanagan, C.D. O'Dowd, 2012: Impact of volcanic ash plume aerosol on cloud microphysics. Atmospheric Environment, 48C, 205-218.

However, the procedure described in the above reference refers more to the retrieval of the extinction and backscatter in presence of clouds. We have then added to the text the following description for cloud-free cases:

"The extinction coefficient is calculated by inverting the 1.064 μm LIDAR power profiles (Klett, 1981; Ferguson and Stephens, 1983) in the region where the signal is not completely attenuated, i.e. up 15 km for the CHM15K in cloud-free conditions (but subject to the optical thickness of the total column). A LIDAR ratio S = 45 sr is assumed for the probing wavelength at 1064 nm, a mixture of continental and maritime aerosols and in the range of 50%-80% of relative humidity (Ackermann, 1998). The raw LIDAR signal (number of photons) is transformed into received power by use of Plank law combined with the LIDAR equation at any range R. The obtained LIDAR power is then corrected for the square of the range R and normalized by the LIDAR constant, the latter being calculated directly along the molecular part of the LIDAR signal (for a non-opaque profile). Because at 1064 nm the molecular backscatter is very weak this procedure needs to perform the molecular calibration for integration times not shorter than an hour and preferably during nighttime to avoid the solar background. The procedure to obtain the extinction must take into account the effect of the multiple scattering only when high concentration of particles (haze or cloud) occurs along the LIDAR profile. Multiple scat-

ACPD
13, C1334–C1344, 2013

tering (η) is in fact a complex function of the field of view of the LIDAR, the distance of the haze/cloud, the particles concentration, the breadth of particles size distribution and the layer optical depth. The multiple scattering affects the amplitude of the signal received by the LIDAR at time t and range R by modifying the LIDAR ratio S as ηS and can cause smaller extinction than in reality ($\eta < 1$). When all the above parameters influencing the value of η are negligible the multiple scattering can be neglected by keeping $\eta = 1$."

J. Ackermann, "The extinction-to-backscatter ratio of tropospheric aerosol: a numerical study," J. Atmos. Ocean. Technol. 15(4), 1043–1050 (1998)

(4) The entire section 4 (Discussion) repeats a lot of things said before in sections 3.2 and 3.3. It is less a discussion than a continuation of the results section. P361, l27: The entire paragraph is actually something new here and could be (at least partly) moved to the results section. The discussion section is not the best place for introducing new results.

Answer: The results presented in the section 4 (Discussion) have been opportunely moved to the section 3 (Results).

(5) On P352, l23 the authors say that "Data from the ceilometer were carefully cloud screened to avoid any bias due to cloud scattering." On p354, l4 the authors further say "The AERONET cloud screened Level2 data were used in this work." So the natural question is in which way the cloud screening has actually been done. Please clarify how the cloud screening was performed.

Answer: The range corrected lidar signal in clouds is characterized by a steep increase at the cloud base. The cloud screening was performed by discarding those raw profiles showing positive gradient larger than a given threshold. A threshold of 500 photons per count was applied on the raw signals from CHM15K to avoid any contribution from liquid clouds. The manuscript was opportunely changed.

ACPD
13, C1334–C1344, 2013

Minor comments:

P 347, l11: “with the deepest values” –> “with the lowest values” ?

We assume that at midday typically the PBL reaches its maximum height. Consequently, “deepest” was replaced with “highest”.

P 347, l15, l23; P348, l6: The authors use several times the expression “PBL depth”. It is maybe more convenient to use “PBL (top) height” instead.

The term “PBL depth” was replaced with “PBL height” through the text.

P 350, l7: occupy –> cover ?

“Occupy” was replaced with “cover”.

P350, l9: making this region one of the most polluted –> making this region to one of the most polluted

The sentence “. . .making this region one of the most polluted. . .”, was replaced with “. . .making this region to one of the most polluted. . .”.

P353, l18: but which may also characterise the nocturnal atmosphere –> but which are also typical for the nocturnal atmosphere ?

The sentence “. . .but which may also characterise the nocturnal atmosphere”, was replaced with “. . .but which are also typical for the nocturnal atmosphere”.

P 353, l22: were obtained with a meteorological station –> were obtained at a meteorological station

The term “with”, was replaced with “at”.

P360, l12: overhanging –> overlying ?

The term “overhanging”, was replaced with “overlying”.

P361, l16ff: The authors preselected/predefined three different scenarios for their anal-

ACPD

13, C1334–C1344, 2013

ysis. ATL, NAF and REG. Why is then argued here that “The presence of African air masses above Barcelona during NAF could be one of the reasons for the good agreement observed between radiosondes and ceilometer in estimating the SML heights during NAF.” I mean you have selected such days when air masses were advected from the Saharan desert. So it is first no surprise that African air masses were above Barcelona during NAF and it is secondly not a stand-alone argument for coincident results. Please rethink your arguments.

Here we argue that a possible reason for the good agreement observed between the lidar and radiosoundes SML heights under NAF (compared with REG and ATL) was the presence of abrupt changes in the vertical profiles of backscatter and potential temperature at the SML top caused by the differential advection of different kind of air masses. These abrupt changes might help in reducing the differences in SML top retrieval from the two techniques.

In order to avoid confusion the sentence was modified as it follows: “The reason for the good agreement observed between radiosondes and ceilometer in estimating the SML heights during NAF could be the differential advection of air masses at different heights observed under the NAF scenario. The 5-day back-trajectories ending in Barcelona at 12:00 UTC and calculated for the NAF days (two examples are shown in Figure SI-3 in Supporting material) display the differential advection with the air mass ending at 1000 m a.g.l. clearly coming from Africa and those at lower altitudes having different origins. This differential advection may have caused an abrupt change in physical (aerosol) and thermodynamic (potential temperature) properties at the top of the SML, thus minimizing the differences typically observed between ceilometer and radiosondes in estimating the SML height. To support this, the opposite trend is seen for the ATL scenario when the air masses had the same origin at the altitudes considered (cf. Figure SI-4) and the largest difference between the SML heights can be observed.”

P 364, l4: The summary could become part of the missing section “Conclusion”. Following the references provided your first two items aren’t really surprising results. This

ACPD
13, C1334–C1344, 2013

brings me back to my general comment at the beginning about the overall goal/scientific question answered by this paper.

The section 4 (Discussion) was removed and a section Conclusion, including the summary, was added. We would like to comment that while the second item of the summary is not totally new, the first item does. With daily variation (DV) we refer to the difference between day and night which can be estimated only if continuous measurements are available. Previous studies in Barcelona have dealt either with a climatological analysis of PBL height based on the three 30-min regular measurements per week performed within EARLINET-ASOS or with the analysis of specific events. This is the first time that 24h measurements of PBL top over one month are presented for Barcelona.

P 372 pp: Fig 1: Please enhance these images (a lot). Your readers have probably less good eyes than you ... Figs 2 and 3 are much better, Figs. 4 to 6 could/should also be enhanced.

Figure 1 was enhanced.

Interactive comment on Atmos. Chem. Phys. Discuss., 13, 345, 2013.

ACPD

13, C1334–C1344, 2013

Interactive Comment