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Biogeosciences Discussions

Interactive comment on "Monitoring presence and streaming patterns of Icelandic volcanic ash during its arrival to Slovenia" *by* F. Gao et al.

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The authors wish to thank the reviewer for extensive and valuable comments and suggestions, which were very helpful for improving the manuscript.

1. Comment regarding the abstract: Row 7-8 of P3864: "The initial arrival of volcanic ash to Slovenia was detected at ground level using in-situ measurements during the night of 17 April 2010". Please clarify what kind of measurements to prove this. If PM10 and SO2 were used, Fig.2 shows a peak of concentration on 16 April. If anions of F- was used. Fig.3 shows it arrived on 17 April. There was on precipitation on 16 April, if there were, F- would appear or not?

Response: The arrival of volcanic ash from explosive eruption of Eyjafjallajökull to

Slovenia was initially detected in the analysis of the precipitation, which occurred in Ljubljana on 17 April 2010, at 01:00 UTC. Analysis of the precipitation sample (distinct peak in F- concentration) indicated the presence of volcanic ash. In addition, satellite images (Meteosat-8 satellite) show the arrival of volcanic ash to Slovenia between 00:00 UTC and 06:00 UTC on 17 April. The corresponding satellite images with marked ash belt are attached as Fig.1. Meteosat-8 image for 16 April, 18:00 UTC shows the dust belt from the 14 April eruption did not yet reach Slovenia, and there were no precipitation on 16 April to check ash deposition on that day. However, analysis of the precipitation on 13 and 14 April shows some small but detectable traces of F- (about 10 times smaller than on 17 April), which may be due to ash from the first phase of smaller eruptions of Eyjafjallajökull starting from 20 March. Had there been precipitation on 16 April before 18:00 UTC, similar small concentration of F- would be expected. The concentrations of PM10 and SO2 never significantly exceeded the average value (Fig.3 in the attachment) and these measurements were used only to show the extent of the environmental impact of the presence of volcanic ash. The abstract has been modified accordingly to clarify this.

2. Comments to 2. Synoptic situation: 2.1 – Row 13-15 of p3866: Satellite images show the volcanic ash reached during the night of 17 April. Row 23-24 of P3876 (6 Discussions and conclusions) says "The second arrival of volcanic ash, which could not be predicted from satellite images due to lower ash concentrations and lower streaming altitudes". That means satellite images may "miss" the first arrival since it may be "invisible" for satellite. (see the above measurements on Abstract). Authors should check the satellite images, PM10 and SO2 data, anions in precipitation and model simulations again. The precise time of the first ash arrival should be pointed out with the hour detail, which may be different for various measurements and sites.

Response: In the case of first arrival on 17 April 2010, volcanic ash to Slovenia was detected (large peak in F- concentration) in the analysis of the precipitation, which occurred in Ljubljana on 17 April 2010, at 01:00 UTC. Meteosat-8 satellite also show

the arrival of volcanic ash to Slovenia between 00:00 UTC and 06:00 UTC on 17 April. The corresponding satellite images with the marked ash belt are attached as Fig.1. In the case of the second arrival on 20 April 2010, no ash could be identified from from Meteosat-8 images. Additional detailed analysis was performed using multi-spectral Meteosat-9 data from Spinning Enhanced Visible and Infrared Imager (SEVIRI). Three channels centered at 10.8μm, 12 μm and 8.7 μm were combined into dust RGB (Lensky, 2008) and the difference between brightness temperatures from channels centered at 10.8 μm and 12 μm was used by to monitor volcanic ash clouds. The areas with high concentration of volcanic ash in the atmosphere were detected and monitored in between 16-20 April, which allowed monitoring the ash cloud from the source, traveling over Europe towards Slovenia. Over central Europe the concentrations of ash were so high that the cloud could have been unmistakeably detected by SEVIRI. On 17 April 2010 (morning and throughout the day) detectable concentrations of volcanic ash over Slovenia were observed by SEVIRI (Fig.2, left). In the following days no detectable ash signal over Slovenia was observed, because on 18 April ash-loaded air masses mixed with ash-free air masses arriving to Slovenia from the SW. On 20 April the concentration of volcanic ash was too low to be seen by SEVIRI (Fig.2, right). Please see the answer to the comment on the abstract.

3. Comments on 3.1 Ground based measurements 3.1.1 – Row 13 of P3867: Since some large particles exist (as authors said in the row 1 of P3875 and showed in Fig.10), TSP (Total Suspended Particles) or TPM as did by airborne measurements, if available, seems more appropriate.

Response: In the ground measurements we only measured the PM10 particles (particle size smaller than 10 micrometers) using the environmental monitoring station in Ljubljana. Therefore, we can not present TPM or TSP as the data on the concentrations of larger particles is not available.

4. 3.1.2 – Row 20-23 of P3867: Detailed information of the instrument positions and situations should be explained, since it may affect the measurement.

Response: All ground measurements including PM10, SO2 and precipitations were performed at the same site, which is located within the Ljubljana city (urban area with possible influence of traffic and heating). The measurements of PM10 were performed at two different heights (1.5 m and 4.0 m above the ground). We have modified the PM10 graph in Fig.3 (attached, left) accordingly to show the two measurements. SO2 measurements (Fig.3, right) were performed at the height of 4.0 m above the ground, and precipitation was collected at the ground level. We have modified the manuscript accordingly to clarify these points.

5. 3.1.3 – Row 7 of P3867: How about the results in Nova Gorica?

Response: Sorry for the mistake. Actually, the weather station in Nova Gorica (operated by Slovenian Environmental Agency), which performed the measurements of SO2 concentration from 2003 to 2009 was discontinued in 2010, as in the last 5 years SO2 concentrations were continuously found to be below the lower assessment threshold. We have modified the text accordingly (deleted “not only in Ljubljana, but also in Nova Gorica”).

6. 3.14 – Row 18 of P3868: SO4- should be SO42-. Please correct others in manuscript and those in Fig.3.

Response: The typo has been corrected everywhere in the manuscript.

7. Comments on 3.2 Lidar-based remote sensing 3.2.1 – Row 18 of P3869: Time-height indications of the lidar range corrected signal may give more details of the presence and variations of the ash layers.

Response: We fully agree with the reviewer’s suggestion and have inserted the THI diagram of the range corrected signal (RCS) for the Nova Gorica lidar measurements between 19:50-22:50 CET on 20 April 2010 (see the attached Fig.4).

8. 3.2.2 – Row 25 of P3869: More details for calculation by Klett method: reference altitude, reference value, molecular effects...

Response: In the calculation of optical variable (backscatter coefficient), the reference height was set to be the height where just pure molecular attenuation took place, which was about 5-6 km above the sea level for both Nova Gorica and for Otlica, with the reference value for the BS of about 3e-6. The molecular contribution was subtracted after the inversion procedure using values yielded by the US standard atmospheric model. We have modified the manuscript accordingly.

9. 3.2.3 – Row 5 and 16 of P3871: Since the complete overlap range is > 1000m, any quantitative value in the "part-blind" area should be careful, if without any correction.

Response: During the night of 20 April 2010, two ash layers were observed in the measurements by the Nova Gorica lidar. Both were within the complete overlap range. In the measurements of the Otlica lidar, two ash layers were also observed, however, the lower one is within the incomplete overlap. We fully agree that the Otlica data below 2 km a.s.l. is not credible for the description of the accurate information of the ash layer due to partial overlap, however, we believe it can still be used as a qualitative indicator of the presence of ash layer at this height. We have clarified this in the "Discussion and conclusions" section of the revised manuscript and modified the Fig.5 (attached) accordingly (BS values for Otlica below 2 km a.s.l. are omitted), as well as the attached Fig.7 showing the peak positions of the aerosol layers.

10. 3.2.4 – Row 27 of P3871 to Row 3 of P3872: the dependence of the aerosol optical thickness, or aerosol extinction coefficient on wavelength, usually refered to Angstrom exponent, is inversely relative to the average size of the particles in the aerosol. Here the Angstrom exponent is almost -1?

Response: The measurements in Germany by Ansmann et al. show that there was a considerable amount of large and very large particles in the measured layer, whereas in the second arrival of ash to Slovenia there was not, as in general, the majority of large particles deposits on the ground in a few days after the emission into upper troposphere. As the particles were in our case much smaller, this may explain for the

larger Angström exponent, as also suggested by the referee #1.

11. 3.2.5 – Fig.4: There are position shifts between the profile data and it's successive mark, i.e. curve 4 marked with "(e)" instead of "(d)", curve 5 marked with "(f)" etc.

Response: We have replotted the figure as the referee suggests. Based on additional suggestions regarding this plot by referee #1, we have switched to the backscatter coefficient instead of the atmospheric extinction presented the case for four consecutive time intervals. Please see the attached Fig.5.

12. Comments on 3.3 Airborne measurement 3.3.1 – Row 17-18 of P3872: "Every 300m of altitude, a new adhesive tape was exposed for the next 90m to a direct, unfiltered stream of air". This means sampling of 90m for every 300m of altitude, then 210m sampling gap? Please give more details about the adhesive tape and sampling.

Response: The adhesive tape we used was a standard double sided tape, and we employed no filters. The adhesive tape pads (exposed to unfiltered stream of outer air, which was divided into two branches before the expansion box) were used with the purpose to sample air layers - collect aerosols for subsequent chemical and petrographic analysis, while the mass concentration profile was measured by 3016 IAQ. The sampling procedure by double sided adhesive tape pads yielded 9 samples during the ascent of the aircraft (the tape pads were exchanged 9 times during the ascent), which represent the cumulative effect of aerosols in the elevation intervals of 550-640m, 850-940m, . . . and 2950-3040m, with sampling gaps of 210m between these intervals. We have modified the manuscript to clarify this points.

13. 3.3.2 – Row of P3873: here "1.0 micrometer" means "profiles of 1.0 micrometer", (c) of Fig.8? Please clarify.

Response: Yes, that is correct. We have replotted the Fig.8 (now Fig.6 in the attachment) according to the suggestions of Referee #1 (we removed consecutive profiles). As now labels (a), (b)... are no longer needed, we have also modified the figure caption

and the manuscript text accordingly.

14. Comments on 4. Identification of ash particles 4.1 – Row 25-28 of P3874: it seems the adhesive tape can give or measure the particle density profile as the laser particle counter did at the aircraft. How about the concentration profiles from the tap, with similar results shown in Fig.8 and Fig.9? For the title of Fig.9, please make it clear with "from the laser particle counter" instead of "from the airborne measurements".

Response: The sampling procedure by double sided adhesive tape did not yield a continuous mass concentration profile, only nine samples at different height intervals (see answer to question 3.3.1). Since this measurement was intended for sample collection only and its resolution is very poor, we did not include the concentration profile obtained in this way. We have modified the manuscript and the figure caption to clarify the sampling procedure and the device which provided vertical concentration profiles.

15. 4.2 – Row 15-18 of P3874: I was puzzled by the Table 3 and Fig.11. There are "Mn" peaks (blue and red line) in Fig.11 but no "MnO" observed. Those peaks stand for other elements, such as O, Fe? Or the measurement error of the X-ray sensor made it "disappear"?

Response: Energy dispersive x-ray spectroscopy detects only the presence of particular elements rather than compounds. Electrons within elements are excited from their ground state and the energy of the emitted x-rays upon the return of the electron to its ground state is measured. Each measured peak indicates a single possible transition. Since heavier elements (such as Fe) have several possible transitions from higher orbitals back to ground state, the presence of these elements requires the combination of multiple peaks (multiple transitions) to confirm the elements presence within the sample. The presence of compounds or oxides such as MnO is not measured directly, but can be inferred when the correct peaks are present within a particular sample. Particularly, the presence of oxides can be inferred reliably, since measurements are made

under high vacuum conditions of materials in their solid state. Therefore, an oxygen peak can only be connected to an oxide within the sample.

16. Comments on 5. Simulation of air flow trajectories 5.1 – For clear discriptions, please use the precise timing instead of "night", "afternoon"...

Response: In the first arrival, forward trajectories start at 15 April 2010, 21:00 UTC and predict the transport time to Slovenia to be 30 hours, which was found to agree with the satellite images and precipitation results (first precipitation which contained volcanic ash occurred on 17 April 2010, at 01:00-02:30 UTC). In the second arrival, simulations show that volcanic ash arriving on 20 April was brought by air masses continuously streaming for more than 15 hours from the north at altitudes below 6 km, starting on 19 April 2010 at 23:00 UTC. The text has been modified to provide precise timing information.

17. Comments on 6. Discussion and conclusions. 6.1 – More details of the precise timing for airborne mission should be given, Row 4 of P3872 isn't enough. I wonder when it started from Divaca, how long it took for the spiral climb, when to Vrhnika...

Response: The measurement began at the altitude of 610 m above sea level (a.s.l) above Divaca at 16:00 UTC, 20 April 2010. The spiral climb at the rate of 2.5 m/s from 610 m a.s.l. to 3050 m a.s.l. took 16 minutes, leveled flight from Divaca to Vrhnika (40 km away) took 10 minutes and the spiral descent at Vrhnika (from 3050 m a.s.l. to 1220 m a.s.l.) took 12 minutes. The text has been modified to provide precise flight and timing information.

18. 6.2 – With the precise timing of the airborne measurement, linear regression shouldn't be done with the simultaneous measurements between Divaca and Nova Gorica. I mean, the aerosol above Nova Gorica 15:20 CET are definitely not the same above Divaca at 15:20 CET. They were different aerosols even they might be from the same volcanic ash. The wind speeds, directions should be considered, then we may know when the aerosol above Nova Gorica was blew to Divaca (or inverse). Ok, maybe

this is too ideal.

Response: We fully agree with the reviewer that even with data taken at the same time, due to different locations the aerosols may not be the same. However, as the mass concentration is a better quantitative indicator of the presence of ash particles in the atmosphere compared to its optical properties (such as backscatter or extinction coefficient), we investigated the presence of the correlation between simultaneous airborne and lidar measurements. Vertical profiles visually show the same trend with the altitude (Fig. 14, left in the manuscript) and the correlation coefficient of 0.51 shows the two data sets actually are correlated (Wilks, 1995). The correlation is in fact a bit weak due to reasons the reviewer has pointed out (locations around 40 km apart, influence by the flow of the air masses) but is nevertheless present. We have considered to correct for the effects due to streaming of air masses, which would require the detailed wind field information for altitudes between 500 m and 3 km in the area of the measurement campaign, which is in our case unavailable.

References:

Raut, J.-C. and Chazette, P.: Radiative budget in the presence of multi-layered aerosol structures in the framework of AMMA SOP-0, Atmos. Chem. Phys., 8, 6839-6864, doi:10.5194/acp-8-6839-2008, 2008.

Wilks, D. S.: Statistical Methods in the Atmospheric Sciences, Academic Press, Burlington, MA01803, USA, 1995.

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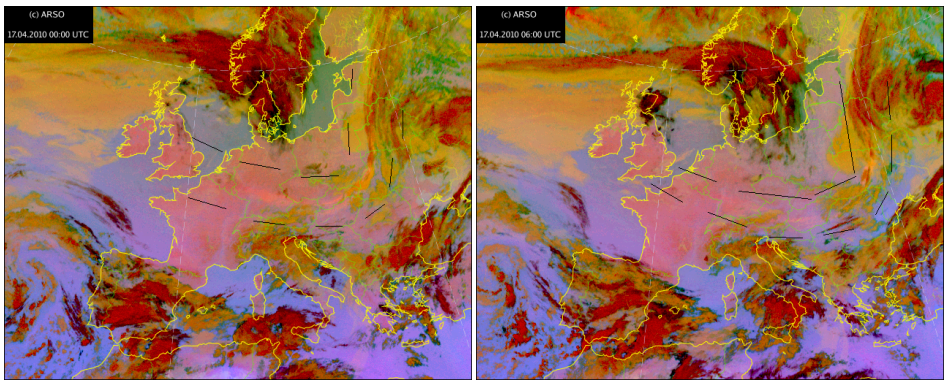

Fig. 1. Meteosat-8 satellite images for 17 April 2010, 00:00 UTC and 06:00 UTC showing the approach of the volcanic ash belt to Slovenia.

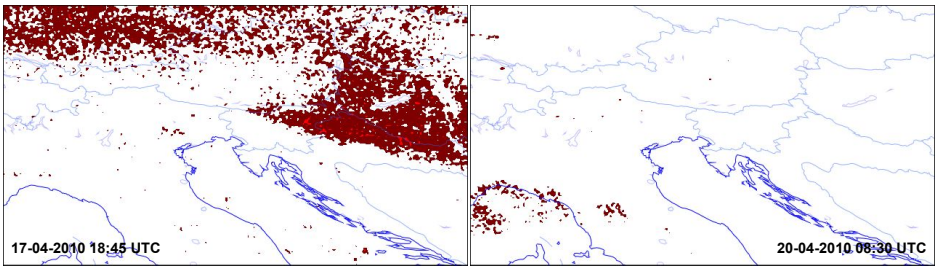

Fig. 2. Meteosat-9 satellite data from Spinning Enhanced Visible and Infrared Imager show the presence of volcanic ash over Slovenia in detectable quantities on 17 April 2011 and its absence on 20 April.

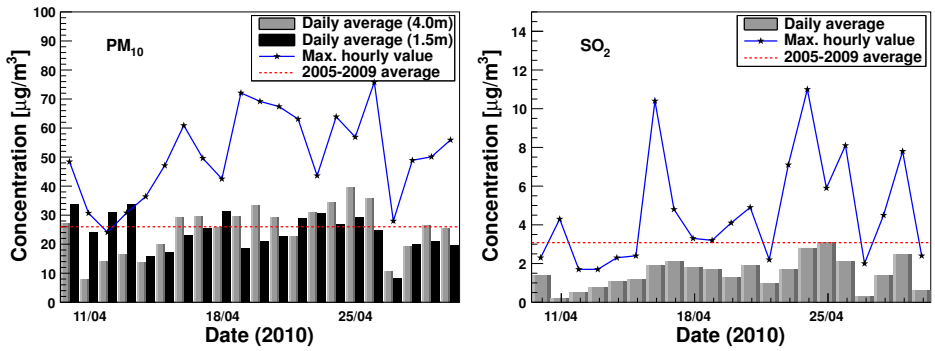

Fig. 3. Monitoring results of the concentration of solid particles (PM10, left) and sulphur dioxide (SO2, right) in the air in Ljubljana from 10 April to the end of April 2010.

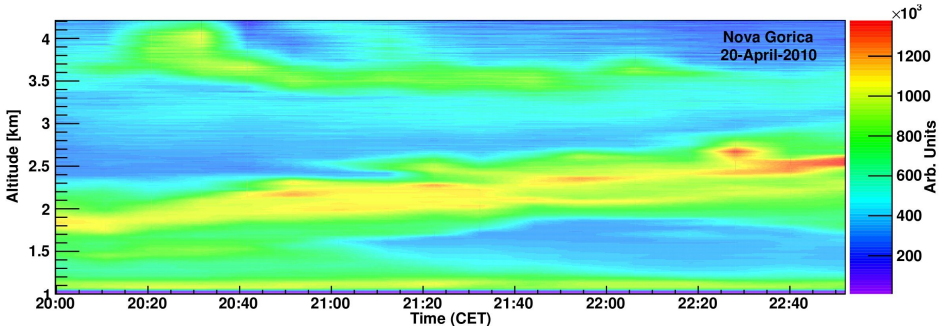

Fig. 4. Time-height-indicator of the range corrected signal (RCS) for the Nova Gorica lidar measurements between 19:50-22:50 CET on 20 April 2010.

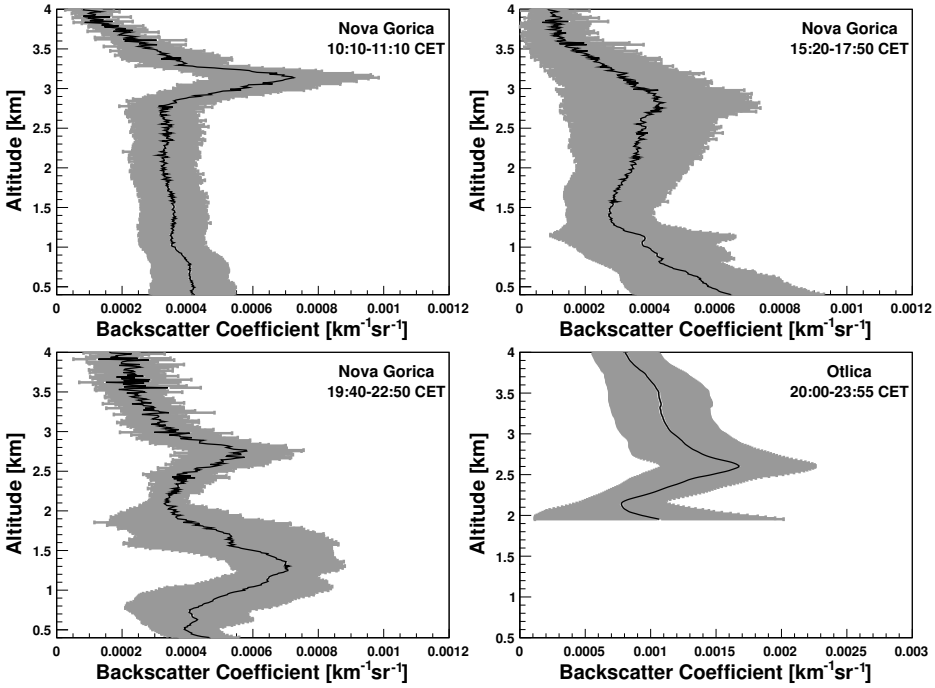

Fig. 5. Atmospheric backscatter profiles with uncertainties (grey), obtained from measurements by the Nova Gorica and Otlica lidars on 20 April 2010.

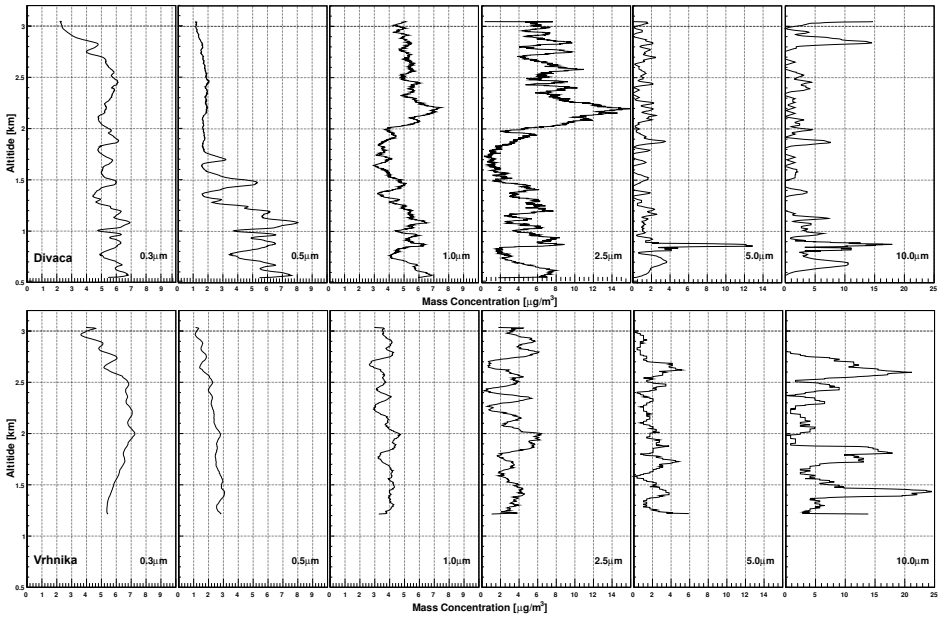

Fig. 6. Aerosol concentration profiles for six different aerosol dynamic equivalent diameters measured on 20 April 2010 above DivaclŇa (top) and above Vrhnika (bottom).

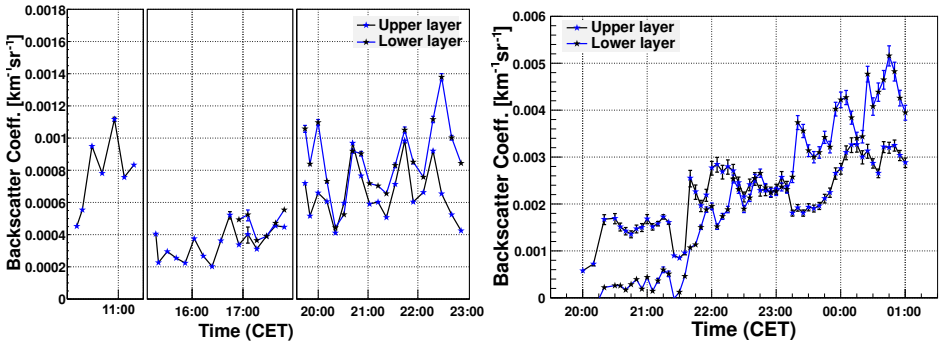

Fig. 7. Variation of the peak atmospheric backscatter coefficient in lidar profiles measured on 20 April 2010 (left: Nova Gorica, right: Otlica).