The authors wish to acknowledge the anonymous reviewer #2 for his/her detailed and helpful comments to the manuscript.
In the following, a detailed reply to the general and specific comments by the anonymous reviewer #2 is provided. In the following the reviewerøs comments are reported in normal style while the corresponding authorsø reply is reported in italic.

General comments
This paper presents the atmospheric observatory CIAO near Potenza in Italy where a number of state-of-the-art remote sensing and in-situ measurements are carried out in a operational way.
The paper is well written and contains a lot of useful information. The potential that lies in the synergy of using different remote sensing techniques in a complementary and redundant way at one site is impressively demonstrated. Therefore the paper should be published. My biggest concern is that there are to many individual subtopics treated in a very detailed way and papers overarching intention is sometimes out of sight. Therefore I wonder if it wouldnøt make more sense to streamline this manuscript and focus on its main objective, which could be operative practice and the strategy of the observatory in general. The detailed description like the Raman Lidar and Kalman filtering techniques might be placed into a separate publication? However, this decision should be left with the editor.

The authors are very glad to see that the anonymous reviewer #2 agrees on the importance of spreading the potentialities and results achieved by existing ground-based infrastructure for atmospheric observation in peer-reviewed literature.
The manuscript provides the first detailed description in literature of the CIAO infrastructure for atmospheric studies. Therefore, authorsø intention was to describe in great detail the whole infrastructure including the equipment, data archive, scientific objectives, expertise and observation strategy. This also requires the discussion of a few examples of the measurements provided by the techniques operative at CIAO and of the algorithms implemented for the full exploitation of the collected datasets. This is the reason why the authors provided the examples reported In section 4. It is true that these examples are related to three different important subtopics (radiosoundings, water vapour Raman lidar, and integration of lidar and microwave data), but at the same time they are related to only one of the atmospheric parameters routinely investigated at CIAO, i.e water vapour. The authors think that CIAO observation strategy, described in the manuscript, could be probably more clear if a few related measurement examples are provided, making the manuscript self-explanatory.
The quantitative assessment of specific sub-topics in this manuscript is probably too much for the scope of a single paper.

Specific comments
Chapter 2.1:
The description of the lidars is very detailed can already be found in some of the referenced articles. It would be more useful in this chapter to explain more clearly why there are three LIDAR systems, which one is used for what and how they interact according the principles of ñredundancy and complementarityò.

The detailed description of the equipment operative at CIAO has been never published before: previous peer-reviewed papers just provide a brief description of the instruments whose data are discussed in the papers for addressing specific scientific issues. This manuscript aims at providing in a single paper an encompassing description of the whole infrastructure operative in Potenza in order to make the spreading of CIAO scientific activity complete and straightforward. The presence of multiple lidar systems provides clear redundancy scenario with the possibility to continuously intercalibrate the three lidar systems by comparing the measured atmospheric aerosol parameters and water vapour. In particular, MUSA and PEARL, characterized by a different design but equipped for the detection of backscattered radiation at the same wavelengths, allows us a point-

to-point comparison of the simultaneous aerosol profiles. MUSA and PEARL are also designed for depolarization measurements: they can provide same products but they are characterized by a different receiver design for the depolarized radiation detection. MUSA has the capability to provide a high accurate calibration of aerosol depolarization thanks to its capability to perform the ±45° calibration technique. PEARL collects at the same time the parallel, perpendicular components of the visible depolarized radiation and the total backscattered radiation. According to what already assessed in the peer-reviewed literature, this allows us to provide high accurate calibrated measurements of the depolarization ratio in the upper troposphere. However, the complementarity of the two aerosol systems is again clear and enables a comparison of performances of different calibration methods. Another key issue for redundancy is the fact that PEARL is a fixed system and MUSA is mobile. This allows us to participate in measurement campaigns without creating gaps in the CIAO database.

Finally, PEARL and CIAO water vapour Raman lidar are able to provide simultaneous water vapour measurements enabling a direct comparison of mixing ratio profiles.

According to what discussed above and in order to better explain in the text the redundancy and complementarity concept resulting from the use of multiple lidar systems, the paragraph at the end of Chapter 2.1 has been modified as follows: òBoth MUSA and PEARL allow independent measurements of the aerosol extinction and backscatter coefficients, and therefore of the lidar ratio at 532 nm and 355 nm (Ansmann et al., 1990; Pappalardo et al., 2004). An iterative approach (Di Girolamo et al., 1995) is used for retrieving the aerosol backscatter coefficient at 1064 nm from the elastically backscattered lidar signal only. Therefore, MUSA and PEARL allow for a point-to-point comparison of the retrieved aerosol parameters. Moreover, both MUSA and PEARL are designed for depolarization measurements. Aerosol linear depolarization ratio measurements are obtained accordingly to Freudenthaler et al., 2009: in particular, the calibration of depolarization channels is made automatically using the ñ±45° methodò for MUSA, while for PEARL the traditional ñ0° methodò is used. The use of different calibration methods is due to the different receiver design for the depolarized radiation detection. MUSA has the capability to provide a high accurate calibration of aerosol depolarization thanks to its the presence of a linear polarized waveplate installed on motorized rotation mount. In the visible, PEARL collects not only the total backscattered radiation, but, at the same time, the parallel and perpendicular components of the depolarized radiation. According to the results reported in the peer-reviewed literature, this allows us to provide high accurate calibrated measurements of the depolarization ratio in the upper troposphere. An assessment of the calibration performance in the lower troposphere at CIAO is also planned. However, the complementarity of the two aerosol systems is again clear in terms of redundant calibrated measurements of depolarization. Another key issue for redundancy is the fact that PEARL is a fixed systems and MUSA is mobile. This allows CIAO to participate in measurements campaign without creating significant gaps in the database.

In addition to MUSA and PEARL, CIAO is also equipped with a UV Raman lidar system for water vapour measurements (Mona et al., 2007), operational at CNR-IMAA since July 2002. It performs measurements simultaneously with PEARL. This system is based on a Nd:YAG laser with a repetition rate up to 100 Hz and typically operating at 50 Hz. Radiation at 355 nm is transmitted into the atmosphere coaxially with respect to a F/10 Cassegrain telescope used as a receiver. The telescope is of the same type as PEARL. The backscattered radiation is selected by means of dichroic mirrors and interference filters and then is split into three channels, corresponding to the elastic backscattered radiation at 355 nm, the N_2 Raman shifted signal at 386.7 nm and the water vapour Raman shifted signal at 407 nm. Interference filter bandwidths are kept below 1.0 nm and 0.3 nm for night-time and daytime operations respectively, thus reducing the solar background during daytime measurements and limiting the effects of both atmospheric temperature variations on the measured signals (Behrendt et al., 2002) and interferences from liquid water Raman scattering (Whiteman et al., 2001). As for PEARL, the spectrally selected radiation is then split for each wavelength into two channels in order to preserve the linearity of the lidar signals over all altitude ranges. Photomultiplier tubes are used as detectors and both low and high range signals are acquired in photon counting mode. The typical vertical resolution of the raw profiles is 15 m with a temporal resolution of 1 minute.

The water vapour Raman lidar provides measurements of the water vapour mixing ratio profile as well as independent measurements of the aerosol extinction and backscatter coefficients at 355

<u>nm. Therefore, the presence of two lidar systems able to provide water vapour measurements (PEARL and the dedicated water vapour Raman lidar) enables a direct comparison of co-located mixing ratio profiles.</u>
*<u>All these aspects crucially contribute to make CIAO strategy in line with the principles of complementarity and redundancy for both aerosol and water vapour measurements.</u>***ò**

Chapter 2.2.
The radar is obviously not related to the microwave profiler and deserves its separate chapter.

In the revised version of manuscript, the radar and microwave profiler are described in different chapters, 2.2 and 2.3 respectively. Moreover, chapter 2.3 (radar) has been updated considering that the current version of the radar system is now equipped with a 3D scanning antenna.

Chapter 3
My feeling is that it would be better to have this chapter in front of chapter 2 since it describes the overarching principles of the observatoryôs strategy. The descriptions in chapter 2 can then refer to this chapter and describe which data products are retrieved from each instrument, which quality assurance procedures apply, etc.

A change in the order of the chapter 2 and 3 is feasible even though the authors think that the description of CIAO instruments should be preliminary to the discussion of the products available in the database and of the integrated observation strategy. However, if recommended by the Editor, the authors are ready to modify the order of the two chapters.

Chapter 4.1 and 4.2e
Which are the criteria that make an agreement ñoptimalò? (p. 5271, line 12). On the same grounds: what means ñaccurateò on page 5273, line 8?

*The term accurate was intended to underline the good agreement of the profile obtained by applying the integration of lidar and microwave measurements in comparison to co-located radiosoundings, as shown in the case study discussed in the manuscript. In order to avoid possible misunderstanding related to the terminology, at the line 12 p. 5271 **ñ**optimal**ò** has been replaced by **ñ**very good**ò**. This meets also the similar comment provided by the reviewer #3. Moreover, at the line 8 p. 5273, **ñ**accurate**ò** has been eliminated.*

Chapter 4.3
I am not able to follow these equations and to provide a judgment on whether this makes sense or not. I am sure it does. However, from my point of view, it would be more useful to explain only the purpose and basic principle of the Kalman filtering in this chapter. The mathematical formalism can be provided in an appendix to the manuscript or in a separate publication

*In the revised version of the manuscript, Kalman filter theory is briefly described in the Appendix A, added to the previous version according to the reviewer**ô**s suggestion and in order to increase the manuscript readability.*

In line 12-15 of page 5275 the main goal is presented. This sentence needs more explanation.: again: what is ñaccurateò? In the presence of clouds and during daytime, the lidar data in the upper-atmosphere are not available. I wonder what the Kalman filter can do about this situation other than simply rely on the microwave retrieval only? To what extend does is make sense to talk about ñintegration of two techniquesò in this respect.

During daytime measurements, Raman lidar technique is able to provide high-resolution water vapour mixing ratio profiles up to 4-5 km a.g.l.; during cloudy conditions water vapour can be measured up to a few hundreds of meters above the cloud base if observed clouds are thick enough (LWP > 40-50 g/m^2). Otherwise, in case of thinner clouds and during night time Raman lidar can provide the profile of the water vapour mixing ratio in whole troposphere. The application of the proposed Kalman-based retrieval scheme during daytime or cloudy conditions allows us to preserve the high resolution of lidar observation, where available, and to integrate it with the microwave observations. Obviously, below the maximum altitude level available from lidar data we will have a real data integration, while above we will have a passive retrieval only. However, since the Kalman filter is an iterative filter in time, also the daytime/cloudy profiles will benefit from the previous full range lidar measurements assimilated in the Kalman scheme and used as a guess for the following temporal steps, i.e the last lidar night time clear sky profile or the last co-located radiosounding available. In addition, both the transition error matrix retrieved from climatologically long time series of lidar data and the cross-covariance error terms optimize the physical consistency of the profile portion retrieved below the lidar profile with that retrieved above the lidar profile and based on microwave observations, potentially reducing the bias between the ñtrueò water vapour mixing ratio profile and the microwave retrieval.

It is not clear to me what the sentence in line 18 on that page tries to say: ñKalman scheme basically moves from using two equation groups. ò

According to the reviewerôs suggestion and as mentioned above, the theory of Kalman filter has been moved to a separate appendix (Appendix A). The corresponding sentence at line 18 has been replaced in the appendix A with the following: òKalman filter is based on two groups of equations.ò

On page 5278 line 8 and 9 you say twice that ñthe case study is relative to the measurementò and I still donôt under stand what you mean by this.

In the revised version of the manuscript, the paragraph at the lines 7-9 has been replaced with the following. ñA case study relative to the integration of lidar and microwave measurements collected from 17:00 UTC up to 00:00 UTC on 20/02/2004 is reported in order to show the algorithm performancesò

Chapter 5

In line 12 you mention that the observatory is one of the fist in Europe. It would have been useful to find a short overview of the history of CIAO somewhere in the manuscript, e.g. in chapter 2.

Here, the author apologizes for the misunderstanding. In the text of the manuscript, CIAO is mentioned as ñone of the first European observatoriesò This is wrong. Authorsô intention was to include CIAO between the main European observatories for ground based remote sensing of the atmosphere, as granted by GCOS with the invitation to join GRUAN network, along with other observatories like Cabauw, Lindenberg and Payerne, whose history and tradition is much longer than CIAO. The term ñfirstò was originally referred to the fact that CIAO was one of the first European observatories equipped with a co-located multi-wavelength Raman lidar, a cloud radar and a microwave profiler. In order to avoid confusion, this sentence has been removed in the revised version of the manuscript.

Line 19-20: I am not sure if you have shown the ñgood performance of the calibrationò : : : at least not in this paper. It might be a good idea to emphasize at this point that the extraordinary infrastructure of the site allows to demonstrate, and to validate, the performance of such advanced techniques.

The example provided in section 4.2 aims at reporting about the good performances of Raman lidar calibration using the integrated water vapour estimation provided by the microwave profiler.

According to the reply provided to the general comments by the reviewer, an assessment of the good performance of the water vapour Raman lidar calibration using the microwave profiler as a reference instrument will be part of an extensive paper regarding water vapour Raman lidar measurements, including the description of the calibration procedures and statistics of the performances of both the calibration methods over a long period (about two years). The performances reported in this manuscript are only the result of the experience gained at CIAO in using this further calibration methods.
However, in agreement with the reviewerôs suggestion, the authors revised this part of manuscript emphasizing how the extraordinary infrastructure operative at CIAO allows us to demonstrate and to validate the performances of these advanced techniques. The paragraph at line 19-20 has been replaced by the following: ñIn particular, we show an example of the calibration of water vapour Raman lidar profiles obtained using the IPWV retrieved by the microwave profiler as reference measurement. This calibration method shows performances comparable with those obtained using the radiosounding calibration, with a variability of the calibration constant that is lower than 7% and a difference between the two calibration methods lower than 4%.ò
Moreover at the end of the same section at page 5281, line 7, the following sentence has been added: ñBoth the provided examples of synergy and integration at CIAO shows the potential of this infrastructure in demonstrating and validating the performance of ground based profiling techniques for the observation and monitoring of atmospheric key variablesò
The revised manuscript also includes the typical performances of the two calibration relative methods usually claimed by the scientific community, along with those based on the experience gained at CIAO.

Technical Corrections:
p. 5254 line 9: ñradiometers, and a radarò
p. 5255 line 1: ñ: : : water vapour, and clouds.ò
p 5267 line 11: the link provided is no longer valid, it seems the corresponding page is now found here:
http://www.vaisala.com/en/products/soundingsystemsandradiosondes/radiosondes/Pages/referenceradiosonde.aspx
p. 5275 line 25: probably: ñHere, A is an identity matrixò?
Tab.1 is too small and hardly readable
Fig 4: the lines of the graph d) should be thicker and of more clearly separable color.
All the axis labels need to be larger for legibility.

The revised version of the manuscript has been also modified including all the technical corrections suggested by the reviewer #2.

At p. 5275 line 25 has been corrected accordingly.

To improve the readability of Tab. 1 a large font size will be used. Actually, the font size of the Tab. 1 on page 5288 is also the result of the manuscript typesetting carried out by Atmospheric Measurement Techniquesô staff. The original version of the Tab. 1 had a font size similar to the part of the table on page 5289. If the manuscript will be accepted for publication, the authors will find an agreement with the editing staff to preserve the original font size.
Finally, Fig 4 has been modified according to the reviewerôs suggestion in order to improve its readability and sub-section 4.2 has been renamed as ñCalibration of water vapour Raman lidarò