

This paper presents a relevant infrastructure (the CIAO observatory) for ground-based observation of the atmosphere, devoted in particular to the measurement of aerosol, water vapor and clouds on a long-term basis permitting to build up a climatology data base of their properties.

The paper is structured in two parts. The first one (sections 2 and 3) presents the instruments and installations constituting the infrastructure, as well as the employed measurement strategies aimed to the exploitation of the synergies between the different instruments. The second one (section 4), while still description-oriented, focuses on the example of water vapor measurements through radio soundings, Raman lidar and microwave radiometers, going down to the description of the Kalman-filter algorithm used to merge lidar and radiometer data for enhanced water-vapor profiling.

Although possibly not containing ground-breaking results, the quality of the paper is good, and it certainly includes information that can be used by other researchers to improve their atmospheric measurement techniques.

In addition to minor issues, typos and English writing remarks listed at the end of this review report, I have the following remarks and suggestions:

1. In the present organization of section 2.1, the description of the Raman lidar system for water vapor measurements is placed between those of the two multiwavelength aerosol systems. I suggest reordering the paragraphs so that the descriptions of the aerosol systems are placed next to each other.

2. I have some concerns regarding the description of the Kalman filter algorithm in section 4.3:

a) There is probably a typo in Eq. (5), where $\mathbf{R}^{-1}$ should be $\mathbf{R}$, i.e. the equation should read

$$\mathbf{K}_i = \mathbf{P}_i^b \mathbf{H}_i^T \left[\mathbf{H}_i \mathbf{P}_i^b \mathbf{H}_i^T + \mathbf{R} \right]^{-1}$$

instead of

$$\mathbf{K}_i = \mathbf{P}_i^b \mathbf{H}_i^T \left[\mathbf{H}_i \mathbf{P}_i^b \mathbf{H}_i^T + \mathbf{R}^{-1} \right]^{-1}$$

b) The authors seem to use the same symbol, $\mathbf{x}_i$, to denote the state variables and their estimates. This is apparent in Eq. (3), which, the authors say, corresponds to the “improved a posteriori estimate”. Previously it has been said (line 19 of page 5275) that the state variable is represented by $\mathbf{x}$ (by the way, shouldn’t it be boldfaced?). Different symbols should be used to distinguish the state variables, which never are perfectly known, from their estimates, which are the measurement product.

c) Likewise I think there is a problem with Eq. (1), where the left side should be the state variable at time step $\mathbf{i}$, instead of the background estimate $\mathbf{x}_i^b$ (see Eq. (2) in ref. Han et al. (1997) given in the paper). In my understanding, the background estimate at time step $\mathbf{i}$ is obtained from the projection through the transition matrix $\mathbf{A}$ of the estimate at step $\mathbf{i}-1$, not of the state variable, which is, strictly speaking, unknown (cf. Eq. (3) and the previous paragraph in ref. Han et al. (1997)), like the transition error, for which only its covariance matrix $\mathbf{Q}$ is known.

In summary, I think the authors should revise the description of the Kalman filter and its notation.

3. The discussion of the case study summarized in fig. 4 would be clearer if the way in which the Kalman filter has been initialized (through a radiosounding previous to the time series?; through a lidar measurement also previous to the time series, before the cloud cover blocked the lidar data above 3km – 3.5 km?) were explained. If I'm not wrong, this initialization would be the reason for the Kalman filter output yielding better results above the cloud base than the microwave radiometer alone, as stated in the sentence on lines 19-24 of page 5279, since in the time interval shown in fig. 4a and b the lidar is blocked by the cloud and cannot contribute to improving the estimate above the cloud base. This remark applies as well to the sentence on lines 4-7 of page 5281: "The reported case study also shows that the proposed integration approach is in better agreement with the co-located radiosounding profile with respect to the neural network retrieval applied to the microwave Tbs only".

4. The sentence (starting on line 25 of page 5278) "The comparison with the time series of Fig. 4a shows a slight degradation of the water vapour profile resolution in the PBL with respect to the original lidar measurements. However, this can be compensated for performing a final merging between the filter estimation and the original water vapour lidar profile" prompts the following question: if the filter output has to be merged again with the lidar profile, which was one of the filter inputs, to recover the lost resolution, couldn't a procedure be devised in which modifications are made to the filter to avoid since the beginning this loss of resolution and the consequent proposed feedback to recover the original one in the lidar profile? Could the authors comment on this? At another level, please note that "by" is probably missing between "for" and "performing".

5. Eq. (7) should be further explained: what's δz in that equation? What does $\text{diag}(\mathbf{K}_i \mathbf{H}_i)$ mean?

Other issues

1. Page 5264, lines 24 and 25: the sentence "CT25K ceilometer is able to detect three cloud layers simultaneously..." is not very clear. What's the reason limiting the number of layers that can be detected? If it was a hardware reason, probably the number of layers that can be detected would depend on their optical thicknesses. Is it because of the associated software? By the way, "The" should probably be inserted before "CT25K". The same remark applies to the sentence on lines 7 and 8 of page 5265 referring to the CHM15k ceilometer: "As for the CT25K ceilometer, it is able to detect three cloud layers simultaneously".

2. Page 5265, line 23: the abbreviation "lv2.0" is used before its definition is given on line 19 of page 5267.

3. Page 5271, line 12: "An optimal agreement is observed". "Optimal" has a very strong meaning that I think does not correspond to the sense of the sentence. I would suggest replacing "optimal" by "very good" or something similar.

4. Page 5272, line 16: "resulting stable within 5%". I suggest explicitly stating the period during which this stability has been observed, even if indirectly it can be inferred that it lasted from 2002 to 2008.

5. Page 5276, lines 3-5: “Finally, $\mathbf{Q}$ is the covariance matrices of $\mathbf{w}$, assumed as white Gaussian noise processes with zero-mean”. Is it required in the assumptions of the Kalman filter that the noise is white in addition to Gaussian? Is not the Gaussian assumption sufficient? Note as well that “matrices” is used instead of “matrix” and that the hyphen between “zero” and “mean” should be dropped. The same question and last remark apply to the sentence on lines 7-8 of page 5277: “assumed as white Gaussian noise processes with zero-mean”.
6. Page 5277, lines 28-29, and page 5278, line 1: please check the correspondences between the rms deviations stated as mixing ratio (g/kg) and mass concentration (g/m^3). As the air density appears in the conversion from mixing ratio to mass concentration, shouldn't the assumed air density for the conversion be specified?
7. Table 1. a) General remark: could the font size of the table contents on page 5288 be increased? The font size of the part of the table on page 5289 looks larger and easier to read. b) In the lv2 products from PEARL the wavelengths at which α is measured are missing. c) At the end of the lv2 products for PEARL and MUSA “at δ at 532 nm” should be “and δ at 532 nm”. d) In the text of the paper, an algorithm for retrieving the aerosol backscatter coefficient at 1064 nm is referenced (page 5262, line 27, Di Girolamo et al., 1995), but it is not mentioned in the algorithm column for PEARL and MUSA; should it be included?
8. The caption of fig. 3 mentions a “lower panel”. However the figure only contains two panels on the same line, labeled (a) and (b). Please check that there is not a panel missing and the consistence of the caption. Also, on the third line from the end of the caption “are reported” should be read instead of “is reported”.
9. Fig. 4: the sizes of the panels and of their legends should be increased for enhanced readability.

Typos and minor suggestions

1. Page 5254, line 9: probably “and” is missing before “radar”
2. Page 5255, line 2: inserting commas before and after “as well as their reciprocal interactions” is suggested.
3. Page 5257, line 7: “infrastructure” should be “infrastructures”
4. Page 5257, line 13: the hyphen between “phenomena” and “like” seems to be surplus.
5. Page 5259, line 21: “participation in GAW-GALION” is probably better than “participation to GAW-GALION”
6. Page 5260, line 12: “in order” is probably not necessary.
7. Page 5260, line 18: “with second and third harmonic generators” probably better than “with the second and third harmonic generators”
8. Page 5260, line 25: “devoted to” probably better than “devoted in”
9. Page 5261, line 4: “split into” maybe better than “split in”
10. Page 5261, line 8: “interferential filter”: there are several occurrences of this term throughout the paper. Consider if you might prefer using “interference filter”, which seems to be more common usage.
11. Page 5262, line 14: “ N_2 ” instead of “N2”.

12. Page 5262, lines 18-19: the sentence “For MUSA the calibration of depolarization channels is made automatically using the ± 45 method (Freudenthaler et al., 2009)” is somewhat redundant with that found on lines 28-29 of the same page: “The aerosol linear depolarization ratio measurements are obtained according to Freudenthaler et al. (2009)”. Consider if it is worth keeping that redundancy.
13. Page 5263, line 28: consider if a hyphen should be inserted between “magnetron” and “based”.
14. Page 5264, line 14: “Before the end of 2010...”. This sentence should be updated.
15. Page 5264, line 20: “a CT25K ceilometer”, instead of “CT25K ceilometer”.
16. Page 5264, line 22: “The ceilometer is basically a Rayleigh lidar system...”. Do the authors mean a Mie lidar system?
17. Page 5266, line 9: “pyreliometer” should probably be “pyrheliometer”.
18. Page 5266, lines 13 and 14: “A Trimble GPS antenna/receiver station is already operative, even if its use for providing the integrated water vapour estimation will start by the end of 2010”: please update.
19. Page 5266, line 22: “GPS radar height”. Please check if that the intended term.
20. Page 5268, lines 2 and 3: referring to Table 1 it is said “Finally, the list of the advanced products obtained from the integration of the data provided by different instruments is reported”. However, in the case of the multiwavelength lidars the advanced products are obtained from the data provided by a single instrument.
21. Page 5269, line 5: “difficult for the provision”: probably “for” is surplus.
22. Page 5269, line 12: a semicolon instead of a comma after “within clouds” is suggested.
23. Page 5269, line 13: deleting the comma after “feedback processes” is suggested.
24. Page 5269, line 23: “mean aspects”; please check if “main aspects” was meant.
25. Page 5270, line 13: “either” should probably be moved from before to after “several examples”.
26. Page 5271, lines 5-6: “In both the considered regions”. Probably “In both considered regions” is better.
27. Page 5274, line 16: probably “with” is missing between “than” and “the” at the end of the line.
28. Page 5276, line 23: probably the hyphens in “point-of-view” can be dropped.
29. Page 5280, line 27: check the construction of the sentence starting in that line: “The integration retrieval, though provides a description of the water vapour field with a coarser resolution with respect to the lidar, it is able to provide a more operational product that allows us to override possible limitations in the Raman lidar measurements”.
30. End of Fig. 2 caption: “Both couples” instead of “Both the couples”.