

General comment

We thank the anonymous referees for the constructive comments that have been useful to improve the paper.

Following the comments of the referees, corrections have been applied on the paper.

Below the point-by-point responses to the two referees.

Reply to referee 1

Details

(1) Abstract, line 5: You should first introduce the need for validation and the other objectives before mentioning the campaign!

- The sentence has been changed: 'With the aim of evaluating the performances and the capabilities of the new system with a particular focus on UTLS measurements, and setting up and validating a calibration methodology, a MAido Lidar Calibration Campaign (MALICCA) was performed in April 2013.'

(2) System description: Add manufacturers of the components.

- The utilized optical components were produced, basically, by three companies: the Barr Associates (Raman band pass filters, BP-IFF in the text), the Rocky Mountain Instrument (polarization cubes), and the Andover Corporation (beam splitters and high pass filters, BS and HP-IFF, respectively). The manufacturers have been added in the text.

(3) P. 10371, line 9: "Raman Q branch"

- Done.

(4) P. 10371, lines 17-18: Fig. 1: Shift the introduction of the figure to the beginning of the system description (e.g., to P. 10370, around line 5).

- Done. Figure 1 is introduced at the beginning of the system description.

(5) P. 10374, lines 14-16: This sentence is a little bit confusing. One objective is announced, but several goals are mentioned. Do you mean "by improving"? Still, validating is an objective differing from optimizing.

- The sentence has been reformulated as follows: 'One of the objectives of MALICCA campaign has been to optimize the water vapor measurements acquired by the RMR-H₂O lidar new system, by improving its over-all efficiency'. Furthermore the title of the paragraph 'Measurement validation' has been changed with 'Measurement optimization'.

(6) P. 10375, line 23: I think you should address the overall "detection efficiency" here.

- Done.

(7) P. 10378, lines 2-3: A quantification of the biases does not necessarily imply an optimization of the system. Please, rephrase! For instance: " Due to the very low H2O Raman signal received from the stratospheric a number of of known biases must be taken into consideration."

- Done.

(8) P. 10379, line 9: "the water vapour signal"

- Done.

(9) P. 10379, line 11: "to fluorescence of components"

- Done.

(10) P. 10379, line 15: Replace "Mie" by "particle".

- Done.

(11) P. 10379, line 23: I think the reader has some interest in learning who manufactured the filters resulting in these exceptional OD values!

- see the answer for question #2.

(12) P. 10380, line 9: Why is this noteworthy? You did it, and the results is obvious.

- Ok.

(13) P. 10381, line 26: Vertical resolution is defined rather differently by different groups.
How

is dz defined in your case? dz looks much like a range bin size.

- Yes, in our case we define the vertical resolution as the total number of sampling bins used in the smoothing filter. For the detailed description of the filtering method that has been added at the end of paragraph 3.3 see the last answer of the scientific comments to referee 2.

(14) P. 10382, line 14: I cannot find C in the formula! See also P. 10383, line 2.

- The term 'K' in the formula has been changed with 'C'.

(15) P. 10384, line 9: "work shows"

- Done.

(16) P. 10384, lines 11-12: Do you mean "a movable support that is shifted across the top ..."? "Removable" looks somehow trivial! Also: "and directly illuminates"

- Yes, the sentence has been corrected: ' An ORIEL model 6251NS 75 W Xenon lamp has been mounted on a movable support that is shifted across the top of the primary telescope and directly illuminates its surface.'

(17) P. 10384, line 19 I do not understand "we provide to substitute". Do you mean "we substituted"?

- Yes. The sentence has been corrected.

(18) P. 10389, lines 10-12: The role of the mountain-related circulation should be mentioned.

- A new sentence has been added: 'Furthermore, the role of the mountain-related circulation should be also taken into account.'

(19) P. 10394, lines 6-8: These objectives are not new. Here (in the Conclusion section), one would expect a statement on how well the goals were met. At least you should add such a statement, or reformulate the sentence.

- The sentence has been reformulated: 'The MALICCA campaign, held in April 2013, permitted to optimize the water vapor measurements of the new lidar, to set up a calibration methodology, and to evaluate its performances and capabilities with a particular focus on the UTLS domain.'

(20) P. 10394, line 17: You could emphasize "Most importantly, the absence".

- Done.

(21) P. 10396, line 9: Replace "error" by "uncertainty".

- Done.

(22) P. 10396, line 16: "could attest" suggests that you are not really sure about this! Better: "suggests".

- Done.

(23) Fig. 1: Is 1200 mm the diameter or the focal length?

- 1200mm is the diameter as described in the text (e.g. Pg 10370, line 9)

(24) Fig. 3: "vertical resolution" is not properly defined. I think you mean the number of bins used.

- See the answer of point #13.

Style

(1) P. 10364, line 3: Replace "is devoted to" by "will".

- Done.

(2) P. 10365, line 5: "thus, "

- Done.

(3) P. 10365, lines 9 and 12: Replace the first "to measure accurately" by (e.g.) "to quantify".

- Done.

(4) P. 10365, line 12: "the UTLs"

- Done.

(5) P. 10365 line 16: "suffer from the abundance"

- The sentence has been re-written: 'Spaceborne passive remote sensors are limited by the abundance of cirrus clouds, as well as their coarse resolution...'

(6) P. 10365, line 18, "the lidar technique"

- Done.

(7) P. 10366, line 1: "The acceptance of the Raman lidar approach within NDACC"

- Done.

(8) P. 10366, line 5: "insures"

- Done.

(9) P. 10366, line 6: "Other work, in part based"; not all these systems have been fully approved by NDACC!

- Done.

(10) P. 10367, line 21: Either "by the Network for the Detection of Atmospheric Composition Change" or "by NDACC" (without "the").

- Ok.

(11) P. 10369, line 25: I think you did synchronize the pulse! Better: "were synchronized".

- Done.

(12) P. 10369: "to ensure"

- Done.

(13) P. 10370, line 1: What does "wavelength-dedicated" mean? "wavelength-specific", "wavelength-separating", "two-wavelength",?

- Wavelength-specific.

(14) P. 10370, line 20: "The spectral separation of the backscattered radiation"; "firstly": where is "secondly"?

- The sentence has been re-formulated: 'Figure 1 indicates that backscattered radiation is first separated into the visible separation unit (VSU) and the UV separation unit (USU) by BS1. These permanently-installed units split the Raman from the Rayleigh-Mie signals and have the same configuration in terms of optical path and equivalent optic elements.'

(15) P. 10371, line 12: "in front of the photocathode".

- Done.

(16) P. 10371, line 22: "The data-acquisition electronics consist"

- Done.

(17) P. 10373, line 10: "the Saastamoinen"; "is, thus, converted".

- Done.

(18) P. 10373, line 25: "1200 g"

-Done.

(19) P. 10374, line 17: I would prefer to see "signal-to-noise" ratio although I am aware that detailed hyphenation has become rather rare, which is also the case throughout this paper.

- Done.

(20) P. 10374, line 18: "parasitic"

- Done.

(21) P. 10375: line 26: "columns"

- Done.

(22) P. 10376, line 11: "to increasing or decreasing"?

- Done.

(23) P. 10376, line 14: Replace "the two" by "both".

- Done.

(24) P. 10376, line 15: Into what are the two lasers coupled?

- The two laser beams are coupled into a unique beam. The sentence has been rewritten: 'The performance of the system can be increased by coupling the two Quanta Ray Nd:Yag laser beams into a unique beam through a system of polarization cubes' .

(25) P. 10377, line 25: "nitrogen"

- Done.

(26) P. 10379: line 20: The abbreviation OD must be explained.

- Done.

(27) P. 10379, line 25: "let us consider Fig. 2".

- Done.

(28) P. 10384, line 17: "ratios"

- Done.

(29) P. 10384, line 22: "3 April, respectively"

- Done.

(30) P. 10385, line 23: "However, in the future"

- Done.

(31) P. 10385, line 25: Do mean "measurement"?

- Done.

(32) P. 10385, line 1: "Furthermore, the"

- Done.

(33) P. 10387, line 20: It is easier to read this sentence if you add "on 3 April" again.

- Done.

(34) P. 10388, line 22: " between 15:00 UTC on 11 April and 0:00 UTC on 12 April"

- Done.

(35) P. 10389, line 9: I could not find (Vogelmann et al., 2011) in the list of references.

- Done.

(36) P. 10389, line 21: Remove "far".

- Done.

(37) P. 10389, lines 25-26: "In Fig. 10"

- Done.

(38) P. 10391, line 15: "signal-to-noise"

- Done.

(39) P. 10396, line 20: "In particular, the"

- Done.

(40) P. 10396, line 25, line 28: "testing"

- Done.

(41) P. 10398, line 9: "Van Baelen"?

- Done.

Reply to referee 2

Scientific comments:

- Pg 10365, Line 19, Clarify what is meant by “high spatial and temporal resolution” here. Lidar measurements in the UT/LS are generally integrated over a long time, but these long integrations can be made more frequently at substantially lower cost than frost-point sondes.

The sentence has been reformulated: ‘On the contrary, the lidar technique can provide frequent measurements with relatively high spatial resolution.’

- Pg 10369, Lines 19-27. This is confusing. What configuration is being used? Are both laser transmitting 532 and 355nm? Or is one laser transmitting only 532 and the other 532 and 355? There is talk about combining the beams from both lasers, but later on page 10370 it seems to state that the beams are not combined and that 532 and 355 are transmitted sequentially. Are the lasers being fired individually for 10 minutes or so each? Please simplify and clarify what is being done. Is the reported divergence of the beam 0.5 m Rad before or after expansion. This discussion of Figure 1 should be made more coherent. Fig 1 also indicates that M14 in the beam transmitter is a planar mirror, while the schematic shows the beam diverging off M13. Is M14 really spherical?

Both laser can transmit at 532 and 355nm. To combine their pulses through polarization cubes, each beam has a different polarization that is obtained by the different optical path of the two beams (at the laser outputs the beam polarization is the same for both lasers).

The system is designed to work simultaneously at both wavelengths, however, as specified in the text: ‘Because it was difficult to ensure a beam-expander spherical mirror robust enough to work simultaneously at both wavelengths with the laser power available, it was decided to use wavelength-specific spherical mirrors relatively to the operational configuration (visible or UV). Pure simultaneous comparisons using both wavelengths were not possible and during MALICCA only the UV configuration has been adopted’.

The reported divergence is relative to the beam before the expansion.

M13 is a spherical mirror while M14 is a planar mirror.

The sentence has been corrected and reformulated: ‘The system is designed to work at two wavelengths depending on the requirements. The transmitter is based on two Quanta Ray Nd:Yag lasers operating either at second (532 nm: green) or third (355 nm: UV) harmonic or at both wavelengths simultaneously, with a repetition rate of 30 Hz. Each emitting pulsed laser provides an energy of about 800 and 375 mJ pulse⁻¹, at 532 and 355 nm respectively, and a duration pulse of 9 ns. The geometric divergence of the beam, before the expansion of the 5X beam expander is around 0.5 mrad (nominal, full angle). To increase the performance of the system, pulses of both lasers were synchronized, at 30 Hz, and coupled through polarization cubes. In fact, although at the laser outputs the beams have the same characteristics in terms of polarization, at the entrance of the cubes each laser beam has a perpendicular polarization one to the other because of the different optical path (see Fig. 1). This beam recombination enables the emitter to reach a power of 48 (532 nm) or 22.5 W (355 nm).’

- Pg. 10370 Line 8; Does the reference to Figure 14 in Hoareau 2014, really refer to Figure 1 in this paper? If so it should be corrected, if not then Figure 1 should be mentioned here.

The power of the beam expander telescope should be mentioned here as well.

The reference of Figure 14 in Hoareau 2014 has been removed and Figure 1 is mentioned here. The power of the beam expander is 5X (see the previous answer).

- Pg 10370 Line 14. States that the variable field of view of the telescope is 0.5 – 3.0 mRad, while Table 2 shows it to be 0.1 – 2.0 mRad. Which is correct?

The correct field of view is 0.5 – 3.0 mRad. Table 2 has been corrected.

- Page 10370, Going back to Figure 1, it appears that the polarization of each beam (532 or 355nm) must be different coming from each of the lasers, otherwise the re-combination through the cubes wouldn't work. Are there 1/2 wave plates in the beams to accomplish this? Mirror M8 seems to be mislabeled – shouldn't it be Tmax @355 and Rmax @532?

As written in the previous question, at the laser outputs the beam polarization is the same for both lasers (the 1/2 wave plates are inside the lasers). The different optical path of the two lasers (see Fig. 1) causes a different polarization that allows the beam recombination through the cubes.

Mirror M8 has been corrected.

- Pg 10374, Line 19. This paragraph seems to be talking about optimization of the lidar, not about validation of the measurements. Change "validation" to "optimization"

Done.

- Pg 10379 Line 1 It would be useful to show this data in a figure

We chose not to show this data because the profile of the backscattered signal at 432 nm is basically a profile of the background noise at this wavelength and the paper has already a substantial number of figures.

- Pg. 10379 Line 22, Figure 1 shows only one high pass filter and the bandpass filter before the 407nm detector. Also there appears to be a 407 bandpass filter in front of the 355 nm channels – should be BP-IFF3. The alpha-epsilon nomenclature seems to be left over from the original Figure 1

Figure 1 has been corrected and the nomenclature in the text has been updated.

- Pg. 10382, Line 14. Is C, the calibration constant, represented by K in Eq. 5? This should be consistent

Yes, 'K' in Eq 5 has been replaced by 'C'.

- Pg. 10390, referencing 10421; The X-axis scale for Figure 11 is not in percent but percent/100

Corrected.

- With regard to the discussions about vertical resolution of the lidar, all I have seen in the paper, are several comments that state that “a height dependent sliding scale” is used. How is this defined. There are several methods currently in use within NDACC: a simple integration of adjacent data bins (e.g., a 5 bin integration could be quoted as a 75 meter resolution); a Savitsky-Golay fit to the data over a sliding scale of bins can result in a very different reported vertical resolution. I think it is important for the authors to define what they mean by their vertical resolution in this paper.

A more detailed description of the developed smoothing method has been added at the end of paragraph 3.3 as well as the definition of the vertical resolution: ‘To optimize the compromise between accuracy and resolution, a height dependent smoothing scheme has been implemented. In this first data treatment a simple moving average has been adopted as a smoothing filter. The mean is taken from an equal number of sampling bins (N_b) on either side of a central bin. The value of N_b is automatically computed as a function of height so that, below 13 km, the statistical error is always less than 10%. The resulting WVMR relative error profile, depicted in Figure 3 as the mean profile for the lidar measurements considered in Table 4, has been calculated for a temporal integration of 30 and 120 min. (black and red thick curves, respectively). The total number of bins ($2N_b+1$), which is the vertical resolution (dz) of the water vapor profile, is also represented as a step black curve.’

Technical Comments

- Pg. 10363, Line 8 should end “ focus on UTLS Measurements.”

Done.

- Pg. 10364, Line 3; Change “Thanks” to “Due”; change “is devoted to” to “will”

Done.

- Pg. 10365, Line 4; Remove “Based on these considerations,” replace with “In order”

Done.

- Pg. 10365, Line 5; Remove “thus”

Done.

- Pg. 10365, Line 13; Change “instrumentations” to “instruments”

Done.

- Pg. 10365, Line 16, Should read “ Spaceborne passive remote sensors are limited by the abundance of cirrus clouds, as well as their coarse vertical resolution. . .”

Done.

- Pg. 10365, Line 18, Should be “the lidar technique”

Done.

- Pg. 10365, Line 20; remove “of an” replace with “for”

Done.

- Pg. 10365, Line 23-24 Should read “that retrieves profiles of water vapor mixing ratio (WVMR), with good vertical and temporal resolution, by. . .”

Done.

- Pg. 10365, Line 24-25 Should read “analyzing Raman backscattered”

Done.

- Pg. 10366 Line 1-5 This sentence should be broken apart and clarified. My sense is that the authors are trying to mention that there are two areas of concern that need to be addressed to show that a water vapor lidar is capable to accurately and consistently measure vertical profiles which are suitable to extract long term trends. The sentence as written is not very clear on this.

The sentence has been corrected: ‘The inclusion on the NDACC attests that the technique has achieved a comfortable level of maturity. In particular, to show that Raman water vapor lidars are suitable to extract long term trends, two areas of concern need to be addressed: the capability of measuring water vapor profiles in UTLS with an adequate accuracy and without systematic bias; a calibration method that insure stable and repeatable coefficients.’

- Pg. 10366 Line 6-10. The paragraph is confusing – the second sentence seems not to flow from the first and is disconnected.

The sentence has been reformulated.

- Pg. 10366 Line 14: remove “In a context. . . .characterization”. Start sentence with “Reunion”

Done.

- Pg 10366 line 16: After “crucial” add “for long term monitoring, as well as for studies of physical processes.”

Done.

- Pg 10366 Line 22 Replace “Have been” with “are”

Done.

- Pg 10366 Line 23 Delete “the” at the beginning of the line

Done.

- Pg. 10366 Line 27 Remove “the” before water vapor; Remove “ in the whole troposphere up” Replace with “ from ground level”

Done.

- Pg. 10367 Line 1, Remove “could allow improving” replace with “improve”; change “performances” to “performance”

Done.

- Pg 10367, Line 4 Remove “the” after “between”

Done.

- Pg 10367 Line 11 Add “a” before “few”

Done.

- Pg 10367 Line 14 “resumed” should be “reviewed, and”

Done.

- Pg. 10367 Line 17 Replace sentence with “Section 3 compares the results of different instrument configurations, along with the related bias characterizations, to those theoretically estimated by Hoareau, et al. (2012).”

Done.

- Pg. 10367 Line 21 Delete “the” before NDACC

Done.

- Pg. 10367 Line 23 Delete “the” before “Sect 5”

Done.

- Pg. 10369 Line 2, replace “conceived” with “designed”

Done.

- Pg. 10369 Line 3-4 Add “,” after “stratosphere”, Delete “and” before “temperature” replace with “as well as”; should be a period after “mesosphere”

Done.

- Pg. 10369 Lines 6-10. The sentence is confusing as written. The authors are pointing out

that the measurement of water vapor in the lower stratosphere is difficult for several reasons mostly related to low signals because of 1. The Raman cross-section is very low (as pointed out by the authors); 2. The water vapor mixing ratio decreases by as much as three orders of magnitude from the ground to the lower stratosphere; 3. In the tropics the tropopause is higher than at higher latitudes; and 4. At 408 nm there is significant ambient background even on clear, moonless nights. To increase signal is difficult and expensive (larger telescopes, more powerful lasers). Decreasing the noise is easier and much less expensive. With so much going on here it is less confusing to use a number of simpler sentences rather than one long complex one. This should be rewritten in more simple sentences.

- The sentence has been modified: 'In fact, the measurement of water vapor in the lower stratosphere is difficult for several reasons mostly related to low signals:

- 1) the Raman cross-section is very low;

- 2) the water vapor mixing ratio decreases by as much as three orders of magnitude from the ground to the lower stratosphere;

- 3) in the tropics the tropopause is higher than at higher latitudes;

- 4) at 408 nm there is significant ambient background even on clear, moonless nights.

The adopted technical solutions have been aimed on one hand to increase the counted numbers of backscatter photons and on the other hand to decrease the background noise and any contaminating signals.'

- Pg. 10370, Line 3 "swift" should be "shift"

Done.

- Pg. 10370 Line 18, replace "permits to avoid" with "avoids"

Done.

- Pg 10370 Line 20 – 22, should read "Figure 1 indicates that backscattered radiation is first separated into the visible separation unit (VSU) and the UV separation unit (USU) by BS1."

Done.

- Pg. 10370, Line 23, delete "have the purpose to"

Done.

- Pg. 10370 Line 29 to Page 10371 Line2 "that splits the 355 nm beam into low altitude and high altitude channels to optimize the temperature measurement"

Done.

- Pg 10371 line 17. Delete last sentence – Figure introduced on previous page

Done.

- Pg 10371 Line 19, "Hamamatsu R7400-03g and -020g photomultiplier tubes are used to detect the UV and Visible backscattered returns, respectively"

Done.

- Pg. 10375 Line 1, Change "continued" to "continuous"

Done.

- Pg. 10375, Line 26, Change "column" to "columns"; change "resume" to "show"

Done.

- Pg. 10378 Line 10, change "conceived" to "designed"

Done.

- Pg. 10379 Line 4, change "that are invested" to "excited"

Done.

- Pg. 10379 Line 25 delete "The" in front of "Fig.2"

Done.

- Pg. 10380 Line 9, Shouldn't "cloud base" be "cloud top"?

Done.

- Pg. 10380 Line 9 delete "It is noteworthy that"

Done.

- Pg. 10380 Line 14, "statistical" not "statistic"

Done.

- Pg 10383 Line 22; Delete "the" before NDACC; delete "conceived to foresee an" re- place with "designed to utilize a"

Done.

- PG. 10384, Line 1, delete "have been foreseen" replace with "are used"

Done.

- Pg. 10384, Line 4, delete "it is noteworthy to specify that"

Done.

- Pg. 10384, line 11-12. Is the lamp removed and installed for each measurement? Can this account for some of the variation seen in Figure 4?

The lamp is fixed on a movable support. The sentence has been corrected: 'An ORIEL model 6251NS 75 W Xenon lamp has been mounted on a movable support that, for each measurement, is shifted across the top of the primary telescope and directly illuminates its surface. This configuration affects the variation in Fig 4, as written at the end of paragraph 4.2: 'However, in the future, to gain on lamp stability and ameliorate the method sensitivity, it is planned to wait ten minutes before starting such a measurement and to fix the lamp position so that it will not be subjected to any variation.'

- Pg. 10384 Line 17, delete "the" before "background"

Done.

- Pg. 10384, line 18, "on 3 April, we replaced the PMT"

Done.

- Pg. 10385 Line 19, delete "of even" insert "up to"

Done.

- Pg. 10385 Line 25 delete "that"; replace "arrangement" with "position"

Done.

- Pg. 10386, line 2, should read "Once the ISP's are identified"

Done.

- Pg. 10389, Line 21, delete "faraway"

Done.

- Pg. 10389, Line 25-26, delete "the" before "Fig. 10"

Done.

- Pg. 10390, Line 1, "sessions"

Done.

- Pg. 10390 Line 12, "have been calibrated"

Done.

- Pg. 10391, Line 8, replace "on" with "in"

Done.

- Pg 10391, Line 8, delete “ between the atmospheric layer”

Done.

- Pg. 10391 Line 9, insert “the” in front of “upper”

Done.

- Pg. 10391 Line 10, cut “distant from the launching site(and from the lidar station)” and insert after kilometers on the next line.

Done.

- Pg. 10391 Line 13, delete “the” before “NDACC”

Done.

- Pg. 10391, Line 20, replace “foreseen” with “proposed”

Done.

- Pg. 10392, Line 28, delete “a” before “less”

Done.

- Pg. 10393, Line 16, insert “geometry” after “sampling”

Done.

- Pg. 10394, Line 4, delete “the” before “sea level”

Done.

- Pg. 10394, Line 17, “parasitic”

Done.