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Atmospheric Measurement Techniques Discussions

Interactive comment on "Evaluating different methods for elevation calibration of MAX-DOAS instruments during the CINDI-2 campaign" *by* Sebastian Donner et al.

Anonymous Referee #3

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"Evaluating different methods for elevation calibration of MAX-DOAS instruments during the CINDI-2 campaign" by Sebastian Donner et al. 2019 addresses a very important topic of pointing accuracy of the MAX-DOAS instruments. The authors describe and compare four different methods to measure offset of the actual pointing from the expected pointing. This topic is very important for reliability and consistency of MAX-DOAS observations and is within the scope of the Atmospheric Measurements Technics. I strongly believe this paper can become a great resource for MAX-DOAS community. I recommend publishing it after some changes. Major comments:

1. While the described methods are intended as calibration of instrumental pointing

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accuracy no discussion of the instrument performance evaluation after calibration was applied is presented.

2. The paper mainly focuses on determination of the instrument specific apparent elevation angles of the target and inadequately addresses the errors associated with determination of the absolute position of the calibration targets.

3. The authors often use method precision to describe accuracy. To evaluate usefulness of the presented methods both are needed.

4. Measurements of distances, heights, estimation of water levels have no associated with them measurement accuracy and precision reported. Sometimes details how these measurements or estimations were conducted are missing completely.

5. Fits of Gaussian functions to data have no fitting errors reported.

6. Five Pandora instruments (1 KNMI, 2 LuftBlick and 2 NASA) during CINDI-2 were performing sun scans on a regular basis (once per hour) to actively calibrate their azimuth and zenith pointing. This method should also be described for comparison with the other methods.

7. More emphasis should be placed on the quality of the positioners.

8. More explanation needs to be provide on how exactly the horizon scans can be used as a calibration tool (considering dependence on the FOV, scattering conditions, uncertainty in underlying surfaces, light incident angles, and true horizon).

9. Paper can be reorganized to be more concise. Some of the tables and figures can be merged (e.g. Table 1 and 2) and some eliminated at all. Text has some redundancy and needs proofreading. I recommend creating a table with a summary of each method including: (1) setup and "absolute" prerequisites; (2) measurements needed, their typical accuracy and precision, data analysis involved; (3) advantages; (4) disadvantages; (5) overall expected accuracy and precision of zero-elevation calibration based on CINDI-2 data for different types of instruments.

Minor comments:

P2, L31-32: Do any of the instruments have laboratory done FOV scans? It will be interesting to compare field of view between the lab and in the field

P3, L13-14: This sentence is unnecessary

P3, L28-29: Figure 19 has data for 28 instruments. Why Table 1 lists only 12? Tables 1 and 2 should be combined

P3, L31: There is no need to cite the URL when Kreher et al is already cited.

P4, L2: This sentence is redundant

P4, L5: Five Pandoras participated in CINDI-2. Each of them performed sun scans as part of routine operation that served as azimuth and elevation calibration. This method should be also presented for comparison.

P4, L16: What is "horizontal line of the telescope"? Is it the optical axis of the telescope/fiber setup when the instrument points at zero-degree elevation angle? How do you determine it?

P4, L30: This is another reason why sun scanning by Pandora instruments should be discussed in this paper.

P5, L6: How were the distances measured from the lamp to the instruments? How were the vertical distances measured? The land and the canal banks were covered with grass and are not perfectly flat. What is the uncertainty in all distance measurements?

P5, L8: Information from Fig 2 can be communicated in Fig 3 and Fig 2 removed.

P5, L7: The word "compare" next to most Fig and Table references is unnecessary.

P5, L8: The lamp light was collimated and then "directed". How exactly was this achieved? What was the accuracy of the lamp pointing? How uniform was the resulting beam that was visible on the container?

P5, L19: Which earlier night, 8 Sep 2016, or before that? Is 0.16 deg the offset from the initial "a prior" calibration done in the lab or from the earlier night?

P5, L21: Fig 4 is unnecessary and should be removed.

P6, L14: How did you decide that one direction was better than the other? What was positioning error of the lamp? Please include characteristics of instrument positioners (manufacturer accuracy and precision, and used resolution) in Table 2.

P6, L18: Is 0.16deg the initial calibration? Or is this the effect of the positioner resolution?

P7, L9-10: What is the leveling accuracy of the laser level? What light source is used? How is uniformity of the beam achieved? How accurate is determination of the light source center? What are the requirements of light source installation? It is also assumed that the optical axis of the telescope/fiber setup co-align with the mechanical center of the telescope (e.g. the fiber however can be slightly higher or lower than this estimation). What is the final error in determining this betta (= zero) offset angle between the center of the telescope/fiber and the lamp?

P7, L18-19: Were all the scans done from the same direction (upwards or downwards). Looking at the intensities for scan 2 and 3 they might be an indicator of the positioner backlash or pointing issues.

P9, L5: It is not quite clear how this FOV determination eliminates dependencies on the scattering conditions (wavelength), underlying surfaces and their albedo, as well as solar position.

P10, L23. Should “horizon” be replaced with “horizontal”?

P10, L26: How was “visible horizon” determined? How was "closeness" to the visible horizon determined? Figure 3 suggests that the lamp was at 3.3 m above ground. Is “ground level” referring to 3.3 m above ground?

P10. L29. How was 6.5 to 8.0 m estimated? P11, L13: I recommend combining Fig 12-15 into one figure. These figures give a good sense of the apparent FOV, as the lamp is scanned, impacted by both optics and precision of the positioner. Selecting the azimuth with the maximum intensity is somewhat arbitrary for some of the instruments with asymmetric FOV (e.g. Fig 13).

P11, L20: Differences in positioner pointing precision is also an important parameter of the apparent FOV

P11, L21: Fig 12 suggests that FWHM is about 0.65 deg for the BIRA instrument not 1 deg.

P11, L22: I would say good alignment, center “spot” fiber arrangement and good positioning are the reasons for a relatively uniform FOV. Unless the lamb beam was not uniform.

P12, L23: Isn’t the spread expected due to differences in prior reference calibration of 0 elevation angle?

P13, L9: Precision (repeatability) will be more appropriate here instead of “accuracy”

P13, L16: I would replace “measure of consistency” with: “measure of variability”

P13, L22-23: How were 6.5 and 8 m as a function of wavelength (340 and 440 nm) estimated?

P14, L32: Reading the text that follows you assert this difference is due to surface reflectivity. I also will add effects of FOV and wavelength dependent scattering. For a system with a 0.6 deg field of view placed directly on the ground pointing at 0 deg elevation angle (assuming no obstacles): half of the FOV will receive photons scattered in the atmosphere and half reflected from the underlying surfaces. Since Rayleigh scattering is wavelength dependent more photons at longer wavelength would be scattered in the “above ground” half of FOV. So for the instruments with FOV ∼ 0.6 nm FWHM the telescopes should point at least 0.3 deg below horizon to minimize the effect of FOV size. Considering that the instruments during CINDI-2 were located ∼ 4 m and 7 m above ground this angle should be even larger and depends on the wavelength and distance to obstacles and solar position (SZA and RAA).

P14, L39: Figure 19 does not support this statement. BIRA_4 instrument horizon position is about the same for both wavelengths.

P15, L25-31: It is unclear how apparent horizon measurements can be suitable for pointing accuracy calibration.

P16, L5: The conclusion maybe applies to the better performing instruments, while the rest of them mostly excluded from the analysis.

P16, L12-13: I do not agree that all the instruments showed consistent results. TLS mainly derived dependence for the better performing instruments... Also the authors have not demonstrated that the instruments improved their pointing performance as a result of any of these calibration methods.

P16, L33: I would not call this method accurate since some of the instruments clearly showed asymmetric FOV and different functions other than Gaussian could describe the intensity distribution potentially leading to larger errors.

P17, L1: Precision should not be confused with accuracy. In my opinion the authors have not accounted for all the uncertainties to claim accuracy of +-0.05 deg.

I recommend combining Table 1 and 2 and adding 2 columns with positioner maker, accuracy and precision data.

I do not think Tables 3 and 4 are needed.

Table 5: I think replacing “row” with “container level” might be clearer.

Figure 2 and 3 should be combined

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Figure 3: Upper and lower “panels” instead of “parts”

Figure 4 is unnecessary

Figure 10: It might be good to raise MAX-DOAS instrument in line with the stripe

Figures 12, 13, 14, 15 should be combined to give better idea about apparent FOV for different instruments

Figure 16: intensity distributions in (a, b) clearly do not have Gaussian distributions, please add fitting errors.

Figures 24 and 25: Y-axis = Apparent horizon elevation; X-axis = apparent lamp elevation. Add fitting errors to slope and intercept.

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