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Atmospheric Measurement Techniques Discussions

Interactive comment on "Intercomparison of Pandora Stratospheric NO_2 Slant Column Product with the NIWA M07 NDACC Standard" *by* Travis N. Knepp et al.

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We appreciate the thorough review from referee #1. The manuscript has been updated to implement the recommendations as described below.

1. Section 1: More details on the SAGE missions necessary. For instance, please add some more detail about how the SAGE-III/Meteor instrumentation works (including a short description of its viewing geometry, overpass times, etc.), the key SAGE species measurements (besides NO2), and any other data for which

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SAGE is used. This reviewer is not familiar with this missions, suspects that not all readers will be familiar. Added detail will greatly help to provide context on why validation against Pandora is both necessary and desirable.

(a) More detail was added to introduction.

1. What is the citation(s) for the NIWA M07 instrument being considered a standard for stratospheric NO2 measurements? This is unclear.

   (a) The NIWA group and their instruments have a long heritage of providing data of the highest quality. However, to label this an a “standard” is incorrect. The title and text have been updated to remove confusion in this regard.

1. The NIWA M07 instrument is specifically mentioned only within the last sentence of the introduction; is this the particular instrument that is considered a standard for NO2? Or was it chosen for this intercomparison for another reason, and if so, why? This instrument needs to be introduced along with NIWA rather than at the end of the introduction, to prevent confusion over why the M07 instrument was used.

   (a) Again, the title was updated to remove reference to the NIWA instrument as a community standard. Also, the text was changed to allow introduction of the NIWA instrument under the appropriate section.

1. Section 2.1: “Briefly, the Pandora model used in the current study consisted of. . .” is unclear; is this different from the “normal” working setup of the instrument, or the same? A note on this would be helpful. The statement at the end of the section (“. . .the Pandora only operated in the zenith-observation mode. . .” also contributes to the lack of clarity.

(a) The Pandora instruments have been evolving over time, so it is not accurate, at this point, to say there is a standard hardware configuration (e.g. it is not accurate to say they all have the same spectrometer specs etc.). However, there are general characteristics that remain consistent from version to version. Each instrument undergoes the same calibration procedure and the Pandora group have performed multiple intercomparisons between other Pandora units and other DOAS instrumentation (e.g. at the CINDI and CINDI-2 campaigns). Therefore, it is reasonable to trust in the instruments performance. We specify this specific instrument's hardware for clarity.

What is different here is the *mode* of operation. Normally, Pandora instruments track the Sun or look away from the Sun to do elevation scans after the Sun is well above the horizon. In the current study we evaluate the instruments performance in a zenith-only observation mode, specifically during twilight hours. The text has been updated to elucidate this difference in the operation mode.

1. Section 3: ". . .both instruments were operated in their normal states, not in a customized operation mode. . ." - this gets back to the comment about Section 2.1 about whether Pandora was used the same it has been in previous studies (or not). This statement should be a reiteration of the mode of operation for Pandora (and M07) from Section 2, to make sure it is clear how these instruments were used (and how this does or does not differ from previous studies).

   (a) As noted above and in the text, the only difference between the mode of operation in the current study and past studies is in the orientation of the entrance optics (i.e. zenith only). The intent of the current study and previous studies is different. Under "normal" Pandora operation the instrument will either do elevation scans, Sun tracking, or some combination of the two. The intention of these normal operation modes is to either collect total VCDs

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(Sun tracking) or attempt some vertical profiling (elevation scans). While the elevation scans typically involve a zenith observation, these scans are carried out when the Sun is well above the horizon, not during twilight conditions. Therefore, we cannot provide a comparison with previous studies as the current study is fundamentally different. The current study was carried out to determine whether the Pandora instrument is capable of making twilight observations with the entrance optics oriented in the zenith direction, as stated in the manuscript.

1. Section 3: the statistics thing (troposphere beings so different)

   (a) We are unable to determine what the reviewer means here. No changes made.

1. Section 3: Last sentence ("Since Lauder provides a clean, background-level,. . .") provides a clear statement of the motivation for this work that is not dependent on the specific SAGE mission. This should be perhaps mentioned earlier in the paper (maybe even the introduction after introducing Pandora and Lauder, NZ).

   (a) Given the context, we see manuscript as already meeting the reviewer's request. However, minor wording changes have been implemented within the introduction to bring this out.

1. – Section 4: What are the major retrieval uncertainties for Pandora and M07? These should be briefly described, in Section 2 where the two instruments are initially described. Also should make note of any other known limitations/issues related to the instruments or their retrievals.

   (a) Uncertainties now listed in added section.

1. What does it mean that some datasets were smoothed? Were both Pandora and M07 datasets smoothed, or portions of one or the other instrument's datasets? This statement is unclear. Also, why was five minutes chosen for the averaging time-why not 1 minute, for example?

   (a) We understand the lack of clarity of this statement and appreciate the reviewer bringing this to our attention. When dealing with long time-series data such as the OMI data presented in Fig. 2, the data can appear noisy due to day-to-day fluctuations within the column. This variability can mask trends, and generally make a figure's interpretation difficult. A common technique for bringing out these trends and enhancing a figure's interpretation is to apply a rolling weighted mean, which is what we did in Figs. 2 and 5. Since this "smoothing" was only applied to long time series (i.e. Figs. 2 and 5), this comment was removed from section 4.0. A comment was added to the caption of both Figs. 2 and 5 regarding this smoothing. Again, we appreciate this comment as this would likely have led to confusion of many readers.

   A five-minute block average was applied to both datasets to allow direct comparison of the two data sets. Due to how the data were recorded, the two data sets do not have common time stamps (e.g. Pandora may report an SCD at 12:01:23 while the nearest neighbor for M07 may be at 12:03:11). To temporally align the two datasets a five-minute resampling was performed. This rolling average was done to all data sets and for all analyses. Wording has been changed to clarify this.

1. Section 4.1: Need to explicitly state that the R2 values are given in Table 3, to make it easier for the reader to find the numbers that support the result that the correlation increased with decreasing SZA. Might even be good to list a few R2 values for some of the SZA bins, since to this reviewer, the correlation for the

87.5-90 SZA bin looks strongest when looking at the plots in Fig. 3 (though this was not the bin with largest R2). A follow up question is whether the statistical significance of these correlations was tested, to determine if the correlations were statistically different from each other (at least for the bins containing SZAs less than 92.5); a direct comparison of correlation coefficients can be misleading.

(a) Reference to table added.
Yes, the R-squared values are significantly different at 95% confidence, except for two cases. Now specified in text.

1. Are R2 values available for the sub-correlations for each panel of Fig. 3? An example for at least one panel might be good, showing how the correlation decreased with lower SZA within that SZA bin (and by extension for the other SZA bins).

(a) No. Due to the nature of the intercomparison and the proposed validation application going to smaller bin ranges is not applicable. The statement within the text "Within each panel of Fig. 3 the data are color coded to correspond to the SZA range within each sub-panel and provide insight into how the short-term change in SZA influenced correlation. As an example, in panel a it is observed that data collected at higher SZA (red-shaded points) were further from the one-to-one line than data collected at lower SZA (blue-shaded points)" was intended to call out the fact that as the SZA changed, individual points moved either closer to or further away from the 1:1 line. The text has been updated to this to be better understood.

1. Why can the dependence on SZA not be separated from day-to-day chemical variability? I'm not sure what "day to day chemical variability" refers to, so this statement is confusing. Does this refer to the annual variability of the NO2 column, or daily variability of the column? There needs to be a justification for

this statement. It would seem that the correlation's dependence on SZA is due to daily photochemistry (available sunlight for photochemical reactions involving NOx), as well as limitations of either instrument at high SZA. So to start the analysis presented in Fig. 3 could be extended, to investi- gate how the time series of the NO2 columns from both instruments within each SZA bin and over all SZA's compare, comparing to O3 column data, etc.

(a) Agreed. This part of the sentence was confusing and has been deleted.

1. Section 4.2: Do the authors have a hypothesis for why the tailing behavior was limited to winter conditions? This would be good to state in the paper.

(a) Yes. The "tailing" is only observed at low SCD values. Stratospheric NO_2 follows a seasonal cycle shown in Figure 2, with more NO_2 in the summer, less in the winter. Therefore, it makes sense that we see lower values in the wintertime. A reference to the seasonal cycle has been added to the text.

1. It's true that the R2 values remained high throughout most of the year, but it can be seen that R2 drops during the winter months for most SZA bins in Fig. 5, such as April-July 2015 bin for the 90-92.5 bin, and for the 80-85 bin. Is this just noise, or is this related to the trends observed in slope and SCD ratio for winter vs. summer? It needs some explanation, and this reviewer is not convinced that it can be said that there is no seasonal dependence seen in the correlation at this time.

(a) We agree that there is fluctuation within the April-July bin for SZA between 90 and 92.5 degrees. However, this fluctuation is not indicative of a clear seasonal pattern in the coefficients of regression. We support that by failing to see the same behavior in the other SZA bins, and by seeing a similar behavior in December. Further, we would expect to see a similar pattern as

shown in SCD or %diff panels if there were a seasonal dependence. At this time we cannot conclusively state there is a seasonal dependence in the R^2 values.

1. – Section 5: The second conclusions paragraph is a little confusing to read. Not quite sure what the message is about, particularly about the twilight retrievals. Some rewording should be all that is needed to make the message clearer.

   (a) Paragraph rewritten.

1. – When referencing parts of a figure, such as panel a in Fig. 3, use parentheses to encapsulate the letter to make it easier to distinguish for the reader (e.g.; Fig. 3 panel a Fig. panel (a)).

   (a) Changes made throughout

1. – Fig. 4 says “orrelation” in the plot titles rather than “Correlation”

   (a) We do not see an error in the titles of figure 4. Perhaps this was an error in the reviewer’s file?

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