Author response to the anonymous referees‘ comments:

We thank both anonymous referees for their very sound and constructive comments which helped us to significantly improve our manuscript. In the following, we provide point to point replies to all comments made by the referees.

Anonymous Referee #1

Comments :

Page 6180 (abstract) and page 6195 (summary and conclusions): although regularly mentioned in the other sections, the fundamental condition required for the method to be applicable, i.e. a shift that is constant with time, is not mentioned in the abstract nor in the conclusions.

Explanatory notes were added to the abstract and the summary and conclusions of the manuscript.
Page 6180, line 13: “The proposed concept is suitable in the case of systematic mispointing, i.e. if the mispointing is approximately constant within a given set of measurements.”
Page 6195, line 14: “Note that this approach relies on the assumption that within a suitably chosen set of measurements, the change of the mispointing is negligible compared to the magnitude of the mispointing. Therefore, only the systematic component of the mispointing is constrained by this method.”

Page 6183, line 17-18: This hypothesis (constant mispointing) is the fundamental assumption upon which the entire paper is based. It would be interesting to have an estimate on how often this condition is fulfilled in solar instruments ? In the instruments I know, the mispointing rarely remained constant throughout a single day.

We thank the anonymous referee for highlighting this point. Unfortunately, the assessment on how often this underlying assumption is fulfilled was not given in a sufficiently clear and extensive way in the manuscript. The assessment made to address this issue in our study is based on comparing the scatter of mispointing results within each time bin (= statistical component of mispointing) to the magnitude of the mispointing (= constant systematic component), see also page 6192, line 5-13 of the manuscript.

In order to clarify this point, the following additions were made in the manuscript:
Page 6195, line 21: “The presented correction strategy relies on the assumption that the change of mispointing within each time bin is negligible compared to its magnitude. It has been outlined in Sect. 4.3 that for the September 2012–September 2014 interval this assumption is well fulfilled at the Zugspitze instrument. For other time intervals and for the Garmisch instrument, the assumption is only poorly fulfilled. However, this is due to the fact that in these cases only minor mispointing occurred, which makes a correction unnecessary. The Zugspitze and Garmisch instruments are likely to be well representative for standard NDACC and TCCON instruments. Therefore for ideally configured NDACC and TCCON systems, a mispointing correction is unlikely to lead to significant accuracy improvements. However, for non-standard or poorly aligned systems such as the Zugspitze instrument in the 2012-2014 phase, the correction leads to major quality improvements.”
Page 6193, line 22: “and in general for the Garmisch instrument.”

Page 6183, line 24: after "Neglecting differential solar rotation", add something like "(addressed in Section 3)".

"(addressed in Section 3)" was added to the manuscript.

Page 6184, line 11: suppress "in" (last word of the line).

The manuscript was changed as suggested.

Page 6184, lines 22 to 24: you mention that you compared the shifts retrieved in 2 different wavenumber ranges, but do not mention any result/conclusion about this comparison: were the shifts different, similar, to what extent... ?

As noted rightly by the referee, the use of the shifts retrieved from the different wavenumber intervals was not presented clearly and a reference to Appendix B was missing in the manuscript.

The following text was added to the manuscript to clarify the use of the two sets of shift measurements (page 6184, line 24): "The differences between the measured line shifts in both filters were set as an estimate of the shift measurement uncertainty. This uncertainty is subsequently used for the calculation of the mispointing uncertainty (see Appendix B)."
In order to provide a quantitative overview about the differences between the two wavenumber ranges, the following text was added (page 6198, line 6):"The mean shift difference throughout the April 2006 to March 2015 interval considered in our study was $3.3 \cdot 10^{-7}$*. Compared to the mean magnitude of solar line shifts of* $9.9 \cdot 10^{-7}$*, this corresponds to a mean relative difference of ~33%"*

Page 6188, line 3, formula (5): this formula is a crude approximation of the airmass; at 80◦ SZA, it gives a 3.3 % error on the airmass.

The referee's remark is correct. The formula used to calculate the airmass in page 6188, line 3 is only a crude approximation that results in significant airmass errors at high solar zenith angles.

Additions to the manuscript were made to clarify that i) the "a posteriori scheme" is meant only as a quick approximate correction scheme for reference, ii) an accurate ("a priori") calculation approach has been presented also in the manuscript, and iii) both approaches agree in terms of our geophysical target (XCH_4) surprisingly well, in spite of the simplicity of the a posteriori correction scheme. This is partly due to the fact that the significant airmass error in the a posteriori scheme only results in a much smaller error in the trace gas column correction. In detail, the additions to the manuscript are:
Page 6188, line 11: "Note that Eq. 5 given in the a posteriori method only permits an approximate airmass calculation. In order to achieve higher accuracy especially at high sza, a more sophisticated calculation such as the approach described by Kasten and Young (1989) can be chosen. Furthermore, the a priori scheme includes additional effects such as the influence of mispointing on the ray trace calculation in trace gas retrievals which are not considered in the a posteriori method. However, as shown in Sect. 4.3, the corrected trace gas columns obtained using the a posteriori approach show good consistency with the results from the more sophisticated a priori approach."
Page 6196, line 8: "Note that the a posteriori method is designed as a simplified correction approach. However, as outlined in the previous section, the errors that result from the approximations made are negligible for most typical applications."

Page 6188, line 20: replace "is located in an astronomical dome above the spectrometer that is opened" by "is located above the spectrometer, in an astronomical dome that is opened".

The manuscript was changed as suggested.

Page 6192, line 19: maybe you should mention how many days of observations are typically included in a bin size of 20 spectra (or what period of time between the first and the last day of the bin size).

The mean number of measurement days included in a time bin is 7.1 days.
A similar comment was added to the manuscript (Page 6192, line 19).

Page 6196, line 21: "sun axis" - I suppose this is "sun rotation axis" ?

"sun axis" was replaced by "sun rotation axis" throughout the manuscript.

Page 6196, lines 25 and 26; page 6197, lines 4, 5, 6... : uniformize "Earth rotation axis" or "Earth's rotation axis".

Uniform use of "Earth rotation axis" was adopted.

Anonymous Referee #2

Comments:

Page 6182 Line 4: with "apertures", do you mean "field stops"?

"apertures" was replaced by the correct term "field stops".

Page 6183 Line 4: Here it would be nice to read a bit about possible types of setups which can be used for maintaining the alignment with the solar direction and their advantages/disadvantages.

A short discussion of tracking systems was added at Page 6182, line 24: "The simplest approach to achieve continuous sun tracking is to adjust the observed sky position according to precalculated values. However, such passive tracking does not fulfill typical accuracy requirements. Therefore, most current solar FTIR systems make use of feedback from a quadrant diode to control the solar tracker position and thereby achieve improved pointing accuracy (see e.g. Adrian et al., 1994, Notholt et al., 1995, Washenfelder et al. 2006). Further improvements can be made by using feedback from a camera image of the position of the solar disc on the spectrometer's entrance aperture instead of a quadrant diode (Gisi et al., 2011)."
A further comment discussing advantages/disadvantages of different setups was added in the context of the discussion of the modifications made at the Zugspitze instrument (Page 6189, line 13): "This issue highlights the fact that optimum performance of quadrant diode-based sun tracker systems is only ensured within a narrow range of optical configurations. Great care has to be taken when changing parameters such as solar image size to maintain tracking accuracy. Camera-based setups such as the Camtracker system are less sensitive

to optical system modifications. The installation of such a system therefore enabled to regain high tracking accuracy for the Zugspitze FTIR."

Page 6183 Lines 8 - 14: The same information already appeared on the previous page around line 15. Please reduce the amount of duplication.

The text was shortened to reduce duplication. The modified text is:
"As outlined in the previous section, only the mispointing perpendicular to the solar rotation axis but not the component parallel to the axis can be deduced from the Doppler shift of solar lines.
Therefore, the component of mispointing in zenith direction that causes bias in the retrieved trace gas columns cannot be deduced directly from such measurements."

Page 6186 Line 3: You state, a line shift value constrains the mispointing on a line with constant angular velocity. Is this correct? I would say, that it constrains the mispointing to a line on the sun with constant perpendicular velocity component. The lines with angular velocities are parallel to the solar equator, and comprise all possible line shift values, therefore a measured line shift can't constrain the mispointing to lie on this line.
Please clarify.

The anonymous referee's comment is correct. The erroneous term "constant angular velocity" on page 6186, line 3 was changed to "constant velocity component along the observer's line of sight". A similar change was made on Page 6208, figure caption of Fig. 3.

Page 6189 Lines 5-13: Why was the configuration changed in September 2012, and why did this cause such a significant degradation of tracking accuracy?

The following passage was added to the manuscript to describe the reason for the configuration change and the tracking accuracy degradation (Page 6189, line 13):
"The optical configuration was changed in September 2012 in order to enable radiometric calibration of the measured spectra by means of a high-temperature blackbody source. However, due to the smaller size of the solar image at A_1 in the new setup, tracking accuracy has degraded significantly by the modification. This issue highlights the fact that optimum performance of quadrant diode-based sun tracker systems is only ensured within a narrow range of optical configurations. Great care has to be taken when changing parameters such as solar image size to maintain tracking accuracy. Camera-based setups such as the Camtracker system are less sensitive to optical system modifications. The installation of such a system therefore enabled to regain high tracking accuracy for the Zugspitze FTIR."

Technical corrections/suggestions:

Page 6182 Line 16: "constrain" should read "contain"

„constrain" was changed to "contain information on"

Page 6184 Line 11: remove duplicate word "in"

The manuscript was changed as suggested.

Page 6199 Line 16-17: a word is missing in the sentence, e.g. "for"

"for" was added to the manuscript.

Further changes to the manuscript proposed by the authors:

Page 6185, line 23: *change "phenomena" to "phenomenon"*

Page 6213, figure caption Fig. 8: *change "corrected" to "a posteriori-corrected" to specify which of the presented correction schemes was used for the data shown in the figure.*