We thank the reviewer for the encouraging words and fort he helpful comments which improved the manuscript noticeably. By adding some more explanations and hints from a person not involved in the manuscript preparation enhanced the understanding for the reader.

The replies of the reviewer comments are given in the following manner: Reviewer comments are printed in bold, are labeled, and are listed in the beginning of each answer. The reviewer comments are followed by the author comments and revised parts of the paper. The revised parts of the paper are written in quotation marks and italic letters.

Comments:

1. **Page 2: there are significant discussions for SVC, but techniques presented here a not suitable for dealing with cirrus with such small optical depth- large uncertainties among them.**
   The reviewer is right. In the manuscript a case study of an observed cirrus with higher optical thickness than SVC is presented. However, the sensitivity study (Figure 3) shows that the sensitivity of measured radiance is higher for sideward measurements compared to nadir measurements for cirrus with low optical thickness up to τ=1. The observed cirrus case showed τ in the range of 0.2-1.0 and, therefore, is suitable to test the different observation geometries although it is not in the range of SVC. Using a cirrus with higher optical thickness than SVC as a first test case has the advantage, that the measurement uncertainties are less important for the retrieved τ (higher reflected radiance way above the instrument noise level). Therefore, we think that using a moderate thick cirrus is most suited here. Additionally, Sections 4 and 5 (especially 5.2.1) include a more detailed investigation of the mini-DOAS sideward observations, indicating and emphasizing the advantages of these observations compared to measurements in nadir geometry for all types of thin cirrus clouds including SVC. Furthermore two plots were added to Figure 15 to show the agreement of tau between WALES and the mini-DOAS sideward measurements.

   "The retrieval using mini-DOAS sideward channels is also successful demonstrated for a reduced set of observations limited to Θ_V between 85° and 90°. Differences in τ range up to +-0.73 between SMART and mini-DOAS sideward viewing observations and are partly caused by the different viewing geometries. First, the sideward telescopes view into starboard direction, probing the cirrus cloud top at approximately 8000 m aside the flight track. Second, the nadir observations may suffer from uncertainties in α while the sideward observations are less effected by changes in α. Even for sea surfaces as presented here, αmay change due to different wind speeds. Other potential reasons are the assumed ice crystal shapes in the RTS and different field-of-view of the passive and active remote sensing instruments. This conclusion is apparent from different probability distributions. While SMART and mini-DOAS show a median around τ=0.4, the median for WALES is shifted to lower τ around 0.2, indicating that WALES observed small τ more frequently. The difference of mean values of τ between mini-DOAS sideward channels and WALES is smaller with +-0.05 (15.6%). This shows the advantage of the sideward viewing retrieval due to a reduced surface influence and lower retrieval uncertainty, because of high ε_τ compared to the nadir measurements."

2. **Page 2, last sentenceâ˘A ˘ Tit is not an accurate statement if you consider passive sensor measurements.**
   Sentence is rephrased and the word "inherently" is removed.
   "While satellite observations are suited to study the global coverage of cirrus, their spatial and temporal resolution is still limited and can not resolve the high spatial variability of cirrus."

3. **Page 3: Lines 5-6: the cirrus optical thickness of water clouds does not make senseâ˘A ˘Tre-write.**
   The word "cirrus" is removed from the sentence as water clouds can not be cirrus.
   "For nadir measurements tau and the effective radius r_eff of liquid water droplets can be retrieved by the bi-spectral reflectivity method after Twomey, 1980 and Nakajima, 1990. Ou et al., 1993, Rolland et al. 2000, and King et al., 2004 adapted this method for ice clouds by introducing some modifications with regard to the thermodynamic phase and crystal shape of the ice particles."

4. **Page 4: Line 18: If you conclude that it is impossible here. You don't need any further study in this paper. Yes, it is challenging, which indicates that we need more observational constrains to improve the retrieval.**
   This statement did not ment that cirrus retrieval are in general impossible. "Impossible" referred to the worst conditions where uncertainties may get too large. Most observations will provide conditions where a retrieval is possible but with uncertainties. Therefore, the conclusion was rewritten:
   "In a worst scenario, all these effects render retrievals of τ to become rather inaccurate. However, observations in sideward or limb viewing direction and improvements of retrieval techniques may overcome these limitations."

5. **Page 4, Lines 19-21: The statements here are not accurate. Off-nadir measurements are widely used for space-base cirrus remote sensing. As you know, most satellite passive sensors are wide swath measurements .**
   That is correct. Sideward can mean 1° off-nadir viewing direction. With "sideward" we address measurements close to limb direction (90° viewing direction). We refrain of using the term "limb" measurements because the measurements presented in the manuscript had been performed at viewing angles less than 90°, not limb. We now included an explanation on what we define as sideward measurements and in case literature is discussed where real limb-measurements are applied, we now kept writing limb viewing angle. The word "off-nadir" was replaced by "sideward" in the entire manuscript to avoid misunderstanding.
   "Limb measurements of SVC and cirrus were first introduced and utilized for satellite measurements by Woodbury, 1986. Since then, several applications based on this method were developed and are routinely be used, e.g. for trace gas measurements (Abrams_1996, Wang_1996, Clerbaux_2003, Bourassa_2005, Fu_2007).
   Many trace gas retrievals from aircraft, balloons and satellites are based on ultraviolet (UV)/ visible (VIS)/ near infrared (IR) sideward viewing measurements in combination with

differential optical absorption spectroscopy (DOAS), e.g. performed by Platt_2008. Compared to nadir observations, radiance measurements in limb or sideward viewing geometry are supposed to be more sensitive to optical thin clouds due to their observation geometry. One recent study was accomplished by Wiensz 2013 who used satellite limb measurements especially for SVC investigation in the tropical tropopause layer. This data source improved SVC observations with respect to cloud climatology and microphysics."

6. **Page 4, Line 25, "highly sensitive": An overstatement. Yes, it is more sensitive, but it is highly dependent on the magnitude of off-angle.**
   Replaced the word "highly" by "more" to avoid the overstatement. The influence of the observation angle is shown later in the different simulations of the sensitivity study.
   "Compared to nadir observations, radiance measurements in limb or sideward geometry are supposed to be more sensitive to optical thin clouds due to their observation geometry."

7. **Page 5, Line 15: What does "F" in "FDISORT" mean?**
   FDISORT is the Fortran 77 version of the original DISORT solver:
   "*The Fortran 77 discrete ordinate radiative transfer solver version 2.0 (FDISORT 2) after Stamnes 2000 is chosen.*"

8. **Page 6: Figure 2 caption in the PDF misses words.**
   Caption is corrected.

9. **Page 6, line 15: The statement of "cirrus can not be detected" is not accurate. Cirrus is a general category including high clouds with optical depth up to 3.**
   Sentence is formulated more precisely just refereeing to sub visible cirrus:
   "*Therefore, at λ= 532 nm SVC with τ= 0.03 which is presented in the simulations can not be detected.*"

10. **Page 7, lines 4-5: To draw this conclusion, you'd better to present calculation results with a higher optical depth.**
    Thanks for this suggestion. We added simulations for a cirrus with τ=2.0 in the revised manuscript what helped to illustrate the differences to the SVC case. The simulations for τ=2.0 show that the effect of Rayleigh scattering is significant reduced at 532 nm and a separation between cloudy and clear-sky is possible for such clouds. Nevertheless, the relative difference between cloudy and clear-sky case is still more pronounced for the radiance at 1180 nm and emphasizes the conclusion:
    "For comparison, simulations of a thicker cirrus with τ= 2.0 are presented in Figure 2 (b). Here, the influence of the Rayleigh scattering at λ= 532 nm is reduced and a distinction between cloudy and clear-sky conditions becomes possible. However, the relative difference between cloudy and clear-sky is still more pronounced at λ= 1180 nm.
    The RTS suggest that sideward viewing observations at near IR wavelengths (λ> 900 nm) are more suitable for the detection of SVC and cirrus. As a result the retrieval in Section 4 is performed at 1180 nm and 1600 nm wavelength in the IR region which are sensitive to τand r_eff and not disturbed by Rayleigh scattering."

11. Page 7, line 15: This statement does not consistent with the statements in the next paragraph.

Statement was rephrased and specified for cirrus with optical thickness below 1. It was added that for clouds with optical thickness larger than 1 the sensitivity of sideward observations is in the same range compared to nadir measurements. This shows that sideward measurements are most suited and applicable for cirrus with tau below 1.

"Due to the apparent longer LOS for both Θ_0, sideward viewing sensor orientations yield larger ε_τ of simulated I^V_{RTS} as compared to the nadir geometry for cirrus clouds with $\tau<1$ which includes SVC. This indicates that sideward measurements are most suited to retrieve tau below 1 and for the detection of SVC. The almost linear increase of the nadir radiance I^N_{RTS} indicates a constant ε_τ tau for the investigated range of tau and Θ_0. For $\tau >= 1$ the sensitivity of sideward viewing observations is in the same range compared to nadir measurements or slightly lower depending on the combination of Θ_0 and Θ_V."

12. Page 8, line 1-2: To draw this conclusion, you need to make many assumptions.

Conclusion is extended and explained in more detail.

"For low tau and a high sun, the highest ε_τ is given for the sideward viewing geometry (Θ_V = 78°) for $\tau <= 1$. A similar pattern emerges for low Sun (Θ_0 = 75°) resulting in larger ε_τ and a steep decrease for increasing τ. It shows that ε_τ decreases with tau and for $\tau < 2$ drops below ε_τ of nadir measurements. The sensitivity of I with respect to τ can also be interpreted in terms of the uncertainty of retrieved τ related to an initial uncertainty in measured I. The higher ε the weaker the impact of uncertainties in the measurements on the uncertainties of the retrieved τ. As shown in Fig.3 (b), a high ε_τ is calculated for $I_{RTS,1180}$ for $\tau <= 1$ and indicates a lower measurement uncertainty. Therefore, sideward viewing observations at λ= 1180 nm allow a more accurate determination of τ compared to nadir observations for optical thin clouds with $\tau <= 1$."

13. Page 8, line 7: Based on the statement, it seems that you don't consider angle smaller than 60 degree as the off-nadir observations. That is not right.

See reply to comment 5.

Sideward measurements with angles smaller than 60 degree are not that sensitive as compared to larger angles. This does not necessarily mean that they are not considered but they are unfavorable. The plot should show that depending in the optical thickness and the relative solar azimuth angle the best viewing angle should be selected to reach the highest sensitivity which results in the lowest relative measurement errors and better retrieval results.

"For τ= 0.1 and Θ_0= 25°$ (Fig. 4 a), ε_τ ranges between 5 and 66 mW m^{-2} nm^{-1} sr^{-1}. For larger Θ_V (sideward viewing observations) ε_τ increases significantly reaching the maximum for Θ_V =90° and φ = 0°. Observations under these angles are better suited in comparison to other angle combinations as they enable to achieve the largest possible ε_τ and reduced relative measurement errors which results in increased retrieval accuracy."

14. Page 9, line 9-10: It is hard to understand this sentence.

In the revised manuscript we rephrased the sentence:
"Measurements in sideward viewing geometry strongly dependent on Θ_V especially around Θ_V = 90°. In order to avoid spurious results by mispointing with the sensor, a careful alignment of the optical sensor and an accurate determination is required. Considering these findings, the retrieval of tau in Section 4 is performed for Θ_V <= 60° only."

15. **Page 12, figure 7: It is hard to see the location of the optical port in (b). A better figure may be needed.**
Location of the ports is highlighted in an updated figure and is hopefully visible now.

16. **Page 12, line 12: UV and VIS were defined early.**
Removed.

17. **Page 12, line 13: DOAS was defined early. –Avoid multiple definitions.**
Removed.

18. **Page 15, line 3: "cross-calibrate both instrument" is no right. As you discussed in the paper, SMART is lab calibrated.**
The sentence was rephrased:
"*Since no radiometric calibration is available for mini-DOAS, simultaneous measurements of SMART and mini-DOAS are used to cross-calibrate the mini-DOAS with SMART.*"

19. **Page 16, lines 1-2: Giving absolute numbers are needed, but it will be good to present relative differences too.**
We added relative differences for the nadir and sideward cross-calibration in the revised text.
"…, which results in relative differences of 5.4% at λ= 1180 nm and 1.9% at λ= 1600 nm compared to the SMART absolute values."

20. **Page 18, line 3: Based on Fig. 10, I'd like to say that 2.9 is a big number, which is difficult to support the stable calibration consistent.**
Yes, 2.9 actually is a big number considering the aim to retrieve cirrus optical thickness with reasonable accuracy. We, therefore, included estimates of uncertainties in the retrieval of tau that would be caused by such uncertainties in the calibration.
However, the comparison of the calibrations did not suggest to use a calibration that was done long before or after the measurements. This was now emphasized in the revised manuscript.
Nevertheless, considering the original purpose of the mini-DOAS to remain a precise wavelength calibration for DOAS observations but without need to relying on a radiometric calibration because relative measurements are analyzed, the relative good stability of the calibration was surprising. The radiometric calibration can change between campaigns due to instrument removal and modification but also between flights by switching the instrument on and off. As the deviation is 2.9 and ranging in the uncertainty range of SMART the stability is good taking SMART as a reference. If no subsequent calibration of the mini-

DOAS would be available, radiometric measurements would still be possible considering the uncertainty of 2.9 mW, what may in some application be sufficient.

21. **Page 19, Line 26: The statement here is not consistent with the lowest box in Fig. 11.**
Illustration is corrected so it is in agreement with the text.

22. **Page 20, line 20: Even for lidar guy, it is hard to see contrails in Fig. 13. How about to plot Fig. 13 as a color figure to make the fine feature easy to identify.**
B/W-plot was replaced by a color plot.

23. **Page 22, line 22: For cirrus cloud optical depth around 1, it is hard to claim that the lower layer is obscured by the upper cloud layer. The lower layer can be clearly identified from lidar image.**
This is correct. We did not clearly separate this discussion between lidar and passive sensors. Of course, the lidar can provide vertically resolved measurements and, therefore, is able to separate the second cloud layer. This means that WALES can determine tau of the cirrus (without the lower layer) correctly. On the other hand SMART provides only vertically integrated information as it measures the sum of reflected radiation from both clouds. This partly explains the bias in the retrieval. The paragraph was rephrased.
"A second segment with higher retrieved τ is likely due to an underlying cirrus between 8.5 km and 9.5 km altitude that is also obscured to the detection by WALES. Therefore, a positive systematic offset of the retrieved τ occurs for SMART and mini-DOAS. These data points are excluded from the following analysis. Nevertheless, there is a slight chance that a few cloud fragments of these second cloud layers are still affecting the SMART- and mini-DOAS retrieval. Both passive sensors have a larger FOV compared to WALES and, therefore, are more likely sensitive to cloud layers located below the cirrus."

24. **Page 23, line 3: Is 10% here mean error or random error? You need to explain the +0.2 overestimation.**
The measurement uncertainty of SMART is 14.5% and not 10%. This was corrected in the manuscript. The uncertainty of ±0.2 results from the uncertainty in the measured upward radiance of 14.5%. For this estimation the retrieval was performed twice with a bias of *I* with ±14.5% uncertainty as upper and lower border. We rephrased the paragraph to make this procedure more clear:
"The uncertainty range of tau is determined by running the retrieval twice with a bias of measured $I^{N}_{S,1180}$ with +-14.5% uncertainty at 1180 nm wavelength as upper and lower border. The resulting upper and lower retrieved tau represent the retrieval uncertainty."

25. **Page 23, lines 16-23: Which kind of calibration errors explain the good linear correlations and 0.66 or 0.69 slopes?**
SMART and mini-DOAS relay on a large field of view, in the range of several tenth of meters depending on the distance between sensor ans cloud top, compared to WALES which has a narrow opening angle of 0.08°. Additionally, SMART and mini-DOAS are passive remote

sensing instrument measureing the scattered radiation from the sun which is effected by the entire atmosphere. Contrarily, the WALES measurement is influenced by interactions in the smaller field of view only. Also the food print at cloud top is much smaller from WALES compared to SMART and mini-DOAS. Therefore, WALES has a higher horizontal resolution. This becomes visible in the propability density functions of the three instruments, where the median for WALES is shifted to lower optical thickness, indicating that WALES measured more values of low tau and even cloud free regions. On the other hand SMART and mini-DOAS measurements average over larger areas and do not represent these small fluctuations which can explain the linear offset.
Due to the larger FOV of the passive sensors, there is the chance that SMART and mini-DOAS are still contaminated by a second cloud layer but not WALES. We extended the description of the data selection for the calculation of the averages.
All points which differed clearly were excluded from the calculations. Nevertheless there is a slight chance that few points were classified as cirrus but actually belong to the second cloud layer. This is mostly due to the fact that they could not be separated definitely and because the SMART and mini-DOAS sensors have a larger FOV compared to WALES.

26. **Page 24, lines 10-11: For large ice crystals, why do you expect optical depth difference between 532 nm and 1180 nm?**
For the retrieval of optical thickness the wavelength applied in the retrieval has to be considered as the ice crystal extinction is wavelength dependent (Takano and Liou, 1989, Yang et al., 2012).
Although, this dependence was considered by scaling all results to lambda= 532 nm, the reflected radiance at different wavelengths used for the retrieval have different vertical weighting functions (Platnick, 2000). Depending on the wavelength, the penetration depth of solar radiation into a cloud can vary. While wavelengths close to the UV have a higher penetration depth compared to wavelength close to the infrared region.
This effect might be small in case of vertically homogeneous cirrus but is a potential uncertainty source which have to be considered for vertical inhomogeneous cirrus observed here.
"Additionally, the different wavelengths of the measurements may introduce biases in the retrieved tau due to different penetration depth of the reflected radiation into the cloud (Platnick, 2000). Therefore, the wavelength selection defines the layer in the cloud which is probed. While WALES uses backscatter measurements at λ= 532 nm and λ= 1064 nm the measurements of $I_{S,1180}$ by SMART and mini-DOAS are performed at λ= 1180 nm. Although the retrieval accounts for the wavelength dependence of scattering, absorption and refraction on ice crystals (Takano_1989,Yang_2013) by scaling the retrieved τ at λ= 1180 nm to λ = 532 nm to make it comparable between the different instruments."

Takano, Y. and K. Liou, 1989: Solar Radiative Transfer in Cirrus Clouds. Part I: Single-Scattering and Optical Properties of Hexagonal Ice Crystals. J. Atmos. Sci., 46, 3–19, doi: 10.1175/1520-0469(1989)046<0003:SRTICC>2.0.CO;2.

Yang, P., L. Bi, B. Baum, K. Liou, G. Kattawar, M. Mishchenko, and B. Cole, 2013: Spectrally Consistent Scattering, Absorption, and Polarization Properties of Atmospheric Ice Crystals at Wavelengths from 0.2 to 100 μm. J. Atmos. Sci., 70, 330–347, doi: 10.1175/JAS-D-12-039.1.

Platnick, S., 2000: Vertical photon transport in cloud remote sensing problems. J. Geophys. Res. Atmos., 105, 22919-22935, doi: 10.1029/2000JD900333.