Reply to comments by reviewer #3:

(our replies are boldfaced)

Reviewer 3: amtd-8-C2859-2015

Q3.1: P8309, chapter 4 Model simulations: These simulations have been performed for a very limited subset of possible cloud scenes. E.g. only one kind of cirrus cloud particles has been taken into account. Could you explain, why this restricted amount of simulations should be representative for the large global variability of macro- and microphysical cloud parameters?

- **A very low optical thickness of 0.01 (subvisual) for ice clouds was chosen to cope with the variability of geometrical cloud parameters like radius. The global average cloud optical thickness is about 3.7 and we used 1.0 for water clouds that were mainly found over the oceans (see eg. MUELMENSTAEDT ET AL.: RAIN FROM LIQUID- AND ICE-PHASE CLOUDS, GRL 2015, Fig. S1). The size of hexagonal ice particles also has a very small effect on the CIR (e.g. doubling 1.68->1.67). The main reason is that the optical thickness is fixed. This also is the case for water clouds where a change in radii (half/double) has rather no effect on the CIR. But overall it is a great advantage of this wavelength range that we are nearly independent on the size expect for very small particles (see comparisons to MIPAS in case of volcanic aerosols).**
- **To give the reader more insight into different cloud/aerosol combinations, we added two more simulations.**

Q3.2: An empirical colour index ratio limit of 1.4 has been used for cloud top detection. However, I would like to have seen some examples on how the global distributions vary when changing this values within some reasonable boundaries.

- **Savigny (2005) made model studies for the UT/LS region testing the influence of volcanic aerosols on the CIR (Fig.3). He used a threshold of 1.3 which is good for most of the cases except for high volcanic aerosol levels. We now use 1.4 to reduce false detection of aerosols, but we still find the main volcano events at higher altitudes in our data. A reduction of the threshold would lead to more detections at lower altitudes.**
- **We tested a threshold of 1.5 and the effect on the annual mean was not pronounced. For most of the cloud detections the CIR is much higher than 1.4.**

Q3.3: In favour of the applied detection method it is argued that 'Due to the use of ratios the radiance calibration was not necessary as all multiplicative and height-independent calibration errors cancel out.' However, I would like to see at least a list of possible known issues with the measurements which could have an influence on the cloud detection scheme..

- **It turned out that additive effects cannot be neglected. Stray-light has influenced measurements in the northernmost latitudes when the SZA is high and the SAA low and the sun shines onto the instrument (see e.g Langowski, 2015).**

Q3.4: The tangent points in the figure are positioned exactly in the vertical. However, there is some horizontal displacement due to the limb-scanning. How large is this and could it be indicated in the Figure?

- **As the figure is only a simplified diagram, it is not feasible to add the horizontal displacement. But it is now mentioned in the text. The tangent point of the line-of-sight moves towards the instrument, when measurements are made from below the ground to the upper atmosphere. At the same time the instrument moves so that the tangent points are shifted. These two effects are in opposite directions so that the net displacement of the tangent point is rather small. E.g. SCIAMACHY measures a**

latitude/longitude of 20.32/147.12° at 1.8km and at 20.05°/147.53° at 18.2km. That is a displacement of roughly 0.27° (30km) in latitude and 0.42° (46km) in longitude.

Q3.5: With this term scattering would restricted to spherical particles only but cirrus clouds are definitely no Mie scatterers.

- **Mie theory is used for spherical particles. More complex structures like cirrus cloud particles can be approximated by using ellipsoids with the same volume or surface. Ice crystals of cirrus clouds were modelled as hexagonal prisms (Rozanov, 2014, Fig.9) with 50µm width and 100µm height. This is clarified in the paper.**

Q3.6: Please define 'h' and 'l' clearly – high and low wavelengths or frequencies?

- **Defined in text.**

Q3.7: P8307L23: This is similar to a gradient, why would it not be adequate to attribute the ratio to an altitude between z_th and z_th + delta z_th rather than to z_th?

- **Yes, that is a possibility. That would introduce another height grid which we wanted to avoid. Also z_th is the height around which the FOV is situated.**

Q3.8: P8308L2, 'where the cloud top z_ct is within the field of view': The cloud top can also be slightly above the field of view, just not reaching the FOV of the following tangent height.

- **Yes, there is a gap between two consecutive FOVs due to the instruments characteristics. The sentences have been changed to address this point.**

Q3.9: P8308L5, 'as all multiplicative and height-independent calibration errors cancel out': It would be good to state also which known instrumental errors of SCIAMACHY are still relevant here.

- **Errors due to unknown factors can be broadband spectral features from atmospheric parameters e.g. surface albedo and aerosols.**
- **Additive errors like stray light mainly in the northern hemisphere do not cancel out.**

Q3.10: P8311L23: Please indicate the source of the single-scattering properties of the cirrus clouds. Are those assumed to be randomly oriented? I would be interesting also to test different sizes and a size-distribution of particles.

- **Specifics to ice clouds in SCIATRAN are found in Chapter 6.4 (Rozanov et al., 2014). Particles are randomly oriented. Optical characteristics are calculated using geometrical optics approximation. Ice refractive index from Warren and Brandt. Hexagonal prism 50µm/100µm. The change of particle sizes has neglectable influence on the colour index ratio. The size distribution is given by SCIATRAN.**

Q3.11: P8312L1, 'A total aerosol optical thickness: : :': Could you be a bit more specific about the range of realistic aerosol optical thicknesses and their variability to be able to judge on the validity of the used values

- **Added references on AOT for ocean and land (Remer, 2008). Extremely high values over polluted areas (AOT>0.4) were not taken into account for the tests.**

Q3.12: P8312L7, 'In Fig. 6 calculated colour index ratios are shown': Are those the colour index ratios at the position of the clouds? Please specify.

- **The CIR is calculated at the retrieval height grid corresponding to the tangent heights of the instrument every 3 km. The text and the figures were corrected.**

Q3.13: P8312L23, 'But a CTH at 3 km was not detectable': This test has not been shown as a figure and described above. It should be made clear that this is not visible from Fig. 6. It would be good to show a corresponding figure, e.g. in a supplement.

- **Figure was extended for this reason to cover all interesting cases like very low water clouds. Also the CIR as function of tangent height and sun zenith angle will be added to the supplements.**

Q3.14: P8313L8, 'The influence of CTH changes on the CIR theta was also tested': This is a bit a strange order since now the tests of CTH changes are described. It would perhaps make more sense to mention these tests before (at least before the previous paragraph).

- **We mentioned the CIR dependence on height already in the new figures and add a figure to the supplement.**

Q3.15: P8313L8, 'clouds down to the Earth's surface': Have mountains been excluded from the could-detection?

- **They have not been excluded but as SCIAMACHY mainly detects clouds above 5km except for some oceanic regions (see Fig.7a). The arguments in this section are for the model studies. To make this more obvious to the reader the paragraph has been rephrased.**

Q3.16: P8317L12, 'The fractions are calculated by comparing the number of clouds in that layer with the number of all measurements.': Is this really a cloud fraction or rather a 'cloud-top fraction'? How do you count tangent altitudes below a cloudy altitude: cloud-free or excluded from the calculation? The explanation should be more detailed here.

- **When fraction means a part of an area it is not the best choice for this value. All CIR measurements were taken for a given layer between two atmospheric levels and when the threshold is reached, it is set to 1, otherwise 0. Then a mean is calculated from all measurements giving a mean occurrence frequency [%]. Off course this is more like cloud top fraction, as a cloud is not taken to reach from its cloud top to the ground. So have areas like in the tropics where the high cloud tops shield what is happening below. This will be improved in the paragraph.**

Q3.17: P8318L1, 'But CALIPSO detected no enhancement of cloud fractions over Northern Africa, which indicates that SCIAMACHY possibly detected an enhanced aerosol layer in this region.': Could you confirm this by using the CALIPSO aerosol product?

- **Liu et al., 2008 (fig.2 and 3) showed that aerosols have high occurrence rates over northern Africa corresponding with a rather cloud free scene. Thus SCIAMACHY have measured the dust layer of this area. Corrected and referenced in text.**

Q3.18: P8318L5, Fig. 9c: 'The cloud fraction in the northern hemisphere': In Fig. 9c north of 70deg N there are very high cloud fractions which are not visible at other altitudes (orange-red colours). Might this be a measurement issue?

- **The high values do not appear in the South. Taking Fig. 8a into account, it is due to the viewing geometry. In the northern hemispheres we are in the range of forward scattering where the sun shines directly onto the instrument. Thus the measurements are affected by stray-light. We updated all figures by excluding the first four limb states. This shows a reduction of high values. But this is not be enough to fully get rid of this effect.**
- **Reference added and text adapted.**
- **See: Langowski, M. P., von Savigny, C., Burrows, J. P., Feng, W., Plane, J. M. C., Marsh, D. R., Janches, D., Sinnhuber, M., Aikin, A. C., and Liebing, P.: Global investigation of the Mg atom and ion layers using SCIAMACHY/Envisat observations between 70 and 150 km altitude and WACCM-Mg model results, Atmos. Chem. Phys., 15, 273-295, doi:10.5194/acp-15-273-2015, 2015.**

Q3.19: P8318L20, 'The global colour index ratio': How was this determined / which tangent altitudes were used?

- **We used CIR of every detected cloud within a month for tangent heights from the bottom to 25 km.**

Q3.20: P8322L2, 'We have used a MIPAS verification dataset with measurements from January 2008 to March 2012.': Why have you not used the whole overlapping MIPAS and SCIA period?

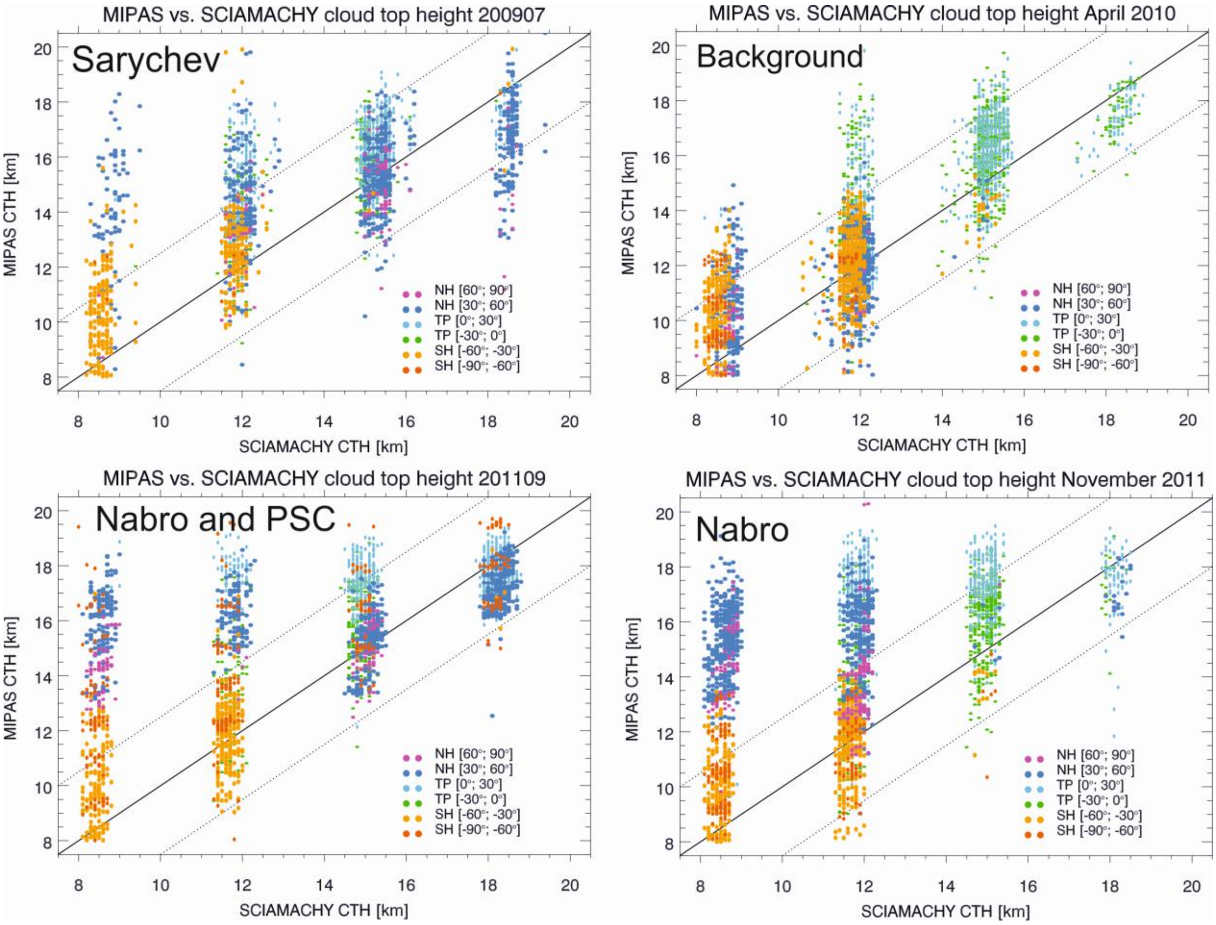
- **MIPAS data was not available for the full period as it had some instrumental problems until December 2007, when it was at 100% duty cycle again. (see e.g. https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/mission-highlights). We decided to only use those measurements starting in 2008.**
- **Mentioned in text.**

Q3.21: P8322L14, ‘This is the region where the lowest possible MIPAS tangent heights were at about 10 km, which can partly explain the differences.’: I don’t understand how this explains the differences at around the 12 km and the 14-16 km SCIAMACHY CTH block in Fig. 14.

- **Correct, not understandable. The paragraph was changed taking into account the water vapour influence on MIPAS results (Greenhough, 2005).**

Q3.22: P8323L24, ‘It has to be noted that the very high CTHs at the end of 2011 were only detected with SCIAMACHY. But also MIPAS measured higher clouds on average during this period.’: This is not clear. How does the comparison look like in this period/latitude range for the co-incident observations?

- **That was unclear and has been rewritten in the paper. A figure showing comparisons from November 2011 will be added to the supplements. MIPAS is more sensitive to the aerosol layers in the lower stratosphere. So while SCIAMACHY already detects the lower clouds again after the larger particles were already sedimented out of the layer, MIPAS still detected aerosols in the northern hemisphere.**
- **The paragraph was restructured.**



Q3.23: P8324L24, ‘The volcanoes emitted sulphur dioxide into the troposphere : : :’: However, direct emission of SO2 into the lower stratosphere cannot be excluded (see e.g.: Pumphrey et al., 2015 (www.atmos-meas-tech.net/8/195/2015/), Höpfner et al., 2015 (www.atmos-chem-phys.net/15/7017/2015/)).

- **OK, changed.**

Q3.24: P8327L21, ‘be explained by differences in the tangent height steps’: Could you suggest other reasons? E.g. the setting of the cloud threshold parameters in case of MIPAS and SCIAMACHY and sensitivity issues between mid-IR and NIR/vis?

- **Yes, sensitivity to aerosols of different size and material seems to be influencing the results as was seen in the Nabro case. This might be further analyzed but is beyond the scope of this paper.**

Technical comments

Q3.25: ‘limb state’, ‘measurement state’: The term ‘state’ is used but has not been defined clearly. It should be clear what is different from a limb-scan.

- **That means the same. For clarity only limb state is now used and defined in the paper.**

Q3.26: P8312L23: ‘clouds tops’ -> ‘cloud tops’

- **corrected**

Q3.27: P8314L26: ‘it leave’ -> ‘it leaves’

- **corrected**

Q3.28: P8317L23: ‘at the height range’: Which range?

- **Paragraph was restructured, height range identified**.

Q3.29: P8318L27: ‘1551 / 1090 nm’ -> ‘1551 nm / 1090 nm’ , also @ P8319L2.

- **Corrected.**

Q3.30: P8321L23: ‘blue dashed line’ Really blue? Isn’t it more black or dark violet?

- **That line is really dark violet; changed text.**

Q3.31: P8336: Please indicate the date of the orbit in the caption.

- **The original orbit number was not stored so use the orbit 24381 and adapted the numbers accordingly in the table. This was also changed in the Fig.6. Furthermore we now have plotted the western and eastern azimuth angles of the four profiles to show more clearly the range of geometry combinations**.

Q3.32: P8352: Could you indicate the eruption dates in the figure?

- **Added the starting month of the eruptions as black vertical lines in the figure.**