Answers to Anonymous Referee #2

General comment.
The topic of retrieval of global cloud properties from satellite observations is very relevant to climate studies. Homogeneous and accurate long time series of clouds are needed to detect possible trends and can be used as observational constraints of climate models. Therefore, the topic of this paper is relevant to AMT. However, the paper has serious shortcomings regarding missing references and comparisons to other relevant research and the questionable values of the reported global cloud results. Therefore, it cannot be published in its current form. Below specific comments are given.

> Specific comments. The main shortcomings are: (1) Results section: no reference is made to other published results from important cloud remote sensing satellite projects and instruments, like ISCCP, MODIS, AVHRR, HIRS, A-train etc.. The GOME data should be compared to other relevant data sources on clouds.

(A.1) In the new draft the introduction will be rewritten and appropriate references will be given.

> (2) The reported global mean cloud top height of 7 km seems much too high, given the fact that thin high cirrus clouds cannot be detected in the visible with GOME using the O2 A-band.

(A.2) Firstly we have extended the analysis from December 2002 until June 2003, in order to preserve the annual cycle and fully exploit GOME functionality. Secondly, we have reanalysed (not recalculated) the dataset, applying a different set of filters, as we discussed in the answer A.1 to Joiner. This reanalysis affects all the plots (which have been redrawn accordingly) and the results that the referee noted as flawed. The new global mean CTH results in 5.6 $\pm$ 1.8 km (variance).

> (3) The lack of low clouds, below about 2 km, in the presented GOME data set indicates a serious algorithm problem. The missing low clouds are clear from Figure 11 and especially from Figure 13. The ratio of low, middle, and high clouds shown in Fig. 13 is completely different from what is currently known from the literature. This has to be explained, especially because of the limited sensitivity of GOME to high clouds (for which thermal IR sensors are needed) and its strong sensitivity to low clouds which are very reflective in the visible and near-IR, which is the spectral range used by the algorithm. If low clouds are missing in the algorithm, the global mean results do not make sense.

(A.3) The referee made a good point. All our reanalysis is based on this consideration and on the statistics of the 7 years SNGome dataset. Special attention is given to screen multi-layer scenes (please see response to Joiner/A.1) and unrealistic clouds with COT $>$ 400 are filtered. Eventually, the results of the reanalysis can be seen in Fig.5 in response Joiner/A.7 and Fig.6 in Joiner/A.8.

(4) In order to retrieve CTH at wavelengths where multiple scattering is important like the O2 A-band, the geometric thickness L of the cloud should be either retrieved or assumed. In section 2, page 4997, line 4, L is mentioned, and there it is said that it is retrieved. However, in the paper no error analysis of the retrieval of L is given and no results of L are shown or mentioned. Does the retrieved value of L cause the deviating (too high) CTH?

(A.4) In fact, the cloud geometrical thickness is retrieved. The value L is neither assumed nor fixed, but reflects the transmission of light through a single-layer cloud, and must be allowed to vary. The error analysis for CBH (therefore for L) has been reported in Rozanov and Kokhanovsky [2004] and Lelli et al. [2011]. What we see is that, in the single-layer model, the retrieved values are accurate and stable for τ in the range [5-50]. As reported in the answer A.1 to Joiner and for some cases in Rozanov and Kokhanovsky [2004], too high L values correspond to multi-layer systems and are now filtered out. Please see also point A.3 in the response to Joiner.

(5) The retrieval model discussed in sect. 2, page 4995, is only valid for water clouds, since the assumed asymmetry parameter g is 0.859 (line 22) whereas ice clouds have a much smaller g. What is the quality of the SNGome retrieval for ice clouds? How does this affect the global mean of cloud properties reported in the paper?

(A.5) In the single-layer approximation, we expect a stronger backward scattering peak for an ice cloud, due to the irregular shape of ice crystals, as compared to water droplets. This implies an increase in the reflection function at nadir, which means an overestimation of CTH. This effect can be seen comparing the two plots of the synthetic study in the answer A.1 to Joiner. The retrieved CTH curve is steeper in the ice case scenario than in the water one. This would increase the global mean of CTH. Besides, we do not process L1 reflectances lower than 0.15, therefore CI are excluded. However, low-level ice clouds (even in mixed-phase) are included in the statistics.

(6) Looking at the zonal mean results of clouds given in Table 7, it appears that if this would be true, the Earth's albedo would be much higher than currently known! By multiplying a cloud fraction CF of about 0.8 with a cloud albedo CA of about 0.6 a value of 0.48 is obtained for the global mean albedo of the Earth caused by clouds. After adding a contribution from the clear sky albedo, this would mean a global mean albedo of about 0.5, which is much higher than the currently accepted value of 0.3 (e.g. Trenberth et al., BAMS, Volume 90, 311 Ð 323, 2008). This is a fundamental problem with the zonal mean cloud results of this paper.

(A.6) We address points 6 and 7 together. Please, see answer A.7.

(7) A possible explanation of the above mentioned deviating results could be that the retrievals of the paper do not belong to all clouds, but only to the thickest clouds, for which the asymptotic relations used in the

SNGome algorithm hold. But this rises the question what the zonal and global mean values refer to.

(A.7) This is certainly true. SNGome holds for clouds with $\tau > 5$ and this has to be kept in mind. Another limitation is the GOME spatial resolution. Horizontal and vertical variability of clouds can introduce systematic biases in cloud albedo. An heterogeneous cloud (which is likely to be sensed by GOME) has always a lower albedo than its homogeneous counterpart, both having the same optical thickness. Thus, treating real clouds as plane-parallel slabs, leads to higher albedos.
On the other hand, we speculate that a positive trend in aerosol optical thickness over ocean, as reported by Thomas et al. [2010] (Table 4, p.4861), impacts cloud albedo through a decrease in mean cloud droplet radius. This effect has been already seen for weak volcanic eruptions over ocean [Gassó, 2008]. The negative correlations shown in Bulgin et al. [2008] between aerosol optical thickness and effective radius corroborate also this hypothesis. However, these results pertain only to oceanic regions, which are affected by continental aerosol outflows. Please note that the AOT signals in Thomas et al. [2010] and Bulgin et al. [2008] are derived from ATSR-2 measurements, therefore temporal and spatial co-registration with GOME are not an issue. AOT trends over land are not yet available in literature, due to missing sensitivity over bright surfaces.

The table with the updated values of zonal averages is reported below.

Region	CF	CTH (km)	COT	CA
35°N - 60°N	0.899 ± 0.182	5.31 ± 2.74	20.39 ± 15.09	0.641 ± 0.110
15°N - 35°N	0.738 ± 0.297	6.66 ± 3.66	18.27 ± 13.35	0.628 ± 0.103
0°- 15°N	0.701 ± 0.303	8.41 ± 3.80	18.29 ± 12.86	0.626 ± 0.100
0°- 15°S	0.732 ± 0.301	7.47 ± 3.96	17.18 ± 11.91	0.615 ± 0.096
15°S - 35°S	0.776 ± 0.272	5.88 ± 3.53	15.34 ± 10.94	0.592 ± 0.091
35°S - 60°S	0.883 ± 0.182	4.88 ± 2.64	18.78 ± 13.64	0.628 ± 0.103

Other specific comments Title and throughout the paper: the name GOME-1 does not officially exist: it is GOME on ERS-2.

(A.8) Corrected throughout the manuscript.

Abstract, line 7: mention that the results of the paper only hold for optically thick clouds, since asymptotic relations are being used.

(A.9) Mentioned.

Abstract line 14 and throughout paper: the average cloud top height of 7 km is very high. This seems to be unrealistic. There is no other basis for this high CTH value.

(A.10) Please, see answer A.2. The actual value is now 5.6 ± 1.8 km (variance).

Introduction: references are too scarce. Mention that clouds are usually better studied with imagers (with spatial resolutions of the order of 1 km) than the coarse resolution spectrometer GOME. Mention relevant studies of these imagers. Give arguments why a study of clouds with GOME is nonetheless relevant.

(A.11) This part will be rewritten in the new draft.

Section 2, p.4993: Here also reference is needed to the FRESCO cloud algorithm for GOME, as published by Koelemeijer et al. (JGR, 2001, 2002), Wang et al. (ACP, 2008) and available as GOME cloud product via www.temis.nl.

(A.12) This will be referenced to in the new version.

Section 2, p. 4994: line 3: this depends on the height of the cloud line 6: single scattering albedo: do you mean plane albedo?

(A.13) Corrected: single scattering $\rightarrow$ plane.

Line 10: middle of the cloud: refer to the earlier papers on this topic, e.g. Sneep et al., JGR, 2008. line 20: mention the GOME spatial resolution

(A.14) Corrected.

p. 4996: line 5: what does the algorithm do with clouds which have optical thickness < 5?

(A.15) The algorithm does not perform any retrieval and sets the parameters to the initial values, flagging the retrievals 0. For the meaning of flags, see answer A.11 to Joiner. In principle, the semi-analytical approach of SACURA can be extended in the thin cloud regime generating LUTs, which allows us find the CTH via interpolation, for a given geometry and radiance. However, due to the coarse pixel size of GOME, clouds with $\tau < 5$ would be highly inhomogeneous in the horizontal direction anyway.

p. 4997: line 4: which equation yields geometric thickness L in the retrieval algorithm?

(A.16) Equation 8, Sec. 2, p. 4997. Please, see also point A.7 in response to referee#1.

p. 4997, line 23: where is the aerosol information in the cloud retrieval coming from?

(A.17) We employ the clear sky aerosol model MODTRAN 2/3-LOWTRAN 7 as reported in Kneizys et al. [1996].

p. 4999, line 3: please discuss here the results shown in figure 3.

(A.18) From Eqs. 64 and 65 in Kokhanovsky et al. [2003], the error that a non black surface A introduces in the determination of τ follows

$$\frac{\partial \tau}{\partial A} = \frac{1}{-\frac{3}{4}\,(1-g)\,(1-A)^2}.$$

Given the input COT of 20 (as in Fig. 3) and the range of solar zenith angles where no bows are expected, only the influence of A affects the total error $\Delta\tau$, whereas the other terms of Eq. 64 will not. As a result the COT will be exclusively underestimated. In regions where a difference in phase functions between forward and inverse problems can be assumed, the successive terms will contribute and sum up to the total $\Delta\tau$. With SZA $\rightarrow 90°$, the increased lightpath through the atmosphere weakens the assumption of the plane parallel geometry of the SACURA approach.

> p. 5001: line 17: please show the results of COT in a figure or discuss them more quantitatively in the text. The COT is very relevant to the spherical albedo given in Table 7.

(A.19) In answer A.5 to Joiner, we discuss in more details the shallow clouds outliers and their relation to COT.

> p. 5002, line 2ff: four orbits of GOME data is statistically insufficient to give a quantitative quality assessment. Furthermore, the smaller pixel size of these four orbits is not representative of the pixel size of the global GOME data set that is the topic of this paper.

(A.20) These orbits have been chosen for the availability of the results for comparison and in view of the fact that the follow-on spectrometers in the family (SCIAMACHY and GOME-2) have a similar spatial resolution.

> p. 5002, line 25: Figure 6 shows large differences in CTH of several km between the two GOME cloud data sets; this should be discussed.

(A.21) We address this issue with answer A.35.

> p. 5003, line 15ff: Comparison to earlier results is needed. Please give here appropriate references to cloud results of other groups, and compare your results. Zonal and global mean cloud results from GOME have been published before by Loyola et al. (2010), International Journal of Remote Sensing, 31:16, 4295-4318.

(A.22) We present the global comparison for CTH, COT and CA derived by SNGome and ROCINN for the 7 years of measurements. Firstly, the ROCINN curves are slightly lower than the ones presented in Loyola et al. (2010). We don't have enough informations about the applied selection. Especially for CTH, in Loyola et. al (2010) the maximum in the tropics is ≈ 1 km higher. SNGome, as compared to the first draft, is lowered by ≈ 1 km or even more for all latitudes. We will discuss the issue in more details in the revised manuscript.

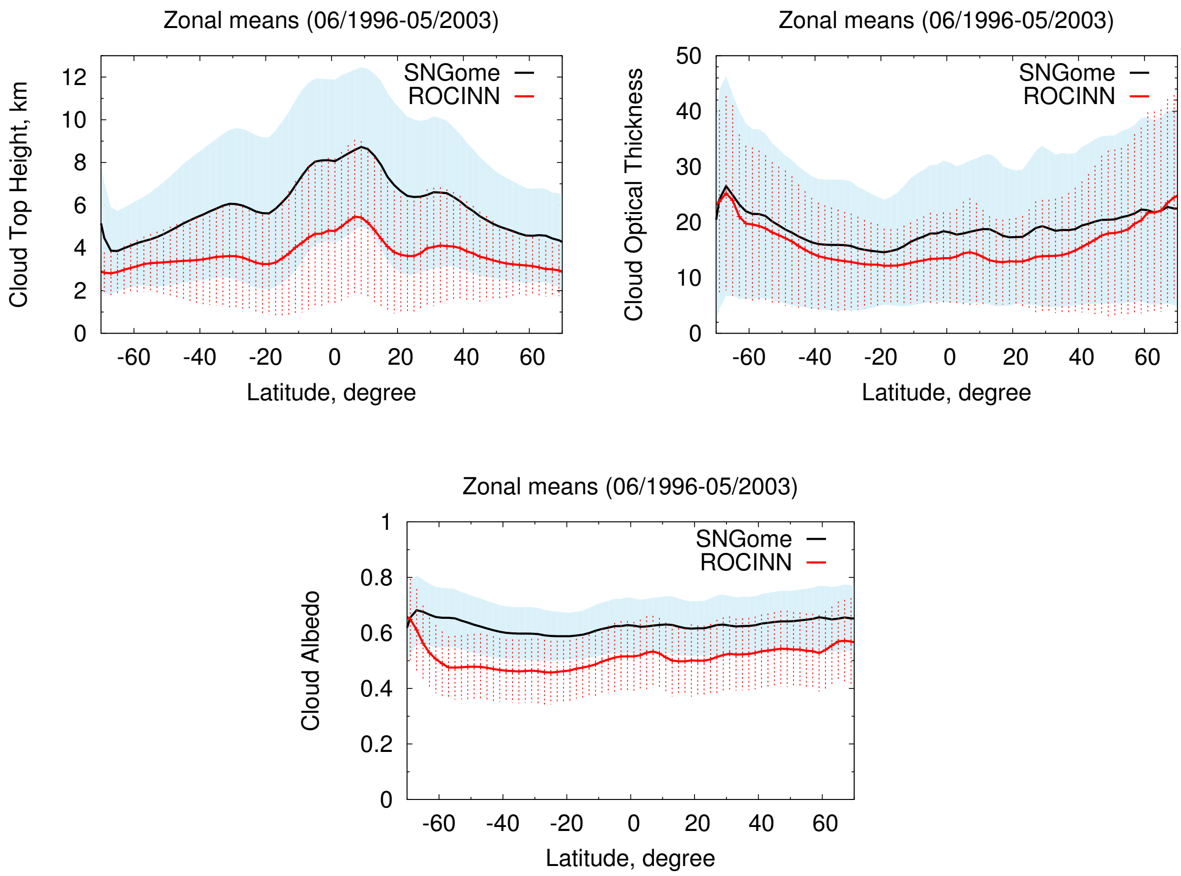


Figure 1: Zonal mean values (and standard deviations) from SNGome and ROCINN for the time window June 1996 - May 2003. Upper left plot: cloud top height. Upper right plot: cloud optical thickness. Lower plot: cloud albedo.

p. 5003, line 27: please use the term "marine stratocumulus clouds", which is the most reflective and abundant low cloud type, typically at an altitude of 1-2 km.

(A.23) Corrected.

p. 5004, lines 10-12: it is a serious algorithm problem if it cannot detect the low clouds which are the most reflective. See earlier comment (3).

(A.24) We have addressed this issue applying a different set of filters.

p. 5006: the study seems to show that the global mean cloud height is that of high clouds, above 6.5 km. This conclusion should be verified by a lot of independent satellite and groundbased information, otherwise it is not acceptable.

(A.25) The mean CTH value, with the new screening, is updated to 5.6 $\pm$ 1.8 km.

p. 5007, lines 21-24: this CTH comparison of GOME with SCIAMACHY is not an independent one, since the same (or a very similar) algorithm was used. The global mean CTH of 7 km has to be confirmed by independent information.

(A.26) Appropriate references to global values of other missions are given in the new draft. The mean global CTH value has been updated, as discussed throughly in the present response.

Specific comments to tables and figures: Table 1: ERS-2 with GOME on board was switched off on 4 July 2011.

(A.27) Corrected.

Table 3: mention the ARM project.

(A.28) In these regard, we describe in more details the data selection and the instrumentation used in the ground-based comparison, following the guidelines of Joiner, answer A.5.

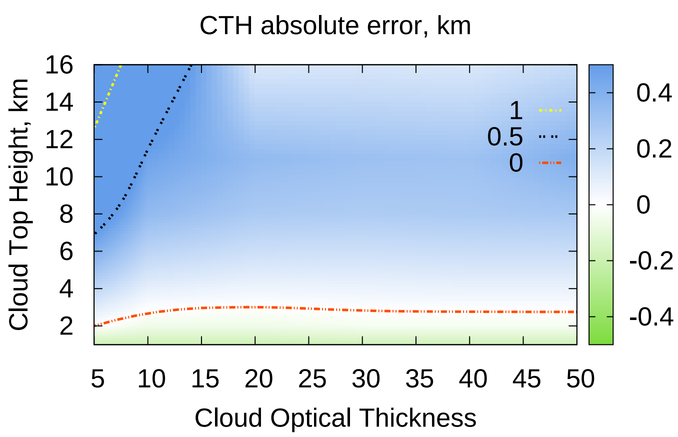
Table 4 and 5: give the number of data points used in the comparison; this indicates the significance of the comparison.

(A.29) Added.

Table 4: define deep and shallow clouds; define the bias. Table 5: define the bias.

(A.30) Corrected.

Figure 1: use a smaller CTH error range to see a larger range of colours and more structure in the plot. To which geometry do these calculations pertain?



(A.31) For this error analysis the following geometry was set: VZA = 0° (nadir view), SZA = 60°, RAA = 0°.

Figure 2: this figure is dominated by strange algorithmic features; please remove this plot.

(A.32) The plot has been redone. Please, see also response to referee#1, points A.16 through A.18.

Figure 3: is very unclear.

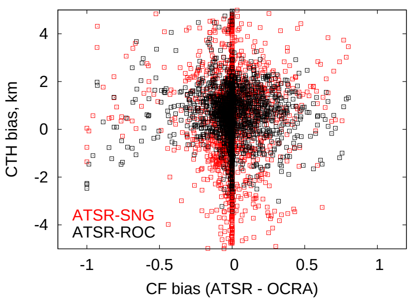
(A.33) See discussion A.18 about the cloud optical thickness.

Figures 4 and 5: mention the number of cases; define deep and shallow.

(A.34) Number of cases augmented and mentioned. The definition of "deep" and "shallow" has been given at line 20, p.5000. We stress the fact that these terms refer only to the physical vertical extent of the clouds and do not refer to the customary "deep convective" systems. The terminology has been adopted for consistency with Sayer et al. [2011].

Figure 6: Please show all three CTH products: SNGome, ROCINN and ATSR, so that the reader can compare the three. Please also show the cloud fraction CF itself, and not only the difference ATSR-OCRA.

(A.35) For just one orbit such a plot would be illegible, due to the high variability of the data along track. Furthermore, applying a running mean filter on the datasets, would smooth the CTH values and alter the real features. On the other hand, the focal reason for the figure was to show that the CTH bias of the two O_2 A-band algorithms is not correlated with the CF bias (ATSR CF - OCRA CF) shared by them. This is an indirect corroboration of the validity of the Independent Pixel Approximation (IPA) as well. Thus we present here two new plots for all four orbits, where this effect can be seen. OCRA itself slightly overestimates CF compared with ATSR. It can be understood through the higher spatial resolution of ATSR, which resolves finer patterns of cloudiness. There is no evidence of a CTH bias cluster in the plot against IR retrievals, for both O_2 algorithms.
The comparison between SNGome and ROCINN discloses a cluster of retrievals where CF underestimation leads to a slight CTH overestimation. This cluster corresponds to low-level clouds (answer A.36, plot 2(c)) of 2-3 km height. Being all parameters equal for SNGome and ROCINN, this bias can be explained through the enhancement of radiation backscattered to the platform, because of the higher fractional cloud cover. Only in this scenario the assumption of a Lambertian cloud model leads to CTH overestimate, with respect to a model where multiple scattering is taken into account.



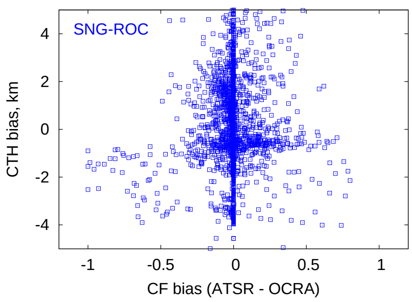


Figure 6: It would be useful to show the correlation between the three CTH products for all data points of the four orbits.

(A.36) In the following figure the scatterplots and relative correlations among the three algorithms are given. We underline that ROCINN algorithm is based on a neural network approach, which relies on the beforehand training of its components and offers a limited space of solutions, whereas SACURA makes no assumption for the sensed scene.

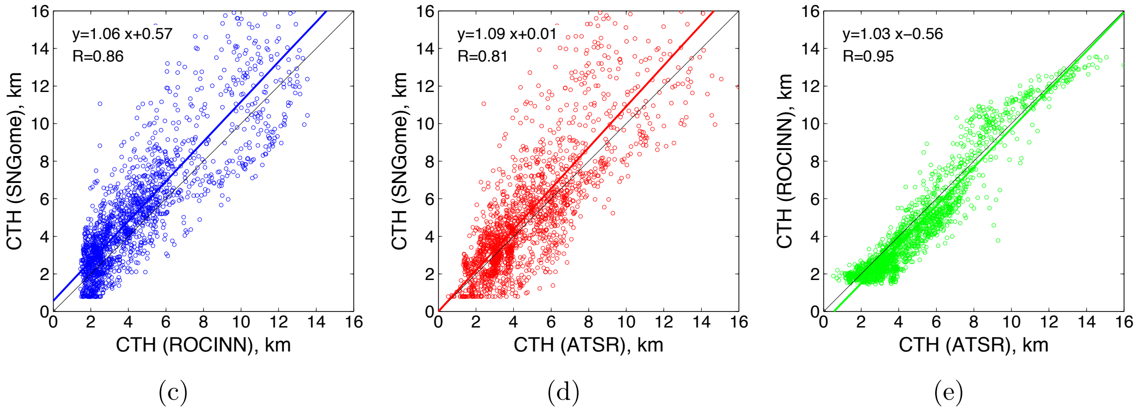


Figure 2: Scatterplots and correlations among the three CTH products.

Figure 7: indicate the months in each subplot.

(A.37) Plots updated and labeled.

Figure 11: indicate in the caption: North = 0 - 70 deg N, South = 0 -70 deg S.

(A.38) Caption added.

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