Response to Referee # 1

black = comments referee
blue&bold = response

The authors describe a daytime cloud property retrieval algorithm using measurements from the instruments AATSR and MERIS onboard ENVISAT. In fact, three algorithms, one for cloud optical thickness and particle effective radius as well as two for cloud-top height, are introduced. The retrieval approaches are generally clearly described and appear to be sound. Evaluation results are mixed but appear to be comparable to what is commonly found for cloud properties derived from passive imagers. The authors are encouraged to more explicitly outline the novel features of their algorithms, because there are many similar algorithms around. One such feature could be the synergy between two instruments, but I do not really get this synergy from the manuscript (except that radiances reprojected on the same grid as well as a synergistic cloud mask are used as input). It seems there are two stand-alone algorithms for AATSR and one for MERIS. Thus, there are actually two independent cloud-top height products instead of one synergy product, which may leave the reader wondering which one to use. Perhaps the outlook could be extended to give at least some ideas for synergetic products, e.g. cloud vertical extension. Another novel aspect, that may be worth some more attention, is the use of vertical extinction profiles from CloudSat observations for the cloud-top pressure retrievals.

It is true that in the first version of FAME-C the synergy lies mainly in the cloud mask, but also in the use of the AATSR derived COT as input in the MERIS-CTP retrieval. It was made more clear in the text that there are two independent cloud top height retrievals. In Sect. 5.2 discussion on the results was extended including more information on the differences of these two cloud top height retrievals in different cloudy situations.

We plan to extensively study differences in AATSR and MERIS CTHs, and how the two independent cloud height retrievals can be linked to cloud vertical inhomogeneity. We consider this out of the scope for this manuscript, but it is mentioned in the outlook in the final section. A first step was made in a small study (Henken et al. 2013), also referred to in the manuscript. It was shown that the choice of the cloud vertical extinction profile for radiative transfer simulations, and computation of the LUTs, can significantly change the retrieved MERIS-CTP.

Specific comments response:

P4910: Acronyms should be written out in the abstract.
Acronyms are written out now.

P4910, L6-8: There is a problem with the use of the term micro-physical: cloud optical thickness and water path are macro-physical rather than micro-physical properties.
***micro-physical cloud properties* was changed to *optical and micro-physical cloud properties.* This was changed everywhere in the manuscript.**

P4910, L22-23: MODIS observations are not a true reference; therefore it is more correct to speak about root mean square difference rather than error.
We agree and therefore changed *root mean square error (RMSE)* to *root mean square deviation (RMSD).*

P4910, L19: Better to write agreement instead of accuracies.
Accuracies* was changed to *agreement.

P4910, L24: several suggests more than two sites.
More than two sites were used, since there are three TWP ARM sites.

P4910, L27: There is so much variation for so few data points, that I think this value of the bias is not meaningful (see later comment). Suggest to remove this from the abstract

Due to a new cloud top height comparison procedure, the numbers have changed. A better cloud top height reference (ARSCL) is taken and more cases are included in the comparison. We decided to keep the (newly computed) value of the bias in the abstract.

P4910: Do you have a conclusion on the MERIS versus AATSR cloud heights?

First conclusions are that for low-level clouds the MERIS cloud top heights show a low bias and RMSD, while for these clouds AATSR cloud top heights show an overestimation. For mid-and high level clouds AATSR cloud top heights clearly show a lower RMSD. MERIS vs AATSR cloud top height needs to be assessed in an in-depth study, especially for vertically extended clouds and multi-layer clouds. This is considered out of scope for this study.

P4911 and further: Acronyms should be written out at first occurrence in the manuscript (GEWEX, MODIS, CALIOP, ARM, etc.).

Acronyms are written out now.

P4911, L13-17: Suggest to mention first amount and height, and then the other properties. Also suggest to write cloud-top thermodynamic phase and effective radius, as well as particle instead of droplet to include also ice crystals.

We adjusted the text as follows: *From observations in the visible, near-infrared and thermal infrared parts of the electromagnetic spectrum cloud macro-physical properties, such as cloud amount and cloud top height, as well as cloud optical and micro-physical properties such as cloud-top thermodynamic phase, cloud optical thickness and effective radius, which describes the cloud particle size distribution, can be retrieved.*

P4912, L2-4: This was indeed an important finding but applies mostly to the differences between the group of sensors mentioned here and other sensors such as lidars and IR sounders.

We have changed the sentence, listing reasons for differences between retrievals for observations from the set of multi-spectral passive imagers.

The sentence was changed to:

Results show that differences in average cloud properties can arise due to ,e.g., retrieval filtering, ice-water cloud misidentification, assumptions on cloud particle shape and size distribution, and the set of spectral channels used in the retrievals.

Also the more up-to-date reference to the publication (same title) in the Bulletin of the American Meteorological Society (2013) is now taken.

P4912, L10: It should be AMSR-E on Aqua.

This was corrected.

P4912, L15: I believe ORAC did not take part in the CREW inter-comparison.

The ORAC reference was removed.

P4912, L18: A reference to the CREW CTH paper by Hamann et al., AMTD, 2014 might be appropriate.

The reference was included.

P4913, L26: These are not only visible but also near-infrared wavelengths.

This was corrected.

P4914, L5: AATSR has one more channel at 0.56 micron. Also, the central wavelengths of two of the mentioned channels are 0.7 (0.66) and 0.9 (0.87) instead of 0.6 and 0.8 micron, respectively.
This was corrected.

P4914, L15-16: Which data were used as truth cloud mask in the neural network?
A combination of simulated data and cluster-labeling in MERIS and AATSR images performed by an expert was used as training data for the neural network. This can be found in the references.

P4914, L18: Is cloud flag the cloud mask? Is cloud abundance a cloud fraction? If yes, is it also used in this study?
Sentence was changed to *...as well as the newly produced cloud mask.*
The cloud abundance parameter or cloud abundance index was a way to not only provide a cloud mask, but also a degree of cloud contamination per pixel. Since it is not a probability, we did not use this index. We removed the mentioning of it in the text.

P4915, L1: This seems strange since one expects the center wavelength to be fixed. On P4921-4922 it is explained (the spectral smile effect). I suggest to give this explanation already here.
The explanation is now given here, the text was extended to:
Furthermore, an empirical stray light correction was applied to the reflectance of the MERIS oxygen-A absorption channel (Lindstrot et al., 2010). For this correction, the spectral smile effect in the MERIS measurements (Bourg et al., 2008), which is the variation of the channel center wavelength along the field-of-view, as well as the amount of stray light in the MERIS oxygen-A absorption channel were determined.

P4915, L5: Again, the use of micro-physical is not correct here.
It was changed to optical and micro-physical properties.

P4915, L21-22: What do you mean with the wavelength dependency not being used in the text? I do see the wavelength appearing in most of the equations
It is used in the equations, but not in the text.

P4915, L14: Observed should be simulated. Also, the forward model equation (2) is not really at top of cloud because it does not consider in- and below-cloud absorption.
***Observed* was changed to *simulated*. The simulations are performed without atmospheric scattering and absorption, therefore in Eq. 2 it is the reflectance above the cloud without the atmosphere, but with lambertian reflecting surface. R_{toc} is now changed to R'_{toc}. Only R_{toc} in Eq. 5 is now the top-of-cloud reflectance taking into account atmospheric absorption below the cloud, by adjusting the surface albedo.**

P4915, L16-17: Couldn't Rayleigh scattering below the cloud be important for semi-transparent clouds?
We expect that Rayleigh scattering below the cloud, particularly for thin, elevated clouds, might be significant. However, we did not quantify the contribution of Rayleigh scattering below the cloud in the retrieval of the cloud optical thickness yet.
P4915, L22: What is meant with 'amount of extinction'?
For clarity, it was changed to: *the back-scattered signal due to single scattering events above the cloud, here only Rayleigh scattering in the visible channel is taken into account.*

P4917, L11: What does 'therefore setting the airmass to 2' mean?
For clarity, it was changed to:
The surface albedo, a, is adjusted to a so called virtual surface albedo , a_v, by

multiplying it with the atmospheric transmittance below the cloud. For the computation of the atmospheric transmittance a diffuse radiation field below the cloud is assumed, which means an air mass factor of 2 is used.

P4917, L6-10: Write out the equation used for transmittance with the coefficients from Table 2.
An Equation was added.

P4918, L4: what kind of observations?
The sentence was removed. Type of observations can be found in the reference.

P4919, Eq. (8): The notation appears to be inconsistent. Why T_ct instead of T_c as in L15-16? Why t_ct-1 instead of t_a as in Eq. (3)?
The T_ct inconsistency was corrected. t_a in Eq. 3 is the two-way transmittance above the cloud, in Eq. 8 it is the transmittance from cloud top to TOA.

P4922, L11-13: To pick one of the extinction profiles from the ISCCP classes, a cloud-top pressure is needed. What is used?
In the radiative transfer simulations a number of cloud top pressures and cloud optical thicknesses were used to create LUTs. Depending on the combination of those two, one of the nine derived cloud vertical extinction profiles in the simulations was assumed.

For more detail on how the extinction profiles are used, the text was extended to:
In the radiative transfer simulations of the MERIS channels 10 and 11 radiances the cloud is divided into a number of cloud layers, each with a thickness of 20 hPa. The appropriate extinction profile, and thus the extinction of each cloud layer, is selected according to the ISCCP cloud classification. This means that the layer cloud optical thickness is different for each cloud layer, while it would be taken constant for all cloud layers when assuming a vertically homogeneous cloud. The total cloud optical thickness is taken from the cloud optical and micro-physical property retrieval.

P4922, L20: It seems the resolution of ERA-Interim is 0.8 rather than 1.125 degrees.
Our ERA-Interim data, provided by Deutsche Wetter Dienst (DWD) within the ESA Cloud CCI project, is on the 1.125 degree resolution. We are aware that now higher resolution ERA-Interim data is freely available, also for atmospheric profiles, and we plan to use those in following FAME-C versions.

P4923, L12: DCHP gives the impression of being one algorithm, but it seems that these are actually two independent OE algorithms (both with a 1-element state vector). Is that correct, or is there any connection?
In this algorithm version, two independent OE retrievals are used. Plural is used in the sentence, i.e., cloud top height properties. For clarity, the sentence was changed to:
Last, two independent cloud top height retrievals ..

We now also use *DCHP-A* and *DCHP-M* in tables 2 and 3.

P4923, L22-23: I would say that optimal estimation can be cast as a minimization of a cost function.
For clearity the sentence was changed to:
In short, the inversion technique aims to minimize the retrieval cost function J given as:..

P4924, L10: K is not the averaging kernel but the weighting function matrix (or Jacobian), i.e. the derivative of F to x. Also, y are observations which by definition do not depend on state parameters.
The wrong naming and explanation of K was corrected.

P4924, L14-15: Add that the observation errors should also obey a Gaussian distribu-

tion. And again, the measurements do not depend on the state parameters.
This was added to the sentence.

P4925, L4-5: Same comment as above.
The wrong naming and explanation of K was corrected.

P4925, L12: Optimal estimation is a maximum likelihood method (independent of the weight given to the prior).
The last part of the sentence was removed.

P4925, L14-19: This is a bit confusing. Is a new cloud phase category 'uncertain' introduced here? If so, it is better to do this on P4918. Also, explain more clearly which LUT (water or ice) is used to retrieve COT-REF for this phase category, and how exactly the forward model parameter uncertainties are set.
Each pixel keeps its original cloud phase as labeled with the simple cloud phase discrimination, either water or ice cloud. However, for those pixels falling within a certain brightness temperature range and with a certain reflectance pair that fits within both our water and ice LUTs, we add a "uncertain phase" flag and compute both the water cloud forward model parameter uncertainty and the ice cloud forward model parameter uncertainty.

This was explained inadequately in the text and was changed to:
For certain pixels that have reached convergence, we take into account the uncertainties due to the rather simple cloud phase discrimination. This is realized by adding the difference in forward model values between the water cloud and ice cloud, keeping everything else constant, to the measurement error covariance matrix. This is done for pixels with...

P4927, L22: Agree very well with what?
For clarity, the sentence was changed to: ***The FAME-C REF values agree very well with the MODIS -TERRA REF values for NAM.***

P4927, L25-26: Use the word difference instead of error, because MODIS is not a true reference (so this is rather an inter-comparison, not a validation)
The word *error* was everywhere replace by *deviation*.

P4927-P4928, discussion of Table 3: A limitation of these comparisons appears to be that the portions of the sky being cloudy or having a certain cloud phase may be quite different, in particular for the uncertain-phase class. This affects the other statistics, and should be clearly mentioned in the paper.
For clarity we added the sentence: ***It should be emphasized that the cloud fractions and the fraction of clouds with a specific phase, in particular cloud phase uncertain, for FAME-C and MODIS-TERRA can be quite different, and consequently this will affect the statistics of the other cloud properties.***

P4928, L15: The meaning of REF and REF16 is not explained.
We added *REF* and *REF16* in brackets for MODIS-TERRA.

P4929, L18-23: Why are not the standard ARM cloud-top heights used? Also, explain why the mean Doppler velocity is used.
The comparison is now performed using the standard ARM cloud top heights (arsclbnd1cloth)

P4930, L1-2: Why does the MERIS retrieval fail more often?
The MERIS retrieval fails more often because often it does not converge before the maximum number of iterations given beforehand. In the radiative transfer simulations we used the CloudSat derived cloud vertical profiles for nine different cloud types. This means, however, that the LUT is not smooth everywhere, due to jumps into a different

cloud type regime, and this sometimes leads to no convergence. For the FAME-C version presented in this manuscript, we did not include a method to deal with this problem. Options are to smooth the locations in the LUT where the jumps take place and to improve our first guess.

We extended the text to:
We assume this difference in cases between both cloud top height retrievals to be partly related to the fact that at the moment the MERIS cloud top pressure retrieval tends to fail more often than the AATSR cloud top temperature retrieval, and is related to the use of the different cloud vertical extinction profiles derived from CloudSat data for different cloud types in the radiative transfer simulations used to create the MERIS LUT. This leads to jumps in the LUT at the cloud type transitions. It is envisaged to deal with this issue in future versions of FAME-C.

P4930: discussion of Fig. 8: The smallest bias is obtained for AATSR for single-layer clouds (as quoted in the abstract). However, this small bias is to a large extent a compensation of large positive bias for two low cloud cases with large negative bias for up to five high cloud cases. So is this bias meaningful?
In the new comparison the number of cases was increased significantly.

P4929-4930 (Section 5.2): The measurements at two sites are combined here. I realize this may be needed to reach a reasonable number of observations, but can anything be said about differences between the sites?
In the plots the results per site are now shown in different colors. We did not compute statistics separately for each site, since the number of cases is relatively low when only considering one site. From visual inspection no clear differences in the results can be seen.

P4930, L7-8: One would expect an O2-A band approach to yield a cloud top lower than the physical cloud top. So please explain this result
The overestimation/underestimaton of CTP/CTH depends on the deviation of the assumed cloud vertical extinction profile from the actual cloud vertical extinction profile (for more information see Henken et al., AIP Conference Proceedings 2012)

One would expect the underestimation of CTH when the extinction of the upper layers of the clouds is assumed too high in the radiative transfer simulations. This is usually the case when assuming a homogeneous vertical cloud profile. We use the inhomogeneous cloud vertical extinction profiles in our radiative transfer simulations to create the MERIS-LUT. The nine cloud profiles used in the simulations are mean profiles derived from 1 year of CloudSat data for 9 cloud types. It might even be the case that our extinction for upper cloud layers is too low since CloudSat does not detect small ice particles. Therefore, one could expect our retrieved MERIs-CTH to be too high.

Explanation is now given in Sect. 5.2

Table 2: Can you give a reference for the 4% uncertainty in reflectance?
The reference (ESA, 2013b) is given in the text where it is also referred to Table 2.

Figure 4: A lot of the cirrus flagged pixels as well as some of the water phase pixels seem to have a reflectance pair located above the forward model solution space. How does the retrieval of COT-REF proceed for these pixels? Is it considered to be failed, or is the closest point in the LUT returned?
Figure 4: It is considered to be failed.

Figure 5: The caption is not clear about whether these pixels are from the orbit segment in Fig. 3 or from all pixels collected over the GER region during three years. The latter

may be preferable to reduce the noise in the figures.
Figure 5: The figure was produced for only the orbit segment presented in Fig.3, but is now produced for all pixels collected over the GER region during the years 2007-2009.

For clarity we changed the sentence to: ....*for all retrieved cloudy pixels for the GER orbit segment as presented in*......

Textual comments response:

We applied all textual corrections.

Table 2: Use consistent notation in the table, i.e. either tau or COT.
Was done.

Figure 2: Add the COT-CTP borders determining the ISCCP cloud classification.
COT-CTP boarders are taken according to the ISCCP cloud classification, which can be found on their website.

Figure 3: What does 'COT+cirrus' mean?
For clarity we have converted the panel COT+cirrus to a Cirrus mask panel

Figure 4: The lower end of the water LUT seems to be invisible. Could you plot it on top of the points?
This was tested, but then the uncertain phase points are hard to see. According to us this is the best way to plot the results.

Figure 5: The caption was expanded: *Histograms of the mean relative phase fraction and of mean relative uncertainty estimates for FAME-C cloud properties cloud optical thickness (COT), effective radius (REF), cloud water path (CWP), cloud top temperature (CTT), and cloud top pressure (CTP), for all retrieved cloudy pixels for the orbit segment above Germany as presented in Fig. \ref{fig:segment}. Results are shown separately for the three cloud phases, water, ice and uncertain, and for all cloudy pixels.*

Figure 5: The GER region has not been introduced yet (it will be in Fig. 6).
It is now introduced.

Figure 8: Add in the caption AATSR (top) and MERIS (bottom) as well as for single-layer (left) and multi-layer (right) clouds.
Was done.

Response to Referee #2

black = comments referee
blue&bold = response

This paper describes the development of an optimal estimation cloud retrieval scheme that is applicable to both the AATSR instrument and MERIS instrument. It is an algorithm paper that needs to be written as it describes one of the algorithms used in the ESA CCI program. The paper is essentially 3 different retrieval schemes with a link via the transfer of optical thickness information into the CTP MERIS products. The paper is reasonably clear and the results what I would expect although in some cases lack convincing statistics.

The 'synergy' aspect of the paper is weak at the moment except for the cloud mask. I would suggest the author make clear the impact of using the AATSR COT information in the MERIS product and tie together the CTT/CTP more clearly.

The paper should be read over by a native English speaker to improve some of the grammar and sentence structure. A spell checker should be used. In general the author should be careful to avoid beginning sentences with 'Also' or 'From' for example.

The authors agree that the number of cases in the cloud top height comparisons is limited. The number of cases in the comparison is now increased by relaxing the selection criteria. Next, the ARSCL cloud boundary product is now used in the comparison, this also lead to a slight increase in suitable cases. In the future, evaluation studies will also be performed using CloudSat and Calipso cloud top height observations. Furthermore, in phase 2 of the ESA Cloud CCI project, cloud properties for a longer time period will be retrieved, extending possible comparisons for in-depth validation studies.

The synergy aspect of the FAME-C retrieval at present mainly lies in the synergistic cloud mask. Furthermore, for MERIS-CTP retrieval the COT is needed as input. With the combination of VIS/NIR from AATSR a more accurate COT retrieval can be performed, compared to a MERIS only COT retrieval. It was made more clearly now in the manuscript that at present two independent cloud top height retrievals are performed in FAME-C. The discussion on the results of both AATSR and MERIS CTH comparisons to radar CTHs was extended.

Specific comments response:

ENVISAT –> Envisat
We changed *ENVISAT* to *Envisat*.

L9 accuracies –> agreement
***accuracies* was changed to *agreement*.**

P4911, L5: 70% of earth's surface needs a reference- could be GEWEX paper.
The reference to the GEWEX paper was added.

P4911, L25: Should also mention AATSR participation as more relevant to this paper.
AATSR reference was added (Sayer et al., 2011)

P4912, L14: ORAC is not a participant in CREW, however did participate in GEWEX
ORAC was removed from the sentence.

P4914, L5: Check you have the appropriate AATSR channel numbering here and be consistent throughout

This was checked, and consistency was applied to the text.

P4914, L8: better reference needed here http://www.esa.int/esapub/bulletin/bullet105/bul105_1.pdf

Two references were added.

AATSR: Global-change and surface-temperature measurements from Envisat, 2001, Llewellyn-Jones et al.

The ESA Medium Resolution Imaging Spectrometer MERIS a review of the instrument and its mission, 1999, Rast et al.

P4914, L18: What are the cloud abundance parameters how do these differ from cloud mask/fraction?

The cloud abundance parameter or cloud abundance index was a way to not only provide a cloud mask, but also a degree of cloud contamination per pixel. Since it is not a probability, we did not use this index. We removed the mentioning of it in the text.

P4914, L20: AATSR has 512km swath

Due to the collocation procedure, the swath width of the synergy product is 493 pixels, thus less than the original AATSR swath width of 512 pixels. Due to curved view of AATSR and collocating AATSR to the MERIS grid, a smaller swath width than 512 pixels is obtained for the synergy product.

This was changed in the text to: ***It should be noted that the synergy product has a swath width of 493 pixels, which is less than the AATSR swath width of 512 pixels. This is related to collocating the curved AATSR grid with the MERIS grid.***

P4919, L24: 2nd not third reprocessing

This was corrected.

P4915, L11: What does ‘conservative scattering’ mean?

With conservative scattering it is meant the scattering of radiation without accompanying absorption. In our opinion this is a well-known definition and does not need further explanation.

P4915, L23: Wavelength seems to be used not removed in the equations below as suggested in the text.

It is used in the equations but not in the text.

P4915, L26: Should Rayleigh scattering below the cloud be significant, particularly for thin cirrus? How were the channels selected for the microphysical retrieval why only 0.6um channel and not other AATSR and MERIS channels?

We expect that Rayleigh scattering below the cloud, particularly for thin, elevated clouds, might be significant. However, we did not quantify the contribution of Rayleigh scattering below the cloud in the retrieval of the cloud optical thickness yet.

Up to now we wanted to develop a working cloud optical and micro-physical retrieval for AATSR and MERIS measurements and started with AATSR channels 0.6 and 1.6 micron. We plan to start using AATSR channel 3.7 as well in the future, however for this channel we have to adjust the retrieval due to the thermal radiation also contributing to the observed radiation in this channel. Also the use of other channels will be considered in the future

P4917, L2: Where does value of 0.044 come from (reference or assumptions in the calculation should be specified)

A reference was added, Wang and King (1997)

P4918, L1: Effective variance of what is a reference needed here?
A reference was added, Minnis et al. (1998)

P4918, L10: What defines a 'thin' ice cloud?
We changed the sentence to: *For optically thin ice clouds (COT < 8) the following equation is used..*

P4919: Be consistent on channel descriptions sometimes 11um used sometimes 10.8
Consistency has been applied.

P4920, L21: L21 Better reference required for RTTOV
A reference to the RTTOV 9 User Guide was added, Saunders et al. (2010)

P4920, L26: Which NWP model? **ERA Interim is mentioned later on?**
For clarity the sentence was changed to: *The atmospheric profiles and surface properties are obtained from ERA-Interim re-analysis and forecasts (to be described in Sect. 3.3).*

P4921, L14: Is the impact of using a standard atmosphere significant?, has it been quantified? Cloud phase seems to be determined in 2 different ways for MERIS and AATSR retrieval, Do the retrievals ever conflict in phase and how is this be resolved?
We refer to the sensitivity study of Preusker and Lindstrot, 2009 (Sect. 4c), where the sensitivity of the measurements to the temperature profile has been investigated. In the same study the maximum errors found, related to different cloud micro-physics, are in the range of 10 hPa. We decided not to produce separate water and ice LUTs for the MERIS measurements, therefore we do not make a cloud phase discrimination from MERIS. The cloud phase discrimination from AATSR measurements is used in the DCOMP retrieval where we have separate water and ice LUTs.

P4921, L24: What are the other error sources?
Other error sources include the presence of multi-layer clouds, and unknown sub-pixel cloud fraction.

We have changed the sentence to*: ...and are much smaller than other error sources such as the presence of multi-layer clouds and unknown sub-pixel cloud fraction.*

P4922, L1: Radiative transfer calculations are performed for varying centre wavelength then are they combined?
They are not combined. The central wavelength is a dimension in the LUT, because the center wavelength varies along the field-of-view for the Oxygen-A-absorption channel.

P4922, L27: What values of surface albedo and emissivity are used?
Two references are added for the fixed ocean and snow surface albedo and surface emissivity. The sentence was changed to :
For water surfaces and surfaces containing snow or ice fractions of more than 50 \%, fixed surface albedo and surface emissivity values are taken from narrowband mean surface albedo (Chen et al., 2006) and surface emissivity (Chen et al., 2003) for water and snow/ice surfaces derived from MODIS-Terra data.

P4922, L12: Please explain in a little more detail how the extinction profiles are used. Given that the MERIS retrieval has a strong negative height bias (shown later) what would be the impact on the retrievals of assuming too low height and using an incorrect profile. Is this significant?
The assumption of the cloud vertical extinction profile can have a large impact on the CTP/CTH retrieval, especially for clouds with large geometrical thicknesses, some examples where shown in Henken et al. (2013). We have also seen this during the retrieval development. Assuming homogeneous vertical profiles generally leads to CTP

overestimation, especially for higher, geometrically thicker, clouds. For accurate CTP/CTH retrievals the cloud vertical extinction profile has to be known, however we do not have access to this information. We decided to use the averaged CloudSat profiles.

For more detail on how the extinction profiles are used, the text was extended to:
In the radiative transfer simulations of the MERIS channels 10 and 11 radiances the cloud is divided into a number of cloud layers, each with a thickness of 20 hPa. The appropriate extinction profile, and thus the extinction of each cloud layer, is selected according to the ISCCP cloud classification. This means that the layer cloud optical thickness is different for each cloud layer, while it would be taken constant for all cloud layers when assuming a vertically homogeneous cloud. The total cloud optical thickness is taken from the cloud optical and micro-physical property retrieval.

P4923, L3: How are the albedo adjusted?
See answer to P4922, L27

P4924, L2: What variables are in each of the state vectors?
We adjusted Table 2 to include the variables that are in the state vectors, and added a reference to this Table in this paragraph.

P4924, L3: What iterative process is used i.ee minimisation method?
We used the Gauss-Newton method. This is now mentioned in the text.

P4924, L4: What first guess is used- This would be useful to know in case it has a strong bearing on the values retrieved.
A new table was included (Table 3), which lists the first guesses used in DCOMP and DCHP-A and DCHP-M.

P4924, L5: What is the convergence criteria?
To clarify this, the text was changed to:

Due to non-linearity in the forward model the minimization is performed within an iterative process. Here, the Gauss-Newton method is used. A first guess, listed in Table 3, is used to start the iteration. The iteration is terminated when the difference between the error-weighted length of two consecutive state vectors is one order of magnitude smaller than the length of the state vector or the maximum number of allowed iterations has been reached. The error covariance matrix of the retrieved state Sx can be computed as follows: ...

P4924, L8: K is not averaging kernel but weighting function
This was corrected.

P4925, L10: What is a very high value? This is a bit vague
The uncertainties of the apriori are now listed in Table 2.

P4925, L12: What is the reference for the forward model parameter uncertainties?
For surface albedo and cloud top height uncertainty in DCOMP we took similar values as were used in Walther et al., 2012. The other forward model parameter uncertainties are either computed from COT_unc or estimated.

P4925, L15: What values are assumed for the uncertainty between ice and water cloud or how is it parameterised.
It would be useful to list somewhere perhaps in table 2. The maximum and minimum range of values for the state vector parameters if any?
Each pixel keeps its original cloud phase as labeled with the simple cloud phase discrimination, either water or ice cloud. However, for those pixels falling within a

certain brightness temperature range and with a certain reflectance pair that fits within both our water and ice LUTs, we add an "uncertain phase" flag. When convergence is reached for those pixels, the difference between the forward modelled values for water and ice LUT is added to the measurement error covariance.

This was explained inadequately in the text and was changed to:
For certain pixels that have reached convergence, we take into account the uncertainties due to the rather simple cloud phase discrimination. This is realized by adding the difference in forward model values between the water cloud and ice cloud, keeping everything else constant, to the measurement error covariance matrix. This is done for pixels with...

The ranges of the state vector parameters are now mentioned in the text (sect. 3.1 and sect.3.2.2)

P4925, L20: in figure 3 the CTT and CTP plots show a similar number of retrievals yet later on (P4930) you mention MERIS retrievals fail approx. 50% of the time. This seems quite serious so I think it needs more explanation/clarification on why they are failing i.e cost, convergence ,other? In Figure 5 the results seem to be limited by a lack of statistics as the results are for only a single scene would it be possible to produce the same plot using the data used in Figure 7.
Also the uncertainties are only valid when the model is a good fit. i.e. when the cost is low (Theoretically 1) This would I presume reduce the number of retrievals further. This plot should only display uncertainties when costs is low this should be made clearer.
In the comparison from section 5.2 we found less valid MERIS-CTP retrievals than AATSR-CTT retrievals, this is not necessarily true for the scene in Fig. 3. The CTH comparison is limited to certain sites and for example to cases where the CTH standard deviation within the pixel box is less then a certain threshold. It can be a combination of this standard deviation threshold, from inspection of the results MERIS CTH often shows a higher variability in the CTHs within the pixel box than AATSR CTH, and the fact that MERIS CTH retrievals fail more often. From experience this is clearly lower than 50 % of the times, but depends on the cloud situation.

The MERIS retrieval fails more often because often it does not converge before the maximum number of iterations given beforehand. In the radiative transfer simulations we used the CloudSat derived cloud vertical profiles for nine different cloud types. This means, however, that the LUT is not smooth everywhere, due to jumps into a different cloud type regime, and this sometimes leads to no convergence. For the FAME-C version presented in this manuscript, we did not include a method to deal with this problem. Options are to smooth the locations in the LUT where the jumps take place and to improve our first guess.

We changed the text to: ***We assume this difference in cases between both cloud top height retrievals to be partly related to the fact that at the moment the MERIS cloud top pressure retrieval tends to fail more often than the AATSR cloud top temperature retrieval, and is related to the use of the different cloud vertical extinction profiles derived from CloudSat data for different cloud types in the radiative transfer simulations used to create the MERIS LUT. This leads to jumps in the LUT at the cloud type transitions. It is envisaged to deal with this issue in future versions of FAME-C.***

Figure 5: The plot is now computed using all orbit segments covering the GER region in the years 2007-2009. Only successfully converged pixels with a cost below 20 are taken into account. The shapes of the histograms as well as the order of magnitude of the uncertainties did not change significantly.

P4927, L9: What quality flag was used?
We used the MODIS Quality Assurance at 1x1 Resolution.

The sentence was extended: *...for the MODIS cloud optical and micro-physical properties cloudy pixels with a general assessment set to Useful according to the quality flag (Quality Assurance at 1x1 Resolution) are selected.*

P4927, L6: Is the effect of excluding water particles > 30um significant?
Within FAME-C we allow REF for water clouds to become higher than 30 micron. If we would not set the threshold to 30 micron in the comparison, the bias is expected to become significantly larger. We did not perform this comparison and consider this to be out of scope for this manuscript.

P4927, L9: How often does the retrieval converge, why not? **is this significant?**
For 3 regions FAME-C clearly has a higher cloud fraction (only considering "useful" pixels for both) than MODIS-Terra. We think that this is at least partly related to the clear-sky restoral in the MODIS data. These differences in (only useful pixels) cloud fraction also impacts further comparisons of COT, REF and CWP.

P4927, L21: Cirrus contaminated pixels these are removed how? An optical depth threshold?
Pixels that are flagged as cirrus clouds in our DCOMP retrieval. This is done with the cirrus detection described in Sect. 3.1

For clarity we changed the sentence to: *We assume this to be pixels misidentified as cirrus clouds by the cirrus detection method.*

P4928, L1: How often do you get a successful retrieval? What is the definition of a successful retrieval?
A successful retrieval means that the retrieval converged within the allowed maximum number of iterations and with a cost below 20. We did not count this.

Successful retrieval is now defined in Sect. 2.4:
The retrieved uncertainties for all successfully retrieved cloudy pixels, which are defined as cloudy pixels that converged within the allowed maximum number of iterations and with cost < 20...

P4929: The plots in Fig. 8 are rather sparse and quite a few conclusions although possibly valid are drawn on the basis of a few points. Why are only 2 ARM sites used. If more ARM sites were used there would be more points and the analysis would be valid for a better range of meteorological situations. Please investigate incorporating data from more ARM sites. Add correlation to the plots. Given the paper is focussing on uncertainty and there are not many points, uncertainty on each point could be added to the plot.
Some discussion needs to be added here that radar and IR/thermal and MERIS cloud top heights are not actually measuring the same 'height' needs to be added here i.e I would expect a negative bias comparing IR and radar heights.
As mentioned before the QC applied to the CTP and CTT retrievals before comparing needs to be explained.

We used data from 4 ARM sites, since there are three arm sites in the Tropical Western Pacific area (TWP1, TWP2 and TWP3). At those sites, both the Lidar measurements and radar (MMCR) measurements were available from which we estimated cloud base height and cloud top height, respectively.

It was pointed out to us to rather use the official cloud boundary product (ARSCL) available at 5 ARM sites (SGP, TWP1, TWP2,TWP3, and NSA). The comparison is now performed using this product. To increase the number of suitable cases, the maximum allowed standard deviation for the cloud top heights was increased to 1 km (before 0.5 km) and a pixel box size of 9 by 9 pixels is taken (before 5 by 5). Correlation is added to the plot. The points in each plot are averages in space for the FAME-C cloud top

height and averages in time for the RADAR/LIDAR cloud top heights.
The description on how the comparison is performed is extended as well as a more extensive discussion on the results is added to this section.

P4929 How are the MERIS and AATSR Cloud height products combined in the CCI product?
At the moment the MERIS CTP and AATSR CTH are not combined in the CCI product. They are provided separately.
Response to Minor comments

Abstract, L14: Revise sentence structure.
Sentence was changed to:
Also, the optimal estimation method, which provides uncertainty estimates of the retrieved property on a pixel-basis, is presented.

P4913, L2: 'once' used incorrectly
this was changed to: ***Furthermore, two independent cloud height products are retrieved, first, using AATSR brightness temperatures from two infrared channels and, second, using the MERIS oxygen-A absorption channel.***

Figure 2: ISCPP -> ISCCP
This was correct to ISCCP.