Review of 'Cloud optical properties retrieval and associated uncertainties using multi-angular and multi-spectral measurements of the airborne radiometer OSIRIS'

By Christian Matar et al.

General comments

This paper describes an approach for the retrieval of cloud optical thickness and droplet effective radius from multi-angular and multi-spectral satellite measurements. In addition, estimates of the retrieval errors due to different error sources are presented. The main novelty is an attempt to estimate retrieval errors caused by deviations from vertically homogeneous profile and independent pixel assumptions. The topic is important and suitable for this journal. Overall the retrieval setup appears to be sound and the results are plausible. However, I do have some general concerns and questions that need to be addressed before this paper can be published.

- Only one case is studied, which limits the validity of the results. Retrieval errors, in particular those caused by deviations from homogeneous cloud and independent pixel assumptions, will depend on the scene. While discussing more cases may be outside the scope of the paper, these limitations at least need to be mentioned.
- The paper gives a false impression of the current cloud optical and microphysical property algorithms. Firstly, most of these do consider measurement errors and produce retrieval error estimates (e.g., Platnick et al., 2017), unlike what is written in the abstract. Secondly, for many of these algorithms the total retrieval error has been separated into contributions from individual error sources (e.g., Walther and Heidinger, 2012), unlike what is written on page 10.
- It is not clear why polarization measurements have not been included in the retrieval. It looks like these could, amongst others, further constrain the width of the size distribution, which has instead been fixed prior to the retrievals.
- There are many textual mistakes and inaccuracies, of which only some examples have been included in this review.

Specific comments

Title: The paper only deals with liquid clouds. This must be included in the title.

Abstract, L13: Clouds are really characterized by more properties than these two, e.g. the height of the top and base.

Abstract, L16: As mentioned above, measurement errors are considered in most retrieval algorithms.

Abstract, L26: I suggest not to refer to 'traditional' bi-spectral retrievals as 'MODIS-like methods' since these methods are not in any way specific to MODIS.

P1, L36: The statement is still true so why not cite the latest IPCC report here?

P2, L40: Measurements of emitted radiation are also important for cloud property retrievals.

P2, L50: Suggest to cite the more recent Platnick et al. (2017).

P2, L51: The bi-spectral method is applied to many instruments, not 'in particular' to MODIS.

P3, L93: What is 'roughening of the radiative field'?

P4, L110/111: LUT-based retrieval algorithms are very well suited to produce retrieval error estimates. Please remove this statement.

P4, L125: 'model': do you mean 'state'?

P5, Fig. 1: The figure and caption can be improved. Lines cannot be distinguished very well. What are 'optical matrices'? Spectral response functions is probably a more common term. And in what units are these plotted / how have they been scaled? The y-axis only says 'Transmittance'.

P5, L163-165: Can you expand a bit on the viewing angles? Here numbers of 19 and 20 angles are mentioned, later it is 13 angles. How many angles were actually used for the retrievals? Can you also comment on how well the pixels for the different viewing angles are aligned? And if they are aligned at ground level, isn't there a spatial mismatch at cloud altitude?

P6, L175: What is 'LIDAR-LNG'? And what is 'the vertical profile' in Fig. 2b? There is a whole series of vertical profiles.

P6, L179: There are some 'intense white' but also quite dark parts in the reflectance image. Please explain what you mean.

P6, L182: Where do you see a 'white arc' in Fig. 2d? I only see an arc with rainbow colors.

P6, L185: Could you perhaps indicate in the figure where the reflectance is (or may be) affected by sun glint?

P7, Fig. 2 and caption: Please use UTC (not local time) throughout to avoid confusion. What is the background in Fig. 2a? Please add explanation of red arrow in Fig. 2a and red rectangle in Fig. 2b in the caption and not (only) in the text. What is the half-visible text on top of that image? What are all the colors in the legend (most of which do not appear in the figure)? What is the blue bar on the left-hand side of Fig. 2c? I don't think that 490-670-865 nm is a 'true-color' RGB composite. From which viewing angle are these radiances? The contours are not concentric.

P8, L205: It is stated that vector y has dimension n_y but in Eq. (8) it has dimension 2*n_y.

P8, L218: Please state explicitly how x_a and S_a are defined ('large' is too vague).

P8, L225: Suggest to refer to page 10 where the Jacobian is explained.

P9, L250-251: Is this justified? From Fig. 1 it looks like there is considerable absorption, in particular in the 2.2 micron channel, which needs to be accounted for.

P9, L255: What are these 'measurements'?

P9, L258: What is 'independent column approximation'? Is it the same as the 'independent pixel approximation' introduced on page 2? If so, please use consistent terminology.

P9, L264-268: How do you calculate the Jacobian matrix?

P10, L274: The off-diagonal terms are non-zero so it is confusing that they have been written here as zeros. Can you explain?

P10, L276: Do you mean Eq. (7) instead of Eq. (10)?

P10, L287: As mentioned in the general comments, there have been other studies where the types of error were separated.

P11, L300: There are other ways of calibration, e.g. vicarious.

P11, L301: I would argue that calibration usually addresses systematic (not random) errors in the measurements.

P11, L304: According to Eq. (8) the dimension of the measurement vector is 2 n_y x 2 n_y (?)

P11, L306: Do you have a motivation for taking a fixed 5% measurement error?

P12, L341: This value of v_eff is quite small. Could you add some explanation on how it is determined? Wouldn't it be possible to include its determination in the overall retrieval (by including the polarization measurements in the observation vector)?

P12, L336-343: In this case the cloud top height (and thickness) and effective variance can be determined very accurately. However, in 'real life' uncertainties will me much larger (e.g., if you have no lidar available). Wouldn't it therefore be better to work with larger uncertainties so that the resulting error estimates become more representative?

P13, L355-358: In the OE framework errors are assumed to be Gaussian and error estimates reflect 1-sigma of the Gaussian distributions. Can you comment on the Gaussian nature of the forward model related errors? Is it plausible to use the difference between two configurations as 1-sigma of the uncertainty, or would these configurations rather reflect two extremes?

P13, L358: What is the square of a matrix?

P13, L363: To estimate retrieval errors due to deviations from the assumption of vertical homogeneity, a specific alternative cloud model is outlined in detail. However, it should be realized that this is just one possibility. For example, real profiles have a varying degree of sub-adiabaticity, which is not considered here. What would be the effect on the uncertainty estimates?

P14, Fig. 3: The cloud is placed between 5 and 6 km. Where do these numbers come from? They are not the same as on page 12. Please include the settings (top and bottom height, cloud optical thickness, maximum effective radius, …) for this particular figure in the caption.

P15, L396-398: Is it correct to determine the maximum effective radius such that the average effective radius of the heterogeneous and homogeneous profiles are the same? Shouldn't R_eff be weighted with extinction? Or, alternatively, a requirement to arrive at the same liquid water path for both profiles seems better justified.

P15, L407: Only the IPA seems to be addressed here. What about the PPH assumption?

P15, L409-411: It seems to be stated that the PPH assumption includes the IPA, whereas in earlier parts of the manuscript they were introduced as different things (which I think they are).

P16, Fig. 4: Does the scene contain clear-sky pixels? If so, how are they reflected in the COT and Reff maps? Are there any failed retrievals? If so, how are they reflected in the maps?

P16, caption Fig. 4: Is the date a typo or is this really a different case from the one introduced in Fig. 2?

P16, L436: A figure with COT and Reff uncertainties as functions of COT and Reff would be very instructive to illustrate this.

P16, L435: The uncertainties in COT appear to be very low. Is a retrieval error of 0.5% realistic? For thin clouds COT depends approximately linearly on the reflectance. How can a reflectance

measurement uncertainty of 5% result in an order of magnitude lower uncertainty in COT? Is this thanks to the combined information from different viewing angles. But, if that's the case, isn't the assumption of uncorrelated errors between the measurements from these different angles much too optimistic?

P17, 459-460: Could this estimate be too optimistic? In case of broken clouds, sun glint can have a relatively much higher impact on the measured reflectance, which would not be captured here.

P18, L474: For COT it seems to be rather something like 8 %.

P19, L481-484: This is a firm statement, for which no evidence is provided.

P19, L485-486: There are no sub-pixel measurements, and sub-pixel cloud variability is not represented in this work. Again, this is a statement without proof. A PPH error estimate should be added to the retrieval setup, so the PPH effect can be quantified.

P20, Fig. 8: How is radiance defined here? Is it the sun-normalized radiance or true reflectance? From which of the 13 viewing angles are these measurements taken?

Fig. 9: Nice figure, illustrating the different response of thin and thicker cloud portions to 1D versus 3D radiative transfer.

P21, L508-509: Is the nearest-nadir view used for the mono-angular retrievals?

P21, Fig. 10: I am shocked by the enormous differences between the mono- and multi-angular retrievals. Ok, for the cloud bow geometries it is well known that mono-angular retrievals do not work. However, for other geometries the mono-angular retrieval should give a reasonable solution, in particular for a reasonably 'well-behaved' cloud field as studied here. This asks for further clarification. Can you also include a scatter-density plot comparing COT and Reff from the two retrievals on a pixel basis?

P22, L530-531: Apparently both retrievals fail to converge in some cases. But there do not seem to be missing values in Figs. 4 and 10. How can that be explained? What output does the algorithm give in case of no convergence? Are these cases included in the statistics? Are statistics based on a common set of mono- and multi-angular successful retrievals?

P22, L531-532: Is the multi-angle retrieval expected to retrieve smaller Reff? Can you explain that? And why would smaller Reff lead to lower COT?

P22, L533-534: This is not true. The measurement pair can be outside the 2D LUT space (and I guess this is what happens in the reported 5.9% cases of failed convergence).

P24, Fig. 12: The decrease in retrieval error from mono- to multi-angular retrievals is spectacular, especially with respect to the vertical homogeneity and IPA assumptions. Can you explain in some more detail how that is achieved? Still, differences between the two retrievals (Fig. 10 vs. Fig 4) appear (much) larger than accommodated by the respective error estimates. Can you comment on that?

P24, Fig. 12: The mean Reff retrieval error due to measurement errors is 12.55 in Fig. 11 but 12 in this figure, which is not consistent.

P25, L596: In Fig. 12 the mean COT error is 4%, not 5%.

P25, L605-607: Please remove since this was not shown (or alternatively include in the retrieval error estimates).

Technical corrections

P1, L22: Acronyms (POLDER in this case) must be written out.

P1, L16/L17: '… without considering … the choice of ancillary data': What does it mean that the choice of ancillary data is not considered?

P1, L31: 'uncertainties on': should be 'of'. Occurs frequently throughout. Please correct.

P2, L53: The second sentence does not follow from the first, so the word 'Therefore' is misplaced.

P3, L76: increase -> increasing

P3, L80: 'radiations' is not really a word.

P3, L90: by its -> in

P3, L96: vertical -> vertically

P4, 113: Usually, the acronym is put between brackets after the full name instead of the other way round.

P4, L124: Bayesian (with capital)

P9, L242: Add lambda_a and lambda_b after wavelengths.

P9, 239: Italic case is not needed here (similar occurrences throughout).

P9, 240: Variables in italic (R in R_eff should be italic). (similar occurrences throughout).

P9, L243: (8) is duplicated.

P9, L250: 'All the' -> 'the two'?

P10, L271: 'implantation': do you mean 'implementation', 'inclusion', ..?

P10, L271: adjust -> adjusts

P10, L306: 'measurement errors that cover the measurement errors'?

P11, L13: Italics appearing here and there are not needed and confusing.

P12, L327: Should (17) and (18) be reversed?

P12, L328: Should this be K_b_i instead of K_i?

P12, L340: for -> to

P14, Fig. 3: Minus sign in the x-axis label is confusing.

P15, L395: exctinction -> extinction

P15, L417: minimized -> underestimated (?)

First paragraph on page 16: here I give a more complete inventory of textual mistakes as guidance for the rest of the manuscript.

P16, L422: Both bispectral and bi-spectral occur in the manuscript.

P16, L423: weak -> weakly

P16, L423: .. channel partially absorbed by ..: how can a channel be absorbed?

P16, L424: on -> to

P16, L424: Remove ‘up to’ (?) I guess all viewing angles are available. By the way, does this mean that n_y = 13?

P16, L425-426: ‘This error is straightforward’: how can an error be straightforward?

P16, L429: ertically -> vertically

P17, L443: As noted before, do not write variables like COT, and mathematical operations like RSD, in italics.

P17, L457: ‘enlarge the directions’: what does that mean?

P19, caption Fig. 7: ‘model’ missing after ‘forward’?

P19, L478: What are ‘these differences’?

P21, L503: assumption -> assumption

P21, Fig. 10: For comparability with Fig. 4 it would be good to use the same color scales. Can you also add the mean values? Also, add some whitespace between the maps and the color bars.

P22, caption Fig. 11: Add ‘angle’ after ‘scattering’.

P22, Fig. 11: Is this figure for the mono-angular retrieval?

P23, L542: spatially -> spatial

P23, L557: ‘to the’ is duplicated.

P23, L557: what is a ‘homogeneous assumption’?

P24, L571: ‘retrieve’ is duplicated.

P24, L583: horizontal -> horizontally, vertical -> vertically

P25, L587: for -> to

P25, L590: what is ‘miss-knowledge’?

References: Journal names are missing in all references.

References

Platnick, S., Meyer, K. G., D., K. M., Wind, G., Amarasinghe, N., Marchant, B., Arnold, G. T., Zhang, Z., Hubanks, P. A., Holz, R. E., Yang, P., Ridgway, W. L., and Riedi, J., 2017: The MODIS Cloud Optical and Microphysical Products: Collection 6 Updates and Examples From Terra and Aqua, IEEE T. Geosci. Remote, 55, 502–525, doi: 10.1109/TGRS.2016.2610522.

Walther, A. and Heidinger, A. K., Implementation of the daytime cloud optical and microphysical properties algorithm (DCOMP) in PATMOS-x, J. Appl. Meteorol. Climatol., 51, 1371-1390, doi:10.1175/JAMC-D-11-0108.1.