Answer to Anonymous Referee #2

Green – reviewer's comments
Black – authors' reaction to comments

Interactive comment on "Synchronous starphotometry and lidar measurements at Eureka in High Canadian Arctic" by K. Baibakov et al.

Anonymous Referee #2
Received and published: 24 March 2015
We thank the Anonymous Reviewer #2 for taking the time and providing a detailed and rigorous review of the manuscript. Our answers are given in a comment-by-comment fashion below.

Unless otherwise indicated, section numbers refer to both the submitted and revised manuscripts (in other words those sections whose numbering did not change between the submitted and revised versions of our manuscript)

Summary :

This paper presents aerosol optical depth measurements taken in a remote location in the Canadian Arctic for multiple case studies. These measurements include methods from lidar and starphotometry in a novel combination useful for retrieving fine mode aerosol optical depth in the Arctic night. In this difficult environment for measurements, this paper presents and tests methods for screening clouds in aerosol optical depth time series and therefore presents a more robust view of slight nocturnal variations in polar aerosol optical depth. This method and presented data will be a good foundation for further climatic studies of high Arctic aerosol optical depth.

Paper is within the scope of Atmospheric Measurement Techniques and is recommended for publication with revisions. Please find comments for consideration below.

General Comments:
1. The paper is well written and well structured, with few problems. Some work on figures should be made for increased clarity (see below for specifics).
Please see detailed responses below.

2. Abstract lacks specificity, especially with the use of vague words such as "good agreement" and "moderately well". Agreement should be quantified and reported.
The abstract was modified to take into account the reviewers' comments and suggestions

3. The CRL lidar measures polarization, yet it is not used for cloud screening, especially for ice crystals. Although a note on page 2040 indicates that data for 2011 was not available, there is also data from 2012 presented that could benefit from cloud screening using depolarization ratios. Please bring the comment on the availability of the data earlier in the manuscript and comment on its use for data measured in 2012.
Inserted the following paragraph in section 4.4 (CRL processing):

"The CRL also measures linear depolarization ratio (DR) defined as a ratio of the orthogonal and parallel components of the backscattered light. DR is primarily dependent on particle habit (i.e. the gamut of possible shapes between spherical particles and complex crystals) but can also be used as a means of discriminating fine mode particles from coarse mode particles (see for example O'Neill et al., 2012). Consequently, DR could potentially be used for partial cloud/ice crystals screening validation. The CRL DR hardware and processing algorithms, however, are still in development and so only sporadic measurements are available. Only DR data obtained on Feb. 21, 2011 was used for the purposes of this paper."

4. There is no reference to what stars were used or at what range of airmasses that were sampled.
Added new Section 4.1.5 to list the measurement stars and associated air mass range. The latter was in most cases between 1 and 2.

5. In uncertainty calculations (Sect. 4.3.2. and Appendix A), there is no mention of uncertainty in airmass calculations for the different atmospheric species. Although at low airmass, such considerations is much less significant than other sources of errors, there is no such indication in the manuscript. (This point is linked with the previous point). An example comparison of two airmass calculations, at high airmass, was described by Russell et al. (2005)
We added an acknowledgement to section 4.3.1 that air mass calculations at large solar zenith angles can lead to uncertainties in AOD estimations. Given small air masses (see previous answer), we think that these uncertainties are negligible in the present work.

6. There are many references to unpublished data, is there any other source possible which has been published?
When we made reference to unpublished data it was because, there were currently no published sources. This was the only way to give appropriate credit to the authors.

7. The Angstrom exponent, which has been used in the past for cloud screening (e.g., Shinozuka et al., 2011), is not discussed and may prove a valuable comparison to other cloud screening tools presented in this manuscript.
We are familiar with that technique (O'Neill, who is a co-author of the present paper was a co-author of Shinzuka paper). The combination of using the AOD standard

deviation in all channels and the behavior of the Angstrom exponent is really just the "temporal" cloud screening combined with the "spectral" cloud screening cast in a different form (except that our technique is arguably less subjective). This is the choice we made for our cloud screening analysis : we don't believe that comparisons with a related cloud-screening algorithm will add any significant insight as far as the goals of this paper are concerned.

8. In Sect. 4.4, the CRL is described to measure down to 200 m, but all figures show measurements down to 0 m. In addition, there is no discussion about the effect of not measuring the lowest aerosols. This may be an effect plaguing all data comparison.

The CRL measures below 200m down to the ground, but it is difficult to correct for the overlap region in this altitude range. The end result of incomplete overlap correction is that the CRL-derived AODs can be underestimated. This underestimation, however, should not be a significant amount given the small altitude range (0-200m) and the inclusion of the AOD partial contribution from that region. Furthermore, fine-mode aerosol profiles, which are the main subject of interest to us, never, in our experience, show dominant AOD contributions from the bottom most 200m This renders the fine-mode overlap problem less critical.

9. The structure of Sect. 4.5.2 could be improved to facilitate the reader's comprehension. This could achieved by splitting Fig. 2 into two separate figures, and discussing Fig. 2a first, then the sensitivity study of Fig. 2b.

We kept the figure labels as they were because the figures must be together. We did however make a number of changes to Figure 2 (including, reversing the order of the figures 2a and 2b) and its associated text in an attempt to address the criticism that "the structure of Section 4.5.2 could be improved"

10. In discussions, there is many references to the shape of Rx2 vs. βtrh, but the reference Fig. 3b is lacking in those details. In addition, Fig. 3a does not seem necessary and may hinder comprehension. Figure 3 should be revised accordingly.

Not sure that we understand this comment so we have done our best to provide an interpretation and an answer as to what we think the reviewer meant. All discussions about the "shape of Rx2 vs. βtrh" were in reference to Figure 2 : Figure 2a (which has now become Figure 2b) has virtually all the details necessary to understand the March 9, 2011 case. This one event was chosen as an illustration to help the reader understand the behavior of the curves in Figure 2b (now Figure 2a) and to convince him or her of the general suitability of any derived parameters (such as the β_{thr} ranges of Figure 3). Providing this type of detail for every single event (which is what we interpret the reviewer to be asking us to do, given the comment "Fig. 3b is lacking in those details") would be excessive in our opinion (and in the opinion of at least one other reviewer who wanted us to reduce the technical details found in the paper) : rather we believe that derived parameters such as the $\Delta\beta_{thr}$ values of Figure 3b can be accepted as adequately illustrated outputs of our β_{thr} sensitivity analysis. Finally we think that Figure 3a is essential to an understanding of how we arrived at the values of the top graph of Figure 3b (describing that in the text would be much more difficult for a reader to understand).

11. Term optically active is not defined. Please define.
"Optically active" refers to significant increases in AOD and backscatter coefficient in starphotometry and lidar data respectively. Added a footnote to the text.

12. Please indicate clearly at what wavelengths the different optical thicknesses are reported from CRL and SPSTAR.
SPSTAR data is reported at 500nm, while CRL data refers to the 532nm backscatter signal. Added a sentence at the beginning of Section 5 to reiterate this point.

13. Please elaborate on the systematic difference between τ_f and τ_f' on 9-10 March 2011.
This aspect was already explicitly commented on in the sentence beginning with "If one compares the τ_f' variation of …" of Section 4.5.2. The idea was that the classification algorithm (between the left panes and the right panes of Figure 5) had "suddenly" declared the 5 km plume to be aerosols and this drove up the τ_f' values in a fairly low frequency fashion). At a higher level (in terms of intrinsic systematic errors such as calibration and algorithmic shortcomings) the reviewer's comment is dealt with in the sentence "The $<\tau_f'> - <\tau_f>$ differences of …" (the last sentence of the same paragraph). A sentence was also appended to the paragraph in question to indicate that systematic differences (such as those of Figure 2) were further discussed in a new Subsection (4.5.3) on lidar AOD errors and in the event analysis of Section 5.

14. Please increase the font size on nearly all figures
15. When showing optical depth, please indicate where there is missing data, and not just link data from two nights together.
The graphs was improved in the revised version of the manuscript with the reviewers' comments in mind

Specific Comments:
16. Acronym SPSTAR not defined: p. 2014, line 5
We removed the acronym from the abstract

17. Typo: course -> coarse: p. 2014, line 20
Fixed.

18. Acronym CALIOP not defined: p.2018, line 15
Acronym is now defined.

19. Typo: course -> coarse p. 2025, line 25 (foot note)
Fixed.

20. Sentence concerning a summary of transfer calibration is slightly confusing: p. 2026, lines 25-30
Equation 5 shows that in order to estimate M_0 (extra-terrestrial instrumental magnitude as measured by the starphotometer) for any star, one needs to know M (measured magnitude on the ground), m (air mass) and τ (optical depth). With m known and M measured directly, one obtains a value of τ using a Langley calibration procedure on one particular star. This τ value can then be used ("transferred") to estimate M_0 of other stars, assuming horizontal homogeneity of the atmosphere. In any case, we judged that the text did not require extra technical details as the calibration process is discussed in the papers referenced in Section 4.2.

21. Uncertain meaning of "~", please be more specific: p. 2028, line 27
'We retained the "~" nomenclature since, in our viewpoint, it is a commonly accepted symbol representing "of the order of"'

22. Verb tense should be reviewed "as discussed in Sect 5.1": p. 2033, line 9
Changed the end of the phrase to read "as will be discussed in Sect. 5.1, is due to thin-cloud contamination".

23. Acronym PSC not defined: p. 2036 , line 2036
Acronym is now defined.

24. Typo: "inasmuch" p. 2037, line 6
Not clear what the reviewer is referring to. According to Cambridge American English Dictionary the correct spelling of the phrase is "inasmuch as", exactly as it appears in text.

25. Units or measurements not indicated "<~0.01": p. 2038, line 10
The text refers to errors in lidar AODs which are unitless. Changed "The lidar errors..." to "The errors in lidar AODs...".

26. Please be more specific "total integrated value": p. 2039, line 23
Modified to read: "For the most extreme vertical profiles between 6:00 and 8:00, the first 250m can contribute more than 80% to the column integrated τ_c' value (and more than 60% to the column integrated τ_a')". The τ_c' and τ_a' values are shown in Figure 7.

27. All 3 pane figures, right corner numbers can be confounded with right axis, please move
Done

28. Fig 2b, middle pane, y-axis is not correct

Corrected

29. Fig2a, pane 3, please add legend for orange and blue–it is not defined anywhere
Corrected.

30. Fig 2b, x-axis units unclear
Bottom pane of (former) Figure 2b indicates that the common units are /m/sr.

31. Fig 2b, middle pane, there is 2 dashed black [lines]in the legend and figure, they are indistinguishable.
Figure 2 was completely redone to address a number of such issues

32. Fig 3b, please add legend for symbols related to specific dates.
We left the description of the symbols in the figure caption because, in our opinion, a legend on the figure would simply make the graphs too busy.

33. All 3 pane figures, pane 3 y –axis label should have a space between “Height” and “(km)”
34. Fig 6, y-axis, please label the change in day
The graphs were improved in the revised version of the manuscript

Bibliography :

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Shinozuka, Y., Redemann, J., Livingston, J. M., Russell, P. B., Clarke, a. D., Howell, S. G., Freitag, S., O’Neill, N. T., Reid, E. a., Johnson, R., Ramachandran, S., Mc- Naughton, C. S., Kapustin, V. N., Brekhovskikh, V., Holben, B. N. and McArthur, L. J. B.: Airborne observation of aerosol optical depth during ARCTAS: vertical profiles, inter-comparison and fine-mode fraction, Atmos. Chem. Phys., 11(8), 3673–3688, doi:10.5194/acp-11-3673-2011, 2011.
[in reference to Q7]