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Atmospheric Measurement Techniques Discussions

Interactive comment on "Science impact of MODIS C5 calibration degradation and C6+ improvements" *by* A. Lyapustin et al.

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Lyapustin et al. start out by showing examples of trends observed in MODIS C5 Terra aerosol, cloud and land surface products that are thought to be false. They attribute these trends to changes in MODIS Terra calibration, which they describe in some detail along with changes applied in the MODIS C6 calibration procedure. Then they show that although most of the false trends are gone or reduced in the C6 products, Terra could still benefit from a correction for polarization sensitivity. Finally, using "stable" desert sites they show that some residual trend still remains in the C6 products; and then present a method for de-trending the C6 products using correction factors determined with the application of the MAIAC algorithm.

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Interactive Discussion

Discussion Paper

Main comments: 1. The paper could be useful to inform the general users of MODIS products about the implications of sensor degradation and shortcomings in calibration of MODIS, and to document these implications.

No reply needed.

2. Together with the cited references the explanation of the MODIS C5 and C6 calibration approach should be adequate for the majority of the readers of the paper and for the users of MODIS products. The "overview of the long-term calibration trends in aerosol, cloud, and surface reflectance C5 products from MODIS Terra and Aqua", however, could use some more in-depth analysis. For example, giving an estimate of trends is almost mandatory in trend analysis, yet there are no levels of uncertainties provided in this paper. (Although Table 1 lists the standard deviations they are not discussed.) If they are not needed for this work, it must be stated so and justified.

Reply: As the Reviewer correctly mentions, trends in the MODIS geophysical products are brought in this paper with the main goal of supporting presented calibration analysis. A more detailed characterization and analysis of trends per se, and of their potential radiative, climate etc. impact is planned by co-authors R. Levy and S. Platnick, but it is clearly beyond the scope of this paper. Following Reviewer's recommendation, we changed the second sentence in Sec. 2 as follows: "While detailed trend analysis is beyond the scope of this paper, Figures 1-2 provide an illustration using the time-series of aerosol and cloud products, reported in the joint MODIS Atmosphere Team C5 Level 3 monthly product for the period 2002-2013."

3. The work, as the authors state, is triggered by the different trends observed in the MODIS Terra and Aqua C5 products. But they never actually say that these two products should have the same (or at least much less different) trend in reality. Now, this is of course obvious for many researchers in the field, but may not be so for the "broad MODIS user community".

Reply: As we mentioned in the paper, there was a confluence of un-physical trend

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reports from different disciplines including the “ocean color”. However, to enforce the point of the Reviewer, we have changed the aerosol side of the story as follows (p. 7286, top): “Changes in MODIS Terra calibration were first noticed by the “dark-target” (DT) aerosol algorithm (e.g. Levy et al., 2007a,b; Remer et al., 2008) group from an apparent divergence between Terra and Aqua AOD (0.55 mkm) over land [Levy et al., 2010]. This divergence, which is not supported by the ground-based AERONET [Holben et al., 1997] sunphotometry, becomes more obvious with the longer time series (Fig. 1, top).”

4. The soundness of de-trending, of course, hinges on the stability of the desert sites chosen. How confident one could be that this is indeed the case, given what the authors also state as the “accuracy of this vicarious calibration approach is not as high as the one based on the direct Moon view”.

Reply: This set of desert sites was carefully selected and recommended for satellite calibration by CEOS based on multiple criteria including the long-term stability. While the real stability of these site is not known (and answer to this question would require independent high precision measurements which presently do not exist) it should be sufficiently high for the duration of the MODIS program.

Also, does the fact that a particular algorithm (MAIAC) is used to determine the cross-calibration factors limit its applicability? In other words, would the same corrections to TOA reflectance apply when a different aerosol, cloud and atmospheric correction algorithms are used? How uncertainties in the MAIAC retrievals affect the de-trending and cross-calibration factors?

Reply: The developed technique is based on the knowledge of surface BRDF and geometric normalization. In this regard, it is completely generic and can be used with other remote sensing algorithms which provide adequate cloud masking, aerosol retrieval and atmospheric correction. The developed C6+ L1B post-processing algorithm has been delivered to MODIS Adaptive Processing System (MODAPS) which runs

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MODIS Land operational processing for standard algorithms. MODAPS global testing showed definite improvements confirming validity of developed corrections.

5. Will the method (PC correction) that leads to C6+ be applied to the MODIS data distributed to the public? In other words, are all MODIS L1B data and L2/L3 products going to be reprocessed? If not, is the recommendation of the authors to users to apply the cross-calibration coefficients presented in Table 2?

Reply: The developed corrections (C6+ L1B) will be applied for MODIS Land C6 re-processing and forward processing. Plans for the atmospheric group of algorithms are in discussion.

Other comments: 1. While reviewing the paper it was not always clear to me if the trend plots are from the quoted published papers or from the current work.

Reply: These are the latest results obtained for this work (for the period of submission). To emphasize this fact, we changed the sentence (Ln. 19, p. 7285) as follows: "While detailed trend analysis is beyond the scope of this paper, Figures 1-2 provide an illustration using the time-series of aerosol and cloud products, reported in the joint MODIS Atmosphere Team C5 Level 3 monthly product for the period 2002-2013."

2. Since the C6 products are already out consider changing the reference to them from "will be available".

Reply: This phrase (Ln.15, p.7287) was correctly used with regards to algorithm MAIAC which is not part of Collection 6 re-processing and will be available later.

3. Page 7284, line 16: Instead of just saying that the signal in ocean color is small, it would be useful to quote a reference value relative to those for aerosol and surface reflectance.

Reply: This phrase is used correctly in the particular context. We cannot provide one number because of high natural variability of, for example, estuarine or coastal waters whose reflectance can be high not only in the Blue but also in the red-NIR part of

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spectrum (for very turbid waters).

4. Page 7285, line 2: List the reference, if exists, to the trend in cloud optical thickness.

Reply: No such reference presently exists for the cloud optical thickness. We are also not aware of trend reports from other groups for the MODIS COT product.

5. Page 7287, line 25: Please specify the period of analysis in Fig 3b. From this figure it appears to start July 2002 and end May 2013. If this is the case then the period is not 11.5 years, right?

Reply: Thank you for this correction. The period of analysis "October 2002 – April 2013" was added, and the total time period changed to $\sim$11.6 years.

6. Page 7288, line 14: Moon AOI: Would it be more appropriate to call this as space view since this should be available during every rotation of the scan mirror just like the SD view? I can't imagine MODIS "sees" the Moon during every scan.

Reply: It does not. The very next sentence says that: "The Moon observations usually require a spacecraft roll maneuver that is conducted about nine times a year." We have adopted this terminology to be consistent with the MODIS calibration team and their publications.

7. Page 7291, line 10 and Figure 6: I assume correction for calibration drift is applied in both columns (left and right) of Fig. 6, and the only difference is that the right column also has polarization correction, while the left one does not. Is my assumption correct?

Reply: Yes.

8. Page 7291, lines 16-18: Could a deficiency of Rayleigh scattering correction, that is residual Rayleigh contamination, also produce a blue reflectance that is larger than the green and red reflectances?

Reply: Hypothetically, yes, if lower Rayleigh optical depth were used, but it still would not explain the striping.

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9. Page 7291, lines 20-26: How well does the polarization sensitivity estimated from a monthly average reflectance represent the instantaneous sensitivity? This might be useful to know.

Reply: Shown is the effect of polarization sensitivity of MODIS Terra on TOA reflectance. Monthly averaging is used to obtain a representative statistics for clear sky conditions from observations. The instantaneous sensitivity is a function of scan angle, band, detector number, mirror side etc., but it is not really known as OBPG also needs a sufficient (monthly) statistics to produce trending coefficients. Because the change in polarization sensitivity of MODIS Terra is relatively slow, the instantaneous value should be rather close to a monthly value for a given month. We experimented with linear interpolation between monthly values to represent a daily value, but did not find any noticeable difference with just using fixed monthly values.

10. Page 7291, line 27 and Figure 7a: Is full correction applied in the "corrected" component?

Reply: A full polarization correction. To avoid misunderstanding, the respective sentence was changed as follows: “Figure 7a shows the effect of full polarization correction . . .”

11. Page 7292, lines 7-9: Is there an explanation for the observed difference in polarization sensitivity of MS1 and MS2?

Reply: The exact cause of this difference is unknown. The most plausible explanation was given in the Introduction, p. 7283: “The first event occurred during pre-launch thermal vacuum testing when a portion of the nadir aperture door was overheated. As a result, a strip of door paint (epoxy) evaporated and coated part of the optics and the scanning mirror. The affected parts were visually cleaned, but either some contamination remained or protective coating was damaged resulting in differences between the two sides of the scan mirror . . .” The most plausible cause is a residual thin film, with different thickness for MS1 and MS2 which changes over time and affects

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polarization sensitivity.

12. Page 7293, lines 1-4: Could you please clarify? Does this mean that PC is not significant for AOT? That is, the MCST C6 L1B already removes the spurious trend and Terra C6 trend now agrees with C6 Aqua trend. However, at least according to MAIAC, without PC correction Terra C6 BRF still has a positive trend that is not seen in Aqua C6 BRF. (Is the polarization sensitivity of Aqua negligible?)

Reply: PC is significant for AOT as it removes the mirror-side related striping in MODIS Terra. The mentioned paragraph discussed the effect of the long-term change of MODIS Terra gain and polarization sensitivity on MAIAC retrievals. Specifically, MAIAC separates the atmospheric (aerosol) and surface contributions based on the short-term ($\sim$2 weeks) variability which is not affected by the long-term sensor calibration change. Therefore, MAIAC would correctly derive AOT and put all of the sensor trend into the Blue-band surface reflectance record. By contrast, the standard MODIS "Dark Target" (DT) algorithm estimates Blue-band (B3) surface reflectance from the shortwave infrared band B7 (2.1 mkm) which had little degradation. Therefore, the estimated B3 surface reflectance of DT algorithm is trend-free, while the entire B3 calibration trend will appear in the derived AOT based on estimated B3 reflectance. The polarization sensitivity of MODIS Aqua was characterized pre-launch and apparently remains stable as we have not seen any related artifacts.

13. Page 7293, line 13: How many of the CEOS-recommended desert calibration sites have been used?

Reply: This discussion was provided next on page 7294 (Ln 23): "This procedure has been applied to seven CEOS desert sites independently. As a result of this analysis, we selected 4 sites (Libya1, Libya2, Libya4, Egypt1) which gave relatively similar trends (within a factor of 2–3 difference). . . ."

14. Page 7294, line 19, and Figure 10: Please make text and figure consistent (there is no blue color in the figure).

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Reply: Thank you for this comment. The typo was corrected as follows: "...Fig. 10, where the left plots show C6 Terra (with PC for B3) and the right plots show C6 Aqua data."

15. Page 7294, lines 20-21: I do not see how sampling biases are avoided by using "daily" values. Terra and Aqua observe the same area at two different times of the day, and atmospheric/surface conditions can be different.

Reply: The developed procedure is based on cloud-free observations. With seasonally variable cloudiness, a single monthly average value would represent a different number of clear-sky observations during a particular month. Thus, daily values are used to avoid such possible bias. Next, the surface properties of desert sites do not really change during the day, and changes in the view geometry are cancelled through geometric (BRDF) normalization. Finally, the typical AOT over these sites is low with low variability except days with dust storms which were excluded based on AOT threshold.

16. Page 7296, line18: Contrary to what is said in the paper, the C6 to C6+ change in NDVI does not appear to be small; in the early period it is almost as large as that for C5 to C6.

Reply: The exact phrase is "... the largest difference for MODIS Terra appears between C5 and C6 versions, while C6 to C6+ change is smaller" and it does not contradict the Reviewer's statement.

17. Figure 1: Is the unit for _R indeed % per decade, like the caption says? If yes, then according to the figure the trend is -0.267% decade-1 for Terra C5 AOD over land. However, the text on page 7286, line 5, says the trend is about -27%.

Reply: Figure 1 gives "-0.267 per dec (rel)" which is about -27% per decade. The word "per" is "per" and not "percent".

18. Figure 1: It would also help to explicitly define _R. For example, it is the change divided by the mean value for the period considered.

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Reply: The Figure 1 caption (p. 7305) was adjusted as follows for easier understanding: "The shown linear trend slopes are given in units of AOD or AE per decade (Beta_B) and % change per decade (Beta_R)."

19. Figure 1: Is there an inconsistency in the notation regarding _R and _B? For example, if _R and _B are the absolute change per decade and fractional change per decade, respectively, then should not "_R = -0.049 per dec (abs)" for Terra AOD over land be _B?

Reply: Thank you for this comment. The error was corrected and Figures were updated.

20. Figure 3b: As one of the objectives is to show the absence of drift in the Terra C6 data, would it be more convincing to show Terra C6 NDVI instead of, or in addition to, Aqua C6 in Fig. 3b?

Reply: This is shown later in Fig.13 after all corrections were introduced. The goal of Fig. 3b was (p. 7287): "To illustrate MODIS Terra C5 calibration artifact on NDVI, we selected a 500km tile in Georgia, USA . . . . The monthly mean area-average NDVI are presented in Fig. 3b showing a decreasing trend of about -0.01 per decade in Terra C5 (red) as compared to Aqua C6 (blue) data."

21. Figure 7a: Consider changing the caption to explicitly say that the TOA reflectance is displayed.

Reply: The caption of Fig. 7a was changed as follows: "Figure 7a. Magnitude of polarization correction (Corrected - Uncorrected) for MODIS Terra B3 TOA reflectance. Red and black lines represent mirror sides 1 and 2, respectively."

22. The papers Levy et al., 2007a,b, Levy et al., 2009, and Remer et al., 2008 are quoted in the paper but they are missing from the reference list.

Reply: The respective references were added.

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