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Atmospheric Measurement Techniques
Discussions

Interactive comment on "An SNR-Optimized Scanning Strategy for Geostationary Carbon Cycle Observatory (GeoCarb) Instrument" *by* Jeffrey Nivitanont and Sean Crowell

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"The manuscript deals with the optimization of geographic coverage, which is a problem of interest for geostationary satellite remote sensing. The approach presented in the manuscript is new and deserves publication in AMT. However, the approach and its underlying assumptions need to be better explained and the discussion of the results needs to be made clearer. The manuscript needs to be revised addressing the issues identified below.

1. The proposed scheme aims at enhancing the yield and quality of a geostationary CO2 observation system by optimizing the scanning strategy with a focus on the Signal

to Noise Ratio (SNR). Many other parameters that are expected to drive the yield and quality of such observations are not taken into account. Degraded CO2 product quality is expected not only in cases with low SNR, but also in many other conditions e.g. when viewing geometries are slant, when target air masses contain clouds or aerosol, and when clouds cover parts of the field of view thus increasing the risk of spatial straylight. The choice of focusing on SNR needs to be justified, and the approach regarding other potential drivers need to be explained and motivated."

We do include slant geometry into our calculation of SNR. We acknowledge that cloud contamination can cause bias in our measurements, but quantifying that effect is an open research topic and beyond the scope of this paper. The long viewing slit of GeoCarb means that at any given time there is a high probability that part of the slit will be obscured by clouds. Therefore, adaptive scanning to avoid clouds is beyond the scope of this first demonstration. Our algorithm seeks to maximize SNR by looking at the drivers that are more stationary processes such as the airmass and surface reflectance.

"2. The link between radiometric noise and the total CO2 uncertainty need to be discussed in more detail (beyond reference to O'Brian, 2016 and Eq. 3). The main contributors to the CO2 product uncertainty budget need to be discussed, and it needs to be explained why the optimization is driven by the random radiometric error."

The model we use is an empirical model of retrieval uncertainty as a function of SNR, not the actual physical models used in the L2 algorithm. We would like to point out that we are not minimizing total CO2 uncertainty, but rather uncertainty due to stationary processes such as the solar zenith angle, surface reflectance, and airmass. We have added additional explanation to Section 3.3 as to how we linked SNR to retrieved CO2 uncertainty.

"3. The objective function given (Eq. 5) minimized in the optimization scheme seems incomplete. The SNR depends on the radiance signal level (Eq. 2) hence also on the solar zenith angle (SZA) (Eq. 1). However, the SZA does not appear explicitly in the objective function. The penalty on slant illumination conditions seems to be missing."

The penalty for slant illumination is contained in the airmass factor, m. As a matter of fact, we initially had SZA explicitly in our objective function. However, the viewing slit of the GeoCarb instrument is so long that the slant penalty accounted over the entire area of a scanning block can outweigh other penalties such as overlapping coverage. This would cause the algorithm to pick too many overlapping blocks and extend the scan past the usable daytime. Therefore, we found that the SZA accounted by the airmass factor was sufficient.

"4. The top-level concept of the optimization scheme needs to be explained upfront (i.e. briefly in the abstract and in more detail in the introduction). Please clarify key elements such as a) that the scheme is to be applied off-line to determine a static scanning strategy, b) that near-real time information e.g. on cloud conditions is not taken into account, c) that the scheme is implemented by incrementally adding observation blocks, d) that the selection of the added blocks is performed by optimizing parameters X, Y, Z."

a) The technique demonstrated in the paper was indeed applied offline and it has been noted in the manuscript. We would like to point out that this IO routine could be applied online with real-time information.

b) The technique demonstrated in the paper assumes cloud-free atmosphere. This has been specified in sections 2, 3, 3.3, and 4. We know that this is physically incorrect and we believe that, in the future, the IO routine can be modified to take in real-time cloud information if it were available for the entire scanning region. Although as previously mentioned, that area of research is beyond the scope of this paper. We would like to reiterate that this is just a demonstration of a technique and not the proposed scanning strategy for the GeoCarb mission.

c), d) Additional explanation of the main idea of IO has been added to the abstract and

introduction.

"5. It is concluded that the IO based solution outperforms the "obvious human" solution. This statement needs to be either better supported addressing a the apparent weaknesses listed below, or revised. Weaknesses include: a) the "obvious human"solution is to some degree arbitrary, there might be better guesses; b) comparisons are shown only for two cases with similar time of day, the situation can be different for other times; c) improvements in Amazonia and degradations at other places are reported (Fig 8), but it is not clear how global performances are determined and compared; d) differences in the total number of usable observations are reported (Section4.1) but the basis of these numbers is unclear; How is the number of 'usable soundings' determined? Are there thresholds on SZA, AMF, SNR, albedo, .. ?"

a) Prior to submitting this paper, the Moore et al (2018) had not been published. We possessed a tentative strategy and chose "obvious human" solution as a stand in for calling it the "proposed strategy" up until now. We have changed the language to say "proposed scanning strategy" rather than "obvious human" solution, referring to Moore et al (2018) as the source document for the GeoCarb mission description.

b) Part of the technique is that the algorithm chooses a timeframe for scanning by using a specified "starting airmass factor (AF) threshold" parameter. After specifying a starting AF threshold, the decision of when and where to start scanning is left to the algorithm. This is specified in Section 3.2.

c) Global performance in our context is meant to signify the aggregate predicted observational uncertainty (from Eq. (3) now Eq. (4)) over our satellite viewing area. We altered the language of the manuscript to clarify this.

d) We chose an SNR of 100 as our threshold as to what constitutes a usable sounding. In the empirical model of predicted CO2 retrieval uncertainty as a function of SNR, a SNR of 100 translates to a 2 ppm XCO2 retrieval uncertainty, which is within the first proposed accuracy per sample of XCO2 mentioned in Polonsky et al (2014). We have added extra explanation to the manuscript to clarify this.

“6. Section 4.2 reports a sensitivity analysis based on the assessment of regression coefficients. The conclusion of this analysis is unclear. Please clarify the conclusion in Section 4.2 and discuss the result in the overall context, in Section 5.7. Figures 5 and 10 are not understood. Specify, also in the caption, which parameter is plotted on the ordinate, what the colour coding means, which distributions are represented by the ‘violins’. Why are distributions plotted as double-sided graphs?”

The x-axes of Figs. 5 and 10 are labeled as “starting threshold” in reference to the starting airmass factor threshold that the algorithm takes as a parameter. The colors are not in reference to any specific attribute of the distribution, rather it just makes it easier to distinguish between different distributions. We chose to represent our distributions as violins because we felt that it makes it easy for the reader to identify areas of high density within each distribution.

The sensitivity analysis was performed post-simulation runs as a check to see if the algorithm would exhibit unexpected behaviors when perturbed and concluded that it does not. These results are not tied to the main results of this paper. Therefore, the sensitivity analysis was moved to the appendix.

“Technical Corrections Section 3.6 The iterative determination of scanning blocks might be dependent on the starting point (the location of the first scanning block). Have various different starting positions been investigated?”

As mentioned in response to comment 5, the algorithm takes a specified starting airmass factor threshold as an argument and then it decides when and where to start scanning. As a pseudo-sensitivity check early in conducting our experiments, we did try to force the algorithm to start at different areas, but it would return to scanning generally the same geographic locations as other algorithm-selected strategies within a short time after starting the scan.

“Section 3.5.2 Is full and contiguous coverage of the continental Americas within +/- 50deg lat within a day a hard boundary conditions for the optimization?”

Yes. We have added additional explanation to the background section that explains that this geographic region includes the regions of interest for the six major science hypotheses stated in Moore et al (2018).

“Page 4 line 18: the aerosol optical thickness of 0.3 is considered very large. Please justify. Aerosol optical depth depends on wavelength. What is the reference wavelength for the optical depth values provided?”

We chose an aerosol optical thickness of 0.3 because it is considered a worst-case scenario for clear-sky retrievals and would give us conservative estimates of predicted observational uncertainty. This decision was based on the experience of the ACOS and OCO-2 team, referenced in the manuscript. We have added additional language clarifying that we are looking at the weak CO2 (1.61 micron) band.

“Page 4 Eq 2: please provide units of parameters N0 and N1 (which should be sameas the units of I)”

Units have been added clarifying that I, N0 and N1 are in units of nW (cmˆ2 sr cmˆ(-1))ˆ(-1)

“Page 4 Eq 3: please clarify the meaning of sigma (introduced as the observational uncertainty). Clarify whether it is taken as the dominant contribution to the XCO2vertical column uncertainty. Discuss the validity of this assumption.”

Additional explanation of sigma was added to Section 3.3, which explains that sigma is derived from the posterior covariance given by the L2 algorithm.

“Page 4 Eq 3: Specify units of sigma.”

The manuscript has been fixed to say that sigma is in units of ppm.

“Page 5 Eq 4: eq 2 established a simple noise model. Eq 5 established an alternative more simplistic noise model. Why is the latter needed?”

The more simplified model in Eq. 5 is an intermediate step to explaining the formulations of the objective function. It has been moved to be an inline equation rather than a numbered equation block.

“Page 5 line 7: unclear what is meant with “multiplicative inverse””

Additional language was added to clarify that we mean, one divided by the radiance.

“Page 5 Eq 5: ‘s’ is used in an inconsistent way. It is introduced as an index to label the candidate block. It appears as a parameter in the argument AF, where it probably should not appear since x and y already capture the horizontal spatial dimensions. At the same time it represents an area in the spatial overlap operation; instead a dedicated variable (eg A_s) should be used to represent the area of the candidate block s.”

We realized that having set operations in the equation could be ambiguous to the reader. The terms in the objective function were reformulated to exclude set operations.

“Page 5 Eq 5: specify across which domain the median is evaluated. I guess it is the area of the candidate block ‘s’.”

Additional language was added to clarify that we meant the area of the candidate block, s.

“Page 5 Eq 5: The variables E and I should be introduced as ‘areas of’ the target landmass and of the selected scan blocks.”

The terms in the objective function were reformulated to be more clear to the reader.

“Page 5 Eq 5: the distance delta is not well defined. Please clarify from which point to which point is it to be evaluated.”

Additional language was added to clarify that delta is the shortest linear distance from the boundary of the last selected scan block to the candidate scan block. A diagram

has also been added to clarify the terms of distance, overlap, and coverage.

“Page 6 Section 3.5 discusses a finite number of possible locations of a scan block, which suggests that blocks can be located only at discrete positions. Please clarify whether this is correct. If so, introduce this constraint explicitly and specify the grid of candidate locations.”

Additional explanation was added to Section 3.5, referencing the explanation of the formulation of scan blocks in Section 3.1.

“Section 3.5 Page 6 Section 3.5 line 9-10: The formulation “...a Greedy heuristic algorithm was employed to find a minimal covering set as a lower-bound estimate for set cardinality “ is not understood. Please clarify what is meant with the term ‘cardinality’ in the present context?”

The term ‘cardinality’ has been changed to say “set size”.

“Page 7 line 7-10 very long sentence, meaning is unclear. Please split and reformulate. Page 7 line 7-10 The variance of predicted errors is mentioned. On which parameter and over which domain is this variance evaluated?”

We believe that the commenter is referencing to Page 8 lines 7-10. The entire Section 3.7 (now Sect. 3.6) has been reformulated for clarity.

“Page 7 line 7-10 Please clarify and elaborate how to the optimum at weights=1 is found.”

We changed our language to say that the weighting of the terms have negligible effects on the predicted error. We point that the spread of error medians and variances is approximately 0.01 ppm and ultimately decided that the weights shall remain equal to 1.

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