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Atmospheric Measurement Techniques Discussions

Interactive comment on "Quality controls, bias, and seasonality of CO_2 columns in the Boreal Forest with OCO-2, TCCON, and EM27/SUN measurements" *by* Nicole Jacobs et al.

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We are grateful to referee #1 for their review of this manuscript and identification of important points where clarification was needed. The referee's endorsement of the paper is appreciated. In the text below, we detail responses to each of the referee's comments. Page and line numbers refer to the originally submitted discussion paper.

referee comment: "Abstract, page 2, line 1 following: Concerning the sentence "...seasonal variability in biases was observed, and this variability was more pronounced at the TCCON sites than when comparing to EM27/SUN observations in Fairbanks." Is that a robust finding,i.e., does this suggest that EM27/SUN is better than TCCON?"

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Discussion paper

Our study uses only two instruments from the TCCON network and one EM27, all of which are deployed at different locations, so the present work is not sufficient to suggest which instrument is better, and that answer might also depend upon the application. It is possible that the seasonal stability in OCO-2 bias relative to the EM27 at Fairbanks could be due to the EM27 spectral resolution (∼0.5 cm-1), which is much closer to that of OCO-2 (∼0.3 cm-1) than TCCON (∼0.02 cm-1). While the EM27s used in Fairbanks were calibrated against the Caltech TCCON, there is no TCCON in Fairbanks and vertical distributions of CO2 at these two sites are likely to differ. An analysis of OCO-2 data compared to long term EM27 observations at multiple TCCON sites would be necessary to more fully address whether the relative seasonal stability in OCO-2 bias at Fairbanks is due to geography or instrumentation. There are a small number of sites that have published analyses or data from EM27 observations alongside a TCCON for multiple consecutive years, but we are not aware of any that have published results comparing multiple years of EM27 measurements to OCO-2. Sha et al., 2019 (AMTD, doi: 10.5194/amt-2019-371) present thorough comparisons amongst EM27 observations, TCCON observations, and TCCON measurements truncated to a lower resolution, as well as other infrared spectrometers, using a full year of measurements at Sodankyla, Finland. Their results suggest that the EM27 may retrieve higher XCO2 in spring than the TCCON, and this could result in reduced seasonal dependence in bias. Their results also suggest that factors such as temperature and water vapor may play a role in the differences between EM27 and TCCON retrievals of XCO2. In general, the EM27 is a relatively new instrument and has yet to undergo the extensive effort that has been applied to TCCON measurements, so more research is needed. A sentence was added to the abstract and conclusions to clarify this point, and the discussion in section 4 (page 21, line 28) was enhanced with this citation and further discussion.

referee comment: "Page 3, line 12 following: Concerning the discussion of the trend in the CO2 seasonal cycle amplitude: Please consider also this recent publication: Yin et al., 2018, Changes in the Response of the North-

ern Hemisphere Carbon Uptake to Temperature Over the Last Three Decades, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2018GL077316"

Thank you for calling attention to this study, which will also be helpful in future research of Boreal Forest seasonal cycles. Citation of Yin et al., 2018, was added at page 3 line 12 and some additional description of their findings was added at the end of the first paragraph in the introduction.

referee comment: "Page 5, line 28 following: Concerning the suggested new quality control filters for Boreal Forest regions: Are they limited to this region or can they also be used for the global data?"

The alternative set of quality controls proposed in this manuscript are specifically validated in the Boreal Forest (the biome covering the majority of land between 50N and 70N latitude) and yield the optimal combination of throughput and data quality when applied to these data. Our analysis only vetted these quality control parameters using ground-based observations from three Boreal Forest sites, so it is unknown how they will affect data quality when applied to regions south of 50N or over the high Arctic (Greenland and places with abundant sea ice). The Boreal QC yields slightly higher standard deviation than the B9 QC, and while this may be a worthwhile sacrifice to increase data throughput at high latitudes, it may not be worthwhile for a region that already has high data throughput with B9 QC. In particular, some aerosol filters were removed in the Boreal QC, which are redundant for these Boreal sites but could be important over urban areas. Stricter bounds placed on the slope of the continuum albedo in the strong CO2 band (albedo_slope_sco2) in the Boreal QC may also cause unexpected cuts in regions outside of what was considered. If one intended to apply the Boreal QC to another region, we recommend a careful comparison to well-established ground-based validation data within the region of interest before making any decision. While there is some effort made to clarify this point within the paper, we also added some language to the end of the introduction (near page 5, line 28) to clarify that the alternative quality filters are designed and vetted for the Boreal Forest.

referee comments: "Captions Fig. 3-5: I recommend to write “flagged bad” (e.g. bad with quotes) or equivalent instead of just “flagged”. It would then be easier for the readers to understand(if this is correct) that the figures show the number of rejected observations and not the number of accepted observations. Perhaps one may also extend a bit the main text as the figures may wrongly suggest that there are less good data in summer than in winter although the opposite is probably the case (one may also report the fraction(percentage) of rejected pixels per months; does this number depend on season ?).

Figures 5 and 6: Perhaps add also the relative (percentage) increase for each month(just a recommendation; not mandatory as this info is partially provided in Fig. 7)."

First, captions in Fig. 2, 3, and 4 were modified to read "flagged bad", as suggested, and corresponding references in the text were also changed from "flagged" to "flagged bad". In response to your suggestion about showing fraction (percentage) of rejected pixels, we took what may be a slightly different approach than intended and decided to modify Figures 5, 6, and 7, as well as making other revisions to section 3.2. Figures 5 and 6 were the maps of additional spatial coverage from using Boreal QC instead of B9 QC, and they were changed to show the difference in the number of soundings between Boreal QC and B9 QC in each 1x1 degree geographic grid cell, on a diverging color scale and including small reductions in throughput. These maps are now much more informative and give a more holistic perspective on the changes in throughput from the Boreal QC. As suggested, we changed Fig. 7 to show the fraction of soundings passed by each QC relative to the total number of soundings over land north of 50N rather than showing the absolute number of soundings passed. We believe that this better represents the improvements in data throughput because for some months there are already fewer data points prior to quality filtering as a result of pre-screening done on the OCO-2 Lite file data or from lack of data collection.

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