Responses to reviewers' comments on "Validation of formaldehyde products from three satellite retrievals (OMI SAO, OMPS-NPP SAO, and OMI BIRA) in the marine atmosphere with four seasons of ATom aircraft observations"

We appreciate the valuable feedback and support from two reviewers and Jean-Francois Muller regarding the publication of this manuscript following revisions. In response to their suggestions, we have carefully revised the manuscript. To facilitate the review process, we have included the reviewers' comments in black text, with our responses in blue. All comments have been addressed, and the corresponding changes to the manuscript are tracked.

Referee #2

This manuscript systematically analyzes the differences and sources of remote sensing datasets of formaldehyde column concentrations over the oceans using ATom data and multiple satellite HCHO inversion results. I believe that this work has important implications for both satellite dataset developers and users, especially given the scarcity of validation of oceanic atmospheric observations. The article should be finally published after addressing the issues below.

Major comments:

1. On the significance of the study for data developers and users: The oceanic atmosphere HCHO retrieval may be highly noisy due to the instrument detection limits. Therefore, this study is of great importance to both satellite data developers and users in this area. In my opinion, quantitative assessment of the data quality and futher suggestions on retrieval improvement should be emphasized in the manuscript (e.g., abstract and introduction) in relation to the existing knowledge and shortcomings in the data application work, in order to directly highlight the significance and conclusions of the study to the readers. For example, it would be informative for readers to have the mean bias for each satellite HCHO products in the abstract and conclusion section.

   Mean biases are added to the abstract, results and discussion and conclusion.
   Abstract: added "The agreement is also reflected in the mean bias (MB) for OMI SAO ($-0.73\pm0.87)\times10^{15}$ molec $cm^{-2}$, OMPS SAO ($-0.76\pm0.88$) $\times10^{15}$ molec $cm^{-2}$, and OMI BIRA ($-1.40\pm1.11$) $\times10^{15}$ molec $cm^{-2}$."

   Conclusion: added "The mean bias for OMI SAO, OMPS SAO, and OMI BIRA is -0.73 ($\pm0.87$) $\times$ $10^{15}$ molec $cm^{-2}$, -0.76 ($\pm0.88$) $\times$ $10^{15}$ molec $cm^{-2}$, and -1.40 ($\pm1.11$) $\times$ $10^{15}$ molec $cm^{-2}$, respectively."

The mean bias values are also added to Table 2, 3, and 4 and discussed in the paper.

Introduction lines 89-97 describe the potential HCHO retrieval issues over the remote ocean atmosphere. Changed “Consequently, validation of satellite HCHO over the remote ocean would aid in assessing the satellite’s ability to capture background HCHO levels accurately and enhancing our understanding of these baseline levels. To “Consequently, quantitative assessment of satellite HCHO over the remote ocean is crucial for assessing the satellite’s ability to accurately capture background HCHO levels and deepening our understanding of these baseline levels.” Added “Refining satellite HCHO retrievals will reduce potential bias in applications such as estimating VOC emissions and atmospheric oxidant levels.”

2. Regarding the heterogeneity and transformation of atom and satellite observations: The transformation of atom in situ observations into atmospheric column concentrations is essential to the comparisons results described in this paper. Although partially mentioned in L120-130, some doubts may remain. For example, missing atom data and the absence of observations in the upper atmosphere (> 10km) require interpolation and averaging, how much do these treatments affect the results? What percentage of Atom data is missing? Are there any uncertainties in the molecule number concentration method? Also in L127-129, "Average gas profiles from OMI SAO HCHO retrievals are used to estimate the contribution of HCHO above 10 km to the total HCHO column": how to derive the ratio of HCHO columns above 10 km from OMI SAO retrievals? It should be total column HCHO retrieved from OMI spectral measurements. Does such conversion relying on OMI SAO HCHO affects the comparisons with other satellite products such as BIRA product.

   We have revised the text to better explain our process for selecting columns, including considerations of missing data percentage. For the portion of HCHO above 10 km, we rely on model results (satellite a priori profiles) and we have provided a clearer explanation of this process. Additionally, details on how molecule number concentration is calculated have been added to the Supplementary information.

   Changed “Columns are filtered to include only profiles with solar zenith angle smaller than 80°, minimum altitude <= 600 m, maximum altitude >= 8 km, fraction of missing interpolated grids < 0.2, and fraction of missing extrapolated data <0.25.” to “ Columns are filtered to include only profiles with solar zenith angle smaller than 80°, minimum altitude <= 600 m, maximum altitude >= 8 km, fraction of missing measured data in the altitude profiles < 0.2, and fraction of missing extrapolated data between 0 to 10 km <0.25. The average missing interpolated data within 0 – 10 km is 8%, mostly due to lower resolution TOGA data are used during ATOM 4. The

data gaps are typically small and lack significant structure, so we expect them to contribute to random error rather than introduce any systematic bias. The average missing extrapolated data between 0 – 10 km is 5%. “

Changed “Average gas profiles from OMI SAO HCHO retrievals are used to estimate the contribution of HCHO above 10 km to the total HCHO column. “ to “Most HCHO > 10 km were not measured during ATom field campaign so modeled results, average gas profiles from OMI SAO HCHO retrievals, are used to estimate the contribution of HCHO above 10 km to the total HCHO column. The gas profiles in OMI SAO retrieval are from GEOS-Chem 2018 monthly climatology 0.5º×0.5º (Table 1).”

Line 128 changed “The calculated fraction of HCHO above 10 km (relative to the total column) is $0.045 \pm 0.002$.” to “The fraction of HCHO above 10 km (relative to the total column) is $0.045 \pm 0.002$, calculated by the integrated gas profiles above 10 km divided by the integrated gas profiles from 0- 40 km.”

SI Added “Molecule number concentration is calculated by Eq.(S1)

$M=Na \times P/R/T$ (S1)

Where Na is Avogadro’s number $6.022 \times 10^{23}$ mol-1; P is pressure in mbar; R is gas constant $8.314 \times 10^{4}$ $cm^3$ mbar $K^{-1}$ $mol^{-1}$ and T is temperature in K.

3. When comparing different satellite products, may the author use the convolution of averaging kernels in satellite HCHO rertievals with Atom measurements, to minimizing the impact the using different a priori profiles in AMF calculations.

   Line 400 added “The convolution of averaging kernels in satellite HCHO retrievals with ATom measurements was not performed for three reasons: 1) AMFs are likely minor contributors to overall retrieval error in the study regions. 2) In the remote oceanic atmosphere, the shape factors for three retrievals are generally very similar (Figure 6a). Adjusting them to match ATom measurements could systematically alter the AMF of the retrievals but it would not significantly affect the differences among them. 3) HCHO level distributions or shape factors above 10 km are not available from ATom measurements, potentially introducing additional uncertainties in the clean oceanic atmosphere due to high scattering weights (or averaging kernels) at high altitudes.”

Minor comments:

1. L243-245: the unit of column density should be molecules cm -2?

   The units are corrected.

2. Table 2-4: other metrics such as mean bias should be added and discussed in the main text
   Mean biases are added in Table 2-4. They are discussed in the main text.