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# First Results of Cloud Retrieval from Geostationary Environmental Monitoring Spectrometer

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## Item-by-item responses to Reviewer 2's comments:

We appreciated Reviewer 2's interest in our study and your valuable suggestion. We have carefully reviewed your comments and revised the manuscript as clearly as possible. We have highlighted the revised sections in blue in the manuscript. The revised manuscript has been proofread.

General comments:

This manuscript presents a generally well written study on the algorithm retrieval results of GEMS cloud products. The author presented comprehensive analysis including comparison with the different satellite products along with the algorithm results. I suggest the publication of the paper after minor revisions.

Specific comments:

Line 11: 'the first geostationary orbit satellite' → I recommend that to be more specific as the GEMS is not the first geostationary orbit satellite instrument.

[Reply] We revised the words in lines 11 as follows:

*"the first environmental geostationary orbit satellite"*

Line 26: missing periods.

[Reply] We entered periods.

Line 23,29: It may not be a serious problem, but I suggest you distinguish the word between "satellite" and "instruments".

[Reply] We revised the satellite to instruments.

Line 30: gases(GHG) → gases (GHG)

[Reply] We put the space between words and parentheses.

Line 31: Please check typo "using use spectrometers GHGs".

[Reply] We revised the sentence in lines 30-31 as follows:

*"Satellites now monitor global warming by measuring greenhouse gases such as carbon dioxide and methane using spectrometers in the near-infrared and shortwave-infrared regions"*

Line 41: 'characteristics vary greatly depending on the spectral band.' → Do you have any reference or evidence for this sentence? Or did you want to say retrieval results greatly depending on the instrument characteristics?

[Reply] We intend that the characteristics of clouds are depending on the instrument characteristics.

Line 58: I thought the spectral resolution of GEMS is about 0.6nm, while sampling is 0.2nm. Could you check again?

[Reply] We revised the 0.2 nm to 0.6 nm.

Line 60: 'keeping the Sun-Earth-satellite angle constant' → do you mean constant VZA?

[Reply] Yes, we revised the words in lines 59 as follows:

*"in a sun-synchronous orbit (SSO) while maintaining the Solar Zenith Angle (SZA) variation"*

Line 64-65: Could you provide a reference for this? Or I think you can probably explain it with low SNR, etc.

[Reply] We added the reference and revised the manuscript in lines 62-63 as follows:

*"This reduces the quantity of radiation energy reaching the satellite and extends the beam path, resulting in a lower signal-to-noise ratio (Vandaele et al., 2018) and cloud retrieval errors."*

Line 84: 'with a resolution of 0.2 nm' → Could you check this again? I thought the spectral resolution of GEMS is about 0.6nm.

[Reply] We revised the 0.2 nm to 0.6 nm.

Line 92: Could you provide some references?

[Reply] Cloud phase is typically based on 8.7 micron and cloud top properties are based on thermal bands therefore, the cloud top heights from UV-VIS bands are less than those retrieved by thermal bands. I also added references: Compernolle et al., 2021 and Kim et al., 2019.

Line116: Why? Are there no CRF products from other satellites?

[Reply] The CRF is only converted from ECF considering wavelength dependency and it is significantly related to ECF, therefore we did not need more comparison for CRF. This is the reason why there are no CRF products from other satellites.

Line 144,147,152: Just curious. Why is there no consideration of $NO_2$ in this equation? I think the impact may be significant, especially over East Asia. What do you mean that the absorption by nitrogen dioxide is linear?

[Reply] We decided the gases in cloud retrieval process based on fitting residual. In the fitting residual analysis, both of $NO_2$ and $O_3$ did not cause remarkable error, but only $O_3$ caused error in high cloud conditions. Therefore, we added the $O_3$ absorption effect.

We apologize for the confusion caused by mistakenly describing it as linear, we deleted in manuscript in lines 127-129 as follows:

*"In addition, even though $NO_2$ absorption coefficients exist in the spectral range of the input reflectance, their effects are disregarded because the impact is negligible."*

In addition, we acknowledged the effects of $NO_2$ absorption on the GEMS cloud retrieval algorithm, so we attempted to account for $NO_2$ absorption via the adoption of QDOAS, etc. We also included the related discussion in lines 426-427 as follows:

"*Also, QDOAS application enable to consider the $NO_2$ absorption. We anticipate the improvement of the GEMS cloud retrieval algorithm in the future through consider those remaining issues."*

Line 168: Do you have any reference paper for VLIDORT NGST?

[Reply] We added the reference for the VLIORT NGST in lines 146 as follows:

*"while GEMS used the VLIDORT NGST version (Spurr et al., 2006)."*

Line 173: 'which has the most similar algorithm design' → Do you mean as a prototype?

[Reply] We revised the sentence in lines 175-176 as follows:

"*which has the most similar to spectral resolution and cloud prototype algorithm of GEMS*"

Line 174: 'operates simultaneously with GEMS' → I suggest 'in operational since 2018' rather than operates simultaneously.

[Reply] We revised the words following your suggestion.

Line 175: 'the same orbit' → Does it mean the same geostationary orbit?

[Reply] Yes, we revised it in lines 177 as follows:

*"the same GEO orbit "*

Line 182: 0.6 → 0.6nm

[Reply] We added the unit.

Line 243: Just curious. Are there any standards to select the cases?

[Reply] We choose the cases following some reasons. The case used to have occurred in GEMS FOV. And then we choose the specific day for each case have to be captured on all platforms. And the meaning of each case is as follows:

East Asia has experienced a severe problem with the high concentration of aerosol. Considering the purpose of GEMS to monitor the atmospheric environment, we need to validate a high-concentration case. The second case is for the typhoon, the typhoon is a very good case to validate cloud products because typhoon brings various cloud type. The last case is for sea fog, as I mentioned in the manuscript, sea fog is often between Korean Peninsula and China. Sea fog acts on the bright surface, therefore errors in their pressure cause very large errors in the gas retrievals. Therefore, we choose the sea fog cases and analyzed the cloud products.

Line 258: 'the nearest neighbor method was based on' → 'the nearest neighbor method was used based on'?

[Reply] We revised as suggested in lines 262.

Figure 1: Reason for the stripe pattern?

[Reply] The striped pattern caused by look-up table interpolation processes was eliminated after the systematic error was resolved as follows:

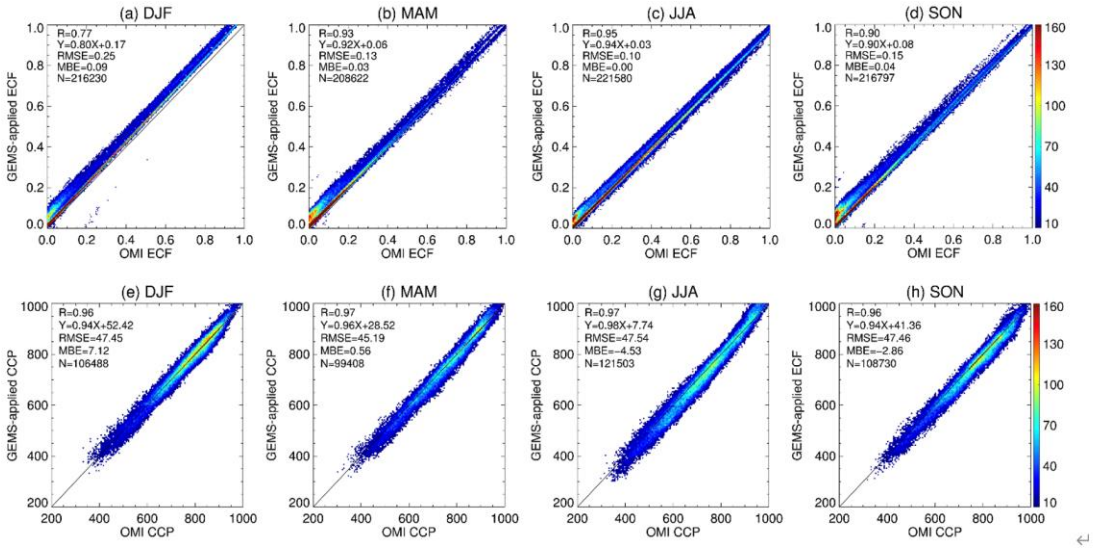


**Figure 2: Cloud products for random days in each month of 2007 (classified by seasons: DJF-winter, MAM-spring, JJA-summer, SON-autumn) for comparison with cloud products from the OMI algorithm. The top panel shows the density scatterplot for effective cloud fraction (ECF) and the bottom panel shows the density scatter plot for cloud centroid pressure (CCP). The x-axis represents the values from OMI, and the y-axis represents the cloud products from the GEMS algorithm. The solid line indicates the 1:1 line, and the correlation coefficient (R), regression equation, root mean square error (RMSE), mean bias error (MBE), and number of pixels (#) used in the analysis are presented.**

Line 280: It would be better if you could add the reason briefly.

[Reply] We revised the manuscript in lines 284-289 as follows:

*"However, many previous studies (Vasilkov et al., 2008; Sneep et al., 2008; Loyola et al., 2018; Compernolle et al., 2021) reported that the accuracy of CCP retrieval using O2-O2 absorption was significantly lower for areas with an ECF less than 0.2."*

Figure 2: Caption 'March 5th' → 'March 25th'.

[Reply] We revised the typo.

Figure 1-4: I can see that you are using the term “GEMS ECF” or “GEMS CCP”. This is not GEMS data, but GEMS algorithm applied results. I suggest you distinguish between real GEMS products and GEMS algorithm applied products in the Figure, but I’ll let the author decide it.

[Reply] We changed the expression to GEMS-applied ECF, GEMS-applied CCP

Figure 3: Reason for the stripe pattern?

[Reply] Same problem in Fig. 1 (original manuscript). The striped pattern caused by look-up table interpolation processes was eliminated after the systematic error was resolved as follows:

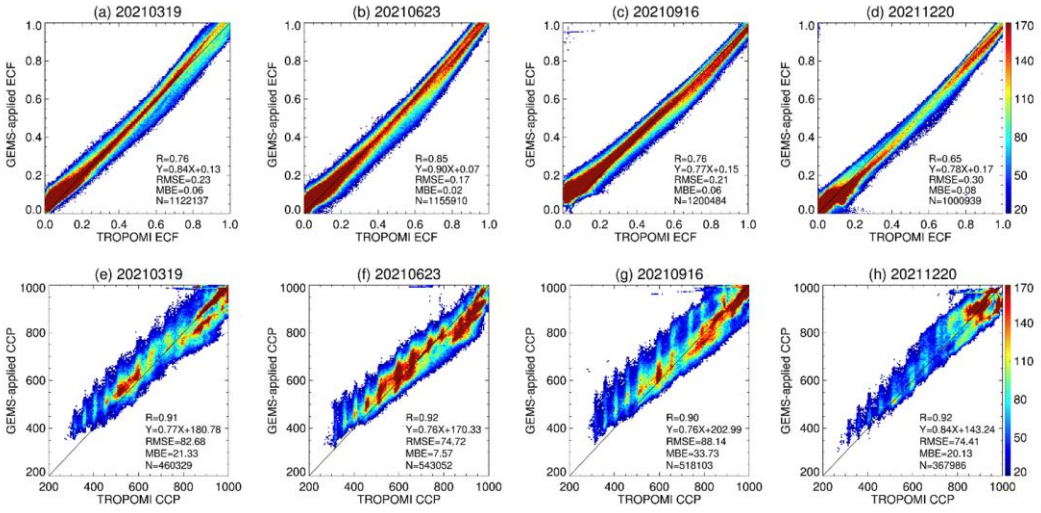


**Figure 4: This figure is similar to Figure 1 but for TROPOMI. To verify the performance and seasonal dependency of GEMS cloud retrieval algorithm, cloud retrieval results were compared with those of TROPOMI for random days in March, May, September, and December 2021. The top panel shows the results for ECF and the bottom panel shows the results for CCP in a density scatterplot. As definitions of cloud pressure differ between GEMS and TROPOMI, the density scatterplot was generated using the mean value of CTP and CBP (mean cloud pressure, mCP) from TROPOMI. The x-axis shows the TROPOMI values, and the y-axis shows the GEMS cloud retrieval results. The solid line represents the 1:1 line, and the correlation coefficient and regression equation are also displayed.**

Line 329: Just curious. Which channel does the AMI use for the cloud retrieval?

[Reply] The AMI uses the VIS (0.6 ㎛, 0.8 ㎛) and IR (10.4 ㎛) channels for cloud mask retrieval.

Line 350: Why does the GEMS tends to estimate lower cloud heights than TROPOMI cloud pressure?

[Reply] $O_2$-$O_2$ is related to the square of pressure and converged very low cloud, therefore it is sensitive to very low clouds (larger than 700 hPa, scale pressure is located around 700 hPa). We changed and added in the manuscript in lines 350-355 as follows:

*“Comparing TROPOMI CH with GEMS CH revealed that, in general, GEMS tends to concur with TROPOMI CH in low cloud (less than 6 km) conditions, but estimates lower cloud heights than TROPOMI cloud pressure calculations for high cloud (over 6 km). The scale pressure of O2-O2 absorption is approximately 700 hPa, and this altitude becomes the reference for the relationship between TROPOMI and GEMS cloud pressure. Consequently, while lower clouds*

*display cloud heights comparable to TROPOMI, clouds at higher altitudes have the characteristic of estimating lower altitudes."*

Line 367: Again, why does the GEMS tends to estimate lower cloud heights than TROPOMI cloud pressure?

[Reply] GEMS tended to underestimate in high and thick cloud conditions, therefore, we added in the manuscript in lines 377 as follows:

*"GEMS tended to underestimate cloud height compared with TROPOMI in high and thick cloud conditions."*

Line 398: Maybe you can add a brief reason why GEMS cloud height is the lowest.

[Reply] We revised the manuscript in lines 409-411 as follows:

*"The GEMS cloud retrieval algorithm is sensitive to high pressure greater than scale pressure; as a result, GEMS estimates of cloud height were the lowest among the four satellites, corresponding to the height at which clouds reflect radiation."*