Manuscript ID: amt-2023-91

First Results of Cloud Retrieval from Geostationary Environmental Monitoring Spectrometer

Bo-Ram Kim, Gyuyeon Kim, Minjeong Cho, Yong-Sang Choi*, and Jhoon Kim

Item-by-item responses to Reviewer 1's comments:

We appreciated Reviewer 1's interest in our work as well as your insightful recommendation. We have carefully considered your suggestions and made improvements to the manuscript. We have kept track of the manuscript's updated sections. Proofreading has been done on the updated manuscript.

1) L19-L32: This paragraph is too broad to include the manuscript. Although the cloud is important for the radiation field, the manuscript will be merely focused on cloud retrieval.

[Reply] We have revised the first paragraph to include only essential information regarding weather satellite observations and cloud issues, incorporating the reviewer's feedback. Additionally, we have structured the second paragraph to provide more detailed insights on cloud effects. The updated manuscript in L19-L35 as follows:

Atmospheric composition has been monitored continuously by several satellite-loaded instruments since 1978: Total Ozone Mapping Spectrometer (TOMS), the Ozone Monitoring Instrument (OMI), Global Ozone Monitoring Experiment (GOME), SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY), and Tropospheric Monitoring Instrument (TROPOMI) (Hsu et al., 1997; Burrows et al., 1999; Bovensmann et al., 1999; Levelt et al., 2006; Veefkind et al., 2012). These spectrometers measure the ultraviolet (UV) and visible (Vis) radiation centered at 240 to 790 nm (Hsu et al., 1997; Burrows et al., 1999; Bovensmann et al., 1999; Levelt et al., 2006; Veefkind et al., 2012). It is then required to estimate the beam path length of the radiation to retrieve precise atmospheric compositions from the radiation measured by these spectrometers. The beam path length of the radiation is the entire path length of incoming and reflected solar energy by Earth's surface until reaching the satellite. Thus the calculation requires to consider geometric factors such as solar zenith angle (SZA) and viewing zenith angle (VZA).

The beam path length should be also calculated not only for a clear-sky condition, but also for a cloudy-sky condition. This is because cloud layers can shorten the beam path length by blocking the beam from atmospheric components below the clouds. Cloud reflectance is typically greater than that of most surfaces (excluding snow and ice) and this cloud effect can inevitably result in significant errors in the observations of atmospheric variables (Hong et al., 2017; Chimot et al., 2018). Therefore, to obtain accurate concentrations of atmospheric components, it is necessary to evaluate and quantify the cloud effects on the beam path length.

2) L163-L167: I am confused as to why the cloud models (LER and MLER) are explained. During the retrieval, the used points for LER and MLER have to be clarified.

[Reply] "MLER" stands for Mixed LER model. In this study, we assumed the reflectance characteristics of clouds to be LER and set the albedo to 0.8, to valuate cloud reflectance values for each pixel. Therefore, it can be considered that we used the MLER cloud model. Please refer to L95 for the explanation of the abbreviation "MLER", as follows: *"the mixed Lambertian equivalence reflectivity (MLER) cloud model"*

3) Section 3.1: For the readability, all used satellite sensors' specifications are listed as Table.

[Reply] We added the sensor's specification in Table 2:

Table 1: Overview of the cloud products included in this study.

Instrument	Spectral range (nm)	Cloud product name	Variable	Cloud spectral range (nm)
OMI	270–314, 306–380, 350–500	OMCLDO2	Effective cloud fraction Cloud height	460–490
TROPOMI	270–495, 710–775, 2305–2385	ROCINN CRB	Cloud fraction Cloud albedo Cloud pressure/height	758–766
GEMS	300–500	GEMS CLD	Effective cloud fraction Cloud centroid pressure	460–485
AMI	470, 511, 640, 856, 1380, 1610, 3830, 6241, 6952, 7344, 8592, 9625, 10403, 11212, 12364, 13310	GK2A CTH	Cloud top height	8592–13310
CALIOP	532, 1064	VFM	Vertical feature mask	532, 1064

4) L196-L200: The adopted method is too confused. Why did the GEMS cloud retrieval algorithm adopt to the OMI radiance? The purpose and details of methodology is needed.

[Reply] Since GEMS cloud retrieval algorithm is based on OMI's cloud retrieval algorithm, we aimed to evaluate the performance of the GEMS cloud retrieval algorithm by comparing it to OMI level 2 cloud products for validation first. We used OMI's level 1B data as proxy data for the GEMS cloud retrieval method in order to optimize consistency between the two algorithms' experimental settings. The purpose and details of methodology are clarified in the beginning of Chapter 3, as follows: *"To evaluate the performance of the GEMS cloud retrieval algorithm, cloud products were produced using OMI radiance data, which are similar to the GEMS spectral resolution and cloud prototype algorithm."*

5) L221: Why L2-VFM data of CALIOP was used? The L2-VFM only show the existence of cloud layer, not a profile.

[Reply] CALIOP is the only active sensor satellite operated simultaneously with GEMS, and while it may not provide information on low-level clouds in thick cloud cover, it can be regarded as the instrument that most accurately detects the presence of clouds. As the definitions of the cloud height products were all different depending on satellite instruments, we utilized CALIOP's

VFM data which can show the vertical presence of clouds, in our comparisons between GEMS and CALIOP. The expression "cloud-aerosol profile" has been modified to *"cloud-aerosol vertical existence"* in L213.

6) Section 5: Not only the long-term retrieval results used by non-GEMS sensors' radiance, the author also has to evaluate the long-term retrieval performance of cloud retrieval algorithm using GEMS radiance. Please add the long-term performance result of GEMS cloud algorithm using GEMS Level 1 radiance.

[Reply] Thank you for your suggestion. We added *Section 5.4 Monthly Cloud Product Validation* and Figure 12 to present the evaluation result for the long-term retrieval performance as follows:

5.4 Monthly Cloud Product Validation

For the monthly validation of GEMS cloud products, we randomly selected 3 days of each month from 2021 to 2022 and conducted the validation against TROPOMI data. To exclude the influence of variations in GEMS observation areas due to changing seasons, we employed the full west mode and selected the times when TROPOMI observation paths were present for the validation. Collocation was performed using the same method as described in Section 4.2, to assess the cloud products from both satellites. For certain periods, TROPOMI provides cloud products in both the OFFL (Offline) and RPRO (Reprocessed) versions, so we presented the correlation coefficients from the validation using both products (Fig. 12). In addition, we accounted for land cover since the precision of cloud product retrievals can vary between water and land due to factors like surface reflectance, as indicated by the results of scene analyses.

For 2 years of monthly validation results, in the case of ECF, there appeared to be no significant monthly variations in accuracy where higher accuracy was observed over ocean as compared to land, in general. Furthermore, the difference in validation results based on TROPOMI versions was not pronounced. On the other hand, for CCP, substantial monthly variations in accuracy were observed, especially a noticeable decrease in CCP correlation coefficients during the summer seasons (June, July, August) over ocean. Additionally, variations in accuracy were evident depending on TROPOMI versions, with the newly provided RPRO version showing improved correlation with GEMS.

The difference in ECF accuracy based on land cover can largely be attributed to the use of OMI climatology values for surface reflectance as input data. It is expected that this accuracy difference between the land and water based on land cover will significantly decrease when surface reflectance data observed by GEMS is applied as inputs.

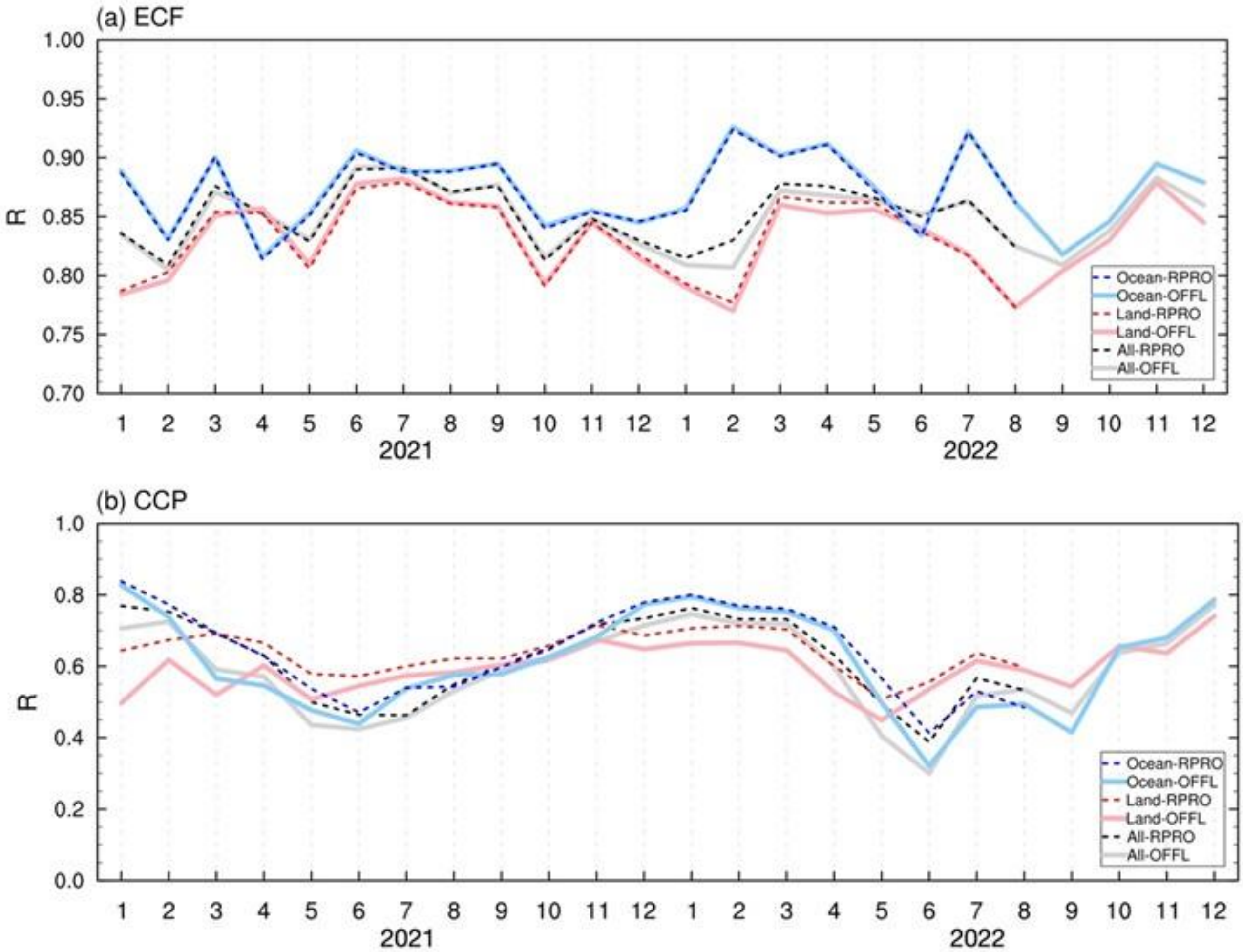

Figure 1: The monthly correlation coefficient (R) values between GEMS cloud products and TROPOMI OFFL version (solid line) and RPRO version (dotted line) are presented in Figures (a) for ECF and (b) for CCP. The red and blue lines respectively represent water and land.