# PRELIMINARY VALIDATION RESULTS OF THE OMI $O_2$–$O_2$ CLOUD PRODUCT

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## ABSTRACT

Cloud correction is an important step in the retrieval process of trace gases from OMI spectra, and can be based on cloud properties stored in the OMI $O_2$–$O_2$ cloud product. A first validation of the OMI $O_2$–$O_2$ cloud product using MODIS/Aqua data is presented here. The average difference between the effective cloud fraction of the OMI $O_2$–$O_2$ cloud product and the effective MODIS cloud fraction derived from the MODIS cloud optical thickness is 0.05, with a $1\,\sigma$ width of 0.15. An average difference between MODIS infra-red cloud top pressure and OMI $O_2$–$O_2$ cloud pressure of about 100 hPa with a $1\,\sigma$ width of about 200 hPa is found.

## 1. INTRODUCTION

OMI is an imaging spectrometer for the 270 nm – 500 nm wavelength range on board of EOS/Aura [1]. To correct trace gas columns retrieved from OMI for the presence of clouds, a cloud product is made from the OMI data, based on the $O_2$–$O_2$ absorption band at 477 nm [2, 3]; another cloud product is made based on Raman scattering in the UV. In this paper our aim is to validate the $O_2$–$O_2$ cloud product. The OMI $O_2$–$O_2$ cloud product contains an effective cloud fraction, a cloud pressure, and a series of diagnostic fields.

EOS/Aura is the last satellite in the “A” train. At the front of the “A” train, about 15 minutes ahead of Aura, another satellite of the EOS program is found: EOS/Aqua. One of the instruments on Aqua is MODIS, which produces is a “cloud optical properties” product, containing a cloud fraction, cloud top pressure, cloud optical thickness, and a host of other cloud related fields. Since Aura and Aqua follow the same ground track, the MODIS products are useful to validate the OMI cloud products. The present study uses a single day, and compares 1.2 milion OMI pixels with MODIS data.

### 1.1 Regridding MODIS/Aqua onto the OMI measurement grid

Aura and Aqua have nearly identical ground tracks, but co-locating the measurements is still a large computational effort, not in the least because of the large volume of data: the MODIS cloud product alone is 9 GB *per day*, for the sun-lit side only. The process of the regridding is illustrated in Fig. 1.

The OMI latitude-longitude centers are used to construct boxes that represent the measurements. The MODIS geolocation data is then searched for measurements that fall within each box, using some optimization steps to speed up the process. A MODIS pixel is considered to fall in a particular OMI box if the centre lies within the boundary. The matches are used to construct an effective cloud fraction and cloud pressure from MODIS data on an OMI grid. The regridded data is then written to disk for later analysis and comparison to OMI data.

## 2. VALIDATION OF OMI $O_2$–$O_2$ EFFECTIVE CLOUD FRACTION WITH MODIS/AQUA MEASUREMENTS

Before validating the OMI cloud fraction it is important to understand the meaning of the effective cloud fraction of OMI. The OMI pixels are $13 \times 24\,\mathrm{km}^2$ (in nadir), and thus there may be significant variability of the cloud cover within a single pixel. The effective cloud fraction is the part of the pixel which is covered by a thick model cloud (Lambertian surface), with an albedo of 0.8, creating the same top of atmosphere reflectance as the clouds in the scene. From earlier experience, it is known that this effective cloud fraction is a suitable measure for cloud correction in trace gas retrievals. The effective cloud fraction is a combination of the geometric cloud fraction and the cloud optical thickness, and should not be compared to the MODIS (geometric) cloud fraction.

### 2.1 Obtaining an effective cloud fraction from MODIS' cloud optical properties

To obtain an effective cloud fraction from MODIS data, the MODIS cloud optical thickness $\tau_c$ at 650 nm was used. The first, rather computationally expensive, step is to use a lookup table to translate all cloud optical thicknesses into

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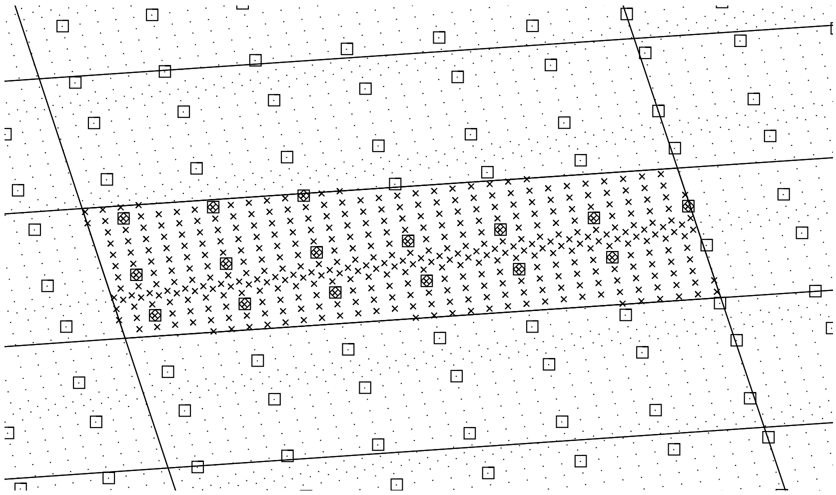

Fig. 1. Co-location of OMI and MODIS measurements. The dots indicate the centre of $1 \times 1\,\mathrm{km}^2$ MODIS cloud optical thickness pixels, the squares those of the $5 \times 5\,\mathrm{km}^2$ MODIS cloud pressure pixels, while the lines show the boundaries of OMI pixels.

reflectances. This is done before averaging the MODIS pixels that co-locate with a particular OMI pixel, because the reflectance is related to the cloud optical thickness in a non-linear way. The cloud reflectance function $R$ was used for this transformation of $\tau_c$ into the effective cloud fraction $c_{\mathrm{eff}}$:

$$c_{\mathrm{eff}} = \frac{R(\tau_c; \theta_0, \theta, \phi - \phi_0)}{0.8} \tag{1}$$

The viewing geometry was taken from the OMI data, and assumed to be the same for all matching MODIS pixels corresponding to a single OMI measurement.

The lookup table of $R(\tau_c)$ was obtained from a radiative transfer calculation for an isolated cloud. The cloud phase as detected by MODIS is not used at this moment; all clouds are treated as water clouds with a C1 particle size distribution (6 µm radius). The radiative transfer calculation was performed at 450 nm.

### 2.2 *Preliminary* validation results for the OMI effective cloud fraction

We analysed a single day of OMI and MODIS measurements, 16 orbits in total. These measurements were taken on August 28th, 2005. Fig. 2 (a) shows a scatter density plot of both effective cloud fractions. Both cloud fractions show a correlation of 87 % between them, and an average difference of 0.05. If the cloud-free pixels are removed, the correlation coefficient drops to 81 %. Fig. 3 shows the distribution of differences of the effective cloud fraction. The central bin are the pixels for which both retrievals agree that a pixel is cloud free. The width of the distribution of the differences ($1\sigma$) is 0.15.

## 3. VALIDATION OF THE OMI $O_2$–$O_2$ CLOUD PRESSURE USING MODIS/AQUA MEASUREMENTS

MODIS retrieves a cloud top temperature from thermal infra-red radiances, and from that a cloud top pressure. The retrievals by OMI on the other hand use the depth of a molecular absorption band of oxygen to retrieve a cloud height. Scattering within and below clouds generally leads to a lower cloud height from OMI than from MODIS' infra-red radiances.

### 3.1 *Preliminary* validation results for the OMI cloud pressure

Fig. 4 (a) shows a scatter density plot of both effective cloud fractions. The cloud pressures show a correlation of 55 %. Fig. 5 shows the distribution of differences of the cloud pressure. The width of this distribution and its central value depends strongly on the selection of pixels; here only pixels with an OMI $c_{\mathrm{eff}} > 0.05$ are taken into account. The width of this distribution is 210 hPa, with an average difference of 92 hPa. Increasing the value of the cut-off $c_{\mathrm{eff}}$, reduces the width of the distribution of differences, and increases the average difference. This is shown in Fig. 4 (b). A tentative

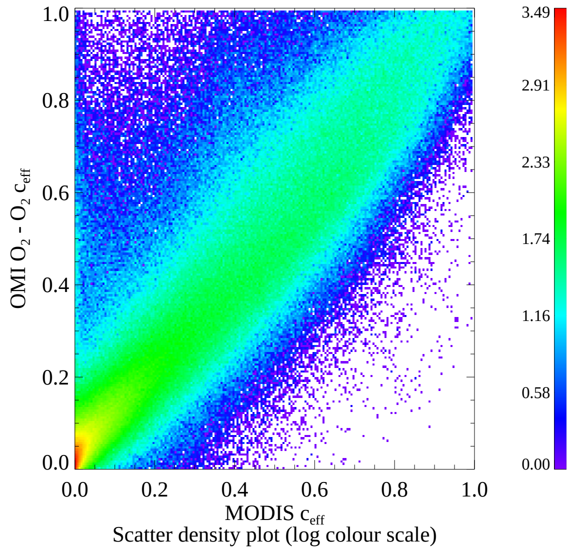


Fig. 2. Scatter density plot of the MODIS $c_{\mathrm{eff}}$ against the OMI $c_{\mathrm{eff}}$ on a logarithmic scale. The cloud free and the fully cloudy pixels have been removed for clarity.

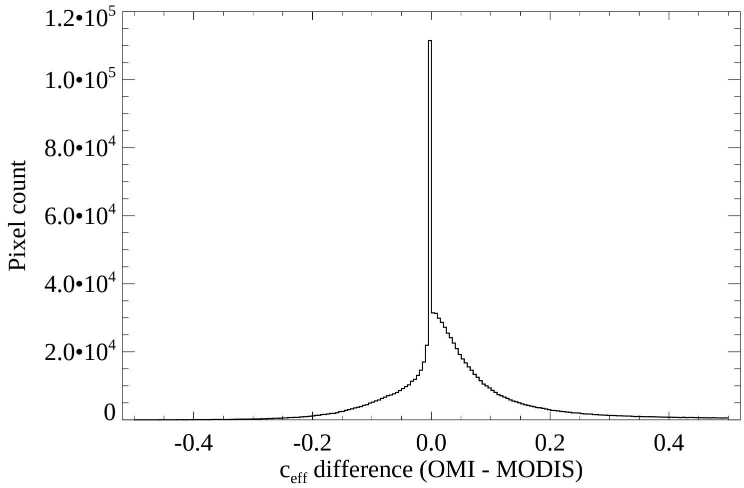


Fig. 3. Histogram of the differences in the effective cloud fraction (OMI – MODIS).

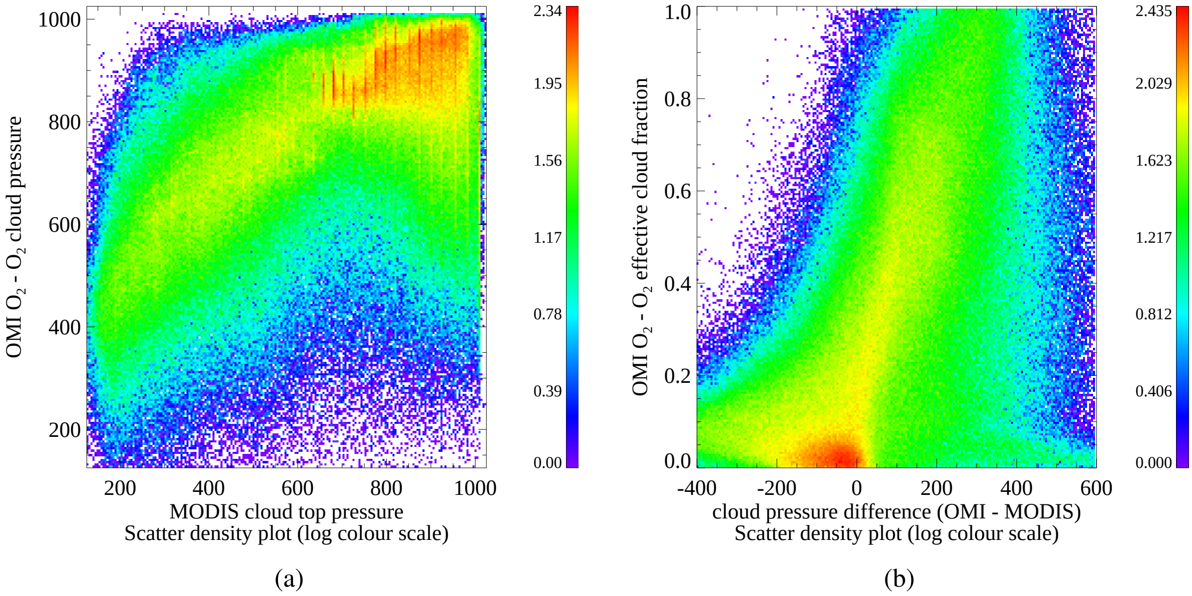


Fig. 4. (a) Scatter density plot of the OMI cloud pressure against the MODIS cloud top pressure on a logarithmic scale. Pixels with an OMI effective cloud fraction lower than 0.05 have been removed. (b) The difference in the effective cloud fraction against the cloud pressure. It seems that for low cloud fractions the MODIS infra-red signal is contaminated by thermal radiation from the ground.

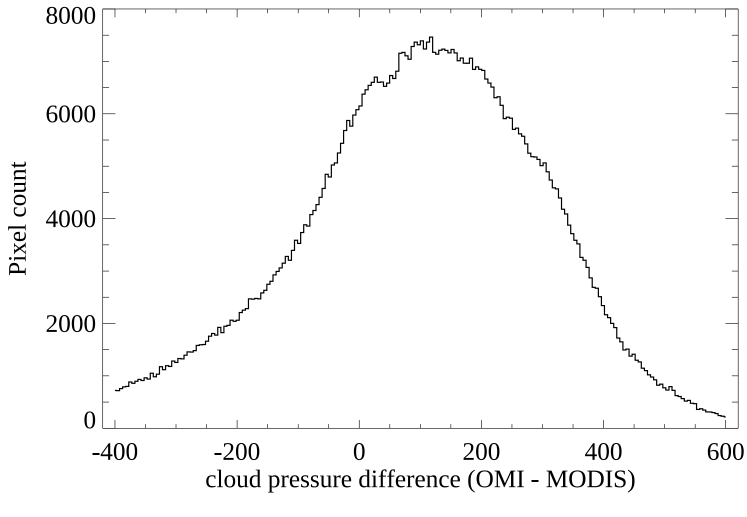


Fig. 5. Histogram of the differences in the cloud pressure (OMI – MODIS). Pixels with an OMI effective cloud fraction lower than 0.05 have been removed.

interpretation of this figure is as follows: the MODIS thermal infra-red radiances are contaminated by surface radiation for low effective cloud fractions. For high effective cloud fractions the ground is sufficiently shielded, and there MODIS retrieves a cloud top, while OMI looks well into the cloud – and thus retrieves a higher cloud pressure.

## 4. DISCUSSION

The original OMI scientific requirement for the error in $c_{\text{eff}}$ is $\leq 0.1$, and for the error in $p_{\text{c}}$ is $\leq 100\,\text{hPa}$ [4]. This preliminary validation result shows that the OMI $O_2$–$O_2$ effective cloud fraction well meets its requirement on average; however, there is still room for improvement to decrease the spread in the difference between OMI and MODIS. The cause could be in either instrument or interpretation of the measurements; some possible causes for offset and spread include: difference in the time of overpass, inaccuracies in the surface albedo databases used by both the MODIS and OMI retrieval algorithms, differences in the cloud radiative transfer models used in the MODIS retrieval and in our transformation from cloud optical thickness into a reflectance, and calibration issues.

The OMI $O_2$–$O_2$ cloud pressure just meets its requirement on average; however, the spread is very large. Probably the different retrieval wavelength ranges make the OMI and MODIS cloud pressure products hard to compare directly. Ground based radar detection and Cloudsat/Calipso satellite retrievals are needed to better quantify the accuracy of the OMI $O_2$–$O_2$ cloud pressure product.

## 5. REFERENCES


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