SCIAMACHY CLOUD PRODUCT VALIDATION

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Abstract

Radiative scattering by clouds leads to errors in the retrieval of column densities and concentration profiles of atmospheric trace gas species from satellites. The SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY) instrument on the Envisat satellite, principally designed to retrieve trace gases in the atmosphere, is also capable of detecting clouds. Cloud fraction is retrieved using the Optical Cloud Recognition Algorithm (OCRA). In this paper, this Level 2 operational cloud product is compared to the results from other cloud algorithms such as FRESCO (Fast Retrieval Scheme for Clouds from the Oxygen A-band). It is shown that the retrieved cloud fractions correlate well between OCRA and FRESCO since the 28th April 2004. FRESCO provides a consistent set of cloud products by retrieving simultaneously cloud fraction and cloud top pressure. Moreover, FRESCO retrievals are corroborated with cloud top pressure from MODIS. Other algorithms such as HICRU (cloud fraction) and SACURA (cloud top pressure) are also available to validate independently these cloud products.

Key words: FRESCO; OCRA; cloud fraction; cloud top pressure.

1. INTRODUCTION

SCIAMACHY (SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY) is a spaceborne spectrometer that flies on Envisat since March 2002. The instrument is a national contribution by Germany-DLR, the Netherlands-NIVR and Belgium-BUSOC to the European Space Agency satellite Envisat. SCIAMACHY measures the solar radiation reflected from the atmosphere in the wavelength range between 240 and 2380 nm. This is recorded at relatively high resolution (0.2 to 1.5 nm) over the range 240 to 1750 nm, and in selected regions between 2000 and 2400 nm. SCIAMACHY is extended as compared to its precursor GOME (Global Ozone Monitoring Experiment; [1]) with a wavelength range extending in the near IR region and able to operate with new viewing geometries namely limb and sun, moon occultations. The primary scientific objective of SCIAMACHY is the global measurement of various trace gases on a global scale [2].
The trace gases that SCIAMACHY detects, like O_3, NO_2, BrO, SO_2, CO and CH_4, occur not only in the stratosphere but also in the troposphere, where clouds reside. To detect these trace gases accurately, the presence and properties of clouds have to be known, in order to correct for the effect of clouds. The three cloud parameters that most strongly influence trace gas measurements are: cloud fraction, cloud albedo or cloud optical thickness, and cloud top pressure. Microphysical cloud parameters, like particle size and shape, are of minor importance [3].

Clouds affect the path of photons through the atmosphere and therefore change the interpretation of the depth of an absorption band. Taking ozone as an example, the effect of clouds on ozone retrieval can be regarded as due to two main effects [3]: (1) albedo effect: clouds act as a reflecting boundary below the ozone layer and enhance the depth of the ozone absorption bands, and (2) ghost column effect: clouds shield tropospheric ozone from observation. A third, smaller effect exists, which is the enhancement of the photon path inside clouds, causing an enhancement of the absorption line depth inside clouds [4].

In order to correct for the albedo effect of clouds, it is necessary to retrieve the cloud fraction and cloud albedo (or cloud optical thickness) or, equivalently, the product of cloud fraction and cloud albedo, which we call the effective cloud fraction. In order to correct for the ghost column effect of clouds, it is necessary to retrieve both the effective cloud fraction and the cloud top pressure.

The above cloud effects not only occur for O_3 but also for other gases. Especially for NO_2, much of which is residing in the troposphere in polluted circumstances, the ghost column effect is very important [5]. Therefore, a cloud detection algorithm suitable for trace gas retrievals for SCIAMACHY should be able to detect at least effective cloud fraction and cloud pressure. If the cloud

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pressure is available, then the tropospheric ozone column can be determined by comparing cloudy and clear pixels, using the convective-cloud-differential technique [6].

This paper is devoted to the SCIAMACHY cloud products' validation. The operational Level 2 cloud fraction from OCRA is investigated and compared with the retrievals obtained from FRESCO. Moreover, the scientific cloud top pressure product from FRESCO is compared to results from the O_2-O_2 method and from another satellite instrument, namely MODIS on EOS/Terra.

2. Cloud retrieval techniques for SCIAMACHY

For reasons of timeliness and co-location, it is most practical to retrieve cloud parameters from the SCIAMACHY data itself. To this aim various SCIAMACHY channels and atmospheric absorption bands can be chosen. In the case of GOME, the Polarisation Measurement Devices (PMDs) had been used by several groups to detect cloud fraction. The advantage of the PMDs is that they have a better spatial resolution than the spectral channels. Reference [7] have developed various cloud algorithms for GOME, among which the Optical Cloud Recognition Algorithm (OCRA) technique. This technique uses the color of PMD images to select cloud free scenes for a global database of cloud free reflectances. The difference between the current PMD reflectances and this cloud free database is used to retrieve cloud fractions. To detect cloud pressure, however, the PMDs cannot be used because they have insufficient spectral resolution to detect absorption lines of well-mixed absorbers like oxygen. In the SCIAMACHY range there are several oxygen or oxygen-oxygen absorption bands. The strongest band is the O_2 A-band at 760 nm. Figure 1 shows the absorption lines of Oxygen in this region.

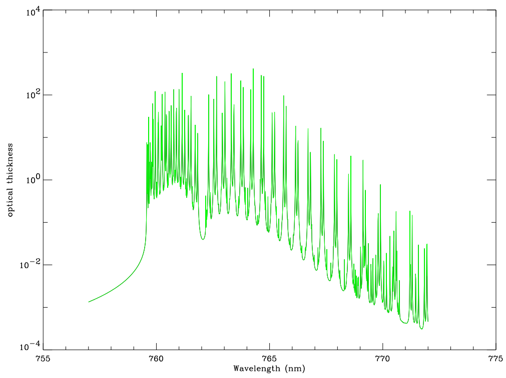

Fig. 1. The Oxygen molecular absorption optical thickness in the Oxygen A band of the Mid-Latitude Summer atmosphere.

There is also the weaker O_2 B-band around 680 nm, and several weak O_2-O_2 lines. The Initial Cloud Fitting Algorithm (ICFA), which is used in the operational data processing of GOME, uses the O_2 A-band [8], [9]. ICFA only produces the cloud fraction; cloud pressure is taken from a climatology. Validation of ICFA has been performed by [9], and it was shown that ICFA produces inaccurate cloud fractions. The GOME-CAT (Cloud retrieval algorithm) method [10] uses a combination of PMD data and O_2 A-band data to retrieve cloud fraction, cloud optical thickness and cloud pressure. In the results of this algorithm, however, the cloud optical thickness appears to be unreliable.

Recently, an intercomparison of different cloud retrieval algorithms that exist for GOME was published by [11]. They compared ICFA, OCRA and FRESCO cloud fractions with groundbased synoptical observations. It was shown that the effective cloud fraction as used by FRESCO underestimates the real cloud fraction for optically thin clouds, as expected, but correlates well with synoptical cloud observations. Other recent cloud algorithm comparisons for GOME and SCIAMACHY have been performed. Reference [12] developed an advanced PMD technique for cloud fraction retrieval, called HICRU (Heidelberg Iterative Cloud Retrieval Utilities). SACURA (SemiAnalytical CloUd Retrieval Algorithm) from [13] determines the cloud top pressure and geometrical thickness using measurements of the cloud reflection function.

Apart from the O_2 A-band, also the 477-nm absorption band of the collision-complex O_2-O_2 has been used for retrieval of cloud fraction and cloud pressure from GOME [14]. The O_2-O_2 method will be used as operational cloud detection method for OMI, to be launched on board of EOS-Aura in July 2004. The O_2-O_2 method is more sensitive to low clouds than to high clouds, due to the pressure-squared dependence.

Another atmospheric scattering process that can be used for cloud pressure retrieval is Raman scattering. Raman scattering is the inelastic part of Rayleigh scattering by nitrogen and oxygen, which fills-in solar Fraunhofer lines in scattered light from the Earth. The amount of filling-in is more or less proportional to the pressure of the cloud. Recently, this Raman method has been successfully applied to GOME data [15].

In cloud retrievals from satellite, it is very important to have a good estimate of the surface albedo. The reason is that cloud detection is usually performed by comparing the measured reflectivity with the expected reflectivity from a cloud-free scene. Recently, a new spectral surface albedo database based on 5.5 years of GOME data has been published [16]. This database is freely available and is used in FRESCO in this study.

2.1 FRESCO method

The FRESCO (Fast Retrieval Scheme for Cloud Observables) method has been developed by [17] as a simple, fast, and robust algorithm to provide cloud information for cloud correction of ozone. FRESCO uses the reflectivity in three 1-nm wide windows of the O_2 A-band: 758-759 nm, 760-761 nm, and 765-766 nm. The measured reflectivity is compared to a modeled reflectivity, as computed for a simple cloud model. In this model the cloud is assumed to be a Lambertian reflector with albedo 0.8 below a clear atmosphere, in which only O_2 absorption is taken into account. To simulate the spectrum of a partly cloudy pixel, a simple atmospheric transmission model is used, in which the atmosphere above the ground surface (for the clear part of the pixel) or cloud (for the cloudy part of the pixel) is treated as a purely absorbing, non-scattering, medium. The retrieved parameters are the effective cloud fraction (between 0 and 1) and the cloud pressure. Absorption by oxygen inside the cloud is neglected.

FRESCO is used in the fast-delivery processing of GOME ozone data [18] and in the SCIAMACHY ozone processor TOSOMI, which provides ozone data from SCIAMACHY within the ESA TEMIS project (see http://www.temis.nl).

FRESCO has been validated regionally and globally [17], [13], [11], and is proven to be reliable. However, FRESCO overestimates the cloud fraction retrievals over the Sahara region. This is under investigation but a possible explanation could be the higher albedo over this desert, from sand and aerosols, than in the low resolution surface albedo database used by FRESCO. Secondly, FRESCO overestimates cloud top pressure by on average about 50 hPa, as compared to infrared techniques. A possible reason is the fact that photon paths inside the cloud enhance the O_2 A band depth. We note that for cloud correction of ozone and other trace gases, a qualitatively similar path enhancement is expected.

2.2 OCRA method

OCRA was developed by [19]. It is a PMD algorithm using the ”red”, ”green” and ”blue” PMDs for cloud fraction determination. The cloud fraction is calculated from a linear interpolation of the current PMD reflectance between a minimum (cloud free) value and a maximum (totally cloudy) value, the latter being fixed by scaling factors. An average of the results of the three PMDs is used. Reflectances of cloud free scenes are stored on a global grid. They are determined once from a large set of historic data using color distances between measured PMD color and the white point in the chromaticity diagram. Reflectances with the largest distance to the white point are selected to represent the cloud free case at a certain grid point. Currently, a database calculated from GOME PMD measurements is applied. For the totally cloudy case, one scaling factor is used for each PMD, representing the maximum reflectance.

3. VALIDATION RESULTS

In this section we directly intercompare the retrieved cloud paramaters from the different cloud algorithms. More specifically, results obtained by applying the FRESCO algorithm to SCIAMACHY data are compared with the equivalent Level 2 operational cloud fraction from OCRA. Moreover, the retrieved cloud top pressure results are assessed against another satellite instrument based values (MODIS).

3.1 Cloud fraction

Firstly, Figure 2 illustrates a comparison between OCRA and FRESCO cloud fraction retrievals for the validation reference dataset. This dataset corresponds to the states shown in Figure 3 covering the period from August to October 2002. A good agreement is obtained between OCRA and FRESCO with a standard deviation of 0.1. The discrepancies at the cloud fraction value of 1.0 are due to FRESCO algorithm assumptions at high latitudes. Indeed, in these regions, the algorithm switches to snow/ice mode where an effective cloud fraction of 1.0 is assumed.

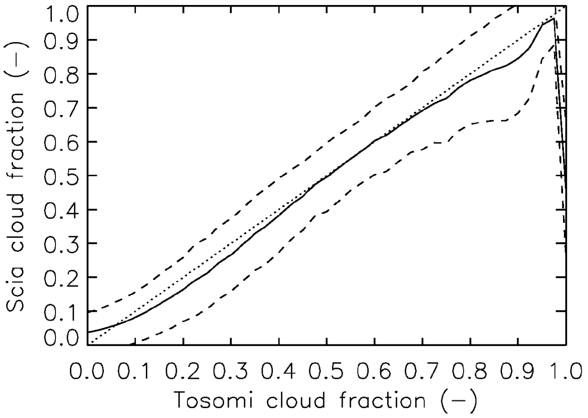

Fig. 2. Comparison of cloud fraction derived from SCIAMACHY Data between OCRA (Scia) and FRESCO (Tosomi) retrieval cloud algorithms for the validation reference dataset.

Secondly, a more specific comparison between OCRA and FRESCO cloud fraction retrievals is shown in Figure 4. This concerns the SCIAMACHY data from the reference orbit 2510 (August 23, 2002). It is clear that both cloud fractions correlate well. The linear fit gives a determination coefficient (R^2) of 0.95 with a slope of 0.94.

However, plotting the cloud fraction difference between OCRA and FRESCO as a function of the viewing zenith angle (Figure 5) for the same orbit produces a rather surprising parabolic response. It was found that this dependency in scanning angle is due to an inadequate definition of reflectances in OCRA, which takes the

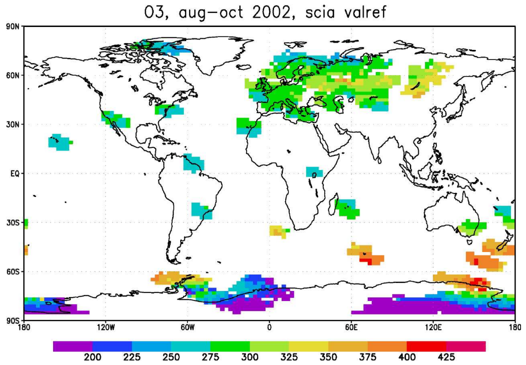

Fig. 3. SCIAMACHY measurements locations corresponding to the validation reference dataset used in the comparison between OCRA and FRESCO cloud fractions of Figure 2. The measurements date from the period from August to October 2002.

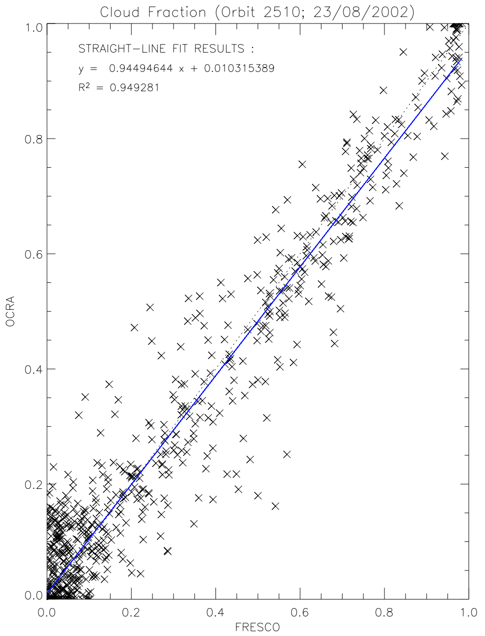

Fig. 4. Comparison of cloud fractions derived from the OCRA and FRESCO algorithms using SCIAMACHY data of orbit 2510 (August 23, 2002). The dotted line is the one-to-one agreement while the solid blue line is the best fit produced by a regression analysis.

cosine of this angle into account.

Furthermore, in Figure 6 the retrieved cloud fractions from both FRESCO and the O_2-O_2 method are compared with OCRA values in the case of the orbit 2510, corroborating the previous results.

The good correlation in the retrieved cloud fraction values between OCRA and FRESCO with the verification orbit 2510, but also 2509, is also found for SCIAMACHY data on Near-Real-Time orbits since April 28, 2004 (Figures 7 and 8). Indeed, beforehand, an error with a Near-Real-Time Level 1-2 processor initialisation file prevented OCRA to retrieve accurate values of cloud fraction.

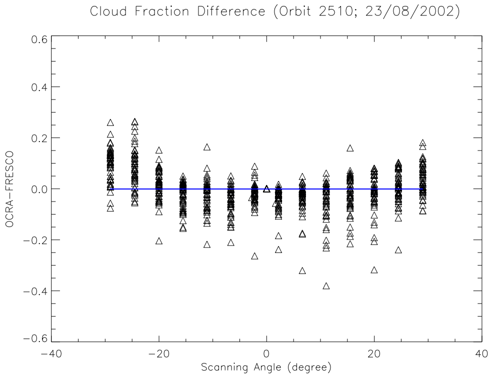

Fig. 5. Cloud fractions difference between OCRA and FRESCO as a function of the scanning angle. This is derived from orbit 2510 of SCIAMACHY data (August 23, 2002).

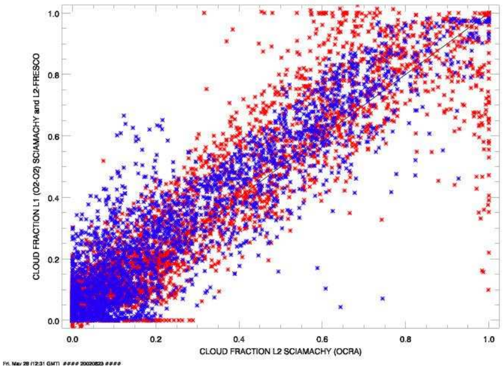

Fig. 6. Comparison of cloud fraction derived from FRESCO (blue) and the O_2-O_2 method (red) against OCRA using SCIAMACHY data of orbit 2510 (August 23, 2002).

Another promising cloud algorithm (HICRU) is currently applied on SCIAMACHY data to retrieve cloud fraction. First results (Figure 9) showed that the retrieved cloud fractions agree well with the values obtained from GOME data and, also, with images from Meteosat [20].

3.2 Cloud top pressure

The comparison between SCIAMACHY operational Level 2 and FRESCO cloud top pressures from the reference orbit 2510 (August 23, 2002) underlines a strong disagreement. Indeed, while FRESCO provides a consistent set of cloud parameters (simultaneous retrieval), the operational product is derived from the ISCCP monthly mean cloud top height database, which is a climatology based on measurements of clouds from satellites (MeteoSat, GMS, GOES and NOAA). However, in a future version of the operational processor, an oxygen band algorithm for cloud top pressure retrieval will be included.

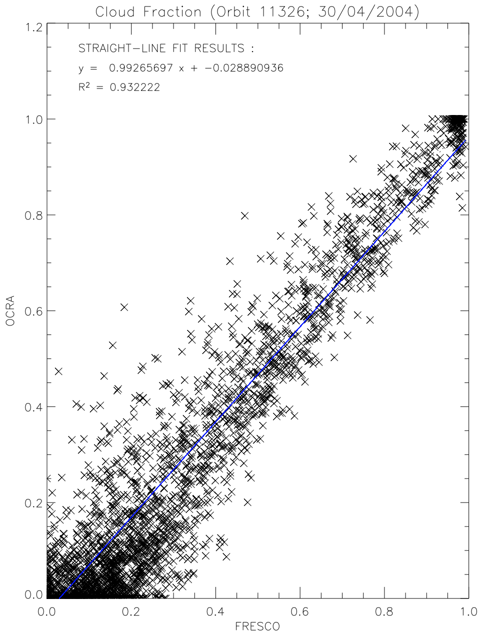

Fig. 7. Comparison of cloud fraction derived from the OCRA and FRESCO algorithms using SCIAMACHY data of orbit 11326 (April 30, 2004). The dotted line is the one-to-one agreement while the solid blue line is the best fit produced by a regression analysis.

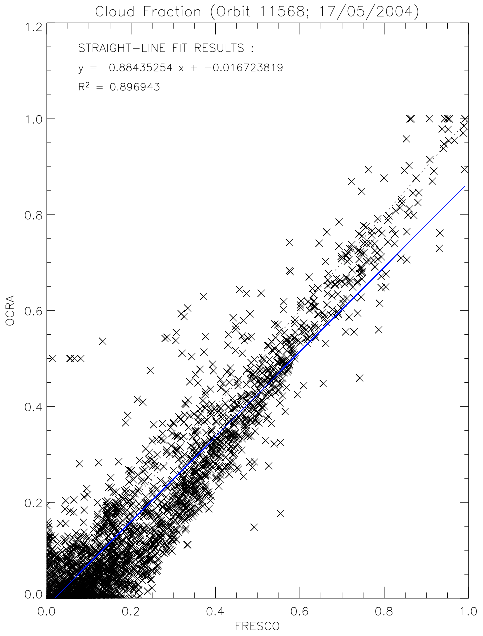

Fig. 8. Comparison of cloud fraction derived from the OCRA and FRESCO algorithms using SCIAMACHY data of orbit 11568 (May 17, 2004). The dotted line is the one-to-one agreement while the solid blue line is the best fit produced by a regression analysis.

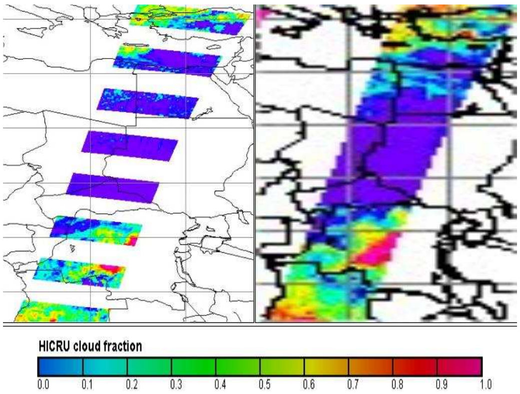

Fig. 9. Comparison of cloud fraction derived from the HICRU algorithm using SCIAMACHY (left) and GOME (right) data from January 24, 2003.

This is corroborated in the comparison of the SCIAMACHY operational product (Figure 10) and FRESCO (Figure 11) retrieved results with MODIS [21] co-located values for the orbit 2510. MODIS Level 2 granules overlapping the SCIAMACHY 2510 orbit are processed. While the operational product exhibits important differences with MODIS values, FRESCO shows a reasonable agreement with differences about 100 hPa.

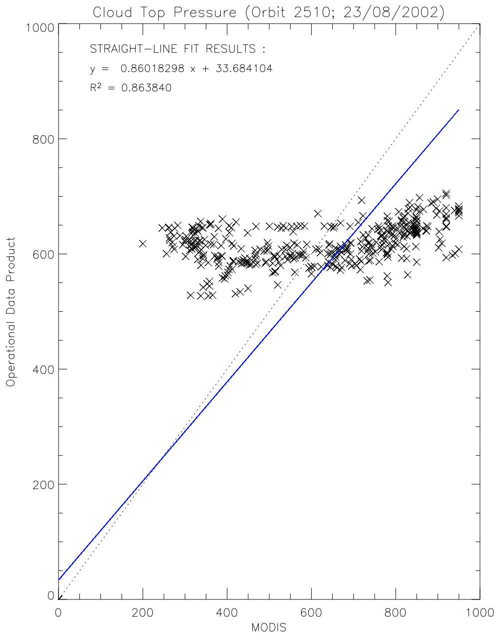

Fig. 10. Comparison of the SCIAMACHY operational cloud top pressure with MODIS co-located values for the orbit 2510 (August 23, 2002). The dotted line is the one-to-one agreement while the solid line is the best fit produced by a regression analysis.

Furthermore, in Figure 12, the retrieved cloud top pressures from FRESCO (blue), the O_2-O_2 method (red) and the operational product (black) are compared with MODIS co-located values in the case of

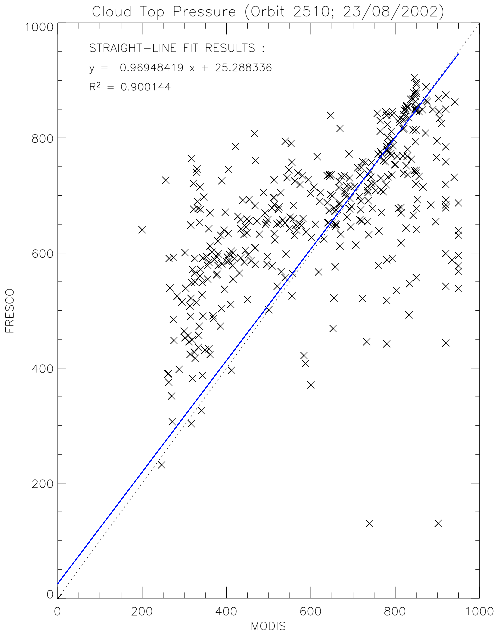

Fig. 11. Comparison of cloud top pressure derived from FRESCO using SCIAMACHY data with MODIS co-located values for the orbit 2510 (August 23, 2002). The dotted line is the one-to-one agreement while the solid line is the best fit produced by a regression analysis.

the orbit 2510. For FRESCO and the O_2-O_2 method, only the retrieved values concerning optically thick clouds are considered (cloud optical thickness of 5 or more). This improves the correlation of FRESCO with MODIS obtained in Figure 11 and confirms the slight overestimation in FRESCO retrieved values. To complete this validation, there are also other algorithms which should be employed such as SACURA (see http://www.ww.iup.physik.uni-bremen.de/scia-arc) providing cloud top pressure retrieval (dataset not yet available on-line) using SCIAMACHY data [13].

4. CONCLUSION

To validate SCIAMACHY cloud products, an intercomparison has been undertaken between the results of the operational algorithm OCRA and other algorithms such as FRESCO or the O_2-O_2 method. Moreover, the validation has been extended with MODIS co-located data in the case of the cloud top pressure. This shows that OCRA operational Level 2 cloud fraction product correlates well with FRESCO and the O_2-O_2 method using SCIAMACHY data. The accuracy of this product is about 0.1, as compared to FRESCO, and could even be improved by correcting from the scanning angle dependency. However, for the current implementation of the OCRA method in the operational SCIAMACHY processor, this is the first, and encouraging validation study. Further studies will be needed to define OCRA optimised parameter settings. In terms of cloud top pressure, FRESCO matches well the MODIS values with an accuracy about 100 hPa while SCIAMACHY operational product is derived from a climatological database. Therefore, FRESCO provides a consistent set of cloud parameters by its simultaneous retrieval. The validation of these cloud products should be completed by using other available algorithms such as HICRU (cloud fraction) or SACURA (cloud top pressure) which evaluate independently cloud fraction and cloud top pressure.

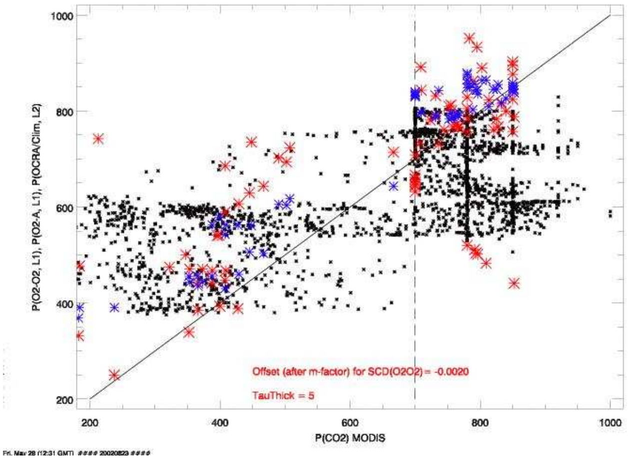

Fig. 12. Comparison of cloud top pressure derived from FRESCO (blue), the O_2-O_2 method (red) and SCIAMACHY operational product (black) against the MODIS co-located values for the orbit 2510 (August 23, 2002).

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5. REFERENCES

1. Burrows, J. P., et al., The Global Ozone Monitoring Experiment (GOME): Mission Concept and First Scientific Results, *J. Atm. Sci.*, 56, 151–175, 1999.

2. Bovensmann H., J. P. Burrows, M. Buchwitz, J. Frerick, S. Noel, V. Rozanov, K.V. Chance and A.P.H. Goede, SCIAMACHY: Mission objectives and measurement modes', *J. Atm. Sci.*, 56, 127–150, 1999.

3. Koelemeijer R.B.A., and P. Stammes, Effects of clouds on the ozone column retrievalfrom GOME UV measurements, *J. Geophys. Res.*, D, 104, 8281-8294, 1999a.

4. Newchurch, M. J., X. Liu, J. H. Kim, P. K. Bhartia, On the accuracy of Total Ozone Mapping Spectrometer retrievals over tropical cloudy regions, *J. Geophys. Res.*, 106 (D23), 32315-32326, 10.1029/2000JD000151, 2001.

5.Boersma K. F., H. J. Eskes, E. J. Brinksma, Error analysis for tropospheric NO_2 retrieval from space, *J. Geophys. Res.*, 109, doi:10.1029/2003JD003962, 2004.

6. Valks, P.J.M., A.J.M. Piters, J.C. Lambert, C. Zehner and H. Kelder, A Fast Delivery System for the retrieval of near-real time ozone columns from GOME data, *Int. J. Remote Sensing*, 24, 423-436, 2003a.

7. Von Bargen, A., T. P. Kurosu, K. Chance, D. Loyola, B. Aberle, R.J. Spurr, Cloud retrieval algorithm for GOME. Final Report, *ER-TN-DLR-CRAG-007*, ESA/ESTEC, October 2000.

8. Kuze, A., and K.V. Chance, Analysis of cloud top height and cloud fraction from satellites using the O_2 A and B bands, *J. Geophys. Res.*, 99, 14482-14491, 1994.

9. Koelemeijer R.B.A., and P. Stammes, Validation of Global Ozone Monitoring Experiment cloud fractions relevant for accurate ozone column retrieval, *J. Geophys. Res.*, D, 104, 18,801-18,814, 1999b.

10. Kurosu, T.P., K. Chance, R.J.D. Spurr, A. v. Bargen, and D. Loyola, GOMECAT - a Cloud Retrieval Algorithm for the European Space Agency's Global Ozone Monitoring Experiment, Manuscript in preparation 2002.

11. Tuinder, O.N.E., R. de Winter-Sorkina, P. Builtjes, Retrieval methods of effective cloud cover from the GOME instrument: an intercomparison, *Atmos. Chem. Phys.*, 4, 255-273, 2004 (www.atmos-chem-phys.org/acp/4/255).

12. Grzegorski, M., Determination of cloud parameters for GOME with broad band spectrometers and from absorption bands of oxygen dimer (in German), *Diplomarbeit, Univ. Heidelberg*, 2003.

13. Kokhanovsky, A.A., V.V. Rozanov, E.P. Zege, H. Bovensmann, and J.P. Burrows, A semianalytical cloud retrieval algorithm using backscattered radiation in 0.4-2.4 μm spectral region, *J. Geophys. Res.*, 2003, Vol. 108 (D1), doi 10.1029/2001JD001543.

14. Acarreta, J.R., J.F. de Haan, P. Stammes, Cloud pressure retrieval using the O_2-O_2 absorption band at 477 nm, *J. Geophys. Res.*, Vol. 109, doi:10.1029/2003JD003915, 2004.

15. Joiner J., A. P. Vasilkov, D. E. Flittner, J. F. Gleason, P. K. Bhartia, Retrieval of cloud pressure and oceanic chlorophyll content using Raman scattering in GOME ultraviolet spectra, *J. Geophys. Res.*, 109, doi:10.1029/2003JD003698, 2004.

16. Koelemeijer, R.B.A., J.F. de Haan, and P. Stammes, A database of spectral surface reflectivity in the range 335 – 772 nm derived from 5.5 years of GOME observations, *J. Geophys. Res.*, 2003, Vol. 108 (D2), doi 10.1029/2002JD002429.

17. Koelemeijer, R.B.A., P. Stammes, J.W. Hovenier, and J.F. de Haan, A fast method for retrieval of cloud parameters using oxygen A-band measurements from the Global Ozone Monitoring Instrument, *J. Geophys. Res.*, D, 106, 3475-3490, 2001.

18. Valks P. J. M., R. B. A. Koelemeijer, M. van Weele, P. van Velthoven, J. P. F. Fortuin, H. Kelder, Variability in tropical tropospheric ozone: Analysis with Global Ozone Monitoring Experiment observations and a global model, *J. Geophys. Res.*, 108, doi:10.1029/2002JD002894, 2003b.

19. Loyola, D., A New Cloud Recognition Algorithm for Optical Sensors. *In IEEE International Geoscience and Remote Sensing Symposium*, volume 2 of IGARSS 1998 Digest, p. 572-574, Seattle, 1998.

20. Grzegorski, M. et al., 'Determination of cloud parameters from satellite instruments for the correction of tropospheric trace gases', EGU General Assembly, Nice, France, 25-30 April 2004.

21. Platnick, S., M.D. King, S.A. Ackerman, W.P. Menzel, B.A. Baum, J.C. Riédi, and R.A. Frey, The MODIS Cloud Products: Algorithms and Examples from Terra, *IEEE Transactions on Geoscience and Remote Sensing*, 41, 2, 459-473, 2003.