LIMB–NADIR MATCHING FOR TROPOSPHERIC NO_2: A NEW ALGORITHM IN THE SCIAMACHY OPERATIONAL LEVEL 2 PROCESSOR

Markus Meringer[1], Sergei Gretschany[1], Günter Lichtenberg[1], Andreas Hilboll[2], Andreas Richter[2], and John P. Burrows[2]

[1] *Remote Sensing Technology Institute (IMF), German Aerospace Center (DLR), Oberpfaffenhofen, Wessling, Germany*
[2] *Institute of Environmental Physics (IUP), University of Bremen, Bremen, Germany*

ABSTRACT

SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric ChartographY) aboard ESA's environmental satellite ENVISAT observed the Earth's atmosphere in limb, nadir, and solar/lunar occultation geometries covering the UV–Visible to NIR spectral range. Limb and nadir geometries were the main operation modes for the retrieval of scientific data. The new version 6 of ESA's level 2 processor now provides for the first time an operational algorithm to combine measurements of these two geometries in order to generate new products. As a first instance the retrieval of tropospheric NO_2 has been implemented based on IUP–Bremen's reference algorithm. We will detail the single processing steps performed by the operational limb–nadir matching algorithm and report the results of comparisons with the scientific tropospheric NO_2 products of IUP and the Tropospheric Emission Monitoring Internet Service (TEMIS).

1. INTRODUCTION

SCIAMACHY's scientific measurement data was obtained by two main viewing geometries: In nadir mode the atmospheric volume directly under the instrument was observed, while limb mode looked at the edge of the atmosphere. The instrument was operated in such a way that the same atmospheric volume was first observed in limb and about 7 minutes later in nadir geometry. One of the fundamental ideas of the SCIAMACHY's development was to combine these measurements in order to derive new data products. This procedure is called limb–nadir matching.

The instrument's broad wavelength range allows to retrieve a multitude of atmospheric trace gas concentrations and other geophysical parameters. The current version 6 of ESA's level 2 (L2) processor retrieves NO_2 in both, limb and nadir geometry, using fit windows of 420–470 nm and 427–452 nm, respectively. Now, for the first time within the operational L2 processor, these results are combined to derive a new product by limb–nadir matching, tropospheric NO_2.

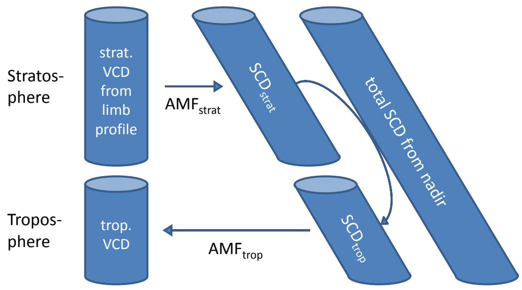

Figure 1. Basic principle of limb–nadir matching as applied for tropospheric NO_2 retrieval.

The basic idea of the limb–nadir matching algorithm is to use limb profile data to calculate a stratospheric column, and to subtract this intermediate result from a total column obtained from nadir measurement data. Fig. 1 sketches such an approach in a simplified way, which converts vertical column densities (VCD) to slant column densities (SCD) and vice versa by air mass factors (AMF). There are additional processing steps and corrections required to achieve the quality of an operational product. We outline them in this paper, following IUP's reference algorithm [1, 2].

2. PROCESSOR INTEGRATION

The limb–nadir matching algorithm needs limb profiles and nadir slant columns of the full orbit as input. Therefore it is implemented as a processing step that starts after the limb and nadir retrievals. Since the limb–nadir matching does not require any time–critical fitting or radiative transfer calculations, it turned out that the algorithm can be implemented as post–processing step that does not need parallel computation. This is illustrated in Fig. 2, which sketches the workflow of the L2 processor. The limb–nadir matching is located subsequent to the limb retrieval algorithm and the nadir retrievals, which are based on differentially optical absorption (DOAS) and infrared absorption spectrometry (IAS) methods.

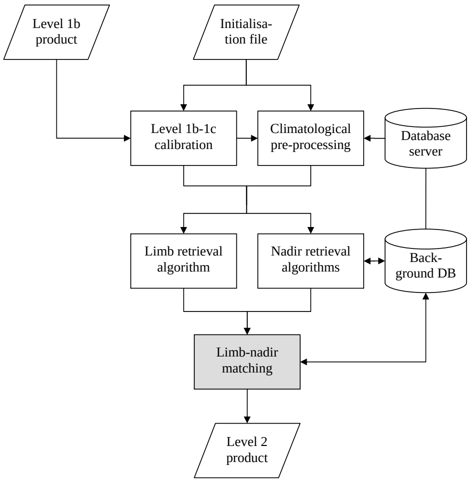

Figure 2. Flowchart of the SCIAMACHY L2 processor with the newly integrated limb–nadir matching algorithm, highlighted grey.

3. ALGORITHM INPUT/OUTPUT

The limb–nadir matching for tropospheric NO_2 retrieval requires input of the following L2 data sets, which are part of the operational L2 product: limb NO_2, nadir NO_2, nadir cloud and aerosol, limb geolocation, nadir geolocation and state geolocation.

Beyond L2 data, tropospheric NO_2 retrieval needs access to several databases (DB): ECMWF tropopause height DB, TOMS albedo climatology, Pacific background climatology, AMF LUT for tropospheric NO_2, MOZART NO_2 climatology and NO_2 limb–nadir offset DB. While the first five are obtained from external sources, the latter is written by the limb–nadir matching algorithm itself.

Results of the limb–nadir matching algorithm are written to a nadir measurement data set of the SCIAMACHY L2 product. The following data fields are used: VCD, SCD, fitting output flag and tropospheric AMF to ground. Tropospheric AMF to cloud top can also be accounted for, but this option is not operational in processor version 6. The VCD field has five entries to store intermediate results as shown in Fig. 3.

4. DETAILED PROCESSING

Fig. 3 sketches a flowchart of the operational limb–nadir matching algorithm. Numbers associated with the processing steps refer to corresponding subsections below.

4.1. Integrating limb stratospheric profiles

Stratospheric slant columns are computed by integration of partial columns from limb profiles, from top of atmosphere (TOA) to the tropopause.

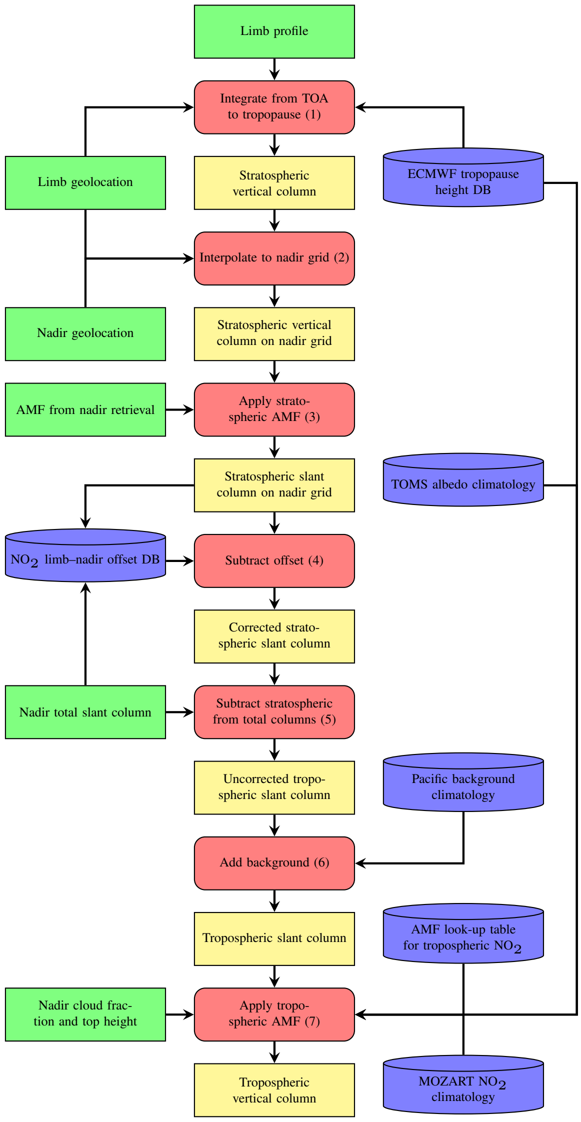

Figure 3. Flowchart of the limb–nadir matching algorithm. L2 input is colored green, databases blue, intermediate and final results yellow and processing steps red.

4.2. Interpolating limb stratospheric slant columns to the nadir grid

As limb profiles are sparse compared to nadir measurements, the limb stratospheric vertical columns need to be interpolated to the positions of the nadir pixels. This is done by associating the limb columns with their four line of sight (LOS) angles, e.g. -25°, -8°, +10°, +27°, and by performing a 2–dimensional interpolation to the nadir geolocations based on their LOS angles and latitudes. Note that only the descending parts of the orbits and forward scans are used.

4.3. Applying stratospheric AMF

AMF_{strat} are computed by the radiative transfer model LIDORT using the climatology of the Halogen Occultation Experiment (HALOE) stratospheric NO_2 profiles. They are applied to convert limb stratospheric vertical columns VC_{strat}^{limb} into stratospheric slant columns:

$$SC_{strat}^{limb} = VC_{strat}^{limb} \cdot AMF_{strat}.$$

4.4. Subtracting offset between nadir total slant column and stratospheric slant column

Experience shows that small but significant offsets exist between the slant columns from limb SC_{strat}^{limb} and nadir slant columns SC_{total}^{nadir} even over clean regions, and that these offsets vary with latitude and season. This is the result of systematic errors in one or both data products. Since the tropospheric column in less polluted regions is very sensitive to the stratospheric correction, these offsets need to be accounted for. In order to do this, a data base of daily difference

$$Offset = SC_{strat}^{limb}(Pacific) - SC_{total}^{nadir}(Pacific)$$

over the Pacific reference sector (180 - 220°E longitude) is computed as a function of latitude (5° bins). This data base is constantly being updated with new values as they become available. The processor uses the same interface as already supplied for SO_2, HCHO and CHOCHO. In the retrieval, the $Offset$ is interpolated to the current latitude and subtracted from the SC_{strat}^{limb}, resulting in

$$SC_{strat} = SC_{strat}^{limb} - Offset.$$

4.5. Subtracting limb stratospheric slant columns from total slant columns

The tropospheric slant column is computed as the difference between the nadir NO_2 total slant column and the stratospheric slant column:

$$SC_{trop} = SC_{total}^{nadir} - SC_{strat}.$$

4.6. Adding Pacific background to tropospheric slant column

Applying the aforementioned offset to the retrieved SC_{strat}^{limb} any tropospheric NO_2 present in the reference region will result in a low bias of the columns. Therefore SC_{trop} obtained in the previous step must be corrected for the tropospheric NO_2 background levels:

$$SC_{trop}^{corr} = SC_{trop} + SC_{trop}^{model}(month, latitude).$$

Climatological NO_2 data derived from the Oslo chemistry–transport model simulations [3] are used for this purpose as SC_{trop}^{model}.

4.7. Applying tropospheric AMF

Tropospheric vertical columns are derived from the tropospheric slant columns by division with the air mass factor

$$VC_{trop} = SC_{trop}^{corr}/AMF_{trop}.$$

Block AMFs are read from a look–up table used in the operational processing of the GOME-2 data (based on [4]) and depend on five parameters including the viewing geometry. After several interpolation and accumulation operations, taking NO_2 profiles from MOZART climatology into account, AMF_{trop} is calculated from these block AMFs.

5. VERIFICATION RESULTS

A standard verification set of 216 orbits was used to verify the correctness of the operational limb–nadir matching algorithm. Tropospheric NO_2 VCDs retrieved by the operational L2 processor were compared with corresponding reference data of scientific products provided by IUP and TEMIS. IUP's reference algorithm is described in [1, 2], for the TEMIS approach see [5].

Figure 4 shows a global map of differences between the operational results and the reference data. Figure 5 depicts a scatterplot of operational versus reference data. Figure 6 plots operational tropospheric NO_2 VCD, as well as differences between operational and reference data in dependence of latitude. A global map of the results retrieved by the operational algorithm is shown in Fig. 7.

Based on the successful verification, the limb–nadir matching algorithm for tropospheric NO_2 was accepted for ESA's operational level 2 processor version 6 and the new retrieval will be included in the forthcoming reprocessing campaign of the entire SCIAMACHY mission.

6. OUTLOOK

The operational limb–nadir matching has been programmed in a generic way, meaning that the application to further trace gas species, such as BrO or O_3, will require moderate adaptations only.

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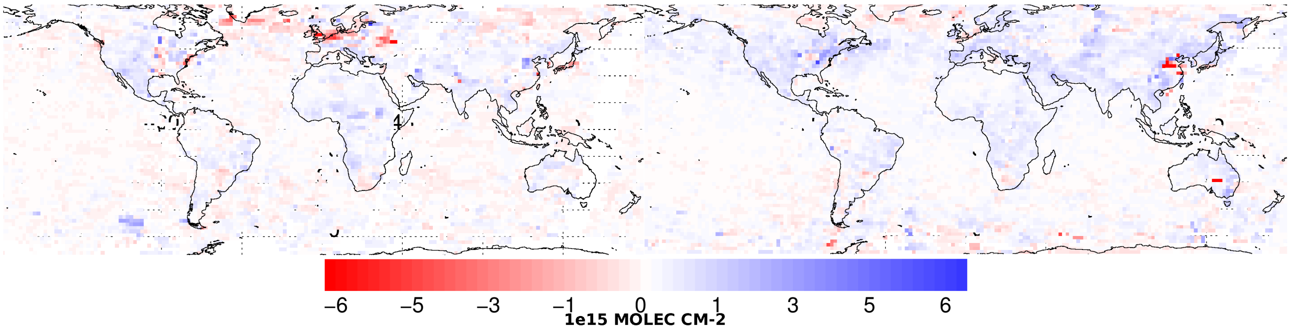

Figure 4. Global maps of differences of the operational tropospheric NO_2 VCD and the reference data (left: IUP, right: TEMIS).

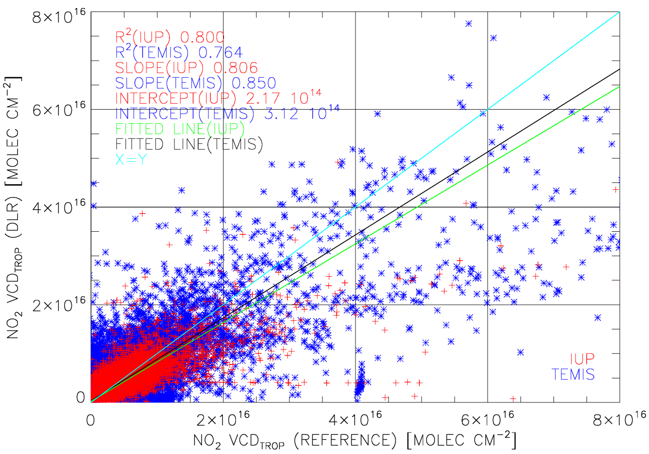

Figure 5. Scatterplot of operational tropospheric NO_2 vs. reference data.

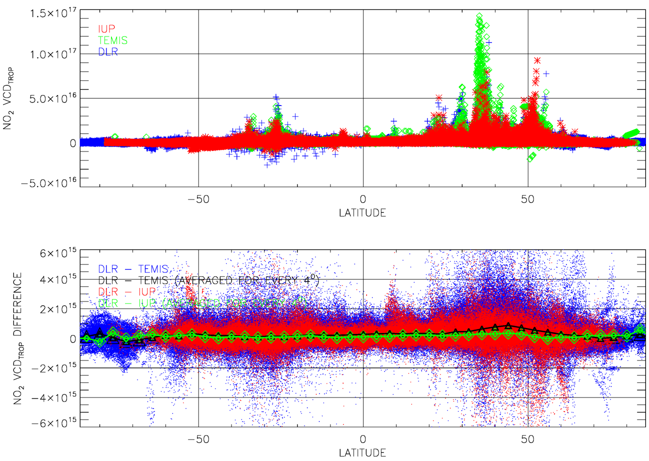

Figure 6. Tropospheric NO_2 vs. latitude (top) and differences of operational and reference data vs. latitude (bottom).

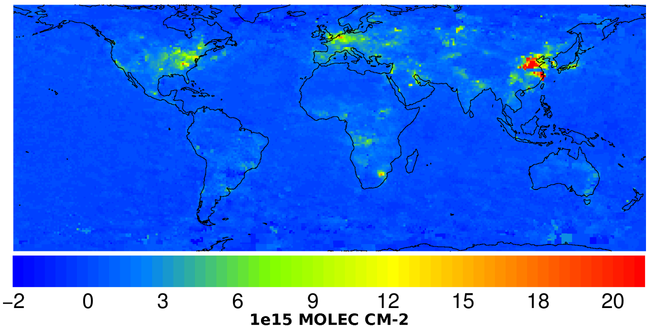

Figure 7. Global map of tropospheric NO_2 VCD (based on the verification orbits only).

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