Product Specification Document

Long Range Transport of Tropospheric NO_2 observed by the OMI instrument

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1. PRODUCT DESCRIPTION

Air pollution is not only a local problem, it can also effect the air quality far away from the source. To obtain a better understanding of the long range transport of air pollution, we use satellite measurements to monitor the outflow of air pollutants.

Although the techniques described below can be applied globally, here we constrain ourselves to the North Atlantic region. Due to predominant westerly winds in this region, long range transport usually occurs from the East coast of North America towards the West coast of Europe. In the case of tropospheric NO_2, under favorable meteorological conditions this trace gas can be transported fast enough (regarding its life time) to cross the Atlantic ocean (Stohl et al., 2003) and affect overseas air quality.

The slant column density of NO_2 can be retrieved with space born spectral instruments operating in the UV/VIS range. By using OMI measurements, we have the advantage of having daily global coverage with a relatively high resolution (13 by 24 km at nadir). Retrievals of the slant column are done with the DOAS technique. From this, the vertical tropospheric column is derived using a combined modeling / retrieval / assimilation approach (see Boersma et al., 2004, for a description of this method).

Due to the shielding effects of clouds, the measured slant column is insensitive to the exact value of the NO_2 column below the clouds: the clouds hide a ghost column which the satellite instrument is incapable to measure. This insensitivity is reflected in low values of the averaging kernel working on the atmospheric layers. To avoid too much uncertainty in the retrieved tropospheric vertical column, normally only tropospheric NO_2 retrievals are used which are done at a cloud radiance fraction smaller than 50%.

For our purposes, we want to include the clouded pixels as well in order to get a full picture of the chemical outflow. To do so, we apply a corrected airmass factor on the slant column, obtaining an *observable* (but shielded) value of the tropospheric NO_2 vertical column density. For a fully clouded retrieval it calculates the tropospheric column above the cloud; for a cloud free retrieval it calculates the whole tropospheric column. Trajectory simulations show that transatlantic transport typically takes place at 4-6 km altitude (Stohl et al., 2003), mainly above the clouds. Due to the short lifetime of NO_2 at low altitudes, we can neglect the presence of transported NO_2 below the clouds. Furthermore, we assume that surface sources such as ships are not significant. This means that above the oceans the clouded and cloud free retrieval values can be taken together above oceans to form one congruent field.

All retrieved values are gridded on a 0,5º x 0,5º grid, which facilitates statistical analysis of the results. In the images, continents are masked for the reasons described above. The data files contain the global gridded field, and is published in self explanatory ASCII, together with cloud pressure and cloud fraction information.

The long range transport service offers images and data in near real time (NRT) and in an archive. The NRT product is based on the NRT DOMINO product, which uses forecasted ECMWF meteorological data. The archived data is based on a separate calculation, using the ECMWF analysis.

2. DERIVATION OF THE USED FORMULA

The idea is to calculate the value of the observable tropospheric vertical NO_2 which does not contain traces of a modeled ghost column, based on the available values of the DOMINO product.

Within DOMINO, the tropospheric slant column $N_{s,trop}$ is determined by subtracting the modeled stratospheric part $N_{s,strat}$ from the DOAS retrieved total slant column N_s:

$$N_{s,trop} = N_s - N_{s,strat} \qquad \text{(I)}$$

Next, the air mass factor *AMF* is needed to get the tropospheric vertical column density from the tropospheric slant column density. DOMINO uses a radiative transfer model (which gives the partial air mass factor for each tropospheric layer m_l) together with the model predicted NO_2 profile $\boldsymbol{x}$ to calculate this AMF (Palmer et al., 2001):

$$AMF = \frac{\sum_l m_l x_l}{\sum_l x_l} = \frac{N^*_{s,trop}}{N^*_v} \qquad \text{(II)}$$

Here, index l indicates all model layers in the troposphere; the * indicates model values. To take cloudiness into account, each partial AMF is calculated for both clear sky and a fully clouded case. The effective partial AMF is obtained by weighing the two results with cloud radiance fraction w:

$$m_l = (1-w)\, m_{l,clear} + w\, m_{l,cloudy} \qquad \text{(III)}$$

Because of the screening effect of clouds, $m_{l,cloudy}$ becomes very small below the cloud height, reflecting the insensitivity of the measurement for the column below the clouds (called the *ghost column*, N_{ghost}). As a result, for cloudy cases the AMF from (II) is not a good quantity to directly relate the retrieved slant column $N_{s,trop}$ to the real tropospheric vertical column N_v. To avoid ghost column difficulties, we introduce here another quantity: the observable tropospheric vertical column N_{obs}, which stands closer to the $N_{s,trop}$ by having its ghost column removed:

$$N_{obs} = (1-w) N_v + w\,(N_v - N_{ghost}) \qquad \text{(IV)}$$

Analogous to (II), AMF_{obs} could be defined as the ratio between the model predicted slant column density and the model predicted observed column density:

$$AMF_{obs} = \frac{N^*_{s,trop}}{N^*_{obs}} \qquad \text{(V)}$$

This AMF_{obs} can now be used to calculate the observable tropospheric vertical column from the retrieved tropospheric slant column. Combining relation (I) to (V) results in:

$$N_{obs} = \frac{N_{s,trop}}{AMF_{obs}} = \frac{N_s - N_{s,strat}}{AMF}\,\frac{N^*_{obs}}{N^*_v} = \frac{N_s - N_{s,strat}}{AMF}\,\frac{N^*_v - wN^*_{ghost}}{N^*_v} \rightarrow$$

$$N_{obs} = \frac{N_s - N_{s,strat}}{AMF}\left(1 - w\frac{N^*_{ghost}}{N^*_v}\right) \qquad \text{(VI)}$$

Using the conventions used in the DOMINO product, this can be written as:

$$vcdobs = vcdtrop\left(1-(crfrac/100)\frac{ghostcol}{fcvcdtr}\right) \qquad \text{(VII)}$$

Name	Range	Description
vcdobs	[-5.0 – 5e2]	Retrieved tropspeheric vertical column density, with the modelled ghost column removed [10^{15} molec.cm^{-2}]
vcdtrop	[-5.0 – 5e2]	Retrieved tropospheric vertical column density [10^{15} molec.cm^{-2}]
ghostcol	-	Vertical column between surface and cloud level, derived from model values [10^{15} molec.cm^{-2}]
crfrac	[0, 100]	Cloud readiance fraction in percentage; derived from cloud fraction of FRESCO.
fcvcdtr	[-5.0 – 5e2]	Model forecasted tropospheric vertical column density [10^{15} molec.cm^{-2}]

3. KNOWN ARTIFACTS

One has to be a bit careful to interpret the data and images calculated with (VI). As explained before, this method shows the tropospheric NO_2 column densities as sensed by the OMI-instrument, which is not corrected for the shielding effect of clouds. Emission sources can be shielded in cloudy scenes, while in unclouded scenes unexpected emission sources could distort the picture when concentrating on transport of NO_2 above the clouds.

Furthermore, there ar some other artifacts in the data which are listed below. Unfortunately, several of these artifacts increase the noise level on the data which hides the more subtle shapes of long range transport of NO_2. However, the quality of the data is expected to improve considerably with the upcoming reprocessing of the OMI data.

3.1 Clusters of high NO2 values

Sometimes spots can be seen with very high NO_2 values (more than 10^{16} molecules/cm^2), especially around the tropics. These spots are closely related to optically very dense clouds. Instead of being caused by i.e. lightning, the high values are caused by saturation of the OMI photon counters. The DOAS fit based on these distorted spectra results in unrealistic values of NO_2. While the DOMINO product filters out the negative values, it still uses the positive values. In the upcoming reprocessing of the level 0-1 and 1-2 data these features are likely to disappear by detecting and handling saturation effects properly.

3.2 Cross track gradient

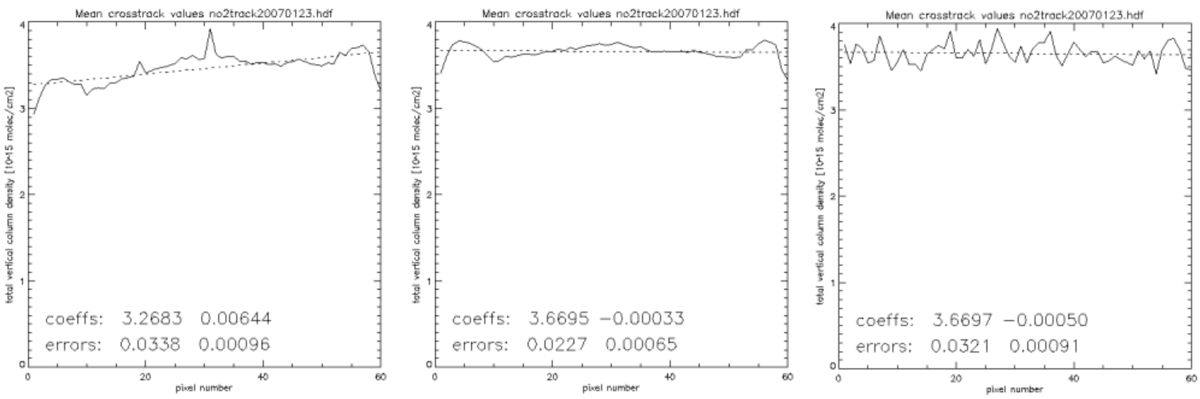
Due to calibration errors in the level 0-1 processor, often the west-pixels of the detector array show lower values than the east-pixels, see Figure 1a. There is a cross track gradient from pixel 1 to 60, which changes from day to day. Looking at the total NO_2 vertical column density, this gradient can cause differences between eastern pixels and western pixels up to 0.8 10^{15} molecules/cm^2. The cross track gradient disappears when using the newest reprocessed level 1 data (Figure 1b).

3.3 Destriping side effects

All individual pixels in the detector array have their own characteristics. Although this is taken care of at the moment of calibrating the measurements, there is still a pixel-dependent offset detectable in the level 2 product (Figure 1c). This shows up as striped features along the track. The destriping algorithm in DOMINO tries to smooth out these individual offsets, but introduces a small increment of the values in the west side pixels (1-10) and the east side pixels (51-60), which can be up to 0.3 10^{15} molecules/cm^2 when looking at the total NO_2 vertical column density (Figure 1b). New destriping algorithms are currently under investigation.

3.4 Overlapping tracks

OMI senses the actual state of the atmosphere at 12h30 local time. By making composite images of several orbits, one has to take into account that there is a time difference of 1h30 between two consecutive tracks (the western track being sensed after the eastern track). During this time interval the situation in the overlap area might have changed considerably. Right now, the overlap shows an averaged value of the two tracks.



(a) (b) (c)

Figure 1 Mean value of total NO2 column density as retrieved for each pixel in the detector array, for all retrievals done by the OMI instrument on 23 January 2007. Due to the high number of measurements, peak values for e.g. industrial areas tend to average out. (a) shows the current OMI NO2 product. A cross track gradient can clearly be distinguished. (b) This gradient disappears when using the OMI NO2 product based on the new level 0-1 and 1-2 reprocessing. However, there is a small increment of the NO2 values at the West and East pixel, introduced by the current destriping algorithm. (c) Mean cross tracks values with the new reprocessing, but without the stripe correction.

4. REFERENCES

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