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Merged ozone profiles from four MIPAS Processors

Alexandra Laeng[1], Thomas von Clarmann[1], Gabriele Stiller[1], Bianca Maria Dinelli[2], Anu Dudhia[3], Piera Raspollini[4], Norbert Glatthor[1], Udo Grabowski[1], Viktoria Sofieva[5], Lucien Froidevaux[6], Kaley A. Walker[7], and Claus Zehner[8]

[1]Institut für Meteorologie und Klimaforschung, Karlsruhe Institute of Technology, Germany
[2]ISAC-CNR Bologna, Italy
[3]Earth Observation Data Group, Oxford University, United Kingdom
[4]IFAC-CNR Firenze, Italy
[5]Finnish Meteorological Institute, Finland
[6]Jet Propulsion Laboratory, California Institute of Technology, USA
[7]University of Toronto, Canada
[8]ESA ESRIN, Frascati, Italy

Correspondence to: Alexandra Laeng
(alexandra.laeng@kit.edu)

Abstract. The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) was an infrares limb emission spectrometer on the Envisat platform. Currently, there are four MIPAS ozone data products, including operational Level-2 ozone product processed at ESA with the scientific prototype processor being operated at IFAC Florence and three independent research products: ISAC-CNR/University of Bologna, Oxford University and KIT-IMK/IAA. Here we present a dataset of ozone vertical profiles obtained by merging ozone retrievals from four independent Level 2 MIPAS Processors. We also discuss the advantages and the shortcomings of this merged product. As the four processors retrieve ozone in different parts of the spectra (microwindows), source measurements can be considered as nearly independent. The information content of the merged product is hence more important. The precision of the merged product is better than that of any parent dataset.

The merging is performed on profile per profile base. Parent ozone profiles are weighted based on the corresponding covariance matrices, the correlations between different profile levels are taken into account. The intercorrelations between the processors' errors are evaluated statistically and are used in the merging. The height range of the merged product is 20-55 km, and statistical covariance matrices are provided as diagnostics. Validation of the merged dataset is performed by comparing it with ozone profiles from ACE-FTS and MLS. Even though the merging is not supposed to remove the bias, around the ozone volume mixing ratio peak the merged product has a smaller (up to 0.1 ppmv) bias with respect to ACE-FTS than any of the parent datasets. The bias with respect to MLS is of the order of 0.15 ppmv at 20-30 km height, and up to 0.45 ppmv at larger altitudes. Comparison with ACE-FTS looks better than with MLS, however this is the case for all parent processors as well.

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1 Introduction

The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) was an infra-red (IR) limb emission spectrometer onboard the ENVISAT platform. It measured during day and night at 6 to 70 km (up to 170 km in special modes), pole-to-pole, producing more than 1000 profiles/day. Around 30 species, temperature and cloud composition could be derived from these measurements. In 2002-2004, the instrument operated in full spectral resolution, with a vertical resolution of about 3.5 - 6 km for the retrieved ozone product; this period of MIPAS operations is referred to as the full resolution (FR) period. Due to a failure of the instrument's mirror slide in 2004, the operations were suspended during almost a year and were resumed in 2005 with reduced spectral, but improved vertical resolution. The corresponding period until the loss of communications with the ENVISAT platform in April 2012, is referred to as the reduced resolution (RR) period of MIPAS operations.

MIPAS Level-2 data are operationally processed at ESA, with the scientific prototype processor at IFAC Florence (Raspollini et al., 2013). Beyond this, there are three independent scientific Level-2 processors: at ISAC-CNR/University of Bologna (Carlotti et al., 2006; Dinelli et al., 2010), at Oxford University (http://www.atm.ox.ac.uk/MORSE/) and the IMK/IAA Processor at KIT, Karlsruhe (von Clarmann et al., 2003, 2009). Henceforth, the four processors will be referred to as the ESA, Bologna, Oxford, and KIT processors. This often lead to confusion in the scientific community about their differences and which one to use. The homogenized description of the four processors is given in Laeng et al. (2015). The main similarities and differences between the four processors can be summarized as follows:

- all four processors use the same level-1b spectra provided by ESA, but the level-2 retrieval algorithms are different
- all four processors use microwindows instead of the full spectrum; for the rationale behind this approach see (von Clarmann and Echle, 1998; Echle et al., 2000; Dudhia et al., 2002), but microwindow selection differs
- all four processors apply a global fit approach in a sense that the tangent altitudes of a limb scan are processed simultaneously rather than sequentially (Carlotti, 1988), however they use different regularization approaches
- the Bologna processor uses a full 2D-approach, that is all measurements in a complete orbit are processed simultaneously
- the KIT processor accounts for horizontal temperature gradients in the ozone retrieval, the other processors consider atmospheric variation in the altitude domain only.

In the frame of ESA's Ozone Climate Change Initiative project, a Round Robin evaluation of ozone products from the four MIPAS processors was performed. The details of this comparison can be found in Laeng et al. (2015). Due to its slightly better performance in the UTLS, the ozone dataset from KIT-IMK/IAA processor was chosen to be used in further activities of the Ozone CCI Project. However, the question arose regarding how to optimize the use of all MIPAS data products. This gave rise to an independent activity, merging the ozone data from the four MIPAS datasets, which is presented in this paper. Two years of data from the four MIPAS processors were merged, namely 2007 and 2008.

The merging is performed on profile per profile base. Parent ozone profiles are weighted based on the corresponding covariance matrices, the correlations between different profile levels are taken into account. The intercorrelations between the processors' errors are evaluated statistically and are used in the merging. Since different processors use different parts of the spectrum (microwindows), the source measurements can be considered as nearly independent with respect to the primary measurement errors. Therefore there is an expectation for the merged product to be better than the individual contributing datasets. This expectation, however, relies on the assumption that the dominating source of error is measurement noise, or any other source of random error which is uncorrelated between the parent data sets. It is a priori unclear if these assumptions are justified, particularly in the case of climatological datasets that necessarily average a large number of profiles, where random errors average out while systematic errors survive. No a priori statement can be made if the biases of the parent data sets average out. The small sample size (four processors only) is an obstacle to the identification of outliers. It only takes one processor to significantly deviate from the true profile and the merged product will be worse than any of the other three. However, contrary to the merging of data from multiple sensors, the following issues do not apply to the merging of multiple data products of a single sensor: sampling issues, different degradation of instruments, and insufficient time overlap.

2 Merging approach

The merging is performed on profile per profile base. Our choice is to always use all four processors' values. The merged profile is constructed as a weighted mean of the four parent profiles. For each processor, the errors at different height levels are correlated. Therefore, the value of the merged profile at each level is a linear combination of all the levels of all four processors. The weights depend on the quality of the error estimates: the better the error estimates of a processor are, the larger its contribution to the merged profie is. The merging is performed on a fixed pressure grid which corresponds approximately to the MIPAS RR nominal tangent altitude grid. On the upper and lower ends of the profiles, it occurs frequently that not all four processors provide data. The height range was hence limited to 62 - 0.8 hPa ($\sim$ 20-50 km). The merged profile is obtained as

$$\mathbf{x}_{\text{merged}} = \left(\begin{pmatrix} e & e & e & e \end{pmatrix} \mathbf{C}^{-1} \begin{pmatrix} e \\ e \\ e \\ e \end{pmatrix} \right)^{-1} \begin{pmatrix} e & e & e & e \end{pmatrix} \mathbf{C}^{-1} \begin{pmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \mathbf{x}_3 \\ \mathbf{x}_4 \end{pmatrix} \qquad (1)$$

where e is $n \times n$ identity matrix, $\mathbf{x}_i, i = 1,2,3,4$ is the profile from the processor i, and $\mathbf{C}$ is the processor intercorrelation $4n \times 4n$ matrix defined as follows:

$$\mathbf{C} = \begin{pmatrix} \mathbf{S}_{\mathbf{x}_1} & \mathbf{S}_{12}^T & \mathbf{S}_{13}^T & \mathbf{S}_{14}^T \\ \mathbf{S}_{12} & \mathbf{S}_{\mathbf{x}_2} & \mathbf{S}_{23}^T & \mathbf{S}_{24}^T \\ \mathbf{S}_{13} & \mathbf{S}_{23} & \mathbf{S}_{\mathbf{x}_3} & \mathbf{S}_{34}^T \\ \mathbf{S}_{14} & \mathbf{S}_{24} & \mathbf{S}_{34} & \mathbf{S}_{\mathbf{x}_4} \end{pmatrix} \qquad (2)$$

where $\mathbf{S}_{\mathbf{x}_i}$ is the random retrieval error covariance matrix of processor i, $\mathbf{S}_{ij}$ (i and j correspond to processors) are $n \times n$ matrices defined by

$$\mathbf{S}_{ij} = \mathbf{R}_{ij} \sqrt{\text{diag}(\mathbf{S}_{\mathbf{x}_i})} \sqrt{\text{diag}(\mathbf{S}_{\mathbf{x}_j})} \qquad (3)$$

with $\mathbf{R}_{ij}$ being $n \times n$ matrices representing the correlation of errors on different levels of two processors.

The covariance matrice of the merged profile is given by

$$\mathbf{S}_{\mathbf{x}_{\text{merged}}} = \left(\begin{pmatrix} e & e & e & e \end{pmatrix} \mathbf{C}^{-1} \begin{pmatrix} e \\ e \\ e \\ e \end{pmatrix} \right)^{-1} \qquad (4)$$

As the vertical resolutions of the four processors are very close (see Laeng et al. (2015) for details), our choice is not to take the averaging kernels into the merging formalism. See Ceccherini et al. (2015) for a merging formalism involving the averaging kernels but omitting the correlation between the random errors of the parent datasets.

3 Correlation coefficients

In order to estimate the correlation of errors between the processors, some assumptions are made. The errors of retrieved atmospheric profile, i.e. the components of the difference between the retrieved profile and the true state of the measured air parcel of the atmosphere, can be classified in different ways: by their origin, by correlation characteristics, by way of assessment. When classifying the errors by correlation characteristics, the errors are divided into random, systematic, and correlated. Typical exemple of a random error is the instrument noise. Parameter error can also have strong random component. “Systematic errors” appear in the same manner in multiple measurements and thus do not cancel out by averaging. Typical systematic errors are model errors, errors in spectroscopic data, calibration errors. Errors can be systematic in many domains. Conventionally this term is applied to errors systematic in the time domain; we follow this convention.

In the real world, most of the errors are correlated, meaning they are neither fully random nor fully systematic. Futher, components of the total error can add additively or multiplicatively. Our choice is to neglect both these facts : we assume that a retrieved atmospheric profile can be written as

$$\hat{\mathbf{x}} = \mathbf{x} + \epsilon_{systematic} + \epsilon_{random}. \tag{5}$$

where $\hat{\mathbf{x}}$ is the retrieved profile while $\mathbf{x}$ is the true profile. For shortness, we call “random error” the random component of the error ϵ_{random}. It includes measurement noise and randomly varying parameter errors. We further assume that random error correlations between the retrieved profiles from different processors are mostly due to error correlations in the measurements which are used. Although Oxford and ESA processors use identical measurements (microwindows), it is not clear if there is really much correlation in the structure of their deviations from true O_3 profiles, or if the differences in the retrieval algorithms dominate. A straightforward way to evaluate the intercorrelation of random errors of different processors is to examine the statistics of differences between each pair of processors. If the assumption was true then Bologna’s coefficients with ESA and KIT processors should be very close to zero, because the Bologna processor uses microwindows that are completely disjoint from the ESA and KIT processors (the summary of microwindows used by the four processors can be found in Laeng et al. (2015)). Hence, we need an estimate for the correlation coefficient between the random error of the values of processor i at height p and the random error of the values of processor j at height q ($i,j = 0,1,2,3$). The random errors are deduced from the Equation 5 as

$$\hat{\mathbf{x}}_i^p - \mathbf{x}^p - \epsilon^p_{systematic,i}, \quad \text{and} \quad \hat{\mathbf{x}}_j^q - \mathbf{x}^q - \epsilon^q_{systematic,j}. \tag{6}$$

By definition, the correlation coefficient $\mathbf{x}_{X,Y}$ between random variables X and Y is

$$\rho_{X,Y} = \frac{cov(X,Y)}{\sigma_X \sigma_Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y} \tag{7}$$

where cov stands for covariance, E stands for mathematical expectation operator, μ_X stands for the expectation values of X, μ_Y stands for the expectation values of Y, σ_X stands for the standard deviation of X, σ_Y stands for the standard deviation of Y. In our case, the random variables would be the random error of the values of processor i at height p and the random error of the values of processor j at height q ($i = 0,1,2,3$). At a fixed height, for each processor its systematic error component is constant. As correlation coefficient does not change if the random variables are linearly transformed, the systematic component can be neglected when calculating correlation coefficients between the random errors. Hence, we need just to calculate the correlation coefficient between the following random variables:

$$X = \hat{\mathbf{x}}_i^p - \mathbf{x}^p \quad \text{and} \quad Y = \hat{\mathbf{x}}_j^q - \mathbf{x}^q. \tag{8}$$

The expectation of X (or Y) is estimated as mean difference between the retrieved profile and the truth over all geolocations:

$$\mu_X = \frac{1}{N}\sum_{l=1}^{N}(\hat{\mathbf{x}}_{i,l}^p - \mathbf{x}_l^p) \quad \text{and} \quad \mu_Y = \frac{1}{N}\sum_{l=1}^{N}(\hat{\mathbf{x}}_{j,l}^q - \mathbf{x}_l^q) \tag{9}$$

where the vector $\hat{\mathbf{x}}_{i,l}$ is the profile retrieved by processor i on the l-th geolocation and $\hat{\mathbf{x}}_{i,l}^p$ is its p-th level; $\mathbf{x}_l$ is the true profile on the l-th geolocation and $\mathbf{x}_l^p$ is its p-th level.

We note by N the number of profiles in the whole 2007–2008 sample. On each geolocation k, $k = 1,...N$, we will use the best estimate of the truth $\mathbf{x}$ that we have, namely the mean profile of the four processors on this geolocation; we note it by $\overline{\mathbf{x}}_k$, $k = 1,...,N$, and its p-th level is noted by $\overline{\mathbf{x}}_k^p$. Then realisation of $X - \mu_X$ on the k-th geolocation is:

$$(X-\mu_X)_k = \hat{\mathbf{x}}_{i,k}^p - \mathbf{x}_k^p - \frac{1}{N}\sum_{l=1}^{N}(\hat{\mathbf{x}}_{i,l}^p - \mathbf{x}_l^p) = \hat{\mathbf{x}}_{i,k}^p - \overline{\mathbf{x}}_k^p - \frac{1}{N}\sum_{l=1}^{N}(\hat{\mathbf{x}}_{i,l}^p - \overline{\mathbf{x}}_l^p) \tag{10}$$

(the true profile $\mathbf{x}_k$ was replaced by its estimate $\overline{\mathbf{x}}_k$) and similarly the realisation of $Y - \mu_Y$ on the k-th geolocation is :

$$(Y-\mu_Y)_k = \hat{\mathbf{x}}_{j,k}^q - \overline{\mathbf{x}}_k^q - \frac{1}{N}\sum_{l=1}^{N}(\hat{\mathbf{x}}_{j,l}^q - \overline{\mathbf{x}}_l^q) \tag{11}$$

We use hence the following estimator of the correlation of the random errors of the processors. The correlation coefficient r_{ij}^{pq} between the random errors of processor i at height p and the random errors of processor j at height q is:

$$r_{ij}^{pq} = \frac{\sum_{k=1}^{N}(\hat{\mathbf{x}}_{i,k}^p - \overline{\mathbf{x}}_k^p - \frac{1}{N}\sum_{l=1}^{N}(\hat{\mathbf{x}}_{i,l}^p - \overline{\mathbf{x}}_l^p))(\hat{\mathbf{x}}_{j,k}^q - \overline{\mathbf{x}}_k^q - \frac{1}{N}\sum_{l=1}^{N}(\hat{\mathbf{x}}_{j,l}^q - \overline{\mathbf{x}}_l^q))}{\sqrt{\sum_{k=1}^{N}(\hat{\mathbf{x}}_{i,k}^p - \overline{\mathbf{x}}_k^p - \frac{1}{N}\sum_{l=1}^{N}(\hat{\mathbf{x}}_{i,l}^p - \overline{\mathbf{x}}_l^p))^2(\hat{\mathbf{x}}_{j,k}^q - \overline{\mathbf{x}}_k^q - \frac{1}{N}\sum_{l=1}^{N}(\hat{\mathbf{x}}_{j,l}^q - \overline{\mathbf{x}}_l^q))^2}} \tag{12}$$

Another way to look at this formula is to say that the third term in each bracket is the bias of corresponding processor, by taking it out of the first term we obtain a debiased profile, and then the second term in the bracket is just the mean around which the variation of debiased profiles is calculated.

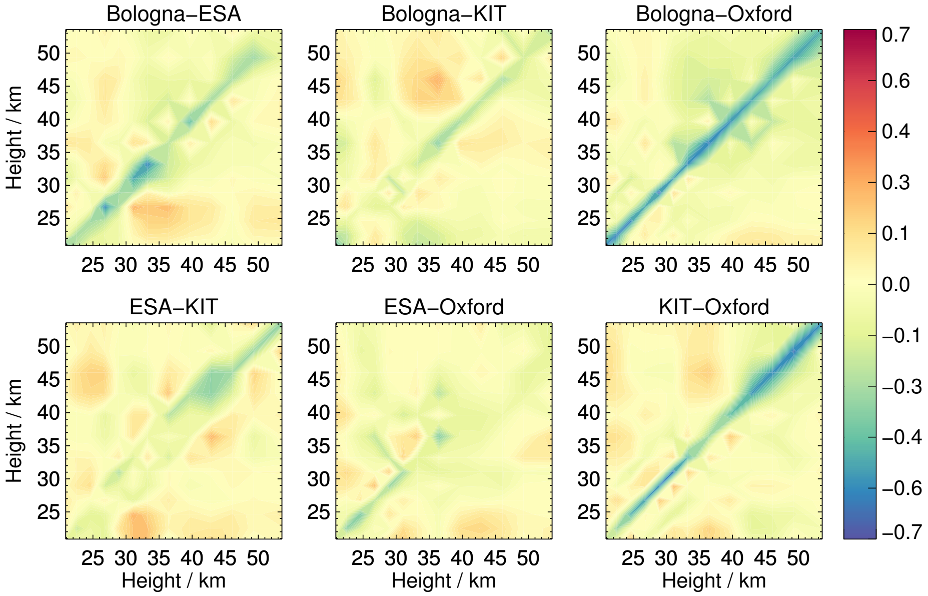

Figure 1. Correlation of errors of four processors calculated by formula 12. Obtained matrices are not symmetric, which is to be expected. The errors are non-negligibly correlated for all six pairs, which means that the coefficients can not be assumed zero and must be taken into the merging formula.

Note that the obtained matrices are not symmetric, which is to be expected: there is no reason why the random errors of Bologna at height 20 km and random errors of KIT at height 35 km would be correlated exactly as the random errors of Bologna at height 35 km and random errors of KIT at height 20 km.

Figure 1 demonstrates that the errors are non-negligibly correlated for all six pairs, with minimal value -0.6 and maximum 0.26, which means that the coefficients r_{ij}^{pq} can not be assumed zero and must be taken into the merging formula. The assumption that error correlations between the retrieved profiles from different processors are mostly due to error correlations in the measured spectra turns out to be false: Oxford and ESA use identical measurements, but the highest correlation is observed in Bologna-Oxford and KIT-Oxford cases. However the similarities/differences in the retrieval algorithms seem also to play a role, and that could explain some high absolute values of the coefficients. Although even for processors using fully disjoint microwidows the inter-processor correlations are sufficiently small, a gain in precision can be expected by data merging if these correlations are adequately taken into account.

4 Statistical covariance matrices

To construct the processor intercorrelation matrix as given by Eq. 2, the covariance matrices from all four processors are needed for each profile. The total covariance matrix contains the inputs from noise, smoothing [1] and systematic components:

$$\mathbf{S}_{total} = \mathbf{S}_{noise} + \mathbf{S}_{syst} + \mathbf{S}_{smoothing}. \tag{13}$$

The ESA and KIT processor provides

$$\mathbf{S}_{noise} = \mathbf{G}\mathbf{S}_{\mathbf{y}}\mathbf{G}^T. \tag{14}$$

The Oxford processor provides

$$\mathbf{S}_{\mathbf{x}} = \mathbf{S}_{noise} + \mathbf{S}_{smoothing} = (\mathbf{A}\mathbf{S}_a^{-1})^{-1} = \left(\mathbf{K}^T\mathbf{S}_{\mathbf{y}}^{-1}\mathbf{K} + \mathbf{S}_a^{-1}\right)^{-1}. \tag{15}$$

So a diagnostic of Oxford processor which would be directly comparable with a diagnostic of ESA and KIT would be

$$\mathbf{S}_{\mathbf{x}} - \mathbf{S}_{smoothing} = (\mathbf{A}\mathbf{S}_a^{-1})^{-1} - (\mathbf{I}-\mathbf{A})^T\mathbf{S}_a(\mathbf{I}-\mathbf{A}) \tag{16}$$

But $\mathbf{S}_a$ are not provided by Oxford processor. Hence the use of the statistical covariance matrix $\mathbf{S}_{noise}$ is the only option for the Oxford dataset.

The use of statistical covariance matrices is the only option for Bologna processor as well: this processor performs a 2D-retrieval and retrieves simultaneously pressure, temperature, H_2O and O_3, which is reflected by the big size of covariance matrices (of order 1632×1632, coming from 96 scans $\times$ 17 heights per orbit). Hence, these covariance matrices $\mathbf{S}_{noise}$ are stored only for sample orbits.

While for the remaining two processors, ESA and KIT, genuine covariance matrices $\mathbf{S}_{noise}$ are available, we have decided to use empirical covariance matrices for all four. The reasons are the following. First, the purpose of taking the covariance matrices into the merging is to control the weight of each processor in the average. Here it is more important that the covariance matrices are evaluated in a consistent way than having a particularly good covariance matrix for a subset of profiles. Second, this approach proved to be more robust: using analytic covariance matrices when available (ESA and KIT) led to singular processor intercorrelation matrices in 80% of the cases, while for the scenario when for all four processors the statistical covariance matrices are taken in the merging, the corresponding processor intercorrelation matrix is invertible in 100% of the cases. The estimator of covariance matrix of a processor i is obtained from the formula for the correlation of errors by taking $i = j$:

$$\mathbf{S}_{\mathbf{x}_i} = \frac{1}{N}\sum_{k=1}^{N}\left(\mathbf{x}^p_{i,k} - \overline{\mathbf{x}}^p_k - \frac{1}{N}\sum_{l=1}^{N}(\mathbf{x}^p_{i,l} - \overline{\mathbf{x}}^p_l)\right)\left(\mathbf{x}^q_{i,k} - \overline{\mathbf{x}}^q_k - \frac{1}{N}\sum_{l=1}^{N}(\mathbf{x}^q_{i,l} - \overline{\mathbf{x}}^q_l)\right) \tag{17}$$

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[1] The inclusion of the smoothing error in the error budget is critically discussed in von Clarmann (2014).

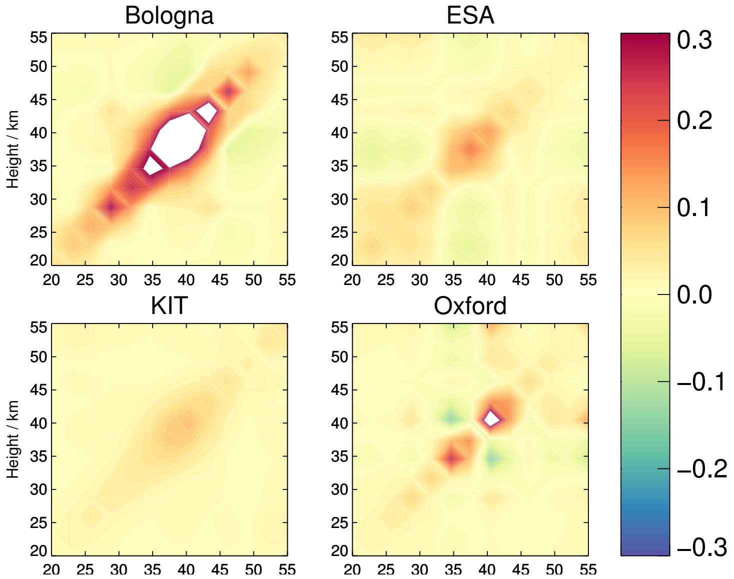

Figure 2. Statistical covariance matrices of four parent MIPAS processors. The white areas in Bologna and Oxford plots are for values bigger than 0.3 : up to 0.82 for Bologna and up to 0.44 for Oxford processors.

Calculated on summer profiles in the 20°S-20°N latitude band, no significant correlation due to natural atmospheric variability is introduced. The obtained covariance matrices are shown in Figure 2. The results obtained are consistent with the error bars validation from Laeng et al. (2015).

215 5 Merged profiles and their validation

Figure 3 shows an example of the merging of the four individual parent profiles into one merged profile for the tropical summer geolocation 33441_20080723T072843Z (0.2degS, 40.5degE). Just for the information, we also plotted in this figure the closest ozonesonde profile (from Nairobi station (1.3degS, 36.8degE) which is shown in black. [2] The Figure 3 should be viewed in the context, 220 namely that ozonesonde profiles themselves can have uncertainties up to 10% and have poor quality at the heights over 35 km.

Merging of various data products from the same instrument is not necessarily supposed to remove the bias. Instead, it is supposed to ameliorate the precision of the product since the parent processors rely on different spectral information (different microwindows). At heights where the precision of the 225 merged product is better than the precision of any of the parent datasets, the merging is successful. Figure 4 shows simultaneous comparison of the four parent MIPAS datasets and the merged MIPAS

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[2] Nairobi station was choosen because in the frame of Ozone_cci project, an evaluation of overestimated is the ozone amount was performed which happens to be ∼5% and is due to the use until 2010 a 1% KI solution concentration.

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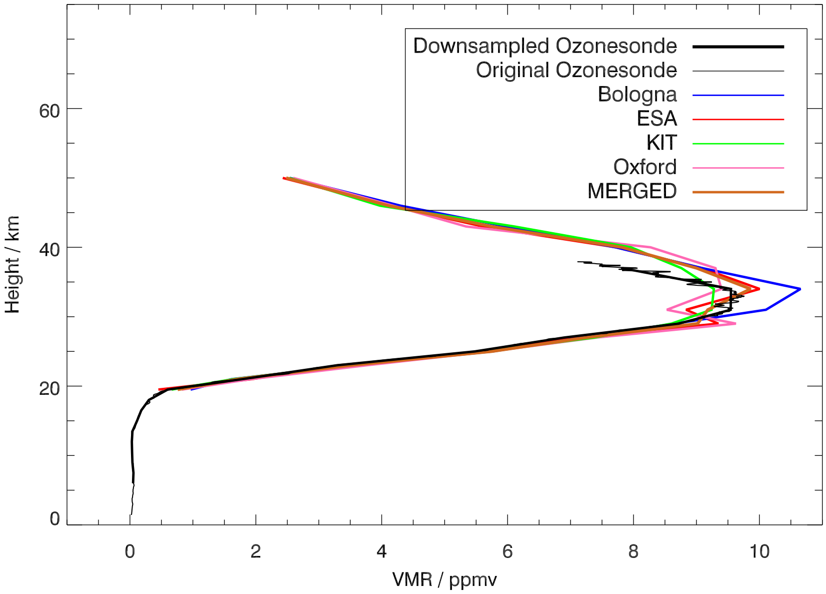

Figure 3. Parent MIPAS profiles and resulting merged MIPAS profile on geolocation 33441_20080723T072843Z (0.2degS, 40.5degE) together with closest ozonesonde profile from Nairobi station (initial and downsampled). The profile from the Bologna processor is the blue line, from the ESA processor is red, from the KIT Processor is green, and that from the Oxford processor is pink. The merged profile is the brown line, the ozonesonde profiles are black.

dataset with ACE-FTS Version 3.5 ozone dataset, for collocation criteria 5 hours and 500 km. In terms of precision hence the merging is a success at 20-28 and 39-43 km. At 28-38 km, KIT's precision in terms of standard deviation of the differences is better than the precision of the merged product. At 44-52 km, ESA's precision is better than the precision of the merged product. Although the merging is not supposed to remove the bias, in terms of bias: at 24-28 and 33-37 km, the merged product agrees with ACE better than KIT, while at all other heights, KIT agrees better. Interestingly, in integrated view over the altitude range around the ozone vmr peak, where all four processors have a known positive bias (Laeng et al., 2015), the merged product is performing better than any of the four processors (middle panel of the Figure 4).

Figure 5 shows simultaneous comparison of the four parent MIPAS datasets and the merged MIPAS dataset with MLS version v3.3 dataset, for collocation criteria 4 hours and 250 km. At 20-25 km, the precision of the merged product is better than the precision of any individual dataset. When looking at the whole height range, the overall precision of the merged product is better than the precision of any of the parent datasets. The overall agreement of the merged product with MLS is worse than with ACE-FTS; this is also the case for all parent datasets. In terms of the bias, the merged

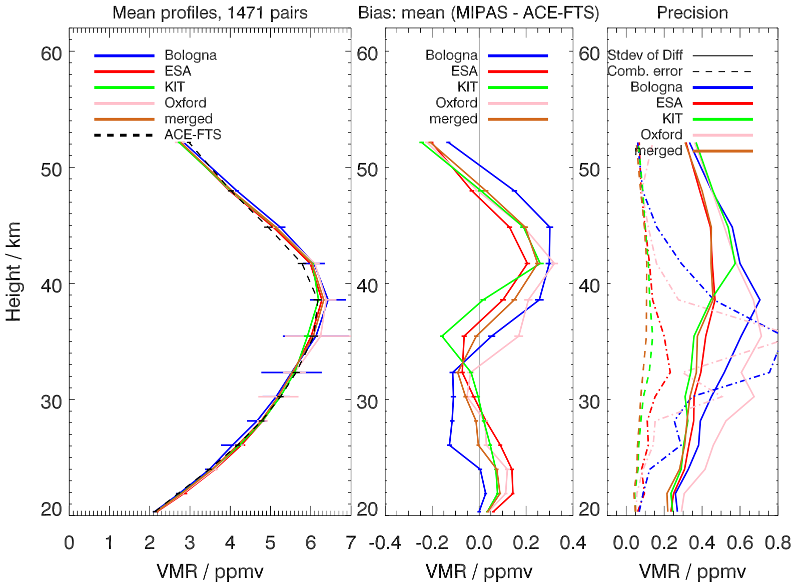

Figure 4. Mean profiles (left panel), bias (middle panel) and precision validation (right panel) of the four parent datasets and merged MIPAS dataset with respect to ACE-FTS ozone profiles in 2007-2008.

product performs better at 24-33 and 41-45 km, while KIT performs better at the remaining heights. In particularly, unlike for comparison with ACE, around the ozone vmr peak the agreement of KIT is better than the agreement of the merged dataset.

6 Conclusions

We created merged ozone profiles from four independent MIPAS Level 2 processors. The novelty of the product is that the merging is performed in a mathematically clean way: the weighting of parent profiles is realized by corresponding inverse covariance matrices, the correlations between different profile levels are considered, and the intercorrelations between processors' errors are evaluated statistically and are used in the merging. In comparison to the individual parent datasets, the merged product has a restricted height range (20-55 km) and only a statistical covariance matrix can be provided. Validation of the merged dataset is performed by comparing with ozone profiles from ACE-FTS and MLS. Comparison with ACE-FTS looks better than with MLS, however this is the case for all parent processors as well. Despite the fact that the merging is not supposed to remove the bias, the high bias around the ozone vmr peak known for the parent profiles is reduced in comparison with ACE-FTS (but not with MLS). The overall precision of the merged product is better than that of any of the four processors.

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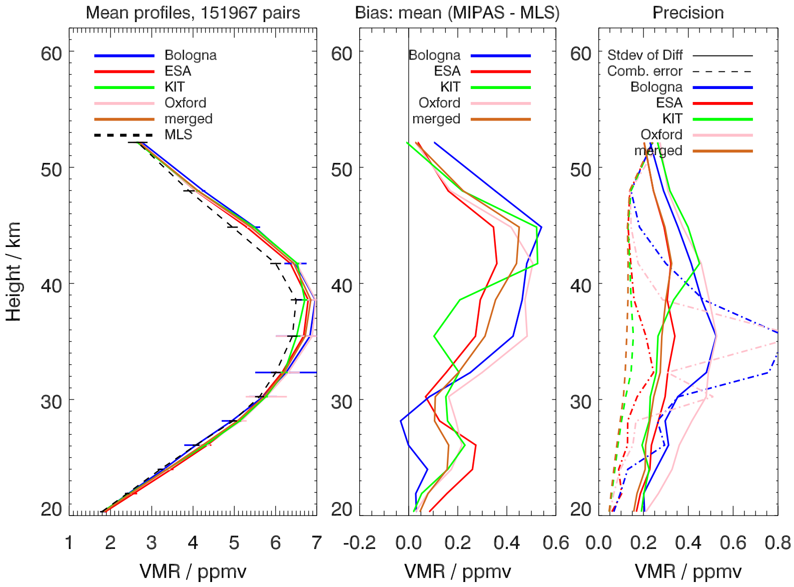

Figure 5. Mean profiles (left panel), bias (middle panel) and precision validation (right panel) of the four parent datasets and merged MIPAS dataset with respect to MLS ozone profiles in 2007-2008.

7 Data availability

The merged MIPAS data product is available at http://www.esa-ozone-cci.org

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