Product Quality Readme File

MIPAS Level 2 version 7.03 products

Field	*Contents*
Document Title	Product Quality Readme File for MIPAS Level 2 version 7.03 products
Reference	ENVI-GSOP-EOGD-QD-16-0141, issue 1.0, 07/09/2016
Affected Dataset	This Readme file applies to all MIPAS Level 2 products generated with the ESA Level 2 ML2PP processor version 7.03 (MIP_NL__2PW) and the MIPAS Auxiliary Data Files version 8.06.
Applicable Documents	[AD1] MIPAS Level 2 Algorithm Theoretical Baseline Document (ATBD), IFAC_GA_2007_12_SC, issue 6, 11 February 2013 [AD2] MIPAS Level 2 Processing Input/Output Data Definition (IODD), PO-RS-ESA-GS-0177, issue 7B, 3 June 2015 [AD3] MIPAS Product Specification, PO-RS-MDA-GS-2009 Volume 12, issue 5B, May 2015 Available at: https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/products-and-algorithms/products-information
Change Log	This document shall be amended by releasing a new edition of the document in its entirety. The table below records the history and issue status of this document.

Issue	Date	Change
1.0	07/09/2016	First release

Inputs	MIPAS Quality Working Group, MIPAS validation teams, MIPAS IDEAS+ (Instrument Data quality Evaluation and Analysis Service) team
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Approval	Angelika Dehn (ESA-ESRIN)

Contents

Description

1. MIPAS mission overview

The ENVISAT mission with on-board the MIPAS instrument lasted ten years, from the 1st of March 2002 until the 8th of April 2012. In 2004 MIPAS suffered a major anomaly affecting the Interferometer Drive Unit (IDU) with serious impact on performances. To avoid the mechanical blockage of the instrument, ESA took the decision to interrupt MIPAS regular operations on the 26th of March 2004. Different tests with different slides configurations and spectral resolutions were performed for the identification of the error source. Despite such a serious problem, ESA succeeded the recovery of the instrument in January 2005, after only few months of tests.

MIPAS was operated at 100% of its duty cycle from July 2002 to March 2004. Due to the mentioned instrument anomaly, the operations were reduced significantly with respect to its duty cycle during 2005 and 2007. At the beginning of 2005 MIPAS was operated at only 30% duty cycle which was progressively increased until December 2007, when it was successfully recovered back to 100% operations, after 3.5 years since the first failure. The adopted duty cycle has a direct consequence on the overall number of observations acquired by MIPAS in the different periods. Moreover due to the MIPAS major anomaly in 2004 it was necessary to modify the acquisition scenarios and to completely re-characterize the instrument.

2. MIPAS operations

The acquisition baseline was defined by the "MIPAS Science Team" and was regularly revised along the mission in order to adapt the measuring scenario to scientific requirements, such as special operations in support to calibration/validation campaigns or special events. Different measurements modes were thus implemented.
In addition, due to the Interferometer Drive Unit major anomaly in 2004 it became necessary to modify the acquisition scenarios and the mission target itself.
Different phases can be therefore identified along the MIPAS mission, characterized by a different spectral resolution and a different limb scanning pattern with different vertical and horizontal sampling.

- **Commissioning Phase: 1st March – July 2002**

ENVISAT launch, SODAP and MIPAS cal/val phase.

- **Full Resolution (FR) phase: 1st July 2002 – 26th March 2004**

MIPAS original measurement mode acquiring full spectral resolution measurements (0.025 cm^{-1}). During this phase, MIPAS measurements were mainly acquired in Nominal Mode with 17 sweeps per scan; only few orbits were commanded in the Special observation Mode and in the Upper Atmosphere observational scenario for scientific purposes.

- **Mission suspended: 26th March 2004 – 9th August 2004**

- **Reduced Resolution (RR) phase: 9th August 2004 – 17th September 2004**

MIPAS was tested for acquiring 41% reduced spectral resolution measurements (0.0625 cm^{-1}). For this phase, Nominal Mode operations have 17 sweeps per scan.

- **Mission suspended: 17th September 2004 – 10th January 2005**

- **Optimized Resolution (OR) phase: 10th January 2005 – 21st October 2010**

MIPAS was operated in double slides configuration for acquiring 41% reduced spectral resolution measurements (0.0625 cm^{-1}). Operations were based on an "event driven scenario" with priority to validation campaigns and special observations. The instrument duty cycle increased from 30% up to 100% i.e. continuous operations since 1st December 2007. During this phase, beside the most frequent Nominal Mode, several measurements have been acquired in e.g. UTLS-1 (Upper Troposphere-Lower Stratosphere), MA (Middle Atmosphere) and UA (Upper Atmosphere) modes. The new Nominal Mode has 27 sweeps per scan. The other observation modes were updated for the new instrument configuration and optimized wrt vertical and horizontal spacing.

- **ENVISAT extended mission: 21st October 2010 – 8th April 2012**

MIPAS was still operated in Optimized Resolution (OR) but the ENVISAT platform was moved to a lower altitude with drifting orbit.
Details of the MIPAS performance after the ENVISAT orbit lowering can be found at: https://earth.esa.int/sppa-reports/envisat/mipas/monthly/2010-11-01/MIPAS_MR_20101101_20101130.pdf

3. Level 2 retrieval algorithm and products

The Level 2 retrieval algorithm ([3], [4], [5]) performs the global fit of a few selected spectral intervals (microwindows) of the acquired spectra; the retrieved state vector includes the volume mixing ratio profile of the target species, profiles of the (frequency independent) atmospheric transparency [6] and (tangent altitude independent) radiometric offset for each microwindow. The code minimizes the chi-square function using the regularizing Levenberg-Marquardt approach [7] and then the residual non-physical oscillations are reduced by an a posteriori Tikhonov regularization with a self-adapting strength ([8], [9]).

3.1. Handling of Averaging Kernels

The averaging kernel matrices and the covariance matrices of the retrieved state vectors are calculated taking into account all the steps performed during the retrieval process as described in [10].
The usage of the averaging kernel matrices for validation activities is described in [11].

3.2. Products overview

The Level 2 products consist of a number of geophysical parameters derived from the measured atmospheric limb emission spectra and some instrument auxiliary information, including e.g. the pointing information.
The following geophysical parameters are retrieved during the on-ground processing chain:

- atmospheric pressure (p) at the line-of-sight (LOS) tangent altitudes;
- kinetic temperature (T), represented on the grid of the pressures at the LOS tangent altitudes;
- LOS tangent altitudes correction data for the acquired LOS tangent heights;
- volume mixing ratio (VMR) vertical profile data of the 15 MIPAS target species (H_2O, O_3, HNO_3, CH_4, N_2O, NO_2, CFC-11, $ClONO_2$, N_2O_5, CFC-12, COF_2, CCl_4, HCN, CFC-14, HCFC-22), represented on the acquired scene grid;
- the associated variance/covariance data;
- concentration vertical profile data of the 15 target species, represented on the acquired scene grid;
- integrated vertical column density profile data of the 15 target species.

In addition, different types of information related to the data acquisition, the actual measurement scenario and the instrument settings are included in the Level 2 products, in particular:

- geolocation of the LOS tangent points, corrected for the atmospheric refraction;
- initial guess profiles;
- spectroscopic information;
- algorithm-specific parameters (e.g. convergence parameter, spectral intervals selection, ...);
- spectral signal-to-noise ratios;
- settings of essential instrument parameters;
- information on scene measurements;
- various types of product confidence data (PCD).

4. ML2PP version 7.03 processor upgrades

The MIPAS Level 2 ML2PP processor version 7.03 was developed introducing both scientific improvements and format updates, and was adopted for the reprocessing of the MIPAS full-mission data set.

4.1. Algorithm modifications

The major processor upgrades of the new Level 2 version 7.03 compared to the previous baseline version 6 are the following:

- **Additional retrieved species**

The output products generated by the new processor ML2PP v7.03 contain five additional species, retrieved at the end of the chain in the following order: COF_2, CCl_4, HCN, CFC-14, HCFC-22.

- **Handling of $COCl_2$**

The proper handling of the $COCl_2$ interfering species in the retrieval chain leads to a reduction of the CFC-11 bias.

- **New IVS regularization for H_2O and weakest species**

In the previous processor ML2PP V6 an a-posteriori regularization was applied in the retrieval of all species except H_2O. This regularization scheme in the old processor had the strength to be altitude independent and was

determined by the retrieval error. However it resulted too weak for the H_2O retrieval.
The new IVS regularization, implemented in the ML2PP v7.03 processor, consists of an optimized self-adapting and altitude-dependent regularization scheme described in [1]. This kind of regularization is used for the retrieval of H_2O and all other species of the retrieval chain, except O_3 and HNO_3 for which the regularization as implemented in ML2PP V6 is applied ([8], [5]).

- **New continuum retrieval approach**

A new continuum retrieval approach [2] is implemented in ML2PP v7.03:
For each layer i_{th}, instead of retrieving the continuum cross-section k_i, the transmission $\xi_i=exp(-k_iC)$ due to the continuum is retrieved. While the sensitivity of the forward model to k_i vanishes for large enough values of k_i (due to the exponential dependence), the new variables ξ_i are polynomially connected with the optical transparency of the layer due to the continuum. Thus they are tightly linked to the measured spectra. The main effect of this improvement is that a larger stability of the retrievals is reached, with a better convergence towards the minimum of the χ^2.

4.2. Auxiliary Data Files changes

The main upgrades of the Level 2 Auxiliary Data Files v8.06 used together with processor ML2PP v7.03 are listed below:

- **Upgraded microwindows for the FR mission**

New microwindows (MW) with improved information content are used by the processor ML2PP v7.03 for the FR mission period. Their usage is leading to a reduction of the detected bias in FR measurements for CH_4, N_2O and CFC-12.

- **Diurnally varying climatological profiles**

Diurnally varying climatological profiles are used to define interfering species and initial guess profiles of the target species.

- **Systematic error profiles**

The estimation of the systematic error profile for each species and five reference atmospheric conditions (mid-latitude day-time, mid-latitude night-time, equatorial day-time, polar summer day-time, polar-winter night-time) is reported at: http://eodg.atm.ox.ac.uk/MIPAS/err/.

4.3. Products identifiers

The Level 2 products generated by ML2PP v7.03 are identified by the fields reported in the product filename and/or Main Product Header (MPH), see table 1, to unambiguously summarise the processing configuration adopted:

Table 1

MPH Field	Value
Processing stage flag	W
Processing centre	DSI
Software version	ML2PP/7.03

The default product filename counter is set to "1000", and it is increased in case of corrective processing activities; however only one product per orbit is available in the L2 data set. Table 2 shows an example filename.

Table 2

Example Filename
MIP_NL__2P**WDSI**20090808_120004_000060152081_00267_38898_**1000**.N1

4.4. Products format and tools

The MIPAS Level 2 products generated with ML2PP v7.03 have an updated format due to the introduction of five additional retrieved species ([AD2], [AD3]). Owing to this, the BEAT, VISAN and CODA software have been updated in order to read the new products, allowing fields' extraction and data handling. The latest BEAT version 6.10, VISAN version 3.12.1 and CODA version 2.17 are aligned to the new specifications. The format definition of the new data is also available on-line at:
http://www.stcorp.nl/beat/documentation/codadef/ENVISAT_MIPAS/products/MIP_NL__2P_v4.html

4.5. Products quality filtering

Users are recommended to check the quality flags listed in the table below, in order to make use of the highest quality spectra data of the new MIPAS Level 2 version 7.03 dataset.

Table 3

Record	Field name	Description	Value for highest data quality
MPH	Product Error	Possible values: 0 or 1. If 1, errors are reported in the product.	0
Scan Information MDS	Quality flag	Quality indicator PCD (Product Confidence Data). Possible values: -1 or 0. If -1, all information in DSR is blank or zero.	0
	Marquardt p-T flag	Flag indicating if Marquardt limit is exceeded for p-T retrieval. Possible values: 0 or 1.	0
	Marquardt VMR flag	Flag indicating if Marquardt limit is exceeded for VMR retrieval. Possible values: 0 or 1.	0
	Chi-2 p-T flag	Flag indicating if chi-square limit is exceeded for p-T retrieval. Possible values: 0 or 1.	0
	Chi-2 VMR flag	Flag indicating if chi-square limit is exceeded for VMR retrieval. Possible values: 0 or 1.	0
XXX[(1)] retrieval MDS	Convergence ID	Possible values: 0, convergence reached 1, maximum number of macro-iterations exceeded 2, maximum number of micro-iterations exceeded 3, maximum run-time exceeded 4, retrieval failed 5, convergence reached and final matrix singular 6, maximum number of macro-iterations exceeded and final matrix singular 7, maximum number of micro-iterations exceeded and final matrix was singular 8, maximum run-time exceeded and final matrix was singular 9, retrieval failed and final matrix was singular	0

[(1)] XXX stands for p-T, H_2O, O_3, HNO_3, CH_4, N_2O, NO_2, CFC-11, $ClONO_2$, N_2O_5, CFC-12, COF_2, CCl_4, HCN, CFC-14, HCFC-22. There is one MDS for each measured limb scan.

- **Negative values** may occur in the products; they have to be taken into account when performing data averages in order not to introduce a positive bias.

5. Level 2 version 7.03 dataset

Data reprocessing is fundamental to improve the quality of the existing data sets and generate coherent long term series of geophysical parameters to be used for atmospheric applications, such as climate studies and trend analysis. The latest MIPAS Level 2 full-mission reprocessing campaign has been performed using the ML2PP processor version 7.03. The reprocessed dataset covers the entire MIPAS operational mission lifetime period, from the 1st of July 2002 up to the 8th of April 2012.

The latest available MIPAS Level 1b v7.11 dataset has been successfully processed to Level 2; in total 34936 products(*) have been generated, with a total data volume of about 1.3 TB. Table 4 gives an overview of the number of orbits available. The status of the MIPAS consolidated Level 2 data set version 7.03-W is also available at:
https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/products-availability/level-2

Table 4

Year	Level 1b v7.11 products available	Level 2 v7.03 products available	Percentage of L2 availability wrt L1b products
2002	1898	1886	99.37 %
2003	4421	4392	99.34 %
2004	1126	1126	100 %
2005	1663	1655	99.52 %
2006	2039	2034	99.75 %
2007	3266	3261	99.85 %
2008	4760	4758	99.96 %
2009	4870	4862	99.84 %
2010	4827	4823	99.92 %
2011	4800	4791	99.81 %
2012	1348	1348	100 %
Total	**35018**(*)	**34936**(*)	**99.77 %**

(*) *few orbits are split in two separate products.*

Access to MIPAS products can be provided through ESA Fast Registration.

5.1. Dataset characterisation

Please find below a list of known reprocessing features, which might affect the quality of the data.

- **Improved L1b v7.11 dataset**

The Level 2 v7.03 dataset has been processed by making use of the latest available Level 1b dataset v7.11 [18]. The following improvements were introduced in the L1b products:

- a more sensitive spike detection algorithm, reducing oscillations in the affected spectra;
- pointing improvement, taking into account the instrument alignment matrix and the elevation mirror non-linearity;
- new offset validation method to better reject corrupted offset calibration data;
- a better radiometric accuracy by an improved in-flight characterisation of detector non-linearity (important for trend estimation from MIPAS L2 products).

  This modification was implemented by changing the radiance level of the non-linear bands A, AB and B as a function of time. The impact of this correction is a small positive trend in radiances (below 2%) over the 10 year mission. The radiance level difference with respect to the previous versions is more pronounced at the beginning of the mission during the Full Resolution mode of MIPAS. This issue is reflected in the Level 2 v7.03 dataset, resulting in a colder Temperature in the Full Resolution mission. Furthermore, a drift in L2 products time-series along the Optimized Resolution mission has been introduced, that should correct for the instrumental drift present in previous versions. Details in section 6.2.

- **ECMWF auxiliary files availability**

The computation of the corrected altitudes for MIPAS Level 2 products requires the availability of ECMWF analysis files (AUX_ECA_AX). However the ECMWF dataset is not complete for years 2002-2012; thus ~6% of the MIPAS Level 2 v7.03 products have been reprocessed without this information and hence the ECMWF corrected altitude is missing. Details are reported in section 6.1.

- **Non-nominal Level 0 input files**

The Level 2 v7.03 dataset has been processed starting from the MIPAS Level 0 consolidated dataset, covering a time window between the 1st of July 2002 and the 8th of April 2012 (end of the mission).
In a few cases the Level 0 products have non-nominal duration:

- products shorter than 30 seconds but not adjacent to any instrument unavailability;
- pairs of products belonging to the same absolute orbit but not overlapping in time – the duration of each file is shorter than expected (i.e. no duplications);
- products belonging to adjacent orbits but wrongly cut (i.e. not at the satellite ascending node crossing);
- products longer than 7000 seconds, covering more than one orbit.

In addition products with a wrong absolute orbit assignment have been identified.
The corresponding Level 1b v7.11 and Level 2 v7.03 products are affected; however besides the product duration inconsistencies, the science content of the products is of nominal quality.
The list of all non-nominal Level 0 products is reported in section A.1.

- **Data quality degradation operational events**

The most significant quality degradation in the products have the following causes:

- Decontaminations: along the mission, ice accumulated on the MIPAS optics causing a loss of signal at the detector. For this reason regular instrument decontaminations (cooler switch-off) were executed in order to remove the ice contamination. During decontamination periods, MIPAS was not in measurement mode; after decontamination periods the noise error was reduced but the temperature was not yet stable (see point below). As a consequence the products are of slightly reduced quality and data shall be used with caution.
- Temperature stabilization: after planned or unplanned instrument switch-offs, the detector temperatures needed some time to reach operational thresholds and stabilise. During those time intervals the MIPAS measurements might be of a degraded quality. The list of events is reported at: https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/mission-highlights
- Platform pointing anomalies: the instrument pointing accuracy might be reduced during ENVISAT pointing anomalies, or when platform attitude modes different from the Stellar Yaw Steering Mode (SYSM) were operated (e.g. Yaw Steering Mode [YSM] or Fine Pointing Mode [FPM]). The list of affected mission intervals is provided in section A.2.

6. Overview of the retrieved species

Full details of the verification and validation of MIPAS L2 v7.03 (hereafter called simply V7) retrieved species are provided in reports [12], [13] and [14]. In this document the main results of the verification and validation are summarised.

6.1. Altitude

Three different altitude scales are provided within the MIPAS Level 2 products:

- the instrument engineering altitudes, taken from the input Level 1b product;
- the MIPAS corrected altitudes, which are reconstructed using MIPAS pT retrieval and the hydrostatic equation;
- the ECMWF corrected altitudes, computed from a co-located ECMWF anchor-point and the MIPAS retrieved pT levels.

The validation of the altitude scales provided in the MIPAS Level 2 products V7 with respect to co-located radiosonde data has been performed by BIRA-IASB [12]. This analysis covers the vertical range from surface to around 10 hPa (~31 km), so no quality assessment was done in the upper half of the vertical profile.

Users are strongly recommended to use the ECMWF corrected altitude scale, when available in the product.

- **ECMWF corrected altitudes scale**

No difference in data quality is found between the ECMWF corrected altitudes scale provided for the Full Resolution mission and the Optimized Resolution mission. The bias in the MIPAS-sonde comparisons is generally less than 100m (<200m around 10hPa and 30S-90S) and the spread is generally less than 100m. There are no clear patterns in the comparison time series: the amplitude of the annual cycle is typically less than 50m (and at most 100m), and the overall stability is better than 50m/decade (at most 100m/decade). The dependence on latitude of previous quality indicators is rather weak. See 3-month smoothed time series below.

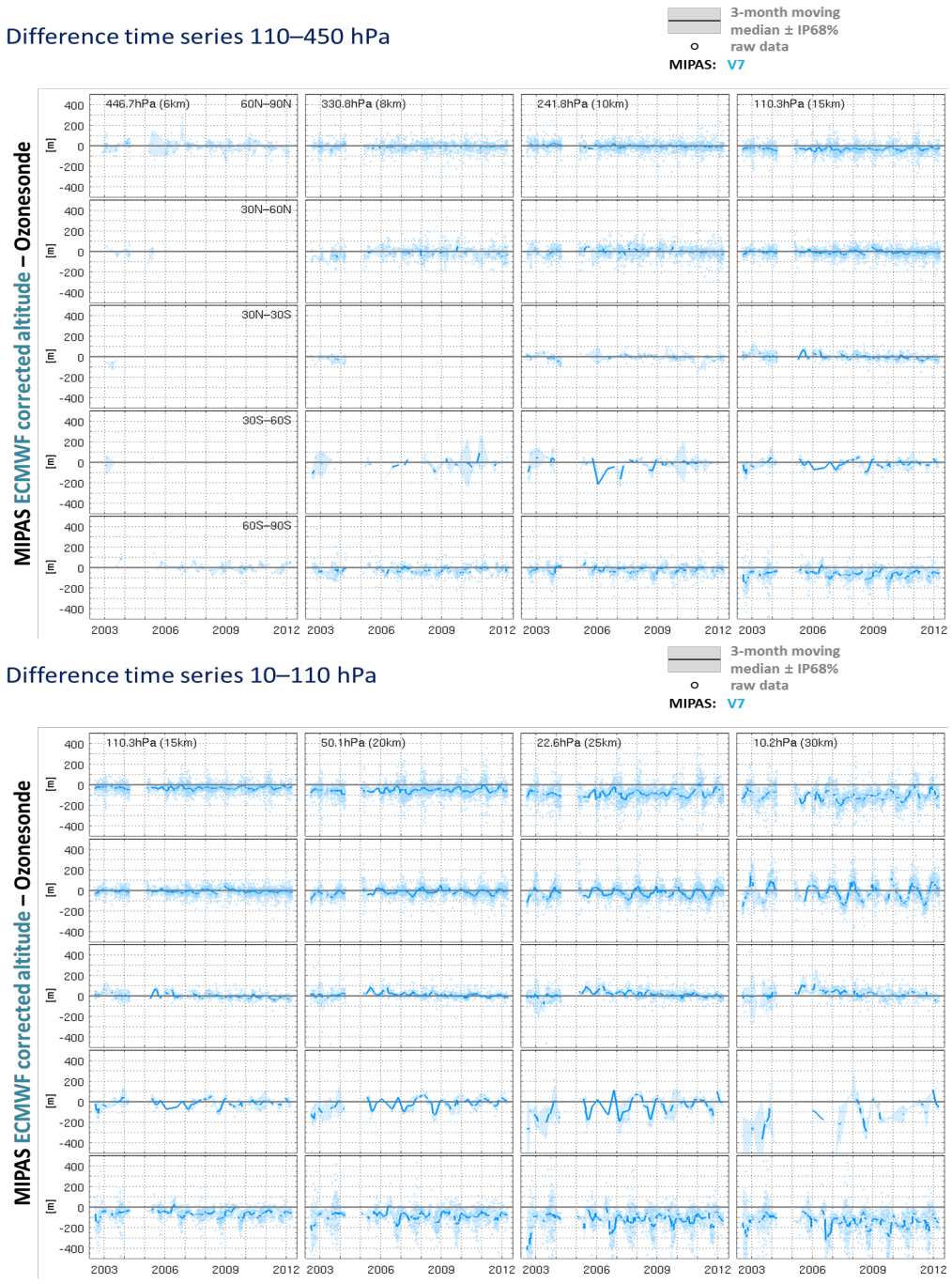


Figure 1

- **MIPAS corrected altitudes scale**

The MIPAS corrected altitudes scale shows a general negative bias during both Full Resolution and Optimized Resolution part of the mission. The V7 products are less biased than previous reprocessed versions V5 and V6 during the FR period, but not for the OR period. There is a negative drift for all

versions, sometimes more pronounced for V7 than for the previous versions V5 and V6; a very clear annual cycle is also evident. The agreement with correlative measurements degrades at higher latitudes. See 3-month smoothed time series below.

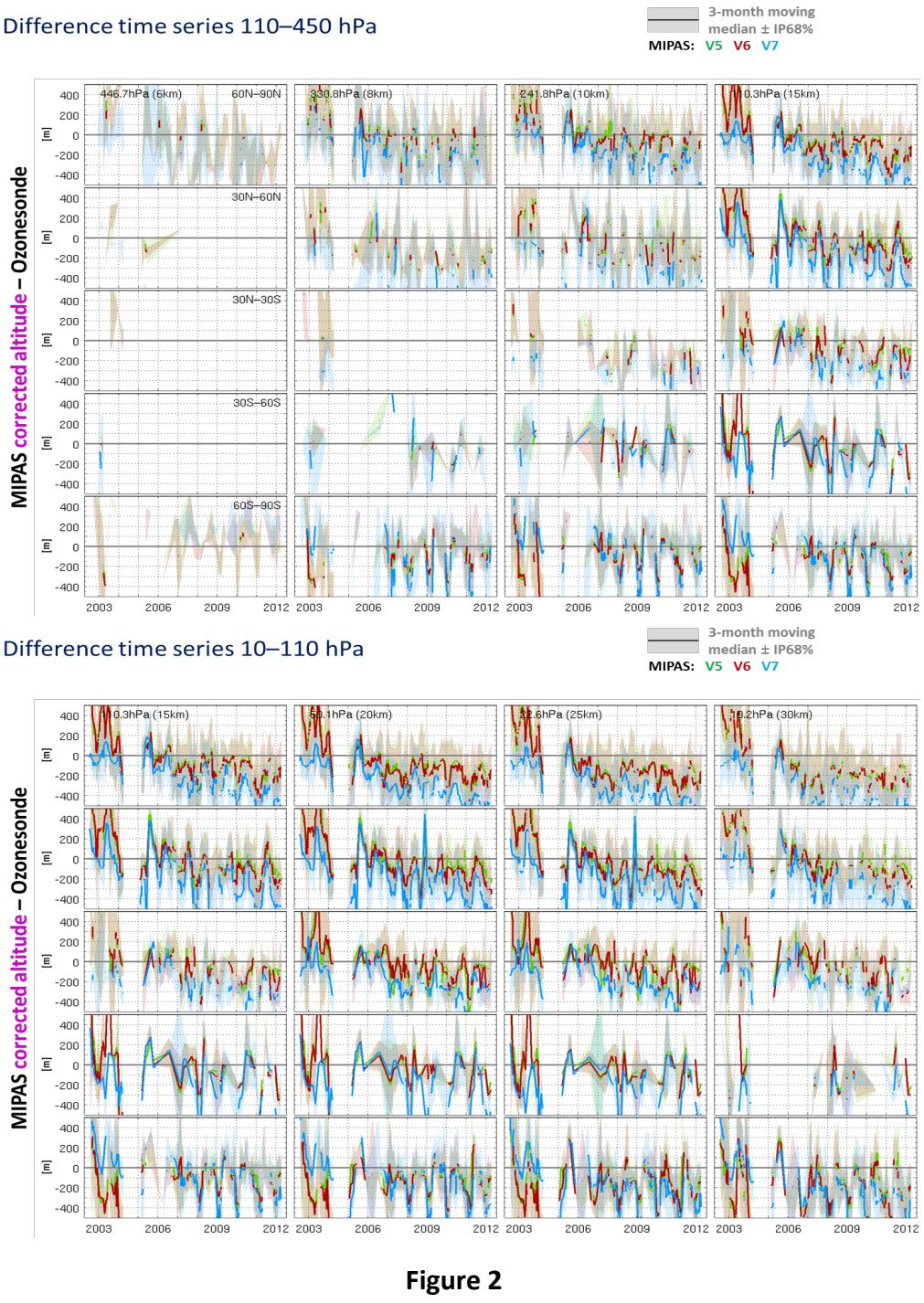


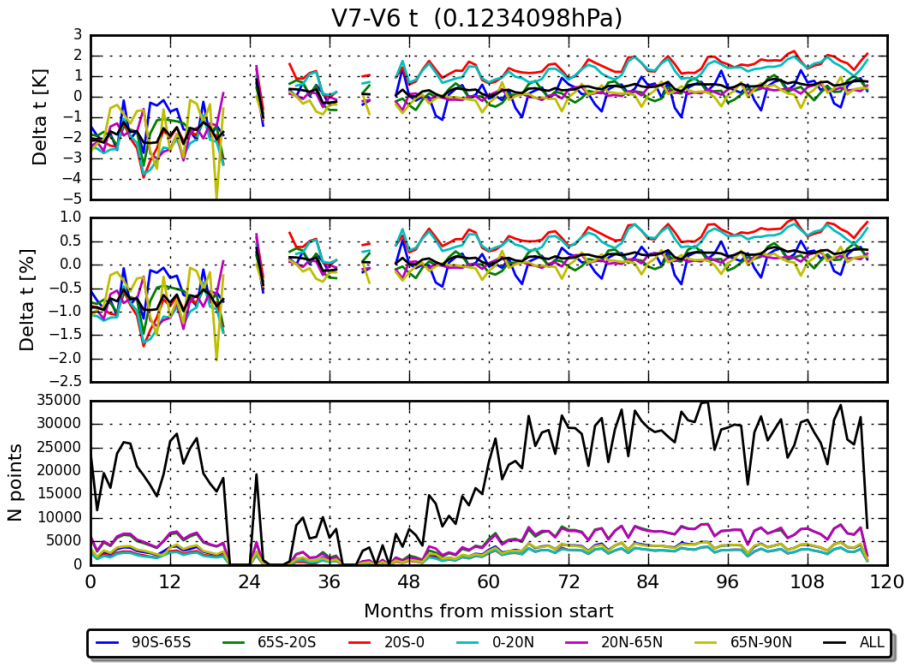
Figure 2

6.2. Temperature (T)

Validation reports:	[12], [13]
Comparison with V6:	[14]
Operational modes:	all
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_pt.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

In Figure 3 the results of the comparison of L2 V7 temperature with respect to previous L2 V6 at different pressure levels are shown (see [14] for reference). The FR V7 temperature is clearly colder than V6 data, by (0.5-1.5 K); smaller differences between V6 and V7 are found for OR temperature data.

Differences in the FR temperatures are mainly due to the new Non-Linearity correction scheme applied to the L1b v7.11 radiances (section 5.1).



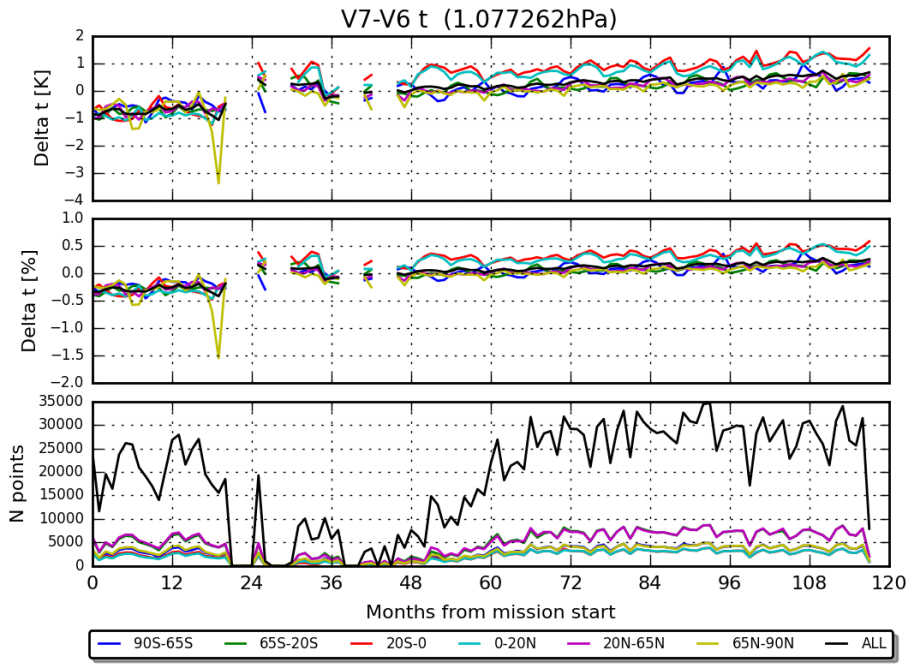


Figure 3

The validation of the temperature product (Figure 4) with respect to co-located ground-based measurements by lidar (dashed) and radiosonde (solid) confirms previous analysis: MIPAS V7 differs clearly from the V5 and V6 data in the Full Resolution mission. The new V7 temperature data is generally colder, which leads to a larger negative bias (up to ~1.5 K at high latitudes) with respect to ground-based instruments. A comparison between the L2 V7 Temperature profiles of MIPAS instrument on-board ENVISAT with respect to the MIPAS instrument on-board balloons [13] confirms that in the FR mission a negative bias is found between 20 and 30 km of altitude (Figure 6).
In the Optimized Resolution mission, the three datasets are more consistent, all show a cold bias at all latitudes. In the Tropics the validation with MIPAS balloon measurements [13] indicates a positive bias below 15 km.

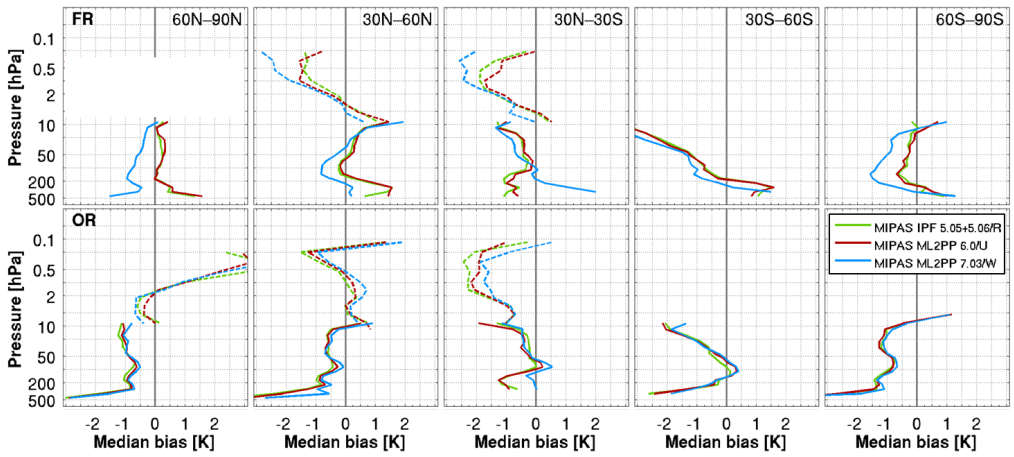


Figure 4

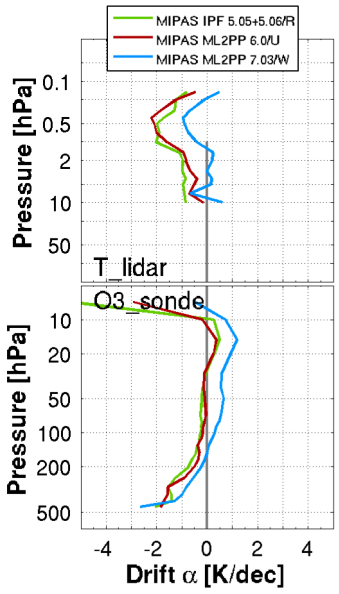


Figure 5

In addition a clear positive drift of ~0.5-1.5 K/decade is seen in the time series of the differences between V7 and V6 datasets. This change results in an improved agreement with sonde and lidar time series for pressure >100hPa and <10hPa. However, in the lower stratosphere, the V7 data drift to too warm temperature relative to radiosonde, while this was not an issue for earlier MIPAS processors [12]. The drift relative to ground-based data is only computed for the OR period.

A comparison between the L2 V7 Temperature profiles of MIPAS instrument on-board ENVISAT with respect to the MIPAS instrument on-board balloons [13] confirms that in the FR mission a negative bias is found between 20 and

30 km; in the OR mission a clear positive bias in the lowermost stratosphere and around the tropopause is instead visible. The mean difference is within ±2 K.

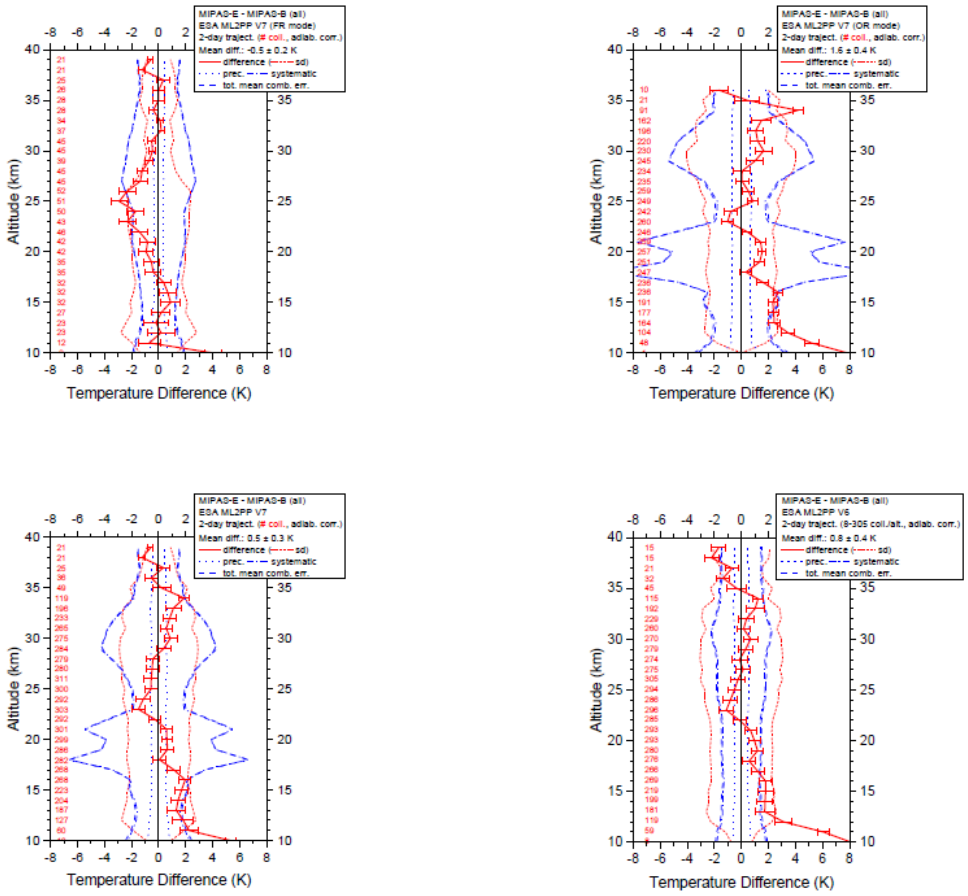


Figure 6

In summary, V7 Temperature during the FR mission period is affected by a negative bias not present in previous data versions. Users are recommended to use Level 2 V6 FR Temperature. The V7 measurements during the OR mission period are similar to those obtained with previous data set versions, except for the long-term behaviour.

For OR measurements a negative bias emerges from the ground-based validation [12], especially at high latitudes, while the MIPAS-B (MIPAS on-board balloon) validation [13] indicate a positive bias below 15 km. This inconsistency of the validation results may be due to the fact that the bias is latitude dependent.
Furthermore the V7 Temperature time series is characterized by a drift that

seems to correct the negative drift present in V6 Temperature in the middle and upper stratosphere, while the correction seems to be too large in the lower stratosphere.

6.3. Water Vapor (H_2O)

Validation reports:	[13]
Comparison with V6:	[14]
Operational modes:	all
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_h2o.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

The H_2O product of V7 in the FR mission period is about 5-10% larger than V6 respectively around 1-10 hPa. The cause of this can be attributed to both the new MWs used for the analysis of the V7 FR measurements and to the correction in the radiance due to the non-linearity correction. Very small differences between V7 and V6 are found for H_2O measurements of the OR mission period.

The comparison of V7 H_2O profiles with MIPAS balloon measurements indicates, for FR measurements, a positive bias up to 20% in MIPAS-ENVISAT H_2O profiles in the middle and upper stratosphere, however the differences stay within the predicted error budget. The bias is about 5% larger in the V7 data compared to V6 data.

For the OR mission, differences with respect to balloon measurements are very small (well within 5%) in the altitude range 17-23 km, a bit larger above, but always within the predicted error budget, while in the lowermost stratosphere and upper troposphere L2 V7 significantly overestimates H_2O and exceeds the combined systematic error bars.

A negative drift (about -0.3%/year at 1 hPa and -0.13%/year at 10 hPa) is visible in the time series of the differences between V7 and V6 H_2O measurements, that corrects for the instrument drift present in V6 measurements.

6.4. Ozone (O_3)

Validation reports:	[12], [13]
Comparison with V6:	[14]
Operational modes:	all
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_o3.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

Version 7.03 overestimates ozone relative to co-located ozonesonde and lidar measurements, with a magnitude that depends mildly on latitude and pressure. The positive bias is about 5% in the middle and upper stratosphere, and 10-15% in the lower stratosphere. The FR and OR data differ by about 5% with a sign that depends on pressure. This discrepancy should not be neglected when trend studies are performed on the entire MIPAS data record. No significant evidence was found of a seasonal cycle of the bias, nor of a long-term drift of the bias during the OR phase. The latter is less than 1-2% per decade and likely has a positive sign (i.e. larger increase in V7 ozone when compared to correlative data). See plots below.

The new V7 data set is overall very consistent with the V6 data. A few minor differences were noted. For instance, the bias of FR data in the UTLS region changed by 5-10%. V7 ozone is 1-2% larger than V6 during the OR mission phase, which leads to a larger positive bias. The OR data should also result in 1-2% per decade more positive trends in the middle and upper stratosphere. Earlier versions exhibited a small negative drift at these altitudes, the new data set has a small positive drift of equal magnitude.

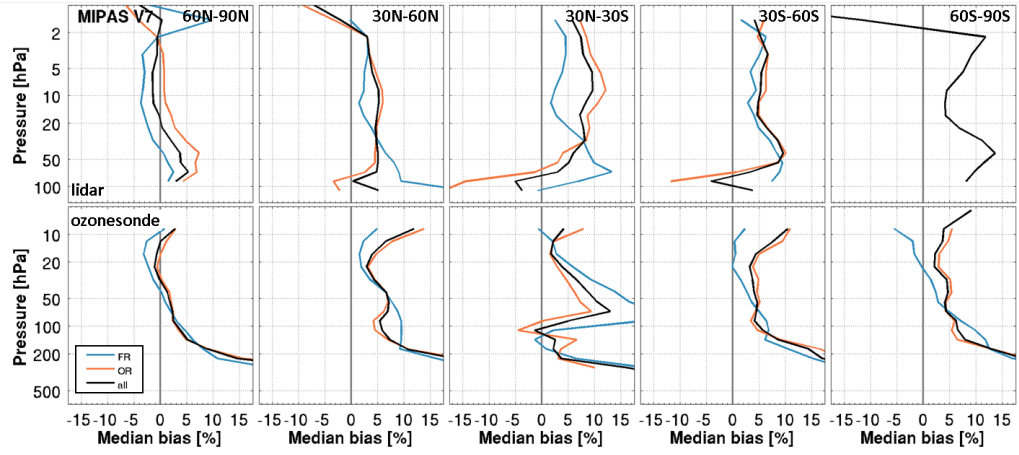


Figure 7

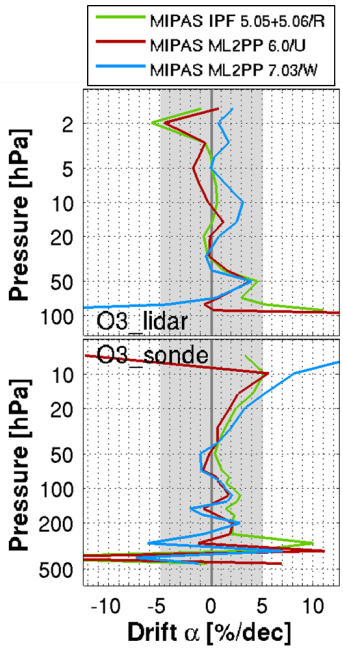


Figure 8

6.5. Nitric Acid (HNO_3)

Validation reports:	[12], [13]
Comparison with V6:	[14]
Operational modes:	FR-NOM, OR-NOM, UTLS-1, MA
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_hno3.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

Differences between V7 and V6 are small. In the OR mode, MIPAS-E (MIPAS on-board ENVISAT) data tend to be systematically higher (5-10%) than MIPAS-B (MIPAS on-board balloon) data, but differences remain within the combined uncertainty with the exception of the region around the VMR maximum. These results are consistent with results reported by Wang et al. [19] and for comparisons with FTIR reference data [12]. The latter however show large relative biases and spreads at all stations from the Arctic to the Tropics: Above 25 to 35 km, the bias is strongly positive (up to 25 %), decreasing below to a minimum of the order of -20 % at roughly 22 km

altitude in the Arctic or higher towards the equator. From this minimum towards the ground, the bias again increases to the same high values as for the stratosphere. Although these bias statistics are usually significant, the corresponding spreads range between as low as 5 and as high as 40 %, typically decreasing towards increasing height from the surface, yet reaching a minimum around the altitude of the most negative bias [12].
Note that these validation results with ground-based FTIR measurements are not always consistent with the MIPAS balloon validation. One has to consider that the FTIR measurements have roughly only one degree of freedom within the 12-30 km altitude range, so that it is difficult for them to capture the shape of the profile and comparison results have to be interpreted with caution.
HNO3 profiles show significant seasonal bias dependences, with more negative bias values in local winter times around the FTIR bias minimum (around 22 km). Towards higher altitudes, seasonal differences typically become smaller, while they grow and often invert towards the ground. No significant drifts can be observed.

6.6. Methane (CH_4)

Validation reports:	[12], [13]
Comparison with V6:	[14]
Operational modes:	all
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_ch4.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

The V7 CH_4 dataset presents some differences with respect to the V6 dataset. In particular in the FR mission around 100 hPa CH_4 values are 5-10% smaller than the corresponding values in V6, while at higher altitudes for both FR and OR measurements V7 CH_4 is about 3-5% larger than V6, the correction being variable with altitude. The increase is however mostly covered by the product's random uncertainty of 2 to 5 %.
An improved agreement of L2 V7 data compared to V6 data is recognized when comparing with MIPAS-Balloon measurements at low altitudes for FR measurements. Especially the pronounced bias in the lowermost stratosphere and upper troposphere visible in V6 data for FR measurements (identified in Payan et al., 2009 [15] and in Engel et al., 2016 [16]), has been reduced thanks to the new microwindows used for the analysis of the FR

measurements. At higher altitudes the value of V7 CH_4 increases and the agreement with correlative measurements slightly reduces. In general both the validation with MIPAS balloon measurements and the validation with FTIR measurements highlight a positive bias around 5% in V7 CH_4 profiles, with a small vertical dependence of the bias. No seasonal dependence of the bias has been detected.

The assimilation of CH_4 measurements (both V6 and V7) with BASCOE data ([17]) and the comparison with ACE has highlighted that MIPAS profiles are of good quality. However, this study has also allowed to diagnose some issues:

- Time series of MIPAS profiles show unexpected discontinuities, occurring once or twice a year. These have been proven to be due to discontinuities in the radiometric gain of band B that may be as high as 2% generally occurring after decontamination periods. Abrupt discontinuities in the gain that are not properly handled by the weekly updated calibration files affect the retrieval of the species whose spectral lines are in band B. A list of periods for which discontinuities in the gain of band B have been detected is provided in Table 5. It is recommended to filter out the CH_4 (and N_2O) profiles measured in the listed periods.

Table 5

Year	Start date	Stop date
2002	30 July	12 August
	06 September	12 September
	25 September	15 October
	14 November	26 November
2003	24 February	03 March
	30 March	15 April
	28 August	13 September
	29 November	12 December
2004	08 February	15 February
2005	07 February	11 February
	22 May	03 June
2006	27 March	21 April
	30 August	19 September
	23 November	08 December
2007	27 May	06 June
	11 July	23 July
	23 September	03 October

	16 October	28 October
	01 December	08 December
2008	07 May	22 May
	29 September	19 October
2009	23 October	11 November
	29 November	14 December
2010	04 May	19 May
	14 July	21 July
	11 October	20 October
	20 October	28 October
2011	07 April	14 April
	17 May	25 May
	08 September	21 September
	19 October	27 October

- The second issue that has been detected in [17] is the presence of occasional outlier profiles in the tropical lower stratosphere, probably due to the presence of un-flagged clouds. The recommendation is to use CH_4 V6 and V7 profiles in the tropical lower stratosphere with caution.

6.7. Nitrous Oxide (N_2O)

Validation reports:	[12], [13]
Comparison with V6:	[14]
Operational modes:	all
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_n2o.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

For N_2O very similar statements as for CH_4 are valid concerning the quality assessment.
V7 N_2O dataset presents some differences with respect to V6 dataset, in particular for the FR measurements around 100 hPa and 1 hPa N_2O values are smaller than the corresponding values in V6, while for OR measurements V7 N2O is about 3-5% larger than V6 at 10 and 100 hPa. The correction is variable with altitude, but mostly covered by the product's random

uncertainty of 2 to 5 %.
Differences in V7 seem to go in the direction of compensating the negative bias detected at low altitudes (around 100 hPa) in OR V6 N_2O and the positive bias detected at the same altitudes in FR V6 N_2O by the validation of V6 measurements with BONBON measurements [15], but the correction in V7 is generally smaller than the bias of V6. However, a reduction of the positive bias at low altitudes for FR measurements is highlighted by the validation with MIPAS balloon measurements. At higher altitudes a positive bias (5-10%, variable with altitude) characterises N_2O V7 profiles above 100 hPa.
No seasonal dependence of the bias has been detected. Though, As well as for CH4 profiles, in the time series of N_2O some discontinuities have been detected. Please refer to Table 5 for filtering out N_2O profiles in the reported periods.
Furthermore, occasionally outlier profiles in the tropical lower stratosphere are detected, due to the presence of un-flagged clouds. The recommendation is to use N_2O V6 and V7 profiles in the tropical lower stratosphere with caution.

6.8. Nitrogen Dioxide (NO_2)

Validation reports:	[13]
Comparison with V6:	[14]
Operational modes:	all
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_no2.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

Very small differences with respect to V6 are present in V7 NO2 profiles.
The statistical trajectory match analysis indicates a bias of L2 V7 NO2 data in comparison to MIPAS-Balloon instrument, which is becoming increasingly significant from lower to higher altitudes.

6.9. Trichloro(fluoro)methane (CFC-11)

Validation reports:	[13]
Comparison with V6:	[14]
Operational modes:	FR-NOM, OR-NOM, UTLS-1, MA
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_f11.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

V7 CFC-11 corrects for the positive bias which was present in the V6 dataset thanks to the handling of the $COCl_2$ interference that was not taken into account in previous reprocessing. V7 CFC-11 is about 10 to 20% smaller than V6 CFC-11.

An improved agreement of L2 V7 data compared to V6 data is also recognized by the comparison with MIPAS-Balloon instrument, where the agreement is well within 5% at least up to 20 km (Figure 9). V7 CFC-11 is of scientifically useful data quality at least below 25 km. Above 20 km for FR measurements and above 25 km for OR measurements the agreement with respect to MIPAS-Balloon instrument degrades up to 20%.

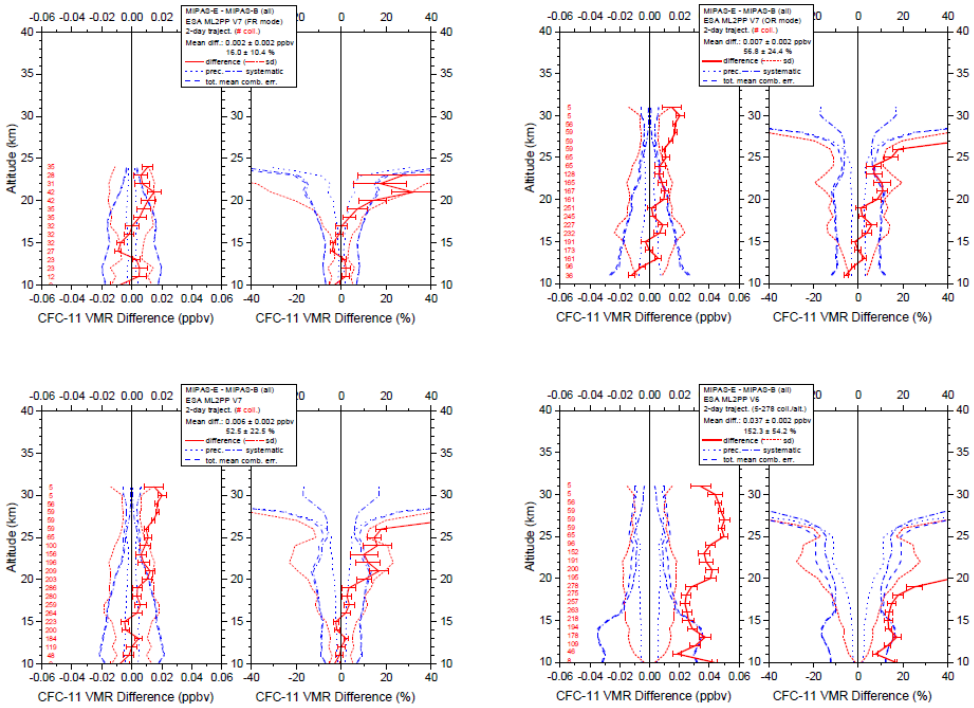


Figure 9

6.10. Chlorine Nitrate ($ClONO_2$)

Validation reports:	[13]
Comparison with V6:	[14]
Operational modes:	FR-NOM, OR-NOM, UTLS-1, MA
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_clono2.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

Differences between MIPAS-ENVISAT V6 and V7 data are small, but the V7 $ClONO_2$ products are characterized by a significant χ^2 reduction with respect to V6 dataset, indicating a better simulation of the observations. The comparison with MIPAS-Balloon measurements shows that both datasets are consistent in the altitude region where ClONO2 concentrations are most relevant. Only at the upper altitude edge of the comparison (around 35-40 km) the mean differences exceed the combined systematic errors, especially for FR measurements.

6.11. Dinitrogen Pentoxide (N_2O_5)

Validation reports:	[13]
Comparison with V6:	[14]
Operational modes:	FR-NOM, OR-NOM, UTLS-1, MA
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_n2o5.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

Differences between V6 and V7 datasets are small, with slightly lower N_2O_5 values around VMR maximum.
The agreement between MIPAS-ENVISAT and MIPAS-Balloon measurements is well within the combined errors between about 20 and 34 km; below about 20 km and above 34 km mean differences exceed the systematic errors suggesting a careful use of the V7 N_2O_5 data for scientific studies in these altitude regions.

6.12. Dichloro(difluoro)methane (CFC-12)

Validation reports:	[13]
Comparison with V6:	[14]
Operational modes:	FR-NOM, OR-NOM, UTLS-1, MA
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_f12.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

An improved agreement of L2 V7 data compared to V6 data is recognized from the comparison with MIPAS-Balloon measurements. Differences are well within 5% in the altitude range 6-30 km, with the only exception of the range between 20 and 25 km, where the (MIPAS-ENVISAT)-(MIPAS-Balloon) differences show a positive “bump” whose maximum is between 10 and 20%, worst for FR case (Fig. 7).
The CFC-12 mean differences between V7 and MIPAS-Balloon remain within the combined errors.

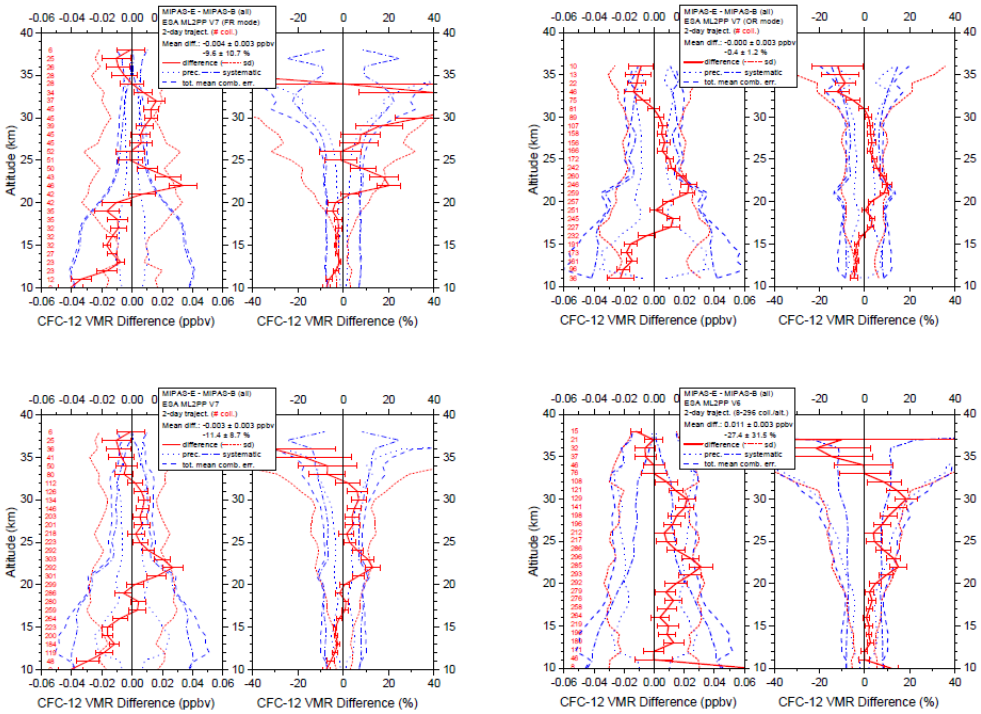


Figure 10

6.13. Carbonyl Fluoride (COF_2)

Validation reports:	[13]
Comparison with V6:	new product
Operational modes:	FR-NOM, OR-NOM, UTLS-1
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_cof2.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

This is a new species of V7 dataset.
The general profile shape (as measured by MIPAS-Balloon) is reproduced by MIPAS-ENVISAT. VMR differences stay within 20% and no unexplained biases (in terms of combined error bars) are evident.

6.14. Carbon Tetrachloride (CCl_4)

Validation reports:	[13]
Comparison with V6:	new product
Operational modes:	FR-NOM, OR-NOM, UTLS-1
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_ccl4.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

This is a new species of V7 dataset.
Comparison with MIPAS-Balloon instrument shows that L2 V7 CCl_4 values are well within 10% below 25 km, while above about 25 km there is evidence of a positive bias that cannot be explained by the systematic error limits.

6.15. Hydrogen Cyanide (HCN)

Validation reports:	[13]
Comparison with V6:	new product
Operational modes:	FR-NOM, OR-NOM, UTLS-1
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_hcn.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

This is a new species of V7 dataset.
From the comparison with MIPAS-Balloon measurements a clear positive bias is visible in the MIPAS-ENVISAT profiles in the FR period exceeding the combined systematic error limits above about 15 km. Deviations between the two instruments are still significant but smaller in the OR phase and remain within the combined error budget.

6.16. Tetrafluoromethane (CFC-14 or CF4)

Validation reports:	[13]
Comparison with V6:	new product
Operational modes:	FR-NOM, OR-NOM, UTLS-1
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_f14.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

This is a new species of V7 dataset.
A general agreement between L2 V7 data and MIPAS-Balloon instrument in the upper and lower stratosphere can be stated. However, some unrealistic large CFC-14 values are visible in the middle stratosphere (around 26 km, especially FR mode) and in the tropopause region. CF_4 profiles have to be used with caution.

6.17. Chloro(difluoro)methane (HCFC-22)

Validation reports:	[13]
Comparison with V6:	new product
Operational modes:	FR-NOM, OR-NOM, UTLS-1
Vertical range & resolution:	https://earth.esa.int/web/sppa/mission-performance/esa-missions/envisat/mipas/sensor-modes
Microwindows:	http://eodg.atm.ox.ac.uk/MIPAS/mw/mw_f22.html
Systematic errors:	http://eodg.atm.ox.ac.uk/MIPAS/err/

This is a new species of V7 dataset.
In the FR period differences between MIPAS-ENVISAT and MIPAS-Balloon instruments remain within 10% for all altitudes. In the OR observation period this holds for altitudes below 28 km. Above this altitude, a significant negative bias is visible in the MIPAS-ENVISAT data.

Annexes

A.1. Non-nominal Level 0 input files

Wrong orbit numbering:

Year	Orbit	Product
2008	35153	MIP_NL__0PPLRA20081119_205614_000060772074_00028_35152_0133.N1

Split products' orbits:

Year	Orbit	Product
2003	5824	MIP_NL__0PPLRA20030411_223424_000012582015_00259_05824_0959.N1
		MIP_NL__0PPLRA20030411_225007_000051102015_00259_05824_0473.N1
	6730	MIP_NL__0PPLRA20030614_053754_000016462017_00163_06730_2285.N1
		MIP_NL__0POLRA20030614_060437_000043912017_00163_06730_1337.N1
	6826	MIP_NL__0PPLRA20030620_223410_000012972017_00259_06826_0067.N1
		MIP_NL__0POLRA20030620_225557_000047372017_00259_06826_0309.N1
2005	15150	MIP_NL__0PPLRA20050122_105825_000000352034_00066_15150_0868.N1
		MIP_NL__0PPLRA20050122_105900_000060792034_00066_15150_0870.N1
	19057	MIP_NL__0PPLRA20051022_093757_000000352041_00466_19057_0713.N1
		MIP_NL__0PPLRA20051022_093832_000000152041_00466_19057_0714.N1

Non-nominal duration products:

Year	Orbit	Product
2002	2665	MIP_NL__0PPLRA20020903_060239_000076632009_00106_02665_1232.N1
	2666	MIP_NL__0PPLRA20020903_081025_000044022009_00107_02666_1228.N1
2005	19559	MIP_NL__0PPLRA20051126_112221_000073842042_00467_19559_0899.N1
	19566	MIP_NL__0PPLRA20051126_230632_000074352042_00474_19566_0902.N1
2006	20416	MIP_NL__0PPLRA20060125_081522_000075472044_00322_20416_0358.N1
2007	28027	MIP_NL__0PPLRA20070711_011253_000094962059_00418_28027_1792.N1
	28933	MIP_NL__0PPLRA20070912_081157_000000092061_00322_28933_7398.N1
2010	46136	MIP_NL__0PPLRA20101226_215921_000053443097_00001_46136_3531.N1
	46137	MIP_NL__0PPLRA20101226_232727_000067533098_00002_46137_3553.N1

2011	47718	MIP_NL__0PPLRA20110416_004833_000000273101_00290_47718_3559.N1
	48051	MIP_NL__0PPLRA20110509_050649_000036563102_00192_48051_4262.N1

Orbit duplication:

Year	Orbit	Product
2005	18206	MIP_NL__0PPLRA20050823_224021_000058222040_00115_18205_0458.N1
		MIP_NL__0PPLRA20050823_224914_000060342040_00116_18206_0460.N1

A.2. Platform pointing anomalies

Mission interval		Affected orbits	Anomaly
9 Dec 2003 10:00:00	12 Dec 2003 17:48:32	9280 - 9328	Platform attitude test
21 Jun 2004 07:56:33	22 Jun 2004 11:50:18	12070 - 12087	Platform attitude anomaly
13 Mar 2008 03:16:37	13 Mar 2008 19:28:44	31553 - 31559	Platform attitude anomaly
15 Feb 2009 03:38:34	16 Feb 2009 13:09:00	36402 - 36422	Platform attitude anomaly
5 Mar 2009 19:18:01	6 Mar 2009 15:10:02	36664 - 36681	Platform attitude anomaly
11 Jan 2010 11:34:56	11 Jan 2010 19:05:37	41130 - 41135	Platform attitude anomaly
26 May 2010 12:12:12	26 May 2010 16:26:04	43063 - 43066	Platform attitude anomaly
22 Oct 2010 04.20.01	02 Nov 2010 10.25.02	45191 - 45353	Orbit lowering manoeuvres

Acronyms

ADC	Analogue to Digital Converter
ADF	Auxiliary Data File
ADS	Annotation Data Set
AK	Averaging Kernels
ATBD	Algorithm Theoretical Baseline Document
BEAT	Basic ENVISAT Atmospheric Toolbox
BIRA-IASB	Royal Belgian Institute for Space Aeronomy
CBB	Calibration Blackbody

CFI	Customer Furnished Items
CODA	Common Data Access Toolbox
CTI	Configuration Table Interface
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DS	Deep Space
DSI	Data Service Initiative
ECMWF	European Centre for Medium-Range Weather Forecasts
ESA	European Space Agency
FPM	Fine Pointing Mode
FR	Full Resolution
FTIR	Fourier Transform InfraRed spectrometer
ID	Identifier
IDEAS	Instrument Data quality Evaluation and Analysis Service
IDU	Interferometer Drive Unit
ILS	Instrument Line Shape
IODD	Input / Output Data Definition
IPF	Instrument Processor Facility
IVS	Iterative variable strength
KIT	Karlsruhe Institute of Technology
L0	Level 0
L1b	Level 1b
L2	Level 2
LOS	Line Of Sight
LTE	Local Thermodynamic Equilibrium
MA	Middle Atmosphere
MDS	Measurements Data Set
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MIPAS-B	MIPAS instrument (KIT) mounted on balloons
MPH	Main Product Header
MW	Microwindow
NESR	Noise Equivalent Spectral Radiance
NOM	Nominal
OM	Occupation Matrix
OR	Optimized Resolution
p	Atmospheric Pressure
PCD	Product Confidence Data
QWG	Quality Working Group
RR	Reduced Resolution
SPPA	Sensor Performance, Products and Algorithm
SYSM	Stellar Yaw Steering Mode
T	Atmospheric Kinetic Temperature

	UA Upper Atmosphere UTLS Upper Troposphere Lower Stratosphere V5 Version 5 MIPAS Level 2 V6 Version 6 MIPAS Level 2 V7 Version 7 MIPAS Level 2 VMR Volume Mixing Ratio YSM Yaw Steering Mode ZPD Zero Path Difference
Reference Documents	[1] M. Ridolfi and L. Sgheri, "Technical Note: Iterative variable strength (IVS) regularization for MIPAS retrievals", issue 0.999, 25 July 2011. [2] M. Ridolfi and L. Sgheri, "Technical Note: New retrieval variables for the continuum profile", issue draft, 06 July 2012. [3] M. Ridolfi, B. Carli, M. Carlotti, T. von Clarmann, B. M. Dinelli, A. Dudhia, J. M. Flaud, M. Höpfner, P. E. Morris, P. Raspollini, G. Stiller, and R. J. Wells, "Optimized forward model and retrieval scheme for MIPAS near-real-time data processing", Appl. Opt. 39(8), 1323–1340 (2000). [4] P. Raspollini, C. Belotti, A. Burgess, B. Carli, M. Carlotti, S. Ceccherini, B. M. Dinelli, A. Dudhia, J. M. Flaud, B. Funke, M. Hopfner, M. Lopez-Puertas, V. Payne, C. Piccolo, J. J. Remedios, M. Ridolfi, and R. Spang, "MIPAS level 2 operational analysis", Atmos. Chem. Phys. 6(12), 5605–5630 (2006). [5] P. Raspollini, B. Carli, M. Carlotti, S. Ceccherini, A. Dehn, B. M. Dinelli, A. Dudhia, J.-M. Flaud, M. López-Puertas, F. Niro, J. J. Remedios, M. Ridolfi, H. Sembhi, L. Sgheri, and T. von Clarmann, "Ten years of MIPAS measurements with ESA Level 2 processor V6 – Part 1: Retrieval algorithm and diagnostics of the products", Atmos. Meas. Tech.6, 2419-2439 (2013). [6] M. Ridolfi and L Sgheri, "On the choice of retrieval variables in the inversion of remotely sensed atmospheric measurements", Opt. Express 21, 11465-11474 (2013). [7] A. Doicu, T. Trautmann, F. Schreier, "Numerical regularization for atmospheric inverse problems", Springer, 2010. [8] S. Ceccherini, "Analytical determination of the regularization parameter in the retrieval of atmospheric vertical profiles", Opt. Lett. 30, 2554–2556 (2005). [9] M. Ridolfi and L. Sgheri, "Iterative approach to self-adapting and altitude-dependent regularization for atmospheric profile retrievals", Opt. Express 19, 26696-26709 (2011). [10] S. Ceccherini and M. Ridolfi, "Technical Note: Variance-covariance

matrix and averaging kernels for the Levenberg-Marquardt solution of the retrieval of atmospheric vertical profiles", Atmos. Chem. Phys. 10, 3131-3139 (2010).

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