VALIDATION OF MIPAS-ENVISAT BY CORRELATIVE MEASUREMENTS OF MIPAS-STR


(1) Forschungszentrum Karlsruhe GmbH, Institut für Meteorologie und Klimaforschung, Postfach 3640, 76021 Karlsruhe, Germany, Email: corneli.keim@imk.fzk.de
(2) Alfred-Wegener-Institut für Polar- und Meeresforschung, Forschungsstelle Potsdam, Telegrafenberg A43, 14473 Potsdam, Germany, Email: gathen@awi-potsdam.de
(3) Central Aerological Observatory, Dolgoprudny, Moscow region, Email: alexey@cao.mipt.ru
(4) Institute of Atmospheric and Oceanic Sciences, Bologna, Italy, Email: f.ravegnani@isac.cnr.it
(5) DLR Oberpfaffenhofen, Institut für Physik der Atmosphäre, 82234 Wessling, Germany, Email: hans.schlager@dlr.de
(6) JWG-Universität Frankfurt, Institut für Meteorologie und Geophysik, Fach 194, Georg Voigt Strasse 14, 60325 Frankfurt am Main, Germany, Email: M.Volk@meteor.uni-frankfurt.de

ABSTRACT

We report on the validation of profiles from the MIPAS-Envisat on-line processor of ESA version 4.61 with correlative measurements derived from MIPAS-STR onboard the high-altitude aircraft M55-Geophysica. The validation is made for the July 22, 2002, orbit 2051 in the region of the campaign base in Forlì, Italy [1] and for several orbits in February / March 2003 around Kiruna, northern Sweden.

This paper includes a careful comparison of the MIPAS-STR data with O3 sondes and with in-situ measurements from the Geophysica obtained during ascent, descent and occasional dives. To obtain accurate N2O and CH4 profiles close to the MIPAS-Envisat tangent points we used the MIPAS-STR measurements of CFC-11 and CFC-12 and correlations [2] obtained by the HAGAR instrument.

1 THE MIPAS-STR INSTRUMENT

MIPAS-STR (MIPAS-STRatospheric aircraft) is a cryogenic Fourier transform emission sounder operating in the middle infrared. The emission method allows limb and upward viewing, yielding about 2 km vertical resolution below the Geophysica flight level (up to 20 km) and mainly column data above. Reduced vertical information above the flight level is obtained by upward measurements with several elevation angles. The final results are 2-dimensional distributions of the trace gases along the flight track in an altitude range covering the lowest stratosphere and the upper troposphere. The first deployment of MIPAS-STR was made during the Antarctic campaign APE-GAIA in 1999 [3]. The performance of the instrument has been considerably improved in recent years.

The pointing of the limb measurements was made at fixed tangent heights between 6.0 km and the flight altitude with a spacing of 1.25 km. Considering the instrumental field of view of 0.44 degrees (FWHM) oversampling by a factor 2-3 was applied at the lower tangent heights. In addition upward measurements at elevation angles of 0, 1, and 3 degrees, as well as 10 degree deep space, cold and hot blackbody measurements were performed. Two-sided interferograms were obtained with a maximum optical path difference L of 14.4 cm, resulting in a spectral resolution (1/2L) of 0.035 cm^-1. For a flight altitude of 18 km the complete sequence, including calibration, takes some 160 seconds. This results in a horizontal resolution in flight direction of about 30 km.

The data shown in this paper are obtained from channel 1 which covers the wavenumber range of 770 - 970 cm^-1. In channel 1 spectral features of CO2 (used for temperature retrieval), O3, HNO3, CFCs and several other trace constituents are present.

2 LEVEL-1 PROCESSING

Level-1 processing of the MIPAS-STR data provides the input data for the profile retrieval described in the next section. Basically, it converts raw interferograms of the atmospheric measurements stored during the flight into radiometrically calibrated atmospheric spectra (in radiance units) for each tangent height or elevation angle. The spectral gain and offset of the instrument were obtained from the deep space and cold blackbody measurements of each individual sequence. The deep space spectra were corrected for the contained atmospheric features. About 50 individual gain and offset spectra were analysed per flight to obtain average values and their linear variation with time. Level-1 processing also provides the necessary auxiliary data which are derived from the stored housekeeping information and from the line of sight calibration and the field of view measurements made before and after the flights. The auxiliary data include information on the corrected flight altitudes, elevation- and azimuth angles, and relevant instrument parameters.

3 DATA RETRIEVAL SCHEME

The atmospheric radiative transfer model KOPRA (Karlsruhe Optimised and Precise Radiative transfer Algorithm) [4] and its inversion algorithm KOPRAFIT were used. In the inversion procedure the Tikhonov-
Philips regularisation method [5,6] was adopted:

\[ x_{i+1} = x_i + \left( K_S^T S_y^{-1} K_x + \gamma^2 L^T L \right)^{-1} \left[ K_S^T S_y^{-1} (y - f(x_i)) + \gamma^2 L^T (x_i - x) \right] \]

(1)

where \( i \) denotes the iteration index; \( x \) the vector with the unknowns; \( x_a \) the a-priori values; \( y \) the measurement vector; \( S_y \) the measurement covariance matrix of \( y; f \) the forward model; \( K \) the spectral derivatives matrix; \( \gamma \) the regularisation parameter and \( L \) the first derivative regularisation operator. Regularisation is necessary for each retrieved atmospheric parameter because (i) the chosen retrieval grid (0.5 km) is much finer than the tangent altitude spacing and (ii) at lower tangent altitudes spacing was smaller than the instrumental field-of-view. The regularisation strength has been made as small as possible and was adjusted just to avoid oscillations in the results. We can judge whether its value is suitable by viewing the vertical resolution determined as FWHM of the columns of the averaging kernel matrix.

4 DESCRIPTION OF THE FLIGHTS

All validation flights are performed with the goal of an excellent coincidence in time (<1 h) and space (<200 km) between MIPAS-STR and MIPAS-Envisat [8]. The following Fig. 1 to Fig. 5 show the flight track of the individual flights together with the location of the tangent points of MIPAS-STR and MIPAS-Envisat (version 4.61). The tangent points are colour coded depending on the tangent height (dark blue for 6 km, red for 20 km).

4.1 22 July 2002

Fig. 1 shows the flight track of the 22.7.2002 flight. For validation, two sets of profiles are selected (indicated as ‘north’ and ‘south’ in the figures of section 6). ‘North’ is the mean of all profiles measured from the northern leg between 9:06 and 9:27 UTC. ‘South’ is the mean of all profiles measured from the southern leg between 7:28 and 7:59 UTC.

4.2 28 February 2003

Fig. 2 shows the flight track of the 28.2.2003 flight. For validation, three profiles of MIPAS-Envisat are selected and compared with the mean of the six nearest MIPAS-STR profiles.

4.3 2 March 2003

Fig. 3 shows the flight track of the 2.3.2003 flight. For validation, three profiles of MIPAS-Envisat are selected. Each is compared with the mean of six collocated MIPAS-STR profiles. The location of the two northern profiles is covered twice by the MIPAS-STR profiles. In the southern part of the flight, a dive was performed, so that this MIPAS-Envisat profile is exactly collocated with the profiles obtained by the in-situ instruments aboard the Geophysica.

4.4 8 March 2003

Fig. 4 shows the flight track of the 8.3.2003 flight. Unfortunately, no Envisat profiles are collocated. But this flight is very useful to investigate the quality of the
MIPAS-STR profiles because in the northernmost part a dive was performed, and an ozone sonde was launched from the 'R(esearch)V(essel) Polarstern' nearby the dive.

4.5 12 March 2003
Fig. 5 shows the flight track of the 12.3.2003 flight. For validation, four profiles of MIPAS-Envisat are selected and compared with the mean of the six nearest MIPAS-STR profiles. This flight was performed without dive, but two ozone sondes were launched near the northern part, one from Ny-Ålesund and one from the 'RV Polarstern'.

5 QUALITY OF THE MIPAS-STR DATA
5.1 Estimated error budget
Two dominating error sources exist in the retrieval chain. One is connected to the use of HITRAN spectral line data for the radiative transfer calculation in the forward model. The error is estimated to be below 10%. The second error stems from the retrieved temperatures used to obtain the trace gases. A temperature error of 2 K results in an upper limit vmr error for HNO$_3$ and O$_3$ of < 10% and for CH$_4$ and N$_2$O of < 5%.
Effects such as NLTE, uncertainties in the pointing of the instrument, horizontal atmospheric inhomogeneity along the line of sight, or - for CH$_4$ and N$_2$O - the error of the used correlation can cause further errors, which were considered of minor importance.

As the error sources are independent they sum up to:
- total error for HNO$_3$ and O$_3$: < 14%
- total error for CH$_4$ and N$_2$O: < 11%.

5.2 Comparison with in-situ instruments
To check the measurements of MIPAS-STR, we compare with two sets of in-situ data:
- Aboard the Geophysica several in-situ instruments are flown. During ascent and descent profiles are measured which are compared to the limb measurements of MIPAS-STR. Some of the flights are performed with dives (descent down to 10 km followed by an ascent back to flight-level), and additional in-situ profiles are gained.
- For ozone, also profiles observed by sondes launched from Ny-Ålesund and from the ‘RV Polarstern’ are compared to the limb measurements of MIPAS-STR.
To illustrate the agreement of the MIPAS-STR and in-situ profiles, we selected typical examples from the 8.3.2003 and 12.3.2003 flights.

Fig. 6 shows profiles of CFC-11 and CFC-12 of the 8.3.2003 flight. The in-situ instrument HAGAR [8,9] obtained the profiles during the dive (upper figure) and during ascent and descent (lower figure). The compared profiles of MIPAS-STR are averages over two profiles each just before and after the dive as well as after ascent and before descent. In both cases, the MIPAS-STR profiles are east- and west-viewing, the distance between the lowest tangent points is about 500 km.
Considering the observed variability in the atmosphere, the retrieved profiles of CFC-11 and CFC-12 agree with the HAGAR measurements within the estimated errors.

Fig. 7 and Fig. 8 show profiles of O$_3$ of the 8.3.2003 flight. The in-situ instruments FOX [10] and FOZAN [9] obtained the profiles during the dive (Fig. 7) and during ascent and descent (Fig. 8), the compared profiles of MIPAS-STR are averages over two profiles each just before and after the dive, after ascent and before descent. The profile of an ozone sonde launched nearby the dive (see Fig. 4) is also shown in Fig. 7.

During ascent (left panel of Fig. 8) the two in-situ ozone instruments aboard the Geophysica, FOX and FOZAN,
agree very well. The profiles obtained in the dive (Fig. 7) show a discrepancy between FOX and FOZAN, while the sonde and FOX agree very well. Unfortunately FOX stopped working after the dive.

Fig. 9 shows profiles of O₃ of the 12.3.2003 flight. The two plots compare the MIPAS-STR profiles with the two ozone sondes launched nearby (see Fig. 5).

The comparisons shows the "smoothing" of the MIPAS-STR data due to the vertical resolution of 2-3 km. Taking in account the different vertical resolutions, the ozone values of MIPAS-STR agree (within the estimated errors) with the sondes and with FOX, and, except for the dive, also with FOZAN.
6 COMPARISON OF MIPAS-STR AND MIPAS-ENVISAT PROFILES

MIPAS-Envisat Level-2 data version 4.61 is used for comparison. The figures below (Fig. 10 to Fig. 26) show the MIPAS-Envisat profiles together with an average over collocated (mostly six) profiles of MIPAS-STR. The profiles of methane and nitrous oxide are calculated from retrieved CFC-11 and CFC-12 profiles using correlations measured by HAGAR. For the 22.7.2002 flight only the correlations of CFC-11 with N2O and CH4 are used. They stem from flights in Forlí in October 2002. For the Kiruna 2003 campaign, the correlations are obtained during the same arctic campaign.

The validation for the 22.7.2002 flight was already presented for MIPAS-Envisat Level-2 data version 4.55 in Frascati 2002 [1].

Generally the MIPAS-Envisat profiles are expected to be so good as they can be validated one by one. It should not be necessary to make averages.

6.1 Temperature

Fig. 10 shows the MIPAS-STR temperature profiles together with two nearby MIPAS-Envisat profiles. Also the ECMWF-analysis interpolated exactly at the time and the location of the MIPAS-Envisat tangent points is shown. Above 150 hPa MIPAS-STR temperatures in the south are maximally 3 K lower compared to the northern measurements. Below 150 hPa the profiles are similar since there the tangent point geolocations are overlapping (see Fig. 1). MIPAS-Envisat profiles of temperature show significant deviations from the MIPAS-STR results as well as from the ECMWF profiles.

6.2 Ozone (O3)

O3 profiles of the 22.7.2002 flight are shown in Fig. 11. MIPAS-STR profiles from the south and the north are very similar. The complete MIPAS-Envisat profile of scan 13 agrees very well with MIPAS-STR while of scan 12 only the measurement at 260 hPa is close

Fig. 12 to Fig. 14 show O3 profiles for the flights of 28.2., 2.3. and 12.3.2003. Each panel compares one Envisat profile. In the top left panel of Fig. 12 the Envisat profiles of the next orbit on the same latitude is added, because of the strange shape of the profile. The two top panels of Fig. 13 show each two profiles of MIPAS-STR, the east- and the west-viewing one, compared with one Envisat profile.

Most of the Envisat profiles (10 out of 12) correspond well with the MIPAS-STR profiles. The exceptions give the impression, that the quality can still be improved.
For the MIPAS-STR retrieval we initially used the same spectroscopic database as the version 4.55 ESA processor. We repeated the retrieval with new spectroscopic data similar to version 4.61. The reprocessed profiles are indicated 'new' in the legends. With some exceptions, the Envisat profiles of HNO$_3$ do not agree with the MIPAS-STR profiles. The values measured by MIPAS-Envisat are higher than those measured by MIPAS-STR, even when the same spectroscopic database is used. A remaining difference in the retrieval of MIPAS-Envisat and MIPAS-STR is the treatment of the 'continuum', which is currently under investigation.

Fig. 16 to Fig. 18 show HNO$_3$ profiles for the flights of 28.2., 2.3. and 12.3.2003. The figures are organised similar to those of ozone.

For the MIPAS-STR retrieval we initially used the same spectroscopic database as the version 4.55 ESA processor. We repeated the retrieval with new spectroscopic data similar to version 4.61. The reprocessed profiles are indicated 'new' in the legends. With some exceptions, the Envisat profiles of HNO$_3$ do not agree with the MIPAS-STR profiles. The values measured by MIPAS-Envisat are higher than those measured by MIPAS-STR, even when the same spectroscopic database is used. A remaining difference in the retrieval of MIPAS-Envisat and MIPAS-STR is the treatment of the 'continuum', which is currently under investigation.

Fig. 16 to Fig. 18 show HNO$_3$ profiles for the flights of 28.2., 2.3. and 12.3.2003. The figures are organised similar to those of ozone.

For the MIPAS-STR retrieval we initially used the same spectroscopic database as the version 4.55 ESA processor. We repeated the retrieval with new spectroscopic data similar to version 4.61. The reprocessed profiles are indicated 'new' in the legends. With some exceptions, the Envisat profiles of HNO$_3$ do not agree with the MIPAS-STR profiles. The values measured by MIPAS-Envisat are higher than those measured by MIPAS-STR, even when the same spectroscopic database is used. A remaining difference in the retrieval of MIPAS-Envisat and MIPAS-STR is the treatment of the 'continuum', which is currently under investigation.
6.4 Methane (CH₄)

CH₄ profiles of the 22.7.2002 flight are shown in Fig. 19. MIPAS-STR profiles from the south and the north are very similar. The old ESA data version 4.55 were zigzagging around the MIPAS-STR values. The new data for orbit 2051 are still poor, e. g. the values for 180 hPa are unrealistically high.

Fig. 20 to Fig. 22 show CH₄ profiles for the flights of 28.2., 2.3. and 12.3.2003. The figures are organised similar to those of ozone.

For CH₄ some of the Envisat profiles correspond well with the MIPAS-STR profiles but others are far away and unrealistic.
6.5 Nitrous Oxide (N_2O)

N_2O profiles of the 22.7.2002 flight are shown in Fig. 23. MIPAS-STR profiles from the south and the north are very similar. Except for the unrealistically high values at 180 hPa, the MIPAS-Envisat profiles of scans 12 and 13 agree very well with MIPAS-STR. This is in contrast to CH_4 (Fig. 19), which is retrieved from the same channel. The two MIPAS-Envisat N_2O profiles of scan 12 and scan 13 behave similar. This is in contrast to O_3 (Fig. 11) and HNO_3 (Fig. 15), where the complete profiles differ considerably.

Fig. 24 to Fig. 26 show N_2O profiles for the flights of 28.2., 2.3. and 12.3.2003. The figures are organised similar to those of ozone.

Some of the N_2O profiles of MIPAS-Envisat correspond roughly to the MIPAS-STR profiles but the others scatter around the correlative measurements.
7 CONCLUSIONS

The MIPAS-Envisat validation was preceded by a quality check of the MIPAS-STR data.

- The ozone profiles of MIPAS-STR agree well with the compared in-situ profiles.
- The CFC-11 and CFC-12 profiles of MIPAS-STR agree well with the compared in-situ profiles. Therefore CFC-11 and CFC-12 are used to calculate CH₄ and N₂O profiles from in-situ correlations.
- The comparison of HNO₃ to the NOₓ and NO_y in-situ measurements of SIOUX [10] aboard the Geophysica is still in progress but necessary to understand the discrepancy in the HNO₃ profiles of MIPAS-STR and MIPAS-Envisat.

The early 22.7.2002 MIPAS-Envisat measurements of orbit 2051 are still poor in the reprocessed data version 4.61.

- The two scans used for validation behave different for the individual gases. For both, O₃ and HNO₃, one complete profile is in agreement with MIPAS-STR, the other profile has higher values. For N₂O the vmr on a single pressure level is unrealistic, while the rest of the profiles is in agreement. For CH₄ the profiles show strong ‘zigzag’ features comparable to version 4.55.

The arctic validation in spring 2003 showed a better quality of the MIPAS-Envisat profiles.

- O₃: the MIPAS-Envisat profiles generally are in good agreement with MIPAS-STR profiles, but some profiles scatter around the correlative measurements.
- HNO₃: nearly all MIPAS-Envisat profiles have higher values than the MIPAS-STR profiles. This discrepancy is content of the actual MIPAS-STR retrieval investigation. Comparisons with in-situ profiles show encouraging improvements from a new treatment of the continuum.
- CH₄: some of the MIPAS-Envisat profiles are in good agreement with MIPAS-STR, but many profiles show outliers on several pressure levels.
- N₂O: the MIPAS-Envisat profiles strongly scatter around the correlative MIPAS-STR profiles.

8 ACKNOWLEDGEMENT

Financial support for this project by the ESA (contracts 10249/01/NL/SF and 16039/02/NL/SF), the European Union (APE-INFRA: EVR1-CT-2001-40020), the German Federal Ministry of Education and Research (FKZ 01SF9953/8 and 50EE0203) and the Italian Space Agency (CNR/ASI I/R/27/00, I/R/073/01 and I/R/186/02) is gratefully acknowledged. This project is part of the activities of the Geophysica-EEIG.

9 REFERENCES