VALIDATION OF MIPAS-ENVISAT VERSION 4.61 OPERATIONAL DATA WITH BALLOON AND AIRCRAFT MEASUREMENTS: H₂O


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ABSTRACT

Embedded in the ENVISAT validation programme of the chemistry instruments GOMOS, MIPAS, and SCIAMACHY, a number of remote sensing and in situ techniques from balloon and aircraft platforms were employed since the launch of Envisat on March 1, 2002. In this paper we will be focusing on the validation of MIPAS-Envisat (MIPAS-E) off-line products, by presenting the results of the intercomparison between MIPAS-E H₂O vertical profiles as well as aircraft and balloon correlative measurements as obtained within the ESABC programme [1]. First priority is given to the validation of processor v4.61 data. However, to get a more complete picture, individual results of 2002 and 2003 balloon observations are also compared with earlier versions of the MIPAS-E operational processor or with data processed with scientific processors run at expert support laboratories. Some general remarks are finally expressed, along with specific recommendations to fully exploit the available ESABC validation dataset.

Unfortunately, by the date of the ACVE-2 conference, re-analyzed operational MIPAS-E data was almost only available for the year 2002 limiting the number of validation cases with the new operational version 4.61 (v4.61). Based on these few cases, the MIPAS-E H₂O profiles as processed with v4.61 are in good agreement with airborne observations between about 15 and 30 km altitude in all cases with a good coincidence in time and space between the MIPAS-E observations and the correlative measurements. However, due to the very limited number of good validation cases available so far, this statement cannot yet be regarded as conclusive and representative. Low biases in MIPAS-E H₂O compared to the correlative measurements appear frequently in the lowermost stratosphere pointing at a retrieval problem in this crucial altitude region. Retrievals of MIPAS-E H₂O profiles as obtained by different processors appear to be generally rather robust as proven by a statistics of inter-comparisons of H₂O profiles between the operational v4.61 data and data processed with the IMK scientific processor, provided that a considerable number of spurious and unphysical data has been removed from the v4.61 data prior to the statistical assessment. This points at the need for an automatic quality control of the operationally retrieved H₂O data.

Further validation coincidences in different geophysical situations will have to be considered using v4.61 data before a final quantitative assessment on the quality of the MIPAS-E operational H₂O data can be given.

1. INTRODUCTION

The absolute necessity of validating satellite instrument products is obvious from experience with prior space instruments (as, e.g., described in [2]). Increasing complexity of space instruments and enhanced diversity of products provided from instruments like MIPAS on ENVISAT (called MIPAS-E hereafter) demand for even increased efforts in validation. Apart from satellite measurements, balloon-borne observations are a very useful tool to obtain distributions of a large number of molecules with sufficiently high vertical resolution over most of the stratospheric altitude region. However, due to a large logistical effort, the number of these flights is very limited. This holds similarly for aircraft observations, which may cover larger horizontal regions compared to balloons, but are restricted to the lowermost stratosphere. Ground-based measurements can be carried out routinely all over the year but, apart from Lidar observations, the vertical resolution is generally very low.
This paper outlines the current status of the ESABC validation activities of MIPAS operational data concerning the molecule H$_2$O, i.e. based on balloon-borne and aircraft-based observations, as reported during the ACVE-2 meeting in Frascati (Italy) from 3-7 May 2004. Validation reports for H$_2$O based on ground-based measurements and satellite-satellite comparisons are given elsewhere in this issue. The comparisons were preferably made to the most recent ESA operational v4.61 data of MIPAS. However, unfortunately almost no v4.61 data for the year 2003 were available by the time of the ACVE-2 meeting. Therefore, some comparisons to older version 4.5x data or comparisons to non-operational data as retrieved in expert support laboratories have also been considered in this evaluation.

2. AIRCRAFT OBSERVATIONS

A considerable number of aircraft missions with the Geophysica and Falcon aircraft was devoted to Envisat validation. Unfortunately, due to unavailability of v4.61 data of MIPAS-Envisat, only small subsets of aircraft data gained during campaigns based in Forli/Italy in October 2002 could be used for validation so far. Comparisons have been provided from the H$_2$O Differential Absorption Lidar (DIAL) [3] operated on the Falcon and the in situ Ly-$_\alpha$ hygrometer FISH operated on the Geophysica [4]. Figure 1 illustrates the flight tracks chosen in relation to MIPAS-E footprints in order to allow good coincidences with the MIPAS-E measurements as well as consistency checks of different instrument techniques deployed on the Falcon and the Geophysica, respectively.

![Fig. 1](image1.png)

Fig. 1. Flight tracks of the Falcon and Geophysica aircraft along with three scans of MIPAS-E over Italy on October 24, 2002, illustrating the procedures of flight planning implemented to allow best possible coincidences between the different types of observation.

![Fig. 2](image2.png)

Fig. 2 displays an inter-comparison between a FISH profile recorded during a Geophysica ascent and a collocated DIAL measurement obtained on board the Falcon aircraft on 24 October 2002, proving that the two measurements agree among each other within about +/- 0.5 ppmv.

![Fig. 3](image3.png)

Fig. 3 shows comparisons between the H$_2$O DIAL sensor and MIPAS-E for five coincidence events at mid-latitudes in October 2002. All coincidences were almost perfect in time (< 2 hrs) and space (< 50 km). The lowest two to three data points of MIPAS-E H$_2$O can be compared to the in-situ measurement. It appears that the v4.61 data are slightly improved as compared to the v4.53 data. In three of the five cases there is a low bias in the lowermost MIPAS-E H$_2$O data compared to the correlative observation. More cases have to be compared with v4.61 processed data for all coincidence events and the different vertical resolutions of the two measurement techniques need to be taken into account to obtain a statistically more quantitative evaluation.
3. BALLOON-BORNE OBSERVATIONS

A remarkable number of balloon-borne observations of H$_2$O have been obtained since the launch of Envisat. This list includes remote sensing sensors such as the FIRS-2 instrument [5] and MIPAS-B [6] - the balloon-borne version of MIPAS, as well as in-situ instruments such as the Tuneable Diode Laser (TDL) spectrometer CHILD [7], the frost point hygrometer ELHYSA [8], France and the Ly-α hygrometer FISH [4].

Unfortunately, only two cases of direct comparison of MIPAS-E H$_2$O measurements as processed with the latest processor version 4.61 to coincident balloon-borne measurements have been available by the time of the ACVE-2 conference: On 24 September 2002 a mid-latitude flight was carried out with MIPAS-B. For this flight a perfect coincidence in terms of time and location between MIPAS-E and MIPAS-B could be achieved for two MIPAS-E scans of orbit #2975 (Figure 4).

The comparison of the H$_2$O profiles for this coincidence reveals a perfect agreement between MIPAS-B and MIPAS-E in the 15 to 26 km region (about 120 to 20 hPa) when looking at the latest v4.61 data. V4.61 data appear improved vs. v4.55 data. In the upper part of the profile MIPAS-E tends to overestimate H$_2$O compared to MIPAS-B. Above about 25 km (~ 20 hPa) the H$_2$O profile of MIPAS-E starts to oscillate with amplitudes larger than the associated error bars.

Fig. 3. Comparison of a suite of aircraft Lidar measurements obtained in Oct. 2002 by the H$_2$O-DIAL sensor (blue solid lines) onboard the Falcon with collocated MIPAS-E observations based on v4.55 (green) and v4.61 (red). The uncertainties of the DIAL H$_2$O measurements are: < 10% up to 15.5 km, < 20% up to 16.3 km, and < 40% up to 17.0 km.

Fig. 4. Colour-coded plot of potential vorticity (PV) at the 675 K isentropic level above Spain and France, overlaid with MIPAS-E orbit #2975, scan records 3, 4, and 5 (red bars) and collocated MIPAS-B scans (black bars). In addition, one of the adjacent GOMOS occultations is shown. The scan record 4 of MIPAS-E is completely matched by the north looking MIPAS-B scan.

Fig. 5. Direct comparison of MIPAS-Envisat and MIPAS-Balloon H$_2$O at mid-latitude along with absolute differences and combined error bars (1 $\sigma$).
Another direct comparison to MIPAS-E v4.61 data with an excellent coincidence (distance < 200 km, time offset < 1 hr) has been possible for a balloon flight carried out with the in-situ frost point hygrometer ELHYSA at high latitudes, but outside of the polar vortex, in March 2004 (Fig. 6). The agreement between the two measurements can be rated as excellent, at least between 15 and 27 km. Another flight of ELHYSA was carried out inside the polar vortex on January 16, 2003, again with very good coincidence in space and time. However, for this validation event, v4.61 data have not yet been available, unfortunately. The comparison to the v4.55 reveals a good agreement in terms of profile shape but a slight low bias of MIPAS-E in the order of 0.5 ppmv (not shown).

Water vapour measurements at sub-tropical latitudes were performed with the sub-mm Fourier transform spectrometer FIRS-2 over New Mexico in October 2002. Although a good coincidence with one MIPAS overpass could be obtained the corresponding v4.61 data have not yet been available. Instead, H2O profiles from overpasses situated upwind and downwind of the balloon observation have been compared in Fig. 7. For these cases the mismatch was rather large (~ 1000 km, ~8 hrs) and the comparison with the closest overpass is still pending. Anyhow, the shape of the H2O profiles from MIPAS-E and FIRS-2 are quite similar, while MIPAS-E shows a slight low bias of ~ 0.5 ppmv above 20 km. Below 15 km the H2O profiles of MIPAS-E show unphysical large oscillations.

In the stratosphere H2O is produced by oxidation of CH4. Therefore, the quantity [H2O + 2*CH4] is expected to be constant within the stratosphere. This quantity can be used as a test of the robustness of the H2O and CH4 retrievals. Figures 8 and 9 display comparisons of [H2O + 2*CH4] as obtained from MIPAS-E measurements vs. collocated balloon measurements of MIPAS-B (Fig. 8) and of the in-situ sensor CHILD (Fig. 9). The expected value is in the order of 7.3 (+/- 0.5) ppmv [10, 11]. The MIPAS-E data appear within the expected range, at least between about 15 and 30 km. However, at higher altitudes oscillations are increasing and MIPAS-E tends to show a high bias.
Fig. 9. Comparison of total hydrogen ($H_2O + 2*CH_4$) from a CHILD flight in September 2002 (red solid line) at mid-latitudes and two collocated MIPAS-E scans (triangles), along with reference values from literature (blue box, cf. Fig. 8). The time offset between the plotted MIPAS-E values and the CHILD measurements was about 12 hrs since the collocated MIPAS-E overpass data were not yet available. The $2\sigma$ uncertainty of the CHILD total hydrogen is estimated to 0.7 to 1.4 ppmv (increasing from lower to upper altitudes [7]).

Various other validation cases are potentially useful but either MIPAS-E v4.61 data have not yet been available or imperfect coincidences between the Envisat and the correlative measurement demand for some trajectory matching before a quantitative assessment becomes possible. An example of the latter approach is illustrated in Figures 10 and 11. Fig. 10 displays 4-day forward and backward trajectories from locations sampled with FISH on the Geophysica aircraft, taking into account a coincidence limit of < 100 km and < 0.5 hrs. With this approach the number of useful coincidences can be increased by a factor of 4 to 8, and even allows validation from airborne measurements that were not optimised for validation. Fig. 11 presents intermediate results of this study, based on the old retrieval version v4.55, indicating a slight high bias of MIPAS-E vs. FISH. To fully exploit this approach all corresponding MIPAS-E v4.61 data points are to be provided than just in the temporal and spatial vicinity of the aircraft or balloon flights.

4. COMPARISONS TO CLIMATOLOGY AND PROCESSOR INTER-COMPARISONS

Comparison of satellite data to climatology can be a useful method to identify problems in satellite data, although it must not be regarded as geophysical validation. Such an assessment has to be done with care since it can lead to wrong conclusions, when ‘new’ geophysical situations are detected by the
satellite instrument which had not been included in the climatology.

Examples for H₂O are shown in Figure 12. The comparison is to reference atmospheres constructed for the MIPAS project as reported in [12]. The climatological data for water vapour are based on UARS, SAGE II and ECMWF as described in [13]. The upper panel shows a statistics of MIPAS-E H₂O data for the latitude region 20 to 60° S in January 2003 as compared to the climatological mean and the 3-σ standard deviation. It is worth remarking that the max/min limits are well characterised in the stratosphere but are more uncertain for the upper troposphere. The lower panel of Figure 12 represents MIPAS-E data points sampled in July 2003 in the same latitude band as compared to the corresponding winter mid-latitude climatology. While in austral summer (Jan. 2003) the MIPAS-E values are well within the climatological range above 20 km, an extreme scatter is obvious in austral winter (July 2003), reaching values down to 0.1 ppmv and up to 600 ppmv within the stratosphere and mesosphere: those values are definitely outside the climatological min/max values and are completely unphysical. Also, from looking at the mean values of MIPAS-E only, these problems would not have been obvious.

We conclude, that there is a considerable number of unphysical (corrupted) values in the NRT (near-real-time) v4.5x data base that have to be removed. Furthermore, it has to be investigated what has caused such strange values and to what extent this behavior is also seen in the v4.61 off-line data.

Finally, Figure 13 presents a retrieval/processor comparison. Here, differences of mean daily profiles...
over all latitudes between the ESA operational data (version 4.61) and the H\textsubscript{2}O results inferred at IMK with the in-house scientific processor [14, 15] (using the version 4.53 level 1b data) are shown for the period from 18 September to 13 October 2002. Apart from some persistent oscillations which still are not understood the general agreement for most daily means is quite promising. However, some daily means appear corrupted leading to large differences between the operational and the scientific retrievals. Removing the day with most spurious data improves the statistics a lot (lower panel). But still after removal of the most conspicuous day, profiles of three days behave differently, pointing at some remaining spurious data.

5. CONCLUSIONS AND OUTLOOK

In this paper we have reviewed the status of the ESABC MIPAS H\textsubscript{2}O validation, as based on available results from individual balloon and airborne campaigns. Despite the remarkable number of successful flights that offered a wealth of measurements to be compared with co-located MIPAS-E H\textsubscript{2}O VMR profiles, only very limited statistical conclusions can presently be made. This is partly due to a lack of data processed with the latest version 4.61 (almost completely missing for 2003) and partly because aircraft or balloon observations not always show an optimal space and time overlapping with the target MIPAS-E overpasses. Hence, some further analyses supported by suitable modelling (e.g. trajectory-mapping) are required to allow a more conclusive comparison with the satellite data.

In-situ as well as remote techniques using different spectral domains have provided sufficiently independent information for the validation process. For airborne comparisons the quality of coincidence in time and space between the validation measurement and the satellite observation is particularly crucial since only a restricted number of coincidences can be provided.

Table 1 gives an overview on the validation results obtained so far, restricted to v4.61 comparisons. The ‘quality rating’ corresponds to the quality of agreement between the satellite measurement and the correlative observation.

In summary, by combining the available individual validation results described in the previous sections, the following common features and trends in the available intercomparisons have been identified:

- in general, good agreement is found in the altitude range between 15 and 30 km;
- significant low biases are observed in several cases at the lowest one to two altitude points of the MIPAS-E H\textsubscript{2}O profiles (cf. e.g. ELHYSA, FISH, H\textsubscript{2}O-DIAL, MIPAS-B);
- comparisons to climatology and to results retrieved with the IMK scientific processor indicate a considerable amount of spurious, unphysical data in the v4.61 data base. Furthermore, the large unreasonable scatter in austral winter as compared to austral summer (cf. Fig. 12) needs to be understood.

Validation activities need to be continued with the inclusion of further validation cases (especially for the year 2003) to achieve a statistically more reliable

| Table 1. Summary of validation review for H\textsubscript{2}O (only v4.61). |
|-----------------------------|-----------------------------|-----------------------------|
| **Quality rating:** | ++ very good, + good, o fair, ? unclear. |
| **Balloon:** | |
| ELHYSA (i) | March 2003, high latitudes | ++ (2) |
| MIPAS-B (r) | Sep. 2002, mid-latitudes | + (2) |
| **Aircraft:** | |
| H\textsubscript{2}O-DIAL (r) | Oct. 2002, mid-latitudes | o? (3) |
| FISH (i) | Oct. 2002, mid-latitudes | o? (3) |
| **Total hydrogen (H\textsubscript{2}O + 2*CH\textsubscript{4}):** | |
| CHILD (i) | Sept. 2002, mid-latitudes | o? (4) |
| MIPAS-B (r) | Sept. 2002, mid-latitudes | + (5) |
| **Processor inter-comparison:** | |
| ESA v4.61 vs. IMK V1 with v4.53 level 1-b | |

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<th>Comments:</th>
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<tr>
<td>(r) remote sensing technique</td>
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<td>(i) in-situ technique</td>
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<tr>
<td>(1) coincident data missing, low bias in nearest MIPAS-E overpasses.</td>
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<tr>
<td>(2) good agreement between 15 and 30 km, slight high bias in MIPAS-E above 30 km, oscillations increasing with altitude.</td>
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<td>(3) MIPAS-E tends to low bias in tropopause region, whereas for higher altitudes the trajectory match analysis indicates a slight high bias. More comparisons and analyses based on v4.61 needed for conclusive evaluation.</td>
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<tr>
<td>(4) MIPAS-E profiles noisy, but within expected range, CHILD appears to be at the high boundary of the reference values. Needs to be re-analysed with coincident v4.61 data.</td>
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<td>(5) above ~ 30 hPa pressure altitude MIPAS-E profile noisy and tendency of high bias.</td>
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<tr>
<td>(6) consistent within +/- 0.5 ppmv in most daily means, however large scatter in UTLS and mesosphere, indication of spurious data.</td>
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evaluation. Mismatches have to be corrected with the help of forward/backward trajectory matches to increase the number of coincidences. If necessary, different vertical resolutions of the sensors should also be considered during the validation processes as well as error budgets for the calculation of combined errors. Last but not least, some important geophysical situations such as the tropics, have not been covered yet by the validation campaigns.

ACKNOWLEDGMENTS

The study presented here is based on active contributions by a large number of technicians and researchers working together with the authors in their research institutions. Financial support by ESA, EU and national funding agencies is gratefully acknowledged. We thank the CNES balloon launching team and the SSC Esrange people for excellent balloon operations, P. Wursteisen as ESA representative for active support at the campaign sites and the Free University of Berlin (K. Grunow and B. Naujokat) for meteorological support and trajectory calculations. Thanks go also to the Geophysica and Falcon crews for excellent flight operations.

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