VALIDATION OF MIPAS CH_4 PROFILES BY STRATOSPHERIC BALLOON, AIRCRAFT, SATELLITE AND GROUND BASED MEASUREMENTS

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ABSTRACT/RESUME

The ENVISAT validation programme for the atmospheric instruments MIPAS, SCIAMACHY and GOMOS included a number of balloon-borne, aircraft, other satellite and ground-based correlative measurements. In particular the activities of validation scientists were coordinated by ESA within the ENVISAT Stratospheric Aircraft and Balloon Campaign or ESABC. In parallel to the contribution of the individual validation teams, the present paper provides a synthesis of comparisons made between MIPAS CH_4 profiles produced by the current ESA operational software (Instrument Processing Facility version 4.61 i.e. IPF v4.61) or by the IMK-FZK scientific processor and correlative measurements obtained from balloon and aircraft experiments as well as from satellite sensors or from ground-based instruments.

1. INTRODUCTION

As recommended by ESA, validation results presented and discussed during the second Atmospheric Chemistry Validation of ENVISAT (ACVE-2) workshop in May 2004 at ESRIN, Frascati had to be compared with products generated by the latest version of the operational processing software. For the MIPAS CH_4 profiles discussed here, the corresponding products were generated by the Instrument Processor Facility or IPF v4.61, but due to the late release and/or incomplete space/time coverage of the corresponding validation dataset, several correlative measurements had to be compared with non-official products. Fortunately, methane profiles generated by the IMK-FZK scientific processor have been provided to several validation teams for comparing their own correlative measurements with MIPAS derived profiles. This is specially true for 2003 validation campaigns for which the ESA IPF v4.61 products were not yet available by the time of ACVE-2.

The correlative measurements for MIPAS CH_4 profiles considered here (see Table 1) have been obtained by balloon experiments (section 2) and by aircraft experiments (section 3) participating in the ENVISAT Stratospheric Aircraft and Balloon Campaign (ESABC) coordinated by P. Wursteisen [1].

Table 1 : ESABC, satellite and ground based contribution to the validation of MIPAS CH_4 profiles.

	Instrument	Flight date/campaign period		Latitude coverage	MIPAS dataset available for validation
Balloon	MIPAS-B	24 Sept.	2002	Mid latitude	IPF v 4.61
	TRIPLE	24 Sept.	2002	Mid latitude	IPF v 4.61
	SPIRALE	2 Oct.	2002	Mid latitude	IPF v 4.61
		21 Jan.	2003	High latitude	IMK-FZK scientific product
	LPMA	4 March	2003	High latitude	IMK-FZK scientific product
Aircraft	MIPAS-STR	22 July	2002	Mid latitude	IPF v 4.61
Satellite	HALOE	From 22 July to 27 Dec. 2002		Mid and high latitudes	IPF v 4.61
Ground	NDSC FTIR	Fall	2002	High and mid latitudes	IPF v 4.61

Balloon measurements provide high vertical resolution profiles in most of the stratosphere, which are suitable for very detailed comparisons with MIPAS products, but these data have only a limited horizontal sampling. Aircrafts provide observations with a wider geophysical coverage and can be optimised for a tighter space and time coincidence with MIPAS measurements, but in the lower stratosphere only. Even if a very significant effort from the

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validation scientists and balloon or aircraft operation teams has been put into the acquisition of CH_4 profiles in good space and time coincidence with MIPAS, the number of such correlative data is not yet high enough for a fully significant statistical analysis.
An interesting complementary dataset with more global coverage and allowing higher statistics is provided by the satellite observations of HALOE (section 4).
In the same type of approach, ground-based profiles of CH_4 derived by inversion of atmospheric solar absorption spectra recorded using Fourier transform infrared spectroscopy (FTIR) can be used for increasing the statistics of MIPAS comparisons (section 5), but with a much coarser vertical resolution of the ground-based data in the stratosphere (~ 8 km).
Finally, in section 6, with the caveat that the amount of data available for comparisons is still limited, some preliminary conclusions and recommendations are given.

2. BALLOON-BORNE MEASUREMENTS

The balloon experiments for which CH_4 profiles (as well as the corresponding MIPAS data) were available at the time of ACVE-2, include FTIR remote sensing instruments operating in limb thermal emission such as MIPAS-B [2] or in solar occultation such as LPMA [3] as well as *in situ* samplers such as the Bonbon cryosampler [4] and *in situ* diode laser spectrometers such as SPIRALE [5]. They are discussed in sequence, a priority being given to the balloon experiments of the 2002 campaigns for which IPF v4.61 MIPAS CH_4 profiles are available. In the case of the balloon flights of the 2003 campaigns, only IMK-FZK scientific products were available for comparison. In this latter case the IMK products are based on level 1b data version v4.55 for the respective time periods.

2.1 MIPAS-B results

The MIPAS balloon-borne instrument of Institut für Meteorologie und Klimaforschung, Karlsruhe-Forschungzentrum (IMK-FZK), Karlsruhe, Germany called MIPAS-B [2] is covering exactly the same spectral region as MIPAS-E (the ENVISAT instrument) and is operating in the same mode (limb thermal emission). The MIPAS-B flight of 24 Sept. 2002 from Aire-sur-l'Adour (43 N, 0 E) allowed an extremely good space and time coincidence with a night-time MIPAS-E limb scan. In Fig. 1, the vertical mixing ratio profiles of CH_4 and the corresponding errors are plotted as a function of pressure for the two MIPAS versions IPF v4.55 and v4.61 together with the MIPAS-B balloon profile. The "oscillations" observed in v4.55 are significantly reduced in v4.61 (but still present in the lower stratosphere), which confirms that the latter version is indeed the one to consider for comparison. The differences MIPAS-B minus MIPAS-E v4.61 have to be compared with the combined (root sum squares) error and seem to indicate a small positive bias of MIPAS-E in the lower stratosphere. The overall agreement between the two profiles is quite good (maximum relative difference smaller than 17 %).

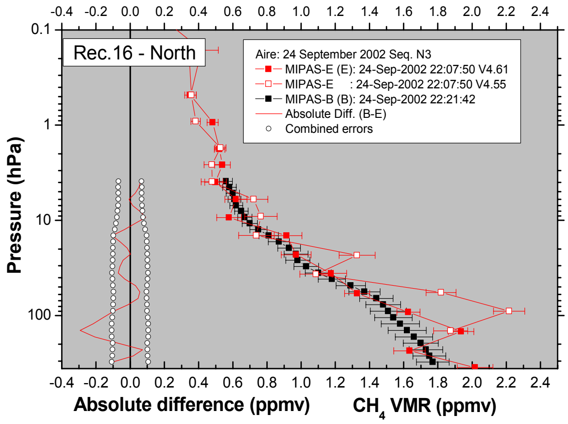

Fig.1. Validation of MIPAS CH_4 v4.55 and v4.61 profiles by MIPAS-B on 24 Sept. 2002 with MIPAS-B minus MIPAS-E v4.61 differences and combined error bars on the left. Note that MIPAS-B error bars show 1-σ accuracy while MIPAS-E errors only take into account spectral noise

2.2. Cryosampler results

The flight of the cryosampler Bonbon [4] of Institut für Meteorologie und Geophysik, J.W. Goethe Universität, Frankfurt, Germany, took place the same day as the MIPAS-B flight on 24 Sept. 2002, also from Aire-sur-l'Adour. The v4.61 MIPAS-E CH_4 mixing ratio profiles from 3 limb scans are plotted as a function of altitude on the left panel of Fig. 2, whereas a larger statistics is achieved by combining five-days forward and backward trajectories "MIPAS-E transported" profiles (shown on the right panel) matching the cryosampler profile. The picture emerging from this comparison is slightly different from the previous comparison in the mid stratosphere, where MIPAS-E results appear to have a negative bias. The overestimation of CH_4 by MIPAS-E in the very low stratosphere seems to be confirmed.

2.3. SPIRALE results

The SPIRALE instrument [5] from Laboratoire de Physique et Chimie de l'Environnement (LPCE, Orléans, France) also took place in the mid latitude fall 2002 ESABC campaign from Aire-sur-l'Adour. Since MIPAS-E was not operating on 2 Oct. 2002 when SPIRALE was launched, the comparison is only possible with backward trajectories starting from MIPAS-E measurements on 26, 27 and 28 Sept. and ending at the SPIRALE location on 2 Oct. SPIRALE being an *in situ* diode laser spectrometer with a fast measurement rate, the correlative mixing ratio profile of Fig. 3 (plotted as a function of potential temperature for consistency with Lagrangian modelling) exhibits a fine structure, which is not captured by the trajectory mapping.

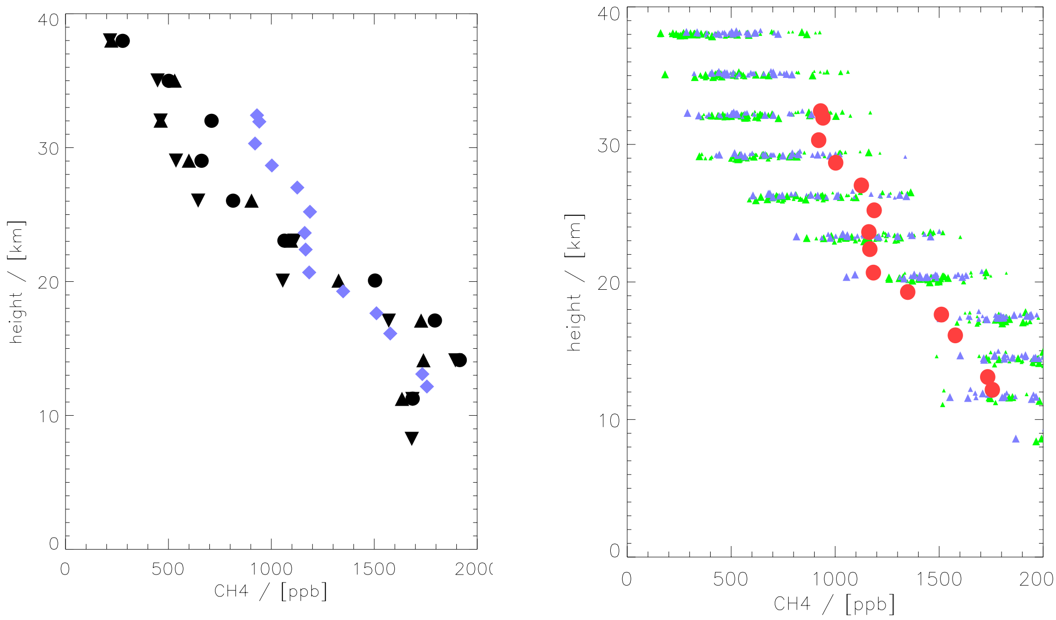

Fig. 2. Validation of MIPAS CH_4 v4.61 profiles by the Bonbon cryosampler on 24 Sept. 2002.
The left panel is a direct comparison with 3 nearest MIPAS profiles for the same day.
The right panel displays 5 days backward and forward trajectory transported profiles for a larger statistics

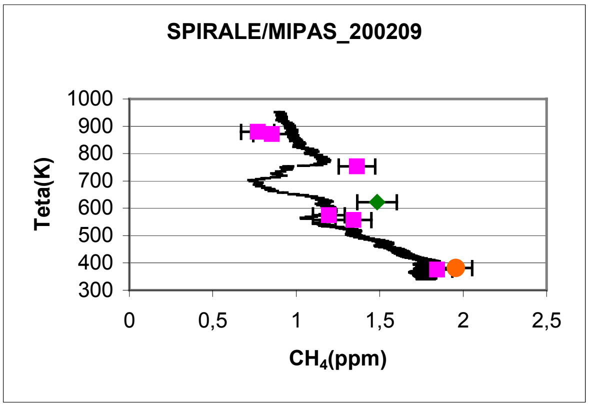

Fig. 3. Validation of MIPAS CH_4 v4.61 profiles by SPIRALE during the fall 2002 ESABC campaign from Aire-sur-l'Adour

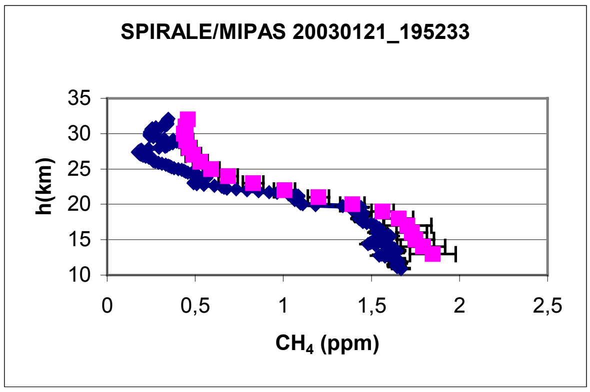

Fig. 4. Validation of the MIPAS CH_4 profile derived with the IMK-FZK scientific processor (purple squares) by the 21 Jan. 2003 flight of SPIRALE (dark blue diamonds) during the winter 2002/2003 ESABC campaign from Esrange

The SPIRALE instrument was also flown during the winter 2002/2003 ESABC campaign from Esrange (Kiruna, Sweden) on 21 Jan. 2003. The MIPAS v4.61 CH_4 profile is not available for that period, but the IMK-FZK scientific processor profile for 21 Jan. 2003 was available and is presented together with the SPIRALE profile as a function of altitude in Fig. 4. The IMK-FZK profile is quite smooth (a difference with IPF profiles due to regularization [6,7]) and is in reasonable agreement with the SPIRALE profile, which is exhibiting much finer scale structure.

2.4. LPMA results

The balloon-borne FTIR instrument of LPMA [3] was operating in solar absorption and in its long wave infrared optical configuration (LWIR) during a flight dedicated to the MIPAS validation on 4 March 2003 from Esrange (Kiruna, Sweden) in the Arctic. The IPF v4.61 data was not available for this date and the IMK-FZK scientific product was used for comparison. As can be seen in Fig. 5 the agreement between the 2 profiles in the altitude range 19-27 km is quite good (within the respective error bars). In the upper part of the profile some differences do exist and may be real due to the approximate geographical co-location in the upper region of the vortex.

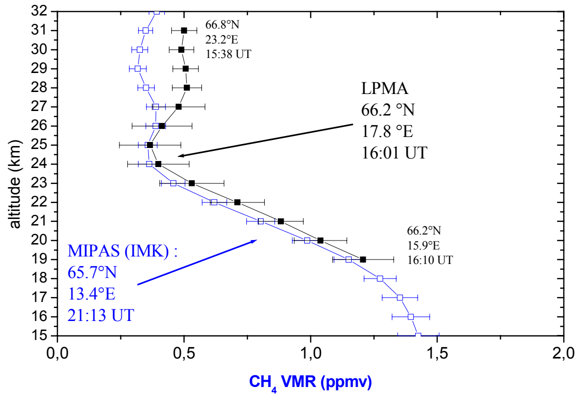

Fig. 5. Validation of the MIPAS CH_4 profile derived with the IMK-FZK scientific processor by the 4 March 2003 flight of LPMA during the ESABC campaign from Esrange

3. AIRCRAFT OBSERVATIONS: MIPAS-STR RESULTS

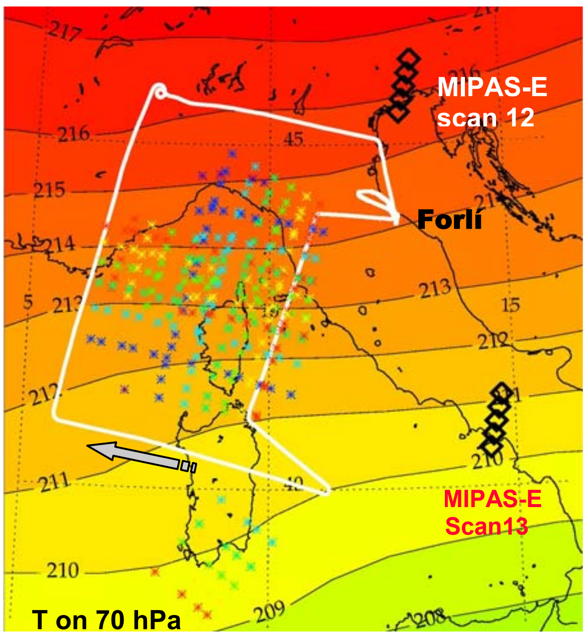

Fig. 6. Flight pattern of the M-55 Geophysica, MIPAS-STR line-of-sight and MIPAS-E tangent points colour coded as a function of tangent altitude (6 km = dark blue, 20 km = red)

The number of aircraft observations and/or the available MIPAS data for CH_4 profiles validation is quite limited at this time. The FTIR instrument MIPAS-STR [8] is operated by Forschungzentrum Karlsruhe, IMK-FZK on the M-55 Geophysica aircraft. MIPAS-STR is recording thermal emission limb spectral from float in the same spectral domain as MIPAS-E, but with a reduced altitude coverage (~ 6 to 21 km). But because of its capability to optimise its flight pattern as a function of the predicted MIPAS-E measurement points, the space and time geolocation can be quite good as seen in Fig. 6 for the MIPAS-STR flight of 22 July 2002 and the corresponding ENVISAT measurements. The corresponding vertical mixing ratio profiles of CH_4 are plotted as a function of tangent pressure (Fig. 7). The vertical resolution of MIPAS-STR in the upper troposphere lower stratosphere (UT/LS) is quite interesting for a detailed comparison with MIPAS-E. The problems of the IPF profiles are observed in these conditions: MIPAS-E profiles of CH_4 (both for v4.55 and v4.61) do indeed present “oscillations” which are not observed in the MIPAS-STR profiles in this UT/LS region, leading to relative differences which can reach ~ 30 % in this altitude range difficult for satellite measurements.

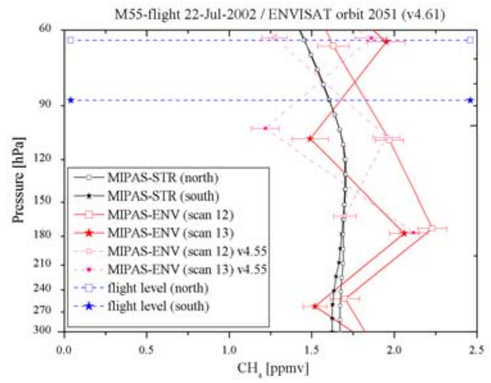

Fig. 7. Validation of MIPAS CH_4 v4.55 and v4.61 profiles by MIPAS-STR on 22 July 2002 during a M-55 Geophysica flight from Forli, Italy

4. SATELLITE MEASUREMENTS: HALOE RESULTS

Satellite-satellite intercomparisons are another method to assess the quality of a new space instrument, once another one, considered to be already validated by independent measurements, is stable and is producing reliable profiles. This is the case for the Halogen occultation Experiment (HALOE on board UARS) providing since 1991 vertical mixing ratio profiles of CH_4 [9] (and several other species) in the full stratospheric range using solar absorption gas correlation radiometry. The Institute of Environmental Physics (IUP) of University of Bremen has been using HALOE version v19 data for comparison with coincident MIPAS-E measurements [10]. Figure 8 displays comparisons for a high latitude profile and a tropical profile in good coincidence (same day, distance between HALOE and MIPAS tangent point less than 250 km). This choice of two quite different profiles is made to demonstrate the possibility of global coverage for the satellite-satellite comparison.

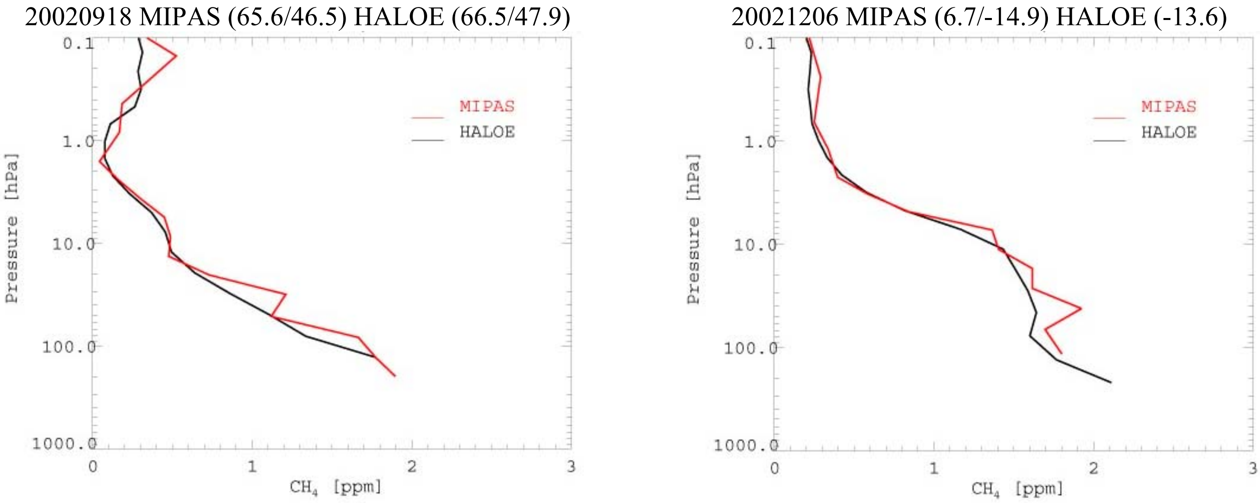

Fig. 8. Comparison between individual HALOE and MIPAS profiles in two different geographical regions (high latitude and tropics)

A statistical comparison is then feasible as shown in Fig. 9 for a set of 110 coincident CH_4 profiles obtained by HALOE and MIPAS. A small positive bias (~ 5 % at 1 hPa) of MIPAS with respect to HALOE is observed increasing at lower altitudes (~ 15 % at 100 hPa) as seen with other correlative measurements. But the consistency between the two satellite sensors (within their respective error bars) is quite satisfactory.

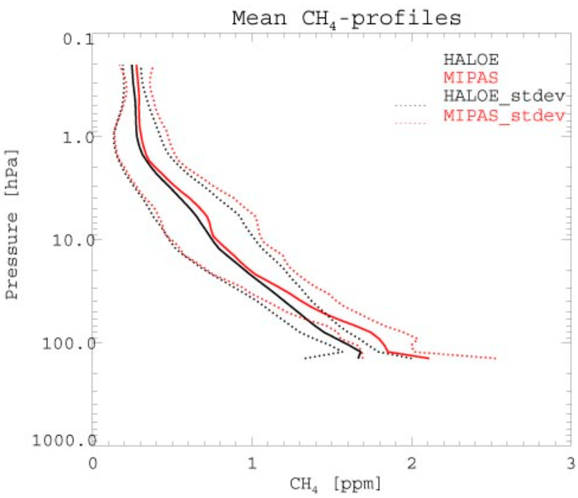

Fig. 9. Statistical comparison of 110 coincident measurements of HALOE (in black) and MIPAS (in red) with the corresponding average and average ± standard deviation profiles

5. GROUND-BASED RESULTS

The validation of MIPAS CH_4 profiles by ground-based measurements is difficult but possible using atmospheric absorption spectra recorded at high spectral resolution (0.002 cm^{-1}) by the Bruker FTIR instruments of the Network for Detection of Stratospheric Change (NDSC). The inversion of the corresponding spectra which can be recorded at each ENVISAT overpass of the station when the sky is clear and the sun is present is providing mixing ratio profiles with a vertical resolution of about 8 km is the stratosphere [11]. The continuity of the ground-based FTIR observations at the NDSC sites is ensuring a larger number of coincidences with ENVISAT than for balloon or aircraft measurement, but comparison has to account for the proper averaging kernels of the FTIR measurements. This effect can be seen in Fig. 10 for a single MIPAS profile (with possibly an outlier at the lowest tangent altitude).

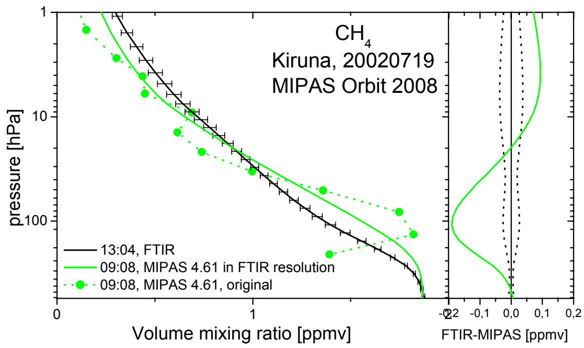

Fig. 10. Comparison of a retrieved NDSC profile of CH_4 with the corresponding coincident MIPAS profile with and without applying the averaging kernel of the ground-based FTIR to the higher vertical resolution of the MIPAS profile

A more statistically significant comparison is presented in Fig. 11, where the mean mixing ratio difference and the relative difference with the corresponding MIPAS data are plotted as a function of altitude for a set of 17 CH_4 coincident measurements. A positive bias of

MIPAS data with respect to FTIR values is observed in the lower atmosphere. The difference is quite small in the range 21 to 27 km where the sensitivity of the FTIR measurements is still reasonably good.

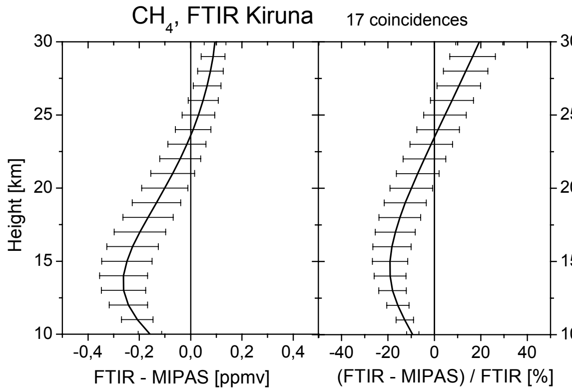

Fig. 11. Mean difference and relative difference between 17 ground-based FTIR CH_4 profiles and the corresponding MIPAS profiles

6. CONCLUSION

The MIPAS CH_4 profile validation exercise presented here is resulting from comparisons of the IPF v4.61 or IMK-FZK datasets available at the time of the ACVE-2 meeting with correlative profiles obtained from balloon-borne, aircraft, satellite and ground-based instruments. Even if the data for comparison are already significant in number, a firm conclusion is still awaiting further analysis. The following interim observations apply however

- overall MIPAS is indeed measuring CH_4 reliably at a level of precision better than 15 %
- a systematic positive bias of MIPAS with respect to several types of correlative measurements is present in the lower stratosphere/upper troposphere (for pressure above 100 hPa)
- the comparisons in the UT/LS are somehow complicated by the tendency of the current IPF v4.61 MIPAS algorithm to generate "oscillating" or zigzag profiles in the UT/LS. This is seen as a larger rms difference between MIPAS and correlative measurements when a statistics can be made as for the HALOE-MIPAS comparison
- the accuracy is difficult to assess before a better control of the quality of the MIPAS profiles is available. Systematic biases can still be masked by large rms differences due to spurious values or "oscillations". The profiles produced by the IMK-FZK scientific processor (using regularization) may help solving these comparison issues as they are smoother than the corresponding IPF v4.61 profiles
- ground-based FTIR profiles have demonstrated their potential for higher statistics and mid-term trends in the MIPAS-correlative data comparison. But care has to be applied in this case because of the reduced intrinsic vertical resolution of the FTIR profiles: the proper averaging kernels have to be used to smooth the corresponding MIPAS profiles before comparison

7. REFERENCES

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8. ACKNOWLEDGEMENTS

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