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Validation of ozone measurements from MIPAS-Envisat: First results

1. Introduction

Vertical profiles of ozone are retrieved with the IMK scientific semi-operational processor from spectra measured by the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) aboard the environmental satellite Envisat. The results are intercompared with those obtained by the MIPAS balloon instrument (Aire sur l'Adour) and the ground-based FTIR (Kiruna).

2. Intercomparison strategy

The intercomparison strategy follows the method described in [1,2].
Necessary profiles and matrices:

- retrieved profiles $\hat{\mathbf{z}}$, corresponding covariances $\mathbf{S}_z$ (containing all relevant errors, except smoothing error), averaging kernels $\mathbf{A}_{zz}$, and *a priori* profiles $\mathbf{z}_a$ for both instruments with corresponding altitude (or pressure) grids.
- profile $\mathbf{x}_c$ and corresponding covariance $\mathbf{S}_c$ of a comparison ensemble ($\mathbf{x}_c$ here was chosen to be $\mathbf{z}_a$ of one of the retrievals) with corresponding altitude (or pressure) grid (which serves as intercomparison grid).

Intercomparison method:

- selection of suitable altitude range and transformation (with interpolation matrix $\mathbf{W}$) to the same (intercomparison) grid: profiles: $\mathbf{x} = \mathbf{W}\mathbf{z}$, covariances: $\mathbf{S}_x = \mathbf{W}\mathbf{S}_z\mathbf{W}^T$, averaging kernels: $\mathbf{A}_{xx} = \mathbf{W}\mathbf{A}_{zz}\mathbf{W}^*$, where $\mathbf{W}^*$ is the pseudo-inverse of $\mathbf{W}$ with $\mathbf{W}^*\mathbf{W} = \mathbf{I}$.
- adjust individual retrievals $\hat{\mathbf{x}}_i$ for different *a priori* profiles by adding $(\mathbf{A}_i - \mathbf{I})(\mathbf{x}_{ai} - \mathbf{x}_c)$.
- it follows for the covariance of the difference:

$$\mathbf{S}_\delta = (\mathbf{A}_1 - \mathbf{A}_2)^T \mathbf{S}_c (\mathbf{A}_1 - \mathbf{A}_2) + \mathbf{S}_{x1} + \mathbf{S}_{x2}. \quad (1)$$

- if $\mathbf{S}_\delta$ is singular → eigenvector expansion: $\mathbf{S}_\delta = \mathbf{L}^T \mathbf{\Lambda} \mathbf{L}$:

$$\chi^2 = (\hat{\mathbf{x}}_1 - \hat{\mathbf{x}}_2)^T \mathbf{S}_\delta^{-1} (\hat{\mathbf{x}}_1 - \hat{\mathbf{x}}_2). \quad (2)$$

If the value of χ^2 is in agreement with a χ^2-distribution of p degrees of freedom (number of non-zero eigenvalues λ_i of $\mathbf{S}_\delta$), the profiles are validated. I.e., χ^2 is comparable to p.

3. Validation with ground-based measurements

FTIR ground-based measurements are performed regularly from Kiruna (67.8°N, 20.4°E). Two selected cases are intercompared for minimum temporal and minimum spatial difference (Fig. 1) during September–November 2002. $\mathbf{S}_c$ is calculated from an ensemble of ozone sonde profiles measured at nearby Sodankyla (67.4°N, 26.7°E). Errors due to HITRAN uncertainties are not considered, since both instruments use HITRAN as spectroscopic database.

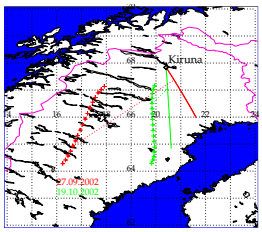

Figure 1: Solid lines show the rays of FTIR (red: 27.09.2002, 9:33; green: 19.10.2002, 10:16. Crosses mark the tangent points of MIPAS-Envisat (red: 27.09.2002, 9:08; green: 19.10.2002, 20:47). Dashed lines mark the minimal distance at 20 km altitude (red: 327.8 km; green:67.0 km).

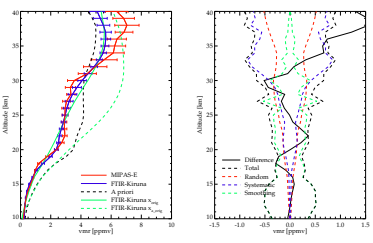

Figure 2: Intercomparison for 27.09.2002. Left: MIPAS-Envisat (red) result and error bars (random + systematic errors), FTIR (blue) result and error bars (random errors only), dashed black: common *a priori* $\mathbf{x}_c$ ($= \mathbf{x}_a$ of MIPAS-Envisat), solid green: original FTIR result without adjusting to MIPAS-Envisat $\mathbf{x}_a$, dashed green: original FTIR $\mathbf{z}_a$. Right: solid black: difference between MIPAS-Envisat and FTIR results, dashed black: common total error ($\mathbf{S}_\delta$), dashed red: common random error, dashed blue: common systematic error (MIPAS-Envisat error only, dominated by ILS errors at higher altitudes), dashed green: common smoothing error. $\chi^2 = 40.6$, $p = 31$; i.e., profile is validated.

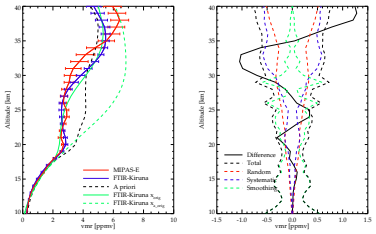

Figure 3: Intercomparison for 19.10.2002. Description of profiles and errors like in Fig. 2. Below 20 km the estimated total error of the difference is dominated by the smoothing error (like in Fig. 2). This is mainly due to the large differences in the averaging kernels. $\chi^2 = 30.1$, $p = 31$; i.e., profile is validated.

4. Validation with balloon measurements

A balloon-borne version of MIPAS (MIPAS-B) has been launched from Aire sur l'Adour (43.7°N,0.3°W) on 24.09.2002 especially for the validation of MIPAS-Envisat. $\mathbf{S}_c$ is calculated from an ensemble of ozone sonde profiles measured at Payern (46.8°N, 7.0°W). Like in the ground-based FTIR case, errors due to HITRAN uncertainties are not considered in the error estimation for both instruments.

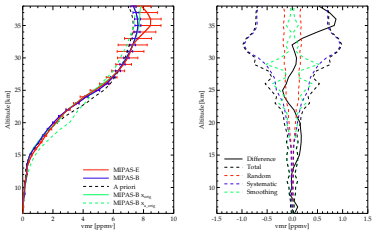

Figure 4: MIPAS-B north limb sequence matches nearly perfectly with the MIPAS-Envisat sequence from 22:07. Description of profiles and errors like in Fig. 2, except that MIPAS-B errors also contain systematic errors. The χ^2 analysis show 3 different levels of agreement: profile is validated above 19 km ($\chi^2 = 21.9$, $p = 20$), differences are a bit large above 8 km ($\chi^2 = 63.4$, $p = 31$), and differences are too large below 8 km. Smoothing error is not as important as in the FTIR case since the averaging kernels are quite similar.

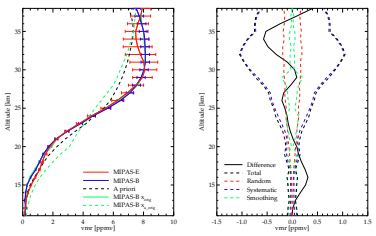

Figure 5: MIPAS-B south limb sequence matches very good (70 km horizontal offset) with the MIPAS-Envisat sequence from 22:06. Description of profiles and errors like in Fig. 2 and Fig. 4. The χ^2 analysis shows that the profile is validated above 18 km and below 13 km. χ^2 values including the region from 14 and 17 km are too high ($\chi^2 = 78.9$, $p = 28$). Estimated systematic errors are dominating the total error budget above 22 km. Smoothing error is important at lower altitudes (like in Fig. 4).

5. Summary and Outlook

- Ozone results of MIPAS-Envisat are validated (with few exceptions) for the cases shown above.
- Intercomparison method allows quantitative validation. Error estimation for smoothing ($\mathbf{S}_c$) and systematic errors, as well as transforming and inverting matrices has to be done carefully.
- Intercomparison of MIPAS-Envisat and FTIR results show agreement in the sense of χ^2-test for the whole considered altitude region (although temporal and spatial match was not perfect and only random errors considered for FTIR). Smoothing error becomes important due to very different averaging kernels (different vertical resolution).
- Intercomparison of MIPAS-Envisat and MIPAS-B results show agreement for most altitude regions. Differences in the MIPAS-B south case between 14 and 17 km needs further investigations. Systematic error estimation of one or both instruments is too pessimistic at higher altitudes (MIPAS-Envisat error estimation due to ILS uncertainties?).
- Validation will be continued with ground-based FTIR → more stations and longer time-period will be considered, estimation of systematic errors.
- Validation will be continued with MIPAS-B (March 2003) and started with many other instruments (HALOE, POAM II, SAGE II, ILAS, etc.).

References

[1] C. D. Rodgers, World Scientific, 2000, pp. 192–196.
[2] C. D. Rodgers and B. C. Connor, J. Geophys. Res., 108, 2003.