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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Technical Note: Regularization performances with the error consistency method in the case of retrieved atmospheric profiles" *by* S. Ceccherini et al.

Anonymous Referee #1

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General comments This paper considers an important problem of regularization of the retrievals from satellite measurements. It presents a regularization approach, which was applied to measurements by MIPAS instrument on board the Envisat satellite. The paper contains interesting results. However, I have several concerns about the methods used.

1) Regularization is a commonly used approach for stabilizing ill-posed or ill-conditioned inverse problems. The authors state that the MIPAS inversion problem is ill-conditioned. (Please quantify the ill-conditioning, e.g. in terms of the condition number of the inversion matrix at iteration steps). However, authors do not apply regu-

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larization in the inversion, where it is logically needed, but they apply the regularization as a posteriori “cosmetic” smoothing. Being implemented in the inversion (in the current application, in the non-linear optimization procedure), regularization stabilizes the inversion and can significantly improve the retrievals in case of ill-conditioned problems. A posteriori regularization, as applied in this paper, only smoothes the final profiles and thus does not affect the inversion process, for the individual retrievals. As shown in the paper, it has indirect effect on subsequent retrievals by providing more realistic initial-guess values. Optimality (or non-optimality) of the chosen regularization approach should be proved by comparison with the retrievals that use regularization implemented in the iteration algorithm. As far as I know, such methods that use regularization in the inversion algorithm have been already developed and applied to MIPAS measurements [e.g., Gil-Lopez et al., 2005; Glatthor et al., 2006].

References: Gil-Lopez et al.(2005): Retrieval of stratospheric and mesospheric O3 from high resolution MIPAS spectra at 15 and 10 μm, Adv. Space Res., Vol. 36, No. 5, pp. 943-951, doi:10.1016/j.asr.2005.05.123.

N. Glatthor et al.(2006): Retrieval of stratospheric ozone profiles from MIPAS/ENVISAT limb emission spectra: a sensitivity study, Atmos. Chem. Phys., 6, 2767-2781.

2) The motivation for application of the error consistency method, which is a kind of Tikhonov-type regularization with a smoothness constraint applied a posteriori, requires a special discussion. It is well known that ozone profiles can be not smooth: they can have laminae in the lower stratosphere, which are caused by horizontal large-scale advection and wave activity (e.g., [Reid et al., 1993], [Noguchi et al., 2006]). Please justify the constraint on the smoothness of ozone profiles.

References: Reid, S. J., Vaughan, G., and Kyro, E.: Occurrence of Ozone Laminae Near the Boundary of the Stratospheric Polar Vortex, J. Geophys. Res., 8883-8890, 1993.

Noguchi et al. (2006): A global statistical study on the origin of small-scale ozone

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vertical structures in the lower stratosphere, J. Geophys. Res., 111, D23105, doi:10.1029/2006JD007232.

3) It looks very strange that the actual vertical resolution shown in Fig.1 and 2 of the manuscript is smaller than IFOV at lower altitudes. Is the spatial smoothing over the instrument field of view taken into account in the forward model?

A figure showing exemplary averaging kernels would be also very useful.

4) Application of the error consistency method requires very accurate error estimates, which should include not only errors due to measurement noise but also various modelling errors. The “reduces chi-square” values equal to ~2.6 (Table 1) indicate that errors are underestimated (not all modelling errors are taken into account). Please describe the structure of the error estimates in more detail, with the focus on the current application. Furthermore, the covariance matrix Sx (Eq.(6)) present only one part of the error, which is due to noise in measurements. Another part of error, so-called “smoothing error” (discussed in detail in [Rodgers, 2000]), which is caused by deviation of averaging kernels from delta-functions, is not taken into account (and not shown in Fig.1 and 2). This should be indicated and discussed as well.

5) As it is shown in Figure 2, the differences between regularized and non-regularized profiles are significantly larger than the retrieval errors, which is in contrast with the basic assumption and interpretation of the error consistency method. The authors explain this discrepancy by the influence of off-diagonal elements of the covariance matrix Sx, which makes the simplified interpretation of Eq.(7), “the differences between the regularized and the non-regularized profiles must be on average equal to the errors of the regularized profile”, not valid. However, the discrepancy seems to be very large, and therefore it should be resolved and quantified. It can be done either by theoretical estimating the influence of off-diagonal elements in Eq.(7) (with realistic correlations) or by computing the mean of the expression in the left-hand side of Eq.(7), based on real profiles and covariance matrices, and comparing them with n. Such an illustration

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would confirm correctness of the application of the method.

Overall, I rate that the paper can be published in the Atmospheric Chemistry and Physics journal, provided the authors will undertake major revisions of the manuscript.

Specific comments

P13308L17-18: The statement “The regularization is used to retrieve smooth profiles by decreasing the retrieval errors at the expenses of the vertical resolution.” is not correct in general: there are many regularization methods that do not use smoothness constraint; for example, the methods that use total variation constraint or “impulse” prior (more details can be found in the literature on the theory of inverse problems, e.g., in the recent monograph by J. Kaipio and E. Somersalo: Statistical and Computational Inverse Problems. Springer Verlag, 2004)

P13312L19-20: “For this reason it is necessary to use both the Levenberg-Marquardt method and the Tikhonov regularization”. It is not necessary: the regularization can be easily implemented in the non-linear optimization algorithm, see also comment 1 in “General comments”.

P13312L22-23: “The objective of the Tikhonov regularization is to limit the oscillations of the retrieved profile”. Again, the main objective of regularization is to restore the stability of the inversion.

P13314L15-17: “Moreover, the regularization modifies the profile only in the altitude range where the oscillations are present, leaving unchanged the profile shape where it is already smooth.” This is the general feature of regularization with the smoothness constraint. However, the amount of regularization is the same for all altitude levels in your regularization, since λ is constant (Eq.(8)). In order to introduce altitude-dependent smoothing, you need to define altitude-dependent regularization parameter.

P13315. I think it is better to use “normalized chi-square” instead of “reduced chi-square”.

Interactive comment on Atmos. Chem. Phys. Discuss., 6, 13307, 2006.

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