Assimilation of infrared limb radiances from MIPAS in the ECMWF 4DVAR system

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Introduction

ECMWF is developing the capability to directly assimilate emitted clear-sky infrared limb radiances from the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS). It is the first time that the assimilation of limb radiances into a numerical weather prediction (NWP) system is being investigated. The developments have been prompted by the success of the assimilation of nadir radiances.

MIPAS is a very high spectral resolution sounder (0.025 cm^{-1} wavenumber resolution) onboard ESA's Envisat satellite. It provides 59,605 spectral points or channels in 5 bands in the range 685-2410 cm^{-1}. In the nominal scanning configuration, it gives one scan about every 5º latitude for 17 tangent altitudes between 6 and 68 km. The field of view (FOV) is 3 km in the vertical and 30 km in the horizontal.

Channel selection and information content

A subset of MIPAS data has been selected for assimilation studies. The iterative method of Dudhia et al. (2002) has been applied to select 325 channels over channel-specific tangent altitude ranges (Fig. 1). This selection aims to maximise the information content relative to the error estimate in the *a priori* (i.e., the ECMWF short-term forecast). The control variables are profiles of temperature, humidity, and ozone.

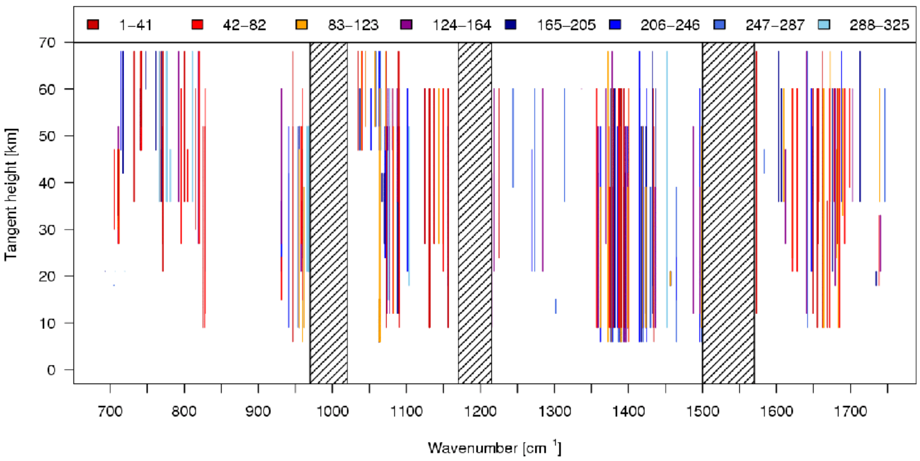

Figure 1: Location of the selected MIPAS channels and tangent heights. Colour coding gives the ranking in the selection.

Figure 2 shows that the selected MIPAS radiances have the potential to significantly reduce the analysis error of humidity and ozone throughout the stratosphere. Temperature errors are also significantly reduced in the stratosphere above about 30 km. MIPAS limb radiances are able to resolve background errors at much finer vertical resolution than nadir radiances (not shown).

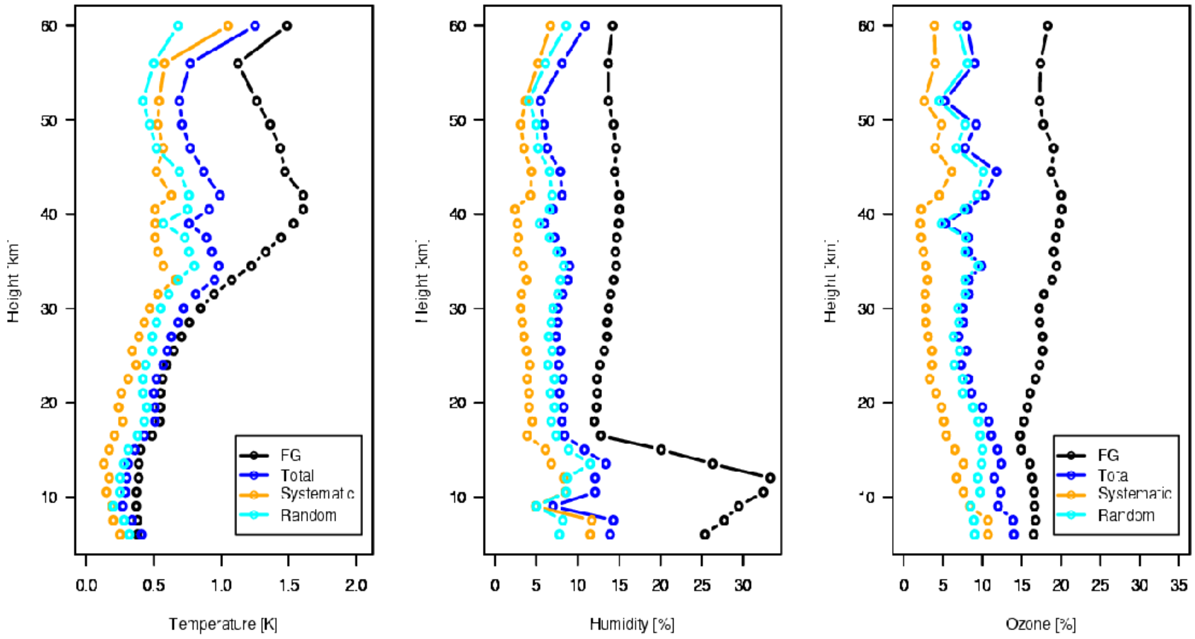

Figure 2: Theoretical reduction of analysis error that can be achieved with the selected MIPAS data. Black is the ECMWF background error; cyan the retrieval error expected if only MIPAS instrument noise and the background error are taken into account; orange is the estimate of errors introduced through the forward model (e.g., spectroscopic uncertainty, fixed climatology for certain gases, etc); blue the expected total retrieval error.

Assimilation framework

The above subset of MIPAS data is being used for assimilation studies with ECMWF's 4DVAR system. Two experiments are compared here, the control run without MIPAS radiance assimilation, and an experiment with the assimilation of MIPAS radiances. Both experiments use 6-hourly 4DVAR and an analysis and model resolution of T159 (approx. 125 km), with 60 levels in the vertical. The approach to the limb radiance assimilation is as follows:

- The radiative transfer model used is RTMIPAS, a regression-based fast radiative transfer model that follows RTTOV methodology (Bormann et al. 2004, 2005; see also Bormann et al. in these proceedings).
- Results presented here are based on using a 1-dimensional observation operator that assumes local horizontal homogeneity for the limb radiance calculations. Work on taking horizontal structure into account in the assimilation is in progress.
- Cloud-affected radiances are screened out using the method of Remedios and Spang (2002).
- Tangent pressure information is taken from ESA's level 2 data, since the satellite's engineering pointing information is not considered accurate enough.

- Correction of radiance biases is described below.
- Radiances with tangent altitudes above 60 km are excluded, to avoid radiances sensitive to regions above the ECMWF's model top at 0.1 hPa. Similarly, radiances with tangent altitudes below 9 km are not used to avoid errors arising from neglecting horizontal gradients in the radiative transfer calculations.

For both experiments, other observations are used as in operations, except for the following: MIPAS ozone retrievals are not assimilated in our experiments. GPS radio occultation bending angles are assimilated, in order to provide additional temperature information for the lower stratosphere and upper troposphere (Healy and Thépaut 2005). In contrast to operational practice, the humidity analysis for the stratosphere is switched on, following the developments of Hólm et al. (2002).

Correction of radiance biases

Following the experience for nadir radiances, it is considered essential to correct so-called radiance biases in MIPAS data before the assimilation. If the MIPAS radiances are assimilated without bias correction, inconsistencies appear in the bias of analysis departures for different MIPAS radiances with weighting functions peaking at similar heights. Designing a bias correction for MIPAS radiances is made more difficult by the presence of biases in the model fields in the stratosphere, especially for humidity and ozone.

To resolve the ambiguity between model and radiance biases, an iterative method is being investigated, which involves repeated assimilation and tuning of subsets of the selected MIPAS channels over a 14-day study period. Such an iterative method provides some scope to separate between model and radiance biases, given that for each tangent altitude many MIPAS channels are available with weighting functions peaking around this tangent altitude.

Currently, bias correction is done with the so-called "γ/δ" method (e.g., Watts and McNally 2004), which scales optical depths in the radiative transfer model with a channel-specific γ, and models the remaining bias with a constant δ. This approach has been found to give a good first model for the biases observed over a range of tangent altitudes for a large number of channels (Fig. 3).

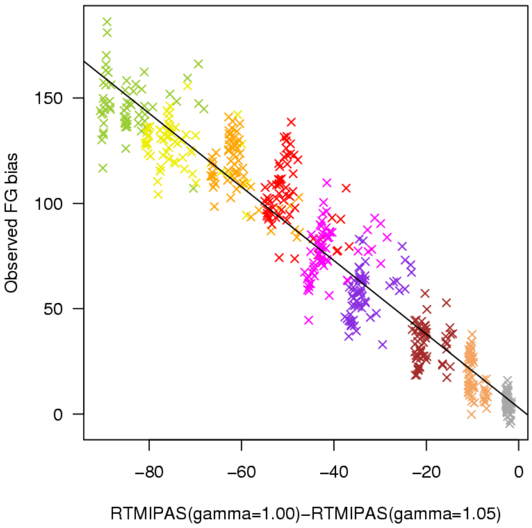

Figure 3: FG biases (from 30º x 20º longitude/latitude boxes between 45S and 45N) vs the signature of a 5 % perturbation in gamma (calculated with a mean atmospheric profile per longitude/latitude box) for a MIPAS temperature channel (both in nW/(cm^2 sr cm^{-1})). Colour coding shows tangent height bands with grey for 60 km and green for 27 km.

Assimilation trials

Preliminary assimilation trials over the 14-day period 18-31 August 2003 show the following key results:

- MIPAS radiances can be assimilated while maintaining a similar level of fit to other observations sensitive to stratospheric temperature.
- The assimilation of MIPAS radiances has a significant impact on the mean temperature, humidity, and ozone analyses in the stratosphere, qualitatively in agreement with a reduction of known biases in the model fields (Figures 4, 5). For instance, the stratospheric analyses are considerably wetter with the MIPAS radiances assimilation, correcting for a known dry bias in the stratospheric humidity fields. Comparisons to other independent observations are required to verify quantitatively to what extent biases are reduced.
- Analyses with MIPAS radiances agree better with MIPAS level 2 retrievals in the regions expected from the information content study (Fig. 6). This provides a first cross-validation of the radiance assimilation.

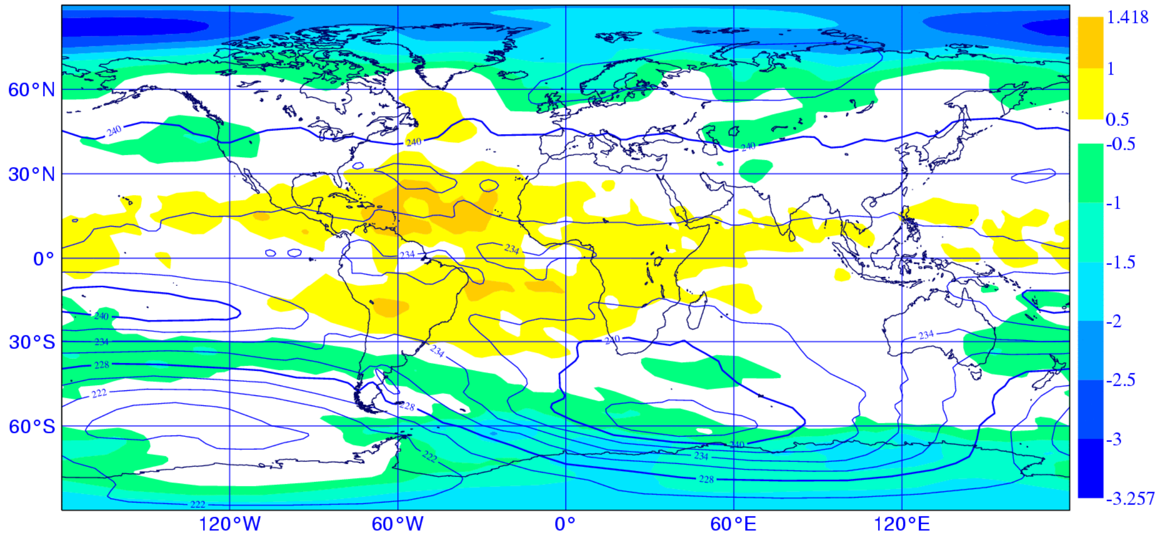

Figure 4: Difference in mean temperature analyses [K] at 5 hPa between the experiment with and the one without MIPAS radiance assimilation.

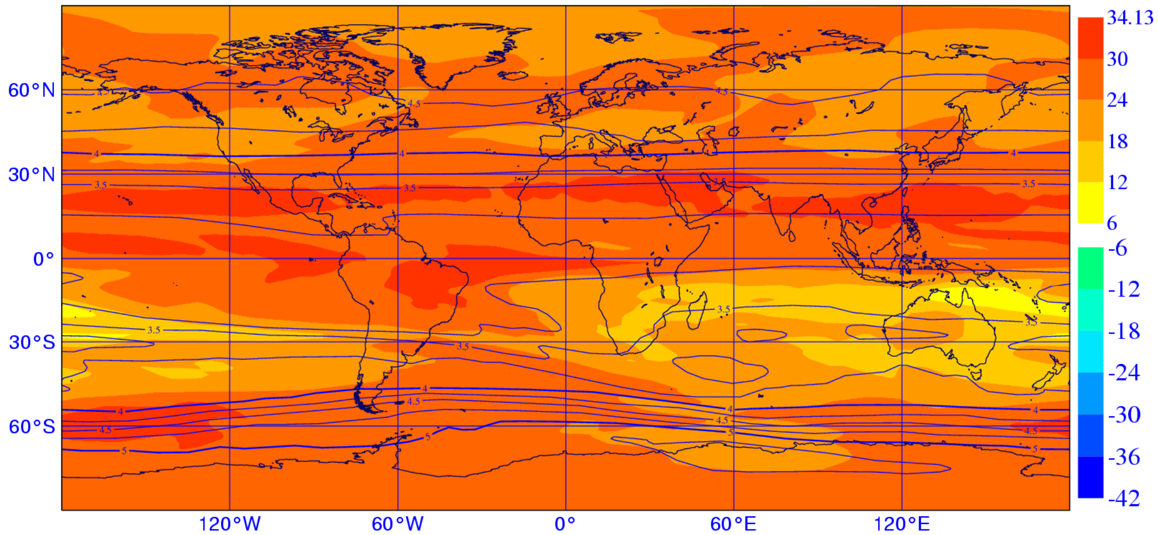

Figure 5: Relative difference in the mean humidity analyses [%] at 12 hPa between the experiment with and the one without MIPAS radiance assimilation.

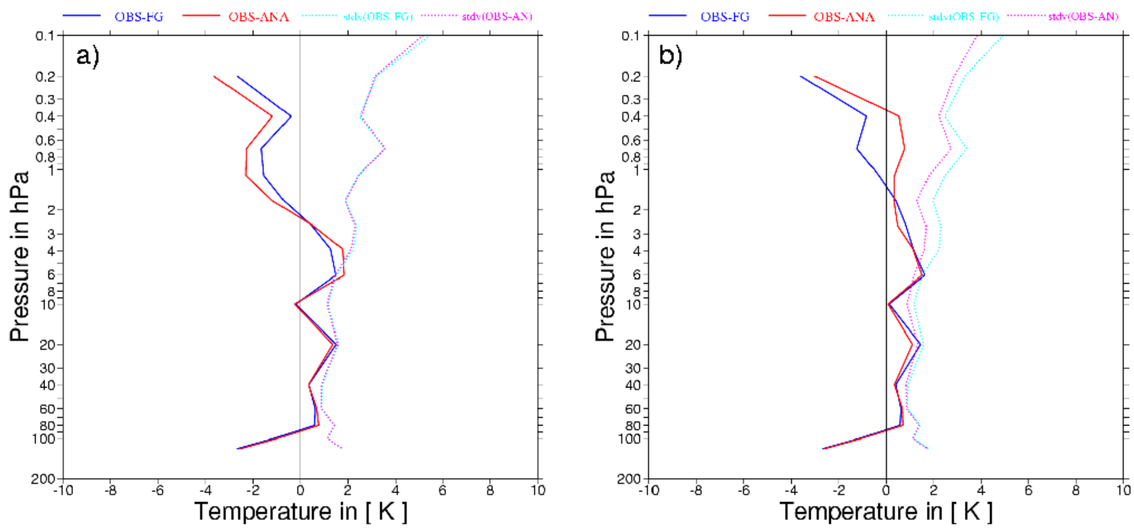

Figure 6: Departure statistics for ESA's MIPAS temperature retrievals (bias - solid; standard deviation - dotted) for the region 0-20S, without (a) and with (b) MIPAS radiance assimilation.

Conclusions

Limb radiances from MIPAS have for the first time been directly assimilated into an NWP model. The results highlight the considerable potential of limb radiances to improve the analyses of temperature, humidity, and ozone in the stratosphere. Provided radiance biases are adequately addressed, assimilation of MIPAS radiances appears to correct considerable biases in the mean stratospheric analyses, and these biases qualitatively agree with known deficiencies in ECMWF model fields. Further work is needed to validate the resulting analyses against other observations in the stratosphere. More work is also required to characterise the temporal stability of the radiances biases, refine the assigned observation errors, and to investigate the influence of a 2-dimensional observation operator versus the 1-dimensional operator used in these experiments.

The above approach of direct assimilation of radiances could be adopted to the assimilation of data from EOS-Aura's MLS.

Acknowledgements

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