

## 1 Answer to the first referee

We thank the referee for reading a quite long paper and suggesting improvements. For each referee's comment (reported in italics) the answer is provided below it.

### 1.1 First Referee

#### 5 1.1.1 Major comments:

*My main comment concerns the treatment of horizontal inhomogeneities. A first order model is used, which only accounts for linear variations using a horizontal gradient. Statistically, improvements are achieved, e.g. with regard to day/night differences (ascending/descending orbits). However, in situations of high (small scale) variability, e.g. due to wave breaking, using a linear gradient may even be counterproductive. For example, the authors state that closest coincidences of ERA-Interim ECMWF data for each MIPAS profile were used for computing the horizontal gradients of temperature, water vapour and ozone. How is the gradient then calculated? By simple linear interpolation? Since the horizontal resolution of the ERA-Interim data is higher than that of MIPAS (distance of the tangent points), the calculation of an effective gradient would make sense, which also accounts for smaller-scale variability along the line of sight. If a simpler procedure was chosen, the authors could briefly discuss this and state that essentially a statistical (climatological) improvement was targeted.*

15 The inclusion of the Horizontal Gradient (HG) model in the ORM has been long debated, especially after Kiefer et al., 2010 found the so-called ascending descending (AX-DX) differences, correctly attributed to the fact that horizontal variability in the atmosphere along the line of sight was not taken into account. The AX-DX differences can be appreciated by calculating, separately, for the AX and DX parts of the satellite orbit, the profile zonal means. Being of the order of the measurement noise error, the effect is hardly visible in the individual profiles.

20 The introduced HGs permit to model a linear horizontal variation of the atmospheric state parameters. While the linear approximation does not allow to account for the smaller-scale variability along the line of sight, still, it is better than the "constant" approximation corresponding to the horizontal homogeneity assumption. We agree that there may be situations (e.g. due to wave breaking) in which the externally supplied HGs do not improve the capability of the forward model to reproduce the actual observation. These situations, however, should be regarded as "exceptions", because from the statistical point of view the quality of the fit turns out to be improved when HGs are modelled.

25 The dataset used for the calculation of the HGs influences the reduction of the AX-DX differences. In Figure 1 we compare, for different latitude bands, the temperature AX-DX differences obtained with HGs extracted from various sources. In this case, the processed orbits refer to the measurements acquired in December 2007 (Optimized Resolution, OR mission phase).

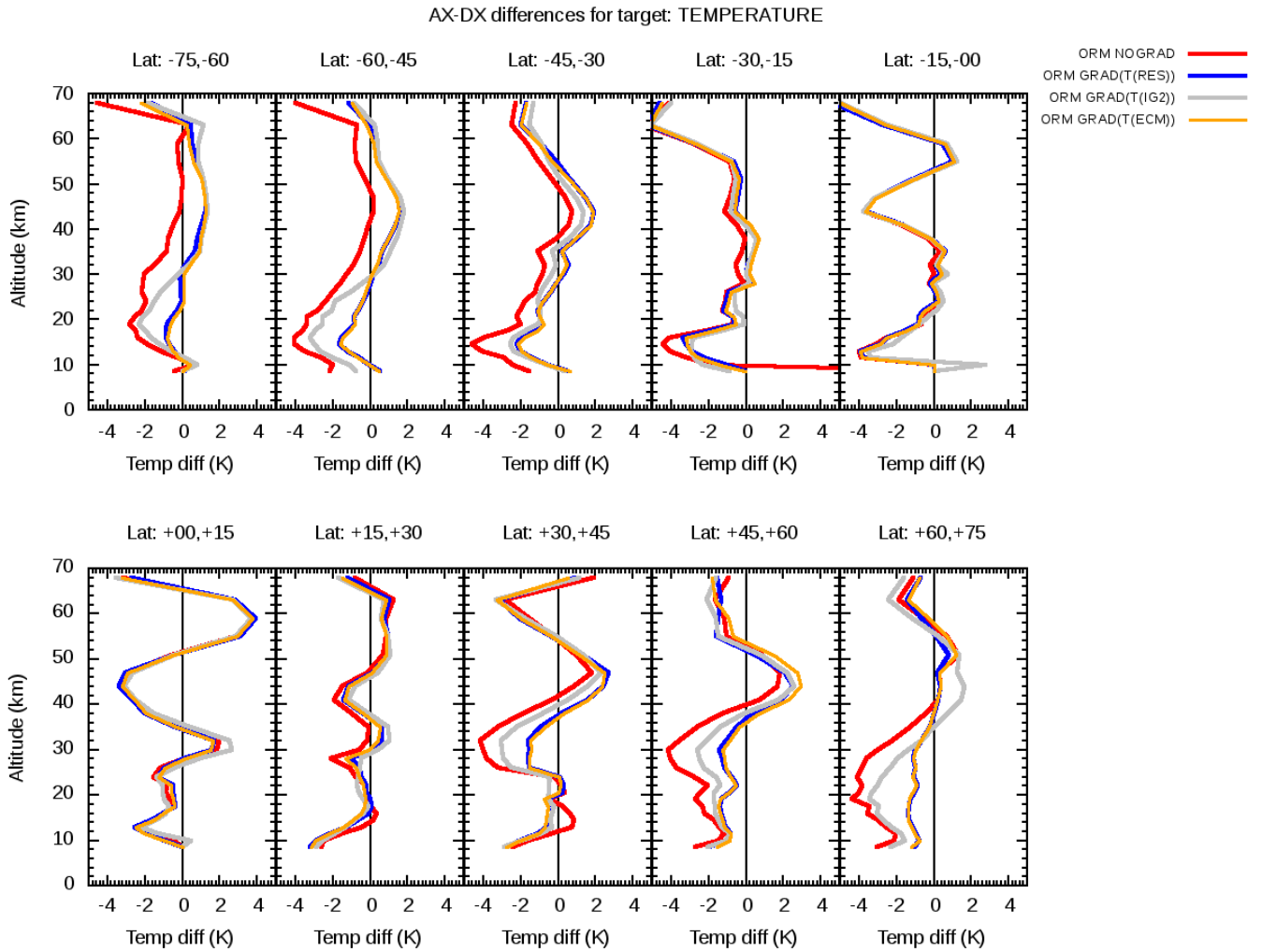
30 The red curves refer to the AX-DX differences obtained by setting to zero the HGs. As we can see, the HGs extracted from the IG2 (Remedios et al, 2008) climatology provide only a marginal reduction of the AX-DX differences (grey curves) as compared to the cases of assuming HGs extracted from ECMWF (gold curves) or from a previous ORM processing with no HG model (blue curves). The HGs calculated from profiles retrieved in a previous ORM processing without gradients, and HGs calculated from ECMWF profiles reduce the AX-DX differences by very similar amounts. This result points at the fact that HGs inferred from ECMWF, though computed from simple profile differences, actually act as "effective" HG estimates as those obtained from a previous ORM analysis assuming no horizontal variability. Conversely, the mere climatological estimate based on the IG2 database shows a worse performance. Note that, as expected, the temperature AX-DX differences do not vanish completely everywhere. Since the AX profiles are measured at night time, and the DX profiles at day time, the solar tides are still visible in the differences.

40 In the revised manuscript we modified the text of Sect. 4.1 to include the information and the explanations included in this answer to the reviewer.

*Other comments:*

*l.11 Introduce IG2 (Level 2 Initial Guess). The abbreviation is used a few times, but not explained until l. 318.*

Done



**Figure 1.** AX-DX differences in various latitude bands (see plot's key) for the retrieved temperature profiles.

45 l.23 *The effects are not limited to the region from the surface to the mesosphere. For example, solar activity also affects the thermosphere.*

Corrected

l.26. *I find the Kidston et al. citation a bit too specific here. I would therefore also use another citation, e.g., from the IPCC.* We have cited also 'Climate change 2021: the physical science basis, IPCC'

50 l.27 *A citation for the air quality aspect is missing.* We have added as an example the reference to this recent paper:  
Mingcheng Wang, Qiang Fu, Stratosphere-Troposphere Exchange of Air Masses and Ozone Concentrations Based on Re-analyses and Observations, JGR Atmosphere, <https://doi.org/10.1029/2021JD035159>, 2021

l.30 ... *period (Fischer et al., 2008).* Done.

55 l.33 *Indicate approximately how large the resolution is.* We have added that the vertical resolution varies for most trace species, in the altitude range 6-40 km, between 3 and 5 km for the FR measurements, between 2 and 5 for the OR measurements.

l.42 *The statement does not apply to every tangent point since a global fit procedure is used?* Yes, indeed we write 'spectra', all the spectra of a limb scan are simulated and fitted at once.

l.78 *I would put the Fischer quote at the end of the sentence.* Done.

l.85 *A sketch of the measurement geometry would be helpful for some readers.* We have added a reference to Fig.5 of Fischer et al.

60 l.88 *What is meant by revisit time of three days? It should be about a month.* We meant that after three days we get an almost global coverage of MIPAS measurements, but it is true that 'revisit time' has a different meaning. In the revised paper we reworded the sentence.

l.112 *Both ... vary* Corrected

l.130 *I would say what is meant. Horizontal gradients of temperatures and trace gases.* Done

65 l.140 ... *and lower thermosphere?* Done

l.143 *I assume that this sequential procedure is also iterated?* No, the procedure is not iterated. The consecutive limb scans of an orbit are analysed sequentially. In general, the profiles retrieved from a given limb scan turn out to be a sufficiently good approximation of the atmosphere to be used as a background, to process the next scan.

70 l.165 *Briefly state the purpose.* We have added that IG2 are used 'for defining initial guess profiles, assumed profiles of the interfering species, horizontal gradients'

.171 *Statistically, it shows an improvement.* We have reworded the text as follows: 'For most of the retrieved gases we observe that the chi-square in V8 is significantly smaller than in V7. The improvement is more relevant in the OR phase of the mission, where the reduced spectral resolution makes more critical the interference of non target gases.'

l.193 *mean retrieved profiles* Done

75 l.221 *in about » about* Corrected

l.257 *better "between observed and simulated spectral features".* Corrected

l.258 *consistency check is o.k., but the 7.6 μm region should not be further included in the HNO<sub>3</sub> retrieval itself by just to account for HNO<sub>3</sub> interferences in the 7.6 μm region.* The sentence refers to a separate study published in Perrin et. al 2016. For the HNO<sub>3</sub> V8 retrievals only microwindows in the 11 μm region are actually used (see <http://www.atm.ox.ac.uk/group/mipas/err/>).

80 l.268 ... *improves the spectral simulations...* corrected

*Legend Figure 10: Perhaps spell out FR and OR again.* Ok

- l.331/332 The sentence is difficult to understand. It has been reworded.
- l.333 *If necessary, give some details for priority system.* We have added a reference to the paper Dinelli et al., 2021.
- l.337 *mb » hPa* Corrected
- 85 l.357 *Delete space after "range".* Done
- l.364 *What do you mean by 0 hPa?* This is what is written in the paper that is cited in the paper. The “0 hPa” is the number quoted in table 1 of Chipperfield 2006 TOMCAT paper - <https://rmets.onlinelibrary.wiley.com/doi/epdf/10.1256/qj.05.51>. This value of “0 hPa” is based on the values from Briegleb, 1992. We have replaced “0 hPa” with “top-of-atmosphere”.
- l.406 *I don't understand this big difference between models levels and pressure levels right away.* This is how ERA-Interim
- 90 data are provided. For data provided on pressure levels the lowest pressure is 1 hPa, for data on model levels the lowest pressure level is 0.1 hPa.
- A small change in the text has been done for clarity reasons: Data on model levels were adopted instead of pressure levels in order to obtain a greater vertical coverage since they are released up to 0.1 hPa (about 65 km altitude) versus 1 hPa (about 50 km altitude), respectively. The adoption of levels with a fixed pressure scale implies an inhomogeneous upper limit of the
- 95 profiles along the orbit.
- l.486 *I would somewhat rewrite how you reduce outliers after the retrieval, e.g. ... after the retrieval based on a more sophisticated quality flag.* Actually this is only an introduction. Later, Sect. 6.2 describes the details of the procedures used to reduce the number of outliers in the products.
- l.620 *long-term evolution* Done
- 100 *Figure 23: Improve quality of symbols and lines in the plot.* Done
- l.655 *... observed scene multiplied...* The sentence has been reworded.
- l.840 *Remove the first parenthesis.* Done