MIPAS OBSERVATIONS OF STRATOSPHERIC TRENDS

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ABSTRACT

MIPAS has been making measurements of atmospheric infrared emission spectra since July 2002, giving a global dataset spanning almost 5 years — potentially long enough to start making assessments of any trends in stratospheric temperature and composition.

However, any analysis is complicated by the fact that MIPAS operated until March 2004 with a spectral sampling of 0.025 cm^{-1} then, after a lengthy interruption, resumed operations in January 2005 sampling at 0.0625 cm^{-1}. The nominal scan pattern was also changed: from 17 spectra per limb scan for the high resolution to 27 spectra per limb scan for the reduced resolution.

ESA-processed L2 data for the reduced resolution have only recently started to become available, so for this study retrievals for 15 selected days throughout the mission have been performed using the Oxford retrieval algorithm MORSE.

With such a limited dataset, and significant inter-annual variability, it is not possible to conclude unambiguously whether the results show evidence of either a bias between the two modes of MIPAS operation or evidence of an atmospheric trend.

Key words: MIPAS; stratosphere; composition; temperature; trends.

1. MIPAS OPERATIONS

The Michelson Interferometer for Passive Atmospheric Sounding has been making measurements of the earth's infrared limb emission spectra since July 2002. However, following problems with the interferometer slide mechanism, operations at the original 'full' resolution (sampling spectra at 0.025 cm^{-1}) ceased in March 2004 and resumed in January 2005 in 'reduced' resolution mode (0.0625 cm^{-1} sampling), achieved by restricting the mirror movement to 40% of its maximum range. Fig. 1 illustrates the change in spectral features that results, although note that the spectral noise is also reduced by a factor $\sqrt{R}$, where $R = 0.4$ is the reduction in resolution.

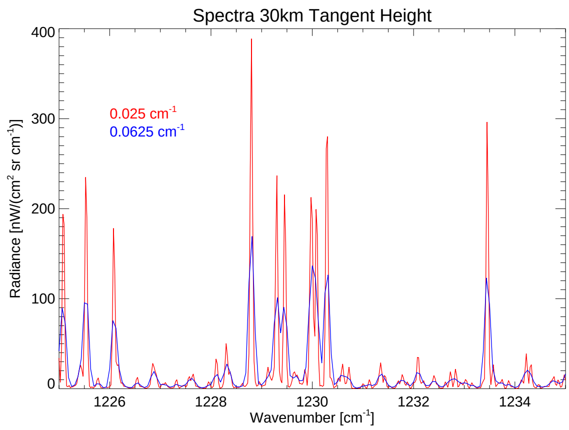

Figure 1. Simulated atmospheric spectra for 30km tangent height viewed at the full (red) and reduced (blue) resolutions. The features between 1228 cm^{-1} and 1231 cm^{-1} are actually due to methane and this is one of the spectral regions commonly used for methane retrievals.

When operating in full resolution mode, almost all measurements were taken with a nominal scan pattern ('FR17') consisting of a 17 spectra from heights from 68 km down to 6 km (Fig. 2), resulting in approximately 1000 profiles per day spaced at 500 km intervals along-track. The same scan pattern was also used during a trial period of reduced-resolution operations during Aug/Sep 2004 ('RR17') but since the reduced resolution spectra are acquired at a correspondingly faster rate, this generated over 2000 profiles per day. At the beginning of 2005 a new 'nominal' mode was defined ('RR27') consisting of 27 spectra from 71–6 km at mid-latitudes, but with a latitudinally varying offset. This potentially generates around 1300 profiles a day spaced at 400 km along-track.

Unlike the full-resolution operation, with the reduced resolution a wide variety of different scan patterns have been used for different applications. Apart from the nominal RR27 scan pattern a significant number of observations have also been taken in the 'UTLS1' mode. This consists of spectra at 19 tangent points with similar coverage to the RR27 pattern in the lower atmosphere but fewer tangent points at higher altitude.

The change in spectral resolution and limb-sampling

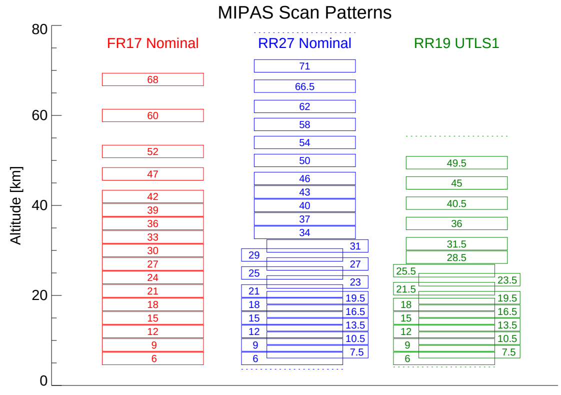

Figure 2. Projection of the MIPAS FOV on to the atmospheric limb for various scan patterns used to generate operational products. Red and Blue are the nominal modes for full and reduced resolution respectively, and green the reduced-resolution UTLS1 mode. Where the vertical sampling is less than 3 km the boxes are shown offset for clarity. The dotted lines represent the upper (equator) and lower (polar) limits of the projections around the orbit for the floating altitude grids.

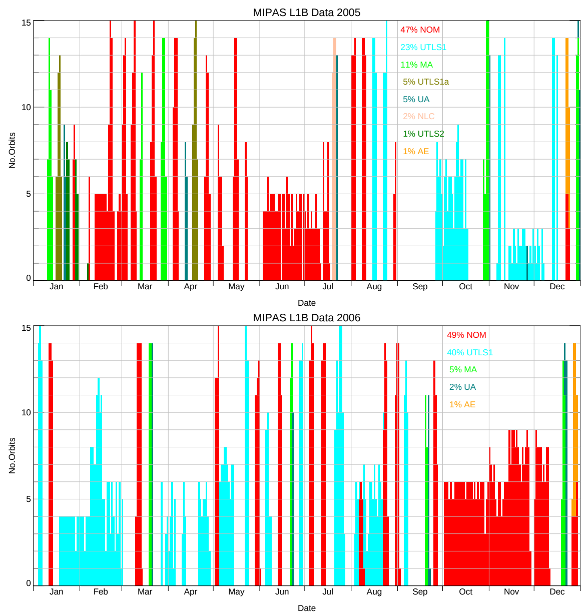

Figure 3. L1B data for 2005 (top) and 2006 (bottom). For each day the histogram shows the number or orbits for which MIPAS was making atmospheric observations with the different colours indicating the different scan patterns used.

has also necessitated a new microwindow selection, i.e., the retrievals of temperature and composition from the reduced-resolution data do not use identical regions of the spectrum to those used for the full-resolution retrievals.

MIPAS has also been constrained to operate on a reduced duty-cycle, interpreted either as the number of orbits per day for which MIPAS was switched on, or as the number of days in a week or similar period. Originally MIPAS was restricted to operate with a duty cycle $<$50% but recently this has been relaxed to 60% and, if the instrument continues to perform reliably, is likely to be further relaxed in future. Operations through 2005–2006 are summarised in Fig. 3, which particularly illustrates the number of days for which MIPAS was only switched on for 3–5 orbits, usually selected to provide overpasses for particular localised atmospheric measurement campaigns.

2. DATA SELECTION

To analyses the trends in stratospheric composition as a whole, it is desirable to sample the entire globe within a timescale short compared with dynamic effects, e.g., 24 hours.

As well as scanning in elevation, MIPAS routinely operates with an azimuth scan which is varied sinusoidally around the orbit. This ensures that, while the Envisat sub-satellite point orbit only reaches $\pm 80°$ latitude, the MIPAS tangent point extends to the poles. Thus, in any one orbit, MIPAS scans the full latitude range.

In full resolution mode, MIPAS operated almost continuously for 14–15 orbits per day, ensuring complete longitudinal coverage on most days. However, as shown in Fig. 3, MIPAS has only been operating for the full 14 orbits on a limited number of days in reduced-resolution mode.

In order to ensure full vertical coverage of the entire stratosphere and avoid further complications caused by changes in operating mode, it is also desirable to restrict the analysis to days for which MIPAS operated in the nominal mode, further limiting the data considered suitable for this analysis (i.e., just those days shown by the red columns extending to 14 orbits/day in Fig. 3).

The ESA L2 processor has recently been adapted to cope with the new reduced resolution nominal and UTLS1 modes[1] but, to date, only a limited amount of suitable data has been processed (most early processing has concentrated on the UTLS1 data taken during campaign support).

For this study, therefore, it has been decided to use the Oxford processor 'MORSE' to retrieve selected days spaced approximately at the equinoxes for the high resolution data and augmented with near-solstice days for the low resolution. This uses the same microwindows and a similar forward model to the ESA processor, but is an optimal estimation scheme rather than a regularized least-squares-fit. It is not expected that the difference in retrieval schemes should lead to significantly different results.

Each retrieved profile is interpolated to a uniform pressure grid, masking out points which are cloud contaminated or for which the error has not significantly improved on the *a priori* uncertainty. These profiles are then simply averaged on each pressure surface within 5 degree latitude bins. Finally the zonal means are area-weighted (using the cosine of the central latitude) to construct a global mean.

3. TREND CORRECTIONS

The raw global mean data is shown by the open circles in Fig. 4. Before the data are used to derive bias or trend information, corrections are applied to allow for the CO_2 trend and annual/semi-annual cycles caused by the uneven sampling.

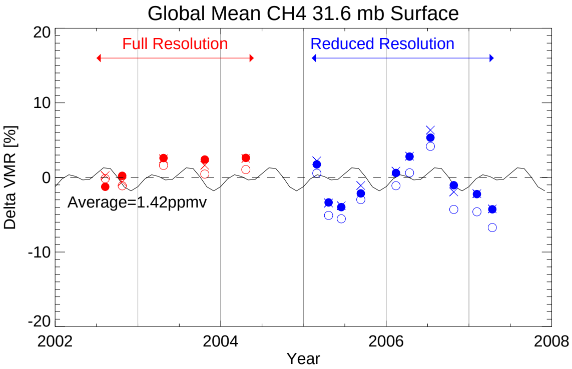

Figure 4. Global mean values of CH_4 on the 31.6 mb surface for the selected days, plotted as a deviation from a mean value. The open circles are the raw data, the crosses are after the CO_2-pressure correction and the solid circles after the fitted annual/semi-annual signal (solid line) has been subtracted.

Retrievals from satellite limb infrared measurements usually rely on the assumption that the CO_2 concentration profile is known in order to establish the tangent point pressure and temperature. Knowing the temperature and pressure profiles then allows the concentrations of other gases to be derived based on the relative strength of their spectral features.

The retrievals performed here using MORSE, and all the ESA-processed full-resolution data to date, have assumed a fixed CO_2 profile value of 363 ppmv in the stratosphere. This was a reasonable value at the time of Envisat's launch (actually 2001 conditions) but it is well-known that atmospheric CO_2 is increasing at a rate of approximately 0.5%/year[2].

Using the 'incorrect' CO_2 actually has very little impact on the MIPAS temperature retrieval but, since the pressure retrieval effectively works by counting the number of CO_2 molecules in a limb path, the retrieved pressures will be overestimates of the true tangent pressures by an error increasing at 0.5% per year. The concentrations of other gases are then retrieved using this incorrect pressure, effectively ratioing the number of other gas molecules to those of CO_2 in the path, hence these retrievals will underestimate the true tangent point concentrations by 0.5% per year. A second complication is that trends in MIPAS data are compared on pressure surfaces so it is also necessary to correct for the 'drift' in the vertical coordinate relative to the true pressure.

Such effects amounting to a few percent are usually negligible when comparing MIPAS measurements to other data, but for this analysis they can be significant.

A CO_2 correction is therefore applied to the temperature T and log of the volume mixing ratios $\ln v$ as follows:

$$\Delta T = \left(\frac{dT}{d\ln p}\right)\gamma(t-t_0) \qquad (1)$$

$$\Delta \ln v = \left[1+\left(\frac{d\ln v}{d\ln p}\right)\right]\gamma(t-t_0) \qquad (2)$$

where ΔT and $\Delta \ln v$ are the applied corrections, $d/d\ln p$ is the vertical gradient of the quantity with respect to log (pressure), γ is the fractional increase in CO_2, assumed to be 0.005/year, and t is the time elapsed since the reference point t_0, assumed to be the start of 2002.

The vertical gradient terms correct for the drift in the pressure grid. For example, the '100 mb' pressure surface at the start of 2004 would actually be 99 mb so, so the 100 mb value at the start of 2002 should actually be compared with the 2004 value apparently at '101 mb'. For stratospheric temperatures, this correction contributes about -0.05 K/yr to the observed trend. The extra '1' in the $\ln v$ correction is to correct for the direct impact of the incorrect pressure on the volume mixing ratio (VMR) retrieval, i.e., overestimating the tangent pressure by 1% would lead to an underestimate of the tangent VMR by 1%, hence contributing +0.5%/yr to the VMR trend. Except for regions where the VMR gradient is steep, this is usually the dominant term in the VMR trend correction.

After the CO_2 correction has been applied, sinusoidal annual and semi-annual cycles are fitted, and then subtracted from the data to allow for any regular variations in the atmospheric concentrations. For global averages, as shown in Fig. 4, the impact is relatively minor although the annual cycle, in particular, is obviously more significant when the analysis is restricted to high latitude bands.

4. RESULTS

Figs 5–11 show the results for the temperature and 6 molecules that form the ESA L2 products.

For each plot, the results for two different interpretations are listed. The 'Bias' refers to the mean of the reduced resolution data minus the mean of the full resolution data, i.e., interpreting the results as due to instrumental differences. The 'Trend' refers to the best straight line fit through the data, i.e., interpreting the results as a linear atmospheric trend (there is no reason to assume that MIPAS retrievals themselves would be subject to a linear variation with time).

Apart from the fit to the globally averaged values, separate fits have also been applied to north, south and equatorial regions divided by the latitudes ±20° (each approximately one third of the earth's surface area) to give some indication of the robustness of the signal.

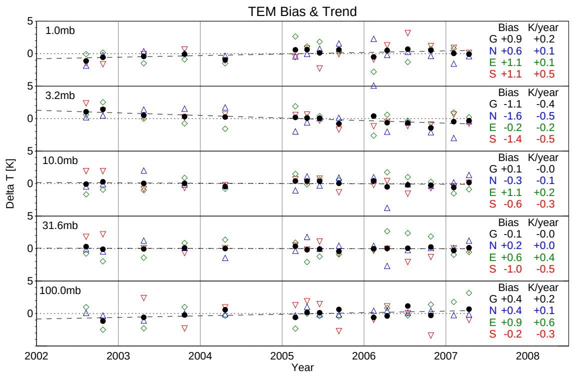

Figure 5. Global mean temperature at various pressure levels, shown as a deviation about the mean values of the time series. The solid black dots are the globally averaged values, the red triangles are the average between 20°–90°, the green diamonds the average between 20°S–20°N and the blue triangles the average between 20°N and 90°N. The dashed line is the trend fitted to the globally averaged values. Figures on the right refer to the bias (reduced resolution − full resolution) and the trend fitted to each type of average.

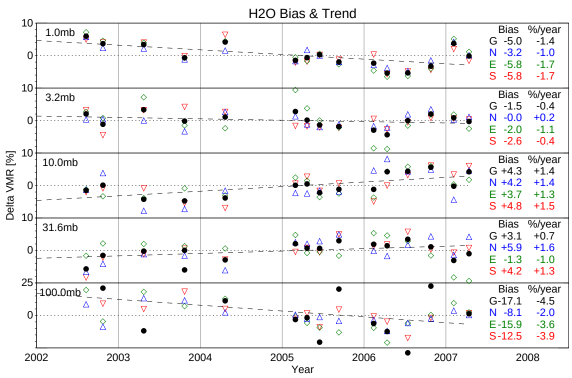

Figure 6. As Fig. 5 but for water vapour.

5. CONCLUSIONS

The results are summarised in Table 1.

The plots clearly show significant data variability, making it difficult to unambiguously ascribe either an instrumental bias or an atmospheric trend to the data. However, where the analyses applied separately to the southern, equatorial and northern regions have the same sign as the global analysis, it is at least possible to be more confident about the sign of the bias/trend for some molecules at certain pressure levels.

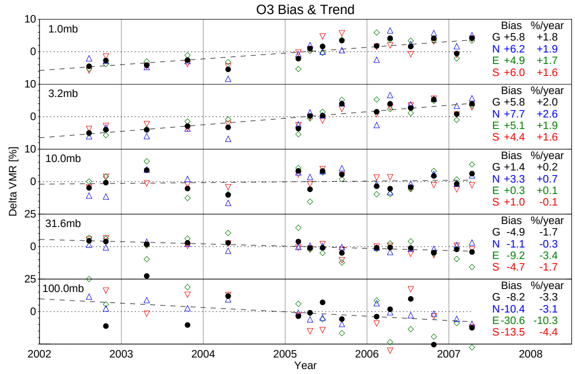

Figure 7. As Fig. 5 but for ozone.

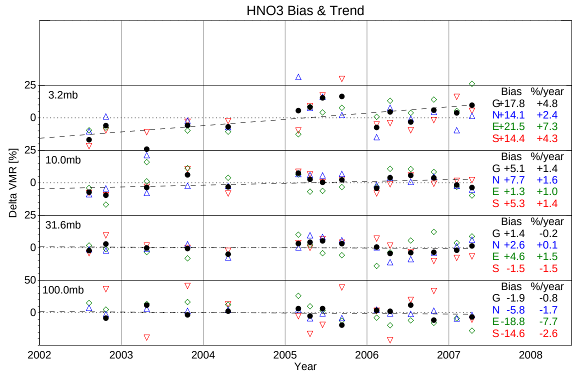

Figure 8. As Fig. 5 but for nitric acid.

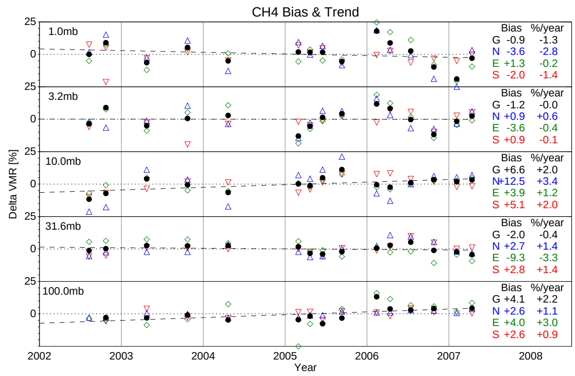

Figure 9. As Fig. 5 but for methane.

Although there is little consistency at low altitudes, there do seem to be clear patterns emerging at the high altitudes, particularly among the chemically active molecules (O_3, HNO_3 and NO_2).

Given the lack of consistency (and often sign inversions) between adjacent pressure levels, it may be possible to extract a clearer signal by vertically integrating the profiles, e.g., extracting total column amounts above the 100 mb surface. As more ESA-processed reduced-resolution data becomes available it will be possible to

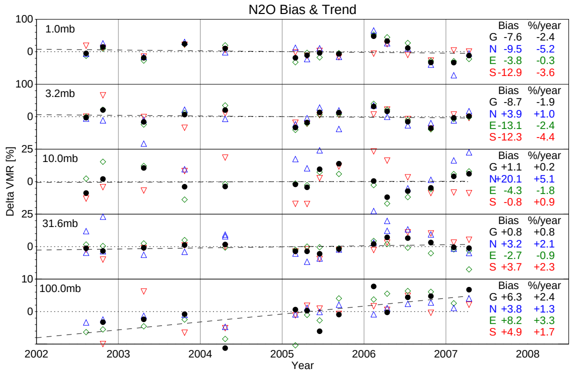

Figure 10. As Fig. 5 but for nitrous oxide.

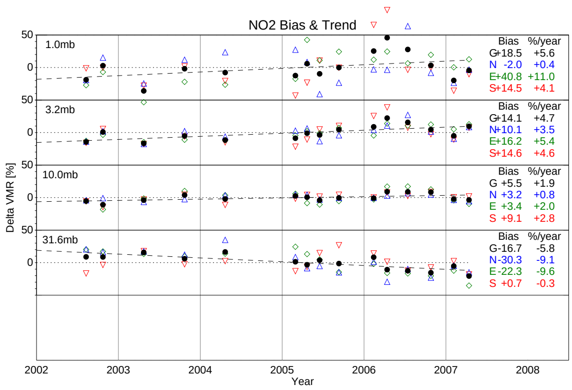

Figure 11. As Fig. 5 but for nitrogen dioxide.

Table 1. Summary of the global trends fitted to each species for various pressure levels. Bold font indicates cases where the sign of the global trend is also that of all 3 divisions into latitude bands.

	TEM	H_2O	O_3	HNO_3	CH_4	N_2O	NO_2
1 mb	**+0.2**	−1.4	**+1.8**		**−1.3**	**−2.4**	**+5.6**
3 mb	**−0.4**	−0.4	**+2.0**	**+4.8**	−0.0	−1.9	**+4.7**
10 mb	−0.0	**+1.4**	**+0.2**	**+1.4**	**+2.0**	+0.2	**+1.9**
30 mb	−0.0	+0.7	**−1.7**	−0.2	−0.4	+0.8	**−5.8**
100 mb	**+0.2**	**−4.5**	**−3.3**	**− 0.8**	**+2.2**	**+2.4**	

include many more days in such an analysis, allowing better filtering of atmospheric variability. Finally, as the MIPAS dataset continues to extend, it should be possible to identify trends with greater precision.

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