MIPAS Linear mesospheric retrieval

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INTRODUCTION

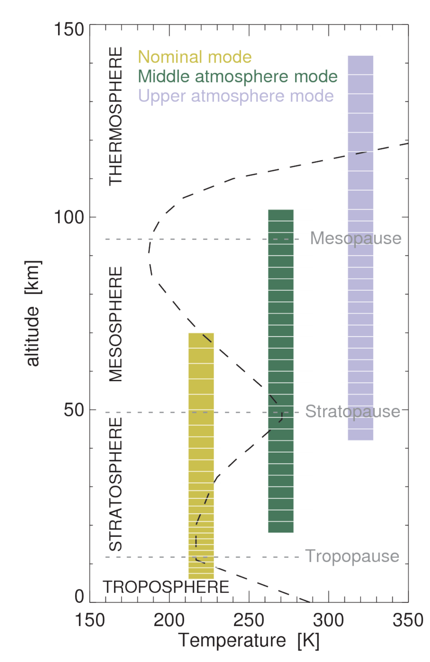
Normally, the inversion of atmospheric radiances into atmospheric parameters (such as temperature, pressure and gas concentrations) follows an iterative approach. This scheme implies that the result of the previous iteration is used as an input in the current iteration until convergence criteria are fulfilled. In order to fulfil those criteria in the mesosphere, the number of measurements required increases mainly due to the low signal to noise (S/N) ratio and hence there can be a much longer processing time.
The reason for the low S/N ratio is that in the mesosphere the atmospheric path becomes optically thin. This fact may allow the inversion of atmospheric radiances using a linear (non iterative) scheme that uses the entire emission bands of the molecules. Presumably, this would provide retrievals of improved precision, if not accuracy, compared to the operational products.

This poster describes a linear retrieval scheme used for the inversion of MIPAS limb radiances into temperature and pressure.

MIPAS

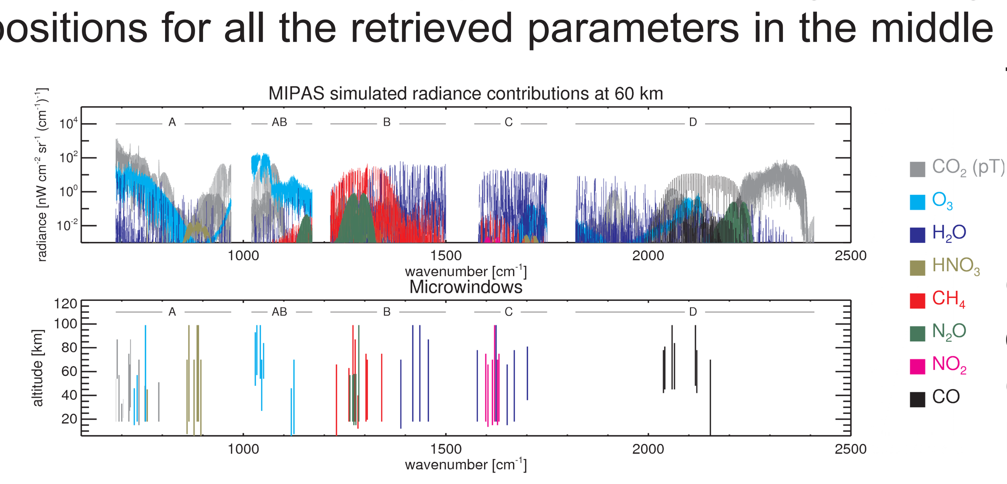
MIPAS is a high resolution Fourier Transform Spectrometer on board the ENVISAT satellite (launched in March 2002). It makes global measurements in the infrared spectrum in the range 685-2410 cm^{-1}. MIPAS nominally scans between 6 to 70 km, but under special viewing modes its altitude coverage can be extended well into the thermosphere.

The figure on the side illustrates the most common MIPAS observational modes.



ITERATIVE INVERSION SCHEMES

In general, all the MIPAS inversion schemes developed so far exploit redundancy in the MIPAS measurements which allows the selection of subsets of spectra (Microwindows) that maximize the information content. The use of microwindows instead of broader spectral intervals helps to reduce the size of the matrices involved in the inverse problem as well as the computing cost of the forward model.
Below is a simulated spectrum for a tangent height of 60 km with the microwindow positions for all the retrieved parameters in the middle atmosphere (MA) observations.



These Microwindows are currently used in the MIPAS Orbital Retrieval using Sequential Estimation (MORSE) developed in Oxford University for the MA observations.
Operational L2 products for the MA observations are not available.

LINEARIZATION

When the atmospheric path becomes optically thin, it can be shown that the radiance received by MIPAS is given by:

$$L = \sum_i B(T_i)\frac{p_i}{RT_i} l_i \sum_j v_{ij}\sigma_{ij}$$

L: Radiance
B: Planck function
T: Temperature
p: Pressure
l: lenght along the path
R: Gas constant
v: absorber concentration
σ: absorption coefficient
i: atmospheric layers
j: absorbers

This equation explains that when the optical path is optically thin, the inverse problem might be treated linearly. For example, assuming that the temperature and the pressure are known and observing an spectral region where the radiation is mainly from one gas, the only remaining unknown in the previous equation will be the gas concentration and therefore,

$$L_i = \sum_i \alpha_i v_i$$

SIMULATED DATA

Simulated data was used to test the linearity of the problem. Using a radiative transfer model, methane emission lines were simulated for the measurements as well as for the initial guess for a fixed temperature and pressure in the two cases.
The retrieved profile was computed using a linear least square fit of the form:

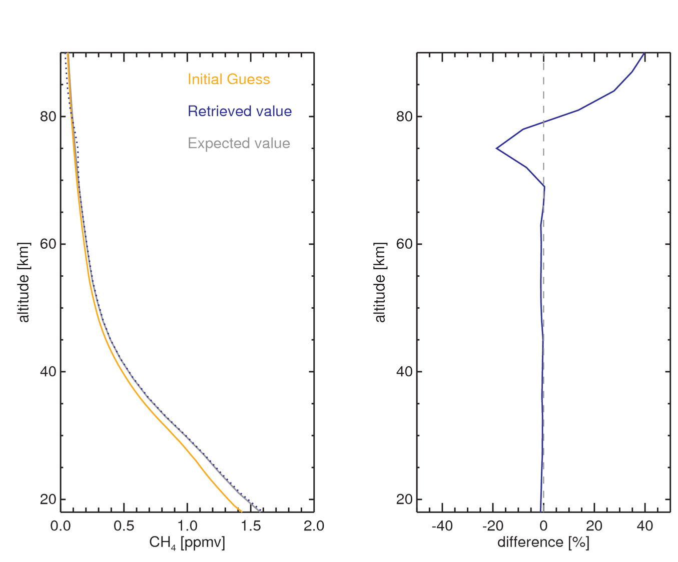
$$\mathbf{x} = \mathbf{x}_0 + (\mathbf{K}^T\mathbf{K})^{-1}\mathbf{K}^T[\mathbf{y} - \mathbf{F}(\mathbf{x}_0)]$$

x : retrieved profile
x_0 : initial guess (IG)
y : measurements
F(x_0): Forward model for IG

K: Jacobian matrix with values

$$K_{ij} = \frac{\partial F(v_i)}{\partial v_j}$$

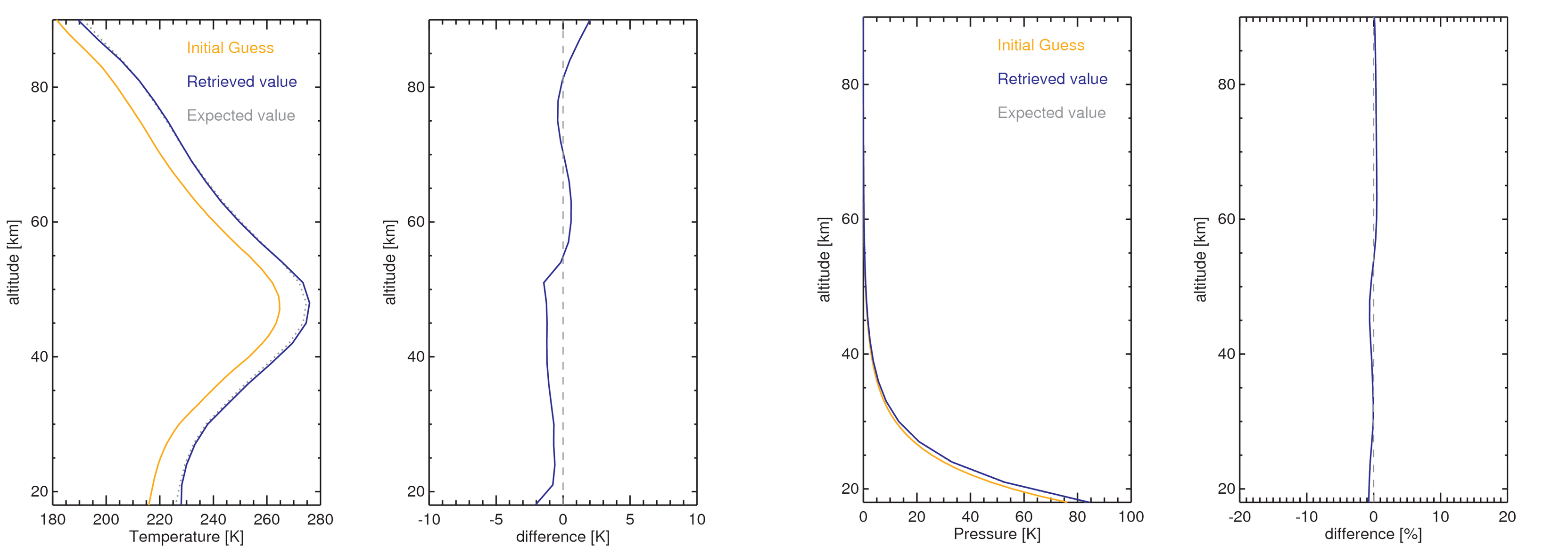
This Figure displays the initial guess, expected and the retrieved value. The expected value corresponds to a 10% increment of the initial guess.
As can be seen, there is good agreement apart for the high altitude levels. This offset has been identified as numerical noise in the radiative transfer model.
This retrieval was performed with all the CH_4 emission lines found between 1215 - 1500 cm^{-1} which corresponds to one of the spectral regions where MIPAS measures.



These results suggest that at least the retrievals of gas concentration can be done linearly in a single iteration without running the forward model during the inversion scheme. However, before retrieving any gas concentration it is necessary to know the atmospheric temperature and pressure.

SIMULATED pT RETRIEVALS

In order to test the linearity of the temperature retrieval, simulated data was used again. CO_2 spectra for the initial guess, the temperature Jacobians as well as the perturbed atmosphere (the simulated measurements) were computed. In this case, the perturbed atmosphere is 10K warmer than the initial guess.
Figure below (left) shows the initial guess, the expected and the retrieved temperature. In addition, it shows the relative difference between the expected and the retrieve temperature. Except for the upper tangent heights, there is good agreement between the expected and retrieved temperature to within 1K difference.
Figure below (right) displays the results of the pressure simulated retrieval. In this case, the perturbed atmosphere corresponds to a 10% increment of pressure from the initial guess.



The simulations presented in the previous sections suggest that it should be feasible to retrieve pressure and temperature linearly assuming that the expected value is not too far from the linearization point (the initial guess). When dealing with real measurements the altitudes derived from the on board pointing knowledge will provide an additional piece of information to constrain the temperature and pressure retrieval via the hydrostatic equation, therefore improving these retrievals.

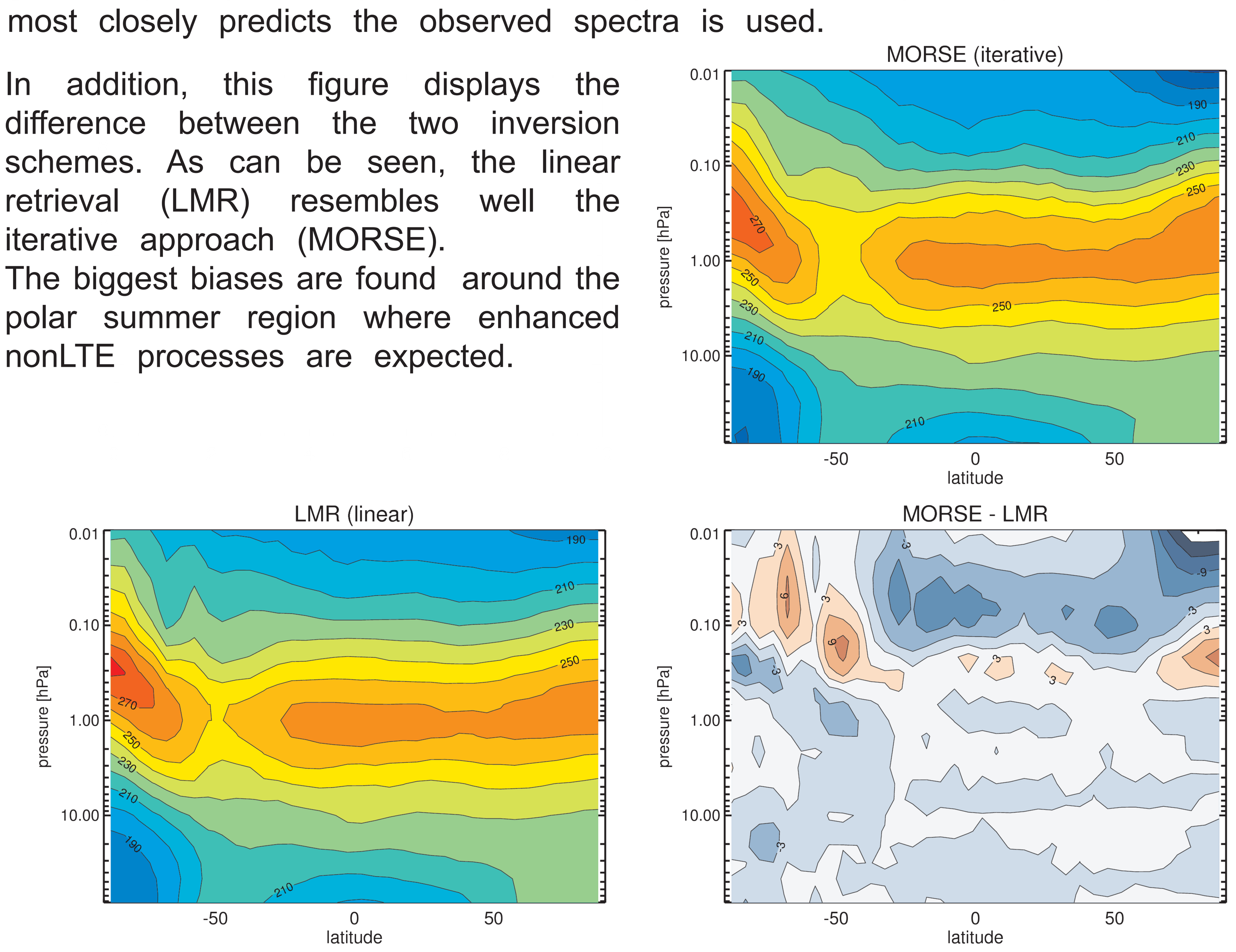
pT RETRIEVALS

Having demonstrated the linearity of the problem, a practical implementation will now be examined. The pT retrieval starts with the Level 1B data from the spectral range 685-970 cm^{-1}. The first step is to identify mesospheric emission lines of gases other than CO_2 and also CO_2 lines affected by non-LTE processes to be masked out of the measurements. This is done to avoid errors due to interfering lines of other molecules, or errors due to a difference between the local kinetic temperature and the vibrational temperature.
To do this, spectral masks for each tangent height are used to isolate emissions from CO_2 in the correspodent spectral range. These spectral masks are created simulating a spectrum with all the emitting species of that spectral region and comparing it against a CO_2-only spectrum. The emission lines that do not change by more than 10% are used.
Only lines that are above 10% of the expected NESR (noise equivalent spectral radiance) for the measurements are used in order to avoid poor signal to noise (S/N) ratio. These masks are generated individually for all tangent heights between 18-90km.
After this masking process, temperature and pressure are retrieved by a linear square fit as previously described.

pT RESULTS

This figure shows the temperature zonal mean for the 9th September 2007 for MORSE and for the Linear Mesospheric Retrieval (LMR).
The linear inversion scheme is carried out at each scan using three precomputed initial guesses (an equatorial, polar summer and polar winter atmospheric profiles), the one that most closely predicts the observed spectra is used.

In addition, this figure displays the difference between the two inversion schemes. As can be seen, the linear retrieval (LMR) resembles well the iterative approach (MORSE).
The biggest biases are found around the polar summer region where enhanced nonLTE processes are expected.



CONCLUSIONS

An alternative algorithm to retrieve temperature and pressure from MIPAS limb radiances has been introduced. This algorithm exploits the linear properties of an optically thin path making it possible to perform the inversion without re-running the radiative transfer model. This new algorithm uses the whole spectral band of the molecule rather than a small subset of it (the microwindows) and therefore, potentially, could lead to a higher precision.
Even if the linear retrieval results are not as good as the iterative scheme ones, the result of the linear scheme can be used as the first iteration step saving a lot of iterations due to its proximity to the answer.

FUTURE WORK

- Implement the linear retrieval algorithm to VMR retrievals updating the precomputed Jacobians according to the temperature and pressure retrieved.
- Comparison of the linear retrievals against other datasets.

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