Combined Ozone Retrieval using the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) and the Tropospheric Emission Spectrometer (TES)

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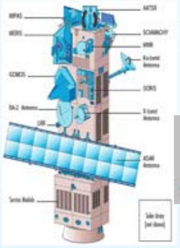
Abstract

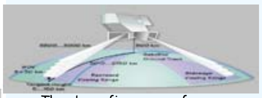
The main advantage in combining limb and nadir geometries is that it allows the stratospheric and tropospheric ozone concentrations to be separated which makes it possible to improve the tropospheric ozone retrieval. The Tropospheric Emission Spectrometer (TES) is a high-spectral-resolution infrared imaging Fourier transform spectrometer operated by NASA's Jet Propulsion Laboratory (JPL). It has a spectral range from 3.2µm to 15.4µm and at present is mostly operating in the nadir mode. TES routinely measures temperature and concentrations of O3, H2O, CH4, CO, HNO3, and N2O.

A local optimal estimation retrieval code (the MIPAS Orbital Retrieval using Sequential Estimation (MORSE)) was used to retrieve Volume Mixing Ratios (VMR) from the low resolution ESA level 1B MIPAS data and level 1B TES data. A joint retrieval was achieved by using the MIPAS retrieved VMR profiles as the apriori for the TES retrieval. A similar method could be used in the future to combine MIPAS and IASI.

The Michelson Interferometer for Passive Atmospheric Sounding (MIPAS)

MIPAS was launched on 1st March 2002 on ESA's ENVISAT satellite and measures infrared emission spectra from the limb of the atmosphere at a spectral resolution of 0.0625cm-1 since August 2004. MIPAS has both a backwards (used for routine observations) and a sideward view (used for special observations).

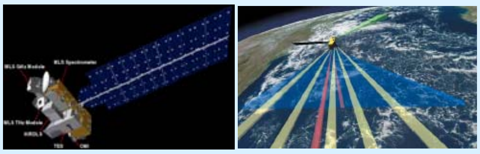




The above figures are from http://envisat.esa.int

The Tropospheric Emission Spectrometer (TES)

The Tropospheric Emission spectrometer (TES) was launched on NASA's EOS AURA satellite in July 2004. TES is a high-spectral resolution infrared-imaging Fourier transform spectrometer developed, built, tested and operated by NASA's Jet Propulsion laboratory (JPL). TES has a spectral range from 3.2µm to 15.4 µm and is capable of performing both nadir and limb observations. TES routinely measure temperature, concentrations of O3, H2O, CH4, CO, HNO3, NO2.

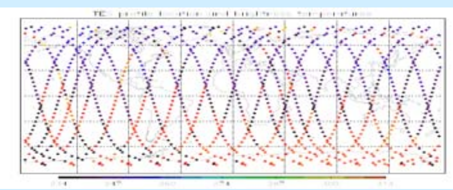


[http://aura.gsfc.nasa.gov/spacecraft/index.htm] [Image produced by Jesse Allen (ssai)]

The figure on the left shows the location of each instrument on the AURA satellite. The field of view of each instruments on AURA are shown in the figure on the right (red = TES, blue = OMI, yellow = HIRDLS and green = MLS).

Profile Selection

Six TES profiles and corresponding MIPAS profiles where selected for this study. The TES profiles where selected to be over the ocean to avoid any complications due to retrieving over land. Clean sky profiles have been used to avoid cloud contamination of the measurements at the lower altitudes.



This figure is a global map of the brightness temperatures of the TES scans for the 28th January 2005.

The brightness temperature of the scan was used to determine if that scan was over clear sky (high brightness temperature indicating clear sky and low brightness temperature indicating that there are probably clouds in that view). The closest MIPAS scan to the selected TES scans was used for the retrievals.

Joint Retrieval

Limb viewing instruments have a longer path length than nadir viewing instruments which allows them to detect smaller concentrations of trace gasses that can not be detected by nadir viewing instruments. However the longer the path length, the greater the possibility of the scan being contaminated by clouds for the lower altitudes. Therefore limb geometries provide more accurate stratospheric retrievals whereas nadir geometries produce more accurate tropospheric retrievals.

Combining limb and nadir measurements takes advantage of the strengths of both viewing geometries. This makes it possible to separate out the stratospheric ozone contribution to the total ozone column allowing for a better tropospheric ozone retrieval.

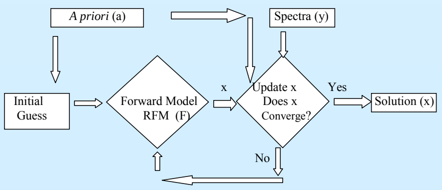
Retrievals scheme

A local optimal estimation retrieval code (the MIPAS Orbital Retrieval using Sequential Estimation (MORSE)) was used to retrieve Volume Mixing Ratios (VMR) from the low resolution ESA level 1B MIPAS data. This retrievals uses the Oxford Reference Forward Model (RFM) and the same microwindows as are used for the ESA operational retrievals. This constrained the solution to be close to an *a priori* solution, in this case a standard equatorial atmosphere. The solution is found by minimizing the cost function χ^2 (Eq.1).

$$\chi^2 = (\mathbf{y}-\mathbf{F}(\mathbf{x}))^T \mathbf{S}_y^{-1}(\mathbf{y}-\mathbf{F}(\mathbf{x}))+(\mathbf{x}-\mathbf{a})^T\mathbf{S}_a^{-1}(\mathbf{x}-\mathbf{a}) \quad \text{Eq.1}$$

Where $\mathbf{F}(\mathbf{x})$ is the forward model estimate, $\mathbf{x}$ is the retrieval state vector, $\mathbf{y}$ is the measured spectrum, $\mathbf{a}$ is the *a priori* estimate and $\mathbf{S}_y$ and $\mathbf{S}_a$ are the covariances of $\mathbf{y}$ and $\mathbf{a}$ respectively.

This method is less sensitive to noise than other methods, but can introduce an *a priori* bias into the profiles. The flow chart below shows the mechanism of the retrieval process.



A similar optimal estimation retrievals code was used to retrieve temperature, ozone and water vapour profiles as well as surface temperature and pressure from TES level 1B data. This retrieval also used the Levenberg-Marquardt method to prevent the retrieval from not converging.

The joint retrievals were achieved by using the MIPAS retrieved temperature, pressure and ozone profiles as the *a priori* for the TES nadir retrievals. The MIPAS retrieved profiles are on a slightly different altitude from that of the TES nadir retrievals so the profiles and the corresponding covariances were interpolated to the appropriate altitude grid (Eq.2-3).

$$\mathbf{x}'=\mathbf{B}\mathbf{x} \quad \text{Eq.2}$$

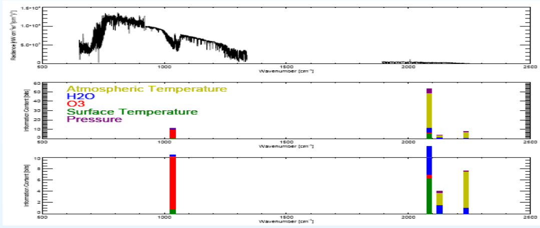
$$\mathbf{S}_x'=\mathbf{B}\mathbf{S}_x\mathbf{B}^T \quad \text{Eq.3}$$

TES Microwindow Selection

To select the microwindows for the TES nadir retrieval a simulated spectrum, covering the TES spectral range, was split into three wavenumber-wide microwindows. The information content was calculated for surface temperature, pressure, temperature, ozone and water vapour for each microwindow using the Eq.4.

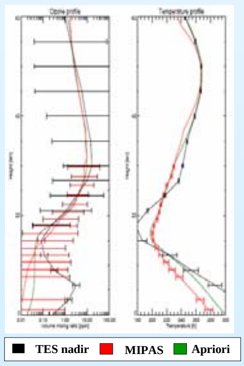
$$\text{Information content} = -0.5 \log_2 (|\mathbf{S}_x| / |\mathbf{S}_a|) \quad \text{Eq.4}$$

Where $\mathbf{S}_x$ and $\mathbf{S}_a$ are the covariances of the state vector and the *a priori* respectively. The four microwindows with the largest total information content where selected for the TES nadir retrieval.



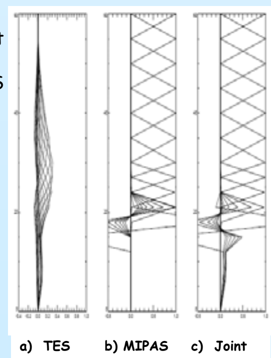
The top plot shows a typical TES nadir spectrum . The middle plot shows the location of the four selected microwindows and the corresponding information content for a joint retrieval of surface temperature, pressure, ozone, water vapour and atmospheric temperature profiles. The bottom plot is a blown up version of the above plot. The width of the microwindows has been increased by ± 10 cm-1 from the central point for this plot.

Initial Results



A TES nadir retrievals was run using the previously described retrieval and microwindows using the TES l1B data for scan 51 of orbit 2855 for the 28th January 2005. The retrieved Ozone and temperature profiles are shown in the Figure below along with the MIPAS retrieved profiles from the closes scan to the TES Scan and the climatology profiles. It can be seen that there is a problem with the TES retrieval at low altitudes which needs to be solved before a joint retrieval can be attempted.

The averaging kernels where calculated for the measurement and apriori covariances of the TES nadir retrieval, the MIPAS retrievals and a joint retrieval. These show that as expected the TES averaging kernels are broader than those for MIPAS. MIPAS had a larger number of independent pieces of information then the TES. The number independent pieces of information did increase for the combined retrieval but not by as much as expected.



$$\mathbf{A}= \mathbf{I}-(\mathbf{S}_x\mathbf{S}_a^{-1}) \quad \text{Eq.5}$$

$$\text{Number of independent pieces of information} = \text{Trace}(\mathbf{A}) \quad \text{Eq.6}$$

Conclusion

The results show that there needs to be further work on the TES nadir retrieval. The analysis of the averaging kernels and the independent pieces of information indicated that the microwindows selected for the TES nadir retrievals are not as suitable for a joint retrievals, therefore a new set of microwindows needs to be selected for the joint retrieval.