A joint retrieval of CO and vibrational temperature from MIPAS-ENVISAT

Joanne Walker and Anu Dudhia

Atmospheric, Oceanic and Planetary Physics, Oxford University, UK

Abstract

MIPAS is a limb viewing fourier transform spectrometer operating in the infrared. It scans the tangent altitude range 5-68 km at a vertical resolution of approximately 3 km. CO has various natural and anthropogenic sources including forest fires and industry. In the troposphere, CO is the main sink of the principal oxidising agent - the OH radical - and so reduces its capacity for the removal of other atmospheric pollutants. In the stratosphere, its intermediate lifetime makes it useful as a tracer for stratospheric motions and tropospheric-stratospheric exchange. However, the retrieval of CO from a limb sounding IR instrument is complicated because of non-LTE effects. Ordinarily, the internal vibrational energy level populations are controlled by collisions between molecules and follow the translational (kinetic) energy distribution of the ambient gas (LTE). However, if collisions are infrequent, radiative processes can lead to a non-Boltzmann distribution of the internal energy level populations (non-LTE). CO is strongly affected by non-LTE in the IR down to around 60 km and modelling these processes is difficult. These effects are especially problematic in the limb viewing geometry due to the long path length travelled through the upper atmosphere. However, using a joint CO and vibrational temperature retrieval it is possible to estimate the non-LTE effects without modeling the energy level populations. Instead, we retrieve a parameterisation of the non-LTE effects, T_v, directly from the observed spectra.

The non-LTE Problem

At high pressures collisions between CO and the ambient gas ensure the populations of the vibrational states of CO follow the kinetic energy distribution of the surrounding gas (Local Thermodynamic Equilibrium [LTE]). However, at low pressures, other processes dominate. During the day, CO is excited into higher energy states, mainly pumped by solar radiation. Few collisions mean that these states are maintained out of equilibrium with the surrounding gas. If collisions are infrequent, radiative processes can lead to a non-Boltzmann distribution of the internal energy level populations (non-LTE). CO is strongly affected by non-LTE in the IR down to around 60 km and modelling these processes is difficult. These effects are especially problematic in the limb viewing geometry due to the long path length travelled through the upper atmosphere. However, using a joint CO and vibrational temperature retrieval it is possible to estimate the non-LTE effects without modeling the energy level populations. Instead, we retrieve a parameterisation of the non-LTE effects, T_v, directly from the observed spectra.

Retrieval Precision

Retrieval precision is calculated using an a priori uncertainty of 100% for CO 14 and 10% for T_v, as:

\[ \text{S}_v = \left( \frac{kT_v h}{k} \right)^{-1} \]

where \( S_v \) is the instrument noise covariance; \( k \) is the forward model covariance and \( S_v \) is the a priori uncertainty covariance. The plots below show the expected precision. We expect retrieval errors for CO of better than 20% at most altitudes and better than 15% below around 18 km.

Retrievals from Real Data

A comparison of the CO only LTE retrieval using MORSE (MIPAS Orbital Retrieval using Sequential Estimation) [1] and the new joint retrieval of CO and T_v, using LMRVT from a daytime scan is shown below. The T_v climatological profile has been derived from a non-LTE populations model [4]. Using the joint retrieval the T_v profile is close to the climatological profile and the retrieved CO VMR is lower at higher altitudes, as expected.

Vibrational Temperature of CO Isotopologues

The non-LTE characteristics of the weak isotopic lines are not well understood but may affect the CO retrieval. CO isotopologues in the Earth’s atmosphere in order of abundance are: 12C16O, 13C16O and 12C13O.

By averaging 3050 spectra from a single day (01-01-2003), isotopic lines become visible.

The plots below show the observed radiance plotted against the RFM modelled LTE radiance. At 68 km the observed radiance is enhanced with respect to its LTE value due to non-LTE effects. The non-LTE enhancement differs between isotopes. At 33 km the observations are closer to the modelled LTE radiance.

Conclusions and Future Work

If we do not attempt to account for non-LTE, we retrieve unrealistically high values of CO in the daytime at high altitudes. However, we can perform a joint CO, T_v, retrieval to account for these non-LTE effects. This does not significantly degrade retrieval precision below around 21 km. The joint retrieval produces T_v that is reasonably consistent with expected values and the retrieval of CO appears to be improved. Investigations into the CO isotopologues suggest that they may have slightly different T_v and we have been able to make an estimate of these T_v profiles.

References