Retrieval of Tropospheric CO Profiles Using Correlation Radiometer:
I. Retrieval Experiments for a Clear Atmosphere

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ABSTRACT

This paper discusses the retrieval scheme associated with the gas correlated radiometer—MOPITT which will be on board of EOS—AM1 to measure the global vertical profiles of carbon monoxide. The vertical resolution and retrieval errors caused by errors in the temperature profiles and in the surface temperature have been assessed. The main results are:

a. Assuming the noise equivalent radiance (NER) of $1.8 \times 10^5$ W m$^{-2}$ sr$^{-1}$, the surface temperature can be deduced from the wide band signals with uncertainty less than 1 K, and the atmospheric term of the modulated signal can be deduced with errors almost equal to the NER which does not significantly increase errors in the retrieved CO profiles.

b. With typical uncertainty in temperature profiles, errors in the retrieved profiles at latitudes lower than 70$^\circ$ are generally less than 20% with the first guess of 100 ppbv. (If a better first guess was used, the errors may decrease).

c. By incorporating the total column CO amount derived from the reflected solar radiation in 2.3 $\mu$m spectral region into the retrieval, the accuracy of the retrieved CO profile below 6 km may be greatly improved.

d. In the retrieval experiment with 10 CO profiles representing the typical CO profiles, the r.m.s. relative / absolute errors of the retrieved CO profiles are about 10% / 15–20 ppbv.

Key words: CO retrieval, Correlation radiometer, MOPITT

1. Introduction

Measurement of CO profiles in the troposphere is of primary importance for improving our understanding of the global system. This opinion has been put forward in the report of the World Meteorological Organization (1985): “Definition of trends and distribution for tropospheric CO is essential.” (World Meteorological Organization, 1985). This is because Carbon monoxide (CO) plays a very important role in the chemistry of the troposphere and lower stratosphere through its influence over hydroxyl radical (OH) and ozone concentration. Because of its short atmospheric residence time (2–3 months) and nonuniform geographical distribution, it is necessary to monitor the temporal—spatial change of CO around the globe. For this purpose, a gas correlation radiometer—Measurements of Pollution in the Troposphere (MOPITT) was proposed by Drummond at University of Toronto and selected for EOS—AM1 platform. The operation of this instrument is based on the correlation spectroscopy technique which has been used successfully for radiometers on board Nimbus 4,5,6 and 7 (Abel et al., 1970; Curlic et al., 1974; Ellis et
al., 1973; Drummond et al., 1980). Technical improvements include the combination of two modes of modulation: pressure modulation radiometer (PMR) and length modulation radiometer (LMR). The former has been used in several applications while the latter is a new design suitable for the detection of lower troposphere where the atmospheric pressure is higher.

As an initial study of the retrieval schemes for MOPITT project, this paper describes the retrieval scheme using the gas correlation signals in two spectral regions: the CO fundamental band around 2140 cm\(^{-1}\) (4.7 \(\mu\)m) and the first overtone around 4260 cm\(^{-1}\) (2.4 \(\mu\)m), the achievable accuracy and other related problems. CO profiles measured by Seiler and Fishman (1981) are used in a line–by–line code to simulate the upward propagating atmospheric radiation and the signals measured by the PMRs or LMRs. A non–linear iteration scheme is proposed to retrieve CO profiles from these signals. The total column CO amount derived from the 2.3 \(\mu\)m reflected solar radiation is used to improve the retrieval accuracy in the near–surface layer. The effects of the absorption by other gases such as methane, ozone, water vapor and nitrous oxide on the measurement as well as the retrieval in the presence of solid clouds will be discussed in a separate paper. Discussing the basic retrieval scheme and corresponding limits and accuracy, this study will lay a basis for further operational retrieval algorithms.

2. Basic equations

The principle behind correlation spectroscopy is that of spectral selection of radiation emitted or absorbed by a gas using a cell containing a sample of the same gas as the filter. Using two cells containing different amounts of the gas concerned, the differential transmittance of the two cells will be zero in the whole spectral interval except at the center or near the wing region of the absorption lines of this gas. This is equivalent to a filter which can selectively pass the radiation modulated by certain gas, but eliminate the interference by other gases. The modulation of gas in the cell can be achieved by many methods. For tropospheric detection, Drummond at the university of Toronto proposed to use combinatively LMRs and PMRs. Technically, LMR can be modulated to higher cell pressure. It is more suitable for the detection of lower troposphere. Due to a first approximation, it is the product of the mass of gas and the half width of absorption line that affects the transmittance of the cell, PMRs may be equivalent to LMRs in the discussion of retrieval scheme. The radiative transfer equations in a plane–parallel atmosphere for a two state correlation radiometer (PMR or LMR) are:

\[
S_{w0} = \frac{1}{2} G_w \int_{\Delta r} \tau_{iw} \left[ I_r - \int_0^{p_s} q(p)(I_r - B_r) \frac{k_r(p)}{g} \tau_r(p) dp \right] dv,
\]

\[
S_{m0} = G_w G_m \int_{\Delta r} \tau_{im} \left[ I_r - \int_0^{p_s} q(p)(I_r - B_r) \frac{k_r(p)}{g} \tau_r(p) dp \right] dv,
\]

where \(S_{w0}\) is the wide band radiance (W m\(^{-2}\) sr\(^{-1}\)), \(S_{m0}\) is the side band radiance (W m\(^{-2}\) sr\(^{-1}\)) or modulated signal, \(G_w\) and \(G_m\) are the electronic gains of the wide band and side band channels, respectively, \(p_s\) is the pressure at the ground surface, \(p\) is the atmospheric pressure, \(I_r\) is the surface emission which is a function of the surface temperature, \(B_r\) is the Planck function as a function of atmospheric temperature (pressure), \(\tau_r(p)\) is the atmospheric transmittance, \(k_r(p)\) is the CO absorption coefficient, \(q(p)\) is the CO mixing