The Brewer Umkehr algorithm for ozone profile retrieval: a complete account of multiple scattering of light

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Abstract. Umkehr measurements are the source for determination of the ozone vertical distribution. The standard Umkehr retrieval algorithm uses approximate scheme for account of multiple scattering of light: a multiple scattering correction is subtracted from measured intensities (or N-values), but following retrieval uses the weighting functions calculated for single scattering. A version of retrieval algorithm, which treats multiple scattering completely both in the radiance correction and in the weighting functions, is under investigation.

Intorduction

The Umkehr measurements became a regular source of the vertical ozone distribution since beginning of 1960th. Daily measurements of the ozone profile are performed now at more than hundred stations equipped with Brewer and Dobson spectrophotometers. *Mateer and Dutsch* [1964] proposed a computer algorithm for retrieval of ozone profile for application to Dobson instruments. The algorithm was repeatedly revised later, what strongly improved quality of obtained ozone data. *Mateer and DeLuisi* [1992] improved ozone climatology and temperature dependens of ozone absorption cross sections. An algorithm of *Petropavlovskih et al.* [2000] uses new aerosol climatology taking into account volcanic eruptions. *Petropavlovskih et al.* [*2000*] improved quality control of Umkehr radiance data and proposed an approach to their corrections. Based on Dobson algorithm an algorithm for the Brewer spectrophotomer was developed by C.T. McElroy [*McElroy et al. 1989*, *1995*].

This work proposes an approach to reduce retrieval error of Umkehr ozone profile by improving treatment of multiple scattering radiance in the Umkehr algorithm.

Treatment of multiple scattering radiance in standard Umkehr algorithm

A standard Umkehr retrieval algorithm uses approximate scheme to compute multiple scattering of light. A radiative transfer model taking into account only single scattering of light is the basis for real-time processing of data. To correct measured radiance, a look-up table of multiple scattering corrections for preset atmospheric scenarios is used. But besides radiance the retrieval algorithm uses the weighting functions (WFs), which are derivatives of radiance with respect to ozone profile. The WFs are calculated using single scattering approximation. But necessary multiple scattering correction isn't applied in this case.

The simplified scheme for consideration of the WFs results in increased errors of the ozone retrieval, which was first noticed in paper [*Elansky and Postylyakov, 2000*]. Since that time, a radiative transfer model MCC++ was developed for application in retrieval algorithms. The MCC++ model take into account all orders of scattering and may calculate both intensities and weighting functions for application in Umkehr algorithm [*Postylyakov 2004a, 2004b*].

The MCC++ code employs Monte Carlo method of conjugate walk for spherical atmosphere. It is fast enough to be used in a real-time Umkehr retrieval. The MCC++ code allows calculating the weighting functions necessary for inversion of Umkehr radiance measurements within 18 min (Run time was estimated for calculation with accuracy 0.1-1% at the PC based on the AMD Athlon 1460 MHz.). The Umkehr weighting functions are calculated simultaneously at 6 wavelengths from 306.3 to 329.5 nm and 8 solar zenith angles from 77^{O} to 90^{O} for 20 atmospheric layers of 5-km thickness.

Error analysis in case of approximate calculation of weighting functions

We compared retrieval errors of a Brewer algorithm, which take into account approximate weighting functions calculated for single scattering radiance, with errors of an algorithm based on a radiative model treating all orders of scattering. Both

algorithms use the radiance intensity computed for all order of scattering.

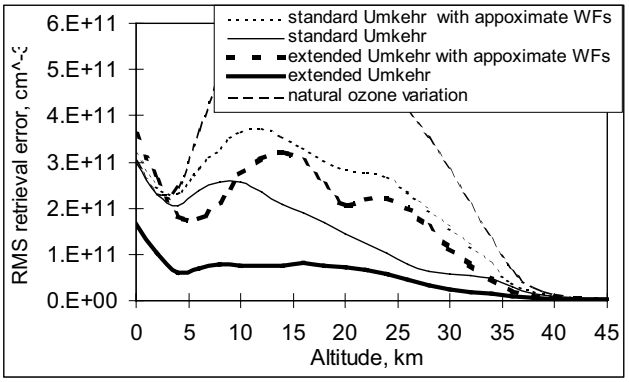

Figure 1. Ozone retrieval rms errors of the extended and standard Brewer Umkehr algorithms for the exact and approximate WFs.

The rms errors of the standard network Brewer Umkehr method for exact and approximate weighting functions is show in Figure 1. More accurate radiative transfer model (with multiple scattering) gives better result not only bellow 15-20 km, where multiple scattering is significant, but at all altitudes, as well as for estimation of total ozone content.

Authors proposed earlier a new extended Brewer Umkehr algorithm [Elansky et al. 1999]. Unlike the standard algorithm, retrieving ozone profiles from ratios of the radiations at the pairs of the wavelengths, the extended method uses measured values (radiation) directly. The elimination of unnecessary transformation of experimental data from the algorithm has made it possible to reduce the error of the ozone profile retrieval. Figure 1 shows that the extended Umkehr algorithm is more sensitive to radiative transfer model in comparison with standard one. However, when model with multiple scattering is used, errors of extended algorithm are less then errors of standard algorithm. Moreover the extended algorithm reduces errors by a factor of 1.5-2 below 20 km.

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The algorithms, error analysis and retrieved ozone profiles obtained with improved algorithm, completely taking into account multiple scattering, will be presented. The first results of comparison of ozone vertical profiles retrieved by the improved algorithm, profiles [Kosmidis et al. 2004a, 2004b] retrieved by algorithm developed by McElroy et al [*1989*, *1995*] and ozone sounds at Thessaloniki (40.5 N, 23.0 E) will be analyzed.

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