Intercomparison of O3 profiles observed by SCIAMACHY, ground based microwave and FTIR instruments

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Introduction

The ozone profile is of interest because ozone is one of the most important trace gases in the atmosphere. Ozone is a green house gas and provides shielding from UV radiation. Following the discovery of the ozone hole [1] a large effort has been put into understanding the reason for it and to establish a network for monitoring the further development of the ozone layer. Although the emission of human made chemicals (CFCs) has been curbed, the rise in the water vapor content of and the decrease of the temperature in the stratosphere still give reasons of concern about the ozone layer (e.g. [2]).

Remote sounding instruments are used to monitor various atmospheric properties like trace gases from ground or satellite. In the upper stratosphere and above very few if any in-situ measurements are available. All remote sounders are indirect instruments in the sense that they measure a more or less complicated function of the quantity of interest [3]. In order to understand and interpret the data taken it is necessary to understand the relationship between the true atmospheric state and the quantity measured. It is also necessary to validate and compare remote sounders on a continuous basis in order to enhance the quality of the measurements and to assess the stability of the combination instrument/retrieval [3].

The instruments

O_3 profiles from SCIAMACHY on Envisat

SCIAMACHY, the Scanning Imaging Absorption spectrometer for Atmospheric CHartographY BB1999 is a novel satellite-borne scientific instrument capable of performing spectroscopic measurements of the chemical composition of the Earth's atmosphere in three different observation geometries: nadir, solar/lunar occultation and limb scattering. SCIAMACHY covers the spectral range from 220 nm to 2380 nm with a spectral resolution varying from 0.2 nm to 1.5 nm depending on wavelength. In limb scattering geometry the instrument line of sight follows a slant path tangentially through the atmosphere. The geometrical field of view of SCIAMACHY in limb scattering mode is about 2.8 km vertically and 110 km horizontally. The Earth's limb is viewed in flight direction and scanned from tangent heights of about 0 km up to 100 km in steps of 3.3 km. Furthermore, at every tangent height step an azimuthal (horizontal) scan is performed covering about 960 km at the tangent point. Therefore the limb measurement mode amounts to an averaging over about 1000 km perpendicular to the orbit track. Along the flight track the averaging occurs over a distance of about 400 km.

The stratospheric O_3 profiles used here are derived from SCIAMACHY limb scattering measurements in the Chappuis-bands of O_3. The retrieval algorithm employed is similar to the one described in [4]. A linearized version of optimal estimation (OE) is used together with the radiative transfer model SCIARAYS to iteratively retrieve stratospheric O_3 concentration profiles. The altitude range from about 15 km up to 40 km can be covered with this technique.

The millimeter-wave radiometers BreRAM and RAM

The millimeter-wave radiometers RAM (**R**adiometer for **A**tmospheric **M**easurements at Ny Alesund, 78N, 11E) and BreRAM (**Bre**men **R**adiometer for **A**tmospheric **M**easurements at Bremen, 53N, 8E) are very similar. The instruments are heterodyne millimeter-wave radiometers tuned at the frequency of O_3 lines at 142 GHz (RAM) and 110.836 GHz (BreRAM). Both instruments are operated in total power mode. In order to resolve the spectra the instruments use AOS spectrometers with a bandwidth of about 1 GHz and a effective resolution of 1.3 MHz. The receiver noise temperature is about 3000 K. This enables both instruments to measure a spectrum of the O_3 line every half an hour. Millimeter-wave radiometers are insensitive to meteorological conditions and clouds and do not depend on sun light. Millimeter-wave radiometers provide therefore the most complete time series of the ozone profile.

The O_3 profile information is retrieved from the spectra using Optimal Estimation Methods (see section 3 and [5]). Information about the vertical ozone distribution between 15 km and 55 km with a height resolution of 15 km at its best can be obtained.

The RAM instrument at Ny Alesund is routinely compared to sonde measurements taken at Ny Alesund. Hence the RAM is validated up to 25 km. Comparisons to LIDAR and satellite measurements have been undertaken with good results.

The infrared spectrometer FTIR

Solar and lunar absorption measurements using FTIR spectroscopy (Fourier Transform Spectroscopy) have been performed at Ny Alesund since 1992 [6]. If weather conditions permit, spectra are recorded at a maximum resolution of 0.005 cm^{-1}. Vertical profiles of ozone were retrieved from these spectra with the SFIT2 algorithm developed at NASA Langley Research Center and the National Institute for Water and Atmospheric Research (New Zealand) [e.g. 7]. Based on [8] and [9] a spectral interval between 1000 and 1004 cm^{-1} was choosen for the retrieval. Daily launched balloon sondes provide pressure and temperature profiles and the initial vmr-profiles of water up to 30 km. The initial vmr-profiles of ozone are based on ozone sondes launched once or twice a week at Ny Alesund. For all other gases the initial vmr-profiles are based on balloon observations performed in the Arctic at Fairbanks. The spectral line parameters were taken from the ATMOS database ATMOS1996.

Comparison of profiles

After applying the Optimal Estimation method in order to retrieve a profile from the measured spectrum an instrument model is obtained. The instrument model relates the true atmospheric profile to the retrieved profile.

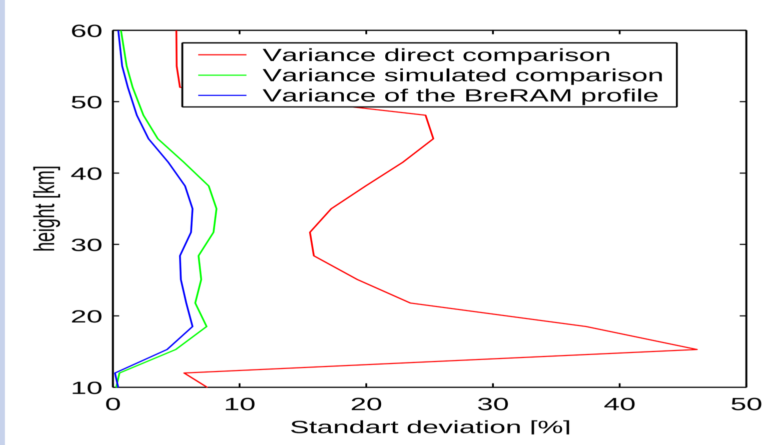

Figure 1: Expected Standart deviations of direct comparison comparison with simulated profile and the BreRAM profile.

The following notation is used:

- A is the averaging kernel matrix
- x_{True} is the true ozone profile
- $\hat{x}$ is the retrieved ozone profile

Index 1 denotes quantities derived from the ground based instruments BreRAM, RAM, FTIR, respectively. Index 2 denotes quantities derived from SCIAMACY measurements. The instrument model is:

(1) $$\hat{x} = x_a + A(x_{True} - x_a)$$

In the following will be assumed that all retrievals $\hat{x}_1$, $\hat{x}_2$ are obtained using the same a priori profile x_a. An retrieval 1 is simulated by an retrieval 2 by

(2) $$\hat{x}_{12} = x_a + A_1(\hat{x}_2 - x_a)$$

The difference of the measured and the simulated profile is

(3) $$\Delta_x = \hat{x}_1 - \hat{x}_{12} = (A_1 - A_1 A_2)(x_{True} - x_a)$$

with the covariance

(4) $$S = (A_1 - A_1 A_2) S_a (A_1 - A_1 A_2)^T + S_1 + A_1 S_2 A_1^T$$

In figure 1 is the expected deviation of the difference. It is obvious that the comparison using simulated profiles is much better than the direct comparison of the profiles by $\Delta x = \hat{x}_1 - \hat{x}_2$.

Results

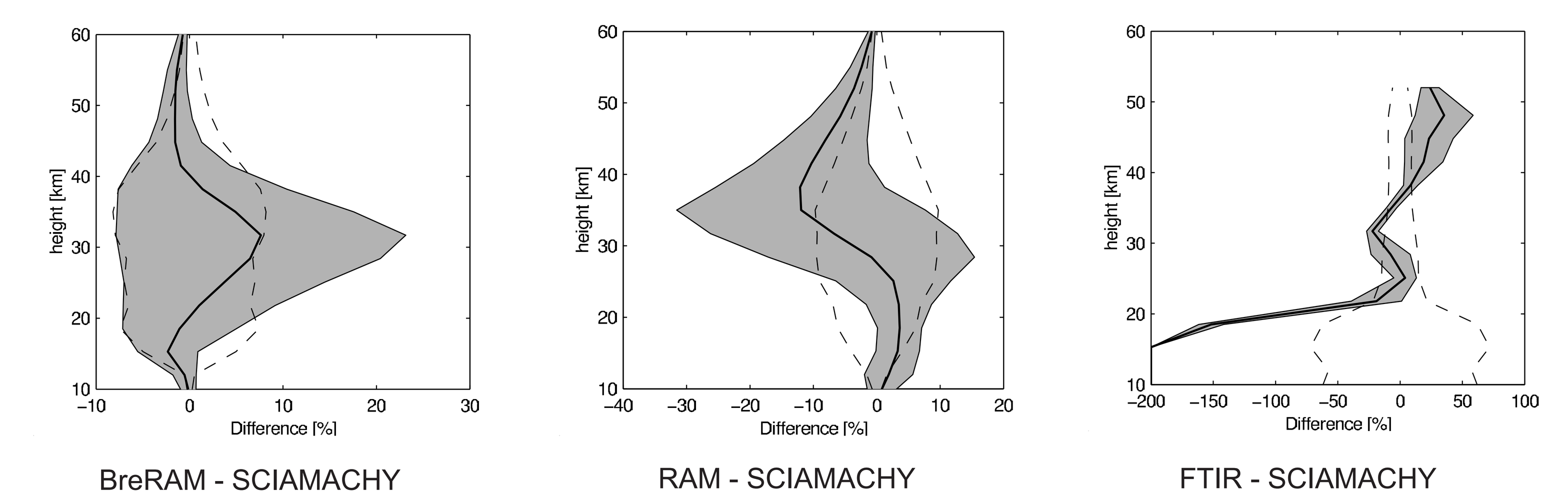

Figure 2: Relative mean differences($2*(\Sigma(\hat{x}_1-\hat{x}_{12})/(\hat{x}_1+\hat{x}_{12}))$). The shaded area is the standard deviation of Δx and the dashed line denotes the expected deviation of Δx ($diag(S)^{0.5}$).

The relative mean differences between BreRAM/RAM and SCIAMACHY show good agreement (figure 2). The RAM measures higher vmr than the SCIAMACHY instrument above 35 km. The SCIMACHY and FTIR instruments differ significantly below 20 km and between 30 and 35 km altitude. There are very sparse conincident measurements SCIAMACHY/FTIR with most of them on the 1th of August 2003. This renders the statistical comparison preliminary. However, the general shape is found and the results are included for completeness.

The SCIAMACHY instrument still exhibits a pointing error for all measurements used in this study. This might contribute to the differences between the RAM and the SCIAMACHY instruments.

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RAM

SCIAMACHY