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SIMULATION AND DATA PROCESSING OF GOMOS MEASUREMENTS

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ABSTRACT

In this paper the data simulation and data inversion studies for stellar occultation measurements are discussed. The specific application is the GOMOS instrument which has been proposed for the first European Polar Platform, POEM-1.

1. INTRODUCTION

The global mapping and monitoring of the atmosphere is one of the most important tasks of the present day atmospheric physics. In this endeavor instruments aboard polar orbiting satellites will play a central role. Here we report on the data analysis of one of the proposed instruments. This instrument is called GOMOS or Global Ozone Monitoring by Occultation of Stars. GOMOS has been proposed for the European Polar Platform by Service d'Aeronomie du CNRS (France) and the Finnish Meteorological Institute (Bertaux et al., 1988; Bertaux et al., 1991). GOMOS has been accepted for flight aboard the first polar platform, POEM-1, in 1998.

The GOMOS instrument consists of a pointing platform, a telescope, two diffraction gratings and two-dimensional CCD-detectors. The pointing platform picks up 25-40 different stars per orbit and follows them from a tangent height of 100 km down to 15 km. The spectrum of a star is measured at about 1.7 km intervals. CCD allows a good spectral resolution, which in GOMOS is 0.6 nm (the pixel size is 0.3 nm). The spectral range extends from 250 nm up to 675 nm and separate channels are located at 750 nm and 950 nm with a better spectral resolution of 0.06 nm. The large wavelength range accompanied by the good resolution allows us to monitor several gases like O_3, NO_2, NO_3, H_2O, O_2, neutral density, and aerosols. For more details on the GOMOS project and instrument, see Leppelmeier et al. (this volume).

In order to estimate the capabilities of the stellar occultation method we have to create a data processing chain from the simulated measurements to the final data products. This paper will give a summary of the work for the data simulation and data inversion carried out at the Finnish Meteorological Institute.

2. DATA SIMULATION

The signal simulation consists of four different tasks. First we must calculate the coordinates of the possible measurement points. The calculation can be performed after the orbit of the satellite is fixed and the preliminary designs of the satellite and the instrument are available. Critical items are the required signal to noise ratios and the perturbations exerted on the satellite by the instrument's pointing maneuvers. Different measurements scenarios have been investigated by Korpela, 1991. The obvious solution for the second task, the stellar spectrum simulation, is to use the blackbody model. While this gives a reliable starting point in estimating the signal to noise ratios the finer details like Fraunhofer lines are not included. Therefore we have also made use of the solar spectrum which is damped to stellar values.

The largest task of the signal simulation is the calculation of the transmission of atmosphere. While comprehensive simulation packages like LOWTRAN are available we have preferred to construct a specialized simulation model (Kyrölä et al., 1992). The composition of the atmosphere is described by functions: $f_j = f_j(z, \theta, t)$ giving number densities of different constituents as a function of altitude, latitude, and time. The present version of the program includes the neutral density, aerosols, O_3, NO_2, and NO_3. The cross sections of different absorbers are included as tables and possible temperature dependence is taken into account by linear interpolation from cross section tables measured at different temperatures. The solar light scattered into the instrument's input aperture is calculated using single scattering approximation. The significant attenuation due to atmospheric refraction is also included. The wavelength region is 250-675 nm covering the main measurement region of GOMOS.

The last step in the signal simulation is the instrument simulation. This includes adding the noise components (photon noise, dark current and read-out noise), performing the instrumental convolution, and applying the appropriate instrumental parameters on the signals.

3. DATA INVERSION

The main data product of an occultation measurement is the horizontal transmission function of the atmosphere. The transmission function is the basis for all the more detailed information about the atmospheric composition.

To obtain the tangential transmission function we must first estimate the solar scattering signal and the dark current which are mingled with the occultation signal itself. The scattering term can be estimated from that part of the CCD where the stellar light is not distributed (note the two-dimensional nature of the CCD). We can also make an estimate of the attenuation due to scintillations and refraction. The GOMOS instrument will include two fast photometers which facilitate the detection of scintillations. The remaining transmission is only due to absorption and scattering and it is called T_{obs}.

In order to extract more specific information about the atmosphere we must present a model which connects the tangential transmission function with the atmospheric composition. The Beer-Lambert law gives

$$T_{obs}(\lambda,\ell,t) = e^{-\tau(\lambda,\ell,t)} \qquad (1)$$

where the extinction coefficient (or the optical depth) can be written as

$$\begin{aligned} \tau(\lambda,\ell,t) &= \sum_j \int_\ell \rho_j(z(s),\theta(s),t)\sigma_j(\lambda,T(s))ds \\ &= \sum_j \mathrm{N}_j(\ell,t)\sigma_j(\lambda) \end{aligned} \qquad (2)$$

The tangential column density of the gas j along the measurement line ℓ is

$$N_j(\ell,t) = \int_\ell \rho_j(s,t)ds \qquad (3)$$

The second equality in Eq. (2) holds only for gases having temperature independent cross sections. Otherwise it can serve as a good approximation if the tangent point temperature is used as a reference temperature. The second form in Eq. (2) decouples the spectral and spatial problems which greatly simplifies the inversion problem. In the following we assume this separability. Alternative solutions for the inversion problem are discussed in references (Chu et al., 1989; Kyrölä et al., 1992; Tamminen et al., 1992)

4. SPECTRAL INVERSION

We have approached the spectral inversion problem posed by Eqs. (1)-(2) using probability concepts. Due to a relatively large amount of noise the inherently Poissonian noise processes can reasonably well be approximated by Gaussian processes which makes the problem much more easy to approach. The tangential column densities are determined by using the maximum likelihood method. We have carried out extensive comparisons between the original nonlinear formulation given by Eq. (1) and the obvious linearised formulation and found that the nonlinear formulation gives consistently the most reliable results. The following figure (Fig. 1) gives the inversion results for ozone as a function of the tangent height and the visual magnitude of the star. The dependence of the ozone retrieval accuracy on the spectral type of the star is exemplified in Fig. 2. The retrieval accuracy for NO_2 and NO_3 is shown in Fig. 3.

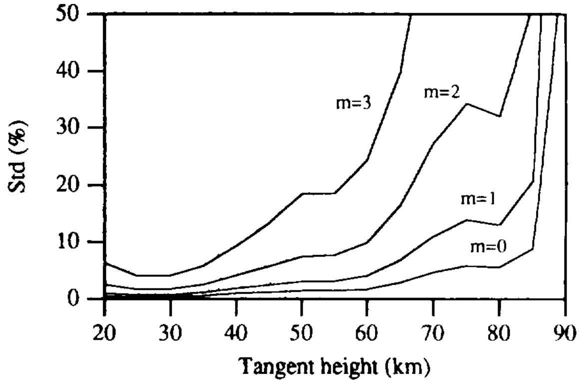

Fig. 1. Retrieval accuracy for the tangential column density of ozone between 20-90 km. The stellar spectrum here is equal to the solar spectrum damped to magnitudes 0-3.

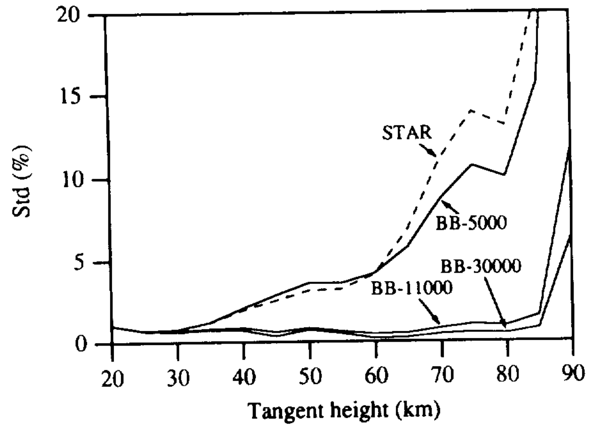

Fig. 2. Impact of the spectral type of the star on the retrieval accuracy of ozone (m=1). "STAR" is the damped solar spectrum.

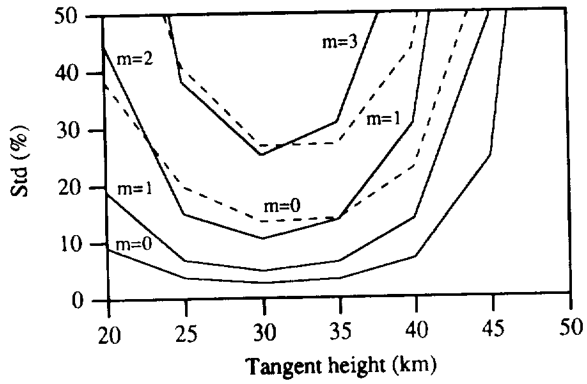

Fig. 3. Retrieval accuracy for NO_2 (solid line) and NO_3 (dashed line). The stellar spectrum is equal to the solar spectrum.

5. VERTICAL INVERSION

The vertical inversion problem is posed by Eq. (3). Assuming a spherical symmetry and ignoring the refraction the problem can be reduced to the well-known Abel-integral inversion (Roble and Hays, 1972). In a realistic case we divide the atmosphere into volume cells and face a discrete inversion problem. Traditionally a local inversion is performed i.e., the measurements at the same location but with different tangent heights are inverted using for example the onion-peel method. With stellar occultations we can have a large number of measurements with adjacent locations so we can also try to do a kind of atmospheric tomography. We are studing several methods both for local and global inversion. A preliminary example of the results is shown in Fig. 4 (Tamminen et al., 1992).

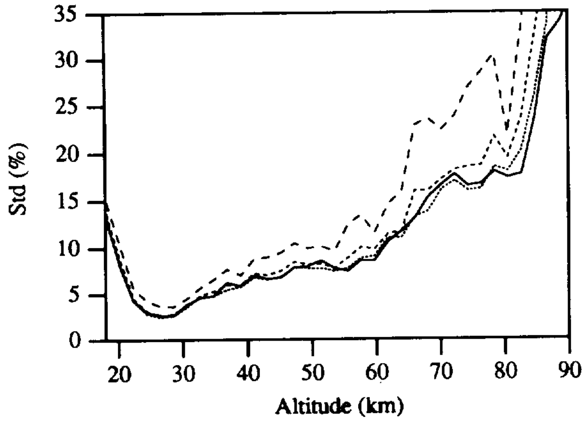

Fig. 4. An example of the retrieval accuracy for ozone density in the global inversion. The solid line represents the calculation by the onion-peel method combined with the LSQR method. The other curves are applications of the algebraic reconstruction technique.

6. CONCLUSIONS

The stellar occultation technique offers a promising method to study the global distributions of important trace gases in the Earth's stratosphere. The measuring principle is stable and stars as light sources yield to a global coverage and to a good vertical resolution. The method is therefore especially good for monitoring the global ozone trend.

The characteristic property of the data inversion in the stellar occultation method is the large amount of data. To comply with the amount of data we are inclined to divide the inversion problem into two subproblems. In the first stage the spectral information is inverted which results in tangential densities of different atmospheric constituents. In the second step either a local vertical inversion is performed i.e., we invert the measurements with the same star or we can make a global inversion where measurements with different stars are combined to produce a global map of the atmosphere. The latter method is mathematically closely related to computerized tomography.

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