GOMOS - Global ozone profiler

E. Kyrölä and J. Tamminen

Finnish Meteorological Institute
Geophysical Research Division
P. O. Box 503,
FIN–00101 Helsinki
FINLAND

Tel: +358 9 1929 4640
Fax: +358 9 1929 4603
E-mail: errki.kyrola@fmi.fi
http://www.geo.fmi.fi

The Global Ozone Monitoring by Occultation of Stars instrument (GOMOS) will be launched on board ESA's Envisat satellite in 2002. GOMOS will measure ozone and trace gases in the atmosphere by detecting the absorption of starlight in UV, visible and infrared wavelengths. GOMOS will deliver ozone and other trace gas profiles at altitudes 15-90 km with a good vertical resolution and with a global coverage. As a self-calibrating method stellar occultation measurements provide a basis for long-term monitoring of ozone profiles. GOMOS has been developed and will be operated by ESA. Finland has a special interest in GOMOS: The Finnish Meteorological Institute was one of the main proposers of the instrument in 1988 and has thereafter played a major role in the project.

Introduction

Ozone is a minor constituent (mixing ratios of order part per million) in the Earth's atmosphere but plays a crucial role in shielding Earth's biosphere against solar UV-radiation. Ozone is also a central element in the stratospheric chemistry and it has an important role in determining the thermal structure of the atmosphere. Observations in the mid of 1980's revealed a large springtime ozone hole over Antarctica and subsequent analysis have shown a general slow declining trend of total ozone content in the stratosphere. The principal reasons for these two processes are understood presently quite well. The key ingredient is the release of man-made CFC-gases to the atmosphere. The international treaties starting from Montreal 1988 have led to a decline in the amounts of CFC-gases released to the atmosphere. This has already been reflected in the amounts of CFCs in the atmosphere. These decreasing trends will affect the stratospheric ozone concentrations slowly - the recovery time of the ozone is about 50 years. The coupling of the enhanced greenhouse effect and the ozone problem is a new dimension in the ozone problem and consequences are not yet clear, partly because the greenhouse warming estimates vary considerably. A continuous, global monitoring of ozone is needed for years to come.

The most important requirements for the monitoring of the ozone in the stratosphere are: a good vertical resolution, a good global coverage, and the suitability of measurements for the long-term trend detection. The GOMOS (Global Ozone Monitoring by Occultation of Stars) instrument on board ESA's Envisat satellite is an instrument that is able to answer to these main ozone-monitoring requirements identified. The Finnish Meteorological Institute (FMI) has a special interest in GOMOS. FMI proposed GOMOS (together with the Service d'Aeronomie from France) for ESA's POEM-1 satellite in 1988. The satellite is now called Envisat.

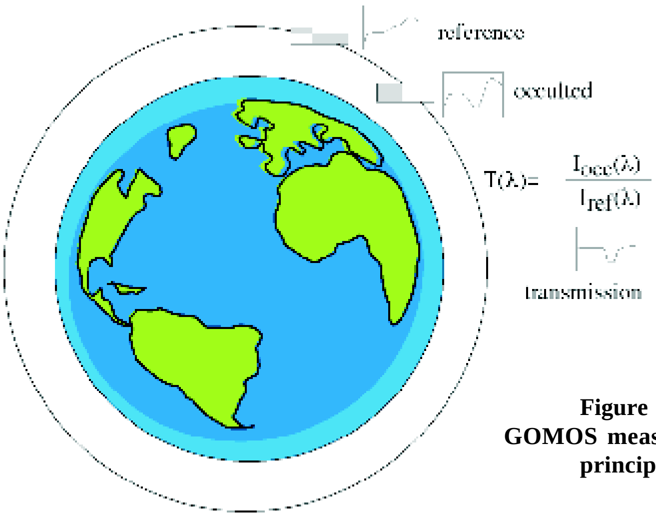

Figure 1. GOMOS measurement principle

Dr. Erkki Kyrölä is leading the Aeronomy research group at the Geophysical Research Division of the Finnish Meteorological Institute. He is one of the original proposers of the GOMOS instrument. He has been involved in the development of the GOMOS measurement principle since 1988 and has been leading the GOMOS Expert Support Laboratory work at FMI. He is a member of the GOMOS SAG. Kyrölä is also a member of the Odin Science Team and leading FMI's effort to establish a Level 2 processing centre for OSIRIS data.

Phil. Lic. Johanna Tamminen is preparing a Ph.D. thesis on Markov chain Monte Carlo methods and the application of these methods on geophysical inversion problems. She has taken part in the development of GOMOS Level 2 inversion algorithms and the GOMOS mission planning algorithms.

GOMOS

The GOMOS instrument is a spectrometer using the stellar occultation measurement principle in monitoring ozone and other trace gases in the Earth's stratosphere (see Bertaux et al., 2000; Envisat special issue, 2001; Envisat-GOMOS, 2001). The main wavelength region is the ultraviolet visible channel 250-675 nm. Additional two channels are in the infrared at 756-773 nm and at 926-952 nm. The species covered by GOMOS are O_3, NO_2, NO_3, H_2O, O_2, OClO, BrO, neutral density, temperature, and aerosols. The two fast (1 kHz) photometers allow investigations of atmospheric turbulence. Photometer data provide also high-resolution temperature profiles. Measurements cover the altitude region 15-100 km.

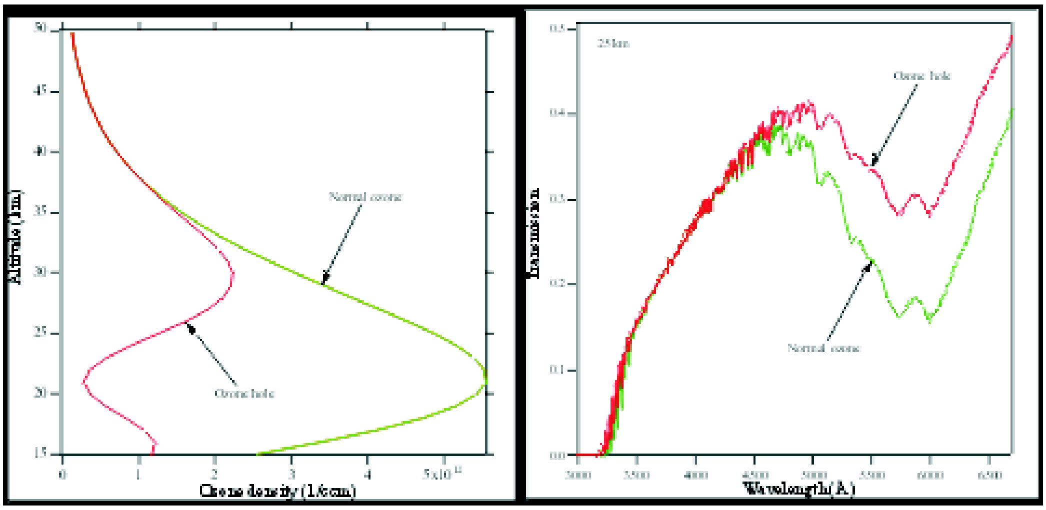

Figure 2. Left: Simulated ozone profiles in Antarctica during normal and ozone hole conditions. Right: Theoretically calculated horizontal transmissions through the Antarctic stratosphere during normal and ozone hole conditions at 25-km tangent height. The transmission through the stratosphere increases considerably during the ozone loss

The important benefit of occultation measurements is the self-calibration. The reference stellar spectrum is first measured when a star can be seen above the atmosphere. During the occultation repeated observations through the atmosphere at descending altitudes provide spectra with absorption features (see Fig. 1). When these occulted spectra are divided by the reference spectrum, nearly calibration-free horizontal transmission spectra are obtained. Transmissions provide the basis for retrieval of atmospheric constituent densities (see Fig. 2). The self-calibration means that GOMOS measurements can be used to create long time series and data from any new similar instrument can be joined with the GOMOS data without difficult calibration questions. The limb viewing geometry, the point source nature of stars and short enough measurement integration time mean a good vertical resolution. The vertical integration distance is less than 1.7 km. A typical global coverage of measurements is shown in Fig. 3. During 24 hours, the total number of occultations is 400-600. Measurements are obtained from both nightside and dayside of the Earth.

The GOMOS data processing levels are 1b and 2. Main level 1b products are transmission spectra, photometer fluxes and limb radiance spectra from dayside occultations. Level 2 products are geophysical data like ozone and other trace gas profiles. The ground processing is divided to the near-real time processing and the off-line processing. ESA will take charge of the near-real time processing of Levels 1b and 2 and the off-line processing of Level 1b. The off-line processing centre for Level 2 will be located at the FMI's Arctic Research Centre in Sodankylä (the FIN-CoPAC facility). The dissemination of off-line data will be through DLR's D-PAC in Oberpfaffenhofen. Some part of the Level 2 products will be delivered directly to various Meteo Offices and other users, as fast delivery products (available within 3 hours of ground reception).

Finland, FMI and GOMOS

As already mentioned FMI was the one of the original GOMOS proposers in 1988. After the proposal FMI's aeronomy group in the Geophysical Research Division has been extensively involved in almost all areas of the GOMOS project. These include mission definition and planning, instrument definition, data processing algorithm development, development of in-flight calibration and geophysical validation, and development of the ground processing facilities.

The development work for GOMOS in Finland has been based on several joint projects between FMI and the Finnish and foreign industrial companies. The GOMOS work in Finland has been funded directly by TEKES but most of the funding has been channelled through contracts from ESA.

The Instrument Application Software delivered by *Space Systems Finland Ltd.* (SSF) will control the measurements and the pointing of the instrument. SSF has also delivered software for the Envisat ground stations. The software will be installed in the ground processing centres of ESA and the Finnish Meteorological Institute in Finland. SSF has also delivered the Software Maintenance Facility, which is used to validate and maintain the application software during the development phase and in orbit.

Patria Finavitec Oy Systems Divsion has supplied the Science Data Electronics unit, which controls the spectrometers, photometers and star tracker sensors. It collects science data, pre-processes and packs GOMOS data. In addition Patria has delivered ground support and test equipment. *VTT (Technical Research Centre of Finland)* has participated in all phases of the GOMOS-development in 1988 - 1997. VTT has been responsible for the characterisation of the GOMOS-grating including imaging quality measurements and definition of the optimum focal plane location.

GOMOS data utilisation and continuation

GOMOS is expected to produce data in a continuos fashion at a rate of about 5 Gigabytes per day. After the operational processing chain the size of the central Level 2 product, the profiles of trace gases and temperature, is about 300 kilobytes. It is clear that the information content of data is so large so that a detailed, continuos inspection is beyond any available resources. This means that the effective utilisation of operational satellite data must be based, at least partly, on the operational approach. For atmospheric instruments like GOMOS the assimilation approach seems to offer a way to proceed. In assimilation measurement data is fused with the atmospheric model. FMI and other GOMOS ESL-partners have participated in the MSDOL-project (funded by EU) to study GOMOS-data assimilation to a chemical transport model ROSE. The aim is to provide global ozone maps from GOMOS measurements (see Fig. 3) and also to help in the geophysical validation of GOMOS measurements. The assimilation process itself gives a valuable information about the correctness of the used atmospheric model. The better atmospheric models will give possibilities for chemical forecasting in the short and long-term.

GOMOS data will be used to investigate the change in the stratospheric and mesospheric chemical composition. Especially for the Nordic countries the development of the arctic ozone hole will be of central interest. In addition to trace gas profiles GOMOS is able to measure temperature profiles and aerosol distribution including the detection of stratospheric clouds. The presence of clouds in a very cold, dynamically stable stratosphere is the key ingredient in the polar ozone loss and GOMOS is able to monitor all these elements.

The most important contribution form GOMOS is expected to be data for accurate trend analysis of the stratospheric and mesospheric trace gases especially ozone. Envisat's expected lifetime is 5 years. In order to make meaningful trend analysis this life span is too short and GOMOS data must be joined with similar instruments in the past and in future. In the past there are no operational stellar occultation measurements so we need to look for future. As a potential successor for GOMOS, FMI has proposed (with several Finnish and foreign partners) a small stellar occultation instrument named COALA for satellite missions planned ESA, NASA and NASDA. So far without success. For the new presently open Earth Explorer Opportunity mission call FMI has proposed an instrument called OLIVIA (Occultation and limb viewing of the atmosphere). This concept is based on COALA but enhances the bright limb measurement capability of the instrument following the successful demonstration of the bright limb method by Odin's OSIRIS instrument.

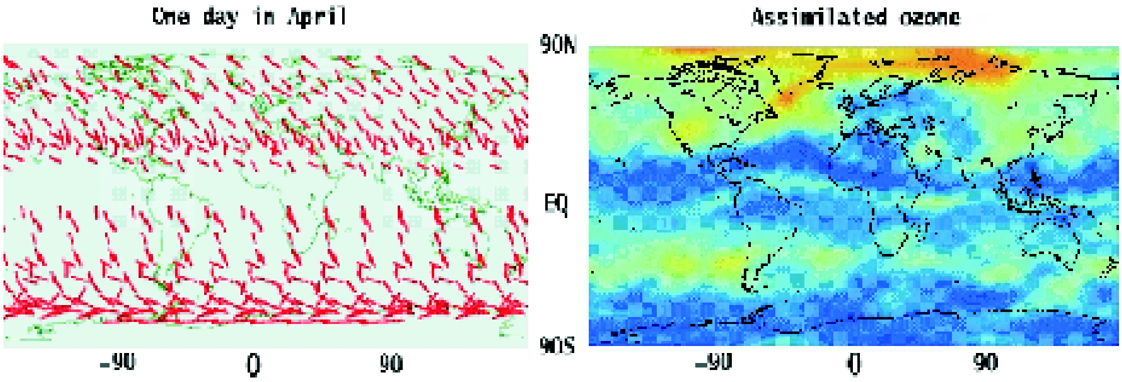

**Figure 3.
Left: Distribution of GOMOS measurement points during 24 h. the distribution of occultations varies as a function of the season.
Right: Simulated GOMOS ozone measurements assimilated to chemical transport model.**

References

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