SCIAMACHY – A Hyperspectral Sensor for Global Atmospheric Studies

S. Noël, H. Bovensmann, J. P. Burrows, and J. W. Kaiser
Institute of Environmental Physics
University of Bremen, FB 1
D–28334 Bremen, Germany
Telephone: +49-421-218-9666
Fax: +49-421-218-4555
Email: Stefan.Noel@iup.physik.uni-bremen.de

***Abstract*— The Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) is a hyperspectral space-based spectrometer covering almost continuously the spectral range between 240 nm and 2380 nm. SCIAMACHY will measure both the extraterrestrial irradiance and the earthshine radiance, i.e., sunlight which is transmitted, reflected or scattered by the Earth's atmosphere or surface. Measurements will be performed in nadir, limb, and both solar and lunar occultation geometry. Inversion of the SCIAMACHY measurements will provide the amount and distributions of a large number of atmospheric constituents in the stratosphere and troposphere (O_3, NO_2, H_2O, CO_2, CH_4, N_2O, BrO, CO, O_2, NO, SO_2, H_2CO, OClO, and possibly ClO).**

I. Introduction

SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography) is a space-based spectrometer which is part of the atmospheric chemistry payload of ESA's environmental satellite Envisat which is scheduled for launch in 2001.

The SCIAMACHY instrument was conceived to improve our global knowledge and understanding of a variety of issues of importance for the chemistry and physics of the Earth's atmosphere (troposphere, stratosphere and mesosphere) and potential changes resulting from either anthropogenic behavior or natural phenomena such as:

- Stratospheric Ozone: the focus being the behavior of the 'ozone hole' and mid-latitude ozone as the halogen loading of the stratosphere reaches its maximum
- Tropospheric pollution arising from industrial activity and biomass burning
- Troposphere-stratosphere exchange
- Special events such as volcanic eruptions, solar proton events, and related regional and global phenomena

The SCIAMACHY project is funded by Germany, The Netherlands, and Belgium. A smaller version of SCIAMACHY, the Global Ozone Monitoring Experiment (GOME), is already operating successfully on the ERS-2 satellite, which was launched in 1995 (see e.g. [1]). A detailed description of the SCIAMACHY mission and instrument is given in [2].

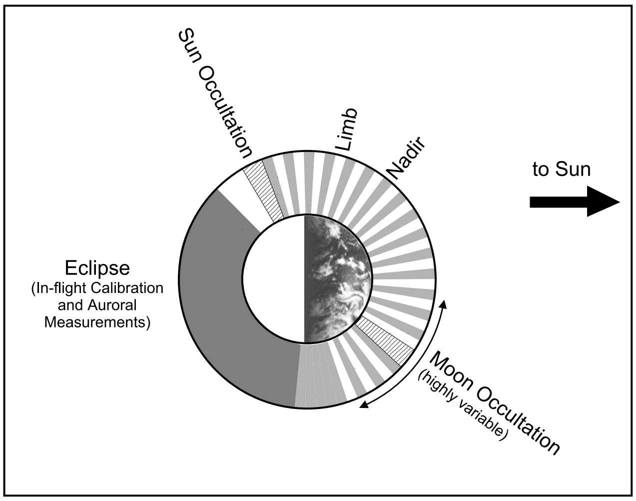

Fig. 1. Typical sequence of SCIAMACHY measurements during one Envisat orbit.

II. SCIAMACHY Measurements

SCIAMACHY will perform measurements of both the extraterrestrial irradiance and the Earthshine radiance, i.e., sunlight which is transmitted, reflected or scattered by the Earth's atmosphere or surface. The measured spectra will cover almost continuously the wavelength range from 240 nm to 2380 nm. Recent calibration measurements have shown that this spectral range may even be extended down to about 215 nm. Measurements will be performed in nadir, limb, and both solar and lunar occultation geometry. Fig. 1 shows the typical sequence of measurements during one orbit.

During most of the sunlit part of the orbit limb and nadir measurements will alternate. Solar occultation measurements will be performed once per orbit on the northern hemisphere. At times when the moon is visible for SCIAMACHY also moon occultation measurements will be performed. This will be the case for about one week per month on the southern hemisphere. The eclipse part of the orbit is filled mainly with calibration measurements. The addition of dedicated auroral measurements on the nightside is currently under discussion. With this measurement pattern global coverage will be achieved in 6 days.

A. Nadir Measurements

The nadir observational mode is used by many other space-borne remote sensing instruments, also by GOME. In nadir mode SCIAMACHY is looking downwards to the Earth. Scans perpendicular to the flight direction are performed. The nominal ground swath size is 960 km, but there is also the possibility to use a smaller swath size of 120 km. The integration times and thus the spatial resolution in nadir mode is for most of the orbit not limited by the sensitivity of the instrument but by the available data rate. To overcome this problem, a flexible instrument concept has been developed which allows to define spectral regions with shorter integration times (higher spatial resolution) than others. The actual definition of these spectral regions is currently under discussion. Therefore it is at the moment not possible to specify the spatial resolution for each individual data product. However, using this feature it is expected that for most data products a typical nadir spatial resolution of about 30 km (along track) × 60 km (across track) will be achieved.

B. Limb Measurements

SCIAMACHY will be one of only a few instruments performing limb measurements in the UV-VIS-NIR spectral region, among these the OSIRIS instrument on ODIN, which was launched in early 2001. In limb geometry the instrument looks tangentially to the Earth's surface towards the edge of the atmosphere. While probing tangent altitudes from 0 to 100 km, SCIAMACHY will perform scans in horizontal (across-track) direction with a swath size of about 960 km at the tangent point. The vertical resolution of the limb measurements will be about 3 km. The limb viewing geometry is especially suited to derive information on the vertical distribution of atmospheric constituents.

C. Occultation Measurements

SCIAMACHY will perform solar occultation measurements as well as lunar occultation measurements on a regular basis. The viewing geometry in these observational modes is similar to limb. In solar occultation the sun is observed directly through the atmosphere, in lunar occultation the moon.

The opportunities for solar occultation measurements by SCIAMACHY are limited by the sun-fixed orbit of Envisat and the forward viewing direction. SCIAMACHY will perform measurements of the rising sun through the atmosphere once per orbit over the northern hemisphere. Solar occultation measurements will cover the tangent altitudes from the surface up to about 100 km. During the occultation measurement, vertical scans over the complete sun will be performed with a vertical resolution at the tangent point of approximately 2.6 km. Due to this scanning the same tangent altitude is probed several times.

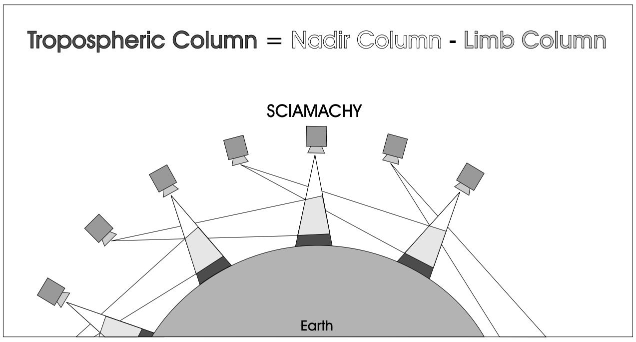

Fig. 2. Retrieval of tropospheric columns from the combination of near-simultaneous limb and nadir measurements.

During lunar occultation measurements, SCIAMACHY directly observes the rising moon through the atmosphere, covering tangent altitudes from about 17 km to 100 km. There are also lunar occultation measurements below 17 km planned, but these measurements will most likely be affected by the presence of clouds. Therefore the quality of these low-altitude moon occultation measurements has to be assessed on an individual basis. Lunar occultation measurements place a special challenge on mission planning, as the moon is only visible (with a phase larger than 0.5) for about one week per month in the southern hemisphere. Moreover, the actual start and end times of these lunar observation opportunities vary strongly from month to month, and they differ for each year. Based on the current operational concept it is foreseen to perform lunar occultation measurements at least every second orbit during times when the moon is visible for SCIAMACHY.

The large variability of the lunar occultation measurements is of special scientific interest, because large regions of the southern hemisphere (about 20 °S to 90 °S) are covered by lunar occultation measurements, whereas solar occultation measurements are limited to a small latitudinal range between about 50°N and 70 °N.

D. Tropospheric Measurements

SCIAMACHY is one of only a few space-borne instruments which will be able to retrieve tropospheric information for a large number of atmospheric species on a global scale. This will be achieved by a special combination of nadir and limb measurements. For this purpose, the limb observations are performed in such a way that the observed atmospheric volumes in limb closely match those observed during a subsequent nadir measurement when the identical area on the ground is overflown. The delay between this measurements is just about 8 minutes.

The combination of these near-simultaneous limb and nadir measurements enables the retrieval of tropospheric columns by subtracting the limb stratospheric column from the total nadir column, as illustrated in Fig. 2. This approach is similar to the one used by Fishman et al. who determined tropospheric ozone

	Nadir Total Column Amount and Distribution			Limb Stratospheric Profile and Distribution		
	UV/Vis	IR	UV to IR	UV/Vis	IR	UV to IR
Near Real-Time	O_3 NO_2 OClO * SO_2 * H_2CO * BrO **	H_2O N_2O CO CH_4 #	Clouds Aerosol			
Off-Line	O_3 NO_2 BrO OClO * SO_2 * H_2CO * UV Index**	H_2O N_2O CO CO_2 CH_4	Clouds Aerosol	O_3 NO_2 BrO**	H_2O CO_2 CH_4 Pressure Temp. N_2O** CO**	Aerosol

*observed under special condition (volcanic eruption, ozone hole, heavy tropospheric pollution)

#reduced quality at CO fitting window

**recommended by Science Advisory Group, implementation under negotiation with agencies

Fig. 3. SCIAMACHY operational geophysical products.

columns from the combination of TOMS total nadir columns with SAGE II occultation profiles or SBUV nadir profiles [3,4]. The great advantage of SCIAMACHY is that the same instrument will be used for the derivation of both the stratospheric profile and the total column, and that the SCIAMACHY operations are especially optimized for the tropospheric research. Because alternating limb and nadir measurements with appropriate limb-nadir matching will be performed throughout most of the sunlit part of the orbit, it will be possible to derive tropospheric columns not only for O_3 but also for NO_2, CO, CH_4, H_2O, N_2O, SO_2, H_2CO, and BrO, and aerosol parameters.

III. SCIAMACHY Products

From the inversion of the various measurements described above the amounts and distribution of numerous atmospheric constituents in the stratosphere and troposphere (O_3, NO_2, H_2O, CO_2, CH_4, N_2O, BrO, CO, O_2, NO, SO_2, H_2CO, OClO, and possibly ClO) can be derived. A list of operational trace gas products is shown in Fig. 3. Near real-time products will be available after about 3 hours, off-line products typically 2 weeks after sensing. In addition to the trace gas columns and profiles given in Fig. 3 the calibrated Earthshine radiance and solar irradiance spectra will also be operational products. All operational products will be regularly processed, quality controlled, and archived.

There will also be a large number of scientific products derived on a case study basis, among these trace gas concentrations determined from occultation measurements and the tropospheric products mentioned above. Typical precision estimates for the SCIAMACHY products derived from sensitivity studies are summarized in Table I. Note that actual values for the profile precisions depend on altitude. A more detailed description of the precision estimates for occultation and limb is given in [5, 6].

Acknowledgments

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TABLE I
Precision estimates for SCIAMACHY products.

Molecule	Nadir Total Column	Vertical Profile: Occultation Solar	Vertical Profile: Occultation Lunar	Limb	Nadir–Limb Tropospheric Column
O_3	1%#	1%	2%	1%	5%
NO_2	2%#	5%	10%	10%	10%
NO_3	5%	50% (day)	10% (twilight)	?	–
BrO	5%#	20%	?	50%	–
OClO	5%#	10%	20%	25%	–
ClO&	20%	50%	?	50%	–
H_2CO†§	20%#	–		–	25%
SO_2†	10%#	–		–	10%
H_2O	1%	1%		10%	5%
N_2O	5%	2%		50%	10%
CO	5–10%	2%		50%	10%
CO_2	1%	1%		10%	5%
CH_4	1–5%	1%		10%	5%
NO‡	20%	1%		10%	–
O_4	5%	10%		20%	10%
O_2	1%	1%		10%	10%
$O_2(^1\Delta_g)$	1%	1%		10%	–

† in the polluted troposphere
§ e.g. for biomass burning
‡ column densities above 40 km
& under ozone hole conditions
# feasibility shown with GOME data