NADIR, LIMB, AND OCCULTATION MEASUREMENTS WITH SCIAMACHY

S. Noël[1], H. Bovensmann[1], M. W. Wuttke[1], J. P. Burrows[1], M. Gottwald[2], E. Krieg[2], A. P. H. Goede[3], and C. Muller[4]

[1] *Institute of Environmental Physics, University of Bremen, FB 1, D–28334 Bremen, Germany*
[2] *DLR–DFD/IMF, D–82230 Weßling, Germany*
[3] *SRON Ruimetonderzoek, NL–3584 Utrecht, The Netherlands*
[4] *IASB–BIRA, B–1180 Brussels, Belgium*

ABSTRACT

The Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) is a contribution to the ENVISAT-1 satellite, which is to be launched in mid 2001. The SCIAMACHY instrument is designed to measure sunlight transmitted, reflected and scattered by the Earth's atmosphere or surface simultaneously from the UV to the NIR spectral spectral region (240 – 2380 nm) in various viewing geometries. 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, $O_2(^1\Delta_g)$, NO, SO_2, H_2CO, (ClO,) and OClO).
This paper concentrates on the characteristics of the SCIAMACHY mission. In particular, the measurement strategies for the different observational modes – nadir, limb, and both solar and lunar occultation – and their operational implementation are described.

INTRODUCTION

SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography) is a space-based spectrometer covering almost continuously the spectral range between 240 nm and 2380 nm.

Proposed in 1988 by the SCIAMACHY Science Team (Burrows et al., 1988), SCIAMACHY was selected as part of the atmospheric chemistry payload of ESA's environmental satellite ENVISAT-1 which is scheduled for launch in mid 2001. The SCIAMACHY project is funded by Germany, The Netherlands, and Belgium. A descoped version of SCIAMACHY, the Global Ozone Monitoring Experiment (GOME), is already operating successfully aboard the ERS-2 satellite, which was launched in 1995 (see e.g. Burrows et al., 1999).

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 observational geometry. By the inversion of the ratio between the upwelling radiance and the extraterrestrial irradiance the amounts and distribution of numerous atmospheric constituents will be derived (O_3, NO_2, H_2O, CO_2, CH_4, N_2O, BrO, CO, O_2, $O_2(^1\Delta_g)$, NO, SO_2, H_2CO, OClO, and possibly ClO).

More details on the characteristics of the SCIAMACHY instrument and the data products can be found in e.g. Bovensmann et al. (1999) or Noël et al. (1999). The present paper focuses on a description of the various measurement modes of SCIAMACHY and their operational implementation.

MEASUREMENT MODES

The ability to make atmospheric measurements in several observational geometries (nadir, limb and lunar/solar occultation) is one of the most prominent features of the SCIAMACHY instrument. The combination of the different measurement modes will yield unique results. However, the realisation of such a project places a challenge on both instrumental design and mission planning. This is described in more

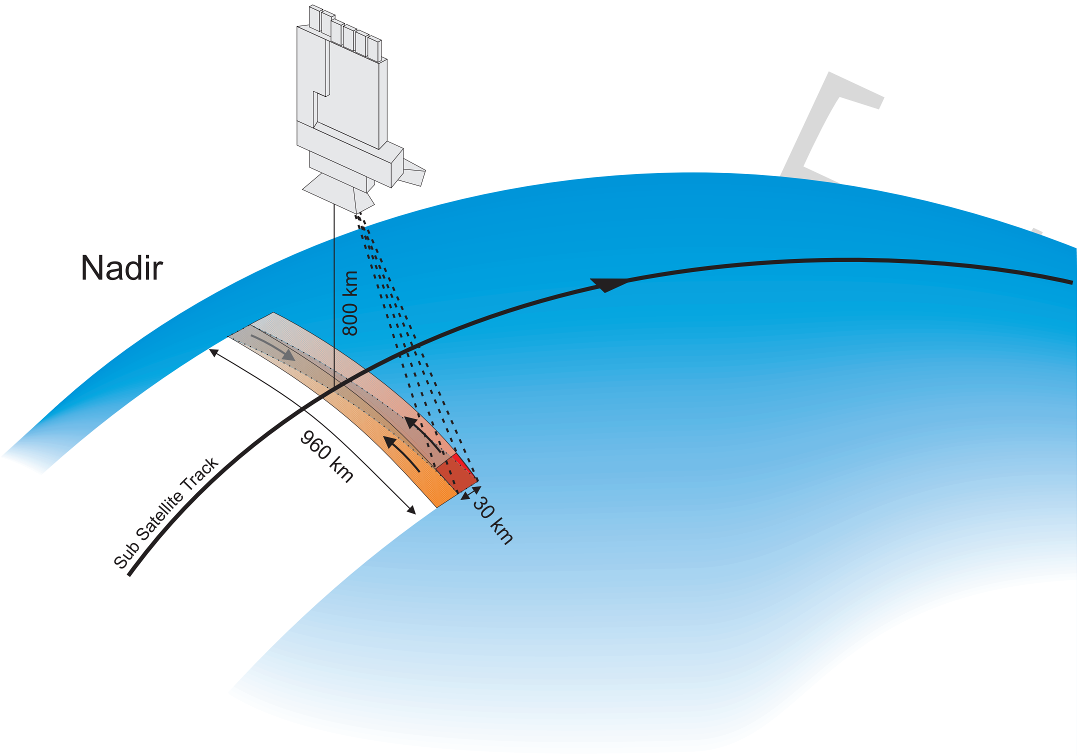

Fig. 1. Nominal nadir scan mode of SCIAMACHY.

detail below.

Nadir Measurements

In nadir measurement mode the atmospheric volume directly under the instrument is probed. This observational mode is used by many other space borne remote sensing instruments, also by GOME. A typical nadir scan is shown in Figure 1. In nadir mode scans across track will be performed with a duration of 4 s, followed by a fast 1 s backscan. This pattern is repeated several times for a total duration of either 65 or 80 s, depending on the orbital region. The nominal ground swath size is 960 km, but there is also the possibility to use a smaller swath size of 120 km. The typical spatial resolution is about 30 km (along track) $\times$ 60 km (across track).

Limb Measurements

In limb geometry the instrument looks tangentially to the Earth's surface principally in spacecraft flight direction towards the edge of the atmosphere. 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.

The nominal limb scan pattern for SCIAMACHY is displayed in Figure 2. Scans will be performed in horizontal (across-track) direction for 1.5 s, equivalent to a swath size of about 960 km at the tangent point. During one such scan the tangent altitude is kept fix by correcting for the curvature of the Earth's surface. At the end of the horizontal scan the line-of-sight is stepped upwards, and the next horizontal scan is performed in reverse direction. This way tangent altitudes from 0 to 100 km are probed. The vertical resolution of the limb measurements will be about 3 km.

One feature of the limb measurements is of special significance: The limb observations are performed in such a way that the observed atmospheric volumes in limb match closely those observed during a subsequent nadir measurement when the identical area is overflown with a delay of approximately 8 minutes. The reason for this requirement is that 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

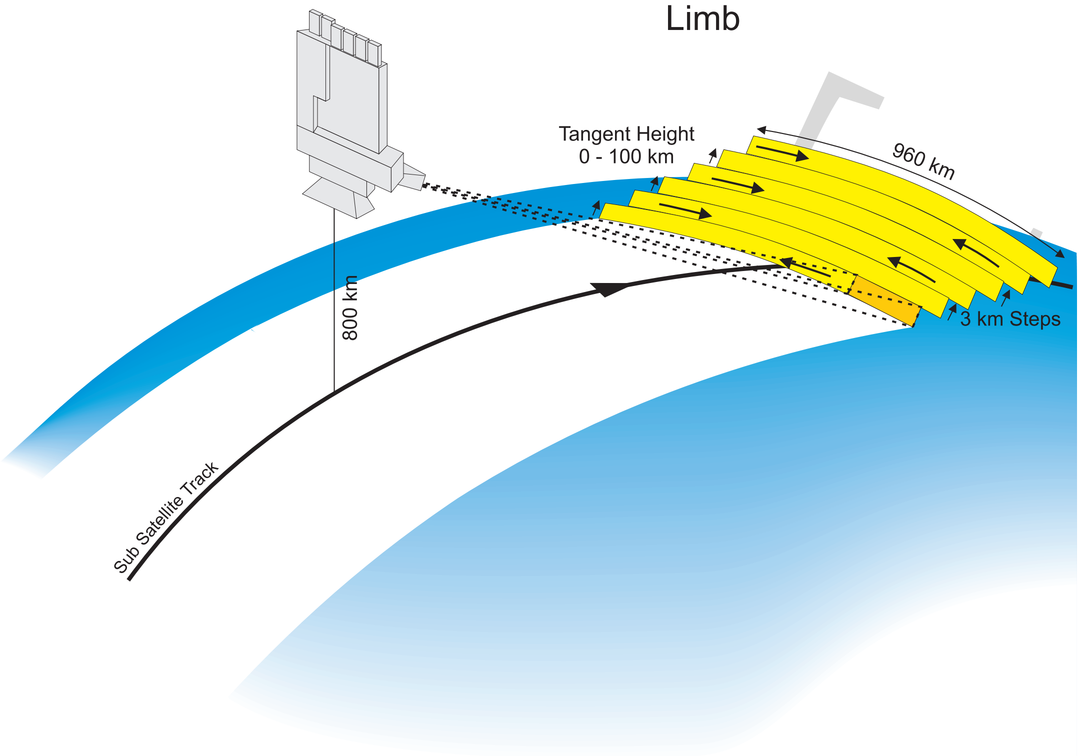

Fig. 2. Nominal limb scan mode of SCIAMACHY.

column. A similar approach has been used to determine tropospheric ozone columns from the combination of TOMS total nadir columns with SAGE II occultation profiles or SBUV nadir profiles (Fishman et al., 1990, 1996). However, from SCIAMACHY measurements 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.

This limb-nadir-matching has significant implications for the operational concept. It requires an accurate synchronisation of the measurements, an appropriate scan speed, and even a special yaw steering correction to take into account the satellite attitude and compensate for the rotation of the Earth between the limb and nadir measurements. This is handled by the current operational concept and special correction algorithms for the instrument line-of-sight. Alternating limb and nadir measurements with appropriate limb-nadir matching will be performed throughout most of the sunlit part of the orbit.

Solar Occultation Measurements

The observational geometry in occultation mode is similar to limb. In solar occultation the sun is observed directly through the atmosphere, in lunar occultation the moon. Solar occultation measurements from space have been successfully performed by e.g. SAGE-II.

Because of the forward viewing direction and the sun-fixed orbit of ENVISAT-1, SCIAMACHY can only observe the rising sun. The SCIAMACHY sun follower has a relatively small field of view of $0.72° \times 2.2°$. Thus, the approximate position of the sun has to be known in advance of the measurement. For the solar azimuth this is no problem as it can be calculated from the orbital position, but the solar elevation, i.e. the exact time of sunrise, depends on atmospheric refraction which is variable and may only be estimated by models. Moreover, the operational concept requires fixed time intervals, so it is of crucial importance to have a clear definition of 'sunrise' and the start time of a measurement.

To solve this problem, a (nearly) refraction-independent definition of the sun-fixed event (sunrise) has been chosen. The time of sunrise is defined as the time when the centre of the geometrical sun reaches 17.2 km tangent altitude. This criterium has been chosen, because at this altitude the geometrical sun and the refracted image of the sun overlap and rise with almost identical, well-defined elevation rates. All other

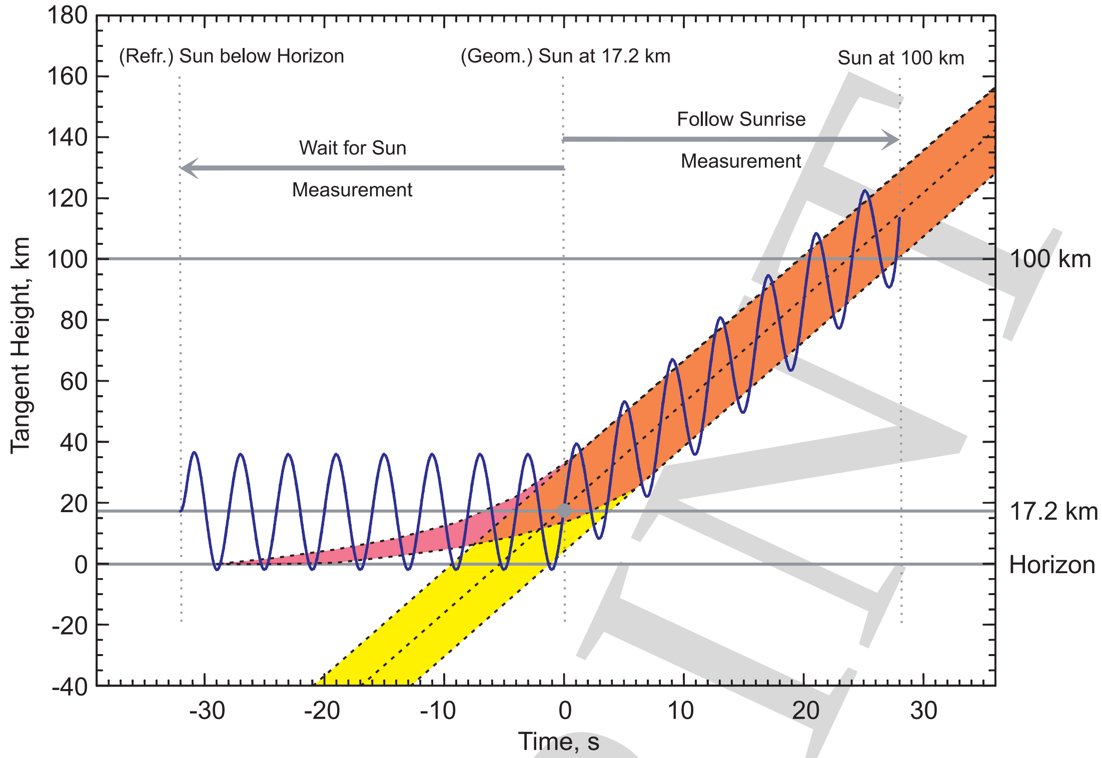

Fig. 3. Solar occultation scan strategy. Dark grey: Size of refracted sun. Light grey: Size of geometrical sun. Black oscillating line: Tangent point altitude during scan.

occultation measurement times are defined relative to this time.

The resulting solar occultation scan strategy is illustrated in Figure 3. The sun follower is only used to fix the azimuthal position of the sun. Vertical scans around 17.2 km tangent height (± 0.33° in 4 s) are performed for a pre-defined fixed time interval until the centre of geometrical sun reaches 17.2 km. Then the sun is followed with its (known) solar elevation rate (≈ 0.06°/s) up to 100 km.

During the whole occultation measurement, vertical scans over the complete sun (± 0.33° in 4 s) are performed with a vertical resolution at the tangent point of approximately 2.6 km. Note that due to this scanning the same tangent altitude is probed several times.

Solar occultation measurements as described before are included in the operational concept of SCIAMACHY and will be performed each orbit.

Lunar Occultation Measurements

For lunar occultation measurements a similar observational strategy is used as that for solar occultation measurements. During lunar occultation measurements, SCIAMACHY directly observes the rising moon through the atmosphere. As moon and sun have about the same angular size, moonrise is defined in analogy to sunrise by the centre of the geometrical moon reaching 17.2 km. The scan strategy for lunar occultation measurements is to point at this altitude for a pre-defined time until moonrise. Then the moon follower (which is in fact the sun follower combined with a larger aperture providing a field of view of 2.2° × 2.2°) is used to lock on the moon in both azimuth and elevation. The rising moon is then followed up to 100 km while pointing to the centre of the illuminated part of the moon. Note that in contrast to solar occultation no scans over the moon will be performed.

Because ENVISAT-1 will fly on a sun-fixed orbit, the SCIAMACHY mission planning concept is also sun-oriented. Therefore 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, start and end times of these lunar observation opportunities vary strongly over the year, and they differ for each year. Therefore, a flexible operational concept had to be developed to handle

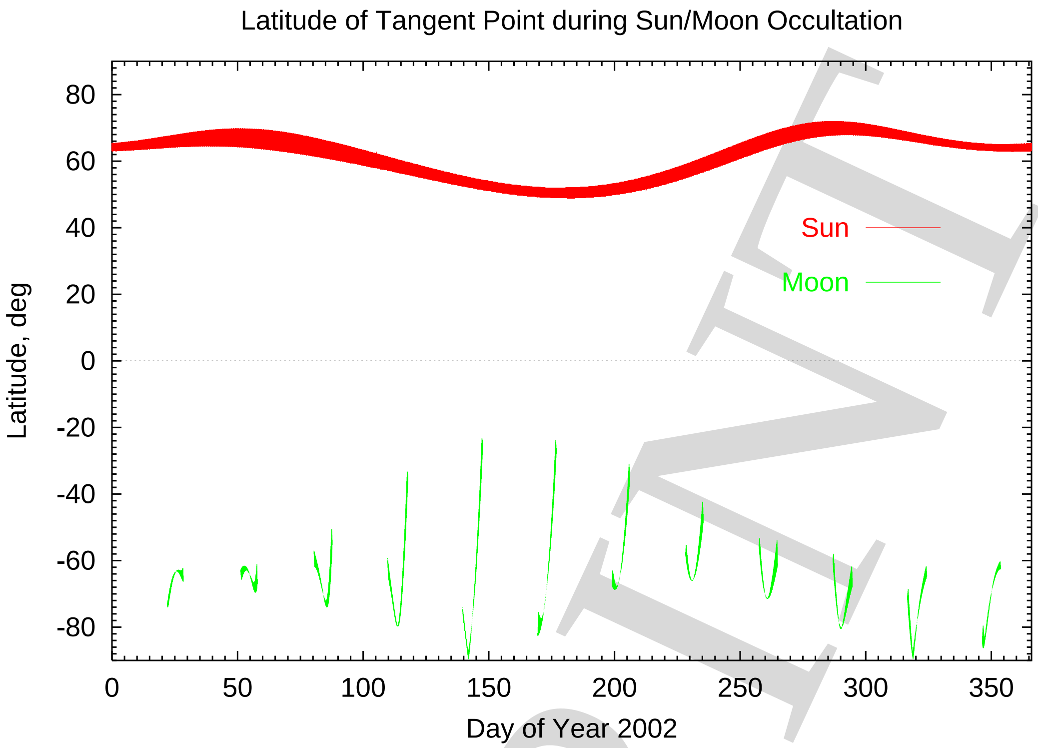

Fig. 4. (Northern) latitude of tangent points for SCIAMACHY solar and lunar occultation measurements in the year 2002.

these large variations. Currently it is foreseen to perform lunar occultation measurements at least every second orbit during times when the moon is visible for SCIAMACHY.

However, it is this large variability which makes lunar occultation measurements very interesting from the scientific point of view. Whereas solar occultation measurements are limited to only a small latitudinal range between about 50 °N and 70 °N, lunar occultation covers large regions of the southern hemisphere (about 20 °S to 90 °S). This is illustrated by Figure 4 which displays the latitudes of the tangent points during solar and lunar occultation measurements for the year 2002.

SUMMARY

SCIAMACHY measurements will be performed in nadir, limb, and solar/lunar occultation geometry and cover almost continuously a spectral range from the UV (240 nm) to the NIR (2380 nm). From these measurements the amount and distribution of a large number of atmospheric constituents will be derived. The combination of near-simultaneous nadir and limb measurements of the same ground scene will enable tropospheric columns of these constituents and parameters to be retrieved on a global scale.

The SCIAMACHY measurements are realised by a flexible concept on both instrumental and operational side. This concept will be verified and optimised during the commissioning phase. At the present time (summer 2000), the SCIAMACHY instrument is tested, calibrated, and integrated on ENVISAT-1 and thus almost ready for launch in 2001.

ACKNOWLEDGMENTS

This work has been funded as part of the SCIAMACHY Scientific Support Study by the BMBF via GSF/PT–UKF under grant 07UFE12/8 and by the University of Bremen.

REFERENCES

Bovensmann, H., J. P. Burrows, M. Buchwitz, J. Frerick, S. Noël, et al., SCIAMACHY — Mission Objectives and Measurement Modes, *J. Atmos. Sci.*, **56**, 127–150, 1999.

Burrows, J. P., K. V. Chance, P. J. Crutzen, H. van Dop, J. C. Geary, et al., SCIAMACHY — A European Proposal for Atmospheric Remote Sensing from the ESA Polar Platform, Max-Planck-Institut für Chemie, 55122 Mainz, Germany, 1988.

Burrows, J. P., M. Weber, M. Buchwitz, V. Rozanov, A. Ladstätter-Weißenmayer, et al., The Global Ozone Monitoring Experiment (GOME): Mission Concept and First Scientific Results, *J. Atmos. Sci.*, **56**, 151–175, 1999.

Fishman, J., V. G. Brackett, E. V. Browell, and W. B. Grant, Tropospheric Ozone Derived from TOMS/SBUV Measurements during TRACE A, *J. Geophys. Res.*, **101**, 24069–24082, 1996.

Fishman, J., C. E. Watson, J. C. Larsen, and J. A. Logan, Distribution of Tropospheric Ozone Determined from Satellite Data, *J. Geophys. Res.*, **95**, 3599–3617, 1990.

Noël, S., H. Bovensmann, J. P. Burrows, J. Frerick, K. V. Chance, et al., Global Atmospheric Monitoring with SCIAMACHY, *Phys. Chem. Earth (C)*, **24**, 427–434, 1999.