SCIAMACHY NOMINAL OPERATIONS AND SPECIAL FEATURES

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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. 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). A list of SCIAMACHY operational Level 2 data products is shown in Fig. 1. Additional scientific products are planned from process studies.

Proposed in 1988 by the SCIAMACHY Science Team [1], SCIAMACHY is a contribution to 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. [2].

More details on the characteristics of the SCIAMACHY instrument and the data products can be found in e.g. [3] or [4]. The present paper focuses on a description of the scientific measurements of SCIAMACHY during nominal operations and their implementation. Emphasis is placed on the special features of SCIAMACHY which are important for data users in the calibration/validation context, among these the definition of spectral regions of interest with higher spatial resolution and the possible combination of limb and nadir measurements to derive tropospheric information for a large number of atmospheric constituents.

A description of nominal calibration and monitoring activities which have a direct impact on the operational data processing and thus on the quality of all data products can be found in an accompanying paper [5].

	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. 1: SCIAMACHY operational Level 2 products.

MEASUREMENT MODES

The ability to perform atmospheric measurements in nadir, limb and lunar/solar occultation geometry is one of the most important features of the SCIAMACHY instrument. The combination of these different measurements will yield unique results, but also places a challenge on both instrumental design and mission planning. Large efforts have been made to define an operational concept by which an optimum of scientific information can be drawn from the SCIAMACHY measurements. The individual measurement modes and some 'special features' associated with them, which are important for data users, are described in the following subsections.

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 Fig. 2. 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 spatial resolution of SCIAMACHY measurements is generally determined by signal-to-noise requirements, i.e. the detector filling, and the maximum available data rate.
Simulations have shown that for nadir measurements between about 60°N and 60°S the data rate is the limiting factor for the spatial resolution. To be in line with the data rate requirements on-board coadding of measurement data is necessary. This results an reduction of the spatial resolution to a typical nadir pixel size of about 30 km $\times$ 240 km (along/across track).
However, from a scientific point of view a higher spatial resolution is desired, especially for the retrieval of O_3, NO_2, and H_2O amounts, and for cloud and aerosol detection.
This is achieved by the so-called 'cluster concept': For SCIAMACHY it is possible to define – in addition to the physical channel boundaries – special spectral regions with no (or less) coadding. Up to 16 clusters may be defined for each of the 8 channels, in total 64 clusters are allowed. The current nadir cluster definition uses 56 clusters with appropriate definition of coadding factors, which increases the typical spatial resolution for all major atmospheric constituents measured by SCIAMACHY to about 30 km $\times$ 60 km.
Furthermore, SCIAMACHY measurements use different exposure times not only for different spectral regions but also depending on orbital position to guarantee an optimal signal-to-noise ratio for different illumination conditions.
The resulting spatial resolution for some important atmospheric constituents is shown in Fig. 3 as a function of geographic latitude for spacecraft equinox conditions. The PMDs (Polarisation Measurement Devices) are broadband sensors with

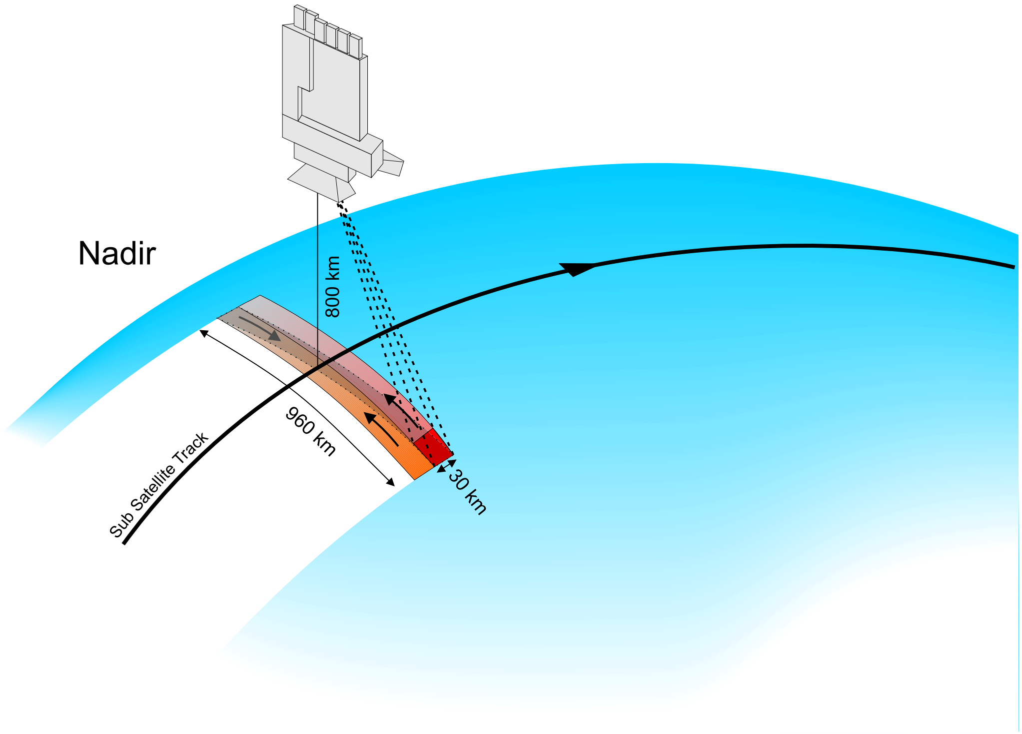

Fig. 2: Nominal nadir scan mode of SCIAMACHY.

a (constant) higher spatial resolution used for polarisation correction and cloud detection. Note that because of the sun-fixed ENVISAT-1 orbit the illumination conditions and thus also the spatial resolution vary over the year for a certain geolocation.
An update of the cluster definitions and the associated exposure times/coadding factors using the information derived from recent on-ground calibration activities and first in-flight measurements will be performed during the SCIAMACHY commissioning phase.

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 Fig. 4. Scans will be performed in horizontal (across-track) direction for 1.5 s. This is equivalent to a swath size of about 960 km at the tangent point. The tangent altitude is kept fix during one such scan 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 importance: The limb observations will be 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. By this it will be possible to derive tropospheric columns by subtracting the limb stratospheric column from the near-simultaneous limb total nadir 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 [6; 7]. 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

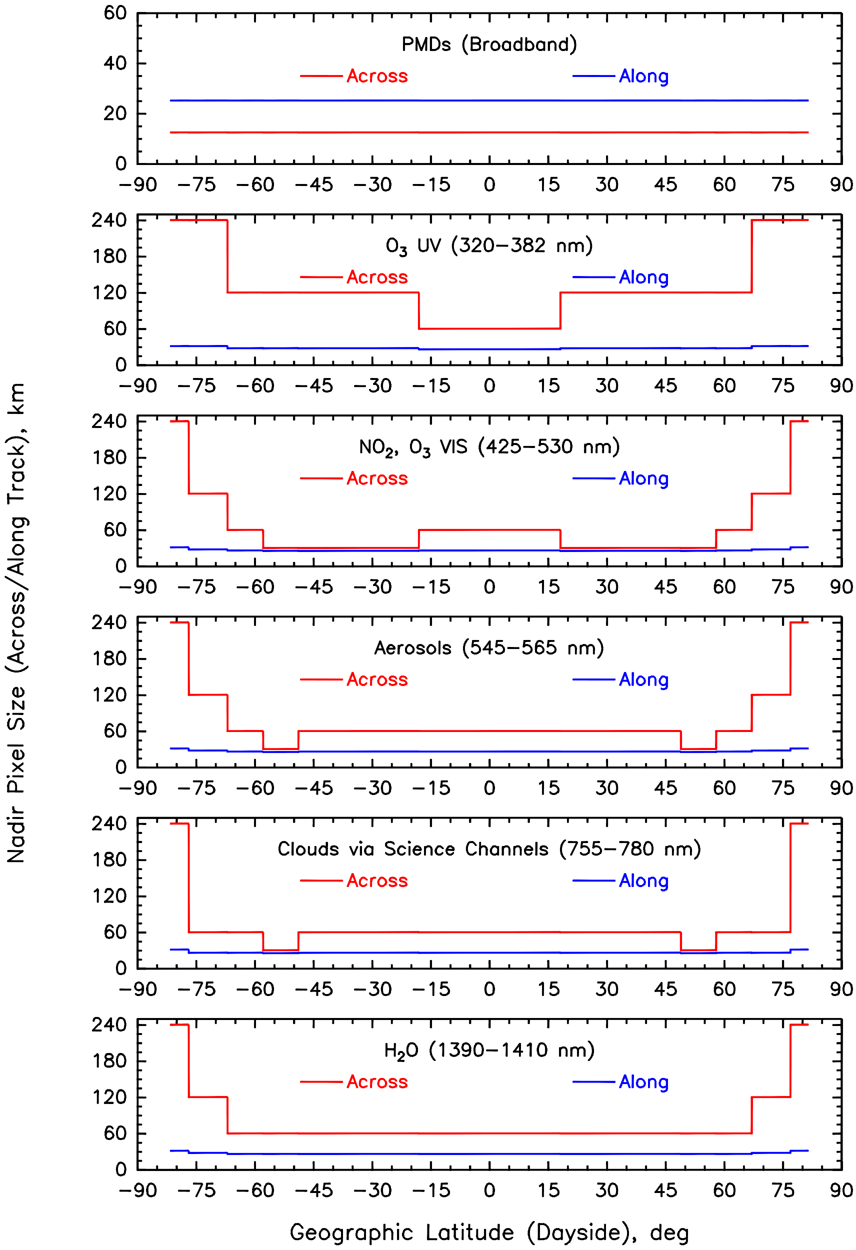

Fig. 3: Expected nadir spatial resolution as a function of geographic latitude at spacecraft equinox.

and nadir measurements with appropriate limb-nadir matching will be performed throughout most of the sunlit part of the orbit, thus providing the possibility for global tropospheric products.

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 sun-fixed orbit of ENVISAT-1 and the forward viewing direction of SCIAMACHY only the rising sun can be observed once per orbit. To make an optimal use of this opportunity a special scan strategy has been developed. This scan strategy has to consider that 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 very well 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,

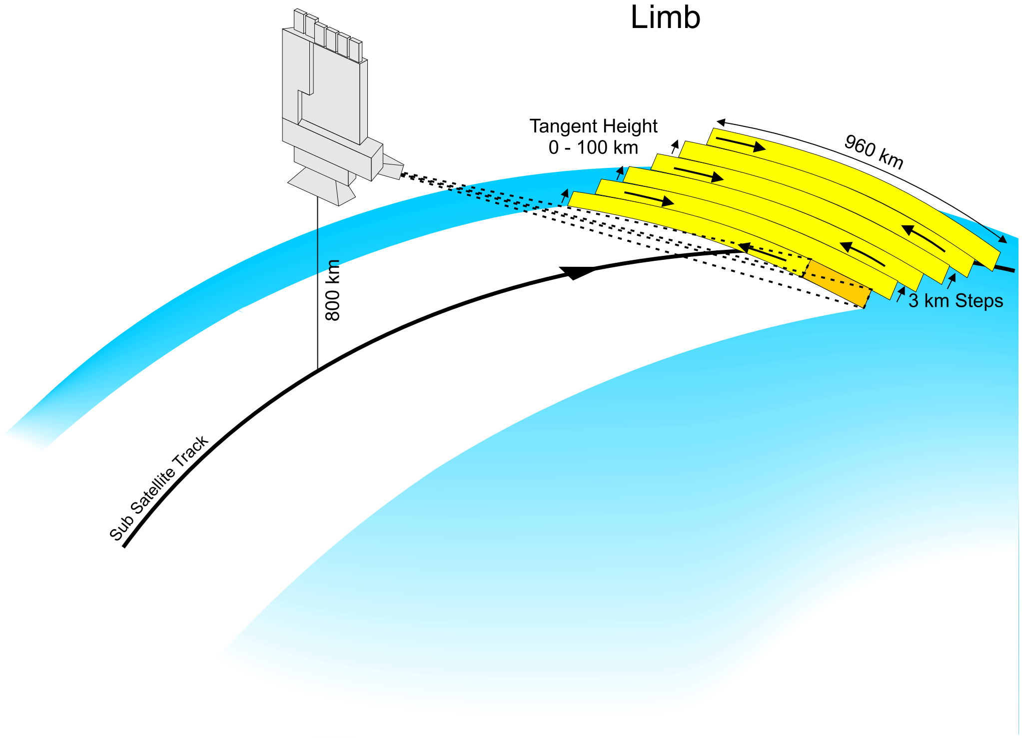

Fig. 4: Nominal limb scan mode of SCIAMACHY.

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 occultation measurement times are defined relative to this time.

The resulting solar occultation scan strategy is illustrated in Fig. 5. The sun follower is only used to fix the azimuthal position of the sun. Vertical scans around 17.2 km tangent height 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 ($\approx 0.06°$/s) up to 100 km.

During the whole solar occultation measurement, vertical scans over the complete sun ($\pm$ 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.

Lunar Occultation Measurements

Lunar occultation measurements use a similar observational strategy as 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 $2.2° \times 2.2°$) 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

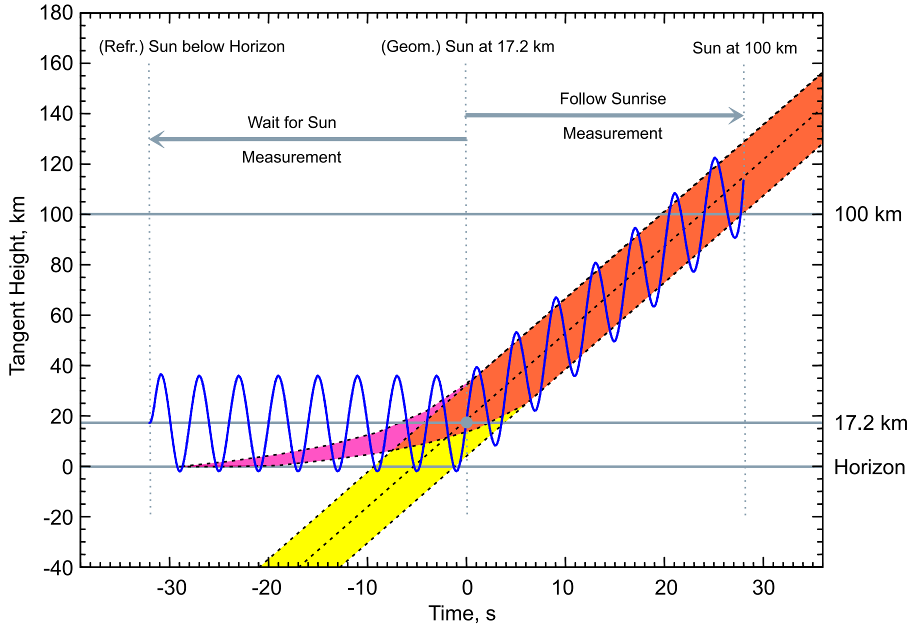

Fig. 5: Solar occultation scan strategy. Pink: Size of refracted sun. Yellow: Size of geometrical sun.

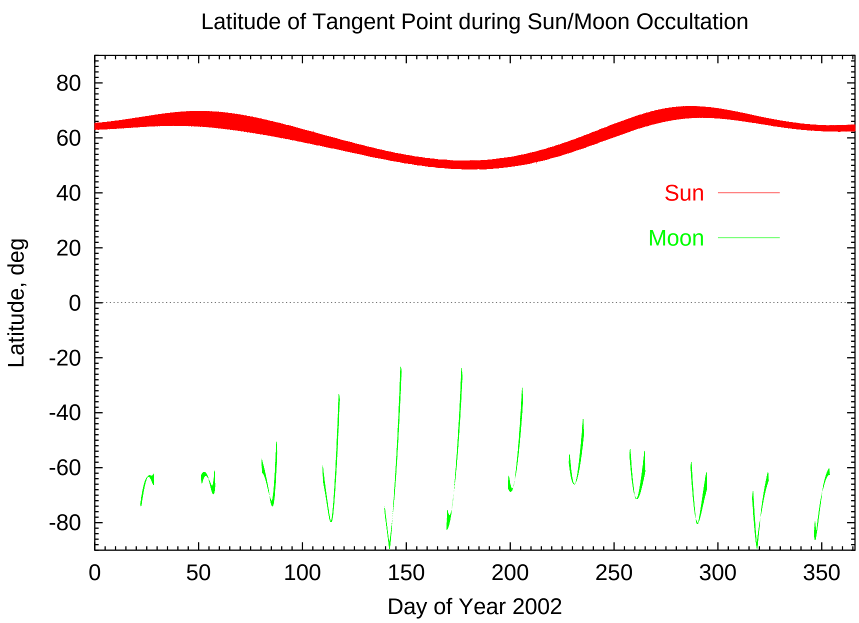

Fig. 6: (Northern) latitude of tangent points for SCIAMACHY solar and lunar occultation measurements in the year 2002.

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 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 Fig. 6 which displays the latitudes of the tangent points during solar and lunar occultation measurements for the year 2002.

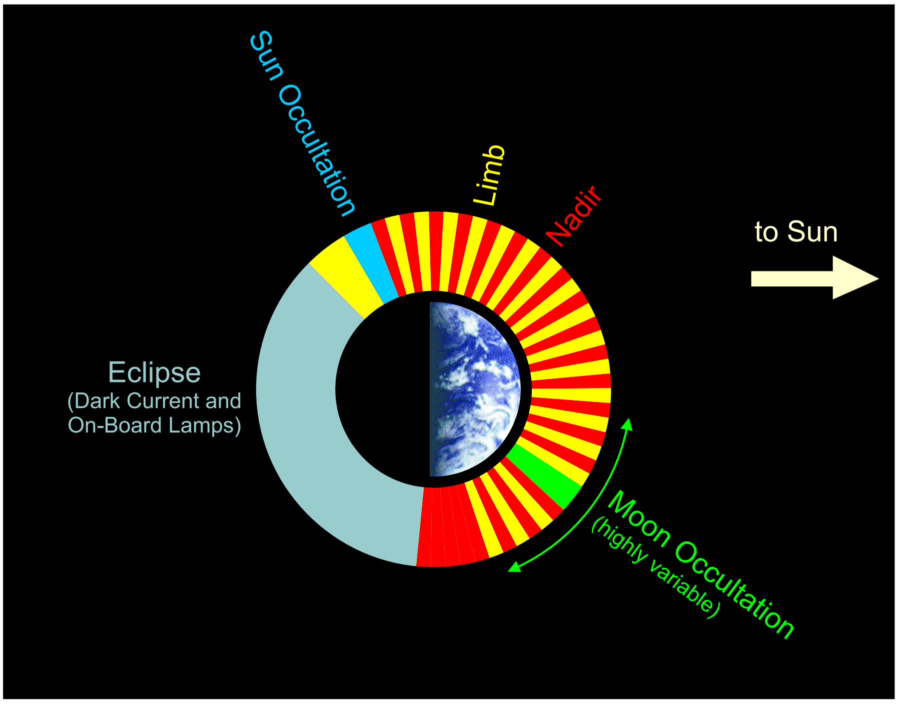

Fig. 7: Typical sequence of SCIAMACHY measurements performed during one orbit of ENVISAT-1.

In-flight Calibration and Monitoring

Dedicated calibration measurements will be performed on daily, weekly, and monthly basis using the internal lamps (spectral lamp and white light source) as well as direct observations of sun and moon in different viewing geometries. By analysis of the results of these measurements changes of the instrument performance will be monitored and corrected. In this context so-called ‘m-factors’ will be regularly computed, which then are used by operational data processing. This way instrument degradation is automatically taken into account.
In-flight calibration and monitoring are therefore essential to ensure the quality of the SCIAMACHY data products. More detailed information about the SCIAMACHY calibration and monitoring concept are given in [5].

Sequence of Measurements in Orbit

ENVISAT-1 will fly in a polar, sun-synchronous orbit with an orbital period of about 100 min and an ascending node crossing time of 10.00 LT. Fig. 7 shows a typical sequence of measurements which will be performed by SCIAMACHY during nominal operations within one orbit.
The sunlit part of the orbit mainly consists of alternating limb and nadir measurements. During each sunrise solar occultation measurements will be performed over the northern hemisphere. As noted before, the moon will be visible for SCIAMACHY for about one week per month over the southern hemisphere. During these times lunar occultation measurements will be performed typically every second orbit. The eclipse part of the orbit is mainly used for calibration measurements, especially dark current measurements and measurements using the on-board lamps. This nominal measurement scenario results in a global coverage within 6 days.

SUMMARY

SCIAMACHY measurements will be performed in nadir, limb, and solar/lunar occultation geometry. They will almost continously cover the spectral region from the UV to the NIR. From these measurements the amount and distribution of a large number of atmospheric constituents will be derived. A typical nadir spatial resolution of 30 km $\times$ 60 km will be achieved by a special cluster concept. Tropospheric columns can be derived from the combination of near-simultaneous nadir and limb measurements on a global scale. Regular in-flight calibration and monitoring activities will be performed to ensure the data product quality.

All this is realised by a flexible concept on both instrumental and operational side. This concept will be verified and optimised during the commissioning phase.

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