The SCIAMACHY instrument on ENVISAT-1

S. Noël[a], H. Bovensmann[a], J. P. Burrows[a], J. Frerick[a],
K. V. Chance[b], A. H. P. Goede[c], and C. Muller[d]

[a]Institute of Environmental Physics, University of Bremen,
FB 1, D–28334 Bremen, Germany

[b]Harvard-Smithsonian Center for Astrophysics, Cambridge,
MA 02138, USA

[c]SRON ruimteonderzoek, NL–3584 Utrecht, The Netherlands

[d]BIRA–IASB, 3 Avenue Circulaire, B–1180 Brussels, Belgium

ABSTRACT

SCIAMACHY (Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY) is a contribution to the ENVISAT-1 satellite, which is to be launched in spring 2000. The SCIAMACHY instrument is designed to measure sunlight transmitted, reflected and scattered by the Earth's atmosphere or surface. The instrument measures simultaneously from the UV to the NIR spectral spectral region (240 – 2380 nm). Observations are made in alternate nadir and limb viewing geometries and also for solar sunrise and lunar moonrise occultation. Inversion of the SCIAMACHY measurements will provide the following: the amount and distributions of some important trace gases O_3, BrO, OClO, ClO, SO_2, H_2CO, NO_2, CO, CO_2, CH_4, H_2O, N_2O, p, T, aerosol, and radiation flux profiles, cloud cover and cloud top height. Combination of the near simultaneous limb and nadir observations enables the tropospheric column amounts of O_3, NO_2, CO, CH_4, H_2O, N_2O, SO_2, and H_2CO to be detected. SCIAMACHY will provide new insight into the global behaviour of the troposphere and the stratosphere.

Keywords: SCIAMACHY, ENVISAT-1, spectrometer, hyperspectral, remote sensing, ozone, troposphere

1. INTRODUCTION

The Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) is a space based spectrometer designed to measure both the extraterrestrial irradiance and sunlight which is transmitted, reflected and scattered by the Earth atmosphere or surface. Inversion of the ratio of the upwelling Earthshine radiance to the extraterrestrial solar irradiance will yield amounts and distribution of a large number of atmospheric constituents.

The SCIAMACHY instrument was proposed in summer 1988 by the SCIAMACHY Science Team.[1] It is a national contribution to the ESA ENVISAT-1 mission funded by Germany, The Netherlands, and Belgium. SCIAMACHY complements well the other ENVISAT-1 atmospheric chemistry payload, especially the GOMOS and MIPAS instruments. After its launch in spring 2000, ENVISAT-1 is planned to operate for four years. A smaller version of SCIAMACHY, the Global Ozone Monitoring Experiment (GOME)[2] is currently operating successfully on ERS-2.

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

1. Stratospheric Ozone: the foci being the behaviour of the 'ozone hole' and mid-latitude ozone as the halogen loading of the stratosphere is predicted to decrease during the time of the ENVISAT-1 mission.

2. Tropospheric pollution arising from industrial activity and biomass burning

3. Troposphere–stratosphere exchange

4. Special events such as volcanic eruptions, solar proton events, and related regional and global phenomena

Send correspondence to S. Noël, E-mail: Stefan.Noel@iup.physik.uni-bremen.de

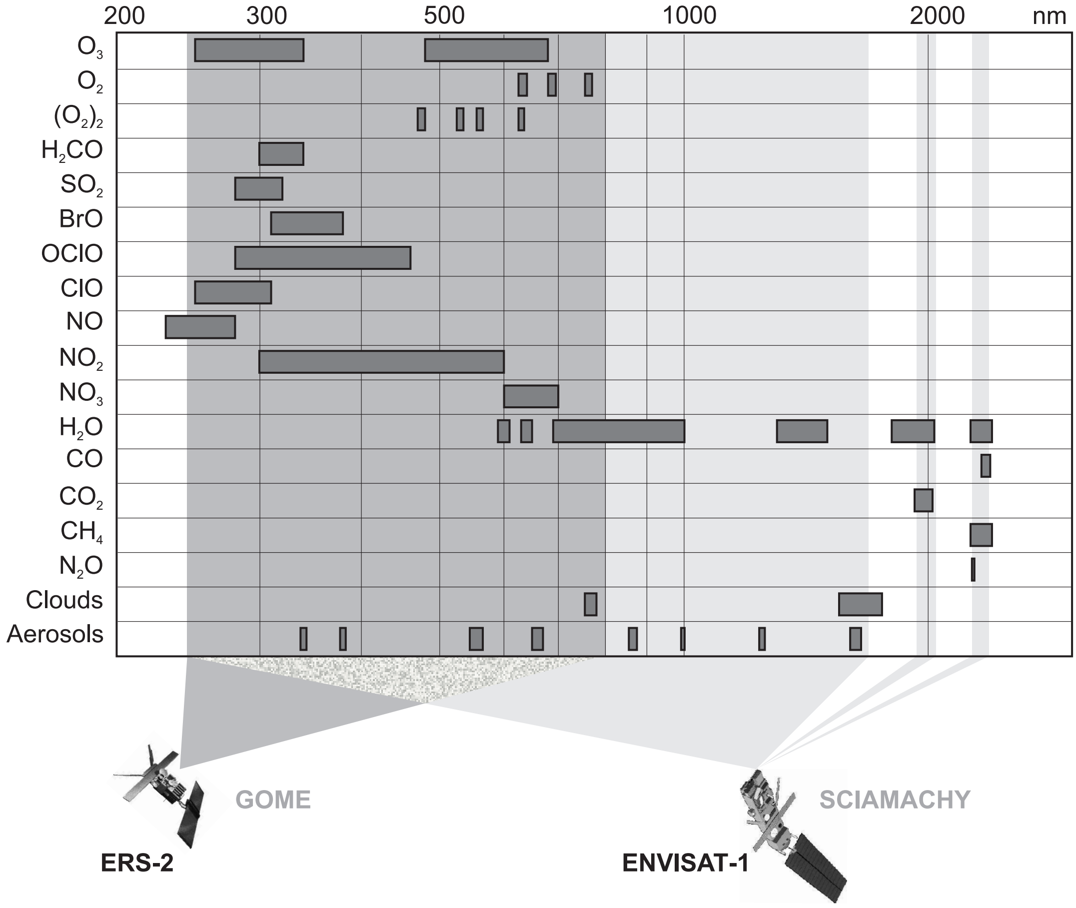

Figure 1. Spectral range of SCIAMACHY and GOME and associated atmospheric constituents.

SCIAMACHY is an passive hyperspectral UV-VIS-NIR sensor. It comprises an imaging double spectrometer which measures light continuously from 240 nm to 1750 nm and at two selected spectral windows in the NIR (1940 nm to 2040 nm and 2265 nm to 2380 nm). As can be seen from Fig. 1, a large number of atmospheric constituents have significant absorption features in the wavelength regions covered by SCIAMACHY. Compared with its precursor instrument GOME, the inclusion of the NIR spectral range will allow SCIAMACHY to additionally detect such important trace gases as CO, CO_2, methane, and N_2O.

Its high dynamic range of 7 to 8 orders of magnitude will allow SCIAMACHY to measure both direct sunlight and earthshine. Depending on the wavelength region, the spectral resolution of the SCIAMACHY instrument varies between 0.2 nm (in the UV-VIS) to 1.5 nm (in the NIR). The spectrometer will be operated at a temperature of 258 K (stable to 0.25 K). The detectors are cooled to temperatures between 235 K and 150 K with a stability of 0.02 K. Together with a high straylight suppression ($<10^4$) a radiometric accuracy better than 4% (absolute) and 1% (relative) in combination with a spectral stability between 0.015 nm and 0.005 nm will be achieved.

More information about the SCIAMACHY instrument and mission can be found in Refs. 3–6.

2. MEASUREMENTS

2.1. Observational Geometries

Atmospheric measurements will be performed in nadir, limb and occultation geometry (see Fig. 2). In nadir mode, the atmospheric volume directly under the spacecraft will be observed. Across track scans will be performed covering an area of up to about 480 km left and right of the ground track. In limb mode the instrument observes the edge

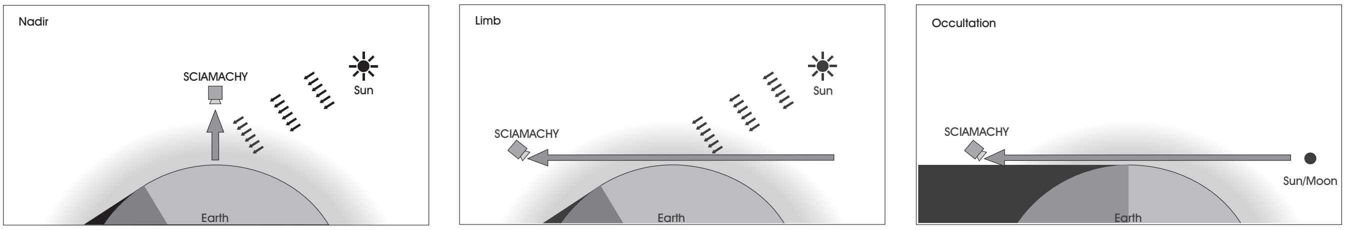

Figure 2. Observational geometries of SCIAMACHY.

of the atmosphere. Horizontal scans over a width of approximately 960 km will be performed at tangent altitudes from the ground to about 100 km. In occultation mode the observational geometry is the same as in limb mode, but measurements are performed at times where the sun or the moon are in the instrument's field of view.

The spatial resolution of the measurements depends in general on the sensitivity of the instrument to the intensity of the incoming light. Therefore the spatial resolution shows a spectral characteristic. For SCIAMACHY, the available data rate is an important additional factor in this context. Due to the data rate limitations it is necessary to co-add data on board of the spacecraft which essentially reduces the spatial resolution. However, the flexible operational concept of SCIAMACHY allows for the definition of special spectral windows with reduced (or even no) co-adding. By this a typical nadir spatial resolution of about 30 km $\times$ 60 km (along/across track) will be achieved for all major atmospheric constituents. The vertical resolution for limb and occultation measurements will be about 3 km.

2.2. Sequence of Measurements in Orbit

Similar to ERS-2, ENVISAT-1 will fly in a polar, sun-synchronous orbit with an orbital period of about 100 min. Fig. 3 shows a typical sequence of measurements which will be performed by SCIAMACHY during one orbit.

The eclipse part of the orbit is mainly used for calibration measurements, i.e. dark current measurements and measurements using the on-board lamps.

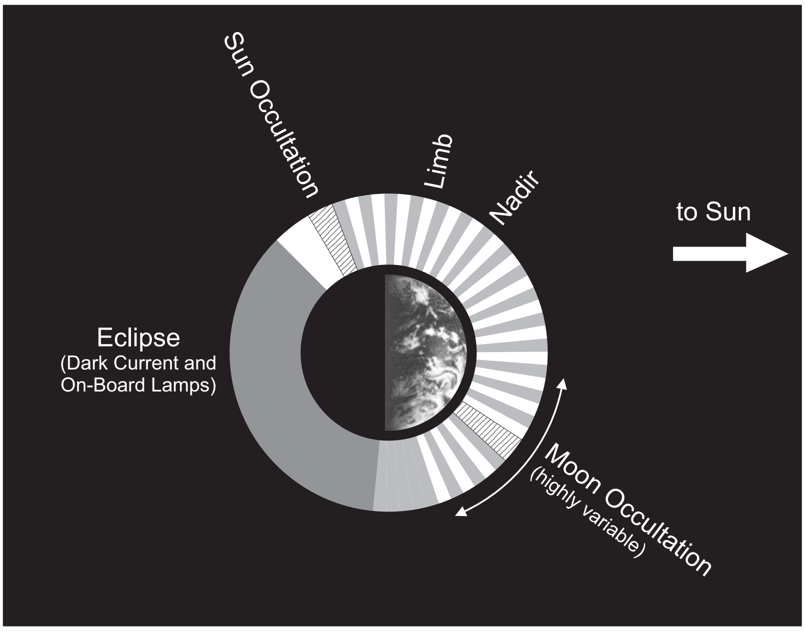

Figure 3. Typical sequence of SCIAMACHY measurements performed during one orbit of ENVISAT-1.

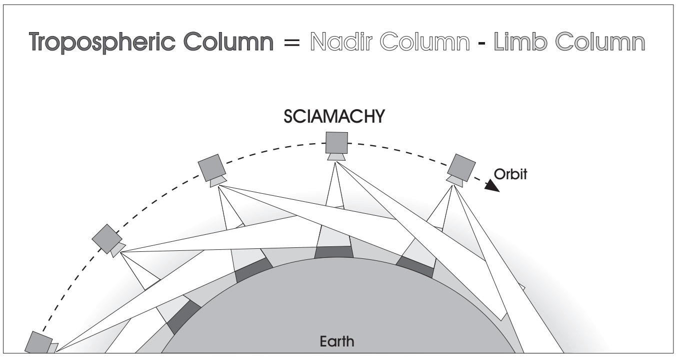

Figure 4. Derivation of tropospheric columns from alternating limb and nadir measurements

During each sunrise solar occultation measurements will be performed over the northern hemisphere. Depending on season, these measurements will cover a latitudinal range at the tangent points from the north pole to 65°N.

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 every second orbit. Lunar occultation measurements provide a challenge for mission planning because the time and place of the visibility of the moon show a large variability over the mission time. Moon occultation measurements will cover tangent latitudes between 30°S and 90°S over the year.

A special feature of SCIAMACHY is the combination of alternating limb and nadir measurements which enables the tropospheric column amounts of several trace gases to be determined. This is why alternating limb and nadir measurements will be performed for most time of the sunlit part of the orbit.

The approach taken to determine the tropospheric column is to subtract the stratospheric/mesospheric column derived from limb measurements from the total nadir column (see Fig. 4). This residual technique was developed by Fishman et al.[7,8] who derived tropospheric ozone columns from the combination of TOMS total nadir columns with SAGE II occultation profiles or SBUV nadir profiles. To reduce possible error sources, SCIAMACHY limb and nadir measurements are carefully matched such that effectively the same atmospheric volume will be observed first in limb and then 8 min later in nadir mode. From the combination of the alternating limb and nadir 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 down to the surface or the cloud top. Moreover, this information will be available on a global scale. At the equator global coverage will be achieved within 6 days.

3. EXPECTED RESULTS

3.1. Signal-to-Noise

To estimate the performance of the SCIAMACHY instrument, signal-to-noise (S/N) values have been calculated. The general procedure is illustrated in Fig. 5.

Calculations are performed for all four viewing geometries: nadir, limb, solar, and lunar occultation. The standard scenario used for the calculation is given by: Geographic latitude 55°N, spring season, day-of-year 63 (equivalent to spacecraft spring equinox), 1976 US Standard Atmosphere, tropospheric/background stratospheric aerosols, no clouds, no precipitation. For nadir three different values for the surface albedo are used: 5%, 30%, and 90%, which may be considered representative for ocean, land, and ice, respectively. For limb and occultation modes a constant albedo of 30% has been chosen and different tangent altitudes from the surface to 90 km are simulated. For a given scenario the ENVISAT-1 orbit propagator software (provided by ESA) is used to determine the observational geometry parameters, i.e. the orbital position of the spacecraft, the exact timing, and the viewing direction.

The above parameters are taken as input for the radiative transfer model MODTRAN[9] to calculate the corresponding radiance spectra. These spectra are then fed into the SCIAMACHY Instrument Simulator Software (provided by SRON) which determines for a given instrument configuration the S/N values. The Instrument Simulator utilises

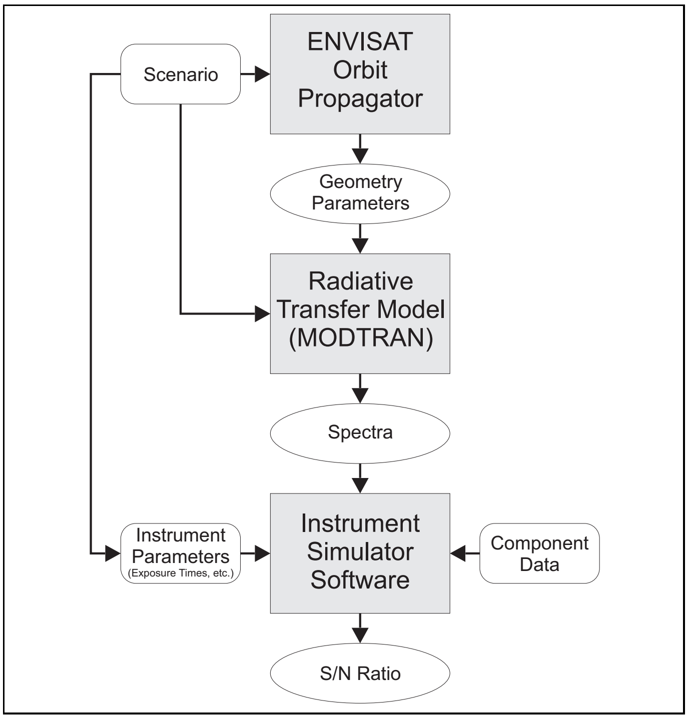

Figure 5. Schematic diagram of procedure to determine S/N ratios.

parameters describing the performance of the individual components determined either by the manufacturer or during on-ground calibration measurements. The instrument parameters (e.g. the instrument mode and the exposure times) are chosen to match the input scenario.

The spectra derived with MODTRAN and the resulting S/N ratios are displayed in Figs. 6 and 7 for nadir and limb geometry. Figs. 8 and 9 show the corresponding results for solar and lunar occultation mode. Because of the large difference in intensity, the UV part of the spectra and S/N ratios is given in an additional graph.

As can be seen from these figures, S/N ratios are mainly determined by the intensity of the incoming light. Thus signal and S/N ratio show similar characteristics.

In nadir mode, higher albedo results in higher signals and thus better S/N ratios. In limb mode, the signal decreases with increasing tangent altitudes as the atmospheric density, i.e. the number of scattering particles, decreases. The situation is reverse for occultation, where the measured signal is determined by directly transmitted light and maximum intensities occur at high tangent altitudes where absorption is low.

Except for solar occultation where the intensity of the incoming light is naturally high, all calculated radiances have the same magnitude. The instrument compensates the high signal for direct solar observations by smaller pixel exposure times, an smaller aperture and an additional neutral density filter in the light path. This results in S/N ratios of generally the same magnitude for all geometries.

In the UV spectral region, the large absorption by atmospheric ozone leads to a rapid decrease of the penetration depth of radiation towards lower wavelengths. The resulting altitudinal dependence of both the incoming radiance and the expected S/N ratios is especially evident in the limb and occultation pictures.

However, the calculations show that typical S/N values of 1000 or larger may be reached for most parts of the spectrum. Even in the UV region S/N values are sufficiently high.

3.2. Operational Trace Gas Products

Operational processing is forseen to be undertaken mainly by ESA and DLR-DFD. All operational data products will be regularly processed, quality controlled and archived.

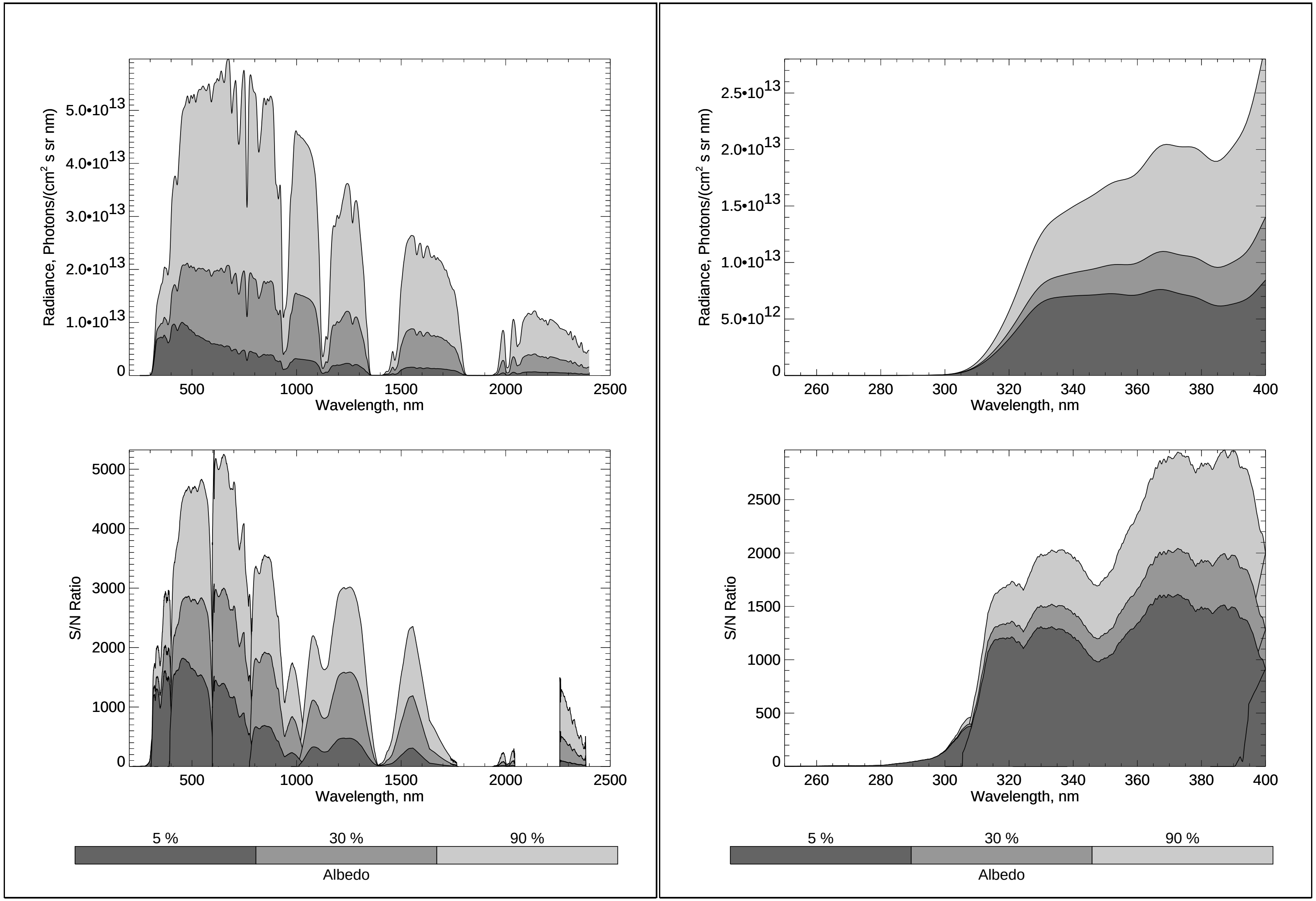

Figure 6. Calculated spectra and S/N ratios for the full and UV wavelength ranges (nadir mode).

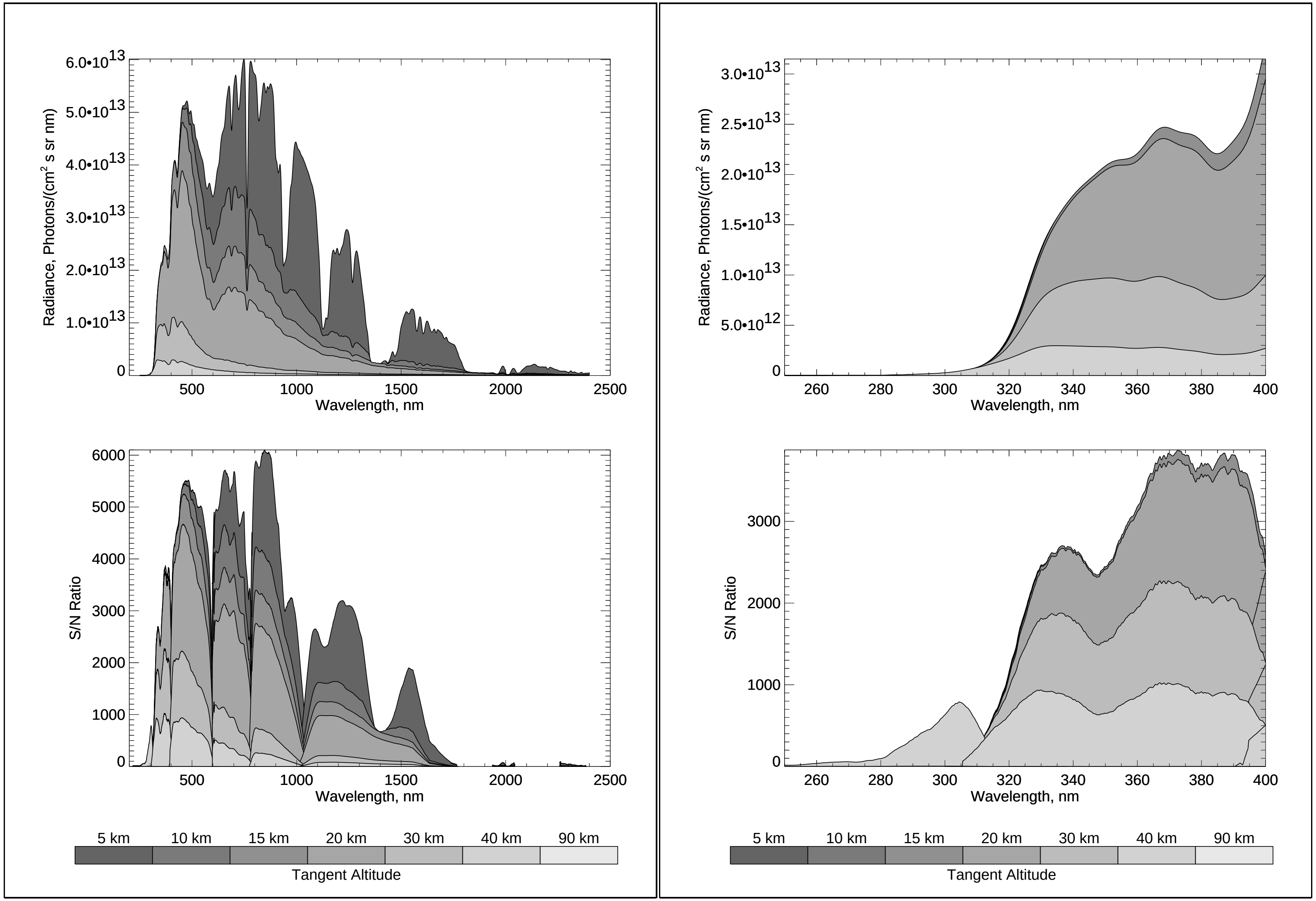

Figure 7. Calculated spectra and S/N ratios for the full and UV wavelength ranges (limb mode).

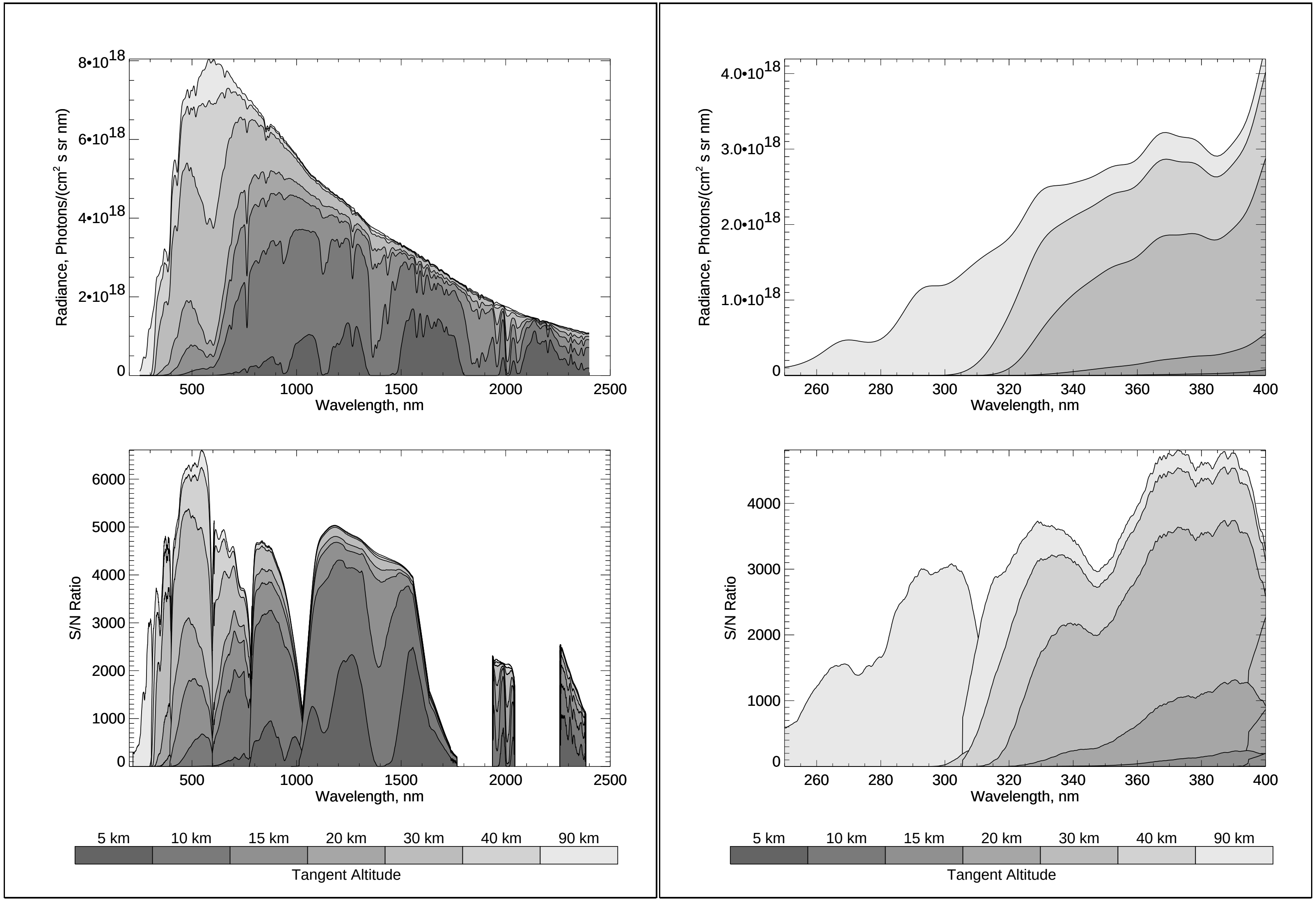

Figure 8. Calculated spectra and S/N ratios for the full and UV wavelength ranges (solar occultation mode).

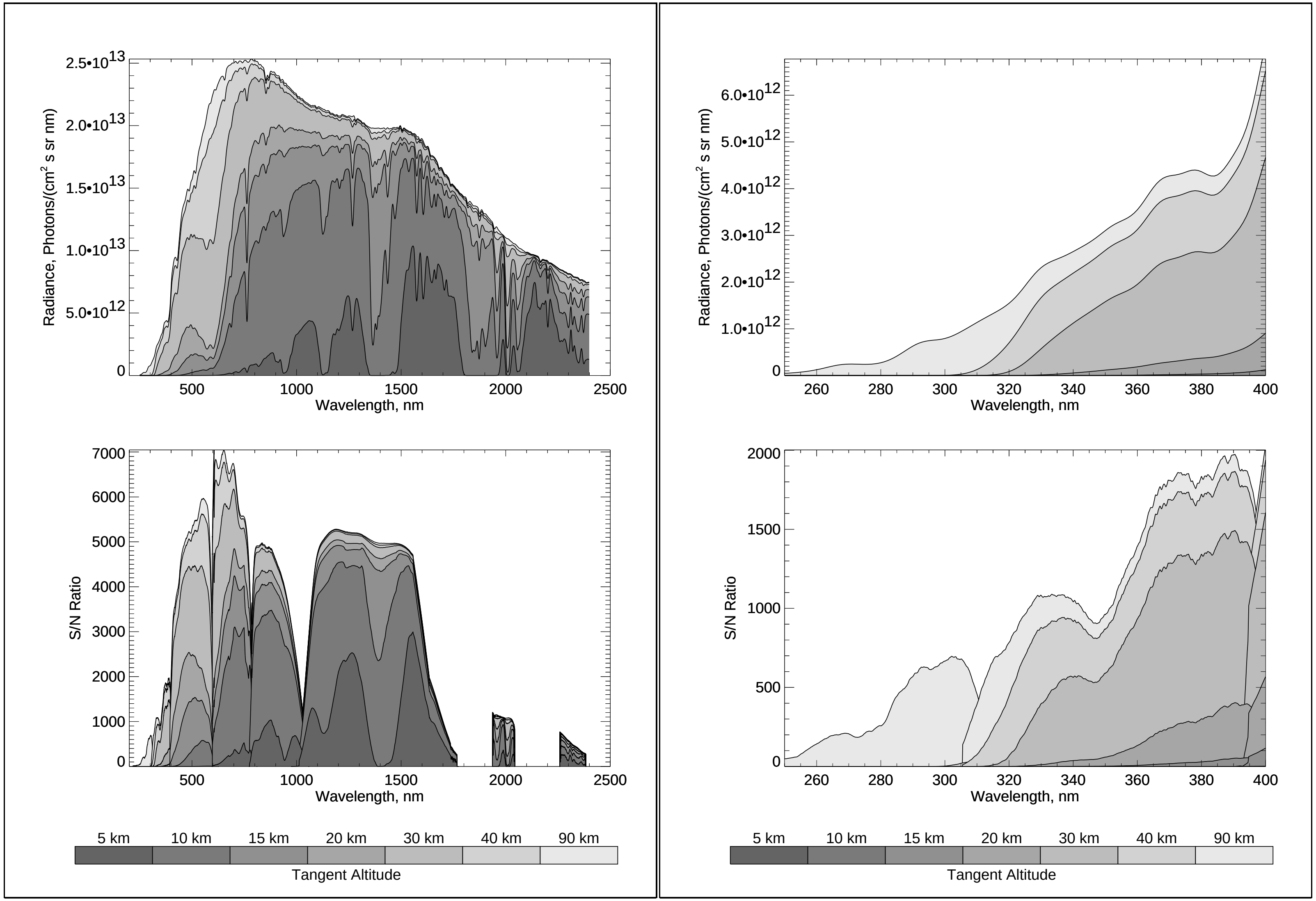

Figure 9. Calculated spectra and S/N ratios for the full and UV wavelength ranges (lunar occultation mode).

	Nadir Total Column Amount			Limb Stratospheric Profile		
	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 Pressure Temp.	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

Figure 10. SCIAMACHY Level 2 Operational Products

The operational products are structured in different levels. Raw data, i.e. detector count rates as function of pixel position, build the Level 0 data. Calibration of Level 0 data yields the corresponding radiance and irradiance spectra which form the Level 1 data product. Geophysical information, e.g. columns and profiles of atmospheric trace gases, is contained in the Level 2 data which are produced by inversion of Level 1 data using appropriate retrieval models.

For SCIAMACHY there will be two kinds of Level 2 products: Near-real-time data and off-line data Near-real-time will be directly processed at the ground stations and delivered within hours after spectrum acquisition. Off-line data use ancillary information like processed pressure and temperature fields, etc., and are thus expected to have a higher-precision.

A complete list of SCIAMACHY Level 2 products is given in Fig. 10. In addition to these operational products, scientific products from occultation and limb measurements (e.g. O_2, $O_2(^1\Delta_g)$, NO, and ClO) and derivation of higher level products (such as tropospheric columns) are planned from process studies.

4. SUMMARY

SCIAMACHY is a space-based spectrometer which measures almost continuously from the UV to the NIR spectral region. It is part of the atmospheric payload of the ENVISAT-1 satellite which will be launched in spring 2000. SCIAMACHY will perform atmospheric measurements in nadir, limb, and both solar and lunar occultation geometry. These measurements will yield highly-resolved radiance and irradiance spectra and mesospheric/stratospheric profiles/columns of O_3, NO_2, H_2O, CO_2, CH_4, N_2O, BrO, CO, O_2, $O_2(^1\Delta_g)$, and NO on a global scale. Under special conditions, i.e. for large tropospheric pollution or ozone hole conditions, columns and possibly profiles of SO_2, H_2CO, ClO, and OClO may be derived. Additionally, information about cloud coverage, cloud top height, aerosols, temperature and pressure will be obtained from the spectral features of O_2 and CO_2. By the combination of near-simultaneous nadir and limb measurements it will be possible to derive tropospheric columns of O_3, NO_2, CO, CH_4, H_2O, N_2O, SO_2, H_2CO, and BrO down to the surface or to the cloud top.

ACKNOWLEDGMENTS

This work has been funded as part of the SCIAMACHY Scientific Support Study by the BMBF under grant 50EP9207 and the University of Bremen.

REFERENCES

1. J. P. Burrows, K. V. Chance, P. J. Crutzen, H. van Dop, J. C. Geary, T. J. Johnson, G. W. Harris, I. S. A. Isaksen, G. K. Moortgat, C. Muller, D. Perner, U. Platt, J.-P. Pommereau, H. Rodhe, E. Roeckner, W. Schneider, P. Simon, H. Sundqvist, and J. Vercheval, *SCIAMACHY – A European proposal for atmospheric remote sensing from the ESA Polar Platform*, Max-Planck-Institut für Chemie, 55122 Mainz, Germany, 1988.
2. J. P. Burrows, M. Buchwitz, M. Eisinger, V. Rozanov, M. Weber, A. Richter, and A. Ladstätter-Weißenmayer, "The Global Ozone Monitoring Experiment (GOME): Mission, instrument concept, and first scientific results," in *Proc. 3rd ERS Symposium, 17-21 March 1997*, pp. 585–590, (Florence), 1997.
3. J. P. Burrows, E. Hölzle, A. P. H. Goede, H. Visser, and W. Fricke, "SCIAMACHY – Scanning Imaging Absorption Spectrometer for Atmospheric Chartography," *Acta Astr.* **35**(7), pp. 445–451, 1995.
4. H. Bovensmann, J. P. Burrows, M. Buchwitz, J. Frerick, S. Noël, V. V. Rozanov, K. V. Chance, and A. H. P. Goede, "SCIAMACHY – Mission objectives and measurement modes," *J. Atm. Sci.* , 1998. in press.
5. S. Noël, H. Bovensmann, J. P. Burrows, J. Frerick, K. V. Chance, and A. H. P. Goede, "Global atmospheric monitoring with SCIAMACHY," *Phys. Chem. Earth* , 1998. (submitted).
6. S. Noël, J. P. Burrows, H. Bovensmann, J. Frerick, K. V. Chance, A. H. P. Goede, and C. Muller, "Atmospheric trace gas sounding with SCIAMACHY," *Adv. Space Res.* , 1998. (submitted).
7. J. Fishman, C. E. Watson, J. C. Larsen, and J. A. Logan, "Distribution of tropospheric ozone determined from satellite data," *J. Geoph. Res.* **95**, pp. 3599–3617, 1990.
8. J. Fishman, V. G. Brackett, E. V. Browell, and W. B. Grant, "Tropospheric ozone derived from TOMS/SBUV measurements during TRACE A," *J. Geoph. Res.* **101**, pp. 24069–24082, 1996.
9. G. P. Anderson, F. X. Kneizys, J. H. Chetwynd, J. Wang, M. L. Hoke, L. S. Rothman, L. M. Kimball, R. A. McClatchey, E. P. Shettle, S. A. Clough, W. O. Gallery, L. W. Abreu, and L. E. A. Selby, "FASCODE/MODTRAN/LOWTRAN:Past/present/future," in *18th annual review conference on atmospheric transmission models, 6–8 June 1995*, 1995.