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A report prepared by the members of the SCIAMACHY Validation and Interpretation Group.

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Foreword

The aim of this document is to review the requirements for the validation of the SCIAMACHY products. It describes the different aspects of the SCIAMACHY validation and lists the associated requirements. It also indentifies the need for a 'core' validation and the necessities for its successful execution. The core validation programme provides a minimal but essential validation of SCIAMACHY. The core validation should be complemented by other validation projects selected via the Announcement of Opportunity (AO). Another important aspect that is highlighted, is the need for long-term validation during the lifetime of the SCIAMACHY instrument.
The SCIAMACHY Validation Requirements Document is the first one in a series of documents devoted to SCIAMACHY validation.

This document has been prepared by the members of the SCIAMACHY Validation and Interpretation Group (SCIAVALIG):

H. Kelder (Chair)	KNMI	The Netherlands
U. Platt (Co-chair)	Univ. Heidelberg	Germany
P. Simon (Co-chair)	BIRA-IASB	Belgium
R. Timmermans (Scientific Secretary)	KNMI	The Netherlands
I. Aben	SRON	The Netherlands
J. Burrows	IFE	Germany
C. Camy-Peyret	CNRS-LPMA	France
E. Hilsenrath	NASA	USA
B. Kerridge	RAL	United Kingdom
K. Künzi	IFE	Germany
J.-C. Lambert	BIRA-IASB	Belgium
J. Lelieveld	IMAU	The Netherlands
P. Levelt	KNMI	The Netherlands
D. McKenna	FZJ	Germany
D. Perner	MPI Mainz	Germany
A. Piters	KNMI	The Netherlands
E. Attema (Observer)	ESA-ESTEC	The Netherlands
W. Balzer (Observer)	DLR-DFD	Germany
S. Bruzzi (Observer)	ESA-ESRIN	Italy
M. Durville (Observer)	NIVR	The Netherlands
A. Friker (Observer)	DLR	Germany

Valuable input and the final authorisation came from the SCIAMACHY Science Advisory Group (SSAG). I would like to acknowledge the members of the SSAG and SCIAVALIG and also the representatives of the funding agencies NIVR and DARA (now DLR) for their contributions. I would like to mention especially Renske Timmermans whose dedication and conscientiousness was essential for the production of this document.

H. Kelder,
Chairman,
SCIAMACHY Validation and
Interpretation Group

Executive Summary

The SCIAMACHY instrument will fly on board ENVISAT which is planned for launch in 1999. SCIAMACHY measures solar irradiance and Earth radiance spectra, and the SCIAMACHY processor derives from these spectra concentrations of various atmospheric constituents. Validation of SCIAMACHY is essential to ensure the quality of these derived parameters.

The SCIAMACHY Validation Requirements Document describes requirements for the validation of SCIAMACHY and makes recommendations concerning its organisation and the scientific and technical approach to achieve this. This document has been produced by the SCIAMACHY Validation and Interpretation Group (SCIAVALIG), a sub-group of the SCIAMACHY Science Advisory Group (SSAG).

Validation of the SCIAMACHY measurements is a significant challenge, due to the broad range of data products that can be derived in nadir, limb and occultation measurements. In addition to the validation of the calibrated spectra it is necessary to assess the performance of the processing algorithms in converting radiances into atmospheric parameters, and to determine random and systematic errors associated with any resulting data product. An accurate assessment of errors is essential for the use of such data in both scientific and general applications. For a successful validation a well structured approach is needed.

The validation of SCIAMACHY can be divided in three phases. In the commissioning phase a preliminary validation has to be performed. This is followed by the main validation phase, which provides the error assessment for the first official data release of validated SCIAMACHY products. Subsequently the long-term validation of data products aims to ensure their quality — independent of degradation of the instrument — throughout the lifetime of the instrument.
The validation activities will be divided into two complementary parts: a 'core' validation, and validation based on selected AO proposals. The core validation programme provides a minimal but essential validation of SCIAMACHY. The core validation and possibly some AO projects begin in the commissioning phase. After the commissioning phase, the core validation and the AO validation will proceed in parallel contributing both to the main validation and the long-term validation.

The requirements identified in this document are listed on pages vii, viii and ix.

The first chapter of this document describes the ENVISAT mission, the scientific objectives of SCIAMACHY and its characteristics.
In the second chapter the SCIAMACHY data products are described.
Chapter 3 focuses on the validation objectives and strategy.
An overview of the different sources of validation data and tools and models for validation is given in Chapter 4. In Table 4.1 the proposed data sources for the validation of the SCIAMACHY products are identified.
Chapter 5 is dedicated to the core validation. The proposed data sources for core validation are listed in Table 5.1.
The details of the three validation phases, including the time schedule, are given in chapter 6.
The final chapter elaborates further on long-term validation which is considered essential for monitoring the quality of the products with respect to ageing or sudden changes in instrument performance. The long-term validation is also needed for providing information required for the validation of advanced and value added data products.

List of Requirements

R1. The SCIAMACHY validation programme must be constructed such that it accommodates appropriately all phases of the operational life of the SCIAMACHY instrument. (p. 31)

R2. The validation should comprise both a core and AO validation programme, existing in parallel during the complete lifetime of the instrument. (p. 13)

R3. The core validation is required to ensure a minimal but essential validation of SCIAMACHY data products. The principle idea is to use one "local" validation source (e.g. balloons, sondes, aircraft) and one "global" validation source (satellites) for each data product (see Table 5.1). The core validation should make optimal use of existing national capacities. It is recommended that the national bodies supporting SCIAMACHY supply the necessary funding for this core validation. (p. 13, 25)

R4. SCIAMACHY data should be available for validation to all co-ordinating (and participating) groups of the core validation as indicated in Table 5.1. (p. 25)

R5. The validation has to start in the commissioning phase and continues with a main and long-term validation. (p. 31)

R6. It is essential to validate the irradiance and radiance products (both nadir and limb) of SCIAMACHY in the commissioning phase because all higher level products depend on the accuracy of these products. (p. 12, 31)

R7. The level 2 products need to undergo a preliminary validation in the commissioning phase. To achieve this goal a ground-based, balloon and aircraft campaign is required (see Table 4.1). (p. 31, 32)

R8. It is required that the main validation phase is continued for about 12 months after the commissioning phase, to cover the different seasons. (p. 14, 33)

R9. All level 1 and 2 products need to be rigorously validated in the main validation phase by intensive campaigns collecting data from ground-based, airborne and satellite instruments (see Table 4.1). (p. 32)

R10. A long-term validation is required for the identification of the long-term changes of the products (e.g. due to degradation of the instrument) and for the validation of new or advanced SCIAMACHY data products. This necessitates a regular, optimised, repetition of the essential elements of the main validation. (p. 33)

R11. The long-term validation should be continued throughout the lifetime of SCIAMACHY. (p. 35)

R12. It is necessary to determine random and systematic errors associated with any SCIAMACHY data product. (p. 12)

R13. All SCIAMACHY NRT and OL operationally retrieved products, recommended by the SSAG (Table 2.2), need to be validated. Particular consideration has to be given to the validation of the new data products (i.e. data products not retrieved from GOME data). Besides these operational products also additional products should be validated. (p. 5, 15, 31)

R14. Validation on a global scale for all data products is in principle needed. The measurements should be distributed over the whole globe but also attention should be paid to specific areas of critical importance for atmospheric studies. (p. 14)

R15. The validation strategy is to rely on measurements based on demonstrated/validated techniques. New instrumentation should be considered as correlative measurements. (p. 17)

R16. The ground-based stations should be the basis of the validation programme. Of particular importance are data collected by networks. (p. 17, 33)

R17. Validation requires the collection of data from a large number of representative locations and conditions. Optimal use should be made of available data and where necessary specific measurements should be provided. (p. 11, 33)

R18. Ideally several independent observation methods should be used for validation. (p. 11)

R19. Reprocessing of data is required when significant improvements can be expected. (p. 11)

R20. Iterative validation and reprocessing, converging to high quality data products is required. The process of validation and reprocessing has to be repeated for a given data product up to the point at which its error either is less than that required for a given application or reaches its theoretical limit. (p. 11, 12)

R21. An easily accessible data base for validation is required. The data base is meant for measurements obtained during the validation phase and should have common formats for all types of data. (p. 14)

R22. It is important to use data assimilation as tool for validation and interpretation. Therefore, appropriate data-assimilation facilities should be created. (p. 12, 15)

R23. Development of software tools is required, e.g. a coincidence predictor, software for data assimilation, cataloguing and data-base tools. (p. 12)

R24. Provision of auxiliary data (atmospheric parameters etc.) not measured by SCIAMACHY but needed for validation studies is required. (p. 12)

R25. Campaigns for ground-based and airborne measurements, preferably coincidental with the overpass of the satellite, are to be exploited. (p. 14)

R26. Measurements from satellite instruments are very useful for SCIAMACHY validation, e.g. from SAGE III, SEVIRI, GOME, TOMS, MOPITT etc.. Use of these data should be encouraged. (p. 14, 33)

R27. Validation workshops should be held typically every six months for the complete lifetime of SCIAMACHY. (p. 35)

R28. To validate the large stream of global data being received from SCIAMACHY, participation in the Announcement of Opportunity of a variety of scientific validation projects should be encouraged. (p. 13)

R29. SCIAVALIG will propose potential reviewers and criteria for the selection of AO proposals on SCIAMACHY data. The agencies providing the SCIAMACHY instrument should use this input in the negotiations with ESA during the AO evaluation exercise. It is recommended that at least the chairmen of the SCIAVALIG will review the projects proposed for selection. (p. 13)

R30. Experience obtained during the validation of GOME and the UARS and ADEOS satellites should be exploited. (p. 12)

R31. The validation of the SCIAMACHY instrument should be embedded in the ENVISAT chemistry validation. Validation campaigns organised for GOMOS and MIPAS should be co-ordinated with the SCIAMACHY validation campaign and vice versa. (p. 12, 14)

R32. Special attention should be paid to the performance of collocated measurements with the MIPAS and GOMOS instruments. (p. 14)

R33. The GOMOS and MIPAS measurements should be easily available and preferably in near-real time for the SCIAMACHY validation groups and vice versa. (p. 14)

Contents

1 Introduction

One of the tasks of the SCIAMACHY Science Advisory Group (SSAG) is to give advise on validation and to assist in validating SCIAMACHY data products. These activities are coordinated by the SCIAMACHY validation and interpretation group SCIAVALIG (see Annex A for members).

Validation is the process of assessing by independent means the quality of the SCIAMACHY data products. Interpretation is the subsequent activity of the scientific analysis of the validated SCIAMACHY data.

The inversion of the measurements made by the SCIAMACHY instrument will produce a unique amount of global data: concentrations of trace gases, which play an important role in the chemical and physical processes determining the behaviour of the troposphere and stratosphere, atmospheric radiances in the UV, visible and near IR region as well as several other important geophysical data.

The validation of these data will be a large scale operation, and requires a well structured approach. This document defines the requirements for this validation.

1.1 The ENVISAT Mission

The ENVISAT mission will be ESA's third Earth observation remote sensing satellite. It is to be launched by the Ariane 5 rocket, in 1999. Like its predecessors, ERS-1 and 2, ENVISAT will fly in a polar orbit at 800 km altitude and 98.5° inclination. The orbital period is 100 minutes.

ENVISAT carries 10 instruments on its payload module. They cover a wide variety of remote sensing tasks ranging from land/sea surface applications to atmospheric research (The ENVISAT Programme, ESA bulletin 76 and ESA, ENVISAT-1 Mission & System Summary, 1997).

As is the case for ERS-1 and 2, the ESA concept for the ground segment comprises complementary ESA and nationally provided facilities. Among the national facilities, the "Processing and Archiving Centres" (PACs) will play a role in operational data processing, archiving and user service provision (ENVISAT Ground Segment Concept, ESA-PB-EO(94)24)

1.2 The ENVISAT Payload

The objective of the ENVISAT mission is to provide novel global information about the Earth's environment for the research areas:

- atmosphere
- land
- ocean
- ice/snow

Therefore, ENVISAT carries a number of different sensors. These instruments are listed in Table 1.1. It is also indicated whether the instrument is financed by ESA (ESA Developed Instrument-EDI) or a participating member state (Announcement of Opportunity Instrument-AOI).

1.3 The SCIAMACHY Instrument

The SCIAMACHY Project was initiated to provide global knowledge about the amounts and distributions of tropospheric, stratospheric and mesospheric trace constituents and parameters which play an important role in the physical and chemical processes, which determine the behaviour of the atmosphere (Burrows et al., 1988). SCIAMACHY was proposed for flight as part of the Polar Platform in response to the ESA Announcement of Opportunity. The development is managed by the German Aerospace Center (DLR) and the Netherlands Agency for Aerospace Programmes (NIVR) with a contribution from the Belgian Institute for Space Aeronomy (BIRA-IASB). This development is financially supported by the German Ministry of Science, Research and Technology within the ATMOS-programme, the Ministries of Economic Affairs, of Education, Culture & Science and of Housing, Spatial Planning & the Environment in the Netherlands and the Office of Science, Technical and Cultural Affairs in Belgium.

1.3.1 Scientific Objectives

The primary objective of SCIAMACHY is to determine vertical and horizontal distributions of important atmospheric constituents and parameters (trace gases, aerosols, radiance, irradiance, clouds, temperature and pressure) from measurements of radiances reflected by and upwelling from the atmosphere and Earth's surface (The ENVISAT Programme, ESA Bulletin 76, Scientific Requirements Document for SCIAMACHY Data and Algorithm Development, Chance et al. 1997). The measurement of the radiances will be done in different viewing geometries: nadir, limb and solar and lunar occultation.

1.3.2 The Instrument

SCIAMACHY is a passive remote sensing spectrometer observing backscattered, reflected, transmitted, or emitted light from the Earth between 240 and 2380 nm, in the following viewing geometries:

- Same atmospheric volume first in limb and after a short time (8 min.) in nadir;
- Atmosphere in solar or lunar occultation;
- Direct solar or lunar observations for in-flight calibration.

Table 1.2 lists the characteristics of the 8 spectral channels.

A detailed description of the SCIAMACHY instrument is given in the Scientific Requirements Document (Bovensmann and Burrows, 1997).

Table 1.1: *Primary objectives (marked with an 'x') for the scientific payload planned on ENVISAT (EDI = ESA Developed Instrument; AOI = Announcement of Opportunity Instrument). Two ENVISAT instruments are not included in this table: 1) DORIS (Doppler Orbitography and Radio-positioning Integrated by Satellite), which determines the precise orbit of ENVISAT, and 2) LRR (Laser Retro-Reflector), which will be used to complement DORIS for the restitution of the orbit.*

Instrument	Type	Atmosphere	Land	Ocean	Ice/Snow
Advanced Synthetic Aperture Radar (ASAR)	EDI		x	x	x
Advanced Along-Track Scanning Radiometer (AATSR)	AOI (United Kingdom)		x	x	
Medium-Resolution Imaging Spectrometer (MERIS)	EDI			x	
Advanced Radar Altimeter (RA-2)	EDI		x	x	x
Microwave Radiometer (MWR)	EDI	x			
Michelson Interferometer for Passive Atmospheric Sounding (MIPAS)	EDI	x			
Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY)	AOI (Germany, Netherlands, Belgium)	x			
Global Ozone Monitoring by Occultation of Stars (GOMOS)	EDI	x			

Table 1.2: *Characteristics of the SCIAMACHY spectral channels.*

Channel no.	Wavelength Range (nm)	Detector Pixel Resolution (nm)	Spectral Resolution (nm)
1	240-314	0.12	0.24
2	309-405	0.13	0.26
3	394-620	0.22	0.44
4	604-805	0.24	0.48
5	785-1050	0.27	0.54
6	1000-1750	0.74	1.48
7	1940-2040	0.11	0.22
8	2265-2380	0.13	0.26

2 SCIAMACHY Products

2.1 Introduction

Near-Real Time (NRT; which are to be delivered in less than 3 hours after sensing) products as well as Off-Line Processor (OLP; which are to be delivered 2-3 weeks after sensing) products will become available for the scientific community from SCIAMACHY and other ENVISAT instruments. In addition to these operational level 1 and 2 products, other scientific data products will probably be retrieved.

It is important to point out that, although this document only considers the validation of operationally retrieved products, the SCIAVALIG subgroup recommends the validation of the additional scientific data products as well (**R13**). Experience shows that operational algorithms are usually improved or enhanced by comparison with scientific data products.

2.2 Heritage: GOME Data Products

The SCIAMACHY data processing (see Annex B) will be based on the GOME data processing, as GOME is a SCIAMACHY precursor, and there is already experience with GOME data processing. The DOAS (Differential Optical Absorption Spectroscopy) retrieval algorithm for derivation of column densities of trace gases, developed by scientists from the University of Bremen and Heidelberg and the Max-Planck-Institut Mainz, has been converted into an operational algorithm at DLR-DFD. The retrieval of ozone profiles is under development at the University of Bremen, RAL and DLR-DFD. Similarly aerosol and cloud retrieval development is proceeding by a team composed of the IMGA-CNR, University of Bremen and Telespazio for the I-PAF.

The GOME operational data products at the end of 1997 are (Hahne, 1997):

- Level 1 data products:
  - Earth radiance spectrum (240-790 nm).
  - Solar irradiance spectrum (240-790 nm).
  - Earth polarisation in 3 bands.
  - PMD subpixel radiances in 3 bands.
- Level 2 data products:
  - O_3 slant column and vertical column (DOAS retrieval).
  - NO_2 slant column and vertical column (DOAS retrieval).
  - ICFA cloud cover fraction.

Table 2.1: *Spectral information contained in the SCIAMACHY channels (from SRDDA document, Chance et al., 1997).*

channel	wavelength(nm)	species and parameters	remarks
1	240-314	O_3, NO, $C\ell O$ and SO_2	$C\ell O$ only under high $C\ell O$ and low O_3 conditions
2	309-405	O_3, O_4, NO_2, ($C\ell O$), $OC\ell O$, BrO, SO_2, HCHO and aerosol	
3	394-620	NO_2, NO_3, H_2O, O_2, O_3, O_4 and aerosol	
4	604-805	NO_3, O_3, O_2, O_4, H_2O, clouds p, T and aerosol	
5	785-1050	O_3, O_2, O_4, H_2O and aerosol	
6	1000-1750	$O_2(^1\Delta_g)$, O_4, H_2O, clouds, aerosol, CH_4, O_3 and CO_2	water/ice clouds
7	1940-2040	CO_2, H_2O and p, T	
8	2265-2380	CO, CH_4, N_2O and H_2O	

Other scientific data products are demonstrated to be feasible:

- BrO, $OC\ell O$, SO_2 and possibly HCHO (University of Bremen, Max-Planck-Institut Mainz)(Eisinger et al., 1997).
- Ozone profiles (RAL, University of Bremen and KNMI)(Munro et al., 1996, de Beek et al., 1997b, van der A, private communication).
- Imaging Browse Product (Cloud detection using PMD's) (Koelemeijer et al., 1996)

Provided that GOME remains in operation during the SCIAMACHY validation period, it clearly can be used to check the consistency of the SCIAMACHY products (especially in nadir viewing mode) with the equivalent GOME products. For the long-term validation, use should be made of GOME-2 measurements on board Metop (ESA WPP-123, OMI – Ozone Monitoring Instrument for Metop, 1996).

2.3 SCIAMACHY Data Products

Besides four partly overlapping spectral channels, in the UV-Vis wavelength range, SCIAMACHY has four extra channels in the near IR (see Table 1.2), enabling the measurement of, among others, CO, H_2O, N_2O, CO_2, CH_4, aerosols, and absorption by clouds. Table 2.1 lists, for each spectral channel, the species with spectral features in the corresponding wavelength range.

The limb and occultation modes of SCIAMACHY enable profiles of trace gases, aerosols, pressure and temperature in the stratosphere to be retrieved. In the nadir mode the DOAS retrieval

Table 2.2: *SCIAMACHY Level 1 and Level 2 Operational Products.*

Level 1	– Earth radiance spectrum (240-2380 nm) (nadir, limb and occultation mode) – Solar irradiance spectrum (240-2380 nm) – Earth fractional polarisation in 6 spectral bands (direction of polarisation in 1 band) – PMD subpixel radiances in 7 bands

Level 2	Nadir			Limb		
	UV/Vis	IR	UV-IR	UV/Vis	IR	UV-IR
NRT	O_3 NO_2 SO_2^* $OC\ell O^*$ H_2CO^* BrO^* †	H_2O N_2O CO CH_4^{**}	Cloud cover frac. Cloud top height Aerosol abs. index			
OLP	O_3 NO_2 SO_2^* $OC\ell O^*$ H_2CO^* BrO^* UV index †	H_2O N_2O CO CH_4 CO_2 p, T	Cloud cover frac. Cloud top height Aerosol abs. index	O_3 NO_2 BrO^* †	H_2O N_2O † CO † CH_4 CO_2 p, T	Aerosol abs. index

(*) Observed under special conditions or after averaging.
(**) Secondary product, necessary for retrieval of CO and N_2O.
(†) SSAG recommended products (not yet officially confirmed).

algorithm can be used for the UV and visible ranges. In the IR range, a variant of DOAS is being developed by SAO. For profile retrieval in nadir and limb mode the Optimal Estimation or statistical regularisation and single vector decomposition techniques for retrieval combined with a forward radiative transfer model will be used. For the nadir mode such a forward model has been developed called GOMETRAN and is being extended to SCIATRAN (de Beek et al., 1997a). For the limb observations such a model is under development at the University of Bremen. As an ancillary parameter cloud information is needed. This can be retrieved from the O_2 A-band and the PMD subpixel information, using for example the ICFA (Initial Cloud Fitting Algorithm) or ACFA (Advanced Cloud Fitting Algorithm) approach. More information on retrieval algorithms can be found in the Scientific Requirements Document for SCIAMACHY Data and Algorithm Development (Chance et al., 1997).

The meteorological community is foreseen by ESA as one of the primary users of the NRT products. For this community O_3 and H_2O are important products. For the atmospheric chemistry community O_3, NO_2, N_2O, and CO are important NRT products. The OLP products were chosen as a result of their importance for atmospheric chemistry and physics (SRDDA document, Chance et al., 1997).

The agreed level 1 and level 2 SCIAMACHY data products, based on GOME experience and the needs from the scientific community, are listed in Table 2.2 (version as agreed on 12$^{\text{th}}$ SSAG, February 1997). In Table 2.3 the estimated precision, altitude range, resolution and limitations are given for the different SCIAMACHY products.

Table 2.3: *Details of SCIAMACHY products (C = Column, P = Profile). The estimated precisions are from the SCIAMACHY Mission Objectives and Measurement Modes (Bovensmann et al., 1997). Note that for limb profiles the precision depends strongly on altitude. Altitude ranges and vertical resolutions are given according to the SRDDA document (Chance et al. 1996). The groundpixel sizes listed here are merely an indication. They vary with exposure times which in turn vary with wavelengths and solar zenith angles. The listed ground pixel sizes are based on the pixel exposure times expected to be used approximately between solar zenith angles 30° and 55° for a swath width of 960 km (SCIAMACHY Operations Concept, SOST, 1996). If more than one channel is observing the same product, the smallest pixel size is indicated.*

Level	Product	Column/Profile	Estimated Precision	Altitude range	Ground Pixel size	Vertical Resolution	Remarks
Level 1	Spectral Solar Irradiance	—					
	Spectral Earth Radiance/ Albedo	—			30–240 × 30 km		
	Polarisation	—					
Level 2	O_3	C (nadir)	1 %	—	30 × 30 km	—	
		P (limb)	10 %	20–50 km		3 km	
	NO_2	C (nadir)	2 %	—	30 × 30 km	—	
		P (limb)	10 %	20–40 km		3 km	
	BrO	C (nadir)	5 %	—	120 × 30 km	—	
		P (limb)	50 %	20–25 km 20–30 km		3 km 3 km	normal conditions ozone hole conditions
	H_2O	C (nadir)	1 %	—	60 × 30 km	—	
		P (limb)	10 %	20–53 km		3 km	
	N_2O	C (nadir)	5 %	—	240 × 30 km	—	
		P (limb)	10 %	20–35 km		3 km	

Table 2.3: *continued*

Level	Product	Column/Profile	Estimated Precision	Altitude range	Ground Pixel size	Vertical Resolution	Remarks
Level 2	CO_2	C (nadir)	1 %	—	240 × 30 km	—	
		P (limb)	10 %	20–50^+ km		3 km	
	CO	C (nadir)	5 %	—	240 × 30 km	—	
		P (limb)	10 %	20–35 km		3 km	
	CH_4	C (nadir)	1 %	—	240 × 30 km	—	
		P (limb)	10 %	20–40 km		3 km	
	Pressure	P (limb)				3 km	
	Temperature	P (limb)				3 km	
	Cloud Cover	—		—	30 × 30 km	—	
	Cloud Top Height	—		—	15 × 30 km	—	
	Aerosol Abs. Index	C (nadir)		—	120 × 30 km	—	
		P (limb)				3 km	
	$OClO^*$	C (nadir)	5 %	—	120 × 30 km	—	under ozone hole conditions
	SO_2^*	C (nadir)	10 %	—	120 × 30 km	—	
	H_2CO^*	C (nadir)	20 %	—	120 × 30 km	—	polluted tropospheric conditions, biogenic emissions and biomass burning

* Special products

3 Data Validation, Objectives and Strategy

3.1 Introduction

The activity of validation is that process by which operational and scientific data products, are shown to be valid. Validation has several different aspects. It establishes the precision and accuracy of the data product and thus the error estimate in the data product. The errors associated with a given product, arising from random or systematic errors (e.g. absorption cross section knowledge) need to be defined within the product. The algorithm and data product developer normally provides this as part of the algorithm.

Validation typically involves the collection of data for a particular data product (e.g. total O_3 column) from other systems or devices measuring this product. Validation requires the collection of data from a large number of representative locations and conditions (**R17**), as all such effects may influence the particular product.

Validation involves the comparison of a particular data product (and its associated errors), with the same product (and its errors) obtained from a different method or source. Ideally several independent observation methods are used (**R18**). In this manner systematic errors associated with a satellite product have often been identified, leading to an improvement of the accuracy of that particular data product. Validation is therefore an iterative approach.

One of the important aspects of validation is the quality control of the end data product of a satellite mission. It helps to establish the sources of inaccuracies in the retrieval algorithms and consequently to improve the data products. Reprocessing of data is required when significant improvements can be expected (**R19**). The latter needs to be planned into the processing scheme from its outset.

The process of validation and reprocessing is recommended to be repeated for a given data product up to the point at which its error either is less than that required for a given application or reaches its theoretical limit (arising from either instrument noise or the shot noise limit) (**R20**).

The final objective of validation of SCIAMACHY data products is to provide data sets for atmospheric and climate change studies, having a known accuracy for as long as the instrument takes measurements.

3.2 The Need for Validation

Earth-observing instruments on satellites measure electromagnetic radiation which has been emitted, absorbed, transmitted, scattered or reflected by the Earth's atmosphere and surface. Atmospheric constituents or physical properties may be estimated by considering how the incident solar spectrum has been modified by the Earth's atmosphere. The process of deriving atmospheric parameters may be broken down into two stages:

1. The derivation of spectrally and radiometrically calibrated, geolocated spectra of electromagnetic radiation observed by the satellite instrument.
2. The inversion of these data and the derivation of data products for atmospheric constituents, physical parameters or surface parameters by using suitable algorithms and the necessary processing environment.

Validation and calibration are essential parts of both of these stages. Radiances and irradiances must be validated (**R6**) to ensure that detectors and collection optics produce spectra conform the expected performance of the instrument. It is essential that the actual performance of the combined instrument sub-systems is known so that spectra are calibrated correctly. In addition to the validation of the calibrated spectra it is necessary to assess the performance of the processing algorithms in the inversion of radiances into atmospheric parameters and to determine random and systematic errors associated with any resulting data product (**R12**).

Validation of the SCIAMACHY measurements is a significant challenge, due to the broad range of data products that can be derived in nadir, limb and occultation measurements. Experience obtained during the GOME validation should be exploited . The robust validation of the UARS and ADEOS satellite, which boards instruments that match SCIAMACHY's measurement capabilities, should also be taken into account (UARS Correlative Measurements Program, 1995) (**R30**).

The validation of the SCIAMACHY instrument should be embedded in the validation of the GOMOS and MIPAS instruments on board of the ENVISAT mission (**R31**). This exploits the synergy between these instruments.

3.3 Objectives

The objective of the validation of SCIAMACHY is to establish the validity and accuracy of the measurements made by SCIAMACHY and the data products both operational and scientific. These objectives will be achieved by the following:

1. The collection of suitable validation data e.g. measurements from ground-based, airborne and satellite platforms.
2. The development of an easily accessible validation data base and a data assimilation facility for validation. The data base should have common formats for all types of data. There should be a readily accessible database installed for facilitating data assimilation (**R22**).
3. The development of appropriate tools: coincidence predictor, software for data assimilation, cataloguing, database tools (**R23**).
4. The provision of auxiliary data (atmospheric parameters etc.) not measured by SCIAMACHY but needed for validation studies (**R24**).
5. The analysis of SCIAMACHY and validation datasets.
6. The assessment of the uncertainties of SCIAMACHY data products (**R12**).
7. The iterative validation and reprocessing, converging to high quality data products (**R20**).

3.4 Validation set-up

The SCIAVALIG proposes and strongly recommends that the validation comprises both a core and AO validation programme (**R2**).

3.4.1 Core Validation

The core part of the SCIAMACHY validation is envisaged as being undertaken primarily by relevant groups from the countries which have funded the development of SCIAMACHY. The core validation is to validate with a minimum set of data, which the national and international bodies supporting SCIAMACHY are recommended to supply (**R3**). The principle idea is to have one "local" validation source (e.g. balloons, sondes, aircraft) and one "global" validation source (satellites) for each data product. It is intended that this basic or minimum set of data and the core validation activities will be complemented and enhanced by the wide ranging activities envisaged to occur as a result of the release of the AO for validation of SCIAMACHY within the ENVISAT framework.

The proposed SCIAMACHY core validation plan is described in Chapter 5. It is recommended that it makes optimal use of existing national capacities (**R3**).

3.4.2 AO Validation

To validate the large stream of global data being received from SCIAMACHY, a variety of scientific validation projects should be encouraged (**R28**). The Announcement of Opportunity for the ENVISAT missions, issued by ESA, will include an AO call for SCIAMACHY validation. Peer experiments will be selected, which then are expected to find funding from their relevant national funding agencies. There are two risks associated with this procedure. The first is that the responses to the ENVISAT AO will not necessarily focus on SCIAMACHY data products. Secondly the experience from GOME was that not all projects selected as a result of the AO received national funding or in due time.

It is proposed that the AO validation is open to all scientists. One important objective of the AO with respect to SCIAMACHY, is to extend to all parts of the globe the collection of data needed to validate the SCIAMACHY data products.

The SCIAVALIG subcommittee assumes as part of its responsibility to prepare:
(i) a list of potential reviewers for the selection of AO proposals
(ii) criteria for the selection of AO proposals with respect to SCIAMACHY.
These will be proposed to the SSAG and it is recommended that the agencies providing the SCIAMACHY instrument use this input in their negotiations with ESA during the AO evaluation exercise. It is recommended that at least the chairmen of SCIAVALIG will review the projects proposed for selection (**R29**). After completion of the AO evaluation, the SCIAVALIG subcommittee will produce a SCIAMACHY Validation Handbook, describing the results of both core and the AO validation proposals.

3.4.3 Foci for Validation

SCIAMACHY will measure under different conditions. Some measurements will be easier to validate than others. The following distinctions can be made with respect to these conditions:

- Cloudiness: Clear and fully clouded conditions are easier to simulate than partly clouded conditions.
- Underlying surface: Sea surface, with its uniform elevation, albedo, and more uniform temperature, is less complex than the land surface.
- Solar zenith angle: Small solar zenith angle is better understood and radiative transfer is simpler for small solar zenith angles.
- Atmospheric conditions: The retrieval of trace gases might be dependent on various atmospheric conditions (e.g. ozone hole vs. tropical conditions). These should be considered separately.

It is recommended to start validating the easier cases (e.g. clear sky, small solar zenith angle) before the more complex ones. After understanding the errors made in the simpler situations, we can proceed to the more difficult cases.
Within each case, the dependence on other atmospheric parameters can be studied.

3.4.4 Data Sources for Validation

Validation will be done using ground-based, airborne and satellite measurements. A co-ordinated validation programme is required . At least one year of measurements are needed to cover the different seasons (**R8**). In this validation programme, measurement campaigns for ground-based and airborne measurements, preferably coincidental with the overpass of the satellite, are to be exploited (**R25**). A data base for measurements obtained during the validation phase of the instrument is to be created and is necessary for efficient validation (**R21**). Only the members of the validation team should have access to this data-base until the official release of data. All PIs and co-PIs of the accepted validation proposals should be part of this validation team.

Comparison with validated satellite measurements will be done using measurements at the same geolocation and time. As GOMOS and MIPAS will be validated at the same time, their measurements cannot be used as a primary source of validation during the first phase of validation. However, validation campaigns organised for GOMOS and MIPAS should also be used for SCIAMACHY validation and vice versa (**R31**). A special co-ordination activity in order to perform collocated measurements with the MIPAS and GOMOS instruments is also required (**R32**). The GOMOS and MIPAS measurements should be easily available and preferably in near-real time for the SCIAMACHY validation groups and vice versa (**R33**). Measurements from other satellite instruments (not on ENVISAT) are very useful for SCIAMACHY validation, e.g. from SAGE III, SEVIRI, GOME, TOMS, MOPITT etc. (**R26**). In Table 4.1 ground-based and satellite data which can be used for the validation of the several products of SCIAMACHY are listed.

Validation of the data on a global scale for all data products is needed (**R14**). In practice this can be achieved by comparison of SCIAMACHY data with measurements from the surface (ground, ship), from aircraft or balloon and from satellite instruments. These should also be performed in specific areas of critical importance for atmospheric studies, such as:

- Tropical marine regions
  (tropical stratosphere, loss of ozone in the tropical remote troposphere)
- Tropical continental areas
- Mid-latitude continental sites (stratospheric ozone, pollution, CO, CH_4)
- High mid-latitude sites (polar front) (stratospheric ozone loss, ozone loss-event warning)
- Polar sites (polar stratospheric ozone loss, polar tropospheric ozone loss events, polar tropospheric halogen activation)

The SCIAMACHY validation is to build on the lessons learned from the GOME validation (ESA WPP-108, 1996, ESA, proceedings of the third ERS Symposium Florence, 1997, GOME Validation Campaign, Experimenters Handbook, draft, 1994) (**R30**). As SCIAMACHY has considerably enhanced capabilities compared to GOME, particular consideration has to be given to the validation of the new data products (**R13**). For instance it is important to validate SCIAMACHY with respect to methane and carbon monoxide measurements. For this, the use of MOPITT measurements is envisaged.

3.4.5 Data-Assimilation Models for Validation

Data assimilation is an important tool for the validation of satellite measurements (see also section 4.2.2) (Levelt et al., 1996a, 1996b and "*Studies of Ozone Distributions based on Assimilated satellite measurements (SODA)*", an EU project proposal, 1996-1999). Data-assimilation models were already used for, e.g., the validation of the ERS scatterometer on the ERS-1 (Stoffelen and Anderson, 1997) and ERS-2 satellites, the validation of the UARS instruments (Swinbank et al., 1993) and the validation of GOME (Piters et al., 1996a, 1996b). Exploiting data-assimilation models fully makes it possible to determine random and systematic errors in the measurements and perform on-line quality control of the instruments. Data which largely differ are directly indicated. Assimilating measurements (ground-based or other satellite measurements) into a validated atmospheric model enable continuous, collocated comparison with assimilated SCIAMACHY measurements. Therefore it is also important to create, or to have access to, data-assimilation facilities for validation and interpretation (**R22**). In the Netherlands SCIAMACHY data-assimilation facilities will be set-up.

4 Validation Campaign

4.1 Identification of Validation Sources

The validation strategy is to rely on measurements based on demonstrated/validated techniques from ground-based, ship-based, aircraft, balloon and satellite measurements (**R15**). New instrumentation should be considered as correlative measurements which could be used in the validation programme, provided that their data products have been validated independently. This implies that simultaneous observations performed from ENVISAT cannot in a first stage be used for validation but only for 'co-located' comparisons with relevance to the long-term validation programme.

The following validation sources can be distinguished:

- In situ surface observations .
- Remote surface observations (Lidar, Brewer, Dobson, SAOZ, FTIR and MW).
- Airborne observations (Sondes, balloons, rockets, aircraft — regular airplanes operating below 13 km, e.g. "DLR FALCON" and "CESSNA", and stratospheric airplanes operating above 18 km, e.g. "GEOPHYSIKA").
- (Validated) satellite data from other missions (e.g. TOMS, ATSR-2, GOME, SAGE III, MOPITT).
- Model Calculations.

The ground-based stations should be the basis of the validation programme (**R16**). Of particular importance are data collected by networks such as NDSC (Network for Detection of Stratospheric Change) for the stratosphere (Lambert et al., 1997) or TOR (Tropospheric Ozone Research network) for the troposphere, where data continuity is secured and the data is reliable and well validated. The following list gives an overview of existing networks and data centres which can be used for validation:

- Dobson/Brewer network.
- WOUDC (World Ozone and Ultraviolet Data Centre) which archives a.o. ozone soundings.
- NDSC. This network of a dozen of primary sites and two dozen of complementary stations will form the backbone of stratospheric ozone observations. European countries are actively involved in this network.
- SAOZ/UV-visible network, in which the EC has supported campaigns to validate and standardise this observation method for stratospheric species.
- TOR is important for the tropospheric measurements.
- Local networks, also important for tropospheric measurements.

All these networks have their own policy with respect to data distribution and use by external scientists and/or research groups. Networks are often part of international programmes like IGBP (IGAC), or WMO/WCRP (GCOS, GAW, SPARC).

In Annex C a description is given of different satellite and ground-based instruments, networks, balloon and aircraft measurements. For the list of products which should be validated, the main validation sources are presented in Table 4.1.

Several categories can be used when considering instruments, techniques and strategies for the validation of SCIAMACHY:

1. Categories divided on the basis of the platform used:
    - Surface instruments (usually ground-based but also ship)
    - Airborne instruments (aircraft and balloon)
    - Space instruments (which must have already been validated themselves)
2. Categories divided by the measurement technique used:
    - In situ
    - Remote sensing
3. Categories based on the product to be validated:
    - Spectral radiance and irradiance
    - Column and profiles of atmospheric constituents
    - Total optical thickness and vertical profiles with detailed properties (optical, chemical) of aerosols
    - Surface properties (albedo, spectral reflectance)

    The distinction between level 1 and level 2 products is important here, as the logical pathway for the processing is to go from spectral data to geophysical quantities.
4. A temporal division of the validation related to the operational lifetime of SCIAMACHY:
    - A major validation effort in the commissioning phase to detect early problems, provide accuracy bench marks and qualify basic algorithms.
    - A main validation phase to check the consistency of the key products on a global scale and fine tune the algorithms.
    - A long-term validation phase to verify that the overall system (space and ground segment) is indeed in a position to distinguish between real geophysical trends and ageing of a space instrument.

It is not necessary here to examine all the possible combinations involved as a result of the classification discussed above. However a realistic and cost effective approach, based on what has already been performed for previous validations of space instruments, would lead to the following classification.

1. Validation based on existing observing systems:
    - Regular sounding stations (PTU and O_3)
    - Permanent observatories (in situ sampling, remote sensing instruments, i.e. lidar and spectrometers in the microwave, infrared, visible and UV).

Table 4.1: *Main validation sources. C = Column, P = Profile, NRT = Near-Real Time, OLP = Off-Line Processor, AQ = Additional Quantity, RTM = Radiative Transfer Models. Note: Only satellite instruments which are expected to be active in the period 1999-2004 are listed (this is the time period which covers the expected lifetime of SCIAMACHY). Some of these future satellite instruments may actually not be usable, because they may not be validated yet.*

SCIAMACHY				Validation by			
Level	**Product**	**Column/ Profile**	**Product type**	**Satellite instruments probably active in 1999-2004**	**Ground Based**	**Balloon/Sondes**	**Aircraft**
Level 1	Spectral Solar Irradiance			GOME, SOLSTICE II, SOLSPEC, VIRGO, SBUV-2	Measurements, RTM	UV-vis spectrometer, IR interferometer	UV-vis spectrometer, IR interferometer
	Spectral Earth Radiance/ Albedo			GOME, SAGE III, AATSR/ATSR-2, TOMS, SBUV-2, MERIS	Measurements, RTM	UV-vis spectrometer	UV-vis spectrometer, IR interferometer
	Polarisation			GOME, POLDER	Measurements, RTM		
Level 2	O_3	C	NRT/OLP	GOME, TOMS, SBUV-2, TOVS, SEVIRI, SAGE III	Dobson/Brewer, UV radiometer, SAOZ, FTIR, UV-vis DOAS		
	O_3	P (limb)	OLP	ILAS II, SMR, OSIRIS, SAGE III, SBUV-2, GOME, MASTER, HIRDLS, MLS, TES	Lidar, MW, Brewer	Ozone sondes, Balloon-FTIRS, FIS, Balloon-DOAS, UV absorption, SAOZ	UV-vis absorption
	NO_2	C	NRT/OLP	GOME, SAGE III	SAOZ, FTIR, UV-vis DOAS		
	NO_2	P	OLP	ILAS II, SAGE III, SMR, OSIRIS, HIRDLS, TES	UV-vis DOAS	Balloon-DOAS, SAOZ Balloon-FTIRS	
	BrO	C	OLP	GOME	UV-vis DOAS, FTS		
	BrO	P	AQ	MASTER	UV-vis DOAS	Balloon-DOAS, SAOZ, Br-resonance fluorescence (in situ)	resonance fluorescence (in situ)

Table 4.1: *continued.*

SCIAMACHY				Validation by			
Level	**Product**	**Column/ Profile**	**Product type**	**Satellite instruments probably active in 1999-2004**	**Ground Based**	**Balloon/Sondes**	**Aircraft**
Level 2 (continued)	H_2O	C	NRT/OLP	SEVIRI, TOVS	FTIR, IR-DOAS, GPS	WMO Radiosonde Network	
	H_2O	P	OLP	SAGE III, ILAS II, SMR, MLS, MASTER, AIRS, HIRDLS, TES	MW, ECMWF	Sonde, FTIRS, TDL, MW, Lyman α Resonance fluorescence (in situ), vis. + IR abs. spectroscopy	TDL, MW, vis/IR abs. spectroscopy, Lyman α Resonance fluorescence (in situ)
	N_2O	C	NRT/OLP		GC, TDL, FTIR	Cryosampler, Grabsampler	GC-ECD (in situ), gas chromatography
	N_2O	P	AQ	ILAS II, SMR, MLS MASTER, HIRDLS		GC, TDL, Cryosampler, Grabsampler	GC-ECD (in situ), gas chromatography
	CO_2	C	OLP		FTIR	Cryosampler, Grabsampler	Grab sampler, abs. measurements
	CO_2	P	OLP			TDL, GC, Cryosampler, Grabsampler	Grab sampler, abs. measurements, TDL, GC
	CO	C	NRT/OLP	MOPITT	IR spectrometer, FTIR	Cryosampler, Grabsampler	Grabsampler, abs. measurements
	CO	P	OLP	SMR, MASTER, TES	NOAA-CMDL network, FTIR	MW, FTIRS, TDL, Cryosampler, Grabsampler	MW, FTIRS, Grabsampler, abs. measurements
	CH_4	C	NRT/OLP	MOPITT	FTIR	Cryosampler, Grabsampler	Grab sampler, abs. measurements
	CH_4	P	OLP	ILAS II, HIRDLS, TES	NOAA-CMDL network	MW, TDL, Cryosampler, Grabsampler	Grabsampler, abs. measurements

Table 4.1: *continued.*

SCIAMACHY				Validation by			
Level	**Product**	**Column/ Profile**	**Product type**	**Satellite instruments probably active in 1999-2004**	**Ground Based**	**Balloon/Sondes**	**Aircraft**
Level 2 (continued)	Pressure	P	OLP	SAGE III, ILAS II	Lidar	WMO Radiosonde Network, NWP analysis, FTIRS	
	Temperature	P	OLP	SAGE III, ILAS II, TOVS, SMR, OSIRIS, AIRS, MASTER, MLS	Lidar, ECMWF	WMO Radiosonde Network, NWP analysis, FTIRS	
	Cloud Cover		NRT/OLP	MVIRI, AVHRR, AATSR/ATSR-2, SEVIRI, MODIS	WMO Network		
	Cloud Top Height		NRT/OLP	AIRS, MVIRI, AATSR/ATSR-2, SEVIRI, AVHRR, MERIS, HIRDLS			
	Aerosol Abs. Index	C	NRT/OLP	POLDER, MODIS, GOME	Lidar, Sun Photometer, NDSC		
	Aerosol Abs. Index	P	OLP	ILAS II, SAGE III, OSIRIS, HIRDLS	Lidar	Backscatter sondes	
	OClO *	C	NRT/OLP	GOME	UV-vis DOAS, SAOZ	Balloon-DOAS, SAOZ	
	SO_2^*	C	NRT/OLP	TOMS, GOME	UV-vis DOAS, NDSC		
	H_2CO *	C	NRT/OLP	GOME		FTS	

* Special products, only observed under special conditions or after averaging.

2. Intensive validation campaign.
   - Dedicated balloon campaigns (at specific sites and seasons) involving combinations or 'clusters' of large multi-instrument payloads.
   - Co-ordinated observation periods (ground, aircraft, small balloons).
3. Long-term validation
   - Multi-year, well focused instrument and product monitoring (mainly for basic spectral measurements and key constituents profiles).
   - Regular overpass validation programme at reference sites (network stations, specially instrumented sites, e.g. NDSC).

In the first case one uses existing instrumentation and data processing algorithms (i.e. with no additional investment) but the geophysical quantities measured in that way are not matching all the innovative capabilities of the SCIAMACHY measurements.

The second type i.e. an intensive validation campaign is certainly to be implemented during the commissioning phase, to really ascertain that the products retrieved by SCIAMACHY are fulfilling the expected precision/accuracy requirements.

The long-term validation is needed from both an operational point of view (stability of the products) and a research perspective (investigation of unexpected or to be demonstrated capabilities) .

4.2 Tools and Models for Validation

4.2.1 Coincidence Predictor

In order to maximise the effectiveness of any validation exercise it is important to make validatory measurements as close in time and space to the SCIAMACHY measurements as possible. To achieve this the PIs in field campaigns need a software tool that they may use locally that permits measurement strategies to be optimised. This predictor software should require only the orbital characteristics of the satellite and should be able to distinguish the footprint of both nadir and limb sounding measurements. A possible tool for this purpose might be the ENVISAT CFIs (Customer Furnished Items), in particular the ESOV (Earth observation Swath and Orbit Visualisation) programme.

4.2.2 Data Assimilation

Data assimilation techniques have already been used extensively in meteorology for several years, enabling a.o. the improvement of the quality of the weather forecast. In data assimilation, satellite observations of, e.g., ozone are fed into an atmospheric model and weighted with model-calculated ozone values in order to obtain the best available description of the atmosphere, and make optimum use of the data. Incorporating data assimilation will lead to a good description of the atmosphere and enable analyses and forecasts of ozone which are consistent with all available real-time measurements of ozone and with all available dynamical information. By extending dynamical models with data assimilation it is possible to obtain maps of, e.g., the ozone distribution at a specific time (a level 4 product). This is in contrast to a level 3 global image product which consists of data measured at different times. For validation of a satellite instrument, several types of measurements, e.g. ground-based measurements, in-situ measurements, are used. Ground-based and in-situ measurements taken at different times and geographical locations than the satellite measurements are less suited for direct comparison (see section 4.2.1). Also, satellite measurements usually represent averages over a large area, whereas conventional measurements often represent local values, which can make the two not readily comparable. Data obtained from other satellite instruments can also be used for validation, but suffer of much of the same problems. Advection and assimilation models, which retain the dynamical information on ozone, make it possible to use non co-located ground-based and satellite measurements for validation. Moreover, data assimilation offers the possibility to identify ground stations which deliver controversial data by comparison with observations of a satellite instrument. Furthermore, models extended with data assimilation also produce statistical information on the quality of instruments and observations. Data assimilation models can also be used for comparison of satellite observations with predicted tracer values, e.g. ozone, based on previous satellite observations. Differences between the tracer amounts directly observed by the satellite instrument and the model predicted tracer amounts gives information on the self-consistency of the satellite instrument and the quality of the model.

5 Core Validation

The core validation is required to ensure a minimal but essential validation of SCIAMACHY data products (**R3**). Table 5.1 shows which SCIAMACHY products should be validated in the core validation and which validation sources should be used to achieve this. The co-ordinating group takes initiative in the validation of the specific product and is point of contact for that validation exercise. The participating group is actively involved in the validation and collaborates with the co-ordinating and other participating groups. SCIAMACHY data should be available for validation to all co-ordinating (and participating) groups of the core validation as indicated in Table 5.1 (**R4**). In Annex C a description is given of the different satellite instruments which are listed in this table.

Below a brief summary is given of the reasons for using the specific validation sources for the core validation.

Networks. Networks are going to play an important role in validation activities (e.g. NDSC). Networks consist of well instrumented stations performing routine observations over a long period. Sensors of importance are: ground-based devices to perform in situ measurements, radio- and ozonesondes, DOAS spectrometers observing scattered solar light, lidar systems observing backscattered laser light, Dobson, Brewer, FTIR and MW sensors operating in solar occultation or thermal emission mode.

Models, Atmospheric Chemistry Models. Models can be used to check for consistency in the data, and to get some information on constituents for which no reliable measurements are available.

Balloons. In the mid-IR configuration the LPMA FTIR spectrometer has proven its capabilities to retrieve profiles for O_3, NO_2, CH_4 and N_2O with a 5 to 10% accuracy. The combination of the FTIR (CNRS) and UV-vis (Heidelberg) spectrometers is unique and offers a good accuracy and vertical resolution. SAOZ balloons measure vertical profile of O_3, NO_2, BrO, $OC\ell O$, p and T. While there are specialised instruments for NO_2, CH_4 or water vapour, these would require an entire balloon payload alone. For CO there are no alternatives offering the required accuracy.

Cryo- or Grabsampler, Lyman-α fluorescence hygrometer (H_2O) and Chemical conversion resonance fluorescence instrument ($C\ell O$ and BrO). These are well established techniques. The instruments have been used successfully in previous projects (EU programmes SESAME, THESEO; ADEOS and HALOE intercomparisons; national programmes). They have a high vertical resolution (cryo- and grabsampler approx. 1km; $H_2O < 30$ m; $C\ell O$ and BrO approx. 100 m); Complementary validation of MIPAS/ENVISAT is intended (e.g. vertical profiles of CFCs). Complementary with MIPAS, LPMA and DOAS/SAOZ balloon experiments.

Satellites. Satellite measurements are needed to obtain validation on a global scale.

Table 5.1: *Specification of the core validation. The 'data sources' listed in column 2 are a subset of those listed in Table 4.1, and are the minimum required to ensure the quality of the validation. A 'coordinating group' is listed for each data source in column 5. This group is capable of performing the core validation using this data source. Other groups can be included later. The required 'frequency of observation' and 'global coverage' (column 3 and 4) are only listed for ground-based, balloon, and aircraft measurements. L=launch, Heid./IFE/MPI=Heidelberg/IFE Bremen/MPI-Mainz.*

SCIAMACHY Product	**Data sources used for 'core' validation**	**Frequency of observation**	**Global coverage**	**Coordinating group**	**Participating groups**
Spectral Solar Irradiance	SOLSTICE(II)	n.a.	n.a.	BIRA	
	SOLSPEC	n.a.	n.a.	BIRA	IFE
	GOME	n.a.	n.a.	IFE	IFE
	VIRGO	n.a.	n.a.	BIRA	NASA
	Balloons	2-3 × p. season	mid- and polar lat.	Heid./IFE/MPI	LPMA
Spectral Earth Radiance/ Albedo	GOME	n.a.	n.a.	KNMI	
	SBUV-2	n.a.	n.a.	NASA-GSFC	IFE
	TOMS (albedo)	n.a.	n.a.	NASA-GSFC	
	AATSR	n.a.	n.a.	KNMI	
	Balloons	2-3 × p. season	mid- and polar lat.	Heid./IFE/MPI	BIRA, LPMA
Polarisation	GOME	n.a.	n.a.	KNMI	SRON
	POLDER	n.a.	n.a.	KNMI	SRON
O_3 (C)	GOME	n.a.	n.a.	KNMI	IFE, DFD
	TOMS	n.a.	n.a.	KNMI	NASA
	Brewer/Dobson	daily	all latitude bands	KNMI/BIRA	
	SAOZ	daily	all latitude bands	BIRA	
	DOAS	daily	all latitude bands	Heid./IFE/MPI, BIRA	
	FTIR	daily	all latitude bands	BIRA	AWI
	Models	n.a.	n.a.	KNMI	

Table 5.1: *continued.*

SCIAMACHY Product	**Data sources used for ‘core’ validation**	**Frequency of observation**	**Global coverage**	**Coordinating group**	**Participating groups**
O_3 (P)	SAGE III	n.a.	n.a.	NASA-Langley	IFE, AWI
	GOME	n.a.	n.a.	IFE-Bremen	RAL
	Ozonesondes	10 × p. season p. latitude band	4 latitude bands	KNMI	AWI
	Lidar	2-5 × p. week	4 latitude bands	BIRA	AWI,CNRS
	MW	1 × p. hour	5 NDSC stations	IFE	DWD, AWI
	Balloons	2-3 × p. season	mid- and polar lat.	Heid./IFE/MPI	CNRS, Jülich
	Models	n.a.	n.a.	KNMI	
NO_2 (C)	GOME	n.a.	n.a.	AWI	DFD
	FTIR	daily	all latitude bands	BIRA	AWI
	DOAS	daily	all latitude bands	Heid./IFE/MPI, BIRA	
	SAOZ	daily	all latitude bands	BIRA	
NO_2(P)	SAGE III	n.a.	n.a.	NASA-Langley	IFE, AWI
	UV-vis DOAS	daily	all latitude bands	Heid./IFE/MPI	
	DOAS Balloon	20 × p. year	all latitude bands	BIRA	LPMA/CNRS
	Balloons	2-3 × p. season	mid- and polar lat.	Heid./IFE/MPI	LPMA/CNRS
BrO (C)	GOME	n.a.	n.a.	BIRA	
	UV-vis-DOAS	daily	all latitude bands	Heid./IFE/MPI, BIRA	
BrO (P)	Balloons	2-3 × p. season	mid- and polar lat.	Heid./IFE/MPI	Jülich, LPMA
	UV-vis-DOAS	daily	all latitude bands	Heid./IFE/MPI	

Table 5.1: *continued.*

SCIAMACHY Product	**Data sources used for ‘core’ validation**	**Frequency of observation**	**Global coverage**	**Coordinating group**	**Participating groups**
H_2O (C)	TOVS	n.a.	n.a.	KNMI	
	radiosondes	2 × p. day	mainly Northern mid-lat.	KNMI	
H_2O (P)	SAGE III	n.a.	n.a.	NASA-Langley	IFE, AWI
	MW		5 NDSC stations	IFE	BIRA
	ECMWF	n.a.	n.a.	KNMI	
	Balloons	2-3 × p. season	mid- and polar lat.	Heid./IFE/MPI	CNRS, Jülich
N_2O (C)	FTIR	1 × p. week	Jungfraujoch, Ny-Alesund	BIRA	AWI
N_2O (P)	Grab-/Cryosampler	1-4 × p. year	mid- and polar lat.	Uni-Frankfurt	CNRS, Jülich
CO_2 (C)	FTIR	1 × p. week	Jungfraujoch	BIRA	
CO_2 (P)	Cryosampler	1-2 × p. year	mid- and polar lat.	Uni-Frankfurt	FZJ
CO (C)	FTIR	1 × p. week	Jungfraujoch	BIRA	IFE, AWI
	MOPITT	n.a.	n.a.	SRON	NCAR, KNMI
	IR spectrometer	1 × p. week	Toronto	KNMI	Uni. Toronto (Yurganov)
CO (P)	Balloons	2-3 × p. season	mid- and polar lat.	Heid./IFE/MPI	LPMA/CNRS
CH_4 (C)	FTIR	1 × p. week	Jungfraujoch	BIRA	
	MOPITT	n.a.	n.a.	SRON	NCAR, KNMI

Table 5.1: *continued, * = Special products, only observed under special conditions or after averaging.*

SCIAMACHY Product	**Data sources used for ‘core’ validation**	**Frequency of observation**	**Global coverage**	**Coordinating group**	**Participating groups**
CH_4 (P)	Balloons	2-3 × p. season	mid- and polar lat.	Heid./IFE/MPI	LPMA/CNRS
	Cryosampler	1-2 × p. year	mid- and polar lat.	Uni-Frankfurt	FZJ
Temperature Pressure (P)	TOVS	n.a.	n.a.	KNMI	IFE
	ECMWF	n.a.	n.a.	KNMI	IFE
	Radiosondes	2 × p. day	mainly Northern mid-lat.	KNMI	IFE
Cloud Cover	MVIRI (Meteosat)	n.a.	n.a.	KNMI	
	AATSR	n.a.	n.a.	KNMI	
Cloud Top Height	MVIRI (Meteosat)	n.a.	n.a.	KNMI	
	AATSR	n.a.	n.a.	KNMI	
Aerosols	Lidar	1-3 × p. week	Ny-Alesund	AWI	
	Backscatter sondes	10 × p. winter	Ny-Alesund	AWI	
	Sun photometers	2 × p. week	global	KNMI	
OClO* (C)	DOAS	daily	high + middle lat.	BIRA, Heid./IFE/MPI	
SO_2* (C)	TOMS	n.a.	n.a.	NASA-GSFC	
HCHO* (C)	GOME	n.a.	n.a.	Heid./IFE/MPI	

6 Validation Phases

All SCIAMACHY NRT and OLP operational data products need validation (**R13**). However, various products from SCIAMACHY are unique and will require special attention regarding validation by means of ground or other satellite measurements.

The validation programme must be constructed such that it accommodates appropriately all phases of the life of SCIAMACHY (**R1**). There are three distinct phases of validation of SCIAMACHY data products: the commissioning phase, the main validation phase, and the long-term validation phase (**R5**).

6.1 Commissioning Phase

The objectives of the commissioning phase are:

a) Functional test;
b) In-flight verification of performance;
c) Preliminary Validation of level 1 and level 2 products.

After the launch of ENVISAT, it is necessary to outgas SCIAMACHY to remove volatile contaminants. Thereafter functional testing of the various parts of the instrument lead to the in-flight performance of the instrument being established.

Having demonstrated that the instrument is performing successfully, the solar, lunar and atmospheric measurements of SCIAMACHY will then commence. The operational requirements for validation during the commissioning phase are given in annex D. It is essential to validate the irradiance and radiance products (both nadir and limb) of SCIAMACHY because all higher level products depend on the accuracy of these products (**R6**).

In addition to demonstrating the accuracy of level 1 products, the level 2 SCIAMACHY products need to undergo a preliminary validation (**R7**). It is envisaged that this preliminary validation will proceed into the main validation phase. The commissioning phase validation schedule is given in the following list. This schedule reflects to some extent the likelihood of products being available shortly after launch.

Step 1 Level 1:
Earth radiance spectrum, solar irradiance spectrum, reflectance/albedo and Earth polarisation.

Rationale – errors in these products can result in errors being propagated into higher level products. Polarisation influences radiance and reflectance/albedo accuracy.

Step 2 Level 2:
Total column (nadir): O_3, NO_2 .
Vertical Profile (limb): p, T, O_3, NO_2, aerosol.
Cloud cover fraction and cloud top height.

Rationale – likely to be available.
Aerosol is new.
Validation is already been practised in different campaigns.

Step 3 Level 2:
Total column (nadir): CO, N_2O, CH_4, H_2O, BrO, $OC\ell O$, SO_2, CO_2, H_2CO, p, T, aerosol, UV index*.
Vertical profile (limb): H_2O, CO_2, CH_4, BrO*, N_2O* and CO*.
*SSAG recommended products (not yet officially confirmed).

Rationale – these are mostly 'new' products and therefore pose new challenges.

Note that the different steps can be overlapping in time.

This list represents a pragmatic assessment rather than scientific priorities. The latter would be to have all the SCIAMACHY products available from the launch date. The objective of the agencies supporting SCIAMACHY operational product development directly (DLR and ESA), is the simultaneous delivery of all products listed above available shortly after launch. The above may change, depending upon the difficulties encountered in the development of the operational system.

The products listed in "Step 1" and as many of the operational "Step 2/3" products as possible, should undergo a preliminary validation during the commissioning phase, to enable a preliminary data release at the end of the commissioning phase. To achieve this goal a co-ordinated ground-based, balloon and aircraft campaign is required (**R7**). This preliminary release must be accompanied by a detailed description of the knowledge of the systematic and random errors.

A rigorous validation of these preliminary validated products and the remaining products needs to follow in the next two phases of validation.

6.2 Main Validation Phase

The objectives of the main validation phase are:

a) The collection of SCIAMACHY data products and the relevant validation data;
b) The analysis of the validation data;
b) The derivation of the accuracies of the level 1 and level 2 data products from SCIAMACHY.

Each Level 1 and 2 product needs to be rigorously validated in this period. An intensive campaign collecting data from ground-based, airborne and satellite instruments forms the basis of these activities (**R9**). Analysis of these data and of the SCIAMACHY data products establishes the accuracy of SCIAMACHY data products.

It is recommended that the main validation phase is continued for 12 months after the commissioning phase (**R8**). The official data release is proposed for the end of this main validation phase.

An overview of the time schedule of the main validation phase and the desired accuracies (i.e. the maximum deviations between SCIAMACHY and validation measurements) are given in Table 6.1. Times indicate the period in which the accuracies should be achieved.

The current plan is success orientated, should problems be encountered during the main validation phase, an adjustment of the plan is necessary.

6.3 Long-Term Validation Phase

One of the most important scientific contributions of SCIAMACHY is the establishment of trends in the geophysical parameters (trace gas distributions, atmospheric constituents, pressure and temperature fields) to be measured. Since the performance of all instruments is likely to degrade in time, it is essential that a long-term validation of the SCIAMACHY data products is undertaken. This necessitates a regular, optimised, repetition of the essential elements of the main validation (**R10**). The primary objective of the long-term validation phase is to establish a reliable data record from which trends can be derived.

This objective can be split in the following detailed objectives of the long-term validation phase:

a) To update regularly the validation of SCIAMACHY data products after new SCIAMACHY ground processor versions are issued.

b) The identification of the long-term changes or degradation of the instrument in space and its impact on the accuracies of the SCIAMACHY data products.

c) The identification of possible influences on the trend behaviour of the SCIAMACHY data products.

d) To provide input to SCIAMACHY algorithms improvement or development.

e) To validate new or advanced SCIAMACHY data products.

The validation strategy implemented at the beginning of observations must be continued on a long-term period with the adequate resources to provide high quality data products on which scientific studies on to the Earth's atmospheric environment can rely.

The long-term validation strategy necessitates the regular comparison at critical times and locations of the data products of SCIAMACHY with the data from ground based and aircraft/balloon borne measurements (**R10**). The use of the data from the NDSC (Network for the Detection of Stratospheric Change), including ESMOS (European Stratospheric MOnitoring Stations) and SCUVS, Dobson, Brewer and tropospheric measurement sites will be of essential importance (**R16**). Where possible, satellite data from other instruments flying at the same time should be used (see Annex C) (**R26**). A balanced approach is required making optimal use of available data and the provision of specific measurements where necessary (**R17**).

Table 6.1: *Schedule for the achievement of desired accuracies during the main validation phase.*

Time after commissioning phase	Data product	Desired Accuracy
+ 0-2 Months	Level 1 Radiance	A detailed description can be found in the SIRD document
	spectral resolution	
	spectral accuracy	
	S/N	
	Radiometric accuracy	
	Level 1 irradiance	Same demands as Radiance
	spectral resolution	
	spectral accuracy	
	S/N	
	Radiometric accuracy	
	Albedo	
	spectral resolution	
	spectral accuracy	
	S/N	
	Polarisation	
+ 0-3 Months	Level 2 nadir	
	O_3 and NO_2 column	3% and 10% resp.
	Clouds	(1)
+ 0-6 Months	Level 2 limb	
	O_3 and NO_2 profiles	10%
	p, T profiles	3%
	aerosol profile	10%
+ 0-12 Months	Level 2 nadir (columns)	
	CO, CH_4, N_2O, H_2O, BrO, $OC\ell O$, p, T, SO_2, CO_2, aerosol, UV index*	5-10%
	H_2CO	20%
	Level 2 limb (profiles)	
	H_2O, CO_2, CH_4, N_2O*, CO*	10%
	BrO*	50%

(1) Cloud cover and cloud top heights should be retrieved in order to obtain the required accuracy on level 2 products.

* SSAG recommended products (not yet officially confirmed).

6.4 Validation Schedule

The overall time schedule for the validation phases is as follows (time is given in months after launch L):

A)	**Commissioning phase**	
	Outgassing	L – L+1
	Functional Testing	L+1 – L+3
	Commissioning phase data	L+3 – L+6
	Campaigns using ground based and airborne (balloons and aircraft) sensors	L+3 – L+6
	End of commissioning phase	L+6
	Analysis of commissioning phase data	L+3 – L+9
	Commissioning phase workshop	L+9
	Preliminary data release	after L+9
B)	**Main validation phase**	
	Collection of data	L+6 – L+18
	Analysis of data	L+6 – L+20
	Main validation Workshop	L+20
	Official data release	after L+20
C)	**Long-term validation phase**	
	Collection of data	from L+18
	Analysis of data	from L+18
	Validation workshops	L+32, L+38, L+44, etc.

Apart from the official workshops at the end of the commissioning phase and main validation phase, resulting in recommendations on data release, it is planned that there will be intermittent but regularly validation workshops, typically every six months (**R27**). Finally it is necessary that the long-term validation will be continued throughout the lifetime of SCIAMACHY (**R11**).

The following time schedule for the preparation and realisation of the SCIAMACHY instrument and validation is employed (this time schedule has to be tuned to the ENVISAT time schedule, when available):

Early 1996	The formation of the SSAG Validation and Interpretation subgroup (SCIAVALIG). The definition of Terms of Reference for SCIAVALIG.
End 1997	Announcement of Opportunity (in ENVISAT context).
Early 1998	Completion and publication of the SCIAMACHY Validation Requirements Document.
31 May 1998	Deadline for AO-call submission proposals.
October/November 1998	Assessment of the scientific/validation aspects of the proposals by referees and confidential assessment by chairmen of SCIAVALIG.

31 December 1998	Final evaluation and selection of the proposals.
Begin 1999	First Principal Investigator (PI) meeting: objective is to tune the preparation of validation.
1999	Validation meetings (concerning core and AO-call validation).
January - March 1999	Preparation of Validation Handbook.
November 1999	Launch of ENVISAT.
December 1999	The switch on of SCIAMACHY.
Dec. 1999 - February 2000	Functional testing. Testing of measurements modes. Commencement of mission time line.
February - May 2000	Collection of data for commissioning phase validation.
February - August 2000	Analysis of validation data.
August 2000	Workshop and preliminary recommendations.
May 2000 - May 2001	Collection of data for main validation.
May 2000 - July 2001	Analysis of main validation data.
July 2001	Main validation workshop.
May 2001	Planning of the long-term validation, using lessons learned from the main validation.
July 2002	Workshop presenting results of the first year of long-term validation.
From July 2002	Continuation of the long-term validation with yearly updates of the SCIAMACHY data quality disclaimers.

Note: If there is a change in launch date, the timeschedule for all activities taking place after the launch of ENVISAT will be changed accordingly.

Annexes

Annex A

The SCIAMACHY Validation and Interpretation Group (SCIAVALIG)

Chair:	H. Kelder (KNMI)
Co-chairs:	U. Platt (Univ. Heidelberg) P. Simon (BIRA-IASB)
Scientific Secretary:	R. Timmermans (KNMI)
Members:	I. Aben (SRON) J. Burrows (IFE) C. Camy-Peyret (CNRS) E. Hilsenrath (NASA) B. Kerridge (RAL) K. Künzi (IFE) J.-C. Lambert (BIRA-IASB) J. Lelieveld (IMAU) P. Levelt (KNMI) D. McKenna (FZJ) D. Perner (MPI Mainz) A. Piters (KNMI)
Observers:	E. Attema (ESA) W. Balzer (DLR-DFD) S. Bruzzi (ESA) M. Durville (NIVR) A. Friker (DLR)

Addresses

Dr. H. Kelder, KNMI, Postbus 201, 3730 AE de Bilt, The Netherlands. Tel. +31 30 2206472, fax +31 30 2210407, email: kelder@knmi.nl

Prof. Dr. U. Platt, Universität Heidelberg, Institut für Umweltphysik, Im Neuenheimer Feld 366, D-69120 Heidelberg, Germany. Tel. +49 6221 54 6339, fax +49 6221 54 6405, email: pl@uphys1.uphys.uni-heidelberg.de

Prof. Dr. P. Simon, Belgian Institute for Space Aeronomy, 3 Avenue Circulaire, B-1180 Brussel, Belgium. Tel. +32 2 373 0400, fax +32 2 375 9336, email: paul.simon@oma.be

R. Timmermans, KNMI, Postbus 201, 3730 AE de Bilt, The Netherlands. Tel. +31 30 2206594, fax +31 30 2210407, email: timmermr@knmi.nl

Dr. I. Aben, SRON, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands. Tel. +31 30 2538579, fax +31 30 2540860, email: I.Aben@sron.ruu.nl

Prof. Dr. J. Burrows, Institut für Umweltphysik, Universität Bremen, Postfach 330440, D-28334 Bremen, Germany. Tel. +49 421 218 4548, fax +49 421 218 4555, email: John.Burrows@gome5.physik.uni-bremen.de

Prof. C. Camy-Peyret, CNRS, Tour 13/Boite 76, 4 Place Jussieu, F-75252 Paris CEDEX 05, France. Tel. +33 144274476 Paris (169157606 Orsay), fax +33 144277033 Paris (169157530 Orsay), email: camy@ccr.jussieu.fr

Dr. E. Hilsenrath, NASA GSFC, Code 916, Building 21 Room 257, Maryland 20771, USA. Tel. +1 301 286 6051, fax +1 301 286 1754, email: hilsenrath@ssbuv.gsfc.nasa.gov

Dr. B. Kerridge, Rutherford Appleton Laboratory (RAL, Science and Res. council, Chilton, Didcot, Oxfordshire OX 11 OQX, UK. Tel. +44 1235 446524, fax +44 1235 445848, email: B.J.Kerridge@rl.ac.uk

Prof. Dr. K. Künzi, Institut für Umweltphysik, Universität Bremen, Kufsteiner Straße, D-28359 Bremen, Germany. Tel. +49 421 218 3909, fax +49 421 218 4555, email: kunzi@physik.uni-bremen.de

J.-C. Lambert, Belgian Institute for Space Aeronomy, 3 Avenue Circulaire, B-1180 Brussel, Belgium. Tel. +32 2 373 0468, fax +32 2 375 9336, email: lambert@bira-iasb.oma.be

Prof. Dr. J. Lelieveld, IMAU, Princetonplein 5, 3584 CC Utrecht, The Netherlands. Tel. +31 30 253 2921, fax +31 30 254 3163, email: J.Lelieveld@fys.ruu.nl

Dr. P. Levelt, KNMI, Postbus 201, 3730 AE de Bilt, The Netherlands. Tel. +31 30 2206667, fax +31 30 2210407, email: levelt@knmi.nl

Prof. D. McKenna, FZJ, D-52425 Jülich, FRG, Germany. Tel. +49 2461 61 2065, fax +49 2461 61 5346, email: D.MCKENNA@fz-juelich.de

Dr. D. Perner, Max-Planck Institut für Chemie, Abt. Luftchemie, Saarstraße 23, D-55122 Mainz, Germany. Tel. +49 6131 305450, fax +49 6131 305436, email: DIP@MPCH-Mainz.MPG.de

Dr. A. Piters, KNMI, Postbus 201, 3730 AE de Bilt, The Netherlands. Tel. +31 30 2206433, fax +31 30 2210407, email: piters@knmi.nl

Dr. E. Attema, ESA Earth Science Division, ESTEC, Postbus 299, 2200 AG Noordwijk, The Netherlands. Tel. +31 715654461, fax +31 715655675, email: eattema@estec.esa.nl

Ir. W. Balzer, DLR-DFD, Postfach 1116, D-82230 Weßling, Germany. Tel. +49 8153 281187, fax +49 8153 281443, email: Wolfgang.Balzer@dlr.de

Dr. S. Bruzzi, ESA, 8-10 Rue Mario Mikis, F-75015 Paris, France. Tel. +33 153697281, fax +33 153697674, email: sbruzzi@hq.esa.fr

Ir. M. Durville, NIVR, Postbus 35, 2600 AA Delft, The Netherlands. Tel. +31 15 2782015, fax +31 15 2623096, nivr@lr.tudelft.nl

Dr. A. Friker, German Aerospace Center, Bonn-Oberkassel, (German Space Agency), Königswinterer Straße 522-524, D-53227 Bonn, Germany. Tel. +49 228 447 580, fax +49 228 447 700, email: Achim.Friker@dlr.de

Annex B
Data Processing

For the products up to level 2 (i.e. retrieved geophysical quantities on the observational grid) ESA has been given the responsibility for the ground segment and the processing of data. As SCIAMACHY is an AO (Announcement of Opportunity) instrument, the algorithms for level 0-1 and level 1-2 processing are to be provided by the AO providers (Germany, The Netherlands and Belgium). These AO providers are represented by the German Space Agency (which is part of DLR) who acts also on behalf of the other co-providers (The Netherlands and Belgium).

Three different processors (level 0-1, level 1-2 NRT and level 1-2 OLP) are being developed. The level 0-1 processor and the level 1-2 NRT processor, which benefit from the GOME experience, are developed in adherence to an industrial engineering scheme (proposed by ESA). This general approach has been criticised by the PI and SSAG. It is considered to be high risk since the operational algorithms for the SCIAMACHY NRT data products have not all been preceded by proven scientific prototypes, The problems experienced in the past by ATSR with such an approach should not be repeated for SCIAMACHY. The approach means, that the work is split into two separate steps: algorithm specification and algorithm implementation. The first step is executed by the German Remote Sensing Data Centre DFD (which is part of the German Aerospace Establishment). Scientific input is considered mainly in this first step. The DFD therefore is required to keep contact with the Data and Algorithm Subgroup (SDAG) of the SCIAMACHY Science Advisory Group (SSAG). The second step (implementation) is executed by a software engineering company, and it is intended that DFD has the role of a supervisor with respect to the industrial work, keeping the science interface with the SDAG open. The level 1-2 OL processor will be developed following the established and successful approach used for the GOME processor development. The technical specification and implementation, are performed by DLR-DFD. The scientific specification is provided by the scientists developing the scientific prototypes and the SDAG acting for SSAG.

Higher level algorithms and products are to be created nationally. In the Netherlands a priority is given to the development of value-added products.

The responsibility for the validation of the different products lies with the algorithm provider (i.e. DLR for ESA products) who will be supported by ESA. The SSAG (and consequently its validation subgroup SCIAVALIG) is acting as scientific consultant to the responsible entity and therefore the validation will highly rely on this group's work.

A draft detailed description of the products up to level 2 (including level 0 but excluding level 2 OLP products) can be found in the ESA ENVISAT Ground Segment Product Definition Guidelines document (PO-TN-ESA-GS-00231).

Annex C
Validation sources

C.1 Satellites

The approved atmospheric chemistry satellite missions around the year 2000 are listed in Table C.1, together with the corresponding instruments. In Figure C.1 current and (approved as well as proposed) future satellite missions are shown. The products which can be retrieved from these instruments are listed in Tables C.2 (troposphere) and C.3 (stratosphere). This is followed by more detailed information per instrument (EOS reference Handbook 1995, 1995 CEOS yearbook).

Table C.1: *Missions around the Year 2000.*

Mission	**Instrument**	**Expected time frame**
METEOR-3M 1	SAGE III	1998-2001
NOAA series (K-N & N')	AVHRR/3 SBUV/2 TOVS	1998-2009 1998-2009 1998-2009
ADEOS II	ILAS II POLDER	1999-2002 1999-2002
ENVISAT-1	AATSR ASAR GOMOS MERIS MIPAS MWR SCIAMACHY	1999-2004 1999-2004 1999-2004 1999-2004 1999-2004 1999-2004 1999-2004
EOS-AM 1/2	ASTER EOSP MISR MODIS-N MOPITT	1999-2004 2004-2007 1999-2007 1999-2007 1999-2004
ISSA	SAGE III SOLSPEC	2001-2006 2001-2006
METOP-1	GOME-2	2002-2005
EOS-CHEM 1	HIRDLS TES MLS Ozone Instr.	2002-2008 2002-2008 2002-2008 2002-2008

Figure C.1: *Current and (proposed or approved) future missions from 1998-2012.*

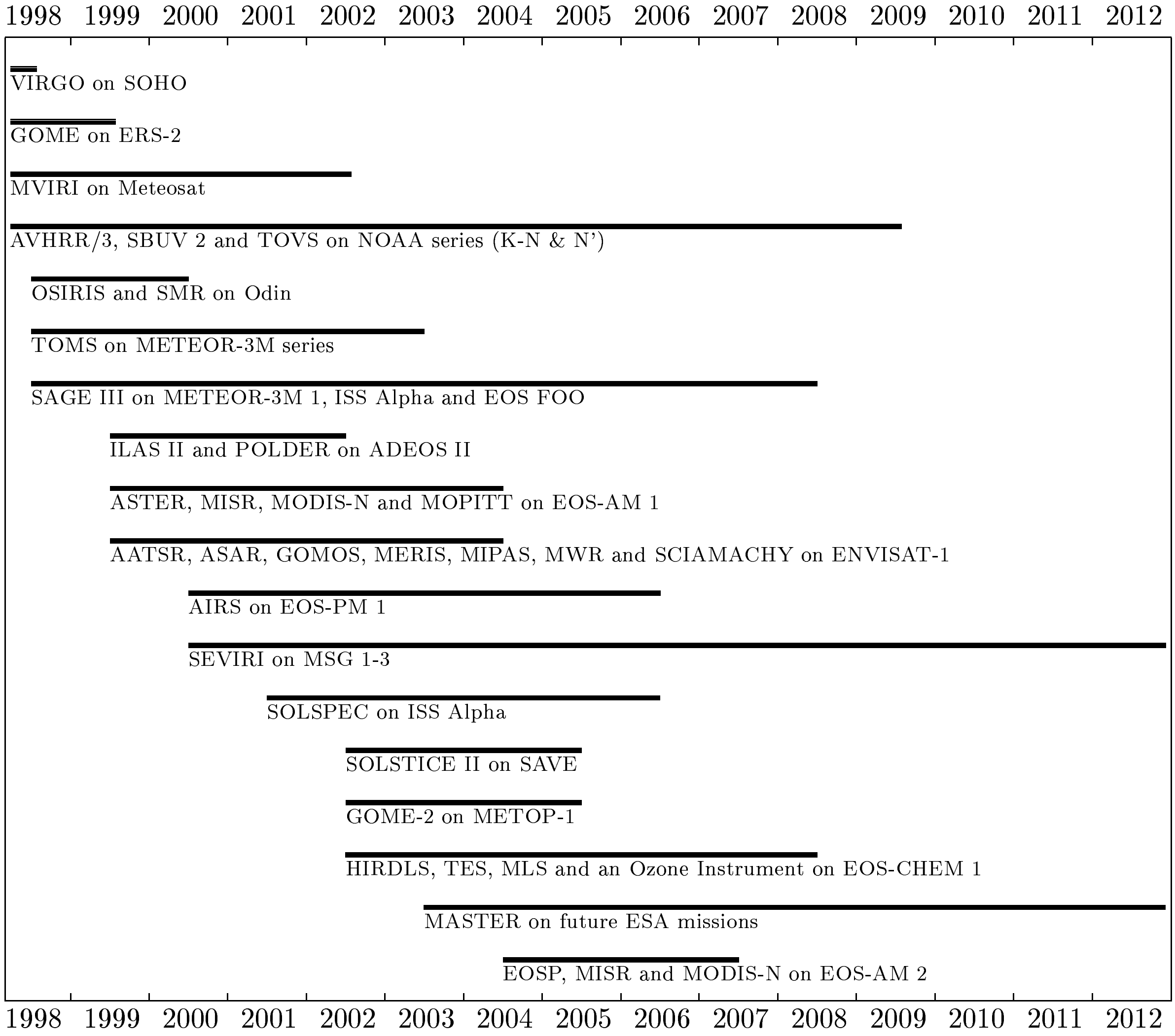

Table C.2: *Satellite instruments and their products retrieved in the troposphere. p=profile, c=column, ut=upper troposphere, x indicates that some information concerning this product is measured, phys. par. = physical parameters (p, T, clouds etc. see text for details), * = not all species of this group are measured.*

Instrument	Phys. par.	aerosol	CO_2	CO	CH_4	H_2O	HOx^*	O_3	NOx^*	$C\ell Ox^*$	N_2O	SO_2	HCHO	BrO
AATSR	x	x												
AIRS	x					p								
ASTER	x													
ATSR-2	x	x												
AVHRR/3	x													
EOSP	x	x												
GOME	x							p,c	c	c		c	c	c
GOME-2	x	x						p,c	c	c		c	c	c
HIRDLS	ut	ut			ut	ut		ut	ut		ut			
MASTER	ut			ut		ut		ut		ut	ut			ut
MERIS	x	x				x								
MIPAS	x	x		ut	ut	ut	ut	ut	ut	ut	ut			
MISR	x	x												
MLS						ut		ut			ut	ut		
MODIS-N	x	x												
MOPITT				c,p	c									
MVIRI	x													
MWR						x								
Ozone Instr.								c	c					
POLDER	x	x				x								
SBUV-2								c						
SCIAMACHY	c	c	c	c	c	c	c	c	c	c	c	c	c	c
SEVIRI	x							c						
TES				p	p	p		p	p					
TOMS								c						
TOVS	p					c		c						

Table C.3: *Satellite instruments and their products retrieved in the stratosphere. p=profile, c=column, x indicates that some information concerning this product is measured, phys. par. = physical parameters (p, T, clouds etc. see text for details), * = not all species of this group are measured.*

Instrument	Phys. par.	aerosol	CO_2	CO	CH_4	H_2O	HOx*	O_3	NOx*	CℓOx*	N_2O	SO_2	HCHO	BrO
ATSR-2	x	x												
AVHRR/3	x													
EOSP	x	x												
GOME	x							p,c	c	c		c	c	c
GOME-2	x							p,c	c	c		c	c	c
GOMOS	p	p				p		p	p	p				p
HIRDLS	p	p			p	p		p	p		p			
ILAS II	x	p			p	p		p	p		p			
MASTER	p			p		p		p		p	p			p
MIPAS	p	p		p	p	p	p	p	p	p	p			
MLS						p	p	p	p	p	p	p		
MOPITT				c	c									
OSIRIS	p	p						p	p					
Ozone Instr.	x							c	c					
SAGE III	p	p				p		p	p	p				
SBUV-2								c						
SCIAMACHY	p,c	p,c	p,c	p,c	p,c	p	c	p,c	p,c	c	c	c	c	c
SMR	p			p		p		p	p	p	p			
TOMS								c						
TOVS	p					c		c						

AATSR

Mission: ENVISAT-1.
Time frame: 1999-2004.
Viewing Geometry: Two-angle.
Spectral range: 7 channels in the visible and IR (555, 659, 865, 1600, 3700, 10850 and 12000 nm).
Application/Products: a.o. cloud cover and cloud top height, sea and land surface temperature.
Altitude Range: n.a.
Spatial Resolution: 1 km x 1 km.
Swath width: 500 km.
Accuracy: Sea surface temperature: < 0.5K over 0.5 deg × 0.5 deg (lat/long) area with 80% cloud cover. Land surface temperature: 0.1K relative.

AIRS

Mission: EOS-PM 1.
Time frame: 2000-2006.
Viewing Geometry: Nadir.
Spectral range: Visible-SWIR: 0.4-1.7μm. TIR: 3.4-15.4μm.
Application/Products: Temperature/humidity sounding.
Altitude Range: Surface to 100 mb.
Spatial Resolution: Vertical: 1-2 km, horizontal: 13.5 km at nadir.
Swath width: 1650 km.
Accuracy: Temperature retrieval: 1K.

ATSR-2

Mission: ERS-2.
Time frame: 1995-1999.
Viewing Geometry: Nadir, along-track scanning.
Spectral range: 4 SWIR-TIR channels: 1.6, 3.7, 11.0 and 12 μm. 4 Visible/Reflected channels: 0.65, 0.85, 1.27 and 1.6 μm. Microwave channels: 23.8 and 36.5 GHz with a bandwidth of 400 MHz.
Application/Products: Sea surface temperature, land surface temperature, cloud top temperature, cloud cover, aerosols, vegetation, atmospheric water vapor and liquid water content.
Altitude Range: n.a.
Spatial Resolution: IR ocean channels: 1 km x 1 km. Microwave near nadir viewing 20 km instantaneous field of view.
Swath width: 500 km.
Accuracy: Sea surface temperature to <0.5K over 0.5 deg × 0.5 deg (lat/long) area with 80% cloud cover. Land surface temperature: 0.1K.

AVHRR/3

Missions: NOAA series K-N & N'.
Time frame: 1998-2009.
Viewing Geometry: Nadir, cross-track scanning.

Spectral range: Five spectral channels (1: 0.58-0.68 μm, 2: 0.75-1.1 μm, 3: 3.55-3.93 μm, 4 and 5: 10.5-12.5 μm).

Application/Products: Applications for channel 1 include daytime cloud and surface mapping. Applications for channels 3 (3.55 to 3.93 micrometers), 4 and 5 (10.5 to 12.5 micrometers) include sea surface temperature monitoring and day/nighttime cloud mapping, snow and ice extent, ice or snow melt inception, and temperatures of radiating surfaces.

Altitude Range: n.a.

Spatial Resolution: 1.1 km (compressed global area coverage (GAC) data recorded at 4 km resolution).

Swath width: 3000 km (approximate), 55.4 deg. scan off nadir.

Accuracy:

EOSP

Mission: EOS-AM 2.

Time frame: 2004-2007.

Viewing Geometry: Nadir & limb.

Spectral range: Visible and near-infrared (0.41 to 2.25 μm) (12 channels).

Application/Products: Global maps of cloud and aerosol properties from retrievals of 12-channel radiance and polarisation measurements. Specific products are:

- Cloud-top pressure, with 30 m vertical resolution and 40 km horizontal resolution.
- Cloud particle phase at cloud top, with 100 km horizontal resolution.
- Cloud particle size at cloud top, with 100 km horizontal resolution.
- Cloud optical thickness, with 40 km horizontal resolution.
- Aerosol optical thicknesses at an altitude range of 0 to 35 km, with 40 km horizontal resolution.
- Atmospheric correction radiances covering the spectral region from 0.41 to 2.25 μm, with 40 km horizontal resolution.

Altitude Range: see products.

Spatial Resolution: 10 x 10 km at nadir, see products.

Swath width: Limb to limb scan (± 65 deg).

Accuracy: 5% radiance. 0.2% polarisation.

GOME

Mission: ERS-2.

Time frame: 1995-1999.

Viewing Geometry: Nadir.

Spectral range: 240 – 790 nm with a resolution of 0.2 to 0.4 nm.

Application/Products:

- Solar irradiance: Once a day GOME measures the solar irradiance spectrum.
- Earth radiance: An Earth radiance spectrum is obtained for every ground pixel.
- Earth polarisation: Is measured in 3 bands.
- Ozone column.

	– Ozone profile: Ozone profiles are not yet derived operationally, but probably will be in the near future. – NO_2 column. – BrO column: only scientific data processing. – HCHO column: only scientific data processing. – $OC\ell O$ column: only scientific data processing.
Altitude Range:	0 - 60 km (for O_3 profiles).
Spatial Resolution:	40 × 320 km (nominal). Global coverage in 3 days. Vertical: for height 0 to 12 km: 6km and for height 14-60 km: 4 km.
Swath width:	960 km.
Accuracy:	The GOME total ozone column has a precision better than 2% and an accuracy depending on solar zenith angle (better than 5% for solar zenith angles less than 60°). The accuracy of the NO_2 column for regions with relatively low tropospheric NO_2 is estimated to be about 10%.

GOME-2

Mission:	METOP-1.
Time frame:	2000-2005.
Viewing Geometry:	Nadir.
Spectral range:	240-790 nm.
Application/Products:	Basically the list of observable species/parameters for GOME-2 will be the same as for GOME-1.
Altitude Range:	0 - 60 km (for O_3 profiles).
Spatial Resolution:	(At 960 km swath) Horizontal: 40 × 40 km to 320 × 320 km. Vertical: for height 0 to 12 km: 6km and for height 14-60 km: 4 km.
Swath width:	to 1920 km.
Accuracy:	Ozone columns: $< 1\%$. Ozone profiles 0-12 km: $< 10\%$, 14-60 km: $< 5\%$. Precision $< 1\%$.

GOMOS

Mission:	ENVISAT-1.
Time frame:	1999-2004.
Viewing Geometry:	Stellar occultation.
Spectral range:	UV-Visible: 0.25-0.675 μm, NIR: 0.756-0.773 μm, 0.926-0.952.
Application/Products:	Stratospheric profiles of ozone, NO_2, NO_3, H_2O, temperature profiles and aerosols plus some other trace species.
Altitude Range:	15 - 40 km (for O_3 15 - 90 km). Note: 15 km to be replaced by 20 km for daytime occultations.
Spatial Resolution:	Vertical 1.7 km.
Swath width:	n.a.
Accuracy:	Self-calibrating. The quality of GOMOS data is best at night, at day it depends on solar angles, and it varies a lot between different targeted stars.

HIRDLS

Mission:	EOS-CHEM 1.
Time frame:	2002-2008.
Viewing Geometry:	Limb.
Spectral range:	TIR 6-18 μm in 21 channels.
Application/Products:	HIRDLS is designed to sound the upper troposphere, stratosphere and mesosphere to determine global distribution of temperature and concentrations of O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC_{11}, CFC_{12}, $C\ell ONO_2$, aerosols and the locations of polar stratospheric clouds and cloud tops.
Altitude Range:	5-80 km.
Spatial Resolution:	4 degrees longitude x 4 degrees latitude (400 x 400 km) and 1 km vertical resolution; Programmable to other modes and resolution.
Swath width:	6 profiles across 2000-3000 km.
Accuracy:	5-10% mixing ratio absolute accuracy.

ILAS II

Mission:	ADEOS II.
Time frame:	1999-2002.
Viewing Geometry:	Limb, solar occultation.
Spectral range:	Infrared region (2-13 μm) and the near visible region (753 to 784 nm).
Application/Products:	O_3, HNO_3, CH_4, N_2O, H_2O, CFC_{11}, CFC_{12}, $C\ell ONO_2$, NO_2, aerosols, pressure and temperature.
Altitude Range:	10-60 km.
Spatial Resolution:	Horizontal: IR 13 × 2 km, visible: 2 × 2 km. Vertical resolution: 1km.
Accuracy:	5% (1% for ozone).

MASTER

Mission:	future ESA missions.
Time frame:	2003-2013.
Viewing Geometry:	Limb.
Spectral range:	Microwave: 199-207, 296-306, 318-326, 342-348 GHz.
Application/Products:	Upper troposphere/lower stratosphere profiles of O_3, H_2O, CO, HNO_3, SO_2, N_2O, $C\ell Ox$, pressure and temperature.
Altitude Range:	Higher troposphere, lower stratosphere.
Spatial Resolution:	3 km.
Accuracy:	1 - 1.5 K.

MERIS

Mission:	ENVISAT-1.
Time frame:	1999-2004.
Viewing Geometry:	Nadir.
Spectral range:	Visible and near-infrared range, 390 - 1040 nm in 15 bands.
Application/Products:	Measurement of the solar reflected radiation from the Earth's surface and from clouds through the atmosphere. The data will be used for

	the generation of large scale maps, a.o. for clouds, aerosol and water vapour.
Altitude Range:	n.a.
Spatial Resolution:	Full resolution: 0.25 km × 0.25 km. Reduced resolution: 1 km × 1 km.
Swath width:	1150 km (global coverage in 3 days).
Accuracy:	Solar Reflectance absolute accuracy: $< 2\%$.

MIPAS

Mission:	ENVISAT-1.
Time frame:	1999-2004.
Viewing Geometry:	Limb.
Spectral range:	4.15 μm - 14.6 μm.
Application/Products:	By operational data processing (on-line and off-line) distributions of the following parameters will be produced: p, T, O_3, H_2O, CH_4, N_2O and HNO_3 (later others could be added). Scientific data processing in Karlsruhe will lead to trace gas profiles of the following species (planned): NO, NO_2, N_2O_5, HNO_4, $C\ell ONO_2$, CFC-11, CFC-12, CFC-22, CO and others.
Altitude Range:	5 - 80 km (NO_2 20 - 40 km, aerosol 5- 30 km).
Spatial Resolution:	Vertical resolution: 3km, horizontal resolution: 30km.
Accuracy:	Radiometric precision 1-3%.

MISR

Mission:	EOS-AM 2.
Time frame:	2004-2009.
Viewing Geometry:	Nine viewing angles. Nadir, forward and afterward of nadir.
Spectral range:	Four spectral bands centered at 443, 555, 670 and 865 nm.
Application/Products:	Two standard Level 2 science products: The top of Atmosphere/Cloud product and the Aerosol/Surface Product.
Altitude Range:	n.a.
Spatial Resolution:	Spatial sampling: 275, 550 or 1100 m.
Swath width:	360 km.
Accuracy:	Level 1 products absolute 3-6% relative 1-2%, Level 2 products parameter dependent. 0.03 hemispherical albedo, 10% aerosol opacity.

MLS

Mission:	EOS-CHEM 1.
Time frame:	2002-2008.
Viewing Geometry:	Limb.
Spectral range:	Microwave. Spectral bands: 200, 300, 600 GHz and 2.5 THz.
Application/Products:	Lower stratospheric temperature and concentrations of O_3, $C\ell O$, $HC\ell$, HNO_3, H_2O, N_2O, OH and upper tropospheric concentrations of H_2O and O_3. Furthermore MLS measures SO_2, and other gases mentioned above, in volcanic plumes.

Altitude Range: 0-80 km.
Spatial Resolution: 3 x 300 km horizontal x 1.2 km vertical.
Accuracy: Level 1 B radiance < 3%.

MODIS

Mission: EOS-AM 2.
Time frame: 2004-2007.
Viewing Geometry: Cross-track scanning.
Spectral range: 36 spectral bands; 21 within 0.4 to 3.0 μm and 15 within 3 to 14.5 μm.
Application/Products: MODIS will provide specific global data products, which a.o. include the following:

- Surface temperature.
- Cloud cover.
- Cloud properties characterised by cloud droplet phase, optical thickness, droplet size, cloud top pressure and emissivity.
- Aerosol properties defined as optical thickness, particle size and mass transport.
- Cirrus cloud cover.

Altitude Range: n.a.
Spatial Resolution: Surface temperature 1 km, cloud cover 250 m by day 1 km by night.
Swath width: 2300 km at 110° (± 55°).
Accuracy: Surface temperature 0.2 K for ocean and 1 K for land.

MOPITT

Mission: EOS-AM 1.
Time frame: 1999-2004.
Viewing Geometry: Nadir.
Spectral range: 4.6 and 2.3 μm band for CO, 2.2 μm band for CH_4.
Application/Products: Total column amount of CO and CH_4 and CO profiles.
Altitude Range: 0-15 km.
Spatial Resolution: Horizontal 22 km, vertical resolution for CO profiles 3km.
Swath width: ±25 degrees about nadir.
Accuracy: CH_4 columns 1%, CO columns 10%, CO profiles 10%.

MVIRI

Mission: Meteosat.
Time frame: 1997-2002.
Viewing Geometry: Nadir.
Spectral range: Visible-NIR: 0.5 to 0.9 μm, TIR: 5.7 to 7.1 μ (water vapour), 10.5 to 12.5 μm.
Application/Products: a.o. cloud cover and cloud top height.
Altitude Range: n.a.
Spatial Resolution: Visible: 2.5 km, water vapour: 5 km, (after processing) TIR: 5 km.
Swath width: Full Earth disc.

MWR

Mission: ENVISAT-1.
Time frame: 1999-2004.
Viewing Geometry: Near nadir viewing.
Spectral range: Microwave. The frequencies are 23.8 and 36.5 GHz, with a 400 MHz bandwidth.
Application/Products: The altimeter path delay due to atmospheric humidity, the vertically integrated water vapour content, and the integrated cloud liquid water content (but not used quantitatively).
Altitude Range: n.a.
Spatial Resolution: 20 km.
Swath width: 20 km.
(Estimated) Accuracy: On the brightness temperatures 3K absolute accuracy, but about 0.5K radiometric sensitivity. The water vapour is obtained with less than 0.3 g/cm^2 uncertainty. The estimated accuracy on the liquid water content is 0.05 km/m^2.

OSIRIS

Mission: Odin.
Time frame: 1998-2000.
Viewing Geometry: Limb.
Spectral range: Imaging spectrograph: 280-800 nm, near-infrared (NIR) telescopes: operating at 1.27 micrometers; each of the continuous bands being 10 nanometers in bandwidth.
Application/Products: Aerosols, p, T, O_3, O_2, O_4, NO, NO_2 and possibly $C\ell O$.
Altitude Range: 20 - 70 km , 70 - 120 km for NO.
Spatial Resolution: Vertical resolution: 1-2 km possible.
Accuracy: Ozone: 15%.

POLDER

Mission: ADEOS II.
Time frame: 1999-2002.
Viewing Geometry: nadir.
Spectral range: The measuring wavelength are 443, 670 and 865 nm.
Application/Products: Polarisation of the solar light.
Altitude Range: n.a.
Spatial Resolution: 6 × 6 km.
Swath width: 2400 km (across track) × 1800 km (along track).
Accuracy: Expected accuracy of 2-3%.

SAGE III

Missions: METEOR-3M N1, International Space Station Alpha and EOS flight of opportunity (FOO).
Time frame: 1998-2001, 2001-2006, 2005-2008.
Viewing Geometry: Solar and lunar occultation.
Spectral range: Nine spectral regions between 290-1550 nm.

Application/Products:
- Ozone profiles, from the mid-troposphere to 85 km.
- NO_2 profiles, from the tropopause to 45 km.
- H_2O profiles, from the planetary boundary layer to 50 km.
- NO_3 profiles (stratosphere) from lunar occultation measurements.
- OCℓO profiles (stratosphere) from lunar occultation measurements.
- Aerosols and clouds, from the troposphere into the stratosphere and where appropriate, the mesosphere.
- Temperature/pressure profiles.

Altitude Range: see products.
Spatial Resolution: 1-2 km in the vertical.
Swath width: n.a.

SBUV-2

Missions: NOAA 9, 11, 14, K, M, N & N'.
Time frame: 1996-2009.
Viewing Geometry: Nadir, no scan mirror.
Spectral range: Small bands in the wavelength region 100-400 nm.
Application/Products: Spectral Earth radiance, solar irradiance measurements and trace gases including ozone distribution.
Altitude Range: 25-55 km.
Spatial Resolution: 170 km. Vertical resolution O_3 profile: 8-15 km.
Swath width: Nadir pointing.
Accuracy: Total ozone concentration: absolute accuracy of 1%.

SEVIRI

Missions: MSG1, MSG2 and MSG3 (EUMETSAT).
Time frame: 2000-2012.
Viewing Geometry: Nadir.
Spectral range: Visible: 0.56-0.71 μm, 0.5-0.9 μm (broadband). NIR: 0.71-0.95 μm. SWIR: 1.44-1.79 μm. TIR: 3.4-4.2 μm, 8.3-9.1 μm, 9.8-11.8 μm, 11.0-13.0 μm, 5.35-7.15 μm, 6.85-7.85 μm, 9.46-9.94 μm, 13.04-13.76 μm.
Application/Products: a.o. cloud cover, cloud top height and total ozone.
Spatial Resolution: 1 km for one broadband visible channel, 3 km for all other channels.
Swath width: Full Earth disc.

SMR

Mission: Odin.
Time frame: 1998-2000.
Viewing Geometry: Limb.
Spectral range: Frequencies: 118.25-119.25 GHz, 486.1-503.9 GHz, 541.0-580.4 GHz. Bandwidth: 100 MHz to 1 GHz.
Application/Products: p, T, O_3, CO, NO_2, N_2O, NO, O_2, CℓO and H_2O.
Altitude Range: 20-80 km.
Spatial Resolution: 11-12 km.

SOLSPEC

Mission:	International Space Station Alpha.
Time frame:	2001-2006.
Viewing Geometry:	Sun pointing.
Spectral range:	180 to 3000 nm.
Application/Products:	Solar spectral irradiance.
Altitude Range:	n.a.
Spatial Resolution:	n.a.
Swath width:	Full solar disc.
Accuracy:	Absolute accuracy of 2% in the UV and 1% in the visible and the infrared.

SOLSTICE II

Mission:	SAVE.
Time frame:	2002-2005.
Viewing Geometry:	Sun pointing.
Spectral range:	5-440 nm (solar UV irradiance from 30 to 440 nm, the solar UV irradiance from 115 to 320 nm at much higher resolution, and extreme UV irradiance between 5 and 20 nm).
Application/Products:	Solar ultraviolet irradiance.
Altitude Range:	n.a.
Spatial Resolution:	n.a.
Swath width:	Full solar disc.
Accuracy:	Absolute: 3-5%. Relative: 1%.

TES

Mission:	EOS-CHEM 1.
Time frame:	2002-2008.
Viewing Geometry:	Limb and nadir.
Spectral range:	2.3 to 15.4 μm at a spectral resolution of 0.025 cm^{-1}.
Application/Products:	Vertical concentration profiles of O_3, CO, CH_4, H_2O, NO, NO_2, CFCs and nitric acid from the surface to the lower stratosphere.
Altitude Range:	Limb: 0-32 km.
Spatial Resolution:	Vertical (limb): 2.3 km. Horizontal (nadir): 50x5 km (global) or 5x0.5 km (local). The horizontal resolution of the data products is 53 x 169 km.

TOMS

Missions:	METEOR-3M series.
Time frame:	1998-2003.
Viewing Geometry:	Nadir.
Spectral range:	6 narrow spectral bands centered at the following wavelengths: 308.6, 312.5, 317.5, 322.3, 331.2, 360.0 nm.
Application/Products:	Albedo, total column amounts of ozone.
Altitude Range:	n.a.
Spatial Resolution:	47 x 47 km.
Swath width:	3100 km.

Accuracy:	Ozone: 1-2%, the precision of the TOMS albedo measurement is better than 0.8% at all wavelengths.

TOVS

Missions:	NOAA series K-N and N'.
Time frame:	1998-2009.
Viewing Geometry:	Nadir.
Spectral range:	19 bands in the following wavelength regions: 690 nm, 3760-4570 nm, 6720-14950 nm and MW a.o. the 5.5-mm oxygen band.
Application/Products:	Water vapour content, temperature profiles and O_3 total columns.
Altitude Range:	temperature profiles: 0 - 65 km.
Spatial Resolution:	20 × 20 km.
Swath width:	2800 km.
Accuracy:	Ozone total columns: 5-7%.

VIRGO

Mission:	SOHO.
Time frame:	1996-1998.
Viewing Geometry:	Sun pointing.
Spectral range:	320-900 nm.
Application/Products:	High-precision, high-stability and high-accuracy measurements of the solar total and spectral irradiance and spectral radiance variation.
Altitude Range:	n.a.
Spatial Resolution:	n.a.
Swath width:	Full solar disc.

C.2 Description of Ground-based Instruments and Networks

Various ground-based remote-sensing techniques provide complementary high-quality measurements of column amount and of vertical distribution of stratospheric ozone and other trace constituents at low, middle and high latitudes, as well as information on aerosol content.

The **Dobson** spectrophotometer measures the ozone column amount with an accuracy of 2-3% for Sun elevation higher than 15°. It is a double-monochromator based upon the differential absorption method in the ultraviolet Huggins band where ozone exhibits strong absorption features. The measurement principle relies on the ratio of the direct sunlight intensities at two standard wavelengths. The most widely used combination, recommended as the international standard, is the couple of pairs of wavelengths referred to as the AD pair (305.5-325.4; 317.6-339.8 nm). Since 1958, Dobson spectrophotometers have been deployed in a world-wide network.

The **Brewer** grating spectrophotometer is similar in its principle to the Dobson, but it has an improved design and is fully automated. The determination of the ozone column abundance is obtained from a combination of five wavelengths in the spectral region between 306 and 320 nm. Since the 1980's, Brewer instruments are operated in network as well.

Differential Optical Absorption Spectroscopy (DOAS) applied to UV-visible zenith-sky observations performed at twilight allows the measurement of column amounts of various trace constituents such as ozone, NO_2, O_4, H_2O, $OC\ell O$ or BrO, and of vertical distributions of NO_2. The DOAS retrieval technique consists in studying narrow absorption features after removal of the broad band signal where scattering processes interfere. Based on this technique, several **SAOZ** (Systeme d'Analyse par Observation Zenithale) and other **UV-visible DOAS spectrometers** have performed network operations since the late 1980's and have monitored column amounts of ozone and NO_2 from the Arctic to Antarctica, with an accuracy of about 3-5% for ozone and 10% for NO_2. UV-visible DOAS spectrometers are also operated in solar occultation mode during stratospheric balloon flights, providing vertical distributions of ozone, NO_2, BrO and $OC\ell O$ in the upper troposphere and in the stratosphere up to about 35 km.

Fourier transform infrared spectrometers (FTIR) are used to derive from high spectral resolution measurements of the solar spectrum the column amounts of a large number of atmospheric trace constituents that offer absorption features in the infrared range, including ozone, nitrogen compounds, $HC\ell$, HF, CO, CH_4, CFCs, etc. Typical relative uncertainties are currently around 5% for ozone, $HC\ell$, HF and HNO_3, 10% for NO and NO_2, and 25% for $C\ell ONO_2$.

Ozone sondes measure the O_3 concentration through the amount of electrons generated in an electro-chemical reaction of O_3 in a KI solution (ECC sonde). The sonde is attached to a balloon, which reaches its maximum altitude at about 30–40 km. At this altitude the balloon bursts and the sonde falls down. Attached to the ozone sonde is a **radio sonde**, measuring pressure, temperature, and humidity. The vertical resolution of the profile is prescribed by the combination of the upward velocity (approximately 5 m/s) of the sonde and the time interval between the measurements (10 seconds), and is of the order of 100 m. The precision of the ozone concentrations is approximately 2%, and the accuracy is 5%. About 30 operational ozone sonde stations exist world-wide, the largest concentration of stations being in the Northern mid-latitudes.

The **Differential Absorption Lidar (DIAL)** technique provides accurate vertical distributions of ozone. A stratospheric lidar yields an accuracy within 3% over the whole 15-45 km altitude range and a precision varying typically from 0.5% to 10% corresponding to the related vertical resolution which varies from 0.5 to 8 km with increasing altitude. These observations require essentially clear sky conditions.

Aerosol lidar measurements provide vertical distribution of scattering ratio and particle backscatter at one or several given wavelengths (355, 532 and 1064 nm are typical). Aerosol profiles are obtained from about the tropopause up to 30-35 km with an altitude resolution of 15-75m and with a precision of 2% for the scattering ratio profile and a precision from 8 to 16% (volcanic/background) for the vertically integrated particle backscatter. An aerosol model is used to retrieve aerosol extinction, mass, and surface data from backscatter profiles. The depolarising effect of aerosols can be recorded by a polarising beamsplitter, and depolarisation measurements are used to distinguish between particles of different shapes and phase states. Soundings with **backscatter sondes** add in-situ information about particle concentration profiles.

Rayleigh lidars allow the observation of the atmospheric temperature from the Rayleigh backscattered signal in the upper troposphere, the stratosphere and the mesosphere, while **Doppler lidars** observe atmospheric winds.

Microwave radiometry, which is based on the study of collision broadened emission lines of atmospheric constituents with high frequency resolution, allows to infer altitude profiles of atmospheric trace gases in the range of 20 to 70 km, and is well suited to investigate their short term variations in the stratosphere and in the mesosphere. Observations are insensitive to weather conditions and aerosol load. Ozone radiometers working at 142 or 110 GHz yield an accuracy of 10-15% with an altitude resolution of approximately 8-12 km. The frequencies of 278 and 204 GHz are routinely used to measure vertical distributions of $C\ell O$. Microwave radiometers using newest technology of superconducting diodes allow measurements at different frequencies for the observation of other minor constituents such as H_2O, HO_2, HNO_3, SO_2, or N_2O.

Sunphotometers measure the direct sunlight in ca. 6 narrow spectral bands between 360 and 1000 nm. By using the Langley method the optical thickness of the atmosphere can be determined. After subtraction of the Rayleigh optical thickness and the ozone optical thickness, the aerosol optical thickness is obtained. AERONET (AErosol RObotic NETwork) is an optical ground based aerosol monitoring network and data archive consisting of sunphotometers. This network provides globally distributed near real time observations of aerosol spectral optical depths, aerosol size distributions, and precipitable water in diverse aerosol regimes.

The **Network for the Detection of Stratospheric Change (NDSC)** is based upon the complementarity of the aforementioned ground-based techniques (Lambert et al., 1997). Dedicated to the physics and chemistry of the stratosphere, this network of high-quality remote-sounding research stations consists of about seventeen sites distributed in five primary stations (Arctic, Alpine, Hawaii, New Zealand, Antarctic) fully equipped with almost all the observation techniques and completed by two dozens of secondary stations. It is a major contributor of the Global Ozone Observing System (GO_3OS) of the World Meteorological Organisation (WMO) within the framework of its Global Atmosphere Watch (GAW). Complementary to the NDSC, seventeen SAOZ and other NDSC-qualified UV-visible DOAS spectrometers constitute the so-called **SAOZ/UV-visible DOAS network** that monitor ozone and NO_2 column amounts at a variety of sites in the world, from the Arctic to the Antarctic. The instruments operated at the NDSC and UV-visible DOAS stations regularly participate to blind instrument intercomparison campaigns in order to control their quality, to assess their accuracy, to examine their consistency with other types of instruments, and to certify them for use in the NDSC.

CMDL network: The CMDL cooperative sampling network is an ongoing collaboration between government agencies and universities around the world. Samples of air are collected on a weekly basis at about 70 locations and the shipped to Boulder for analysis of CO_2, CO, CH_4, H_2, and most recently N_2O and SF_6. Most sites are located in the marine boundary layer, while a few are situated on mountaintops or in areas of regional scale pollution.

C.3 SCIAMACHY Validation with Balloons

C.3.1 Introduction

Depending on the size and mass of the payloads to be launched for validation purposes, several types of balloons can be used and are recalled here for completeness:

- Meteorological type balloons for PTU and ozone soundings (meteo balloons).
- Small balloons for payloads in the class 50 - 100 kg (small balloons).
- Bigger stratospheric balloons for payloads in the class 100 - 500 kg.

This last type of balloon is often referred to as BSO (for open stratospheric balloon in French).

C.3.2 Validation with meteo balloons

Several meteo balloons are launched every day over Europe according to standardised procedures by national weather services participating in the WMO activities for PTU soundings and, in a less intensive manner, for ozone soundings (activities co-ordinated by the O_3GO and WOUDC). Specific campaigns with this type of balloons, like the MATCH project, have been used for co-ordinated studies of ozone profiles where a second balloon is sounding the air mass sampled a few days before at another location by a first balloon. The cost of an ozone sounding is about 1 kECU and the manpower needed is 2 persons per launch (1 technician for balloon preparation and launch, 1 more specialised staff for ECC sonde preparation, tracking and handling the reception station at 400 MHz, processing the recorded files and maintaining the database locally). These need can be fulfilled by personnel also involved in other activities in meteorological stations where regular sounding (PTU and O_3) capabilities are existing, however, and it is a matter of co-ordination and negotiation with the relevant national agencies to use the sounding data at best for the validation of SCIAMACHY. Ozone soundings with this type of balloons, however, should be launched on a daily basis to accompany any major SCIAMACHY validation campaign with bigger payloads at the appropriate site for a proper day to day monitoring of the O_3 profile between the flights of the bigger payloads.

C.3.3 Validation with small balloons

These balloons, of the class 5000 - 15000 m^3, are more expensive and need more experienced and dedicated personnel as well as specialised launching sites. Existing teams at the Andoya launching range (Andeness, Norway) and ESRANGE (Kiruna, Sweden) are good examples of the available national facilities for launching payloads of the SAOZ type that could contribute to regular correlative measurement studies for SCIAMACHY, in parallel with the normal scientific activities with this type of lightweight instrumentation (provided proper arrangements are negotiated between the scientists in charge and the SCIAVALIG team). Several SAOZ type instruments are (or will be soon) available and instrument preparation could be made by local personnel with launch decision taken by the responsible scientists (remotely by computer communication or phone) depending on ground conditions, satellite overpass and geophysical situation. An intercomparison campaign of various ECC or Brewer sondes accommodated on the same gondola under small balloons of the above type is scheduled by WMO.

C.3.4 Intensive validation balloon campaigns

Location and time

Intensive balloon campaigns have already been conducted from several launching sites (see Table C.2) either in the frame of general scientific programmes initiated by the European Union i.e. the European Arctic Stratospheric Ozone Experiment (EASOE) and the Second European Stratospheric Arctic and Mid-latitude Experiment (SESAME) or for dedicated space instrument validations i.e. the ILAS validation balloon campaign. It happens that for various reasons (e.g. monitoring of ozone chemistry in the Arctic, overpass of a sun synchronous satellite with a solar occultation instrument) the most intensive part of these campaigns generally took place from ESRANGE (near Kiruna, Sweden) during the Feb./March period. This is not a definite necessity, however, and interesting locations and periods for the validation of a space instrument like SCIAMACHY could well be organised at other places and times as can be seen in Table C.2.

Table C.2: *Launching sites and favourable periods for validation of SCIAMACHY with BSO. The appreciation of the facilities is based on the space available for integrating a large number of payloads within the timeframe of an intensive validation campaign and on the local accommodation capabilities for the corresponding large number of scientists. Improvements are to be expected in the Gap and Leon sites.*

Site	Location	Possible launch periods	Facilities
Aire-sur-l'Adour France	43N, 0E	Apr.,May, Sept., Oct.	good
Gap France	44N, 6E	June, July	reasonable
Leon Spain	42N, 5W	Nov., Feb., March, Apr.	limited
ESRANGE, Kiruna Sweden	68N, 22E	Jan., Feb., March, Aug., Sept.	good

Balloon launches at the sites listed in Table C.2 are performed by the CNES launching team of Aire-sur-l'Adour (permanent base) but the team (and its equipments) can move, when needed, to Gap (each year in June usually) and to Kiruna or Leon (on notice).

As can be seen there is no facility at tropical or equatorial latitudes, but the possibility to launch from such regions is explored by CNES.

Planning

Since a validation campaign will need the co-ordination of many scientists and institutions, advanced and careful planning is necessary. A core group with one campaign leader has to be appointed for decision making about priorities of payload launches as instrument readiness, ground conditions, stratospheric winds and satellite overpass change on a day to day basis. Some flexibility is needed however, since a perfect coincidence of the air masses sampled by the space sensor and the balloon instrumentation is impossible. There are cases where it would be better to catch an unperfect coincidence but actually perform a flight, rather than wait for hopefully better conditions with the assurance of a longer (hence more costly) campaign and the risk of not being able to perform the flight anyway because of ill predicted bad weather. Models (box, trajectory and/or CTM (Chemistry Transport Model)) will be needed anyway to assess and assimilate the measured profiles and can be used to interpolate in space and time if the coincidence between the balloon and the space measurements is not good enough.

Constraints proper to balloon campaigns

In previous campaigns, experience has shown that conflicting situations can occur when too many experiments with too many objectives are competing for a limited number of launch windows. Since a given big campaign will usually attract various experiment teams wanting to benefit from the presence, at one remote site, of a well trained and equipped launching team, a clear contract or MOU (memorandum of understanding) is recommended to define precisely the commitments of the various partners involved: experiment teams that have a limited budget for travel and accommodation, host facility which normally is requesting a usage fee proportional to the duration of the campaign, launching team which also notify to each payload an invoice depending on the overall number of flights and days during which it has been on duty and/or standby. If recovery is to be made in Russia, advance negotiation about the number of such flights is strongly recommended. Margins must exist however (as far as time and cost are concerned) so as to make the validation balloon campaign possible at all. The goal however will generally be to achieve "cluster" flights i.e. flights of complementary payloads that could enhance science benefits if flown in a short time interval. A negotiation is needed with CNES to define the feasibility and constraints of such cluster flights.

Complementary information

The ephemeris of the satellite will evidently be needed (and this data is not the most difficult to predict), but good weather forecast and the capability to predict balloon and airmass trajectories is also necessary. These tools are existing and rely on easy access to the ECMWF predictions (5 days in advance and possibly 8/10 in the near future) and are implemented by the CNES meteorologist. The validation campaign will advantageously benefit, however, as has been done in the campaigns quoted above, from support of stratospheric experts e.g. the FUB (Freie Universität Berlin) group that can help in documenting and predicting high altitude winds and temperature that are of uppermost importance for a well optimised validation experiment. Precise meteorological profiles i.e. p and T as a function of altitude (for remote sensing as well as in situ instruments) will be necessary for the careful processing of the balloon and of the space data to be validated. Precise GPS localisation of the payload is now available from CNES, but these data should be explicitly requested as they are very important, specially for remote sensing instruments for which the knowledge of the observation geometry is critical for accurate retrievals.

Complementary measurements

The daily ozone sounding at the site of the intensive validation campaign have already been mentioned. There is the possibility to co-ordinate both the balloon and satellite profiles and the derived columns with column measurements (using MW, FTIR or UV/vis spectrometers) performed from the vicinity of the launching site. Lidars (for ozone and aerosols) can also be used directly for profile comparisons, if operational during the campaign at the appropriate location. Airborne campaign and measurements could well be co-ordinated (as has already been done in the past campaigns) both with the balloon launches and the satellite overpasses. The SCIAVALIG group, based on the existing cooperations between scientists involved in ground, aircraft, balloon and space experiments will have to optimise the available resources in an efficient but flexible enough manner.

C.4 Aircraft

Aircraft are excellent platforms to validate space experiments, because an aircraft can operate virtually everywhere on the globe under most weather conditions and in all seasons. Furthermore campaigns can be planned to very closely match in time and space the observing characteristics of a space sensor.

The following research aircraft have been used successfully in satellite sensor validation campaigns and/or atmospheric research campaigns:

FALCON Germany.

Operated by DLR, Oberpfaffenhofen in Germany. This aircraft (operating below 13 km) can be equipped with the following instrumentation: Lidar for ozone and aerosols, microwave radiometer to measure O_3, N_2O, $C\ell O$, $HC\ell$, $HOC\ell$, HO_2, H_2O, HNO_3, and instruments to perform in situ measurements at flight altitude.

Operation costs are:	per flight hour	6600 German Marcs (incl. vat)
	per day	6900 German Marcs (incl. vat)

(In addition per diem is needed for flight crew, expenses for air traffic control and costs for landing and hangar on airports outside of Oberpfaffenhofen. A typical 12 day campaign in the arctic, including approximately 18 flight hours amounts to 250,000 German Marcs incl. vat).

M-55 GEOPHYSIKA, High-altitude Aircraft, Russia/Italy.

The activities of the Russian aircraft M-55 are co-ordinated in Western Europe by L. Stefanutti (CNR-IROE, Florence) and by his deputy R. MacKenzie (European Ozone Research Coordinating Unit, Cambridge).

Aircraft characteristics

The aircraft flies at a cruising altitude of up to 21 km and cruising speed of 720 km/h. The payload weight is 1500 kg max. (at 21 km) stowed in several bays of 0.5 m^3 and 2.0 m^3. The endurance is 6.5 hours (i.e. track of 4000 km). The aircraft requires a runway of only 1500 metres and can even operate during adverse weather conditions. Flights can be repeated every 2 days, dependant on the complexity and nature of the payload.

It is not recommended to base campaigns in Russia. Campaigns in higher latitudes are based in Rovaniemi, Finland, while an airport near Roma, Italy, is preferred for campaigns at lower latitudes.

Payload for ACVT

The preferred payload for the ACVT (Atmospheric Chemistry Validation Team, which is set up to validate the data products generated by GOMOS, MIPAS and SCIAMACHY) is composed of the sensors MIPAS-STR and SAFIRE-A.

These instruments, plus 12 other chemistry instruments, form the Airborne Polar Experiment (APE). Test flights will be performed in the course of 1998 near Roma, Italy.

The MIPAS-STR is a version of MIPAS which has been adapted to STRatospheric flights on aircraft. It was originally designed for the German aircraft STRATOS-B. Its characteristics correspond to the space-borne MIPAS instrument.

SAFIRE-A is a Fourier Transform Spectrometer for the observation of the atmospheric emission spectrum in the far Infrared spectral region. The project involves Italian, British, French and US groups. The instrument is capable of measuring the vertical distribution from tropopause to flight altitude and the vertical column above flight height of the minor stratospheric constituents that display features in the far infrared region, namely O_2, O_3, H_2O, H_2O_2, OH, HO_2, HDO, $HC\ell$, $HOC\ell$, $C\ell O$, N_2O, HNO_3, NO_2, HBr, HF, CO and HCN.

For the APE experiment, some of the sensors are:

FOZAN (Fast Ozone Analyser) operates on the chemiluminescent reaction between the ozone and the air flow and the solid-state sensor.
ECOC (Electro-Chemical Ozone Cell) is an ozonometer.

FLASH (Fluorescent Airborne Stratospheric Hygrometer) and ACH (Aircraft Condensation Hygrometer) are both used for water vapour measurements.
GASCOD (Gas Absorption Spectrometer Correlating Optical Differences) operates in the ultraviolet and visible spectral regions and enables several trace gases (O_3, NO_2, BrO, $OC\ell O$) to be measured simultaneously.

Charging policy

Two budget lines need to be considered. The first is required for the operations of the aircraft, and for the Russian maintenance team of 26 technicians. The second budget is needed to cover the sensor costs, and the scientific teams, usually originating from western laboratories and institutes. The latter budget is function of the number of instruments, the size of the team required for the implementation/operations and location of the campaign.

Cost estimates are as follows for one month of activities, including 25 flight hours:

- M-55 costs and maintenace team: 400 kECU
- Sensors and scientists: 200 kECU per large instrument

CESSNA TU Delft, Netherlands.

In 1993 the initiative was taken to modify and employ chemical instrumentation on a Cessna Citation twin-jet, operated by the Technical University Delft. Several adjustments and modifications have been implemented to accommodate air inlets and instruments for atmospheric chemistry measurements. Over the past years seven European groups have participated in these efforts as part of the EC supported project STREAM (Stratosphere and Troposphere Experiments by Aircraft Measurements). Advantages of the relatively small twin-jet aircraft are its flexibility and the possibility to reach the lower stratosphere ($\sim$ 13 km). At the same time, its small size limits the payload and endurance. This handicap is overcome by the development of light-weight automated instruments. The aircraft is equipped to measure nitrogen oxides, ozone, water vapor, aerosols, sulfur species, carbon monoxide, carbon dioxide, hydrocarbons and many other gases to quantify the chemistry of the atmosphere. In September 1997 a project proposal has been submitted to the Netherlands Geosciences Foundation to extend the payload and introduce aircraft modifications to enable remote sensing measurements. The operation costs are 25000 Dutch Guilders per flight.

Annex D
Operational Requirements

D.1 Introduction

Since the first preliminary data release is planned shortly after the commissioning phase, the validation carried out during this phase should already give a good indication of the quality of the SCIAMACHY data. This Annex lists the requirements for the first validation phase. The requirements are divided in two categories: general requirements (**GR**) and operational requirements (**OR**). Although most of the commissioning phase validation should be carried out under nominal operation, it is possible that some of the operational requirements listed below may affect the sequence of timelines performed during the commissioning phase, or even may make it necessary to define additional timelines.

This list of requirements is still under discussion in SCIAVALIG and SSAG. It should be regarded as preliminary. Other requirements may come up in the discussion, and some of the requirements listed below might be removed.

D.2 General Requirements

GR 1 At least three months of the commissioning phase should be used to perform measurements directly useful for validation of the operational products.

GR 2 Special attention should be paid to a good communication between the people performing the validation (e.g. SCIAVALIG) and people concerned with SCIAMACHY operations and functional testing (e.g. SOST). Important findings of both groups should be communicated as quickly as possible via fax or e-mail. Regular meetings, approximately once every two months, with all people involved are advisable.

GR 3 All data retrieved from SCIAMACHY measurements, including the functional test data, should be easily and quickly available for validation.

GR 4 Access to the data during the commissioning phase for all (core) validation groups should be organized well before launch. Distribution via, e.g., CD-ROM should be anticipated for files which are too large for FTP-transfer.

D.3 Operational Requirements

OR 1 The major part of the measurements in the validation period of the commissioning phase should be performed in the same observation scenario as is foreseen for the routine operations phase. Priority should be given to routine scientific measurements above regions covered by ground stations used for validation.

OR 2 Proper validation of the polarisation measurements requires a nadir static timeline (i.e. no scanning) for at least 3 days. Part of these measurements might be obtained during functional testing.

The following requirements are valid when GOME is still in operation during the commissioning phase of SCIAMACHY.

OR 3 Priority should be given to routine scientific measurements during GOME small swath width observations.

OR 4 Priority should be given to routine scientific measurements at high latitudes (above 60 N), where GOME and SCIAMACHY measurements overlap.

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List of Acronyms

AATSR	Advanced Along Track Scanning Radiometer
ACVT	Atmospheric Chemistry Validation Team
ADEOS	ADvanced Earth Observing System
AIRS	Advanced Infra-red Sounder
AO	Announcement of Opportunity
AOI	AO Instrument
APE	Airborne Polar Experiment
ASAR	Advanced Synthetic Aperture Radar
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATMOS	Atmospheric and Ocean Surface Programme (German Atmospheric Research Programme)
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AWI	Alfred Wegener Institut
BIRA-IASB	Belgisch Instituut voor Ruimte-Aëronomie- Institut d'Aéronomie Spatiale de Belgique (Belgian Institute for Space Aeronomy)
CFC	ChloroFluoroCarbon
CMDL	Climate Monitoring and Diagnostics Laboratory
CNES	Centre National d'Etudes Spatiales
CNRS	Centre National pour la Recherche Scientifique
DARA	Deutsche Agentur für Raumfahrt-Angelegenheiten (German Space Agency)
DFD	Deutsches Fernerkundungs-Datenzentrum (German Remote Sensing Data Centre)
DLR	Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center
DOAS	Differential Optical Absorption Spectroscopy
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
D-PAC	German PAC
DWD	Deutscher Wetterdienst
EC	European Commission
ECC	Electrochemical Concentration Cell
ECMWF	European Centre for Medium-range Weather Prediction
ECU	European Currency Unit
EDI	ESA Developed Instruments
ENVISAT	Environmental Satellite
EOS	Earth Observing System
EOSP	Earth Observing and Scanning Polarimeter
ERS	European Remote Sensing Satellite
ESA	European Space Agency
EU	European Union
FIS	Far Infra-red Spectrometer
FLASH	Fluorescent Airborne Stratospheric Hygrometer
FOO	Flight Of Opportunity
FTIR	Fourier Transform Infra-red Radiometer
FTIRS	Fourier Transform Infra-Red Spectrometer
FTS	Fourier Transform Spectroscopy
FZJ	ForschungsZentrum Jülich
GASCOD	Gas Absorption Spectrometer Correlating Optical Differences
GAW	Global Atmospheric Watch

GC	Gas Chromatography
GC-ECD	Gas Chromatography using Electron Capture Detector
GCOS	Global Climate Observing System
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of Stars
GPS	Global Positioning System
GS	Ground Segment
GSFC	Goddard Space Flight Center
HALOE	Halogen Occultation Experiment
HIRDLS	HIgh-Resolution Dynamics Limb Sounder
ICFA	Initial Cloud Fitting Algorithm
IFE	Institut für Fernerkundung
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere and Biosphere Programme
IGDR	Interim Geophysical Data Record
ILAS	Improved Limb Atmospheric Spectrometer
IMAU	Institute for Marine and Atmospheric research Utrecht
IMG	Interferometric Monitor for Greenhouse gases
IMGA	Instituto per lo studio delle Metodologie Geofisiche Ambientali Institute for the study of Geophysical and Environmental Methodologies
IPAF	Italian PAF
IR	Infra-Red
ISSA	International Space Station Alpha
KNMI	Koninklijk Nederlands Meteorologisch Instituut Royal Netherlands Meteorological Institute
LPMA	Laboratoire de Physique Moleculaire et Applications
LRR	Laser Retro-Reflector
MASTER	Mm-wave Acquisitions for Stratospheric/Tropospheric Exchange Research
MERIS	Medium-Resolution Imaging Spectrometer
METOP	METeorological Operational Satellite
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MISR	Multi-angle Imaging Spectro Radiometer
MLS	Microwave Limb Sounder
MODIS	MOderate resolution Imaging Spectro radiometer
MOPITT	Measurements Of Pollution In The Troposphere
MPI	Max-Planck Institut
MR	Medium Rate
MVIRI	METEOSAT Visible and Infra-Red Imager
MW	MicroWave
MWR	MicroWave Radiometer
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NDSC	Network for the Detection of Stratospheric Change
NIR	Near Infra-Red
NIVR	Nederlands Instituut voor Vliegtuigontwikkeling en Ruimtevaart Netherlands Agency for Aerospace Programs
NRT	Near-Real time
NWP	Numerical Weather Prediction
ODUS	Ozone Dynamics Ultraviolet Spectrometer
OL	Off-line
OLP	Off-line Processor
OSIRIS	Odin Spectrometer Infrared Imaging System
PAC	Processing and Archiving Centre
PAF	Processing and Archiving Facility

PI	Principal Investigator
PMD	Polarisation Measurement Device
POLDER	Polarisation and Directionality of the Earth's Reflectance
PTU	Pressure, Temperature, Humidity
RA-2	Advanced Radar Altimeter
RAL	Rutherford Appleton Laboratory
RIS	Retro-reflector In Space
RTM	Radiation Transfer Models
SAFIRE-A	Spectroscopy of Atmospheric Far Infra Red Emissions - Airborne
SAGE	Stratospheric Aerosol and Gas Experiment
SAO	Smithsonian Astrophysical Observatory
SAOZ	Système d'Analyse par Observations Zénithales
SBUV	Solar Backscatter UltraViolet Instrument
SCARAB	Scanner for Radiation Budget
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Chartography
SCIAVALIG	SCIAMACHY Validation and Interpretation Group
SCUVS	Stratospheric Climatology from UV/VIS Spectrography
SDAG	SCIAMACHY data and algorithm group
SESAME	Second European Stratospheric Arctic and Mid-latitude Experiment
SEVIRI	Spinning Enhanced Visible and Infra-Red Imager
SIRD	SCIAMACHY Instruments Requirements Document
SMR	Sub Millimeter Receiver
SODA	Studies of Ozone Distributions based on Assimilated satellite measurements
SOHO	Solar and Heliospheric Observatory
SOLSPEC	Solar Spectrum Instrument (from 180 to 3,200 Nanometers)
SOLSTICE	Solar/Stellar Irradiance Comparison Experiment
SOST	SCIAMACHY Operations Support Team
SPARC	Stratospheric Processes and their Role in Climate
SRDDA	Scientific Requirements Document for SCIAMACHY Data and Algorithm Development
SRON	Space Research Organization Netherlands
SSAG	SCIAMACHY scientific advisory group
SWIR	Short Wave Infra-red
TDL	Tunable Diode Laser
TES	Tropospheric Emission Spectrometer
THESEO	Third European Stratospheric Experiment on Ozone
TIR	Thermal Infra-red
TIROS	Television and InfraRed Observation Satellite
TOMS	Total Ozone Mapping Spectrometer
TOR	Tropospheric Ozone Research network
TOVS	TIROS Operational Vertical Sounder
UARS	Upper Atmosphere Research Satellite
UV	Ultra-Violet
VIRGO	Variability of Solar Irradiance and Gravity Oscillations
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation
WOUDC	World Ozone and Ultraviolet Data Centre