Assessment by DLR of the GCOS Climate Monitoring Principles for SCIAMACHY

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The SCIAMACHY mission had been designed both to improve our knowledge in atmospheric composition and global atmospheric change. These objectives also serve the needs of climate monitoring. Although GCOS principles have not been specifically addressed in SCIAMACHY mission requirements as the SCIAMACHY mission was initiated and implemented before GCOS Climate Monitoring Principles were specified, SCIAMACHY is considered to contribute significantly to climate monitoring.
The operational requirements of SCIAMACHY, together with its hosting ENVISAT platform, such as robustness, timeliness, high revisit frequency, data quality and reliability makes the system more than adequate for climate monitoring. In view of this, it is of interest to explore to which extent the SCIAMACHY mission complies with the GCOS recommendations.
It is shown below that ESA's usual approach for EO missions' development and operation in general and the specific SCIAMACHY requirements in particular are to a large extent compatible with the GCOS climate monitoring principles.

Effective monitoring systems for climate should adhere to the following principles[1]:

1. The impact of new systems or changes to existing systems should be assessed prior to implementation.

When SCIAMACHY had been designed the scientific objectives of SCIAMACHY had a strong relation to climate monitoring and global change, as it was planned to add continuous measurements of important climate parameters like CO_2, CH_4, H_2O, O_3, extraterrestrial solar irradiance etc. SCIAMACHY allows the observation from space of many of these parameter for the first time, having thereby a large impact for climate monitoring. By being compliant with ESA's ENVISAT mission it was ensured that SCIAMACHY fulfils the general rules for mission implementation. The currently discussed mission extension beyond 2010 adheres to the same principles.

2. A suitable period of overlap for new and old observing systems is required.

In the general framework of the ENVISAT mission extension SCIAMACHY operations and data processing requirements undergo a detailed investigation aiming at extending the mission for as long as possible with the goal to overlap with any forthcoming atmospheric Sentinel mission. In addition, SCIAMACHYs nadir UV-VIS observations are bridging the data gap between GOME/ERS-2 and GOME-2/METOP thereby allowing to have a more then 25 years data record of important climate parameters like O_3, H_20 and solar extraterrestrial irradiance.

3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e., metadata) should be documented and treated with the same care as the data themselves.

By being an integral part of the ENVISAT mission it is ensured that SCIAMACHY is in line with this requirement and consistent with operational and maintenance procedures as well as configuration control policies currently applied to ESA EO missions regarding mission operations, cataloguing and

[1] The ten basic principles (in paraphrased form) were adopted by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999. This complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by the Committee on Earth Observation Satellites (CEOS) at its 17th Plenary in November 2003; and adopted by COP through decision 11/CP.9 at COP-9 in December 2003.

metadata, data products information contents, algorithms and processor maintenance/evolution, re-processing activities, etc. Auxiliary data enhance processing and utilisation of remote sensing payload data that are not captured by the same data collection process as the instrument data. This may include calibration data measured on-board, external calibration files from sources other than the satellite, processor configuration files, and any other files needed by the instrument processors such as orbit state vectors, time correlation files, operational meteorological data (e.g. coming from ECMWF), etc. Auxiliary data files can be classified as mandatory or non-mandatory to a specific ground processing level. All auxiliary data are documented and accessible, some auxiliary data sets are included in the data products themselves and accessible through the catalogues.
Due to SCIAMACHY's AO status both DLR and NIVR provide mission lifetime long support in these areas. Particularly strong emphasis is put on instrument operations and calibration & monitoring issues. This permits detailed documentation of the SCIAMACHY status throughout the mission.

4. **The quality and homogeneity of data should be regularly assessed as a part of routine operations.**

   Since operational SCIAMACHY data processing is embedded in ENVISAT's Payload Data Segment it is in line with this requirement and consistent with ESA's EO data quality procedures.
   Quality Control (QC) activities are carried out operationally on a routine basis both off-line or fully integrated in the processing centres. These activities are run either in automatic mode or by operators.
   Due to SCIAMACHY's AO status additional data products are provided by scientific facilities. Although the strict ESA data quality requirements do not apply, these products are also developed compliant with usual data processing rules. Specific expert groups, initiated and maintained by DLR and NIVR have set up means to review the quality status of scientific products on a regular basis. The data sets are continuously validated.

5. **Consideration of the needs for environmental and climate-monitoring products and assessments, such as IPCC assessments, should be integrated into national, regional and global observing priorities.**

   SCIAMACHY's atmospheric geophysical parameters portfolio (level 2) is driven by the requirements of monitoring of global atmospheric change with special emphasis on anthropogenic impacts. Particularly the amount of tropospheric greenhouse gases shall be retrieved enabling to better understand global warming and climate change. Thus a sound basis exists for the generation of environmental and climate monitoring products , for example via data assimilation.
   In this respect the scientific products mentioned under 4) are of prime importance since they enhance SCIAMACHY's output significantly. Whenever new geophysical parameters are considered relevant for climate monitoring their retrieval can be reliably demonstrated in scientific products and further transferred to the operational environment.

6. **Operation of historically-uninterrupted stations and observing systems should be maintained.**

   SCIAMACHY data are preserved and accessed via the ENVISAT Payload Data Segment. Thus it is ensured that long-term storage follows ESA's EO requirements.

7. **High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution.**

   SCIAMACHY is a global mission executing measurements continuously along the orbit. Global coverage is defined by the parameters of the ENVISAT orbit and the swath setting of the instrument. With a wide swath global coverage is achieved within 6 days at the equator, covering also many regions where no ground based data are available at all. The operations concept has been optimized to

allow alternating nadir/limb observations on the illuminated part of the orbit such that the same volume of the Earth's atmosphere is observed in both configurations facilitating the retrieval of tropospheric information. Even on the night side atmospheric measurements of the mesosphere are regularly executed.
A formal change request process ensures that operations modifications can be implemented without endangering the continuity of measurements. This permits to react quickly to new scientific requirements.
SCIAMACHY retrieves the following poorly observed GCOS relevant parameters: CO_2, CH_4, H_2O, O_3, extraterrestrial solar irradiance, Earth spectral radiance TOA UV-VIS-SWIR. In addition regions sensitive to change, e.g. polar regions, tropical rain forest, industrial growing areas like east Asia, are regularly monitored by SCIAMACHY.

8. **Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation.**

   These requirements have been considered in the design of the SCIAMACHY mission. Operation requirements undergo review and modifications, whenever appropriate.

9. **The conversion of research observing systems to long-term operations in a carefully planned manner should be promoted.**

   SCIAMACHY is a research-type mission. The experience gained serves as input to studies and requirement definitions of future operational atmospheric missions like GOME-2/MetOp, GMES Sentinel 4 and Sentinel 5 and future greenhouse gas mission.

10. **Data management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.**

    Since SCIAMACHY is part of the ENVISAT mission, access, use and interpretation of the data by climate monitoring systems is ensured. This includes provision of a consistent long-term archive of the mission products, supported by multi-mission catalogues.

Furthermore, operators of satellite systems for monitoring climate need to:
(a) Take steps to make radiance calibration, calibration-monitoring and satellite-to-satellite cross-calibration of the full operational constellation a part of the operational satellite system; and
(b) Take steps to sample the Earth system in such a way that climate-relevant (diurnal, seasonal, and long-term interannual) changes can be resolved.
Thus satellite systems for climate monitoring should adhere to the following specific principles:

11. **Constant sampling within the diurnal cycle (minimizing the effects of orbital decay and orbit drift) should be maintained**

    The ENVISAT orbit is sun-synchronous, thereby ensuring constant local time of observations at the equator. SCIAMACHY's requirements on ground track stability are not so strict since the spatial resolution is in the order of a few ten kilometres (depending on the selected integration times). As one spin-off of the SCIAMACHY mission, a geostationary SCIAMACHY-type mission (GeoSCIA) concept was proposed and promoted to space agencies by the SCIAMACHY team and is currently under consideration as a component of MTG/Sentinel 4.

12. Overlapping observations should be ensured for a period sufficient to determine inter-satellite biases

SCIAMACHY on ENVISAT provides data continuity between GOME-1 on ERS-2 and GOME-2 on MetOp. This is particularly true since GOME-1 and -2 are descoped variants of the SCIAMACHY design. The similar orbits for ENVISAT, ERS-2 and MetOp facilitate intercomparisons between the three instruments even further. Additionally, SCIAMACHY supporting facilities and institutes are also involved in the GOME missions. Thus it is ensured that the experience gained in all three missions is used efficiently.

13. Continuity of satellite measurements (i.e. elimination of gaps in the long-term record) through appropriate launch and orbital strategies should be ensured

SCIAMACHY was defined as one major contributor to the sequence of European atmospheric chemistry missions. In the course of the current discussions for a mission extension beyond 2010 detailed studies are performed to adapt the operations concept to modified ENVISAT requirements, particularly what concerns orbit properties. This shall ensure smooth and continuous instrument operations for more than a decade.

14. Rigorous pre-launch instrument characterization and calibration, including radiance confirmation against an international radiance scale provided by a national metrology institute, should be ensured

SCIAMACHY underwent a thorough on-ground characterization and calibration programme, including a radiance calibration traceable to a NIST standard. In-flight calibration & characterization was verified during the commissioning phase.

15. On-board calibration adequate for climate system observations should be ensured and associated instrument characteristics monitored

With the start of the routine operations phase regular calibration activities occur in order to provide the information necessary for data processing. Additionally, continuous monitoring of the instrument ensures appropriate accounting of degradation effects. Both in-flight calibration and monitoring are part of the operations concept throughout the mission lifetime.

16. Operational production of priority climate products should be sustained and peer reviewed new products should be introduced as appropriate

All SCIAMACHY products up to level 2 are based on user requirements. New products are being developed in close cooperation with the different users. For details see response to items 4 and 5.
Higher level products are the result of activities and programmes where new applications and corresponding products are being developed.

17. Data systems needed to facilitate user access to climate products, metadata and raw data, including key data for delayed-mode analysis, should be established and maintained

The operational SCIAMACHY products use the capabilities provided within the framework of the ENVISAT Payload Data Segment. The interface accesses an extensive data archive, from which all data is available to users. Availability is ensured for a long time after the end of a mission. Additionally toolboxes are available for users. Depending on progress made in level 1b and level 2 algorithm development, reprocessing has to occur. This includes all measurement data obtained in standard measurement configurations, i.e. reprocessing generates complete sets of improved data products.
See also response to items 4 and 5.

18. Use of functioning baseline instruments that meet the calibration and stability requirements stated above should be maintained for as long as possible, even when these exist on de-commissioned satellites

SCIAMACHY mission extension follows the guidelines set by ENVISAT's mission extension. The relation between required modifications on platform, e.g. orbit, and SCIAMACHY level are studied in detail as well as the resulting impact on the scientific objectives of the mission. Together with the findings for the other instruments onboard ENVISAT a common approach to the mission extension is elaborated and finally implemented. SCIAMACHY maintains expert teams to reconfigure the instrument, its operations and data processing algorithms according to the needs of the mission extension.

19. Complementary in-situ baseline observations for satellite measurements should be maintained through appropriate activities and cooperation

SCIAMACHY providing agencies together with ESA maintained an extensive geophysical validation programme including air-borne, balloon-borne, ship-borne, ground based & space spaced measurements. The data is appropriately archived and maintained. In addition external atmospheric chemistry remote sensing projects contribute to validating SCIAMACHY products. Whenever such activities are planned, SCIAMACHY operations can be modified to optimize the spatial and temporal coincidence of the corresponding measurements.

20. Random errors and time-dependent biases in satellite observations and derived products should be identified

Error analysis is a pre-requisite for providing high quality SCIAMACHY data products. Both for operational and scientific data products the analysis is based on existing calibration, monitoring and validation results. In addition instrument and platform status information contribute to verify data quality.
Due to SCIAMACHY's AO status DLR and NIVR maintained functionalities, e.g. SCIAMACHY Operations Support together with the Quality Working Group, closely interact with the ENVISAT ground segment to continuously improve data quality. These activities are required not only until the end of the in-orbit mission lifetime, including all foreseen mission extensions, but usually still occur beyond this milestone.

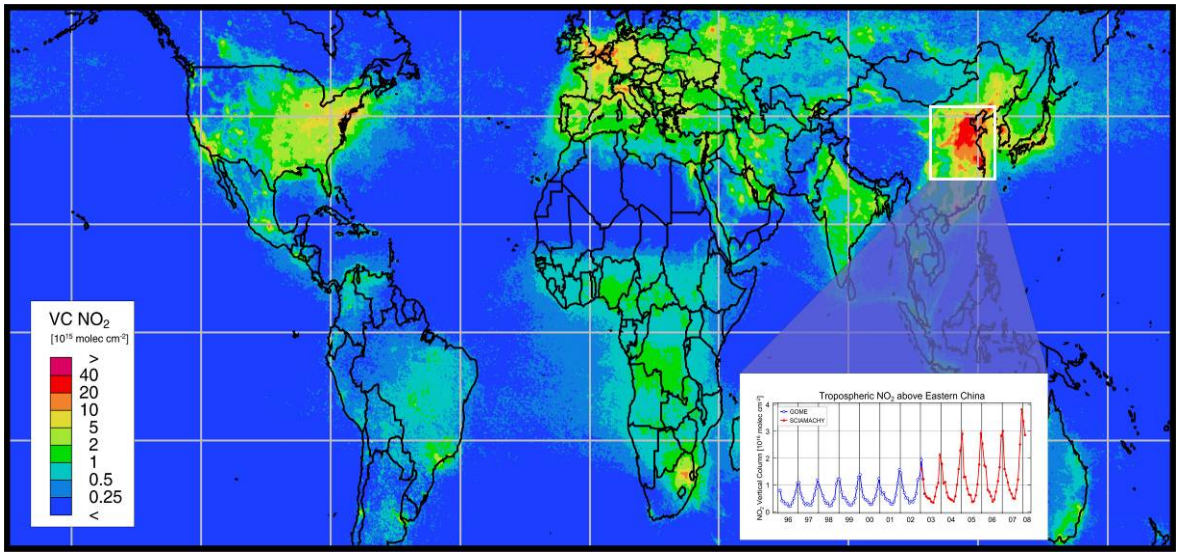
Conclusion

The SCIAMACHY mission is compliant with all the GCOS Climate Monitoring Principles. Its share of responsibilities between DLR/NIVR/BIRA and ESA together with the integration into the ENVISAT payload complement ensures that the SCIAMACHY mission is operated and maintained along ESA's EO guidelines.

SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography)

The SCIAMACHY instrument is a German/Dutch/Belgian contribution to the ESA ENVISAT mission. SCIAMACHY has been launched on ENVISAT with an Ariane-5 at 1st March 2002. Since the successful finalization of the Commissioning Phase in December 2002 SCIAMACHY has been operated nominally. All mechanisms of SCIAMACHY are still working perfectly.

Measuring several trace gases SCIAMACHY helps to improve our knowledge about the green house gases, the stratospheric ozone chemistry, the global impact of tropospheric pollution, the exchange between the stratosphere and the troposphere and the natural modulations of atmospheric composition.



Pollution export (here: nitrogen dioxide): West European and North American efforts on environmental protection are more than outweighed by the deterioration over Eastern Asia

More detailed information (including scientific and application results) can be found under:

http://www.sciamachy.de/#english
http://www-iup.physik.uni-bremen.de/sciamachy/index.html
http://envisat.esa.int/instruments/sciamachy/
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