2. ENVISAT – SCIAMACHY's Host

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Abstract: ENVISAT is Europe's ambitious Earth Observation enterprise to study the many facets of the Earth system. It carries 10 remote sensing instruments with SCIAMACHY, MIPAS and GOMOS forming the atmospheric chemistry mission. SCIAMACHY, although provided by national space agencies to ESA, is an integral part of the payload. Orbit and attitude of ENVISAT determine the framework of SCIAMACHY's observing capabilities. As a polar, sun-synchronous satellite, ENVISAT provides a stable platform for orbiting the Earth every 100 min. All instruments share the available on-board resources, particularly on-board data handling capabilities. The ENVISAT ground segment consists of the Flight Operation Segment for platform and instrument control and of the Payload Data Segment for measurement data acquisition, processing, archiving and dissemination. The SCIAMACHY data processing occurs at the LRAC and the D-PAC, depending on whether the data is of type level 0, 1b or 2. Access to SCIAMACHY data follows the general ENVISAT data policy with the exception that the instrument providing agencies receive a separate copy of such data.

Keywords: ENVISAT – Orbit – Flight Operation Segment – Payload Data Segment – Product levels

The decision to place SCIAMACHY onto the ENVISAT platform (Fig. 2-1 and 2-2) made it part of ESA's most ambitious Earth observation mission. Being a 'derivative' of the Columbus programme, ENVISAT is composed of the Polar Platform and the payload complement consisting of 10 instruments (ESA 1998, ESA 2001a). With an overall length in orbit of more than 25 m, it is the largest satellite ever built by ESA (Table 2-1). The instrument complement was selected to permit studies of many aspects of the complex Earth system (Table 2-2). This system is considered to be driven by interactions of its main 'spheres', i.e. lithosphere/geosphere, hydrosphere, atmosphere, cryosphere and biosphere. The goal of the mission is to obtain insights into local and global processes of our environment. With a current in-orbit mission lifetime of 8 years, ENVISAT generates a large data repository for long-term analyses in Earth sciences. Seven instruments of the payload complement have the status of an ESA developed instrument (EDI). SCIAMACHY, AATSR and DORIS are Announcement of Opportunity Instruments (AOI). They were provided by national agencies, developed under their responsibilities. Each AOI is an integral part of the payload following the same guidelines as the EDI. However, tasks in instrument operation and data processing are shared between ESA and the AOI providers. Overall the ENVISAT instruments utilise various remote sensing methods. Active microwave sensors (ASAR, RA-2) are supplemented by passive microwave (MWR, DORIS) and optical (AATSR, MERIS, MIPAS, GOMOS, SCIAMACHY, LRR) sensors.

Together with MIPAS (ESA 2000) and GOMOS (ESA 2001b), SCIAMACHY forms ENVISAT's atmospheric mission. The three atmospheric instruments operate in different wavelength ranges using different measurement principles. They complement each other such that synergistic views are generally possible. While SCIAMACHY as an absorption spectrometer in the UV-SWIR range is requiring sunlight, MIPAS – operating in the thermal infrared – can measure over the complete orbit. This is also the case for GOMOS, where the UV-VIS component of stars in occultation is used to probe the atmosphere. SCIAMACHY is viewing in flight direction (limb mode) and towards the sub-satellite point (nadir mode). MIPAS looks along-track into anti-flight and across-track into

anti-sun direction. GOMOS can steer its line-of-sight (LoS) towards stars which set between anti-flight and across-track anti-sun direction (Fig. 2-3). Additionally, the optical imaging instruments MERIS and AATSR (Advanced Along Track Scanning Radiometer) deliver data for scientific applications in the fields of clouds, aerosols and water vapour. Their nadir views overlap with SCIAMACHY's nadir geometry, thus permitting synergistic analyses.

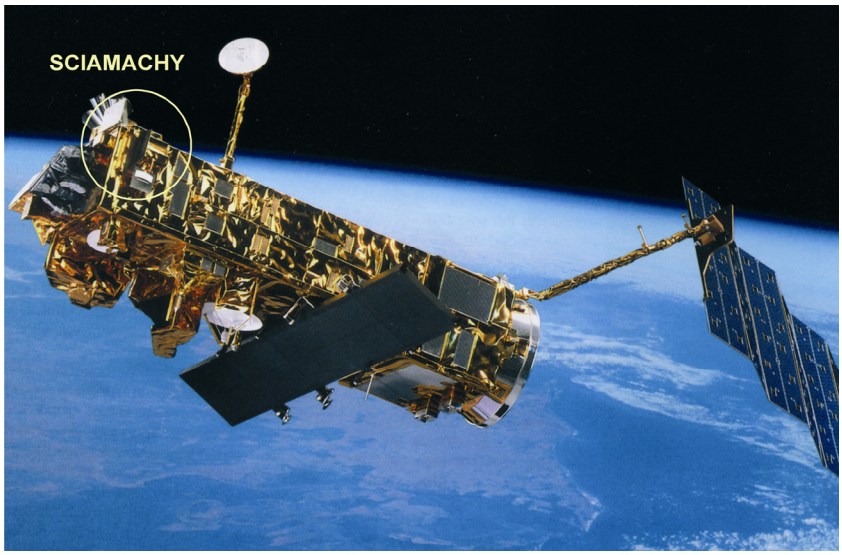

Fig. 2-1: Artist's impression of ENVISAT in orbit. SCIAMACHY is located at the upper right corner of the payload front panel. (Photo: ESA)

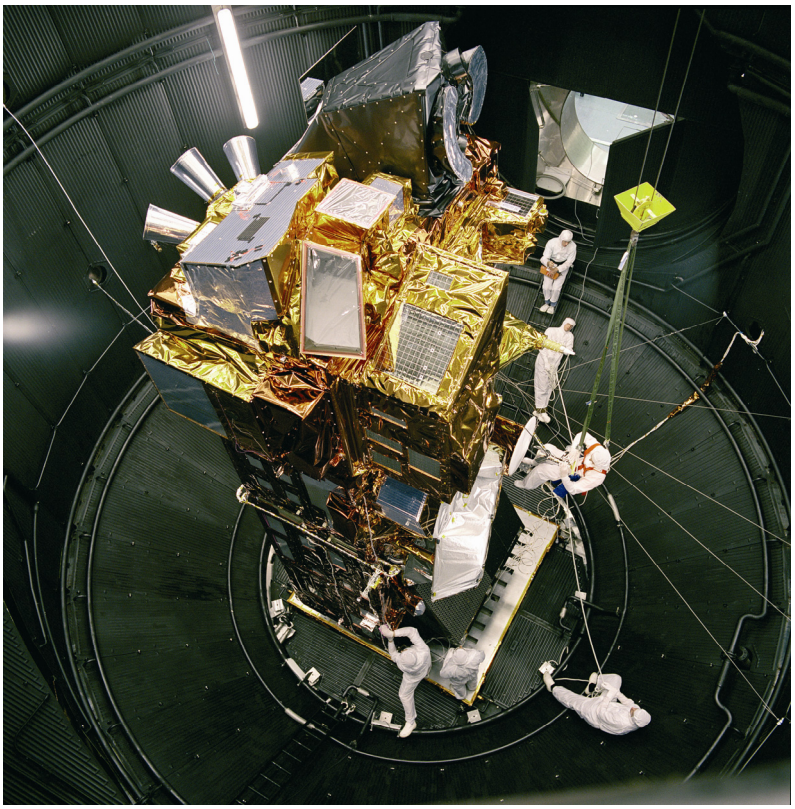

Fig. 2-2: ENVISAT in ESTEC's test facility. (Photo: ESA)

ENVISAT Parameters	
Dimensions	26 m × 10 m × 5 m
Total Mass	8140 kg
Payload Mass	2050 kg
Launcher	Ariane-5
Launch	1 March 2002

Table 2-1: ENVISAT characteristics.

Instrument	Lithosphere	Hydrosphere	Atmosphere	Cryosphere	Biosphere
ASAR	×	×		×	×
RA-2	×	×		×	
MWR			×		
DORIS	×				
MERIS	×	×	×	×	×
AATSR	×	×	×	×	×
GOMOS			×		
MIPAS			×		
SCIAMACHY		×	×	×	×
LRR	×	×		×	

Table 2-2: The ENVISAT payload complement and applicable components in the Earth system.

Orbital Parameters	
Semi-major axis	7159.50 ± 0.07 km
Inclination	98.55° ± 0.01°
Eccentricity	0.001165 (-0.001165/+0.005)
Argument of perigee	90.0° ± 3°
Mean altitude	799.8 km
Orbital period	100.6 min
Type	Polar, sun-synchronous
Mean local time at DNX	10:00 a.m. ± 5 min
Orbits per day	14 11/35
Repeat cycle	35 days (501 orbits)

Table 2-3: Nominal ENVISAT orbit.

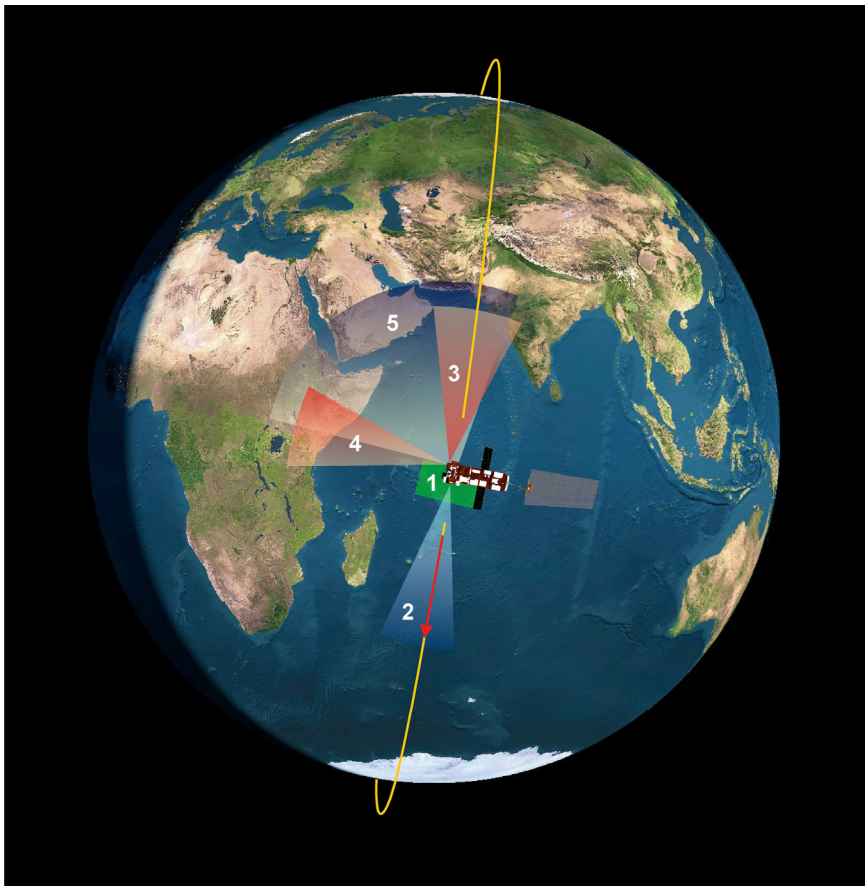

Fig. 2-3: The total field of views of the atmospheric mission instruments. SCIAMACHY viewing comprises nadir (1) and limb in flight direction (2). MIPAS looks into anti-flight direction (3) and sideways (4) for special events monitoring. GOMOS can observe setting stars in anti-flight and sideways direction (5). (Courtesy: DLR-IMF)

2.1 ENVISAT Attitude and Orbit

Attitude and orbit of the ENVISAT platform are contributing to the status of the SCIAMACHY line-of-sight. Both are controlled by the Attitude and Orbit Control System (AOCS). It provides attitude determination and attitude and orbit control capabilities (Bargellini et al. 2006). Attitude measurements are performed via gyroscopes, Earth sensors, Sun sensors and star sensors while the control function uses reaction wheels/magnetorquers and hydrazine thrusters. The platform is three-axis stabilised with ENVISAT's local relative orbital reference coordinate frame forming an orthogonal right-hand system with the -Y (roll) axis pointing close to the velocity vector of the platform and the Z (yaw) axis pointing in the direction of the outward local normal of the Earth's reference ellipsoid (Fig. 2-4). For the specification of target directions, azimuth and elevation angles are defined. Azimuth is measured clockwise from the -Y axis around the -Z axis to the projection of the target LoS in the plane perpendicular to the orbital plane containing the velocity vector. Elevation is the angle between that projection and the target LoS (Milligan et al. 2007).

The attitude mode of ENVISAT for nominal operations that offers the best pointing performance is the *stellar yaw steering mode* (SYSM). In this mode, the position of a star from the uplinked star catalogue as measured by two star trackers is compared with the predicted position to derive prediction updates. Yaw steering is required by the microwave imaging instruments in order to compensate for the rotational velocity of the Earth's surface at the sub-satellite point. It is achieved via small rotations about the roll, pitch and yaw axis, with the transformation around yaw being by far the

dominant component. The maximum yaw amplitude of ±3.92° occurs when ENVISAT passes the equator at ascending or descending node, the minimum amplitude of 0° is reached close to the poles. In total, yaw steering imposes a sinusoidal 'wobble' of the platform around the flight direction. In the illuminated part of the orbit, the platform is turned to the right side of the flight direction, in the eclipse part to the left. For measurements with long line-of-sight requiring high spatial resolution, as is the case for SCIAMACHY operating in limb mode, the quality of the scientific results, e.g. altitude profiles, is strongly dependent on the precision of the platform attitude. Even small perturbations in the order of a few 10^{-3} deg can significantly impact the measured altitudes in limb profiles.
The orbit of the hosting platform was selected to be similar to its precursors, ERS-1 and ERS-2. Thus, ENVISAT was placed in a polar, sun-synchronous orbit with a morning descending node crossing (DNX) time. Sun-synchronicity yields identical illumination conditions whenever crossing the equator. The selected Mean Local Solar Time (MLST) at DNX of 10 a.m. means that the Sun is always positioned left of the spacecraft, relative to the orbital plane. Detailed orbit parameters are given in Table 2-3. Since SCIAMACHY is located at the upper right corner on the payload module front panel, the Sun can only be seen when pointing the instrument's line-of-sight to the left.

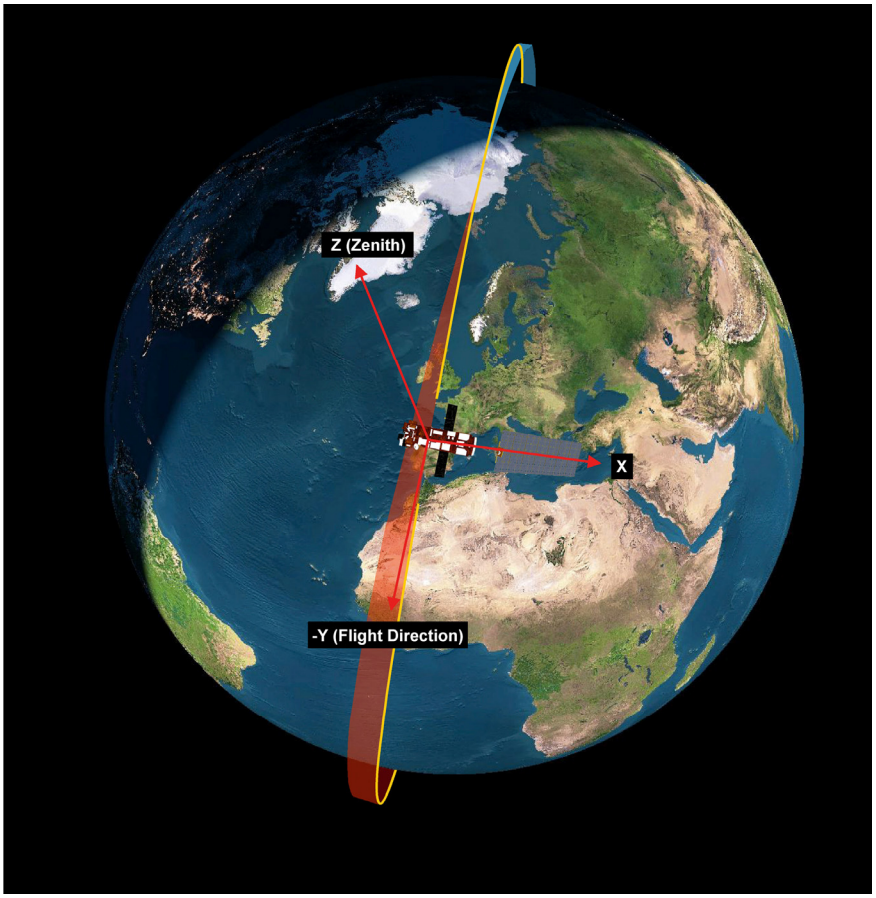

Fig. 2-4: The coordinate system specified in the ENVISAT mission. Platform and instruments use the same definitions. The red/blue areas right and left of the orbit sketch the platform yaw steering range. It gradually increases from pole to equator and decreases from equator to pole. The local -Y axis always points to that side, where Earth rotation moves the surface towards the sub-satellite track. (Courtesy: DLR-IMF)

ENVISAT operations have to ensure that the actual ground track does not deviate by more than ±1 km from the reference orbit. However, orbit perturbations slightly modify the specified reference orbit with time. Once the 1 km deadband is going to be violated, an orbit control manoeuvre has to adjust the actual orbit. These manoeuvres can either correct for the effect of air drag on altitude (*In-Plane*,

Stellar Fine Control Manoeuvre – SFCM) or adjust the inclination which drifts due to solar and lunar gravity perturbations (*Out-of-Plane*, Orbit Control Manoeuvre – OCM). Orbital manoeuvres are executed by short firings of the thrusters. Since each firing consumes hydrazine, the available on-board resource 'fuel' diminishes with time. The originally available 314 kg of fuel is reduced by several kg per OCM but only by less than 100 g per SFCM. In addition, non-nominal manoeuvres, such as e.g. space debris collision avoidance manoeuvres or manoeuvres triggered by platform anomalies, further reduce the available fuel. SCIAMACHY continues measurements during In-Plane manoeuvres. While executing an Out-of-Plane manoeuvre, SCIAMACHY measurements are interrupted but the thermal status of the Optical Bench Module (OBM) and the detectors remain unchanged.

2.2 ENVISAT On-board Resources

The total ENVISAT payload shares the same on-board resources. Thus, instruments may not interfere with each other. For SCIAMACHY, this is particularly important with respect to the allocated data rate (Fig. 2-5). The data rate depends on an instrument and its measurement mode. The Regional Mission of ASAR (Advanced Synthetic Aperture Radar) and MERIS produces data with high and medium rates aiming at acquiring information with high spatial resolution for specific areas. Providing maximum coverage of the Earth is the goal of the Global Mission. It generates data with a lower rate and is established by all other instruments together with ASAR and MERIS in their low rate modes. Global Mission instruments are operated continuously throughout the orbit. Measurement data from the Global Mission instruments are processed on-board via the High Speed Multiplexer (HSM). SCIAMACHY uses HSM resources together with MERIS in Reduced Resolution (RR) mode. As long as MERIS runs in RR mode, only the low rate data can be used by SCIAMACHY. This MERIS mode is operational for solar zenith angles < 80°. Although SCIAMACHY is able to generate data with a data rate of 1.8 Mbit/sec yielding measurements with high spatial resolution, for most parts of the orbit only the low rate of 400 kbit/sec can be achieved. Only when ENVISAT is close to sunrise during each orbit, the solar zenith angle condition is not fulfilled for MERIS and measurements with the higher rate are possible for SCIAMACHY when observing a solar occultation.

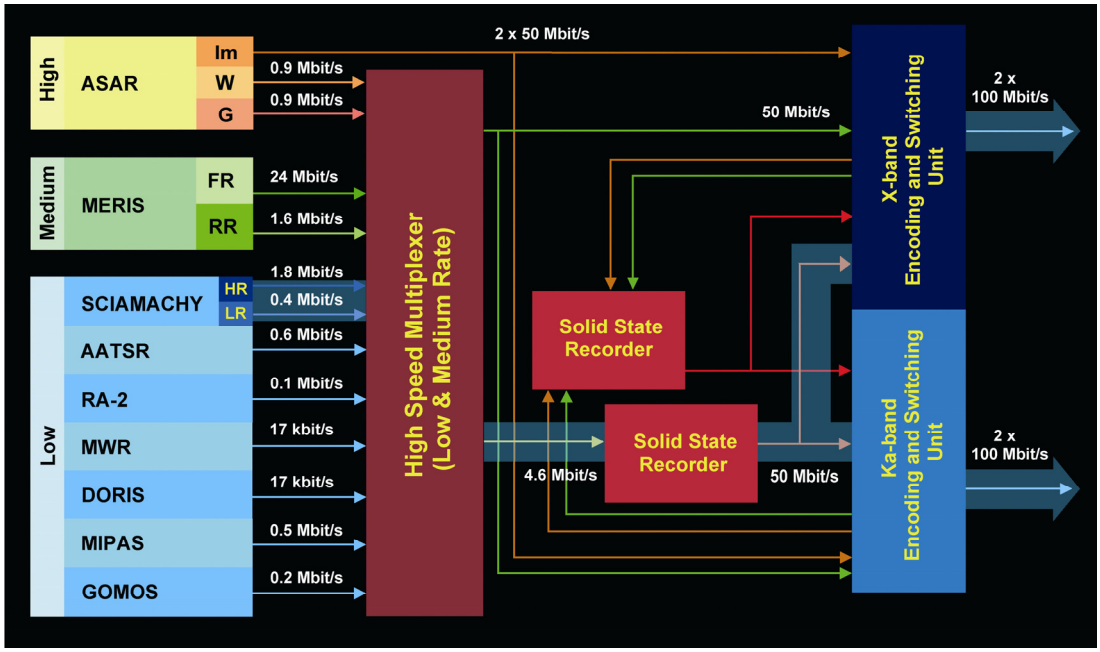

Fig. 2-5: Schematic view of the ENVISAT on-board data handling. SCIAMACHY shares HSM resources with the other instruments generating low rate data. Full orbit data of the Global Mission is stored on one of the solid state recorders and then disseminated to ground via X-band or Ka-band. (Courtesy: DLR-IMF)

ENVISAT measurement data can be transmitted to ground stations via the Artemis data relay satellite using the Ka-band. The antenna on the platform is located on the upper payload panel just above SCIAMACHY's sub-solar port, i.e. the instrument window allowing observations of the Sun when it has reached highest elevation each orbit. When the antenna dish is deployed in operating position, it vignettes SCIAMACHY's sub-solar window. Therefore, sub-solar measurements necessary to monitor the long-term behaviour of optical components can only be executed when the Ka-band antenna has been moved to its parking position. This is accomplished via the ENVISAT/SCIAMACHY mission planning process by applying strict planning rules.

2.3 ENVISAT Ground Segment

All information generated by the instruments, i.e. housekeeping (HK) telemetry reporting the instrument status and measurement data, is either downlinked directly via S-band or as part of the science data stream via the X-band or the Ka-band link. The X-band link transmits measurement data to the high latitude receiving ground station at Kiruna while the Ka-band link connects ENVISAT via the Artemis data relay satellite with the receiving station at ESRIN. In the early phase of the mission when Artemis was not operational, only Kiruna and an additional X-band station at Svalbard were used. In the nominal 'Kiruna-Artemis' scenario, Global Mission data are provided to Kiruna for 8 orbits per day, to ESRIN via Artemis for 6 orbits per day. HK telemetry is mainly sent via the command and control (C&C) S-band link of the Kiruna station and its supplementing Svalbard C&C facility. This telemetry stream is only available for the coverage interval of Kiruna or Svalbard visible orbits. Of the 14.3 orbits per day, 9-10 are orbits with Kiruna coverage intervals amounting up to 12 min (spacecraft elevation > 5°). In addition, low elevation coverage may also be used. Each coverage in a daily cycle occurs at a different time relative to ascending node crossing (ANX) depending on the actual location of the orbital track.

ENVISAT and its instruments are controlled via the Flight Operation Segment (FOS) and the Payload Data Segment (PDS) – see Fig. 2-6, Fig. 2-7 and Table 2-4. FOS handles all command and control issues including flight dynamics aspects. In addition, mission planning is performed in cooperation with the PDS. FOS comprises the ENVISAT Flight Operation Control Centre (FOCC) at ESOC and the S-band station at Kiruna. The PDS is the responsible entity for ENVISAT measurement data. It is a Europe-wide distributed ground segment.

Central control of the PDS occurs at the Payload Data Control Centre (PDCC) at ESRIN. The Payload Data Handling Stations in Kiruna (PDHS-K) and Frascati (PDHS-E) not only receive X-band or Ka-band data but also process and disseminate data in near-realtime (NRT). X-band data reception for the Regional Mission is complemented by the Payload Data Acquisition Station (PDAS) in Matera/Italy. For data products in offline (OL) mode processing, archiving and distribution is shared among several facilities. At the Low Rate Reference Archive Centre (LRAC), located at Kiruna, level 0 data are consolidated and archived. From these consolidated products, the Processing and Archiving Centres (PAC) generate, archive and disseminate consolidated level 1b and level 2 products. Also NRT products from the two PDHS are collected at the PAC and can be distributed, if required. Although implemented at national remote sensing facilities, PACs are an integral part of the PDS. They are controlled by the PDCC, which also drives product generation via order mechanisms. In order to maintain a certain product quality throughout the PDS, PDCC executes product quality monitoring.

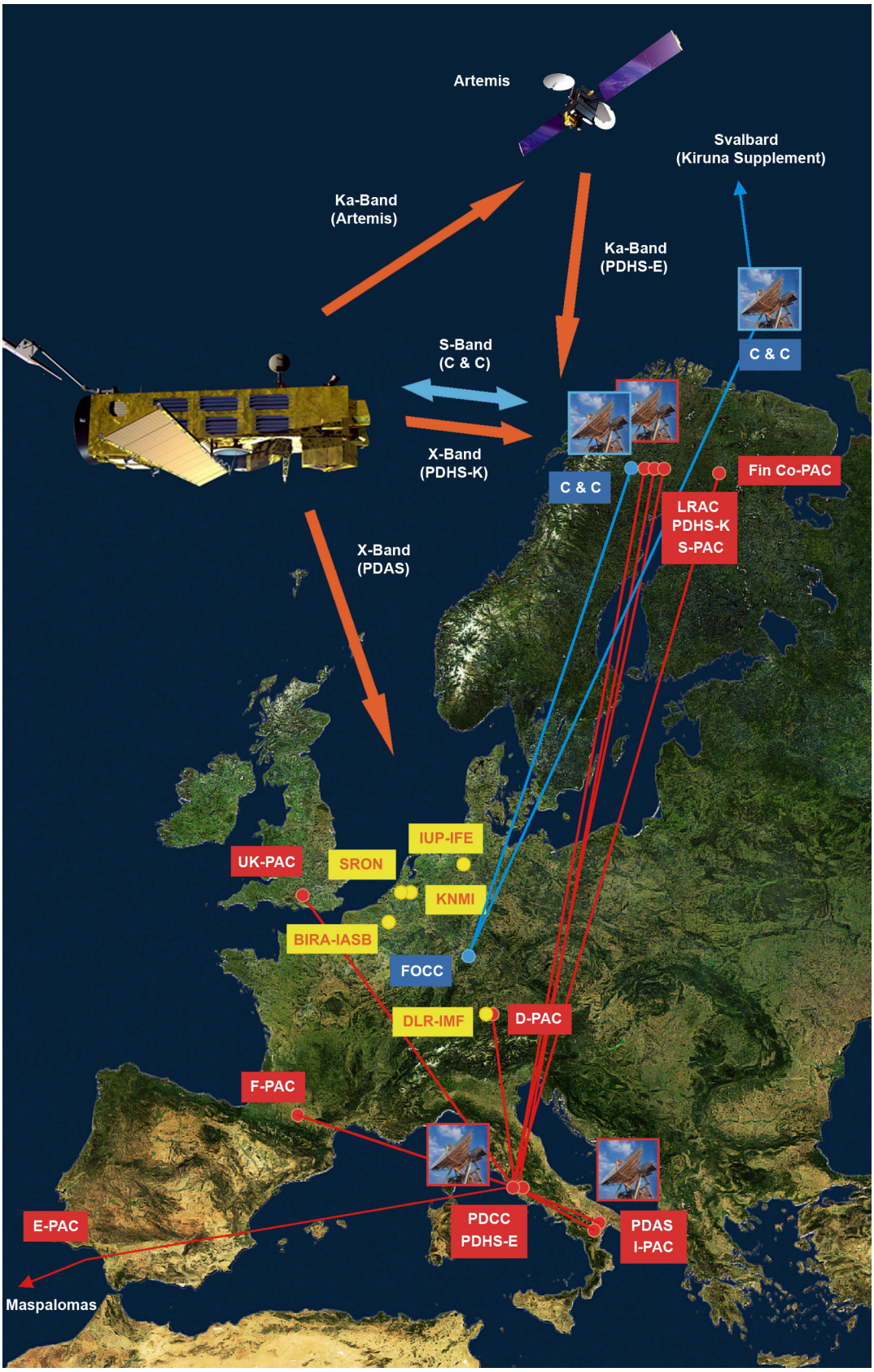

Fig. 2-6: The Europe-wide distributed ENVISAT ground segment (FOS: blue, PDS: red, national facilities serving the SCIAMACHY mission: yellow). (Courtesy: DLR-IMF; background map: ESA)

Fig. 2-7: The ESA centres hosting major ENVISAT ground segment facilities with ESOC/Darmstadt (top) and ESRIN/Frascati (middle). The bottom photograph shows ESA's S-band and X-band station at Kiruna-Salmijärvi. (Photos: ESA, S. Corvaja)

Ground Segment	Location	Facility
Flight Operations	Darmstadt (ESOC)	FOCC
	Kiruna-Salmijärvi (ESA)	C & C station
	Svalbard (KSAT)	C & C station
Payload Data	Frascati (ESRIN)	PDCC, PDHS-E
	Matera (ESA)	PDAS
	Kiruna-Salmijärvi (ESA)	PDHS-K, LRAC
	Oberpfaffenhofen (DLR)	D-PAC
	Sodankylä (FMI)	Fin Co-PAC
	Kiruna-Salmijärvi (SSC)	S-PAC
	Maspalomas (INTA)	E-PAC
	Toulouse (CNES)	F-PAC
	Matera (ASI)	I-PAC
	Farnborough (NRSC/Infoterra)	UK-PAC

Table 2-4: ENVISAT ESA ground segment facilities.

2.4 ENVISAT Data Products

The ENVISAT ground segment concept defines product levels which fall under the responsibility of the PDS. These are

- Raw data: Instrument raw data is generated from the X- and Ka-band demodulator output. It serves as input for the level 0 data.
- Level 0: Produced from the raw data, level 0 contains instrument source packets as received from the instrument with a small header attached by the Front-End Processor at the receiving stations.
- Level 1b: These are geolocated products in engineering or physical units. Level 1b products are generated by transforming the associated level 0 product via certain algorithms, calibration and auxiliary data.
- Level 2: This is the highest product level supported by the ENVISAT PDS. It represents the final geolocated geophysical product. The level 2 product is generated from the level 1b product by applying algorithms to convert calibrated engineering quantities into geophysical parameters.

Level 0 to level 2 products generated within the PDS are referred to as *operational products*. Products higher than level 2, often referred to as value-added (VA), are processed under the responsibility of ENVISAT data users. Their generation is not a PDS task. While VA products often provide regional or global coverage, level 0 to level 2 products are – with the exception of GOMOS – always orbit oriented. In addition to the operational level 2 products, users may generate scientific level 2 products according to their own requirements. They supplement the operational chain by either applying new retrieval algorithms or concentrating on trace gas species where operational retrieval algorithms still have to be developed.

Product levels 1b and 2 can be generated in NRT or OL mode. NRT products are processed and disseminated within a few hours from sensing. Because of stringent time requirements, level 2 NRT data may sometimes not cover the complete data set contained in the level 1b product. When distributed on media, NRT products show a larger time delay from sensing. NRT data are unconsolidated. Unconsolidated products are characterised by using NRT auxiliary information

available at time of product generation, e.g. not the most precise orbit state vectors or calibration data. Additionally, NRT products have start/stop times which are defined by data receiving coverage times. They do not cover complete orbits and may overlap.

Consolidated products benefit from *a posteriori* knowledge of information concerning calibration, auxiliary data and precise orbit. The start/stop times of consolidated products refer to ANX of the corresponding orbit, i.e. a consolidated product is usually generated from two unconsolidated products. Consolidated data show no overlaps. Time gaps are only present when the instrument was not recording data, either planned or unexpectedly due to an anomaly. A consolidated product is the best representation of the scheduled and executed measurements. In the case of SCIAMACHY, a consolidated product begins with the first measurement state (see chapter 4) starting just after ANX and ends when the last measurement state, which started just before the next ANX, has run to completion.

Product generation in the PDS uses auxiliary data. Auxiliary data may come from instrument calibration and monitoring measurements, the satellite platform itself or sources external to the PDS. For each product, product confidence data is attached providing the results of an evaluation of the overall quality of the product against predetermined thresholds. If a product does not meet the predefined quality level, a flag is set.

For each instrument, algorithm and processor development is controlled by a Quality Working Group (QWG). This QWG also takes care of those aspects of operational instrument performance monitoring which are related to product quality. Each QWG is composed of personnel from scientific and engineering facilities having proven expertise on the particular fields covered by the individual instruments. Additionally, ESA operational team members supplement the group. Due to the AOI status, the SCIAMACHY Quality Working Group (SQWG) was established later than the groups for the EDI payload by combining existing activities both on national agencies and ESA side. The SQWG work also benefits largely from the progressing algorithm evolution in the framework of science product generation.

2.5 Data Access

Details of SCIAMACHY product handling in the PDS are listed in Table 2-5. The status shown corresponds to end 2009. As the mission progressed, tasks had been shifted between centres and may still be changed in the future. Changes also apply for product dissemination when technical progress requires modifications for access mechanisms. The PAC serving the atmospheric mission on ENVISAT is the D-PAC, located at the German Remote Sensing Data Center (DFD) at the DLR premises in Oberpfaffenhofen/Germany. D-PAC interfaces with PDHS, LRAC and the FIN-CoPAC to receive products from SCIAMACHY, MIPAS and GOMOS for archiving, further processing and dissemination. Usually, NRT products are distributed from the PDHS using the dedicated Data Dissemination System (DDS), which is based on leased EUTELSAT transponder capacity. Besides the PDS internal satellite links, several SCIAMACHY specific DDS terminals had been set up in Germany and The Netherlands. The DDS system is designed to support data transfer of up to dedicated 7 Mbit/sec at user level. This is sufficient to receive the NRT level 0 and level 1b products generated each day from SCIAMACHY data. Developed initially only for Commissioning Phase requirements, the DDS has become a robust and stable data transfer mechanism. A specific fast delivery (FD) service has been set up for SCIAMACHY level 2 products at the D-PAC. It provides certain level 2 information within 24 hours from sensing.

Guidelines for data access are defined in the ENVISAT data policy. Data utilisation is classified as ‘Category 1’ (C1) and ‘Category 2’ (C2). Under C1, research and applications in support of the ENVISAT mission objectives including long-term studies of the Earth system are summarised. C2 users are all others not falling under C1, i.e. operational and commercial entities. Due to the scientific character of the atmospheric sensors on ENVISAT, access to SCIAMACHY, MIPAS and GOMOS data is always as for C1. Identification of C1 users was originally based on peer review processes, e.g. ESA announcements of opportunity for data exploitation or research and application development programmes of participating member states or European organisations. Since most of the SCIAMACHY products are now systematically available either on Internet or via DDS, both in near-realtime or offline, a simple registration through ESA’s EO Principle Investigator Portal

(http://eopi.esa.int/) is sufficient to register and get access to SCIAMACHY data as C1 user. The SCIAMACHY data are cost-free when available on Internet or via DDS, and provided at cost of reproduction when needed on media.

Level [a]	Dissemination Timescale	Source	Task [b]	Medium [c]
cL0[d]	OL	LRAC	G, A	
cL1b	OL	D-PAC	G, A, D	DVD, ftp
cL2	OL	D-PAC	G, A, D	ftp
L0[d]	NRT	PDHS	G, A, D	DDS
L1b	NRT	PDHS	G, D	DDS, ftp
L2	FD[e]	D-PAC	G, D	ftp
L2	NRT	D-PAC	A	

a) cL = consolidated Level
b) G = generation, A = archiving, D = dissemination
c) only the standard media are listed
d) only access for selected users
e) fast delivery service (24 hours from sensing)

Table 2-5: SCIAMACHY products in the PDS.

The status of SCIAMACHY as an AOI grants additional data rights. As stipulated in the Flight Operation and Data Plan (FODP), which identifies responsibilities both for ESA as ENVISAT mission provider and DLR/NIVR as SCIAMACHY instrument provider, SCIAMACHY data are delivered at no charge to the instrument providing national agencies.

General help on ENVISAT can be obtained via ESA's EO user service (http://earth.esa.int/services/). It provides information on EO mission documentation, EO data catalogues, software tools for reading and processing EO data and EO data product definitions and content. This website also links to the EO help desk at ESRIN which acts as the central facility for user services in the PDS. EO help is contacted via EOhelp@esa.int. A user may also wish to learn about the actual performance of ENVISAT and its instruments. This request is supported by ESA's dedicated ENVISAT website (http://envisat.esa.int/). Specific websites with detailed information on SCIAMACHY operations and performance, as well as science product status also exist on AO provider (AOP) side. (see chapters 4 and 8).

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