The Payload Data Segment

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The Envisat Payload Data Segment (PDS) provides the services needed for the exploitation of all of the instrument data. Its development has been the subject of a contract between ESA and Alcatel Space Industries as the Prime Contractor, supported by a consortium of thirteen companies. Twenty-three different facilities or subsystems have been developed and the result is a large distributed system with operational sites in seven European countries.

Introduction

The Envisat Ground Segment is composed of the Flight Operations Segment (FOS) and the Payload Data Segment (PDS). The main functions of the PDS are:

- aquisition of the low- and high-bit-rate instrument data via the X-band channel when in direct visibility of the Envisat satellite, or via the Artemis data-relay satellite's Ka-band channel
- processing (systematic or on-request) of the received data in near-real-time (within 3 hours after sensing) or off-line, up to Levels-0, 1 and 2
- short- or long-term archiving of the products generated
- dissemination of the products to scientific and commercial users
- provision of user services.

The mission users may consult the archives, request past or future Envisat products, and plan instrument observations for the ASAR and the MERIS full-resolution instruments.

The PDS operations are co-ordinated from the Payload Data Control Centre (PDCC) located at ESRIN, in Frascati (I). The Envisat products that it provides are always in the form of computer-readable files, classified according to a progressive level of processing:

- *Level-0*: reformatted, time-ordered satellite data (no overlap) in computer-compatible format
- *Level-1b*: geo-located engineering-calibrated product, either 'unconsolidated' (i.e. generated in near-real-time) or 'consolidated' (i.e. generated off-line)
- *Level-2*: geo-located geophysical product generated in near-real-time or off-line
- *Browse*: subset of Level-1b, for quick viewing and product-selection purposes.

In total, the the PDS delivers 77 different types of products. Processing algorithms have been developed by a number of Expert Support Laboratories (ESLs) and are implemented in the PDS as specific Instrument Processing Facilities.

PDS architecture

The PDS comprises the following Centres and Stations:

- The *Payload Data Control Centre (PDCC)* at ESRIN in Frascati (I) is responsible for the instrument and ground-segment planning and for the overall PDS monitoring and control. It also co-ordinates the user services and provides quality and engineering support for the products.
- The *Payload Data-Handling Stations (PDHS)* in Frascati (Ka-band) and in Kiruna, Sweden (X-band) acquire measurement data down-loaded from the spacecraft, process it and disseminate the products, according to PDCC directives. A short-term rolling archive is provided. Local services are also offered to users. A reduced PDHS will be installed at Svalbard, to provide back-up support for Level-0 data acquisition and processing, complementing the five daily Kiruna-blind orbits.
- The *Payload Data-Acquisition Station (PDAS)* in Fucino (I) acquires only measurement data

(in X-band) and forwards it to the PDHS station at ESRIN for processing.
- *The Low-rate Reference Archive Centre (LRAC)* in Kiruna archives and processes the global low-rate data off-line, to provide a complete consolidated low-rate Level-1b data set for the ESA Developed Instruments (EDIs) and ASAR-LR Instruments, and a pre-consolidated Level-1b product for other Announcement of Opportunity Instruments (AOIs). Local services are also offered to internal users.
- The *Processing and Archiving Centres (PACs)*, located in various ESA Member States, archive and process off-line high-rate data and generate off-line Level-2 products for regional high-rate or full-resolution instruments and global low-rate instruments. There are six PACs: UK-PAC, D-PAC, I-PAC, F-PAC, S-PAC and E-PAC. The Finnish Meteorological Institute (FMI) is associated with the D-PAC.
- The *National Stations (NS-Es)*, located in ESA Member States, acquire data and provide ESA services.

Figure 1 shows the locations of the various PDS Centres and Stations and lists the main functions of each of them (except the PACs, where only the instruments are listed).

PDS services

The PDS design is based on the development of a limited number of basic facilities implementing a single function, and the systematic re-use of those facilities as building blocks in the various centres at the various geographical locations. For example:
- all centres and stations offer user services based on the same User Service Facility (USF)
- low-bit-rate processing at the two PDHSs and the LRAC is performed using the same hardware platform and software
- ASAR processing at the two PDHSs and three PACs (UK-PC, D-PAC and I-PAC) is also performed using the same hardware platform and software.

The various PDS services, implemented using one or more facilities in combination, are

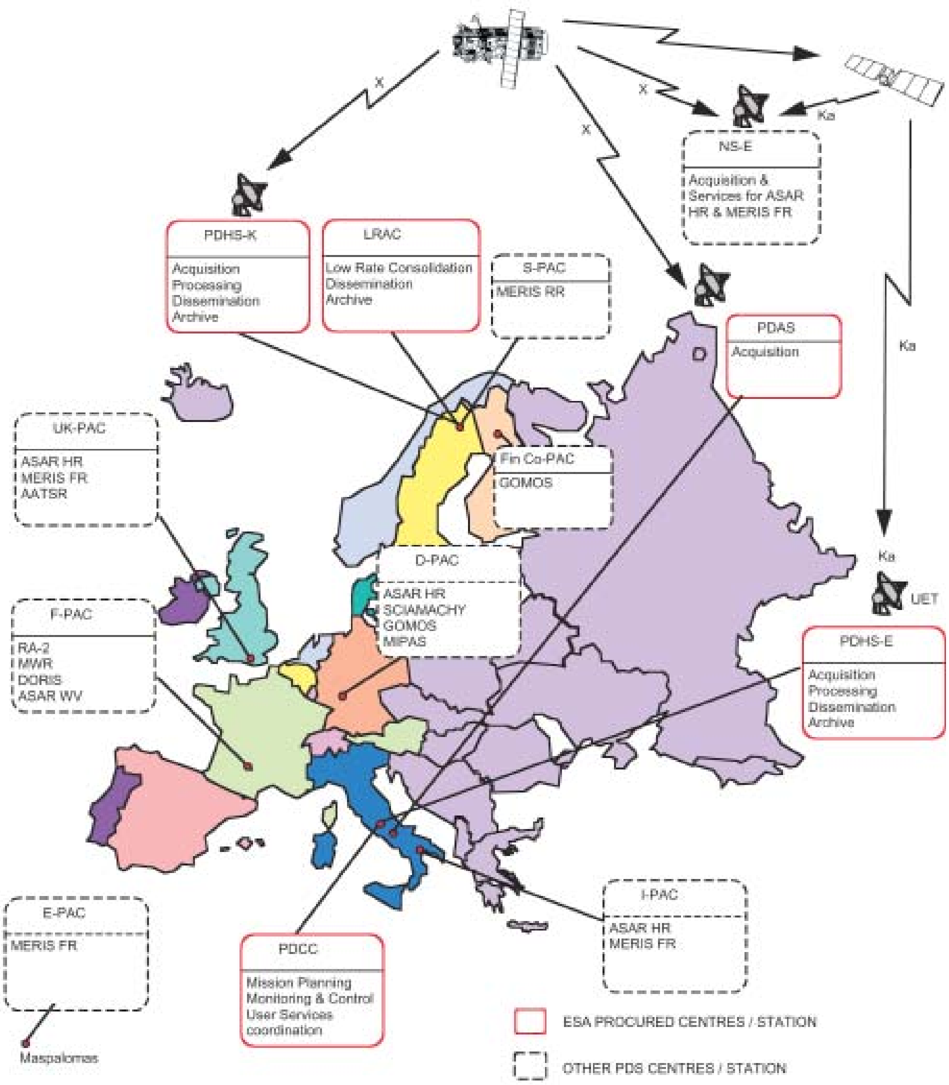


Figure 1. Locations and primary functions of the various Payload Data Segment (PDS) centres and stations

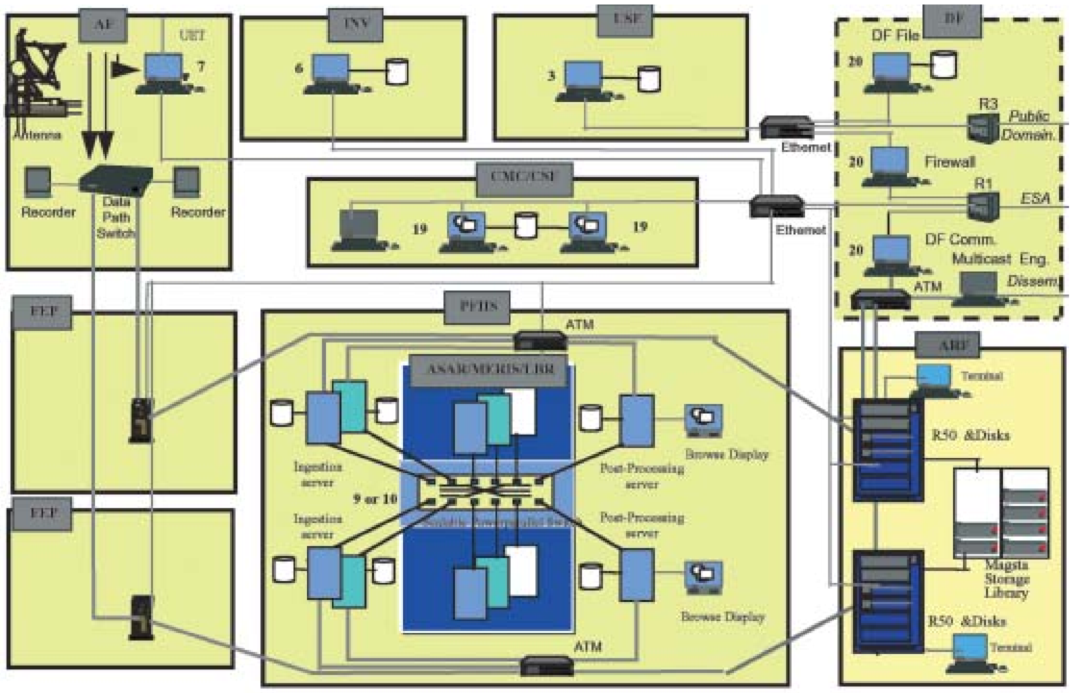


Figure 2. The PDHS architecture and facilities

acquisition, data processing, archiving, dissemination, user services, mission planning, monitoring and control, and ancillary services.

Acquisition

Envisat downlinks its instrument data via two simultaneous time-multiplexed 100 Mbps links, which carry both the real-time and on-board-recorded observational data. On-board solid-state recorders allow for low-rate and high-rate instrument recording, with up to 12.5 minutes of ASAR high-rate data or up to 40 minutes of MERIS full-resolution data.

Figure 3. The User Earth Terminal reception antenna at ESRIN, for Envisat data acquisition via Artemis

The Kiruna-Salmijarvi station includes a 15 m X/S-band receive/ transmit antenna, which has already been used for ERS-1 and ERS-2, and serves X-band payload acquisition and TT&C operations. The station is also equipped with a new 13 m X/S-band receive/transmit antenna, allowing increased flexibility and serving as a backup. The Frascati station includes a 12 m Ka-Band receive-only antenna, a so-called ‘User Earth Terminal’ (UET), to acquire Envisat data relayed via Artemis. Both stations are equipped with new multi-mission programmable demodulators, developed under the ESA ARTES-4 technology programme and specifically tailored for Envisat.

The nominal acquisition scenario with the Artemis Ka-band inter-orbital link available is based on the Kiruna (X-band) and Frascati (Ka-band UET) stations. If the Ka-band is temporarily unavailable, the back-up scenario is to use the Kiruna and Svalbard stations. At each station the data is received, demodulated, real-time de-multiplexed and ingested into the processing facilities for Level-0 product generation and archiving. As a backup measure, raw data is always recorded on high-rate digital recorders and can be replayed if necessary for backlog ingestion. In the nominal scenario, both stations will operate on an equal-share basis, covering complementary acquisition periods of twelve hours per day and seven passes each.

Data processing

The Front-End Processor delivers instrument source packets to the Processing Facility Host Structure (PFHS). The delivery is done in near-real time at half the acquisition rate, making it possible to ingest a complete pass well before the start of the next acquisition. The PFHS hosts the different Instrument Processor Facilities (IPFs). In particular, it manages all of the production activities, performs the generation of Level-0 products from the data received via the FEP, and distributes the higher-level production work between the different IPFs. Seven IPFs have been developed, one for each instrument: ASAR, MERIS, AATSR, GOMOS, RA-2/MWR, MIPAS, SCIAMACHY. These IPFs generate the Level-1b, Browse and Level-2 products. The PFHS may also retrieve Level-0 data from the archive for the high-level processing of previously acquired data.

The PFHS architecture is based on a simple robust and scalable concept: a number of autonomous computers (nodes) connected by a high-speed parallel switch (IBM-SP2 architecture). Four nodes are dedicated to data ingestion and Level-0 processing, and two are dedicated to data output and overall PFHS management. The remaining nodes each contain the software of all seven IPFs and can be dynamically activated to behave as any required instrument processor. This makes it possible to increase the processing capacity just by adding new nodes, and to optimise the resource usage so that it can be adapted easily to any mission-utilisation scenario, whilst still ensuring a minimal impact from any hardware failures.

The LRAC in Kiruna will ingest the data from low-rate instruments received at the PDHSs and consolidate them by regenerating orbit-based products.

Archiving

The PFHS output products are sent to the Archiving and Retrieval Facility (ARF), where they are permanently stored on tape (standard IBM-3590 10 GB magnetic tapes). Each ARF is equipped with a media-handling robot allowing unattended archiving and retrieval operations.

At the PDHSs, data is archived temporarily for a period of about four weeks, covering the time needed to transfer tape copies to the final archiving destinations at the PACs.

Dissemination

The PDS products (Level-0, 1 and 2) are made available to users either:

– in Near Real Time (NRI), 3 hours or 1 day after sensing
– off-line, several days or more after sensing.

Electronic data delivery is also available:

– via the Internet, through the web-based user services on-line archive for the smaller products (typically below 1 Mbyte), such as browses and a configurable set of high-level products
– via the Data Dissemination System based on Direct Video Broadcasting (DVB) technology, operated at 2.5 Mbps in broadcast- or multicast-mode for fast delivery (within three hours or one day of sensing), to users equipped with the corresponding receiving facilities.

Figure 4. The processing facilities at ESRIN

The physical-media service allows users to receive products on one of several media – CD-ROM, Exabyte, DAT, DLT, and 3590 – selectable at the time of ordering.

User Services

The Envisat PDS User Services provide a uniform access point for all Envisat users to access a wide range of services, mainly for the consultation of Envisat PDS archives, mission and product information, and the ordering of past or future products. In the latter case, the user can either select from already planned acquisitions, or request the specific planning of satellite observations for regional-mission instruments (ASAR and MERIS).

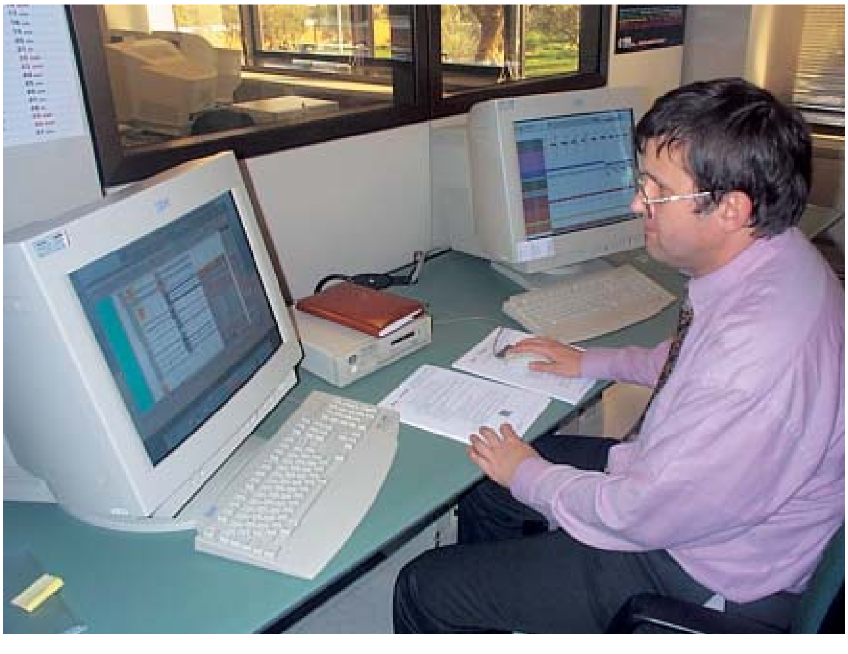
The User Services are implemented via three different facilities: the User Services Facility (USF), providing the web-based Internet access, the Inventory Facility (INV), a database containing the mission data catalogue, and the User Services Coordination Facility (USCF), coordinating the distributed USFs and managing ancillary services like user registration and order follow-up.

The architecture is distributed, with instances of the USFs and INVs at all PDHS and PACs providing points of access in several countries. A user accessing any of the USFs will be provided with the same services and the same data visibility. Each INV holds a catalogue of the data archived in its centre or station. A central INV in the PDCC automatically receives daily snapshots of the distributed catalogues, thereby providing a universal central PDS catalogue. More detailed information about the User Service Facility may be found in a separate article this Bulletin.

Mission planning
A High-Level Operations Plan (HLOP) defines the Envisat mission-operations strategy and high-level operating rules. The HLOP is translated into a Reference Operations Plan (ROP), which defines mission scenarios for the whole mission, to optimise the utilisation of the instruments and ground resources with respect to the users' requests for products, the scientific objectives of the various instruments, the satellite and ground-segment constraints, and the instrument calibration and characterisation requirements.

The ROP is used both in the Payload Data Segment (PDS) and the Flight Operations Segment (FOS), and consists mainly of a set of files used for configuring and driving the PDS–FOS mission planning and ground segment. The ROP, for example, defines global instrument utilisation according to a Global Mission Definition (GMD) and provides the Background Regional Mission (BRM) utilisation for regional instruments, defining the default observations to be carried out in the absence of overruling user orders.

Figure 5. Operating the mission planning facilities at the PDCC



The Envisat Mission Planning includes three components:

- The *Global Mission (GM)* defined by the ROP in the form of orbit scenarios per instrument MERIS RR, GOMOS, MIPAS, RA-2, MWR, AATSR, SCIAMACHY, DORIS. The FOS, using the GMD file generated by the RGT, performs the Global Mission planning.
- The *Background Regional Mission (BRM)*, addressing ASAR HR, ASAR LR and MERIS FR, defined on the ROP as a set of orbital segments or geographical zones enabling detailed planning of instrument operations.
- The *Regional Mission (RM)*, addressing ASAR HR, ASAR GM and MERIS FR, driven by user requests, expressed in terms of zones and/or segments.

At the PDCC, the Mission Control Facility channels the users' observation requests, received via USFs and analysed and filtered for constraint compliance, to the FOS in the form of a weekly Preferred Exploitation Plan. This plan defines the required regional instrument activities for a period of typically two weeks ahead. The FOS analyses the request, checks compliance with satellite utilisation constraints, and reports back to the PDS with a Detailed Mission Operation Plan (DMOP), defining the exact satellite planning for all instruments, both global and regional.

By processing the DMOP, the Mission Control Facility creates a Global Acquisition Plan (GAP), defining the high-level activities to be carried out in each of the PDS operational centres and coordinating their complementary operations. For example, acquisitions at Frascati and Kiruna should be followed by reception of products at the LRAC for low-rate-instrument consolidation and the reception at the PACs of circulation tapes for archiving and high-level processing.

Monitoring and control
The Global Acquisition Plan (GAP) is processed by the Ground Segment Planning (GSP) facility within the PDCC, which elaborates the detailed directives to be executed for each of the operational centres, taking into account the available centre or station resources and operational statuses. As a result, the GSP generates 48-hour plans which are sent to the stations, and medium-range plans (two weeks) which are sent to the LRAC and PACs.

At each centre or station, a Centre Monitoring and Control (CMC) facility receives the plans and performs the detailed Centre scheduling. The CMC uses these directives to generate final facility instructions, which effectively command the facilities' operations. In return, the facilities provide instruction reports detailing all information associated with the instruction's execution, such as actual product ingestion, generation and archiving times, results, diagnostics and error codes. The CMC consolidates this information into Centre production and performance reports, which are then forwarded to the GSP. The GSP compiles all Centre reports and builds a database with details of the operations, which is then used to build management reports and to investigate any problems.

The CMC also provides for real-time Centre monitoring via an interactive graphical user interface, allowing the operators to supervise progress in the operations and take corrective actions when needed. In addition, the CMC also manages local user orders, received via the USF, which can be serviced locally without involving the PDCC, e.g. deferred production from locally archived data sets.

As indicated above, the monitoring and control architecture provides several encapsulation layers (DMOP, GAP, 48 h and MR plans, centre schedules and facility instructions), containing detailed knowledge in higher layers and permitting centres and stations to be reconfigured with no impact at PDCC level. In particular, the GSP and CMC are configured with special Operation Constraints Definition (OCD) files, written in a language specifically developed for the PDS. These files provide the GAP-to-plans and plans-to-instructions mapping in a highly flexible way, and allow the modification of or the creation of new operational sequences as a result of progressive operations experience without the need to modify existing software. This has proved to be a very powerful tool during PDS integration.

Ancillary services

Other services internal to the PDS have also been implemented:

– The Product Quality Facility, recently renamed QARC (for Quality Assessment and Reporting Computer), provides an integrated platform with functions for the long-term characterisation of the PDS and Envisat satellite systems and instrument performance, as well as the capability to perform detailed interactive analyses of PDS products. With these functions, the PQF provides the elements needed to support the investigation of anomalies, queries and complaints from users.
– Auxiliary data circulation is very important for the success of the production services. Such data includes instrument calibration and data, and orbit-element data. The auxiliary data circulation is centralised and coordinated by the MCF.
– Common Services Facilities (CSF), regrouping all of the components that are common to several facilities, providing UNIX middleware services, such as common file- and message-transfer mechanisms, back-up, installation, host redundancy, etc. Together with the CSF, a Detailed Data Dictionary (DDT) containing interface-control databases and centralised definition of formats has allowed many of the integration problems that often occur in such a large development effort with several different suppliers, to be avoided.
– The Engineering Support Facility (ESF) provides integrated configuration-control services and a reference platform that can be configured as any PDS centre or station and will be used for maintenance, anomaly-investigation, testing and validation purposes.

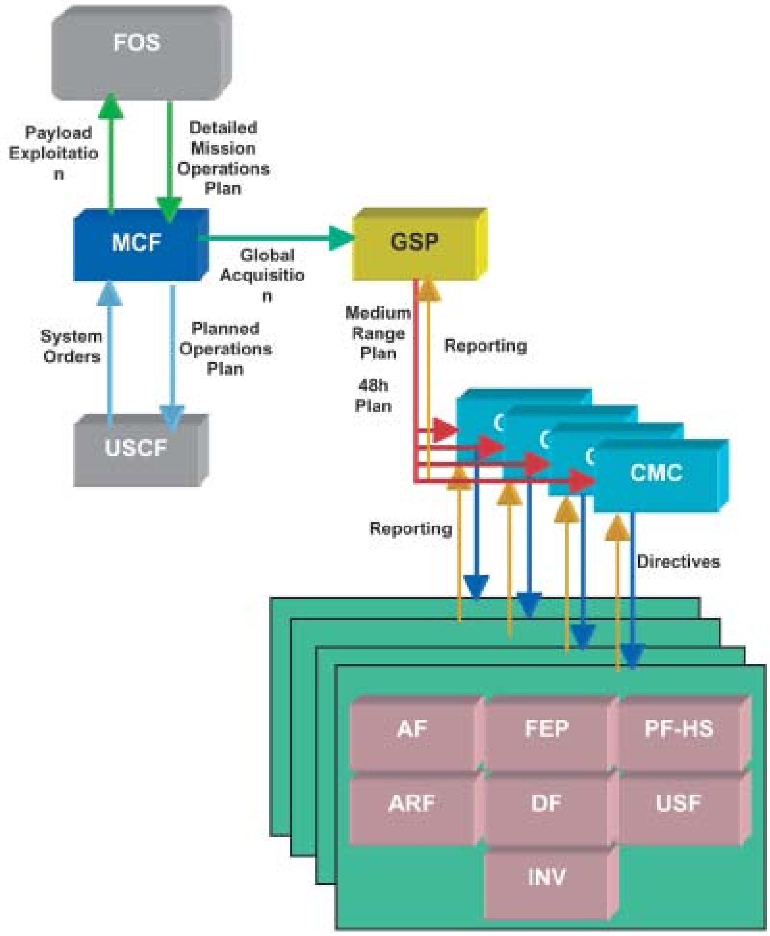


Figure 6. The mission-planning loop in the PDS

PDS development and validation

The PDS's development and validation has followed a classical approach, starting with testing and acceptance activities at unit and component level and progressing to facility, station or centre level. The validations of the PDS instrument processors used Level-0,

Figure 7. Acquisition facility equipment

Level-1 and Level-2 instrument products and auxiliary data, simulated by the Expert Support Laboratories (ESLs). The end-to-end validation of the PDS facilities used a highly representative satellite-to-ground data stream, simulated by the Data Flow and Format Simulator (DFFS).

The PDS validation started with the validation of the PDHS in Frascati, followed by that of the PDCC, also in ESRIN, then that of the PDHS in Kiruna, then that of the LRAC also in Kiruna, and ended with the acceptance of the complete PDS.

Additional PDS validation testing using real satellite instrument data recorded during the satellite assembly, integration and test (AIT) phase has been performed to verify the compliance of both the satellite and the ground segment with the satellite-to-ground interface specifications. The Envisat mission-planning loop, involving both the FOS and PDS, has also been extensively tested on a separate representative platform as part of the GSOV.

Conclusion

The development of the Payload Data Segment has shown that it is important to have a set of detailed requirements, interface-control documents, mission conventions and technical guidelines precisely defined at an early stage in the project. They also need to be rigorously applied to all of the components of such a widely distributed system. The decomposition of the overall PDS into manageable building blocks avoided the duplication of software or hardware developments, and allowed a coherent and optimised set of integration and validation activities at all of the various PDS locations.

One of the major challenges during the Payload Data Segment's development was the generation of a representative and coherent set of test data, allowing the static and dynamic integration and validation of the test activities at the facility, centre and the overall-PDS levels.