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ERS-1
SYSTEM

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FOREWORD

In July 1991 the European Space Agency launched ERS-1, the largest and most sophisticated free-flying satellite built so far in Europe and carrying a core set of active microwave sensors, supported by additional complementary instruments:

- Active Microwave Instrument – capable of operating as a Synthetic Aperture Radar (image or wave modes) or a Wind Scatterometer
- Radar Altimeter
- Along Track Scanning Radiometer – combining an infra-red radiometer and a microwave sounder
- Precise Range and Range-rate Equipment
- Laser Retro-reflectors.

The ERS-1 Programme has been designed to serve a large variety of users with a comprehensive range of products and services – in response to this, and other very challenging mission objectives, the ERS-1 ground segment is a combination of centralised and distributed facilities. The key components of the user interface and payload exploitation are based at the ESA facility, ESRIN, in Italy, while the monitoring and control of the satellite are the responsibility of the European Space Operations Centre (ESOC) in Germany. Taking advantage of existing specialist centres, ESA Processing and Archiving Facilities have been established in France, Germany, Italy and the UK, which will handle the data received by ESA ground stations and a network of other receiving stations around the world.

The prime uses of ERS-1 data are in the study of oceans, ice and meteorology and data is being collected for the first time, on a routine basis, from the remote areas of the polar regions and southern oceans. In addition the all-weather high resolution imaging capability will collect valuable information on land areas and the coastal zones. ERS-1 is both an experimental and pre-operational system, since it will demonstrate the new concepts and technologies of the space and ground segment. It will also illustrate some operational requirements for the fast delivery of data products providing significant contributions to meteorology, sea state forecasting and monitoring of sea ice distribution.

This ERS-1 System document provides information on the satellite, its instruments, the ground facilities and services from a data user's point of view. However, it does not cover the technical details of the space segment, the data products, calibration and validation activities or how the customer interfaces with user services. These topics are covered in companion ESA publications:

- **The Data Book of ERS-1**
  The Data Book of ERS-1 (ESA BR-75) contains scientific and technical details on the spacecraft sub-systems, the instruments and calibration and validation equipment and campaigns.

- **ERS-1 Product Specification**
  ERS-1 Product Specification (ESA SP-1149) provides detailed specifications for available ESA products, together with a brief introduction to the ERS-1 space and ground segment and a summary of the characteristics of each instrument.

- **ERS-1 User Handbook**
  The ERS-1 User Handbook (ESA SP-1148) provides information on ordering products, the services available through the Central User Service and details on accessing the ERS-1 catalogue, which notifies users of the availability of data products and planned acquisitions.

The ERS-1 System document has a long history. The concept of a user document on the ERS-1 satellite started in 1986 within the UK Earth Observation Data Centre programme and culminated in the release of the 'UK ERS-1 Reference Manual' in January 1991. The document was developed using the ESA technical documents and specifications and passed through a number of technical reviews by team members of the UK EODC programme. In late 1990, ESA approached the EODC to discuss the possibility of updating the UK document for an international audience. The ERS-1 System is the result of those discussions. Its format and scope is different to that of the UK document, in that it is hoped its concise style more closely addresses the needs of data users, rather than the programme scientists. In addition the document has been updated and harmonised, to avoid repetition with other publications in ESA's user documentation set for ERS-1, as outlined above.

So many organisations and individuals have been involved in the generation of this document; for example in the provision of information, illustrations and photographs and the undertaking of reviews, that specific acknowledgements have not been possible. In particular the following organisations are thanked: ESA-ESRIN; ESA-ESTEC; Defence Research Agency; Rutherford Appleton Laboratory; Earth Observation Sciences and Mullard Space Science Laboratory, University College London. In addition ESA gratefully acknowledges the previous work undertaken within the UK space programme, as funded by the British National Space Centre and the permission given by the Earth Observation Data Centre to re-use material prepared for the 'UK ERS-1 Reference Manual'.

1. OVERVIEW

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1.1 Mission objectives

In July 1991 the European Space Agency (ESA) launched the first European Remote Sensing Satellite (ERS-1), a forerunner of a new generation of satellites for environmental monitoring (Figure 1.1). ERS-1 uses advanced microwave techniques to acquire measurements and images regardless of cloud and sunlight conditions. Such techniques have been used previously only by the short-lived Seasat mission in 1978, and during brief Space Shuttle experiments. In comparison to contemporary satellite systems, ERS-1 is unique in the measurement of certain parameters, including those of sea state, sea surface winds, ocean circulation and sea and ice levels, as well as all-weather imaging of ocean, ice and land. It also measures the sea's surface temperature with greater accuracy than any of the current space systems. Much data will be gathered from remote areas such as the polar regions and the southern oceans, where little comparable information has previously been collected.

The nature of the satellite's orbit and its complement of sensors enables a global mission providing worldwide geographical and repetitive coverage, primarily oriented towards ocean and ice monitoring, but with an all-weather high resolution microwave imaging capability over land and coastal zones.

ERS-1 is both an experimental and pre-operational system, since it has to demonstrate that the concept and the technology for the space and ground segments have achieved the required performances. The ERS-1 system was also designed to satisfy some operational requirements for data products needed within a few hours of the observations being made, allowing it to make significant contributions to meteorology, sea state forecasting and monitoring of sea ice distribution. Also, the system is expected to demonstrate the feasibility of supporting part of the operating costs by commercialising its products.

The fast delivery of standard products assumes an appropriate ground segment with all the necessary capabilities, not only for data acquisition and proc-essing, but also for data validation, data quality control, data distribution and archiving. It is expected that a gradual transfer of applications from experimental to operational status will take place during the lifetime of ERS-1, preparing users for the satellite systems to be launched later in the 1990s.

Figure 1.1. ERS-1 launched by Ariane 4 on 17 July 1991 from Kourou, French Guiana.

1.2 Satellite concept

The ERS-1 programme is composed of a satellite, with its ground-support equipment; a launch vehicle; and a ground segment consisting of a control centre and facilities for data acquisition, processing, archiving and dissemination. The overall ground segment encompasses facilities controlled by ESA, as well as a number operated by national organisations.

The satellite concept is based on the re-utilisation of the Multi-mission Platform, developed within the French SPOT programme. This platform provides the major services for the satellite and payload operation, in particular attitude and orbit control, power supply, monitoring and control of payload status, and telecommunications with the ground segment.

1.3 Payload summary

ERS-1 (Figures 1.2 and 1.3) carries instrumentation consisting of a core set of active microwave sensors supported by additional, complementary instruments:

- **Active Microwave Instrument** (AMI) combining the functions of a Synthetic Aperture Radar (SAR) and a Wind Scatterometer. The SAR operates in image mode for the acquisition of wide-swath, all-weather images over the oceans, polar regions, coastal zones and land. In wave mode the SAR produces imagettes (about 5 km x 5 km) at regular intervals for the derivation of the length and direction of ocean waves. The Wind Scatterometer uses three antennae for the measurement of sea surface wind speed and direction.

- **Radar Altimeter** (RA) provides accurate measurements of sea surface elevation, significant wave heights, various ice parameters and an estimate of sea surface wind speed.

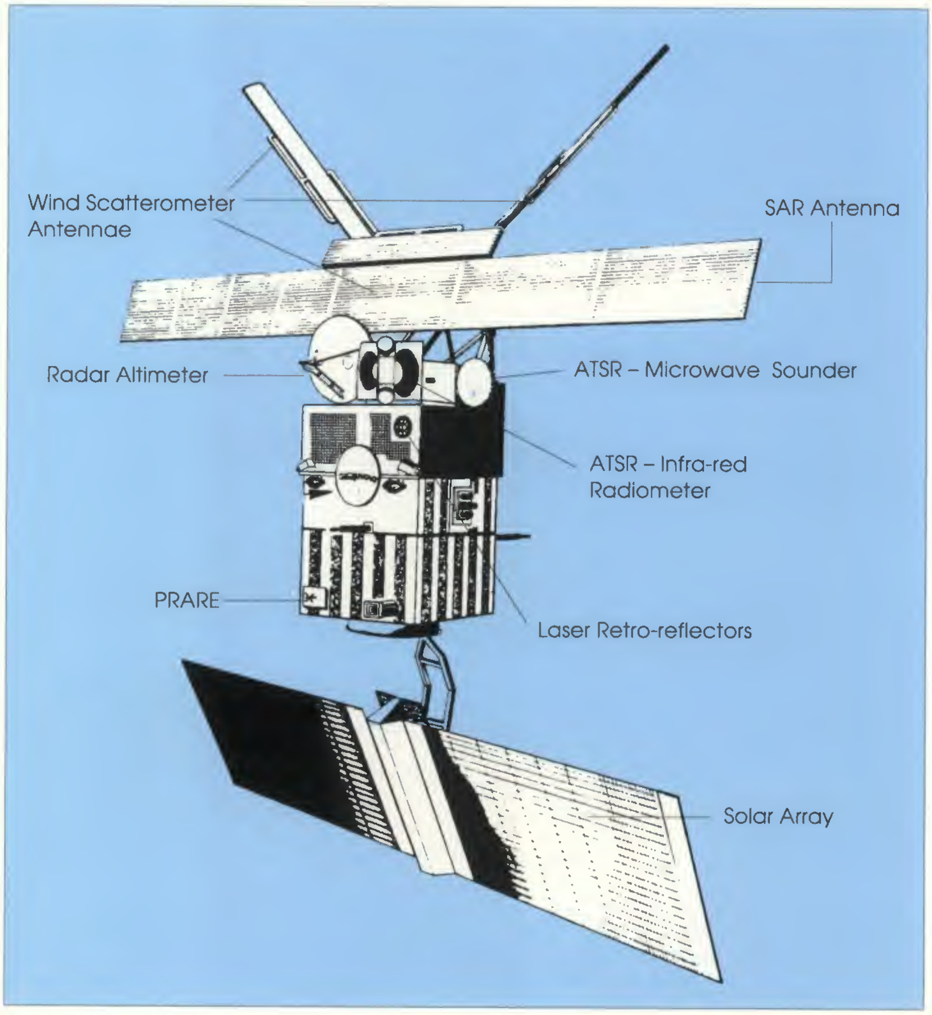
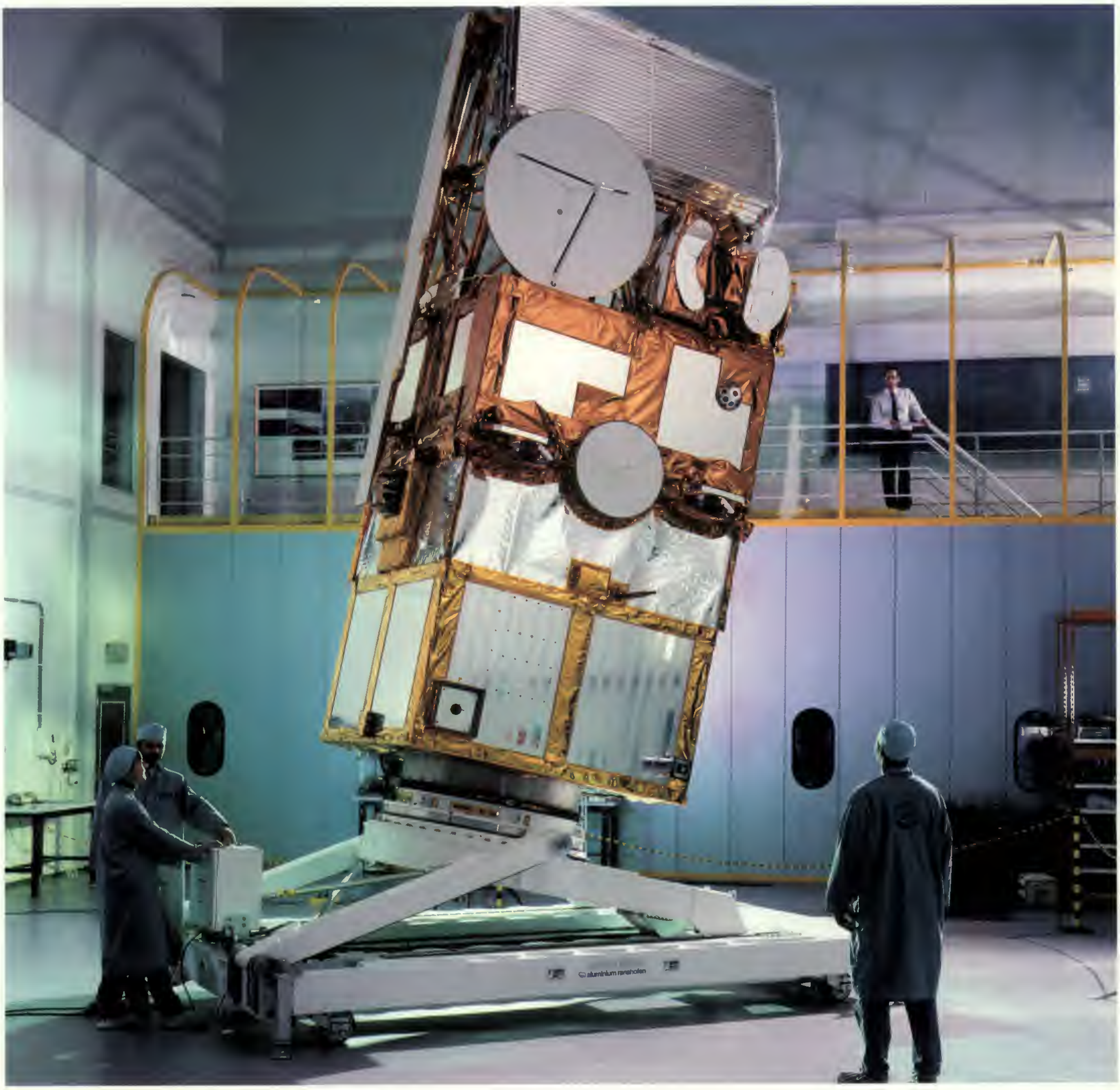


Figure 1.2. The ERS-1 instruments.

- **Along Track Scanning Radiometer** (ATSR) combining an infra-red radiometer and a microwave sounder for the measurement of sea surface temperature, cloud top temperature, cloud cover and atmospheric water vapour content.
- **Precise Range and Range-rate Equipment** (PRARE) an all-weather microwave ranging system, which was designed to perform high-precision two-way range and range-rate measurements using ground-based transponder stations. These measurements were to be used for orbit determination and geodetic applications Unfortunately the PRARE suffered fatal radiation damage early in the mission.
- **Laser Retro-reflectors** (LRR) allowing measurement of the satellite's position and orbit via the use of ground-based laser ranging stations.

The ATSR and PRARE are jointly referred to as the Announcement of Opportunity package, which resulted from proposals for additional instrumentation from the scientific community.

Figure 1.3. ERS-1 spacecraft in launch configuration, the arrays and antennae folded, during tests at ESA's ESTEC facilities in Noordwijk, The Netherlands.
(Photo, ESA)



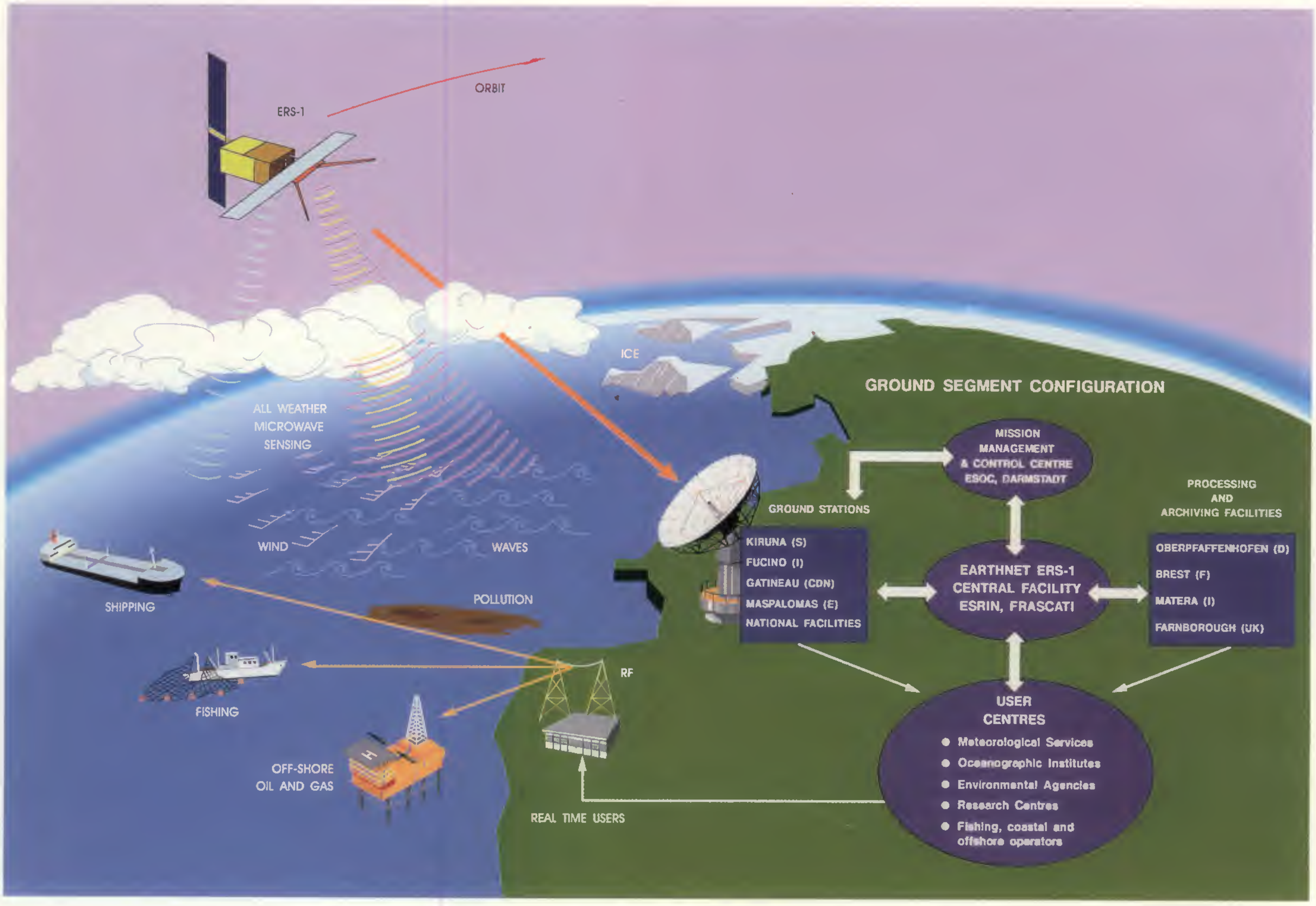


Figure 1.4. The ERS-1 ground segment.

1.4 Ground segment

The ERS-1 ground segment (see Figure 1.4) includes facilities for the satellite's control and operations, for reception, archiving and processing of the instrument data and provides services to satisfy user requirements for products. It consists of the following:

- **Earthnet ERS-1 Central Facility** (EECF) in Italy, carries out all user interface functions, including cataloguing, handling of user requests, payload operation planning, scheduling of data processing and dissemination, quality control of data products and system performance monitoring.

- **Mission Management and Control Centre** (MMCC) in Germany carries out all satellite operations control and functional management, including overall satellite and payload operational scheduling. It also controls the Kiruna ground station.

- **ESA ground stations** at Kiruna (Sweden), Fucino (Italy), Gatineau and Prince Albert (Canada) and Maspalomas (Canary Islands, Spain), provide the main network for data acquisition and the processing/dissemination of fast-delivery products.

- **National ground stations** around the world will receive ERS-1 high rate data by arrangement with ESA, extending the coverage potential of the SAR imaging mission.

- **Processing and Archiving Facilities** (PAFs) located in Germany, France, Italy and the UK are the main centres for the generation of off-line precision products and the archiving and distribution of ERS-1 data and products.

- **User centres and individuals,** such as national and international meteorological services, oceanographic institutes, various research centres and individual users.

1.5 Operational capabilities

The ERS-1 mission is global, however, its pre-operational nature and some technical and practical considerations, e.g. satellite power-supply capability and ground station coverage, impose limits to the achievable payload duty cycle and, therefore, flexibility is a major requirement in establishing payload operating modes.

The satellite availability is defined as the proportion of time for which valid measurements are made by the satellite and corresponding data is transmitted. Causes of non-availability will include link disturbances, e.g. rain and operational constraints, such as shadowing, planned re-configurations, manoeuvres for altitude correction and repeat cycle changes. With the exclusion of satellite and instrument failures and the execution of experimental modes, e.g. roll-tilting, satellite availability will be not less than 95% from the end of the commissioning phase until three years after launch.

The low bit rate (LBR) instruments – Radar Altimeter, Wind Scatterometer, SAR in wave mode and the ATSR, will be operated to provide as much global coverage, with an observation priority of oceans, then permanent ice sheets and finally land areas. Over the ocean it is intended to operate the Radar Altimeter and Wind Scatterometer continuously with an interleaved SAR wave mode every 200 km. The ATSR will operate uninterrupted for long periods (at least several days, nominally on a permanent basis) over ocean, ice and land surfaces. Data acquisition for the LBR instruments may be limited by energy shortages, on-board recording capacity and conflicts between wind/wave mode and the SAR image mode in coastal areas. Figure 1.5 shows the comparative positioning of the swath coverage for different instrument measurement modes.

The SAR mission is built around user requests and a plan to obtain a set of regional coverages of specific land/ice surfaces and coastal areas of interest. The aims for image acquisition are as follows:

- annual collection of full data sets for land surfaces, coastal areas and permanent ice sheets for each ground station coverage area
- regular revisits to selected areas for monitoring renewable resources, coastal areas and the marginal sea/ice zones and to identify seasonal effects.

It is assumed that the SAR can be operated for 12 minutes per orbit (up to four minutes during eclipse), either without interruption or split to enable coverage of discrete segments (up to a maximum of six per orbit, and not exceeding an average of four over the lifetime of the satellite). Each segment will have a minimum length of at least one minute, and consecutive segments will be separated by at least 30 seconds.

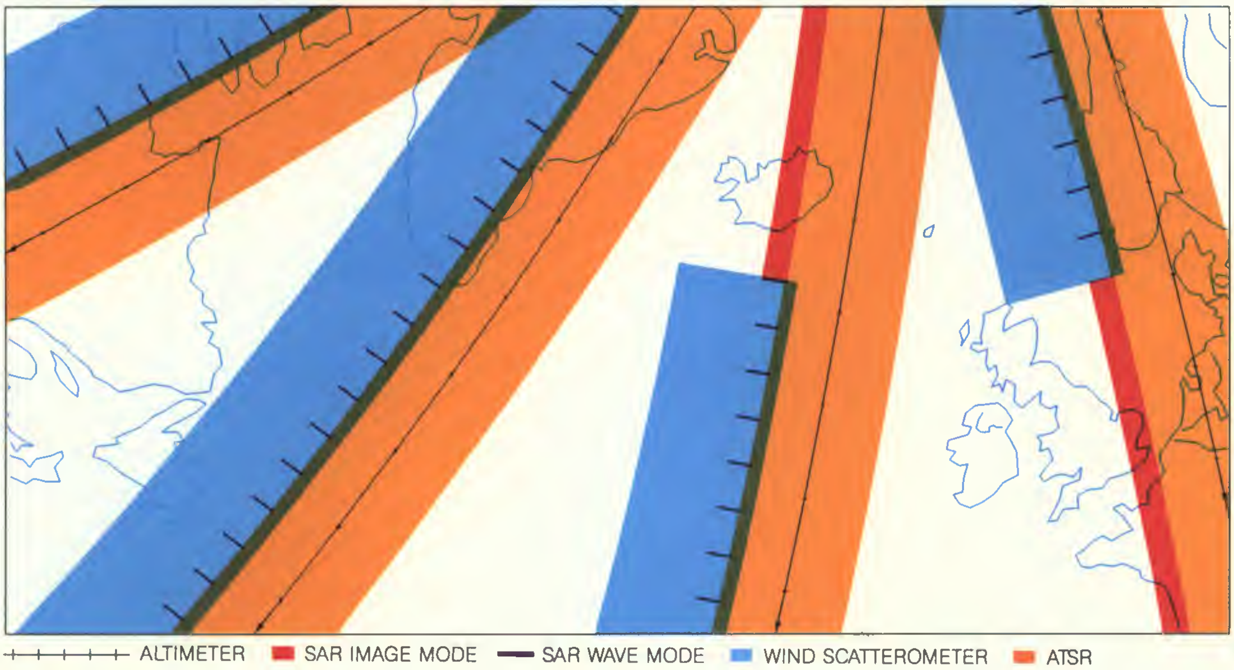


Figure 1.5. Comparison of the swath coverage for different instrument measurement modes.

Figure 1.6. Artist's impressions of ERS-1

- a) **over the Atlantic Ocean**
- b) **over the coast of Brazil**
- c) **over the Arctic**
- d) **over the forests of Colombia.**

1.6 Mission phases

The ERS-1 mission is sub-divided into six main phases:

- orbit acquisition
- commissioning phase
- first ice phase
- multi-disciplinary phase
- second ice phase
- geodetic phase.

Each phase is a period where the main parameters and characteristics of the mission are left unchanged, particularly the orbital characteristics and the priorities for sensor operations. As a set the phases permit the achievement of the mission objective to increase our knowledge of the oceans, ice zones, coastal regions and land areas (Figure 1.6).

1.6.1 Orbit acquisition

The launch and early orbit phase (LEOP) began with the launcher countdown and ended

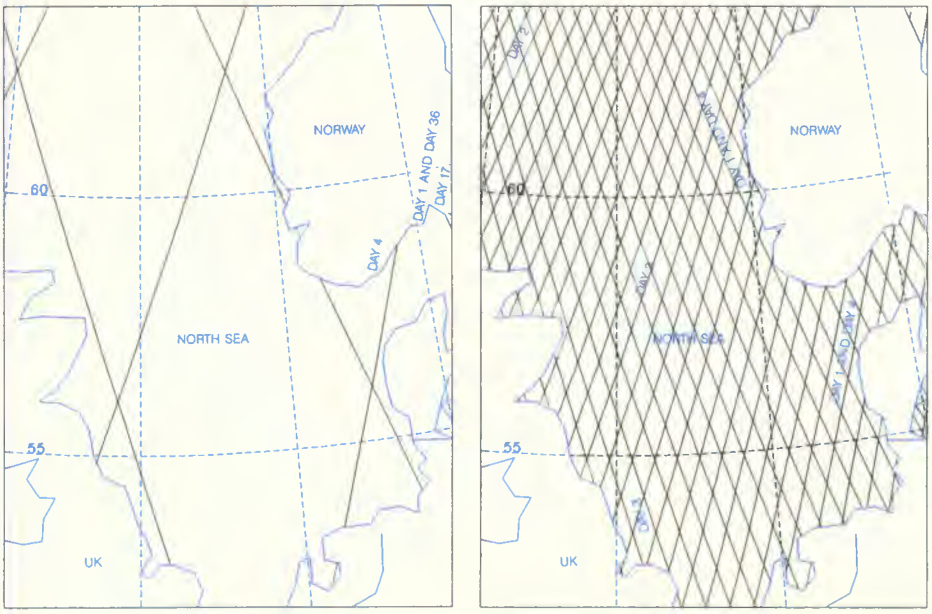


Figure 1.7. Comparison of swath density of Radar Altimeter tracks over the North Sea using 3-day (left) and 35-day (right) repeat cycles.

c

d

with the satellite achieving nominal attitude and orbit. It lasted two weeks (17 July to 30 July) and included initial switch-on and functional check-out of the satellite. The 3-day repeat cycle provided frequent revisits to a number of dedicated calibration sites under constant geometrical and illumination conditions.

1.6.2 Commissioning phase

The commissioning phase started immediately following the acquisition of the nominal orbit, initial switch-on and functional check-out of the satellite. Its duration was 4.5 months with a 3-day repeat cycle with maximum priority given to performing engineering calibration and geophysical validation tasks. It ended on 12 December 1991 with a check out of the spacecraft roll tilt mode capability.

1.6.3 First ice phase

The first ice phase (28 December 1991 to 30 March 1992) with a 3-day repeat cycle, was optimised for the specific requirements of Arctic ice experiments. The objectives of the phase being to support, with a high repetition of observations, all experiments in the polar and marginal ice zones which require SAR data. The following activities dominate this phase:

- scientific and application related experiments over Arctic, Antarctic and associated ice and sea ice extension areas
- pilot projects and other activities which frequent revisiting (e.g. pollution monitoring)
- projects and investigations related to inland ice and snow covered areas.

1.6.4 Multi-disciplinary phase

The main limitations of a 3-day cycle are the restricted global coverage for the imaging SAR and the wide separation of the Radar Altimeter tracks. The 35-day repeat cycle of the multi-disciplinary phase (14 April 1992 to 15 December 1993) provides SAR imaging of every part of the Earth's surface (Figure 1.7), with at least twice the frequency coverage at middle and high latitudes. Further, the density of altimeter tracks increases to give a separation between ground tracks of only 39 km at 60° latitude.

The objectives of this long phase are:

- determination of the reference mean sea surface with the Radar Altimeter
- study of ocean variability at various scales with the LBR instruments
- systematic mapping of land surfaces within visibility coverage of the ground stations, in support of all land applications.

The following activities dominate this phase:

- Announcement of Opportunity experiments
- mapping projects
- agricultural projects
- forest monitoring projects
- mapping of tropical forests every six months
- regular re-visits of test sites
- other areas critical from an environmental viewpoint
- maritime applications.

ERS-1 was operated in an experimental roll tilt mode within a window of ten days at the beginning of this phase, in the period 4 to 13 April 1992.

1.6.5 Second ice phase

The second ice phase lasts from January to March 1994, with the same orbital characteristics as the first ice phase.

1.6.6 Geodetic phase

With a repeat cycle of 176 days, the geodetic phase (April 1994 to the end of the mission) enables the acquisition of a high density of altimeter measurements and thus the main objective of the phase is to improve the determination of the geoid with the Radar Altimeter. The other LBR instruments will operate nominally, while the SAR operations will follow a profile similar to those of the multi-disciplinary phase.

2. THE SATELLITE

2. THE SATELLITE

To meets its mission objectives ERS-1 has been placed in a near-polar orbit at a mean altitude of about 780 km with an instrument payload comprising active and passive microwave sensors and a thermal infra-red radiometer. The satellite (Figures 2.1 and 2.2) is large, weighing 2400 kg before launch and measuring 12 m x 12 m x 2.5 m, making it the largest and most sophisticated free-flying satellite built so far in Europe.

Figure 2.1. ERS-1 fully deployed inside th Intespace test facility, Toulouse, France. (Photo, ESA)

ACRONYMS

AMI	:	Active Microwave Instrument
AOCS	:	Attitude and Orbital Control System
ATSR	:	Along Track Scanning Radiometer
HPA	:	High Power Amplifier
IDHT	:	Instrument Data Handling and Transmission
MMCC	:	Mission Management and Control Centre
OBC	:	On-board Computer
OBDH	:	On-board Data Handling
PDU	:	Power Distribution Unit
PRARE	:	Precise Range and Range-rate Equipment
SAR	:	Synthetic Aperture Radar

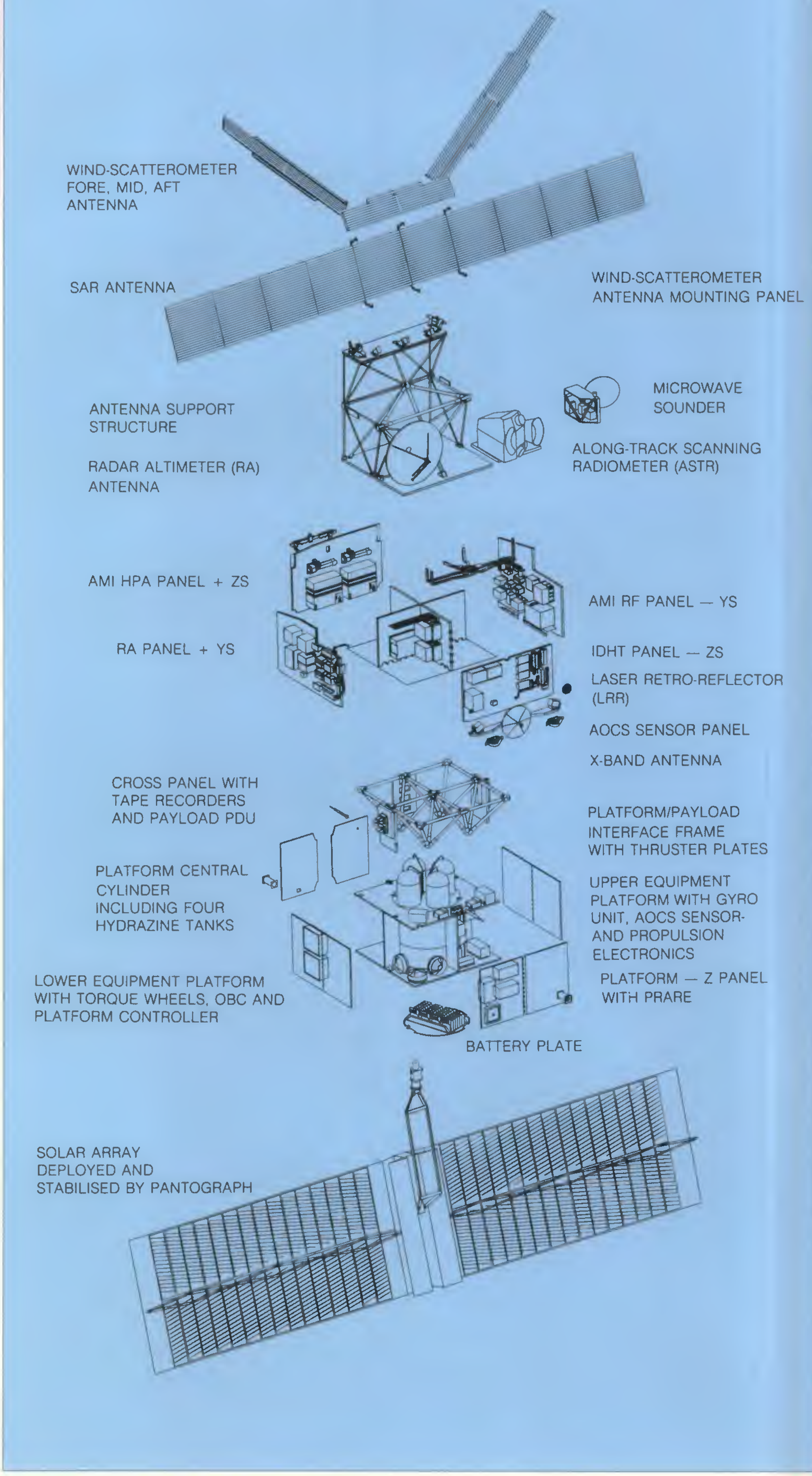


Figure 2.2. Exploded view of ERS-1 and summary technical specifications.

Orbit

Type:	near-circular, polar, Sun-synchronous
Altitude:	782 to 785 km
Inclination:	98.52°
Period:	about 100 minutes
Orbits per day:	14.3
Repeat cycle:	3-day, 35-day and 176-day

Instruments: Active Microwave Instrument comprising a Synthetic Aperture Radar (image and wave modes) and a Wind Scatterometer; Radar Altimeter; Along Track Scanning Radiometer; Precise Range and Range-rate Equipment; and Laser Retro-reflectors

Mass

Total mass:	2157.4 kg
Total payload:	888.2 kg
Total platform:	1257.2 kg
AMI:	325.8 kg
Radar Altimeter:	96.0 kg
IDHT:	74.0 kg
ATSR:	55.3 kg
PRARE:	12.0 kg
Laser Retro-reflectors:	2.5 kg

Electrical Power

Peak power:	≤ 2600 W
Permanent power:	≤ 550 W
Power supply voltage:	23-37 V
On-board energy:	2650 Wh max

Attitude and Orbital Control

Type:	3 axes stabilised Earth pointed
Absolute rate errors:	≤0.0015°sec (3 sigma)
Maximum errors:	bias 0.11° (pitch/roll) 0.21° (yaw); harmonic and random 0.03° (pitch/roll) 0.07° (yaw)
MMCC prediction accuracy:	30 m (radial), 15 m (cross) 1000 m (along)
MMCC orbit restitution:	25 m (radial), 15 m (cross) 60 m (along)

Data Handling

On-board computer:	word length : 16 bits
Payload memory capacity:	20 K words max
Payload data exchange:	OBDH type bus
Number of payload users:	8 redundant

Communications

Transponder:	coherent S-band (2 kbit/s)
Transmission power:	50 to 200 mW max
Telemetry rate:	2048 bit/s
Telecommand rate:	200 bit/s
Data down link:	– X-band (105 Mbit/s high rate link for SAR image mode) – X-band (15 Mbit/s low rate link for real-time and playback of LBR data) – on-board recorders provide 6.5 Gbits storage – S-band telemetry links for housekeeping data

2.1 Platform

The spacecraft platform provides the major services required for satellite and payload operation. These include attitude and orbit control, power supply, monitoring and control of payload status, telecommunication with ground stations and telemetry of payload and platform housekeeping data. In addition, the PRARE instrument is mounted on the platform.

The platform was modified with respect to the SPOT programme to meet the unique needs of the ERS-1 mission. The major modifications included extension of the solar array power and battery energy storage capability; modification of the attitude control sub-system to provide yaw steering and geodetic pointing; and the development of new software for payload management and control.

The ERS-1 platform consists of:

- **Service Module** carrying the house-keeping sub-systems and interfaces with the propulsion module, payload, solar generator and the battery compartment.
- **Propulsion Module** carrying the propulsion units of the Attitude and Orbital Control Sub-system (AOCS) consisting of four hydrazine tanks and a set of thrusters.
- **Solar Array Sub-assembly** consisting of two 5.8 m x 2.4 m wings, on which are mounted a total of 22260 silicon solar cells supplying more than 2000 W of electrical power.

  Following launch the two wings were deployed by a pantograph mechanism (see Figure 2.3) and the whole array rotates through 360°, with respect to the satellite, during each orbit to maintain sun pointing. During the sunlit phase (66 minutes) of each orbit, the solar array provides electrical power to all of the on-board systems and charges the spacecraft's batteries.
- **Payload** consisting of an Active Microwave Instrument comprising a Synthetic Aperture Radar (image and wave modes) and a Wind Scatterometer; a Radar Altimeter; an Along Track Scanning Radiometer (infra-red radiometer amd microwave sounder); a Precise Range and Range-rate Equipment; and Laser Retro-reflectors.

The platform structure is a rigid framework, with the load of the instruments transmitted directly through a central tube by metal struts.

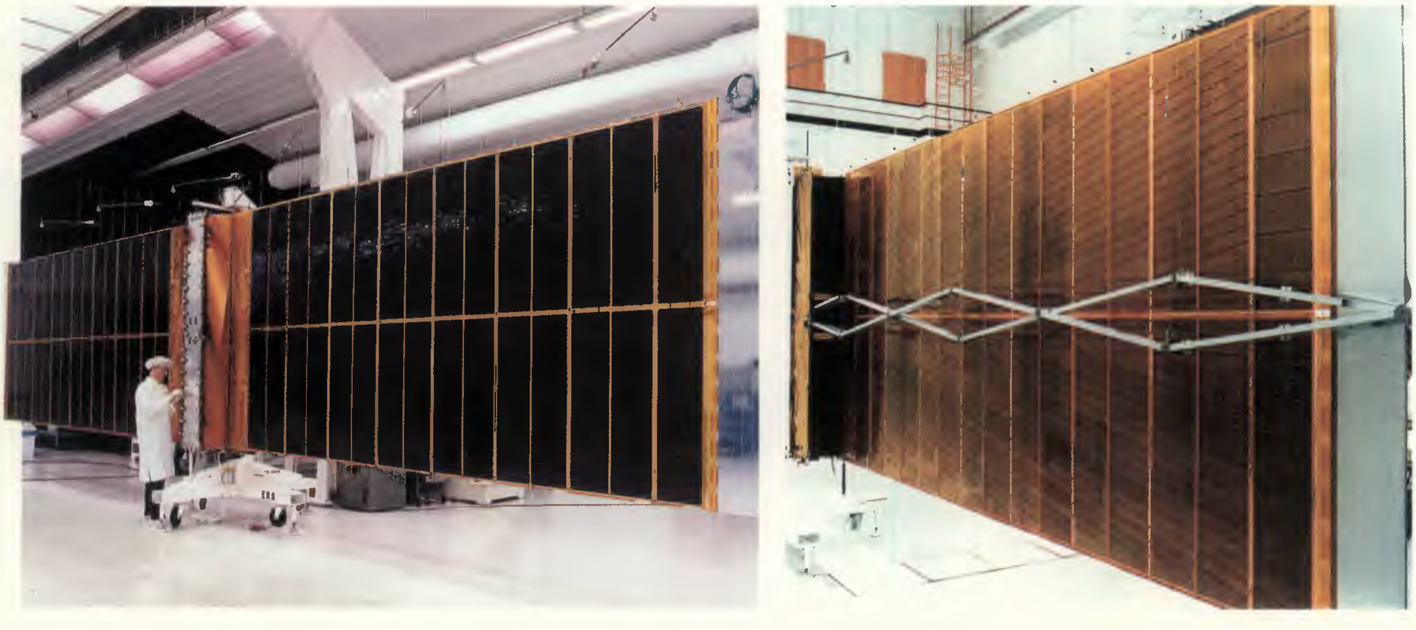


Figure 2.3 Front and rear sides of ERS-1 solar array. The rear view shows the pantograph deployment mechanism. (Photo, Aerospatiale)

2.2 Payload module

There are two main parts to the payload module (see Figure 2.4): the Payload Electronics Module (PEM) and the Antenna Support Structure (ASS).

The PEM is an aluminium face-sheet/honeycomb structure supported by nine internal vertical titanium beams. The central beam lies at the intersection of two internal cross-walls, so that the PEM is effectively divided into four separate compartments. Each outer panel is dedicated to a particular instrument, to simplify integration logistics. The payload is separated from the platform by a non-load-bearing electromagnetic shield. An aluminium-honeycomb panel closes the opposite end of the structure, stabilising the beams and providing the interface to the ASS at the beam locations. These provide a load path from the ASS to the platform.

The ASS (Figure 2.5), is composed of carbon-fibre-reinforced plastic (CFRP) tubes, with titanium at the high-load bearing structural elements. The lower part of the assembly consists of five tripods, three support points for the SAR antenna and two intermediate support points for the upper assembly. A CFRP plate at the top, which carries the Scatterometer antennae, is supported by three further tripods attached to the intermediate points and the SAR central point. The Altimeter's antenna is attached at three node points by a triangulated strut system.

The payload module also contains a dedicated Instrument Data Handling and Transmission (IDHT) system (see also Section 2.4), which permits the SAR image mode data to be transmitted directly to the ground stations and the data from the LBR instruments to be transmitted to the ground in real-time or recorded on one of two on-board tape recorders (Figure 2.6). The tape recorders have been designed to store a full orbit of LBR data on 3000 ft of 1/4-inch magnetic tape, leading to a total data recording capacity of 6.5 Gbit. The IDHT is located on the Earth-facing panel of the PEM, with the tape recorders mounted inside one of the cross-walls.

The remote sensing instruments of the payload are described in Chapters 3 to 6.

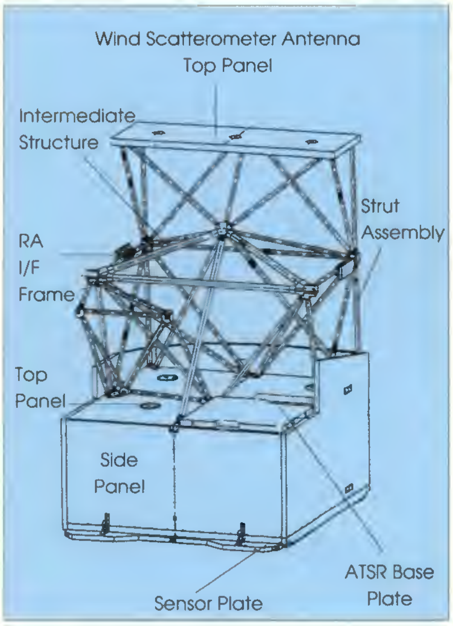


Figure 2.4. The ERS-1 payload support structure showing the box-like Payload Electronics Module and the complex strut assembly of the Antenna Support Structure.

Figure 2.5. Part of the Antenna Support Structure with the antennae removed.

Figure 2.6. One of the two 6.5 Gbit tape recorders, which each hold 3000 ft of 1/4-inch tape. (Photo, ESA)

2.3 Satellite operation

The satellite is controlled by the Mission Management and Control Centre (MMCC) via the Kiruna ground station. The satellite operation schedule is up-linked and stored on the satellite's on-board computer (OBC) for the next 24 hours, through a set of time-tagged macro-commands. The timely execution of these macro-commands is controlled by the OBC. The platform has an automatic reconfiguration capability in case of failure. If the reconfiguration fails, the spacecraft goes into safe mode, with the payload switched off, the solar array parked in the canonical position, and the satellite placed in a Sun-pointing attitude, awaiting further intervention from the ground. The payload element has no automatic reconfiguration. In case of failure the identified instrument is switched off waiting for reconfiguration by ground control. The OBC, the Instrument Control Units (ICUs) and the RA tracker are in-flight programmable. The AMI, RA and IDHT all have redundant sub-systems, with the exception of their antennae.

ERS-1 carries a significant number of software packages run by different processors spread throughout the platform and the payload. In the platform, the OBC runs the 'Centralised Flight Software', which incorporates all the basic functions needed to conduct the mission in an optimal fashion. In addition, each payload element (AMI, RA, ATSR and IDHT) contains its own decentralised ICU. These five computers are linked by the On-board Data Handling (OBDH) bus, and communicate with each other via a high level packetised protocol. This set of interdependent computers plays a critical role.

ERS-1 is a complex satellite, with many modes, parameters and logical conditions to be set and respected throughout each orbit. It is required to have autonomy for a full 24 hours, and this is only achieved by providing intelligent payload elements controlled by a capable central computer. The main functions of the OBC flight software are:

- managing the platform and its payload, including overall power regulation, power distribution and thermal control of the platform sub-systems, the PEM, the antennae and the AOCS
- monitoring the spacecraft, in order to detect and neutralise any critical failure and thereby preserve the mission
- scheduling the mission programming commands transmitted from the ground
- reporting to the ground either on the real-time status of the platform and payload, or from dedicated memory where any significant event history has been recorded.

2.4 Data communications

ERS-1 has two telemetry systems. An S-band (2 kbit/s) Telemetry, Telecommand and Control (TTC) system to transmit the ICU formats for housekeeping purposes and an X-band Instrument Data Handling and Transmission (IDHT) system for the science data. Three data streams are transmitted from the IDHT (see Figure 2.7). The first, a dedicated X-band link, contains the high-rate data for the SAR image mode, with auxiliary data and a copy of the S-band telemetry data, at a total rate of 105 Mbit/s. The other sensors have their data combined, again with a copy of the S-band data and satellite ephemeris information, into a (comparatively) low-rate data channel, operating at 1.1 Mbit/s, which will be continuously recorded by an on-board tape recorder. This recorder will be replayed at 13.6 times recording speed (in reverse order to save rewind time) over the ground stations, to form a second data channel, at 15 Mbit/s. It will share the second X-band link with the live transmission of the combined low-rate data, which constitutes the third data stream.

2.5 Orbit information

To carry out its mission ERS-1 must orbit so that its instruments can scan along predetermined paths designed to give optimum coverage for a set number of orbits. To achieve this, ERS-1 is a three-axis-stabilised, Earth-pointing satellite in yaw steering mode (YSM). The elliptical orbit is Sun-synchronous, near polar, with a mean altitude of 785 km, an inclination of 98.5° and a local solar time at the descending node of 10.30 a.m.

ERS-1 has a range of attitude sensors. The long-term reference in pitch and roll is obtained from an infra-red Earth sensor. The yaw reference is obtained once each orbit from a narrow field Sun sensor, which is aligned to view the Sun when the satellite is at a

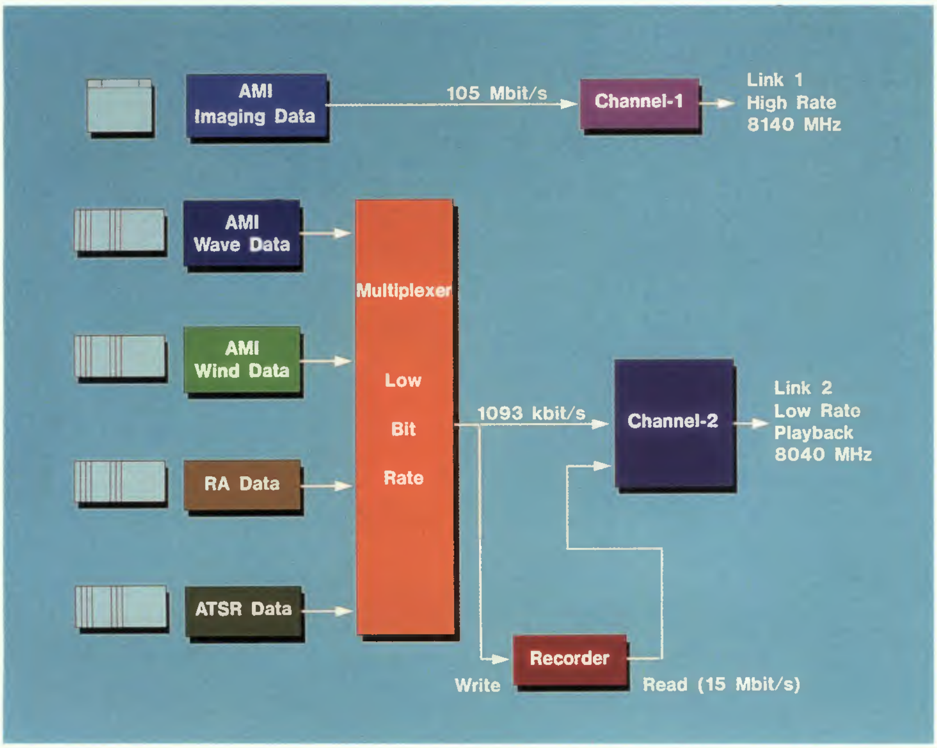


Figure 2.7. Block diagram of the Instrument Data Handling and Transmission System for X-band transmission of the science data.

particular point in its orbit. The short-term attitude and rate reference is obtained from three of six gyroscopes. Finally, there are two wide-field Sun-acquisition sensors for use in safe mode, when the satellite is Sun, rather than Earth, pointing. The primary means of attitude control is provided by a set of reaction wheels, which are nominally at rest. They can be spun in either direction, exchanging angular momentum with the satellite in the process. Monopropellant-type thrusters on the thruster plates are used in different combinations to maintain and modify the satellite's orbit and to adjust its attitude during non-nominal operations.

The ERS-1 mission will also include a number of adjustment manoeuvres to synchronise the orbital period with various requirements for ground coverage (see Section 1.5). The orbital parameters for the three planned repeat cycles of 3, 35 and 176 days are as follows:

	3-day	35-day	176-day
semi major axis:	7153.138	7159.496	7156.297
inclination:	98.516°	98.543°	98.529°
mean altitude:	785 km	782 km	~780 km
orbits per cycle:	43	501	2527

The transition from one orbital configuration to another, to adjust the repeat cycle, requires up to two weeks to stabilise the orbits to within 1 km of the nominal ground track. With the transition made at certain times in the orbital cycle stabilisation of orbit to within 5 km can occur after 24 hours. LBR and SAR operations are re-started 48 hours after the start of the orbit change manoeuvre. However, because of the need to update various parameters both on-board the satellite and on the ground the quality of fast delivery LBR products are not guaranteed for two weeks after any manoeuvre.

For the roll tilt mode (RTM) mode campaign in early April 1992 the satellite body is rotated by 9.5° allowing operation of the SAR imaging mode at an incidence angle of 35°. The attitude control system performances of the roll tilt mode are not significantly different to the nominal YSM with the same angular rates and harmonic and random errors and only slightly different static errors, i.e. about 0.05° maximum difference. During the roll tilt sequences the satellite is in a Fine Pointing Mode (FPM), which features no yaw steering and Earth centroid pointing, rather than geocentric pointing.

3. ACTIVE MICROWAVE INSTRUMENT

3. ACTIVE MICROWAVE INSTRUMENT

The Active Microwave Instrument (AMI) operating at a frequency of 5.3 GHz (C-band) combines the functions of a Synthetic Aperture Radar (SAR) and a Wind Scatterometer (WNS). Through its set of four antennae (three for the Scatterometer and one for the SAR – see Figure 3.1), the Earth's surface is illuminated and the backscattered energy is received to produce data on wind fields and wave spectra, and to prepare high resolution images.

A functional block diagram of the AMI hardware is shown in Figure 3.2. Its measurement functions are implemented by three modes of operation: the image mode (SAR), the wave mode (SAR) and the wind mode (WNS). To achieve a low mass and to reduce cost and complexity several sub-systems (e.g. transmitters) are common to both the SAR and the Wind Scatterometer. As a result the SAR in image mode and the Wind Scatterometer cannot be operated in parallel, but the wind and wave modes are capable of interleaved operation – wind/wave mode.

In addition to the measurement modes, the AMI can be operated in experimental, calibration and support modes. The main experimental mode involves the tilting of the satellite around its roll axis by 9.5° to achieve a SAR incidence angle of approximately 35°. This roll tilt mode (RTM), performed during early April 1992, has relevance to land application studies.

The operational capabilities of the AMI equipment, provided sufficient power is available on-board, are as follows:

- the SAR in image mode can be operated for a maximum of 12 minutes per orbit, either continuously or split to enable coverage of discrete segments – a maximum

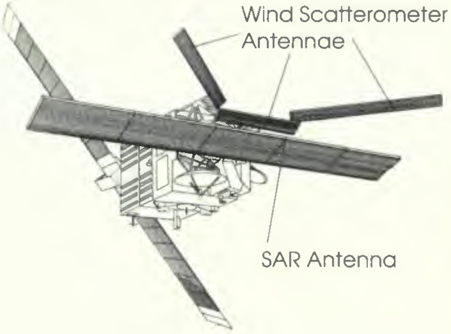
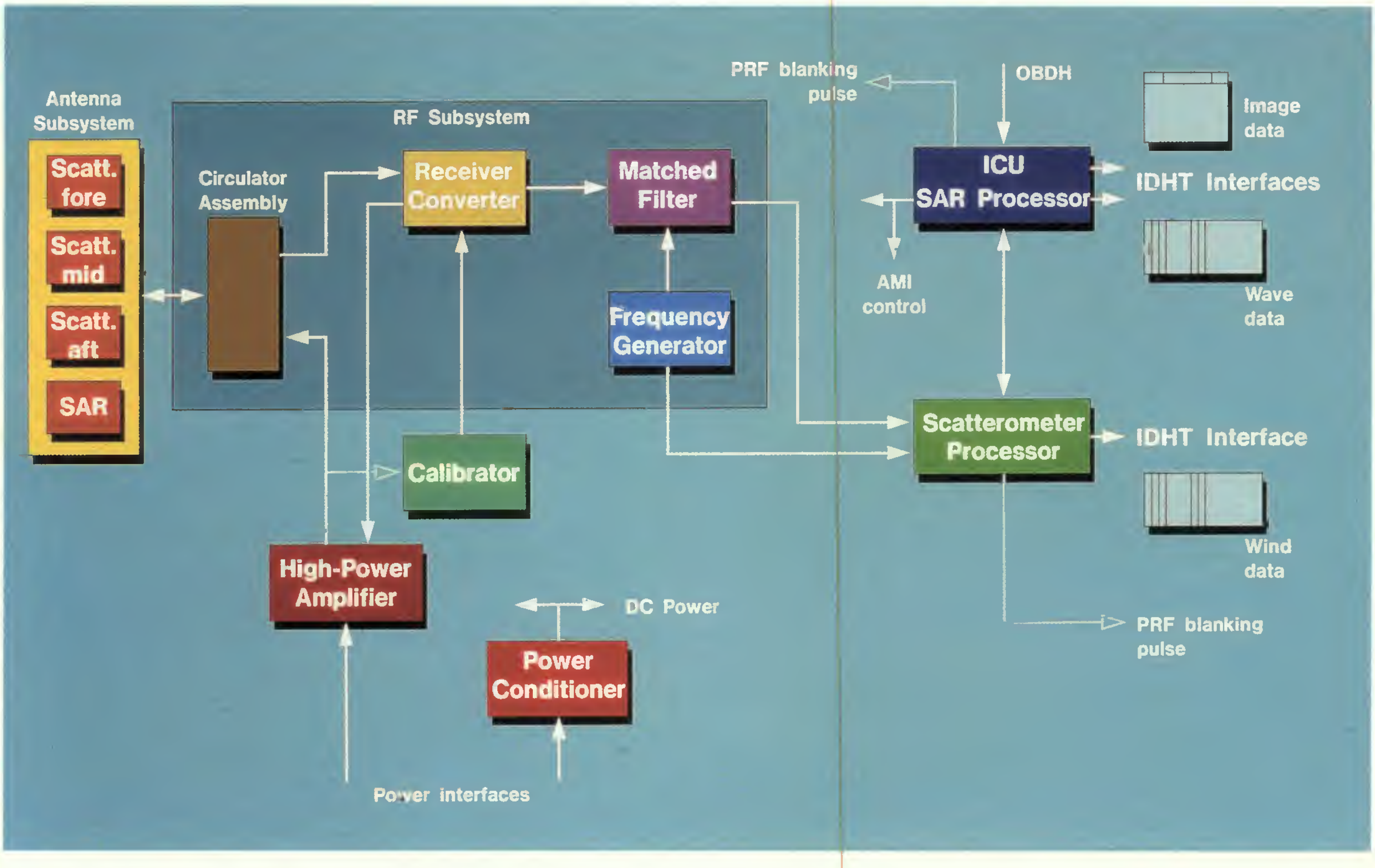


Figure 3.1. Location of the AMI antennae. Along with the solar array, the AMI antennae provide ERS-1 with its distinctive shape. The SAR antenna and the fore and aft Wind Scatterometer antennae were all folded for launch and deployed during early orbits.

Figure 3.2. AMI functional block diagram. Several of the AMI sub-systems are shared between the SAR in image mode and the Wind Scatterometer and therefore they cannot be operated at the same time, although the SAR in wave mode and the wind mode can be interleaved.



of six segments is planned (four on average) for each orbit (see Section 1.5)

- in wave and wind measurement interleaved mode the AMI can be operated continuously
- it is not possible to operate the SAR for imaging and the Wind Scatterometer simultaneously.

The main technical characteristics of the AMI antennae are:

Frequency:	5.3 GHz (C-band)
Bandwidth:	15.55 ± 0.1 MHz
Peak power:	4.8 kW (at power amplifier out)
Polarisation:	Linear Vertical
Antennae size:	SAR – 10 m x 1 m WNS – 2.5 m (mid) and 3.6 m (fore and aft)
Incidence angle:	SAR – 23° nominal (35° in roll-tilt mode) WNS –18°-47° (mid) and 25°-59° (fore and aft)
Transmit pulse width:	37.12 ± 0.06 μs (SAR); 70 μs and 130 μs (WNS)
Quantisation:	SAR image mode – 5I, 5Q (OGRC); 6I, 6Q (OBRC) SAR wave mode – 4I, 4Q (OGRC); 2I, 2Q (OBRC) WNS – complex I/Q 8 bits each
Signal-to-noise contribution:	308.3 dB Hz (SAR); 282 dB Hz (WNS)
Uncompensated gain stability:	4.6 dB (SAR); 4.1 dB and 4.8 dB (WNS)
Compensated gain stability:	1.84 dB (SAR); 0.3 dB and 0.48 dB (WNS)
Calibration pulse delay:	45 μs (SAR); 135 μs (WNS)

where two figures are given for WNS the first one refers to the mid antenna and the second to the fore and aft antennae. OGRC = on-ground range compression; OBRC = on-board range compression.

3.1 SAR image mode

In image mode the SAR provides high resolution two-dimensional images with a spatial resolution of 26 m in range (across track) and between 6 m and 30 m in azimuth (along track). Image data is acquired for a maximum duration of approximately 12 minutes per orbit. As the data rate is too high for on-board storage it is only acquired within the reception zone of a suitably equipped ground receiving station (see Section 7).

The main characteristics of the SAR in image mode are:

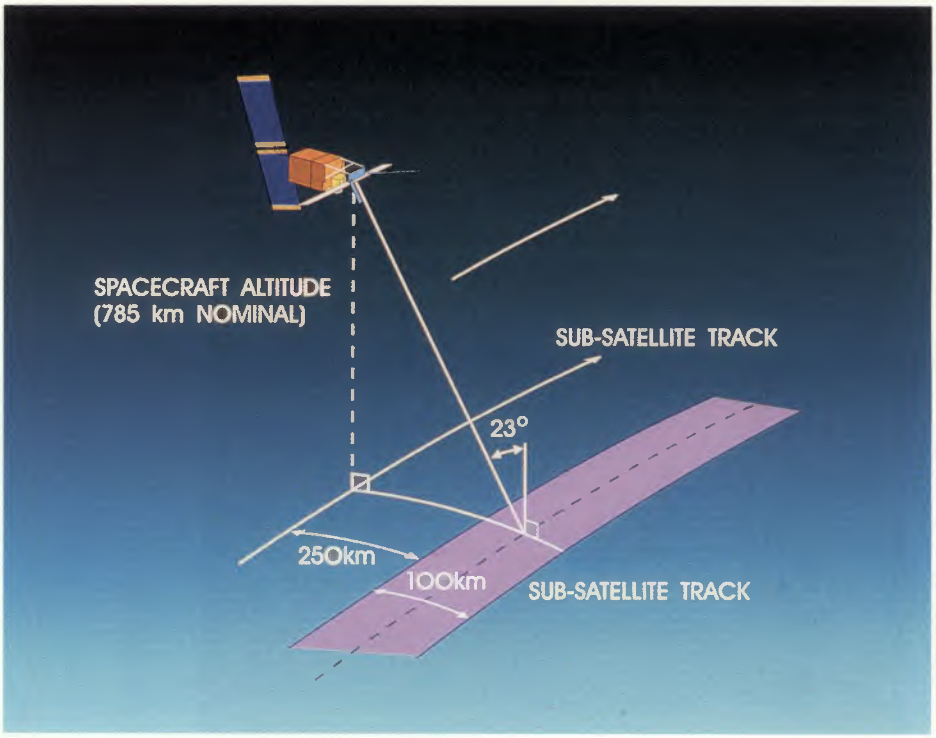
Spatial resolution:	along track ≤30 m; across-track ≤26.3 m
Peak sidelobe ratio:	along track ≥20 dB; across-track ≥18 dB
Spurious sidelobe ratio:	along track ≥25 dB; across-track ≥25 dB
Integrated sidelobe ratio:	≥8 dB
Ambiguity ratio:	along track ≥20 dB; across-track ≥31 dB
Radiometric resolution:	≤2.5 dB at σ° = -18 dB
Dynamic range:	≥21 dB
Radiometric stability:	≤0.95 dB
Cross polarisation (one way):	≥15 dB
Maximum operation time:	10 minutes per orbit
Swath width:	102.5 km (telemetered) 80.4 km (full performance)
Swath standoff:	250 km to the right of the satellite track
Localisation accuracy:	along track ≤1 km; across-track ≤0.9 km
Incidence angle	
near swath:	20.1°
mid swath:	23°
far swath:	25.9°
Incidence angle tolerance:	≤0.5 °

The rectangular antenna of the SAR (see Figure 3.3) is aligned along the satellite's line of flight to direct a narrow beam sideways and downwards onto the Earth's surface (Figure 3.4) to obtain strips of high resolution imagery of about 100 km in width. Imagery is built up from the time delay and strength of the return signals, which depend primarily on the roughness and dielectric properties of the surface and its range from the satellite.

The SAR's high resolution in the range direction is achieved by phase coding the transmit pulse with a linear chirp and compressing the echo by matched filtering; range resolution being determined by means of the pulse travel time; and the azimuth resolution is achieved by recording the phase as well as the amplitude of the echoes along the flight path.

Figure 3.3. The AMI SAR antenna. The largest AMI antenna, with a radiating area of 10 m x 1 m, is a slotted waveguide array composed of metallised carbon-fibre reinforced-plastic, here photographed during planar near field-tests.
(Photo, ESA)

Figure 3.4. SAR image mode geometry. In image mode the SAR obtains strips of high resolution imagery approximately 100 km in width, 250 km to the right of the sub-satellite track.



During operation, the command to generate a radar pulse is initiated by the SAR processor. A 'short pulse' signal is generated and is used as the input to a dispersive delay line (Surface Acoustic Wave (SAW) device) which produces the linear Frequency Modulated (FM), or 'chirped' pulse. This chirp signal is generated at a programmable Pulse Repetition Frequency (PRF) in the range 1640-1720 Hz and is passed to the transmitter and up-converter, where it is mixed with the local oscillator signal (5176 to 7442 MHz), produced within the Frequency Generator. The level of the RF output pulse (peak power) is controlled by the Automatic Gain Control (AGC) loop. This output is amplified by approximately 45 dB by the High-Power Amplifier sub-system before it is routed via the waveguide through the Circulator Assembly to the SAR antenna.

The echo signal received by the SAR antenna is routed via the waveguide through the Circulator Assembly to the receiver. The received radar echo is then amplified in a Low-Noise Amplifier and mixed with the local oscillator signal to provide a signal at the intermediate frequency as input to the IF Radar. The echo signal is sent to the SAR processor where it is resolved into in-phase and quadrature components.

The nominal operation mode is an on-ground range compression (OGRC) of the received pulse, providing complex samples with 5 bits in-phase (I), 5 bits quadrature (Q), while an on-board range compression (OBRC) mode provides complex samples of 6 bits I, 6 bits Q. The ground processing requires auxiliary data (chirp replica, noise measurement, calibration pulse), in addition to the radar echo, in order to produce the required image.

3.2 SAR wave mode

The SAR wave mode provides two-dimensional spectra of ocean surface waves (see Figure 3.5). For this function the SAR records regularly spaced samples within the image swath. The images are transformed into directional spectra providing information about wavelength and direction of wave systems. Automatic measurements of dominant wavelengths and directions will improve sea forecast models, but the imagettes can also show the effects of other phenomena, such as internal waves, slicks, small scale variations in wind and modulations due to surface currents and the presence of sea ice.

The idea behind the wave mode is that much useful information can be obtained from the power spectra of ocean waves. In particular, the wavelengths and directions of swell wave systems can be measured readily from spectra. Series of spectra can be used to determine the evolution of such systems. While operating in wave mode the SAR measures the

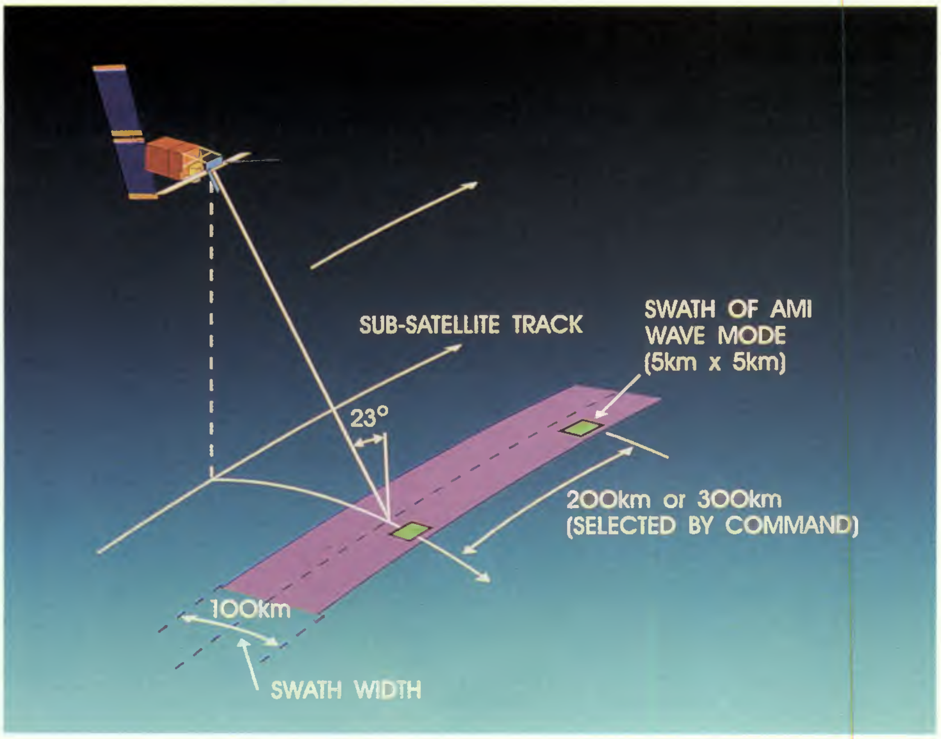


Figure 3.5. SAR wave mode geometry. The wave mode generates 5 km x 5 km (OGRC) or 5 km by 9.6-12 km (OBRC) images at intervals of 200 km along track within the image mode swath.

change in radar reflectivity of the sea surface due to the ocean surface waves. In this mode the system operates as a SAR (see image mode), however the wave mode differs in that the RF power and hence imaging capability are reduced.

The SAR characteristics in the wave mode are the same as those of in image mode, except for the following characteristics:

- the swath width corresponds to between 9.6 km and 12 km in OBRC mode depending on position, or 5 km in OGRC, every 200 km along track
- the data rate permits global operation
- the swath position is programmable anywhere within the SAR imaging swath
- the A/D quantisation is 4 bits I, 4 bits Q, in OBRC mode, and 2 bits I, 2 bits Q, in OGRC mode
- the data can be generated in a stand-alone mode or interleaved with wind data.

The main technical characteristics of the SAR in wave mode are listed below:

Wave direction / length:	0 – 180° (180° ambiguity) / 100 – 1000 m
Accuracy direction / length:	±20° / ±25%
Spatial resolution:	along track ≤30 m; across-track ≤26.3 m
Peak sidelobe ratio:	along track ≥20 dB; across-track ≥18 dB
Spurious sidelobe ratio:	along track ≥25 dB; across-track ≥25 dB
Integrated sidelobe ratio:	≥8 dB
Ambiguity ratio (point target):	along track ≥25 dB; across-track ≥31 dB
Radiometric resolution:	≤2.0 dB
Dynamic range:	-12 to 3 dB
Radiometric stability:	≤0.95 dB
Cross polarisation (one way):	≥15 dB
Swath length:	≥5 km
Swath width (with OBRC):	≥9.6 km (far swath) 12 km (near swath)
Swath width (with OGRC):	≥5 km
Swath position step size:	≤2.5 km
Localisation accuracy:	along track ≤2 km; across-track ≤1.8 km
Incidence angle tolerance:	≤0.5 °

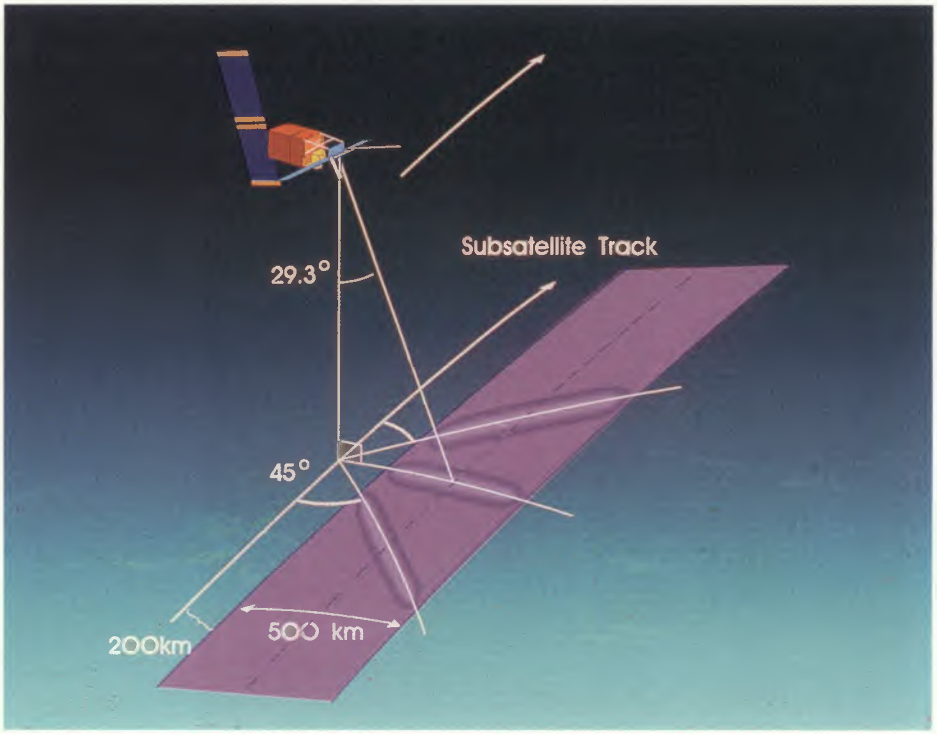


Figure 3.6. Wind Scatterometer geometry. The three Wind Scatterometer antennae generate radar beams 45° forward, sideways and 45° backwards across a 500 km wide swath, 200 km to the right of the sub-satellite track.

3.3 Wind Scatterometer

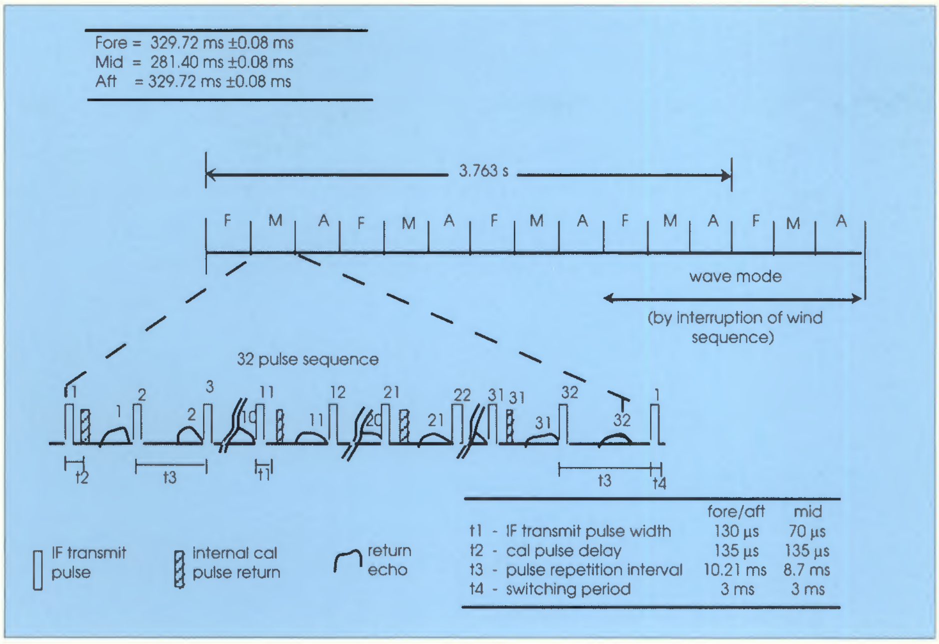
The purpose of the Wind Scatterometer is to obtain information on wind speed and direction at the sea surface for incorporation into models, global statistics and climatological datasets. It operates by recording the change in radar reflectivity of the sea due to the perturbation of small ripples by the wind close to the surface. This is possible because the radar backscatter returned to the satellite is modified by wind-driven ripples on the ocean surface and, since the energy in these ripples increases with wind velocity, backscatter increases with wind velocity.

The three antennae generate radar beams looking 45° forward, sideways, and 45° backwards with respect to the satellite's flight direction. These beams continuously illuminate a 500 km wide swath (see Figure 3.6) as the satellite moves along its orbit. Thus three backscatter measurements of each grid point are obtained at different viewing angles and separated by a short time delay. These 'triplets' are input into a mathematical model to calculate surface wind speed and direction.

The main technical characteristics of the Wind Scatterometer are listed below:

Spatial resolution:	≥45 km (along and across track)
Radiometric resolution	
(4 m/sec):	≤8.5% (mid beam) ≤9.7% (fore/aft beam)
(24 m/sec):	≤6.5% (mid beam) ≤7.0% (fore/aft beam)
Radiometric stability	
CMIS:	≤0.57 dB
IIS:	≤0.46 dB
Cross polarisation:	≥15 dB
Swath width:	≥500 km
Swath stand-off:	200 km to right of sub-satellite track
Localisation accuracy:	±5 km (along and across track)
Wind direction range/accuracy:	0 - 360° / ±20°
Wind speed range/accuracy:	4 m/s - 24 m/s / 2 m/s or 10 %

A transmit pulse is produced by the Scatterometer Electronics and is amplified by the IF Radar unit, converted to an RF signal in the transmitter/converter unit and amplified by



	fore/aft	mid
t1 - IF transmit pulse width	130 µs	70 µs
t2 - cal pulse delay	135 µs	135 µs
t3 - pulse repetition interval	10.21 ms	8.7 ms
t4 - switching period	3 ms	3 ms

Figure 3.7. Wind Scatterometer measurement sequence. The four series of regularly spaced measurements for each antenna are denoted as F, M and A for fore, mid and aft antennae.

the High-Power Amplifier. The transmit signal is routed to the correct antenna by the Circulator Assembly, which in this mode is under the control of the Scatterometer Electronics.

The received signal is down-converted, amplified by the IF Radar and routed to the Scatterometer Electronics. A measurement sequence of 3.763 seconds (see Figure 3.7) corresponds to 25 km along the sub-satellite track at a satellite altitude of 785 km and is continuously repeated in the wind mode without any gap. This sequence involves four sets of measurements, regularly spaced, for each antenna beam (fore, mid and aft). Each series corresponds to 32 measurement pulses on each beam. Noise measurements and internal calibration are regularly performed in the interval between the transmitted pulse and the reception of the return echo.

For the mid-beam, the return echo is filtered and sampled in complex form I and Q, while for the fore and aft beams, as the doppler variation is significant over the swath width (20 kHz near swath to 140 kHz far swath), a programmable doppler compensation law is applied to the received signal before filtering and complex sampling.

4. RADAR ALTIMETER

4. RADAR ALTIMETER

The Radar Altimeter is a Ku-band (13.8 GHz) nadir-pointing active microwave sensor designed to measure the time return echoes from ocean and ice surfaces. Functioning in one of two operational modes (ocean or ice) the Radar Altimeter provides information on significant wave height; surface wind speed; sea surface elevation, which relates to ocean currents, the surface geoid and tides; and various parameters over sea ice and ice sheets.

The Radar Altimeter operates by timing the two-way delay for a short duration radio frequency pulse, transmitted vertically downwards. The required level of accuracy in range measurement (better than 10 cm) calls for a pulse compression (chirp) technique. In ocean mode a chirped pulse of 20 μs duration is generated with a bandwidth of 330 MHz. For tracking in ice mode an increased dynamic range is used, obtained by reducing the chirp bandwidth by a factor of four to 82.5 MHz, though resulting in a coarser resolution.

4.1 Measurement objectives

The Radar Altimeter for ERS-1 has been designed to meet very demanding constraints and has the following major objectives:

- global measurements of the height of the ocean waves (as significant wave height or SWH) – such measurements are extremely important to marine users and scientists wishing to understand the ocean's dynamic behaviour, plus the Radar Altimeter will provide measurements to latitude 82° N/S, extending to regions which previously had no regular observations, and includes the major wave-generation regions in the southern oceans

- measurements of the satellite's height above the local mean sea surface, with an unprecedented precision (equivalent to 1 cm in 100 km) – the applications of this remarkable dataset are numerous, for example the operational monitoring of the boundaries of major ocean currents, which are likely to have significant economic benefits

- global measurements of wind speed – these can be used to complement the AMI wind field measurements and also combined with the Radar Altimeter measurements of SWH to distinguish swell from wind-driven waves

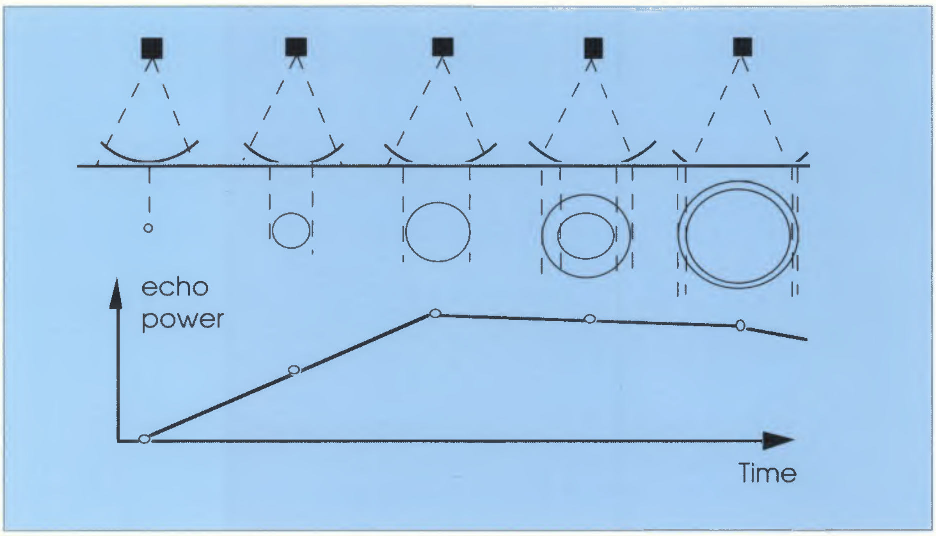
- the ability to make measurements over ice with the long term monitoring of the topography of the ice sheets providing a vital warning capability for any substantial shift in the world's climate.

4.2 Measurement principles

The key principle behind the altimeter is that the information required is in the shape and timing of the returned radar pulse. Figure 4.1 shows a pulse being reflected from a flat surface. As the pulse advances, the illuminated area grows rapidly from a point to a disk, as does the returned power. Eventually, an annulus is formed and the geometry is such that the annulus area remains constant as the diameter increases. The returned signal strength, which depends on the reflecting area, grows rapidly until the annulus is formed, remains constant until the growing annulus reaches the edge of the radar beam, where it starts to diminish (see graph on Figure 4.1).

Irregularities on the surface, larger than the pulse width, cause the returned pulse to be distorted and stretched. The effect of this is to impose an additional slope on the leading edge of the returned signal strength curve (see Figure 4.2). This slope is related to the ocean wave height and the mid-point of this leading edge slope is equivalent to the

Figure 4.1. Intersection of an altimeter pulse with the surface. As the illuminated area grows the returned signal strength grows rapidly until an annulus is formed. The area then remains constant until the growing annulus reaches the edge of the radar beam, and then starts to diminish.



reflection from the average position of the surface (i.e. the mean sea surface). By measuring the total area under the curve, the average reflectivity of the surface may be obtained.

Clearly the altimeter requires a very short pulse width and full analysis of the pulse shape must be carried out quickly since the pulse shown in Figure 4.2 is so short. Both of these time requirements have been avoided by translating from time to frequency, using the so-called full-deramp technique. The altimeter therefore operates with frequency-modulated rather than time-modulated signals and the analysis of pulse shape is a spectrum analysis, performed by the processor. The characteristics of this processor and the control of the radar are varied according to the mode of the Radar Altimeter. The most important is the acquisition mode, during which the radar finds the approximate distance to the surface and then switches to one of the tracking modes – ocean or ice.

4.2.1 Measurements over ocean

The process by which the characteristics of the ocean become embedded in the return signal are described above. The return pulse shape as a function of time is the convolution of three functions:

- the average flat surface impulse response, which is a function incorporating the antenna beam weighting and the geometric spreading of the radar pulse along the original surface
- the probability distribution of surface heights over the sea surface, expressed in terms of delay times
- the altimeter system point-target response, which is a function of pulse width.

The resulting return pulse shape is shown in Figure 4.2. In general terms the ocean mode encompasses the following echo characteristics:

- time delay with respect to the transmitted pulse – this provides the measure of altitude
- slope of the echo leading edge, which is related to the width of the height distribution of reflecting facets, and thus to wave height parameters such as SWH
- the power level of the echo signal, which depends on small scale surface roughness, and thus on surface wind-field parameters over the ocean.

Real echoes are composed of the sums of signals from many point scatterers, each with individual phase and amplitude. Therefore, the individual echoes have statistical characteristics superimposed on the pulse shape. In order to reduce uncertainties in the determination of pulse characteristics, the altimeter averages pulses together to reduce this statistical effect. When in ocean tracking mode, the mean sea-level point (mid point of the leading edge) on the time axis is maintained in the centre of the range window. The time interval between the transmitted pulse and this point is effectively the classical radar measurement of range.

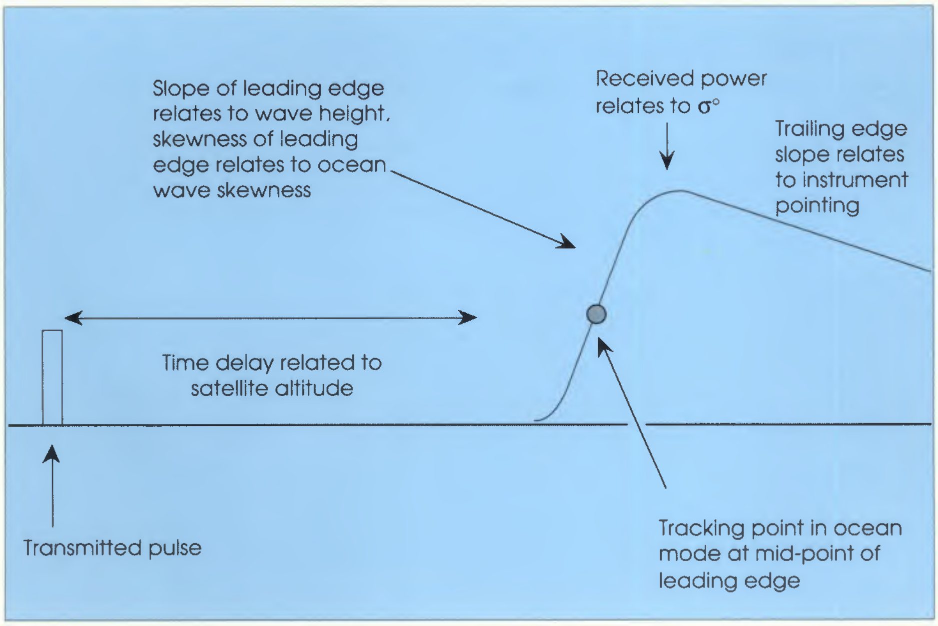


Figure 4.2. Average profile of an ocean return waveform. Over ocean surfaces, the distribution of the heights of reflecting facets is gaussian or near-gaussian, and the echo waveform has a characteristic shape that can be described analytically, as a function of the standard deviation of the distribution, which is closely related to the ocean wave height.

4.2.2 Measurements over ice

From other surfaces the waveform shape does not always conform to the simple Brown Model. The return echo from sea ice appears more specular than that from the ocean and has a peaked trace. The variability of the range measurement is of the same order as that from the ocean and this surface can therefore be tracked using the altimeter ocean tracking mode. The situation is different for continental ice, as the typical return echo has unpredictable shape and more importantly can have a larger variability in surface elevation (see Figure 4.3).

In order to maintain track of the surface, the Radar Altimeter, in ice mode, benefits from a wider observation window. The required increase in the size of the observation window

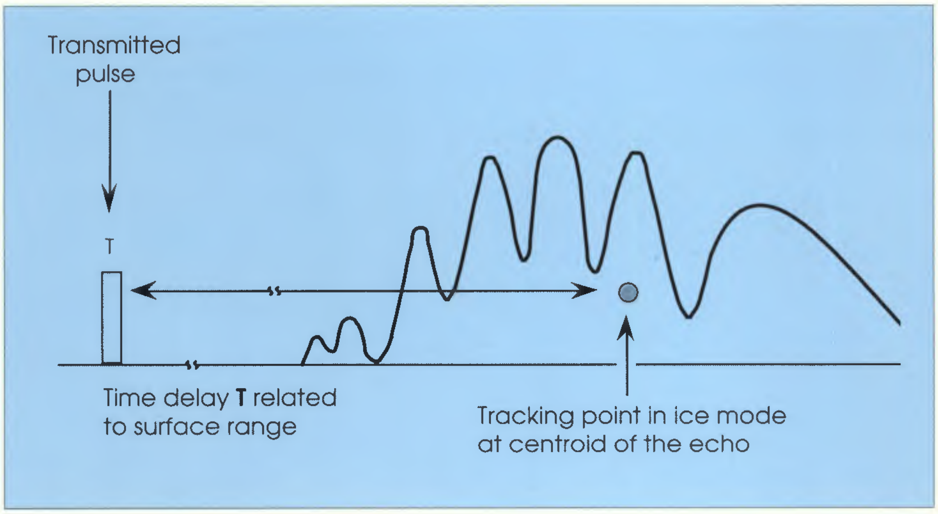


Figure 4.3. An altimeter waveform over continental ice where the typical return echo has unpredictable shape and can have a larger variability in surface elevation.

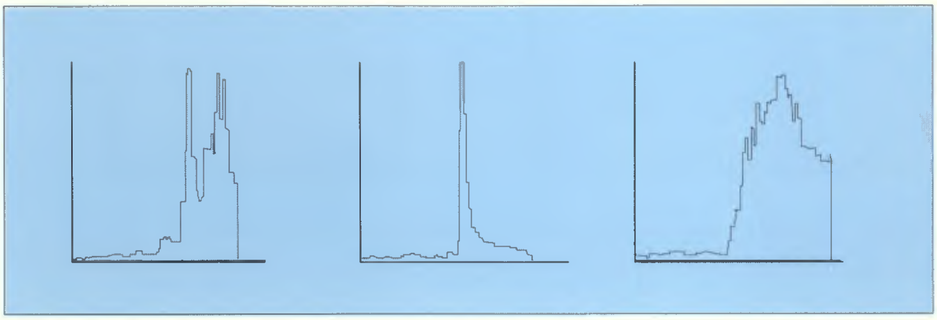
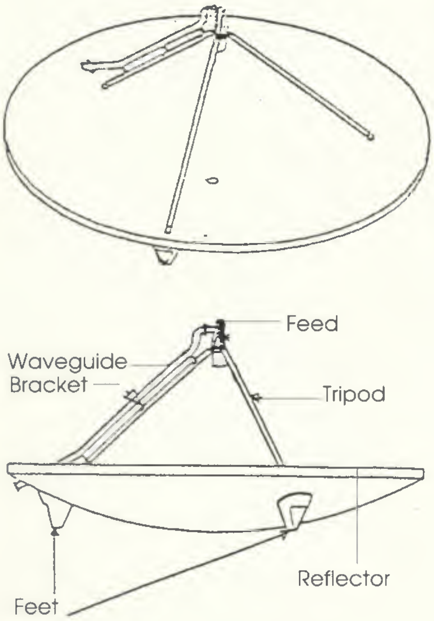


Figure 4.4. Some examples of non-ocean waveforms: land (left), sea ice (centre) and mid-ocean atolls (right).

is obtained by reducing the pulse bandwidth by a factor of four. This solution does not change the intermediate frequency (IF) bandwidth and is equivalent to enlarging the filter bandwidth without using a different filter; therefore it does not introduce major hardware changes into the system. In ice mode, tracking the echo of unpredictable shape is achieved by tracking the centre of gravity of the return pulse rather than the leading edge. This technique is used as the location of the centre of gravity is always unique, whereas there may be more than one leading edge, so avoiding any ambiguities. Some examples of non-ocean waveforms are shown in Figure 4.4.

Figure 4.5. The Radar Altimeter antenna consists of a reflector, waveguide feed, tripod plus supporting structure, horn feed and the waveguide.



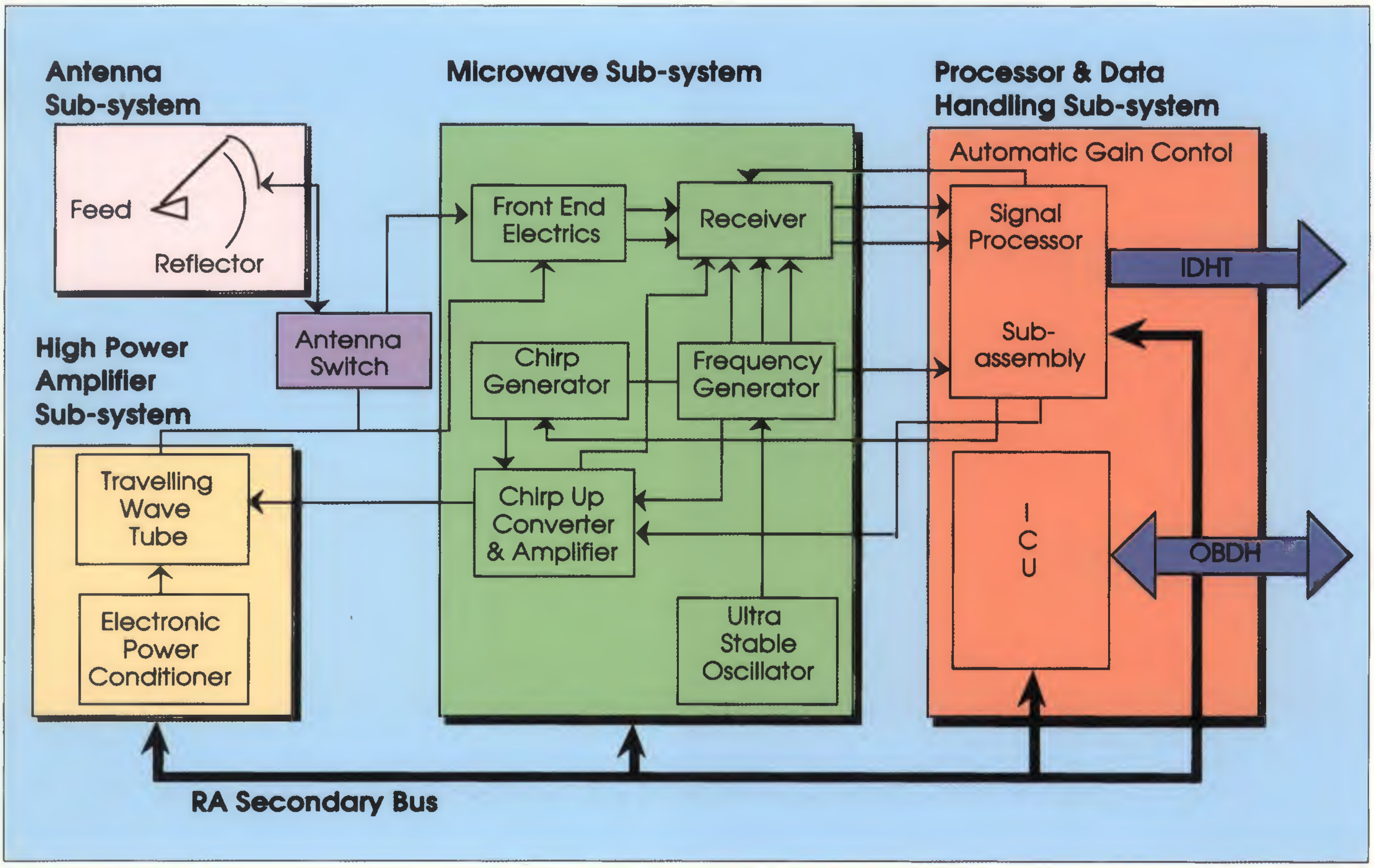
4.3 Functional description

The Radar Altimeter antenna is shown in Figure 4.5 and a block diagram illustrating the functioning of the Radar Altimeter is shown in Figure 4.6.

The Frequency Generator units provide the transmit signal at a frequency of 450 MHz to the chirp generator. This generates a chirped output with a bandwidth of 165 MHz (ocean) and 41.25 MHz (ice), gated within a pulse of 20 µs. This signal is up-converted and multiplied (using C- and L-band LO signals) to 13.8 GHz, with 330 MHz (ocean) and 82.5 MHz (ice) bandwidths. The required power output level (42 dB) is generated by the High Power Amplifier (HPA), which is realised as a Travelling Wave Tube and Electronic Power Conditioner (TWT/EPC) combination. A harmonic filter at the TWT output attenuates the harmonics of the RF signal. The transmitter signal is fed to the antenna.

The returned signal is routed to the receiver via the Front End Electronics, with an insertion loss of approximately 1.6 dB. The received chirp signal is deramped by mixing it with the LO chirp at a frequency of 15.025 GHz. The deramped output (first IF) is at 1.225 GHz. The signal is then amplified to recover the conversion loss, filtered and mixed with a second LO chirp (1.3 GHz) to provide a second IF of 75 MHz. The second IF signal is filtered, using a Surface Acoustic Wave (SAW) device with a bandwidth of 3.2 MHz and passed via a step attenuator. This provides an overall gain adjustment over a 62 dB range, implemented as two 31 dB step attentuators with a step size of 1 dB. The output is then coherently detected by a quadrature IF mixer to obtain the received signal.

Figure 4.6. Radar Altimeter instrument block diagram.



The Processor and Data Handling Sub-system (PDHSS) performs tracking and the necessary processing of the radar echoes in order to maintain the echo within the radar range-window.

In summary, the main instrument parameters and technical characteristics of the Radar Altimeter are listed below:

Mass:	≤ 96 kg
Antenna diameter:	1.2 m
DC power:	≤134.5 W
Data rate:	≤ 15 kbit/s
RF frequency:	13.8 GHz (Ku band)
Bandwidth:	ocean mode : 330 MHz ice mode : 82.5 MHz
Pulse repetition frequency:	1020 Hz
RF transmit power:	50 W
Pulse length:	20 µs chirp
Altitude measurement:	10 cm (1σ, SWH = 16 m)
Significant wave height:	0.5 m or 10% (1σ) whichever is smaller
Backscatter coefficient:	0.7 dB (1σ)
Echo waveform samples:	64 x 16 bits at 20 Hz
Beam width:	1.3°
Foot print:	16 km to 20 km (depending on sea state)

5. ALONG TRACK SCANNING RADIOMETER

5. ALONG TRACK SCANNING RADIOMETER

The ATSR consists of two instruments, an Infra-Red Radiometer (IRR) and a Microwave Sounder (MWS). Both are nationally funded experiments resulting from an ESA Announcement of Opportunity for a scientific add-on package.

The IRR is a four-channel infra-red radiometer used for measuring sea-surface temperatures (SST) and cloud-top temperatures. It was designed and constructed by a consortium, consisting of Rutherford Appleton Laboratory, Oxford University, Mullard Space Science Laboratory, UK Meteorological Office and CSIRO in Australia.

The MWS is a two channel passive radiometer designed and built under the responsibility of Centre de Recherche en Physique de l'Environnement (CRPE). The MWS is physically attached to the IRR and its data is merged with that of the IRR prior to transmission to the ground.

The ATSR (see Figure 5.1) was designed to provide the following types of data and observations:

- sea surface temperature with an absolute accuracy of better than 0.5 K and a spatial resolution of 50 km, in conditions of up to 80% cloud cover
- images of surface temperature with 1 km resolution, 500 km swath and relative accuracy around 0.1 K
- measurement of the atmospheric integrated water content (vapour and liquid) in order to compute the most problematic path delay in the signal of the Radar Altimeter.

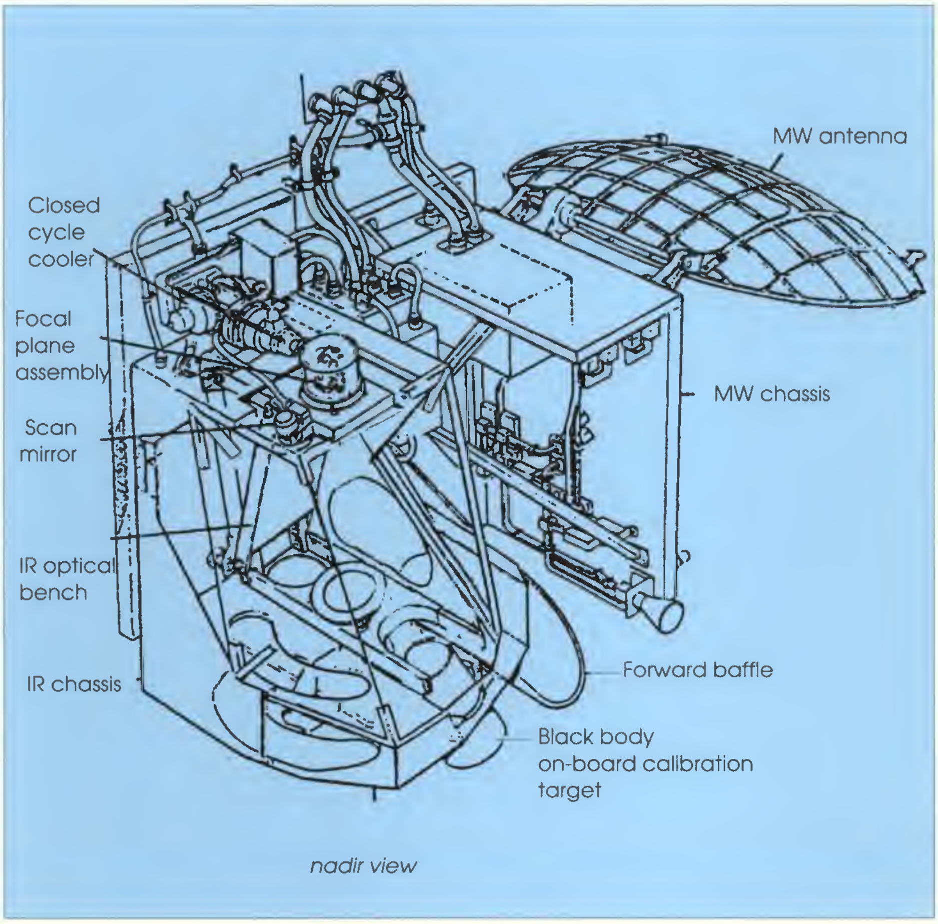
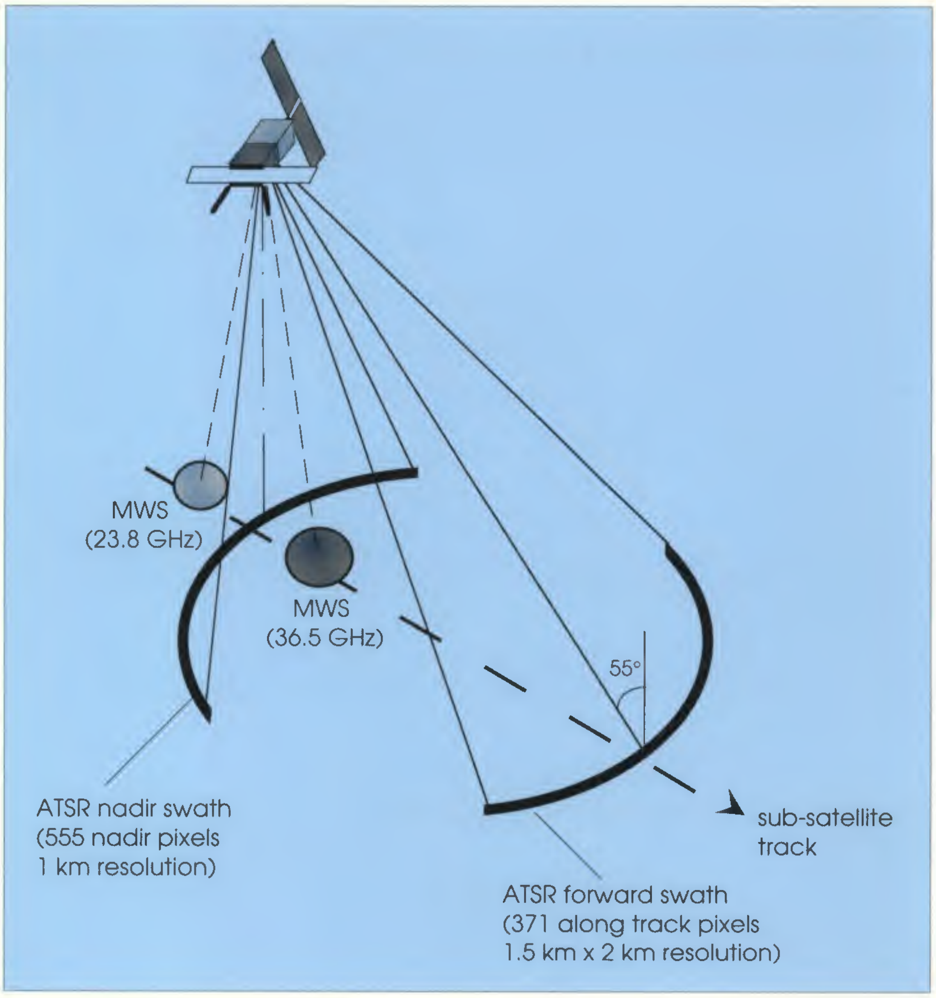


Figure 5.1. The Along Track Scanning Radiometer consists of two instruments, an Infra-red Radiometer and a Microwave Sounder.

Figure 5.2. ATSR viewing geometry. The IRR views the surface at two angles, one close to the nadir (0°) and the other at 47°. The two MWS channels collect data forward and behind the nadir point with a separation of 60 km.



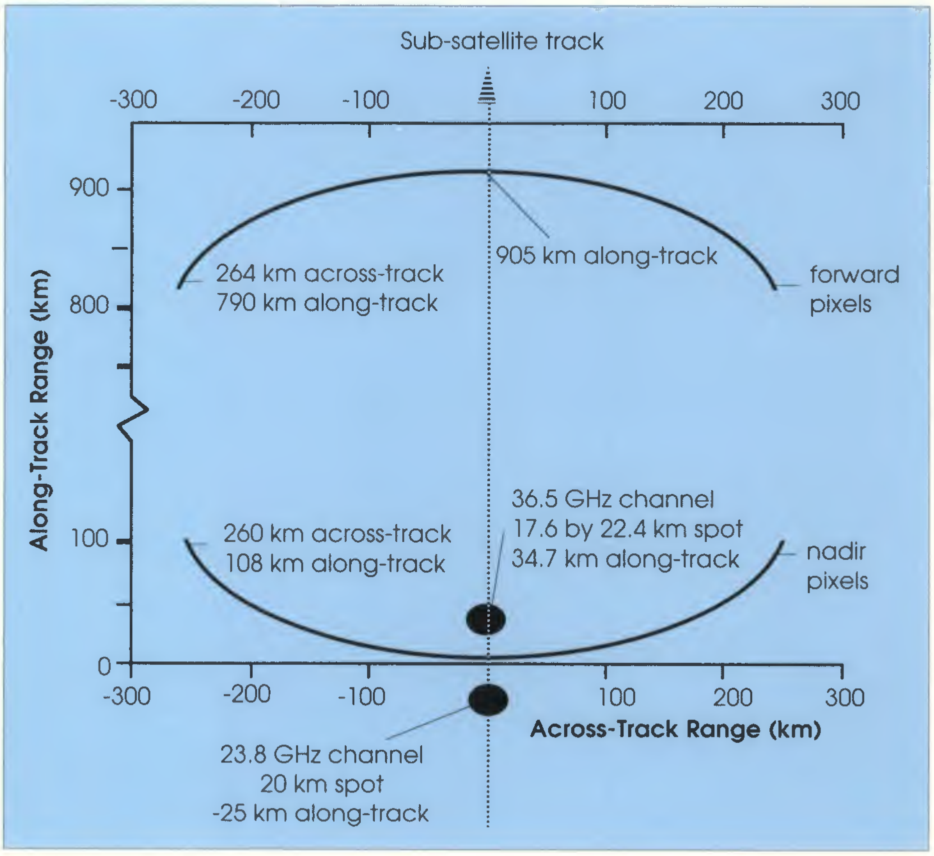


Figure 5.3. IRR scans and MWS footprints projected on to the Earth's surface. The IRR swaths are 500 km in width, and separated by about 900 km. The pixels making up the nadir view are 1 km x 1 km, while the forward view pixels are about 1.5 km x 2 km. The MWS footprints are 22.4 km x 17.6 km (forward view) and 21.2 km x 21.2 km (rear view) .

The viewing geometries for the IRR and MWS are shown in Figures 5.2 and 5.3. The novel feature of the IRR is the viewing of the same area through a near-vertical atmospheric path and an inclined path of different length some way along the satellite track. Assuming the atmosphere is horizontally stratified locally and stable during the two minutes it takes the sub-satellite point to reach the along-track point, this technique permits the atmospheric correction to be more accurately determined than by previous methods. Data from these two swaths is combined to retrieve accurate and precise atmospheric corrections for the radiometric measurements.

The swaths are produced by a scanning mirror with an axis of rotation inclined 23.45° from the vertical. Thus, the field of view by the instrument's detectors via the scan mirror is a near elliptical path on the Earth's surface. However, not all of the scan is used to collect measurement from the surface, since it is interrupted by calibration measurements. Nominally both swaths are 500 km in width, while the two views are separated by approximately 900 km in along-track distance. The pixels making up the nadir view are 1 km x 1 km, while the forward view pixels are larger, due to the viewing perspective and are about 1.5 km x 2 km. Each pixel contains measurements from three channels.

The footprints of the two MWS channels are not co-incident on the Earth's surface, as one channel views slightly forward of the nadir point and the other slightly behind, although both are on the sub-satellite track. The footprints are 22.4 km x 17.6 km (forward view) and 21.2 km x 21.2 km (rear view) with a separation of 60 km.

5.1 ATSR – Infra-red Radiometer

Although the IRR is simple in concept, it involves several technically advanced features. On-board calibration, which must be achieved with great precision, is carried out by the incorporation of two controlled reference targets (black bodies) into the instrument scan pattern. The black bodies have been carefully designed for high emissivity, uniformity, stability and precise monitoring. The other advanced technical feature is the use of a new mechanical cooler mechanism which ensures that the detectors reach temperatures of as low as 77 K, without the use of large and cumbersome passive radiators.

The IRR uses spectral channels which are very similar to those on recent NOAA meteorological satellites, with many improvements in accuracy. As an imaging radiometer its four channels are fully co-registered by a common fieldstop and sense at wavelengths of 1.6, 3.7, 10.8 and 12 µm, defined by beam splitters and multi-layer interference filters. The instrument is housed in a carbon-fibre composite structure which ensures that the optical alignment is maintained. A schematic view of the IRR is shown in Figure 5.4.

The main technical characteristics of the IRR are:

Objective:	sea surface temperature, cloud observations, land and ice surface emissivity
Spectral channels:	4 co-registered channels at 1.6, 3.7, 10.8 and 12 µm (only 3 channels operational at the same time – 10.8, 12 and either 1.6 or 3.7)
IFOV:	1 km x 1 km (nadir), 1.5 km x 2 km (forward view)
Swath width:	500 km
Scanning method:	mechanical – rotating plane mirror, providing two views (nadir and 47° to nadir) about 900 km apart; and field of view conically scanned
Detector:	single element HgCdTe (10.8 and 12) and InSb (1.6 and 3.7)
Cooler:	Stirling cycle – ensures temperatures as low as 77 K
Radiometric precision:	<0.1 K
Predicted SST accuracy:	0.5 K over a 50 km x 50 km area with 80% cloud cover
Calibration:	two on-board black bodies referenced in the scan pattern
Instrument housing:	carbon fibre composite structure featuring an independent optical bench ensuring optical alignment

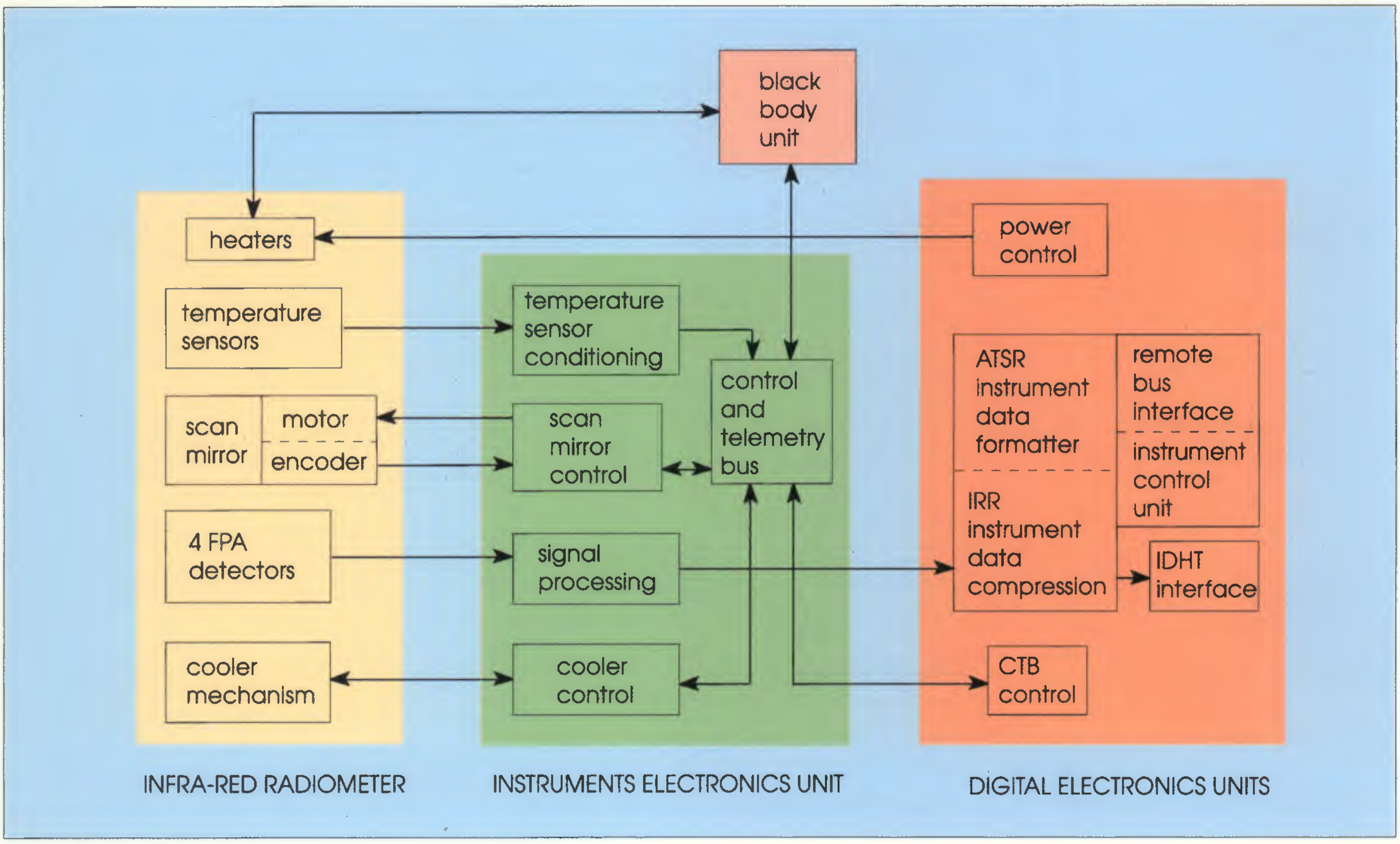


Figure 5.4. Schematic of the ATSR showing the IRR, the instrument electronics and digital electronics units and the black body calibration unit.

Radiation from the Earth's surface is directed by an inclined rotating flat scan mirror on to an off-axis paraboloid (see Figure 5.5). The field stop is positioned at the focus of the paraboloid to define the field of view of the instrument. Beyond the field stop the beam is separated into four components of different spectral bands. Three of these component beams (corresponding to the 3.55 to 3.93 μm, the 10.4 to 11.3 μm and the 11.5 to 12.5 μm bands respectively) are re-imaged by three off-axis ellipsoidal mirrors on to separate detectors. The fourth beam (1.58 to 1.64 μm) is re-imaged by an aspheric silicon lens on to its detector. The 1.6 μm channel was added to the original three channel radiometer to improve sea surface temperature retrievals by detecting cloud during day-time operation of the IRR. To minimise the cost and design effort of adding this channel the same detector/pre-amplifier combination has been used as for the 3.7 μm channel. Therefore, either the 1.6 μm or the 3.7 μm channel can be operational at any one time.

Details of the four spectral band detectors are provided below:

Channel	1.6 μm	3.7 μm	10.8 μm	12 μm
Waveband: (μm)	1.58-1.64	3.55-3.93	10.4-11.3	11.5-12.5
Detector:	Photovoltaic InSb	Photovoltaic InSb	Photoconductive HgCdTe	Photoconductive HgCdTe
Detector size: (μm square)	200	200	190	190
Condensing optics:	Aspheric Si lens	Off-axis ellipsoid mirror	Off-axis ellipsoid mirror	Off-axis ellipsoid mirror

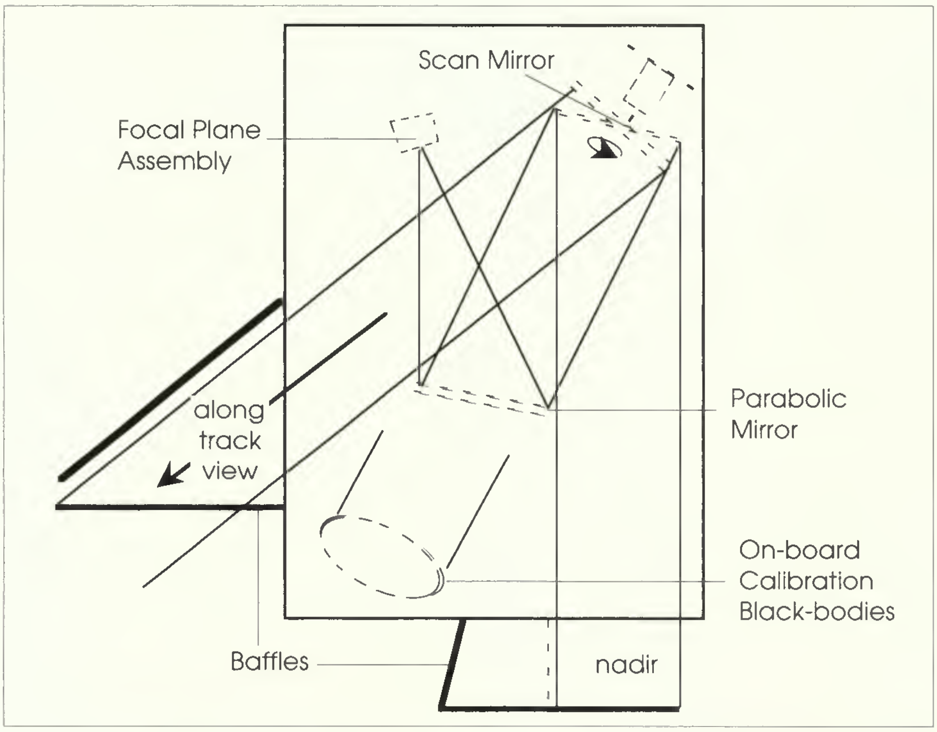


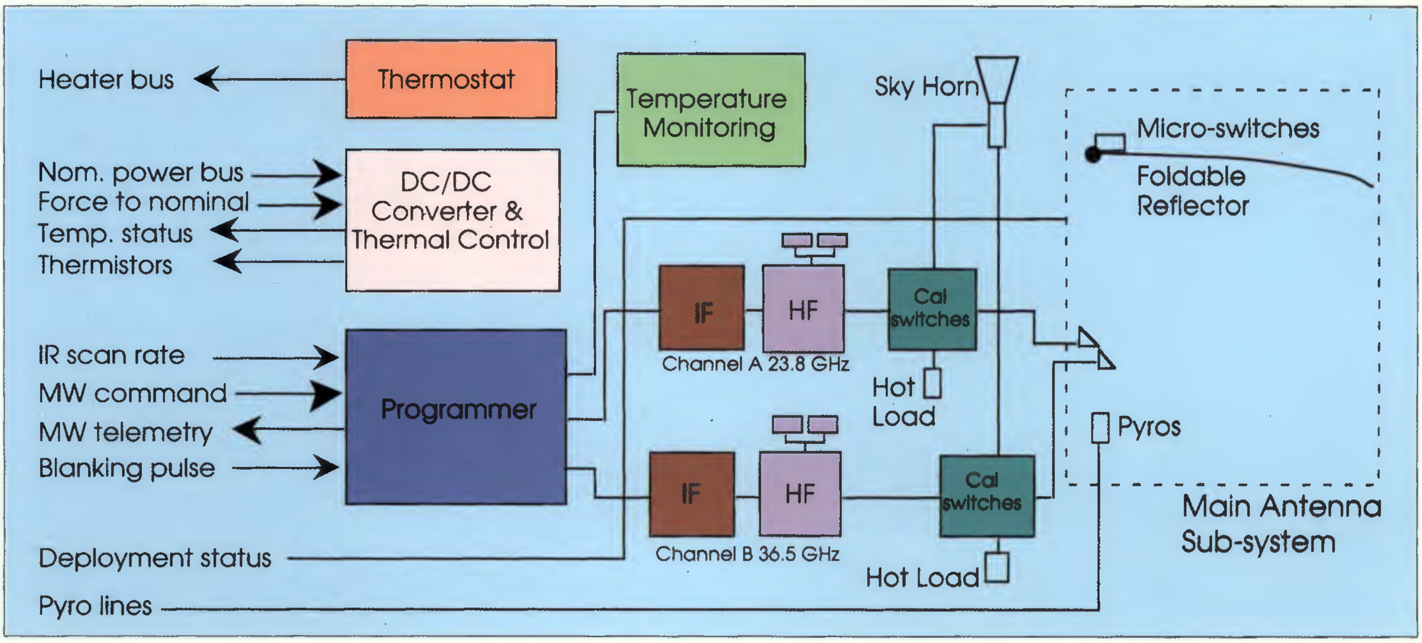
Figure 5.5. ATSR fore-optics. Radiation from the Earth's surface, viewed to nadir and along track, is directed by an inclined rotating flat scan mirror via an off-axis parabolic mirror to the focal plane assembly.

5.2 ATSR – Microwave Sounder

The MWS (Figure 5.6) has two channels, at 23.8 GHz and 36.5 GHz, both with a 200 MHz bandwidth. Each channel operates in the Dicke mode, comparing the antenna temperature to an internal reference temperature at a switching frequency of 1 kHz. The output signal from the synchronous detector is integrated and sampled every 150 ms (synchronised with the IRR scan rate) and transmitted to the ground as a numerical count, together with the reference load temperature and various internal temperatures.

Further integration is possible during processing to improve the radiometric resolution. Internal calibration is done by connecting the antenna input, either to a sky horn receiving the cold sky background radiation, or to a second internal reference load. The main antenna is an offset parabolic reflector antenna, with one feed horn for each frequency. Each channel is then pointing at an angle close to the nadir; the 36.5 GHz channel in the forward direction, the 23.8 GHz in the backward direction. Each channel is linearly polarised, in the orbit plane (V polarisation).

Figure 5.6. Schematic of the MWS. Internal calibration is achieved by connecting the antenna input, either to a sky horn receiving the cold sky background radiation, or to a second internal reference load.



The antenna is an 60 cm Cassegrain offset parabolic reflector with the following characteristics:

Channel:	23.8 GHz	36.5 GHz
Pointing angle:	-1.93°	2.50°
Measured gain:	40.62 dB	42.0 dB
3 dB aperture (along track/cross track):	1.52° / 1.51°	1.61° / 1.37°
3 dB footprint (along track/cross track):	21.2 km / 21.2 km	22.4 km / 17.6 km
20 dB aperture (max):	4.2°	4.1°
Main lobe efficiency:	0.91	0.91
First secondary lobe:	-24 dB	-35 dB

Reflector projected diameter:	0.60 m
Focal length:	0.35 m
Antenna:	60 cm off-axis paraboloid Cassegrain
Receiver:	Dicke
Calibration:	ambient loads within the instrument, consisting of a terminated waveguide and a set of skyhorns

The 7.5 cm skyhorn has the following characteristics:

Channel:	23.8 GHz	36.5 GHz
3 dB aperture:	15° x 15°	14.1° x 19°
20 dB aperture:	50°	50 x 36°
Measured gain:	21.2 dB	20.9 dB

6. PRECISE ORBIT DETERMINATION INSTRUMENTATION

6. PRECISE ORBIT DETERMINATION INSTRUMENTATION

The ERS-1 sensor complement includes two instruments – the Precise Range and Range-rate Equipment (PRARE) and the Laser Retro-reflectors (LRR) (see Figure 6.1) to provide precise orbit determination for the referencing of height measurements made by the Radar Altimeter. The PRARE suffered a fatal failure, due to radiation damage to its Random Access Memory, after some five hours of nominal operations from switch on. Although PRARE data will not be received from ERS-1 during its lifetime a description of the instrument is included here for completeness. The PRARE system is capable of incorporation, with minimum modification, in other spacecraft in a variety of orbits and an improved version is being built for ERS-2.

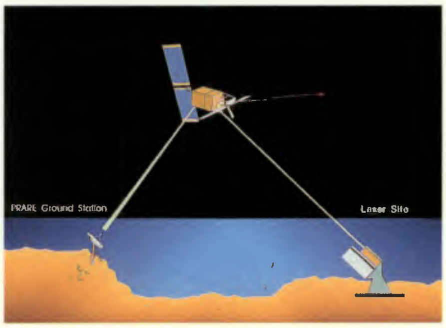


Figure 6.1. PRARE and Laser Retro-reflectors range measurement.

6.1 Precise Range and Range-rate Equipment

The PRARE is an 'Announcement of Opportunity' instrument. As the national experiment of the Federal Republic of Germany, it was developed by the Institut für Navigation (INS) at the University of Stuttgart, Kayser-Threde GmbH, and the Deutsches Geodätisches Forschungsinstitut (DGFI). It is a satellite tracking system to perform two-way microwave range and range-rate measurements to ground based transponder stations. The PRARE system within the ERS-1 mission consists of the following elements:

- space segment on-board ERS-1
- ground segment including a number of ground stations operated all over the world, a master station located in Oberpfaffenhofen, Germany, a command station in Stuttgart, Germany, one calibration station in Wettzell, Germany and a backup master station in Tromsø, Norway.

The system was designed to:

- provide precise satellite-to-ground or satellite-to-satellite range and range-rate information in all-weathers
- guarantee very reliable measurements through cross-checks and calibration procedures
- ensure highly effective operation of the ground segment through data collection and dissemination via the satellite itself and control of the global network via one central ground station
- allow fast product generation at an archiving, processing and distribution centre.

The PRARE measurement principle involves two signals sent from the sensor on-board the satellite, one signal in the S-band (2.2 GHz) and the other in the X-band (8.5 GHz). Both signals are modulated with a PRN code (pseudo random noise). The time delay in the reception of the two simultaneously emitted signals is measured at the ground station with high accuracy (<1 ns) and re-transmitted to the on-board memory for ionospheric correction of the data. Ground station collection of meteorological data allows correction for tropospheric refraction. The PRARE technical characteristics are listed below.

Down-link	
X-band:	8489 MHz 10 Mbit/s PSK (10 MHz bandwidth) 1 W transmit power
S-band:	2248 MHz 1 Mbit/s PSK (1 MHz bandwidth) 1 W transmit power
Up-link	
X-band:	7225.296 MHz 10 Mbit/s PSK (10 MHz bandwidth)
Ground transponder:	60 cm parabolic dish, 2 W transmit power
Satellite antenna:	Cross dipoles at X- and S-band
Ranging accuracy:	5 – 10 cm (predicted)

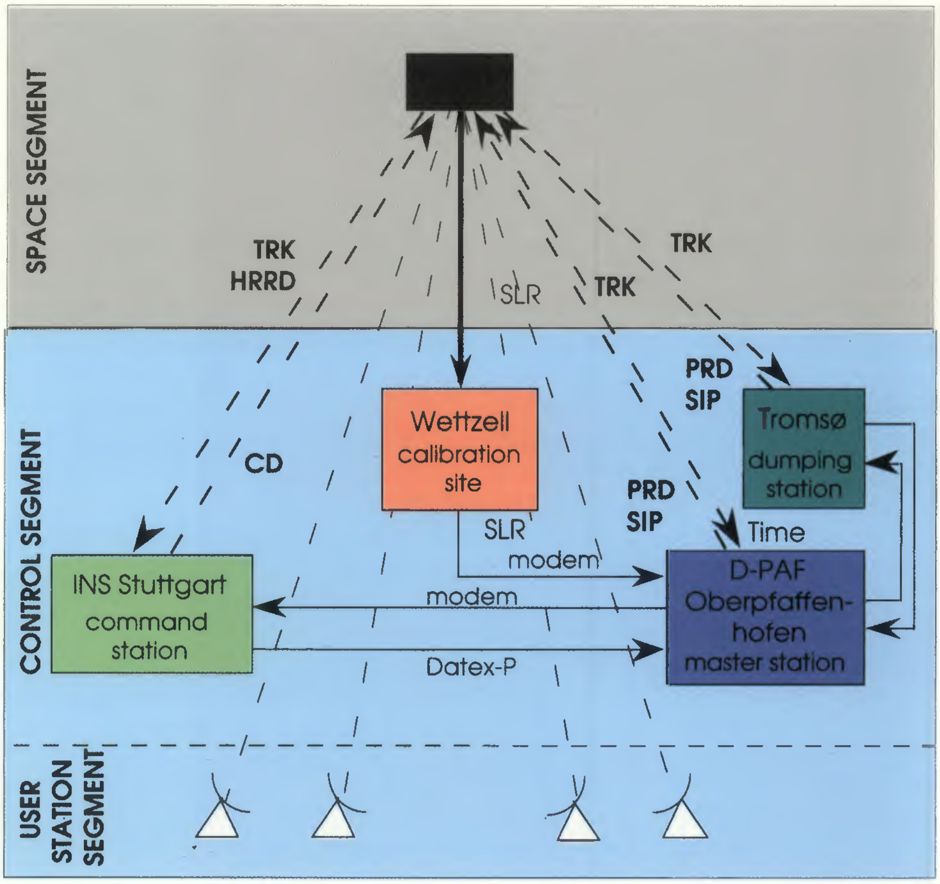
The PRARE satellite package consists of a box 400 mm x 240 mm x 180 mm, weighing 17 kg, which requires 27 W raw electric power during operation and 9 W in stand-by mode. The antenna consists of two pairs of crossed dipoles. The instrument is integrated inside the platform, with the dipoles on the platform's Earth facing surface. The instrument is almost self-contained, requiring minimum interface to the host satellite, the power supply, the command status link and the mechanical/thermal subsystems. It contains, not only the tracking functions, but also its own data transmission and data memory.

Transmission of PRN-coded X-band signal starts as soon as the satellite is within line of sight of the ground station (above 20° elevation angle), with the precise ranging beginning above 40° elevation angle. The received X-band signal is transposed to 7.2 GHz, coherently modulated with the regenerated PRN code and meteorological data acquired by the ground station prior to re-transmission to the satellite. In the space segment the PRN-code is fed into a correlator to determine the two-way slant range between the satellite and the ground station and the received carrier frequency evaluated in a doppler counter to derive relative velocity of the spacecraft to the ground station. Both measurements and the ground station data are stored in the on-board memory. Four independent correlators and four doppler counters in the space segment allow simultaneous measurements to up to four ground stations in a code multiplex mode.

The PRARE system consists of the following ground segment components:

- a control segment consisting of a command station, master station, calibration station and additional dumping station
- a user station segment consisting of a number of low-cost tracking ground stations requiring minimum attention, which are small in size, highly mobile and have a low power consumption.

The concept of the PRARE space and ground segments is shown In Figure 6.2. The command station's prime task is to receive the stored tracking and corrective data and the high rate real time data from the satellite , to perform time synchronisation and to transmit



LEGEND
CD : control data
HRRD : high rate real time data
PRD : predictions
SIP : station interrogation plan
SLR : satellite laser ranging
TRK : tracking and corrective data dump

Figure 6.2. PRARE space and ground segments.

control data to the satellite. The command station at the Institut für Navigation, Stuttgart is linked directly to the master station, which processes the PRARE tracking and corrective data on a daily basis. The master station (at the D-PAF in Oberpfaffenhofen) provides the system support data and controls the operation of the PRARE ground stations. Both the master station and the back-up and dumping station at Tromsø receive tracking and corrective data from the satellite and send predictions to the satellite together with the station interrogation plan (SIP). A calibration site is located at Wettzell.

There are two types of tracking user stations – primary and secondary. The primary ground stations operate as regenerative coherent transponders and contribute the space-ground-space range and doppler data for precise orbit and station position determination. Secondary ground stations operate as 'listen-only' stations, using the one-way doppler signal in S- or S/X-band and the broadcast satellite ephemerides for on-line position determination at the site. The S-band receive-only stations are of particular interest to many users due to their simple design with an omni-directional antenna and their exceptional low cost. The relative positioning in centimetre accuracies which can be derived with these stations, in particular when tracking in an interferometric mode, will be appropriate for many geodetic/geodynamic applications.

6.2 Laser Retro-reflectors

The Laser Retro-reflectors (LRR) are used as a target by ground-based laser ranging stations. The operating principle involves the measurement of the time of a round trip of laser pulses reflected from an array of corner cubes mounted on the Earth-facing side of ERS-1's Payload Electronics Module (see Figure 6.3). These measurements allow:

- calibration of the Radar Altimeter altitude measurement to ±10 cm
- improvement of the satellite orbit determination ensuring the production of a global ephemeris accurate to better than 0.5 m for the radial component.

The technical characteristics of the LRR are summarised below:

Wavelength:	350 nm to 800 nm optimised for 532 nm
Efficiency*:	≥ 0.1 end of life
Reflection coefficient*:	≥ 0.75 end of life
Field of View:	elevation half cone angle 60°, azimuth 360°
Diameter:	≤ 20 cm

* *performances not guaranteed at 350 nm*

Figure 6.3. The Laser Retro-reflectors. Each corner cube is individually made, to compensate for satellite motion in reflecting incident laser energy back exactly along its incoming path.

7. GROUND SEGMENT FACILITIES

7. GROUND SEGMENT FACILITIES

The ERS-1 programme has been designed to serve a large variety of users with a comprehensive range of products and services. In response to this, and other very challenging mission objectives, the ERS-1 ground segment has been established using a set of distributed facilities with central monitoring and control.

The ground segment consists of an ensemble of facilities responsible for the acquisition, processing, distribution and archiving of the satellite data and of the derived products. Several factors have influenced the design of the ERS-1 ground segment:

- the roles of the ESA establishments
- the technical constraints of the satellite on data acquisition
- specific user requirements for fast delivery services
- national expertise in particular scientific fields
- the desire to provide a primary user gateway to the system
- the need for a high level of automation in routine operations.

The responsibilities of the ESA establishments have influenced, to some extent, the distribution of the various tasks. The user interface and exploitation of the payload data has been implemented within the Earthnet ERS-1 Central Facility (EECF) at ESRIN in Frascati, Italy by the Earthnet Programme Office (EPO), while the satellite planning and control functions, including the control of the Kiruna station are the responsibility of the Mission Management and Control Centre (MMCC) at ESOC in Darmstadt, Germany.

The characteristics of the ERS-1 space segment in terms of its multi-sensor payload, orbit configurations and power requirements have imposed the implementation of a network of ground stations around the world to acquire the high bit rate SAR data (for which only direct readout is possible). In addition facilities had to be provided to permit the downloading, once per orbit, of the on-board recorded low bit rate data.

Specific user requirements have called for the implementation of specific processing tools and fast delivery services at the ground stations operated by or for ESA to allow user centres to be furnished quickly with selected data products.

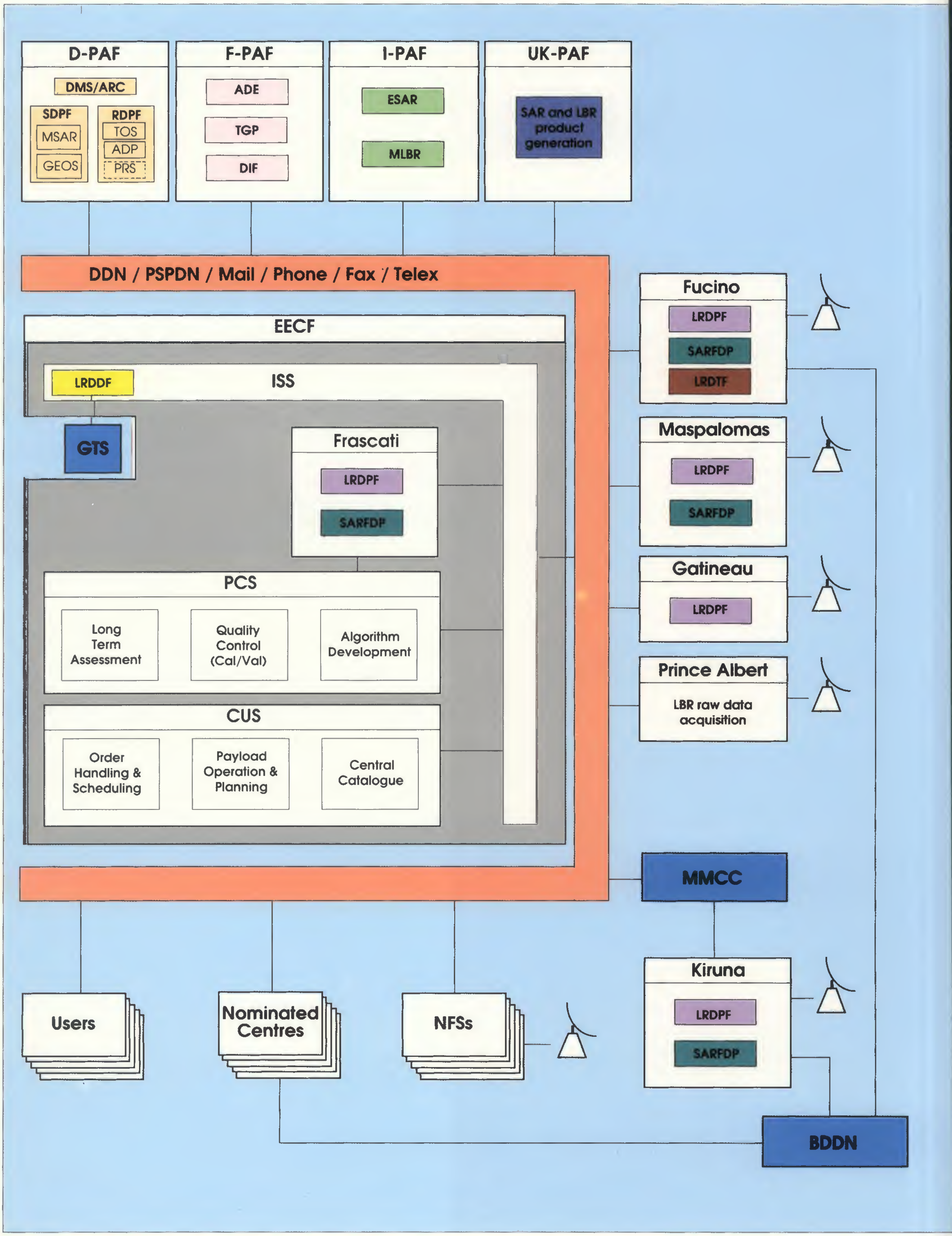
An important feature of the ground segment concept is that various user interfaces are considered key components. In practice the Central User Service (CUS) of the EECF will constitute the primary user gateway to the system.

Products will be disseminated either via fast delivery of selected products to nationally nominated user centres for operational applications or by off-line delivery to individual end users from the Processing and Archiving Facilities (PAFs).

The ERS-1 ground segment (see Figure 7.1) has been implemented as a distributed set of specialised facilities with centralised key functions for monitoring and control. The various elements of the ground segment are described in the remainder of this section, while their functions of relevance to users are covered in Chapter 8.

7.1 Earthnet ERS-1 Central Facility

Within the ESA Directorate for the Observation of the Earth and its Environment, the Earthnet Programme Office at the European Space Research Institute (ESRIN) in Frascati, Italy (Figure 7.2) has been entrusted with developing the facility, which will concentrate the services for the user community. Known as the Earthnet ERS-1 Central Facility (EECF) it provides the external users' gateway to the ERS-1 system (Figure 7.3) and one of its main tasks is to aid the exploitation of the ERS payload data.


D-PAF
DMS/ARC
SDPF
MSAR
GEOS
RDPF
TOS
ADP
PRS
F-PAF
ADE
TGP
DIF
I-PAF
ESAR
MLBR
UK-PAF
SAR and LBR product generation
DDN / PSPDN / Mail / Phone / Fax / Telex
EECF
LRDDF
ISS
GTS
Frascati
LRDPF
SARFDP
PCS
Long Term Assessment
Quality Control (Cal/Val)
Algorithm Development
CUS
Order Handling & Scheduling
Payload Operation & Planning
Central Catalogue
Fucino
LRDPF
SARFDP
LRDTF
Maspalomas
LRDPF
SARFDP
Gatineau
LRDPF
Prince Albert
LBR raw data acquisition
MMCC
Kiruna
LRDPF
SARFDP
Users
Nominated Centres
NFSs
BDDN

Acronyms

D-PAF	**German Processing and Archiving Facility**
DMS/ARC	Data Management System / Archives
SDPF	SAR Data Processing Facility
MSAR	Multi-sensor SAR Processor
GEOS	Geocoding System
RDPF	RAT (Radar Altimeter) Data Processing Facility
TOS	Tracking Data and Orbit Processing System
ADP	Altimeter Data Processing System
PRS	PRARE System
F-PAF	**French Processing and Archiving Facility**
ADE	Atelier Donnees Entree Sous-système
TGP	Traitement et Gestion des Produits Sous-système
DIF	Diffusion Sous-système
I-PAF	**Italian Processing and Archiving Facility**
ESAR	ERS-1 SAR Facility
MLBR	Mediterranean Low Bit Rate Processing Facility
UK-PAF	**UK Processing and Archiving Facility**
EECF	**Earthnet ERS-1 Central Facility**
ISS	**Interface Sub-set**
LRDDF	Low Rate Data Dissemination Facility
PCS	**Product Control Service**
CUS	**Central User Service**
MMCC	**Mission Management and Control Centre**
NFS	**National and Foreign Stations**
BDDN	**Broad-band Data Dissemination Network**
Receiving Stations	
LRDPF	Low Rate Data Processing Facility
SARFDP	SAR Fast Delivery Processing Facility
LRDTF	Low Rate Data Transcription Facility
DDN	**Data Dissemination Network**
PSPDN	**Packet-Switched Public Data Network**
GTS	**Global Telecommunication System**

Figure 7.1. ERS-1 ground segment facilities, responsible for the acquisition, processing, distribution and archiving of the satellite data and its derived products.

The EECF drives the operations of most of the ground segment facilities, including provision of activity schedules to the ground stations and processing and archiving centres. From the user's point of view, the EECF offers a set of system services to provide customers with an insight into the global catalogue of data products and the schedule for future operations, as well as product ordering services. The EECF comprises three main elements:

- Central User Service (CUS)
- Interface Subset (ISS)
- Product Control Service (PCS).

These services are explained in more detail in Chapter 8.

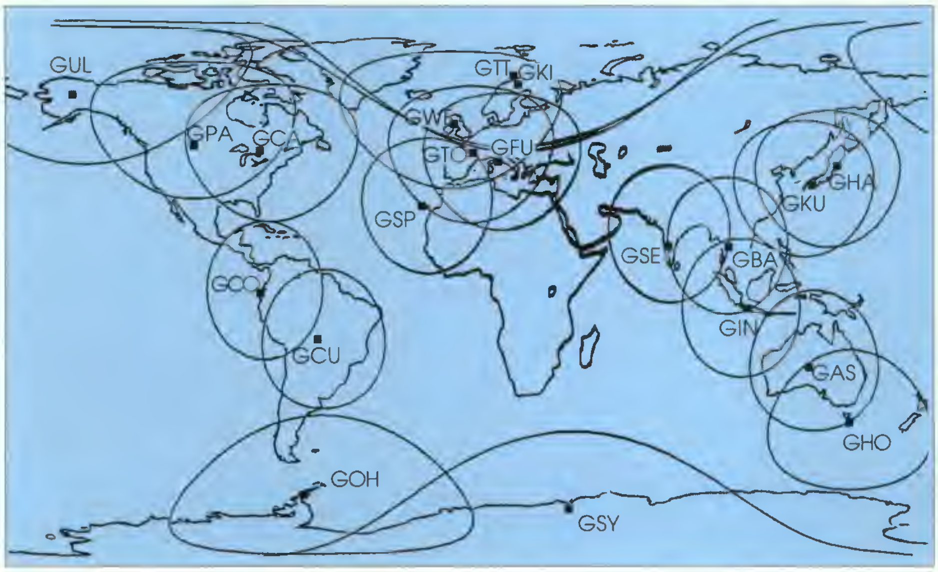
7.2 The ground stations

The ERS-1 orbit – near-polar and sun-synchronous and the need for direct readout of the SAR telemetry have necessitated the involvement of a number of ground stations around the world. The ground stations available for ERS-1 data acquisition are shown in Figure 7.4 and can be classified into two categories: ESA network and national and foreign facilities.

In addition the ESA network is divided into types related to their ownership and the facility controlling its operation (see below).

Figure 7.2. An aerial view of the ESRIN establishment, Frascati. Italy.

Figure 7.3. The Earthnet ERS-1 Central Facility of the Payload Data Co-ordination Centre at ESRIN.



GAS – Alice Springs, Australia
GBA – Bangkok, Thailand
GCA – Gatineau, Canada
GCO – Cotopaxi, Equador
GCU – Cuiba, Brazil
GFU – Fucino, Italy
GHA – Hatoyama, Japan
GHO – Hobart, Australia
GIN – Jakarta, Indonesia
GKI – Kiruna, Sweden
GKU – Kumamoto, Japan
GOH – O'Higgins, Antarctica
GPA – Prince Albert, Canada
GSE – Hyderabad, India
GSP – Maspalomas, Canaries
GSY – Syowa, Antarctica
GTO – Aussaguel, France
GTT – Tromsø, Norway
GUL – Fairbanks, Alaska
GWF – West Freugh, Scotland

Figure 7.4. ERS-1 ground stations and their coverages.

7.2.1 ESA ground stations

The ESA ground station (see Figure 7.5) network consists of:

- Kiruna, Sweden
- Fucino, Italy
- Maspalomas, Canary Islands
- Gatineau, Canada
- Prince Albert, Canada.

Except for the Kiruna station (also known as Salmijaervi), which is fully dedicated to ERS operations, the stations of the ESA network are owned by national entities and are operated as multi-mission stations hosting ESA facilities for ERS operations. Kiruna is controlled by the Mission Management Control Centre (see Section 7.4), while the others are under the control of the Earthnet Programme Office. In addition there is a reference processing system (see Section 8.1.3) in Frascati, Italy.

7.2.2 National and Foreign Stations

In addition to the ESA network, some national (belonging to countries participating in the ERS-1 programme) and some foreign (non-participating countries) ground stations are covered by a memorandum of understanding (MOU) to acquire ERS-1 data (see Figure 7.4). Of particular importance are the Antarctic ERS facilities installed at the Syowa and O'Higgins bases by Japan and Germany, respectively, as they permit the acquisition of repetitive sets of SAR data in areas of high scientific and application interest, covering more than two-thirds of the southern polar region.

Figure 7.5. ESA ground stations – Kiruna (left), Fucino (centre) and Maspalomas (right).

Figure 7.6. The four ESA PAFs in Germany (top left), France (top right), Italy (bottom left) and UK (bottom right).

7.3 Processing and Archiving Facilities

When the ground segment was being defined it became apparent that very specialised expertise in several areas was needed to ensure good exploitation of the data generated by ERS-1. Subsequently four ESA member states proposed joint national/ESA endeavours, which came to be known as Processing and Archiving Facilities or by their acronym 'PAFs', which are based at existing organisations well-established in particular fields of science and applications.

The four PAFs (Figure 7.6) are managed and located as follows:

• D-PAF	Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR), in Oberpfaffenhofen, Germany
• F-PAF	Institut Francais de Recherche pour l'Exploitation de la Mer (IFREMER), in Brest, France
• I-PAF	Agenzia Spaziale Italiana (ASI), in Matera, Italy
• UK-PAF	Defence Research Agency (DRA) in Farnborough, United Kingdom.

The data services provided by the PAFs are explained in Chapter 8.

7.4 Mission Management and Control Centre

Historically all of the tasks associated with monitoring and controlling ESA satellites have been carried out at the European Space Operations Centre (ESOC) in Darmstadt, Germany, thus it was here that the ERS Mission Management and Control Centre (MMCC) was established (Figure 7.7).

The MMCC undertakes the following tasks:

- monitoring and control of the satellite and its payload, including correct execution of the operations plan uplinked to the satellite on a daily basis
- monitoring and control of the Kiruna ground station, including acquisition of the satellite telemetry, uplinking of telecommands and fast delivery processing elements
- generation of the detailed mission operations plans, based on the satellite status and on-board resources and the payload exploitation plans received from the EECF
- system software maintenance for the spacecraft and the Kiruna station
- generation of the predicted orbit, needed to prepare the operations plan for the satellite and ground stations, calculation of the actual (restituted) orbit, and overall flight dynamics services.

The MMCC is linked to the EECF by a high speed link and to the Kiruna station.

Figure 7.7. Main control room at the European Space Operations Centre (ESOC) in Darmstadt, Germany.

7.5 Data dissemination facilities

ERS data will be disseminated via various facilities at transmission and reception sites within the ground segment using satellite and telecommunication links. The Low Bit Rate Fast Delivery Products (LBRFDP) generated by the ESA ground stations will be centralised at the EECF (on the ISS) and re-distributed to nationally nominated user centres via standard land lines. An alternative of using a satellite link at low rate, e.g. 64 kbits/s, for quick dissemination, at least in Europe, is also being considered. One of the ERS-1 mission objectives is to provide to the user community FD products within three hours from instrument observation. The nominal solution for the distribution of FD products is to use public network land lines. However, for the distribution of SAR products the capacity of the land lines is insufficient and satellite links are deemed necessary.

The Broad-band Data Dissemination Network (BDDN) system is designed to transmit high rate FD products from the Fucino and Kiruna ground stations (and possibly Maspalomas in the near future) to nominated receiving stations by means of a satellite telecommunication channel (see Figure 7.1). The EECF is connected with these ESA ground stations and appropriate user centres via low speed land lines or equipment connections. Both Kiruna and Fucino ground stations are equipped with a SAR FD processor and with monitoring and control sub-systems for FD products distribution. In addition, the transmit stations will be connected through standard low speed lines with the EECF for schedule and control purposes. The BDDN Network Supervision Centre has been established at ESRIN and ensures scheduling and monitoring of SAR FDP transmission based on CUS inputs upon user requests.

8. DATA SERVICES

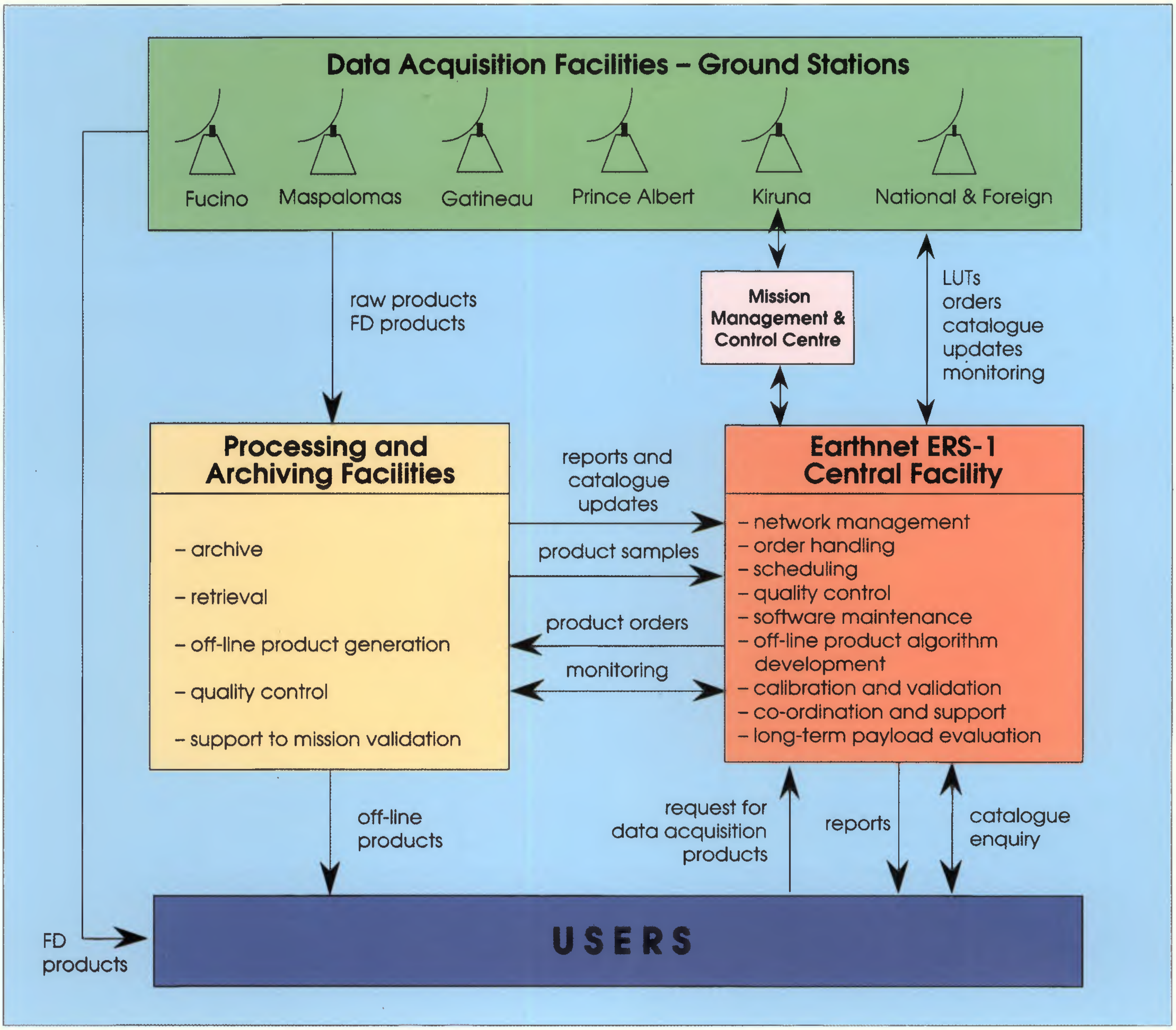
8. DATA SERVICES

The ground segment is characterised by the de-centralisation of archiving and precision processing functions to national organisations and the centralisation of monitoring and control functions at ESA Establishments. The Earthnet ERS-1 Central Facility (EECF), located at ESRIN in Frascati, Italy, operates as a real-time management system dedicated to the supervision of all activities concerning the ERS-1 mission, data acquisition, product generation, and dissemination of data and products to the user community. For users the ERS-1 ground segment consists of a number of data services (see Figure 8.1), namely:

- user services co-ordinated at the EECF
- data acquisition, processing and distribution of fast delivery products
- archiving and retrieval of products and telemetry data
- off-line product generation.

This chapter only describes the functions of the data services and not how a user interfaces with them, which is covered by the ERS-1 User Handbook.

Figure 8.1. ERS ground segment data services and data flow.



8.1 User services

The EECF provides three main services as shown in Figure 8.2, namely:

- Central User Service (CUS)
- Interface Sub-set (ISS)
- Product Control Service (PCS)

Each is addressed briefly here to show their importance within the ERS ground segment to the fulfilment of the mission objectives and the optimum exploitation of ERS data.

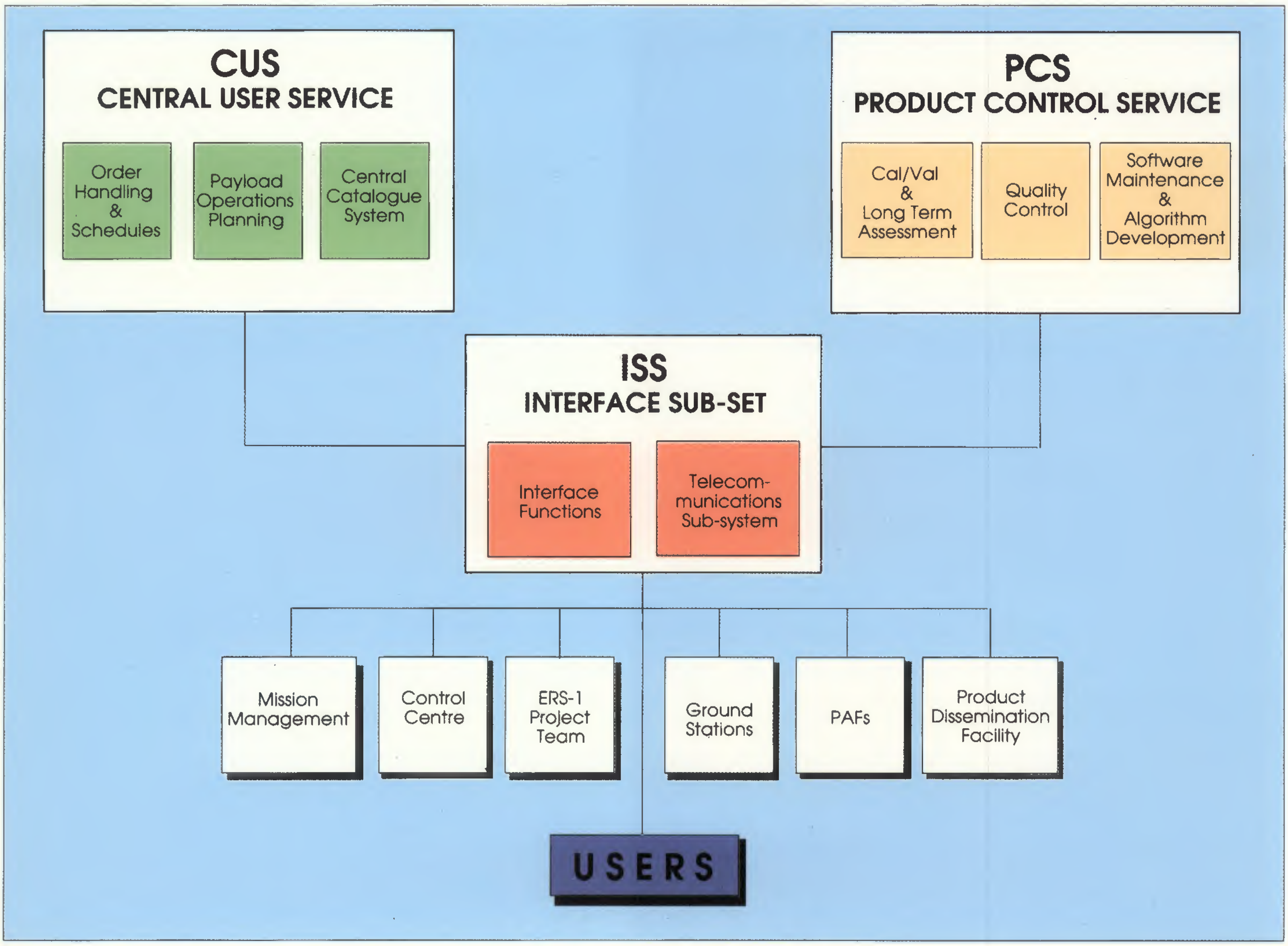
8.1.1 Central User Service

The CUS is designed as a real-time management system dedicated to the planning and supervision of all data acquisition and archiving, product generation and dissemination activities. It incorporates a variety of functions dedicated to providing a user-friendly interface between the ERS-1 system and its users, including catering for user's needs in terms of information and products and translating those needs into system operating plans and product orders.

To support these tasks the CUS includes the following user services:

- an on-line worldwide central catalogue of ERS raw data and selected products
- an on-line facility for investigating the payload operations plans
- an on-line facility for accepting and handling user requests/orders for data products
- tools for planning the instrument operations, on the basis of user requirements, mission objectives and system constraints
- facilities for monitoring and controlling data acquisition, processing, archiving and distribution activities carried out by the ERS ground segment.

Figure 8.2. The Earthnet ERS Central Facility and its services.



Users will primarily interact with the CUS through on-line terminals, but a 'Help and Order Desk' is available to process other forms of communication, which, if necessary, will also help users to clarify their requirements or propose alternative solutions.

8.1.2 The Interface Sub-set

The ISS is the technical interface between the EECF and any external entity, handling all EECF interfaces and the telecommunication links within the ground segment and with users. The ISS is therefore the physical gateway to the ERS system for users and is logically divided into two sub-systems, one providing external telecommunications and the other a set of interface functions. The telecommunications sub-system acts as a core node of the ground segment telecommunications systems, providing the functions to link internal and remote users or computers and the control system and network elements. The ISS provides various support functions, such as generation of reports, translation and validation of user requests, accessing the global products catalogue and browsing of the high rate distribution plan.

Via connections with the other operational facilities, the ISS receives activity reports from the ground stations and PAFs and dispatches product orders. The low bit rate fast delivery products generated at the ground stations are collected by the ISS for routing to the nominated user centres. Also, in the context of data dissemination, the ISS handles the re-formatting of the LBR FD products into the World Meteorological Organisation (WMO) code for delivery into the international meteorological telecommunication system.

8.1.3 Product Control Service

The PCS carries out tasks associated with the monitoring and control of the quality of ERS data products. In undertaking this role it co-ordinates the following activities:

- standardisation, development and maintenance of algorithms
- product quality assessment and control
- calibration and validation activities
- assessment of long-term sensor performance
- end-to-end system performance control.

The quality assessment and control of ERS data products is of prime importance from the users' point of view and for many applications it is critical. It is also fundamental for ESA to assess instrument behaviour and the performance of the satellite against its specifications providing vital feedback for future programmes.

The production of high quality, calibrated and validated products is of paramount importance to the success of the ERS-1 mission. Calibration and validation activities are, therefore, designed to ensure customer confidence in products, in terms of precision, accuracy, reliability and repeatability. To calibrate the instruments ESA established a number of campaigns in Europe and around the world through Principal Investigators – the results of these studies will be reported in scientific journals and special ESA publications.

Calibration is the activity of deriving correction factors to be used in ground processing in order to compensate for biases in the measurement data. There are three main types of activity:

- internal – monitoring of functions and parameters within the instrument
- external – comparison against natural or man-made targets with known parameters
- geophysical – use of data to tune models which derive geophysical parameters, e.g. wind speed/direction, wave height/length, etc., with the averaging of detected deviations over many events.

Validation is the evaluation of the accuracy and validity of product parameters by comparison with independent measures. Long loop performance assessment (LLPA) involves monitoring the performance of the end-to-end system through time. It summarises the outputs of the other calibration and validation activities as functions of time using statistical techniques and provides trends of significant parameter behaviour, reporting any significant changes to the users/scientists communities.

In addition, the following elements are functionally part of the PCS:

- the Frascati station which has high and low rate fast delivery processing chains, as installed at the ESA ground stations
- the Scatterometer Simulator System (SSS) to produce look-up tables for the Wind Scatterometer
- the Scatterometer Calibration Processor (SCP) used for external calibration of the Wind Scatterometer
- the PCS Kernel composed of three units:
  - the Data Management and Monitoring Sub-system (DMS) for data management and system configuration and operations control
  - the Verification Mode Processor to produce and analyse SAR precision products
  - the ArMor validation system, which ingests relevant geophysical data and meteorological parameters to permit comparisons with ERS-1 data.

8.2 Data acquisition and fast delivery product processing

ERS-1's orbit and the need for direct read-out of the SAR telemetry have necessitated a global network of ground stations, either within the ESA network or made available by national (ESA member) or foreign (non ESA members) entities. The ESA network, which has been established to ensure the acquisition of global LBR data and regional SAR data over Europe, consists of:

- Kiruna (Sweden)
- Fucino (Italy)
- Maspalomas (Canary Islands, Spain)
- Gatineau (Canada)
- Prince Albert (Canada).

The primary functions of the ESA ground stations are:

- real-time data acquisition – when the satellite is visible from a ground station – the SAR data is transmitted at a rate of 105 Mbit/s on a carrier at 8140 MHz and the LBR data at a rate of 1093 kbit/s (after spectrum spreading) on a carrier at 8040 MHz
- acquisition of LBR data from the on-board tape recorder – the data is played back at a rate of 15 Mbit/s and transmitted to the ground at 8040 MHz
- data processing and generation of fast delivery products – a number of standard products within three hours of satellite acquisition for distribution to primary user centres.

It should be noted that LBR data cannot be recorded on-board while previously recorded data is being replayed. The LBR data is, therefore, directly transferred during these periods. The instrument data is sent to the PAFs for archiving and off-line product generation – the SAR data and FD products directly, the LBR data via Fucino, where they are transcribed onto optical disks.

8.3 Processing and archiving

As described in Chapter 7 there are four PAFs:

• D-PAF	Oberpfaffenhofen, Germany
• F-PAF	Brest, France
• I-PAF	Matera, Italy
• UK-PAF	Farnborough, UK.

The functions of the PAFs have been harmonised by ESA and each has an agreed area of responsibility for archiving and product generation. They will be responsible for:

- long-term archiving and retrieval of ERS-1 raw data, auxiliary information and relevant surface data
- generation and distribution of off-line geophysical and precision products
- supporting long-term sensor performance assessment, calibration and geophysical validation, demonstration campaigns and pilot projects
- interfacing with the EECF for update of the catalogue and supporting user services.

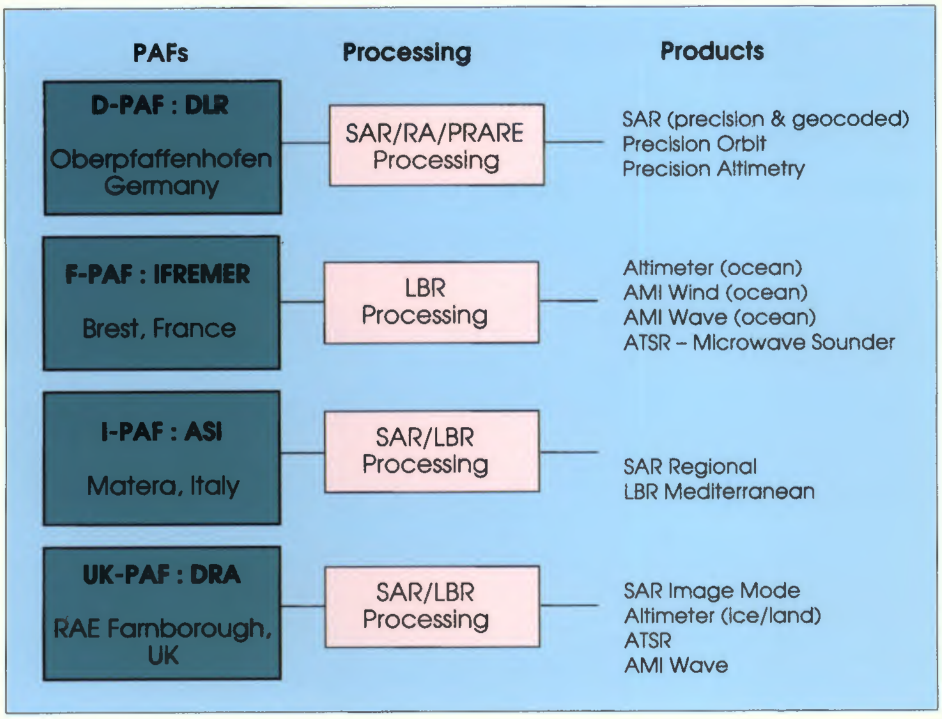


Figure 8.3. Harmonised responsibilities of the Processing and Archiving Facilities.

The PAFs will share the responsibility for product generation, in order to make efficient use of national expertise and it is intended that their operations continue for 12 years after the launch of ERS-1. A summary of the off-line products to be generated by each of the PAFs is shown in Figure 8.3 and the services offered by each PAF are listed below.

- **D-PAF**
  - primary archive of raw data acquired by the German Antarctic Research Station at O'Higgins
  - primary processing centre for SAR precision and geocoded image data, higher level altimetry products and precision orbit calculations.

- **F-PAF**
  - primary archive for LBR data (SAR wave mode, Wind Scatterometer and Radar Altimeter) over the oceans and associated FD products
  - secondary archive of the global ATSR data set
  - primary processing centre for LBR data over oceans
  - processing centre for ATSR – Microwave Sounder data
  - storage of relevant ESA provided campaign data.

- **I-PAF**
  - regional archive of SAR and LBR data (raw, processed and FD) acquired over the Mediterranean by the Fucino station
  - regional processing of SAR and LBR products of the Mediterranean.

- **UK-PAF**
  - primary archive for raw and processed SAR and ATSR data, LBR data over ice and land and SAR FD products
  - secondary archive for global LBR dataset
  - primary processing centre for SAR and LBR data over ice and land
  - primary processing centre for ATSR data
  - secondary processing centre for wave data products
  - storage of campaign data.

ABBREVIATIONS AND ACRONYMS

ABBREVIATIONS AND ACRONYMS

A/D	Analogue/Digital
ADE	Atelier Donnees Entree Sous-système (F-PAF)
ADP	Altimeter Data Processing System (D-PAF)
AGC	Automatic Gain Control
AMI	Active Microwave Instrument
AOCS	Attitude and Orbit Control Sub-system
ASI	Agenzia Spaziale Italiana
ASS	Antenna Support Structure
ATSR	Along Track Scanning Radiometer
BDDN	Broad-band Data Dissemination Network
CFRP	Carbon Fibre Reinforced Plastic
CRPE	Centre de Recherche en Physique de l'Environnement
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTB	Control and Telemetry Bus
CUS	Central User Service
DC	Direct Current
DDN	Data Dissemination Network
DGFI	Deutsches Geodätisches Forschungsinstitut
DIF	Diffusion Sous-système (F-PAF)
DLR	Deutsche Forschungsanstalt für Luft- und Raumfahrt
DMS	Data Management and Monitoring Sub-system (EECF)
DMS/ARC	Data Management System / Archives (D-PAF)
D-PAF	German PAF (see DLR)
DRA	Defence Research Agency (formerly Royal Aerospace Establishment)
EECF	Earthnet ERS-1 Central Facility
EPC	Electronic Power Conditioner
EPO	Earthnet Programme Office
ERS-1	European Remote Sensing Satellite-1
ESA	European Space Agency
ESAR	ERS-1 SAR Facility (I-PAF)
ESOC	European Space Operations Centre
ESRIN	European Space Research Institute
ESTEC	ESA Technical Establishment
FD	Fast Delivery
FDP	Fast Delivery Product
FM	Frequency Modulated
F-PAF	French PAF (see IFREMER)
FPA	Focal Plane Assembly
FPM	Fine Pointing Mode
GEOS	Geocoding System (D-PAF)
GST	Ground Station
GTS	Global Telecommunication System
HF	High Frequency
HgCdTe	Mercury Cadmium Telluride
HPA	High Power Amplifier

I	In-phase
ICU	Instrument Control Unit
IDHT	Instrumentation Data Handling and Transmission
IF	Intermediate Frequency
IFOV	Instantaneous Field of View
IFREMER	Institut Francais de Recherche pour l'Exploitation de la Mer
InSb	Indium Antimonide
I-PAF	Italian PAF (see ASI)
IRR	Infra-red Radiometer
ISS	Interface Sub-system
LBR	Low Bit Rate
LBRFDP	LBR Fast Delivery Processor
LEOP	Launch and Early Orbit Phase
LLPA	Long Loop Performance Assessment
LO	Local Oscillator
LRDDF	Low Rate Data Dissemination Facility
LRDPF	Low Rate Data Processing Facility
LRDTF	Low Rate Data Transcription Facility
LRR	Laser Retro-reflectors
MLBR	Mediterranean LBR Processing Facility (I-PAF)
MMCC	Mission Management and Control Centre
MOU	Memorandum of Understanding
MSAR	Multi-sensor SAR Processor (D-PAF)
MWS	Microwave Sounder
NFS	National and Foreign Stations
NOAA	National Oceanographic and Atmospheric Administration
OBC	On-Board Computer
OBDH	On-Board Data Handling
OBRC	On-Board Range Compression
OGRC	On-Ground Range Compression
PAF	Processing and Archiving Facility
PCS	Product Control Services
PDHSS	Processor and Data Handling Sub-system
PDU	Power Distribution Unit
PEM	Payload Electronics Module
PRN	Pseudo Random Noise
PRARE	Precise Range and Range-rate Equipment
PRF	Pulse Repetition Frequency
PSK	Phase Shift Keying
PSPDN	Packet Switched Public Data Network
Q	Quadrature
RA	Radar Altimeter
RAE	Royal Aerospace Establishment
RDPF	RAT (Radar Altimeter) Data Processing Facility (D-PAF)
RF	Radio Frequency
RTM	Roll Tilt Mode
SAR	Synthetic Aperture Radar
SARFDP	SAR Fast Delivery Processor
SAW	Surface Acoustic Wave
SCP	Scatterometer Calibration Processor
SDPF	SAR Data Processing Facility (D-PAF)
SLR	Satellite Laser Ranging

SPOT	Satellite Probatoire d'Observation de la Terre
SSS	Scatterometer Simulator System
SST	Sea Surface Temperature
SWH	Significant Wave Height
TGP	Traitement et Gestion des Produits Sous-système (F-PAF)
TT&C	Telemetry, Tracking and Command
TTC	Telemetry, Telecommand and Control
TOS	Tracking Data and Orbit Processing System (D-PAF)
TWT	Travelling Wave Tube
UK-PAF	United Kingdom PAF (see DRA)
WMO	World Meteorological Organisation
WNS	Wind Scatterometer
YSM	Yaw Steering Mode

GLOSSARY

GLOSSARY

Active Microwave Instrument (AMI)
Consists of two separate radars, operating at a frequency of 5.3 GHz (C-band), with three modes of operation – a Synthetic Aperture Radar (SAR) for image and wave mode and a three antennae Wind Scatterometer.

Along Track Scanning Radiometer (ATSR)
Consists of two passive instruments – a four-channel (1.6, 3.7, 10.8 and 12 µm) Infra-red Radiometer (IRR) for measuring sea surface and cloud top temperatures and a two-channel (23.8 and 36.5 GHz) Microwave Sounder to provide total water vapour content information.

Ancillary Data
Data other than instrument data needed for the processing and correct interpretation of the instrument's science data (e.g. spacecraft orbit/attitude, instrument pointing information).

Archive
A facility providing long storage and preservation of data sets and associated documentation.

Archived Data
Data received from the ERS-1 satellite and any other data types necessary for later data processing or investigation. Data is copied to archive media, maintained and stored in a library.

Auxiliary Data
Data other than ancillary data and instruments data needed for processing the science data produced by the instrument (e.g. instrument calibration data coefficients).

Catalogue
An ordered collection of concise describers and pointers, permitting the easy location of relevant item(s): in the ERS-1 case the catalogue permits the identification of data products complying with specific requirements, such as geographical area and time coverage, quality etc..

Central User Service (CUS)
Part of the Earthnet ERS-1 Central Facility dedicated to the planning and supervision of all data acquisitions, product generation and dissemination activities.

Commissioning Phase
The initial months after launch for satellite and payload verification and instrument calibration.

Data Centre
An institutionally supported facility providing convenient access to and distribution of data sets (including supporting information and expertise) for a wide community of users. It has a long term charter (not tied to the lifetime of a specific project).

Data Product
1) A homogeneous set of information resulting from raw data processing: it includes annotated, transcribed or decommutated raw data. 2) General term to indicate raw data, validation data, auxiliary data, fast delivery, regenerated, or precision products. 3) A uniformly processed and formatted data set, portion of a data set, or transformed representation of data (e.g. plot, photograph); may be produced by, or for, a project or by a data centre.

Dissemination
Transmission of data from one facility to another or to many other facilities.

Dissemination Schedule
A projected plan which designates at a fixed time in the future the transmission of data from one facility to other facilities.

Earthnet ERS-1 Central Facility (EECF)
Located at ESRIN in Frascati, Italy and carries out all user interface functions, including cataloguing handling of user requests, payload operation planning, scheduling of data processing and dissemination, quality control of data products and system performance monitoring.

ERS-1 Product Catalogue
A data base containing information identifying all the raw data collected and archived, and all the products produced and archived for ERS-1 during the satellite operational lifetime and follow-on. Specific information stored will include the type of data, geographic coverage, time acquired, and reference to product source.

ESA ERS-1 Team
All the ESA management, scientific and support staff involved in various aspects of the ERS-1 mission.

Facility
A collection of hardware, software, personnel, and infrastructures (centralised or decentralised) with an identified functionality necessary for the support of the ERS-1 mission.

Geophysical Product Validation
Verification that ERS-1 geophysical products are consistent with best available independent geophysical measurements.

Housekeeping Data
Engineering data used exclusively for managing the operation, health and safety of a spacecraft, platform, instrument or equivalent.

Instrument
A hardware integrated collection of one or more sensors and associated hardware/ software controls contributing data to an investigation.

Instrument Data
Data produced and transmitted by the science and engineering sensors of an instrument.

Instrument Engineering Data
Data produced by an instrument's engineering sensor(s) (e.g. instrument temperature).

Instrument Science Data
Data produced by an instrument's science sensor(s).

Laser Retro-reflectors (LRR)
Passive optical instrument operating in the infra-red to permit ranging of the satellite by the use of laser ranging stations. Used for the calibration of Radar Altimeter altitude measurements and the improvement of the satellite orbit determination.

Look-up Table
Tables of data containing reference and calibration parameters for fast delivery processing.

Mission Plans
A series of plans containing details on instrument operations, acquisition and processing schedules of various levels of detail and the principals, rules and guidelines related to the ERS-1 satellite operation.

Mission Plan Segments
Specific time periods within an orbit which identify the operational mode of the ERS-1 payload. They are generated from the user requests received by the Central User Service at the Earthnet ERS-1 Central Facility, the national requirements, responses to the Announcement of Opportunity studies, calibration and validation campaigns, and ESA requirements.

Mission Management and Control Centre (MMCC)
Located at the European Space Operations Centre in Darmstadt, Germany, the MMCC carries out all satellite operations control and functional management, including overall satellite and payload operational scheduling.

Near-Real Time Data
Data from the source that are transmitted with propagation delays and minimal delays due to buffering.

Nominated Centres
Scientific institutions and/or engineering establishments receiving ERS-1 data and nominated at national level to provide coordination between the ESA/ERS-1 programme and end users for specific data requirements or to play a significant role in the ERS-1 research related activities.

Playback Data
Data that are stored on a spacecraft, platform, or other carrier that are transmitted at a later time. The data may be transmitted in chronological or reverse time order and may have delays due to processing.

Precise Range and Range-rate Equipment (PRARE)
A highly accurate microwave ranging system used for orbit determination at decimetre levels of accuracy and for geodetic applications.

Product
Final result from the application of data processing algorithms by computer to the raw data acquired by the satellite. The user can select from a range of products. The product media consists of hard copy (e.g. photographic), telecommunication links and various forms of computer compatible media (e.g. CCT).

Product Control Service (PCS)
Part of the EECF, which carries out tasks associated with the monitoring and control of ERS data products.

Radar Altimeter (RA)
A Ku-band (13.8 GHz) nadir-pointing active microwave sensor designed to measure the time return echoes from ocean and ice surfaces providing information on significant wave height, surface wind speed, sea surface elevation and various parameters over sea ice and ice sheets.

Raw Data
1) Instrument data or housekeeping data in the same format as transmitted from the spacecraft or collected on a storage medium on the carrier (e.g. tape recorder, optical disk). 2) The data received from the satellite prior to the application of any on-ground data processing algorithms. The raw data media will be as for products, i.e. hard copy and various forms of computer-compatible media.

Real Time Data
Data from the source that are transmitted with only propagation delays.

Roll Tilt Mode (RTM)
Rotation of ERS-1 satellite by 9.5° allows operation of AMI SAR imaging mode at 35° incidence angle.

Seasat
First satellite designed for oceanography. Launched on 26 June 1978, failed on 10 October 1978. Polar orbiting at 800 km altitude. Instruments - Radar Altimeter, Scatterometer, Scanning Multichannel Microwave Radiometer, SAR and Visible and Infra-red Radiometer.

Shuttle Imaging Radar (SIR)
Synthetic Aperture Radar carried on US Shuttle missions. SIR-A launched in November 1981 and SIR-B in October 1984. SIR-C planned for flights in mid 1990s will utilise multi-polarisation L- and C-band with choice of incidence angle.

Support Data
Includes all data other than the actual satellite acquired raw data, the product data, mission plans, and schedules (e.g. look-up tables (LUTs) and geophysical calibration data).

Telemetry
Electromagnetically transmitted data stream of measured values not including command, computer memory transfer, audio or video signals. The information content of the signal can be analogue or digital format.

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