# FIVE YEARS OF ERS-2 LOW BIT RATE MISSION: ROUTINE CAL/VAL AND LONG LOOP SENSOR PERFORMANCE MONITORING.

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## ABSTRACT

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. Following five years of successful in orbit exploitation**,** a second satellite (ERS-2) was launched on April 21st, 1995 and it is still overflying our planet. ERS-2 is carrying the same payloads as ERS-1 plus a spectrometer instrument: the GOME.

The ERS-2 Low Bit Rate (LBR) Mission includes the Active Microwave Instrument (AMI) operated in wave and scatterometer mode, the Radar Altimeter (RA) instrument, the Along-Track Scanning Radiometer (ATSR) and one spectrometer instrument (GOME). This set of instruments enables the determination of geophysical and physical parameters such as the wind speed and direction, the wave height, length and direction, the distance between the satellite and the earth surface (sea, ice or land) and the concentration of ozone and other trace gasses in the stratosphere.

The LBR data are processed at the ESA ground stations and the products are delivered within three hours from sensing to the major meteorological centers (via the Global Telecommunication System) and research institutes as well as to the Product Control Service in ESRIN.

To ensure the quality of these data, the Product Control Service (PCS) at ESRIN performs the long loop performance monitoring of the instruments since the beginning of the ERS mission. This activity includes several tasks such as the monitoring of the instrument calibration and instrument performance degradation due to aging, the monitoring of the processing stations and the quality control of the products.

The paper describes the results of this monitoring activity. In particular the major events that occurred during the ERS-2 mission (Flight and Ground segments), the calibration status of the ERS-2 instruments and the evolution of the key parameters affected by the aging are reported. The quality of the products delivered is also analyzed and discussed.

The conclusion summarizes the lessons learned during these five years of ERS-2 operations and addresses some guidelines for future missions (ENVISAT, METOP).

## 1. INTRODUCTION

The aim of the ERS Mission has been to serve a large variety of users with a comprehensive range of applications. For this reason the paper presents the routine Cal/Val activities and the long loop ERS-2 instrument performances monitoring in the wide framework of the product quality assurance.

In this context it is possible to establish links among product quality, mission constraints and instrument performances. These links have the scope on one side to ensure to the users a continuous set of validated products of consistent characteristics and, on the other side, to asses the evolution of the instrument quality due to aging or to human action commanded from ground and to take all corrective actions necessary to restore the initial quality.

### The Quality Control Philosophy

A remote sensing mission involves several aspects such as the flight-segment operations, the instrument calibration and aging monitoring, the ground station and the processing facility operations and maintenance, the mission management (to ensure the continuity and to improve the mission performances) and last but not least the scientific community requirements. In order to give a high contribution to these different aspects it is essential to develop a mission quality control strategy.

The methodology adopted in the ERS Mission has been to monitor the whole system performances by analyzing the quality of the data produced by the system itself. Based on the mission strategy and the data source, the control of the following elements were considered essential in the process of quality assessment:

- Platform/Instrument operations
- Ground Station acquisition performance
- Raw data availability
- Ground Station processing performance
- Instrument aging monitoring
- Instrument calibration monitoring
- Quality of the delivered data sets
- Compliance of the delivered products with specifications
- Systems upgrades and configuration controls
- Users concerns
- Reporting

Quality control procedures oriented on routine operations (Platform/Instrument) and on fast delivery products are performed in parallel with the data dissemination. This implies that the users who need to apply their own quality rejection criteria can occasionally receive some bad quality data. On the other hand, this concept allows for a quick provision of data less than three hours from sensing, usually of good quality.

Algorithm validation and systems upgrade require off-line procedures. The validation activities of new algorithms, developed during the mission lifetime, require a good capacity to interact with different communities such as the algorithm experts, industry and mission coordination. In addition to this expertise it is essential to have a reference processing station available to tune the processing. Another important element that runs off-line is the back-up station. This allows the reprocessing of large amounts of data when necessary (new algorithm or new set of processing parameters). This element is essential to provide a consistent data set throughout the whole mission.

Instrument performance monitoring (calibration and aging) requires both strategies (on-line, off-line) and a set of procedures that enable to analyze the data (interactively) and to extract periodically statistical parameters into a database, to be used for long-term characterization of the instrument performances. Moreover these activities require a good knowledge of the instrument and its calibration technique. It is also necessary to investigate instrument or platform anomalies and, if feasible, to propose corrective actions to phase out those anomalies and to ensure the continuity of the mission.

User concerns require a series of efforts. In particular it is important to know the users requirements, to explain what is possible or not in the mission scenario and to interact with industry if new solutions shall be integrated to improve the data quality.

The reporting is essential to share the information acquired throughout the quality control procedures. The reporting is a very general concept and covers a wide range of applications. It has a daily or cyclic (35 days) frequency to report the instruments and products performances or it could have the special issue to report about anomalies, mission events, system upgrades or users complaints.

In order to inform users and provide them with a coherent overview of reports, results of analysis, important instrument or mission events and other PCS activities, the PCS has started its own website to be found at http://pcswww.esrin.esa.it.

**The ERS Ground Segment**

The elements described briefly until now have a proper facility in the ERS ground segment: the Product Control Service (PCS). The ERS ground segment has been established using a set of distributed facilities with central and monitoring control [1]. The facilities are responsible for the acquisition, processing, distribution and archiving of the satellite data and products. The PCS is part of the Central Facility at ESRIN (Frascati – Italy) and is the place where the quality control strategies are carried out.

**The Paper Content**

The paper describes how the quality control strategy has been implemented in the PCS and reports on the major results achieved. It underlines the connection among the users requirements, the mission constraints, the instruments and their impact on the product quality.

The paper is organized with the following Chapters:

Chapter 2 presents the PCS, its major activities and its contribution to the ERS-2 mission.
Chapter 3 shows some results achieved in the monitoring of the calibration of the ERS-2 low bit rate instruments.
Chapter 4 presents some results achieved in the monitoring of the aging of the ERS-2 low bit rate instruments.
Chapter 5 presents some results achieved in the ERS-2 low bit rate products quality monitoring.

The Conclusion at the end summarizes the experience acquired in the PCS.

## 2. THE PCS OVERVIEW

**A description of the PCS and its history.**

ESRIN started to set up the elements of the quality control philosophy and progressively built the PCS inside the APP-ADQ section. Along the years, with the experience acquired on the potential problems to be faced, the system has regularly been expanded to monitor thoroughly the whole mission by the development of essential tools allowing complete analysis of the data received [2].

Today the PCS is a team of engineers with different competencies. Inside the team instrument specialists as well as software engineers are working for the different components of the ERS-2 payload.

**Presentation of the Team**

The role of the instrument specialists covers most of the elements presented in the introduction. They know about the instrument, the processing of the data and their applications. They oversee the on-line operations; they cooperate with the other groups inside ESA (Instrument experts and Operation Teams) to monitor the instrument and platform performance. They are involved in the system upgrades. They have responsibilities in the product quality control and they cooperate in industrial projects.
The software engineers have a key role in the development and in the improvement the automation of a certain number of tasks.
They are involved also in the reporting activities by developing web interface to make available the PCS results.

Instrument experts and software engineers work very closely together and both cooperate and support the activities of the APP-ADQ section.

**The PCS activities**

Today the PCS activities dedicated to the ERS-2 Mission can be gathered in the following groups:

- Daily Quality Control and Daily report
- Ground Segment configuration
- Algorithm validation and Processing chain validation
- Monitoring of Instrument Long-Loop Performances and Calibration
- Investigation of the instrument anomalies and issue of Technical note
- Geophysical validation activities
- Participation to externally developed projects
- In-house developed projects
- Participation to meetings and workshops in relation with the users/scientific communities

**The Daily Quality Control and Daily report activity**

The Daily Quality Control and Daily report activity gives routinely a general view of the mission events. The team is able to identify and respond quickly to the daily operational problem causing a degradation of the data quality.

In particular the AMI, RA and GOME fast delivered products received are systematically opened. The main fields of the Main Product Header, the Specific Product Header and the most important parameters contained in the Data Set Records are plotted as time series or as geographic map. A threshold control is applied to the parameters related to instrument operation. The scope is to detect out of range values that could lead to poor data quality.

The availability of the data is cross-checked with the operational modes of the relative instrument. For example this is a very important task for the AMI instrument that is operated in different modes (SAR image, SAR wave, WindScatt). This mission constraint caused a series of "nominal" data gaps that are recognized and therefore no additional action is required.

The Daily Quality Control system is able to extract critical monitoring parameters (on global or local geographical scale; depending on the application) and to perform daily averages that are the input for the long-term performances analysis. The telemetry data are also analyzed and the most relevant parameters for the AMI and the RA instrument are extracted.

Some reports generated in the ground stations are also analyzed. In particular the availability of the raw data is checked by analyzing the transcription report.

For the AMI (WindScatt and SAR mode) and the RA instruments raw data acquired over calibration site are analyzed and the most relevant parameters are stored inside a database. In the case of AMI a special report is generated for the raw data acquired over the transponders (located in the South of Spain for the WindScatt and in the Flevoland area's for the SAR). The report contains the time evolution of the calibration pulse and echo power. This analysis detects possible anomalies in the calibration plan such as the transponders switch-off or instrument mode not properly set.

For GOME the on-board software is monitored by analyzing the GOME memory dumps (X-band). On a daily basis a dump file is compared with a reference data set and any differences to this template are detected and reported.

At this stage operation anomalies (data gaps, empty products, duplication, wrong processing parameters) and instrument anomalies are identified. Most of these anomalies are kept inside a database and they are used to generate the Daily Report.
The Daily Report collects the results obtained in the product analysis. The Daily Report is delivered by email to the APP-ADQ section, to the ground station and instrument engineers and to the Mission Management Control Centre (MMCC) at ESOC.

The Daily Report is organized in two sections. The first section is manually filled by the instrument experts and mainly contains the anomalies that should be deeply investigated or their possible explanation (when this is possible in a short time). A critical review of the results of the automatic checks that is presented entirely in the second section of the Daily Report.

The daily products monitoring is the first step to assess and to improve the quality of the ERS-2 Mission. In Chapter 5 some results of this basic and important activity are reported.

**Ground Segment configuration**

The scope of this activity is to manage the configuration parameters (Look-Up Table - LUT) in the ERS fast delivery processing chain. PCS is responsible to format and to send every day two sets of LUTs to the ground stations located at Maspalomas and Gatineau. These LUTs contain the ECMWF meteorological forecast for the next 18 and 24 hours. They are used in the processing of the RA and WindScatt data and their availability is essential for the product quality.

The PCS is also responsible for generating new LUTs and the Table 1 shows the most important cases occurred during the ERS-2 Mission and the PCS role.

**Table 1: ERS-2 Mission: Major LUTs change and PCS role**

| DATE | DATA | REASON | PCS ROLE |
|---|---|---|---|
| Mid, Late 1995 | AMI-wave | ERS-1 imagettes have been acquired at near image swath (19.3° incidence angle) until the launch of ERS-2. Since then, the wave swath has been positioned at the centre of the image swath (23° incidence angle) for both satellites. | Validation of the products.<br>Validation of antenna pattern [10]. |
| 19th March 1996 | WSC | End of Commissioning Phase. Gain setting and Final antenna pattern. | Cooperation with ESTEC to define the new antenna pattern and the new gain setting.<br>Send new LUTs.<br>Validation of the products. |
| 18th June 1997 | WSC | On 6th August 1996 was decided to operate with the redundant unit of the calibration sub-system after a long series of failures of the main unit.<br>This action caused a change in the instrument calibration. | Estimation of the calibration change by checking the calibration pulse samples.<br>Update the value of the internal calibration reference energy in agreement with the analysis.<br>Send new Static LUT.<br>Validation of the products. |
| Mid 1996 | RA | End of Commissioning phase. Adjustment of Sigma nought value to be cross calibrated with ERS-1 one. | Send the new LUT:<br>ERA_A_G_REF<br>Validation of the products. |
| Regularly | RA | Compensation of OpenLoop Calibration variations. Adjustment of default value. | Send the new LUT:<br>ERA_TAU_G_REF<br>Validation of the products. |
| 1996 | AMI wave | Correction of the impulse response function. A significant tail-off in the spectrum at high wavenumbers (or short wavelenghts), which extends over the entire spectrum, is due to the impulse response function (IPR), or sensitivity of the system to a given wavenumber in both azimuth and range. | Validation of the products. |
| 30th November 1998 | RA | Upgrade of RA processing. Calculated Wet Tropospheric correction (from MWR data) in the RA products. | Generation of new format for the LUT:<br>ERA_Dynamic<br>Send new LUT<br>Validation of the products. |
| 19th April 1999 | WSC/RA | Two sets of meteorological forecast in the Ground Station. Data are processed using 18 and 24 hours forecast instead of 18, 24, 30 and 36 hours forecast. | Send two sets of LUTs per day.<br>Validation of the products. |
| 7th September 2000 | RA | Compensate for the 0.16 dB drop in the Sigma nought occurred on 16th January 2000. | Send the new LUT:<br>ERA_A_G_REF<br>Validation of the products. |
| N/A | WSC | Upgrade of the scatterometer processing.<br>This activity is on going.<br>New parameters are needed for the | Generation of new format for the LUT:<br>Dynamic Paramer<br>WS Configuration |

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| | | computation of the sigma nought and the Kp.<br>New parameters are needed for the new Ambiguity Removal algorithm. | Validation of the new LUT format.<br>Validation of the products. |

As reported in the Table 1 this activity entails in all cases the validation of the new set of tables, and sometimes the computation of a new set of parameters (as for the WindScatt after the redundancy of the calibration sub-system side A), or the definition of a new format for the tables due to changes in the processing algorithm (as for RA and WSC).

The activity is carried out in cooperation with the ERS Configuration Control Board (CCB) that is the entity in charge of supervision and coordination of the whole ground segment.  In this way the integrity of the system and the quality of the generated products is guaranteed throughout the ERS Ground Segment.

**Algorithm and Processing chain validation**

This activity is strictly related to the one previously described and is mainly dedicated to the validation of the products generated when an algorithm in the fast delivery chain is going to be upgraded. It includes the quality control of the products in comparison to the one produced by the old algorithm and consists often of a recursive process when PCS's work helps in detecting eventual anomalies in the algorithm implemented.

Table 2 shows the most important cases occurred during the ERS-2 Mission and the PCS role.

**Table 2: ERS-2 Mission: Major Algorithm and Processing Chain changes and PCS role**

| DATE | DATA | REASON | PCS ROLE |
|---|---|---|---|
| 25th June 1997 | AMI-wave | Upgrade of UWA processor, from v.5000 to v.7100. (Reengineering of new LRPDF WAVE processor. | Validation of the products and feedback input for implementation of anomaly correction. |
| 07th March 1998 | AMI-wave | Upgrade to UWA processor v.7200 | Validation and acceptance. |
| 09th June 1998 | AMI-wave | Upgrade to UWA processor v.8200 (New LRPDF WAVE processor). | Qualification period. |
| 30th November 1998 | AMI-wave | Upgrade to UWA processor v.8310 | Validation of the products and input for implementation anomaly corrections |
| 11th Jan 1999 | AMI-wave | Upgrade to UWA processor v.8400 | Validation of the products and input for implementation anomaly corrections |
| 24th Aug 1999 | AMI-wave | Upgrade to UWA processor v.8500 | Validation of the products and input for implementation anomaly corrections |
| 30th November 1998 | RA | Upgrade of RA processing. Calculated Wet Tropospheric correction (from MWR data) in the RA products and change of the Range evaluation algorithm. | Validation of the products and input for implementation anomaly corrections. |
| 29th June 1999 | All instruments | Implementation of direct link from Prince Albert station to Gatinueau (DIS) | Validation of the products and input for implementation anomaly corrections. |
| N/A | All instruments | Development of a Stand Alone LRDPF (S-LRDPF) processor chain.<br>This activity is on going | Validation of the products and input for implementation anomaly corrections. |

**Instrument Long-Loop Performances and Calibration Monitoring activities**

This is one of the PCS core activities with the aim of keeping the operational instruments continuously under monitoring in order to detect anomalies and to either propose corrective action or upgrade the processor (LUT and/or algorithm) or to monitor the evolution to warn the users.

In case an anomalous behavior is detected, the PCS responsibility consists in interacting with the instrument specialist and the operation teams to describe and understand the problem and eventually eliminate the cause.

The activity consists of several special investigations of the most important parts of each instrument and its specific calibration schemes, which are, summarized Cyclic or Monthly reports issued periodically.

Table 3 gives references for the Cyclic/Monthly reports issued by PCS. Results of this activity are reported in chapter 3 and 4.

**Table 3: Instrument Long-Loop Performances and Calibration Monitoring: PCS reports references**

| DATE | INSTRUMENT | REPORT | REFERENCE |
|---|---|---|---|
| Since June 99 | RA | Cyclic Report | Downloadable at the web address: http://earth.esa.int/l2/4/eeo4.64 (Altimeter performances, Altimeter Performances during nominal operations) |
| Since May 96 | WSC | Cyclic Report | Downloadable at the ftp server: Pooh.esrin.esa.it Visible at the web address: http://pcswww.esrin.esa.it (Scatterometer performances page) |
| Since April 95 | GOME | Yearly, Monthly, Weekly Report and Gome Long Term Trend analysis results | Visible at the web address: http://earth.esa.int/l2/eeo4.96 |
| Since 4 July 95 | SAR | Cyclic report | http://EARTH1.esrin.esa.it/l2/4/eeo4.128 (SAR performance page) |

**Special Investigations and issue of Technical notes**

The PCS engineers as a second step perform special investigations when an anomaly in the behavior of the Space or of the Ground segment is detected.
In particular, telemetry, auxiliary data, products and reports are analyzed in detail in order to evaluate the nature of the anomaly, try to understand the causes and solve the problem.

This activity is mostly performed in liaison with the instrument specialist and the operation teams in order to combine the widest range of information, knowledge and data to find the best solution.

Once the investigation is completed, PCS responsibility is also to produce a report describing analysis and results and eventually giving operational recommendations to overcome or solve the disturbance.

Table 4 gives a summary of the most important special investigations performed by PCS engineers.

**Table 4: Special investigations performed within PCS**

| DATE | INSTRUMENT | INVESTIGATION | OUTPUT |
|---|---|---|---|
| Since Nov 1996 | GOME | Investigation of the on-board software with respect to Single Event Upsets (SEU); e.g. correlation with occurrences of SEUs and dependency of solar activities. | Input for In-Orbit-Performance meeting, monthly report. Issue of a report presented to the instrument specialist from ESA and from Industry. |
| Aug 1995 | AMI SAR-wave | Investigation of Noise and Pulse in EWAC to ascertain saturation levels. | Investigation on raw data, investigation on possible saturation of data. |
| Jan-Jun 1997 | WSC | Investigation in the calibration sub-system power. | Issue of a report with analysis and results description. |
| Jan-Apr 1998 | WSC | Investigation in the noise power. | Analysis and results description in the cyclic report (42). |
| Since 1998 | GOME | Investigation of Calibration Lamp Line Intensities with respect to degradation. | Input for In-Orbit-Performance meeting. Issue of a report presented to the instrument specialist from ESA and from Industry. |

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| Since Nov 1998 | GOME | Investigation of Scan Mirror Performance for the different GOME operational swath modes. | Input for In-Orbit-Performance meeting. Issue of a report presented to the instrument specialist from ESA and from Industry. |
| Jan-Jun 2000 | RA | Investigation on the continuity of subsequent UTC/SBT time correlation files (PATN and PATM). | Issue of a report with analysis and results description. |
| Jan.-Mar. 2000 | All | Contribution to the planning of the AOCS validation campaign.<br>Investigation of Doppler frequency and sigma naught performances in preparation and during the validation of mono-gyro piloting scheme.<br>Investigation of pointing performances in preparation and during the validation of mono-gyro piloting scheme.<br>Co-operation with ECMWF for the geophysical validation during the AOCS campaign. | Requirements input to mission planning activities<br>Issue of reports describing the method used in the analysis and the results obtained.<br>Recommendation to the Mission management.<br>Implementation of new monitoring scheme for the Doppler frequency (AMI).<br>Publication of a papers (ref. [5]). Issue of a report presented to the instrument specialist from ESA and from Industry. |
| Feb.-March 2000 | RA | Investigation on Sigma nought drop occurred on the 16th of January 2000. | Input to the In Orbit Performance Meeting. Issue of a report presented to the instrument specialist from ESA and from Industry. |
| May-Jul 2000 | AMI | Investigation in the AMI wave operations in co-operation with ESOC. | Issue of a report with analysis and results description. |
| Jul-Aug 2000 | WSC | Investigation on the arc events occurred during the ERS-2 Mission in co-operation with ESOC. | Issue of a Technical note with analysis and results description. |
| September 2000 | WSC | Investigation on the impact of the FPM in the sigma nought in preparation for gyro less operation. | The activity is on going. |

**Geophysical Validation**

The geophysical validation is performed regularly within PCS and represents an important part in the quality assessment of the Fast Delivery products. The work is performed in collaboration with external institutes, in particular meteorological centres (ECMWF, KNMI…), which provide the reference data represented both by independent measurements and forecast models outputs.

Table 5 reports a list of the PCS activities in the framework of geophysical validation. In chapter 5 are reported some results of this activity.

**Table 5: Geophysical Validation activities**

| DATE | INSTRUMENT | REASON | PCS ROLE |
|---|---|---|---|
| Regularly | RA | Geophysical validation of the Sigma nought, Wind Speed and Significant Wave Height fast delivery parameters. | Collaboration with ECMWF: revision of the monthly report and comparison with in-house quality control. |
| Regularly | WSC | Geophysical validation of the Wind Field. Monitoring of the sigma nought acquired over triplets over the Ocean. | Daily Computation of the wind speed biases (speed and direction) using the ECMWF forecast.<br>Collaboration with ECMWF and revision of the cyclic report. |
| Regularly | AMI-wave | Geophysical validation of Wave height data, control of data reception of Wave mode spectra, timeseries of bias and scatter index. | Collaboration with ECMWF: revision of the monthly report and comparison with in-house quality control, |

**Participation to externally developed projects**

This activity is mostly intended as support to the APP-ADQ staff responsibilities when particular investigations are performed or tools are developed by external entities. It consists mainly in user request specifications, document revision and software tests and it includes always an iterative interaction between PCS itself and the company or laboratory performing the actual development of the project.

Table 6 reports a summary of the most important development projects for which PCS engineers gave important contributions.

**Table 6: Projects developed with PCS contribution**

| DATE | INSTRUMENT | COMPANY | REASON | PCS ROLE |
|---|---|---|---|---|
| Feb. 1999-Mar. 2000 | RA | CLS | Development of a study to investigate the impact of the RA antenna off-nadir pointing on the geophysical parameters. | Participation in the definition of the work package and revision of the delivered documents. |
| July 2000 | RA | CLS | Analysis of the 16th January Sigma nought drop on the OPR data and issue of a note to be distributed to the users. | Revision of the final document. |
| June 1999 - on | WSC | GAEL | Developed a web interface (Windmapper) to display the Scatterometer wind field map. | Participation in the definition of the work package and revision of the delivered documents.<br>Participation to the Kick-off and progress meetings.<br>Final validation of the software. |
| January 1999 - on | WSC | SPACETEC | Implementation of a new algorithm to compute the Kp.<br>Improvements in the computation of the sigma nought when source packets are missing due to wave operation.<br>Implementation of a new Ambiguity removal algorithm developed by DNMI. | Revision of the Kp algorithm.<br>Simulated wave operations in the raw data.<br>Participation in the revision of the delivered documents.<br>Validation of the new algorithms.<br>Participation to the progress meetings, FAT and OSAT. |
| January – June 1999 | ATSR/RA/WSC | ACS | El Niño: a 3D real virtual simulator | Creation of the data set used by the application.<br>Sea Surface Temperature (ATSR) anomaly, Sea Level anomaly (RA), Wind Field (WSC).<br>Scientific and technical support to the company responsible of the project. |
| 1995 | SAR | EDS-Scicon | SARCALQ | Participation to acceptance tests and review. |
| 1999 | SAR | DLR | SARCON | Participation to acceptance tests and review. |
| Regularly | MWR | CETP | Microwave Sounder performance during nominal operations. | Revision of delivered documents. |
| 1997-1999 | AMI-wave | SPACETEC | Implementation of upgraded Wave processor. | Validation, acceptance, qualification. |

**In-house developed projects**

The development of new software, algorithms or techniques within PCS itself has the scope to improve the reliability of the data quality assessment and to enlarge the range of analysis performed. In any case each in-house development is performed to provide the user community with statements of higher and higher quality.

Even if the basic quality analysis is performed using the tools developed by external companies, sometimes it arises the need for a special development in case PCS wants to perform a particular analysis on the data or wants to provide the users with better quality products.

Table 7 reports a list of the PCS most important in-house developed projects.

**Table 7:PCS in-house developed projects**

| DATE | INSTRUMENT | REASON | IMPROVEMENT |
|---|---|---|---|
| 1996 | RA | Calculation of Ultra Stable Oscillator frequency and relative Range correction from measurements files | Delivery to the users of a regularly updated correction |
| 1996 | RA | Calculation of Scanning point Target Range correction form raw data | Delivery to the users of a regularly updated correction |
| 1996 | AMI Wave | Calibration/Monitoring tools. | Antenna pattern retrieval, alternative method for derivation of calibration constant over Flevoland tranponder site. |
| 1997-On going | All | Development of several tools which helps to detect the most common problems in the fast delivery data, produces a near real-time report including geographical plots and stores all the problematic events in a database.<br>Development of several tools which extract relevant parameters for the instrument performances monitoring. | Constant quality of assessments.<br>Problematic events focusing<br>Problematic events geographical localization<br>Possibility to perform problematic events statistics. |
| 1996-1997 | WSC | Calibration/Monitoring tools. | For each cycle: Antenna pattern retrieval and Gamma naught Image over the Rain Forest. |
| 1998 – On going | WSC | Cyclone Tracking. To study the CMOD-4 under high winds condition. To design a wind speed correction for data collect over Tropical Cyclones. | To improve the quality of the WSC products [7].<br>To make available (on web) Tropical Cyclone data to the scientific community [8]. |
| November 1999 | ATSR | Averaged Sea Surface Temperature products available in Near Real Time via a new ASST website. | Provide the general public with ASST products, various types of global sea surface temperature maps, basic and in to depth information about the products. |
| 2000 | All | PCS Web | To make available most of the PCS outputs. |
| 1999-On going | RA | Calculation of Scanning point Target Range correction form raw data. New development in relation to algorithm update. | Delivery to the users of a better performing correction |
| May 2000 | ATSR | AIDE – ATSR Image and Display Evaluation | Visual quality analysis for GBT (gridded brightness temperature) and GSST (gridded sea surface temperature) Products. Requested by UK-PAF |

**Links with the users/scientific communities**

Carrying out their work the PCS engineers have established a wide network of links with the user and scientific communities. Those contacts are needed both for information distribution from the PCS to the users/scientists on the instrument and data status and for getting back the users/scientists' feedback and requests.

Those relations are established during the participation to Workshops, Science Advisory Groups and In Orbit Performance meetings and lately to the ENVISAT Calibration and Validation activities; all this not including the Cyclic Report which is regularly distributed to the users or available on the web.

Table 8 gives a summary of activities in contact with the users/scientific communities.

**Table 8: Summary of activities in contact with the users/scientific communities**

| DATE | INSTRUMENT | ACTIVITY | PCS CONTRIBUTION |
|---|---|---|---|
| Regularly | RA | Participation to In Orbit Performance Meeting with instrument specialist and Industry. | Reporting on the ERS-2 RA and Fast delivery data status. |
| Regularly | RA | Participation to ENVISAT RA-2 Science Advisory Group | Reporting on the ERS-2 RA and Fast delivery data status |
| February1999- March 2000 | RA | Participation to feasibility studies for the ENVISAT RA-2 Sigma nought absolute Calibration with a passive technique. | Processing and analysis of ERS-1 and ERS-2 RA and MWR radiometer data and comparison with SSM/I data. Publication of a paper (ref. [6]) |
| May 2000-On-going | RA | Participation to ENVISAT RA-2 Cross-Calibration and Validation activities | Study on the impact of instrumental errors to the total error budget of ERS-2 RA data to be used for the cross-calibration with ENVISAT RA-2 |
| Regularly | WSC | Participation to In Orbit Performance Meeting with instrument specialist and Industry. | Reporting on the ERS-2 WSC and Fast delivery data status. |
| Regularly | WSC | Participation to METOP ASCAT Science Advisory Group. | Reporting on the ERS-2 WSC and Fast delivery data status. Reporting on algorithm or process modification. |
| Regularly | GOME | Participation to In Orbit Performance Meeting with instrument specialist and Industry. | Reporting on the ERS-2 GOME and Fast delivery data status. |
| May 2000 on going | GOME | Participation to ENVISAT Calibration and Validation activities | Algorithm validation and testing. |
| Regularly | SAR | Participation to In Orbit Performance Meeting with instrument specialist and Industry. | Reporting on the ERS-2 SAR status. |
| Regularly | SAR | Participation to ENVISAT Cross-Calibration and Validation activities | Algorithm validation and testing. |

## 3. CALIBRATION MONITORING

**The relative WindScatterometer Calibration over the Brazilian rain forests.**

The objective of the WindScatt calibration monitoring is to ensure the stability of the radar backscattering measurements over the range of the incidence angles during the whole mission lifetime. This is achieved by processing the data acquired by internal and external calibration references.

The internal reference is the calibration pulse. It is a replica of the transmitted signal injected, via the calibration subsystem, into the receiver and it allows the monitoring of the instrument stability.

The external reference targets are the Transponders (to assure the absolute calibration stability) and one natural distributed target: the Tropical Rain Forest in South America [9]. The latter assures the stability of the instrument measurements (sigma nought) over the whole range of incidence angles.

That natural target at the working frequency (C-band) of ERS-2 Scatterometer acts as a very rough surface, and the transmitted power is equally scattered in all directions (isotropic backscattering). Consequently, for the angles of incidence used by the ERS WindScatterometer, the normalized backscattering coefficient (sigma-nought) will solely depend on the surface effectively seen by the instrument.

The incident angle dependency can be removed with the following normalization:

$$\gamma^0 = \frac{\sigma^0}{\cos\theta}$$

The gamma nought values are independent of the incidence angle, allowing the measurements from each of the three beams to be compared.

The PCS is carrying out a monitoring of the gamma nought in order to assess:

- The stability of the reference test area
- The antenna pattern correction
- The stability of the relative calibration during the mission

Figure 1 shows a map of the gamma nought (for ascending and descending passes and for the three antennae) over the reference area.

This type of analysis allows to monitor changes in the scene (as detected at the end of 1997) and to explain the differences noted in the variance of the gamma nought measurements between ascending (test site shows large area with very low signal) and descending passes.

Figure 2 shows the antenna profiles. The PCS carry out this monitoring every cycle (35 days). The quality of the antenna pattern correction is very high. The profiles are flat within 0.3 dB and there is a seasonal effect. In fact in summer the profiles are more flat at the ascending passes while in the winter the result is opposite.

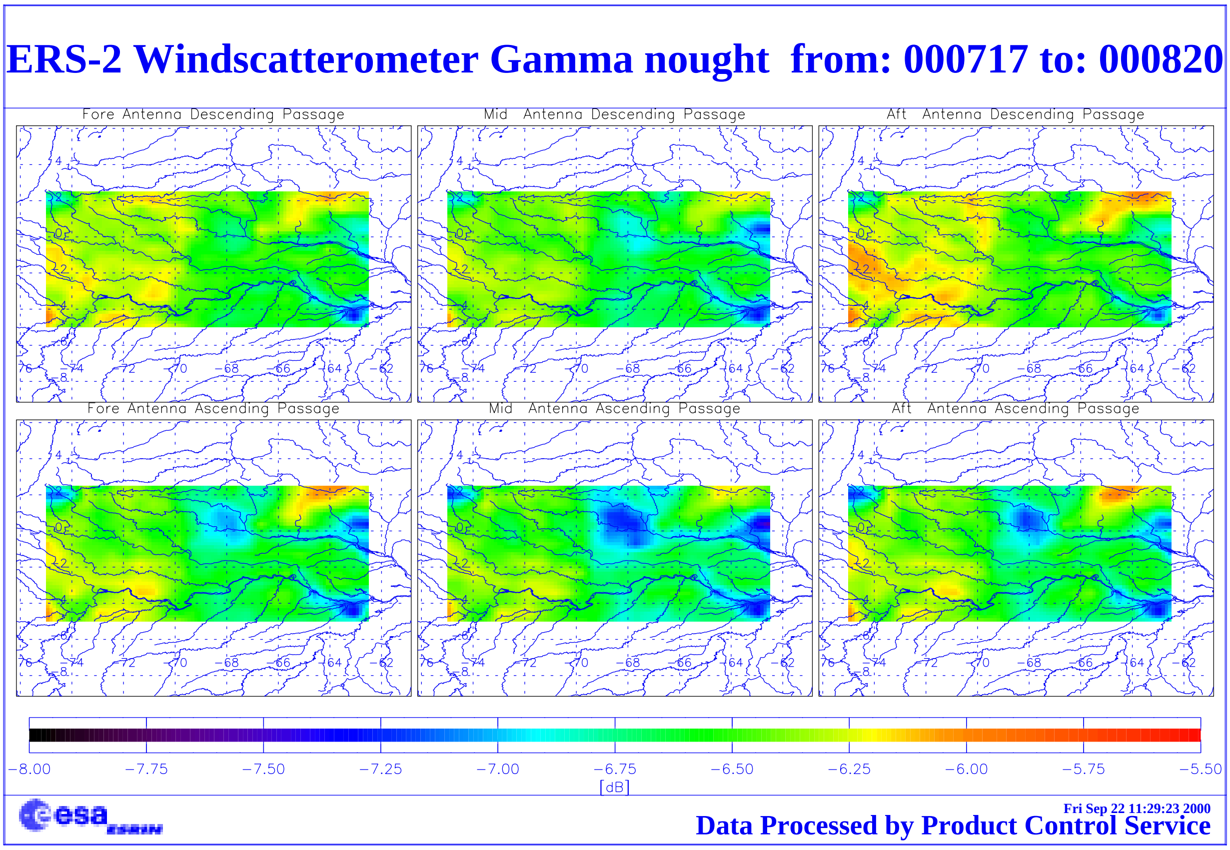


**Fig. 1** ERS-2 WindScatterometer: Gamma nought over the Brazilian Rain Forest

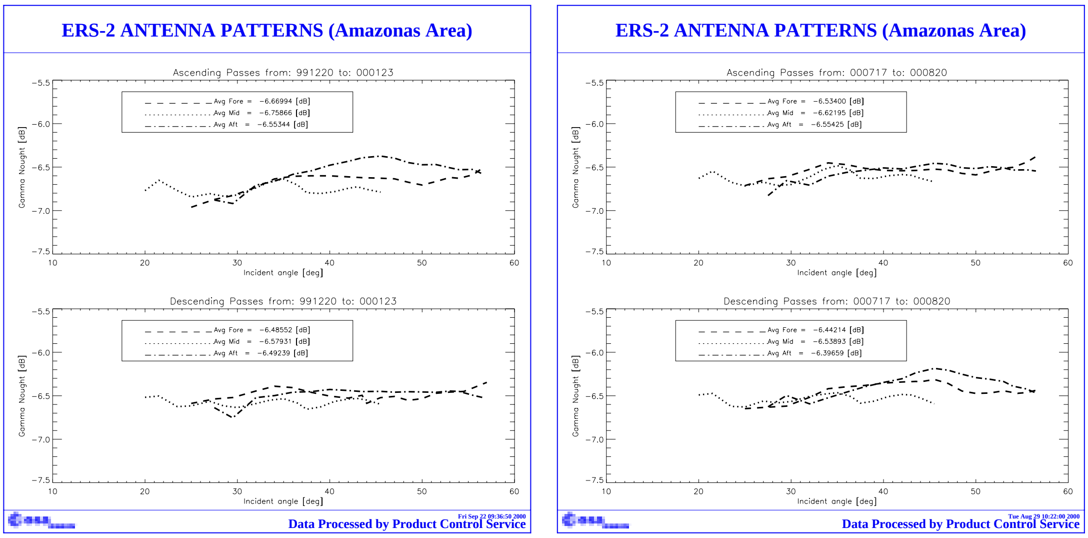


**Fig. 2** ERS-2 WindScatterometer: Antenna Pattern profiles over the Rain Forest. Left panel winter profiles, right panel summer profiles

Every week the PCS computes a histogram of the gamma nought and tries to estimate its maximum. Figure 3 shows the evolution of the gamma noughts maximum during the ERS-2 mission. It is interesting to note the end of the commissioning phase (March 1996) when the gamma nought was calibrated. A small change is recognized on June 1997 due to a new re-calibration (added 0.2 dB) to compensate for the negative bias introduced with the calibration sub-system side B on August 1996.

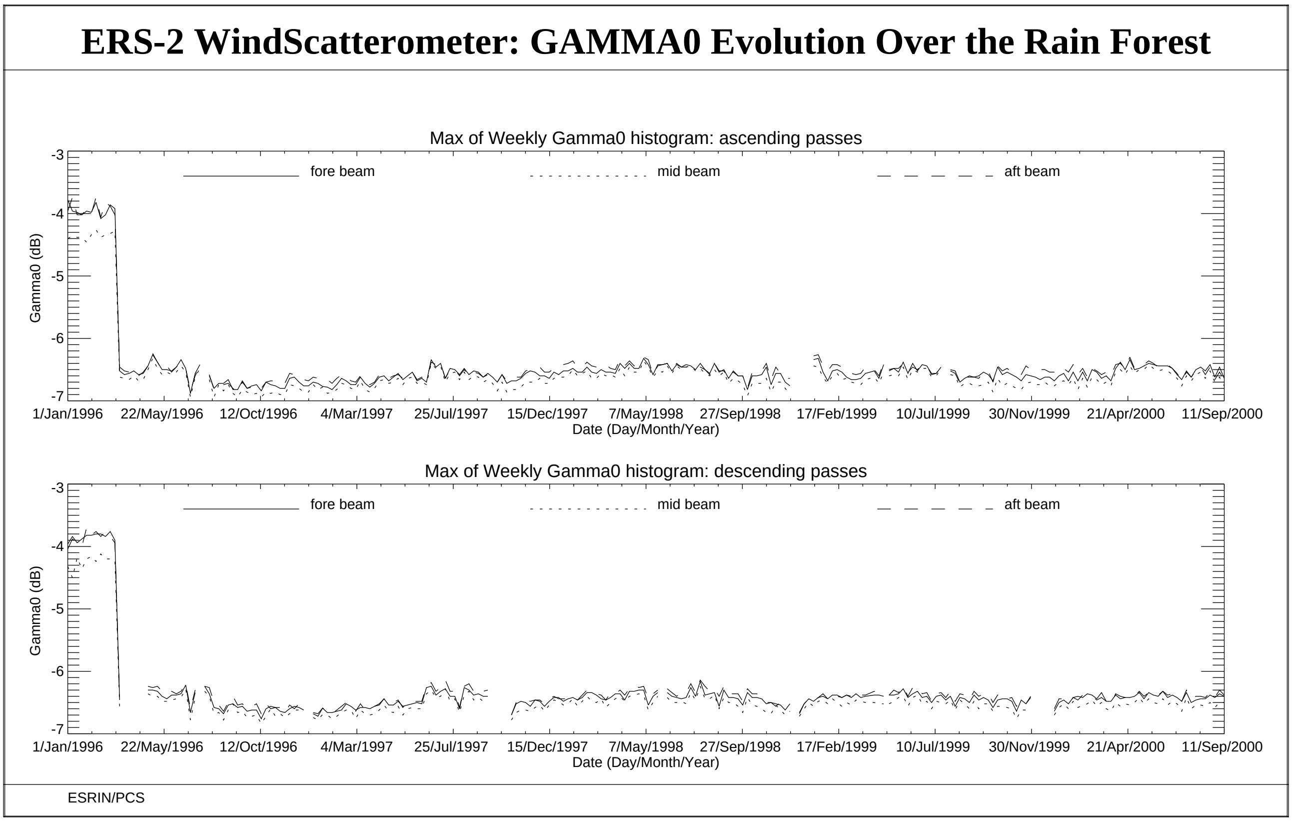


**Fig. 3** ERS-2 WindScatterometer: gamma nought evolution

## The Radar Altimeter internal Calibration

The calibration measurements performed operationally for the Radar Altimeter are executed with the internal calibration technique. It is not an end-to-end absolute calibration because some elements like some ferrite circulators, waveguides and the antenna are outside the calibration path, but it makes a good relative calibration of time dependent variations in the instrument measurements caused by thermal variation around the orbit as well as ageing effects. There are three types of calibration measurements: The Openloop Calibration, the Scanning Point Target Response (SPTR) Calibration and the Ultra Stable Oscillator (USO) Calibration. The Openloop Calibration is related to two parameters: the altimetric range and the received power, which is then related to the normalized backscattering coefficient (Sigma_0). The Openloop Calibration is dedicated in particular to correct for the thermal orbital variation. It does also take into account variability due to instrument ageing. The SPTR and USO Calibration are performed to keep under control time-related effects on some reference parameters used in the evaluation of the altimetric range.

The Openloop Calibration is performd automatically by the instrument and the data are transmitted within the fast delivary products. PCS extracts every day the information and displays it in order to keep under control the calibration performances and eventually use it to explain any occurred anomaly. Figure 4 reports the Openloop Calibration results for the altimetric range due to the internal path delay.

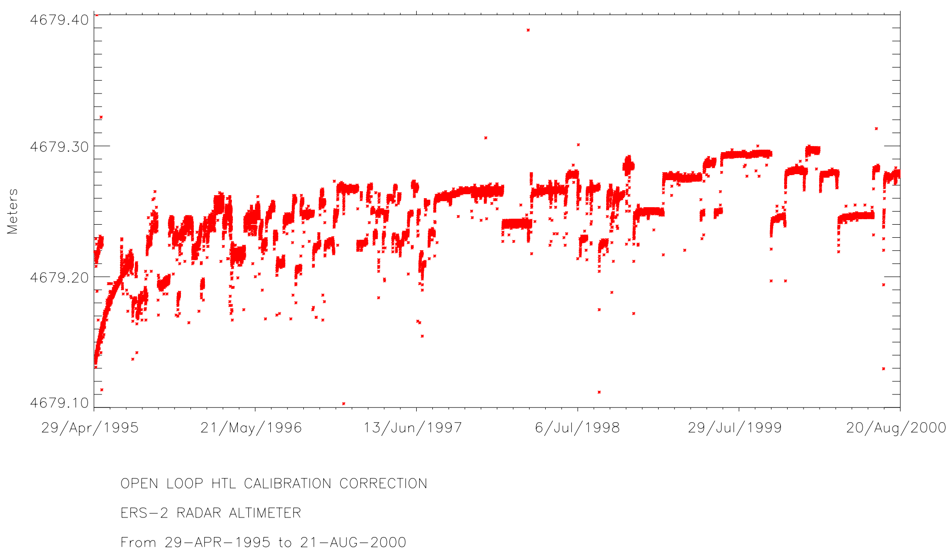


**Fig. 4** ERS-2 RA Open Loop Height Tracking Loop Calibration Correction evolution over the whole mission

The USO and SPTR Calibration are, on the other hand, performed with special measurements. The results are represented by an extract correction to be applied to the altrimetic range by the users. Every week PCS processes the data relative to those particular calibration measurements and provides the correction to be used.

## The SAR Wave internal calibration.

The Fast Delivery processor, running in the ERS2 Ground Segment stations, extracts calibration and replica pulses, present in the telemetry, and generates respectively UIND, UIC products when the SAR is in image mode and UWAND and UWAC products when the SAR is in wave mode (An UWAC is generated when the wave data is compressed on ground, which is not the nominal situation). These products are disseminated to the PCS where the power levels associated to the calibration pulse; the replica pulse and even the noise present in the AMI receiver are analyzed. Accurate estimates of sigma0 measurements are also derived from these power values. The above mentioned products are in parallel ingested into a database at ESRIN to allow the monitoring of the system stability.

Figures showing UWAND power and noise trends can be found in the SAR wave Instrument Performances assessment paragraph (Chapter 4).

**The Microwave Sounder external Calibration**

Over the poles, the space and time coverage is sufficient to draw maps of the brightness temperatures. Moreover, the atmospheric variability is weak, due to the very low water vapor content. Thus, the brightness temperatures are mainly representative of surface emissivity and temperature variations, which slowly vary within the year.

Consequently, the South Pole can be used as a stable target to survey the brightness temperature variations with time. Maps of the 23.8 and 36.5 GHz brightness temperatures measured by the radiometer over the South Pole (latitudes higher than 65 S) are prepared. The ice cap appears colder than sea ice and free water at the two frequencies.

## 4. INSTRUMENTS LONG-LOOP PERFORMANCES

**The GOME Instrument Performance assessment**

For the GOME instrument several parameters are analyzed on a long-term basis, in order to monitor their lifetime behavior:

- Dark Current Analysis:

Using one orbit from each GOME monthly calibration data set, Fixed Pattern Readout Noise (FPRN) and Leakage Current (LC) are monitored. The FPRN has shown only negligible variation during lifetime for all instrument channels, whereas the LC increases linearly by less than ~14% per year in all channels.

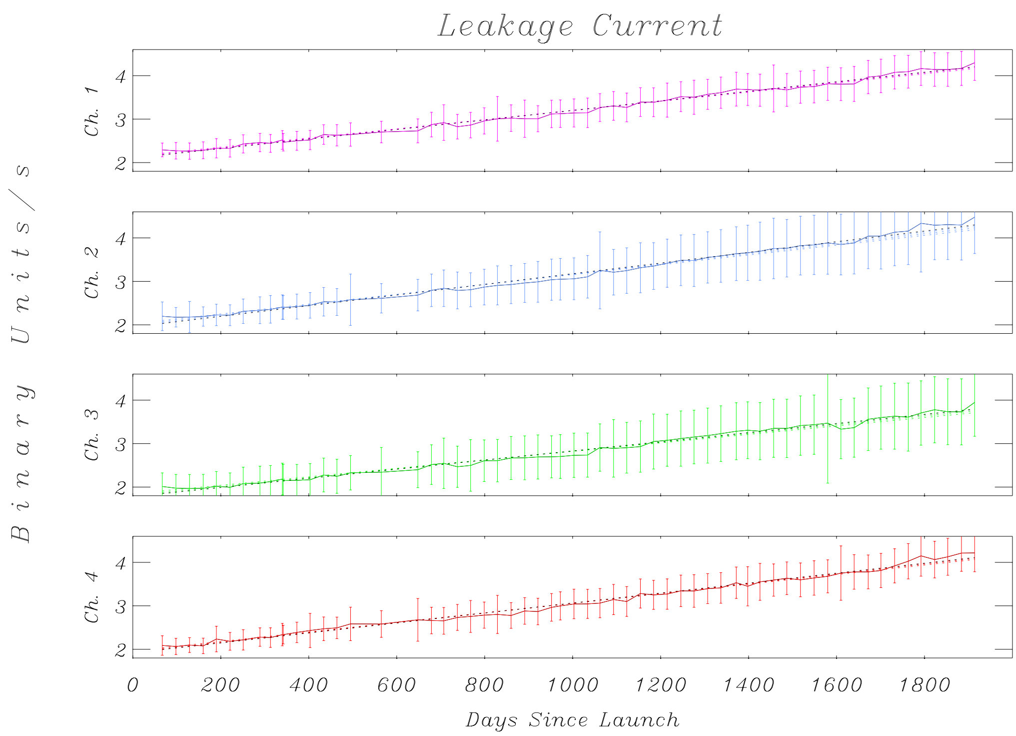


**Fig. 5** Leakage Current (27/06/1995 – 28/07/2000)

- Diffuser Reflectivity:

GOME measures the back-scattered radiance from the Earth's atmosphere and surface and the solar irradiance, which is viewed via a diffuser plate.

In previous instrument (e.g. TOMS, SBUV) these were found to be subject of degradation. Therefore GOME was equipped with a shutter for the diffuser plate and with a diffuser calibration system, which are operated only for a short time each day during one orbit. To analyze a possible degradation an algorithm was developed, which determines the ratio of direct calibration lamp measurements to those via the diffuser.

No significant change for the GOME diffuser plate between (27/06/1995 – 28/07/2000) could be found.

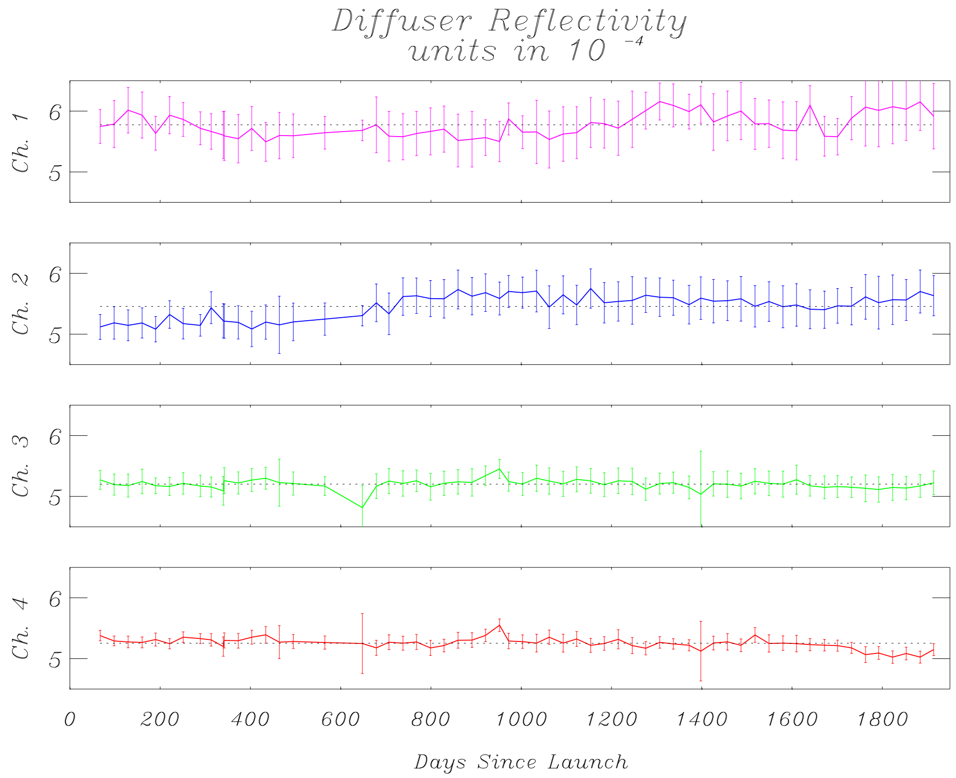


**Fig. 6** GOME Diffuser Reflectivity (27/061995 – 28/07/2000)

- Thermal Environment:

A long-term analysis on the thermal optical parts of GOME was performed for the Polarization Monitoring Detectors, Optical Bench and Predisperser Prism. Seasonal variation can be seen due to the variation in the distance to sun.

A trend shows a small linear increase of about 0.3 K during the current lifetime.

- Scanner Performance:

The GOME scan mechanism contains two non-separable angular contact bearings, which are dry-lubricated with lead and are subject to wear. A possible degradation is monitored by comparing the measurements with the nominal linear scan-mirror motion. [11] Largest deviations occur at the extremities of the swath and are also swath mode dependent. For Narrow Swath, deviations of ~0.15 deg and for Nominal Swath up to ~0.3 deg are found.

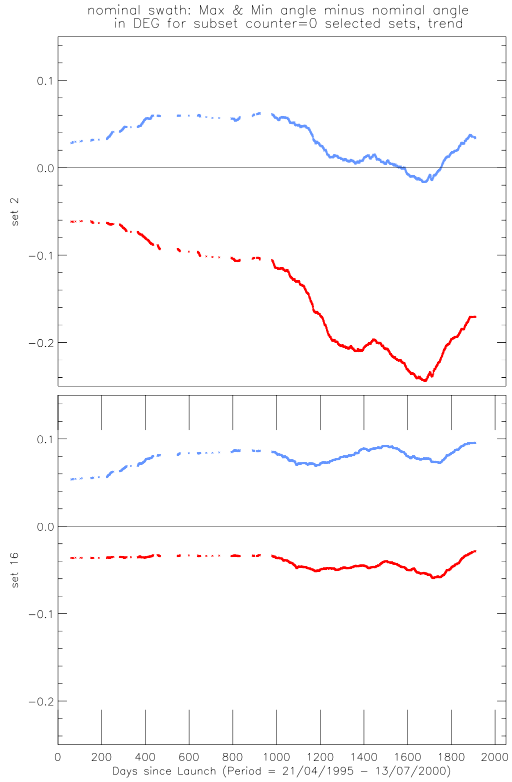


**Fig. 7** Scanner Performance Analysis

- Wavelength-Calibration lamp intensities:

Intensities of emission lines are monitored during life for Cr lines at 427.6 nm, 437.5 nm, and 560.2 nm [12].

**The Radar Altimeter Instrument Performances assessment**

The Radar Altimeter instrument performances are assessed by PCS monitoring the following parameters:

- Acquisition Percentage: the percentage of products in Acquisition Mode since the beginning of the mission. This parameter is useful to determine the capability of the instrument in performing meaningful measurements.

- Internal Instrument Parameters. They are important to keep track of the status of every subsystem internal to the instrument, and try to establish correlation with eventual variations in the measured quantities (e.g. Range, Sigma_0 and Significant Wave Height) and with instrument malfunctions.

- Intermediate Frequency Filter Shape. The trend of the daily differences respect to the shape the IF Filter had at the beginning of the mission (e.g. on the 5$^{th}$ of May 1995) is important in order to monitor if and how the received echo waveforms are distorted by this instrumental component. In particular it is interesting to survey if and how the eventual distortions have been changing during the mission lifetime.

- Off-nadir pointing (mispointing): the angle of which the boresight of the antenna is displaced from the vertical to the observed scene. The analysis of the mispointing variations since the beginning of the mission is important in order to asses if the RA antenna really points at nadir being this one the of the main requirements for all the RA data processing.

Figure 8 reports few Radar Altimeter internal parameters in occasion of an anomaly. The inspection of the parameters variations together with the correlation with colors, representing the instrument functioning modes, allows the anomaly to be better characterized.

Figure 9 reports the mispointing trend since the beginning of the mission, being the more dense set of points around February 2000 data retrieved during the mono-gyro piloting software validation campaign.

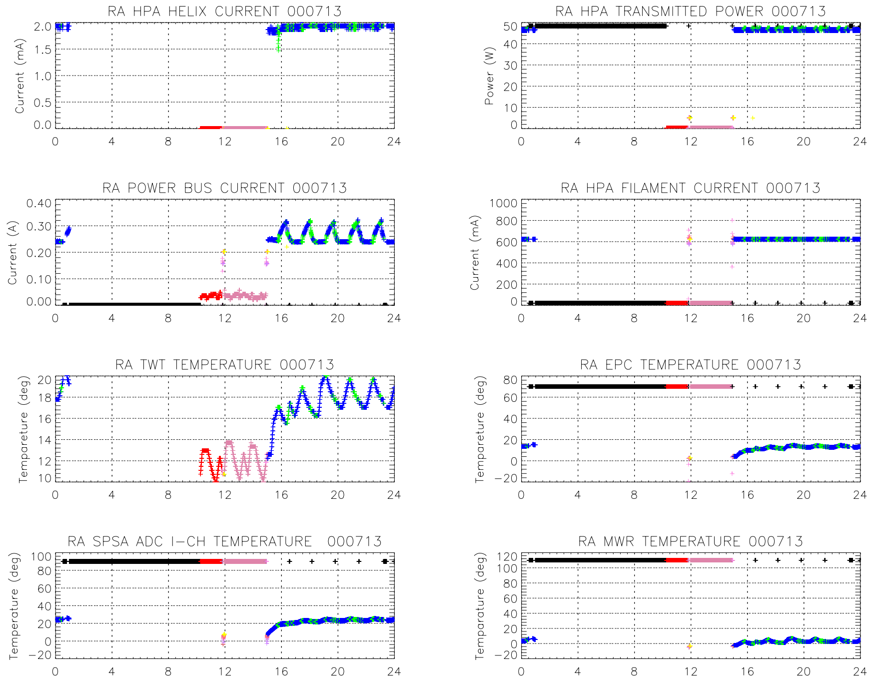


**Fig. 8** ERS-2 RA internal parameters variations in occasion of an anomaly

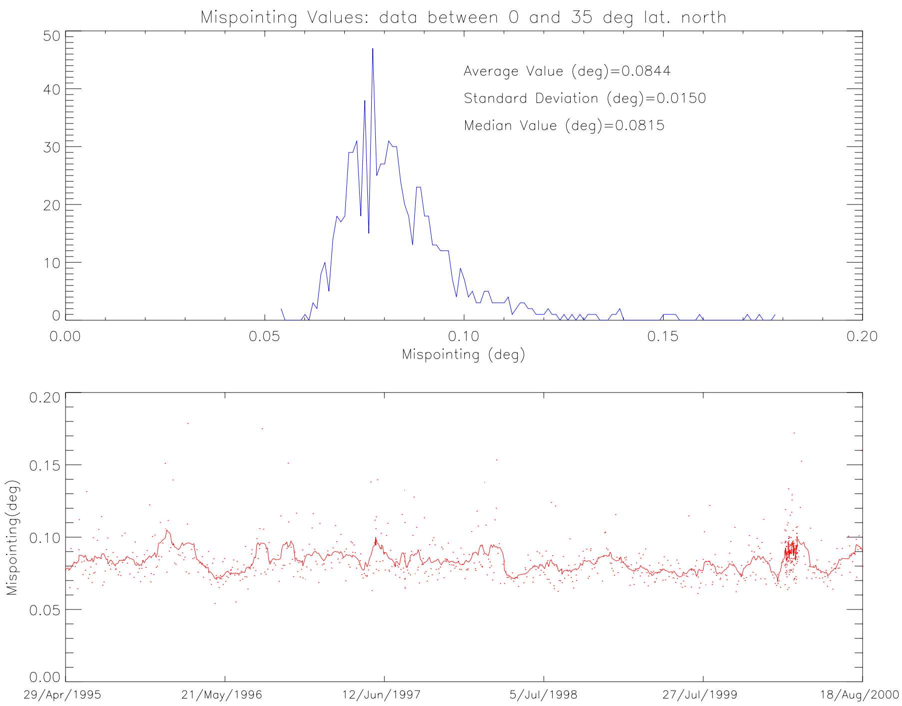


**Fig. 9** ERS-2 RA mispointing trend over the whole mission

**The WindScatt Instrument Performance assessment**

To assess the WindScatt instrument performance the PCS monitors the following parameters:

- Internal Calibration Level to track the evolution of the transmitter and receiver chain.
- Noise power to estimate the instrument noise and to correct the sigma nought. The trend shows that the noise is negligible for the three beams.
- Doppler frequency to monitor the performances of the devices in charge for the satellite attitude (gyroscopes, Earth/Sun sensor). The analysis of the Doppler frequency recognizes the period when the Earth sensor side B was operated and the orbital maneuvers. It is also useful to compare the satellite attitude before and after the 7th February 2000 when a new Attitude On-board Control System (AOCS) configuration was used to pilot the platform.
- Operational modes to assure a global coverage of the WindScatt data.

For the internal calibration level, a power decrease was detected since the beginning of the mission. Figure 10 shows the trend. The PCS has computed the power decrease rate as 0.1 dB/Cycle. On 26th October 1998 2dB were added to the transmitted power to compensate for the decrease. The monitoring is essential to schedule new power increase and to assure that no low-saturation effect is present in the data.

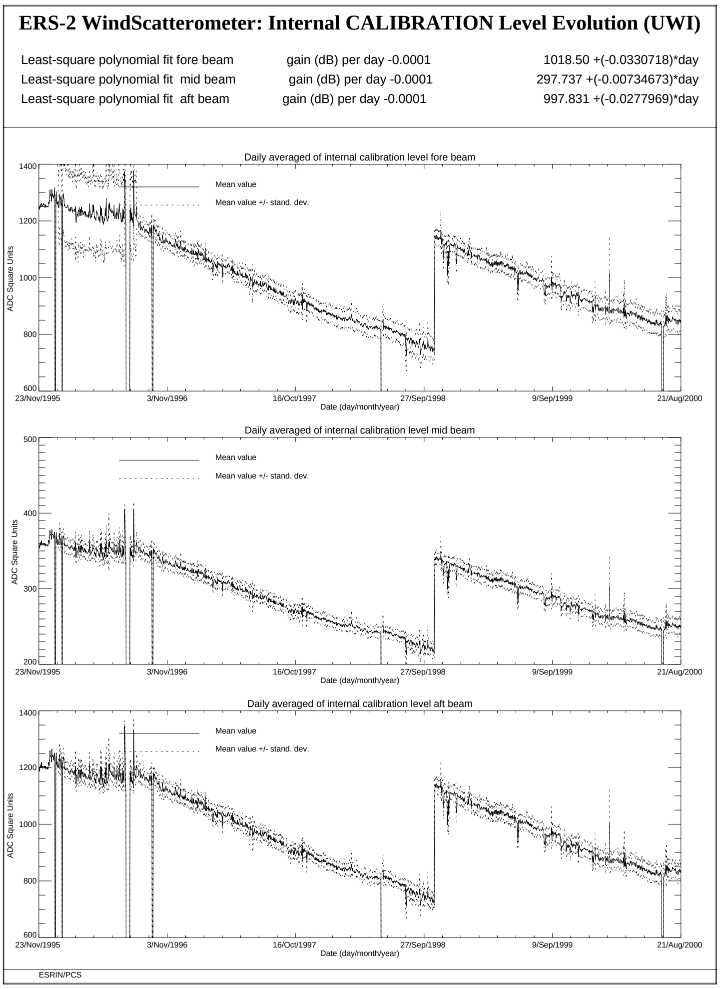


**Fig. 10** ERS-2 WindScatterometer: Internal calibration evolution since the beginning of the mission.

**The SAR wave Instrument Performance assessment**

Trasponders over the calibration site in Flevoland have been monitored to control the stability of the ERS system. VMP PRI products have also been processed and analyzed for this purpose.

Figure 11 is showing the calibration constant measured from the transponders.

The calibration constant has shown a very high level of stability throughout the ERS-2 mission. Transponders have been missing during some acquisition, and some calibration constant were calculated at a considerable lower value than expected, but these occurrences have regularly been correlated to tranponder switch-off or occasional transponder mispointings.

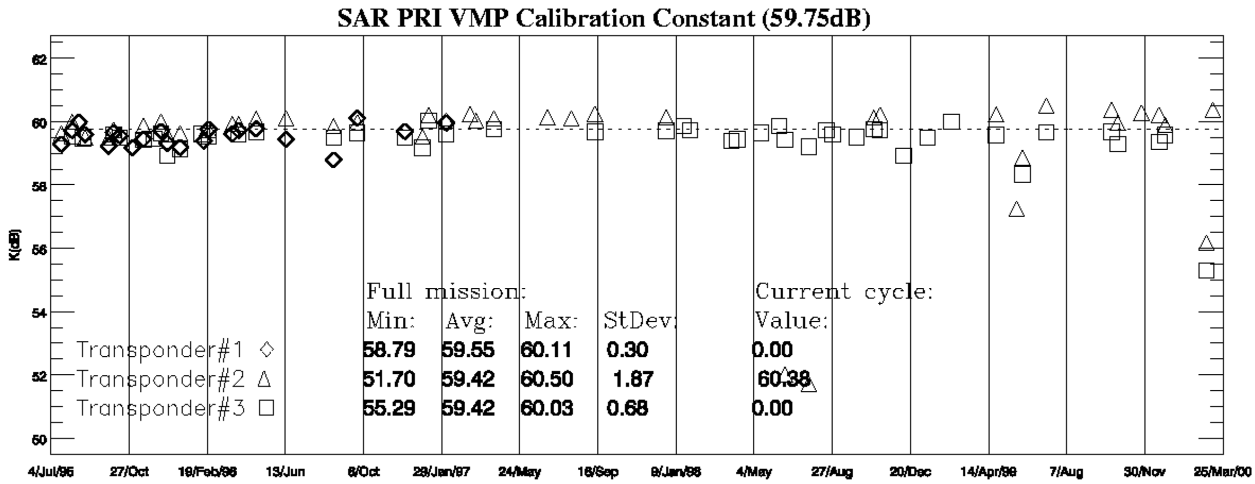


**Fig. 11** ERS-2 SAR Calibration constants over Transponders.

The Calibration Pulse Power shown in Figure 12 has decreased steadily since the beginning of the mission and it is now 2.90 dB lower than the reference level.

The noise power level (see Figure 12) has maintained a value very close to the initial reference level, with variations mostly ranging within 0.1 dB.

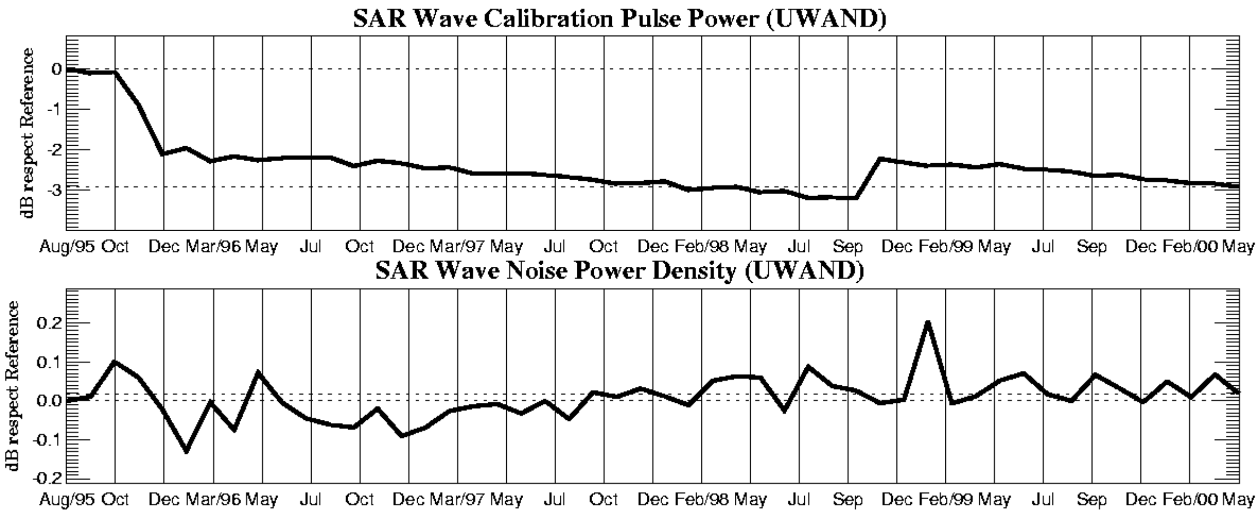


**Fig. 12** ERS-2 SAR (Wave mode) Calibration power (upper plot) and Noise power (lower plot) evolution

### The Microwave Sounder Instrument Performance assessment

The monitoring of the MWR behavior can be characterized by its gain, which is derived from the calibration load measurements (hot load, sky horn measurement). Since the failure on the 23.8 GHz channel in June 1996, the gain on this channel has been stabilized at approximately one tenth of its original value. The two channels are stable: the 36.5 GHz channel has increased by about 1% within the two last years, and the 23.8 GHz channel has slowly decreased by about 3% over the same period. An anomaly occurred on March 27,1998 and had no consequence on the radiometer.

## 5. PRODUCTS MONITORING

### The AMI operational modes assessment

The routine analysis of the AMI working modes allows for the verification of the global product coverage. Differences between the Mission Plan and AMI working modes causing data loss has been detected and solved. Figure 13 compares the new (left panel) and old (right panel) set of parameter in the AMI Mission Plan Schedule (MPS). The decrease of the duration of the gap modes by up to 30 seconds (during the red segments no data are acquired) is clear in particular over the NorthWest, North East Pacific area and over the South Pole.

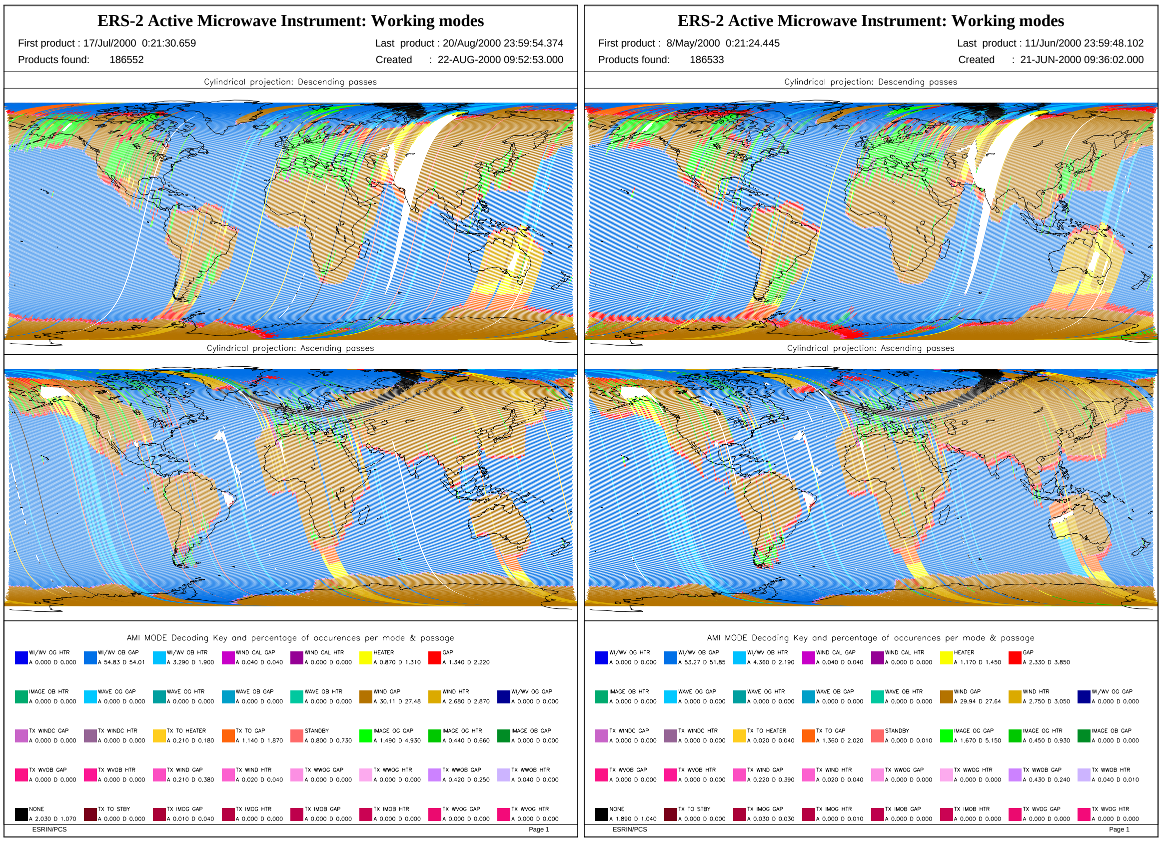


**Fig. 13** ERS-2 AMI working modes. Left panel cycle 55; right panel cycle 53

### The geophysical validation of the WindScatt data

The PCS carries out quality control of the winds generated from the WSCATT data. External contributions to this quality control come also from ECMWF and UK-Met Office. The trend analysis is summarized in the plots of Figure 12. From up to down are shown: the number of valid sigma-nought triplets acquired per day; the evolution of the wind direction quality, the ERS wind direction (for all nodes and only for those nodes where the ambiguity removal has worked properly) is compared with the ECMWF forecast, the monitoring of the percentage of nodes whose ambiguity removal works successfully and the computation of the wind speed deviation: (bias and standard deviation) by using the ECMWF forecast.

The results since the beginning of the mission are: a stable number of valid sigma-nought with a small increase after June 29th 1999 due to the dissemination in fast delivery of the data acquired in the Prince Albert station. An accurate wind direction for roughly 93% of the nodes, a success in the ambiguity removal for more than 90.0% of the nodes.
The ERS-2 wind speed shows an absolute bias of roughly 0.5 m/s and a standard deviation that ranges from 2.5 m/s to 3.5 m/s with respect to the ECMWF forecast. The wind speed bias and its standard deviation have a seasonal pattern due to the different winds distribution between the winter and summer season. Two important changes affect the speed bias plot: the first is on June 3rd, 1996 and it is due to the switch from ERS-1 to ERS-2 data assimilation in the meteorological model. The second change, which occurred at the beginning of September 1997, is due to the new monitoring and assimilation scheme in ECMWF algorithms (4D-Var).

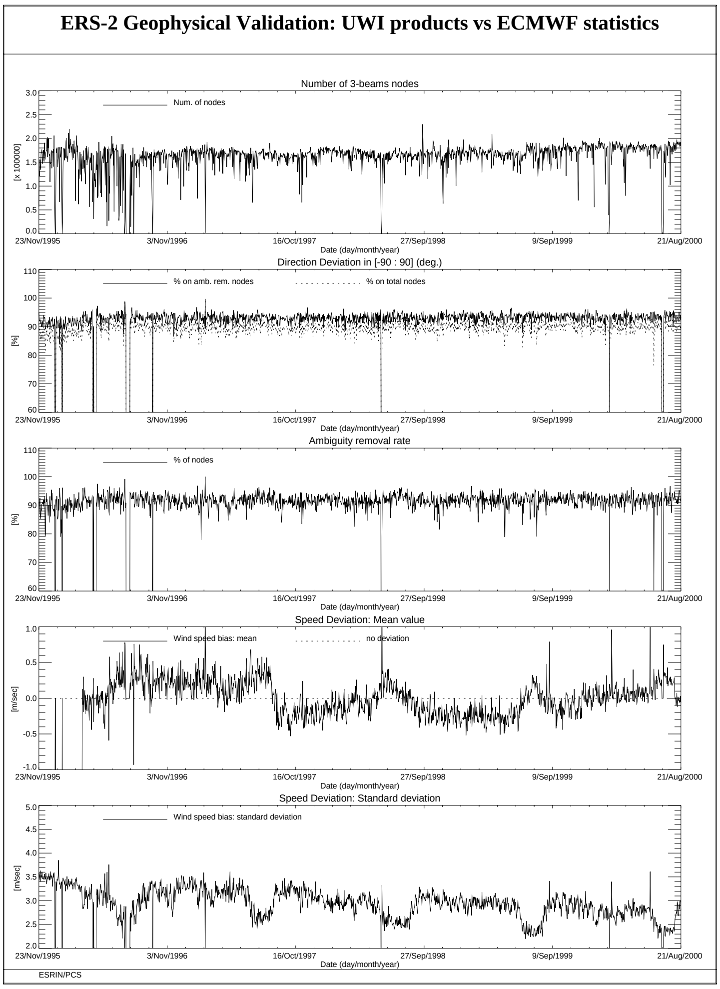


**Fig. 14** ERS-2 WindScatterometer: Geophysical validation since the beginning of the mission

**The Radar Altimeter Fast-Delivery Products (URA) performances assessment**

The performance of the fast-delivery products is determined, within PCS, by means of the following criteria:

- Availability of Data and Quality Assessment: a summary of the percentages of available/not available products and of all the features affecting their quality during every cycle.

- Fast Delivery Data Summary.

- Instrument Mode: an overall picture of the modes the instrument worked in during every cycle.

- Look Up Tables (LUT) Status.

- Data Comparison with Forecasts: the comparison of the fast delivery data with the forecasts performed by ECMWF is useful for the geophysical validation of the products.

Figure 15 shows a plot of geographical displacement of anomalous events. The anomalous events are detected by PCS for every orbit and stored into a database. The analysis of this kind of cyclic geographical plots together with the statistical analysis allowed by the presence of the data base and the comparison with the results of other cycles give the PCS engineers a valid means to characterize in detail any anomalous events occurred.

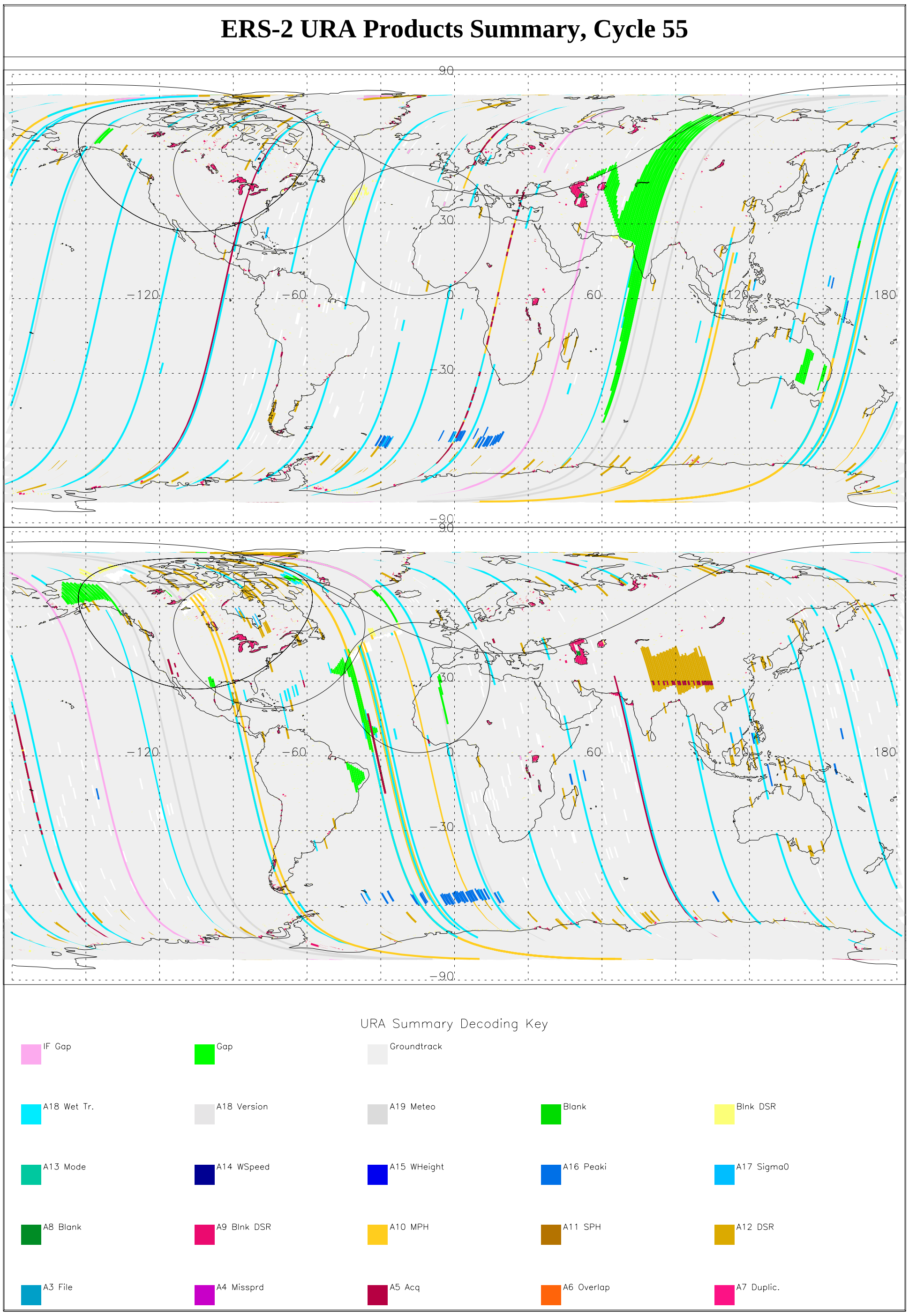


**Fig. 15** ERS-2 RA fast delivery products anomalous events for cycle 55

**The GOME Fast Delivery Products (EGOI) performances assessment**

Also the GOME Fast Delivery data EGOIs (Extracted GOME Instrument Header) are monitored for availability of data and quality assessment. Besides the telemetry data, parts of the science data are monitored at the PCS by producing "Quick-Looks". The images produced, provide quick-look checks on the uncalibrated data:

- Acquisition and coverage from the ground track.
- Instrument performance from the parameters visualized in the images.

Following images are produced:

- Ozone Line Ratio

With this image a relative indication of the global ozone field is given. Shown is the ratio of the intensities received in the ozone lines around 331 nm and 313 nm – after removing the dependence on the solar zenith angle.

Normal features, which can be seen, include the mid-latitude maxima belts around 60 degrees and the Equatorial minimum.

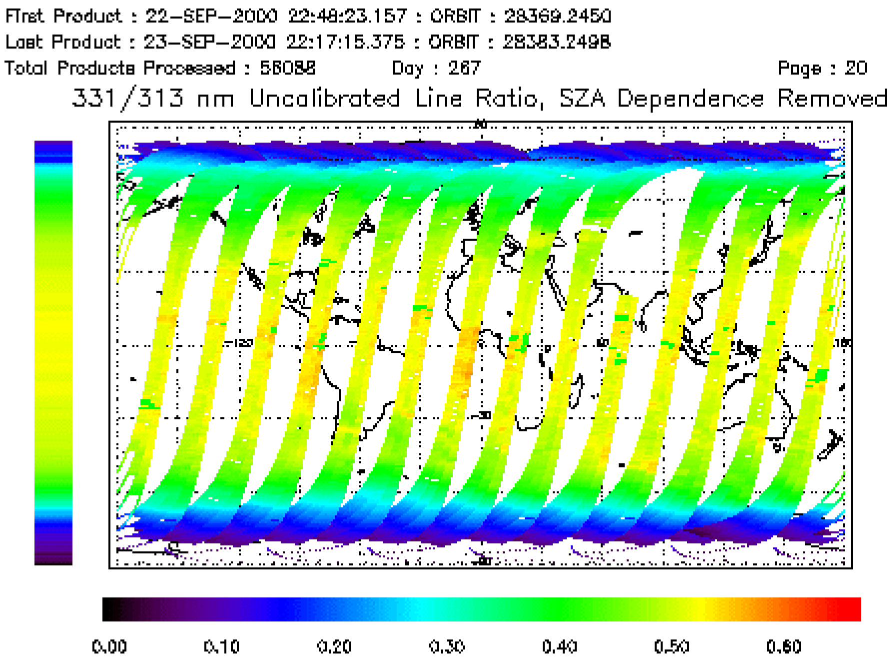


**Fig. 16** GOME Ozone Line Ratio

- PMD Image

This image (see Figure 17) is produced with Polarization Measurement Detector (PMD) data, which give broad band sampling of the Earthshine radiance at wavelengths approximately corresponding to red, green and blue. The outlines of continents can be seen clearly as well as clouds.

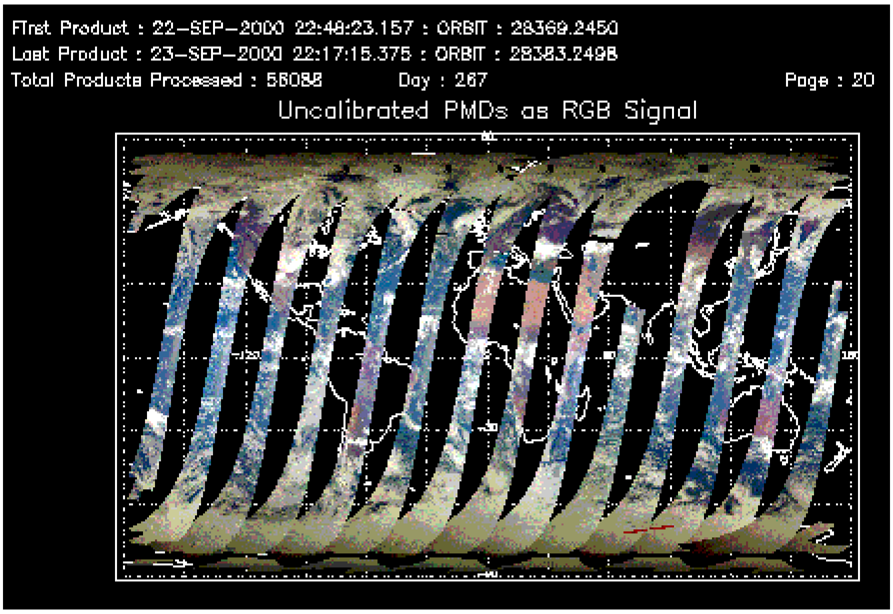


**Fig. 17** GOME PMD Image

- Near IR Intensity

This plot (see Figure 18) shows the data received in the 778nm infra-red window. High values can be seen to correspond to cloud, ice and desert features in the PMD image

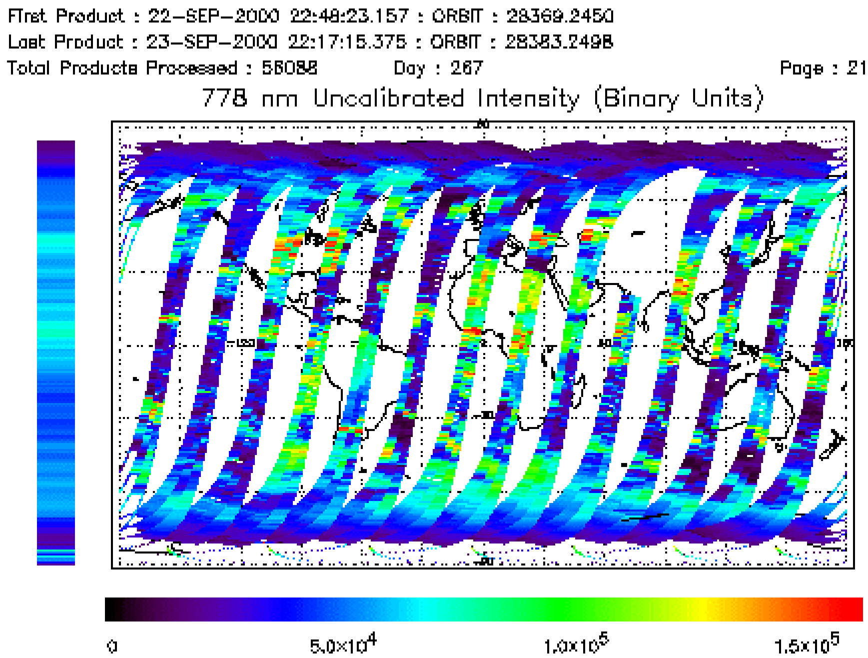


**Fig. 18** GOME Near IR Intensity

**The Near Real Time ATSR Averaged Sea Surface Temperature Products performance assessment [13]**

ATSR-2 data cannot be received directly from the satellite because there is no continuous direct broadcast of data. Instead the ATSR data collected each orbit, together with the low bit rate data from the other sensors on the platform, are stored on an on-board tape recorder for subsequent transmission to the ground. These stored data are then transmitted to the ground during each orbit when the satellite is within the reception range of one of the designated ESA groundstations which are at Kiruna (Sweden), Maspalomas (Spain), Gatineau and Prince Albert (Canada). Kiruna is the main station receiving about 10 out of 14 orbits of data collected each day.

The data received at the groundstations are then supplied to the RAL processing facility, where the ASST products are generated. This facility offers an off-line ASST product generation service, which provides the products with a few days delay. Therefore ESA has developed a near real time service which is now in operation at Tromsø (Norway) ground station. By agreement and because of its geographic proximity, this station can eavesdrop on the 10 orbits of satellite data downlinked to Kiruna each day, and processes this data in near real time to deliver the ASST products to near real time users.

ASST near real time products (products processed at Tromsø) are available through the ASST website at ESRIN: http://odisseo.esrin.esa.it/asst also accessible via the PCS web.

At this site you can download ASST products free of any charge, grouped into one tar file per day. The ASST products remain available at least until RAL has produced its off-line products. Information directly related to the ASST products can be found under ‘Instrument Info’ and ‘Product Info’ as well as in the ‘Beginner’s Guide’. The ‘Beginner’s Guide’, which can be accessed through the home page, provides you with some basic information on the principals of remotely sensed sea surface temperatures, a brief description of the ATSR Instrument and its coverage, and the processing chain which generates the final ASST products.

Furthermore, different kinds of global sea surface temperature maps are available. Firstly, there are the daily updated maps, (available under ‘Latest Maps’) these maps show the sea surface temperature and the sea surface temperature with respect to the corresponding monthly mean in 1995 derived from the dual-view data within the product. The values of the maps are daily updated with the new available data, which replaces the old data. No interpolation or any other operation is performed.

Another kind of images is available under ‘Monthly SST Maps’. These maps represent the sea surface temperature or the sea surface temperature with respect to the sea surface temperature of the corresponding month in 1995, averaged over one month. Whenever off-line ASST products become available at RAL, the maps are replaced with this data.

The maps are available also in ASCII format, and occasionally some information about sea surface temperature related events around the world are included such as El Niño and its global effects in 1997-1998 (see Figure 19).

The same maps are used in 3-D representations of a part of the Pacific Ocean. In these images, the color represents the sea surface temperature with respect to the temperature in 1995, and the height is derived form radar altimeter data. Animations of all maps are available in two sizes under ‘Animations’

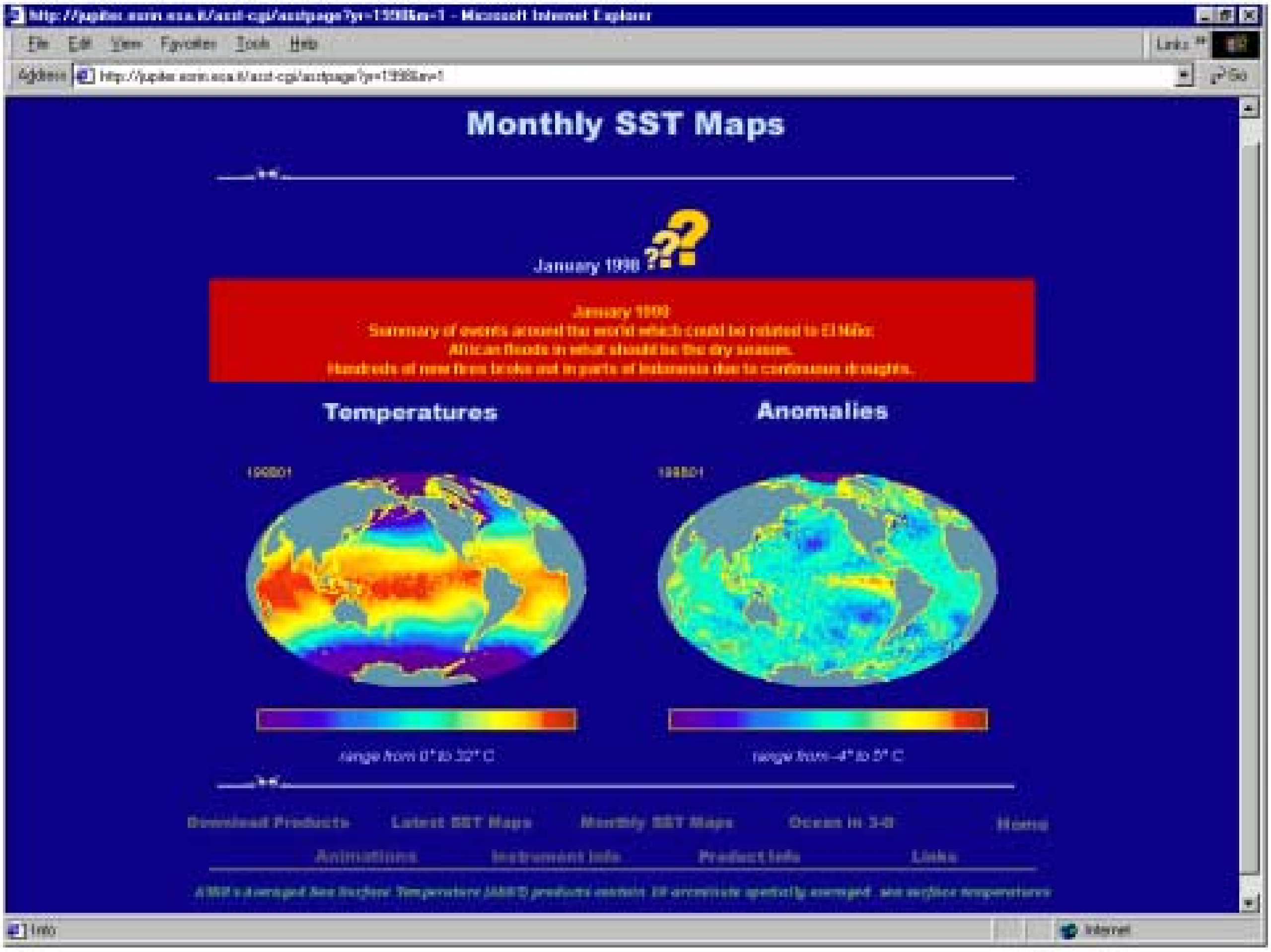


**Fig. 19** El Niño and its global effects in 1997-1998

## 6. CONCLUSIONS

The scope of the routine cal/val and long loop sensor performances monitoring is to assure the quality of the data throughout the whole ERS-2 Mission. To fulfill this objective the PCS has developed accurate strategies to monitor the instruments as well as the ground segment performances. These strategies are regularly revised and updated when required, to ensure and maintain a high data quality, through a recursive process of special investigations and corrective actions. Ultimately the active co-operation among instrument expert, operation teams, scientific community and Industry, has lead to the successful achievements of these objectives. In short, the PCS provides a closing path to the ERS-2 quality system loop, allowing for immediate and positive signaling of courses of actions in order to guarantee and in some cases improve the quality standards set forth by the original mission requirements.

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