The ERS Wind Scatterometer mission:
routine monitoring activities and results.

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Abstract

This paper summarizes the major events occurred since the launch of ERS-1 and ERS-2 Wind Scatterometer, and shows the results from the monitoring of the instrument by looking at the telemetry data stream (e.g. working modes, currents, voltages and temperatures of AMI instrument) and the fast delivery product (e.g. doppler, noise and calibration information). The latter allows also the monitoring of the On-Ground Processing and the geophysical validation of the products. This paper also reports the results of the commissioning phase and describes the calibration status of both ERS-1 and ERS-2 Wind Scatterometer.

This monitoring activity is conducted within the Product Control Service (PCS) at ESRIN.

Introduction

A remote sensing mission involves many aspects: the mission scenario, the instrument calibration and maintenance, the data quality control. In order to monitor these different aspects in the ERS ground segment the Mission Coordination and Product Assurance Section at ESRIN is in charge of ensuring the operational integrity of the overall ERS mission and in particular, the quality of the data products provided to users. The strategy adopted to meet this objective is to regularly monitor both the ERS sensors performance and the ground segment operations by analysing the quality of the ERS products.

The scope of this monitoring activity which is an important task which runs in the background, is two-fold.: first to maintain the quality of the results obtained during the commissioning phase, to assess the evolution of the instrument quality due to ageing or to human action commanded from ground and to take all corrective actions necessary to restore the initial quality.

At this time we have five years of ERS-1 Wind Scatterometer mission (from July, 21st 1991 to June, 3rd 1996 ERS-1 where instruments were put in stand-by) and more than three years of ERS-2 Wind Scatterometer mission since the launch of the ERS-2 satellite on the 21st April 1995. At this point, it is useful to outline the differences between the ERS-1 and ERS-2 Wind Scatterometer missions in terms of events, operations and performance. Moreover it is important to asses the continuity in the sigma nought calibration and in the validation of the geophysical parameters retrieved: the wind speed and direction.

The paper is structured in the following chapters:
- Events since launch.
- Instrument operation modes
- Calibration objectives.
- Commissioning phase activities and results.
- Calibration performance.
- Instrument performance.

Events since launch

The events since launch can be grouped into three main categories.

- Every event linked to the satellite itself; these events are not related to the AMI or to the Ground processing, but do affect the data quality for a certain period of time. In this table we didn’t include the orbit manoeuvres which are occurring roughly every month.
- The instrument anomalies which generally affect the data for a short period (time needed for being alerted and to take the appropriate action). In few cases these anomalies are more difficult to overcome and the data quality could be slightly degraded until the definitive solution is implemented.
- Ground segment events which are mostly installation of scatterometer data processing chain upgrades and Look-Up-Tables loading in the stations.

Table 1, 2 and 3 are covering these three categories of events in reference to ERS-1, table 4, 5 and 6 are relative to ERS-2.

Table 1: ERS-1: Satellite events

13rd July 1991	ERS-1 Launch.
25th July 1991	Phase A: commissioning. 3 days repeat cycle.
28th December 1991	Phase B: 3 days repeat cycle.
14th April 1993	Phase C: 35 days repeat cycle.
6th December 1993	IDHT failure (HR amplification tube).

23rd December 1993	Phase D.: 43 days repeat cycle.
10th April 1994	Phase E/F: 168 days repeat cycle.
21st March 1995	Phase G. 35: days repeat cycle.
3rd June 1996	ERS-1 instruments in stand-by. Check-up period every two 35-days cycle.
29th December 1997	solar panel partial failure: the instruments cannot be powered-on all at the same time.

Table 2: ERS-1: Active Microwave Instrument events

	none.

Table 3: ERS-1: Ground segment events related to scatterometer data

19th September 1991	Scaling by 1.3 dB of all beams. Coarse mid beam correction.
29th October 1991	Gain tuning.
4th November 1991	Coarse Fore and Aft beam correction.
15th January 1992	Sampling correction.
1st March 1992	Final antenna pattern.
1st June 1992	LRDPF 3000
10th June 1992	CMOD3
26th June 1992	LRDPF 3010
24th February 1993	LRDPF 4000 + CMOD4
24th December 1993 14th January 1994	Data reprocessed in backlog with correct tables.
24th March 1994	LRDPF 4100
10th march 1995	SGI LRDPF 6210 (transcription)
22nd March 1995	LRDPF 4200
27th April 1995	LRDPF 4210
3rd October 1995	SGI LRDPF operative at Maspalomas and Gatineau stations.

The AMI instrument on board ERS-1 has not been affected from serious anomaly, on the contrary, the ERS-2 AMI has a different history.

During the initial setting of the ERS-2 spacecraft, the first attempt to switch on the AMI resulted in a serious anomaly causing the instrument to shut down, both in SAR and Scatterometer modes. It was soon discovered that the instrument was prevented from working at nominal power. By reducing the output power to the minimum, engineers succeed in acquiring the first SAR image on the same day, but it was still not possible to run the instrument in Wind mode.

Many test were made to determine the cause and possible solutions to the problem. The anomaly was resolved by setting the redundancy switch at the input to the High Power Amplifier to an intermediate position, thereby using it as a power splitter. The output power was reduced by a factor of two, and, for the first time some wind measurements could be made (November, 16th 1996).

After few months of nominal operation, a new anomaly affected the ERS-2 Wind Scatterometer instrument. The relay used to switch on and off the calibration subsystem was not latching properly and more and more often the instrument was shutting down following a relay failure. On August, 6th 1996 it was decided to operate the instrument with the redundant unit of the calibration subsystem.

Also in August 1996 a major failure of the Scatt electronics required to switch to the redundant unit.

Table 4: ERS-2: Satellite events

21st April 1995	ERS-2 Launch. ERS-2 orbit is approximately 30 minutes behind ERS-1 with a 35 days repeat cycle.
26th January 1996	Attitude and Orbit Control System depointing anomaly.
14th February 1997	Gyroscope anomaly.
3rd June 1998	Depointing anomaly

Table 5: ERS-2: Active microwave instrument events

1st May 1995	Switch-on of the AMI was attempted and failed due to activation of the receiver overload protection circuit.
	Reducing the RF drive level to the HPA. Output power reduction of 1.7 dB.
	AMI Image and Wave mode switch on.
	Attempt to operate in Wind mode failed.
16th November 1995	By use of an updated beam current command the input redundancy switch control circuit was set in an intermediate condition (Power split function).
15th - 25th July 1996	Scatterometer unavailability due to calibration DC converter switch off.
26th July 1996	Switch to Scatterometer electronics side B.
26th July to 5th August 1996	Scatterometer unavailability due to calibration DC converter switch off.
6th August 1996	Switch to calibration subsystem side B.
23rd September 1996	AMI Scatterometer test.
24th September 1996	Calibration DC converter test. Operation without calibration subsystem.
26th September 1996	No doppler information on board after the test.
31st October 1996	AMI Scatterometer test.

December 1997	SBT and noise field corruption
6th June 1998	No doppler information on board after the depointing anomaly.

Table 6: ERS-2 Ground segment events related to scatterometer data

24th April 1995	Installation of SGI LRDPF version 6210.
3rd October 1995	SGI LRDPF version 6300 in operation at Maspalomas and Gatineau stations.
22nd November 1995	Wind mode was introduced as part of the nominal Mission Operation Plan.
15th January 1996	Start of the scatterometer commissioning phase.
19th March 1996	End of the scatterometer commissioning phase. Gain setting, final antenna pattern, new set of LUT in the ground stations.
16th April 1996	Wind scatterometer data distributed.
12nd August 1996	Update of the reference calibration pulse (new Look-Up-Table).
18th March 1997	Installation of SGI LRDPF version 7100.
18th June 1997	Updated of the value of internal calibration reference energy
March 1998	Installation of SGI LRDPF version 8200.
end of 1998	Fast delivery dissemination of data acquired at Prince Albert station

Instrument operation modes

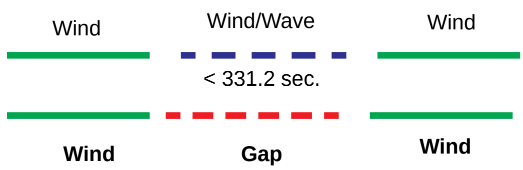
The Wind Scatterometer is part of ERS payload and is combined with a Synthetic Aperture Radar (SAR) into a single Active Microwave Instrument (AMI). This instrument is operated in either SAR or Wind mode. The SAR mode is planned as consequence of users' request and priority is given to descending passes. Another possible working mode is the Wind/wave mode which consist of nominal Scatterometer operations (Wind mode) interrupted every 30 seconds (roughly 200 Km) by a couple of seconds of a short SAR operation in order to acquire small SAR imagettes of roughly 6 x 6 Km from which the wave spectra can be derived. The Wind/Wave mode is the default mode for the AMI on board ERS-1. The different mode of operation has a constraint that comes also from the presence of other instruments on-board. These constraints and rules have consequences on the scatterometer data availability.

The constraints for AMI operations

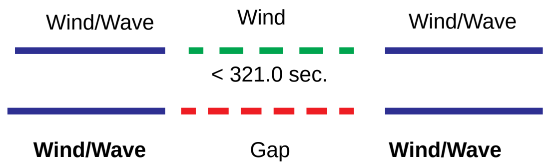
The Wind mode and Wind/Wave mode have the following constraints:

- 8 seconds (~ 53 km) are needed to switch from Wind Only to Wind/Wave or vice versa.

- The instrument is switched to Gap mode (no operation) if a Wind/Wave segment is less than 331.200 seconds (~ 2206 km).

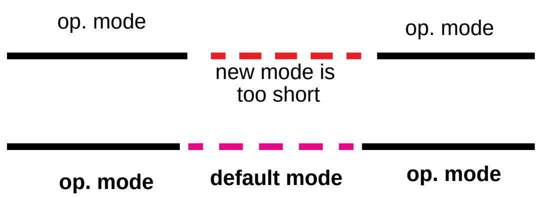


- The instrument is switched to Gap mode (no operation) if a Wind Only segment is less than 321.000 seconds (~ 2138 km).

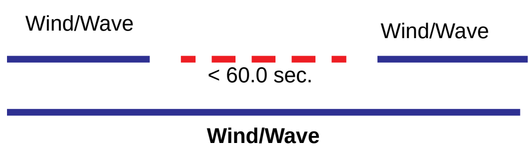


in order to avoid the Gap mode the following rules has been added

- If the AMI cannot switch because the segment is too short, less than 331.200 in Wind/Wave or less than 321.000 in Wind only, the instrument is switched in a default mode (which could be Wind/Wave or Wind Only).



- If two segments of the same mode are separated by less than 60 seconds (~ 400 km) the gap is filled by leaving the instrument in the same mode and these two segments are merged.



- On ERS-2, there is an other constraint. Because of the data rate, the on-board recorder cannot handle at the same time, both the ATSR-2 in High Rate mode (twice the data flow of the same instrument in Low Rate mode) and the AMI in Wind/Wave mode.

The rules from the Mission Operation Plan

In order to optimise the satellite potentiality and to satisfy all user communities, the following rule have been defined:

- Over the Ocean the AMI is in Wind/Wave mode and the ATSR-2 in Low Rate. Over Land the AMI is in Wind mode to allow the ATSR-2 to be switched in High Rate. This strategy preserves the Ocean mission.

The consequences

To satisfy the ATSR community, the ERS-2 AMI is switched from Wind/Wave to Wind Only when the satellite crosses the coast line inland, and back to Wind/Wave when it is back over Ocean. This allows the switching of the ATSR-2 to High Rate mode.

The first consequence is that each time the AMI crosses the coast line, there is a gap in the data of 8 seconds (~53 km). The main problem is between Antarctica and Australia or South America where the distance over the ocean is less than 2206 km. For example: Over Australia, the instrument is in Wind Only mode. When it crosses the coast line it tries to switch to Wind/Wave for a segment less than 331.200 seconds which is not allowed. Then it tries to switch in the default mode which today is also Wind/Wave, and therefore the switch is not allowed too. Then the instrument is switched in Gap mode. The merging doesn't work because the gap is bigger than 60 seconds. A way to solve this problem would be to change the default mode from Wind/Wave to Wind Only. This moves the problem from over ocean, to over Australia which is less than 321.000 seconds long. The only solution to avoid these gaps is to change the land mask over Antarctica in order to have an Antarctic Ocean larger than 2206 km.

Figure 1 and Figure 2 show the 501 orbits for one cycle (35 days) of the ERS-1 and ERS-2 satellite respectively.

Each orbit's segment has a different colour depending on the instrument mode: brown for Wind mode, blue for Wind/Wave mode and green for image mode (SAR). The red and yellow colours correspond to gap modes (no data acquired). For ERS-1 the last cycle was selected (cycle 156). The default mode for the AMI was Wind mode. During this period the AMI activity is summarised in the table 7.

For ERS-2 satellite the loss of data due to the AMI in gap mode, over the ocean between Antarctica and Australia or South America or Africa is clear show in Figure 2.

Table 7: ERS-1 AMI activity cycle 156

AMI activity	ascending	descending
Wind or Wind/wave	92.0	79.0
Image	3.5	13.5
Gap	2.4	4.4
Other	2.1	3.1

During this period (cycle 30) the ERS-2 AMI activity is as shown in table 8

Table 8: ERS-2 AMI activity cycle 30

AMI activity	ascending	descending
Wind or Wind/Wave	91.0	82.0
Image	1.4	8.0
Gap	5.3	8.7
Other	2.3	1.3

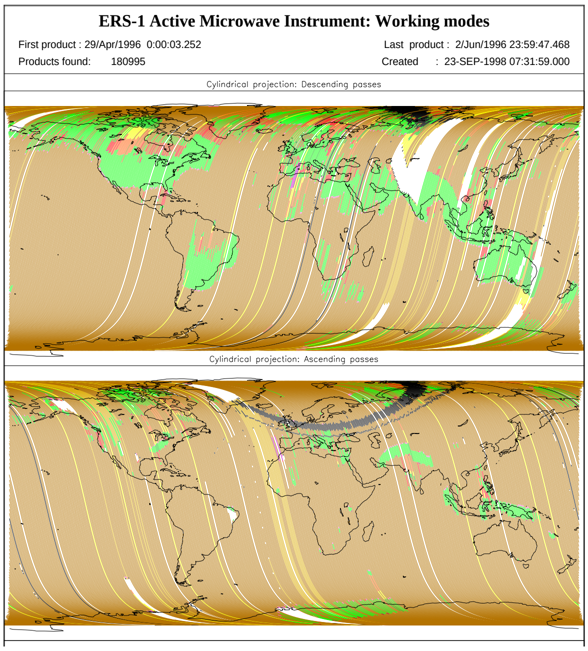


Figure 1: ERS-1 AMI instrument working modes.

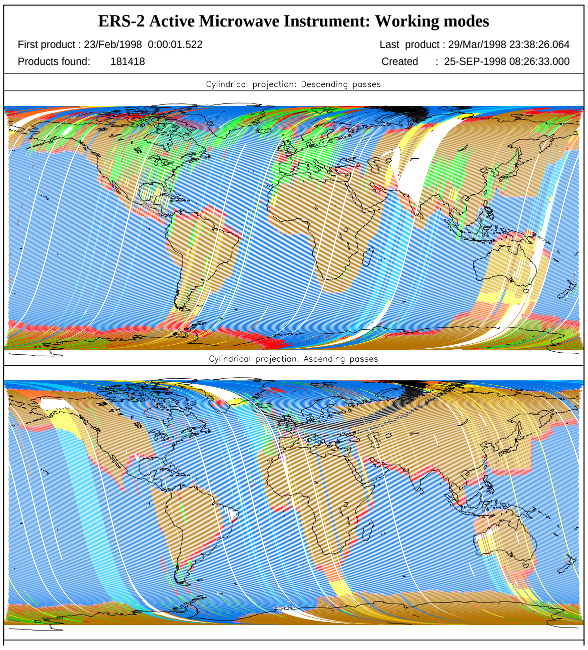


Figure 2: ERS-2 AMI instrument working modes.

Calibration objectives

The most important objective during the commissioning phase was to ensure that the system response is absolutely calibrated in terms of the radar backscattering coefficient (sigma nought) over the range of the incident angles of the instrument. This is achieved using a combination of internal and external references.

Internal reference

The internal reference is the calibration pulse. During the nominal operations, 32 pulses are transmitted on a given beam, followed by 32 pulses on the next beam, and so on. The 1st, 11th, 21st and 31st pulses are directly injected via the calibration subsystem which provides an attenuation and a delay of the pulses, into the receiver. This allow us a monitoring of the instrument stability (e.g. the transmitted power and the receiver chain gain).

External reference

Two different type of external references are used, point targets (transponders) and distributed targets. The difference between these is that point targets provide high accuracy but do not take into account the antenna pattern, while the distributed targets provide the necessary antenna pattern information. These references allow us to ensure that the sigma nought which is expected from a known target, is properly measured by the instrument (absolute calibration), and that the variation over the range of incident angles of the instrument is unaffected by the local attenuation from the antennae (relative calibration).

The transponders

For the ERS Wind Scatterometer mission three calibration transponders are used. These transponders are located in the south of the Spain on a line almost perpendicular to the ground track of ascending as well as descending passes. The transponders have a varying (with transponder electronics temperature), but accurately measured Radar Cross Section (RCS) according to which received Radio Frequency pulses are re-transmitted to the spacecraft. Every time the ERS Wind Scatterometer over-flies the three transponders, it is configured in wind calibration mode and radio Frequency (RF) pulses are transmitted to the three transponders by the fore, mid and aft antennae during periods of 120, 40 and 120 seconds, respectively.

The basic idea of the calibration is to compare the echo data from transponder with simulated data which are generated by the Scatterometer System Simulation (SSS) by using the most accurately known model of the instrument and the actual scenario, in particular the transponder RCS, as input. By comparing the actual and simulated data, the model of the instrument can be update in terms of echo power level. The result of the whole process is the gain constant which is simply the simulated power divided by the actual power. When the model has been updated so the actual and the simulated data agree within a desired accuracy, the updated model is used by the SSS to generate the Look Up Tables (LUT). These LUT are used in the ground processing in order to produce from the echo data the correct sigma nought value.

The rain forest

The tropical rain forest in South America has been used as a reference distributed target. The target at the working frequency (C-band) of ERS-2 Scatterometer acts as a very rough surface, and the transmitted signal is equally scattered in all directions (the target is assumed to follow the isotropic approximation). Consequently, for the angle of incidence used by ERS Wind Scatterometer, the normalised backscattering coefficient (sigma-nought) will solely depend on the surface effectively seen by the instrument:

$$S^0 = S \bullet \cos\theta$$

With this hypothesis it is possible to define the following formula:

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

Using this relation, the gamma-nought backscattering coefficient over the rain forest is independent of the incident angle, allowing the measurements from each of the three beams to be compared. The reference area used by the PCS is located between 2.5 degrees North and 5.0 degrees South in latitude and 60.5 degrees West and 70.0 degrees West in longitude.

Commissioning phase activities and results

The commissioning phase activities were then limited to the following points:

- Set the on-board receiver gain
- Derive the antenna pattern correction for the three antennae from the rain forest and transponder echoes,
- Compute the antennae mispointing,
- Compute the calibration coefficients, and generate the associated Look_Up_Tables,
- Verify that the ERS X-Band data are stable (monitoring of the Long Term Stability of the instrument),
- Compare the ERS-1 and ERS-2 response signal over rain forest and transponders.
- Validate the geophysical products.

Gain setting

ERS-1 on-board gains were optimise to ensure maximum use of the dynamic range of the analog to digital converter (ADC), whilst avoiding saturation. For the ERS-2 the operational transmit power is approximately half the ERS-1. The initial ERS-2 on-board gains were set to the same level as for ERS-1. Once the first corrections to the antenna patterns were made (March 1996), and the stability of the instrument verified, the receiver gain was modified from 18 to 21 dB to take full advantage of the ADC dynamic range.

Antenna patterns

The antenna patterns have been computed over the reference area during the month of May 1996 when both ERS-1 and ERS-2 Wind Scatterometer were operating. The results are shown in Figure 3 and Figure 4 for the ERS-1 and ERS-2 respectively and are very close.

The antenna profiles are flat within 0.3 dB in particular for the fore and aft antenna. The mid antenna shows a ripples which is not found in the fore and in the aft antenna. A small diffracted signal due to the presence of the SAR antenna edge close to the Mid antenna is suspected to be the reason for this. Figure 5 shows the ERS-2 antenna patterns before the commissioning phase. It is clear from the figure the efficiency of the new set of LUT installed in the ground processing on March 1996.

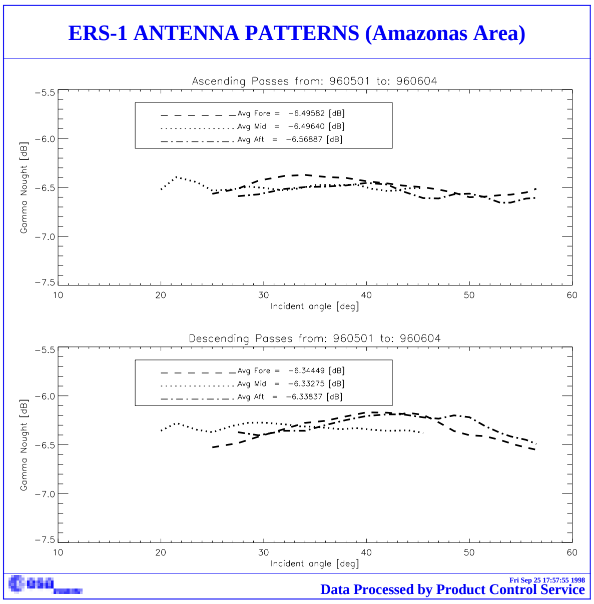


Figure 3: ERS-1 Scatterometer: Antenna pattern over Brazilian rain forest (May 1996).

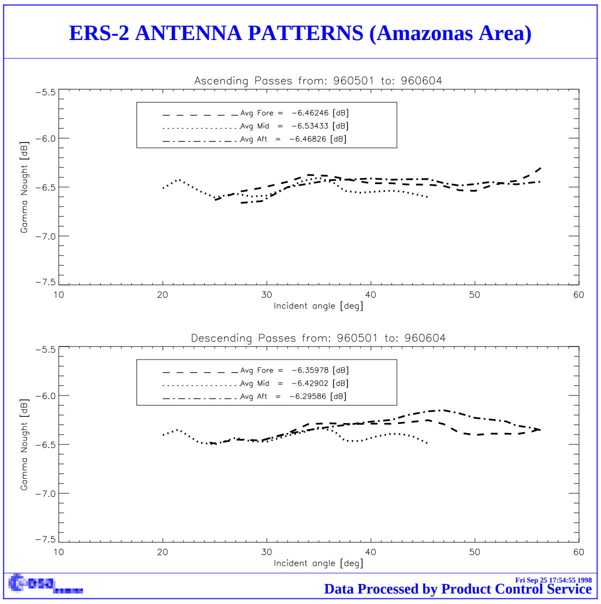


Figure 4: ERS-2 Scatterometer: Antenna pattern over the Brazilian rain forest (May 1996).

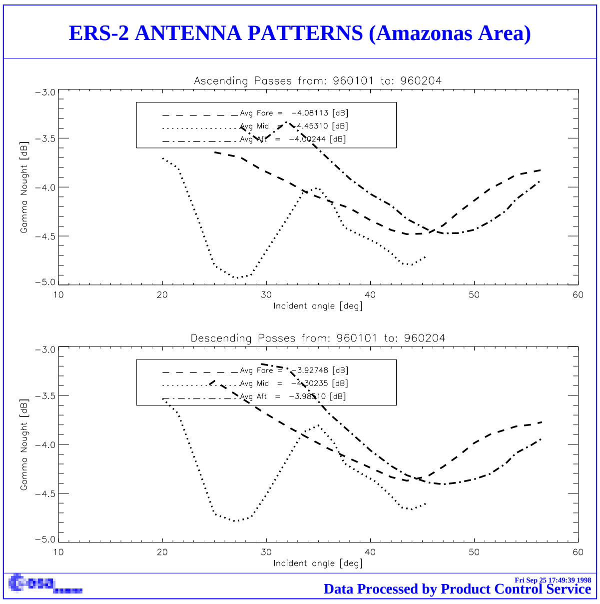


Figure 5: ERS-2 Scatterometer: Antenna pattern over Brazilian rain forest (January 1996 before the commissioning phase).

ERS-1 and ERS-2 signal over rain forest

As the gamma-nought is independent from the incidence angle, the histogram of gamma-noughts over the rain forest is characterised by a sharp peak as shown in Figure 6 and Figure 7.

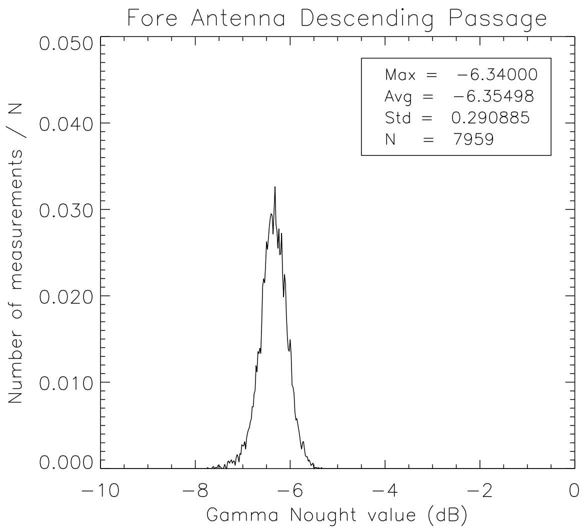


Figure 6: ERS-1 Scatterometer: Gamma nought histograms Fore beam (May 1996).

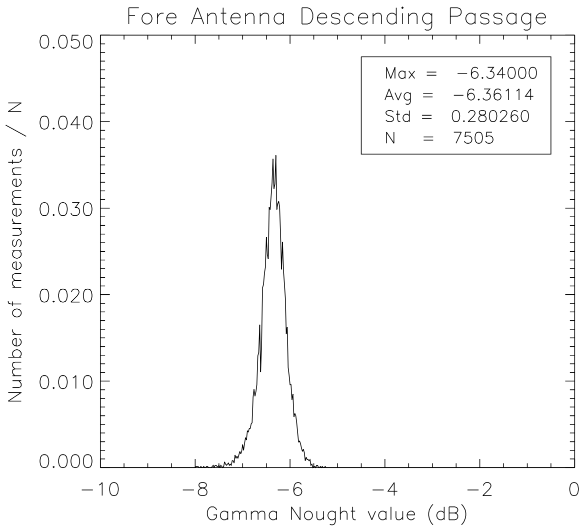


Figure 7: ERS-2 Scatterometer: Gamma nought histograms Fore beam (May 1996).

The peak position allows us to make comparisons among the signal received from the three antennae and between the ERS-1 and ERS-2 Wind Scatterometer.

The position of the peak is computed by fitting the histogram with a normal distribution added to a second order polynomial:

$$F\langle x\rangle = A_0 \cdot \exp\left(-\frac{z^2}{2}\right) + A_3 + A_4 \cdot x + A_5 \cdot x^2$$

where: $$z = \frac{x - A_1}{A_2}$$

The parameters are computed using a non linear least square method called “gradient expansion”. The position of the peak is given by the maximum of the function F(x). Table 8 and Table 9 show the results from the reference area for ERS-2 and ERS-1 Wind Scatterometer respectively.

Table 9: ERS-2 Gamma nought peak position, mean and standard deviation (descending passes, May 1996).

antenna	gamma nought peak position (dB)	gamma nought mean (dB)	gamma nought standard deviation (dB)
fore	-6.34	-6.36	0.28
mid	-6.42	-6.44	0.29
aft	-6.28	-6.30	0.29

Table 10: ERS-1 Gamma nought peak position, mean and standard deviation (descending passes, May 1996).

antenna	gamma nought peak position (dB)	gamma nought mean (dB)	gamma nought standard deviation (dB)
fore	-6.34	-635	0.29
mid	-6.32	-6.34	0.27
aft	-6.32	-6.33	0.29

From tables 8 and 9 it is clear that the assumptions for the gamma nought have some foundation, and that gamma nought is useful as a comparison of the measurements made with the three antennae and with the two Wind Scatterometer without having to take into account the incidence angles. The accuracy of the calibration over the rain forest is within 0.3 dB, the signals from both ERS-1 and ERS-2 Wind Scatterometer are very close. For the ERS-2 the mid beam signal over the rain forest is roughly 0.1 dB less than the one measured with the ERS-1.

Antennae mispointing

Two of the three scatterometer antennae on ERS are mechanically deployed. Small mispointing errors of the antennae may be corrected in the ground processing. The orientation of the normal of each antenna plane can be determined using the transponders, by measuring the difference between the time of the peak's signal (in range and azimuth) of each antenna and when it is expected (using a geometrical model and the orbit propagator). This analysis performed on ERS Wind Scatterometer data shows that the mispointing is negligible.

Gain constant

The plots in Figure 6 show the value of the Gain Constant for ERS-2 Wind Scatterometer computed since January 1996 for the three beams and for ascending, descending and all passes. The data before the commissioning phase was re-processed using the updated set of LUT. The measurements are performed at fixed incidence angle and we have from 3 to more than 10 values for each angle. The plots show an accuracy of 0.5 dB. The bias among the three antennae suggests the introduction of a scaling factor of roughly 0.2 dB, -0.3 dB and 0.2 dB for the fore, mid and aft antenna respectively. This scaling factor has not implemented in the ground station because the results from the Brazilian rain forest do not confirm this bias and because the initial pattern corrections have produced satisfactory results. A fine tuning is an on-going activity.

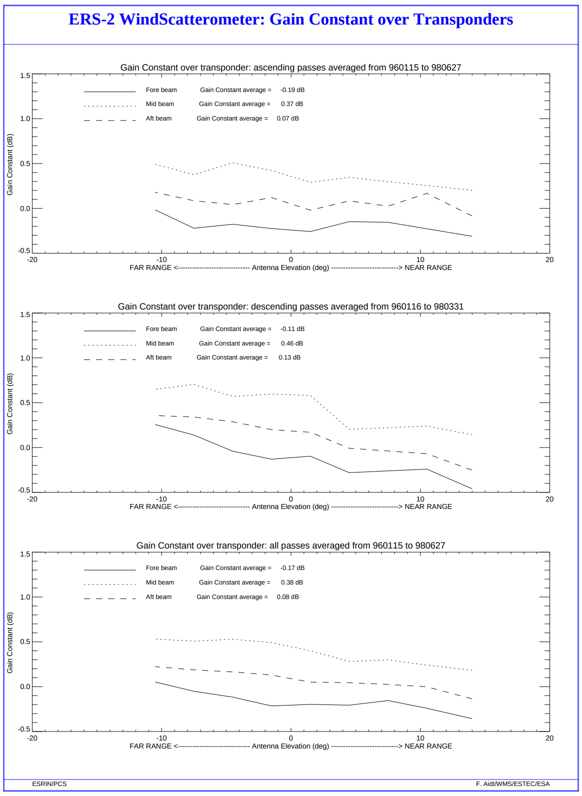


Figure 8: ERS-2 Gain Constants over transponders since January 1996.

Impulse response function

The raw data acquired during skim over the transponders are processed by the Scatt Calibration Processor. The output of this processing is a set of calibration files from which is computed the Wind Scatterometer Impulse Response Function.

Figure 8 and Figure 9 show the along track IRF (fore antenna) for ERS-1 and ERS-2 Wind Scatterometer respectively. The result is that in both cases the spatial resolution defined as the -3.0 dB width is within the nominal resolution (50 Km).

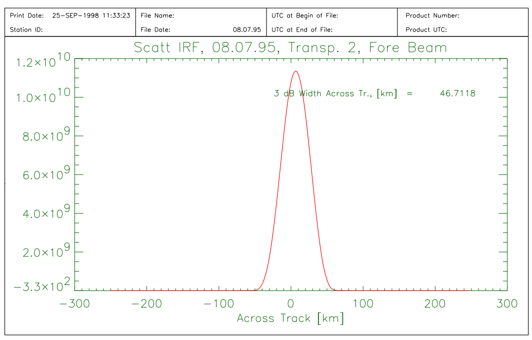


Figure 9: ERS-1 Wind Scatterometer fore beam: impulse response function along track.

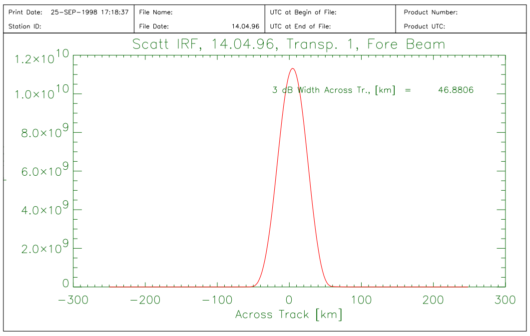


Figure 10: ERS-2 Wind Scatterometer Fore beam: impulse response function along track.

Geophysical products performance

As the output of the Wind Scatterometer is a set of geophysical variables: the wind speed and the wind direction, it is important to check the quality of this variables after the commissioning phase. The quality of the ERS wind speed and direction are everyday monitored in the PCS. The ERS measurements are compared with the ECMWF forecast (24 hours). The result is shown in Figure 11 for the ERS-1 Wind Scatterometer (from 1st August 1996 to 30th May 1996) and in Figure 12 for the ERS-2 Wind Scatterometer (from 23rd November 1995 to 21st September 1998).

The first plot in Figure 11 and 12 shows the percentage of nodes whose ambiguity removal works successfully. The second and third plot in Figure 11 and 12 show the wind speed deviation: bias and standard deviation.

The results for ERS-1 and ERS-2 Wind Scatterometer are comparable. In both cases the ambiguity removal works properly for the 93% of nodes and the wind speed bias is within 0.5 m/s.

One can note three important changes in the wind speed bias for the ERS-2 Wind Scatterometer. The first in the month of March 1996 at the end of the commissioning phase when the new calibration set was installed in the ground processing, the second on 3rd June 1996 when the ERS-2 data were assimilated into the meteorological model and the third at the beginning of September 1997 when important changes were made in the ECMWF algorithms.

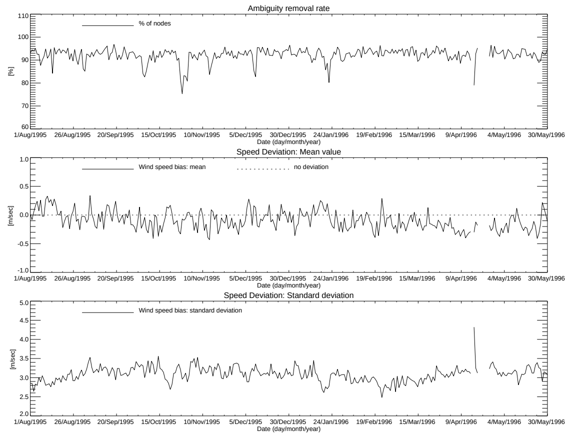


Figure 11: ERS-1 Geophysical validation performance: from 1st August 1995 to 30th May 1996.

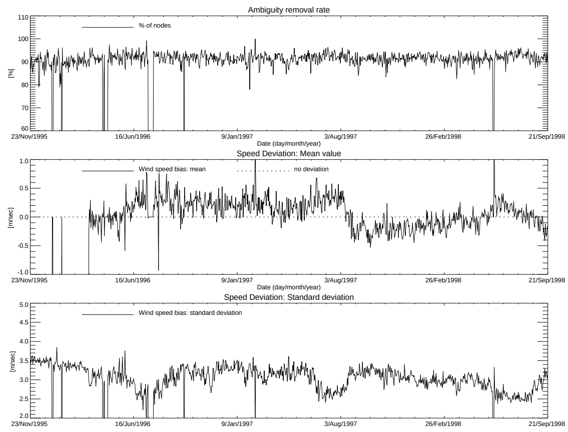


Figure 12: ERS-2 Geophysical validation performance: from 25th November 1995 to 21st September 1998

Calibration performance

The long term stability of the ERS Wind Scatterometer is an important element of the calibration activities. It has to be seen as the extension of the commissioning phase across the entire life time of the instrument. For the ERS mission, the peak position of the gamma nought distribution is weekly monitored.

The Figure 13 shows the evolution of the histograms peak position since January 1996 for the ERS-2 Wind Scatterometer. The step shown in March 1996 is due to the end of commissioning phase when a new Look Up Table was used in the ground stations for Wind fast Delivery products generation.

It is important to note the decrease of roughly 0.2 dB from August 1996 to June 1997. This is linked to the switch of the Scatterometer calibration subsystem from A to B on 6th of August 1996. This new setting caused a little change in the instrument calibration which was corrected on 19th of June 1997 with a new calibration LUT used in the ground processing.

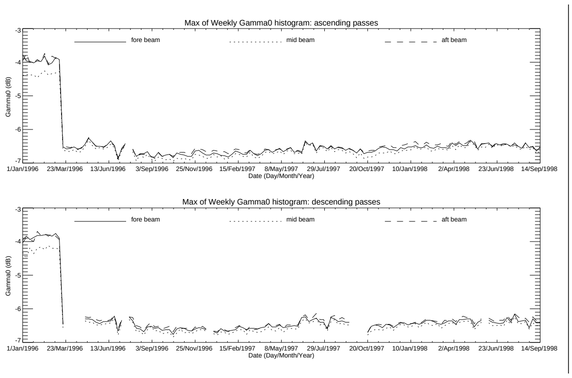


Figure 13: ERS-2 Wind Scatterometer: weekly evolution of gamma nought histogram peak position. From up to down: ascending passes, descending passes.

The analysis of the curve in Figure 13 demonstrates the stability over the whole period, even if a small oscillation can be detected. It is important to outline that the three antennae have very similar response in particular for the fore and aft antenna. One can see a seasonal variation in all three antennae; this signal has an amplitude of roughly 0.2 dB. The stability achieved is within the 0.3 dB.

The result for the ERS-1 Wind Scatterometer is similar to the ERS-2 case.

When ERS-1 was launched, it was agreed that an absolute radiometric calibration of 0.7 dB was enough to satisfy the geophysical data quality requirements in terms of wind speed and direction (instrument specification).

This analysis proves that this target has been reached in the ERS Wind Scatterometer mission. The change of the calibration subsystem from side A to side B in the ERS-2 Wind Scatterometer has also proved that the meteorologist can detect in the wind fields a bias corresponding to less than 0.2 dB, and this led to a re-calibration of the ERS-2 Wind Scatterometer.

Instrument performance

The results reported are a summary of the daily data quality control made within the PCS at ESRIN. This monitoring work has led to continuous upgrade of the instrument status and on the other side a good detection of the instrument problems.

The instrument status is checked by monitoring the following parameters:

- Centre of Gravity and standard deviation of the received signal spectrum.

This parameter is useful for the monitoring of the orbit stability, the performances of the doppler compensation filter, the behaviour of the yaw steering mode and the performances of the devices in charge for the satellite attitude (e.g. gyroscopes, earth sensor).

- Noise power I and Q channel.
- Internal calibration pulse power.

The latter is an important parameter to monitor the transmitter and receiver chain, the evolution of pulse generator, the HPA, the TWT and the receiver.

These parameters are daily extracted from the Fast Delivery products (UWI).

The following parameters are daily extracted from the telemetry data (EGH product):

- Calibration subsystem input and output peak power.
- Travelling Wave Tube (TWT) currents and voltages
- AMI hardware temperatures (only ERS-2).

In the case of ERS-2 AMI the analysis is splitted for the different AMI working modes.

Centre of gravity (CoG) and standard deviation of received power spectrum

Figure 14 shows the evolution of this two parameters (ERS-2 Wind Scatterometer) for each beam. The tendency since the beginning of the mission is a slight increase of the Centre of Gravity (CoG) of the signal spectrum for the three antennae while the result for the standard deviation is more stable, in particular for the mid antenna.

The two steps observed on the plots of the CoG are due to a change in the pointing subsystem (DES reconfiguration) side B instead of side A. The first from 24 January 1996, 09:10:03 to 14 March 1996, 10:22:50, the second from 14 February 1997, 01:25:44 to 22 April 1997, 10:27:30. During these periods side B was switched on. The large deviation from nominal values in the plots of the CoG of the fore and aft beams shown on 26th September 1996 is due to missing doppler compensation information on board of the satellite (no yaw steering mode).

A depointing anomaly occurred on ERS-2 from 03-June-1998 14:43:53 to 06-June-1998 12:47:40; this explains the data gap shown in the plots of Figure 12. After the anomaly the Yaw Steering Mode (YSM) transition was achieved on 07-June-1998 00:48:00 so the daily average of the doppler compensation parameters shows a large deviation from nominal values for the days June, 6th and 7th 1998. After the depointing anomaly, the CoG had an increase of roughly 100 Hz for the three antennae and it stayed stable.

The peaks shown in the plot of mid beam CoG standard deviation are linked to the satellite manoeuvres and the DES reconfiguration.

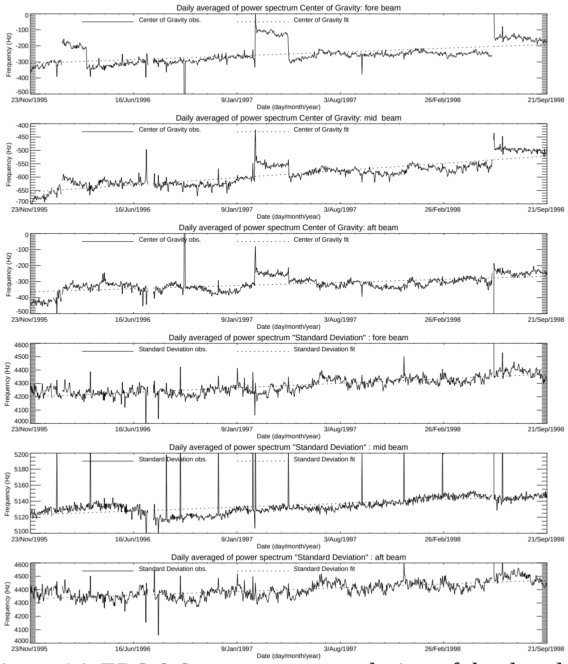


Figure 14: ERS-2 Scatterometer evolution of the doppler compensation from January, 1st 1996 to September, 21st 1998.

Table 9 summarizes the doppler performance of the ERS-2 Wind Scatterometer since the beginning of the mission (mean values).

Table 11: ERS-2 Doppler compensation performance

Antenna	CoG (Hz)	CoG standard deviation (Hz)
fore	-306.5	4198.9
mid	-654.5	5123.0
aft	-361.5	4329.1

Figure 15 and Figure 16 show the evolution of the CoG and its standard deviation for the ERS-1 WindScatterometer since June 1993. The mid beam CoG is roughly 400 Hz greater than the ERS-2 one, the fore and aft CoG are roughly 100Hz less than the ERS-2 ones. The CoG standard deviation is roughly 500 Hz less than the ERS-2 for the three antennae. The variations of the C0G reported in Figure 15 are related with the different ERS-1 operational phases.

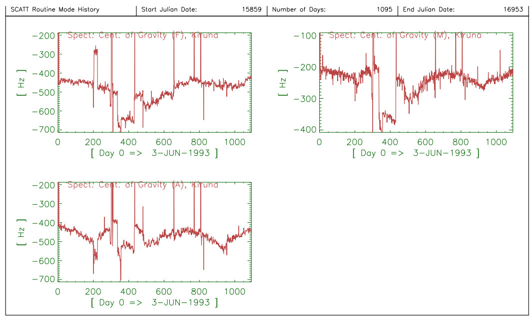


Figure 15: ERS-1 Scatterometer evolution of the COG (mean) from June, 3rd to the end of mission.

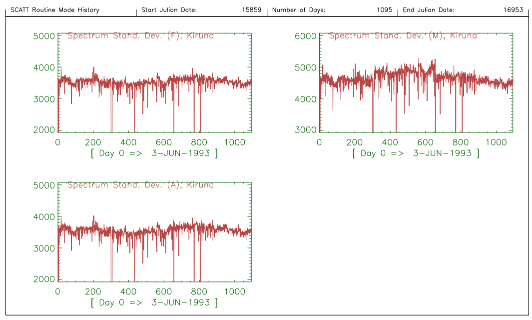


Figure 16: ERS-1 Scatterometer evolution of the COG (standard deviation) from June, 3rd to the end of mission

Noise power level I and Q channel

The results of the monitoring are shown in figure 17 for the ERS-2 Wind Scatterometer. The first set of three plots presents the noise power evolution for the I channel while the second set shows the Q channel.

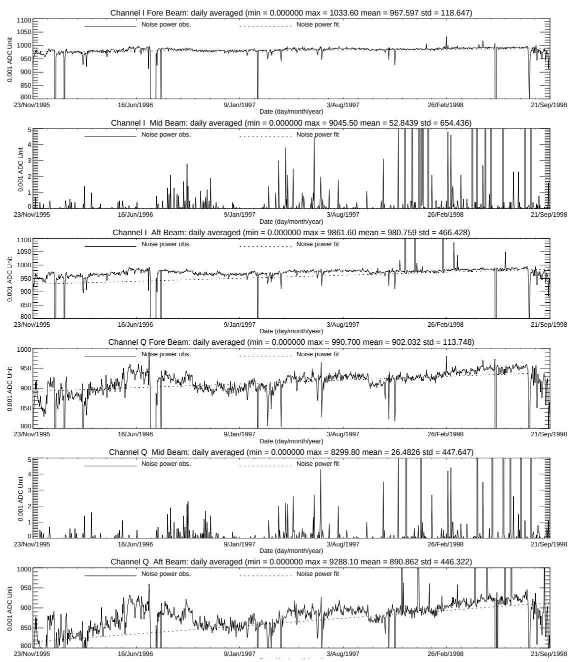


Figure 17: ERS-2 Scatterometer evolution of the noise power from January, 1st 1996 to September, 21st 1998.

The noise level is less than 1 ADC Unit for the fore and aft signals and is negligible for the mid one. From the plots one can see that the noise level is more stable in the I channel than in the Q one.

Since 5th December 1997, some peaks appear in the plots. These high values for the daily mean are due to the presence for these special days of a single UWI product with an unrealistic value in the Specific Product Header noise power field. The analysis of the raw data used to generate these products lead in all cases to the presence of one source packet with a corrupted value in the noise field stored into the source packet Secondary Header.

The reason why noise field corruption began on 5th December 1997 and is going on is at present unknown. It is interesting to note that at the beginning of December 1997, we started to get as well the corruption of the Satellite Binary Times (SBTs) stored in the EWIC product. The impact in the fast delivery products was the production of blank products starting from the corrupted EWIC until the end of the scheduled stop time. A change in the ground station processing in March 1998 overcame this problem.

Since August, 9th 1998 an instability has affected the noise power level (channel I and channel Q); this explains the small decrease in the noise power level shown in Figure 15. Investigations to better understand the case are on-going.

The result from ERS-1 Wind Scatterometer is shown in Figure 18 for the I channel, the Q one is very similar.

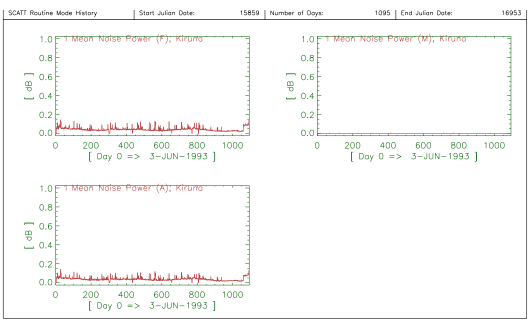


Figure 18: ERS-1 Scatterometer evolution of the noise power level (I channel) from June, 3rd to the end of mission

The noise power is 0 ADC unit for the mid antenna while is roughly 0.1 ADC unit for the fore and aft antenna. In comparison with ERS-2, the ERS-1 Wind Scatterometer has a lower noise level.

Power level of internal calibration pulse

Figure 19 shows the evolution of the internal calibration level for the ERS-2 Wind Scatterometer.

The high value of the variance in the fore beam (see Figure 17) until August,12 1996 is due to ground processing. In fact, all the blank source packets ingested by the processor were recognized as fore beam source packets with a default value for the internal calibration level. The default value was applicable for ERS-1 and therefore was not appropriate for ERS-2 data processing. On August 12, 1996 a change in the ground processing LUT overcame the problem.

Since the beginning of the mission a power decrease is detected. This drift was unexpected. Nothing like that was never experienced with the ERS-1 Wind Scatterometer as shown in Figure 20and Figure 22.

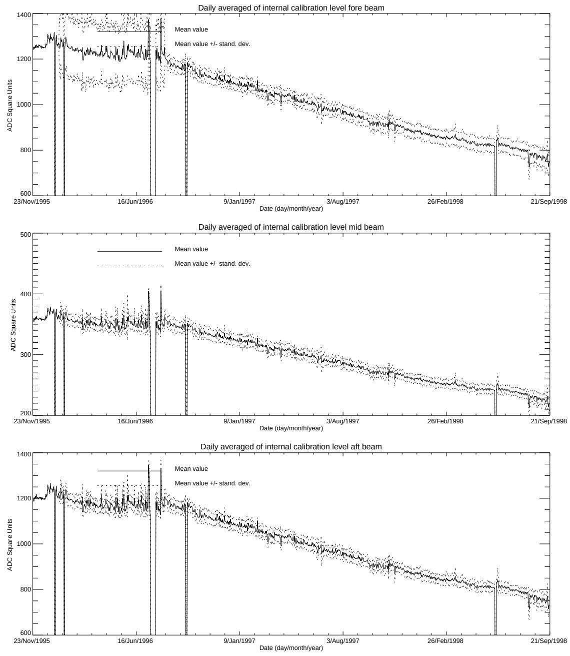


Figure 19: ERS-2 Scatterometer evolution of the internal calibration level: from January, 1st 1996 to September, 21st 1998.

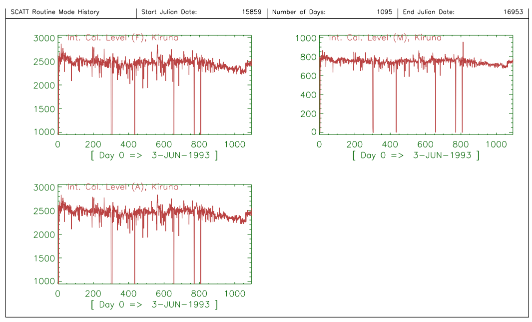


Figure 20: ERS-1 Scatterometer evolution of the internal calibration level from June, 3rd to the end of mission.

It was first necessary to characterise which elements of the chain were producing this power decrease and in particular if the calibration sub-system was not directly involved.

After a long analysis it was finally confirmed that the drift is entirely due to the variability of the input signal to the TWT.

This means that the same drift is observed in the echo and in the calibration pulse and that the final sigma nought is free of any drift as the echo is normalised by the calibration pulse during the processing. The efficiency of the internal calibration to keep the absolute calibration level stable is proved with the monitoring of the gamma-nought level over the Brazilian rain forest. In fact, no drift is noted (see calibration performance paragraph).

In the ERS-2 case the TWT is not working in saturation, so that a variation in input signal is visible in output.

The variability of the input signal can be two-fold: the evolution of the pulse generator and the tendency of the switches between the pulse generator and the TWT to reset themselves into a nominal position.

These switches were set into an intermediate position in order to put into operation the scatterometer instrument (on 16th November 1995). The decrease is estimated to be about 0.0025 dB per day, 2.2 dB since the beginning of the mission.

The power decrease is regular and affects the AMI when working in wind-only, wind/wave and image mode indifferently.

This is clearly shown in figure 19 where the daily average of the input and output calibration subsystem peak power are plotted.

These data are daily extracted from the AMI telemetry (EGH products). The results are split for the different AMI working modes: brown for wind-only, blue for wind/wave.

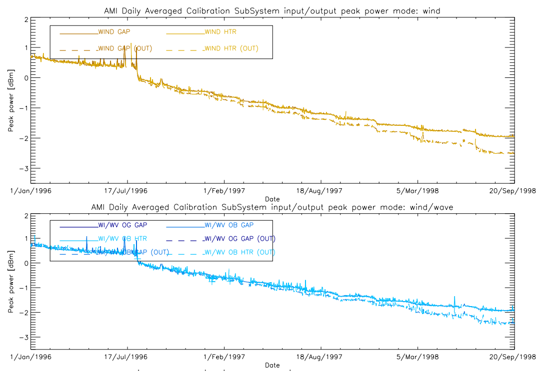


Figure 21: ERS-2 AMI Calibration subsystem input and output peak power from January, 1st 1996 to September, 21st 1998. Wind mode (up) and Wind/Wave mode (down).

Figure 22 shows the calibration subsystem input/output peak power for the ERS-1 Wind Scatterometer. In this case the daily average is relative to the all AMI working modes.

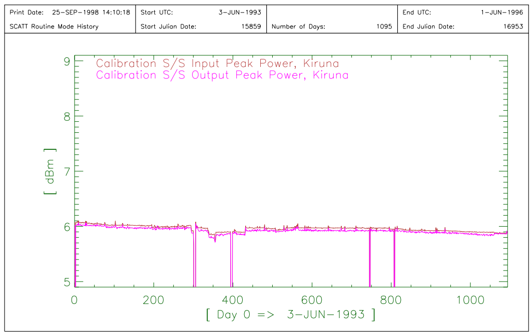


Figure 22: ERS-1 AMI Calibration subsystem input and output peak power: from June, 3rd 1993 to end of mission.

Telemetry results

Figure 23 shows the daily average (all modes) for the TWT average body current, the TWT filament current, the TWT beam current and the TWT collector voltage of the AMI on board ERS-1.

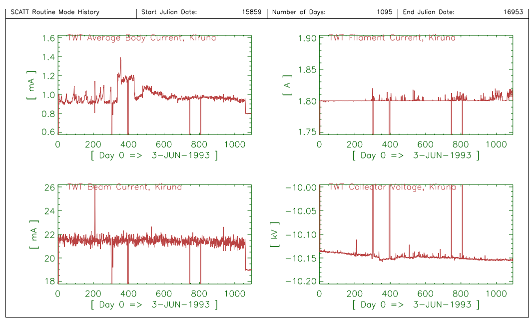


Figure 23: ERS-1 AMI TWT currents and voltages: from June, 3rd 1993 to the end of mission.

Figure 24 shows the same parameters plus the TWT cathode voltage for the AMI on board ERS-2 when AMI is in wind only mode.

In the case of ERS-2 AMI the drift that affects the transmission chain is clear.

Figure 25 shows the temperatures of the main devices (side A) of the ERS-2 AMI instrument when it is operated in wind-only mode. The plots shown a stable evolution of those temperatures.

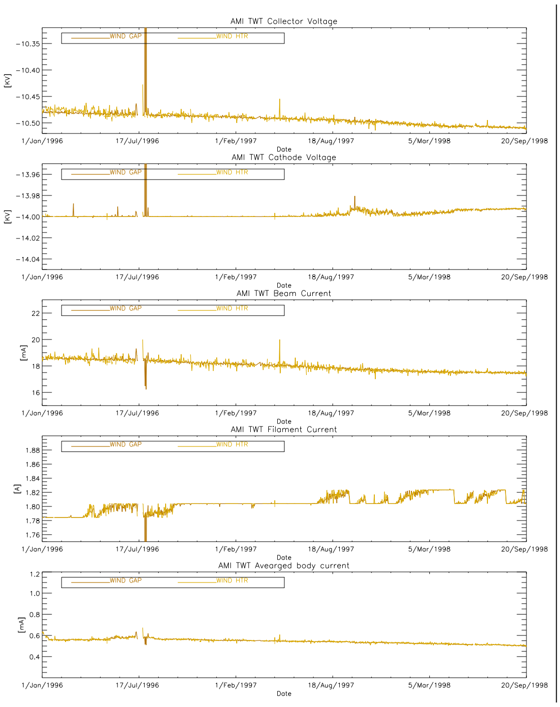


Figure 24: ERS-2 AMI TWT currents and voltages from January, 1st 1996 to 21st September 1998 (only wind mode).

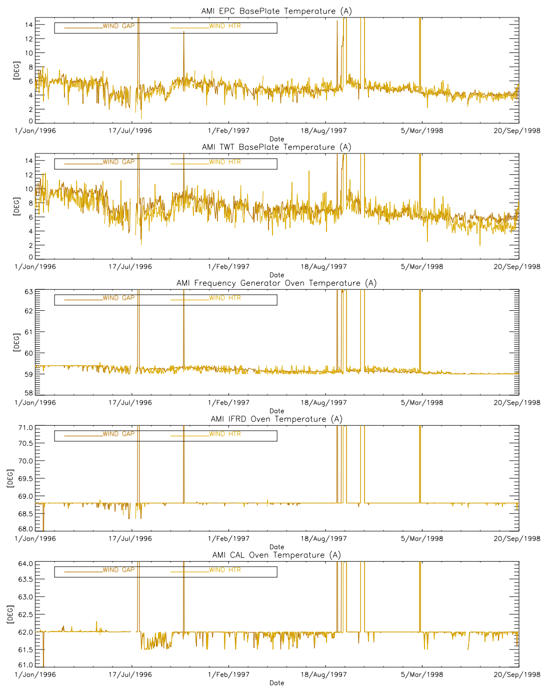


Figure 25: ERS-2 AMI Temperatures (side A): from January, 1st 1996 to 21st September 1998 (wind mode).

Conclusions

During the 5 years of ERS-1 Wind Scatterometer mission no important problems have affected the AMI instrument, on the contrary after the launch of ERS-2 on 21st April 1995 a serious anomaly caused the AMI instrument to shut down. The anomaly was resolved by setting the switch at the input to the HPA to an intermediate position and reducing the power output by a factor or two. This allowed to get wind data since November 1995.

Although the ERS-1 Wind Scatterometer and ERS-2 Wind Scatterometer work with a different level of output power the quality of the measured backscattering is very high and allow the users to have a comparable set of data (a difference of 0.1 dB between the ERS-1 and ERS-2 mid antenna's signal can be underline).

The efficiency of the internal calibration to keep the absolute calibration level stable is verified in the case of ERS-2 Wind Scatterometer. In fact for this instrument a power decrease of roughly 2.2 dB is detected since the beginning of the mission but as waited for no drift is visible in the signal measured over the Brazilian rain forest that is the reference natural calibration target.

The level of the noise is 1 ADC unit for the ERS-2 Wind Scatterometer (fore and aft antenna) while it is very close to 0 ADC unit for the ERS-1 case. The noise for the mid beam antenna is 0 ADC unit for both the ERS-1 and ERS-2 Wind Scatterometer.

The antenna patterns show a flat profiles, within 0.3 dB for both ERS-1 and ERS-2 Wind Scatterometer.

The different operational mode between the ERS-1 and ERS-2 Wind Scatterometer has an impact in the data availability. In particular for the ERS-2 mission the use of the ATSR-2 in high rate mode over the land force the AMI to switch from wind/wave mode to wind only mode when the satellite flies over the land. Due to operational constraint this involve a small amount of data between Antarctica and Australia or South America or South Africa.

The output geophysical variables, wind speed and wind direction, of the ERS-1 and ERS-2 Wind Scatterometer have a comparable quality. In particular the actual ERS-2 wind speed has a bias within 0.5 m/s and a standard deviation of 3.0 m/s with reference to the ECMWF forecast (24 hour); a bias of -0.5 m/s and a standard deviation of 1.6 m/s with reference to the First Guess (FG) analysis; a bias of -0.3 m/s and a standard deviation of 1.6 m/s with reference with the 4D-Var analysis performed by ECMWF.

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