THE ERS-2 SCATTEROMETER: INSTRUMENT AND DATA PERFORMANCES ASSESSMENT SINCE THE BEGINNING OF THE MISSION.

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ABSTRACT

The Quality of the ERS-2 Scatterometer data and the instrument performances are daily monitored at ESA-ESRIN. This activity is routinely performed on the instrument telemetry data and on the user's products with the main scope to detect and face out instrument or satellite degradation due to aging and ground segment anomalies. The aim of the paper is to report to the users community the results of that monitoring activity in term of: events that have impacted the ERS-2 Scatterometer mission since the last ERS-ENVISAT Symposium of Salzburg in 2004, corrective actions put in place to maintain the nominal data quality and presentation of time-series of the key quality control parameters since the launch in 1995. The conclusion summarizes the lesson learned during these sixteen years of ERS-1 and ERS-2 Scatterometer operations; that experience can provide some inputs for the ASCAT mission on Metop.

1. INTRODUCTION

The European Remote Sensing Satellite, ERS-1, launched in 1991, was the first ESA Earth Observation Satellite designed to acquire geophysical information with worldwide geographical and repetitive coverage. A second satellite the ERS-2 was launched in April 1995 and is still into operation. The ERS Scatterometer is a radar working at 5.3 GHz (C-band) designed to acquire the backscattered signal from the Earth surface with three different look angles. Those measurements allow the retrieving of important geophysical parameters as: the winds over the Oceans, the sea ice coverage, the soil moisture. Scatterometer data are routinely assimilated into forecast and nowcast weather model prediction. The Quality of the ERS-2 Scatterometer data and the instrument performances are daily monitored by the DPQC [1]. This activity is routinely performed on the instrument telemetry data and on the user's products with the main scope to detect and face out instrument or satellite degradation due to aging and ground segment anomalies. The results of this activity are available for the users community and regularly reported on a cyclic report on the web site [2].

2. ERS-2 SCATTEROMETER MISSION EVENTS

The ERS-2 Scatterometer mission started in April 1995 with the launch of the ERS-2 satellite and it is still into operation. On 16th November 1995 the first Scatterometer data was received. Different attempts to put the AMI into operation were performed in the previous months failed because the instrument was not able to operate with the nominal power. To reduce the input power, the antenna power switcher was put in an intermediate position.
Since 15th January 1996 to 19th March 1996 the commissioning phase was carried out. During this period the in-flight antenna pattern and the exact gain constant were computed. The calibration level was set at the same level of ERS-1 Scatterometer to assure continuity and data homogeneity between the two missions. The distribution of calibrated data to the users started on 16 April 1996. After few months of nominal operation in July 1996 the instrument was switched-off due to an anomaly in the Internal Calibration unit. The primary unit of the Calibration subsystem was disconnected and the redundant one (side B) was used. Due to a different attenuation gain between the two units, a decrease of roughly 0.165 dB in the calibrated sigma nought was measured. That decrease has been corrected into the ground segment on 18th June 1997 with a new value for the calibration reference energy. The most challenging event for the ERS-2 occurred on January 17th 2001 when the Attitude and Orbit Control System (AOCS), used to pilot the ERS-2 satellite, has been switched in the so-called gyro-less mode (ZGM). The reason of that reconfiguration was to increase the mission safety, after the lost of 5 of the 6 on-board gyroscopes and therefore to preserve the one remaining only for the orbital manoeuvres. With that new AOCS configuration the satellite attitude was slightly degraded in particular for the yaw angle.. The impact in the received signal of the satellite mispointing cannot be corrected in the existing ground processor mainly based on pre-computed Look Up Table derived with the assumption of a very high stability of the spacecraft. As consequence the backscattering coefficients derived from the returned echoes were not calibrated anymore and the distribution of the Scatterometer data to the users was discontinued [3]. With the ZGM operations was achieved a good improvement in the yaw error pointing (roughly from 10° to 2°) for that reason a PCS

study had demonstrated that the processing of Scatterometer data acquired in ZGM was possible and with good results. For that reason a complete review of the Scatterometer processor has been carried out to guarantee the continuity of the ERS Scatterometer mission with the nominal high data quality. ESA contractor engineers, research department and industries had been involved to re-design and re-implement the Scatterometer ground processing chain and in about two years a new ground processor called ESACA (ERS Scatterometer Attitude Corrected Algorithm) has been put into operation on August 21st 2003 (for details about ESACA see [4] and [5]). From that day onward Scatterometer data are available for the end users and meteorological centre via the GTS network. In Fig. 1 the first cyclone tracked with the ESACA processor is shown. The wind speed and direction has been post-processed in ESRIN with a specific algorithm to compensate the retrieved CMOD-4 winds for such extreme case [6].

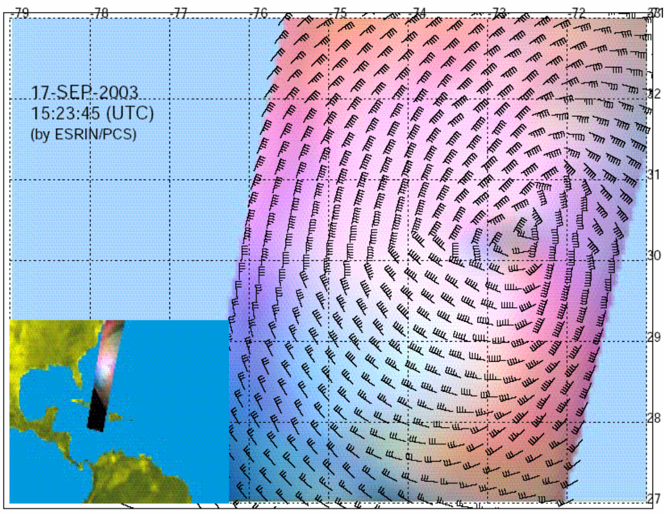

Figure 1. Cyclone Isabel

ESACA winds data are operational assimilated in meteorological model at ECMWF since March 2004 [7]. A further event that had a strong impact on the Scatterometer mission occurred at the end of June 2003 when the two on-board tape recorders have been declared unusable. That fact caused the lost of the global Earth coverage because the data cannot be recorded on-board (in Fig. 2 the Global Mission Scenario is shown). To face out that problem, on one side the ESA engineers at ESOC re-configured the Instrument Data Handling To face out that problem, on one side the ESA engineers at ESOC re-configured the Instrument Data Handling and Transmission (IDHT) on board the satellite in such a way to allow the transmission of the data on the ground every time the

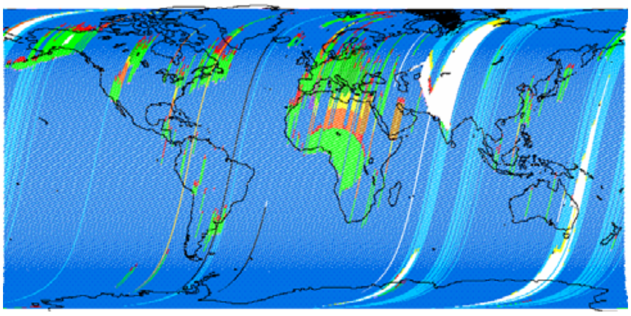

Figure 2. ERS-2 Global Mission Scenario

satellite is within the visibility of an acquisition station and on the other side ESRIN is continuous improving the data coverage by deploying new ground stations. At the existing ground stations in Kiruna (S), Gatineau (C) and Maspalomas (SP) were added new acquisitions in the ground station located in West Freugh (UK), Matera (Italy), Miami (US), Beijing (CN), McMurdo (Antarctica), Hobart (AUS) and Singapore. Nowadays the data coverage of the "Regional Mission Scenario" includes: the North Atlantic, the Mediterranean Sea, the Caribbean, the Gulf of Mexico, a small part of the North West Pacific (Canada and US coast), the Chinese and Japanese Sea, a small part of the Indian Ocean, South-East of Thailand and Indonesia, the Southern Ocean south of Australia and New Zealand and the Arctic and Antarctic regions (Fig. 3). A new Ground station in Mexico will be operational during the summer 2007.

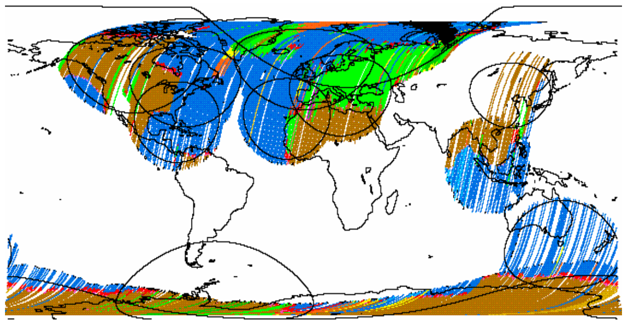

Figure 3. ERS-2 Regional Mission data coverage

Since the beginning of the ERS-1 Scatterometer mission a rich data set of backscattered signal from the Earth is available for long-term studies and research. To accomplish the need of the community research ESA has developed the project Advanced Scatterometer Processing System (ASPS) to re-process the entire data set available from ERS-1 and ERS-2 missions in order to produce high quality and homogeneous long-term Scatterometer measurements of the Earth surface and high quality wind field over the ocean. Additional purpose was to produce scientific products in high resolution adapted for the emerging Scatterometer application on Ice and Land [8]. The first version of the ASPS facility was accepted in July 2005 and a second version was accepted in September 2006. That version has been optimized for a multi-CPU 64-bit architecture allowing a faster data processing. Preliminary ASPS data in nominal and high resolution has been distributed to the ASCAT SAG in 2006 and 2007 for evaluation. The reprocessing of the whole ERS Scatterometer Mission is foreseen to start in July 2007.

3. ERS-2 SCATTEROMETER INSTRUMENT PERFORMANCES

The ERS-2 Scatterometer instrument long loop performances are monitored by analysing the following key parameters:

- The Internal calibration pulse power to monitor the transmitter and receiver chain and track the evolution of the pulse generator, the High Power Amplifier (HPA), the Travelling Wave Tube (TWT) and the receiver.
- The Centre of Gravity (CoG) and standard deviation of the received signal spectrum to monitor the orbit stability and the performances of the Doppler compensation filter.
- The Noise power for both Q and I channel.

The stability of the satellite attitude in term of yaw angle is also monitored via a dedicated product (HEY) generated at the ground station. Yaw information is regularly sent to the flight segment to correct the satellite attitude.
The figure 4 shows the evolution of the daily averaged internal calibration power and its standard deviation for the Fore, Mid and Aft antenna since the beginning of Scatterometer operations in November 1995.

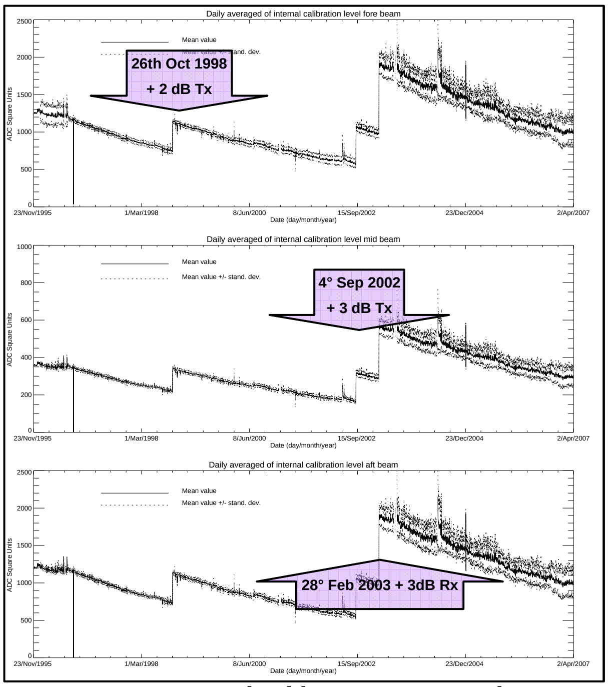

Figure 4. Internal calibration power evolution

The high value of the variance in the fore beam until August, 12th 1996 is only due to the ground processing. On that day, a change in the ground processing LUT overcame the problem. Since the beginning of the mission a regular decrease of the transmitted power has been detected. The reason for that evolution can be two-fold: the evolution of the pulse generator or the tendency of the switches between the pulse generator and the TWT to reset themselves into a nominal position. These switches were set in an intermediate position (on 16th November 1995) in order to put into operation the Scatterometer instrument. The evolution of the internal calibration has been constant monitored by the DPQC and, as reported on the plots, to compensate for the power decrease, corrective actions, in terms of increasing of the transmitted power (1998, 2002) and receiver gain (2003), have been performed.
The figure 5 shows the evolution of the daily averaged Doppler Compensation and its standard deviation for the Fore, Mid and Aft antenna. The aim of that compensation performed on-board and on-ground is to the echo spectrum within the receiver bandwidth in order to optimize the signal to noise ratio.

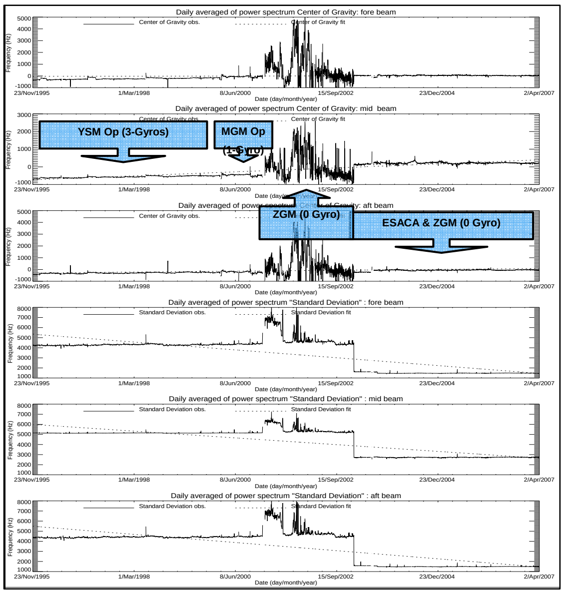

Figure 5. Doppler Compensation Evolution

In January 2000 the nominal 3-gyros AOCS configuration was no more considered safe because 3 of the six gyros on-board were out of order or very noisy. The MGM configuration was implemented to extend the satellite lifetime by using the available gyros one at the time. In January 2001 after a failure of 2 gyros was implemented the ZGM. The new configuration allows to pilot the satellite without gyros to preserve the remaining one for orbital manoeuvres. The impact in the satellite attitude was an error for the yaw angle of few degrees. That error is causing a large Doppler shift in the received echo that has been compensated in August

2003 with the introduction of the new ESACA processing chain. With the new processor the evolution of the CoG of the receiver spectrum is stable.

The evolution of the daily averaged noise power (I and Q channel) for the Fore, Mid and Aft antenna since the beginning of the Scatterometer operations in November 1995 is shown in figure 6. The noise power is stable around 1 ADC unit for the Fore and Aft antenna while the Mid antenna noise power is very low and not measurable. From 5th December 1997 until November 1998 some high peaks appear in the plots. The analysis of the raw data, carried out by the PCS, detected the presence of corrupted values in the noise measurements stored into the source packet Secondary Header. The reason of that field corruption 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 (SBT) stored in the EWIC product. The increase of the noise power on 28th February 2003 is due to the increase of the receiver gain in order to optimize the signal dynamic at the input of the ADC converter. On 17th December 2006 a high peak was detected in the noise power causing a very high daily average. Deep analysis carried out by DPQC found that an acquisition problem corrupted one source packet.

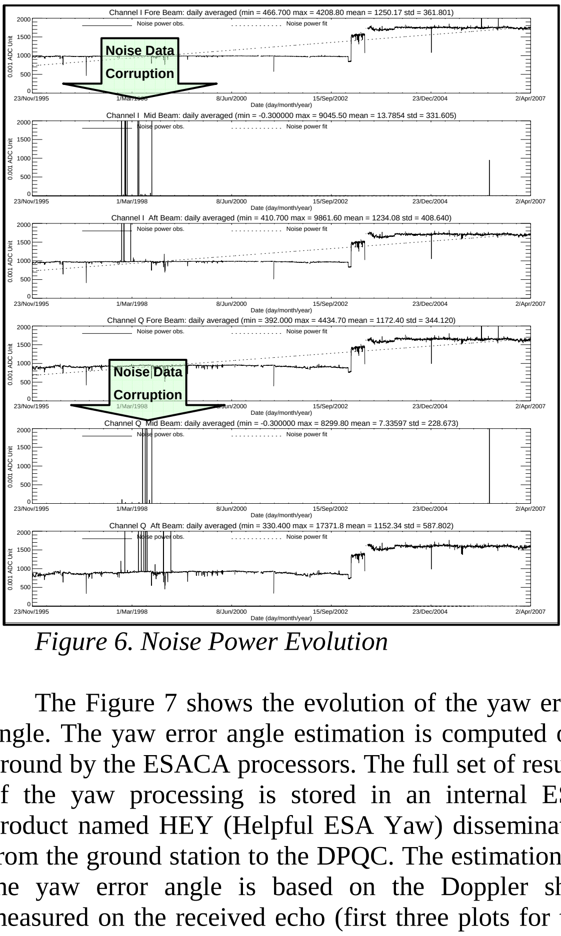

Figure 6. Noise Power Evolution

The Figure 7 shows the evolution of the yaw error angle. The yaw error angle estimation is computed on-ground by the ESACA processors. The full set of results of the yaw processing is stored in an internal ESA product named HEY (Helpful ESA Yaw) disseminated from the ground station to the DPQC. The estimation of the yaw error angle is based on the Doppler shift measured on the received echo (first three plots for the Fore, Mid and Aft antenna) and aims to compute the correct acquisition geometry for the three Scatterometer antenna throughout the entire orbit. The Yaw error angle information is used in the radar equation to derive the calibrated backscattering (sigma nought) from the Earth surface and to select the echo samples associated to each node in the spatial filter. The result of the monitoring (fourth plot) is a yaw error angle within -/+ 2 deg. for most of the orbits. That value is within the specification for the ESACA processor to assure calibrated data. Strong degradation in the evolution of the yaw angle impacts the quality of the sigma noughts. In such cases a flag in the product allows user to discard the measurements. It was also noted that a strong solar activity impacts the yaw performances. The DPQC monitoring gives also input to the flight segment to correct evolving bias in the yaw as occurred in June 2004.

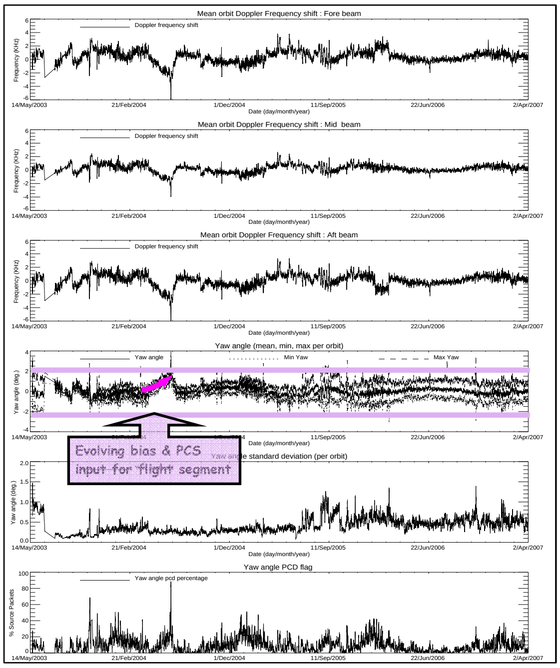

Figure 7. Satellite yaw angle monitoring

4. ERS-2 SCATTEROMETER CALIBRATION PERFORMANCES

The tropical rain forest in South America has been used by the PCS as a reference distributed target to monitor the relative calibration and the antenna pattern of the ERS-2 Scatterometer. The target at the working frequency (C-band) 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 the ERS-2 Scatterometer, the backscattered measurement will depend solely on the surface effectively seen by the instrument. That effect can be removed by normalizing the sigma nought with the cosine of the incidence angle (the Gamma nought).

The Gamma nought histograms are weekly computed by the PCS and the position of the histogram's peak is shown on the Figure 8 for the three antennae, ascending (upper plot) and descending (lower plot) passes. The monitoring shows a very stable instrument calibration within the initial specification (0.5 db) and a geophysical signal with an annual variation of around 0.2 dB. The impact of the ZGM operations is clear visible in the time series from January 2001. The old LRDPF processor was not able to compensate for the degraded satellite attitude and the Scatterometer measurements were not calibrated anymore. In February 2003 a pre-operational version of the new ESACA processor was installed in the ground station at Kiruna (S). Descending passes over the test area are processed in that ground station and the effectiveness of ESACA to keep the original data calibration has been demonstrated during the qualification phase. Due to the new Regional Mission Scenario the calibration monitoring activity over the Brazilian rain forest is temporary suspended. The chance to continue that activity with a new receiving station covering the Brazilian rain forest is under implementation with a new ground station located in Chetumal (MEX) that will be operative in the summer 2007. It is interesting to note that this monitoring activity carried out by the PCS has also provided inputs to characterize the stability of the C-Band backscattering from the rain forest itself [9]. Results of the absolute calibration using transponder are in [1] and for the new calibration chain TOSCA in [10].

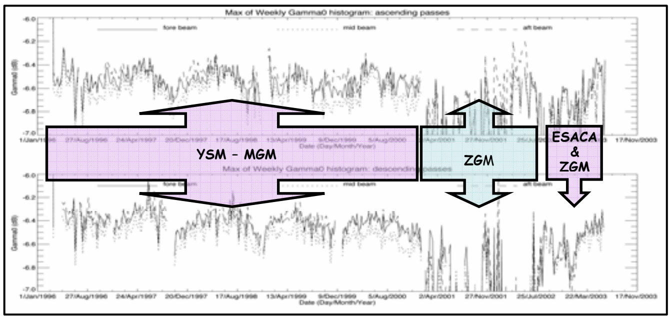

Figure 8. Calibration Monitoring Gamma Nought Evolution

5. ERS-2 SCATTEROMETER WINDS QUALITY

The Quality of the winds products delivered to the end users is monitored by the DPQC including also results from the ECMWF [11]. The daily analysis performed is summarized in the plots in the Figure 9. The first plot shows the number of valid sigma-nought triplets available per day. The number had an increase in June decrease in June 2003 after the failure of the on-board tape recorder and the implementation of the Regional Mission Scenario. The number of nodes increased since 2003 due to the improvement of the ground segment acquisition by adding new ground stations. The second plot shows the wind direction bias between the Scatterometer winds and ECMWF forecast winds (percentage of nodes for which the difference between ERS and ECMWF falls in the range -90.0,+90.0 degrees). The result is a stable value around 92% of nodes in agreement with the forecast direction until the introduction of the new ESACA processor that improved the results up to 98%. The new ambiguity removal algorithm (MSC) introduced with ESACA processor is able to remove ambiguity removal for all nodes. So since February 2003 the ambiguity removal rate is stable at 100%. The following plot shows the evolution of the wind speed bias. During the nominal YSM phase the wind speed bias was around zero with a deviation of few centimetres. During the MGM-YSM phase the bias was around 0.5 m/s. With the introduction of the new ESACA processor the bias further decrease mainly due to the small amount of data available per day (Regional Mission Scenario) so a direct comparison with the nominal phase is not possible. Due to the degraded satellite attitude, wind data was not distributed in real time, between January 2001 – August 2003. That data set will be re-processed within the ASPS project [8].

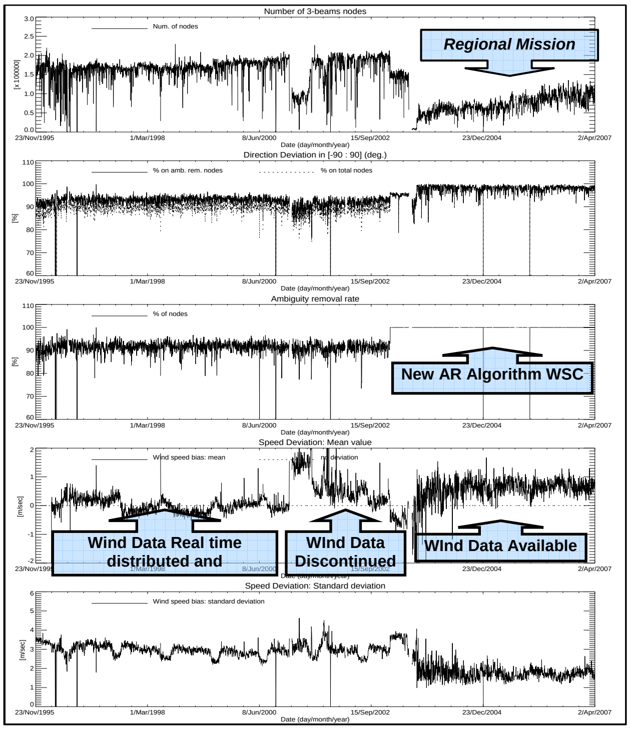

Figure 9. Geophysical Validation

6. CONCLUSION

The ERS Scatterometer mission has provided sixteen years of continuous high quality data and after an interruption of roughly 30 months its wind data are now assimilated into meteorological forecast model. The lesson learnt during these *sixteen* years of ERS-1 and ERS-2 Scatterometer data quality analysis shows that the daily data "screening" is a fundamental source of information to understand the instrument and processing behavior and to detect the anomalies, therefore is very important to translate as much as possible data into graphs and maps. Trends have to be detected in order to trigger corrective actions. This requires the identification of key operational parameter to monitor and to collect statistics. Furthermore the design of a "monitor schema" is an activity that involves expertise throughout the mission lifetime to face out space or ground segment events that degrades the quality of the data.

7. REFERENCES

1. R. Crapolicchio, P. Lecomte, The ERS Wind Scatterometer mission: routine monitoring activities and results, *Proceeding of Emerging Scatterometer Application workshop ESTEC, Noordwijk, The Netherlands 5 – 7 October 1998*, ESA-SP-424, pp 285-298. http://earth.esa.int/pcs/ers/scatt/articles/scatt_work98_performances.pdf
2. PCS Team Wind Scatterometer Cyclic Report http://earth.esa.int/pcs/ers/scatt/reports/pcs_cyclic/
3. R. Crapolicchio, M. Sunda, P. Lecomte, Impact of satellite degraded attitude on ERS-2 Scatterometer data, *Atti Fondazione Ronchi* Anno LIX, 2004 N. 5, pp 599-613. http://earth.esa.int/pcs/ers/scatt/articles/4880-6_two_col.pdf
4. X. Neyt. P. Pettiaux, M. Acheroy Scatterometer Ground Processing Review for Gyro-Less Operations, *Proceeding of 9th International Symposium on Remote Sensing, Crete, Greece 22 - 27 September 2002.* http://earth.esa.int/pcs/ers/scatt/articles/4880-1.pdf
5. P. Pettiaux, X. Neyt., M. Validation of the ERS-2 Scatterometer Ground Processor Upgrade, *Proceeding of 9th International Symposium on Remote Sensing, Crete, Greece 22 - 27 September 2002.*
6. P. Lecomte, R. Crapolicchio, L. Saavedra de Miguel, Cyclone tracking with ERS-2 Scatterometer: Algorithm Performances and Post-Processed Data Example, *Proceeding of the Envisat & ERS Symposium Gothenburg (S) 16 – 20 October 2000* http://earth.esa.int/pcs/ers/scatt/articles/257lecom.pdf
7. H. Hersbach and S. Abdalla, The global Validation of ERS Wind and Wave products at ECMWF, *Proceeding of the Envisat & ERS Symposium Salzburg (A) 6 – 10 September 2004*.
8. R. Crapolicchio, P. Lecomte, The Advanced Scatterometer Processing System for ERS Data: Design, Products and Performances, *Proceeding of the Envisat & ERS Symposium Salzburg (A) 6 – 10 September 2000*7.

9 R. Crapolicchio, P. Lecomte, On the Stability of Amazon rain forest backscattering during the ERS-2 Scatterometer mission lifetime, *Proceeding of ASAR Workshop 2003*, Canada. http://earth.esa.int/pcs/ers/scatt/articles/Paper_for_ASAR workshop.pdf

10. N. Manise, X. Neyt, M. Acheroy, Calibration of the ERS-2 Scatterometer in Gyro-less Mode, *Proceeding of the Envisat & ERS Symposium Salzburg (A) 6 – 10 September 2004.*
11. ESA PCS WEB ECMWF reports: http://earth.esa.int/pcs/ers/scatt/reports/ecmwf/
12. ESA PCS WEB: http://earth.esa.int/pcs/ers/scatt/