CROSS-CALIBRATION OF ERS-1 AND ERS-2 WIND SCATTEROMETERS; TOWARDS A HOMOGENEOUS 20-YEAR-LONG WIND VECTOR MONITORING OF THE EARTH

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ABSTRACT

The importance of long-term, continuous, and homogenous time-series of satellite data is widely accepted and strongly fostered by the international scientific community. The various global projects and initiatives undertaken in the last few years are evidences of that effort. Among those are: the Long Term Data Preservation Working Group [1], the Permanent Access to the Records of Science in Europe (PARSE) [2], or the Global Climate Observing System (GCOS) [3].

One of the examples of long-term monitored variable is the wind vector. Since the European Remote-sensing Satellite (ERS)-1 launch in July 1991 and until ERS-2 decommissioning in July 2011, a continuous and consistent database of backscattering signal from the Earth surface has been built, and is now available.

The Active Microwave Instrument (AMI) [4], which was one of the ERS-1 and ERS-2 payloads, provided radar back-scattering coefficient measurements during the last 20 years by using its three nominal operational acquisition modes: Synthetic Aperture mode (SAR mode), Scatterometer mode (wind mode) and a special combination of the two over ocean where SAR and Scatterometer mode are interleaved (wind/wave mode). The main applications for data acquired in Scatterometer mode is related to the estimation of the wind vector over the sea surface. In that field the ERS-2 Scatterometer measurements give a very valuable contribution to the accuracy of the numerical weather forecast models, being assimilated in several meteorological weather forecast centers since the beginning of the mission.

After the decommissioning of ERS-2, effort has been devoted to achieve a complete reprocessed database, including both ERS-1 and ERS-2 acquisitions [5]. The cross-calibration between these two satellites is a crucial task to obtain the homogeneousness of the wind vector database, and allow its long-term characterization.

The approach followed by ESA in term of: team organization, cross-calibration strategy and validation methodology towards this goal is presented in this paper as well as the preliminary results of the long-term characterization of the wind vector.

Index Terms— Scatterometer, Microwave, C-band, inter-calibration

1. INTRODUCTION

The first satellite of the European Space Agency, the European Remote sensing Satellite (ERS)-1, was launched in 1991, and replaced by ERS-2 in 1995. Since then, wind speed and direction have been measured almost uninterruptedly by the Active Microwave Instrument (AMI). The availability of such a long dataset will allow a number of studies about the global climate and its changes in the last decades. Nevertheless, no meaningful characterization can be achieved without an adequate calibration and cross-calibration of the instruments.

In this paper, a quick overview of the instrument characteristics is presented in section 2. A short summary of the satellite evolution, in terms of main mission events and their consequences on the system configuration is reported in section 3. The methodology followed to achieve intra- and inter-calibration is described in section 4, while an example of intra-calibration is shown in section 5. Finally, the main conclusions of the study are summarized in section 6.

2. THE INSTRUMENT

The Active Microwave Instrument is one of the payloads embarked on both ERS-1 and ERS-2; it is a radar emitting continuous-wave pulses at the central frequency of 5.3 GHz (C-band). AMI can be operated in three different acquisition modes, namely:

- The Synthetic Aperture Radar (SAR) Image Mode, whose outputs are 100 km-wide strips of high-resolution imagery.
- The SAR Wave Mode, which produces 5 km x 5 km images ('imagettes') at intervals of 200 km along track.
- The Wind Scatterometer Mode, which provides measurements of radar backscatter from the sea surface.

The ERS Wind Scatterometer [6] consists of three different antennas looking at 45° forward, sideways, and 45° afterward with respect to the satellite's flight direction. The resulting swath is 500-km wide and is centered 450 km at the right of the satellite’s nadir; the nominal spatial resolution of the ERS Wind Scatterometer is 50 km, each resolved point at the Earth is called node. The geometry of the instrument and its Field Of View (FOV) are shown in Fig. 1.

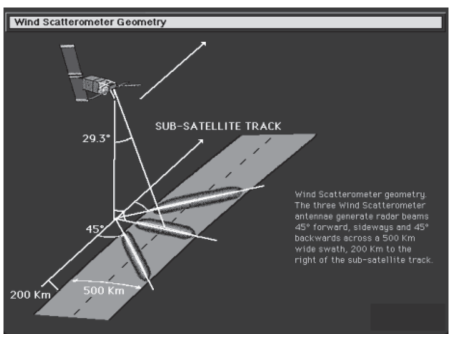


Fig. 1 ERS Scatterometer Geometry and its Field of View

ERS Scatterometer measures the so-called radar cross-section of the Earth surface, which is, on the sea, directly connected to the sea roughness and, in turns, coupled with the surface wind speed.

3. MAIN EVENTS DURING THE MISSIONS

Both ERS-1 and ERS-2 performed way better than expected, being operative during 10 and 16 years, respectively. During their long life, they passed through several different instrumental and orbital configurations: ERS-1 suffered no major damages, but changed 9 different orbital configurations; these are summarized on Table I.

TABLE I: ERS-1 PHASES

ERS-1	
1991, Jul.	ERS-1 is launcher on Jul. 25, 1991. The commissioning phase starts.
1991, Dec.	1st Ice Phase.
1992, Apr.	Roll-tilt Phase during 12 days (April 2-14).
1992, Apr.	1st Multi-Disciplinary Phase.
1993, Dec.	2nd Ice Phase.
1994, Apr.	Geodetic Phase.
1994, Sep.	Shifted Geodetic Phase.
1995, Mar.	2nd Multi-Disciplinary Phase.
1999, Dec.	Last acquisition of ERS-1 is received.
2000, Mar.	The End Of Life of ERS-1 is declared on March 13, 2000.

On the contrary, ERS-2 underwent a number of failures and consequent changes of both the acquisition plan and the ground segment configuration. A brief summary of the main event of the ERS-2 mission is presented in Table II:

TABLE II: ERS-2 MAIN MISSION EVENTS

ERS-2	
1995, Apr.	ERS-2 is launched on April 21, 1995.
1995, Nov.	The first Scatterometer measurement is achieved by setting the antenna circulator system into an intermediate position to avoid arcing in the transmitter. In this new configuration the transmitted power is reduced by a factor of 3dB if compared with ERS-1.
1996, Aug.	Due to an anomaly in the internal calibration unit, the calibration sub-system is switched from side A (nominal) to side B (redundant).
2000, Jan.	Three of the six gyroscope fail, the operation mode is changed from Nominal to Mono-Gyro Mode. In Mono-Gyro configuration the accuracy of the satellite attitude was degraded in particular for the yaw angle.
2001, Jan.	Other two gyroscopes fail, leading to the so-called Zero-Gyro Mode; the single operating gyroscope is only used for important orbital maneuvers.
2001, Jun.	To test a way to compensate for the gyroscopes failure, ERS-2 satellite starts operating only in Wind-Wave acquisition mode.
2003, May.	Nominal acquisition mode is resumed.
2003, Jul.	The on-board tape recorded fails, since then, data are available only when the satellite is within the visibility of some ground station; the mission passes from Global to Regional coverage.
2003, Aug.	ERS Scatterometer Attitude Corrected Algorithm (ESACA) is included in the processing chain to compensate for the switching off of the gyroscopes.
2010, Sep.	Since the impossibility of the transponder repair, the calibration acquisition mode is removed from the orbital planning and substituted by nominal acquisition
2011, Feb.	ERS-2 is lowered by a series of orbit maneuvers. As a consequence of that, the repeat cycle changes from 35 to the 3 day.

2011, Jul.	ERS-2 is decommissioned.

The most important changes in the satellite flight and ground segments are shown in Fig. 2, where the events are chronologically listed between the two time-bars, and their effects on the flight and ground segment are presented in the left and right time bars, respectively; the small bar on the extreme right shows the change in data processor at the ground segment.

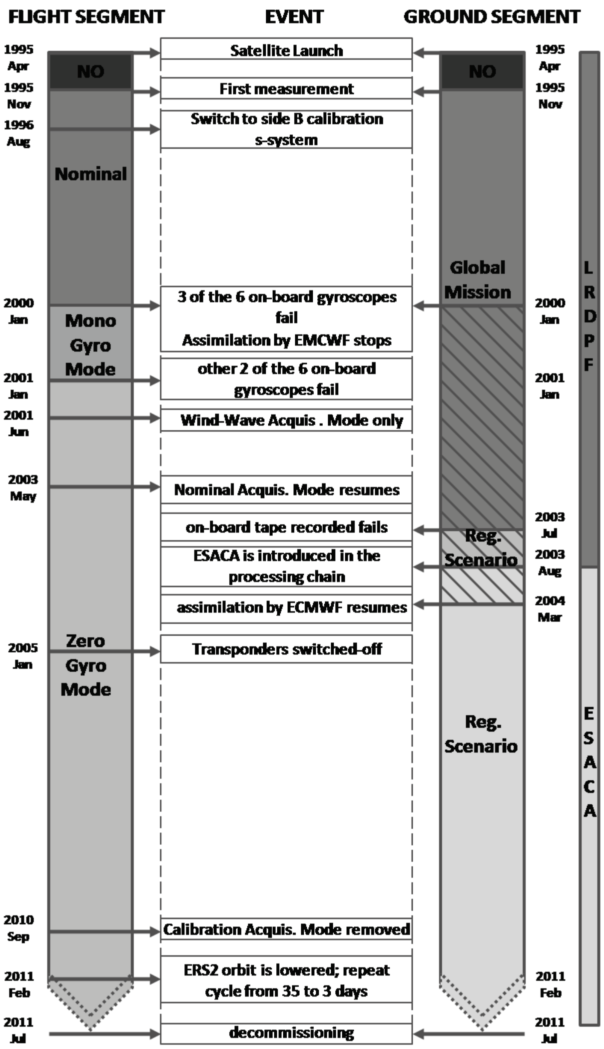


Fig. 2 Main mission events during the ERS-2 mission

4. METHODOLOGY

To ensure the calibration between different instruments or between different phases of the same instrument, the Rain Forest has been selected as reference target. It acts in fact as a very rough surface and stable in time at the C-band, so that the transmitted signal can be assumed to be equally scattered in all directions. Under this assumption, the measured backscattering only depends on the area observed by the instrument. This purely geometrical dependence can be removed by normalizing the σ^0 with the cosine of the incidence angle (γ^0, gamma nought), as expressed in Eqn. 1.

$$\gamma^0 = P/S^0 = P/(S \cdot \cos(\theta)) = \sigma^0/\cos(\theta) \qquad (1)$$

This methodology will be applied to the inter-calibration between ERS-1 and ERS-2, which is currently still on-going. In the next section an example of intra-calibration, using the same technique is presented: The switch between the side-A and side-B (redundant)of the ERS-2 calibration sub-system.

5. THE CASE OF THE ERS-2 SIDE-A / SIDE-B INTRA-CALIBRATION

The switch between the side A and side B of the ERS-2 calibration sub-system occurred on August 6 1996. It caused a change in the calibration pulse measured by the AMI when operating in Scatterometer mode. This calibration change is estimated by comparing the profiles of gamma nought (γ^0) calculated using the rain forest before and after the switch. The period after the switch has been considered as the reference, so that the aim of the calibration is to align the acquisitions performed before that with the reference.

The difference between the two profiles has been considered as the sum of two contributions:

- the geophysical signal due to changes in the geophysical condition of the rain forest plus
- the effect of the switch of the calibration sub-system.

The geophysical contribution has been estimated by averaging the difference between the same periods (before and after the switch) during the following 6 years (1997 - 2002) until the end of the global coverage. The dataset used is reported in Table III

All the statistics for both the gamma nought and the geophysical signal have been calculated separately for the ascending and descending passes and for each of the beams. The results are summarized in Table IV.

TABLE III: DATASET USED

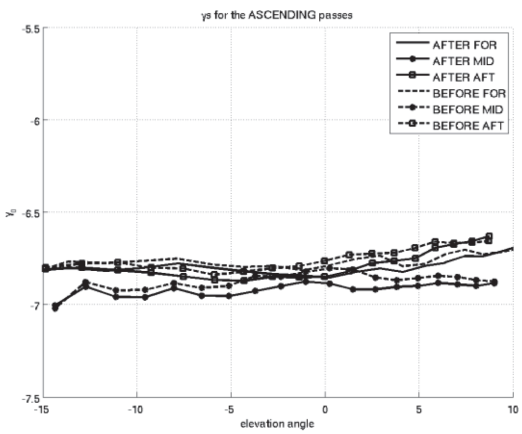
absolute orbit		1996	1997	1998	1999	2000	2001	2002
BEFORE	**09/07**	6370	11594	16820	22043	27283	32507	37832
	06/08	6783	12008	17233	22458	27697	32921	38175
AFTER	**07/08**	6784	12009	17234	22459	27698	32922	38176
	16/09	7369	12595	17820	23045	28284	33508	38723

TABLE IV: SUMMARY OF THE RESULTS

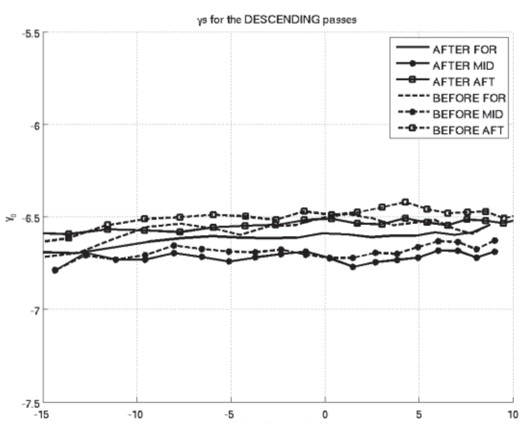
	ASCENDING			DESCENDING		
	FOR	**MID**	**AFT**	**FOR**	**MID**	**AFT**
TOT	0.21	0.22448	0.21308	0.22439	0.21051	0.22271
GEO	0.043099	0.065664	0.049172	0.029094	0.020581	0.026734
σ_GEO	0.027849	0.026701	0.028372	0.036746	0.030735	0.031467
SWITCH	**0.166901**	**0.158816**	**0.163908**	**0.195296**	**0.189929**	**0.195976**

Considering that the same value must be applied to all the beams and passes, and that the difference among different estimations is within the uncertainty associated to the geophysical condition of the reference target (σ_GEO), the average can be considered a good estimator, leading to a correction of 0.18 dB.

The resulting profiles of gamma nought before and after the switch, once applied the correction of 0.18 dB, are shown in Fig. 3a and b for the ascending and descending passes, respectively.



(a)



(b)

Fig. 3 Resulting profiles of gamma nought after the calibration for the (a) Ascending and (b) Descending passes

6. CONCLUSIONS

The importance of an accurate inter-calibration between ERS-1 and ERS-2 has been highlighted within the framework of long-term monitoring of the global climate. To do so, a methodology based on the observation of the rain forest has been proposed. Since the inter-calibration between ERS-1 and ERS-2 is currently still on-going, the switch between the side-A and side-B of the calibration sub-system of ERS-2 has been used as an example. This occurred on August 6 1996 and led to a change in the configuration of the ERS-2 Scatterometer. To assess the magnitude of the aforementioned change, the rain forest has been monitored before and after the switch, and for the same periods during the following 6 years (1997 – 2002) until the end of the global coverage scenario. The geophysical signal due to the change of the condition of the rain forest has been computed and it was found one magnitude order less than the change introduced by the calibration sub-system on the measured backscattering. This finding confirms the stability of the selected natural target and the validity of the approach followed for the intra-calibration. The geophysical signal has been subtracted to the estimated modification of the gamma nought profile before and after the switch to assess the final backscattering change induced the switch to the redundant side-B calibration system. Results indicate that a correction of 0.18 dB should be applied to all the acquisitions performed before the switch.

11. REFERENCES

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