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CALIBRATION OF ACTIVE MICROWAVE SENSORS AT ESA

CGMS is informed about experience at the European Space Agency on calibration of active microwave sensors

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1.- INTRODUCTION

In July 1991, the European Space Agency (ESA) launched the first ESA Remote sensing Satellites ERS-1. ESA's original objectives for this mission were to:

- Increase our scientific understanding of coastal zones, global ocean processes and polar regions
- Develop and promote economic and commercial applications
- Explore the potential of radar data for land based process studies and applications.

Each of these objectives placed rigorous requirements on the standards of engineering and on innovation within ESA and European industry, as there was little previous experience with the technology which needed to be developed. A second of the series, ERS-2 was launched, with an increased payload, in 1995 and is at present in operations, with ERS-1 preserved in hibernation.

2.- THE ERS RADAR INSTRUMENTS

These satellites mainly carry radar instruments:

- an Active Microwave Instrument (AMI), which is operated either as an imaging Synthetic Aperture Radar (SAR) or as a scatterometer. In Image mode, a high resolution SAR capability provides the facility for all weather, day and night imaging of the Earth's surface. In Wave mode, it can be used to measure 2-d spectra of the ocean surface waves. In Wind mode the scatterometer measures ocean surface wind speed and direction. It operates in C-Band (5.3 GHz), vertically polarised.
- a radar Altimeter (RA). This provides accurate measurements of range to ocean and ice surfaces. It can also provide ocean wave height and estimates of ocean surface wind speed. Derived information includes the geoid, bathymetry ocean circulation and other parameters. It operates at 13.8 GHz, in Ku-band.

A microwave radiometer with two channels at wavelengths sensitive to water vapour in the atmosphere is used to provide atmospheric corrections for the altimeter.

Most of the time, the AMI instrument is operated in wind/wave mode which consists of nominal scatterometer operation interrupted every 30 seconds by a couple of seconds of short SAR operations in order to acquire small SAR imagettes from which the ocean wave spectra can be derived.

The other instruments on board ERS satellites are an along track scanning radiometer ATSR and a PRARE for precise tracking and ranging. The latter failed on ERS-1 but worked successfully on ERS-2. A new optical instrument called Global Ozone Monitoring Experiment (GOME) for atmospheric ozone measurements has also been embarked on the ERS-2.

3.- DEFINITIONS

Calibration: the process of quantitatively defining the system (including the instrument) response to known, controlled signal inputs.

Validation: the process of assessing by independent means the quality of the data products derived from the system output.

4.- THE ERS SAR CALIBRATION

4.1 The instrument

Imaging radars obtain information by transmitting known pulses of microwave energy through an antenna and measuring the backscattered energy received by the antenna. The rectangular antenna of the SAR is aligned along the satellite's line of flight to direct a narrow beam of radar energy sideways, illuminating a swath which for ERS is about 100 km wide, with an inclination of 23°. An image of the ground is build from the time delay and strength of the return signals. For a given wavelength, the spatial resolution of a radar system is determined by two factors: the length of the antenna (in azimuth) and the pulse bandwidth (in range). The aperture synthesis technique is used to obtain a better resolution (i.e. of the order of 30m) with a smaller antenna.

The SAR being a multipurpose instrument, it must be calibrated and then validated for a wide range of geophysical applications.

4.2 Absolute calibration

Absolute radiometric calibration is vital to many applications of SAR. It supports the geophysical interpretation of SAR data by relating the digital values to the physical estimation of the normalized radar cross-section $\sigma°$ (also referred as backscatter coefficient).

One objective of the ERS SAR design was to achieve excellent instrument stability and to minimize the effect of signal distortions and the level of spurious signals. However, the SAR ground processors have tools to correct SAR data for system imperfections. The information is derived in two ways:

- Pre-launch testing to characterize the instruments
- Internal calibration pulses (to measure gain drift) and the radar echo signals themselves. Thermal noise is measured when pulses are not transmitted.

4.3 External calibration

The performance of the instrument as a whole is monitored by external calibration. This is achieved by imaging reference targets i.e. transponders or active radar calibration units. The SAR transponders consist of a receiving and transmitting antenna, an amplifier and an optical delay line with a 1.5 µs delay. The transponder returns an amplified and delayed replica of the SAR signal back to the satellite, which appears as a bright spot. Three transponders are deployed in the Netherlands across the SAR swath. The transponder calibration gives excellent absolute gain calibration and provides data for the estimation of the antenna beam pointing biases.

This work was supplemented by considering images of areas found to be stable distributed scatterers through airborne campaigns. The best area was found over the South America rain forest. A database with relevant parameters over the calibration sites is used for long term monitoring of sensor performance and product quality assurance.

4.4 Results

The radiometric stability (standard deviation of the radar cross-section measured on the transponders) was 0.25 dB for ERS-1 and 0.26 dB for ERS-2 over lifetime of the instruments (till 1998). The radiometric accuracy (mean difference between actual and measured transponder radar cross-sections) was 0.07 dB for ERS-1 and 0.15 dB for ERS-2. The peak to peak radar cross-section (maximum difference in transponder radar cross-section measurements) was 1.49 dB for ERS-1 and 1.19 dB for ERS-2. These results indicate an excellent stability and no reduction in the accuracy.

For ocean applications and some land regions, there is a need to correct for Analogue to Digital Convertor (ADC) saturation which could lead to an underestimation of the radar cross section. The loss was more important for ERS-1 than for ERS-2, due to higher gain settings (Meadows et al. in ESA EOQ 62, June 1999).

5.- THE ERS SCATTEROMETER CALIBRATION

5.1 The instrument

The measuring principle of the scatterometer is based on the premise that microwave backscattering is a function of ocean surface ripples which in turn depend on wind conditions. The radar cross-section is anisotropic with respect to the angle between the wind vector and incident radar beam. Several $\sigma°$ measurements of the same area from different directions will allow to determine the wind speed and direction through an empirical mathematical model.

In the case of the ERS series, the different directions are achieved through three antennae with the nominal look angles: 45° foreward 45° aft and broadside. The antennae illuminate a 500 km wide swath, at nodes separated 25 km, and centered within a resolution cell of 50 x 50 km. The earth rotation effects are compensated by steering the satellite about the yaw axis.

Engineering calibration and geophysical validation are both needed since the required data products for the scatterometer are not only sigma nought images, but also geophysical variables (wind speed and direction). The ERS scatterometer data are used by meteorological offices for wind and wave forecasting and to support offshore operations and ship routing. It can also be used for monitoring land surface processes.

5.2 Absolute calibration

The objective of the calibration is to ensure that the system response is absolutely calibrated in terms of the σ° and over the range of incidence angles _ of the instrument i.e. that _° is unaffected by the the antenna patterns. The internal characterization of the scatterometer is similar to the SAR, since the mechanism for producing internal calibration pulses is shared. Characterization is aided by temperature sensors on the antenna surface which provide additional information about temperature antenna gain variations over each orbit.

5.3 External calibration

The scatterometer transponders are similar to the SAR ones, except that there is no need for a the delay line. Three transponders were installed in the South of Spain across the 500 km swath at a cross over point of the ascending and descending pass, to allow different incidence angles. The transponders' time of observation is used to verify proper antenna pointing, and the intensity of the returned signal to achieve absolute calibration . Unlike the SAR case, it is impossible to make the transponder signal much stronger than the surrounding backscattering without saturating the receiver. A special operation mode was used by shifting the transponder echoes in frequency by 540 KHz into a clear part of the pass-band of the receiver. The bias was assessed by comparing ascending and descending passes.

Similarly to the SAR, the tropical rain forest in South America was used as a distributed reference for relative calibration, because it is assumed isotropic and time invariant. This provides the necessary antenna pattern information.

The stability of the instrument in the longer term can be monitored through the coefficient
$\gamma° = \sigma°/ \cos \theta$, being θ the incidence angle.

This is independent of the incident angle, azimuth angle and time. It can be used to illustrate the long term stability of the instrument and to compare each of the three beams over the rain forest test site.

5.4 Results

The required absolute calibration was 0.7 dB; a value of 0.2 dB was achieved for ERS-1. In the case of ERS-2, some anomalies obliged to reduce to half the output power and to use the redundant calibration system. A drift was detected both in the echo and calibration pulse, but not in the σ° , due to the successful calibration corrections in the ground processor.

6.- THE ERS ALTIMETER CALIBRATION

6.1 The instrument

The Radar Altimeter transmits short duration pulses vertically downward and measures the time of propagation until the reception of the return echo. In addition to the timing information, the shape of the returned echo is used to derive information on surface roughness and reflectivity. Essential information needed for retrieving geophysical variables are precise orbit determination and atmospheric corrections.

The ERS RA is intended to measure surface characteristics over both ocean and ice. This requires two tracking characteristics and two different mode of operations.

6.2 Internal calibration

The internal calibration is based on a special waveform, in which the echo generated is a single point target response (SPTR) instead of an ocean echo. The time delay associated with the center of this SPTR can be evaluated accurately by modeling the shape of the point target response and performing a fit to the measured echo. This technique offers a robust calibration of the internal path.

6.3 External calibration

A dedicated campaign was needed for the external calibration to obtain the height bias error, due to elements outside the internal path, after launch. The procedure was to measure the distance f~~o~~rom the satellite to the sea surface with the Altimeter with suitable corrections for propagation effects and compare this with independent means: from the satellite to a tracking network and from the tracking network to the sea surface.

The campaign took place near Venice during the ERS-1 commissioning phase.

- The comparison point was an oceanographic research platform in the open sea off-shore Venice.
- Measurements of the sea level, wind, waves etc were taken from the platform.
- Several satellite laser ranging stations enabled a quasi-geometric solution of the trajectory.
- Dedicated campaigns provided the 3-d positions of all reference points.

- There was a high degree of redundancy to aid error resistance.

The ERS-2 Altimeter calibration campaign was aimed at measuring the difference with the previously calibrated ERS-1 Altimeter. The comparison was done with millions of measurements distributed globally during three 35-day repeat cycles. Several different data processing methods were used to assess robustness of the results.

Validation was done using tide gauges, buoys, models and altimeter data from a non-ESA mission. On-going activities monitor any instrument drifts.

6.4 Results

The bias obtained from the ERS-1campaign, combining the errors with the root sum of squares was -41.5 ± 5.2 cm for ERS-1.

From the ERS-2 commissioning phase, the relative bias between ERS-2 and ERS-1 Altimeter range-to-surface measurements was 0.0 +/- 1.3 cm.

Flying two similar instruments during an overlap period measuring the same target with a very short time-lag and performing a cross-calibration, allowed to unveil small imperfections, below the original instrument specifications, undetectable on ERS-1 alone, and develop successful corrections in the subsequent ground processing which significantly improve the data quality.

ERS-2

what about this then? -- relative calibration

7.- OUTLOOK

The experience gained with the ERS satellites will be used for the calibration of the active microwave instruments to be embarked in the ENVISAT (ASAR, Advanced Altimeter) and METOP (Scatterometer) satellites under development at ESA.

ENVISAT planning is quite well advanced and combines absolute and relative calibration.

8.- BIBLIOGRAPHY

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- New Views of the Earth, 1997, ESA SP 1176/III.
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Further information about ESA Earth Observation satellites can be found in:

http://www.esa.int/esa/progs/eo.html

<u>FIGURE</u>

<u>ERS-1 payload</u>