RADIOMETRIC PERFORMANCE OF THE ADVANCED WIND SCATTEROMETER RADAR ASCAT

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1. INTRODUCTION

The Advanced Wind Scatterometer (ASCAT) instrument [1 & 2] is one of the instruments carried by the ESA / EUMETSAT METOP satellites (METOP A, B & C). The ASCAT is a six-beam radar instrument designed to measure wind fields over the oceans; the instrument also provides useful data for ice and land applications. The radiometric performance of the ASCAT carried by METOP-A is estimated and discussed.

2. ESTIMATION OF PERFORMANCE

Static Bias Errors: Table 1 shows the mean antenna gain bias error between the final estimated antenna gain pattern and the transponder gain at angular position measurements using only the highest samples on each azimuth cut (after transponder bias removal has been performed) for all transponders together and for each transponder alone; these results are taken from reference [3].

Beam	Mean Gain Difference after Bias Removal			
	All - Est	T1-Est	T2-Est	T3-Est
1 LF	+ 0.013 dB	+ 0.012 dB	0.000 dB	+ 0.019 dB
2 LM	+ 0.007 dB	+ 0.016 dB	- 0.009 dB	+ 0.004 dB
3 LA	+ 0.017 dB	+ 0.022 dB	+ 0.012 dB	+ 0.013 dB
4 RF	+ 0.014 dB	+ 0.014 dB	+ 0.012 dB	+ 0.016 dB
5 RM	+ 0.008 dB	+ 0.002 dB	+ 0.022 dB	+ 0.013 dB
6 RA	+ 0.017 dB	+ 0.016 dB	+ 0.022 dB	+ 0.016 dB

Table 1

The mean antenna gain bias ε associated with calibration can reasonable be characterised by the worst case residual bias given in the second column of Table 1. This value is used for all of the six ASCAT antenna beams. The corresponding static bias error in radar back-scattering cross-section is given by e (ε).

$\varepsilon = \pm 0.017$ dB (1) $\qquad e(\varepsilon) = \pm 0.034$ dB (2)

Quasi-Static Bias Errors: Table 2 shows the worst case quasi-static antenna gain error, δ around the orbit away from the calibration position and the corresponding worst case quasi-static error in radar backscattering cross-section, e(δ). These values are calculated theoretically and are reported in reference [3]. The quasi-static errors at the calibration position are zero.

Antenna Beam	δ	e (δ)
1 LF	- 0.0250 dB	- 0.050 dB
2 LM	- 0.0313 dB	- 0.063 dB
3 LA	+ 0.0525 dB	+ 0.105 dB
4 RF	- 0.0075 dB	- 0.015 dB
5 RM	+ 0.0029 dB	+ 0.006 dB
6 RA	+ 0.0150 dB	+ 0.030 dB

Table 2

Zero Mean Random Errors: Table 3 shows the root mean square residual antenna gain error between the final estimated antenna gain pattern and the transponder gain at angular position measurements using only the highest samples on each azimuth cut (after transponder bias removal has been performed) for all transponders together and for each transponder alone; these results are taken from reference [3].

Beam	RMS Gain Error			
	All	T1	T2	T3
1 LF	0.041 dB	0.044 dB	0.036 dB	0.038 dB
2 LM	0.051 dB	0.062 dB	0.043 dB	0.038 dB
3 LA	0.048 dB	0.058 dB	0.040 dB	0.038 dB
4 RF	0.042 dB	0.051 dB	0.028 dB	0.032 dB
5 RM	0.043 dB	0.049 dB	0.041 dB	0.035 dB
6 RA	0.054 dB	0.065 dB	0.052 dB	0.035 dB

Table 3

The root mean square antenna gain error associated with calibration Δ can reasonable be characterised by the worst case RMS gain error given in the second column of Table 3. This error is assumed to be a zero mean Gaussian error. The corresponding zero mean Gaussian random error (one standard deviation) associated with the radar back-scattering cross-section is σ (Δ).

$\Delta = \pm 0.054$ dB (3) $\qquad\qquad$ $\sigma(\Delta) = \pm 0.108$ dB (4)

The transponder radar backscattering cross-section stability error (one standard deviation) [4] is given by:

$\sigma(T) = \pm 0.07$ dB (5)

Therefore the ASCAT radar only zero mean Gaussian random error (one standard deviation) associated with the radar back-scattering cross-section is given by:

$\sigma^2(R) = \sigma^2(\Delta) - \sigma^2(T)$ (6) $\qquad\qquad$ $\sigma(R) = \pm 0.083$ dB (7)

Algorithm Errors: The algorithm bias error, a in equation (8), associated with the calibration algorithm is assumed to be zero for the nominal case of three transponder calibration. This means that there is no additional bias contribution from the calibration algorithm on top of the static calibration bias, ε due to insufficient antenna gain pattern sampling in elevation by the transponders. The algorithm bias is therefore given by:

$a = 0$ dB $\qquad$ $e(a) = 0$ dB (8)

In general this would not be the case if less than three transponders were used and / or not all the nominal cuts (associated with the 29-day ground track repeat cycle) were used.

Radiometric Resolution Errors: The radiometric resolution for distributed targets may be characterised by the relative standard error of the final measurement (i.e. the standard deviation over the mean value), Kp. The value of Kp depends on (i) the spatial resolution of the final measurement (i.e. the number of raw measurements averaged and the weighting function used), (ii) the signal-to-ratio which depends on the distributed target normalised radar backscatttering cross-section (sigma zero) and (iii) the correlation between the raw samples averaged. Typical Kp values for ASCAT are around 0.03 (i.e. 3%).

3. POINT TARGET MEASUREMENTS

The total error on a single measurement of a point target in ASCAT Calibration Mode is therefore given by:

$$e(\varepsilon) + e(\delta) + e(a) + p \, . \, \sigma(R) \qquad (9)$$

where p is 2 or 3 according to whether the 2 or 3 sigma value is required, corresponding to 95.4% confidence or 99.7 % confidence respectively. Note that to give a worst case value, the quasi-static bias has been treated as though it lay anywhere in the range ± Abs(e(δ)). The ASCAT only radiometric accuracies for single measurements of an ideal point target are tabulated in Table 4 for each antenna beam:

Antenna Beam	R.A. 2σ 95.4 %	R.A. 3σ 99.7 %
1 LF	± 0.25 dB	± 0.33 dB
2 LM	± 0.27 dB	± 0.35 dB
3 LA	± 0.31 dB	± 0.39 dB
4 RF	± 0.22 dB	± 0.30 dB
5 RM	± 0.21 dB	± 0.29 dB
6 RA	± 0.23 dB	± 0.31 dB

Table 4

The total error after N measurements of a point target is less than or equal to:

$$e(\varepsilon) + e(\delta) + e(a) + 10\,p\,Log_{10}\left(1 + \frac{(10^{\sigma(R)/10} - 1)}{\sqrt{N}}\right) \qquad (10)$$

The residual bias error, for N equal to infinity, is tabulated in Table 5 for each antenna beam:

Antenna Beam	Residual Bias
1 LF	± 0.084 dB
2 LM	± 0.097 dB
3 LA	± 0.139 dB
4 RF	± 0.049 dB
5 RM	± 0.040 dB
6 RA	± 0.064 dB

Table 5

Another important quantity is the re-calibration error assuming the stability of the ASCAT instrument and the ASCAT transponders. This is the allowed difference between two 58-day 3-transponder extensive calibration campaigns assuming the ASCAT instrument and the ASCAT transponders are perfectly stable. This is given by:

$$e(\varepsilon) + e(a) \quad = \quad \pm 0.034 \text{ dB} \qquad (11)$$

4. DISTRIBUTED TARGET MEASUREMENTS

The total error on a single measurement of a uniform distributed target in ASCAT Measurement Mode is given by:

$$e(\varepsilon) + e(\delta) + e(a) + 10\,p\,Log_{10}\left(1 + \sqrt{(10^{\sigma(R)/10} - 1)^2 + (Kp.10^{SZO/10})^2}\right) \qquad (12)$$

Table 6 shows the total error on a single distributed target measurement for each beam for distributed targets with sigma zero equal to 0 dB, -10 dB and -20 dB assuming a Kp value of 3%.

Antenna Beam	SZO = 0 dB	SZO = -10 dB	SZO = -20 dB
1 LF	± 0.388 dB	± 0.252 dB	± 0.250 dB
2 LM	± 0.401 dB	±0.265 dB	± 0.263 dB
3 LA	± 0.443 dB	± 0.307 dB	± 0.305 dB
4 RF	± 0.353 dB	± 0.217 dB	±0.215 dB
5 RM	± 0.344 dB	± 0.208 dB	±0.206 dB
6 RA	± 0.368 dB	± 0.232 dB	± 0.230 dB

Table 6

Note that as thermal noise is included twice in both σ(R) and Kp, the results are over pessimistic close to the noise floor of the radar. The total error after averaging N measurements of a uniform stable distributed target in ASCAT Measurement Mode is given by:

$$e(\varepsilon) + e(\delta) + e(a) + 10\,p\,Log_{10}\left(1 + \sqrt{\frac{(10^{\sigma(R)/10} - 1)^2 + (Kp.10^{SZO/10})^2}{N}}\right) \qquad (13)$$

5. REFERENCES

[1] ASCAT - Metop's Advanced Scatterometer, R. V. Gelsthorpe, E. Schied & J. J. W. Wilson, ESA Bulletin Number 102, May 2000.

[2] The Advanced Scatterometer (ASCAT) on the Meteorological Operational (MetOp) Platform: A Follow-On for European Wind Scatterometers, J. Figa Saldaña, J. J. W. Wilson, E. Attema, R. Gelsthorpe, M. R. Drinkwater & A. Stoffelen, Canadian Journal of Remote Sensing, Volume 28, Number 3, pages 404-412, 2002.

[3] Radiometric Calibration of the Advanced Wind Scatterometer Radar ASCAT carried on-board the METOP-A Satellite. J. J. W. Wilson, C. Anderson, M. A. Baker, H. Bonekamp, J. Figa Saldana, R. G. Dyer, J. A. Lerch, G. Kayal, R. V. Gelsthorpe, M. A. Brown, E. Schied, S. Schutz-Munz, F. Rostan, E. W. Pritchard, N. G. Wright, D. King & U. Onel, IEEE Transactions on Geoscience and Remote Sensing – DOI: 10.1109/TGRS.2010.2045763.

[4] ASCAT Ground Transponder - First Production Unit System Test Report, D. King, February 2005, Qinetiq/ki/space/TN041140/1.1.